# State of

# Climate Visualization

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Centrum för klimatpolitisk forskning
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# Editorial

## State of Climate Visualization – international research and practical applications

Tina-Simone S Neset, Jimmy Johansson and Björn-Ola Linnér

In a time of global change and global resource constraints the academic community is constantly seeking new ways of communicating current research to inform the public and create a basis for decision making on an individual to global scale. For climate researchers, this challenge is pertinent, given the vast amount of information regarding issues, such as emissions, scenarios, trends, risks and options for mitigation and adaptation that flows through media every day. To create a solid representation of research data and scenarios as well as what impacts of climate change could imply in different regions, climate researchers have over the past years started to collaborate with designers and researchers within the field of visualization. Applications assisting data analysis as well as geospatial and abstract visual representations bear great potential for future research and science communication. We are referring to this transdisciplinary field of research and science communication as *climate visualization*.

Visualization has for many years been used as a tool in climate system and impact research for communicating results between scientists themselves as well as to a broader public through e.g. web-based interfaces and portals and applications of Geographical Information Systems (GIS). Developments over the last ten years have put new demands on climate visualization for three reasons: 1) The enormous development of computer power and graphics can be used to convey the vast amount of information on climate processes and its effects as well as the associated complexities and uncertainties. 2) The need to analyse climate change linkages with other areas in science is increasingly recognized in the scientific community (IPCC 2007, Linnér, 2007). Further, in international negotiations and cooperation, climate change has increasingly been linked to other areas of sustainable development. Visualization will facilitate to demonstrate these linkages. 3) The interactive potential of visualization methods and techniques has increased substantially. Adapting them to the needs of climate change research may significantly assist in analysing and communicating interlinkages, complexity and scientific uncertainties. In a survey of on-going climate visualization initiatives, Nocke et al. (2008) conclude that "recent developments in interactive visualization using alternative visual metaphors are not wide-spread in the climate community. Thus, a major task for future developments is to further bridge the gap between climate and visualization expertise ".

The concept *climate visualization* refers to interactive research platforms, which use computer graphics to create visual images of causes and effects of climate change as well as mitigation and adaptation options. Major challenges are scientific visualization of complex interlinkages between numerous phenomena in nature as well as in society, interrelations across vertical scales over time, substantial uncertainty of feed back mechanisms and often massive numerical representation of scientific results.

These challenges were addressed at a conference on Climate Visualization, which was held in May 2009 at Campus Norrköping of Linköping University, as a co-operation between the

Norrköping Visualization Centre and the Centre for Climate Science and Policy Research. These are the proceedings from this conference presenting both the outline of talks and ongoing discussions in workshops. They display a wide variety of both conceptual approaches and concrete applications. The conceptual contributions show how worldviews are influenced by the visual surrounding (McConville), how visual representations in terms of graphic design are perceived by the user (Simmon) and how scales influence the areas of application of visualization tools for interdisciplinary research (Neset&Glad).

A key challenge facing environmental research and management is to widen public participation; to strengthen consultation on how problems are framed and to contextualize action alternatives as well as to improve the information dissemination process once decisions have been made. Burch and colleagues have analyzed how scientific visualization can increase public knowledge on climate change. Concrete applications of climate visualization are presented in this report by Shalini and Spadaro (Global Adaptation Atlas), Kirk and colleagues at KlimaCampus in Hamburg (Planet Simulator), Irving and Hamilton (Effects of Climate Change on Biodiversity for Public presentations), Gardiner (Sustained Programs for Climate Communication) and Sweitzer (Visualizing an Inconvenient Truth).

Climate visualization is rapidly expanding in three areas: visualization as an analytical tool, as a communication tool and on the epistemological consequences of visualization. Efforts to develop new tools for analysis include visualization techniques that are developed to support, for instance, research on climate policy implications on global land use and resources flows where the emphasis lies on a transdisciplinary approach involving researchers of the visualization and climate community as well as public stakeholders, planners and policy makers. The research focuses among others on visualization of abstract, multiparameter, time-dependant data as well as on linkages between and intra-linkages within natural systems, such as interactions between climate and the biological systems, between natural systems and policies and measures, e.g. consequences of climate policy on forestry.

Another strand of climate visualization research is the evaluation of visual representations. Through reflexive studies critical questions are raised on cognitive and power implications of visualization tools. How is the visualised phenomena selected and how do these choices effect representation of climate change and policy options? Reflexive visualization studies also entail analysis of post process data and modelling results used in secondary visualization applications. Also, interactivity is not inherent by default but needs analyses and evaluation of what is communicated and how it is perceived. User interaction is an important feature in visualization (Kosara et al 2003). Using a fully interactive system can enable flexible and task-specific analysis. For such interactive systems, limitations in human perception, such as change- and inattention-blindness, have to be considered.

The high-level declaration of the 3rd World Climate Conference held in September 2009 in Geneva called for ‘‘a Global Framework for Climate Services’’ which will “strengthen production, availability, delivery and application of science-based climate prediction and services” (WCC 2009). The overview of ongoing climate visualization research and development provided by the Norrköping conference indicate that this field is rapidly developing. By developing interactive climate visualization platforms it is possible to ensure the availability of climate services such as called for by the World Climate Conference, both in immersive environments and on desktop computers, which may provide one important contribution to climate services.

A first effort in disseminating climate visualization to decision makers and other stakeholders, as well as the general public, the Worldview network has during 2009 developed visualization presentations to be used at important political events in the US, within the EU as well as at the

Conference of Parties to the United Nations Framework Convention on Climate Change. These productions are based on existing software and represent geospatial data for emission on the basis of which principles for effort sharing in terms of historical responsibility, national and per capita emissions can be discussed with the audience in an interactive session. The presentations focus further on regional climate models, arctic sea ice level, sea level rise and future emission scenarios following a narrative of policy and IPCC scenarios.

The proceedings from the visualization conference provide examples from all of these three challenges for climate visualization. Although a few renowned colleagues did not have the possibility to attend the workshop as planned, the contributors to this publication represent several leading initiatives in this field. We hope that it will provide the reader with an overview of the development of climate visualization and that it will stimulate further discussions and new initiatives to collaborate on climate visualization.

## References

IPCC (2007). *Climate Change 2007: Mitigation of Climate Change.* Contribution of Working Group III to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change.

Kosara et al (2003). *An Interaction View on Information Visualization*. Proceedings of EUROGRAPHICS 2003.

Linnér, B-O (2006), Authority Through Synergism: the Roles of Climate Change Linkages. *European Environment*, 16(5), pp. 278–289.

Nocke, T.; Sterzel, T.; Böttinger, M.; Wrobel, M. (2008). Visualisation of Climate and Climate Change Data: An Overview, in Ehlers et al. (Eds.) *Digital Earth Summit on Geoinformatics 2008: Tools for Global Change Research* (ISDE'08), Wichmann, Heidelberg , pp. 226–232.

WCC (2009). *High-level Declaration,* World Climate Conference 3. Geneva, Switzerland, 2009.

# Visualizing Worldviews:
## Shifting Perspectives on Global Change

David McConville

1

## Abstract

This essay encourages a reflective approach to communicating the urgency of global change issues. Recognizing that multiple factors shape personal intuitions and interpretations of the world, it seeks to highlight some of the entrenched paradigmatic assumptions that continue to reinforce misperceptions about humanity's relationships to the natural world. Multiple critiques of how these misperceptions arise are summarized, and alternate proposals that encourage expanded comprehension of the integral role played by humans within nested ecosystems are considered. It concludes with a description of a communication strategy based on literal and metaphorical interpretations of the term "worldview," employing immersive scientific visualizations to experientially expand perspectives on these critical issues.

## Introduction

As recognition of the complexities of accelerating global changes has increased, so too has the acute relevance of questions concerning interconnections between individual actions, socioeconomic structures, and processes of the natural world. Though scientific understanding regarding the dynamics of these relationships on a global scale has progressed, effective means of communicating them to the public and decision makers to affect behavior changes remain elusive. But even if successful approaches to enhancing scientific literacy are identified, one recent study suggests that they can sometimes induce the opposite of the desired effect, leading to a diminished sense of personal responsibility while increasing faith in an eventual technological panacea (Kellstedt et al, 2008).

This essay encourages a more reflective approach to communicating the urgency of global change issues. Recognizing that multiple factors shape personal intuitions and interpretations of the world, it seeks to highlight some of the entrenched paradigmatic assumptions that continue to reinforce misperceptions about humanity's relationships to the natural world. Multiple critiques of how these misperceptions arise are summarized, and alternate proposals that encourage expanded comprehension of the integral role played by humans within nested ecosystems are considered. It concludes with a description of a communication strategy based on literal and metaphorical interpretations of the term “worldview,” employing immersive scientific visualizations to experientially expand perspectives on these critical issues.

## Illuminating Worldviews

The term *worldview* is calqued from *Weltanschauung*, coined by Immanuel Kant (1987) in the late 18th century. His single use of the term described the literal “view” or “intuition” of the world that is provided by human sensory perceptions, particularly the sense of vision. Kant asserted that the “mere appearance” of things provides a limited impression of the nature of reality. To account for the capacity of humans to conceive of the infinite, he contended that the mind “must have within itself a power that is supersensible.” By dividing the human experience into perceptual and conceptual domains, he was attempting to rectify what he viewed as a contradiction between the world-intuition informed by finite sensual experiences and the seemingly limitless capacity of the imagination.

The degree to which embodied senses influence perspectives on the world is widely recognized as they are inextricably linked to perception. As Kant suggested, the physiological construction of the senses necessarily limits the range of perceived phenomena, shaping experiences through finite spatial, temporal, and spectral impressions of the world. In the case of vision, the eyes serve as biological transducers that detect and respond to electromagnetic radiation in the wavelengths of the visible spectrum. These stimuli are then converted into chemically mediated signals that the nervous system can perceive and transmit, which are interpreted as “external” visual-spatial events. These sensory experiences undoubtedly provide the strongest intuitions on the nature of reality, as is evidenced by the close connection between scientific advancements and the development of devices that enable empirical observation of phenomena at scales beyond unaided perception.

Since its original use, the concept of *worldview* has largely lost its original association with sensory perception. It is commonly used as a metaphor to describe the conceptual lens or “mental map” of an individual or group, comprised of the cognitive, practical, and emotional frames of reference through which experiences are interpreted. This map is said to enable us to “integrate everything we know about the world and ourselves into a global picture, one that illuminates reality as it is presented to us within a certain culture” (Aerts, et al., 1994). It is frequently used interchangeably with terms such as *perspective* (Esbjörn-Hargens & Zimmerman, 2009), *cosmology*, *outlook*, *world picture*, *knowledge space* (Turnbull, 2000), and *paradigm* (Kuhn, 1962) to outline qualitative and cultural developmental models that emerge from specific assumptions, beliefs, and customs.

In addition to perceptual and conceptual influences, there is expanding recognition within contemporary cognitive sciences that *enaction* plays a significant role in the shaping of experience (Varela et al, 1992). In contrast to the objectivist view that perception is the result of purely passive reception of sensory information, enactive theory holds that perception is inexorably tied to reflexive and iterative processes. This constitutive position asserts that, consciously or not, reciprocation, iteration, and participation are integral to perceptual experience, shaped by the agency of the percipient as well as the biological and sociocultural systems within which they occur.

## Constructing Perception

Questions regarding the exact relationship between observers and the world have been central to the development of Western science and philosophy. The notion of the “objective observer,” in which a percipient is assumed to passively witness an external reality that is ontologically independent, is deeply ingrained within Western thought and discourse. Critics have attributed this dualistic separation to a number of historical influences, frequently asserting that the polarization it reinforces leads to an array of misperceptions. David Abrams (1996) contends that the widespread adoption of the phonetic alphabet in ancient Greece led to a domination of abstract referents that severed the intimate connection between the human and non-human natural realms. He argues that this separation weakened the sensitivity of oral cultures to the rhythms and inflections of local environments, diminishing the perceived importance of participation within sensuous experience. In contrast, Alfred Korzybski (1933) maintains that *all* experiences are constructed of different orders of abstraction, whether communicated through sensory perceptions or the structures of language. However, he asserts that false dichotomies have been imposed on perceptions of the world by the continued application of Aristotle's mutually exclusive "either/or" logic that is deeply imbedded within Western thought. Francisco Varela et al. (1992) further connect the binary compulsion to the emergence of what they call "Cartesian anxiety," suggesting that failed attempts to identify the "ultimate ground" of reality – the driving quest behind reductionist science – inevitably leads to nihilism.

While these linguistic and conceptual factors undoubtedly encourage abstract, binary tendencies, the most intrinsic influences on the formulation of the idealized "objective observer" may well have been the optical instruments that imposed specific technical configurations on acts of observation. For instance, the developments of the telescope and microscope in the 17th century gave rise to new visions and conceptions of a natural world, expanding capabilities to visually scrutinize phenomena at macro and micro scales. But while these enabled a series of revolutionary revelations, including Galileo Galilei's empirical confirmation of the de-centering Copernican cosmology and Antony van Leeuwenhoek's discovery of microorganisms, they bolstered the impression that nature exists independent of human experience.

The perception of an inexorable separation between subject and object was further strengthened by the widespread adoption of what Johannes Kepler termed the *camera obscura*. Latin for "dark room," this device displayed reflections of outdoor images onto indoor surfaces via a tiny aperture in a separating wall (Figure 1). Though its discovery predated the scientific revolution by several centuries (the underlying phenomena had first been described in ancient Greece and later within Alhazen's 11th century *Book of Optics*), it was widely employed from the late 17th century on as a tool for assisting with the study and re-presentation of the "exterior" world. Furthermore, variations on the camera obscura utilizing optics are believed to have been critical in the establishment of single-point linear perspective. This enabled artists to trace a scene projected onto a flat canvas to create the illusion of three-dimensionality on a two-dimensional surface, effectively freezing a fixed view of a seemingly objective world within a representational window.

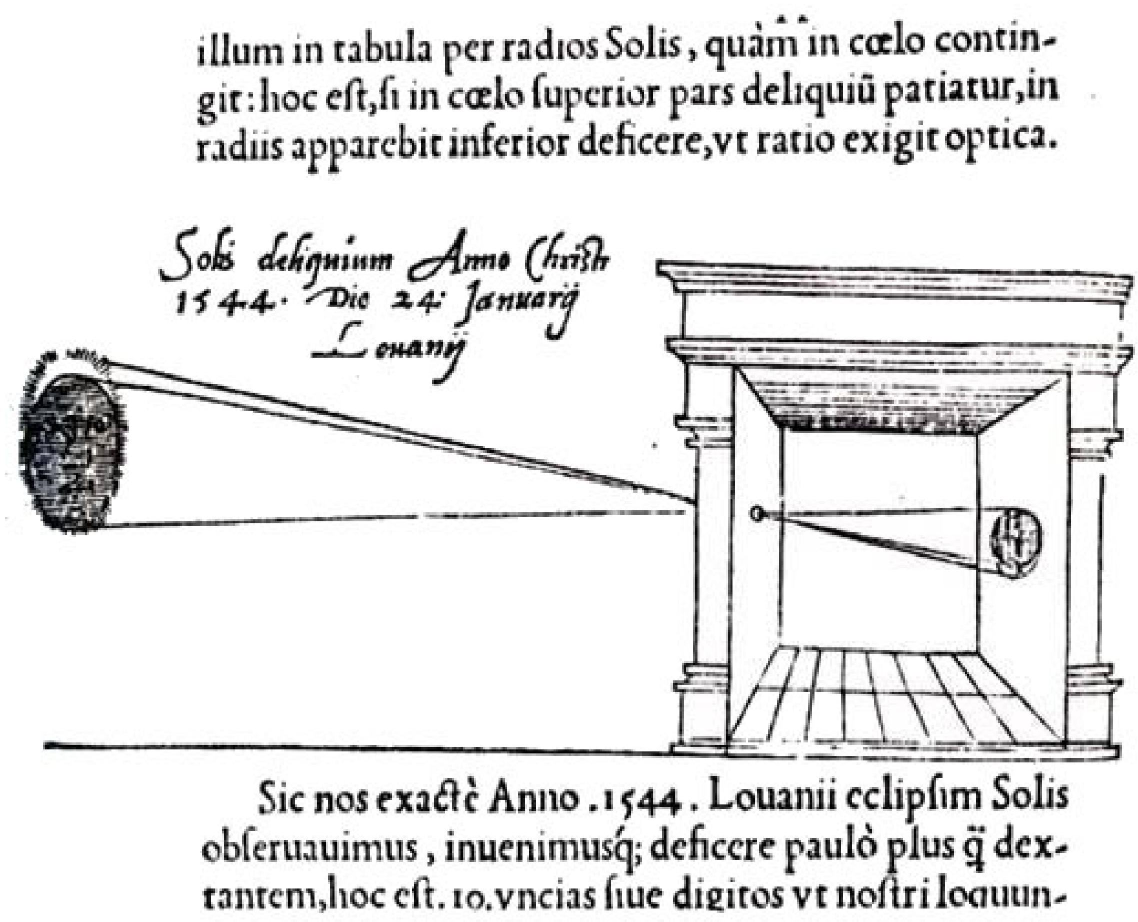


Figure 1. Earliest published illustration of a camera obscura depicting the solar eclipse he observed in Louvain on January 24, 1544 through a camera obscura. By Reinerus Gemma-Frisius.

The confluence of these observational and representational mediation devices and techniques had a profound impact on the construction of the epistemological assumptions embedded within Enlightenment-era scientific and artistic thought. The principles demonstrated by the telescope, microscope, and camera obscura reinforced a dominant dualistic paradigm in natural philosophy in which the perceiving subject was conceived as being independent of the external world (Crary, 1990, p. 30). This is reflected in the diagrammatic interpretations of Rene Descartes, who asserted that the accuracy of his retinal schematics (Figure 2), illustrating the physiological processes of vision, were confirmed by what he called the “natural perspective” of the camera obscura (Wees, 1992, p. 32). Like linear perspective, this provided the illusion of framed scenes unconnected to the observer. Combined with new mathematical formulations and philosophical theories (most notably Kant’s *transcendental idealism*), this rationalization of sight was essential to the establishment of perspectives on the “interiority” of subjective human experience and the “exteriority” of the natural phenomena. As a result, these approaches paradoxically expanded insights into natural processes while fragmenting relationships to them. They reinforced the impression of a critical distance between the human subjects and the observed world (Latour, 1990), fortifying the mechanistic perspective that all natural phenomena are subject to observation, quantification, reduction, and representation.

