THE EARTH SCIENTIST

NATIONAL EARTH SCIENCE TEACHERS ASSOCIATION

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Free NOAA/NASA GOES-R Satellite Poster

INSIDE THIS ISSUE

This image was shot Oct. 7, 2010 by Jay Brooks at Mt. Edith Cavell in Jasper National Park in the Canadian Rockies, during a photography trip the focus of which was shooting patterns on the ice. The colors in the photo were not visible to the naked eye but revealed themselves when the images were viewed on the camera LED review screen. A polarizing filter was used with a Canon 10-22mm wide angle lens mounted on a Canon 7D, ISO 100, F22, .3 sec. at 22mm.

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From the President

by Missy Holzer, NESTA President, 2012-2014

The Common Core ELA's and the K-12 Earth Science Teacher

"Warning...incoming regulations".... Hearing this, teachers around the country can be heard saying "Oh no...not something else!" Adding just "one more thing" to our already burgeoning list of daily tasks of planning-prepping-teaching-assessing isn't so bad when we can define it within our domain of science education. However when the regulations come in wrapped as English Language Arts & Literacy, most science educators dread the "one more thing." The Common Core English Language Arts & Literacy Standards (ELA's) have been adopted in 45 states (not including Alaska, Minnesota, Texas, Virginia, and Nebraska), which means that the 45 states either are considering or have already adopted an implementation and assessment schedule. Do you know what the plan is for your state? If not, a quick perusal of your state department of education website should get you the answers you need.

Now, let's consider the purpose of this "one more thing" added to our teaching plates. Ultimately we want all of our students from every state in our nation to be able to read, comprehend, and express themselves in all subject areas. The Common Core ELA's were created to foster these abilities in our students. However, we need to think beyond the potentially punitive nature of assessments, and think about how we can assist by incorporating literacy lessons; not contrived lessons, but lessons that instead that mirror authentic scientific practices. The first step is to download and read the available document found on the Common Core State Standards Initiative website (www.corestandards.org), and highlight the reading, writing, speaking, listening, language, and literacy standards related to college and career readiness in your subject. To assist in this task, think about your own trajectory into your field of science and what ELA's skills got you to where you are today. It is likely that you are already employing these standards in your lessons and activities, and now you have a deliberate reason to do so.

As mentioned above the idea is not to develop contrived literacy lessons that do not reflect the authentic nature of literacy in our scientific domains, but instead is to read and comprehend scientific texts, assess text for evidence supporting claims, write arguments and informative & explanatory text, etc. The key literacy standards for science can be found on pages 59-66 in the Common Core ELA document, and upon reading it is quite evident that our students are likely engaging in these practices. If you are not already employing these methods and are unsure of where to begin, consider creating a Professional Learning Community (PLC) amongst your colleagues in your school or district. Your district library may be able to help out with access to scientific journals if Internet web searches (try Google Scholar) do not produce challenging grade level appropriate scientific literature.

Assisting our students on their literacy journey should not be left solely to our ELA colleagues. It is also up to us; besides it's fun sharing exciting scientific research with our students taking them beyond the "Why do we need to know this?" attitude to "Oh, now I know why you love science so much!" ... or something like that!

NESTA'S MISSION

To facilitate and advance excellence in Earth and Space Science education.

From the Executive Director

Dear NESTA Members,

We have had a very busy fall so far, with more to come! At the time of writing this column, NESTA has just finished our fall workshops at the NSTA Area conferences in Louisville, KY and Atlanta, GA.

This year, responding to feedback from our members, we have continued our effort to provide topical workshops for teachers, in addition to our Share-a-Thon, and Rock and Mineral Raffle at each of the three Area conferences. We've pretty much maxed out what we can do in one day, by offering four topical workshops in addition to these events, starting at 8 am and continuing through the day, with only half hour breaks, until the Rock and Mineral Raffle finished at 4:30 pm!

We could only do this with the help of many volunteers, and I would like to thank everyone who has helped out at these events! In particular, our Past President, Ardis Herrold was a co-presenter in both Louisville and Atlanta. Ardis and I also teamed up to offer a short course – *Exploring Planetary Science and Astronomy: What Would Galileo Do?* – at both conferences on Saturday morning. Mike Passow (NESTA President-elect) was also a co-presenter in Louisville, as were Michelle Harris (NESTA Mid-Atlantic Regional Director and Share-a-Thon Coordinator) and Parker Pennington (NESTA Rock and Mineral Raffle Co-Coordinator and Appointed Director). In addition to these individuals, we were assisted by our receivers in Louisville and Atlanta – Gary Potter and Randal Mandock, respectively, as well as volunteers who helped out on-site. Thanks to Joe Monaco, NESTA's Volunteer Coordinator, who helped to contact and line up members of NESTA interested in helping out! Overall, we had about 250 participants in our events in Louisville, and nearly 500 in Atlanta! Thanks to all the generous people who provided specimens for the Rock Raffle and to the presenters that shared their resources at the Share-a-Thons this fall!

Please check the NESTA website www.nestanet.org for information about our scheduled NESTA events at the April 2013 NSTA National Conference on Science Education in San Antonio, TX. These San Antonio events are also listed in this journal on page 11.

Best Regards,
Dr. Roberta Johnson
Executive Director, NESTA

Editor's Corner

I truly enjoyed working on this issue of *The Earth Scientist* (TES). I had the chance to collaborate with the authors of the fine articles included within these pages. In this issue of TES, we are fortunate to be able to share with you this wide spectrum of Earth Science ideas and topics: from developing Spacial Thinking, to NOAA Space Satellites.

If you would like to submit an article for potential publication in TES, note that guidelines for submission may be found within this issue of TES on page 42 as well as on line at www.nestanet.org

Finally, the print version of this TES issue includes a poster for your use. The NOAA poster features the GOES-R Satellite and includes the important history of the GOES Satellite missions and details regarding future NOAA GOES Satellites.

Tom Ervin
TES Editor

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2012 Index of *TES* Articles

Why should I open and read my NESTA ENews *emails?*

NESTA's monthly *ENews* provides brief summaries of stories and projects that have a direct link to the Earth Sciences and or the teaching of Earth Sciences. Many of these short articles provide links to more information or complete websites that those interested can follow. The *ENews* also contains information regarding teacher opportunities for research, professional development, and even grants. The reader will also find a calendar with items that have time critical information or may be occurring later that month or the next month. Each month, the *ENews* provides links to a selected state's Earth Science sites. For example in the November 2012 issue we focused on Earth Science resources in Arizona, the state where the December NSTA Area Conference was held.

HELP WANTED!

NESTA needs you to help run our events at the 2013 Spring NSTA in San Antonio. We need volunteers to help with our Share-a-thons, Rock Raffle, and at our Exhibit Hall booth. If you feel that you can help, contact Joe Monaco, NESTA Volunteer Coordinator: monacoj@aol.com

The Earth Scientist

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Advertising is available in each issue of *The Earth Scientist*. If you wish to advertise, visit http://www.nestanet.org/cms/content/publications/tes/advertising.

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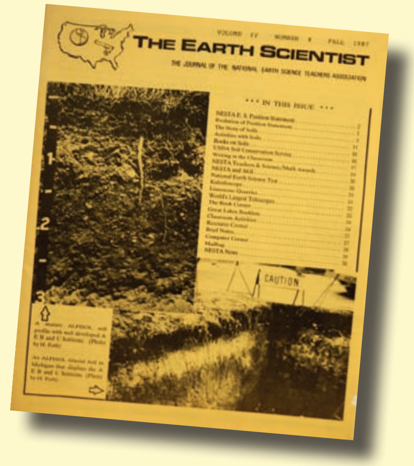
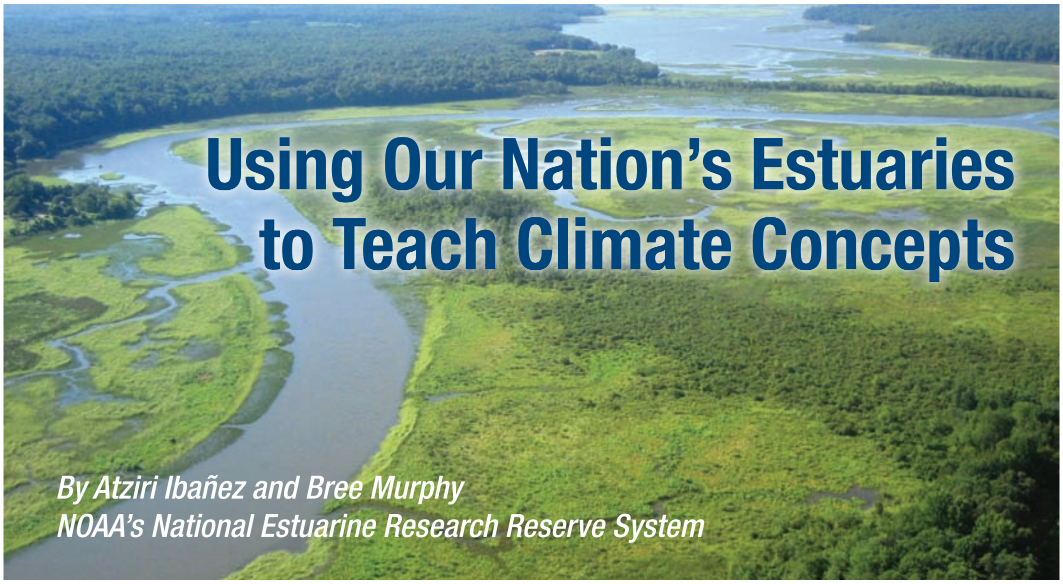
Twenty Five Years Ago in TES

Twenty Five years ago, in 1987, TES was in its fourth year of publication. The cover of Volume 4, issue 4 featured photos of two different soil profiles. These were fitting photos since the first 17 pages of the issue were devoted to a detailed pair of articles, the first titled *The Story of Soils,* followed by another describing *Activities with Soils.* The pair of soil articles included a free transparency to use in your classroom with your Over-head Projector.



These articles were followed by an article on *Writing in the Science Classroom.* Next came an article describing *Crystal Growth and Cooling Rates in Magmas.*

The big news was an announcement that a new, two part Earth science test, developed with the significant participation of members of NESTA, "...will be available for sale in the spring of 1988, through the NSTA." We wonder, does anyone still have a copy of this 1988 Earth science test? It would be great to see a copy and share it with the current generation of NESTA teachers.



Using Our Nation's Estuaries to Teach Climate Concepts

By Atziri Ibañez and Bree Murphy
NOAA's National Estuarine Research Reserve System

Arial view of the Chespeake Bay-Maryland National Estuarine Research Reserve.

Credit: NOAA Estuarine Reserves Division

Abstract

Estuaries can serve as a powerful vehicle for engaging students, developing scientific thinking and problem-solving skills, as well as helping students learn and apply core concepts in biology, chemistry, physics and Earth science. Estuary ecosystems are likely to be affected by the multiple and interacting consequences of climate change, particularly related to temperature, freshwater inflows, sea-level rise, storms and coastal currents. The National Estuarine Research Reserve System (NERRS) serves as a platform to understand and adapt to climate change impacts on estuaries and coastal communities. In addition, it supports educators by providing educational resources and professional development opportunities to help educators teach about estuaries and the connection with climate systems and humans.

Introduction – The Significance of Estuaries

Estuaries have been called the "nurseries" of the ocean. Climate change is likely to influence the functioning of an estuary in a variety of ways, but particularly, it is likely to affect the health, distribution, and abundance of ecologically and economically important fish and shellfish species (Pyke, 2008). This is an important concept that helps students understand and better connect the significance of estuaries to their daily lives. But, understanding the connection between estuaries, the climate system and humans, requires us to go a bit deeper.

Estuaries, where two distinct bodies of water meet and mix (most often were rivers meet the sea), integrate climate influences from both upland and coastal environments resulting in a diverse array of climate impacts. Estuaries vary widely in terms of their geomorphology and bathymetry, relative size of the watershed, physical circulation patterns, and water residence times, and each of these can affect the response to climate change. With regard to bathymetry, estuaries can be shallow or deep, narrow or wide,

Figure 1. Fox River Flats at the head of Kachemak Bay. Kachemak Bay National Estuarine Research Reserve in Alaska is a fjord. Fjords are typically long, narrow valleys with steep sides that were created by advancing glaciers. As the glaciers receded they left deep channels carved into the earth with a shallow barrier, or narrow sill, near the ocean. The sill restricts water circulation with the open ocean and dense seawater seldom flows up over the sill into the estuary. Typically, only the less dense fresh water near the surface flows over the sill and out toward the ocean. These factors cause fjords to experience very little tidal mixing; thus, the water remains highly stratified.

Credit: Terry Thompson

Figure 2. Lake Superior NERR in Wisconsin
The Lake Superior National Estuarine Research Reserve is situated on the freshwater estuary at the confluence of the St. Louis River and Lake Superior, the largest and most pristine of the Great Lakes. Three common characteristics are frequently used to define these freshwater systems: 1) a drowned river mouth; 2) a zone where lake and river waters mix; and 3) influence from seiche or wind tides. A fourth characteristic that some, but not all, freshwater estuaries have is a bar or spit that partially encloses the river mouth. http://freshwaterestuary.uwex.edu/estuary.html Credit: Michael K. Anderson

and they can have sills or not. Some estuaries such as the Hudson River estuary or the Chesapeake Bay have very large areas of watershed compared to the surface area of the estuary itself. For other estuaries such as Narragansett Bay the ratio of watershed area to estuary area is quite small. The physical circulation of an estuary is controlled by the balance between tides and riverine influences as these interplay with bathymetry (Boesch et al, 2000).

Estuaries can be classified based on their geology and their water circulation. In understanding the effect of climate change on estuaries, it is important to recognize the five major types of estuaries classified according to their water circulation which include:

- Salt-wedge estuaries. These are the most stratified, or least mixed, of all estuaries; riverine inputs of freshwater are greater relative to the tidal influence (the Mississippi River in Louisiana is an example);
- Fjords experience very little tidal mixing; thus, the water remains highly stratified. Fjords are found along glaciated coastlines such as those of British Columbia, Alaska, Chile, New Zealand, and Norway;
- Slightly stratified or partially mixed estuaries. In this case, saltwater and freshwater mix at all depths; Puget Sound in Washington State and San Francisco Bay in California, are examples of slightly stratified estuaries.
- Vertically mixed or well-mixed estuaries occur when river flow is low and tidally generated currents are moderate to strong. This type of water circulation might be found in large, shallow estuaries, such as Delaware Bay.
- Freshwater estuaries. These are semi-enclosed areas of the Great Lakes in which the waters become mixed with waters from rivers or streams (NOAA National Ocean Service, n.d.).

