DECISION SUPPORT & CARBON CYCLE SCIENCE:

PRACTICAL STRATEGIES TO RECONCILING THE SUPPLY OF AND DEMAND FOR CARBON CYCLE SCIENCE

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DECISION SUPPORT AND CARBON CYCLE SCIENCE: PRACTICAL STRATEGIES TO RECONCILING THE SUPPLY OF AND DEMAND FOR CARBON CYCLE SCIENCE

Workshop Report
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EXECUTIVE SUMMARY

A group of researchers and practitioners across disciplines and professions gathered to discuss the merits of various strategies to create usable carbon science. While the focus was on carbon specifically, the group included experts on usable climate science and public participation methods in an effort to share experience in this arena with the carbon community.

Participants discussed the following four topics:

- What are the effective criteria for successful "usable science"?
- What has worked in creating science policies that result in 'usable science'?
- How is carbon cycle science currently being used?
- Democracy, public participation and equity in setting science agendas

Certainly as society moves toward considering deliberate carbon management, there is a transition from only focusing on creating basic understanding of the carbon cycle (which of course will continue on its own merit), to a new phase of also producing decision- or policy-relevant information. Participants agreed that the topic of usable carbon science was ripe for focus, as the societal context for carbon management was still emerging and could potentially become an important consideration for resources managers, governments, corporations and individuals. Pockets of use of carbon information include: state governments such as California and Oregon, the Federal government for complying with the United Nations Framework Convention on Climate Change (UNFCCC) and developing national policies, agricultural interests, forestry interests, other natural resource managers, cities, energy-related corporations, and environmental non-governmental organizations.

These various communities will likely have different needs, but the process of producing information to be usable will likely require researchers and programs alike to wrestle with the following questions:

- There are a myriad of potential users, how do we determine, given limited resources and unequal access to information, which uses to focus on?
- The context for use of carbon information is highly uncertain and dynamic. There is a possibility both of working with the few existing users as well as creating new users (preparing the market). How do we strike a balance between these two types of activities?

The criteria for usable science will of course be unique to the situation, but general lessons suggest that the creation of usable science will require a mediated interface of some kind between researchers and potential stakeholders, that research is available to the potential users in a timely manner, and that its application or use leads to improved societal outcomes. Also, the science itself should be credible and transparent, with all assumptions and uncertainties clearly defined.

Participants agreed that there were existing models and experience in the use of scientific information that could be applied to the formation of an effort focusing on usable carbon science. Some of these examples and lessons learned include:

- Start with a "problem-centric" or stakeholder perspective to orient around as research is planned. Such a model is more likely to result in research that meets societal needs rather than beginning from basic science interests.
- Build in a dynamic, two-way relationship that is ongoing between knowledge producers and societal decision makers, or pursue fully-integrated co-production of knowledge. Experience has shown that a mediated

approach such as these is more likely to result in useful information that has a greater chance of being used.

- Allow for community creativity in seeking out projects that might provide good pilots for creating usable carbon science.
- Through appropriate metrics and evaluation procedures, ensure that accountability to the goals of usable science is met. Such governance and metrics may be different than the traditional ones usually relevant for basic research.
- Models exist that can be evaluated for their applicability for organizing a usable carbon science effort. Such models include dedicated institutions, regional integrated sciences and assessment projects, boundary organizations, and grant programs.
- Consider how successful usable carbon science efforts might transition to an ongoing, operational status. Do such organizations exist now for carbon? If not, can the function be incorporated into existing organizations?

There was much enthusiasm for carrying these messages to the broader community and moving forward with considering how to create a usable carbon science effort. Some of these ideas have permeated products such as chapter five of the SAP 2.2 (Synthesis and Assessment Product of the Climate Change Science Program, or State of the Carbon Cycle Report, North America--SOCCR), and have been presented at the Climate Change Science Program Decision Support workshop, the American Geophysical Union fall meeting, and the American Meteorological Society annual meeting.

BRIEF OVERVIEW

The goal of this workshop was to foster an interested community of researchers and develop a research agenda with the ultimate aim of improving the usefulness of carbon cycle science for the broader community of decision makers. Specific objectives included:

- To survey existing knowledge about successful decision support using carbon cycle science
- To enable cross-disciplinary transfer of knowledge about how to design and implement research agendas, projects and programs so that they can effectively serve users needs
- To develop a research and practice agenda for programs and scientists in carbon cycle science who are interested in serving the needs of users outside of the scientific community. Specifically, we will provide input to Section V of SOCCR on how we can improve the application of carbon cycle science in decision support, and create a broader research agenda on generating useful information in the North American Carbon Program (NACP) as NACP goes forward in its implementation.

To this end, 22 participants from the carbon cycle science community, the community of researchers studying science-user interactions in the seasonal to interannual forecast arena, and the science policy research and practitioner communities gathered on June 13-14, 2005 at the University of Colorado, Boulder (see appendix III, participant list).

Substantial progress was made on outlining the options available for carbon cycle science to pursue. Participants at the workshop were quite positive about the workshop itself, the need for a network to continue the dialogue, and the importance of raising awareness about these issues in many different venues, those both scientifically- and community-based. Individuals also carried away from the workshop new information that some directly incorporated into their research endeavors.

Background

The Carbon Cycle Science element of the Climate Change Science Program (CCSP), especially the North American Carbon Program (NACP) has as a primary goal providing near-term information of use to decision makers.[1] However, as demonstrated by several other areas of emphasis in Earth science, generating information that is useful to anyone outside of the scientific community does not automatically result from conducting scientific research. Specific findings include: information provided is not needed; information is needed but not provided; information lacks regional specificity; inaccessible presentation; poor communication; lack of trust in information or deliverers; institutional constraints prevent use of new information; and so on.[2] The concept of managing carbon is a relatively new concept in the spectrum of managing natural resources or environmental issues—while carbon management has been discussed for merely a few decades, water, land and marine resources have been managed by society for centuries. The carbon cycle science community therefore does not have wealth of experience internally from which to draw upon in trying to develop a scientific agenda that will successfully meet the needs of decision makers. Preliminary evidence suggests that carbon cycle science is not currently meeting some important needs ("missed opportunities").[3] The goal of this workshop was therefore to examine options for research agendas to fill this gap.

Workshop Approach

As a first step we established a workshop executive committee made up of individuals from the various communities that we wanted to connect up to examine this question (see appendix I). The executive committee consisted of: Lisa Dilling (University of Colorado, workshop organizer), Maria Carmen Lemos (University of Michigan), Dennis Ojima (Colorado State University), Steve Pacala (Princeton University), Chris Potter (NASA/Ames), and Steve Rayner (James Martin Institute, University of Oxford). Together we developed a participant list representing the various fields and potential users of the information (see appendix III). In our case, the users we were targeting were primarily decision makers for science policy, in other words, program managers at the Federal level.

Our goal in developing the workshop agenda and approach was to create a dynamic exchange with a minimum of time spent passively listening to presentations. As a result, we did not have formal presentations, but rather discussion organized around the following four topics:

- What are the effective criteria for successful "usable science"?
- What has worked in creating science policies that result in 'usable science'?
- How is carbon cycle science currently being used?
- Democracy, public participation and equity in setting science agendas

Each participant was assigned a role to play in the agenda either as discussion "provocateur", "rapporteur" or respondent in a particular topic. Participants gamely accepted this structure, and as a result we were able to focus discussion on the heart of the issues.

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1. Climate Change Science Program Website: http://www.climatescience.gov/Library/stratplan2003/vision/overview.htm
Climate Change Research Initiative (CCRI) website explicitly focused on near-term support, of which NACP was a key component: http://www.climatescience.gov/about/ccri.htm

2. Many references available, some from the seasonal to interannual climate forecasting experience include: Pagano et al. 2002, Eakin and Conley 2002, Pulwarty and Redmond 1997, Letson et al. 2001, Pielke Jr. and Conant 2003, Lemos et al. 2002\

3. Reconciling Supply and Demand – Carbon Cycle Workshop Report: http://sciencepolicy.colorado.edu/carboncycle/workshop/

The latter half of the workshop was spent addressing nuts and bolts to form the heart of the findings and recommendations for this workshop. This discussion focused on the question: ***What are the essential elements of a "usable" carbon cycle science research agenda?*** The details were fleshed out in two sessions of discussion and drafting, the first focused on the elements of creating a research agenda for "usable" carbon cycle science and the second on implementation, gaps and needs, first steps, organizational needs and implications.

Because this structure did not allow for overview talks on aspects that were unfamiliar to some participants because of the very nature of the cross-disciplinary meeting, Lisa Dilling prepared a white paper to familiarize all participants with some of the background literature and foundational arguments that framed the workshop questions and approach (appendix IV). In addition, to help participants more quickly get to know each other, Ami Nacu-Schmidt compiled brief biographies for all participants that was shared in advance of the meeting (appendix V). Many participants remarked that they appreciated these biographies in advance.

Workshop Discussion Summary

1. Criteria for successful "usable science"

There was much discussion among participants as to what "usable science" means. In some sense, all science has the potential to be used—whether or not in the manner intended by the creators of the knowledge itself. Decision makers often use science to justify positions on issues already decided for other reasons, or to lend support and sharpen the debate. Indeed, even blatant "misuse" of science, for example, someone deliberately misrepresenting what a scientific piece of data actually means (for example, stating that the color red in satellite false color images means that the ground in on fire), is in some sense "use" of science. So, we must more clearly qualify what we mean here by "usable science" in a normative sense. By whose opinion or standards are we considering that science is usable? Are we, as scientists, open to changing the supply and how we create it, or are we strictly focused on increasing demand for what already exists?

If we had to characterize the normative stance of the workshop participants, it would be that usable science means that it is produced by some sort of mediated interface, is available to the potential users in a timely manner, and that its application or use leads to improved societal outcomes . Even this short statement contains within it a myriad of assumptions when one attempts to apply it in practice. Which users are to be targeted, given limited resources? Who gets to select the priorities for research? What do we mean by improved societal outcomes? We will return to these questions throughout this report. Timeliness is an important issue. Interestingly, information may not need to be perfectly accurate—sometimes relative information is useful as well. There are likely also many points along a decision process where information could be useful.

There are many specific examples that demonstrate how specific processes and new ways of operating may be necessary in order for research to be useful in different circumstances. The old concept of "throwing research results over the transom" to have them be picked up by society and used seems to no longer be valid in many cases. Creating usable science is a dynamic process that involves both researchers and stakeholders in the information—the research itself evolves and is changed by the interaction. Over the course of a project, directions and priorities may shift and new expertise may be needed as participants zero in on what is achievable and desirable from a decision making perspective.

