Data to Dome

The Science & Data Visualization Task Force

The ground beneath our feet: Earth sciences in the planetarium

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What topics belong inside a planetarium and what is beyond the scope of our mission? Are we limited to astronomy?

Imagine you were telling the "Story of Everything," from the big bang to modern society. This talk would cover any discipline between cosmology, astrophysics, on to geology, paleontology, biology, all the way to history and social sciences. At the end of the hour, you would wish for your audience to walk away with a sense of awe and a glimpse on how everything in the universe fits together with their own life. How far you can walk up this succession of scientific fields without violating your institution's mission is up to you.

This article looks at the prerequisites to successfully venture "off topic," reports some exemplary cases where this has been done, and encourages a fresh look at how we can make the most of our domes. We limit ourselves to earth sciences in this article to make the discussion a bit more manageable, though.

Why earth sciences?

How do geosciences (geophysics, geology, physical geography, oceanography, meteorology, climatology, glaciology) differ from astronomy when it comes to presenting them in a planetarium? We are primarily catering to a different set of viewer expectations, as some examples shall illustrate:

First, there is no prevailing orientation in the cosmos, yet we all have an overwhelming notion of up and down with regard to the ground we stand on. The Earth is layered; we distinguish the inner Earth, landmasses, oceans and the atmosphere. The most interesting stories develop around the boundary conditions between these realms.

The landmasses and, to some extent, the oceans are perceived as two-dimensional, while the other realms are three-dimensional. Therefore, orientation often is key to understanding geoscientific concepts. Tilted domes may have an advantage, since they allow "looking down on the ground" to where we expect things to be.

Second, audiences relate processes on our planet much more directly to their lives, which may make these topics visually challenging. There is no common preconception of what the center of the Milky Way should look like, but we have strong visual expectations towards anything from the outline of a world map down to the physical attributes of a common tree.

Interestingly, many non-astronomical programs in the past have established an artistic style as a technically-manageable visual convention (e.g., a comic style rendering), whereas only few astronomy program producers have felt the necessity to do the same.

Third, the multiple time scales at which geoscientific processes happen are short compared to the time scale of the cosmos. We directly compare geologic time to human time, comparing sea floor spreading rates to the growth of fingernails. We see our environment change just by watching the news, when natural disasters give relevance to climate change.

Fulldome time-lapse photography has a strong learning effect on audiences when they get a new temporal context for phenomena they know very well but rarely appreciate. For example, the accelerated motion of clouds reveals the stratification of the atmosphere.

How do we bring in the data?

The technological requirements for high quality geoscientific visualizations have taken about a decade longer to mature than the astronomical features of digital planetariums, and they still have to catch up.

With the release of Uniview 1.0 in 2005 from SCISS and initial releases of the Worldviewer software from Elumenati in 2009-2011, the capacity to show Earth at high levels of detail became available to fulldome planetariums. The explosion of information being returned from satellites and other remote sensing platforms has increased the availability of geospatial data highlighting any number of Earth phenomena (e.g., see Overpeck et al. 2011 for climate data).

Today, all major planetarium software packages include a high-resolution digital globe of varying degrees of realism. The ability to explore a 3D digital model of the Earth in the dome means that audiences are seeing a high-resolution, visually-compelling representation of Earth, an experience of which may trigger the Overview Effect, an affective response reported by astronauts who viewed Earth from orbit (White 1998).