These differences in physical characteristics, among estuaries, create an exciting real-world puzzle for students to decipher. Table 1 shows how estuaries can be used to support learning about the Climate Literacy Principles & Concepts. While climate change impacts vary regionally, coastal communities and estuaries are clearly on the front lines of climate change. Many estuaries are already experiencing the stresses of coastal development. The coastal land of the contiguous U.S. represents 17% of the nation's continental land area, yet it is inhabited by over half of the U.S. population. Climate change will interact with existing stresses from coastal development, intensifying their negative impacts on estuaries. Both water quality and nutrient cycling within an estuary will likely see dramatic climate-driven impacts. For example, a decrease in precipitation could cause the salinity of the estuary to increase and change how nutrients are flushed from rivers into the estuary. Biological communities of an estuary will also be impacted with local and regional changes in habitat, species range, and food web interactions. A decrease in the amount of freshwater inflow and associated nutrients would likely result in changes in the extent a salt marsh covers, as well a change in the abundance and types of plants that make up the salt marsh community. Climate-driven changes in an estuary system will also result in changes in the overall range of species, favoring some and driving others toward extinction.

The changes are also likely to impact human communities. For example, it is reasonable to expect shifts in coastal economies like fishing, shipping and tourism. Increases in sea level, storm frequency and coastal currents could result in flooding and erosion of man-made infrastructure, like roads, airports, shoreline housing developments and recreation areas. Freshwater estuaries on the Great Lakes are expected to show a decline in water levels, as the lake levels are predicted to

Table 1. Essential Principles of Climate Literacy and the Estuary Connection

Climate Principle	Estuary Connection
Life on Earth has been shaped by, depends on and affects climate	Estuaries are exquisitely sensitive to the climate. Students see this by comparing estuaries across different climatic environments.
We increase our understanding of the climate system through observation and modeling	Observation and modeling lay at the heart of estuaries models. Students use data and models to explore the featured estuaries, including their climatic conditions.
The sun is the primary source of energy for the climate system	Students learn about insolation and the central role of the sun in the estuarine systems. They track solar energy as it warms the water on daily and annual cycles, and as it is converted to food by algae and other aquatic plants and on through the food chain.
Earth's weather and climate systems are the result of complex interactions	Students see the complexity in the rich diversity of habitats and life throughout individual estuaries and across the full range of estuaries.
Earth's weather and climate vary over time and space	By comparing estuaries, students learn about the tremendous variety of weather and climate conditions, and how they vary from one location to another and across the annual seasonal cycles.
Evidence indicates human activities are impacting the climate system	Estuaries are essential harbingers of climatic change. Students learn about experiments scientists are now conducting in estuaries to monitor climatic change, global warming and sea level rise.
Earth's climate system is influenced by complex human decisions involving economic costs and social values	Students learn about how their own behavior is part of a larger picture – that impacts not only nearby estuaries, but also the larger climatic system of which we are all a part. They also learn about the social and economic factors that affect our ability to work constructively to reduce the scope and impact of climate change.

lower overall. Consequently, the Great Lake shipping industry could be highly impacted by leaving coastal infrastructure high and dry.

Our Nation's Estuaries are Living Classrooms that Advance Our Understanding of Climate-Driven Changes

Estuaries can serve as a powerful vehicle for engaging students, developing scientific thinking and problem-solving skills, and helping students learn and apply core concepts in biology, chemistry, physics and Earth science. Further, the growing awareness of the challenges of climate change and planetary stewardship makes it even more imperative that students learn about the connections between the environment and our daily lives. Our nation's estuaries, represented by NOAA's National Estuarine Research Reserves, serve all of these needs with a rich and accessible context for learning.

The **National Estuarine Research Reserve System (NERRS)** is a partnership between the U.S. National Oceanic and Atmospheric Administration (NOAA) and the coastal states. It protects more than 1.3 million acres of coastal and estuarine lands in 28 Research Reserves located in 22 coastal states and Puerto Rico, and is dedicated to long-term research, education and stewardship of estuaries. As a network of living estuarine laboratories, the NERRs are working with local researchers and communities to better understand the implications of climate-driven changes in our estuaries and on our coasts. In addition, Research Reserves are poised to respond to climate change at the local level by educating and training community members to foster behavior change and mitigation. Habitat, land use, sea-level change, as well as biotic and abiotic indicators are key topics for NERRS climate change education efforts.

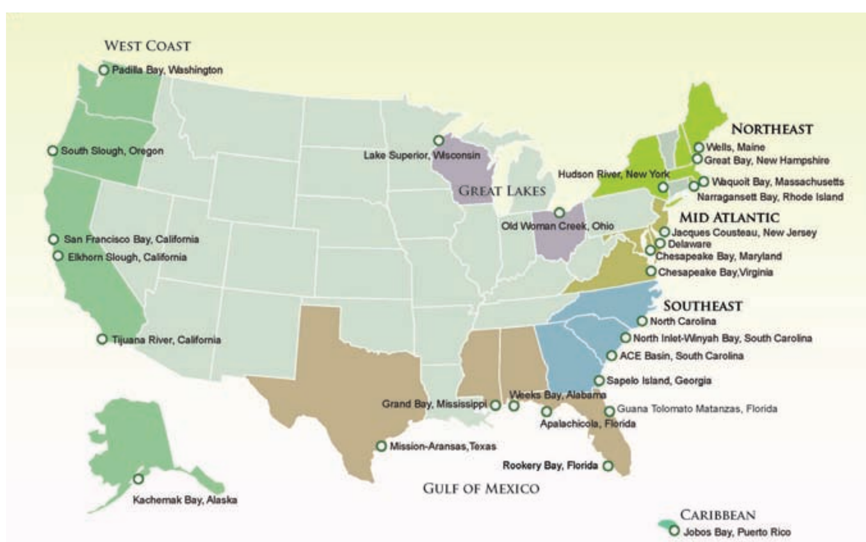


Figure 3. NERRS Map with 28 Research Reserves.
NERRS Map locating all 28 Research Reserves.
Credit: NOAA Estuarine Reserves Division

The NERRS have developed a series of tools for teachers to teach about estuaries and the climate change connection. Most recently the NERRS launched an **Estuaries 101 Middle School Curriculum** (http://estuaries.noaa.gov/Teachers/MiddleSchool.aspx) that weaves climate change information and learning activities throughout the unit. Specifically, six of the 15 activities feature climate extensions that help students understand why and how climate change is impacting estuaries.

Collectively the climate extensions explore:

- how increases in global sea surface temperature impact estuaries
- sea level change in estuaries across the nation
- role of climate change impacts on estuary food webs
- climate change impacts on estuary habitats, like sea grass beds and mangroves
- possible impacts to coastal communities
- ways that NERRS, students, and communities can mitigate the impacts of climate change

Various different professional development opportunities are offered at individual Research Reserves. In general, teacher training programs are designed to increase learners' knowledge of coastal ecology and the impacts of human actions on coastal areas, and to promote ecologically sustainable behaviors. Climate change is a part of these trainings offering educators an opportunity to interact with coastal scientists who are studying the impacts of climate change on estuaries. Additionally, participants learn to access and utilize environmental data while preparing math and science lessons that are exciting for students, meet math, geography and national science education standards, and teach communication and analytical skills using real world scenarios. For example, the Waquoit Bay NERR in Massachusetts currently offers programs that highlight topics such as renewable energy, climate change, coastal processes, eutrophication, and estuarine ecology. For more information, please visit nerrs.noaa.gov and for educational resources estuaries.noaa.gov

About the Authors

Atziri Ibañez is the National Education Coordinator for NOAA's National Estuarine Research Reserve System (NERRS – nerrs.noaa.gov). Ms. Ibañez brings over 15 years of experience in the environmental education field, working with a broad range of student and adult audiences. Through-out her career she has focused on advancing water quality protection projects benefiting people in communities all the way from Panama, El Salvador, Mexico, and currently the United States. Realizing the challenges teachers faced to incorporate NOAA/NERRS online data in their classrooms; she led a study on teacher technology integration of ocean observing data which influenced the design of the NOAA Data in the Classroom modules and various other teacher ready-to-use resources. In her current position, Ms. Ibañez heads a national education program, implemented at 28 Research Reserves, located in 22 of the 35 U.S. coastal states, aimed at increasing estuarine literacy (estuaries.noaa.gov) and promoting the integration of coastal observing data, and other NOAA data, into a variety of classrooms and curricula across the nation. Atziri can be reached at atziri.ibanez@noaa.gov

Bree Murphy is a Program Specialist at NOAA, assisting with the National Estuarine Research Reserve System's education program. Ms. Murphy has a Master's in Education, with a concentration in Science Education, from the University of California-Davis and a Bachelors of Science from The Evergreen State College in Olympia, Washington. She has been working in the marine education field for the last 12 years leading and coordinating education programs, developing science-based curricula, and promoting public understanding and participation in the research and monitoring process. Bree can be reached at bree.murphy@noaa.gov

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National Earth Science Teachers Association Events at 2013 San Antonio NSTA Conference

NATIONAL EARTH SCIENCE TEACHERS ASSOCIATION

All NESTA sessions are in the Henry B. Gonzalez Convention Center, Ballroom A unless otherwise indicated

Tickets for the NESTA field trip will be available through NESTA at www.nestanet.org beginning January 15, 2013.

WEDNESDAY, APRIL 10

NESTA Field Trip – More information coming soon! Check the NESTA website!

FRIDAY, APRIL 12

9:30 – 10:30am	**NESTA Geology Share-a-Thon**
11:00 am – noon	**NESTA Oceans and Atmospheres Share-a-Thon**
12:30 – 1:30 pm	**NESTA Earth System Science Share-a-Thon**
2:00 – 3:00 pm	**American Geophysical Union Lecture (Henry B. Gonzalez Convention Center, Grand Ballroom C1)**
2:00 – 3:00 pm	**Climate Change Classroom Toolkit**
3:30 – 4:30 pm	**Let's Get Well Grounded!**
6:30 – 8:00 pm	**Friends of Earth Science Reception (Grand Hyatt Hotel, Lone Star D)**

SATURDAY, APRIL 13

8:00 – 9:00 am	**Activities Across the Earth System**
9:30 – 10:30 am	**Exploring Planetary Science and Astronomy – What Would Galileo Do?**
11:00 – noon	**NESTA Space Science Share-a-Thon**
12:30 – 1:30 pm	**NESTA Advances in Earth and Space Science Lunchtime Lecture**
2:00 – 3:00 pm	**Our Changing Planet**
3:30 – 4:30 pm	**NESTA Rock and Mineral Raffle**
5:00 – 6:00 pm	**NESTA Annual Membership Meeting**

NESTA gratefully acknowledges co-sponsorship of our events by the following organizations:

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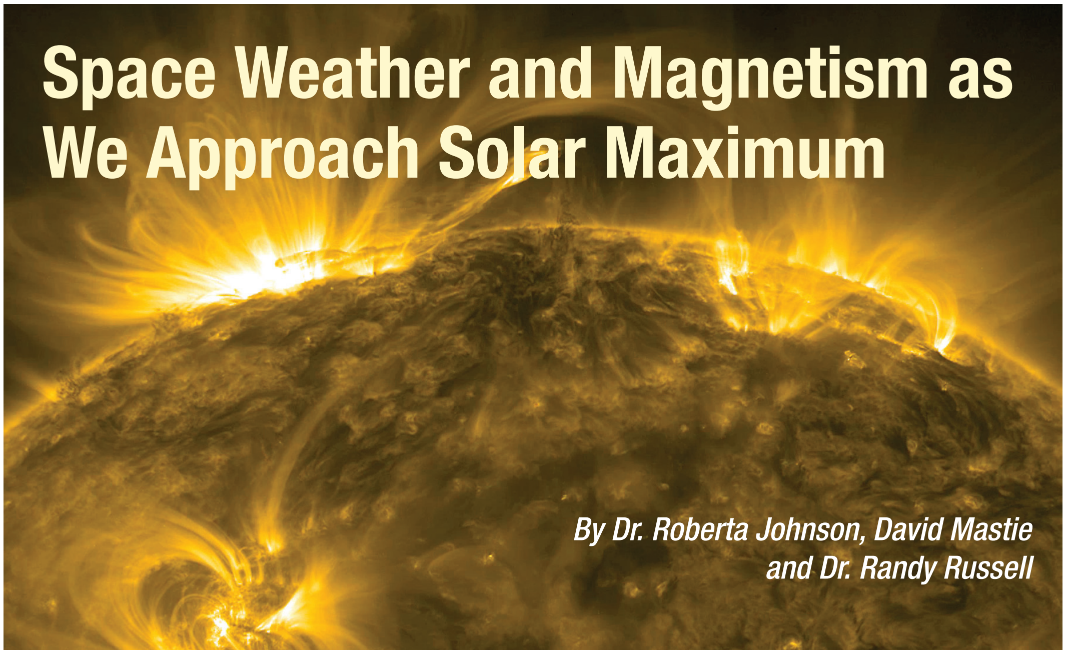

Space Weather and Magnetism as We Approach Solar Maximum

By Dr. Roberta Johnson, David Mastie and Dr. Randy Russell

Magnetic field lines between two active regions extended across about one-third of the Sun to make their connections (July 23-24, 2012). The magnetically powerful active regions were just rotating into view, giving us a wonderful profile of their activity. The lower active region also spurts out several bursts of plasma as well. The looping arcs above each active region shows off the field lines nicely.

Image from http://sdo.gsfc.nasa.gov/gallery/main.php?v=item&id=150 courtesy of NASA, Solar Dynamics Observatory.

Introduction

Many of you may have noticed a recent resurgence of news about solar flares in the media, with many fascinating photographs and videos taken by solar spacecraft equipped with incredible imaging capabilities of dramatic solar phenomena (see Figure 1). These images provide wonderful real-world displays of aspects of fundamental physics and evidence of Sun-Earth coupling at the large scale – many of which are visible (thanks to these images and video) on televisions and computers in our classrooms, homes and offices!

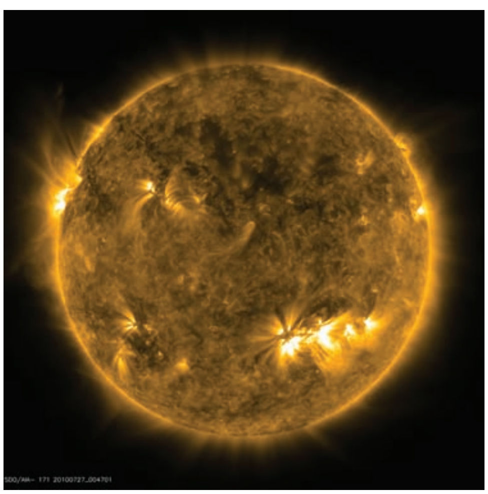

Figure 1. This image of the sun, taken by the Solar Dynamics Observatory at ultraviolet wavelengths on July 27, 2010, shows several bright active regions on the solar disk.

Image courtesy of NASA.

Is this evidence of some ancient Mayan prophecy set for 2012? Is the world going to end?

