Published as part of the Proceedings of the 5th International Symposium on Digital Earth, June 2007, San Francisco, CA, USA http://www.isde5.org/proceedings.htm

NOAA'S SCIENCE ON A SPHERE® EDUCATION PROGRAM: APPLICATION OF A SCIENTIFIC VISUALIZATION SYSTEM TO TEACH EARTH SYSTEM SCIENCE

McDougall, Carrie, NOAA Office of Education, Washington, DC, USA
McLauhglin, John, NOAA Office of Education, Washington, DC, USA
Bendel, William, NOAA Earth System Research Lab, Boulder, CO, USA
Himes, David, NOAA Earth System Research Lab, Boulder, CO, USA

Keywords: digital globe, Earth system science, NOAA, museums, Science On a Sphere, SOS

Introduction

The National Oceanic and Atmospheric Administration (NOAA) is a U.S. Federal Government Agency focused on understanding and predicting changes in Earth's environment, and managing coastal and marine resources. Foundational to this mission is the continuous monitoring, collection, and archiving of data about Earth's processes especially those including oceanic and atmospheric processes such as climate change. NOAA's vision is "an informed society that uses a comprehensive understanding of the role of the oceans, coasts and atmosphere in the global ecosystem to make the best social and economic decisions". Inherent in this vision is an American public that has access to this information and understands Earth as a system and their role as "keystone" players in this large and complex ecosystem—that is, an environmentally literate public. However, assessments indicate that the public's current level of knowledge in this area is low (Coyle, 2005). To improve the public's understanding of these issues, NOAA conducts a multi-faceted education program that brings the research we conduct and the data that drives resource management decisions we make to students, teachers, and learners of all ages.

One of the education programs that NOAA offers is Science On a Sphere®—a large visualization system that uses networked LCD projectors to display animated global datasets onto the outside of a suspended, 1.7-meter diameter opaque sphere. Science On a Sphere® allows NOAA to bring the most recent climate models, daily global weather observations, sea surface temperature measurements, and time-lapse sequences of recent events (just to name a few) to the public. NOAA provides assistance to educational venues, such as museums, science centers, and universities, to publicly display Science On a Sphere®. The sphere can be used to demonstrate the results of global-scale science efforts such as the Global Earth Observation System of Systems (GEOSS). Science On a Sphere® is also a visually stunning exhibit that attracts people and stimulates them to ask questions about what they are seeing (Figure 1). Through the provision of funding and technical assistance, NOAA has created a network of 17 institutions (as of April 2007) that have or will have Science On a Sphere® on display in a public science education venue. These 17 institutions reach over 11 million people annually and work collaboratively to help NOAA improve the program and maximize the effectiveness of this tool as an Earth system science education platform.

Figure 1: Science On a Sphere® at Nauticus in Norfolk, VA: a student group from Portsmouth, VA views the sphere (credit: Hampton University)

Technical Details of the System

NOAA's Science On a Sphere® (SOS) consists of a 1.7-meter diameter opaque sphere onto which 4 video projectors project seamless "movies" of animated Earth system dynamics (Figure 2). The system is built from standard hardware components and is composed of "off-the-shelf" PC's, video projectors, cable, and a carbon-fiber, hollow sphere. The PC's run a version of RedHat Linux. When installed in a room, the sphere is generally suspended from above and surrounded at the corners of the room by four video projectors. A display computer that is responsible for it's quadrant of the sphere drives each video projector and all of the display computers are controlled centrally by a fifth computer, known as the network control computer.