Research that examines the use of information focuses on three general categories under which critiques fall: 1) data are not good enough, or relevant to the problem, or not being communicated well; 2) understanding the different categories of people who may be using information or not, and why; and 3) institutional barriers and constraints may be limiting uptake or implementation of new information. As scientists experiment with deliberately creating usable science, they have pursued different strategies to address these issues, whether explicitly or implicitly, and move forward. Even as it is difficult to define usable science, participants noted that it is still possible to develop processes that improve the chances that such research will indeed be useful. Characteristics of such processes include a functional interaction between researchers and potential users, a large investment of time to build trust, understanding and knowledge and a true commitment to potentially changing research direction based on that interaction.

Interactions for usable science may be envisioned at least two ways—what we might categorize as the "promotion of knowledge" approach and the "two-way assessment and interaction." In the former, researchers or scientists with information that they feel should be "usable" interact with potential users to persuade them to adopt the new information, perhaps tweaking or changing the knowledge as they interact. In the second mode, the line between providers of knowledge and potential users of knowledge might be more blurred, researchers are more open to creating knowledge of a different type or with different content than they might have envisioned going into the process. Such a process has been called "co-production of knowledge" for the sense that both researchers and practitioners contribute to the creation of new knowledge for use. It is clear that creating usable knowledge can be thought of as a dynamic process—a single "build it and they will come" model is widely seen as ineffective.

Do these processes of interactive knowledge generation result in more usable knowledge and "better" societal outcomes? The jury is still out on this question. The participants agreed that while the experience thus far seems to be promising, it was still unknown in an empirical sense whether or not these new ways of interacting between researchers and practitioners resulted in information being used more often or resulted in better societal outcomes. It turns out to be extremely difficult to measure or discern whether science was better used in one particular process compared to another.

So where do we stand in terms of creating usable carbon cycle science knowledge? Clearly there are pockets of use of carbon information—at the state level in California, Oregon and elsewhere, at the national level for UNFCCC negotiation, in some energy and utility corporations, in agricultural and forestry interest groups, and among non-governmental organizations involved in climate change issues and also those working toward biodiversity goals. Some participants suggested that the condition of the market and policy environment for carbon management with respect to climate mitigation will play a large role in determining the future demand for usable carbon knowledge. On the other hand, participants discussed at length the concept of "preparing the market" for carbon management—while federal policies may not be in place at the moment, there is interest at least in the private sector and among those who might be directly affected to lay the groundwork for later policies and markets by providing information now. Some of this groundwork may be in the form of promoting the use of existing information, whether for policy and incentive development, credit for voluntary action or competitive business strategizing. So carbon information is and may be used in this environment in anticipation of a future carbon market or policy.

There was also significant discussion of what usable carbon science might look like in the future. Until now, it is fair to say that the vast majority of carbon science has been focused on studying uncertainties in the global carbon budget, understanding processes related for sinks of carbon, and, more recently, apportioning sinks and sources of carbon to finer scale geographic regions. If we think of knowledge as somewhere along a continuum of scientific problem identification to social problem definition to developing solutions and acting on them, carbon science appears to be largely still within the area of scientific problem identification and elucidation. In order to move forward and create knowledge that might be of more direct short-term use to society, participants discussed the need to consider moving toward solution or option-based knowledge, which might inform societal alternatives for action. How might we provide information on consequences and impacts? On alternatives and adaptation? What is economically and socially feasible? Focusing on alternative generation helps to give direction to what types of science to involve in usable carbon science. A suggestion was made also that perhaps the carbon community could begin to interact more with the engineering and technological communities to move more toward this end of the spectrum. Are there lessons from how health research is organized that might inform how carbon science can add an applied component? Of course there are some areas of carbon research already that are quite applied, but there are missed opportunities and no organized strategy for how carbon science might become more usable. One option is to focus on and learn from groups already experimenting with usable climate science in other areas, such as the Regional Integrated Sciences and Assessments projects (RISAs), in order to build off their knowledge and expertise, while expanding their portfolio to include carbon. It is also clear that there is a delay effect when considering the creation and use of knowledge—what's in use now, for example, is what's already available. We can produce small tweaks in the next 4-5 years, but how do we plan now for generating knowledge that might be useful in the next few decades?

Finally, from a "philosophy of science" perspective, what is the scientist's goal in this, does she have a different notion of usable than the general public? Is it considered usable if someone takes the information provided and makes the decision the scientist would have made? Are we as scientists subconsciously hoping for certain of decision outcomes? Being self-reflexive as a community will allow much more transparent decisions as to what course of research to pursue and why.

2. What has worked in creating science policies that result in "usable science"

One participant laid out a helpful framework of three aspects of policies that are needed to encourage the production of usable science. First, successful policies must create a "mediated interface" between scientists and potential users of science. Both the mediated and interface aspects are important. These mediated interfaces might include an institution, a program, or a specific office. The National Institutes of Health, Offices of technology transfer at universities, and the Defense Advanced Research Projects Agency (DARPA) research programs of the Department of Defense are all examples of effective mediated interfaces. It is important not to bring users to the table naively, that is, without thinking through which users and for which problems, and in full knowledge of the need for the interaction to be mutually influential. Focusing on problems (such as cancer or detecting submarines) makes it more likely that research will be useful. Another suggestion, mentioned above, is to focus on providing options, not just information. Offering options and tradeoffs provides users with more usable knowledge rather than simply an overload of information.

The second aspect of policy frameworks for usable science is to focus on accountability for results. Becoming clearer on what is promised from science and who is served is necessary to increase accountability. The time frame upon which results will be judged is also important. For accountability to be practical, one must have reasonable expectations of success or at least check points for decision to continue or terminate should the pathway not seem to be particularly panning out. Simply saying that research is a long-term investment is not sufficient, as other policy choices could make similar arguments (e.g. long term investments in education, roads, and so on). Remember that here we are talking about research specifically aimed and justified for its ability to be useful to a specific problem—we're not trying to apply these metrics to "blue sky" or "basic" research that is just aiming to provide general knowledge for the future. Usable science is a companion to basic science, not a replacement or a substitute.

The third component of creating successful usable science policies is scientific leadership. This seems obvious, but without sincere leadership that attempts to "do the right thing" in creating the possibility for usable science to occur, it will not likely spontaneously occur, given the current status quo and inertia in the system. Being willing to consider genuine alternative institutional arrangements is a good start, as long as those arrangements are not merely token or purely for show.

Another participant emphasized the need to provide funding for usable science—the above issues are moot if there is no support or funding for it. One example of a newly formed program emphasizing creating usable science out of the National Aeronautics and Space Administration (NASA) data streams is the NASA Applied Sciences program. The NASA Applied Sciences program seeks to use NASA Earth Science to enhance the decision support tools of agencies and organizations that seek to partner with NASA for that purpose, including in the area of carbon management. Key elements in the approach NASA uses in Applied Sciences are to identify a decision support tool in use by the partner agency before beginning a project and benchmark the results of the enhancement decision support tool from the NASA input. Benchmarking describes and quantifies the performance of the tool with the enhancement in place and, in essence, demonstrates the reduction in uncertainty resulting from the enhancement. The NASA approach follows the first mode of science-user interaction discussed above (promotion of existing knowledge). The science is created following traditional scientific priorities, but then scientists work in partnership with potential users to look for opportunities to apply NASA data to specific problems. The users must have an existing decision support system to accommodate the information in question, and must show interest in the project from the get-go. So these projects do not create decision support systems, but rather look for opportunities to input or promote the use of science into existing decision support systems. While NASA has expressed interest in user input into prioritizing and selecting science missions to eventually serve societal goals and does work to assess user needs in mission design through interaction with the scientific community, this type of "end-to-end" approach with non-scientific end users has not yet been put into practice.

As far as carbon specific trends in the area of science policies that create usable science, it was felt that the current context for carbon management policies, i.e. that there was not great activity yet, very much affected the existing policies, institutions and strategies that might be followed. Because of the lack of clear policy signals, the full potential of carbon management is not likely yet realized. There are as yet very few mediated interfaces between potential users and carbon scientists—often individual scientists serve that role in an ad hoc basis. Some felt we were still therefore in a stage of "market preparation," where there was perhaps more effort in the way of promoting carbon information in various sectors. Participants felt that we as yet don't fully know what the decision tools might be, or what might be needed. Certainly there is also some use, for example, in California partnering with Department of Energy. However, as yet, without a strong demand sector, science policies specifically aimed at creating usable carbon science are not the dominant mode.

3. How is carbon cycle science currently being used?

Participants brought up examples of the current use of carbon cycle science in several instances. Use of carbon information is embedded in climate decision processes, as well as land use decisions, for example. These examples included international and national processes, local implementation of voluntary federal policy, private sector firms, and states such as California and Oregon. Certainly there has been use of carbon cycle science by nations and by the United Nations Framework Convention on Climate Change in order to comply with or set up rules for the Convention. Carbon science is used to help nations develop quality inventories, quantify uncertainties, and obtain a better understanding of carbon budgets for negotiating positions and compliance. At the national level, in the U.S., there is use of carbon information for crafting agricultural and farmland conservation policy, and at the local level information is used by those entities who are voluntarily reporting their emissions under Section 1605b of the Energy Policy act. This includes collaborative development, between university scientists and Federal agencies involved in land management (e.g. USDA's Natural Resource Conservation Service and the Forest Service), of on-line decision support tools for carbon management (COMET-VR, http://www.cometvr.colostate.edu; COLE, http://www.fs.fed.us/ne/durham/4104/1605b.shtml). Projects supported by NASA Applied Sciences in the carbon area include CQUEST (a model that can estimate the amount of carbon sequestered given a certain vegetation type and land use history), and other work to inform the 1605b voluntary emissions registry. In the private sector, participants discussed the example of BP/Amoco, a global fuel extraction and distribution company, which has acted internally upon carbon information generated by the Carbon Mitigation Initiative (of which they are a major funder) at Princeton University. At the state level, the examples of Oregon and California were discussed—they have used carbon science in their policy formulation such as in developing offset programs and crafting climate policy responses.

Participants also discussed a broad category of options that could be described as "potential future use" or trends in use. In this discussion, there was a fairly healthy tension between the use of carbon information as persuading, or convincing others that something should be done in general about climate change, and the need for a new focus on creating options and solutions for society to use in its response to the issue of rising carbon in the atmosphere. As one participant discussed this distinction-- "right now there is too much scolding, and not enough problem solving." Some time was spent to discuss the notion of "market preparation." Market preparation within the business sector involves working with decision makers such as executives, building capacity, understanding the potential reasons for engagement with the issue, such as protecting assets, identifying liabilities, seeking lucrative investments, gaining competitive advantage, and so on. The phase of market preparation is necessarily a two-way interaction, as scientists learn what decision makers are concerned with, and decision makers learn what science can provide. And of course many other sectors are similarly involved in "preparing the market" for responding to climate change, such as the religious community, states, non-governmental organizations, from whatever perspective they may come from. The notion of workable solutions is different than simply focusing on convincing a user that there is a problem to respond to in the first place. Providing options and alternatives enables a user more information and flexibility in deciding what might be possible to do in a given situation. Examples of such solution-oriented information include the intersection of energy and carbon issues, sequestration options, and other options that specifically address reduction in emissions.