No. It's not the end of the world – we're just moving into the phase of the solar cycle when we can expect to see dramatic phenomena on the Sun which occasionally will have impact on us here on Earth. This paper provides some background on "space weather" – the term scientists use to refer to solar activity and its impact on interplanetary space (with an emphasis on the near-Earth region) – as well as on Earth's magnetic field, highlighting some of the interesting variability apparent in the Sun-Earth system.

The Sun, Solar Magnetism, Sunspots, and Space Weather

The Sun, a body of hot plasma in the center of our solar system, is the source of almost all energy incident on the Earth, and is responsible for life as we know it. The Sun has a magnetic field with interesting temporal behavior – displaying both cyclical characteristics as well as dynamic behavior. The frequency of some of these sudden dramatic events is tied to the solar cycle.

The Sun's magnetic field, which scientists theorize is produced by currents in the Sun's convection zone, exhibits numerous cycles. The most prominent magnetic cycle, associated with the strong "11-year" periodicity of sunspots, is the 22-year long solar cycle – the time it takes for the orientation of the dipole component of the Sun's magnetic field to switch from one orientation to another and back again. Many people refer to this cycle as the "11-year solar cycle", because of the strong

11-year signal in the sunspot record and the fact that it takes about 11-years for the sun's dipole magnetic field to switch from one orientation to the other. However – since a cycle means a process comes back to where it started – this solar cycle is actually 22-years long (as first shown by George Hale in the early 1900s). Note also that this sunspot cycle is not exactly 11-years – sometimes it is slightly longer, and sometimes it is slightly shorter. It's interesting that the period when humans started launching satellites, in the mid twentieth, was a period of particularly high sunspot number, and that in recent years, peak sunspot numbers in the solar cycle have declined to slightly more than half of the level observed then. Our current solar cycle (see Figure 2) is predicted to be below average in intensity, and to reach a maximum of about 90 in May 2013 (Solar Cycle 24 Prediction Panel, NOAA 2009).

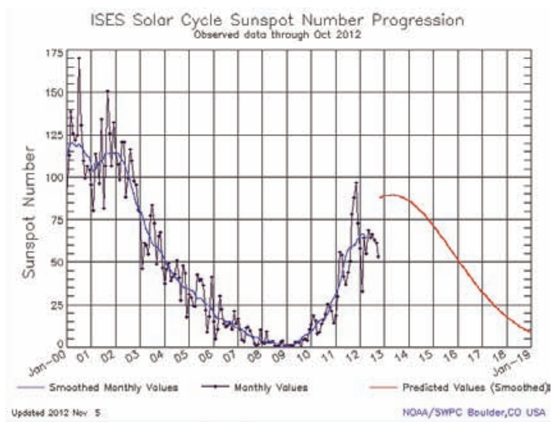

Figure 2. Sunspot number observations and predictions for solar cycle 24. Up to date data is available from the NOAA Space Weather Prediction Center on a monthly basis at http://www.swpc.noaa.gov/SolarCycle/. The observed solar cycle minimum occurred in December 2008, and the consensus prediction of the coming solar cycle maximum is shown in the red curve: a maximum sunspot number of ~90 is predicted in May 2013.

Image courtesy of NOAA.

Figure 3 shows the record of observed sunspots from 1700 to 2010. Although the 11-year cycle is very prominent, it's clear from this record that there are other, longer-term variations in sunspot number. Analysis of sunspot numbers, as well as sunspot number "proxies" (from studies of cosmogenic isotope abundance and dendrochronology) indicate the presence of multiple other possible cycles, including the 87-year Gleissberg cycle, the 210-yr Suess cycle, the 2,300 year Hallstatt cycle, and potentially a 6000 year cycle. In addition to the cycles mentioned above, there are some other interesting features in the sunspot record. These include the "Maunder Minimum", from 1645 to 1717, when virtually no sunspots were observed on the solar surface (and yes, people were looking for them). The earliest observations of sunspots go back to the ancient Chinese (by Gan De, UNESCO Courier, 1988). Wittmann and Xu (1987) have compiled a catalogue of early sunspot observations from 165 BC through 1684.

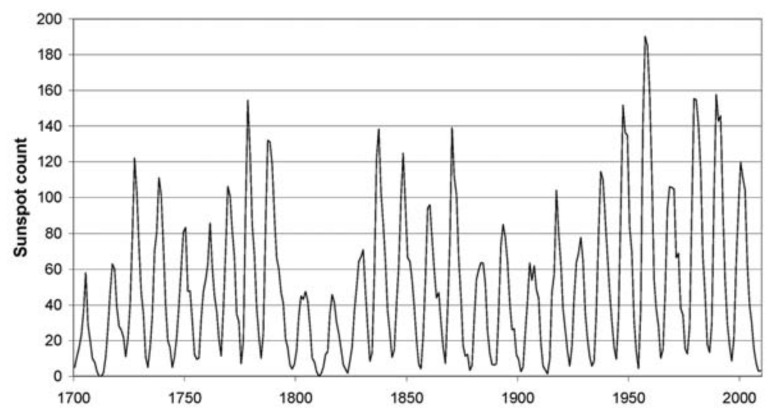

Figure 3. This graph shows the international sunspot numbers from 1700 to 2010. The international sunspot number is produced by the Solar Influences Data Analysis Center, World Data Center for the Sunspot Index at the Royal Observatory of Belgium. See http://www.ngdc.noaa.gov/stp/solar/ssn.html for more information on how sunspot numbers are calculated, and http://www.ngdc.noaa.gov/stp/solar/ssndata.html#international for access to sunspot data tables.

Image courtesy of the World Data Center for Sunspot Index.

Solar scientists have observed activity on the Sun for generations now (and before them, interested observers have noted sunspots for thousands of years), and have shown that sunspots, solar flares, and many other aspects of solar phenomena as well its corollary "geomagnetic activity" (phenomena in the Earth's magnetic environment) are tied to the solar cycle.

The key to understanding why solar flares and other similar phenomena are associated with the magnetic field is because the sun is made of plasma. Because plasmas are ionized, they carry magnetic field with them as they move (the "frozen-in" behavior of plasma). Scientists theorize that, because the plasma-fluid surface of the Sun at the equator rotates faster than it does at the poles (the Sun's "differential rotation" - rotating once every ~25 days at the equator and ~35 days at the poles), the magnetic field at the surface of the sun gets "wrapped up" around the Sun over time (the "Babcock Model" of solar magnetism). Indeed, observations of sunspots show that as a solar cycle begins, sunspots initially erupt at higher solar latitudes and gradually migrate to more equatorial latitudes as solar cycle maximum approaches. This behavior results in the famous "butterfly patterns" seen in long term observations of sunspots. As the surface magnetic fields become more

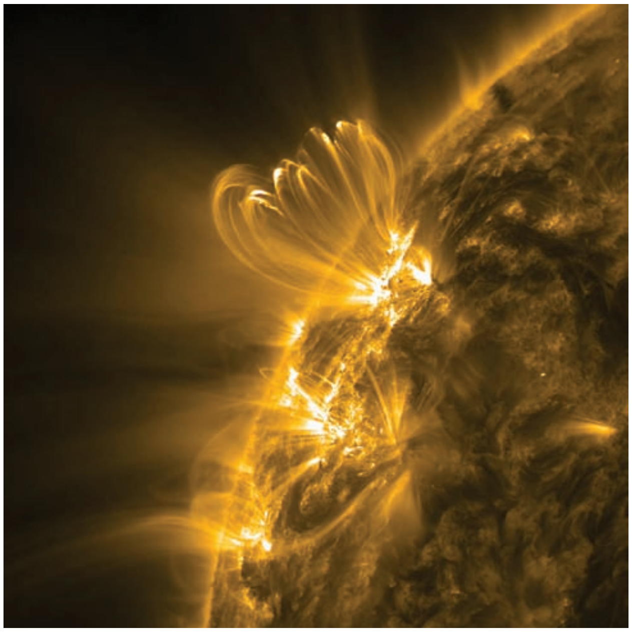

Figure 4. An image of the Sun's limb in ultraviolet light in January 2012, showing cascading loops of superheated plasma following magnetic field lines above an active sunspot region just after a solar flare eruption. The loops are several times the diameter of the Earth.

Image courtesy of NASA.

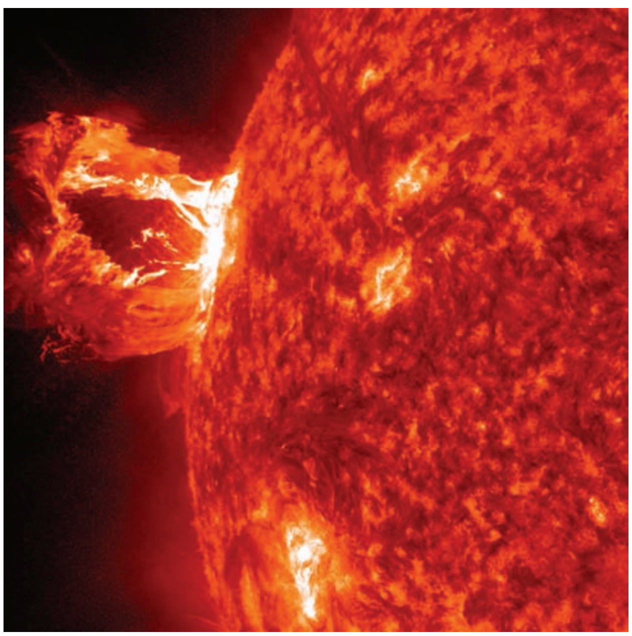

Figure 5. The Solar Dynamics Observatory observed a beautiful prominence eruption shot off the east limb (left side) of the Sun on April 16, 2012. Such eruptions are often associated with solar flares, and in this case an M1.7 class (medium-sized) flare did occur at the same time, though it was not aimed toward Earth.

Image courtesy of NASA.

intense, instabilities in the balance of forces at the Sun's surface can cause the magnetic field lines to erupt out of the surface in enormous magnetic field structures, only to loop back and connect to the solar surface (see Figure 4). At ~3000-4500 K, sunspots are cooler than the surrounding surface at ~5700K, and therefore appear to be comparatively dark. However, sunspots are regions of much more intense magnetic field (pressure balance is achieved through thermal and magnetic pressure in amagnetohydrodynamic fluid). Solar flares erupt from these regions of intense magnetic fields, launching into space impressive prominences (see Figure 5) frequently accompanied by intense high-energy solar radiation (for instance, at X-ray and UV wavelengths). Occasionally massive eruptions in these regions can send enormous clouds of high-energy magnetized plasma into interplanetary space – a "coronal mass ejection" or CME – which can reach the orbit of Earth within one or two-days of the eruption (on the other hand, high-energy radiation from solar flares reachs Earth within about ten minutes, traveling at the speed of light).

As these clouds of plasma and magnetic field travel out into space, they can produce measureable impacts on spacecraft or planetary bodies that find themselves in their path. Depending on where on the solar surface an eruption takes place (and the size of the eruption), we on Earth may, or may not, be impacted by the eruption. If a solar eruption takes place such that the plasma and magnetic field launched into space intersects the Earth, in its orbit about the Sun, then we may see a wide range of interesting "geomagnetic activity" phenomena and occasionally impacts on our technical infrastructure produced by this "space weather". On the other hand, if the solar eruption takes place on a part of the Sun which is oriented so that the cloud will not intersect the near-Earth space environment as it moves out into space, there may be no impact of the space weather event on Earth (other than having wonderful images, videos, and other data to analyze).

Earth's Magnetic Field and Reversals

The Earth's magnetic field plays a critical role in preventing most high energy particles from space from entering Earth's atmosphere. In particular, the solar wind – a stream of energetic charged particles which continuously blows out from the Sun at varying speeds– is deflected around the Earth by the Earth's magnetic field. As a result, the Earth's magnetic field, which is approximately the field of a magnetic dipole tilted at about 11 degrees from the Earth's rotational axis, is stretched out into an elongated teardrop shape known as the "magnetosphere". A small fraction of these high energy particles can sometimes (depending to a large extent on the direction of the magnetic field in the solar wind) enter the Earth's magnetosphere in the high latitude regions, resulting in "aurora" produced by light emitted at varying wavelengths by atmospheric atoms and molecules resulting from interactions with precipitating energetic particles.

The Earth's magnetic field is generated mainly by electric currents in the liquid outer core of the Earth. This layer of the core is composed of highly conductive molten iron. As we know from the equations of electromagnetism, when ionized particles move they produce a current, and currents generate magnetic fields. Geomagnetism is an active area of research, and scientists continue to do research on the details of the behavior of the Earth's magnetic field, including understanding its variation with time and its occasional reversals.

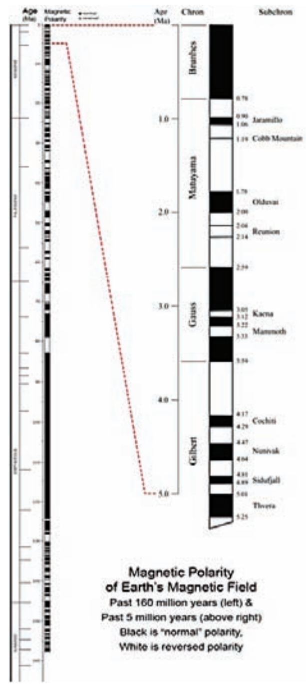

Figure 6. The polarity of the Earth's magnetic field has flipped many times in the past, apparently at random intervals. The graph at the left shows the record of the magnetic field orientation over 160 million years, while the past 5 million years is blown up at the right. Names of major intervals are noted at the right. The Brunhes Chron is shown in more detail in Figure 7.

Image courtesy of the United States Geological Survey.

Without a magnetic field, the Earth's atmosphere would be directly impacted by the solar wind, gradually causing the atmosphere to erode away into space! Clearly, the Earth's magnetic field is important. We know that the Earth's magnetic field changes with time – the record of Earth's ancient magnetic field orientations recorded in the Atlantic Ocean's oceanic crust shows us that. Earth's magnetic field has changed its orientation many times in the past several hundred million years, apparently randomly (Figure 6). We also know that the Earth's magnetic field intensity is currently slowly declining. Sometimes people worry that, because of this current decline, we are on our way to a flip in the Earth's magnetic field orientation, and that that might be dangerous to life on Earth. Figure 7 shows a graph of the Earth's magnetic field intensity as a function of time going back 900,000 years. Although the intensity of the field is declining at present, it has declined many times in the past 900,000 years without flipping orientation (from black to white), so there is no reason to believe that the current decline will lead to a change in the Earth's dipole magnetic field orientation. Even in the event that the Earth's dipole magnetic field does change its orientation at some point in the near future, because the Earth's field is not really a dipole, but instead includes several significant higher-order magnetic poles (quadrupole and higher order components), the magnetic fields generated by these higher-order components of the field would remain to hold off high energy particles. Finally, statistical examination of the record of extinctions on the Earth's surface shows no relationship to changes in the orientation of the magnetic field.