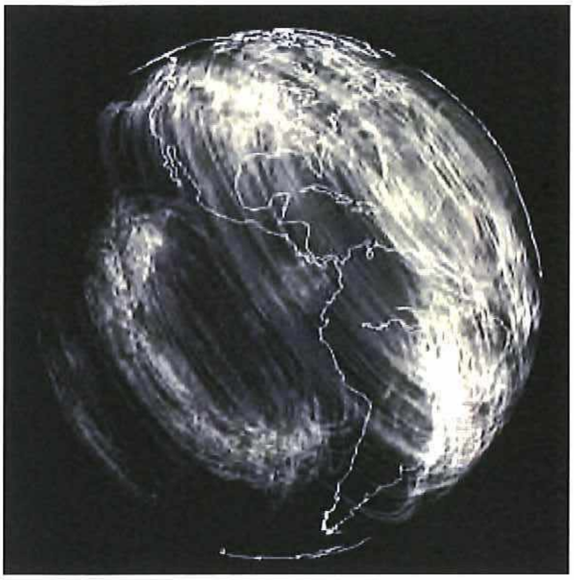
However, planetarium geobrowsers tend not to have as much functionality as the more widely available web-based software that was appearing for the public at the same time (e.g., Keyhole, which became Google Earth, Microsoft's Virtual Earth, NASA's World Wind).

But with minimal abilities to display geospatially-referenced datasets with KML (Keyhole Markup Language) files or to immerse viewers inside panoramic image "bubbles" or hemispherical all-sky images, a new range of educational storytelling opened up.

Beyond geomorphology

The next step is the representation of scientific findings beyond geomorphology. At the moment, most systems more or less neglect the ocean basins since their soft-

Digital Earth presentation with Dr. Bob Raynolds at the Denver Museum of Nature & Science in June 2008. Photo by Ka Chun Yu.



A rendering by M. Turk (Columbia University/NCSA, University of Illinois) made with "yt" of a SPECFEM simulation of the seismic wave field after an earthquake, by D. Peter (ETH Zurich). This rendering emphasizes the body waves. Image courtesy M. Turk.

ware architecture is built on the assumption that all features lie above sea level. Recently, Microsoft's WorldWide Telescope (Goodman et al., 2012) has introduced a number of valuable additions, such as import of local high-resolution terrain, georeferenced placement of 3D models and visualization of subsurface phenomena.

Planetarium theaters now have the opportunity to focus their gaze down towards the Earth as opposed to up towards the sky, reflected best in a new catch-phrase from California Academy of Science's Morrison Planetarium, "We put the planet in planetarium." Let us have a look at how a successful canon of programs can be developed around Earth science topics.

Climate and global change with digital planetariums

The Denver Museum of Nature & Science (DMNS) was one of the first institutions to develop visitor programs with a live presenter that relied on geobrowser capabilities. Equipped with SCISS' Uniview, DMNS worked with Kenji Williams on *Gaia Journeys* in 2007 (which later evolved into Williams' *Bella Gaia*), a program that combined live music and Earth visuals (Yu et al. 2009; www.bellagaia.com).

After a handful of pilot tests in 2007, DMNS began offering a regular bi-monthly live evening lecture series titled *Digital Earth*. Because gross Earth surface features were easily seen in Landsat imagery available from remote WMS (web mapping service) servers, many of the initial *Digital Earth* topics focused on geography, geology, and natural history. However, given the expertise and interests of the presenters, there were an increasing number of talks on Earth systems and global environmental change.

These presentations often reflected on global change's impact on humans, as well as the role of human activity in exacerbating such change. Thus, for topics related to freshwater availability, wildfires, and the state of forests, *Digital Earth* presentations highlighted the way that climate and other human-induced change can, respectively, alter precipitation and snowpack patterns, increase the likelihood of droughts and frequencies of fires, and foster the growth of species like mountain pine beetles that are destroying the western forests of North America.

Evaluations and follow-up interviews showed that these programs had substantial impact on attendees. Visitors were impressed by the immersive and real-time nature of the talks, reflecting that the same presentation on a flat screen would not be as enjoyable (Yu 2009). Interest in a topic was heightened for weeks or months after the presentation, which inspired many to learn more on their own (Yu et al. 2010).

Going beyond highlighting the impacts of global change, the Worldviews Network (Yu et al. 2012) takes live planetarium programs one step further to foster dialogues with audiences about how they can be engaged with ecological issues.