A number of "conditioning factors" that affect the development of the use of carbon science in the future in the United States were discussed. What the rules and policy environment might be for garnering credit or receiving penalty for actions related to carbon is still not established. The call for usable science in the future is therefore highly dependent on the outcome of how such rules operate, if they are established. Of course there is much use of information to promote various actions or options, often in conflicting situations and using conflicting science—this is not the sense in which we are using the term "usable science".

Related to the lack of certainty on the policy environment of the future, at the local level, financial incentives are generally not yet strong enough to compel actions with carbon management as a primary goal. As economics are the first consideration for local users, this is likely to constrain the demand for carbon information at the local level until such time as these incentives might change. On the other hand, should markets or policies shift to more highly value active carbon management, actors may see a financial opportunity and may then preferentially seek out carbon information useful to them. Maintaining credibility with or garnering trust of persons is also a major factor in whether or not information is useful. If participants in the conversation do not trust that the person with information has their best interest in mind, it is unlikely that they will be open to considering, much less using the information. To return to the example above, if the conversation is about "scolding" with few if any options for the participants to consider, it is likely to be a relatively short one. Carbon information is, of course, only one of many considerations of actors who influence carbon management currently. As such, future use of carbon information will need to consider this multiple-constraint context. Finally, creating usable carbon information may require shifts and integration in the community that is knowledgeable about carbon management options, to involve not only atmospheric, oceanic, terrestrial scientists, but also economists, policy scientists and engineers.

One participant suggested exploring the potential user combinations possible by envisioning a three-dimensional diagram with 64 cells. One axis is type of organization, one axis is type of decision maker, and one is problem orientation, such as water management or agriculture. Such a diagram might be useful to identify the various cells, map them out, and discover what might be usable information for any one particular cell. Of course this would only be a suggestion to guide research, these cells would not be archetypes or specific. And of course, some cells might be more important for the issue than others.

4. Democracy, public participation and equity in setting science agendas

For natural scientists not accustomed to working with these issues, it might seem unusual to include the issue of democracy and public participation in dealing with the issue of the use of science. But, in a democracy where public funds are used to support science, where the implications of scientific results are often highly contested, and where the ramifications of science and technology are often not evident immediately, experience shows that democracy and public participation are essential to consider. An additional concern at play is the typical unequal access to information, particularly technical information. In many societies, technical knowledge often translates into power, if the society is a highly technocratic one. In selecting potential users of information, one might be tempted to pursue the "efficient" approach, that is, the approach that quickly connects up your information with people who can already use the information. Such an approach might exacerbate problems of inequity in society. Alternatively, one might be concerned about the equity of resources, and therefore focus on a more "distributional" approach, that takes into account whether information is uniformly available for use. Transparency and public participation are at least a start toward finding out how accessible science is and how it is being used to make decision making. Finally, for the topic of our conference, thinking about reconciling supply and demand for carbon information, the issues of democracy and equity appear almost immediately if one begins to discuss questions of potential users, and whom is to be served given limited resources.

There has been much research on the issue of public participation, although more experience in scoping and reviewing decisions, not necessarily participation throughout a research analysis. Models for participation include (in order of less time and cost to more time and cost): a) standard advisory committees (least involved, least transformative, e.g. EPA), b) committees with stakeholders (NIH with AIDS advocates, sense of transformation), c) negotiated rulemaking, d) deliberative polling (engage with scientific community, there is a change in values), e) multi-stakeholder advisory groups.

Some of the lessons learned from this research include: one size does not fit all; participation may vary depending on the stage of the process; participation in assessments is different than participation in decisions; demand and supply for participation involves incentives and concerns more than agencies would like, less than advocates would like; it is an evolutionary two-way process; public participants are experts in their own rights; leadership has a powerful influence; process does not bring consensus, merely clarifies points of view; and consider what participants get in return, sometimes they want to be part of an ongoing process.

Because carbon management in the U.S. has not yet really emerged into the public radar screen (a large majority of Americans do not know the term carbon sequestration or carbon capture and storage, for example), how to apply these lessons to carbon science and public use has not yet been explored. Perhaps the top-most question was "what is the problem"? Why might we want even want to consider public participation? What are the measures of success- do we know what a good process and a good outcome consist of? Who is included in the process? Is the problem intractable, or is it likely that, with time and effort, some resolution can be reached? More specifically, what is the role of public participation in science policies? In most contexts, science is largely internally self-governed by practicing or trained scientists. For example, the National Science Foundation is both an open institution, in that anyone can submit a proposal, as well as an extremely elite organization, in that only those proposals succeed that meet are judged meritorious by scientific peers, a highly selective process. If one is interested in producing outcomes with scientific knowledge that are of more use to society, is it therefore important to represent "society" somehow in the review, selection and prioritization process? How could this need to have public participation in science policies be accommodated practically, and what are the positives and negatives? Finally, what is the role of scientist in society? Scientists have sometimes emerged beyond their strictly academic or scientific role to raise an issue in the broader media, sometimes to no response, other times with great impact. Our discussion did not resolve these issues, but raising them early in the process of creating usable carbon science was thought to be important.

TOWARD A RESEARCH AGENDA FOR "USABLE" CARBON CYCLE SCIENCE

As many participants remarked, carbon cycle science is not starting from scratch in its endeavor to create "usable" knowledge. We can learn from other earth science examples, such as seasonal to interannual climate forecasting, and those examples farther afield, such as health, food safety, and so on. There are also fledgling efforts at creating usable carbon cycle science underway, at the state level, in agriculture, in forestry, and in carbon and climate modeling. But it is clear that there is potentially a large gap between our current scientific programs and the needs of society—a gap that could be filled by a dedicated program that deliberately supports the creation of usable carbon science. What would such a program look like? There are many options. Here we summarize some of the overarching elements that should be considered when creating such a program, followed by our assessment of the available models for such programs and their components. We conclude with a short section on "next steps."

Elements:

1. Clarify the goal

Before embarking on a program for usable carbon cycle science, it is important to clarify what the community and societal sponsors of research (e.g. governments) want to achieve. It is important not to skip this step and go directly to formulating a program. Clarifying goals allows one to identify the various values operating and in the end, design a much more effective program. For example, is the goal simply making better use of existing information, or does the goal extend to creating new information where needed? The answer will determine how much flexibility to build into the research agenda, who the players should be, and by what criteria progress will be evaluated. We suggest, as a starting point that the goal of a usable carbon science program could be "to produce knowledge in a mediated manner that is useful in a timely way to specific decision makers in specific contexts and enhances the ability of society overall to make good decisions with respect to carbon management." Obviously this goal would need to be further refined should such a program be considered for implementation in consultation with the various participants involved.

2. ***Keep societal stakeholders at the center***

   Because a usable science program, unlike basic science, focuses on application of knowledge in society in a relatively short period of time, keeping societal needs front and center in the program is paramount. There is a wide spectrum of potential users of information, and given that resources are limited, only certain stakeholders will be involved. The process of selecting stakeholders or justifying focus on any particular problems will need to be transparent and clearly justified. The involvement of non-researchers in the research process will require a mediated interface of some kind, whether a project contact, an existing boundary organization, or an office. Such an interface allows a more "iterative" process between researchers and stakeholders, which is often necessary for effective co-production of knowledge.

3. ***Allow dedicated "program" space and funding***

   Participants agreed that creating a usable carbon science program would build on existing programs, adding and extending them while maintaining feedbacks that informed the established basic science programs. Funding would be necessary to entrain researchers into this area, and projects could be selected through an "RFP" (request for proposal) process, although perhaps one with more flexibility for interdisciplinary, interprofessional research (e.g. scientists, engineers, and non-technical decision makers) than currently exists in the carbon landscape. The encouragement of linkages between science and technology programs was seen to be helpful.

4. ***Develop appropriate criteria to approach research***

   Discussion centered on allowing community flexibility in responding to the call for usable carbon science, while acknowledging that the evaluation process for proposed projects would need to build in perhaps different metrics in addition to traditional scientific ones, if indeed the outcome is to effectively meet the desired goal. If the criteria are specific to the ways, methods and outcomes of producing usable science, rather than being prescriptive of the users, tools and disciplines, then projects are able to be proposed in a creative manner that still meets the objectives of the overall program. Such criteria might include, does the project have an effective mediated interface between knowledge producers and potential stakeholders, or even does the project build in co-production of knowledge? What are the proposed deliverables of the project, do they attend to the desired goals of usable science? Participants noted that allowing maximum creativity in choice of problem and user would likely yield the earliest success in soliciting quality projects.

5. ***Foster novel mechanisms to evaluate success***

   One of the features of a successful science policy to create usable science is accountability, in other words, there are means to measure or document that the results of a project meet the goals of the overall program. All projects are in some sense accountable to their sponsors, but those that aim to be usable science may need to explore alternative mechanisms beyond simply counting peer-reviewed papers, conference talks, graduate students trained and the like. If the desired outcome is to produce usable science, then new ways of judging success toward this end will need to be described and implemented. This workshop did not specifically name these mechanisms, but several models exist for evaluating this type of work that could be looked to for a starting point for carbon cycle science.

Sample Models and Components:

Carbon cycle science likely has unique characteristics that may make it more amenable for one type of programmatic structure than another to create usable science. It was not clear to participants which models would be best, although clearly some are more likely to produce usable science than others.

Models:

- "Basic Science" or "Linear" Model: This model posits that science is produced by scientists in disciplines, largely separate from societal considerations. The results of science are then taken into societal decision making by other entities. This model has been extensively critiqued for its inefficiency and often inability to meet the current needs of society for information. Nonetheless it is a powerful model that permeates much of our science policy today.
- "Meditated" Model: This model suggests that the creating of usable science is "mediated" by a process, institution, or individual that deliberately connects and integrates the production of knowledge with the needs of society. These models can exist as boundary organizations (e.g. the Agricultural Extension Service) that do not do much research themselves but serve as two-way translators between entities, as research projects that have deliberately structured themselves to involve individuals from other institutions who might utilize information as part of the research process (e.g. several of the Regional Integrated Sciences and Assessment projects), or as whole programs that mediate the interface between society and researchers through deployment of resources and establishing criteria for success that include use of information in society (Climate and Societal Interaction program of NOAA, NASA Applications program). Such models may focus on a sector, a specific problem, on a level in society (e.g. state), or on a geographical region (e.g. the Southwest).
- "Stovepipe" Model: This model is not generally one that institutions seek to create, but is often the result of trying to categorize science into logical categories. In order to seek organizational practicality, projects may be divided into grouping based on discipline, sector, or region. This model is described here not as one to emulate, but simply to point out that mechanisms are needed to avoid the stovepipe model, especially in the area of usable science, as societal needs are often multifactor and decision makers must be able to make use of knowledge from a broad range of categories.