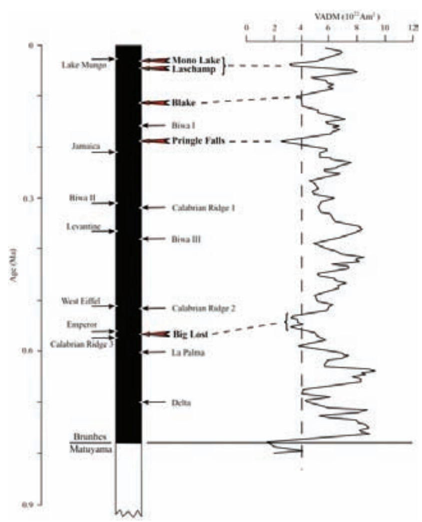

Figure 7. The approximate times of some of the most commonly reported geomagnetic excursions of the Brunhes Normal Polarity Chron (left) and relative paleointensity for the same period. VADM is the virtual axial dipole moment. The vertical dashed line is the critical value of intensity below which changes in the Earth's dipole field orientation have occurred several times in the past.

Image courtesy of the United States Geological Survey.

The Sun and Climate Change?

Climate change is in the news frequently these days. Occasionally you may hear a claim that the climate changes we are seeing are associated with solar activity or changes in the Sun's energy output. While these assertions vary in detail, detailed examination of the Sun and recent climate change shows that these claims are not supported by the data. Specifically, Figure 8 shows a plot of atmospheric temperature anomaly, CO_2 concentration, and sunspot number. During the past several decades, as temperature and CO_2 concentrations have been rising, solar activity as measured by sunspot number has been declining. Of course, there are many details to the question of the Sun's impact on our climate. Those interested in finding out more about the question of whether solar activity or changes on the Sun might be responsible for global warming are advised to visit the Skeptical Science website at http://www.skepticalscience.com, which provides a comprehensive

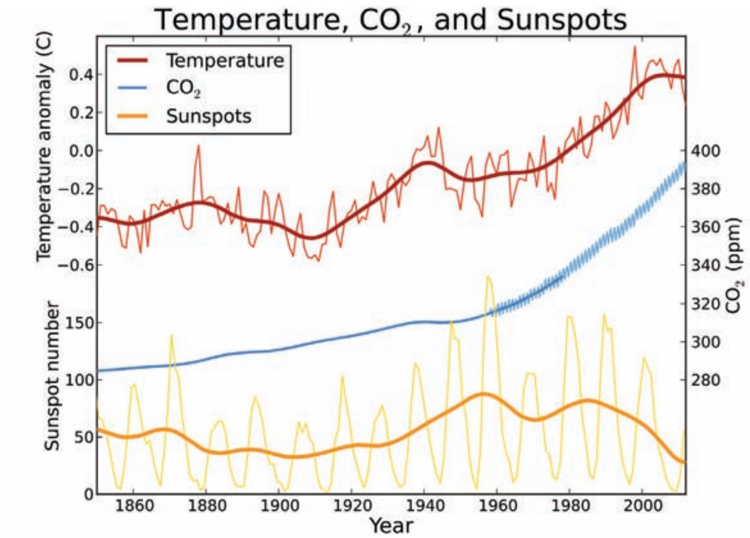

Figure 8. A comparison of global atmospheric temperature anomaly, atmospheric CO_2, and sunspot activity since 1850. Thick curves show the 25 year moving average of the data. During the period of warming over the past several decades, which is associated with a period of rapidly rising CO_2 concentrations, the solar activity as measured by sunspot number has been declining.

Image courtesy of Leland McInnes, Wikipedia, Creative Commons license. Accessed 29 Apr, 2012 at http://en.wikipedia.org/wiki/File:Temp-sunspot-co2.svg.

review of these assertions and what the science says at http://www.skepticalscience.com/solar-activity-sunspots-global-warming-advanced.htm.

Classroom Activities

NESTA, on its flagship educational website, Windows to the Universe, offers a large collection of resources about the Sun, space weather, and Earth magnetism (http://www.windows2universe.org). In addition to the website's hundreds of pages on these topics available at the upper elementary, middle school, and high school levels in English and Spanish, we offer many classroom activities that explore these concepts in our Teacher Resources section. We have offered teacher workshops on space weather and magnetism for over a decade, and the resources shared during these workshops (including activities, interactives, images, animations, worksheets, and more) are all freely available at http://www.windows2universe.org/teacher_resources/main/nsta_magnet_wkshops_fall_2010.html. Favorite activities include:

- The Magnetometer – Students build their own magnetometer and use it to learn about planetary magnetic fields. Available at http://www.windows2universe.org/teacher_resources/magnetism/teach_magnetometer.html.
- Magnetometer Extensions – Students model real-world uses of a magnetometer instrument. Students see how sea floor spreading at mid-ocean ridges deposits a record of the history of the reversals of Earth's magnetic field. They also learn how some ore deposits are found. Available at http://www.windows2universe.org/teacher_resources/magnetism/teach_extension.html.
- Terrabagga – Students build a simulated planet with a magnetic field. They use a simple magnetometer to determine the orientation of the "planet's" magnetic field. Available at http://www.windows2universe.org/teacher_resources/magnetism/teach_terrabagga.html.
- Magnetic Levitation - Students learn about forces (gravity and magnetism) by investigating several configurations of a simple "magnetic levitation" system. Available at http://www.windows2universe.org/teacher_resources/magnetism/teach_magnet_levitate.html.

A page describing the relationship between these activities and the National Science Education Standards is available at http://www.windows2universe.org/teacher_resources/magnetism/magnetometer_standards.html.

The website also includes numerous online interactives to use to learn about magnetism, including Earth's magnetic field, Earth's North Magnetic Pole, Seafloor Spreading and Magnetic Field Reversals, Bar Magnet and Compass, Disk Magnet and Compass. These interactives are all freely available (along with many more) at http://www.windows2universe.org/multimedia_gallery/multimedia_gallery.html under the Interactive Multimedia heading.

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The GOES-R Series: The Nation's Next-Generation Geostationary Operational Environmental Satellites

By Daniel Karlson and Michelle Smith

Abstract

The National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellites (GOES)satellites are a mainstay of weather forecasts and environmental monitoring in the United States. Their images are seen daily on television weather forecasts and are available in real-time from many weather related websites. The next generation of GOES satellites, known as the GOES-R Series, is scheduled for launch in late 2015 and will usher in a new era for geostationary environmental satellites. The GOES-R satellites will provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring to provide critical atmospheric, hydrologic, oceanic, climatic, solar, and space data. GOES-R will provide significant advances in observing capabilities with a new 16-channel imager that will provide 3 times more spectral information, 4 times the spatial coverage, and 5 times the temporal resolution compared to the current GOES imagers. In addition, a new Geostationary Lightning Mapper will provide for the first time a continuous and near real-time surveillance of total lightning activity throughout the Americas and adjacent oceans.

This article is intended to accompany the GOES-R poster included in the print version of this journal, providing for the classroom educator, the important history on the GOES satellite missions and details on the future GOES-R satellite, its instruments, and data products.

For nearly 40 years, NOAA GOES satellites have provided continuous imagery and data of atmospheric conditions and space weather. GOES' data products are utilized by the National Weather Service for weather monitoring and forecasting operations and are the primary satellites used for tracking hurricanes. Their images are seen daily on television weather forecasts and GOES data is used by researchers for better understanding of interactions between land, ocean, atmosphere, and climate. The satellites have also aided in the search and rescue of thousands of individuals in distress around the world.

The GOES spacecraft operate as a two-satellite constellation above the equator, orbiting approximately 22,300 miles above the Earth. Together, the satellites observe nearly 60 percent of the Earth's surface and measure atmospheric temperature and moisture, cloud cover, and the solar and space environment. They circle the Earth in a geosynchronous orbit, continually viewing the continental United States, the Pacific and Atlantic Oceans, Central and South America, and Southern Canada. The eastern and western satellites (known as GOES-East and GOES-West) are respectively positioned to provide the best view from near Africa to beyond the central part of North America and from the center of the United States to beyond Hawaii.

The GOES program is a collaborative development and acquisition program between NOAA and the National Aeronautics and Space Administration (NASA) to develop, deploy, and operate the satellites. Starting with the first GOES in 1974, the two organizations have worked together to advance the technology for geostationary satellite observations.

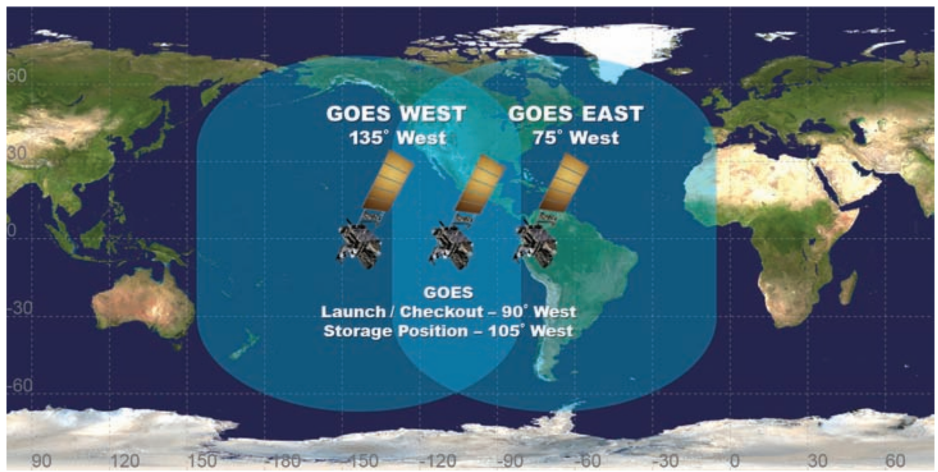

Figure 1. Location of the GOES fleet.

Credit: GOES-R Program

The next generation of geostationary environmental satellites, the GOES-R Series, will mark the first major technological advances in geostationary observations since 1994, when the GOES I-M Series was launched. The satellites will provide improved detection and observations of meteorological phenomena, including improved hurricane track and intensity forecasts, increased thunderstorm and tornado warning lead time, and improved aviation route planning. GOES-R will also advance space weather forecasting, including improved solar flare warnings for communications and navigation disruptions, more accurate monitoring of hazardous energetic particles, and better monitoring of coronal mass ejections. GOES-R is scheduled for launch in late 2015, and will be followed by GOES-S in February 2017, GOES-T in April 2019 and GOES-U in October 2024. The GOES-R series will extend the availability of the operational GOES satellite system through 2036.

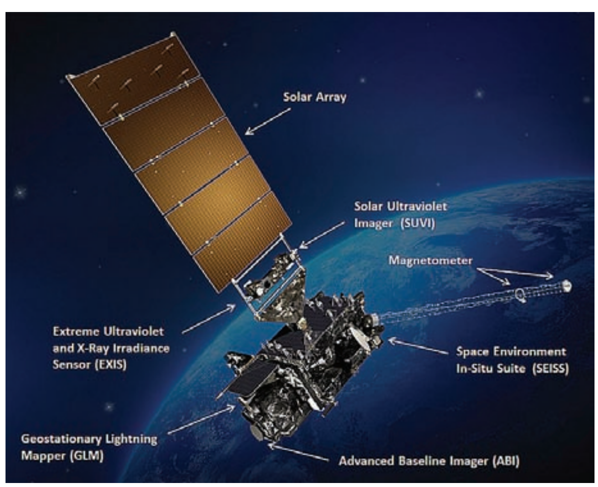

Figure 2. Depiction of the GOES-R spacecraft, indicating the location of each instrument.

Credit: Lockheed Martin Space Systems Company

The GOES-R spacecraft bus is designed for 10 years of operation preceded by up to 5 years of in-orbit storage. The satellite will provide near-continuous instrument observations for the Earth-pointed optical bench and high-speed spacecraft-to-instrument interfaces designed to maximize science data collection. The GOES-R spacecraft will launch aboard an Atlas V 541 expendable launch vehicle from Space Launch Complex-41 at Cape Canaveral Air Force Station, Florida.

The spacecraft will carry three classifications of instruments: nadir-pointing (toward the earth), solar-pointing (toward the sun), and in-situ (in place). Two of GOES-R's instruments point toward Earth. One is the Advanced Baseline Imager (ABI), the primary instrument on board GOES-R for

Figure 3. GOES-R will launch aboard an Atlas V541 expendable launch vehicle, like the one shown here.

Credit: NASA

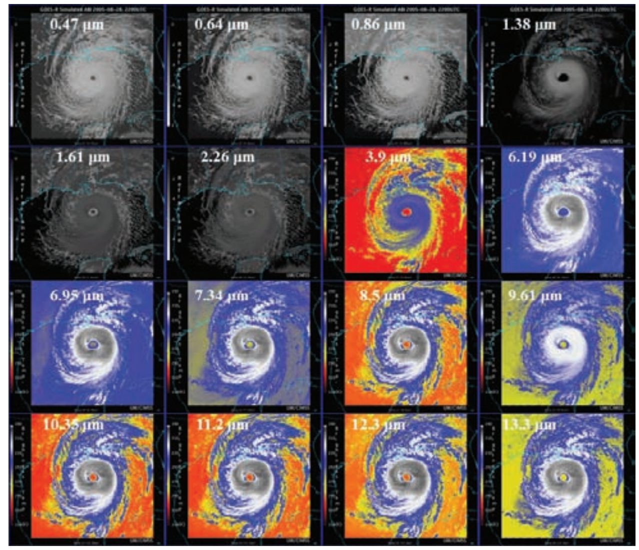

Figure 4.Simulated Hurricane Katrina images from August 28, 2005 for all 16 bands of the Advanced Baseline Imager. The current GOES imager has only five bands.

Credit: Cooperative Institute for Meteorological Satellite Studies (CIMSS)

imaging Earth's weather, climate, and environment. The ABI will be able to view the Earth with 16 different spectral bands (compared to five on current GOES), including two visible channels, four near-infrared channels, and ten infrared channels. It will provide three times more spectral information, four times the spatial resolution, and more than five times faster coverage than the current system. Higher-resolution imagery will allow forecasters to track storms earlier in their development.

The GOES-R ABI will be used for a wide range of applications related to weather, oceans, land, climate, and hazards. It will improve every data product from the current GOES Imager and will introduce a host of new data products for severe weather forecasting, fire and smoke monitoring, volcanic ash advisories, and more. The ABI has two main scan modes. The continuous full disk mode will provide uninterrupted scans of the Earth every 5 minutes, while the flex mode will concurrently allow imagery every 15 minutes, the continental US every 5 minutes, and a mesoscale region as often as every 30 seconds.

