Workshop to Define Collaborative Student Climate Research: Raising the Bar for Climate Science Education in the 21st Century

17-19 November, 2010
NOAA, Silver Spring, Maryland

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Summary

On November 17-19 2010, a Workshop to Define Collaborative Student Climate Research, co-funded by the National Science Foundation and the National Oceanic and Atmospheric Administration, was held in Silver Spring, Maryland. The workshop was premised on the understanding that:

1. Global climate changes and human influence on those changes constitute one of the major science issues for the 21st century;
2. Climate science education must help today's students become informed participants in the debate surrounding climate change and the human response to those changes;
3. Our nation must find new ways to build the scientific and technological expertise needed to understand and respond to climate change;
4. Although understanding the details of Earth's climate and predicting its future course poses major scientific challenges, there are nonetheless many opportunities for students, educators, and scientists to collaborate on pedagogically beneficial climate research projects that will produce results leading to a better understanding of climate and climate change.

The workshop defined what it means for students, teachers, and scientists to engage in climate-related research that passes a "scientific interest" test in which scientists and others have a stake in the results of the research:

Collaborative student climate-related research involves students, teachers, scientists, and other partners working together to identify authentic research questions, acquire and analyze meaningful data, communicate scientifically valid results that will provide educational benefit to participating students, contribute to the professional development of teachers, contribute to our scientific understanding of Earth's climate, and help a wide range of stakeholders make informed decisions about how to respond to climate change.

This definition distinguishes research from "inquiry-based" and other kinds of "learning about" activities. Workshop presentations outlined several research projects in atmospheric, solar, and surface monitoring, oceanography, and carbon sequestration. Some of the proposed projects use existing equipment and protocols and some require additional development, but all are appropriate for collaborations involving students.

The workshop concluded that in order to support authentic student climate research, changes are required in the way teachers are prepared, in the way scientists and their institutions interact with teachers and students, in the way teachers and schools perceive their role in educating their students about Earth's climate, and in the way funding agencies support collaborative research with students. Teachers at all grade levels must be better prepared to conduct inquiry and research with students and they also need to be able to engage in their own research. Scientists must be better at adapting to the needs of teachers and students. Schools must be willing to commit the resources needed to sustain active climate-related research as an integral part of their mission. In their research solicitations, funding agencies must replace generic "educational outreach" provisions with specific guidelines for involving students and teachers in authentic research whenever possible.

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Background

In 2009, the *Institute for Earth Science Research and Education* (IESRE) proposed to the National Science Foundation (NSF) a workshop to address the topic of what it means for students and teachers to conduct authentic climate-related research in collaboration with scientists. This proposal was motivated by the dramatic increase in interest in climate science and its implications, by a desire to involve more students in real science research, and by a perceived need to differentiate authentic collaborative research done by students from other kinds of learning experiences.

The proposal was submitted to NSF's Geosciences Education Program in the Directorate for Geosciences. During the NSF proposal review process in early 2010, the National Oceanic and Atmospheric Administration (NOAA), expressed an interest in co-sponsoring the workshop as part of its climate education initiatives. Following joint discussions among IESRE, NOAA, and NSF, NSF formally accepted the workshop proposal in September of 2010 under award GEO-1000357. The workshop was held at NOAA facilities in Silver Spring, Maryland, 17-19 November 2010. The list of attendees is given in Appendix 1 to this document.

The goal of the Workshop to Define Collaborative Student Climate Research was to produce specific guidance for engaging students, teachers, and scientists in collaborative research about Earth's changing climate, one of the major science and societal issues for the 21st century. Specific workshop objectives included:

1. To define what it means for students, teachers, and scientists to engage in authentic climate-related research that passes a "scientific interest" test in which scientists and others have a stake in the results of the research;

2. To provide guidelines for designing and implementing projects in which students, teachers, and scientists can collaborate to conduct climate-related research that has both pedagogical and scientific value.

3. To identify some specific climate science research projects that can be undertaken collaboratively by students, teachers, and scientists.

The Climate Science Debate: How Does It Impact Science Education?

During the first decade of the 21st century, the importance of climate science has increased dramatically in the face of overwhelming evidence that Earth's climate is changing and that those changes are already having implications for the global society. What can be considered as the consensus scientific view is expressed by the Intergovernmental Panel on Climate Change, which concluded in their fourth report [IPCC, 2007] that:

- Warming of the climate system is unequivocal.
- Some natural systems are already being affected by regional climate changes and there is considerable evidence for changes in other natural and human environments.

Regarding the cause of these changes, the IPCC concludes that:

- Global greenhouse gas emissions have increased dramatically in the Earth system, and at a growing rate, since the start of the industrial revolution in the 19th century, and the cause of this increase is human activity, primarily through the burning of fossil fuels.
- There is *very high confidence* that the net effect of human activities since the mid 18th century has been one of global warming.
- That the observed increase in global average temperature since the mid-20th century is *very likely* due to the increase in anthropogenic greenhouse gas concentration and that it is *likely* that there has been significant anthropogenic warming over each continent except Antarctica.

There are two significant features of climate change as it is being observed at the dawn of the 21st century. First, the observed changes are taking place very rapidly on a geologic time scale and, second, the impact on the global environment and human society is potentially profound and almost universally negative. The magnitude of the technological, economic, and political choices which society must make in response to the challenges of climate changes—especially to the extent those changes result from human activity—has generated intense debate about how to proceed. These choices are inextricably intertwined with the debate about how, how quickly, or even whether, Earth's inhabitants should make the transition to a post fossil fuel economy if for no other reason than to reduce emissions of carbon dioxide (CO_2), the most prominent anthropogenically modified greenhouse gas, into the atmosphere. In the long term, continuing to base global sustainability and development almost entirely on fossil fuels, a finite resource, imposes severe political, economic, and strategic consequences even apart from climate change. The consequence of immediate concern for the future of global climate is very specific: Carbon dioxide is the dominant greenhouse gas over which humans have direct control, through their use of fossil fuels. As long as future global economic development remains directly proportional to energy generation, and as long as energy generation is directly linked to CO_2 emissions from burning fossil fuels, Earth's delicately balanced current climate cannot be maintained.

Predictions by climate scientists about the effects of maintaining a "business as usual" approach to managing Earth's fossil fuel-based energy generation range from the regionally disruptive to the globally catastrophic. There are potentially severe consequences (for agriculture and public health, for example) even on the lower end of the "regionally disruptive" scale. The costs to implement the drastic actions required to mitigate these consequences are potentially enormous, as are the costs of inaction.

The qualifiers in the current IPCC report [IPCC, 2007]—*likely*, *very likely*, *very high confidence*—are extremely important. These qualifiers have been emphasized in more recent versions of IPCC reports in response to criticisms that earlier reports tended to

state without qualification conclusions that were based only on a preponderance of evidence or on incomplete evidence. These terms (italicized in the report) are assigned specific quantitative meanings. For example, a *likely* event has a greater than 66% probability of occurring and a result expressed with *very high confidence* means that the prediction has at least a 9 out of 10 change of being correct. Because Earth's future climate cannot be predicted with certainty, there is, not surprisingly, an enormous public debate about how or whether to respond in the face of this kind of uncertainty.

There is a significant minority of vocal dissenters, including scientists and non-scientists —from authors to politicians to preachers—who disagree with the establishment conclusions about anthropogenic climate change, especially as expressed in the IPCC reports. Their views range from carefully considered skepticism to hostility and outright rejection. Skeptics of anthropogenic climate change have a different interpretation of data characterizing the current state of Earth's climate. They often point out that the shift in terminology from "global warming" to "global (or regional) climate change" represents a retreat from positions previously taken by climate scientists, rather than a growing understanding of regional differences in future climate forecasts. They question whether claims of current rapid changes are accurate, whether computer model forecasts of future climate can be trusted, whether changes have been or can be caused or mitigated by human activity, and whether scientific "consensus" is necessarily the best way to drive policy. In some cases, ethical shortcomings within the climate science community have undermined the consensus view. A brief sampling of these dissenting views is given in Appendix 2.

Regardless of their merit, the views of "climate dissenters" can still raise questions worthy of serious consideration. What are the economic consequences of dealing with or ignoring climate change and its future implications? Is it already too late to avoid disastrous consequences of anthropogenic climate change, or will there not be any serious consequences at all? Will responding to the challenges of climate change by committing to the development of sustainable energy destroy our economy or provide new opportunities for economic development? Does a pro-environmental agenda stifle the development and global dissemination of new technologies or drive it?

Does a response to climate change unfairly target poor individuals and hinder development in currently underdeveloped countries by denying them access to the same technologies and energy sources that developed countries have already exploited? Do climate scientists have an agenda that places their need for funding above research ethics? Have climate scientists been honest about uncertainty in their future climate forecasts or have they deliberately misled the public? Do those who deny the importance of human impacts on climate have an agenda that favors preserving the status quo even in the face of overwhelming evidence that, in the long term, the current scenario of how our planet generates and uses energy is unsustainable?

Do politicians have a responsibility to look to their country's future beyond the next election cycle? Do policy makers understand how to respond to situations where uncertainty is and will continue to be an essential feature of the underlying science? Is there an appreciation of the fact that the uncertainty in climate forecasts cited by climate change skeptics is as likely to underestimate future problems as it is to overestimate them? Is climate change mitigation cost effective? Can (or should) climate change

mitigation be subjected to cost/benefit analyses along with other programs to address global problems?

The purpose of this document is not to even attempt to resolve this dizzying array of questions. The reason for raising the questions is to make the case that the complexity of the debate demands a very sophisticated approach to climate science education in the 21st century. More than any other branch of science, climate science must be "public science" because it cannot be separated from public policy, economic, and societal decisions (including the understanding that inaction is also a decision) that will have dramatic and long-lasting regional and global consequences.

With this background in mind, the challenge is not just to make climate science an attractive career choice for students, but also to ensure that today's students—tomorrow's adults and decision-makers—have a sufficient understanding of climate science to engage in the public debate by demanding that climate science research be conducted openly and ethically, and that decisions about how to react are based on the best available scientific evidence. The urgency of meeting this challenge is encapsulated in a 2009 report from the National Science Foundation, *Transitions and Tipping Points in Complex Environmental Systems*: "People will not rely on scientific information if they don't understand it, or [if] they question the motivation or integrity of the research methods that were used to generate it." [NSF, 2009].

The educational connection has been made in a National Academies of Science publication, *Ready, Set, Science!: Putting Research to Work in K-8 Science Classrooms:* "Knowledge of science can enable us to think critically and frame productive questions. Without scientific knowledge, we are wholly dependent on others as 'experts.' With scientific knowledge, we are empowered to become participants rather than merely observers. Science, in this sense, is more than a means for getting ahead in the world of work. It is a resource for becoming a critical and engaged citizen in a democracy." [Michaels, Shouse, and Schweingruber, 2008].

Nowhere are these statements about science education in general more applicable than to climate science! We believe that the Workshop to Define Collaborative Student Climate Research is a significant step toward meeting this challenge.

Is Science Education in the United States Ready for the Climate Change Challenge?

Climate science education is a truly global issue, but this document focuses on the United States because the primary education responsibility of the workshop sponsors, NOAA and NSF, lies with U.S. students. There is, in our country and elsewhere, a huge community of educators dedicated to improving science education. But climate science presents unique and unprecedented political, economic, environmental, and policy challenges for citizens in the 21st century. It is by no means clear that science education reform is adequately preparing today's students to meet these challenges.

Typically, the best practices of science education around the world revolve around hands-on and inquiry-based education—approaches that are ideally suited to learning about Earth's weather and climate. "Learning about" activities play an essential role in high-

quality science education. However, these kinds of activities almost always stop short of engaging students in actual research. Is this a problem for climate science education?