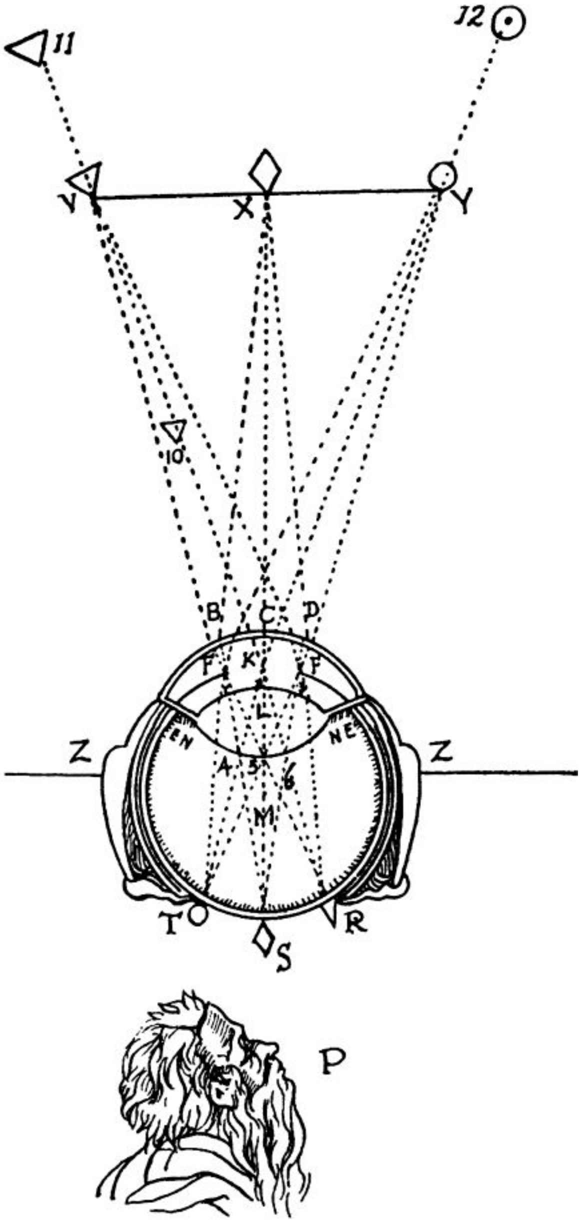


Figure 2. Illustration from René Descartes' La Dioptrique (1637).

## Shifting Perspectives

In the 20th century, advanced methods of observation and modeling revealed that the relationships between perceiver and perceived are considerably more complex and interdependent than previously believed. Quantum discoveries and relativistic theories forced scientists to reconsider many assumptions and develop new models to account for the complexity of systems – including the active, participatory role played by observers within them. As awareness of these findings spread across the arts, sciences, and humanities, it contributed to ongoing reflections on the uncertainty and perspectivalism inherent within all interactions and perceptual acts. The resultant array of "postmodern" discourses, problematizing the dichotomous abstractions of subject/object, self/other, mind/body, and human/nature, initiated substantial intellectual and emotional disruptions within many fields that continue to the present day.

Regardless, the profound implications of these discoveries for the veracity of dualistic logic and assumptions have yet to be meaningfully absorbed within many areas of popular understanding. The lingering linguistic and cognitive impacts of centuries-old polarizing beliefs continue to assert far-reaching influences on contemporary thought. This disconnect has led Fritjof Capra (1996) to argue that the many converging global crises should be considered facets of a single "crisis of perception," precipitated by "the fact that most of us, and especially our large social institutions, subscribe to an outdated worldview." He contends that though some paradigmatic explanations undoubtedly provided an essential framework for the scientific revolution, today they promote "a perception of reality inadequate for dealing with our overpopulated, globally interconnected world." Capra proposes that "radical shifts in perceptions, thinking, and values" are necessary, in which new perspectives are informed by ecological principles derived from the study of the interrelated, dynamically balanced processes and patterns of living systems.[2]

A similar emphasis on the necessity of achieving a non-dualistic, dynamic equilibrium with living systems can also be found within many indigenous knowledge systems. Nancy Maryboy et al. (2006) cite the central importance of what they call "paradox thinking" within the Navajo worldview, in which recognition of the importance of complementarity, continuity, non-linearity, and interconnectedness is derived from close observation of the natural order.

Instead of employing specialization, abstraction, and fragmentation as essential ingredients of empirical thinking, they describe the Navajo view of the world as a nested series of related phenomena that are unified within regenerative and cyclic processes. They assert that this worldview provides fluid movement between practical and expansive perspectives (as opposed to pretending that "whatever exists outside its field of vision is either non-existent or irrelevant") so that problem-solving skills can be informed by and exercised within an holistic "wisdom matrix." Echoing Capra's call for radical perceptual shifts based on ecological principles, Maryboy and her coauthors argue that a revitalization of the cultural wisdom, values, and principles associated with indigenous knowledge systems could transform the "tacit infrastructure of polarity thinking" that "artificially freezes and divides the forms of the living world."[3]

Practitioners in the nascent field of integral ecology (Esbjörn-Hargens & Zimmerman, 2009) have further emphasized the critical importance of recognizing the processes of worldview creation, claiming, "consciousness is embodied in flesh, embedded in culture, and enmeshed in eco-social systems." They contend that cultivating self-reflection is an essential step towards appreciating the unique perspectives of others, identifying with global societies and ecosystems, and appreciating the unbroken whole of existence. They propose that enhancing reflective processes can assist individuals and societies with overcoming seemingly irreconcilable positions, recognizing common values, and facilitating collaboration on necessary courses of action.[4]

## Visualizing the Big Picture

Informed by both modern scientific understanding and indigenous knowledge systems, the *World View* project is currently developing a strategy to provide new perspectives on global changes by focusing attention on the myriad ways in which worldviews are constructed. The heart of this approach involves the combination of mediated communication techniques designed to conceptually and perceptually appeal to a diverse range of modern audiences. It integrates interactive narratives, scientific data, and immersive displays within a social computing environment, seeking to leverage the potential of virtual worlds to stimulate linguistic, emotional, and visual-spatial intelligence (Gardner, 2006; West, 2004). Employing the *Uniview* software platform (SCISS, 2009) and a portable *GeoDome* display system (Elumenati, 2009), participants are immersed within interactively guided journeys of elegantly visualized scientific datasets. These visual simulations and their accompanying narratives are contextualized within a continuous, dynamic virtual space that models vast scales of spacetime across many orders of magnitude derived from observational measurements.

Instead of encouraging participants to "suspend disbelief" and accept the visualizations as representations of objective phenomena, this strategy seeks to facilitate reflection on the nature of subjective perception by enhancing awareness of the multiple factors that influence data collection, evaluation, and visualization. Playing on multiple interpretations of the *worldview* concept, these presentations explore a) the temporal, spatial, and spectral limits of human vision, b) multiple representations of Earth systems presented within a cosmic context, and c) the unique perspectives provided by contemporary mappings of the observable universe. Satellite maps of the non-visible range of the electromagnetic spectrum, as well as spatiotemporal simulations of movement, are used to rhetorically demonstrate the limits of human perception. Global datasets, such as human population, biodiversity distribution, atmospheric carbon accumulation, and polar ice cap retreat, are mapped onto a photorealistic virtual globe, enabling multiple data layers to be interactively examined and correlated (Figure 3). For additional affect, these views are situated within NASA's Digital Universe

Figure 3. Inside the GeoDome Theater displaying Earth visualizations within Uniview's Geoscope. Image credit: Jennifer Saylor.

Atlas (American Museum of Natural History, 2008) to simulate the cosmic context that gave rise to the "overview effect" reported by some astronauts (White, 1987). Furthermore, this Atlas provides the ability to navigate through a three-dimensional model representing observations of 14 billion years of cosmic evolution, the outer boundary of which represents the edge of the observable universe. This affords a novel way to shift epistemic frames of reference while rhetorically illustrating humanity's relative perspective that stems from perceptual paradoxes related to the speed of light (Figure 4).

In addition to seeking instinctive ways of communicating scientific data, this experiential technique is being developed as a means to induce reflexive insights into the nature of perception as well a deeper sense of the profound ecological relationships between humanity, the Earth, and the cosmos. While it is impossible to represent the full complexity of these cognitive, terrestrial, and celestial interactions, the use of contemporary mappings of Earth and space within a sensuous immersive environment is intended to intellectually and affectively convey the extraordinary network of processes and systems necessary to support life. By accentuating the interconnected patterns, flows, and cycles of nature within and beyond the range of human sense perceptions, this approach seeks to highlight the principles underlying the relationships between phenomena. Ultimately, it is hoped that these experiences might provoke a renewed intuition of the world, informed by an enhanced apprehension and appreciation of the nested, holarchical ecosystems within which we are all active participants.

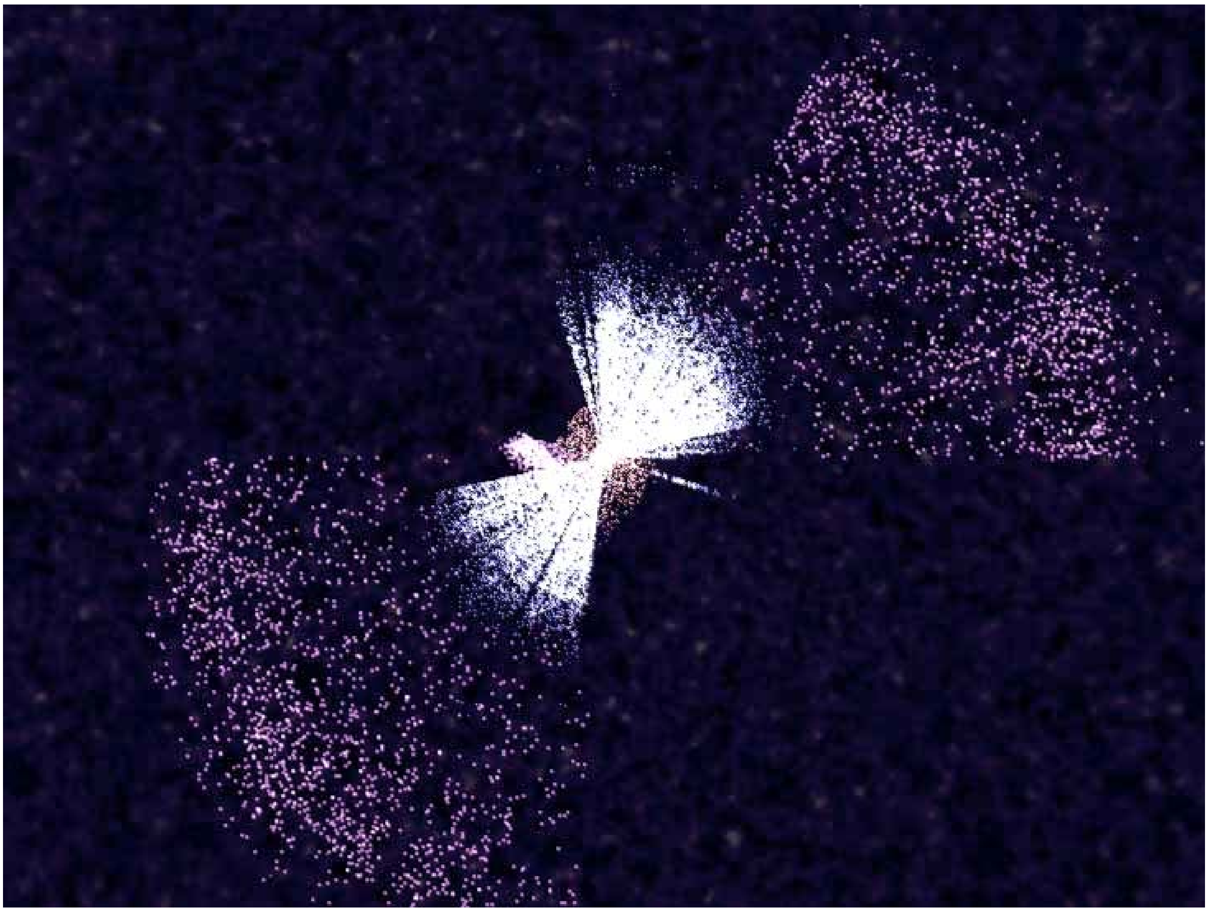

Figure 4. The Digital Universe Atlas visualized within SCISS' Uniview. Image Credit: NASA/American Museum of Natural History.

## Conclusion

As our species navigates the labyrinth of choices before us to deal with the causes and consequences of accelerating global changes, it is wise to recall Albert Einstein's purported admonition that "we cannot solve our problems with the same thinking we used when we created them." The scale, complexity, and uncertainty of these issues will continue to pose significant challenges for efforts to communicate them. Expanding frames of reference to provide new perspectives on their potential causes, consequences, and solutions is critical. Given the deeply ingrained beliefs and practices that shape perceptions of the world, exploring innovative and even unconventional methods is essential if the latticework of paradigmatic influences underlying many current approaches is to be discerned and more effective strategies developed.

The *World View* project seeks to inspire new perspectives on global change issues by inducing shifts in perception at personal, global, and cosmic scales. Rather than overwhelming participants with fragmented facts and figures relating the immensity of the challenges confronting our global community, it attempts to intellectually and emotionally engage them using guided, interactive, and immersive visualizations of artistically-rendered scientific datasets. These techniques are designed to enhance awareness of the extraordinary life-giving systems within which humanity is embedded as well as the encultured, embodied, and enacted processes through which they are perceived. By illuminating both ecological principles and perceptual paradoxes, this project strives to inspire participants to collectively imagine ways of more consciously participating in the necessary transformation of humanity's relationship with our home planet.[5]

## References


Abram, D. (1996). *Spell of the Sensuous.* New York: Vintage Books.

Aerts, D., Apostel, L., De Moor, B., Hellemans, S., Maex, E., Van Belle, H., et al. (1994). *Worldviews - From Fragmentation to Integration.* Brussels: VUB Press.

American Museum of Natural History. (2008, November 9). *Digital Universe Atlas*. Retrieved from Hayden Planetarium: http://www.haydenplanetarium.org/universe.

Capra, F. (1996). *The Web of Life: A New Scientific Understanding of Living Systems.* New York: Anchor Books.

Crary, J. (1990). *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century.* Cambridge: MIT Press.

Elumenati. (2009, July 1). *The GeoDome Immersive Learning Environment*. Retrieved July 1, 2009, from The GeoDome Immersive Learning Environment: http://www.geodome.info.

Esbjörn-Hargens, S., & Zimmerman, M. E. (2009). *Integral Ecology: Uniting Multiple Perspectives on the Natural World.* Boston: Integral Books.

Gardner, H. (2006). *Multiple Intelligences: New Horizons in Theory and Practice.*

Kant, I. (1987). *Critique of Judgment: Including the First Introduction.* (W. S. Pluhar, Trans) Indianapolis: Hackett Publishing Company.

Kellstedt, P. M., Zahran, S., & Vedlitz, A. (2008). Personal Efficacy, the Information Environment, and Attitudes Toward Global Warming and Climate Change in the United States. *Risk Analysis* , 28 (1), pp. 113–126.

Korzybski, A. (1933). *Science and Sanity: An Introduction to Non-Aristotelian Systems and General Semantics.* Fort Worth, TX: Institute of General Semantics.

Kuhn, T. S. (1962). *The Structure of Scientific Revolutions.* Chicago: The University of Chicago Press.

Latour, B. (1990). Visualisation and Cognition: Drawing Things Together. In M. Lynch, & S. Woolgar (eds.), *Representation in scientific practice* (pp. 19–68). Cambridge, MA: MIT Press.

Maryboy, N. C., Begay, D. H., & Nichol, L. (2006). Paradox and Transformation. *WINHEC Journal* .

SCISS. (2009, 1 July). *Scaling the Universe - The Official Uniview Site*. Retrieved 1 July, 2009, from Scaling the Universe – The Official Uniview Site:

http://www.scalingtheuniverse.com

Turnbull, D. (2000). *Masons, Tricksters, and Cartographers: Comparative Studies in the Sociology of Scientific and Indigenous Knowledge.* London: Routledge.

Varela, F. J., Thompson, E. T., & Rosch, E. (1992). *The Embodied Mind: Cognitive Science and Human Experience.* Boston, MA, USA: MIT Press.

Wees, W. C. (1992). *Light Moving in Time: Studies in the Visual Aesthetics of Avant-Garde Film.* Berkeley: Univeristy of California Press.

West, T. G. (2004). *Thinking Like Einstein: Returning To Our Visual Roots With The Emerging Revolution In Computer Information Visualization.* Amherst, NY: Prometheus Books.

White, F. (1987). The Overview Effect: Space Exploration and Human Evolution. Boston: Houghton Mifflin Company.

## Biography

**David McConville** is a media artist and theorist whose work explores the how transcalar visualizations impact perceptions of the world. He is co-founder of The Elumenati (http://www.elumenati.com), an immersive environment design and engineering firm with clients ranging from art festivals to space agencies. He is currently a PhD candidate in the Planetary Collegium (http://www.planetary-collegium.net) and a Director of the Buckminster Fuller Institute (http://www.bfi.org).

## Notes

1 Iris photograph from Rankin's *Eyescapes*, http://www.rankin.co.uk, *The Blue Marble* from NASA's *Visible Earth*, *http://visibleearth.nasa.gov*, Cosmic Microwave Background map from NASA's *WMAP Mission*, http://map.gsfc.nasa.gov.

2 Additional resources concerning ecological literacy and principles can be found at the Center for Ecoliteracy at http://www.ecoliteracy.org.

3 More on Indigenous research and education can be found at the Indigenous Education Institute at http://www.indigenouseducation.org.

4 Descriptions of the integral ecology framework are available through the Integral Ecology Center at http://www.integralecology.org.

5 For examples of initiatives that are based on these principles, see the Buckminster Fuller Institute's Idea Index at http://www.ideaindex.org and the Biomimicry Institute at http://www.biomimicryinstitute.org.