The Network is a collaboration between DMNS, the California Academy of Sciences (the Academy), NOVA/WGBH, the design and engineering firm The Elumenati, and the U.S. National Oceanic and Atmospheric Administration (NOAA) Climate Program Office, with funding from NOAA's Office of Education. Informal science institution partners across the U.S. engage with the Network to develop stories that connect audiences with ecological and biodiversity issues at the local level.

The Network core team works via a one-on-one professional development strategy with staff from a partner planetarium to identify a global change issue that has local impacts, and then to create a narrative with the help of external advisers and experts on this selected topic.

These narratives take advantage of planetarium visualization software's capacity to span cosmic, global, and local perspectives, and to use geospatial datasets to intuitively link the relationships between Earth systems at multiple scales. Although the dome presentations often highlight how ecosystems can be disrupted by human activity, the lecture and the follow-up dialog always emphasize themes of resilience of human communities and natural systems.

By inviting outside experts and advisers into the discussion, audience members are introduced to inspirational solutions to bioregional problems. Discussions often pivot around how the public can remain involved in resolving the identified problems.

The stories that have been created through the Worldviews Network have been collected on its website (www.worldviews.net) as freely available resources for use by the informal

Visualizations from the program *Supervolcanoes*, top: Formation of the Siberian Traps by a broad plume of rising magma pushing toward the surface. Below: A cutaway animation of Grand Prismatic Spring in Yellowstone National Park, a natural hot water spring sustained by the activity of the Yellowstone mantle plume. Both images courtesy Spitz Inc./Thomas Lucas Productions/DMNS.

science education community. In addition to links to external URLs for additional information for a topic, each event page contains storyboards, narratives, instructional videos, and links to datasets used in the presentation.

Inspired in part by DMNS' *Digital Earth* and Worldviews Network presentations and dialogues, the California Academy of Sciences has been running its live monthly *Earth Update* program in Morrison Planetarium since 2010. Although the initial focus was on news from climate and global change science, the program has evolved into one that highlights the work and activities of researchers at the Academy's Institute for Biodiversity Science and Sustainability, without downplaying the effects of global change.

Again following a Worldviews Network model of showing Earth in its cosmic context, *Earth Update* stories typically start by traveling to various locations in the solar system to emphasize that Earth is the only body to have a biosphere capable of supporting human life. The research stories have covered broad topics such as conservation, biogeography, oceans, and human evolution, as well as more focused natural history topics including ants, spiders, sharks, amphibian decline, and beetle impacts on forests.

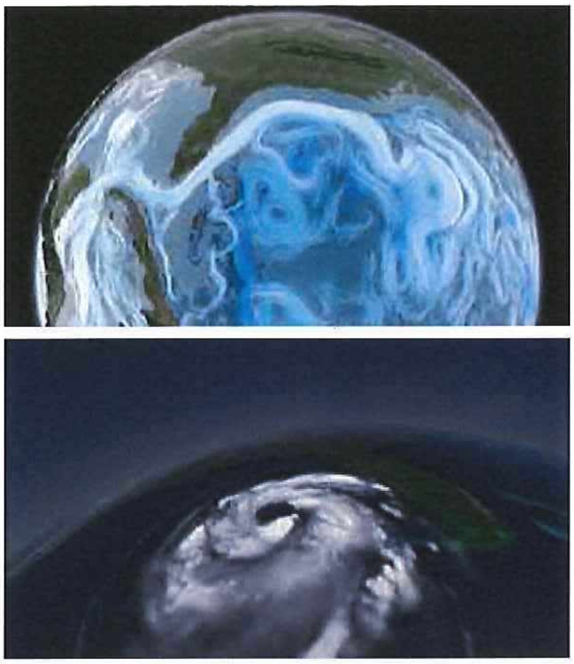
As a live program, it allows presenters to show the most current datasets. In June 2013, shipping lane routes which funnel traffic into San Francisco Bay were updated to minimize the chance of ship strikes between migrating cetaceans and cargo transports. The revised maps were shown to the public in an *Earth Update* program on whales soon after the new maritime rules came into effect, allowing Academy visitors to learn not only about human impact on marine mammals, but ways in which society is mitigating these problems.