The answer to this question might first be considered in the context of the overall quality of a country's science education programs. As is well known, United States students lag behind in science and mathematics achievement compared to students in other developed countries around the world. The 2007 Trends in International Mathematics and Science Study (TIMSS) ranked U.S. 8th graders 11th in science and 9th in mathematics among 59 participating countries [TIMMS & PRLS International Study Center, 2011; National Center for Education Statistics, 2007].

The World Economic Forum, a Geneva, Switzerland-based non-profit organization promoting "a world-class corporate governance system," ranked the quality of U.S. mathematics and science education 52nd out of 139 participating countries in 2009 and 45th in the previous year. [World Economic Forum, 2010] Recently, the "Gathering Storm" Committee of the National Academies of Science concluded that "Today for the first time in history, America's younger generation is less well-educated than its parents." Its number one recommendation is to "move the United States K-12 education system in science and mathematics to a leading position by global standards." [The "Gathering Storm" committee, 2010]. The Organisation for Economic Co-Operation and Development (OECD) estimates that the cost to reform US education to bring its students' performance on Programme for International Student Assessment (PISA) tests to the level of Finland (the highest performing OECD country) is among the largest as a percentage of Gross Domestic Product [OECD, 2010]. The 2009 PISA scores places the U.S. near the middle of OECD countries with scores "not statistically significantly different from the OECD average," [OECD, accessed 2011] a conclusion that prompted U.S. Education Secretary Arne Duncan to remark that a slight increase in U.S. students' science ranking from *below* average is "not much to celebrate… being average in science is a mantle of mediocrity." [quoted from Matthews, 2011].

Federal funding agencies such as NSF, NOAA, and the National Aeronautics and Space Administration (NASA) all recognize the problems faced by our country in developing a scientific and technical workforce prepared to meet the challenges of the 21st century, and they all support various kinds of educational outreach programs in an attempt to encourage students to pursue STEM (science, technology, engineering and mathematics) careers. When considering the process of convincing students to pursue STEM careers, the formal education system can be envisioned as a "leaky" funnel, wide enough at the top to offer opportunities to all students as they enter the educational system, narrowing through the years as students make other choices based on ability and interests, but still wide enough at the end of the K-12 or K-16 process to ensure an adequate supply of scientists, engineers, and technicians to meet our country's needs.

How is climate science faring in this process? One way to answer this question is to look at the kinds of projects our country's brightest secondary school students are entering in high-level science competitions, such as those sponsored by Intel and Siemens, as they pass through the narrow end of the K-12 STEM educational funnel. Among the top 10 Intel Science Talent Search winners in 2009 and 2010, and the top 10 winners in the 2008 and 2009 Siemens Competition, none were even remotely related to climate science. This

suggests that Earth/climate science is losing the battle for the "hearts and minds" of our country's most scientifically gifted students.

There are no doubt many reasons for this situation, but one obvious difference between climate science and the kinds of science students are doing in high-level science competitions is the available level of support. Biosciences and mathematics/computer science are heavily represented in these high-level competitions. In biosciences, a huge research infrastructure has been built by universities and corporations. Anecdotally, considering the very expensive equipment and high level of technical support required, it could even be questioned whether high-level science projects in this field can fairly be called "student research" as opposed to institutional and corporate-sponsored research that happens to be done by students. Regardless of the merits of this argument, it is clear that this infrastructure provides a level of support far beyond that available to students interested in climate science.

In terms of a supporting academic infrastructure, our educational system supports mathematics-related projects by providing a continuous K-12 (and beyond) curriculum. In Earth/climate science, students are fortunate if they have one course on Earth science and perhaps one on environmental science, which may contain little or no material about climate science.

Building a supporting infrastructure requires collaboration among all the stakeholders—students, teachers, and scientists. The concept is not new. A 1996 NSF-funded workshop, *Proceedings of the National Conference on Student & Scientist Partnerships*, stated: "Student and Scientist Partnerships (SSPs) are a new kind of collaboration between science and education based on the ability of students to contribute to scientific research. These partnerships offer science new ways of extending its community and hold the promise of revitalizing education by infusing authentic science into the school culture." [TERC/The Concord Consortium, 1996].

This statement outlines both and educational and scientific justifications for collaborative research with students. However, a decade and a half after the 1996 TERC workshop, and even though the term "student research" is frequently used, it is still rare to find students, teachers, and scientists engaged in collaborations that can fairly be characterized as "research." This workshop has endeavored to make clear the distinction between research and other kinds of student activities and to define how to implement authentic student collaborative research.

Is Climate Science Too Difficult for Students to Understand?

If climate science is simply beyond the capacity of students to understand at the research level, then there is no justification for promoting student research in this field. Certainly, understanding Earth's climate—why it is the way it is today, how it is changing, and what the future holds—is a daunting undertaking and represents one of the major science and technology challenges for the 21st century. In particular, the models climatologists use to predict future climate by combining an understanding of past climates, current observations, and the physics and mathematics underlying climate science are incredibly complex.

However, much of climate science research is still based on observations that are conceptually straightforward. Some quantities that define climate, such as air temperature and precipitation, are familiar because they are the same quantities that define weather. Bio-indicators of current climate—for example, trees, other plants, and animals—can also be very familiar. Thus, many climate science concepts are related to everyday experiences and observations and are therefore understandable by a wide range of students.

One of the best known climate change concepts is the "urban heat island" effect. Here is a straightforward definition which, with a teacher's help, can be understood even by young students:

> "Recent research in Deniliquin [a small town in an agricultural area of New South Wales, Australia, with a population of about 7800] suggests that as country towns grow they experience warmer nights. The warming of the nighttime temperature [even in small towns] is due to the Urban Heat Island (UHI) effect, which is the result of two main features of urban areas. First, buildings, roads and paved surfaces store heat during the day, which is then released slowly over the evening due to the thermal properties of the surface materials and the building geometry which traps the heat stored during the day. The second contributing factor to the UHI is due to the artificial heat released into the urban atmosphere by combustive processes from vehicles, industrial activity and the heat that escapes from commercial and domestic air conditioning." [Morris, accessed 2010]

Note that although the urban heat island effect is generally associated with large cities, this description is being applied even to *small* towns—anywhere human activity generates heat or where human-built structures retain heat—so (with appropriate equipment and data collection protocols) students living almost anywhere can experience and measure this effect.

In addition to heat islands, the general concept of "microclimates" can provide student-friendly windows onto regional and global climate issues. For example, it is easy to understand that, on average, daytime air and ground temperatures on a south-facing slope in the northern hemisphere might be higher than on a north-facing slope in the same area because the south-facing slope receives more direct sunlight. Similarly, nighttime temperatures may be lower at the bottom of slopes or in valleys when air cools and sinks. In these kinds of situations it is easy to envision "microclimate" differences "riding" on top of the weather in that area. Even though the differences may be small, they can have significant and easily observable effects on, for example, where frost forms. Individual frost events are part of weather, of course, but over the longer term persistent microclimate effects can affect decisions about what kinds of crops are best grown on south- or north-facing slopes. Thus, microclimates provide an accessible introduction to regional and global climate change as well as establishing the differences between weather and climate in students' minds.

Defining Authentic Collaborative Student/Teacher/Scientist Climate Science Research

There is a tendency in the science education community to classify any kind of inquiry-based activity, especially any activity that gets students out of their classrooms to make their own observations and measurements in the "real world," as "research." However, definitions do matter and it is important to ask how "research" should be distinguished from other kinds of student activities.

It is useful first to ask "What is student inquiry?" This question has been addressed by the science education community, apparently to differentiate inquiry from more passive learning activities. The National Research Council [1996] gives this definition (reformatted from the original text of the National Science Education Standards):

"Inquiry is a multifaceted activity that involves

- Making observations;
- Posing questions;
- Examining books and other sources of information to see what is already known;
- Planning investigations;
- Reviewing what is already known in light of experimental evidence;
- Using tools to gather, analyze, and interpret data;
- Proposing answers, explanations, and predictions;
- Communicating the results.

Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations."

This is a definition about *process*, not about content. As such, it does not necessarily encompass research. It is possible to have inquiry without authentic science research, but not the other way around. Thus, student inquiry is a starting point for students to learn *how* to do science and student research is the application of the inquiry process to expanding our understanding of how our world works; that is, **research is inquiry *plus* new content.**

To make more clear the distinction between inquiry and research, we propose the following "Is it research?" question: **"If students and teachers follow a project protocol designed in collaboration with scientists, in the prescribed way for an appropriate length of time, when they get done will scientists care whether they did it or not?"** If the answer to this question is "yes," then the activity could be authentic research. But if the answer is "no," then the activity may be valuable for students learning about the science inquiry process, but it is not research.

A "scientific interest" test is critical. Scientists are interested in questions for which answers are not known in advance—it is just this uncertainty that provides the basic incentive for their own research. Sometimes questions have answers that result in peer-reviewed publications. Sometimes the answers are simply interesting rather than profound. Thus, "interest" in student research can range from using data in peer-reviewed

publications to climate issues relevant to a local community to simple scientific curiosity. But, without some compelling motivation for scientists to initiate and remain engaged with student/teacher collaborations, even directed learning activities will not be able to attract the kind of sustainable support they need from working scientists in order to remain viable. With climate science in particular, activities which do not include significant ongoing oversight in response to our rapidly evolving understanding of natural and anthropogenic climate change will have little value for 21st century students, and may actually be detrimental to developing an accurate understanding of this huge and complex topic.

The interest required to address the "Is it research?" question for climate science needs to start with the science community, but there are also other potential stakeholders from which expertise, interest, and support can come. Government officials, public health officials, farmers and agricultural extension agents, sociologists, economists, and community leaders can also satisfy this requirement. In short, any individual or group with a need for better evidence-based climate-related information can provide the interest in results that is needed to sustain authentic student climate research.

It is also worth noting that a scientific interest test may be applied differently in different parts of the world. In developed countries there may already be an extensive infrastructure for monitoring weather and climate. In developing countries, it is entirely possible that student/teacher/scientist collaborations may be the *only* source of reliable climate-related data.

The scientific interest test provides a philosophical starting point for distinguishing authentic research from other kinds of learning activities, but a clear working definition also needs to be provided for developing such projects:

Authentic collaborative student-focused climate-related research involves students, teachers, scientists, and other partners working together to identify authentic research questions, acquire and analyze meaningful data, communicate scientifically valid results that will contribute to our scientific understanding of Earth's climate, provide educational benefit to participating students, create professional development opportunities for teachers, and help a wide range of stakeholders make informed decisions about how to respond to Earth's changing climate

This definition encompasses the two most important features of student activities that can legitimately be called research and that differentiate them from other kinds of active learning experiences: (1) they must be developed in collaboration with the climate science community to ensure their relevance to advancing our understanding of climate and (2) they must identify an audience that cares about the results. Neither of these features is required for inquiry-based student activities and both are typically absent from a wide range of learning activities.

Even though inquiry is not the same as research, these activities should not be treated as completely distinct. Practicing the inquiry process is an indispensable part of learning to do real science, and inquiry-based activities can and should evolve into real research. In an educational setting, a variety of inquiry-based climate-related activities suitable for a range of ages need to be developed; these activities feed the wider end of the educational funnel described above. The difference between inquiry and research may lie in the

nature of the question being investigated, the sophistication of the participants, or the degree of control maintained over the quality of data. But, in any case, a wide range of inquiry activities is a prerequisite for promoting authentic research by students, typically as they approach the narrower end of the education funnel described above.

Within the framework set by this definition, there are some common elements that will characterize any project that qualifies as legitimate student research:

1. Clearly defined research and education objectives;
2. Clearly defined expectations for all participants;
3. Clearly defined logistics;
4. A clearly defined audience interested in project results.