# Energy Visualization – Why, What & How?

Tina-Simone S Neset and Wiktoria Glad

## Abstract

This text explores the field of energy visualization, regarding motivation, content and concepts in an academic and non-academic context. Besides the general challenges and demands on visualization of this resource, we discuss the issues of scale and areas of application within current research. Drawing from examples of geographic methods that are aiming to capture human use of resources, every day life and issues of communication between planners, researchers and individuals, there is great potential for future development of visualization tools both for analysis, participatory approaches as well as science communication.

## Introduction

Within the concept of climate visualization, energy is one of the central resources that links to climate policy, individual consumption, mitigation options and is thus of interest in several thematic contexts. We aim with this text to explore the field of energy visualization and potential areas of application. We argue that this is a new field that shows great potential for the representation and analysis of linkages between the various scales of energy production and consumption. Energy visualization opens up for inter- and trans-disciplinary research and research communication with planners, users and other stakeholders.

## Why energy visualization?

The simple response to this question is similar to other areas of climate visualization: *because we can feature the invisible*. Similar to greenhouse gas emissions, flows of resources, future temperature scenarios and the potential impact of policies, the analysis and communication of the use of energy resources on different scales – from the individual household to the global frame – is a methodological and pedagogical challenge. Whether we focus on quantity, systems or energy sources, energy visualization can be a tool that can be adapted to the needs and demands of a large number of stakeholders.

One of the key challenges of energy visualization is the complexity of issues, areas and fields of stakeholder interest, that has to be integrated to fulfil a sustainability perspective. Many of these issues are hard to grasp within current research. Global current and future energy use (e.g. peak oil, renewable energy, biofuels) is strongly debated in the media over the last years and has thus become a challenge for science communication. Accordingly, the complexity of this field demands new approaches and tools, which visualization can provide.

Visualization can function as a tool for science communication, the analysis of large data sets as well as a platform for decision making and participatory processes (fig 1). As means of visualization lead us back to the usage of images, maps, film, etc., several applications on visualizing energy use in households or simply with focus on everyday life have been developed over the last decade.

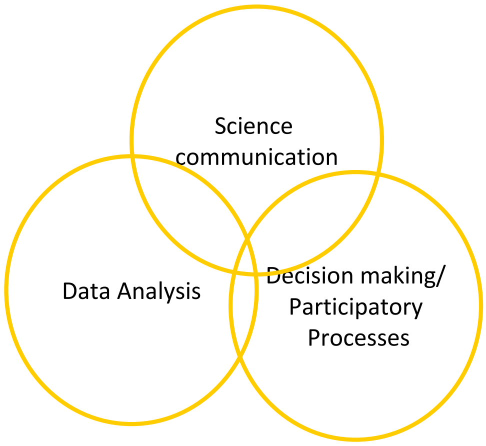


Figure 1. Three research approaches to visualizations.

## What's been done?

Visualization is a wide term, and comprises various forms of visual representation of data but also on qualitative information, knowledge, ideas and concepts etc. The tradition within the academic field of geography has included cartography but also more abstract spatial representations in form of maps, overlying for instance topographic information with socio-economic, health, people's movements etc in order to use a visual tool for analysis and communication of geographic data. Some recent research has focused on the pedagogic and communicative implications of technology-integrated science teaching (Hennessy et al. 2007) and landscape visualization in order to increase awareness of climate change (Sheppard 2005).

The fact that energy flows are invisible to the human eye has engaged researchers in developing methods for "seeing the unseen" (McGormick et al. 1987). The McGormick study acknowledge the importance of developing this field of research in 1987. Mainly disciplines in science and engineering recognized the call the subsequent ten years. Before 1999 social sciences or interdisciplinary research did not develop visualization to any great extent. Consequently, no central core in social science or interdisciplinary visualization could be discovered and it was impossible to define key research areas (Orford et al. 1999). Since science visualizations often were attached with problems of for example lack of contextualization or scaling there should be a great potential for linkages to interdisciplinary research (Tufte 1997).

The most promising area for visualization was considered to be geography, since spatial data use within the discipline and integration of ideas from other disciplines gives geography a leading position in visualization research (Orford et al. 1999). Other than geography visualization in social sciences and interdisciplinary research was predicted a slow growth mainly due to its transdisciplinary character and problems with finding ways to publish.

In the area of data analysis, time geography is a branch of geography which could benefit particularly from the development of visualization techniques. For examples, researcher can easily move from aggregated data to detailed information in specific data points (Orford et al. 1999). Visualization techniques developed at Linköping University use data from time diaries in a visual activity-analysis tool called VISUAL-Time PAcTS (Vrotsou et al. 2009). This application can be used to visualize, analyze and compare activity patterns on different levels, from the individual to the population. New and unexpected patterns in everyday lives of Swedish households have been discovered using this tool and it has also provided rich knowledge about activity patterns in different groups of the population. For example, VISUAL-Time PAcTS has shown how division of labor between men and women differ concerning the activity "go to day care centre with child". Women leave the child in the mornings and men do the pick-up in the afternoons. Activity patterns have also proved to be useful to describe energy use on individual and household levels (Widén et al. 2009).

In the area of decision-making and participatory processes, and data analyses, another research field, partly inspired by the time-geographic approach, is called exploratory visualization (Kraak 2008). Visualizations are used as tools for interaction, to capture dynamics in data, and to generate new knowledge without the preconceptions and constraints of former analytical frameworks (Keller & Keller 1992). For example, the space-time-prism (Hägerstrand 1982) and later developed to a space-time-cube (Andrienko et al. 2003, Kraak 2003, Kapler & Wright 2004, Anundi et al. 2006) show potential to visualize information to users. Visualization tools like CommonGis and Geotime are able to generate time-space-cubes (see figure 2).

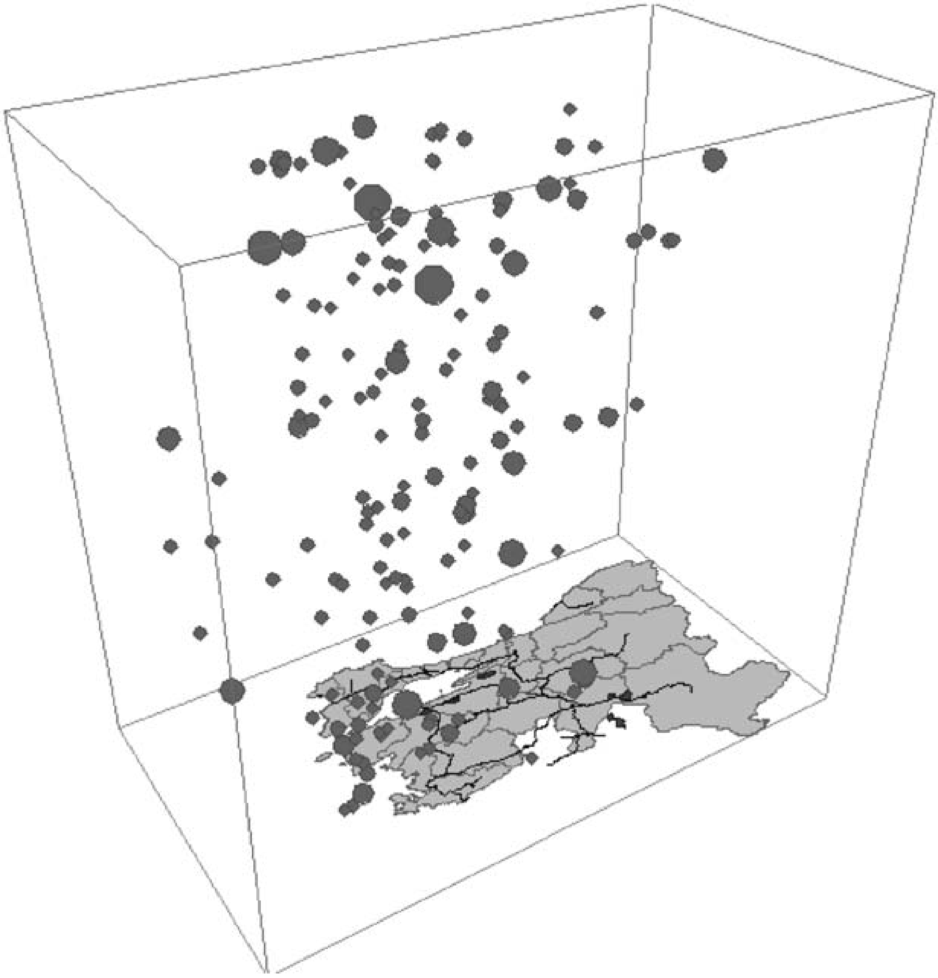

Figure 2. The principles of Space Time Cubes. The geographical map in the plane is completed with vertical axes symbolizing time. The spots are activities and are placed according to appearance, from bottom to top and their relative size might show the magnitude of an activity, for example energy use (Andrienko et al. 2003).

From the perspective of communicating science to laymen, smart metering and advanced visualization has been recognized by the European Commission as promising tools for energy awareness and behavioral changes (Commission of the European Communities 2008). According to the Commission real-time-feedback in Finnish households reduced energy consumption by 7 % and in commercial building the potential is probably 10 %. A Swedish anthology “Visualization of energy use” explores the different available option of smart metering (Pyrko 2008). Results from several minor research project show how visualization has the potential to change energy behavior, especially if combined with price signals. But behavioral change is very complex and feedback mechanisms provided by for example available smart meters has to be flexible to suit different users. Experiments with visualizing energy through different household appliances has shown how difficult it is to have long term effects on behavior since people get used to it and eventually ignore the signals (c f Löfström 2008). This knowledge will be taken into account in our future work on energy visualization.

# What?

*Concepts and Content*

Sustainable resource use comprises an environmental, social and economic dimension which in turn demands a strongly integrated and interdisciplinary approach. To be able to present and explain linkages between fields with a wide variety of academic tradition, data collection, analysis etc, there is a need for common representations. To step beyond the traditional forms of science communication and to enter forms of explanatory models that can show the direct interaction between fields of knowledge is thus possible by means of visualization.

The visualization we focus on in recent studies is focused on energy use, climate change and global resource flows for data analysis, pedagogic and communication purposes. The tools that could be applied within this field can be divided into two categories:

1) Soft-ware that handles large quantities of data which can in form of mappings, flows, charts, and most importantly interactive solutions provide forms of presentation or interactive workshops that could be applied in higher education or other fori.

2) Visualization tools that can be used in everyday-life, in households, by consumers or as means for classroom teaching. Examples for this can be illuminated cables that increase their light-intensity depending on current energy use in the households or interfaces that provide data on a household's individual energy consumption as well as in relation to neighbours.

The general field of energy use and energy resources intertwines natural science, social science, economy on a local to global level. Every single action that we undertake as individuals on this planet, may it be which milk we choose for our breakfast, if we turn out the light when leaving home, which mode of transport we choose during our day or how we choose to vote in the next election has an impact on the global system, on flows of resources, people in remote countries. How these connections can be communicated is a challenge that can be met through visualization.

Energy visualization is a tool for communication, feed back to consumers, planners, stakeholders as well as for pedagogic purposes directed to students as well as the general public. A significant effort can be directed towards the sustainable use of resources, both through representation of complex data sets and through scaling of use-related data and scenarios. As such, it enables us to create storylines that are adapted to local households, to planners, housing companies, students or the general public.

In our current study we explore the potential of energy visualization as a communicative tool. In dialogue with representatives of the housing company we defined a number of visualization efforts that would contribute to their general mission of a) communicating changes in energy consumption on a household/neighbourhood scale b) 'translating' the effect of what changes would imply on a larger (national) scale. Applications for such local energy communication could involve:

- An energy visualization that shows the individual and regional/national energy use
  - for selected energy sources
  - for selected energy demanding activities
- That enables us
  - to zoom in on the potential effects for e.g. land use

- to see who is consuming what and which countries (in terms of consumption) use area elsewhere (e.g. energy footprints/carbon footprints)
- to change single parameters (for instance if biomass for biofuel production is produced in one or the other country) and their effects for global resource flows

As such it could be an interface that communicates on an individual level, through experimenting and understanding as well as 'asking the questions' to test different hypotheses can be made in a vast number of ways.

## How?

## Scales & Planned Applications

Energy use implies resource flows on a number of scales. In terms of communication efforts, this means a translation from the individual user to larger entities (e.g. neighbourhoods, cities, regions) to the national and finally global scale. The strength of scaling up (and down) energy use is to be able to visualize the impact individual choices and minor changes in consumption, be it through behavioural changes or technique, can have on the larger scale. As such, it is a communicative tool to enhance understanding (and potentially create commitment) for local changes.

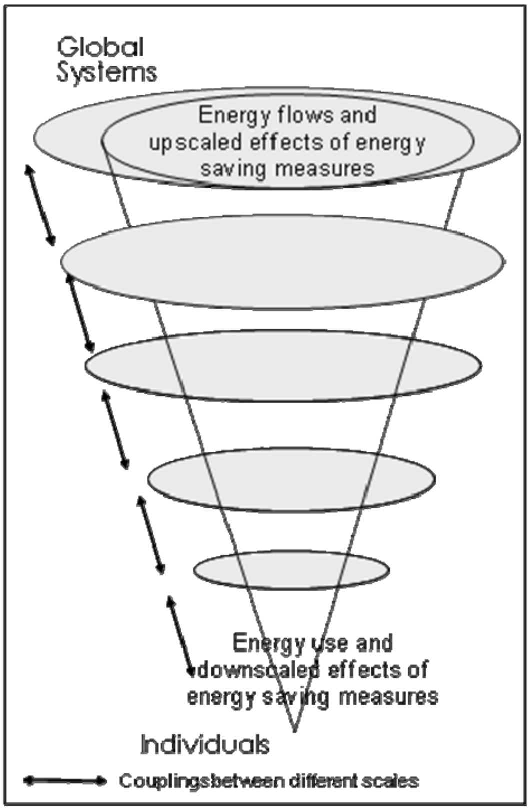


Figure 3. Schematic figure to approach energy visualization from an interdisciplinary perspective.

Given the example of the local households, we include the use of energy through electricity, warm water and heating and see structures on household, building and neighbourhood level. Further, this consumption might be translated to a regional/national scale and compared to the energy implied in biomass (spatial) or other alternative energy sources. Indirect energy flows through the household (e.g. organic waste that is collected separately and will be reused for local biogas production) can be translated in a similar way to generate an understanding for the dimensions of individual energy use.

Results from these studies imply therefore all three areas of visualization (figure 1) and can be used in information visualization for analysis of abstract data, in visual representations through kml/kmz/wms/Arc GIS formats to be used in public communication and decision making (e.g. as part of the decision theatre of the Norrköping Visualization Centre-C) and as a basis to develop new interfaces for communication between researchers, planners, housing companies and the individual consumer.

The challenge of making sense of complex questions remains, and in an increasingly intertwined world of knowledge, the consequences of our actions need to be communicated in a most explicit way in order to facilitate sustainable changes.

## References

Andrienko, Natalia, Andrienko, Gennady & Gatalsky, Peter (2003). Exploratory spatio-temporal visualization: an analytical review. Journal of Visual Languages and Computing 14(6), pp. 503–541.

Anundi, D., Björnstad, M., Gillberg H.,Haraldsson, J.,Mårtensson, I., Nordvall, M., Ståhl, J. (2006) Utvärdering av rymd-tidskuben: en teknik för översiktlig visualisering av spatial-temporal information

Commission of the European Communities (2008) *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Region: Addressing the challenge of energy efficiency through Information and Communication Technologies*. Brussels, 13.5.2008 COM (2008) 241 final.

Hennessy, S., Wishart, J., Whitelock, D., Deaney, R., Brawn, R., la Velle, L., McFarlane, A., Ruthven, K., Winterbottom, M. (2007). *Computers&Education* 48, pp. 137–152

Hägerstrand T., (1982) Diorama, path and project, *Tijdschrift voor Economische en Sociale Geografie*, Vol, No. pp. 323–339.

Kapler, Thomas & Wright, William (2004). GeoTime Information Visualization. IEEE Symposium on Information Visualization (InfoVis 2004). pp. 25–32

Keller P. R., Keller M. M. Visual Cues, Practical Data Visualization, IEEE Piscataway.

Kraak, M-J (2008) Exploratory Visualization. In Shekhar, Shashi. (2008). *Encyclopedia of GIS*. New York: Springer. 301–307.

Kraak, M. (2003). The Space-time Cube revisited from a geovisualization perspective. Proceedings of the 21st International Cartograhic Conference (ICC), ICA Durban s. 1988–1995.

Löfström, E., Palm J., Visualising Household Energy Use in the Interest of Developing Sustainable Energy Systems. Housing Studies, 23(6), pp. 935–940.

McGormick B. H:, and DeFanti, T. A. (1987) Visualization in Scientific Computing. *Computer Graphics* 21 (6 November).

Orford. S., Harris R., Dorling D., (1999) Information Visualization in the Social Sciences: A State-of-the-Art Review. *Social Science Computer Review* 1999: 17; pp. 289–304.

Pyrko J (ed.) (2008) *Visualisering av energianvändning* Institutionen för Energivetenskaper, Lunds universitet; Lunds tekniska högskola.

Sheppard, S R.J (2005). Landscape visualization and climate change: the potential for influencing perceptions and behaviour. *Environmental Science&Policy* pp, 637–654.

Tufte, E. R. (1997) Visual Explainations: Images and Quantities, Evidence and Narrative. Cheshire: Graphics Press.

Vrotsou K., Ellegård K. & Cooper M. (2009) Exploring Time Diaries Using Semi-Automated Activity Pattern Extraction. eIJTUR (electronic International Journal of Time Use research), vol 6, September 2009.

Widén, J., Lundh H., Vassileva, I., Dahlquist, E., Ellegård, K., Wäckelgård, E. (2009), Constructing load profiles for houshold electricity and hot water from time-use data – Modelling approach and validation. *Energy and Buildings* 41 (2009), pp. 753–768.