Participants also discussed some of the characteristics that should be considered if one desires to create a usable carbon cycle science program or entity. These include creating flexible mechanisms, at least a two-way flow of information between knowledge producers and users, if not fully integrated co-production of knowledge, and developing mechanisms to involve users in science policy execution, whether through aspects of setting the agenda for usable science, the process by which it is implemented, the prioritization and selection of activities, and the evaluation process. If possible, participants felt that continuous involvement or at least frequent opportunities for interaction was a key component. Interdisciplinarity was also deemed to be quite important for successful usable science activities. Processes should reflect an awareness of decision making in the "real world," bringing stakeholders or participants into the process of creating usable science early, and look forward to how information might continue to get out on a long term basis--in other words, how do projects transition to operations? In terms of who might be interested in this process it is important to consider multiple agencies as potential customers for information, as well as the community beyond the federal government. For practical implementation terms, options for usable carbon cycle science program might be structured so as to be implementable at different levels, depending on the level of resources and interest among potential sponsors. Partnerships of course were also quite important in order to be able to leverage resources, including in kind contributions.

Next Steps

Participants were enthusiastic about the many potential next steps that could be taken. These steps included inserting language into documents and processes that would ensure consideration of usable science activities. Processes at the international level in particular are looking for ways to improve the science-society dialogue (see for example InterAmerican Institute-IAI, Asia Pacific Network-APN, and the recent ICSU-International Council of Scientific Unions- Strategic Plan). It was suggested that perhaps the NRC could conduct a study of this issue modeled after the 1999 study led by Bill Easterling entitled "Making Climate Forecasts Matter."

In terms of written documents, it was variously suggested that a "one-pager," a synthesis paper and a white paper would be useful in different venues. Various science policy leaders within and without the agencies could be informed on the results of this workshop, with a short 1-2 page document and accompanying visits. Summaries to society journals, newsletters, bulletins, international program newsletters, etc., would help to build interest among the scientific community at large. Outreach beyond the scientific community of course is very important in diagnosing or establishing what society might need from carbon science efforts- this might include going to trade organization meetings, government association meetings, and writing articles of interest for those organizations.

Participants suggested a myriad of venues for discussing carbon information and entraining participants from different sectors who might be interested in usable carbon cycle science. These suggestions included the Western Governor's Association, various user groups, fire safety councils, local government, decision makers from regional databases, program managers, the Carbon Cycle Interagency Working Group, and so forth. There is a need to build interest and focus on concrete examples as this networking is accomplished.

Participants suggested that a two-week summer institute or perhaps a shorter one might be of interest to being to build a community interested in usable carbon science. Such an institute might include tutorial material, hands-on experience, and involve direct experiences with intermediaries. Visitors and speakers could be brought in for a few days if they couldn't make the whole time. Such an activity would need an aspect of continuity as well—one shot activities don't generally work as well. Follow-through could include creating a network of individuals that could be a source of interaction for the future. Participants were quite enthusiastic to continue dialogue and effort for this topic in the future.

Appendices 1: Workshop planning committee members

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carbon cycle science, carbon management

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carbon cycle science, corporate use of carbon information

Chris Potter
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carbon cycle science, non-governmental and resource manager use of carbon information

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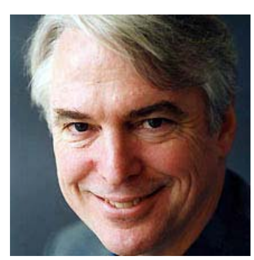
science technology and environment, global change



APPENDICES 2: AGENDA

Monday
June 13th, 2005

8:00 - 9:00 am	Continental Breakfast provided at Benson 380 Welcome, Introductions
9:00 - 9:10 am	U.S. carbon cycle science overview, context and charge to the workshop – Dilling
9:30 - 11:00 am	Discussion: What are the effective criteria for successful "usable science"? (Discussion leaders: Lemos, Ray, Glantz; Rapporteur: Mooney)
11:00 -11:15 am	Break
11:15 -12:30 pm	Discussion: What has worked in creating science policies that result in 'usable science'? (Discussion leaders: Rayner, Pielke, Sheffner; Rapporteur: Wickizer)
12:30 -1:30 pm	Lunch (provided)
1:30 - 2:45 pm	Discussion: How is carbon cycle science currently being used? (Discussion leaders: Law, Pacala, Potter; Rapporteur: Ojima)
2:45 - 3:00 pm	Break
3:00 - 4:00 pm	Discussion: Democracy, public participation and equity in setting science agendas (Discussion leaders: Goldstein, Wilbanks, Craig; Rapporteur: Laird)
4:00 - 5:30 pm	'First take' discussion: What are the essential elements of a "usable" carbon cycle science research agenda? (Rapporteurs from earlier sessions provide initial thoughts; Provocateurs/Respondents: Pfaff, Chen, King, Paustian; Rapporteurs: Logar, Johns)
6:30 pm	Reception and Dinner at Dolan's Restaurant in Boulder. Dolan's, within walking distance from the hotel, is located at 2319 Arapahoe Avenue. See map on page 3.

Tuesday
June 14th, 2005

8:00 - 8:30 am	Continental breakfast provided at Benson 380
8:30 - 10:15 am	Discussion and Drafting: Creating a research agenda for "usable" carbon cycle science: Phase 1- Elements (Moderator, Dilling; Rapporteur, Averill)
10:15 - 10:30 am	Break
10:30 - 12:00 pm	Discussion and Drafting: Creating a research agenda cont.: Phase 2- Implementation, gaps and needs, first steps, organizational needs and implications (Moderator, Dilling; Rapporteur, Maricle)
12:00 - 1:00 pm	Lunch (provided)
1:00 - 2:00 pm	Finalize outline, review next steps for follow-up
2:00 pm	Adjourn

Workshop Roles:

- Discussion leaders: Think about question ahead of time and prepare some initial informal thoughts on question, provoke discussion if necessary, please do not prepare overheads or powerpoint
- Rapporteurs: Think about question, take notes in your session, participate in discussion, be prepared to report summary of discussion to group succinctly at end of first day, try to represent all views
- Provocateurs/Respondents: Participate in discussion, listen throughout the day, think about question of “first take” on “usable” carbon cycle science agenda, respond to summaries of discussion, provoke discussion if necessary

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APPENDICES 4: ADVANCE WHITE PAPER

Decision Support and Carbon Cycle Science:

Practical strategies to reconciling the supply of and demand for carbon cycle science

White paper in rough draft form to spark discussion at workshop June 13-14, 2005

Prepared by Lisa Dilling

ABSTRACT

The Carbon Cycle Science element of the Climate Change Science Program (CCSP), especially the North American Carbon Program (NACP) has as a primary goal providing near-term information of use to decision makers[4]. However, as demonstrated by several other areas of emphasis in Earth science, generating information that is useful to anyone outside of the scientific community does not automatically result from conducting scientific research. Specific findings include: information provided is not needed; information is needed but not provided; information lacks regional specificity; inaccessible presentation; poor communication; lack of trust in information or deliverers; institutional constraints prevent use of new information; and so on[5]. The concept of managing carbon is relatively new in the spectrum of managing natural resources or environmental issues—while carbon management has been discussed for merely a few decades, water, land and marine resources have been managed by society for centuries. The carbon cycle science community therefore does not have wealth of experience internally from which to draw upon in trying to develop a scientific agenda that will successfully meet the needs of decision makers. Preliminary evidence suggests that carbon cycle science is not currently meeting some important needs ("missed opportunities")[6]. There is therefore a need to foster an interested community of researchers and develop a research agenda with the ultimate aim of improving the usefulness of carbon cycle science for the broader community of decision makers.

INTRODUCTION

As carbon cycle science has become more organized in the United States, it has been repeatedly justified by statements that the science conducted in the program will be useful in supporting decision making or informing policy. With the recent emergence of carbon cycle science over the past several years as a prominent element of the U.S. Global Change Research Program, the Climate Change Research Initiative and now the Climate Change Science Program, this goal has been reaffirmed (see Text Box 1).

4. Climate Change Science Program Website: http://www.climatescience.gov/Library/stratplan2003/vision/overview.htm. Climate Change Research Initiative (CCRI) website explicitly focused on near-term support, of which NACP was a key component: http://www.climatescience.gov/about/ccri.htm.

5. References include: Pagano et al. 2002, Eakin and Conley 2002, Pulwarty and Redmond 1997, Letson et al. 2001, Pielke Jr. and Conant 2003, Lemos et al. 2002.

6. Reconciling Supply and Demand – Carbon Cycle Workshop Report: http://sciencepolicy.colorado.edu/carboncycle/workshop/.

Text Box 1. Carbon cycle science has been organized for the past 15 years under the U.S. Global Change Research Program and later, the Climate Change Science Program. These programs have affirmed the goal of producing "usable" science, as has research planning documentation for the carbon cycle element itself. Key milestones from various policy instruments and scientific community planning documents include:

1990: U.S. passes Global Change Research Act creating the US Global Change Research Program (USGCRP) to produce "usable information on which to base policy decisions relating to global change.[7]"

1999: A U.S. Carbon Cycle Science Plan calls for "coordinated rigorous, interdisciplinary research that is strategically prioritized to address societal needs" and states that "the planned activities must not only enhance understanding of the carbon cycle, but also improve capabilities to anticipate future conditions and to make informed management decisions" (Sarmiento and Wofsy, 1999).

2001: U.S. Administration announces Climate Change Research Initiative, of which carbon cycle science is highlighted as one of only a few initiatives to "best support improved public debate and decision making in the near term[8]."

2002: The North American Carbon Program Plan (NACP) seeks "scientific understanding…to meet societal concerns and to provide tools to policy makers," specifically "to inform future decisions on policies to reduce net emissions of CO2 and CH4, and to enhance sequestration of carbon through land management or by other means" (Wofsy and Harriss, 2002).

2003: U.S. Administration reorganizes USGCRP under the Climate Change Science Program "to provide the best possible scientific information to support public discussion and decision making on climate-related issues." Decision support added as key element of Strategic Plan[9].

2004: Draft NACP Science Implementation Strategy has one of its four major research questions: "How can we enhance and manage long-lived carbon sinks ("sequestration"), and provide resources to support decision makers? ("Decision support")[10]."

It is therefore clear that the intent of recently organized carbon cycle science programs is to produce information that supports decision making, rather than simply being basic research. What is less clear are the details of how carbon cycle research is being conducted so that it does in fact support decision making. The program documents are not specific as to which decision makers are to be supported, at what scale, and for what types of decisions.