The second is the GOES-R Geostationary Lightning Mapper (GLM), a unique instrument which will be the first-ever operational lightning mapper flown from a geostationary orbit. The GLM is an optical transient detector and imager that maps total lightning activity continuously day and night over the Americas and adjacent ocean regions. GLM is unique both in how it operates and in the information it collects. While ground-based sensors only provide cloud-to-ground coverage, GLM provides total lightning activity detection with both cloud-to-ground and cloud-to-cloud coverage. The GLM will provide early indication of storm intensification and severe weather events, improved tornado warning lead time, and data for long-term climate variability studies. It is anticipated that GLM data will also have applications to aviation weather services, climatological studies, and severe thunderstorm forecasts and warnings. The GLM will provide information to identify growing, active, and potentially destructive thunderstorms over land as well as ocean areas.

The GOES-R series will fly an array of advanced solar monitoring and space weather sensors that will provide critical information to NOAA's Space Weather Prediction Center (SWPC) in Boulder, Colorado. Two instruments point toward the Sun and will reside on the Solar Pointing Platform

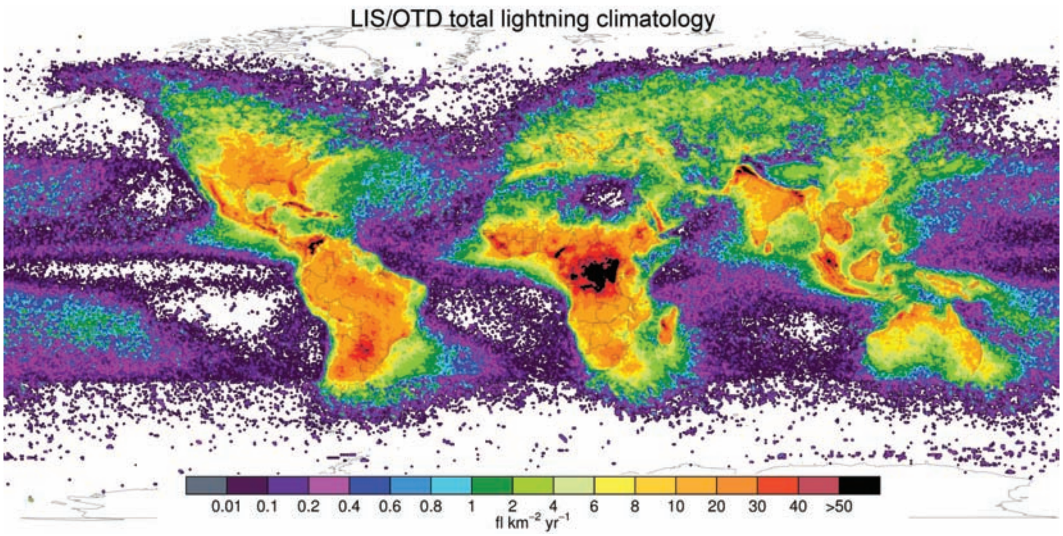

Figure 5.Global distribution of lightning from a combined nine years of observations of the National Aeronautics and Space Administration (NASA)Optical Transient Detector (OTD) (4/95-3/00) and Lightning Imaging Sensor (LIS) (1/98-12/04) instruments.

Credit: NASA

mounted in the yoke of the solar array. The Solar Ultraviolet Imager (SUVI) is a telescope that observes the Sun in the extreme ultraviolet (EUV) wavelength range. SUVI will observe and characterize complex active regions of the Sun, solar flares, and the eruptions of solar filaments which may give rise to coronal mass ejections. Depending on the size and the trajectory of solar eruptions, the possible effects to the Earth's environment include the disruption of power utilities, communication and navigation systems, and possible damage to orbiting satellites and the International Space Station. SUVI observations of flares and solar eruptions will provide an early warning of possible impacts to the Earth environment and enable better forecasting of potentially disruptive events.

The Extreme Ultraviolet and X-Ray Irradiance Sensors (EXIS) detect solar soft X-ray irradiance and solar extreme ultraviolet spectral irradiance. The X-Ray Sensor (XRS) monitors solar flares that can disrupt communications and degrade navigational accuracy, affecting satellites, astronauts, high latitude airline passengers, and power grid performance. The Extreme Ultraviolet Sensor monitors solar variations that directly affect satellite drag/tracking and ionospheric changes, which impact communications and navigation operations. This information is critical to understanding the outer layers of the Earth's atmosphere.

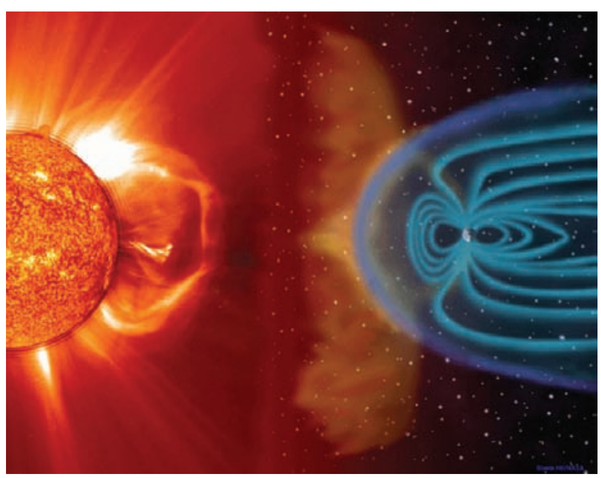

Figure 6.Simulated GOES-R Solar Ultraviolet Imager image.

Credit: Solar and Heliospheric Observatory (SOHO) Extreme ultraviolet Imaging Telescope (EIT), a joint NASA/European Space Agency (ESA) program; and Steve Hill/NOAA Space Weather Prediction Center (SWPC).

GOES-R also has two in-situ instruments that will monitor their own space environment. The Space Environment In-Situ Suite (SEISS) will consist of an array of sensors that will monitor the proton, electron, and heavy ion fluxes at geosynchronous orbit. The information provided by the SEISS will be used for assessing radiation hazards to astronauts and satellites. In addition to hazard assessment, the information from the SEISS can be used to warn of high flux events, mitigating damage to radio communication. The SEISS instrument suite consists of the Energetic Heavy Ion Sensor (EHIS), the Magnetospheric Particle Sensor - High and Low (MPS-HI and MPS-LO), and the Solar and Galactic Proton Sensor (SGPS). Data from SEISS will drive the solar radiation storm portion of NOAA space weather scales and other alerts and warnings issued by SWPC and will improve solar energetic particle forecasts.

Figure 7.Earth's magnetic field, or magnetosphere, protects us from most effects of solar storms and from solar wind.
Credit: Solar and Heliospheric Observatory (SOHO) image composite by NASA

The GOES-R Magnetometer will provide measurements of the space environment magnetic field that controls charged particle dynamics in the outer region of the magnetosphere. These particles can be dangerous to spacecraft and human spaceflight. The geomagnetic field measurements will provide alerts and warnings to satellite operators and power utilities. Magnetometer data will also be used in research. The GOES-R Magnetometer products will be part of NOAA's space weather operations, providing information on the general level of geomagnetic activity and permitting detection of sudden magnetic storms. In addition, measurements will be used to validate large-scale space environment models that are used in operations.

In addition to the space segment components, ground support is also critical to the GOES-R mission. The ground segment consists of the entire ground system, including the facilities, antenna sites, and the software and hardware for satellite command and control and to process, create, and distribute end user products. NOAA is developing a state of the art ground system that will receive data from the spacecraft and generate and distribute real-time GOES-R data products.The ground system will operate from two primary locations: the NOAA Satellite Operations Facility (NSOF) in Suitland, Maryland, and the Wallops Command Data Acquisition Center (WCDAS) at Wallops, Virginia. A third operations facility in Fairmont, West Virginia will serve as the Remote Backup in case of a systems or communications failure at either or both the NSOF and WCDAS.

Figure 8.The NOAA Satellite Operations Facility, located in Suitland, MD, will house the majority of GOES-R mission operations, including Enterprise Management, Product Generation, and Product Distribution.The facility will upgrade four existing antennas for compatibility with GOES-R.
Credit: NOAA

The GOES-R Program is committed to ensuring that the user community is prepared for the new types of satellite imagery and data that will be available from the GOES-R satellite series. A critical component of user readiness is the GOES-R Proving Ground, a collaborative effort between the GOES-R Program Office, NOAA Cooperative Institutes, NASA, the National Weather Service Weather Forecast Offices, the National Centers for Environmental Prediction (NCEP), and NOAA research facilities across the United States. The Proving Ground Program consists of a broad set of field demonstration activities designed to provide testing and evaluation of simulated GOES-R products prior to the launch of the satellites. The Proving Ground was established to prepare operational forecasters for the data that will be available with the GOES-R series and to ensure maximum utilization when the satellites are launched and operational. The Proving Ground is the primary project to prepare NOAA and the user community for the exploitation of GOES-R data and information, to develop training, to gain real-world experience, and to provide product feedback by leveraging existing resources, and to evaluate product tailoring and decision aids. Preparing forecasters for GOES-R data is essential for public safety and the protection of life and property through more advanced forecasts and warnings of hazardous weather.

The GOES-R Program is also committed to fostering education and supporting national Science, Technology, Engineering, and Mathematics (STEM) efforts. Students *are* the future scientists, researchers, forecasters, broadcast meteorologists, and policy-makers. It is essential to engage the youth audience to promote understanding of geostationary environmental satellite technology and to encourage scientific study and exploration. The GOES-R program has a variety of resources designed to educate students and teachers about meteorology, space science, earth-observing satellites, weather phenomena and the advanced capabilities of the GOES-R series and the value the satellites will bring to the nation. Students can benefit from interactive learning modules as well as educational activities and games available online, in print, and through mobile devices. GOES-R's educational partner – the NASA Jet Propulsion Laboratory's SpacePlace and Scijinks Program – maintains relationships with a wide network of schools, libraries, museums, and educational conferences which give the program further opportunity to connect with students across the country.

Educational resources can be found on the GOES-R website in the Education and Outreach section (http://www.goes-r.gov/education/overview.html) as well as at the Space Place website (spaceplace.nasa.gov), which is targeted at elementary school students, and Scijinks website(http://scijinks.gov),which reaches middle and high school students.

The advanced observational capabilities of the GOES-R Series of satellites will provide valuable and critical services to the nation by offering improved forecasting and warning of severe weather, including more accurate hurricane track and intensity forecasts, increased thunderstorm and tornado warning lead time. GOES-R will also offer improved ability to detect wildfires as well as air quality hazards such as aerosols. The aviation industry will benefit from the satellites' ability to detect cloud properties and hazards such as volcanic ash. In addition, GOES-R will provide space weather detection and forecasting advancements such as improved solar flare warnings, more accurate monitoring of energetic particles responsible for radiation hazards to humans and spacecraft, and better monitoring of coronal mass ejections for improved geomagnetic storm forecasting. GOES-R will support improved detection and observations of meteorological phenomena that directly impact public safety, protection of property, and economic health and development. Additional information about GOES-R can be found at http://www.goes-r.gov and in the GOES-R poster which accompanies the print version of this article.

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Making the Case for GeoSTEM Education

By John D. Moore, Peter Dorofy, Missy Holzer and Jenelle Hopkins

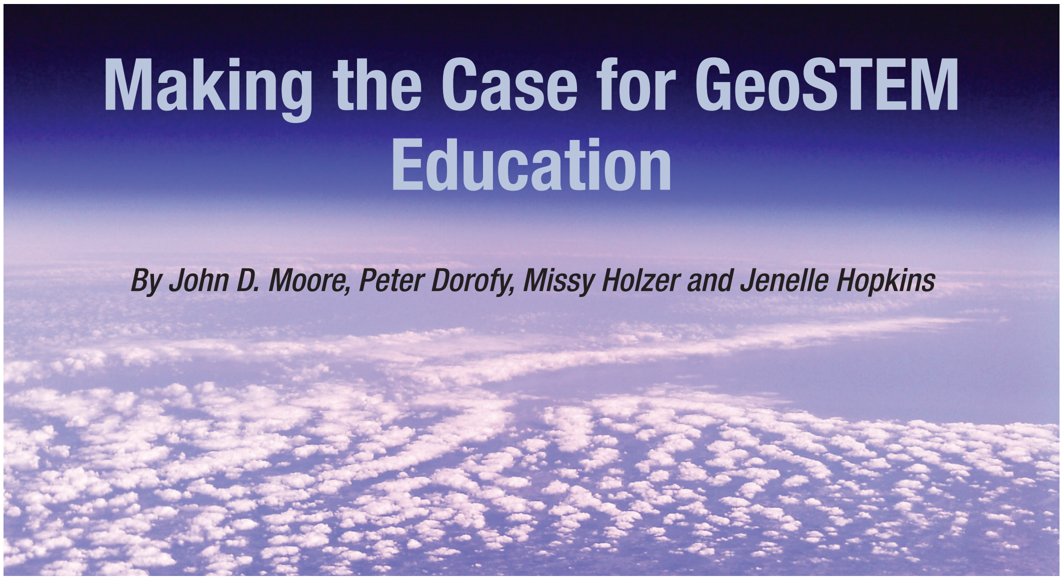

Photo taken from High Altitude BalloonSat Project with Drexel University

Source: Drexel University Space Laboratory

Abstract

As the national Science-Technology-Engineering-Mathematics (STEM) policy makers work through reports, findings, forums, workshops, etc., there emerges an opportunity to present the strong case of why and how the role of the Geosciences community can and should be at the forefront of these discussions. Currently existing within the Geosciences scientific and educational community are policies, frameworks, guidance, innovative technology, and unique interdisciplinary Earth System data sets that will establish a pathway to the role of the Geosciences in the classroom, in the 21st Century workforce, and in society. The question may be raised, "Why GeoSTEM?" But the real question should be … "Why not?"

There is strong support for the Science-Technology-Engineering-Technology (STEM) Education Initiative, in the United States. Perhaps it is because the impact of STEM moves beyond the traditional compartmentalization of topics within the educational community into other areas of interest such as 21st Century Workforce Development, and Career and Technical Education (CTE). STEM has been identified as a major contributing factor linked to our future national economy and security. Therefore, the stakes are high … education, economy, national security. As a nation, we *need* to get this right.

There are several recent and significant publications that provide insight on key issues related to STEM education. They are: "Prepare and Inspire: K-12 Science, Technology, Engineering, and Math Education for America's Future" (President's Council of Advisors for Science and Technology, 2010), "Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics" (National Academy of Sciences, 2011), "A Vision for K-12 Education in the Sciences and Engineering" (NAS K-12 Science Framework, 2011), "Preparing the Next Generation of STEM Innovators: Identifying and Developing our Nation's Human Capital"(National Science Board, 2010), and "Building a Science, Technology, Engineering, and Math Education Agenda"(National Governor's Association, 2011). After reading through these documents and publications, national priorities and potential strategies begin to emerge.

Why GeoSTEM? Why Now?