## Biography

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# Visualization Techniques from Design & Cartography

Robert Simmon

## Abstract

Data visualization has a long history, dating back to the origin of writing, while the history of cartography spans several thousand years. During that time both fields developed effective approaches to display information clearly. Unfortunately, modern computer-based visualization practices often neglect this history. Many data visualizations can be improved by incorporating traditional techniques of visualization and modern design methods based on the knowledge of human perception.

## Introduction

The history of data visualization is intertwined with the history of communication. Cuneiform, the earliest form of writing, evolved out of a system of pictograms used to keep track of stores and taxes in Sumerian city-states (Meggs, 1998). The pictograms were representative symbols used to indicate the types of stored goods, combined with a decimal numbering system that denoted quantity. Over time the pictograms became less literal, and eventually transformed into abstract cuneiform script. The need to record and communicate numerical data triggered the development of written language.

The earliest maps were also developed in the Middle East, with early surviving examples drafted by ancient Babylonians and Egyptians (Wikipedia ‘History of Cartography,’ 2009). By the time of the Roman Empire maps appeared that showed networks and connections instead of simply representing land surfaces. One example is the Tabula Peutingeriana, a medieval copy of a 4th century map of the Roman public roads. The roads linking settlements and towns in the ancient world are drawn on a 6.75-meter-long scroll (Wikipedia ‘Tabula Peutingeriana,’ 2009). Types of locations are differentiated by standardized symbols. Distances between locations along the road network are emphasized, rather than their exact geographic relationships. These early map-makes knew one of the key principles of information design: carefully highlight vital data.

Further developments in thematic maps and data visualization occurred during the Enlightenment. Edmund Halley published a map of the trade winds in 1686. Wind speed and direction were indicated with tapered lines. This was one of the first maps to show quantitative data rather than geographical relationships (Denis and Friendly, 2001–2008). William Smith’s 1815 map: *A Delineation of the Strata of England and Wales, with Part of Scotland*, was the first large-scale geological map (Winchester, 2001). Smith used color to denote different rock types that lay under the British countryside, a qualitative thematic map. *A Delineation of the Strata of England and Wales* was both large (approximately 6 by 9 feet) and detailed, and simultaneously provided an overview of the geology of Britain and details of specific locations. Neither Halley or Smith worked alone. Scientists of the times collaborated with teams of printers, engravers, and other craftsmen who adapted the data to the media. The results were elegant, clear, and effective.

In the 1950s and 60s computer graphics were born, which would begin a revolution in the display of information. Early displays were very small, monochrome, and low resolution.

Full-color displays did not become common until the late 1990s, and screen resolutions (roughly 100 dots per inch) are currently much lower than print (300-2400 dots per inch). For data visualization, computers had a major advantage over tradition production methods: scientists could visualize their own data. This enabled scientists to produce graphics quickly and inexpensively, but designers were now rarely involved in data visualization. Many of the presentation decisions are made by programmers writing commercial software applications, which are often designed to optimize performance or ease programming rather than to produce effective graphics. As a result many valuable graphics techniques—developed over centuries—are neglected in scientific visualization.

*A Definition of Information Design*

> …addresses the organization and presentation of data: its transformation into valuable, meaningful information.
>
> Nathan Shedroff
>
> The art and science of preparing information so that it can be used by human beings with efficiency and effectiveness.
>
> Robert E. Horn

(Visocky-O'grady, 2008)

Information design is a multi-disciplinary field that combines elements of cognitive science, graphic design, and statistical graphics. Practitioners aim to display information clearly with an emphasis on the communication of ideas. Some simple information design principles can transform hard-to-read, unappealing illustrations into figures that are clear and attractive.

## Case Study: Map of Sea Ice Age

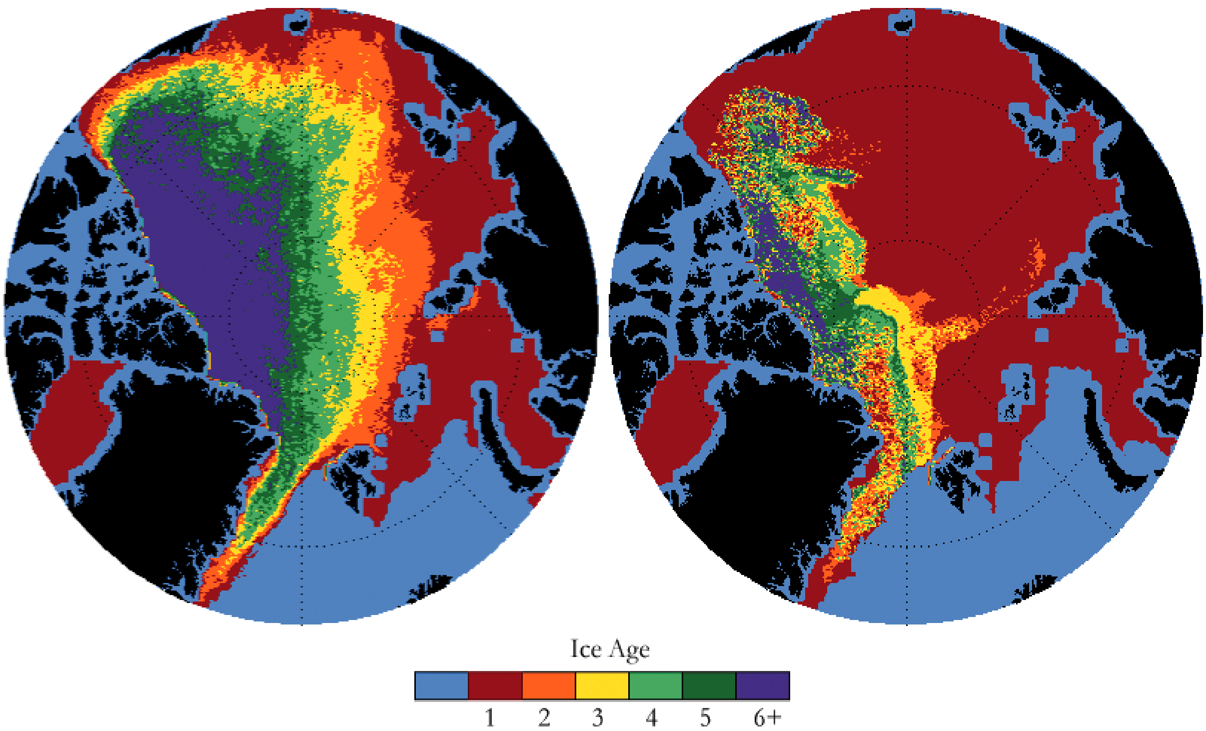



Figure 1. These maps compare the average age of sea ice in the Arctic ocean from 1985-2000 to the age of the ice in February 2008. Although it is possible to distinguish multi-year ice from fresh (one-year-old) ice, the design of the maps makes it more difficult than necessary to interpret the patterns of the ice. (Image courtesy National Snow and Ice Data Center.)

This pair of maps shows the age of sea ice in the Arctic (Cook-Anderson, 2008). On the left is the mean age of ice in February during the years 1985 to 2000; on the right is displayed the age of sea ice in February of 2008. Several of the design choices of the mapmakers obscure patterns in the data, rather than emphasizing important elements.

Graphics for static, low-resolution screen display should be *anti-aliased*. Because the resolution of computer displays is much lower than the ability of the human eye to perceive detail, curved edges and diagonal lines appear stair stepped (below, left) if solid colors are used. Lines and edges with blended colors, however, appear smooth (below, right).

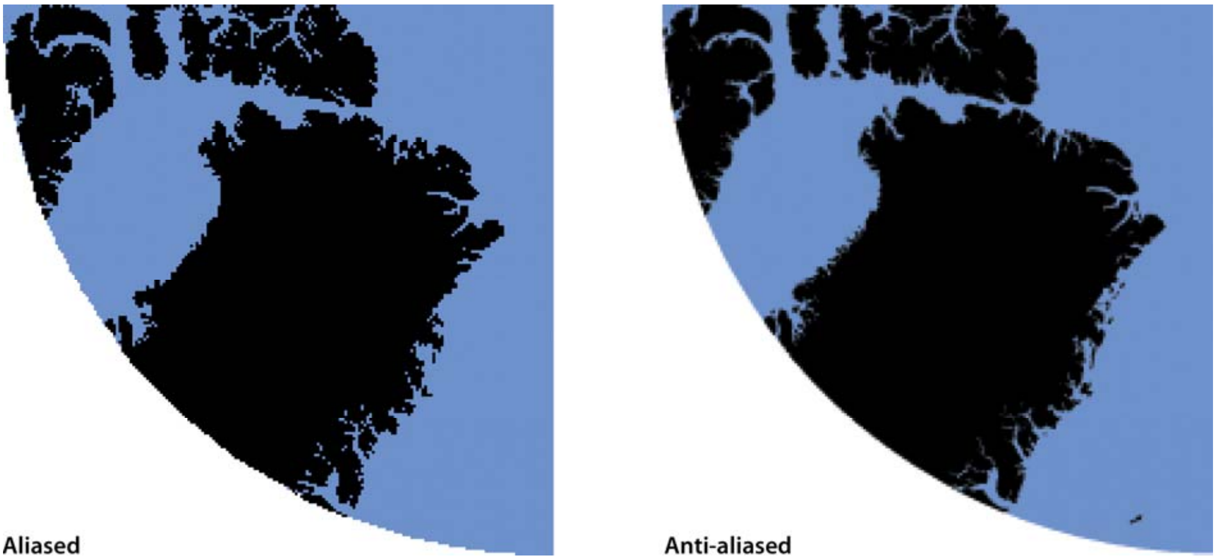



Figure 2. Anti-aliasing is a technique used to smooth curved edges in low-resolution displays. In the original aliased image (left) pixels are either land or ocean, leaving a coarse appearance to the coastline. Applying anti-aliasing to the land mask in this map (right) shows more detail than the original, and reduces the amount of visual noise in areas with high-frequency detail. (Image courtesy Robert Simmon, Sigma Space/NASA Goddard Space Flight Center.)

Another important element of information design is to emphasize the data, rather than ancillary or irrelevant information (Tufte, 2001). One method of emphasizing data is to place it in the foreground of an image. Design elements that are bold, heavy, saturated, and sharp stand out as foreground elements. In the original sea ice age map the ice-free ocean and land areas are visually balanced with the ice-covered areas, so a viewer does not automatically focus on the data. A better approach is to use light, de-saturated colors for areas of no data, while using saturated colors for data. This will provide contrast between data-filled portions of an image and less important information.

Many maps use color to represent numerical values at points in space. Colors and gradients should be chosen to be compatible with human vision so that changes in data are proportional to perceived changes in quantity. Unfortunately one common color scheme, the rainbow (or spectral) palette, distorts the underlying data (Rogowitz and Treinish, 1996). (The rainbow palette is a gradient that progresses through the hues of the rainbow: red, orange, yellow, green, blue, indigo, and violet.)

Figure 3. The "rainbow" palette is a common color scheme used for coding numeric values as colors in data visualization. Unfortunately this palette is difficult or impossible for the human visual system to interpret properly. Some color transitions (blue to green and yellow to red, for example) occur very quickly, which introduces false contrast, while other colors (green in particular) cover wide ranges of the palette, obscuring detail. (Image courtesy Robert Simmon, Sigma Space/NASA Goddard Space Flight Center.)

The rainbow palette has several flaws. First, perceived changes in value are nonlinear. Some regions of the scale appear to change rapidly (the transitions from blue to cyan, green to yellow, and yellow to red), while other regions appear to change very slowly (green). This effect occurs because the red, green, and blue primaries displayed by computer screens are not perceived as equally bright by humans. Secondly, the brightness of the palette is not ordered. (Ware, 2004) Color schemes that vary in either luminance (dark to light) or saturation (dull to bright) have a natural sequence, while those that vary in hue (red to violet) do not.

Perceptual color spaces like Munsell or CIE L*a*b can be used to generate color palettes that display data accurately (Brewer, 2002). Palettes should be designed in the perceptual space, and then mapped to the RGB values of computer displays. One compromise that preserves relationships between data points and allows viewers to accurately read data values is to use a palette that varies uniformly in brightness, while simultaneously changing both hue and saturation. The change in brightness conveys sequential information most strongly, while the shift in hue and saturation helps a viewer distinguish colors from one another. Color-blind viewers (8% of males) can also accurately read these maps, and they retain much of their accuracy when printed in black and white or photocopied.

A special type of color palette, described as a *divergent* palette (Brewer, 2002), is helpful in the display of quantities with positive and negative values, or that vary from a mean. These palettes are centered on a neutral color, and ramp to two equally luminous and saturated values to represent extreme values of equal magnitude. In these palettes, positive and negative values are almost instantly identifiable, and quantities of equal absolute value are equally prominent.

This redesigned map of multi-year Arctic sea ice uses these principles. I have anti-aliased the boundary between land and water, lightened the land area and ice-free water considerably, while applying a perceptually based color palette to the sea ice age data. The oldest ice is dark and saturated, which makes it stand out from the background areas, and patterns in the ice are more clear. There is a slight sacrifice in the ability to interpret the age numerically, but the purpose of the map is to show the drastic decrease between the historical winter ice coverage in the Arctic and the conditions in February 2008.

Data visualization allows viewers to survey and interpret quantitative information quickly and easily. Perception-based principles from graphic and information design enhance these qualities of visualization, and improve the ability of graphics to convey information.

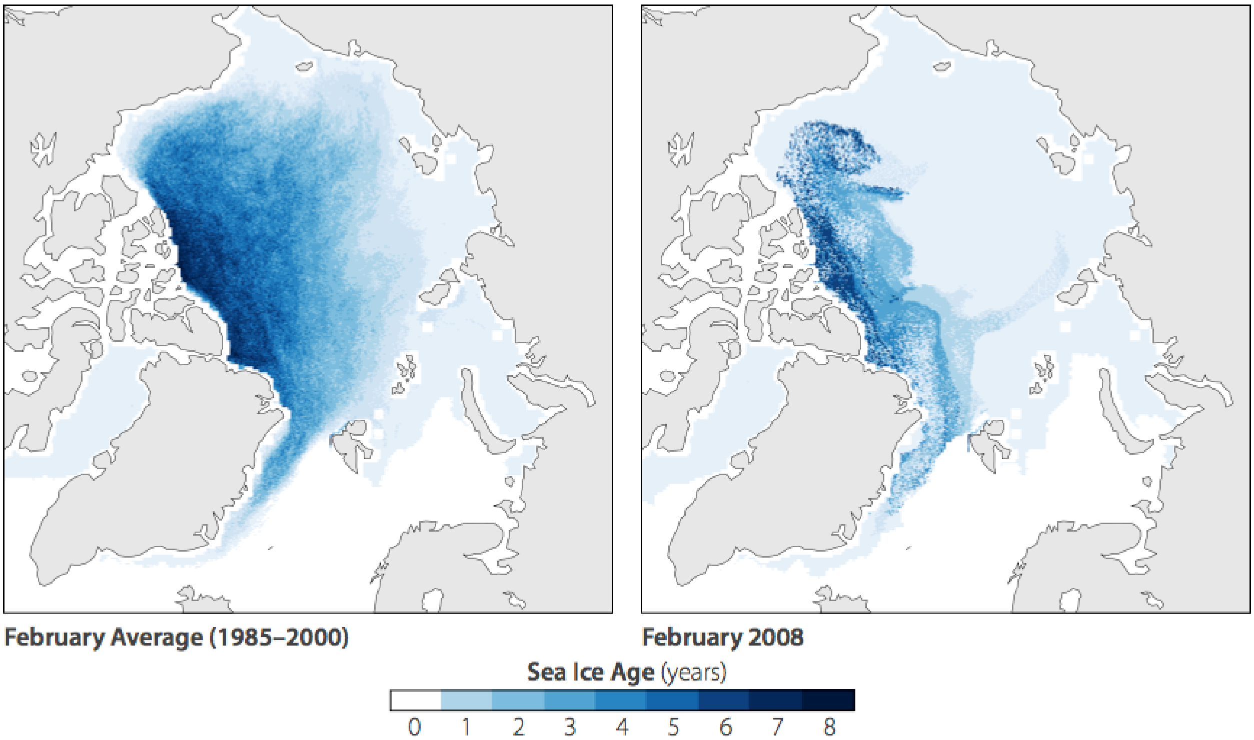



Figure 4. These sea ice maps use simple design principles to enable rapid interpretation of the data and show patterns clearly. The techniques include anti-aliasing edges, reinforcing the contrast between the data and the background, and displaying ice age using a perceptual color palette. (Image courtesy Robert Simmon, Sigma Space/NASA Goddard Space Flight Center, based on data from the National Snow and Ice Data Center.)

# References

Brewer, Cynthia (2002), 'Color Brewer', http://www.personal.psu.edu/cab38/ColorBrewer/ColorBrewer_intro.html, accessed 14 September 2009.

Cook-Anderson, Gretchen (2008), 'Researchers Say Arctic Sea Ice Still at Risk Despite Cold Winter', http://www.nasa.gov/topics/earth/features/seaice_conditions_feature.html, accessed 15 September 2009.

Denis, Daniel J., and Friendly, Michael (2001–2008), 'Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualization', http://www.math.yorku.ca/SCS/Gallery/milestone/index.html, accessed 14 September 2009.

Meggs, Philip (1998), *A History of Graphic Design, 3rd Edition*, John Wiley & Sons.

Rogowitz, Bernice and Treinish, Lloyd (1996) 'Why Should Engineers and Scientists Be Worried About Color?' http://www.research.ibm.com/people/l/lloydt/color/color.htm, accessed 14 September 2009.

Tufte, Edward (2001), *The Visual Display of Quantitative Information, Second Edition*, Cheshire, CT: Graphics Press.

Visocky-O'grady, Jenn (2008), *The Information Design Handbook*, How.

Ware, Colin (2004), *Information Visualization, Second Edition: Perception for Design*, Morgan Kaufmann.

Wikipedia (2009), 'History of Cartography', http://en.wikipedia.org/wiki/History_of_cartography, accessed 14 September 2009.

Wikipedia (2009) 'Tabula Peutingeriana,' http://en.wikipedia.org/wiki/Tabula_Peutingeriana, accessed 14 September 2009.

Winchester, Simon (2001), *The Map That Changed the World: William Smith and the Birth of Modern Geology,* HarperCollins.