There does not appear to be a dedicated part of the integrated U.S. carbon cycle program focused on understanding how to conduct carbon cycle research so that it will be of use to decision makers (although for some related activities in NASA and USDA see later discussion). This may reveal a very common approach to providing information to users

7. http://www.gcrio.org/gcact1990.html. For early evaluation of USGCRP with respect to "usable science" see: Pielke Jr., R. (1995) and Pielke Jr., R. and M. Glantz (1995).

8. http://www.climatescience.gov/about/ccri.htm.

9. http://www.climatescience.gov/Library/stratplan2003/final/default.htm.

10. http://www.carboncyclescience.gov/nacp-sis-may04draft.pdf.

outside the scientific community. The approach has been called by various names—the "linear model", the "loading dock", and several other monikers. What it distills to, in essence, is the belief that science should be conducted fairly independently from societal concerns, and the use of any scientific results by society happens somewhat automatically as a matter of course over time[11]. No explicit mechanism is provided for understanding what information might be of use, or who users might be. The argument for the value of this approach is that science produces its best results when driven by curiosity alone, and that societal demands would detrimentally impinge on the outcomes of scientific research (Bush 1945).

For truly basic research, research that is advancing the frontier of knowledge solely for its own sake, being driven by scientific curiosity alone is likely a fine approach. But for providing information that specifically addresses societal need, it is questionable whether basic research devoid of societal connection is a particularly effective mechanism to meet that goal (Stokes 1997). Previous research in policy-relevant scientific issues such as acid rain, ozone depletion and water management has revealed that providing policy-relevant scientific information is a complex and delicate process (Russell 1992, Parson 2003, Herrick and Jamieson 1995, Pulwarty and Redmond 1997, Pulwarty and Melis 2001, Pielke and Conant 2003, Jasanoff 1990). If deliberate, ongoing mechanisms are not put in place to connect the scientific priority setting process with societal goals, research will tend to proceed on its own assumptions about what might be useful, perhaps only to find over time that its results are not very useful for decision-makers (Russell 1992, Stokes 1997).

Even research which has in mind a societal goal, such as improving farmers' ability to respond to variability of water availability and temperature fluctuations, has been shown to be less than effective at meeting those goals when the linear model approach has been followed (Stern and Easterling 1999). The climate variability community has had perhaps the most experience of the communities within the Climate Change Science Program in trying to understand how its research is or is not useful, and how to improve that situation. This is partially due to the discovery in the 1980s and 1990s that the El Nino Southern Oscillation (ENSO) might be somewhat predictable in advance, and, because of its teleconnections throughout the world, scientists hoped that this new knowledge might be useful to farmers, water managers, and others whose livelihood is vulnerable to a fickle climate[12]. An explosion of effort in climate science revealed the existence of other climate modes, such as the Pacific Decadal Oscillation, and the Arctic Oscillation or the North Atlantic Oscillation, and paleoclimate records made it possible to guess at the variability of ancient climates.

Three programs emerged in the mid 1990s that explicitly sought to make use of this new knowledge—the Human Dimension program, the International Research Institute for Climate Prediction (IRI) and the Regional Integrated Sciences and Assessment (RISA) program[13]. These were initiated as experiments within an agency heavily invested in the physical sciences of climate prediction and diagnostics, the National Oceanic and Atmospheric Administration. Although very different in nature to carbon cycle science research, research from these programs can provide lessons on how to conduct research so that it will be useful to constituents.

It was postulated by scientists that seasonal-to-interannual climate forecasts would be useful to sectors of society because the forecasts have a certain degree of skill in predicting wetter or drier conditions on average a season to a year in advance (Stern and Easterling 1999). In practice, however, several studies have found that climate forecasts are used only in very limited ways at present and therefore do not reach their full potential due to various factors. Regional

11. The linear model was advanced by Vannevar Bush in 1945 when advocating for funding for basic research in post-WWII America.

12. For examples of ENSO's impacts, see Glantz MH. 2001. Currents of Change: Impacts of El Niño and La Niña on climate and society. Cambridge University Press, UK. 252 pp.

13. IRI website: http://iri.columbia.edu/, RISA website: http://www.ogp.noaa.gov/mpe/csi/risa/.

specificity, evaluation of accuracy (to enhance credibility), and format used for presentation are deemed critical to enhancing the usefulness of forecasts in the Southwest U.S. for water management (Pagano et al. 2002). Climate information could be more useful if combined with other types of information that dominate the decision-making process such as market, policy and other economic information (Eakin and Conley 2002). In a study of salmon restoration in the Pacific Northwest, Pulwarty and Redmond (1997) found that forecasts were not used, even though theoretically an accurate forecast of stream runoff volume and timing and other features affected by climate would save money and water resources. In this and other cases, the use of forecasts was constrained by poor communication, inaccessible presentation, and lack of specificity to user location (Letson et.al 2001, Pielke and Conant 2003). The critical recommendation derived from these cases on how to improve such situations comes down to this: "the utility of forecasts can be increased by systematic efforts to bring scientific outputs and users' needs together" (Stern and Easterling 1999).

Carbon cycle science is of course different than climate variability studies, but certainly some key parallels can be drawn. Carbon cycle science has gained prominence in the past few decades not only for its fundamental contribution to understanding earth system dynamics and ecosystems, but also because of the increasingly clear impact of CO_2 emissions on the climate and potential links to decision making. If the finding holds true for carbon cycle science as it has for climate variability studies that "scientific outputs and users' needs" must be brought together in order to make scientific research more usable, then clearly much work remains to be done.

Designing a carbon program to produce "usable science"

How might one define "usable science"? Definitions used thus far place the character of usable science squarely in the realm of meeting users' needs while maintaining the high quality of rigorous scientific research (Glantz 2001). Lemos and Morehouse suggest that "the knowledge produced should directly reflect expressed constituent needs, should be understandable to users, should be available at the times and places it is needed, and should be accessible through the media available to the user community" (Lemos and Morehouse 2005). They define usable knowledge as "that which can be incorporated into the decision-making processes of all stakeholders and which enhances their ability to avoid, mitigate or adapt to stressors in their environment".

A recent National Academy of Sciences panel synthesized lessons learned from what they called "knowledge-action systems" in a specific area of climate variability studies, seasonal to interannual climate forecasting (NRC 2005). They summarized components of effective systems into six main themes: 1) projects develop a problem definition that is collaborative, but user driven; 2) inclusion of participants in the project along the continuum from decision maker to knowledge producer; 3) involvement of appropriate boundary organizations and intermediaries; 4) adopting a learning orientation; 5) appropriate mix of funding partners and instruments; and 6) long term investments in capacity.

It therefore seems clear from these studies and others that creating usable science involves a two-way interaction between scientists and users of scientific knowledge. But which users, and at what scale? How does one select users, and what are the implications of selection of some users over others? And who does the selecting of users—the agency funding the research? The principal investigators? Congress? At what stage are users involved? In the writing of the proposal? Within the first year? In the priority setting process of the agency issuing a call for proposals? What happens if various users' needs are in conflict and resources are limited? Whose priorities are followed, and by what process? These questions go to the heart of priority setting in scientific agendas and the role of public participation in science. Corollary topics are the issue of the distinction between science as a public or private good, and where it is appropriate to allocate public dollars to users needs versus letting users create their own knowledge as they need. In designing a usable science program, it is important to make clear the assumptions and process used to make decisions on these issues.

Moving toward usable science also carries with it several differences in the metrics, reward structure and accountability of projects. As described by Nowotny et al. (2003), this type of knowledge production by definition is more socially distributed, application-oriented, transdisciplinary and subject to multiple accountabilities. Rather than being subject only to standards of peer-review, science produced for use outside the scientific community is also accountable to the users it aims to serve. These multiple accountabilities combined with the transdisciplinary nature of the work can make it difficult for new researchers aiming to make a career in this type of work (Lemos and Morehouse 2005). Non-traditional products such as face-to-face interactions may be more valuable to users than traditional deliverables such as journal articles. The time commitment involved in interactions with users and working in an interdisciplinary environment on longer time scales can be at odds with the reward structure of disciplines that many researchers still experience. Criteria for developing and evaluating usable science projects must therefore take into account these realities. How are these programs evaluated? What does success look like for a usable science program?

A host of accompanying science policy and institutional questions are also associated with designing a usable science program. Some of the questions to consider include: How can a program place a premium on flexibility and responsiveness to users while still managing and evaluating a research program? If for example, projects are to place a priority on joint problem definition between users and scientific researchers, at what point does that problem definition take place? How flexible can the selection process be to allow the evolution of the appropriate team to address users' needs as they become clearer throughout the project? Are funders able to put in place non-traditional metrics that value outcomes with respect to decision support and use of information, and how should such metrics be determined? If the carbon cycle community is relatively new to this concept of usable science, what is the most appropriate sequence or type of program that would allow experimenting in the most efficient, effective way?

Implementing a usable carbon cycle science program has several implications from an institutional perspective. The "knowledge-action systems" studied by an NRC panel suggest that institutions built to conduct usable science must have some stability and continuity, and yet incorporate mechanisms to maintain innovation (NRC 2005). There are also implications for the science policies and the institutions that fund usable science. Because the concept of usable science involves both a user and scientific perspective, it might be necessary for existing agencies to examine their methods for designing programs, perhaps even to the point of revisiting missions, and negotiating roles between agencies.

As part of designing a deliberate usable carbon cycle science program, it may be instructive to consider the scale of programs organized to provide usable science, and the source of funding. Most carbon cycle science is currently funded at the Federal level, through Congressional appropriations. One might consider how (and whether) funding at the national level can appropriately prioritize and develop usable carbon science programs, or if innovations must occur to empower users at different scales to influence priority setting for usable science. Certainly, while the scale of scientific efforts ranges from the global carbon cycle to sub-meter scale plot studies, much less is known about the scale at which users need carbon cycle science (Dilling et al. 2003). The private sector also plays a role in the funding of carbon cycle science, although this is by definition funding activities that are most suited to needs of each individual company. In Australia, an innovative model has blended together private and public sector funds to provide research and technology development activities (NRC 2005). The unique combination of partners ensures that there is active participation and development of research priorities incorporating a user perspective.

The thought of designing research agendas by including non-scientists in their formulation goes against the cultural practices of many established scientific institutions, yet there are signs that more and more science is being done in this fashion. In the era of adaptive management, applications, assessments, "decision support," and co-production of knowledge, it seems inevitable that programs who aim to serve societal needs will need to rethink their processes for establishing research priorities (Sarewitz and Pielke, 2005). Clark and colleagues have examined the process for conducting assessments, which is one method for connecting scientific results to societal need, and established that three main conditions must be satisfied: credibility, legitimacy and saliency (Cash and Clark, 2001 and Cash et al. 2003). These notions apply to assessments per se, but may be of use in designing the research agenda itself as well.