In more detail, authentic collaborative student science projects should include these characteristics:

1. The research must be clearly related to scientifically valid climate science questions that are age-appropriately accessible to students.
2. The outcomes of the research are not known in advance and the explanations of results are evidence-based.
3. The research may involve both the acquisition of new data and the use of existing data ("data mining"). Younger students may rely more on data collection. Projects done by older students may incorporate more analysis of existing data.
4. The project contributes to scientific knowledge and understanding about our current climate and facilitates scientists' search for ways to predict the future course of climate. It may address questions related to the atmosphere, biosphere, lithosphere, hydrosphere, or anthrosphere (the human-created environment).
5. An audience of scientists and other potential stakeholders who will be interested in the results of the research must be identified.
6. The project must have meaning for all participants. To the extent possible, in an age-appropriate way, students should participate in developing research questions and designing ways to approach a problem, rather than having a complete research approach imposed by scientists. The project should capture the interest of students.
7. The research plan should include student-focused inquiry-based and other learning activities which can be integrated with the research activity. All activities must have clearly defined educational outcomes, specifically including those which will help teachers meet science education standards.
8. The project should include a component that specifically addresses research ethics as it applies to climate science.
9. The project should include a reporting/communication component whereby the research question, methods used, and conclusions are communicated not just to scientists, but to all stakeholders.

All such projects will, in common, face two serious challenges:

1. Ensuring that all stakeholders benefit from the collaboration.
2. Ensuring that all participants meet their obligations for the life of the project.

There are many implementation details that need to be addressed, including:

1. A clear statement must identify sources of data required for a project, and who is responsible for providing those data. If students are to collect data, the protocols must be defined. If scientists are providing data, either current or historical, they must be easily accessible in an age-appropriate way.
2. There must be a clear understanding of how student research results will be used.
3. Procedures to ensure the quality of data, and the responsibilities of each group of participants to implement these procedures, must be spelled out in detail. Data quality reports should be communicated to teacher and student participants on a regular basis.
4. Requirements for participation must be clear. These requirements include the suitability of sites for data collection and the availability of the necessary equipment.
5. Time commitments and project schedules must be clearly defined and agreed upon in advance by all participants, including school administrators. As appropriate, project milestones should include a completion date.
6. Teachers need to be motivated to collaborate not only with project scientists, but also with other teachers and other schools, as required for the project.
7. Incentives for student and teacher participation need to be provided and the benefits of participation need to be identified. Student participation should *never* be limited simply to data collection.
8. Scientist partners must provide an infrastructure to support student and teacher participation, including frequent communication during the life of the project, online data reporting, storage, and analysis tools, and access to complementary data.
9. The equipment required to implement the project must be appropriate for student use. Detailed protocols for using the equipment need to be provided.
10. Background materials for teachers and students must be provided. Professional development must be ongoing during the project.
11. Ideally, the research project should provide opportunities for students to develop their own research questions to which data generated during the project can be applied.
12. Opportunities for recognizing student and teacher participation should be provided. These can include co-authorship on publications, certificates of participation, school support, community recognition, help with science fair

projects, and student science conferences to discuss project results with scientists and among their peers.

Finally, it is worth describing what authentic student climate research is *not*:

1. "Learning about" Earth's weather and climate. As noted above, even the best inquiry-based, hands-on learning activities do not, by themselves, qualify as student research.
2. Routine meteorological and other observations and measurements that are not directed toward meeting a specific climate science objective.
3. The "big questions" of climate science, for example, "Is Earth getting warmer?"; "Are sea levels rising?"; "Will the polar ice caps melt?"; "What will our air quality be in 10 years?"

The "big questions" issue is relevant because it is important to be honest with students about what kinds of research they can actually do and what kinds of questions they can reasonably be expected to answer. These big questions are important for climate change, and it is important for students to be introduced to them in an age-appropriate way. However, they are questions to which climate scientists not only do not have definitive answers, but they may not even be sure *how* to answer them. Also, because of the global scale of most of these big questions about climate, as a practical matter they are not reasonable topics for student research.

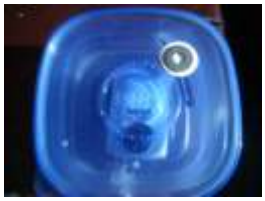
Even after appropriate research projects are clearly defined, there remain many hurdles to implementing authentic student climate research and it is clear that both scientists and educators need to rethink their roles in engaging students in research. Some thoughts about improving teacher preparation and taking a more proactive role in building partnerships between scientists and educators are given in Appendices 3 and 4.

Some Specific Projects for Authentic Collaborative Student Climate Research

During the workshop, participants' deliberations about how to characterize authentic collaborative student research were conducted within a framework of several specific proposed climate research projects. Each of the projects summarized below is conceptually and practically accessible to students. Implementation costs, in personnel and equipment, vary widely, but evaluating these costs was not a significant concern of the workshop. What is relevant is the fact that each project has high scientific and educational potential and is therefore a good candidate for authentic collaborative climate science research. We believe there are many more such projects and we hope this list (in no particular order) will encourage others to contribute their own ideas.

Monitoring Black Carbon in the Atmosphere

Primary contributor: Russell Schnell



During the first decade of the 21st century, black carbon has been found to have a much larger role in climate change than previously thought. When deposited on land surfaces, even small amounts of black carbon can significantly alter surface reflectivity. Black carbon can significantly reduce the reflectivity of snow and ice and hasten loss of polar ice and glaciers.

The local and global distribution of black carbon is poorly understood. Unlike greenhouse gases in the atmosphere, black carbon concentrations can vary by two or more orders of magnitude over distances as small as a few kilometers. This uncertainty and variability hampers scientists' ability to include the effects of black carbon in climate forecasting models.

The dramatic spatial and temporal variability of black carbon argues for the value of inexpensive approaches to monitoring. The device shown here is a snap-lid plastic food container. Inside is an inexpensive air pump intended for use as an air bubbler in aquariums. Air is drawn through a hole about 1 cm in diameter and exhausted through a small tube out the side. On the inside of the lid, three magnets are fastened around the hole with hot glue or epoxy. These magnets hold in place a paper filter and a large steel washer on the outside of the case. The filter collects particulates from the atmosphere as air is drawn through it and after a few hours or days, depending on conditions in the atmosphere, the paper changes color due to the accumulation of particulates. During pollen season, it may turn yellow. If it is gray or black, it has collected black carbon. Even a low-power microscope can be used to observe and identify these small irregularly shaped particles.

Absolute calibration (number or mass of particles per cubic meter of air) is a challenge for this device. However, if one of these devices is placed next to an "official" calibrated particulate monitor and several other identical devices are deployed in the same vicinity, then even the relative discoloration of the filters from site to site can give a very useful indication of how representative the "official" measurements are of conditions in the surrounding area.

This device can be used even by young students to learn about what is in the air they breathe. The operation of the instrument is simple—there are no electronic or digital "tricks" to get in the way of understanding how it works! Older students may want to learn more about particles collected on the filter, which may include dust, pollen grains, and spores in addition to carbon. This can lead to original research. One high school student who collected particulates in the atmosphere by flying a piece of sticky tape on a kite found spores carried in smoke from biomass burning fires originating hundreds of miles away. This discovery, which could change global thinking about the advisability of burning off diseased or harvested vegetation, was reviewed and "fast tracked" for publication as the lead article in a peer-reviewed journal [Mims and Mims, 2004].

The 2010 appropriations act covering the Environmental Protection Agency specifically "authorizes the EPA Administrator to carry out and submit to Congress the results of a study on domestic and international black carbon emissions, including an inventory of the major sources of black carbon, assessments on its impacts on global and regional climate and potential metrics and approaches for quantifying the climatic effects of black carbon emissions (including its radiative forcing and warming effects) and comparing those effects to the effects of carbon dioxide and other greenhouse gases, an identification of the cost-effective approaches to reducing such emissions, and an analysis of the climatic effects and other environmental and public health benefits of those approaches." [P.L 111-88, 2010]

This is an excellent example of a project where local circumstances can greatly enhance the value of student research. When Estonia and Slovenia gained their independence in the early 1990's, there was essentially no professional infrastructure for monitoring air quality in those countries and a student research project using a similar black carbon detector provided the only source of particulate monitoring [Rockwell and Hansen, 1994; Penner and Novakov, 1996].

Sun Photometry to Monitor Aerosol Optical Thickness and Total Precipitable Water Vapor

Primary contributors: David Brooks, Matthijs Begheyn

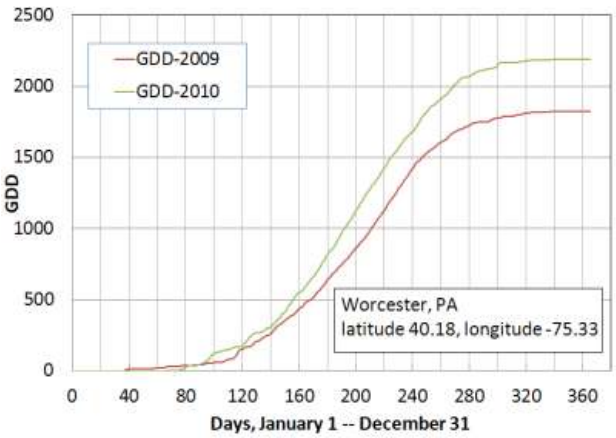
A visible light sun photometer was developed by David Brooks and colleagues in the 1990's for the GLOBE Program. It uses two LEDs as spectrally selective detectors of sunlight to measure aerosol optical thickness at 505 and 625 nm. A near-IR version, developed later, uses filtered photodiodes to measure total precipitable water vapor in the atmosphere.

Sun photometry is an example of an ongoing project that has already demonstrated both scientific and educational value. Despite a growing number of sophisticated ground-based measurements [NASA, accessed 2010; NOAA, accessed 2010], there is still a need for more ground observations to help provide better ground-truth validation for Earth-observing satellites and to fill data gaps. Student results from these instruments have led to co-authorships of articles in peer-reviewed journals and international travel opportunities for teachers and students. [Boersma and de Vroom, 2006; Brooks, Mims, and Roettger, 2007; Brooks *et al*, 2003; Brooks and Mims, 2002].

A program of student-based sun photometry has been active for several years in the Netherlands, where a very high level of scientific and educational support is provided by the Royal Netherlands Meteorological Institute (KNMI) and SME Netherlands, the organization which manages the GLOBE/Netherlands program and, more recently, the regional GLOBE/Europe/Eurasia consortium. The success of the Netherlands program illustrates the kind of scientist/educator cooperation and institutional commitment that is required to sustain these kinds of collaborative research projects.

Using Air/Soil/Water Temperatures for Agricultural Management, Microclimate Analyses, and Characterization of Seasonal and Yearly Changes

Primary contributors: David Brooks, Dev Niyogi



Routine meteorological measurements, air temperature in particular, have long been a feature of student activities for learning about weather. (Literally millions of air temperature measurements have been reported during the GLOBE Program, for example.) Collecting these data and perhaps comparing them with schools in other parts of the world to look for and explain patterns, has often been characterized as "student research." Typically, however, no science oversight or objectives are provided, no data quality control measures are in place, no rationale is provided for collecting the data that would stimulate interest from scientists or others, and data collection protocols may not meet required standards for accuracy.

At the 1996 TERC conference referenced earlier, Robert Tinker observed: "At first blush, meteorology seems ideal for student involvement until you realize that existing meteorological monitoring is so extensive that students can add little, except where their observations are unique. Examples of the latter are: quantifying atmospheric haze, doing microclimate studies, and making observations, such as in the West Pacific, where other reports are not available." [Tinker, 1996]

Measuring air temperature may be useful for students as "learning about" or "compare and contrast" activities, as "inquiry," but such activities have no value for climate scientists unless they are re-designed to have the characteristics of student research as defined above.