## Biography

**Robert Simmon** is a data visualizer and designer for NASA's Earth Observatory web site. With 14 years of experience at NASA, he is an expert at creating clear and compelling imagery from satellite data. He focuses on producing visualizations that are elegant and easily understandable, while accurately presenting the underlying data. His imagery has appeared in newspapers, web sites, and advertisements, and is featured on the login screen of the Apple iPhone.

# Communicating Climate Change: Lessons from Sustained Programs

Ned Gardiner

## Abstract

A central goal of the Worldview Network is to establish a common understanding among decision makers and concerned citizens around the planet about climate science and appropriate adaptation solutions. That baseline must stem from verifiable interpretation of scientific data. Sustained public programs from the American Museum of Natural History in New York City, USA, and the United States National Oceanic Atmospheric Administration provide lessons and point toward best practices for that process. The first step in this interpretation is to identify relevant scientific themes; this job is best done by an authoritative scientific expert. The second step is to render information in simple and understandable ways; this job is best done by experts in media production, such as artists and producers. For the Worldview Network, the production process will not end with publishing and disseminating visualized media. The third step involves working with decision makers and communities to understand scientific and social foundations before collaboratively devising climate adaptation strategies. These steps do not define a closed loop, for the third step will yield new realizations which may be aired through visualization and public discourse. Thus, the Worldview Network will literally help humans evolve new ways of understanding and solving problems at all scales, from local to global.

## Introduction

Scientific data and concepts are essential for devising climate change adaptation strategies, for example by clarifying minimum or maximum rates of sea level rise in a given harbor or changing precipitation regime impacts in an agricultural region. Since the rate of relative sea level change (rise or fall) varies from location to location, scientific expertise will clearly be needed in order for city or regional planners around the world to make site-specific recommendations about adaptation strategies. In regions where relative sea level is rising rapidly, such as the mid-Atlantic coast of the United States, planners face different concerns than planners on portions of Alaska's coast where Earth's crust is rising due to the loss of mass from glaciers (isostatic rebound), thus causing a relative lowering of sea level. Since model projections of precipitation and temperature do not provide sufficient resolution to analyze parameters for a specific locale or year, accurate interpretation of climate models will be needed for agribusiness leaders to deliberate about disease resistance, timing of fertilization, and crop rotation times for agricultural regions. To evolve locally relevant societal responses, scientists must find ways to work directly with business leaders, planners, politicians, and others from all walks of life. Issues such as these are the impetus for launching the Worldview Network.

Others at the workshop have outlined major challenges for using visualization to inform climate change responses around the planet (Editorial, this volume; Vajjhala and Spadaro, this volume) as well as conceptual approaches to communicate complex ideas by helping audiences perceive complex concepts (McConville, Simmon, this volume). This essay focuses on practical considerations for translating specific scientific concepts for public audiences.

The first section establishes the importance of clarifying communication objectives when building geographic visualizations ("geovisualizations"). I draw on three examples from the American Museum of Natural History's Science Bulletins[1] video production group. Turning more explicitly to climate, I discuss how scientists and communicators within the U.S. government's National Oceanic and Atmospheric Administration (NOAA) plan to work with government and business leaders as well as a broader public. These examples demonstrate how the Worldview Network might work with collaborators around the world.

## Science Media for Public Outreach

Science Bulletins produced geovisualizations about Earth's climate, atmosphere, land cover, and biosphere between 2000 and 2008 in collaboration with the U.S. National Aeronautics and Space Administration (NASA) and NOAA. The scientists who collaborated on these visualizations each provided expert interpretation of data they used in their own research. During pre-production of each visualization, I typically spent one or more hours talking with NASA principal scientists. During my first assignment, I sat with Claire Parkinson, the lead investigator of the Aqua satellite, one of NASA's Earth Observing System constellation of satellites. While describing climate phenomena and patterns that cause and result from changes in Arctic sea ice, Dr. Parkinson pointed to images graphics specialists had produced from her satellite observations since the late 1970s. Parkinson had relied on images to complement her quantitative analyses from even those early days when computers were not capable of generating images quickly and easily. Processing data from satellites requires specific skills. Each instrument has its own unique data structures. Although NASA made an effort to document those data formats so that any researcher could use them, processing thousands of sequential frames of images based on satellite images and data would have been very difficult without the direct assistance of programmers working with those NASA on a day-to-day basis. Documenting expert opinion and processing raw, authentic data became hallmarks of Science Bulletins visualizations.

Programming by Science Bulletins was distributed to 41 museums and science centers, mostly in the United States. Given that its audience was well defined, producers were able to cultivate best practices. Rather than meeting joint communications objectives for entertainment and education, the visualizations focused on translating current science topics *per se*. The editorial team included research scientists, whose jobs included identifying significant trends and scientific progress. After identifying and agreeing about core concepts to convey, artists and writers on the team devised ways to translate those concepts. Scientists on the team differentiated small discoveries in recent literature from fundamental concepts. Scientists can serve a crucial role communicating with society and decision makers by identifying and highlighting significant scientific discoveries.

## Land Cover Mapping

Below I describe three visualizations and fundamental principals relating remote sensing to biodiversity science. The first figure (Figure 1a) focused attention on how optical remote sensing is used to map both wildlife habitats and human impacts on those habitats. Colleagues from the University of Maryland and Woods Hole Research Center spent several years mapping roads and land cover in the Congo rainforest bordering the Central African Republic, Republic of Congo, and Cameroon. In many parts of the world such as this region of the Congo, ground surveys are impractical, so remote sensing provides one of the only ways to map natural and man-made features. Optical remote sensing techniques underlie efforts to

1 http://sciencebulletins.amnh.org.

describe both biodiversity and land cover change, so I was determined to teach audiences about the concepts underlying remote sensing. In the first figure below, you see six bands of data from Landsat 7, one of the main instruments that biodiversity researchers use to map remote regions of the planet.

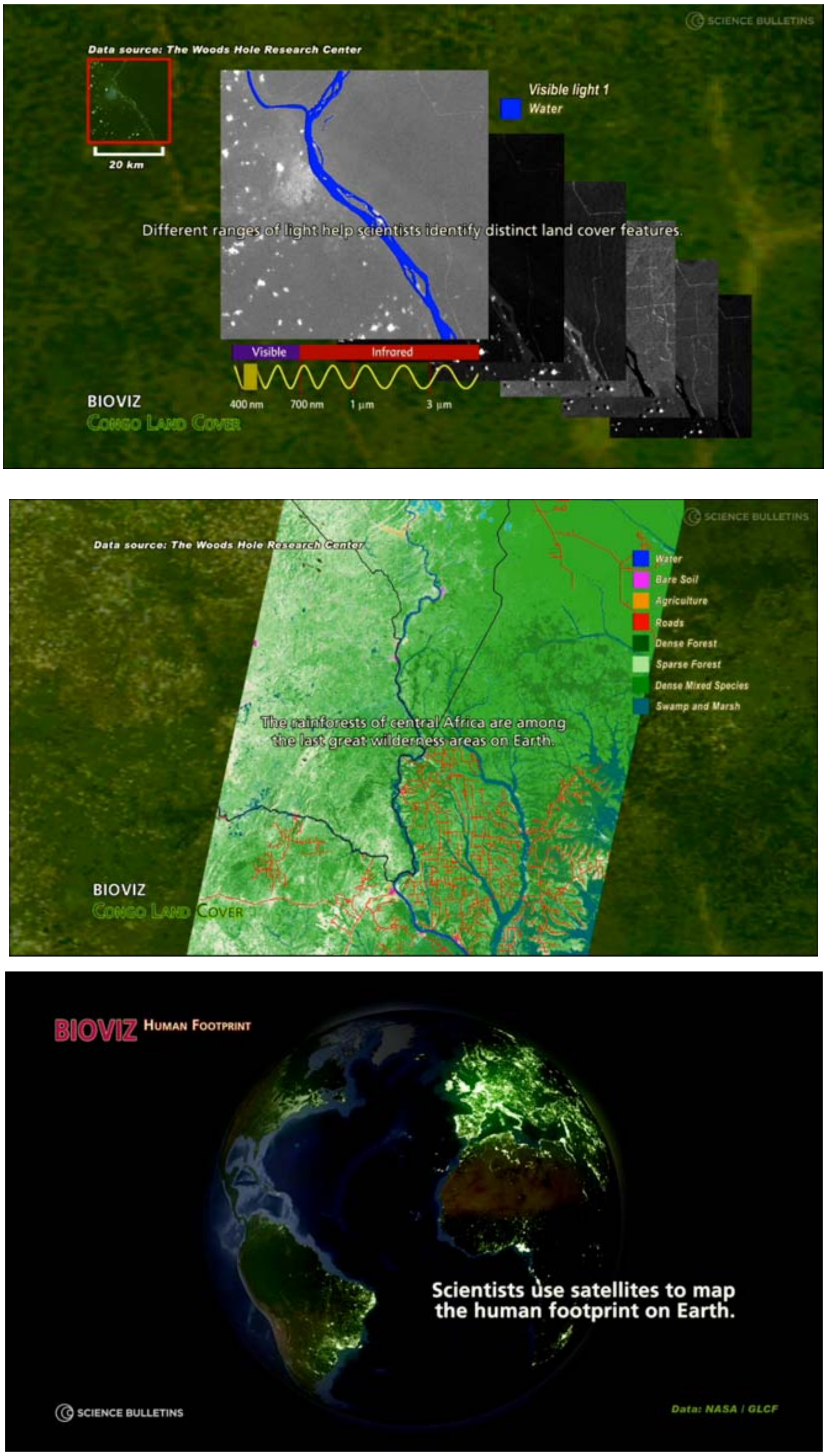



Figure 1. (a) Multispectral optical remote sensing data from Landsat 7 provided researchers information about (b) land cover and roads in Congo's rainforest. (c) Heat signatures from cities are detectable from space, and these data allow us to visualize the human footprint on a planetary basis.

The second figure (Figure 1b) shows a map produced by analyzing those data. We produced several visualizations similar to this one to explain how scientists use remote sensing to inform conservation efforts around the world. The third pane (Figure 1c) shows the distribution and influence of humans around the world based on thermal signatures from cities.

## Fire

Because of their comprehensive perspective, satellites are also used to map phenomena with a broad distribution but that are difficult to track because of their sporadic behavior. In the example depicted below (Figure 2), one can examine fires caused by lightning in boreal regions. Later in the video from which this image was extracted, one sees that people have changed fire regimes in the tropics, where fire is used to clear agricultural lands over large regions. Further, the piece explains that fires in northern California have become more deadly and costly in recent decades because people have built houses and moved into forested landscapes in California's arid, windy Mediterranean climate. This visualization about fire shows global, regional, and local examples of natural and human-altered fire regimes. More importantly, the visualization demonstrates in clear terms the relationship between land uses (i.e., tropical agroforestry or California suburbanization) and fire regimes around the planet. Geovisualization uniquely provides a window into phenomena occurring at multiple spatial and temporal scales.

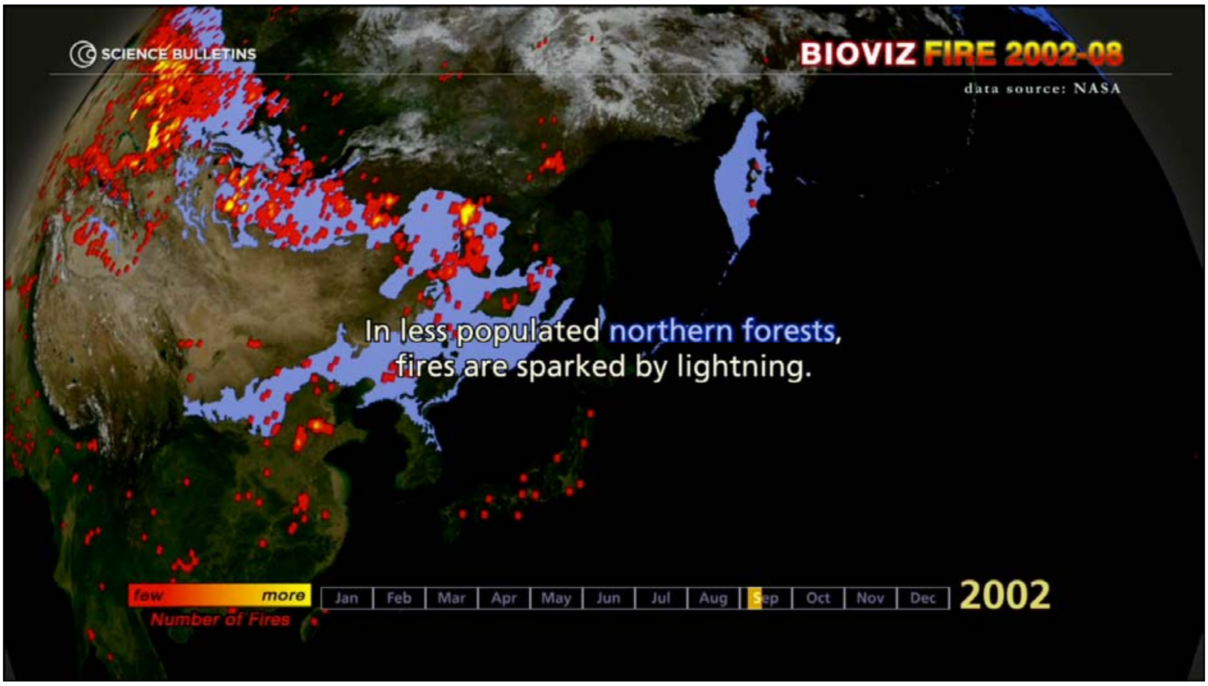



Figure 2. Satellites provide maps of fires daily basis and on a planetary scale. This visualization demonstrates several causes and effects of fires in three terrestrial biomes.

### *Net Primary Productivity*

The air humans and all other oxygen-requiring organisms breath derives from plants on land and in the ocean. How many people on the planet know this? Working with a graduate student in Switzerland and research groups at Oregon State University and the University of Montana, we compiled carbon dioxide uptake estimates based on remote sensing data from both land and ocean (Figure 3). Because those uptake rates share the same units, we were able to demonstrate to our audiences that land and ocean both produce oxygen. Furthermore, we demonstrated that plant carbon uptake rates vary with the seasons outside the tropics. Thus, boreal spring is offset by six months from austral spring. These two seasons are clearly visible in the greening up of the land and ocean. That greenup, representing carbon dioxide uptake by plants, is followed by a decrease in plant productivity several months after the greenup. Using a schematic representation of the Earth-sun relationship, we demonstrated that the seasons themselves are caused by Earth's tilt and consequent differential lighting in the northern and southern hemispheres.

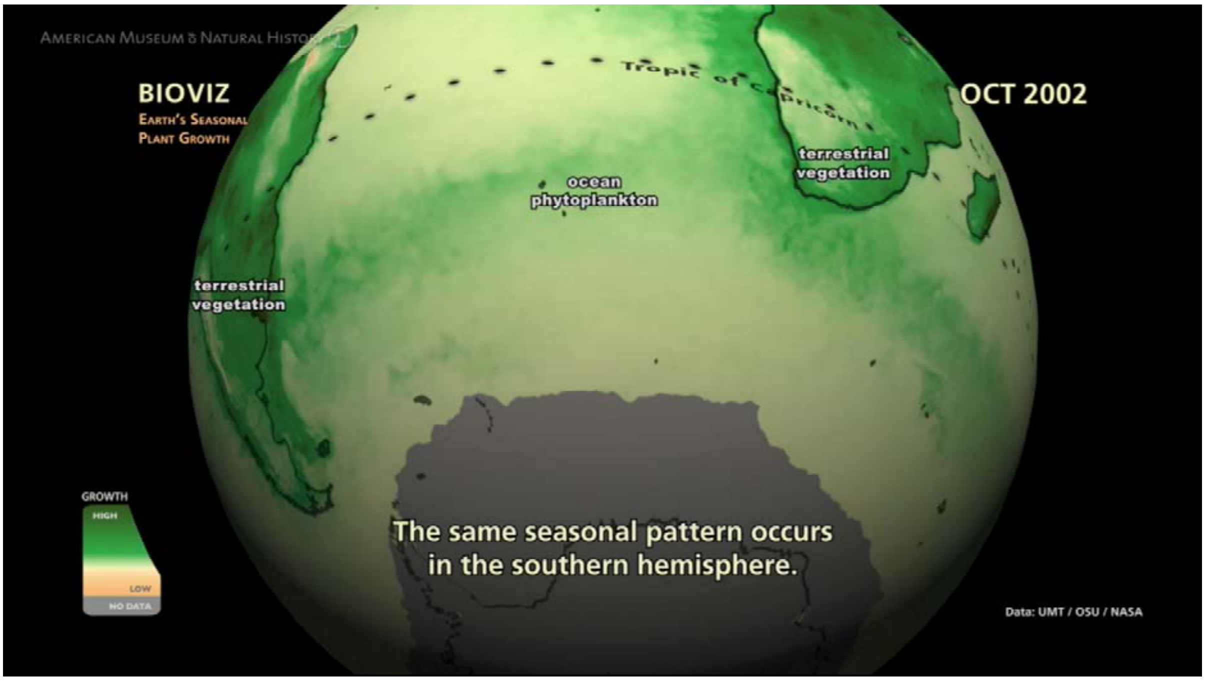



Figure 3. Plant productivity on land and in the ocean can be modeled based on satellite observations and represented using colors to depict rates of carbon uptake by photosynthesis.

## Lessons Learned

The Science Bulletins visualization program was successful because of its stable, end-to-end production process. We were able to work directly with other scientists to digest data, generate image sequences, interpret those images, render them artistically, and refine messages based on scientifically vetted concepts. Bringing together these diverse talents allowed the program to convey complex concepts and innovate methods in geovisualization. The Worldview Network intends to facilitate communication among many audiences. The examples from Science Bulletins demonstrate a functional model for producing content. The integration of scientific expertise into production is a useful benchmark for the Worldview Network.

*Reaching Out, Making Decisions*

Reaching decision makers will require that Worldview members innovate communication techniques. An efficient pathway for using visualization in climate change discussions is an end-to-end process whereby scientists perform data exploration with the same data and tools that policy makers use for discussing adaptation scenarios. If properly interpreted, these data and visualization products can be used to communicate through media outlets with broad, public audiences. Beyond visualization tools and techniques, we will need to evolve qualitative methods for communicating science concepts and adaptation strategies.