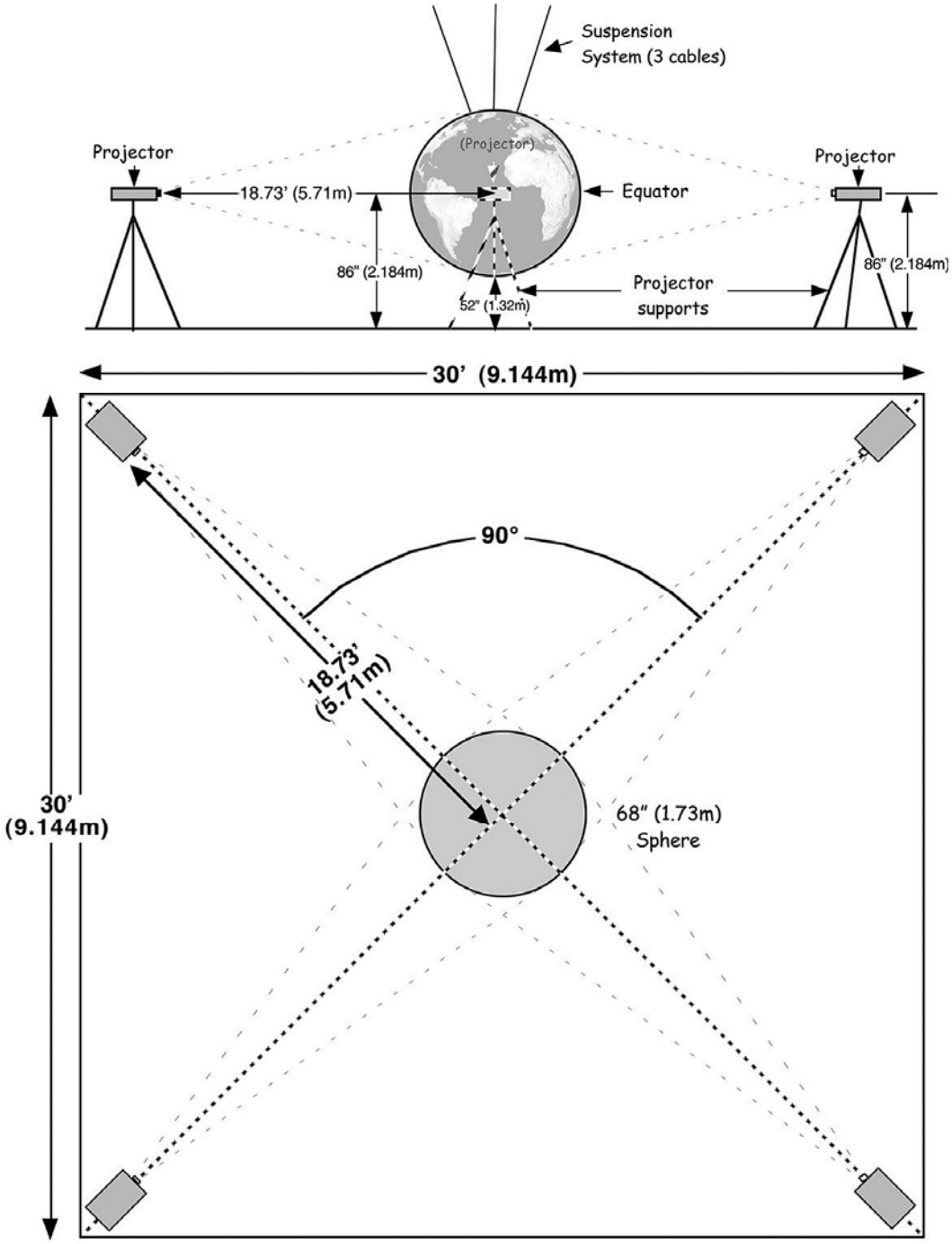

Figure 2: A typical layout of the SOS system, showing the locations of the four projector systems.

The system displays planetary images plotted on an equatorial cylindrical equidistant projection. These images can be played as an MPEG-4 file or as a directory of JPEG images with accompanying MP3 file. Images can be rotated while they are being played on the system. Images typically have a resolution of 2048x1024 dpi or higher.

The SOS system can also display ancillary information that is synchronized with the data being displayed on the sphere. The ancillary information is piped out one of the VGA outputs from the control system and can be split and directed to other monitors in the exhibit. This technique has been used to drive PowerPoint-like presentations onto flat-panel display monitors to provide a more detailed description of the data on the sphere.

Additionally, the SOS system can play sound files that are synchronized and associated with each discrete data set. As the system switches from one data set to another, the appropriate sound file is piped out of the sound card on the network control computer. This feature provides the foundation for running Science On a Sphere® in an unattended mode of operation, where the sphere is displaying data in sequence with audio accompaniment. A wireless microphone system can be tied in for other, narrator-lead demonstrations.

A future software release will provide an Apple Mac port that will provide the option to use Apple hardware to drive the system. Other future software developments will incorporate the use of pushpins, layering, simple path highlighter, and geo-located sprites. These and other software enhancements facilitate the users of the systems in their efforts to create and modify existing content for show on the sphere. General requirements and setup information for the SOS system can be found at: http://sos.noaa.gov/docs/requirements.html.