In spite of these many caveats, several workshop participants were enthusiastic about "upgrading" student meteorological data collection to the level of authentic climate-related research by developing specific science objectives and providing appropriate protocols and equipment. The potential educational advantage of such a plan is that the easily measured quantities—air, soil, and water temperature—are conceptually simple: The diurnal and seasonal cycles that one would expect to see in such data are easy to grasp even for young students: soil and water freeze in the winter; it is usually colder at night than during the day; it is warmer in the summer than in the winter, etc.

The scientific value of temperature data depends critically on how the data are collected. For some purposes, such as examining heat island effects, sensors must be dispersed spatially. Almost always, data should be recorded continuously.[1] For most purposes, air temperature sensors must be of higher quality than is typically used for student activities and low-end commercial weather stations. A specified accuracy of ±0.5ºC is not sufficient for tracking local heat island effects, as those effects may themselves be no more than 0.5ºC. Even worse, a thermistor-based temperature sensor with an accuracy stated in terms of "±" is as likely to exhibit a bias error as a random error. Platinum resistance thermometers are the standard for accurate temperature measurements, but they are more expensive than thermistor-based temperature sensors.

An important justification for continuously record air, soil, and water temperatures is to construct cumulative measures of temperature. For agriculture, "growing degree days" (GDDs) are the standard cumulative measure based on air temperature. In its simplest form, a growing degree day is equal to

$(T_{max} + T_{min})/2 - T_{base}$ if this value is positive and 0 otherwise.

where T_{max} and T_{min} are maximum and minimum daily temperatures. For agricultural purposes in the U.S., a T_{base} of 50ºF is often used. More accurate GDDs can be obtained with more frequent sampling. GDD values can be used to predict the occurrence of many events in agriculture and phenology, such as time of budburst, forest and crop production, time to crop maturity, and the emergence of agricultural pests whose life cycle depends on air temperature. Integrated pest management relies on such data to maximize the effectiveness of chemical or organic pest control strategies and also to minimize the cost and adverse environmental effects of those strategies.

For a site near Philadelphia, PA, the cumulative GDDs shown in the chart at the beginning of this section (using centigrade degrees with a baseline of 10ºC rather than 50ºF) demonstrate at a glance that 2010 was significantly warmer, with a slightly longer growing season, than 2009.

Similar values can be constructed from the same temperature database for cold and freezing degree days—of importance for assessing heating loads and fruit tree production, for example. Related values can be constructed from soil and water temperature records. Cumulative soil temperatures are valuable for management of agricultural pests whose life cycles include stages below ground as well as for monitoring long-term climate-related changes. GDDs and related data products provide "single value" summaries of quantities important to agriculture and biological cycles, and over the longer term they also provide an easy way to characterize entire years. Thus GDDs and related values are of direct interest not only for agriculture but, in the longer term, also for climate science.

These temperature-based projects are attractive for student research because they require only the most basic measurements, yet if implemented carefully they provide multiple results of interest to a range of stakeholders, including climate scientists. A 1999 paper discussing the possibilities of applying GLOBE Program air temperature protocols to

[1] "Continuously" is considered to mean a sampling/recording interval short compared to the time associated with changes of interest in the parameter being measured.

integrated pest management, presented at a GLOBE Program conference, included a high school student and an agricultural extension agent as co-authors [Brooks, Schanbacher, and Suchanic, 1999]. (The idea was never developed by the GLOBE Program.) Students at a K-8 charter school located on the grounds of an environmental education center in Philadelphia, PA, use GDD and insolation data to predict the spring emergence of toads from a small pond near the school. GDD calculations are related to budburst and other phenology indicators. Even young students can use basil plants (extremely frost-sensitive) to test the accuracy of frost forecasts from commercial providers of agricultural information; this kind of (literal) "ground truth validation" could help improve frost forecasts for microclimates.

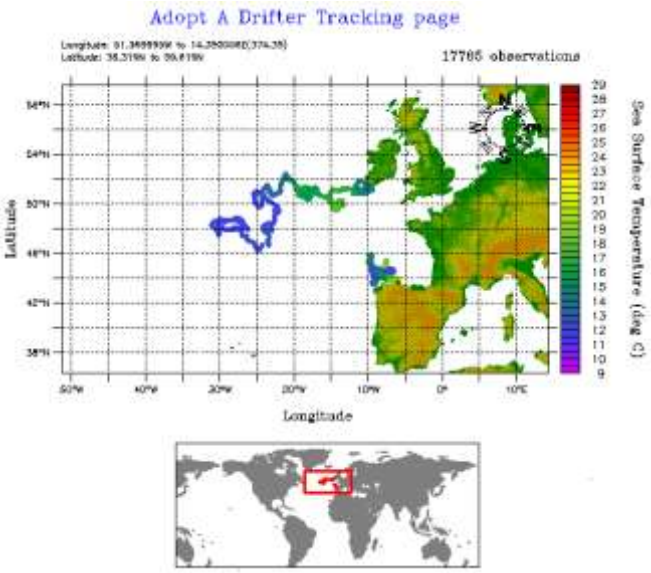
It is not uncommon for frost conditions to occur close to the ground, but not at the slightly higher location of meteorological instruments. The highly localized nature of frost means that measuring temperatures close to the ground and at the 1.5 m height that is standard for air temperature measurements can provide valuable information for agriculture and for understanding the development of low-lying vegetation.

The wide range of possible stakeholders and the cross-disciplinary applications of accurate and continuous temperature data *should* facilitate development of a very wide range of real research projects that will easily meet scientific interest and "Is it research?" tests, along with inquiry projects that can lead to research.

Tracking SST Frontal Zones and Marine Species

Primary contributors: Diane Stanitski, Ruth Krumhansl, Kira Krumhansl

Even though the open ocean environment is not directly accessible to most students, there are nonetheless opportunities for student climate-related research involving oceans. Through its "Adopt a Drifter Program," NOAA already makes available data from about 1250 freely drifting buoys. All buoys transmit their position and sea surface temperature (SST) in near-real time via satellite. Many drifters also report barometric pressure, which is useful for weather prediction models. A subset of drifters also collects subsurface temperature data.



Students can use these data, combined with other marine data accessible online, to look for patterns in real-time and archived data. Because there are so many drifters as part of this ocean array, extra sets of student eyes can help scientists focus their attention on unusual movements or changes in reported data that may be of significance.

Research indicates that endangered and protected marine species such as blue whales and certain sea turtles have a strong tendency to congregate and feed along sea surface temperature (SST) frontal zones [Etnoyer *et al*. 2004, 2006]. The locations of these thermal fronts shift seasonally and interannually. Some have proposed that detecting the locations of SST frontal zones could be used for adaptive management [Hannah, 2009], which involves constantly updating management strategies in response to information gained though monitoring. Climate change is expected to alter the locations and intensity of SST frontal zones, which will further increase the amount of effort needed for effective monitoring.

This project proposes that students could become involved in adaptive management by combining SST data from drifting buoys and satellite imagery with biological data concerning the distribution of marine species. Specifically, protected areas that vary in space and time (mobile protection zones) could effectively be used to manage pelagic species. At present, mobile protection zones represent a novel idea that could benefit from additional data collection to confirm the importance of SST fronts to endangered and protected species. If a policy employing mobile protection zones is established, these fronts will need to be tracked on a real-time basis to ensure that protection areas are appropriately located. Thus, students have the potential to contribute in important ways both to the establishment of key policies concerning the protection of marine species, and to the successful implementation of that policy.

In addition to the global drifter data, potential data sources for this project include: 1) SST imagery from Advance Very High Resolution Radar (AVHRR) available through NASA's Jet Propulsion Laboratory 2.) Marine animal tracking data from the Tagging of Pacific Predators (TOPP) and The Ocean Tracking Network (OTN), two networks collecting comprehensive data in the Pacific and Atlantic oceans 3) The Ocean Biogeographic Information System (OBIS), which is a database repository designed to allow users to analyze dispersions of species over time and space, and plot species' locations as a function of sea surface temperature. Successful implementation of this project will require active partnerships between marine scientists (including those involved in marine conservation policy), teachers and students.

The educational value of such a project rests significantly on the fact that it gives students an opportunity to see for themselves what is happening in the open ocean—an environment that is otherwise not directly accessible. It is worth noting that the same kinds of data development work needed to make such a project accessible for students, including better ways to link ocean observations of physical parameters to biological data, is also required by scientists. Hence, this is a project that will benefit all users of the scientific data.

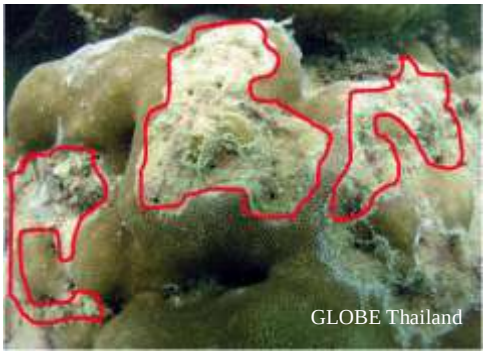
The project is inherently inquiry-based, with many questions flowing directly from observations: Why does the ocean surface temperature vary from one area to another? Why does the temperature change so dramatically along SST fronts? Why do marine species congregate along thermal fronts? How and why does the location of the fronts change over the course of a year? How is climate change likely to affect the nature and location of these fronts? What implications does this have for the management of marine species? Why is it important to have both satellite and in situ data?

This project is particularly interesting as an example of "uncontrolled experiments," where new knowledge about the often unpredictable natural world is acquired by setting up a data collection system to study a particular environment, observing what happens, looking for patterns, thinking critically about data, formulating explanations, and finally, developing hypotheses to guide analysis and future experimentation. This is a common approach in climate science even though it does not neatly conform to the more confining "rules" of the scientific method as often taught in schools. It provides many opportunities to apply computer technology and mathematics and can lead to the development of very sophisticated data gathering, manipulation, and analysis skills. It is also inherently cross-disciplinary, with many applications in environmental and Earth science and biology. Furthermore, because this project concerns the establishment of policies to protect marine species, students' work could be important to a larger group of users beyond the scientific community, including lawmakers and the general public.

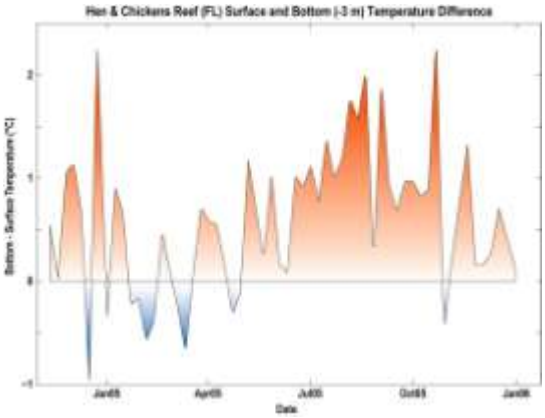
Benthic Habitat Monitoring and Seafloor Temperatures

Primary contributors: Elizabeth Moses and Christopher Moses

Research in the marine environment is critical to understanding climate processes, but even for students living near coastlines, doing authentic research in an ocean environment poses significant challenges. However, there are opportunities for students to collect useful data from shallow, relatively accessible waters.



A large number of marine habitats remain unmapped and many are being lost at rapid rates, partly due to climate-related events. Assessments of extreme events (e.g., mass bleaching of coral) require coverage of large areas in a short period of time. Using standardized methods, student *in situ* observations and photography can be used to document unmapped benthic systems and organism responses to climate-related events. For example, In 2009, a student photo survey of a shallow water reef (~3 m) coral reef in Key West, Florida was the first such survey ever conducted of that reef. The following year, extraordinarily cold temperatures caused a massive die-off of coral in this reef. An analysis of the change was possible only because of student photographs from the previous year.