One interdisciplinary collaborative model is emerging from NOAA's Climate Program

Office. Our “Community Conversations on Climate” program brings together climate science experts, communicators, and community members to examine and discuss issues relevant to a given locality. The first event was May 9 in Phoenix, Arizona and focused on water in the desert southwestern United States. Using SCISS’ Uniview software, we worked with the Elumenati to build a visualization and lecture. The second Community Conversations on Climate event took place at the Chabot Science Center in Oakland, California October 10, 2009.

One of the most challenging aspects of explaining climate concepts to non-scientists is helping people understand vast time and space scales over which climate and Earth processes change. A practical way to contextualize spatial and temporal scaling is to navigate through the digital atlas of the universe. Zooming to the edge of the known universe and back to planet Earth allows one to speak directly to the vastness of space and the long duration of time over which the universe has been evolving.

Navigating back to a view of Earth, one may describe general circulation patterns before focusing on a more specific region. I described the sub-tropical high pressure ridge at 30 degrees north—the boundary between Hadley Cells and mid-latitude Ferrel Cells. This basic concept and global circulation patterns help explain aridity at this latitude, the predicted expansion of Hadley Cells with climate change, and predicted warming and drying. By first describing and emphasizing the processes that give rise to phenomena, it is possible to relate a variety of more specific features that arise from those processes. Once people understand the process of air circulation as we observe it today, they are more apt to understand how circulation patterns are likely to change in the future.

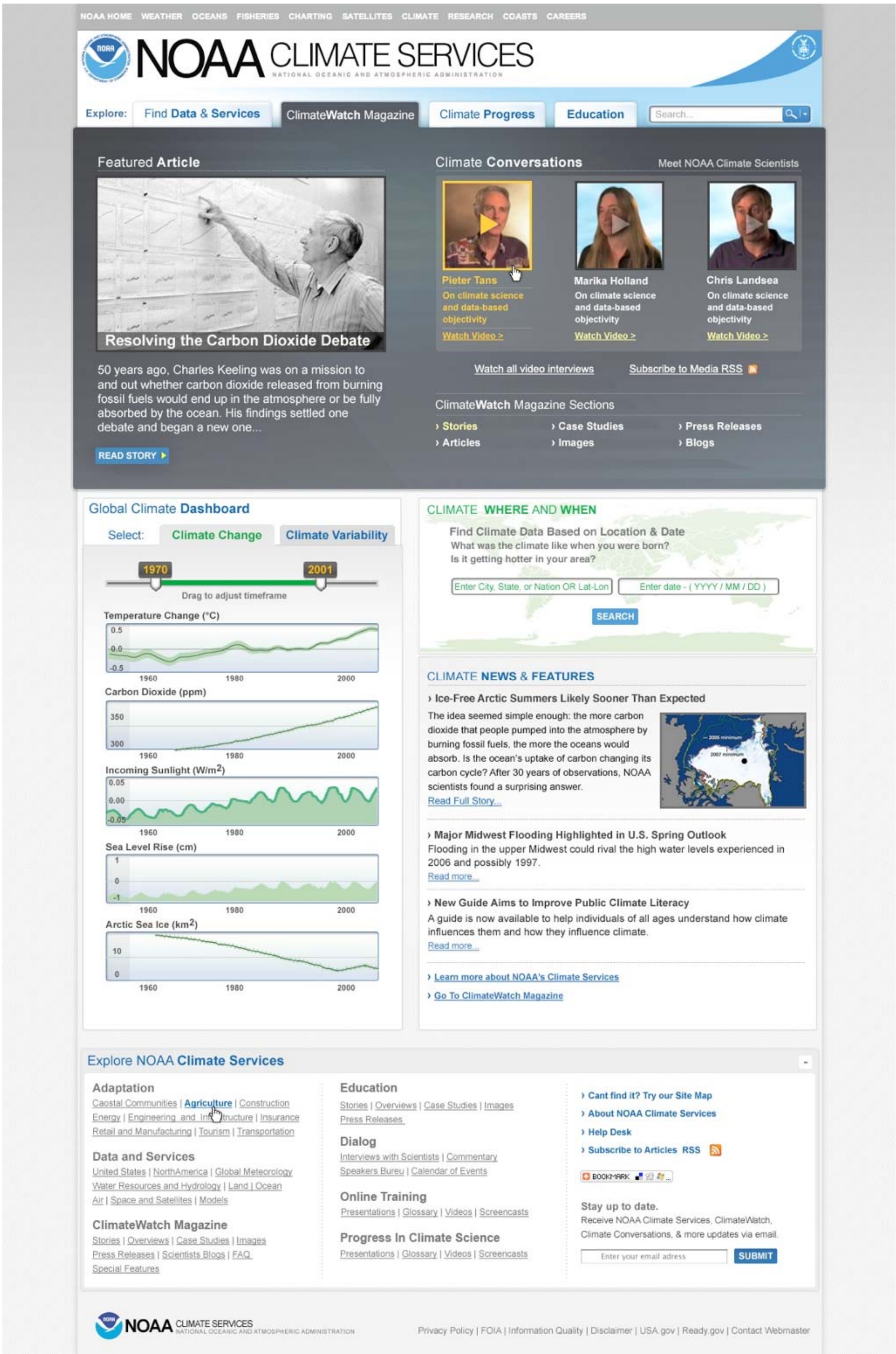
For Arizonans, past climate provides insight into wise precautions for adapting to future climate conditions. At our event on May 9, we focused specifically on water supply. Presenting tree core data, I showed how researchers from NOAA’s National Climatic Data Center have pieced together a 400-year record of water levels in the Colorado River, which supplies Arizona nearly half its fresh water. That reconstruction established that water was more available in the 20$^{th}$ century than at any time in the previous three hundred years. With population growing, groundwater withdrawal rates exceeding infiltration rates, and land uses generating ever more demand for water, citizens were eager to interact more with regional experts about the future of their water supplies.

## Access point: portal

There is increasing pressure for scientists to work with media, educators, citizens, business leaders, decision makers, and politicians to address societal responses to climate change. At NOAA, we will document the methods, data, and stories that help communities understand climate change effects on their own regions through the NOAA Climate Services Portal. This web site (Figure 4) will provide an outlet for the Worldview Network to share its own assets and examples.

### *Conclusions for WorldView*

WorldView’s visualization and communication strategy will incorporate diverse talents of physical, biological, and social scientists alongside media experts, artists, producers, and writers. Through their interaction, interdisciplinary team can render and articulate complex ideas. Participants in the network will clarify their communications objectives and target audiences and will innovate strategies for helping people grapple with and learn from concepts or ideas that may be unfamiliar or complex. The network will profit from successful examples but will necessarily forge new production and communications methods to establish its role as an honest broker of climate information that is simultaneously facile with bringing together citizens, decision makers, and scientists to engender collaborative solutions to the challenges brought by climate change.



# Biography

I am an ecologist trained in landscape ecology, geographic information systems, and remote sensing. Nearing graduation, I surveyed the efforts of my mentors and realized they spent about as much energy defending voiceless ecosystems as they did studying their intricacies and publishing papers that several hundred people on the planet would ultimately read. When offered an opportunity to help design and build a public program aimed at improving museum vistors' understanding of biodiversity and Earth system science, I realized this was perhaps a more direct route to improving humans' understanding of the processes that sustain us all. After several years invested in the production of high definition visualizations about biodiversity and Earth systems science, I shifted my attention to climate issues, where the world stage is set to focus and take action more aggressively than on other global change issues. Working as a contractor to the National Oceanic and Atmospheric Administration, I am now working to translate and clarify climate concepts, data, and services that the United States government generates and provides to the world.

# The Global Adaptation Atlas

Shalini P. Vajjhala and Daniel G. Spadaro

## Abstract

Climate change is a global problem that will likely contribute to a wide range of local environmental changes. Even if society averts the most severe projected impacts of climate change through long term reductions in $CO_2$ emissions, climate changes already underway will present challenges for sustaining livelihoods of communities around the world. Accordingly, adaptation will play a major role in addressing these human sustainability challenges. Decision makers need to understand which climate impacts are important in their region and what their options are for adapting well, to decide how money and resources should be allocated. The *Global Adaptation Atlas* is intended to enable this type of knowledge creation, sharing, and learning. As a web-based mapping application (in development), the *Atlas* will integrate interactive maps of the best-available science on climate impacts and the latest information on adaptation activities, provided free to the public.

## Introduction

### *What Is Adaptation?*

A new issue—adaptation—has recently begun to penetrate policy discussions on how to manage climate change. Even if mitigation successfully stabilizes global greenhouse gas emissions and averts the most severe predicted ecosystem effects of climate change, there will still be significant local and regional impacts on humans in many parts of the world. Impacts are expected to be especially severe in developing countries where populations rely on local natural resources, like the crops they grow and the fish they catch for their livelihoods, and may lack the capacity to respond to and recover from sudden or severe events (IPCC WG2 AR4, 2007)

Adaptation, the process of adjusting to changing environmental conditions, encompasses a broad set of activities designed to reduce human and ecosystem vulnerability to climate change and its potential long-term impacts. Interventions can range in scale and scope from small installations of rain water collection and drip irrigation systems to help farmers weather more severe droughts to national investments in dikes and levees to respond to sea-level rise (McGray et al. 2007). Adaptation remains a daunting challenge, requiring coordination at unprecedented scales from the local to global level across nearly all sectors of the economy and all types of ecosystems. In many cases, the countries and regions in greatest need of adaptation measures are the least equipped to develop, manage, and coordinate large-scale programs.

The global communities is slowly converging around international and national policy options for mitigation, and in parallel, large and small-scale funding mechanisms have emerged to spur investment in adaptation. However, the allocation of adaptation funding remains highly controversial, and limited lessons can be drawn from the decades of experience with mitigation policy design that can be adapted for adaptation policy and investment. The primary reason for this disconnect is a single fundamental difference between the problems of mitigation and adaptation: location, location, location.

*Adaptation Is A Spatial Problem*

Mitigation is a global problem, where emissions reductions anywhere provide benefits everywhere (Pacala and Socolow 2004). In sharp contrast, adaptation is a location specific problem, where responses must be targeted and relevant to the local context to be effective. As a result, the geographic location of key impacts, populations, and resources – where, whom, and how hard droughts, storms, or floods will hit – really matters. Current climate models are not well-suited to evaluate highly localized impacts or adaptation needs. Global assessments have typically been focused on macro-scale trends in natural systems, making it extremely challenging to assess local climate impacts, especially in developing nations. Nonetheless, decision-makers at all levels of government have begun to establish funding mechanisms for adaptation. The largest and most recent of these is the UNFCCC Adaptation Fund. It holds approximately $50 million dollars (USD), a figure that is expected to grow into the hundreds of millions over the coming decades. Yet significant disagreement exists about how to set allocation priorities and identify target areas for new investment. Given the risk of climate change to impacted communities, it is critical, starting now; to use the data we have to inform priorities for adaptation funding and early capacity building efforts, and strengthen the links between science, policy, and practice.

*Why Is Coordination of Climate Adaptation Efforts Important?*

Without careful coordination, we run the risk of investing in adaptation measures in one sector that could duplicate or negate investments in another sector both in the short-term and the long-term. For example, new rainwater collection reservoirs in areas affected by climate change could create large pools of standing water in areas more susceptible to breeding of mosquitoes, which in turn could undercut public health interventions targeting outbreaks of malaria or dengue fever, by changing local exposure to mosquito-borne diseases. As a result, stakeholders not only require information on how the local climate is anticipated to change, but also information on what others in the region and around the world are doing in response. Right now, no central clearinghouse exists for these kinds of data.

*How Can Mapping and Visualization Help Address The Problem?*

Adaptation policy design is a fundamentally spatial problem. The geographic locations of populations, resources, and impacts are central to the decisions being made. Geography is one of the few common threads connecting the science on climate impacts to programs and policies designed to promote adaptation. Therefore, mapping can play a central role in building and maintaining the essential linkages between science, policy, and on-the-ground practice.

## The Atlas: A visualization Solution

We are in the process of developing a web-based digital "atlas" on global adaptation, with maps of the best-available science on climate change impacts and up-to-date information on adaptation activities. Our aim is to use existing GIS (Geographic Information System) software on a web based application platform to layer relevant demographic and natural resource data, just as it is now possible to cue up an existing map and add terrain and satellite information. The real-time information displayed online would allow decision-makers ranging from the leader of a small farming cooperative to the international donor to visualize what impacts are likely to affect their region, what activities are already underway, and what gaps need to be filled with new adaptation activities and measures.

For example, a foundation program officer in Mali working on supporting irrigation systems for agriculture and a local health official concerned about the spread of dengue in the same area would both be able to view the potential impacts of climate change on agricultural productivity and disease spread in the country and across a wider region of West Africa. The public health specialist could address risks of mosquito breeding created by new irrigation ponds or channels and compare locations of new disease vectors against the existing. All would receive tailored feedback from the Atlas on local, regional and global best practices for similar types of projects and relevant parallel efforts.

At a larger scale, for example, program officers at the Gates Foundation, staff at the WHO, and Adaptation Fund staff at the Global Environment Facility (GEF) could search projects to view their own and other current grants in a sector or geographic area to identify opportunities for coordination, anticipate unintended consequences of existing projects, and set priorities for new programs and investments.

*Atlas Design, Structure, and Visualization Principles*

To meet the multiple coordination challenges associated with adaptation, the Atlas will consist of four key building blocks aligned with the following objectives:

1. Synthesize peer-reviewed science on climate impacts
2. Support rigorous data collection and mapping of adaptation projects on the ground
3. Create a tailored outreach vehicle displaying gaps and overlaps (hotspots) of impact and inaction and facilitate dissemination of local and global best practices
4. Sustain long-term monitoring, evaluation, and priority-setting through the development of a spatial data archive

*Building Block 1: Synthesizing Science on Impacts*

The existing body of climate science on human system impacts is very coarse and limited; however, scientists around the world are making strides in creating finer-grained regional and local assessments of impacts and integrating these data across multiple sectors ranging from health to water. To organize the enormous amount of natural and social science information available on climate change impacts, we are compiling climate impact data under five major themes: food, water, land, health, and livelihood. These themes are intended to serve as an organizing framework for evaluating the effects of climate change on natural and human systems and identifying strategies to manage impacts.

The first phase of developing the Atlas involves collecting peer-reviewed data on various climate impacts for specific climate scenarios and layering this data in the online mapping software. The challenge in this phase has been to establish a structure for making robust and transparent decisions about which impacts should be included, at what scales, and for which parts of the world. Other issues include how to avoid missing or double-counting specific impacts across sectors, how to consider multiple-stressors, and how to address model uncertainty associated with system feedbacks.

*Building Block 2: Mapping On-the-Ground Adaptation Projects*

In addition to layering maps of climate impacts, it is essential to gather information on adaptation activities intended to manage and reduce these impacts at various scales – from the community level to the multi-national level. The second building block centers on facilitating the process of collecting data on adaptation activities around the world using an online survey mechanism. Projects to be entered into the Atlas will first be solicited drawn from existing databases of relevant adaptation programs and funds (Hicks et al, 2008) to form a broad, searchable database of adaptation activities over time. The resulting entries can then be overlaid onto maps of climate impacts to illustrate hotspots of impact and inaction (See figures 1, 2, 3 and 4).

This very simple description illustrates how one can begin to visually survey and map adaptation activities on the ground. Our goal is to aggregate and display, at a high level of detail, the locations of specific adaptation projects and the areas they are intended to serve. Envision a collection of thousands of points and areas plotted alongside one another across the world, allowing users to see gaps and overlaps in the types, sizes, and locations of projects relative to key climate impacts. Atlas entries would be regularly updated and solicited using a carefully designed and deployed online survey inviting development practitioners, donors, and program managers to enter descriptive information (sector, size, location, population served, funding source, project timeline, etc.) about their past projects and ongoing programs. With this online system, we aim to overcome the hurdle of conducting repeated and fragmented paper surveys and assessments. As the Atlas database of adaptation projects around the globe grows, it can be filtered and sorted in order to analyze patterns of adaptation investment over time and evaluate their relationships to expected local climate impacts.

*Building Block 3: Creating a Tailored Outreach Vehicle*

The process of conducting online surveys to collect information about adaptation activities opens the door to the third component of the Atlas: outreach and dissemination. A major feature will be real-time outputs tailored to each entry/user on related local and regional efforts and relevant global best-practices for similar types and sizes of projects. A user who enters information (or searches for projects) on micro-insurance programs for small farmers in Mali would be able to view collections of information on projects in the same sector within the same local coverage area in Mali, projects in different sectors (water, health, etc.) in Mali or across West Africa, and projects of similar type and size across the world.

This structured and tailored approach will allow practitioners to rate projects in a large, searchable database for best practices and lessons offered. Because adaptation is both a process and an outcome, capacity building is a fundamental component of promoting successful adaptation. This approach to outreach and education can help build awareness and shape early adaptation measures.

*Building Block 4: Sustaining Long-term Monitoring and Evaluation*

The goal of the final component of the Atlas is to establish a robust platform for monitoring and evaluation. By creating a spatial data archive, the Atlas will support visualization and analysis of areas around the world where data (science) on climate impacts is inadequate, policy action is lacking across regions and sectors, and adaptation-related decisions and activities have the potential to duplicate or negate one another in the absence of coordination.