Existing Programs

Currently, carbon cycle science is funded by at least 6 agencies at the Federal level, each with their own specific mission and culture of operation. These include NASA, NSF, DOE, NOAA, USGS, and USDA. A common denominator of the research conducted by or through each agency is that the scientific peer review factors heavily into the selection and evaluation of projects, reflecting the high priority of scientific merit as a criterion. Beyond that, there are significant differences—NASA and NSF have a mission of basic research, although NASA's research is targeted to space-based missions, and both agencies state that their mission includes the use of their research by society (NSF calls this out in its "broader impacts" criterion). DOE has a long history in sponsoring carbon cycle science research, and currently targets certain investments, such as the network of flux tower sites and modeling capability, as well as now carbon sequestration studies. NOAA primarily invests in atmospheric and oceanic monitoring, with some forays into modeling and projects related to integrated carbon cycle science. USGS has a relatively small program, focusing on a regional carbon studies in the Mississippi basin. USDA traditionally has done scientific research in support of its mission to help agricultural and forestry producers. In recent years, this work has been augmented to provide insights on carbon budgeting and sequestration (e.g. converting forest productivity measurements to carbon stocks, measuring carbon fluxes from and storage in agricultural soils).

A brief glance through the agency programs that dominate funding of the carbon cycle science program (NASA, NOAA, NSF, and DOE[14]) reveal only two potential programs that are specifically geared to forming a connection between carbon science and partners outside of the agency—that of the NASA applications program and the USDA efforts[15]. NASA's Applied Sciences Directorate maintains application programs focused on several national priorities, including carbon management, and is "tasked to provide societal benefits through application of ESE [Earth Science Enterprise] research and technology[16]". Two projects examining carbon management were also funded through the recent interagency carbon NASA Research Announcement (NRA)[17]. These programs appear to be narrowly focused on enhancing the use of NASA-generated data and models, but may provide some insight into the connection of certain types of science to decision-making that may be applied to the broader program. The USDA, about 6% of the national budget allocated to carbon cycle science under the Climate Change Science Program, through virtue of its mandate to produce information of benefit to agricultural and forestry users, may have specific mechanisms to solicit needs of users with respect to carbon cycle science.

Whether these efforts are constructed to produce usable science remains a question for further research and evaluation. Even if perfectly meeting their stated goals, they would only cover two aspects of the problem, approaching it from opposite sides—one from the side of trying to find users for a specific product, remotely-sensed data—and one looking specifically at what agricultural and forestry users might need. Each is incomplete by comparison to a working

14. National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, National Science Foundation, Department of Energy

15. Dilling, 2005. The supply of carbon cycle science. Paper in preparation. Online at: http://sciencepolicy.colorado.edu/carboncycle/workshop/supply_side_ccs_LD.pdf .

16. http://www.asd.ssc.nasa.gov/default.aspx.

17. http://research.hq.nasa.gov/code_y/nra/current/NRA-04-OES-01/winners.html.

definition of usable science. The design of an environment to enable the production of usable science needs to provide the maximum flexibility for exploring the needs of users in the context of available science—in other words being open to the range of potential users and needs.

The current use of carbon cycle science

I am not aware of a systematic survey of the use of carbon cycle science across users, so this discussion will necessarily be incomplete and anecdotal. A recent workshop, intended to make a start at reconciling supply and demand for carbon cycle science, concluded that indeed there was some use of carbon cycle science, but also several "missed opportunities"[18]. The workshop also raised the issue of whether current demands for carbon cycle science were indeed "the right" demands, and how to resolve potential conflicts in demands for research from different stakeholders.

At the international level, there is a clear demand for carbon cycle science, in the form of the Subsidiary Body for Science and Technological Advice (SBSTA) of the Framework Convention on Climate Change (FCCC). This body regularly submits requests for assessments of various aspects of climate change science to the Intergovernmental Panel on Climate Change and subcommittees, who compile reports on issues such as additionality and separation for carbon sinks, verification and reporting measures, forestry, land use and land cover science, and so on (footnote website and check process). It is perhaps less clear how this information makes its way into the policy process of the Framework Convention on Climate Change, and certainly this information is joined by a myriad of information sources with particular agendas at the various conferences of the parties, etc.

At the national level, a recent example of the demand for information occurred in the formulation of the U.S. position on post-Kyoto negotiations, where very detailed assessments of the current forest stocks and capabilities for land use and land management were solicited and used by the White House and agency policy teams working on the issue during the Clinton administration (citation, personal communications). In the current administration, the guidelines for voluntary reporting of emissions are currently being revised, and one might hypothesize some use of science in that process. Numerous bills have emerged in Congress related to carbon sequestration, and climate mitigation[19]. It would be interesting to know what, if any, carbon cycle science information was used in the formulation of these bills. Use of information at the political level is one very specific circumstance, although with potentially a wide-ranging impact, but the question remains as to what priority the national level should play as compared with user needs at the local, state level, private sector or other non-governmental level.

Another unknown within the carbon cycle science community is how much information on carbon cycle science is used at the state level. States are moving forward with climate policies, some of which involve references to carbon (such as carbon trading in the New England states, or reducing carbon emissions).

Anecdotal evidence from the local level suggests minimal usability of current carbon cycle science produced at the national level, beyond perhaps of the "Mauna Loa" CO2 record as a motivating icon and symbol of the importance of action[20]. In some cases, cities interested in their carbon footprint have taken steps to generate their own datasets[21]. Research suggests that cities often promote climate mitigation measures, even those related to carbon, for other reasons than climate (e.g. energy efficiency, cost savings, the appearance of being a "pioneer"), complicating interpretations of

18. Reconciling Supply and Demand – Carbon Cycle Workshop Report: http://sciencepolicy.colorado.edu/carboncycle/workshop/ .

19. E.g. McCain-Leiberman, and over 50 bills from the House and Senate related to carbon sequestration, mostly sponsored by members from agricultural states.

20. Reconciling Supply and Demand – Carbon Cycle Workshop Report: http://sciencepolicy.colorado.edu/carboncycle/workshop/.

21. Cities for Climate Protection campaign, International Council of Local Environmental Initiatives. http://www.iclei.org/co2/.

local carbon mitigation efforts (Bulkeley and Betsill 2003).

Corporations interested in options for carbon sequestration and alternate energy pathways have invested significant resources in at least two initiatives focused on carbon at universities—the Carbon Mitigation Initiative at Princeton University funded by BP/Amoco and Ford, and the Global Climate and Energy Project at Stanford University funded by a consortium of corporations[22]. Other corporations employ in-house staff scientists to perform analyses as well.

Summary and Open Questions

The goal of the workshop that this paper was prepared for is to develop a research agenda for how the carbon cycle community might design a usable carbon cycle science research agenda. A research agenda or plan might include the following elements: 1) setting the stage, or defining the problem to be addressed; 2) outlining the elements necessary to address the problem, including methodologies as well as institutional capabilities; 3) implementation, starting with a survey of what is already in place; 4) identifying gaps and needs (by comparing 2 and 3); and 5) identifying any organizational recommendations, and especially prioritization of first steps.

The workshop agenda is organized into five main questions/discussion periods which should focus us on the first stage of evolving elements of a research agenda. The discussion can take off from ideas discussed in this paper, as well as bring in completely new ideas that have been neglected here. The questions are:

1. What are the effective criteria for successful "usable science"?;
2. What has worked in creating science policies that result in "usable science"?;
3. How is carbon cycle science currently being used?;
4. What's the role of democracy, public participation and equity in setting science agendas?;and
5. What are the essential elements of a "usable" carbon cycle science research agenda?

We have deliberately brought together members of the carbon cycle science community, the climate variability user interaction community, and the science policy community to foster a rich dialogue and sharing of experiences. In addition to considering what lessons might transfer across to the carbon community, we might also consider the ways that such experiences might not apply, or might need to be modified. In what ways is the carbon cycle situation different and similar? Finally, we might also explore how carbon cycle science as an organizing concept may need to adjust to prioritize a user perspective rather than a scientific one.

The time is ripe for research on how to conduct usable carbon cycle science. Science policies indicate an increasing emphasis on usable science and broader impact. The conduct of science itself can benefit from clear strategies for how to approach usable science, increasing the value both of basic research and research conducted in service to societal goals. The increasing interest in carbon management, climate mitigation, and multiple stressors in the environment indicate potential demand from society. The challenge of usable carbon cycle science awaits.

22. Websites: http://www.princeton.edu/~cmi/ and http://gcep.stanford.edu/ .

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Appendices 5: Participant biographies

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Marilyn Averill is a doctoral student in Political Science at the University of Colorado and holds Master's degrees in Public Administration (Kennedy School of Government) and Educational Research (University of Colorado). Her current interests focus on international environmental governance, the politics of science, and science and technology policy. She has served as a teaching fellow for courses in "Environmental Politics," "Mitigation of Climate Change," and "Thinking about Thinking" at Harvard University, but still is rarely able to type the word "environmental" correctly. She worked for eight years as an attorney with the Office of the Solicitor at the U.S. Department of the Interior providing legal advice on natural resources and environmental issues to the U.S. Fish and Wildlife Service and the National Park Service.

Robert Chen, bchen@ciesin.columbia.edu
Center for International Earth Science Information Network, Columbia University

Dr. Chen is CIESIN's Deputy Director and a Senior Research Scientist. He manages the Socioeconomic Data and Applications Center (SEDAC), a data center in NASA's Earth Observing System Data and Information System. He is currently Secretary-General of the Committee on Data for Science and Technology (CODATA) of the International Council for Science (ICSU). He is an ex officio member on both the U.S. National Committee for CODATA of the U.S. National Research Council and the Task Group on Data and Scenario Support for Impacts and Climate Analysis (TGICA) of the Intergovernmental Panel on Climate Change (IPCC). Dr. Chen serves as CIESIN's Technical Representative to the Open Geospatial Consortium (OGC) and participates in the U.S. Federal Geographic Data Committee (FGDC) Historical Data Committee. He is also a member of the Scientific Advisory Council of the Meadowlands Environmental Research Institute (MERI) of the New Jersey Meadowlands Commission. In the past, he has served as chair of the NASA Distributed Active Archive Center (DAAC) Alliance and as a member of the Executive Committee of the NASA Earth Science Information Partner (ESIP) Federation.

At Columbia University, Dr. Chen is a member of the Working Group on Science & Technology Recruiting to Increase Diversity (STRIDE), part of the Earth Institute (EI) ADVANCE Program. He serves on steering committees for the EI Climate and Society Cross-Cutting Initiative and the Center for Hazards and Risk Research (CHRR). In addition to his role as SEDAC Manager, Dr. Chen has managed several cooperative agreements with the FGDC on spatial data management and a project on managing geospatial electronic records with the National Historical Publications and Records Commission (NHPRC). He recently completed a major collaborative project on the assessment of global natural disaster risks with the CHRR, the Hazard Management Unit of the World Bank, and other partners. Dr. Chen has also coordinated CIESIN's spatial analysis and mapping support to the Millennium Development Project led by EI Director Jeffrey Sachs and oversees other projects on poverty mapping, sustainability indicators, and public health applications of Earth science data.