Marine surveys using digital equipment can be conducted successfully by experienced divers or snorkelers with limited scientific background. Standardization and scaling is

key for use in scientific research. With the use of an appropriate scale bar or grid, standardized video or photo transect images can be analyzed to detect changes in mortality, cover and diversity. Free image analysis programs (e.g., Image J; http://rsbweb.nih.gov/nih-image/) are available that can be used to precisely calculate area. One of the main downfalls of this method is that it is very time consuming. For this reason, students who learn basic image analysis techniques can help researchers detect changes in the benthic environment, while allowing non-coastal students to become directly involved in marine research. Underwater digital video and camera equipment can be expensive and requires frequent maintenance. However, in shallow environments where the water is relatively clear and color is not a factor in analysis, inexpensive digital cameras with waterproof housings can be used, as has been done by students in Thailand—see the image above.

Another area of scientific interest is the relationship between satellite-derived sea surface temperatures and sea floor temperatures in shallow waters. The graph above shows the difference between satellite-derived sea surface temperatures (SST) and measured seafloor temperatures in about 3 m of water off the Florida keys, with positive (red) values indicating warmer bottom temperatures than surface temperatures [H. Hudson and C. Moses, unpublished data]. While satellites such as AVHRR are capable of providing accurate estimates of SST, this does not always reflect the bottom temperature experienced by benthic organisms at shallow depths (1-5 m), which at times exceeds coral bleaching thresholds.

Accurate sea floor temperature data are important for monitoring the health of coral reef communities where the coral and other inhabitants are living near their upper thermal limits. In addition to temperature, coral bleaching is a response to high light conditions but light measurements on reefs are minimal. Student observations of atmospheric and oceanic conditions (e.g., cloud cover, sea state, water transparency) can help interpret spatial or temporal variation in organism responses such as coral bleaching.

Measuring Arboreal Carbon Sequestration

Primary contributor: Sarah Silverberg

The global carbon cycle is a key regulator of the Earth's climate and is central to the normal function of ecological systems. Because rising atmospheric CO_2 is the principal cause of climate change, understanding how ecosystems cycle and store carbon has become an extremely important issue. In recent years, the growing importance of the carbon cycle has brought it to the forefront of both science and environmental policy. The need for better scientific understanding has led to establishment of numerous research programs, such as the North American Carbon Program (NACP), which seeks to understand controls on carbon cycling under present

and future conditions. This work is an important part of preparing society to make sound decisions on energy use, carbon management and climate change adaptation.

Teams of scientists and educators at the University of New Hampshire and Charles University (Prague, CZ) have focused on bringing the most cutting edge research and research techniques in the field of terrestrial ecosystem carbon cycling into the classroom. Student methods in field measurements, plant experiments and ecosystem modeling descend directly from work that the participating scientists use in their own research.

In the photo, students are measuring tree diameters in a wooded plot. These data are used to calculate the carbon sequestered by trees in that plot. If the measurements are repeated over time, net primary productivity and carbon uptake can also be calculated. These types of measurements can be used to create a more complete picture of carbon dynamics in terrestrial ecosystems.

In addition to field research, the project incorporates a diverse set of activities geared toward a variety of learning styles. A global carbon cycle adventure story and game let students see the carbon cycle as a complete system, while introducing them to systems thinking concepts including reservoirs, fluxes and equilibrium. Classroom photosynthesis experiments and field measurements of schoolyard vegetation bring the global view to the local level. In addition, computer models, an important scientific tool necessary for understanding climate change, not only reinforce the concepts of systems, but also cover the topics of effects on photosynthesis, biomass and carbon storage in global biomes, and global carbon cycling.

When students take part in the GLOBE Carbon Cycle Project they not only perform introductory activities to learn content, but also have multiple opportunities to participate in research. Early research experiences involve students collaborating with each other in observation and measurement using the provided methods in order to answer a question provided by the teacher. More experienced students are guided through the development of their own research questions which may be relevant to their school or community and then use familiar methods to design a full investigation plan.

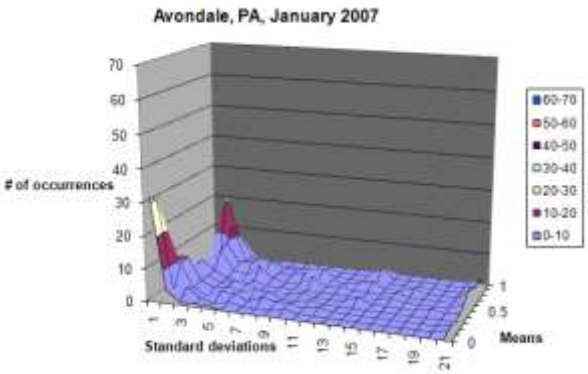
Pyranometry for Monitoring Insolation and Characterizing Cloud Patterns

Primary contributor: David Brooks

Monitoring the solar energy reaching Earth's surface (insolation) is an ideal way for students to start understanding Earth's climate system. The idea that the Earth/atmosphere system must, on average, be in radiative balance with the energy it receives from the sun is a fundamental climate science concept that is an essential component of any Earth science course.

Insolation can be recorded using inexpensive silicon photodiode-based pyranometers developed by the Institute for Earth Science Research and Education, containing less than $10 in parts. These instruments are similar to commercial silicon photodiode-based pyranometers (costing several hundred dollars) that are widely used in agriculture, environmental monitoring, and research. The performance of *IESRE* pyranometers has

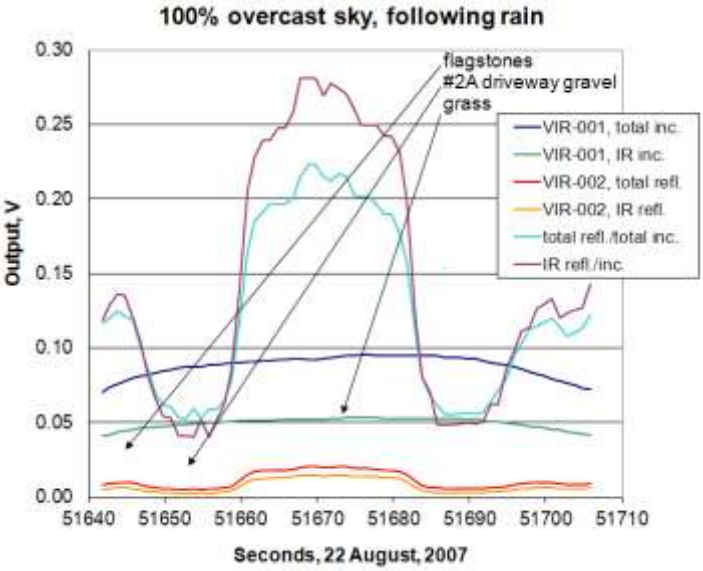
been characterized for several years during the National Renewable Energy Laboratory's annual Broadband Outdoor Radiation Calibration (BORCAL) project [Brooks, accessed December 2010]. Even though the cosine response of these pyranometers is not as accurate as for more expensive instruments, studies have shown that daily integrated insolation typically agrees within a few percent of data from high-quality (and very expensive) thermopile-based pyranometers.



Reliable insolation data are critical for evaluating the suitability of sites for solar energy installations (photovoltaic or thermal). Cumulative measures of insolation can be used to characterize seasonal and longer changes, especially in conjunction with cumulative temperature data as discussed in the previous project. Sampling at high temporal resolution (one minute) can be used to generate daytime cloud statistics and cloud climatologies for sites. Considering the importance of clouds as both an effect and cause of climate change, these climatologies have considerable scientific value. In the contour plot shown here, insolation data from NOAA's Climate Reference Network site in Avondale, Pennsylvania, have been used to generate a summary of daytime cloud conditions for January, 2007, by comparing observed insolation to a clear-sky insolation model. The peak in the rear left-hand corner represents clear days and the peak in the front left-hand corner represents overcast days. The CRN data are hourly averaged, so they are not as attractive as a data source as data recorded at higher temporal resolution would be.

Characterizing Surface Reflectivity

Primary contributors: David Brooks, Dev Niyogi



The inexpensive pyranometer described above can also be used in downward and upward facing pairs to measure localized surface reflectivity (albedo). In contrast to insolation measurements, an absolute radiometric calibration is not required for measuring broadband surface reflectance. Instead, a relative side-by-side calibration of two pyranometers is all that is required. Following the calibration, one instrument is then used to measuring incoming

radiation and the other is used to measure reflected radiation.

It is equally simple and inexpensive to measure near-IR reflectance using a photodetector that is physically identical to the broadband detector except for the fact that its housing filters out visible radiation. As shown in the graph, different surfaces have markedly different reflectivities, and near-IR reflectivity is significantly different from broadband reflectivity. With the addition of a low-pass filter over the broadband detector, an inexpensive instrument can be built to calculate the Normalized Difference Vegetation Index (NDVI), a standardized quantity for characterizing the health of vegetation based on measurements made from Earth orbit.

These ground-based measurements are extremely useful not only for characterizing local conditions, but also for validating satellite-based measurements. Diurnal changes, ground cover, and soil moisture (based even on simple qualitative observations such as the last rainfall date) are all helpful, and they provide multidisciplinary experiences for a wide range of student investigations that have legitimate research value.

Water, Weather, Climate, and Health Research in Nigeria

Primary contributor: Rebecca Boger

The effects of climate change on the spread of disease, water availability, and agriculture is of interest to scientists, resource managers, students and citizens around the world. In developing countries, the lack of an infrastructure for basic meteorological and other environmental data makes predictions of regional and global climate models less accurate. Thus, any properly designed student research project that helps to fill in data gaps across climate zones will meet the "scientific interest" test.

A pilot project is underway in which GLOBE schools in Osun State, Nigeria are working with U.S. and Nigerian universities to collect soil, atmosphere, and mosquito larvae data. Data quality and temporal and spatial resolution are ongoing challenges for scientists seeking to use data collected by K-12 students or other community members. This problem also exists in developed countries, but it is especially acute in developing countries without a strong history of climate research. To address these problems in Nigeria, two commercial data loggers with several soil and atmosphere sensors (air temperature, relative humidity, insolation, barometric pressure, rainfall, and soil moisture and temperature at 3 depths) have been installed in Osun State. These data loggers collect data at 5 minute intervals and the data are sent to Brooklyn College.

High-quality data collection is not the only consideration for collaborative research with students. For the Nigeria project, two additional components have been addressed: packaging of educational materials to promote student research and teacher professional development. Of direct relevance for the Nigerian audience (and elsewhere in the world), educational materials are being developed around health and agricultural themes.

Nigerian teachers have been involved with the installation and upkeep of the data loggers. A workshop has focused on how to involve students in inquiry and research by integrating phenology and meteorology protocols developed for the GLOBE Program along with local knowledge of seasons and agricultural practices.

In a second workshop, teachers participated in a field campaign using a newly developed Africa mosquito larvae protocol. Participants learned about mosquito life cycles, where mosquitoes reproduce and grow, and how malaria is spread. They practiced water sampling techniques and identifying the genus *Anopheles*, which is responsible for transmitting malaria. Participants then sampled a variety of potential water sites (e.g., drainage ditches, tire tracks, puddles, and streams) where larvae could be found. Finally, they shared and organized their data. Although this protocol does not conclusively identify malaria sources (because not all species within the *Anopheles* genus transmit malaria), it does narrow down locations for further research and helps to define relationships between environmental factors and mosquito breeding habits. Ultimately, these relationships are intimately connected to climate change. The protocol is easily accessible for students and provides unique sources of spatial and temporal sampling data that are not otherwise available in Nigeria.

This project has obvious benefits for students and researchers in Nigeria, but the benefits extend beyond local boundaries. The Nigerian work is being done in a predominantly agricultural society, and the lessons learned from climate monitoring there have implications for an improved understanding of building and maintaining secure and sustainable food sources around the globe.