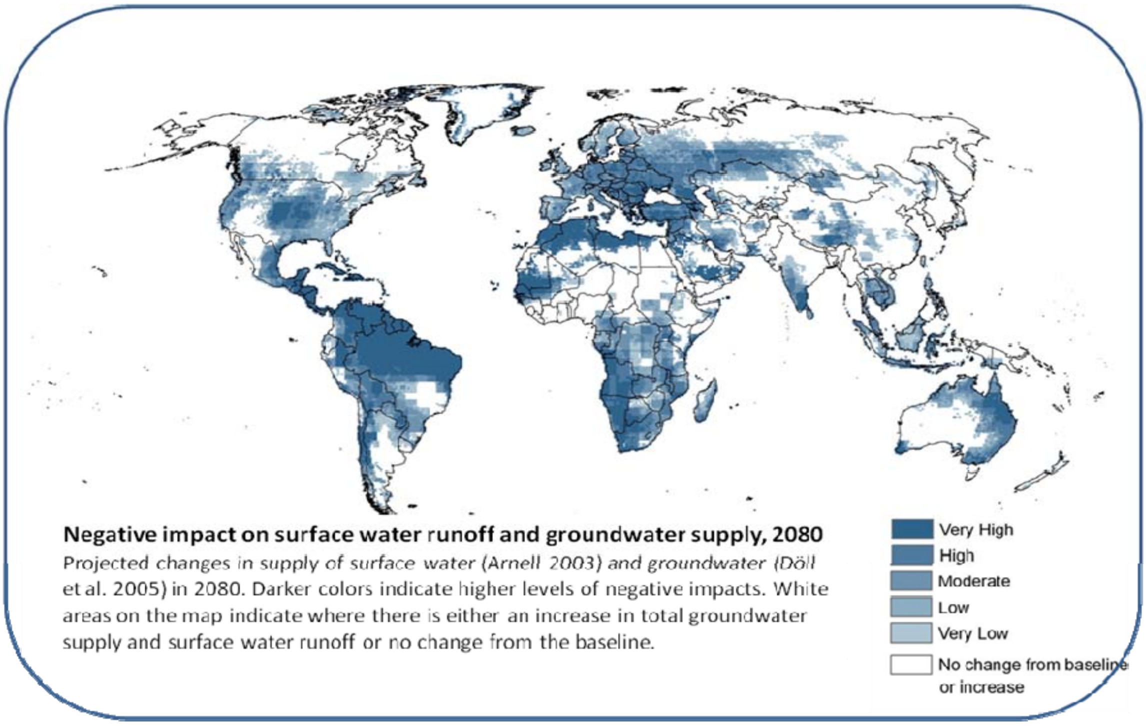
Because it will be made publicly available, this archive also has the potential to support monitoring and assessment activities for local adaptation projects and policies. In addition, the database can be used to help monitor large-scale adaptation funds controlled by international bodies, national governments, the philanthropic community, and the private sector in concert with one another. Monitoring, assessment, and evaluation are critical challenges when it comes to adaptation. The eventual goal of any adaptation measure is to prevent adverse impacts from climate change. As a result, defining and measuring success will depend on having a clear baseline to be able to effectively evaluate both progress and delays.

## Summary

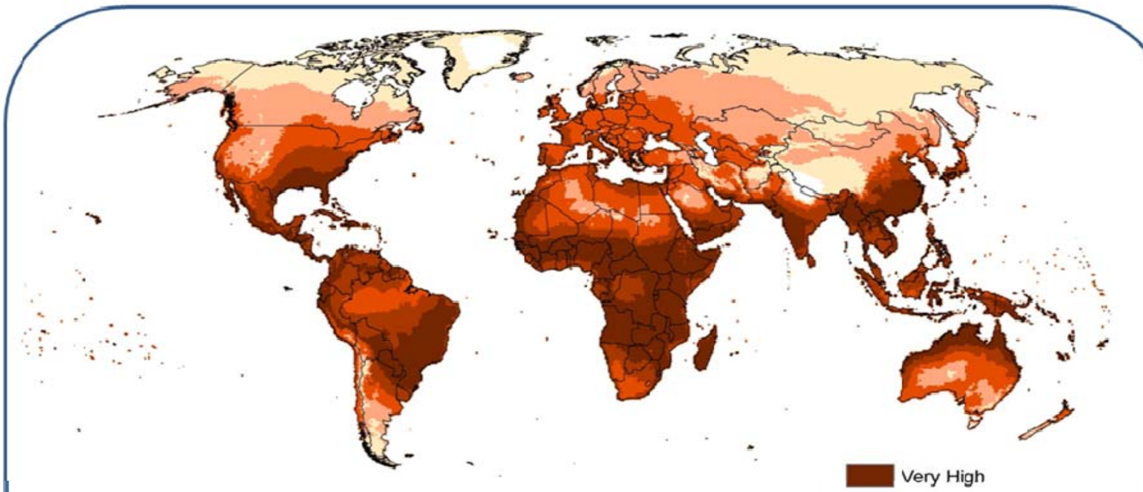
The first phase of the Atlas consists of a one-year application development effort targeted for completion in December 2009. During this year, data and program partners have been established to guide the development of the Atlas and help secure its adoption. In parallel, compilation of climate impact data and adaptation activities are being integrated into the initial application prototype. Phase one will conclude with the launch of a beta-version of the Atlas at the UN Climate negotiations in the 15th Conference of the Parties in Copenhagen in December 2009.

As climate change impacts become evident around the globe, coordinating adaptation activities will become increasingly challenging. The *Atlas* and its map based design for collecting and visualizing projected climate impacts and current adaptation data, is targeted to enable centralized access to diverse data, presented in a visual, easy to understand format, to assist decision makers in allocating climate funds and resources where needed.

**Figures:** Three individual climate impact layer maps generated with the Atlas system and a fourth composite map showing the overlay of the 3 individual layers and the "hot spots" or regions of converging climate impacts that result.

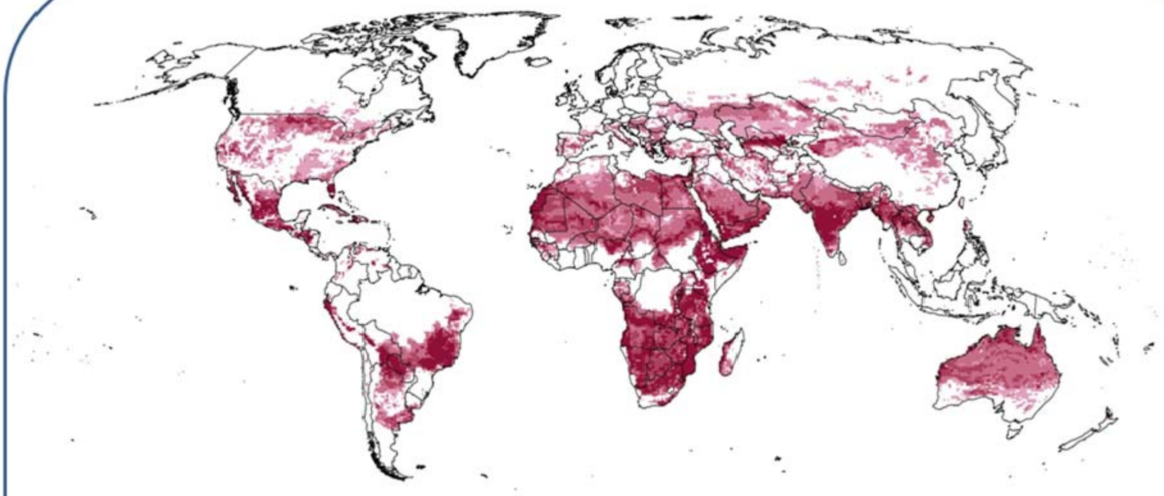



**Negative impact on surface water runoff and groundwater supply, 2080**
Projected changes in supply of surface water (Arnell 2003) and groundwater (Döll et al. 2005) in 2080. Darker colors indicate higher levels of negative impacts. White areas on the map indicate where there is either an increase in total groundwater supply and surface water runoff or no change from the baseline.



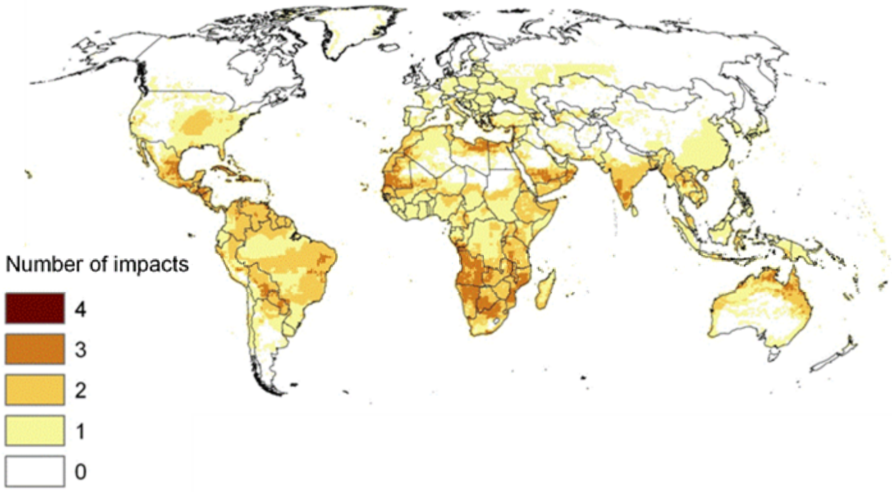

**Increase in probability of dengue fever epidemic, 2080**

Projected increase in probability of a dengue fever epidemic (Hales et al. 2002) i 2080. Darker colors indicate a greater increase in the probability of an epidemic from current levels. White areas on the map show where there is either a decrease in the probability of an epidemic or no change from the baseline.




**Decrease in total number of "good" days per month for tourism, 2080**

Projected estimate of climate-induced loss of total days suited for tourism in 2080 (Amelung et al. 2007). Darker colors indicate greater decrease in the length of the tourism season. White areas on the map indicate where there is either an increase in the total number of "good" days or no change from the baseline.




**Sample overlay map of selected negative climate impact "hotpots," 2080**
Number of impacts in the "high" and "very high" categories in each 1-km grid cell for four major climate impacts: 1) Water: decrease in surface water runoff and groundwater supply, 2) Land: loss due to a 1-meter sea level rise (CRESIS Database), 3) Health: increased probability of dengue fever epidemic, and 4) Livelihood: decrease in number of days suitable for tourism (Vajjhala and Nackoney, in prep).

## References

Hicks, R. L., Parks, B. C., Tierney, M. J., Roberts, J. T., Greening Aid? (2008). Understanding the Environmental Impact of Development Assistance, Oxford University Press.

IPCC, WG2,AR4,Climate Change 2007-Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the IPCC,978 0521 88010-7, Hardback 978 0521 70597-4, Paperback, 2007.l

McGray, A., Hammill, A., R. Bradley, R., E. L., Schipper, E. L., Parry, J. E.. (2007). Weathering the Storm: Options for Framing Adaptation and Development, World Resources Institute.

Pacala, S., Socolow, R. (2004). Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies, *Science* 305 (5686), 968. [DOI: 10.1126/science.1100103].

## Biography

**Shalini Vajjhala** is a Fellow at Resources for the Future and the leader of the Atlas project. Her research focuses on the social impacts of large-scale development and environmental policies with critical public participation components. She has worked extensively on integrating and applying participatory mapping methods and Geographic Information Systems (GIS) technology to diverse issues including climate change adaptation, environmental justice regulation, renewable energy siting, and carbon sequestration risk management. Shalini holds a Ph.D. in Engineering and Public Policy from Carnegie Mellon University. Prior to joining RFF, she worked as an architect, community organizer, and design instructor in Pittsburgh**.**

**Dan Spadaro**, a Vice President in the Technology Division at Goldman Sachs, joined the RFF team through the Goldman Sachs Public Service Program, for one year beginning December 2008, as the full-time Strategic Leader of Technology on the Atlas project. He is a technology professional with over 20 years experience supporting various industries and technologies, with the last 12 years primarily focused on the design, implementation, and support of systems technology infrastructure for financial applications at firms including Morgan Stanley, Deutsche Bank, and Goldman Sachs. Dan holds a B.S. in Engineering Science with concentration in Electrical Engineering/ Computer Science and is currently completing an M.S. in Environmental Science focusing on climate change.

# The Planet Simulator:
## A Coupled System of Climate Modules with Real Time Visualization

Edilbert Kirk, Klaus Fraedrich, Frank Lunkeit and Carmen Ulmen

## Abstract

The Planet Simulator is a **M**odel of **I**ntermediate **C**omplexity (MIC), suitable for climate and paleo-climate simulations and time scales up to ten thousand years or more. It runs on a wide range of hardware and operating systems including massive parallel cluster and workstations with UNIX, Solaris, Linux, MAC OS or any other UNIX style operating system. The priorities in development are set to speed, easy handling and portability. Its modular structure allows a problem dependent configuration. A graphical **Mo**del **St**arter (MoSt) can be used to select a model configuration from the repository, set its parameters, compile and run the model. The model can be run either in production mode for maximum performance or in interactive mode using a **G**raphical **U**ser **I**nterface (GUI). This GUI is both a real time visualization interface for all model variables and a tool for tuning and experimenting with the model.

## Introduction

For more than two decades climate research centres have been developing comprehensive general circulation models (GCMs) of high complexity, mostly for their research interests. As the complexity of these models has been and still is growing considerably on their way to Earth system models, it is not surprising that, for both education and research, models simpler than those comprehensive models at the cutting edge of the development, are becoming more and more attractive: They run fast and can be used to simulate millennia and longer time spans in relatively short real time. They can use inexpensive hardware like workstations with no need to buy time on mainframes. They may be reconfigured for simulating environments that are far away from our present climate and even atmospheres of other planets or moons. The diagnostic of the simulation is easier with fewer interactions occurring in the model. Finally, the understanding of atmospheric or climate phenomena and the identification of mechanisms is enhanced. The Planet Simulator is:

- **modular** – problem dependent configuration
- **parallel** – parallel computer and networks
- **scalable** – horizontal and vertical resolution
- **portable** – hardware independent code
- **interactive** – graphical user interface
- **structured** – clearly arranged and commented
- **open source** – freely available source code
- **compatible** – supports standard data formats like NetCDF and SERVICE

Applying a model like the Planet Simulator in a university environment has various aspects: First, the code must be open and freely available and also the required libraries; it must be user friendly, inexpensive and equipped with a graphical user interface. Second, it should be a flexible and universal tool to be used by researchers designing their own experiments. Third, it should be suitable for teaching project studies in classes or lab, where students practice general circulation modelling, in contrast to technicians running a comprehensive GCM.

The Planet Simulator includes, besides an atmospheric GCM of medium complexity, other compartments of the climate system, for example, an ocean with sea ice, a land surface with biosphere, etc. The source code of the Planet Simulator is portable to many platforms ranging from personal computers to workstations and mainframes; massive parallel computers and clusters of networked machines are also supported. The system is scalable with regard to vertical and horizontal resolutions, provides experiment dependent model configurations, and it has a well readable and rich documented code.

# Model Overview

GCMs consist of a dynamical core based on the first principles, parameterizations for the unresolved processes and representations of the climate subsystems. In the following these modules are briefly presented for the Planet Simulator. A more comprehensive description may be found at "www.mi.uni-hamburg.de/plasim".

### *Dynamical Core*

The dynamical core of the Planet Simulator is based on the moist primitive equations representing the conservation of momentum, mass and energy, which are the:

- prognostic equations for the vorticity and the horizontal divergence
- first law of thermodynamics
- equation of state
- continuity equation
- prognostic equation for water vapour (specific humidity)

The equations are solved numerically on a terrain following $\sigma$ -coordinate system (where $\sigma$ is the pressure normalized by the surface pressure). In the horizontal direction, the conventional spectral approach with the spectral transform method is applied (Orszag 1970; Eliasen et al., 1970). Finite differences are used in the vertical with the vertical velocity being defined between the 'full' (temperature, moisture, vorticity and divergence) levels. The equations are integrated in time by a leapfrog semi-implicit time stepping scheme (Hoskins and Simmons, 1975; Simmons et al., 1978) with Robert/Asselin time filter (Robert 1981; Asselin 1972).

### *Parameterizations and Subsystems*

The effect of unresolved processes is included by simplified parameterizations for boundary layer fluxes and diffusion, radiation and moist processes with interactive clouds. The interaction with other climate subsystems is enabled by adding modules for land-surface processes, vegetation, ocean and sea ice. The parameterization schemes are documented in detail in (Lunkeit et al. 2007).

# Graphics

The graphical user interfaces simplify the task of setting up experiments, modifying boundary values and resolution, setting essential model variables, and running the simulation.

### *The Graphical Model Starter*

The Planet Simulator may be used in the traditional fashion with shell scripts, batch jobs, and network queuing systems. This is usually done for long running simulations on complex machines and mainframes, like vector-computers, massive-parallel-computers and workstation clusters. There is now, however, a much more convenient method by using a graphical user interfaces. The Planet Simulator is configured and setup by the tool MoSt

(Model Starter, screenshot in Figure 1). MoSt is the fastest way to get the model running. It gives access to the most important parameters of the model preset to the most frequently used values. The model can be started by a mouse click on the button labelled 'Save & Run' either with the standard parameter setting or after using the built-in parameter editor in the MoSt window. These parameters set horizontal and vertical resolution, select modules and choose boundary conditions. Depending on all settings MoSt generates a run script for the simulation. The user has the choice of leaving MoSt and continue with the simulation under control of the runtime GUI, or exiting MoSt for further work on the simulation setup within the run directory.