Over the past several years the Geosciences have dominated the news cycle. As we face future natural and human generated hazards and disasters such as the Gulf Oil Spill, not to mention issues

Figure 1. Because of Hurricane Sandy, Long Beach Island on the Jersey Shore experienced massive loss of beach and dunes. Note where the house paint ends on the pilings, representing the pre-Sandy sand elevation/depth. In the roadways, there were reports of up to 4 feet of displaced sand.

Photo by permission of Robert P. Wanton

confronting society such as Climate Change, Sustainability and Energy, the Geosciences have a critical role in the public awareness, safety, and national security of our nation. In the past year we have experienced volcanic eruptions, earthquakes, tsunamis, hurricanes, tornadoes, wildfires, severe drought and flooding, outbreaks of severe weather. Hurricane Sandy with its devastating impacts on Jersey shore, New York City, and inland as far as Chicago, is but the most recent example of the urgent need and use of Geospatial and Environmental Intelligence, and yet it is becoming increasing more difficult to find opportunities in K-12 education for students to engage in such relevant and related studies.

What implications will this have on the 21st Century workforce? To address this issue, some teachers are preparing their students by using satellite and remote sensing technologies to incorporate imagery, data, and real time observations into the classroom. Geographic Information Systems content is being taught as a technical skill, and is used to develop "Geospatial Thinking" in problem solving.

As evidenced by these examples, the Geosciences Education Community has an opportunity to inform and influence policy makers in the development of emerging national STEM Education Initiatives due to its interdisciplinary nature.

The Geosciences Educational Community has provided leadership through establishing several powerful frameworks to meet these challenges. In October 2009, the National Science Foundation's Advisory Committee for the Geosciences (AC GEO) published the "GEO Vision Report", which outlines a vision, goals, challenges, recommendations and a call to action for the geosciences community at large. As stated in the report, the "Geo Vision" is to: foster a sustainable future through a better understanding of our complex and changing planet. In 2010 the National Science Foundation's "Geoscience Education and Diversity Strategic Framework 2010-2015" was released. The Forward captures the discussion:

Figure 2: Geospatial Technologies students conduct LandSat Image Analysis using Image J

Source: John Moore

"As the second decade of the 21st century unfolds, the geosciences community stands at an important threshold. Rapid advances in our understanding of Earth's complex, inter-connected systems have led us to recognize that the well-being of human society is tightly coupled with the behavior and evolution of Earth Systems. Increasingly, human activities play an influential role in the behavior of these systems, particularly those related to climate, environmental quality, and natural resources. Significant challenges will confront a growing population in the coming decades as the impacts of global climate change, sea level rise, ocean acidification, diminished fresh water and other natural resources, and natural hazards are realized. Thus, the scientific questions being explored by geoscientists address issues that are among the most important facing the nation."

The Federal agencies, supported by scientific societies and organizations, have produced and published several literacy documents. "The Literacies", short and to the point, yet extremely robust in terms of content, establish a baseline of underlying principles and concepts that they feel *all Americans* should understand. They include "Essential Principles and Fundamental Concepts for Atmospheric

Literacy", "Ocean Literacy: The Essential Principles of Ocean Sciences", "Climate Literacy: The Essentials Principles of Climate Science"," Earth Science Literacy Principles: The Big Ideas and Supporting Concepts of Earth Science" and "Energy Literacy: Essential Principles and Fundamental Concepts for Energy Education". These literacy documents represent frameworks from which to build, and the guidance required for developing GeoSTEM focused policy documents.

Embrace the Age of "Big Data"

Amazing earth observing programs have been developed since the launch of Sputnik in 1958. The Earth Observing System, which has a fleet of satellites gathering data and images from space, to National Ecological Observatory Network (NEON), a "continental-scale ecological observation system for examining critical ecological issues," to Earthscope, a 10 year program designed to gather seismic data from across North America, to US Integrated Ocean Observing System (IOOS), a "vital tool for tracking, predicting, managing, and adapting to changes in our ocean, coastal and Great Lakes environment," "Big Data" about the earth is becoming more and more available for classroom use. Dr. John Holdren, Assistant to President Obama and Director of the White House Office of Science and Technology Policy, in a statement addressing the issue of "Big Data" reported, "In the same way that the past Federal investments in the information-technology R&D led to dramatic advances in supercomputing and the creation of the internet, the initiative we are launching today promises to transform our ability to use Big Data for scientific discovery, environmental and biomedical research, education, and national security."

In 2010, the National Science Foundation Directorate for Geosciences unveiled its "EarthCube Initiative". EarthCube is the Geoscience Cyberinfrastructure prototype for NSF's Cyberinfrastructure Framework for 21st Century (CIF21) created in an effort to build a unified cyberinfrastructure framework for the geosciences. CIF21 is NSF's flagship effort for Big Data for the following reasons; (1) Cyberinfrastructure (CI) is part of the research fabric of Geosciences, (2) Geoscientists are sophisticated CI users and creators, (3) NSF and other agencies support substantial infrastructure and research that will form the foundation of Earth Cube, and (4) the Community is connected by the science as well as collegial relationships.

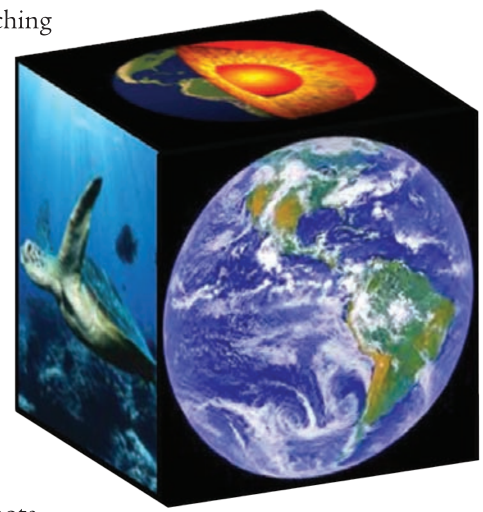

Figure 3. National Science Foundation Earth Cube

Source: NSF Directorate for Geosciences

From Big Data to GeoSTEM a picture of a new classroom laboratory emerges: The Remote Sensing Laboratory … Monitoring the Earth as a System. The Geosciences community explores the interdisciplinary sciences while studying the interactions of the Oceans – Earth – Atmosphere – Space thus meeting one of the criteria of STEM and clearly justifying the creation of GeoSTEM.

The "Next Generation Science Standards" recognizes the accessibility of Big Data for classroom use. This document states that "vast amounts of new data, especially from satellites, together with modern conceptual models, are revealing the complexity of the interacting systems that control the ever-changing surface. And many of the conclusions drawn from this science, along with some of the evidence from which they are drawn, are accessible to today's students" (A Framework for K-12 Science Education, pg. 170). GeoSTEM approaches, bridge from simple professional use of Big Data, to classroom use of Big Data.

Implementing GeoSTEM: The GeoSTEM Master Teacher Corps

The President's Council of Advisors for Science and Technology, and more recently President Obama himself, called for the development of a national "STEM Master Teacher Corps". The Geosciences community, through many existing programs in teacher professional development, can through the creation of a "*GeoSTEM* Master Teacher Corps" have the potential of developing teacher content and leadership that exists within the current community. These GeoSTEM Master

Teachers by bringing cutting edge content, introducing associated technologies, and student opportunities in America's future workforce, will enhance the "Geoscience Pipeline". The Geoscience Pipeline, a K-12 educational and workforce development approach, can also create opportunities for enhancing diversity within that pipeline as a major component of the strategy. It is about incorporating what the United States of America does best, establishing a pathway for innovation. GeoSTEM offers students the opportunity to participate in STEM, not just learn about it. GeoSTEM Master Teachers can guide students along the pathway toward their future. An ongoing GeoSTEM educational endeavor to engage teachers and students in an innovative study of Planet Earth from both earthbound and space borne perspectives using state-of-the-art technologies and educational resources is required. The Institute for Earth Observations at the Palmyra Cove Nature Park and Environmental Discovery Center in New Jersey has a work in progress, identifying the characteristics and potential requirements of a GeoSTEM Master Teacher and provides opportunities for teachers to acquire professional development and collaborate with one another in developing best practices and teacher leadership. A GeoSTEM Master Teachers Corp should possess a documented working knowledge and/ or experience(s) in the following areas:

1. STEM Policy, Geosciences Initiatives and Educational Frameworks
2. Established national and international programs with direct classroom applications
3. Advanced content in the Geosciences and/or Remote Sensing fields
4. Evidence of Leadership

The GeoSTEM Master Teacher should be able to provide evidence that he/she:

- expands the study of our planet through the use of remote sensing and geospatial technologies such as using real time data
- builds upon established Geoscience related field studies, observations, and measurements
- provides leadership for developing STEM (Science, Technology, Engineering, and Mathematics) applications in the classroom
- explores Geoscience career pathways for readiness in the 21st century workforce
- documents professional development for teachers through a series of topics that develop content, classroom applications, and leadership.

Figure 4. CubeSat Prepared for experimental operational test on NASA's Zero G Flight.

Source: John Moore

What Might GeoSTEM Look Like in the Classroom?

Twenty-five years ago a teacher and a small group of students outside of West Chester, PA, began a project to build a satellite receiving station at their school to capture Polar Orbiting Satellite Imagery for use in their classroom. Fast forward to 2012, students design and develop CubeSats, nano-satellites 10cm on each edge, which are launched into space as secondary payloads.

One such project, "Building, Launching, Utilizing, and Educating using CubeSats", BLUECUBE (Moore, J. and Simmons, K.), is stepping students through not only the Engineering process, but the Geoscience applications of the data as well.

According to Moore and Simmons, "We propose altering current educational practices by using CubeSats as a disruptive technology. Just as current scientific research reflects a new era of multidisciplinary studies,

so should the preparation of students reflect crosscutting experiences, knowledge, and critical thinking skills. CubeSats allow educators and students to experience authentic science, conduct relevant research, and acquire marketable skills for the 21st Century workforce. Research shows that students are better engaged by hands-on instruction and learn through experience. Project Based Learning and Systems Engineering allow students to apply the scientific and engineering methods to real world problem solving".

Figure 5 (left). BLUECUBE GeoSTEM Initiative Project

Source: BLUECUBE Project

Figure 6 (right). Peter Dorofy, John Moore, and Drexel University's Space Laboratory students collaborate with Professor Jin Kang Ph.D. in a High Altitude Balloon (HAB) Launch Project.

Source: John Moore

Expanding on proven past laboratory investigations, field work, and investigating the earth as a system, students have the opportunity to study the planet from the top-down, and the bottom-up, applying the Space to Earth: Earth to Space (SEES) Model (Moore, J). A recent "app" release called "SatCam" (University of Wisconsin's Space Science and Engineering Center) demonstrates this process to perfection. Tracking earth orbiting satellites based on a GPS reading from you iPad or iPhone, the app notifies the user of impending satellite passes, prompts the user to take a vertical view picture, horizontal (landscape) , and meteorological observations.

Once the observations are submitted, the satellite image with your marked location is included in your observation record. Therefore, students are making observations from the bottom-up and

Figure 7 (left). SatCam Image of California Coastline near Los Angeles

Source: Space Science and Engineering Center at the University of Wisconsin-Madison

Figure 8 (right). SatCam Image of New Jersey

Source: Space Science and Engineering Center at the University of Wisconsin-Madison

Figure 9. Drexel University HAB BalloonSat Imagery taken over Eastern Pennsylvania

Source: Drexel University Space Laboratory

receiving the top-down image. The notion that students can participate in scientific discovery outside the classroom, anywhere and anytime, gives a student the opportunity to explore the planet and develop personal interests around the planet, even at an international level, and exemplifies proposed strategies in both Science and STEM Education.

A Vision for the Future

Planet Earth will be monitored, observed, and studied as an Earth System, in real or near real time. Policy-makers, decision-makers, scientists, teachers, students, and citizens will not only participate in the process, but come to use such information and data routinely in their daily lives. 3-D data visualizations, virtual field trips, and interactive imagery from space all will contribute to the doing of real science in real time. Policy-Makers have linked STEM Education to our future economy and national security, the GeoSTEM community can deliver added value through leveraging current and future Geoscience-related resources that monitor our planet and protect the life and property of our citizens.

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Peter Dorofy is the Eastern Region Director of the National Earth Science Teachers Association. Peter teaches Geospatial Technologies, Earth Science, and Physics at the Burlington County Institute of Technology in New Jersey. He has a BS degree in Physics and is currently working towards a MS degree in Geosciences. Peter is an American Meteorological Society (AMS) DataStreme Education Resource Teacher as well as GLOBE certified. He also holds certifications in Geographical Information Systems and Remote Sensing. Peter was recognized as the NJ Teacher of the Year by the National Association of Geoscience Teachers and was recently selected as the American Meteorological Society K-12 Distinguished Educator of the Year. Peter can be reached at pdq72@optimum.net

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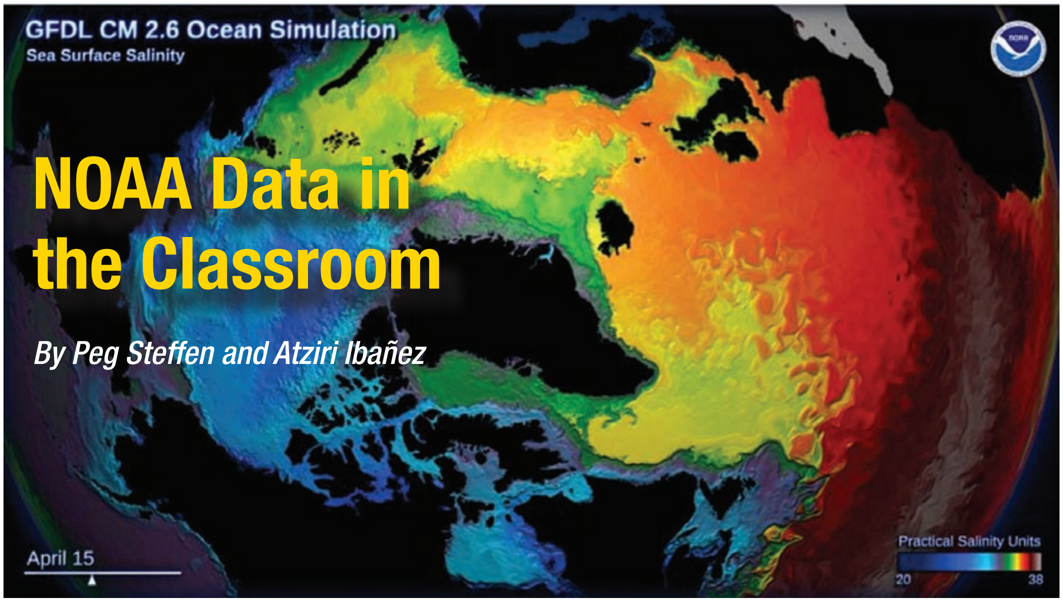

NOAA Data in the Classroom

By Peg Steffen and Atziri Ibañez

Figure 1. A snapshot of Arctic sea surface salinity from the Geophysical Fluid Dynamics Laboratory. This high resolution model - the model grid cells are all smaller than 5 km (3.1 miles) on a side in the Arctic region - produces a wealth of eddies, which play a role in transporting salt and heat in the ocean. The full animation depicts the day-by-day time evolution of sea surface and can be found at http://www.gfdl.noaa.gov/wcrp2011_poster_c37_dixon_th85b_movies

Abstract

The National Oceanic and Atmospheric Administration (NOAA) is a global leader in studying and communicating how the Earth's atmosphere and water systems influence people's lives and how they influence those systems. NOAA possesses an array of observing systems that monitor oceanic, atmospheric, and terrestrial parameters that can be used to teach STEM principles & concepts. Using historical and real-time scientific data offers exciting classroom teaching opportunities to study the processes and interactions of Planet Earth with an emphasis on observing, understanding, and predicting global environmental changes. Data-rich resources are available for project-based and problem-based learning investigations in the physical, earth and biological sciences, providing pathways for students to become informed planetary citizens.