Conclusions

We believe this workshop has convincingly made the case that there is a need for students, teachers, and scientists to collaborate on authentic climate science research projects and many opportunities for them to do so. We have defined what it means for students to do climate-related research, and we have outlined the characteristics all such projects should have to differentiate them from other kinds of learning activities. We conclude that students can do real research if:

1. We expect them to do real research;
2. We are honest with them about what is required to do real research;
3. We provide them and their teachers and schools with appropriate support.

We understand that concluding that students *can* do real research is not the same as concluding that they *will* do real research, either in their classrooms or on their own. We are convinced that student learning outcomes and our national interests will benefit from more students engaging in authentic science research, including climate science research, but we recognize that we have not presented any quantitative evidence to support this assumption. One reason for the lack of this evidence is, of course, the fact that very little authentic research is currently being done by students—not just in climate science.

In any case, it is clear that major efforts are required to move from "*can do"* to "*will do*." We believe there is little evidence that current student/teacher/scientist partnership models have been very effective at promoting authentic collaborative science with students. (See Appendix 4.) If true, different approaches to forming and sustaining science partnerships need to be developed. All groups must increase their involvement in the critical area of climate science education and we believe that authentic collaborative climate research with students can and should be part of this process. We have outlined what we believe are necessary changes in how institutions involved in formal and informal education approach collaborative research with students. We do not minimize the magnitude of the required efforts, which are the joint responsibility of educators, scientists, and funding agencies. Specific needs include:

1. Those responsible for preparing teachers must provide more opportunities and incentives for future teachers to learn how to incorporate real research into their professional lives and classrooms.
2. Practicing teachers must be given time and resources to conduct their own research with students, and they must be more willing to invest in partnerships with scientists and other stakeholders who can guide and share in that research. Professional recognition for science teachers must be based, in part, on these personal investments.
3. School administrators must integrate collaborative research into their institutions' mission and they must find ways to reward teachers who support research in their schools and the students who participate in that research.
4. Researchers must be more innovative in their efforts to collaborate with students and their teachers. They must be more sympathetic to the pressures teachers face every day in the classroom, and they must be willing to commit the resources required to provide ongoing support throughout the life of collaborative projects.
5. Research funding agencies must make sure that climate science research solicitations provide incentives for grant recipients to include collaborations with teachers and students as an integral part of their research plan. Not all research is amenable to this approach, but when it is, generic "education outreach" requirements need to be replaced with specific guidance that addresses both the opportunities and challenges for such collaborations.
6. Projects proposed by scientists must be described in sufficient detail, as outlined above, that it is possible for teachers and school administrators to understand the potential benefits for students and make informed decisions about the commitments that are required for the project to succeed. A detailed "project description template," originally written for workshop participants, is included as an Appendix 5.

We believe that making these investments in sustainable collaborative climate research with students is well worth the effort and will bring many benefits to all participants—students, teachers, and scientists—and to our nation:

1. Students will be better educated about Earth's climate and more students will be inspired to pursue careers in science because they will understand that they can make real contributions to our understanding of Earth's climate.
2. Teachers will see better academic performance and increased levels of engagement from their students, enhanced standing with their peers and students, and a sense of accomplishment for providing their students with inspiring experiences.
3. Scientists will have chances to expand the temporal and spatial sampling that is critical to so much climate science research. They will see their work disseminated to a broader audience, leading to a better public understanding of climate science.
4. Community leaders and policy makers will develop direct links with our country's educational system, through shared interests in understanding our planet's climate.
5. Our nation will be able to regain its international standing as a leader in science education, with an informed public and a STEM-focused workforce prepared to participate fully in one of the most important science issues for the 21st century.

Recommendations for the Future

This workshop has put forth some specific ideas for student climate research, within a framework that defines what it means for students to do authentic research. Additional actions needed to implement these ideas in the future include:

1. Convene a second workshop that will work toward developing an infrastructure for supporting authentic student climate-related research within the framework defined at the November 2010 workshop.
2. Further develop the collaborative research projects presented in November 2010.
3. Establish a permanent website and working group to support collaborative student/teacher/scientist climate-related research, as defined in this document.

The 2010 report from the President's Council of Advisors on Science and Technology (PCAST) [PCAST, 2010] offers several recommendations to improve our nation's international standing in STEM education and is particularly relevant as a guide to future actions to support collaborative student climate-related research. The recommendations include:

"Teachers: Recognize and reward the top 5 percent of the nation's STEM teachers, by creating a STEM Master Teachers Corps."

The reward system envisioned by the PCAST report includes "significant salary supplements as well as funds to support activities in their schools and districts." **Participation in collaborative research with scientists and with their students should be among the criteria used to decide how these rewards are allocated to teachers.**

For science teachers, especially at the secondary school level, engaging in authentic research should be a *prerequisite* to be recognized as a "master teacher."

"Students: Create opportunities for inspiration through individual and group experiences outside the classroom."

The PCAST report suggests a "wide range of high-quality STEM-based after-school and extended day activities…" **Those activities should include programs focused specifically on collaborative research, either classroom/school-based or to support individual or group science fair projects.**

"Schools: Create 1,000 new STEM-focused schools over the next decade."

Of these 1,000 new schools, the PCAST report proposes "at least 200 new highly-STEM-focused high schools." The PCAST report notes that "high schools, and most of the Nation's middle schools, typically have teachers with some STEM expertise, but these teachers often lack meaningful connections to the STEM professional community… Every middle school and high school should have a partner in a STEM field, such as a research organization, college, university, museum, zoo, aquaria, or company, that can bring STEM subjects to life for students and help teachers and students learn about STEM in the workplace."

We believe these partnerships should go even deeper and that **all of these new high schools should include ongoing collaborative research as an integral part of their mission—that is, these new schools should embrace a new paradigm of considering themselves as centers for education *and* research.** Some of these schools should be designated as collaborative climate research institutions, with recognition and support to sustain that mission.

Currently, there are only a small handful of high schools in the U.S. that come even close to embracing such a mission. (See the PCAST report for brief overviews of these schools.) It is significant that some of these public schools are highly competitive selective admissions schools, in which minority populations are often underrepresented. The PCAST report also notes that there are even fewer STEM-focused elementary and middle schools, "even though studies show that student interest—or disinterest—in STEM can solidify by middle school."

We believe that a second workshop is necessary to develop specific guidance for implementing some of the climate science projects already proposed, within a framework of enhanced science/education relationships which will serve as a model for building sustainable scientist/teacher/student collaborative research partnerships. Such a workshop should include participation from project scientists, teachers, school administrators, science educators, and information technology specialists.

This workshop should establish a working group whose responsibilities will include:

1. Setting standards for data collection equipment and procedures;
2. Evaluating existing data for their relevance and appropriateness for collaborative climate research with students;
3. Guiding implementation of technologies for data availability and dissemination.

Often, standards for student data collection have been lax and not always appropriate for science questions that might be addressed through those data. The most obvious reason for this deficiency is that student activities are not considered to be "real" research. In order for student climate-related research to meet the "scientific interest" test discussed in this report, it is absolutely essential for this matter to be taken seriously. More attention needs to be paid to site characterization. Instrument specifications and calibrations must be appropriate for the task. Data collection and quality control protocols must be designed in collaboration with potential users of the data and rigorously enforced.

The working group should be responsible for "vetting" existing data for use by students in collaborative research. We expect that distinctions will need to be made between the large amounts of data available for educational use and data that are suitable for authentic research. This process does not necessarily involve additional investigation of the data themselves, but more likely ensuring that the scientist participants in a particular project have made clear what data are suitable for that project.

Climate data to supplement and provide context to students' own observations or as sources for "data mining" are often not available in a form that is easily accessible to students, especially not in a way that today's media-literate students are used to having available. For example, hourly temperature and insolation data from more than 100 NOAA Climate Reference Network sites around the U.S. are available online in near-real time (see http://www.ncdc.noaa.gov/crn/) in the form of downloadable ASCII text files; it is certainly possible to use such data, but it is sufficiently inconvenient to impose significant hurdles for student projects. Online visualization tools are needed to make it possible for teachers and students to use these data effectively. (Such tools benefit "professionals," too!) Data reporting tools also need to be easy to use. Meeting these requirements does not necessarily depend on the latest cutting-edge technologies; it is more a matter of providing tools that are appropriate for a particular science-driven task.

A basic website was established prior to the November workshop. It currently contains PowerPoint presentations from the workshop and links to other useful documents concerning science education and student research. Support is needed to expand this website to serve as a permanent resource for supporting authentic collaborative student climate science research projects.

Appendix 1: Workshop Participants

Names in bold font are members of the organizing committee.

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Appendix 2: A Brief Summary of Views from "Climate Dissenters"

Primary contributor: David Brooks

As noted in the body of this report, despite overwhelming evidence supporting the conclusion that human activity is contributing to Earth's changing climate, there are still significant minority dissents to this consensus view. These dissenting views may be perceived by the majority of climate scientists as illegitimate distractions. However, to the extent that skeptics can present evidence-based arguments about how to interpret data, they perform a service that is an essential part of the scientific process, ultimately leading to better science. In any case, we believe it is important to at least note these dissents because of the importance of giving today's students the intellectual tools to participate in this debate.

Dissenters often take absolute positions against anthropogenic climate change, for example, "…the recent warming trend in the surface temperature record cannot be caused by the increase of human-made greenhouse gases in the air." [Baliunas and Soon, 2002] Scientific statements about anthropogenic global climate change are often distorted. An article in The Daily Galaxy is titled "Is Global Warming Part of Earth's Natural Cycle: MIT Team Says 'Yes'" [The Daily Galaxy, 2009]. A reading of the original article, as summarized by the MIT press [Chandler, 2008], presents an entirely different picture, noting that "methane levels in the atmosphere have more than tripled since pre-industrial times, accounting for around one-fifth of the human contribution to greenhouse gas-driven global warming." Some scientists suggest that observed climate changes are the result of natural climate cycles that simply are not yet understood. Others believe that apparent global warming can be explained by changes in solar activity—some even believe that Earth's climate is heading into a cooling phase because of recent decreases in solar activity [Soon, 2000].

Concerns about the entire notion of a "scientific consensus," especially as expressed in the IPCC reports. may also be viewed as legitimate. (Non-scientist) author Michael Crichton has reminded us that "the claim of consensus has been the first refuge of scoundrels; it is a way to avoid debate by claiming that the matter is already settled… The work of science has nothing whatever to do with consensus… In science consensus is irrelevant. What is relevant is reproducible results." [Crichton, 2003]

Ethical lapses within the Earth science community include charges of data manipulation, blocking access to data by other scientists, and blatant attempts to stifle dissent. Illegally obtained e-mails from the University of East Anglia (UK) Climate Research Unit, widely disseminated in 2009, depict climate scientists engaging in private conversations that can easily be interpreted as inappropriate for a serious and unbiased scientific dialog. There have also been numerous complaints about the methodologies used by the IPCC to reach its conclusions and its heavy-handed stifling of dissent when writing its reports. There are so many online reports about and interpretations of these incidents that it is pointless to try to select just one as an authoritative reference—a fact that just by itself defines the huge challenges of managing the climate science debate in an ethical and unbiased way.

Disagreements among scientists can be confusing to a lay audience, but it is more troubling when self-proclaimed "experts" add their voices to the debate. A U.S. Senator

has declared (and, by all accounts, continues to believe) that "much of the debate over global warming is predicated on fear, rather than science… [the threat of catastrophic global warming is the] greatest hoax ever perpetrated on the American people." [Inhofe, 2003, 2005] A fundamentalist preacher claims that the connection between CO_2 and warming is "the greatest deception in the history of science" and that "the whole [global warming] thing is created to destroy America's free enterprise system and our economic stability." [Falwell, date uncertain] A science fiction author claims that "environmental organizations are fomenting false fears in order to promote agendas and raise money" [Crichton, date uncertain] and that computer models cannot be relied upon to predict future climate [Crichton, 2007, 2003]. A well known British environmental activist concludes that "global warming—at least the modern nightmare vision—is a myth. I am sure of it and so are a growing number of scientists. But what is really worrying is that the world's politicians and policy makers are not." [Bellamy, 2004].