Finally, *Earth Update* has highlighted the work of citizen scientists at the Academy and elsewhere. Many citizen science programs involve volunteers using their smart phones to geotag the locations of wildlife they have observed to track changing distributions of species from habitat loss, climate change, or (in the case of invasive species) accidental introduction.

Citizen science groups have had the opportunity to see their collective work visualized on the dome, turning Morrison Planetarium into a display for exploring biodiversity data for a mass audience.

Seismology on the dome

The SeismoDome project, at the Hayden Planetarium in New York City, is aiming to bring to the dome screen an immersive exploration of earthquakes: what they are, how they shape the Earth, where they come from, and how we might be able to predict them—and, more to the point, why it's hard to do so!



From the program Dynamic Earth, (top) a visualization of ocean currents and (bottom) Hurrican Katrina by NASA's Scientific Visualization Studio. Both images courtesy Spitz Inc./Thomas Lucas Productions/DMNS.

The California Academy of Sciences and Morrison Planetarium developed and debuted a pre-rendered show on a similar topic last year. The SeismoDome project is designed to be more interactive and less formal, and will only be presented a few times at first.

Scientists from the Lamont-Doherty Earth Observatory, collaborating with visualization experts at the American Museum of Natural History, have developed a show concept that ties together both visual representations, as displayed on the dome, and audio representations of earthquakes.

The centerpiece of the show is a series of visualizations and sonifications of simulations of earthquakes. The simulations, conducted by seismologists from Princeton and elsewhere, show the propagation of waves throughout Earth from the epicenter.

The Earth itself is discretized as cubical zones (with a different discretization used where higher accuracy is needed) when the data is visualized, which contains information about the total displacement of each zone of the simulation from its rest position.

By visualizing this total displacement using volume rendering techniques, the two primary types of waves that result from an earthquake can be displayed. The slower, more evocative type—surface waves—are typically of higher total displacement, and they ripple over the surface of the Earth, focusing at the antipode and generating "wave trains" that—to quote one of the show designers—ring the planet like a bell.

The other class of waves, those that primarily transmit through the body of the planet, are typically of lower displacement and are much more difficult to effectively visualize. These waves, emerging from the epicenter, immediately reflect off the core of the Earth and form complex interference patterns in the hemisphere in which they originate. Simultaneously, they move through the body of the Earth and focus at the other side, causing large scale interference patterns that pulse and move through the body of the planet.

Simultaneously displaying both of these types of waves is challenging, and in many ways becomes more challenging when inside the dome. Typical volume rendering techniques often result in visual confusion, particularly in the dome, where contrast and color must be carefully managed. And, while the location of each class of wave is localized, the spectrum of displacements is continuous—there is no sharp cutoff where the types of waves transition, one to the other. Attempting to distinguish them thusly can lead to misinterpretations of the data.

While this is going on, sonifications of the waves themselves, sped up enormously over the two- or three-hour timescale of the simulation, share a visceral experience of the earthquake with the viewers. The visual cues, of wave field propagation and magnitude, combine with the subconscious cues of interference patterns and beats from the sonification to describe what's happening to the Earth. The visual and aural cues together give much greater detail than could be done by either one alone.

Viewpoints are challenging

Choosing viewpoints can be challenging as well. While it's natural to situate the viewer at the center of the Earth (such that the dome represents the surface of the planet), this makes it much harder to distinguish between the surface and body waves, as well as providing something of a disorienting experience as the continents are presented backwards. However, in combination with the sonification, the speaker locations in the dome can be tightly correlated with the location of the virtual seismometers that provide input to the sonifications, and so this is a compelling viewpoint.