Introduction

NOAA's education community works toward the development of an "environmentally literate public that has a fundamental understanding of the systems of the natural world, the relationships and interactions between the living and non-living environment, and the ability to understand and use scientific evidence to make informed decision regarding environmental issues". They are ready to take appropriate action in the event of severe weather and participate in the national debate on complex issues such as climate change. Scientific concepts of interactive Earth systems including ocean and climate literacy principles are important foundations to NOAA's work, providing data to a larger scientific community."http://www.education.noaa.gov/plan/09_NOAA_Educ_Strategic_Plan_Color.pdf. Many of these data sources can also be used in the classroom to provide students with opportunities to use the practices that scientists employ to investigate and build models and theories about the world, developing an understanding of the nature of science. The recent draft of the Next Generation Science Standards (http://www.nextgenscience.org) identifies science and engineering practices that mirror the practices of professional scientist and engineers. These include:

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data

Table 1. NOAA Data in the Classroom Modules

Topic	Research Question	Data
El Niño	People blame El Niño for all kinds of abnormal weather. But how does El Niño really work?	Sea Surface Temperature and the concentration of Chlorophyll-A
Sea Level	Researchers believe that sea level is rising worldwide. But how are water levels monitored and measured?	Sea Level height Tide levels Storm Surge height
Water Quality	How does water quality affect biological systems?	Water temperature Dissolved oxygen Salinity
Ocean Acidification	What is the impact of increasing carbon dioxide levels on ocean chemistry and marine systems?	Ocean pH Sea-surface temperature Carbon dioxide Carbonate saturation Marine calcifiers

Figure 2. NODE combines a system for accessing data with structured lesson plans that model the use of online data in the classroom. Four modules have been developed: El Niño, Sea Level, Water Quality and Ocean Acidification.

- Using mathematics, information and computer technology, and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Using NOAA data sources, the number of project and problem-based learning activities is limited only by the imagination of the educators and their students. A good introduction to the use of data sets is the **NOAA Ocean Data Education (NODE)** Project (http://www.dataintheclassroom.org). This multimedia program was developed for grades 5-8 to help teachers and students access and use real time scientific data (Table 1) to explore dynamic Earth processes and understand the impact of environmental events on a regional or global scale. Authentic research questions and scaled data interactions provide a stepped entry into accessing and using real-time data.

The NODE Curriculum incorporates a scaled approach to learning to facilitate a transfer of knowledge from one project to another. Entry and adoption levels are teacher-driven. However, they are important first steps when learning something new. The levels of adaptation through invention are more student-directed and open up opportunities to design lessons featuring student driven inquiry.

The Captain John Smith Chesapeake National Historic Trail extends 3,000 miles in the Chesapeake Bay watershed and highlights the exploratory voyages of this explorer in 1607-1609. Students can recreate a journey of their own with NOAA's **Chesapeake Bay Interpretive Buoy System (**Buoybay.org), a network of observing platforms (buoys) that collect meteorological, oceanographic, and water-quality data and relay that information using wireless technology to a variety of users. The latest data from key points up and down the Bay is available on the web, or by calling toll-free 877-BUOY-BAY. These "Smart Buoys" collect and transmit

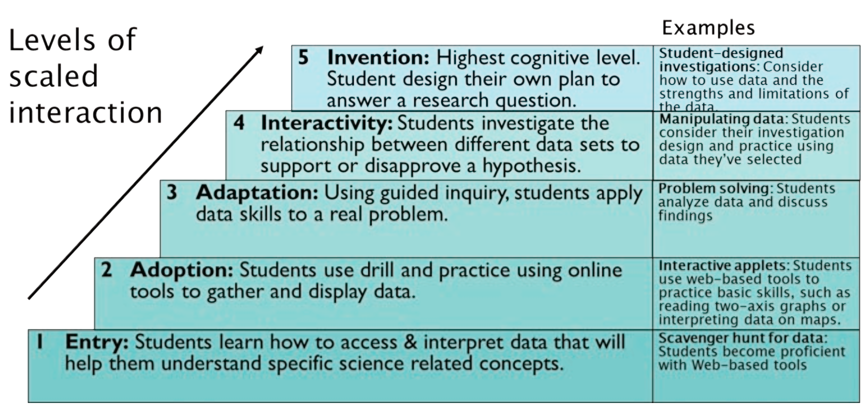

Figure 3. The NODE Curriculum incorporates five levels of interactions with data to facilitate a transfer of knowledge from one project to another.

Figure 4. Chesapeake Bay Interpretive Buoy System is a network of observing platforms (buoys) that collect meteorological, oceanographic, and water-quality data and relay that information using wireless technology to a variety of users.

Figure 5. Moored buoys, like this 10-meter buoy, are the weather sentinels of the sea. They are deployed in the coastal and offshore waters from the western Atlantic to the Pacific Ocean around Hawaii, and from the Bering Sea to the South Pacific. They measure and transmit barometric pressure; wind direction, speed, and gust; air and sea temperature; and wave energy spectra from which significant wave height, dominant wave period, and average wave period are derived.

24-7 real-time weather, water conditions, and water quality data, as well as interpret key points along the trail. Education activities and tutorials encourage student use of the data and include a data graphing option.

The **National Data Buoy Center** maintains approximately 60 moored buoys and 47 Coastal-Marine Automated Network Stations to collect marine atmospheric and oceanographic data in support of the National Weather Service's Warning and Forecast program. The buoys and stations are located around the United States in the deep ocean and coastal zones. The data collected include wind speed and direction, peak wind gusts, air temperature, sea surface temperature, barometric pressure, and wave height. They are transmitted hourly via Geostationary Operational Environmental Satellite (GOES) to the National Center for Environmental Prediction in Suitland, MD, and are available to marine weather forecasters within 30 minutes. The data are now available on the Internet and can be easily accessed and brought into the classroom. http://www.ndbc.noaa.gov. To view buoy and C-MAN station locations, select "Station Information" and then "Station Locations, Information, and Data." Students can "adopt" one or more stations and monitor the observations. The data can be used to track and understand local weather and to solve "real" meteorological and oceanographic problems.

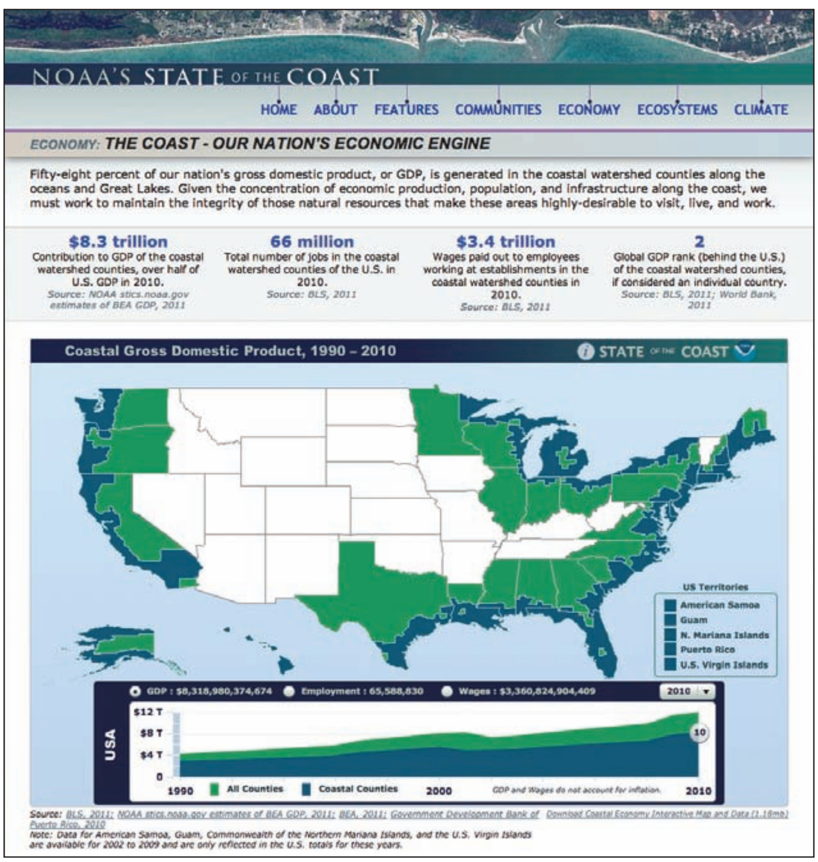

Figure 6. Given the concentration of economic production, population, and infrastructure along the coast, we must work to maintain the integrity of those natural resources that make these areas highly-desirable places in which to work, visit and live.

Within that narrow strip of land and water we call our coast, there is a nationally-significant story to tell. Our well-being as a nation depends on the benefits that flow from healthy coasts: food, clean water, jobs, recreation, and protection from hurricanes.

Facts, detailed statistics, data sets, and visualizations are provided at State of the Coast (http://stateofthecoast.noaa.gov/) and Digital Coast (http://www.csc.noaa.gov/digitalcoast/) highlighting what we know about coastal communities, coastal ecosystems, and about how climate change might impact these areas. Hydrographic, benthic, aerial, land cover and elevation data provide many avenues for science investigation. Interactive historical graphs of invasive species, nutrient pollution and hypoxia, chemical contaminants, water use and populations can serve as a springboard for projects about the complex connections of earth and human systems.

Sea level rise increases the risks coastal communities face from coastal hazards such as floods, storm surge, and chronic erosion. To assess local sea-level rise, NOAA maintains a National Water Level Observation Network of 200 stations throughout the United States. Using at least 30 years of data from 117 of these locations, NOAA analysts calculate relative sea-level trends. Students can access this data at http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml.

Professional Development Opportunities

The **Teachers on the Estuary** (TOTE) Program is a program of the National Estuarine Research Reserve System (NERRS - nerrs.noaa.gov) that offers field-based professional development for middle and high school teachers on watershed and estuary topics at Research Reserves. The program is designed to improve teachers' and students' understanding of the environment using local research examples to support the incorporation of estuary and watershed topics into classroom teaching. The course is also designed to promote stewardship of watersheds and estuaries. Four-day workshops give teachers an opportunity to work with local scientists and experienced coastal educators to explore coastal habitats and carry out field studies.

Figure 7. South Slough NERR operates an automated Campbell CR-10X meteorological station on the campus of the Oregon Institute of Marine Biology to provide continuous digital records of local weather conditions, storm events, and rainfall patterns. The station is located near the mouth of the South Slough estuary and records wind direction, velocity, air temperature, relative humidity, barometric pressure, precipitation, and photosynthetically active radiation.

A highlight of the TOTE training is an opportunity to learn about a series of activities (Estuaries 101 curriculum) that use near real-time and archived data from the System Wide Monitoring Program (SWMP). This coastal monitoring system is found at all 28 reserves, tracking short-term variability and long-term changes in estuarine waters. It monitors a suite of environmental parameters (abiotic, biological, watershed and land use) at more than 120 estuaries and coastal sites nationally, providing a baseline for measuring the health of the nation's estuaries. Students can use these high quality data sets to look at temporal patterns in temperature, salinity, dissolved oxygen, or turbidity, and can find trends over time. Teachers can use the data to make graphs illustrating concepts such as tidal cycles or diurnal cycles in dissolved oxygen and then have their students interpret the graphs. The curriculum activities are accompanied by a data exploration tool that allows teachers and students to compare and contrast near real time data with more than 10 years of water and weather quality data. All the Estuaries 101 Curriculum activities, including the data graphing tool, and tutorials, can be found on the estuaries.noaa.gov site.

A stewardship project is a crucial culminating activity for the TOTE workshop. Stewardship projects address a resource management need in the students' own watershed area; are student driven; include outreach to a broader community (beyond their own class); utilize knowledge or practice skills learned through TOTE training ; involve collaboration with a community organization or volunteer expert in the community. Details about these workshops can be found at http://estuaries.noaa.gov/Teachers/Default.aspx?ID=170.

The **Climate Stewards Education Project** provides opportunities for formal and informal educators to work with NOAA to better understand climate science and inspire our youth to pursue careers in science, technology, engineering, and mathematics (STEM). The program provides multiple opportunities for professional development through monthly webinars, special workshops at NSTA conferences, and summer regional workshops managed by six educators in the program who are regional leaders. The program is supported by an electronic learning community that allows educators to share their projects to actively involve students in problem solving, and stewardship projects. The program has been growing over the past two years and now includes over 130 educators from 40 states. The application season opens annually in late fall.

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Atziri Ibañez is the National Education Coordinator for NOAA's National Estuarine Research Reserve System (NERRS – nerrs.noaa.gov). Ms. Ibañez brings over 15 years of experience in the environmental education field, working with a broad range of student and adult audiences. Through-out her career she has focused on advancing water quality protection projects benefiting people in communities all the way from Panama, El Salvador, Mexico, and currently the United States. Realizing the challenges teachers faced to incorporate NOAA/NERRS online data in their classrooms; she led a study on teacher technology integration of ocean observing data which influenced the design of the NOAA Data in the Classroom modules and various other teacher ready-to-use resources. In her current position, Ms. Ibañez heads a national education program, implemented at 28 Research Reserves, located in 22 of the 35 U.S. coastal states, aimed at increasing estuarine literacy (estuaries.noaa.gov) and promoting the integration of coastal observing data, and other NOAA data, into a variety of classrooms and curricula across the nation. Atziri can be reached at atziri.ibanez@noaa.gov

Opening a Conversation about Spatial Thinking in Earth Science

By Kim A. Kastens and Michael J. Passow

Abstract

Spatial thinking is pervasive in the geosciences. The authors analyzed over 1000 items from recent New York State Earth Science Regents exams, and identified spatial concepts, representations, and/or skills in 63% of the items. This is the first of a series of articles discussing challenges in spatial thinking and suggesting teaching strategies suitable for middle and high school Earth Science courses. One skill on which students tend to fare relatively poorly when tested by Regents exams is crafting descriptions, explanations, or statements of evidence about geospatial phenomena. We suggest that students' observational and descriptive abilities will benefit from activities in which they identify and articulate the similarities and differences among multiple images that are similar at first glance but differ in geoscientifically-significant details.