Prior to joining CIESIN, Dr. Chen served on the faculty of the World Hunger Program at Brown University. He has held research fellowships at the National Center for Atmospheric Research in Boulder, Colorado, the International Institute for Applied Systems Analysis in Laxenburg, Austria, and the National Research Council in Washington DC. He has served on the Steering Committee of the U.S. National Oceanic and Atmospheric Administration (NOAA) Postdoctoral Program in Climate and Global Change and on the Committee on Standards for Geographic Data of the Association of American Geographers. He received his Ph.D. in geography from the University of North Carolina at Chapel Hill and holds Masters and Bachelors degrees from the Massachusetts Institute of Technology.

Rachel Craig, rcraig@nsf.gov
Biogeosciences and Carbon Cycle, National Science Foundation

Rachael Craig is program director at the National Science Foundation for Carbon Cycle and Biogeosciences. She manages the Integrated Carbon Cycle Research Program and the Biogeosciences program. Both of these are programs that span the Directorate for Geosciences. She also is team leader for the Biocomplexity program Coupled Biogeochemical Cycles which is an NSF-wide program involving multiple directorates. In her role as ICCR director Rachael serves as the NSF representative to the Carbon Cycle Interagency Working Group which acts to coordinate the research of multiple federal agencies in carbon cycle research. She also serves as team member for the NSF programs in Environmental Molecular Science Institutes, Ecology of Infectious Diseases, BE Dynamics of Coupled Natural and Human Systems and, in Water Cycle.

Lisa Dilling, ldilling@cires.colorado.edu
Center for Science and Technology Policy Research, University of Colorado

Lisa Dilling studies how to develop science policies to support the use of climate-related research in decision-making. Lisa Dilling, a CIRES Visiting Fellow with the Center for Science and Technology Policy Research, received her Ph.D. in biology from the University of California-Santa Barbara. She spent 6 years in Washington, DC where she managed and expanded a program in integrated carbon cycle research for the Climate and Global Change Program of the National Oceanic and Atmospheric Administration, and co-developed a national interagency program to study the integrated carbon cycle that links together relevant research in 6 Federal agencies for the U.S. Global Change Research Program (now the U.S. Climate Change Science Program). She then spent two years as an interdisciplinary scientist with the Environmental and Societal Impacts group of the National Center for Atmospheric Research, working on the connection of carbon cycle science to policy, communication for climate change, and scales of decision making. Her current research at the Center focuses on the use of information in decision making and science policies related to climate and, in particular, the carbon cycle.

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School of Natural Resources and Environment, University of Michigan

Maria Carmen Lemos is Assistant Professor of Natural Resources and Environment at the University of Michigan. She is also a Senior Policy Analyst with the Udall Center for Studies of Public Policy at the University of Arizona where she develops research initiatives in the U.S-Mexico border. Her research focuses on the human dimensions of global climate change, especially the co-production of science and policy, the role of technocrats as decisionmakers, the use of seasonal climate forecasting in drought planning and water management, the role of stakeholder-driven science in producing usable knowledge, and the broader social and political impacts of the use of technoscientific knowledge in policy making. She was part of an OGP/NOAA funded interdisciplinary project on the socioeconomic and political implications of the use of seasonal climate forecasting on drought-relief and agricultural policymaking in Northeast Brazil. She is currently the PI of two other grant proposals-funded by NSF and NOAA-to understand institutional opportunities and constraints for the use of techno-scientific information, especially seasonal climate forecasting, in water management in Brazil and Chile. Prof. Lemos holds a PhD and a MSc. in Political Science from the Massachusetts Institute of Technology-MIT.

Bruce Goldstein, brugo@vt.edu
School of Public and International Affairs, Virginia Tech

Bruce Goldstein is an Assistant Professor in the Urban Affairs and Planning Program in the School of Public and International Affairs at Virginia Tech. Initially trained as a conservation biologist, Bruce received his Ph.D. from the Department of City and Regional Planning at U.C. Berkeley in 2004. His dissertation examined the difficulties in coordinating scientific involvement in the construction of multispecies habitat conservation plans on the periphery of fast-growing cities of central and southern California. He is currently working on a U.S. Forest Service – funded study of innovation in planning for wildfire at the wildlands-urban interface in an era of devolution of state power over public lands. As these two projects suggest, Bruce is particularly interested in understanding alternatives to deadlock when environmental planning disputes are woven into a tangled mass of ecology, land use, scientific practice, and institutional form.

Tracy Johns, TJohns@unfccc.int
Consortium for Science, Policy, and Outcomes, Arizona State University

Tracy is a Master's student in the Consortium for Science, Policy, and Outcomes at Arizona State University. Her research interests are in the area of international climate change policy, especially in drivers at the interface of climate change science and science policy.

Her thesis work focuses on how uncertainty in carbon cycle science may affect the reporting of emissions and sequestration of carbon in the Land Use, Land Use Change and Forestry (LULUCF) sector of Parties' annual reports to the United Nations Framework Convention on Climate Change, as well as how this will affect the role of the LULUCF sector in meeting emission targets for the first commitment period of the Kyoto Protocol. Tracy is currently doing a six month internship with the UNFCCC in Bonn, Germany.

Anthony King, kingaw@ornl.gov
Oak Ridge National Laboratory

Dr. Anthony W. King is an ecosystem ecologists and modeler in the Environmental Sciences Division of Oak Ridge National Laboratory, Oak Ridge, TN. Dr. King has been with the Division since receiving his Ph.D. in ecology from the University of Tennessee in 1986. With a focus on large-scale ecological processes and understanding terrestrial ecosystems as part of the global Earth system, Dr. King's research experience includes ecosystem modeling, global carbon cycle modeling, land-use change, issues of scale and system organization, including the translation of models across spatial scale and levels of system organization, and error and uncertainty analysis of ecological models. Dr. King has a growing interest in integrating natural and social sciences into models of coupled nature-society interaction for use in sustainability science and decision support. Dr King is currently co-leader with Dr. Lisa Dilling of the first State of the Carbon Cycle Report (SOCCR), one of the synthesis and assessment products (SAR 2.2) called for by the U.S. Climate Change Science Program (CCSP) Strategic Plan. The SOCCR is designed to synthesize and integrate current knowledge of the North American carbon budget and its role within the global carbon cycle, and to provide this information in a form useful for decision support and policy formulation concerning the carbon cycle.

Frank Laird, flaird@du.edu
Graduate School of International Studies, University of Denver

Frank is currently associate professor of technology and public policy at the Graduate School of International Studies, University of Denver. His teaching and research interests there focus on environmental policy, energy policy, science and technology policy, and public policy more generally.

His educational background is interdisciplinary. Frank received a Bachelor's degree in physics from Middlebury College, did one year of graduate work in solid state physics at Edinburgh University in Scotland, and received a Ph.D. in political science, specializing in science, technology, and public policy, from MIT. After graduate school, Frank did post-doctoral work in environmental policy in the Interdisciplinary Programs in Health at the Harvard School of Public Health.

Most of Frank's research has focused on energy policy, particularly the way that renewable energy policies can affect environmental policy. His book Solar Energy, Technology Policy, and Institutional Values (Cambridge University Press 2001) looked at the ways in which institutionally embedded ideas shaped energy policy over a 35 year period. Frank has also published in the areas of climate change policy, environmental policy, democratic theory and S&T policy, and institutions and S&T policy. Frank is currently writing on, among other things, problems of institutional learning in complex S&T issues. Frank is particularly interested in the ways that different institutions cope with S&T issues and how one can improve institutions to make S&T better serve societal needs. His research has been supported by grants from the National Science Foundation.

As part of his service to the larger community, Frank has served on numerous NSF review panels, as well as being a peer reviewer for numerous journals and university presses. Frank has also done volunteer work for the American Solar Energy Society, chairing and serving on its public policy committee, as well as serving on its board of directors.

Beverly Law, bev.law@oregonstate.edu
College of Forestry, Oregon State University

Beverly Law is an associate professor of Global Change Forest Science at Oregon State University. She is the Science Chair of the AmeriFlux network of >100 research sites in the Americas. She also serves on the Science Steering Group of the North American Carbon Program. She is the principal investigator of the DOE-funded Metolius flux sites in different successional stages of ponderosa pine in Oregon, studying the processes controlling carbon dioxide and water vapor exchange between terrestrial vegetation and the atmosphere, and the principal investigator of a regional study on climate and disturbance effects on the carbon balance of Oregon and Northern California (ORCA).

Nathaniel Logar, logar@colorado.edu
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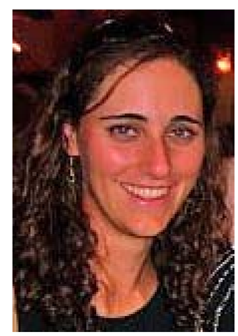
Nat graduated from Brown University in 2000, with a BS in Geology-Biology. Following his undergraduate degree, he worked as a tour guide in Glacier National Park, an assistant on debris flow research for the U.S. Geological Survey in Golden, CO, and an environmental consultant in Boston. His undergraduate work, and his first year of graduate school, focused on climate science, but he chose an interdisciplinary graduate program out of a concern that his scientific research have policy relevance. While he began to learn about policy research in graduate school, his interests shifted from climate change science to science policy. In the past, he has performed research on the FDA approval process for transgenic fish, and as a part of an NSF-funded interdisciplinary group called Carbon, Climate, and Society. His current work focuses on the decision support goals of the USDA's Agricultural Research Program, including its prioritization of global change science and the transfer of scientific information to meet decision maker needs.



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Genevieve Maricle is a graduate student in Environmental Studies at the University of Colorado at Boulder studying Atmospheric Science and Environmental Policy. Genevieve is also a fellow in the NSF Integrated Graduate Education and Research Traineeship Program. Her research focuses on climate services and the transfer of technology from climate research to useful weather and climate products for both decision-makers and climate-sensitive end users. She graduated from Northwestern University with a BA degree in both Mathematics and Environmental Science. Her undergraduate studies were primarily in the sciences but she maintained a keen awareness and interest in the political implications of her work. She became extremely interested in studying problems that transcend traditional disciplinary boundaries as she began to see a disconnect between the scientific and political worlds. This is what drew her to the University of Colorado.

Siân Mooney, smooney@uwyo.edu
Department of Agricultural and Applied Economics, University of Wyoming

Siân Mooney is an Assistant Professor in the Dept. Agricultural and Applied Economics, University of Wyoming. Her professional interests are in the areas of contract and policy design for carbon sequestration and the representation of uncertainty in integrated assessment modeling among other areas. She serves as a member of the Wyoming Governors Carbon Sequestration Advisory Committee and the Ruckelshaus Institute Energy Planning Group.