The SOS software and hardware is sufficiently easy to use that our museum partners are able to create compelling stories with the existing library of data sets.

The Need for an Education Program

Science On a Sphere® has the potential to serve as a unique tool for increasing understanding of environmental literacy principles and geographic awareness among both student groups and the general public. These areas have been shown to be deficient in the public's understanding.

Improving U.S. student performance is a challenge faced by all areas of science, technology, engineering and mathematics (STEM) education. In a report entitled *Sustaining the Nation's Innovation Ecosystem: Report on Maintaining the Strength of Our Science & Engineering Capabilities*, the President's Council of Advisors on Science and Technology reported that "U.S. students are weak in math and science skills and lag behind most of the world in these capabilities. Top U.S. students pursue STEM careers at significantly lower rates than their international counterparts" (President's Council of Advisors on Science and Technology, 2004).

As a component of STEM education, environmental literacy is an area where enhancement is acutely needed. This need extends beyond students to the general public, since environmental literacy is required by every one of us to adequately evaluate the environmental impacts associated with our personal decisions. However, in a report entitled *Environmental Literacy In America*, Coyle reports that "While the simplest forms of environmental knowledge are widespread, public comprehension of more complex environmental subjects is very limited. The average American adult, regardless of age, income, or level of education, mostly fails to grasp essential aspects of environmental science, important cause/effect relationships, or even basic

concepts such as runoff pollution, power generation and fuel use, or water flow patterns." (Coyle, 2005).

Yet these problems due not appear to be caused by a lack of interest in science and technology. A 2006 report from the U.S. National Science Board of the National Science Foundation found that only 10% of Americans surveyed reported not having an interest in science and technology issues (National Science Foundation, 2006). Despite this interest, people may not be connecting with the most appropriate sources for environmental science information. Coyle reported that "children get more environmental information (83%) from the media than from any other source. For most adults, the media is the only steady source of environmental information." (Coyle, 2005).

Geographic awareness is also an area in which the American public is in need of improvement. In a 2005 report entitled *What Works in Geography Education*, the National Geographic Society stated that "Studies conducted over the past twenty years consistently show that Americans possess a poor understanding of geography. This fact stands in stark contrast to the leadership role America plays in the rapidly globalizing and interconnected world of the 21st century." (National Geographic Society, 2005).

In 2001, *The Nation's Report Card* issued by the Office of Educational Research and Improvement of the U.S. Department of Education showed a clear need for improvement in geographic awareness among K-12 students. This report card also showed variations in geographical awareness among gender and race/ethnic subgroups of the student population (U.S. Dept. of Education, 2002). Joseph P. Stoltman, a Professor of Geography at Western Michigan University, summarized the report card by stating that: "The review of the released items suggests that many students in the early grades do not know basic information such as the name and location of the state where they live. Similarly, students at grades eight and twelve do somewhat better with definitional information, but a large proportion were unable to analyze the information related to an environmental issue, provide reasons for or consequences emanating from the issue, or suggest a possible solution to the geographic issue or problem"(Stoltman, 2002).

The need to create programs that address these deficiencies is clearly great and will not be solved by any one program or tool. But entities charged with scientific investigation and information gathering, such as federal science agencies can, and should, make their data and data products available in ways that can address these issues.

Building an Education Program

One effective way for a science agency to make its products useable and available to the education sector and the general public is by partnering with institutions that are in the business of providing science information to the general public. Museums and science centers are identified by U.S. citizens as trusted sources of science information. And, recent surveys show that science and technology museums are more popular in the United States than in other countries. In 2001, 30% of NSF survey respondents said they had visited such a museum in the

last 12 months, compared with 16% of Europeans (in 2005), 13% of Japanese, 14% of Chinese, and 1% of Russians (2003) (National Science Foundation, 2006).

As the data we collect and the models we create become increasingly complex, large, and global, it is increasingly challenging to provide this information to science centers in a way that facilitates delivery to the general public. Also, with increasing abilities in continuous monitoring of Earth's processes, it is now possible to provide near real-time data to these science centers. However, traditional exhibits in science centers and museums tend to be static and therefore, not easily updated. Science On a Sphere® is a tool that solves many of these problems well. It is an ideal tool for displaying large, complex, global datasets. The system can handle continuously updating datastreams so that the most up-to-date data are being shown to the public. And, it is designed to work well in a museum or science center exhibit area.