During a 2000 U.S. Presidential campaign debate with Al Gore, then-candidate George Bush offered the opinion that "some of the scientists, I believe, haven't they been changing their opinion a little bit on global warming? There's a lot of differing opinions and before we react I think it's best to have the full accounting, full understanding of what's taking place." [Bush, 2000]

In a stunning commentary interweaving the economic and societal implications of climate change, the CEO of an Irish budget airline brags that "we will double our emissions in the next five years because we are doubling our traffic. But if preserving the environment means stopping poor people flying so only the rich can fly, then screw it… The best thing we can do with environmentalists is shoot them. These headbangers want to make air travel the preserve of the rich. They are Luddites marching us back to the 18th century." [O'Leary, 2005?]

The climate change debate reaches far beyond climate science itself and even beyond politics. In his 2001 book, *The Skeptical Environmentalist* (and more recently in many other venues), the Danish political scientist Bjørn Lomborg suggests that the poorest people on Earth—those likely to be most severely impacted by global warming—would benefit more from rich countries honoring pledges on aid, opening up their markets, and investing in providing universal access to clean water than they would from aggressive reductions of greenhouse gas emissions. That is, he claims that compared to other global problems, mitigating global climate change has an unfavorable cost/benefit ratio and is simply not cost-effective [Lomborg, 2001].

Appendix 3: Educator Professional and Pre-Service Development for Collaborative Student Research: Starting at the Beginning

Primary contributor: Tony Murphy

Authentic science experiences and inquiry-based learning have been at the center of K-12 science reforms since the mid-nineties and are widely supported by extensive and varied research [American Association for the Advancement of Science, 1990, 1993; National Academy of Sciences, 1996]. It is obvious that if student/teacher/scientist research collaborations are to be authentic and effective that teachers have to be comfortable in a research environment. Invariably, with projects that involve authentic climate-related science, teachers will need to function as intermediaries between scientists (and possibly graduate students) and their own students. Even if teachers have some academic background in climate science, this is a very challenging role, and it is *not* one that teachers can be expected to learn on their own either during their pre-service education or "on the job" in their classrooms. (Teachers who are teaching in classrooms are referred to as in-service teachers, while pre-service are those who have yet to receive their teaching license.)

Inquiry-based practices are becoming a more familiar component of pre-service and professional development programs for science teachers. However, authentic research experiences are not common. In pre-service preparation programs, inquiry experiences, which do not necessarily encompass "real" research, are generally required only for those who become high school science teachers. While research opportunities are generally open to all teachers as professional development opportunities, they are availed of primarily by high school science teachers followed by middle school teachers and a much smaller number of K-6 science specialists. Any successful attempt to reform science to include authentic collaborative science research should begin at the elementary level.

In elementary classrooms today, 38 percent of teachers state that they lack full confidence in their qualifications to teach science and almost as many say they rely more on what they learned in high school science than on what they learned in their teacher preparation courses in college [Bayer Report, 2004]. In addition, research points to further issues with the preparation of elementary educators. These include limited science knowledge, limited pedagogical experiences, and limited confidence, resulting in many elementary teachers avoiding the teaching of science [Lee & Houseal, 2003; Goodrum, Hackling & Rennie, 2001]. If science teaching does occur in elementary classrooms, these factors can impact the quality of that teaching so that there is a tendency to use strategies that are not appropriate for engaging students or learning the nature of Science [Morell & Carroll, 2003; King, Shumow, & Lietz, 2001; Newton & Newton, 2000].

In the same way that this workshop has sought to move beyond inquiry-based activities to authentic student research, teacher preparation and teacher professional development opportunities must enable teachers to have authentic research experiences. This preparation or professional development should include a firm grounding in inquiry-based science for teachers at *all* grade levels—as noted elsewhere in this report, inquiry-based activities serve as the essential prerequisite for authentic research. In addition, if student/teacher/scientist research collaborations are to become a part of the educational experience for middle and high school students, those students need to be prepared with

an understanding of the scientific process and the foundational aspect of inquiry; and this needs to begin at the elementary grades. Therefore elementary, middle and secondary school teachers *all* need to engage in their own authentic research activities. These experiences can be found in individual projects or through participation in ongoing research activities supported by a college or university; for long-term climate-related research, the latter situation would be the most desirable.

The National Science Foundation (NSF) has supported its Research Experiences for Teachers (RET) for many years. The NSF's RET program allows K-12 teachers to work with scientists on research projects in NSF supported laboratories and engage in authentic scientific inquiry. Research has shown that after participating in an RET program teachers are more confident and more likely to participate in other professional development programs [Grove & Dixon, 2007]. In addition to producing more confident and involved teachers, participants also discover firsthand the importance of providing their students with authentic problems instead of labs with pre-set solutions [Musante, 2006]. Teachers also report that they incorporate their research into their classroom curriculum, which establishes credibility with the students and increases student interest [Musante, 2006]. Most teachers who participate in these programs are high school teachers with a smaller number of middle school teachers [Russell & Hancock, 2007].

The National Oceanic and Atmospheric Administration's (NOAA) Teacher at Sea Program is open to all K-12 teachers and one of its aims is to "increase the teachers' level of environmental literacy by fostering an interdisciplinary research experience" [NOAA, accessed 2010]. NOAA is also piloting a Teacher in the Air Program. Just like NSF, NOAA finds that this experience has an incredible impact on the teacher participants, but again those participants are primarily drawn from high and middle schools. A smaller number of teachers from elementary schools participate in this program [Hammond, 2005]. Scowcroft and Knowlton [2005] conducted a survey of numerous teacher research experiences and found similar results and the same trend in the demographics of the participants.

While these kinds of programs offer excellent research experiences for in-service teachers, the need to offer research experiences at the pre-service level is also of great importance. Many state departments of education require that high school science teachers have a research experience as part of their preparation program. However, if elementary and middle school students are to be exposed to inquiry based learning in their classrooms, then their teachers must have research and inquiry-based science experiences as part of their pre-service preparation programs as well.

Based on an analysis of existing research experiences offered for in-service teachers, pre-service high school science teachers, and a survey of pre-service elementary teachers at St. Catherine University, MN, pre-service research experiences should have the following characteristics:

- an extended research experience (8-10 weeks)
- a variety of experiences that would meld with the interests of the pre-service teachers (i.e. ecology, biology, chemistry, earth science, etc.)

- a mentor who is willing to work with pre-service teachers who may have a limited science background (2-4 science courses) but great enthusiasm (the selection of the correct mentor is key to the success of this experience) and
- a stipend with other associated costs covered (travel, accommodation, etc.) [Greenawald and Murphy, 2010]

Many institutions have funded opportunities from the NSF for Research Experiences for Undergraduates (REUs), which already include many of the characteristics listed above. These could play a role in opportunities for elementary and middle school science pre-service teachers if they are redesigned for this specific purpose.

If elementary and middle school science teachers are to become comfortable laying the foundation for authentic and effective student/teacher/scientist research collaborations, then an authentic research experience should become a key part of their preparation and/or in-service professional development opportunities.

Appendix 4: How Can Teachers and Scientists Form Effective Research Partnerships?

Primary contributor: David Brooks

The focus of this workshop has been on *student* climate research. Reaching students is, after all, the overriding goal. However, as the adult participants in a collaborative research project involving students, teachers and scientists have the primary responsibility to work together to provide an environment conducive to successful student research. In order to maximize the scientific and pedagogical value of collaborative research, projects must be designed in a way that keeps the needs of students in mind but also takes into account the significant differences in job demands and working conditions that permeate the culture of scientists and teachers.

In order to better understand the needs of these two groups, we offer the following generalizations:

1. For the most part, science (including climate science) is conducted as a collaborative effort among peers. For the most part, especially in higher-level secondary school science courses, teachers work alone. Collaboration among peers is the exception rather than the rule and daily contacts are on a teacher-to-student basis rather than on a peer-to-peer basis.
2. Scientists' work tends to proceed in a direction and at a pace set by the scientists themselves, with self-imposed deadlines. Classroom teachers usually have a regimented schedule dictated by the school where they teach.
3. Recognition for scientists is based on peer evaluation of their work—a highly personalized process. Recognition for classroom teachers is often based on evaluating the performance of their students by a process that can be more mechanical than personal (e.g., performance on standardized tests).
4. A scientist's work is focused on expanding knowledge. A science teacher's work is focused on delivering existing knowledge to students in innovative ways that hopefully will inspire some of them to pursue careers in science.
5. Scientists tend to have the time and incentives to specialize within their field. Even in higher level science courses, teachers are generalists who must work within much broader content areas and cannot devote large amounts of time to a single topic.

In spite of these differences, it is important that scientists and teachers recognize what they have in common. Scientists and teachers interested in improving science education and in supporting authentic collaborative research are passionate about their work. They are committed to sharing their knowledge and passion with a broader audience, specifically including students who are our future scientists and leaders. As these partnerships are formed it is important to keep these commonalities in mind and have a greater goal of doing what is best for the students and the future of scientific research.

As scientists and educators work together to form collaborative partnerships, there are three essential steps:

1. Finding partners;
2. Agreeing on the terms of a collaboration that will meet the needs of scientists and other partners, teachers, and students;
3. Following through on commitments.

Here is a typical scenario for establishing science collaborations among scientists and teachers: Scientists and science educators design professional development workshops for teachers, focused on a specific area of science. Teachers attend the workshop based on their interest in that science area, their need to improve their content knowledge, a desire to develop new teaching strategies, and the age-appropriateness of the material for their students. Workshop organizers provide background, teaching strategies, ideas for student projects, and protocols for collecting, reporting, and analyzing data. Equipment for conducting experiments and other teaching materials may be provided at no cost in return for teacher participants promising to collect data with their students and report those data back to scientists. (The purpose for reporting the data may not be scientific, but just to help students and teachers understand their observations and measurements.) Often, these programs are conducted during summer school breaks and, usually, participants are paid a stipend for attending. Sometimes, part of the stipend is withheld pending receipt of data from teachers and their students.

This scenario seems to define a promising approach to collaborative research. By bringing together scientists and teachers with some commonality of interests, it facilitates the first step in forming a research team. It provides teachers an opportunity to form partnerships with their peers and gives them access to expertise they would otherwise not have. It provides scientists with access to potential research partners. A workshop's agenda establishes, at least in a general way, the terms of the collaboration.

There are other approaches for forming research collaborations. Scientists can develop local teacher contacts, and they can search for partners through professional organizations such as the National Science Teachers Associations (NSTA) and their state equivalents. They can look for teachers who are already active in science education programs such as The Centers for Ocean Sciences Education Excellence (COSEE, http://www.cosee.net/about/aboutnetwork/sep/), the National Lab Network (http://www.nationallabnetwork.org/), the GLOBE Program (www.globe.gov), and others. Finding teachers directly through local schools might seem a logical approach, but it is typically more effective to use a "middleman" to reach teachers and form partnerships. The middleman could be university outreach coordinators, information education centers, federal agencies with ties to educators, professional and community organizations, or even friends and family that are teachers or know teachers.

Teachers interested in research partnerships can look toward professional organizations, such as the American Geophysical Union (AGU) and the American Meteorological Society, which support extensive education programs and often include education outreach sessions in their conference programs. Federal research agencies such as NASA and NOAA also have extensive public outreach programs with entire offices dedicated to making research and research personnel more accessible to the public, including opportunities for teachers to participate on research teams.