For contextualization, and a better understanding of the body waves, the visualization pulls back and presents Earth floating in space, in what is jokingly referred to as "moon view."

But what about *my* planetarium?

The significance of a topic in the fulldome planetarium world can be measured by how many pre-recorded programs have been developed on it. Global change may have enjoyed priority in the adaptation by the planetarium world since it is one of the most rapidly evolving geoscientific phenomena and is even of political significance.

To name just a few productions, think of *Our Living Climate* by Melbourne Planetarium, *Ice Worlds* by E&S, *Climate Change* by Albedo Fulldome or *Dynamic Earth* by Spitz/Thomas Lucas Productions. On to geology and geophysics, the California Academy of Sciences has produced *Earthquake*, a show on the local tectonic regime of the Bay Area and seismic activity in general. This was a clearly non-astronomical project that was largely justified by their own local earthquake threat.

DMNS has been a co-producer of *Supervolcanoes*, a show that ran in parallel with a local exhibition on volcanology. *Dinosaurs at Dusk* by Mirage 3D covers aspects of paleontology, and the majority of their very successful programs treat topics of non-astronomical natural history.

Yet the projects mentioned so far all have been supported by big institutions with large budgets and agendas. What about smaller initiatives? Prerecorded shows are a good way to test the acceptance of a careful "rebranding" of your institution from a star theatre to a science theatre, keeping in-house efforts low.

Yet the gold standard should be the live presentation and interactive audience engagement. It should not be underestimated that a successful live program on a non-astronomical topic requires substantial knowledge by the presenter.

We may need programs for capacity building and a way to test in advance whether the effort will be well received. Spitz and the Simulation Curriculum Corporation have developed a full earth science curriculum aptly called The Layered Earth which provides classroom activities and educational material that blend with Scidome fulldome visualizations.

Freeware and hardware independent, yet technically a bit more challenging, World-Wide Telescope offers similarly scalable functionality, including an online platform to share and jointly develop real time modules and form partnerships on any level. The data behind the Worldviews programs is also publicly available on the web.

How will geosciences become an integral topic of our trade? Fulldome cosmology teaching only truly got off the ground through the Digital Universe Atlas (the standard toolbox of datasets compiled at AMNH), its first commercial incarnation as Uniview, its demos and success stories, and the adaptation by other vendors because everyone asked for it.

Need a common data standard

Such an effort has not yet been made for the geosciences. Individual institutions and companies work on isolated showcases and features, accessing different proprietary servers for data. The breakthrough data compilation could once more be stemmed by one entity, but alternatively it could be a group effort of institutions adhering to a common data standard that is fully supported by at least one fulldome system.

An informal survey among existing systems shows that, at the moment, KML (known from Google Earth) does not qualify as such a standard.

We envision a tour of our planet the same way we have come to enjoy the standard magic carpet ride out to the cosmic microwave background coined by Carter Emmart of AMNH: Start out in your home town, zoom out into orbit and let the seasons change over your part of the world. Maybe include a hurricane simulation. While you are at it, zoom out a bit more, talk about ice ages and show the waxing and waning of polar ice caps and pack ice. Notice the rise and fall of the sea level.

By now you have raised the point that throughout the quaternary, sea level change mostly affects the continental shelves. Dive into the ocean, talk about how 71% of our planet's surface is covered by water, and why oceanic crust is fundamentally different from continental crust.

Show 3D seismic interpretations, and explain the conveyor-belt-like movement of oceanic crust from the mid-ocean ridges to subduction zones. Have ocean islands burn their way through the crust, leaving tracks of seamounts.

Reveal the convection of the upper mantle as a driving mechanism of plate tectonics and run a paleogeographic reconstruction. Close with the stratification of the Earth by hinting at seismic tomography, how our planet differentiated and how the moon was formed. Get back home, moving fast forward in time.

More or less, you just told the second part of the "Story of Everything."

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