We began to understand the actual impact of Science On a Sphere® on science center visitors in 2004 when we displayed the sphere, temporarily, at the Maryland Science Center (a public science education center) and an evaluation of visitor experience and understanding was conducted. The results of this evaluation indicated that visitors to the sphere stayed far longer at this exhibit than is average for similar exhibits, that they were captivated and intrigued with what they saw, and gained a new appreciation for Earth as an interconnected and dynamic ecosystem (Apley, 2004).

During this experimental exhibit of Science On a Sphere® NOAA provided live presentations of Earth and other planetary datasets, some of which lasted 40 minutes. Data and models were shown of El Niño, one year of tropical cyclones, plate tectonics, the surfaces of the moon, mars, and the sun, and models of carbon dioxide-induced warming. Visitors responded very positively to Science On a Sphere®. On a 5-point scale from poor to excellent, an overwhelming 98% of visitors across all age groups, rated the sphere as either very good (67%) or excellent (31%). When visitors were asked "what most impressed you about the Sphere?" there were three main themes heard throughout the evaluation: an innovative piece of technology, an aesthetic experience, and a versatile educational tool for adults and children (Apley, 2004).

We also began to understand the importance of connecting these global stories to local areas to which the visitors could more directly relate. "While noting the value of a global perspective, visitors were often drawn to images of places with personal relevance. Maryland visitors generally marveled at seeing the path of hurricane Isabel, while visitors from Burma to Arizona eagerly looked at weather patterns near their homes. Another visitor commented on the highlighting of Indiana in the plate tectonics animation, and noted the value of having local places noted." (Apley, 2004).

Based on these evaluation results and the capability provided by the sphere of bringing these large datasets and models to the public, NOAA's Office of Education began offering competitive grants to U.S. public science education venues to create Science On a Sphere® exhibits. In 2005, we funded 5 installations, and in 2006 we funded an additional 6 installations. Currently there are 12 institutions with Science On a Sphere® on display across the U.S. And, by 2008, there will be a minimum of 17 institutions in the U.S. reaching at least 11 million people annually. And, Science On a Sphere® will be seen internationally as part of "Water Planet", a traveling exhibit

offered by the American Museum of Natural History and the Science Museum of Minnesota. Additional information on funding opportunities for U.S. institutions interested in Science On a Sphere® and other spherical display technologies can be found at http://www.oesd.noaa.gov/funding_opps.html.
The Science On a Sphere® system is utilized in a wide variety of exhibit formats in the institutions in which it is currently being shown. Auto-play mode, where content and accompanied audio tracks are delivered via a pre-programmed playlist, is a popular form of operation and is utilized on some level by most of the SOS installations. Some exhibits, such as those at the Maryland Science Center and the Science Museum of Minnesota, augment this auto-play mode with complimentary material displayed through accompanying flat panel screens or projectors. In addition to auto-play mode, most installations also utilize docents to help deliver content to viewers during set times throughout the day.

There is also some work being done to allow visitors to interactively control the content shown on the sphere. The SOS exhibit at the Tech Museum of Innovation features an interactive kiosk that allows visitors to select and rotate SOS content. The Orlando Science Center will feature SOS as part of their upcoming Global Decision Room exhibit which will have visitors make decisions on behalf of the global population and then see the results of their decisions played out on the sphere.

While some exhibits use SOS primarily to highlight global-scale phenomena, such as will be the case in the upcoming Smithsonian Ocean Hall, some exhibits feature content designed to highlight local phenomena. For example, the Bishop Museum has a program that uses SOS to explain why Hawaii has such a favorable climate. Bishop Museum is also working with the Imiloa Astronomy Center to create content that will highlight nautical journeys of Pacific Islanders.

SOS can also be used to highlight specific environmental topics. For instance, the Science Museum of Minnesota is partnering with the American Museum of Natural History to create a water-themed traveling exhibit that will feature SOS and tour both the U.S. and international locations.