The professional development model for forming partnerships is widely used because it seems eminently logical. However, experience shows that this model almost always fails when it includes the expectation of research participation in which teachers and students collaborate with scientists to collect, report, and perhaps analyze data. It is clear at least anecdotally that in these partnerships there still exists a huge gap between a one-way transfer of educational content from the science community to the education community (which, by itself, is a worthwhile result) and a true collaboration that provides significant benefits for students, teachers, *and* scientists.

Even the purely educational benefits of engaging in such partnerships for the purpose of improving inquiry-based science education programs have been found to be modest at best when examined quantitatively. It is not easy to conduct quantitative evaluations on these kinds of programs (because of the difficulty of identifying appropriate control populations, for example). The GLOBE Program is an important exception because it is large enough, uniform enough, and consistent enough in its approach to forming scientist/teacher/student partnerships to make quantitative evaluation possible. The 2006 GLOBE Year 10 Evaluation in US schools [SRI, 2006] concluded that "there is no statistically significant association between mean [achievement test] score and [classroom GLOBE] implementation level… [and] we cannot declare with confidence that there are persistent score differences between No GLOBE and High GLOBE [classrooms]."

Despite the fact that there are tens of thousands of schools with GLOBE-trained teachers, the 2006 SRI study noted that the number of these schools reporting *any* data in the months with maximum reporting (October and November in the U.S. and other northern hemisphere countries) during years 9 and 10 of the GLOBE program never exceeded 1000. The 2006 SRI study also examined "persistence" of data reporting from schools where teachers begin implementing aspects of the GLOBE Program—a metric that is especially germane to the sustainability of collaborative climate research with students and their teachers. About 60% were still reporting some data (often literally just a handful of measurements which would not be sufficient to support any authentic research project) after one year and only about 40% after two years. The study notes that "persistence is critical to GLOBE's scientific mission, but it is also a good indicator of how sustainable the program is within classrooms."

At the beginning of any collaboration among teachers and scientists, there is typically enthusiasm on both sides. Researchers are excited about their work and they see the value of sharing this excitement with teachers and their students. Teachers are always looking for new ways to inspire and engage their students and to improve learning outcomes. Why, then, are these partnership models not more successful in ways that would be cause for optimism about the prospects for sustainable school-based collaborative research?

The hurdles which must be overcome to support successful collaborative research partnerships are higher than those encountered for implementing inquiry-based science activities in the classroom. Initial enthusiasm for a research project may lead both parties to overlook the fact that science research, even if it is not long-term climate-related research, takes time and dedication. For teachers, almost always, the time required will

expand beyond the classroom time slot set aside for a directly relevant curriculum unit. Often, data collection needs to continue even when school is not in session—long holidays and summer breaks are a major impediment to teachers and students participating in successful climate-related research. Researchers take long-term commitments for granted because that is often a primary requirement for research funding, but teachers, whose work tends to focus on relatively short and constantly changing "learning units," may not. In a highly structured school environment, it can be difficult to find the time to tend to "optional" research activities.

Scientists also face hurdles. They may understand on an intellectual level that their work will appear obscure to any lay or non-specialist audience, but they may not appreciate the effort required to give teachers the subject matter background they need to feel confident acting as a mediator between researchers and their students. Often their research funding is limited and redirecting the resources—financial and personnel—initially dedicated to "educational outreach" may start to look like an attractive option. They may not fully comprehend the need to provide support services for teachers and students that they take for granted within their own organizations. They may not be able to adapt their research to teachers' and students' more restrictive schedules. Some projects are better candidates for participation by non-specialists than others. Some researchers simply are better than others at translating science for non-specialists and working successfully with teachers and students.

We believe that of these many obstacles to forming sustainable scientist/student/educator partnerships, the single most important is the fact that, regardless of how those partnerships are formed, they are inherently unbalanced. Disparity in science content knowledge is important, but it can be resolved. The imbalance in terms of consequences and rewards within the partnership is a much more difficult issue.

Generally, research is supported by project-specific funding, with penalties for investigators if they fail to meet expectations and rewards (e.g., publications and additional funding support) when they succeed. Typically, there are no correspondingly direct consequences for teachers or students participating in a collaborative science partnership. A teacher's ultimate goal is to inspire and educate students. When research inquiry-based activities and research partnerships are integrated into science learning, teachers should see more engaged students and measurably improved learning outcomes, and they should be rewarded for those outcomes. Typically, however, those rewards will not be tied directly to participating in a successful research project, nor will a failure to honor commitments to a research project be likely to have direct negative consequences either for a school or for individual teachers. The same imbalance applies to recognition for students, as it is still much more likely in U.S. schools that individual student and group participation in science research will be under-recognized compared, for example, to participation in athletics.

In order for climate-related research involving students to be sustainable, these imbalances need to be addressed not just by individuals, but also at the institutional level. Educators and their institutions need to be as invested in research results as are many scientists and their institutions in improving educational outcomes. Teachers and school administrators must accept the fact that student-focused research in collaboration with scientists, climate-related or not, typically involves deadlines and requires a time

commitment from teachers that may extend beyond their every-day classroom activities. Ideally, long-term commitments should be made at the institutional level and should not rest solely on the interest of one or more individual teachers.

Scientists also have responsibilities. They need to understand that teachers and students must be treated as full partners in a research project. They must understand that when research is conducted with students, individually or as an extension of an existing science curriculum, it must help teachers meet their teaching goals. Invariably, this means that the project must be tied directly to applicable science education standards. Scientists need to take this requirement seriously. Although it is never hard for any authentic research project to meet these requirements "on paper," the details require negotiation and agreement among scientists, teachers, and school administrators. Colleges and universities must recognize that any faculty member seriously committed to partnerships with K-12 teachers and their students is performing an essential institutional service that also supports important national objectives. This recognition is especially important for early-career faculty members who need to focus on gaining tenure.

Appendix 5: Guidelines for Defining and Evaluating Proposed Student/Teacher/Scientist Collaborative Climate Science Research Projects

Primary contributor: David Brooks

The purpose of these guidelines is to provide a systematic way for scientists and educators to propose and evaluate a collaborative student climate research project. Please consider all the issues addressed in these guidelines, with the understanding that not all projects will need to address every issue.

Descriptive Project Title:

Proposing Organization(s)/Individual(s):

DEFINING THE SCIENCE COMPONENT

Research Objectives:

What is the research hypothesis and/or motivation for this project? What are the specific research objectives? What is the relationship of this work to other climate-related research?

Research Methods:

How will this research be conducted?

Site selection

What kind(s) of site(s) is/are appropriate to conduct this research? How many sites are required? Are there site safety issues that need to be addressed?

Instrumentation

Does the project use commercially available instrumentation and/or equipment? If not, what is the status of instrumentation/equipment developed specifically for the project? Who is responsible for providing instrumentation? Who is responsible for calibrating and maintaining the instrumentation?

Data collection

What is the nature of the data collected (manual? data loggers?)? How are data stored, disseminated, and reported? If the data are electronic, what is the approximate size (Mbytes?) of individual data files? How many data files will be collected during the project (total or per year)?

How much time is required for initial setup of equipment required to implement this project? After the initial setup, how much time is required to manage data collection, reporting, and initial analysis? What is the total time over which this project should be implemented? (A month? A season? A year? Ongoing?)

Data accuracy and quality control

What is the expected accuracy of data collected according to the protocol defined

for this project? How does this accuracy compare to accepted scientific standards for these data? How does the expected data accuracy impact their usability for scientific purposes? What are the significant issues of quality control for this project? What steps are necessary to ensure the integrity and quality of data? Can "non-specialists" be expected to address and manage quality control issues on their own? If not, how will these issues be addressed?

Other data needs

What other sources of data are required to implement this project? What other sources of data are required in order to place data collected from this project in a broader climate science context?

Science Outcomes and Metrics for Success:

What are the desired science outcomes? What is the planned use for data collected during this project (research? teaching?) Who besides you will be interested in these data? How will the success of this project be evaluated from a science perspective? Will there be an independent project evaluation and if so, by whom?

DEFINING THE COLLABORATION

Project Management and Structure:

What kind of organizational structure is required to conduct this project? Who has overall responsibility for the project? How will activities be shared among participants? How will participants communicate with each other (face-to-face meetings? online?) How will issues of ongoing data collection and project sustainability be addressed, especially for student/teacher participants?

Project Cost:

What is the initial cost for instrumentation, software, expendables, and other materials required to implement this project? Are there ongoing costs and, if so, what are they? Can any of the equipment needed for the project be put to other uses during or after the project? How will project costs be divided among participants?

DEFINING THE EDUCATION COMPONENT

Student Audience:

How old must student participants be to have a reasonable chance of successfully implementing this project, with appropriate direction from teachers and a science advisor? How old must student participants be in order to interpret and analyze the data they collect? Will they be able to understand the relationship of those data to the area of climate science addressed by this project? (Please note that being able to collect data is not the same thing as being able to understand those data.) What level of science content

knowledge, technology/computer skills, and mathematics skills are required to work with project data?

Implementation:

What is required to implement this project in a school setting? How will potential sites be selected and evaluated? How much time is required for initial setup? How much time per week is required to sustain the project? How will the project be sustained when schools are not in session? Who will be responsible for the project at a school? How will project data be reported? How will project data be made available to participants and others?

Meeting Student Needs:

What kind of feedback will project scientists provide to students? How will science background be presented? How will the age-appropriateness of background materials be assessed? How will participation be acknowledged and rewarded? What kind of one-on-one help is available for individual students (for example, to help with science fair projects)?

Meeting Educator Needs:

What kind of background do teachers need to understand the science associated with this project? What kinds of technology skills to teachers need to guide their students in the implementation of this project? What do they need to know to use the results from this project and integrate them with related material in their classrooms? How, and by whom, will the required professional development be delivered? How much preparation time is required for teachers to be able to implement this project with their students? What kinds of ongoing support are available?

Meeting Science Education Standards:

What is the relationship of this project to national and/or state education standards? How does this project help teachers meet those standards?

Educational Outcome and Metrics for Success:

What will students be expected to learn from participating in this project? How might this project affect students' future academic pursuits and eventual career choices? How will the success of this project be evaluated from an educational perspective? Will there be an independent evaluation of educational outcomes and if so, by whom?

EVALUATING THE PROJECT

Each project should be evaluated for its scientific and educational potential and assigned a score of from 0 (no value) to 5 (highest value) for each category.

Science Value:

Ranking (1-5):

Within the climate science area addressed by this project, what is its value relative

to what is already known? Are the science objectives clearly stated? How will this project advance, augment, or supplement science knowledge in this area? Will project data be useful for teaching others about this area of climate science? Can results from the project be incorporated into published work? (NOTE: some level of "scientific interest" is required for these projects, but that interest does not necessarily have to be at the level of publishable research.) Is the project sustainable over the time span required to achieve the science objectives? Overall, does the science return justify the effort required for the proposed level of collaboration with teachers and students?

Education Value:
Ranking (1-5):

How will this project help teachers and students increase their understanding of Earth's climate? Are the educational objectives (e.g., meeting science education standards) and learning outcomes clearly identified? Does the project demonstrate an understanding of our educational system and how to work successfully with teachers and students to achieve the desired outcomes? Does this project encourage students to consider careers in climate science? How does this project promote science literacy in general and climate science literacy in particular? How does this project advance national goals of improving science/technology/engineering/mathematics (STEM) education? Overall, does the educational return justify the time required for teachers and students to participate in and sustain this project?

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Links to websites were active at the time this document was written, but there is no guarantee that they will be active in the future. It is fair to classify some of these references as "soft" in the sense that they do not refer to primary works and/or peer reviewed publications. This reflects both the nature of the climate science debate and the kind of material that will be available to even a sophisticated public audience. Also note that quotations taken from online sources are often not dated, cannot always be independently verified, and should be considered with these caveats in mind.

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