Introduction: What is Spatial Thinking?

Spatial thinking is what we are doing when we derive meaning from the shape, size, orientation, position, direction, or trajectory of objects, processes or phenomena, or the relative positions in space of multiple objects, processes, or phenomena. Copernicus' inferences about the motion of the Earth relative to the Sun, Hutton's inferences about the gap in geological time recorded by the geometry of rock strata, and Wegener's inference about the motion of continents were great moments in spatial thinking. Spatial thinking pervades science in general and Earth Sciences in particular (National Research Council, 2006; Kastens& Ishikawa, 2006; Grossman, 2009).

And yet, "spatial thinking" is rarely mentioned in materials for either teachers or students of Earth Science. We think, however, that spatial thinking is abundant in Earth Science curricula--just not explicitly discussed. We have analyzed over 1000 test items spanning twelve recent New York State Earth Science Regents exams (http://www.nysedregents.org/earthscience/), and found that 63% of the items involve spatial representations (such as maps or profiles), spatial concepts (such as direction, size or shape), and/or spatial skills (such as envisioning what something would look like from different vantage points) (Kastens, et al, 2011).

This is the first of a series of articles that presents insights from our project on spatial thinking in middle and high school Earth Science. Each article briefly describes a pedagogical challenge that involves spatial thinking and then offers a teaching strategy that we think will help students with this challenge. The pedagogical challenges emerged from our analysis of Earth Science Regents Exams. The suggested strategies were developed through sessions with fifteen Earth Science teachers during 2011 – 2012 Earth2class workshops (http://www.earth2class.org/er/vc/) and subsequently tried out by those teachers in their own classrooms.

Challenge #1: Developing shared language for discourse about spatial phenomena

Our analysis of Regents exams shows that one spatial skill on which students perform poorly is to describe in their own words a spatial phenomenon or state evidence pertaining to a spatial concept. For example, given a drawing of a geological cross-section, students were asked to “Describe one piece of evidence from the cross-section that supports the inference that the fault is older than the basalt intrusion” (June 2010, q. 59). Whereas the average score on all Regents items in our test population was 68.4%, the average for items coded as “Describe/State Evidence” was only 62.2%. In another project, (Kastens and Shipley, unpublished data) one of the most dramatic differences between geoscience experts and novices when asked questions about geoscience data visualizations was that the experts invariably gave rich and nuanced descriptions of the data, while novices’ descriptions were sparse or non-existent.

These findings suggest that there is a needed, but often underdeveloped skill that involves making careful observations of spatial phenomena and articulating those observations in words. We and our students need to develop a common language with which to speak about spatial observations before we or they will be in a position to use such observations as evidence to build scientific claims about mechanism, process or causality. Sometimes, this is a matter of learning new technical vocabulary, such as “dendritic” or “angular unconformity.” But often it is a matter of learning to use non-technical (and perhaps unfamiliar) English words in a precise and rigorous way, for example:

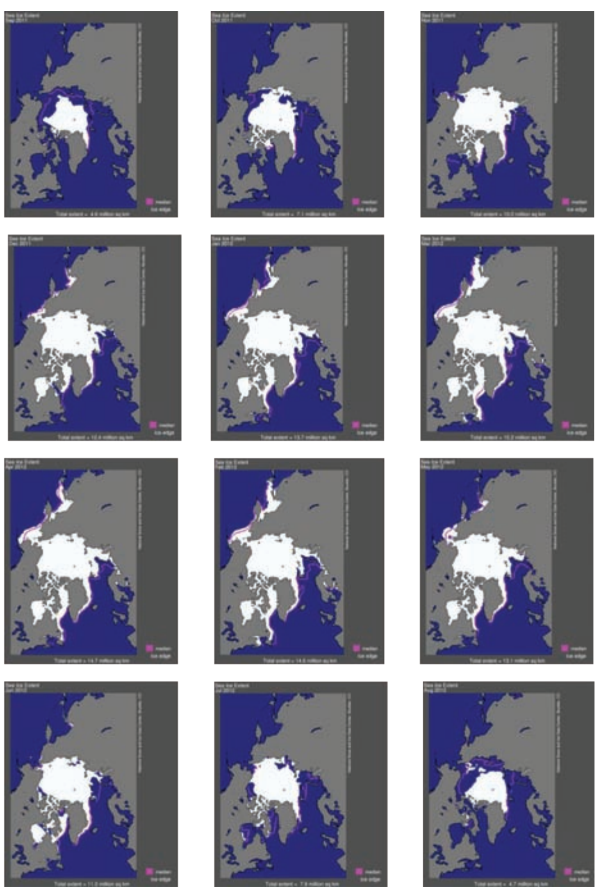


Figure 1. Monthly sea ice extent for the northern hemisphere, Sep 2011 – Aug 2012.

Source: National Snow and Ice Data Center (http://nsidc.org/data/seaice_index/archives/image_select.html)

- **Direction:** N/S/E/W, above/below, upstream/downstream, vertical/horizontal
- **Configuration:** above/below, adjacent to/ distant from, concentric/radial
- **Size:** larger/smaller; volume/area/length
- **Shape:** solid/hollow, angular/rounded, straight/curved
- **Motion:** towards/away from, trajectory, clockwise/ counterclockwise

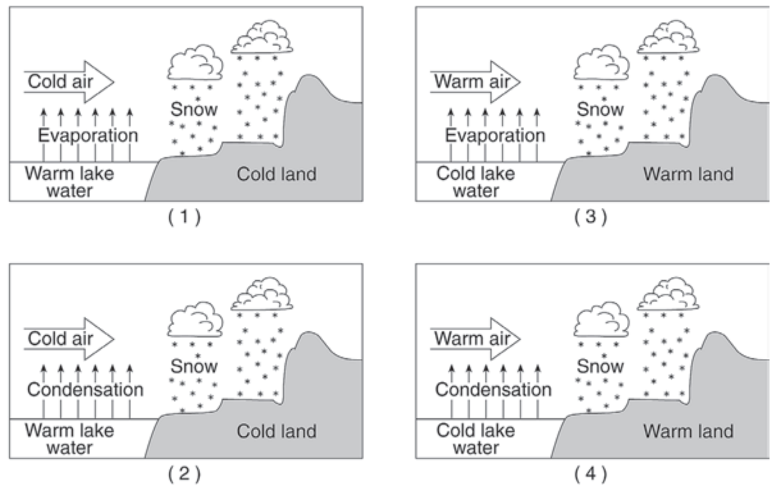
In either case, it is essential that students use terms in geospatial situations, not simply as part of a ‘scientific vocabulary set’ to be memorized. How can we guide students to do this?

Suggested Teaching Strategy: Compare and contrast small multiples

Graphic designer Edward Tufte (1990) coined the term “small multiples” for graphics that include multiple representations that are similar in overall appearance but differ in detail. Small multiples are often used to instruct and assess in Earth Science courses, and they are common in science graphics prepared for the public (figure 1). Interpreting such graphics requires the viewer to discern subtle but significant distinctions in spatial representations.

Our suggested teaching strategy is to have students identify and articulate similarities and differences among small multiples. We see this as a triple win: First, this activity can be fun, a variant on Spot-the-Difference puzzles. Secondly, students strengthen their Earth scientist's eye, their ability to detect geoscientifically significant but subtle details in visual representations. Thirdly, students strengthen their Earth scientist's language, as they grope for words to express the differences they have detected. Simply asking beginning Earth Science students to describe what they see in a geoscience visualization tends not to evoke much detail or insight, perhaps because they don't know what is significant. Providing multiple images telegraphs to students what is significant—it is those attributes that differ from image to image.

For example, in figure 2, students are asked to sort out the similarities and differences among four profile drawings showing the interactions of a lake, the adjacent land, and the overlying air. At first glance, similarities grab the eye, and the images look the same. But careful inspection reveals differences: is the land warmer or cooler than the adjacent lake? Is the lake water warmer or cooler than the overlying air mass? These differences are not arbitrary; they are, in fact, key factors in interpreting land/lake interactions. Detecting and articulating these differences primes students for an explanatory model building on these factors, and gives them language with which to discuss the system interactions depicted in the diagrams. Note the rich spatial language in the ideal answer of figure 2.



What do these images have in common?

- All of the images show a profile view of a coastline, with a lake on the left and land on the right.
- All of the images show the same topography on land, with lowlands near the lake and a mountain farther to the right.
- All of the images show snow falling from clouds above the coastal lowlands.
- All images have a large arrow over the lake pointing towards the land, indicating an air mass moving towards land.
- All images have a group of small arrows pointing upwards from the lake.

What are the differences among these images?

- In images 1 and 2, the lake water is warmer than the adjacent land, while in images 3 and 4 the lake water is colder than the land.
- In images 1 and 2, the air mass moving from the lake towards land is cooler than the underlying water, while in images 3 and 4 it is warmer.
- In images 1 and 3, the small arrows rising from the lake are labeled "evaporation", while in images 2 and 4 they are labeled "condensation."

Figure 2. These four small multiples were the answers to a multiple-choice item on the Regents exam of June 2010. In our suggested activity, students are asked to detect and articulate the similarities and differences among the images. Note the rich spatial language in the ideal answer presented here in Figure 2: "profile," "left/right," "near/farther," "above," "towards," "upwards," "adjacent," "underlying." (Note - Regents Exams from previous years are Public Domain)

Since one of the goals of the activity is to master spatial language, we recommend having students work in small groups, with lots of discussion encouraged. After small group work, the teacher should pull the class together as a whole to combine answers. This is the time to introduce technical vocabulary and more unusual spatial terms--after the concept has arisen from inspection of the diagrams and the need for the term is apparent. For example, in figure 3, the idealized student answer includes "....in a circle, one inside the other…"; *after* that concept is on the table in ordinary English, the term "concentric" will come across as a needed term for an observed Earth phenomenon, rather than as an arbitrary definition to be memorized.

This type of activity can be used on almost every topic in the Earth Science curriculum. It works for a variety of types of images, including empirical data (figure 1), conceptual process models

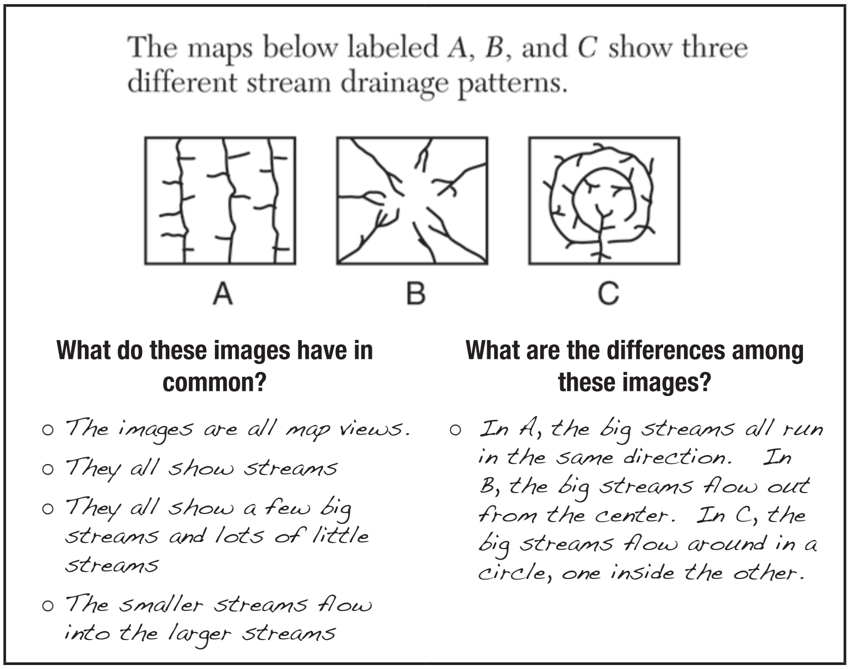


Figure 3. These small multiples appeared as answers to a multiple-choice item on the Regents exam of June 2010. We would encourage students to develop their ideas using their own choice of words (e.g. "around in a circle, one inside the other"), and then introduce the technical terms (e.g. "concentric") only after the need arises. (Note - Regents Exams from previous years are Public Domain)

(figure 2), and schematic representations of Earth observations (figure 3). We have assembled a collection of such activities based on items from the New York Regents Earth Science Exam, downloadable at: http://www.earth2class.org/er/vc/spatial%20thinking/SimilarDifferent%20worksheet.pdf. With repeated use and appropriate feedback, you should be rewarded by hearing your students articulate spatial evidence and spatial lines of reasoning in their discourse around Earth Science topics; in fact, they will have begun to speak and think like Earth Scientists.

Acknowledgements

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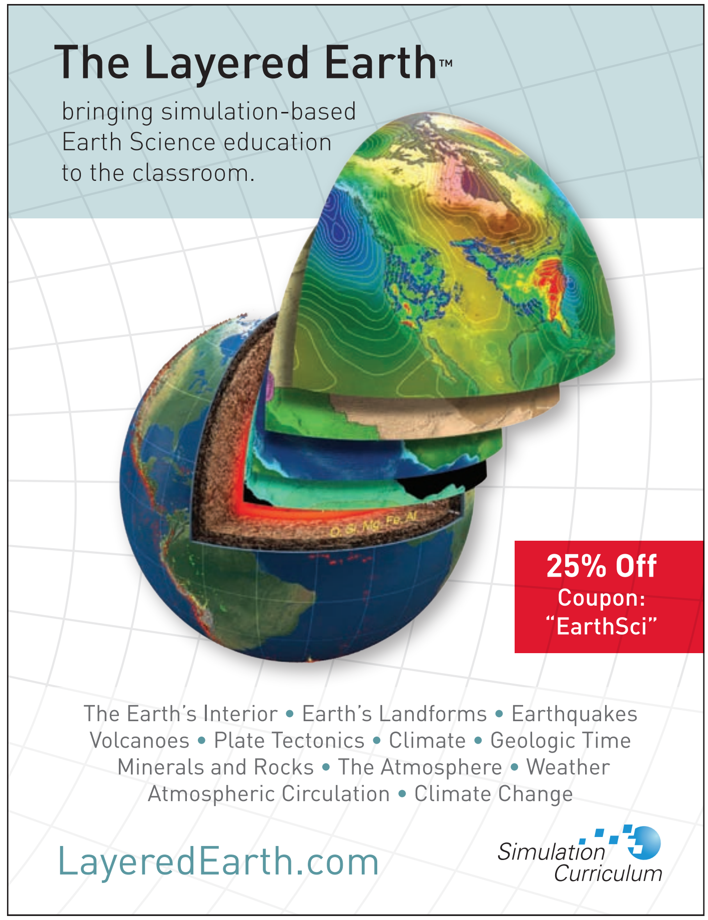

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