Understanding its Educational Impact

After approximately one and a half years of Science On a Sphere® exhibits in public science education venues, we are beginning to understand the educational impact of such a system and how we can use this tool and create content to maximize the impact. Unfortunately, there is insufficient basic research into some of the topics that underlie the practical questions we are confronted with in how best to use this system. For example, the difference in impact of using a sphere versus a flat screen to display global datasets is not well understood. There is also poor understanding of how to prepare data visualizations of dynamic global processes such that they are comprehensible by the general public. Focused studies in these, and other cognitive areas, would dramatically improve the communities' ability to produce the most effective global data visualization tools and content.

The educational goals we have set for the Science On a Sphere® program are ones that will not be achieved fully with SOS alone, but are goals that SOS may be able to contribute to substantially. Ideally, we would like to be able to demonstrate that a science center with an SOS exhibit is able to convey to their visitors that science is exciting and always changing, that there are still so many unanswered questions in science, and how data about Earth is collected and displayed. Specific to Earth system science, our program-level learning objectives include visitors understanding that they have a responsibility to know about and understand these global issues, it is important to their life that they know these global phenomena, and that Earth is one giant ecosystem in which processes are interconnected and functioning as an integrated system. We know, anecdotally, through the museums and science centers with SOS that visitors are gaining appreciation and awareness of these objectives, but we are not currently able to dissect how the SOS exhibit contributes to that gain.

In the coming years we plan to conduct a program-wide evaluation that will include data collection from nearly all of our 17 SOS partners. We plan to collect data that may provide insight into the following questions or issues: when are spherical display systems more appropriate to use than flat screen display systems; how to handle presentations of global stories to an audience that is distributed around the sphere, looking at different geographic areas; what is the most effective way to convey the different spatial and temporal scales over which different processes occur e.g., hurricanes versus large-scale climatic events such as the pacific decadal oscillation. Also, we will be evaluating all new content created for SOS for its ability to effectively deliver Earth system science messages.

Creating Content for the System

The creation of content for this large visualization tool is challenging. Given our charge as a federal agency to understand and predict changes in Earth's environment, and manage coastal and marine resources, it is imperative that we use Science On a Sphere® to show content that is based on the most recent scientific understanding of the phenomenon or shows current events, uses real data or models (when possible), and is global in nature. NOAA, and other similar federal science agencies have numerous data sources with these features, however, creating the context and overall story into which these data fit is not trivial. We have found from our current SOS partners that often the Earth system processes we would like to exhibit on SOS are too complex and involve the interplay of too many different processes. Creating content that delivers these complex messages simply and effectively is our greatest challenge.

Currently, there are primarily two types of content being shown on SOS: movie-style or fully produced content and short, dataset-focused content that require a docent to interpret or an external kiosk or screen that provides explanation. One example of the movie-style content is the recently produced sphere "movie" called "Footprints" by NASA. See http://www.nasa.gov/centers/goddard/visitor/exhibits/footprints.html. There are numerous examples of the dataset-focused content, viewable at http://sos.noaa.gov/gallery/. For a full catalog of what datasets are available for SOS see http://sos.noaa.gov/datasets/.

Our goal is to provide content that touches on all the major topics of Earth system science. However, certain types of Earth system science topics do not lend themselves to SOS as there is

insufficient global data collected about the topic or the data is of low resolution and therefore does not display properly on a large sphere. Additionally we find that the visitors to the SOS exhibits have poor understanding of how global data is collected and visualized in general, as well as a lack of familiarity with the process of pseudo-coloring data to enhance feature detection. This lack of knowledge further hinders their ability to comprehend many of the datasets that are visualized in the manner that is typical for scientists communicating with other scientists. Therefore, a different approach is needed to make these global data visualizations understandable by the general public.

In our next phase of education program development, we will experiment with newly created content that has enhanced labeling of features and provides time indicators for the speed at which a process is being shown. We will also experiment with the tilt of the Earth images and the rotation speed.

In the summer of 2007, a funding opportunity will solicit applications from the community to address these needs for content that is understandable by the general public. We will be providing funding for the development and evaluation of that content as a means to ensure that the content being provided to our SOS partner institutions is the most educationally effective in delivering the desired impacts. See http://www.oesd.noaa.gov/funding_opps.html for information on the funding solicitation.