Dennis Ojima, dennis@nrel.colostate.edu
Natural Resource Ecology Laboratory, Colorado State University

Dennis Ojima is a senior research scientist in the Natural Resource Ecology Laboratory at Colorado State University. His research interests focus on understanding ecosystem dynamics in relation to earth system science, in particular to changes in climate, land use, and biogeochemical cycles to natural and anthropogenic forces. His research areas include global change effects, both climate and land use changes, on ecosystem dynamics and assessments of climate change on ecosystem dynamics. He coordinated the Central Great Plains Climate Change Assessment for the U.S. National Assessment for Climate Change (1997 – 2001, supported by DOE funding). Current US research activities include contributions to the North American Carbon Project, Member-at-Large for the Governing Board of the Ecological Society of America (2005 through 2007). Recent research activities have been aimed at better integration of social science research in the study of environmental sciences, especially in the area of evaluation of changes in ecosystem services and land use decision making. Currently, he is the co-chair of the planning team responsible for developing the new research strategy for integrating human dimensions and ecological sciences for the study of land processes for the IGBP and the International Human Dimensions Programme (IHDP). He has also been conducting ecosystem studies in Eurasia, including Mongolia, Kazakhstan, Uzbekistan, and China studying the linkage between the pastoral land use and their environmental system related to changes in recent social, economic, and political conditions affecting grazing systems of the Eurasian steppe.

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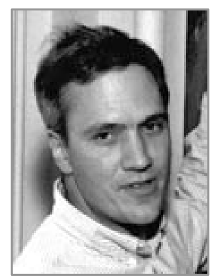

Dr. Pacala completed an undergraduate degree in biology at Dartmouth College in 1978 and a Ph.D. in ecology at Stanford University in 1982. He was Assistant and Associate Professor at the University of Connecticut from 1982 to 1992, and then moved to Princeton University as Professor of Ecology in 1992. He was awarded the Frederick D. Petrie Chair in 2000. He has served on numerous editorial and advisory boards.

Dr. Pacala has researched problems in a wide variety of ecological and mathematical topics. These include the maintenance of biodiversity, the mathematics of scaling, ecosystem modeling, ecological statistics, the dynamics of vegetation, animal behavior, the stability of host-parasitoid interactions, the relationship between biodiversity on ecosystem function, and field studies of plants, lizards, birds, fish, insects, and parasites. Since moving to Princeton University, Dr.

Pacala has focused on problems of global change with an emphasis on the biological regulation of greenhouse gases and climate. He currently co-directs the Princeton Carbon Mitigation Initiative.

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Keith Paustian is Professor of Soil Ecology, Dept. of Soil and Crop Sciences and Senior Research Scientist, Natural Resources Ecology Laboratory (NREL), Colorado State University, Fort Collins. His main fields of interest include agroecosystem ecology, soil organic matter dynamics, global change and greenhouse gas mitigation. He is currently leading research in the US and internationally to elucidate the factors and processes controlling soil carbon dynamics and soil greenhouse gas emissions and to develop better methods to measure and predict changes in soil carbon as a function of management and environmental variables. He is currently as Coordinating Lead Author for the 2006 Revised IPCC Guidelines for National Greenhouse Gas Inventory Methods and is a member of the Scientific Steering Committee for the US Carbon Cycle Science Program.

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Columbia University

Dr. Alexander Pfaff is Associate Professor of Economic & International Affairs at Columbia University & Executive Director of the Center for Globalization and Sustainable Development at its Earth Institute. He received a B.A. summa cum laude from Yale in 1988 and Ph.D. in Economics from M.I.T. in 1995. The focus of Dr. Pfaff's research is interactions between economic activity and the quantity and quality of natural resources and the environment. He has studied deforestation, including implications for carbon sequestration and species habitat, through empirical analysis in the Brazilian Amazon and in Costa Rica. His research also includes: theoretical and empirical analysis of the effect of economic development on environmental quality; theoretical and empirical analysis of the incentives for environmental audits and disclosure by firms; and within water projects, empirical analysis of responses to arsenic contamination of drinking water in Bangladesh and evaluation of water management options that make use of forecasts.

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Roger Pielke, Jr. has been on the faculty of the University of Colorado since 2001 and is a Professor in the Environmental Studies Program and a Fellow of the Cooperative Institute for Research in the Environmental Sciences (CIRES). At CIRES, Roger serves as the Director of the Center for Science and Technology Policy Research. Roger's current areas of interest include understanding the politicization of science, decision making under uncertainty, and policy education for scientists. He serves on the Advisory Panel of the NSF Program on Societal Dimensions of Engineering among other advisory committees. In 2000, Roger received the Sigma Xi Distinguished Lectureship Award and in 2001, he received the Outstanding Graduate Advisor Award by students in the University of Colorado's Department of Political Science. Before joining the University of Colorado, from 1993-2001 Roger was a Scientist at the National Center for Atmospheric Research. Roger sits on the editorial boards of Policy Sciences, Bulletin of the American Meteorological Society, Environmental Science and Policy and Natural Hazards Review. He is author of numerous articles and essays and is also co-author or co-editor of three books.

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Andrea Ray is a Research Scientist at the NOAA OAR Climate Diagnostics Center, Boulder, CO. She recently completed her doctorate in Geography at the University of Colorado, advised by Bill Travis and Jim Wescoat, on the interaction of climate, reservoir management, and the evolving natural resource management context in Western Colorado, and an analysis of the climate information needs of reservoir managers and the stakeholders in reservoir management. Her research interests are on the potential use of climate information and forecasts in natural resource management, including the analysis of management decision processes and how these factors condition the potential usability of forecasts, and pilot activities for development of NOAA climate services. She participates in the Western Water Assessment, a NOAA-funded integrated assessment designed to identify and characterize regional vulnerabilities to climate variability and change, and to develop information, products and processes to assist water resource decision makers throughout the Intermountain West. She also serves on the Science Working Group for the North American Monsoon Experiment, a project funded by NOAA, NASA, and NSF. Previously, she worked in the NOAA Office of Policy and Strategic Planning, and was a program manager for the NOAA Pan-American Climate Studies research program.

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Mr. Sheffner is a program manager with the Applied Sciences Program in the Science Mission Directorate at NASA Headquarters. He joined the civil service in 2001. In his current position he is responsible for programs in three national application areas - carbon management, invasive species, and agricultural efficiency. He serves as a representative from NASA on a number of federal government working groups including the Carbon Cycle Interagency Working Group, the NASA/USDA Interagency Working Group for Earth Science Applications, the Commercial Remote Sensing Space Policy Interagency Working Group, the NSTC/CENR Subcommittee on Ecological Systems, and the National Invasive Species Council.

Mr. Sheffner attained a BA in history from the University of California, Berkeley and a MA in geography from the University of California, Davis. Before joining the civil service, he worked with NASA for more than 25 years in various capacities including principal investigator on projects related to agricultural remote sensing, site manager for a technical support contract with the Earth Science Division at NASA's Ames Research Center, and technical support for implementation of the Landsat 7 program and the Land Remote Sensing Policy Act of 1992. He has taught classes in geography and remote sensing at community colleges and state colleges in California, and held positions with the Universities Space Research Association and the United Nations Economic and Social Commission for Asia and the Pacific.

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California Department of Forestry

Mr. Wickizer was granted a bachelor's degree in Forest Land Management from Northern Arizona University in 1970 at Flagstaff, Arizona. He subsequently worked a short period with the USFS in Region III and then took a job with the California Department of Forestry and Fire Protection in 1973 and has been in their employ since that time. His experience since then includes, Forest Practice Inspector, Forest Practice Review Team Chair, Service Forester, Forest Practice Litigation Coordinator, Environmental Protection Officer for the Department, Regulations Coordinator for the Board and Department of Forestry and Fire Protection, Committee Consultant for the Board, Chief of Department Forest Management

Program, Administrative Chief for Department South Region, and is currently the Department Chief for Environmental Protection, Regulation, and Forest Product Utilization. The Departments interests and efforts in biomass utilization and Global Climate Change are a portion of his program efforts. He is currently a member of the Society of American Foresters' and has served in a variety of capacities, including Nor-Cal Section Treasurer, Section Chair for Land use, and Chapter Chair as well as Chapter Treasurer. Mr. Wickizer contributed to the successful conclusion of numerous projects including; major revisions of the Forest Practice Rules during late 80' and early 90's, completion of the initial Soil Erosion Study, establishment of the original Board Monitoring Study Group in 1989, The 1996 California Fire Plan, as a contributor to the 2004 FRAP report and writing the current Forestry Protocols for the California Climate Action Registry. Mr. Wickizer is on the Board of Directors for the California Biomass Collaborative, a member of Bio-Energy Working Group for the California Energy Commission, and also a Department representative for the Western Carbon Sequestration Partnership under DOE, http://www.westcarb.org.

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Thomas J. Wilbanks is a Corporate Research Fellow at the Oak Ridge National Laboratory and leads the Laboratory's Global Change and Developing Country Programs. The designation "Corporate Fellow" is roughly equivalent to a chaired professorship in a university, limited to about 25 individuals from a research staff of about 1400. During the periods 1998-2002 and 2005-2006, he has chaired the Laboratory's Corporate Fellows, serving as ORNL's chief scientist.

Wilbanks is a past President of the Association of American Geographers (AAG), one of only two non-academics to serve as the president in its 100 years, and has been awarded a number of honors in that field. He conducts research and publishes extensively on such issues as sustainable development, energy and environmental policy, responses to global climate change, and the role of geographical scale in all of these regards. He is the author, co-author, or co-editor of eight books and more than one hundred journal articles, book chapters, and other open-literature refereed publications.

The global change and developing country programs that Wilbanks coordinates at ORNL have led more than 70 projects in 40 developing countries worldwide in the past two decades. He played roles in the first U.S. National Assessment of Possible Consequences of Climate Variability and Change (1997-2000); the IPCC Working Group II (Impacts, Adaptation, and Vulnerability) Third Assessment Report; and aspects of the UNEP et al. Millennium Ecosystem Assessment related to issues of geographic scale. More recently, he is serving as a Coordinating Lead Author for the IPCC's Fourth Assessment Report: Working Group II, Chapter 7: Industry, Settlement, and Society.

He is a member of the Board on Earth Sciences and Resources of the U.S. National Research Council, Chair of NRC's Committee on Human Dimensions of Global Change, and a member of a current NRC panel on public participation in environmental assessment and decision-making. He is also a member of the Scientific Steering Group for the U.S. Carbon Cycle Research Program and a member of the Panel on Earth Science Applications and Societal Needs of the NRC "decadal study" of Earth Science and Applications from Space: A Community Assessment and Strategy for the Future.

DECISION SUPPORT & CARBON CYCLE SCIENCE:

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