A Collaborative Network of Sphere Users

The institutions that currently have Science On a Sphere®, as well as other partners who are creating content for the sphere, have formed a collaborative network. This network communicates with members primarily informally through email and an unmoderated listserve. The network shares tips on the creation of new content, management of playlists, technical improvements made to the system, different ways to display the sphere, and so on. Because we are still in an experimental phase with using this system in museum settings, NOAA and the partners benefit greatly from this collegial dialog among the users. We have already witnessed dramatic improvements being made to the system software that were solicited by the network to our software development team. We have also seen sharing of innovative ways of making the sphere interactive or providing the visitors with interactive kiosks that have sphere-related content shown.

To further facilitate information sharing among the network, NOAA hosted the entire network for a two and a half day meeting in January 2007 in Baltimore, MD (Figure 3). Topics of discussion included new content creation, technical improvements, evaluations, and creating a virtual library to house future content. Annual meetings of the network were requested by meeting attendees and are planned by NOAA.

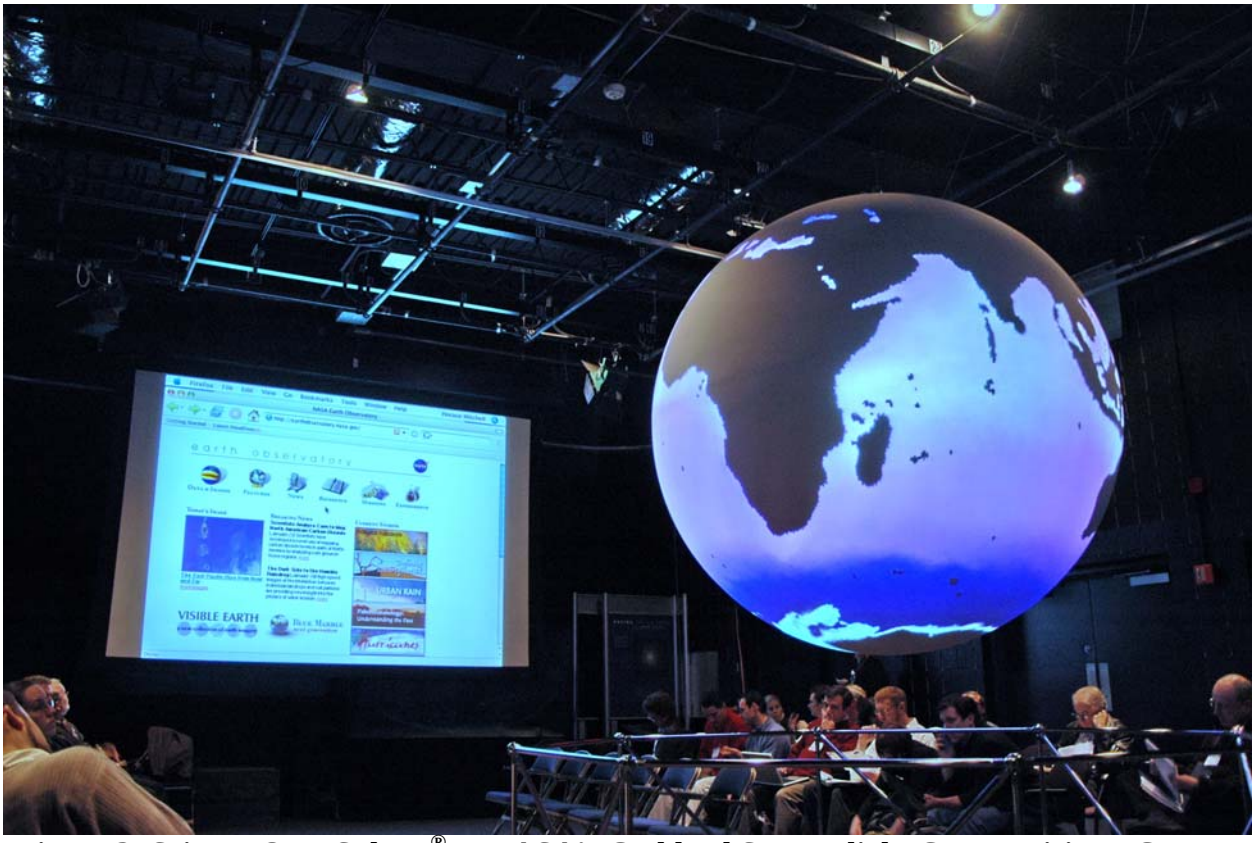

Figure 3: Science On a Sphere® at NASA's Goddard Space Flight Center Visitors Center. Ocean productivity content is being presented to the NOAA SOS Users Collaborative Network Meeting in January 2007. (credit: Brent Beall)

In the next year we will be creating a virtual library to house the content for the sphere and related educational and other accessory materials that each SOS institution has created. Each institution participating in the network has offered to provide their content to this library free of charge so that all may benefit. We hope to continue this model of free exchange of content and ideas as the network grows.

Additionally, NOAA is working in partnership with NASA Goddard Space Flight Center (GSFC) to create content for the sphere that will be distributed through this network that is of common interest to both agencies. NASA GSFC has purchased an SOS unit and has it on display in their public visitors center. Both NOAA and NASA have spheres installed in major research facilities. This proximity of the sphere to places of research and data collection maximizes the rapid experimentation with new data visualizations for the sphere. Through this dual-agency partnership, we anticipate rapid growth of new content on Earth system science topics and non-Earth topics.

Conclusion

NOAA has created and is using Science On a Sphere® to show the public global datasets of Earth in a visually stunning and awe-inspiring way. Working through our museum partners, we are beginning to understand its impact on the public's understanding of complex, global scale

phenomena and processes. We are also experimenting with this system as a method for bringing near real-time data and recently created Earth system science models of cutting-edge issues, such as climate change to the general public in a timely manner. Science On a Sphere® has allowed us to maximize the benefits of a partnership between a U.S. federal science agency with data and scientific resources and U.S. science centers and museums with translation abilities and a captive, science interested audience. We are still understanding all of ways this tool can be used to educate the general public about these Earth phenomena. However, we do have indications that this tool and method of reaching the public with this information may be a powerful way of building understanding about these global phenomena and creating an informed and environmentally literate society.

Summary

The National Oceanic and Atmospheric Administration (NOAA) is a U.S. Federal Government Agency focused on understanding and predicting changes in Earth's environment, and managing coastal and marine resources. Foundational to this mission is the continuous monitoring, collection, and archiving of data about Earth's processes especially those including oceanic and atmospheric processes such as climate change. One of the education programs that NOAA offers is Science On a Sphere®—a large visualization system that uses networked LCD projectors to display animated global datasets onto the outside of a suspended, 1.7-meter diameter opaque sphere. Science On a Sphere® allows NOAA to bring the most recent climate models, daily global weather observations, sea surface temperature measurements, and time-lapse sequences of recent events (just to name a few) to the public. NOAA provides assistance to educational venues, such as museums, science centers, and universities, to publicly display Science On a Sphere®. The sphere can be used to demonstrate the results of global-scale science efforts such as the Global Earth Observation System of Systems (GEOSS). Science On a Sphere® is also a visually stunning exhibit that attracts people and stimulates them to ask questions about what they are seeing (Figure 1). Through the provision of funding and technical assistance, NOAA has created a network of 17 institutions (as of April 2007) that have or will have Science On a Sphere® on display in a public science education venue. These 17 institutions reach over 11 million people annually and work collaboratively to help NOAA improve the program and maximize the effectiveness of this tool as an Earth system science education platform.

References

Apley, A. (2004). *Science on a Sphere Front-end Evaluation*. RMC Research Corporation, prepared for Maryland Science Center.

Coyle, K. (2005). *Environmental Literacy In America*, The National Environmental Education & Training Foundation.

National Science Foundation (2006). *Science and Engineering Indicators 2006 – Volume 1*, America's Pressing Challenge - Building A Stronger Foundation, NSB 06-02.

National Geographic Society (2005). *What Works in Geography Education.* *http://www.nationalgeographic.com/foundation/pdf/what_works_complete.pdf*.

President's Council of Advisors on Science and Technology - Workforce/Education Subcommittee, (2004). *Sustaining the Nation's Innovation Ecosystem: Report on Maintaining the Strength of Our Science & Engineering Capabilities*. http://www.ostp.gov/PCAST/FINALPCASTSECAPABILITIESPACKAGE.pdf

Stoltman, J.P. (2002). N*ational Assessment of Educational Progress in Geography*. *ERIC Digest*. ERIC Clearinghouse for Social Studies/Social Science Education.

U.S. Department of Education (2002). *The Nation's Report Card - Geography 2001*, NCES 2002-484. http://nces.ed.gov/nationsreportcard.