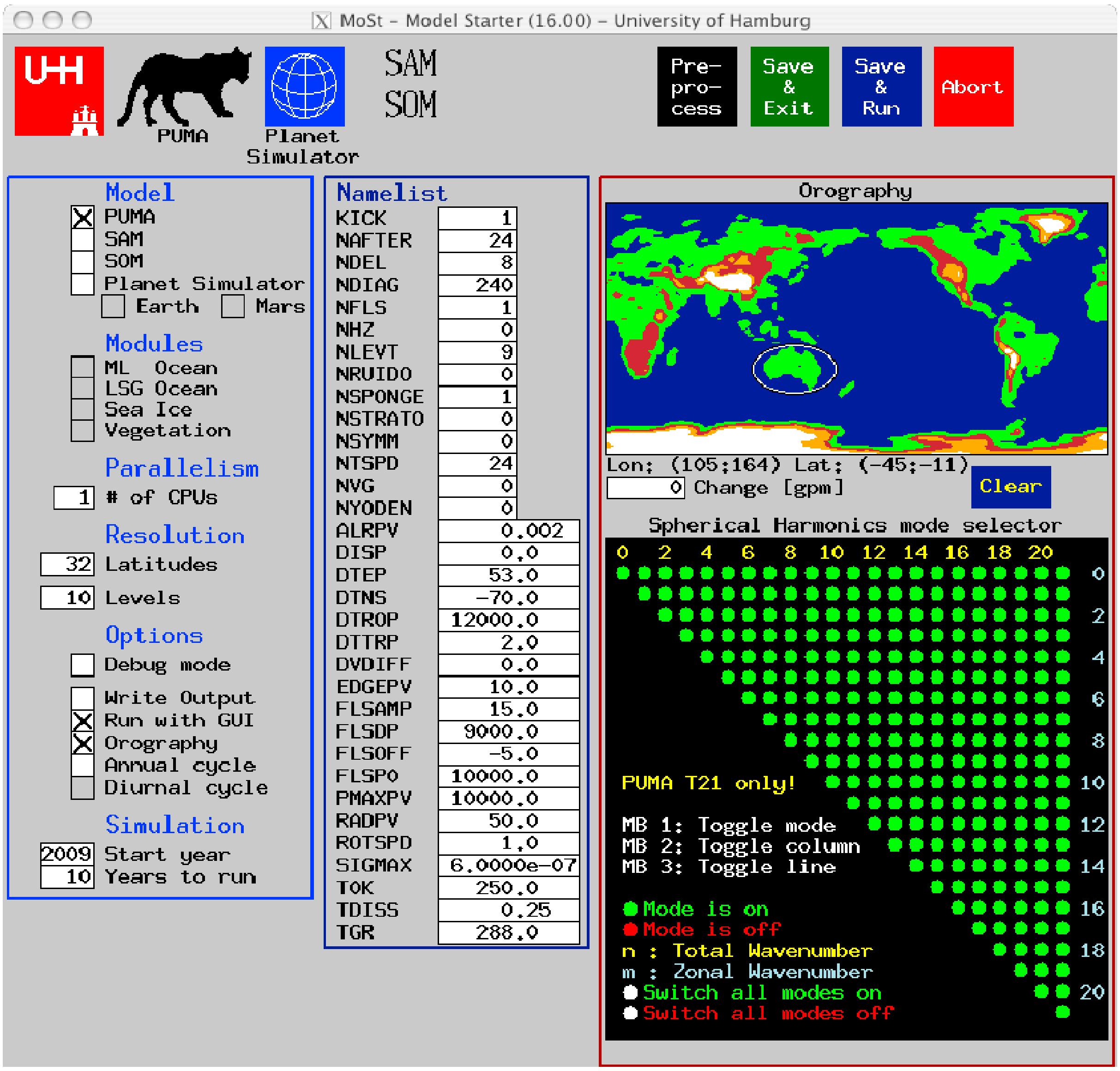



Figure 1. Screenshot of the Model Starter (MoSt) with model and parameter editor, orography editor, and mode selector for enabling/disabling modes of Spherical Harmonics.

### *The Graphical User Interface*

The Planet Simulator can use a two-way interactive GUI (screenshot in Figure 2). The state of the model variables and arrays are displayed in common representations, like:

- zonal mean cross sections
- horizontal fields in cylindrical or polar projection

- time-longitude (Hovmoeller) diagrams
- longitude-height diagrams
- particle tracer moved by the horizontal wind components
- time series
- numerical values

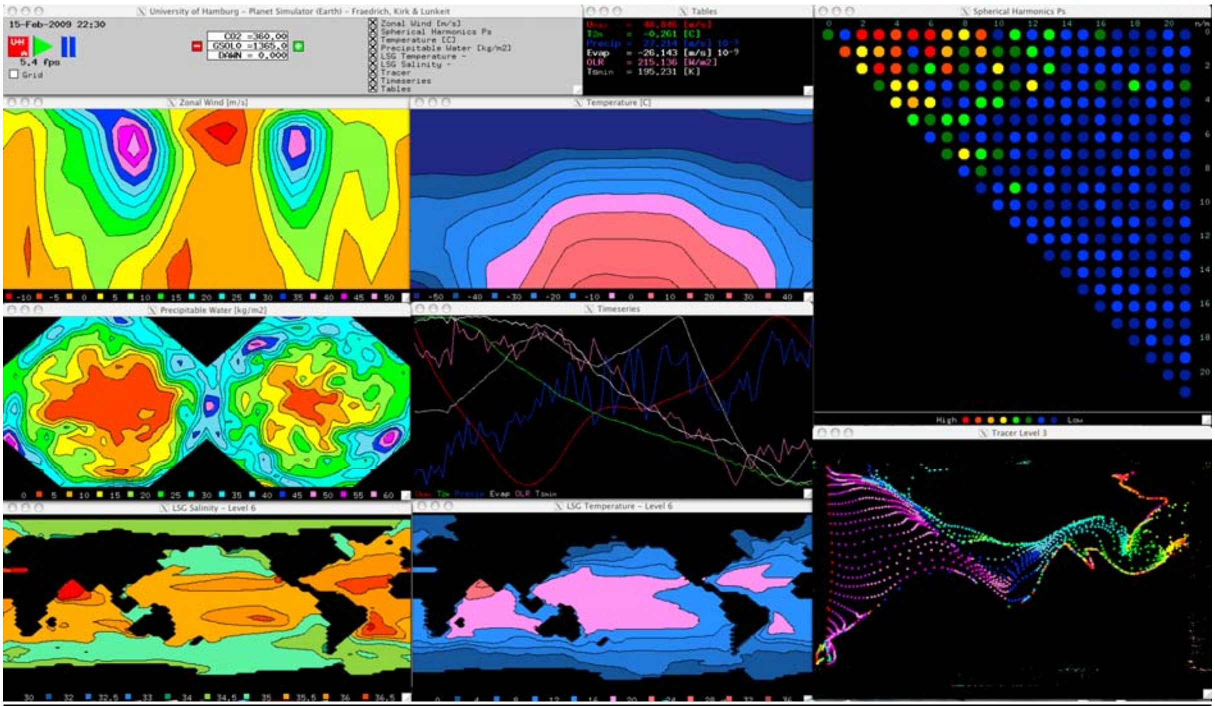



Figure 2. Screen shot of an example layout of the graphical user interface with: a Control window (upper left), b Numerical display of scalar variables(upper middle), c Amplitudes of modes of spherical harmonics for surface pressure (upper right), d Zonal mean cross section of zonal wind (2nd. row left), e Zonal mean cross section of temperature (2nd. row middle), f Precipitable water in polar projection (3rd. row left), g Time series of scalar variables (3rd. row middle), h Salinity of the ocean model (bottom left), i Temperature of the ocean model (bottom middle), j Particle tracer.

Every window can be switched on or off and placed and zoomed by the user. Figure 3 shows a zoomed particle tracer window as an example.

The second purpose is the interaction part of the GUI, which allows the user to change selected model variables during model run. That is, it is not necessary, though possible, to pause the model while changing variables. All model fields or even fields received via coupling from other models can be put on the GUI display.

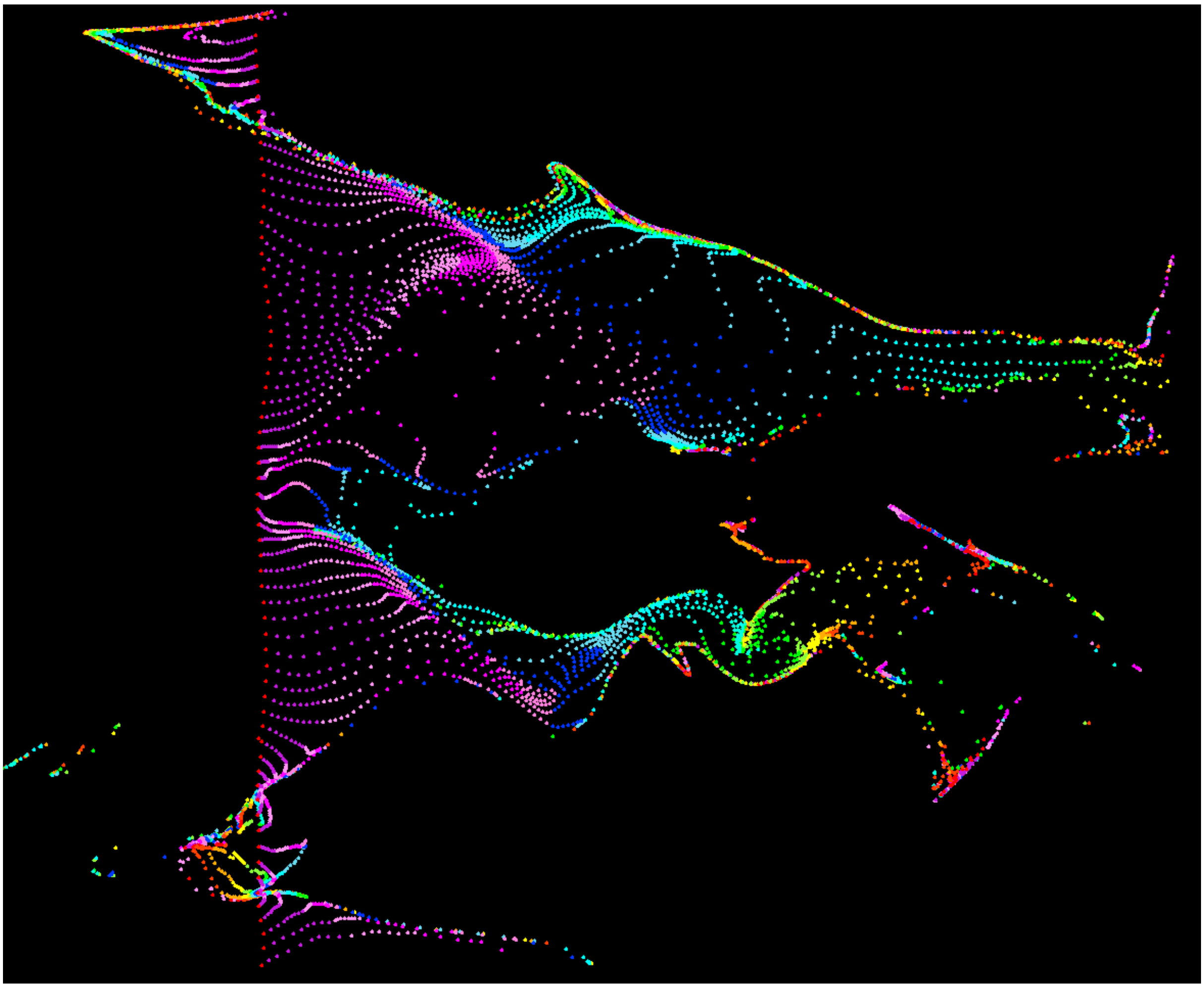


Figure 3. Screenshot of the GUI window "Particle Tracer" showing the movement of particles during the first month after starting the model from a state of rest. The particles are inserted at longitude 180 degrees and the height of 300 hPa. Westerly winds displace particles eastward to the right.

### *Graphics Library and Networking*

Both MoSt and GUI are implemented using the Xlib (X11R5), which is a library of routines for graphics and event communication. As this library is part of every UNIX/Linux operating system and base of all desktop environments, there is no need to install additional software for running MoSt and GUI. Another important property of Xlib is the full network transparency. The display of MoSt and GUI is not locked to the machine running the programs or the model. In fact, the best performance is obtained in running the Planet Simulator on several cores of a remote server while displaying the GUI on the user's workstation. The MoSt and GUI programs automate many tedious tasks, minimize the time to become familiar with the Planet Simulator, and make testing and parameter tuning much easier.

### *Diagnostics and Offline Visualization*

The output of the model is compatible to common data standards, which allows choosing from a huge base of diagnostic programs and visualization tools. Figure 4 shows a screenshot of an offline animation done with the software Avizo. The complete animation can be downloaded or viewed at [http://www.mi.uni-hamburg.de/6472.0.html](http://www.mi.uni-hamburg.de/6472.0.html).

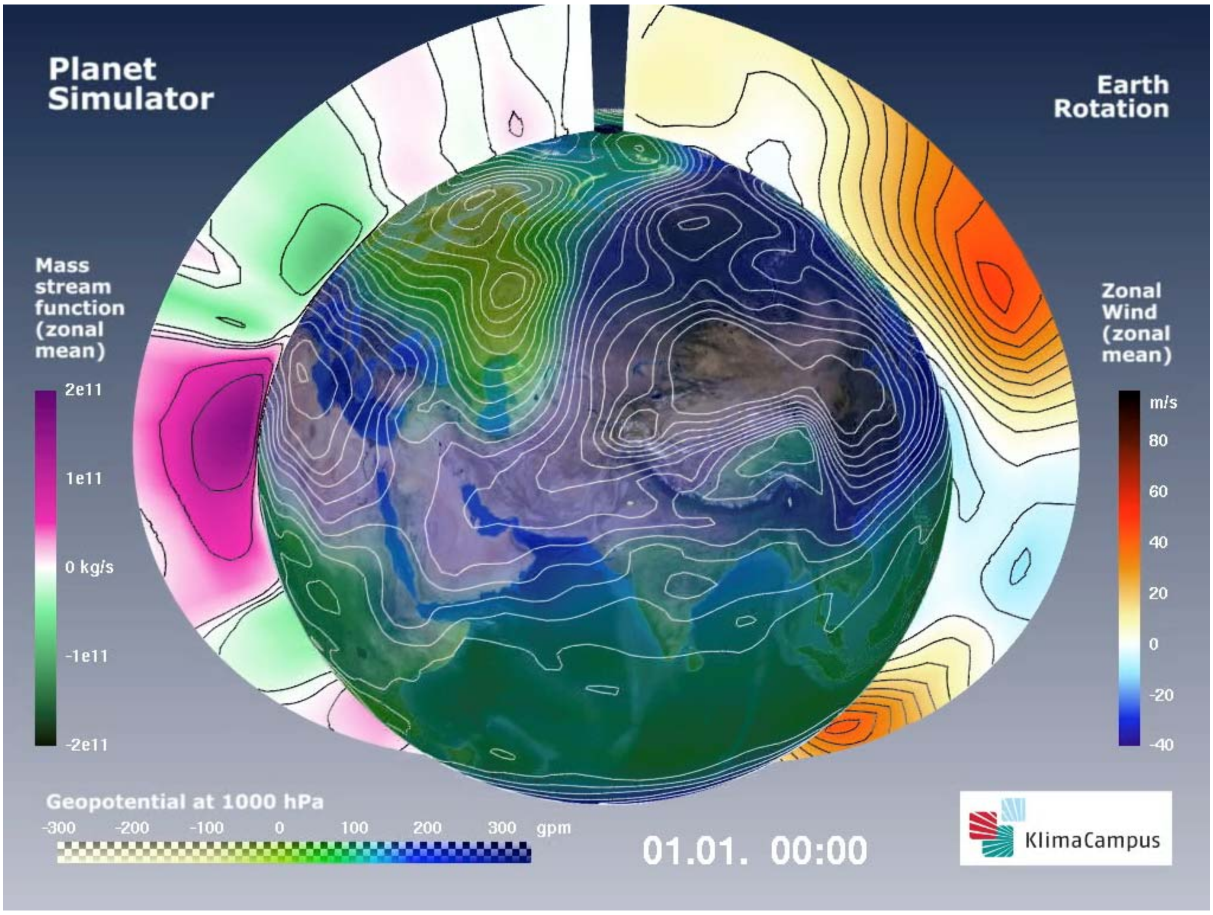



Figure 4. Screenshot from a movie created from model output showing three variables (geopotential height, mass stream function, and zonal wind) in one animation. This is an example of visualization that is not done in real time, but after completion of the simulation.

## Summary and Outlook

The Planet Simulator represents the top model in a hierarchy of global spectral circulation models; other members of this hierarchy are the Portable University Model of the Atmosphere (PUMA), the Shallow water Atmosphere Model (SAM), and the Spectral Ocean Model (SOM) see http://www.mi.uni-hamburg.de/6.0.html. The Planet Simulator supports numerical experiments for understanding the dynamics of the climate of the Earth and Earth-like planets and moons of the solar system. In this sense the Planet Simulator can be used as a simplified virtual laboratory to study the fundamental dynamical and thermo-dynamical issues, to identify feedbacks responsible for the long-term stability of the climate, and explore the causes of sudden losses of stability or abrupt change, like the impact of volcanic eruption, the consequences of a thermohaline circulation breakdown, long-term variability, extremes, etc. Unique features of the Planet Simulator are the graphical user interface and the Model Starter. The Planet Simulator should be considered as an open system in transit based on a dynamical core of the primitive equation atmosphere in the traditional spectral form and sigma coordinates. Given the set of modules, a basic platform for the Planet Simulator is achieved but, more modules are certainly needed to complete it, including, for example, continental ice sheets, more realistic land and marine biospheres, geo-chemical cycles, etc. To test sensitivities or to create super ensemble forecasts, different modules of the same processes may also be useful. Fundamental research in atmospheric physics and dynamics, non-linear analysis and stochastic dynamics may be performed, now allowing for a more complete model hierarchy approach. A first application, comparing a green planet with a desert world, is presented in (Fraedrich et al. 2005).

## Acknowledgements

Some contributions to the Planet Simulator have been provided by Heiko Jansen (sea ice module) and Axel Kleidon (vegetation module). The initial phase of the Planet Simulator development was supported by the BMBF during the years 2000 - 2003. The current development is supported by the excellence cluster CLISAP by means of scientists and compute- and data-servers.

## References

Asselin, R. (1972). Frequency filter for time integrations, *Monthly Weather Review.* 100, pp. 487–490.

Eliasen, E., B. Machenhauer, E. Rasmusson, (1970). On a numerical method for integration of the hydrodynamical equations with a spectral representaion of the horizontal fields, *Institute of Theoretical Meteorology*, University of Copenhagen.

Fraedrich, K., H. Jansen, E. Kirk, F. Lunkeit, (2005). The Planet Simulator: Green planet and desert world, *Meteorologische Zeitschrift*, 14, pp. 305–314.

Fraedrich, K., E. Kirk, U. Luksch, and F. Lunkeit, (2005). The Portable University Model of the Atmosphere (PUMA): Storm track dynamics and low frequency variability, *Meteorologische Zeitschrift*, 14, pp. 735–745.

Hoskins, B. J., A. J. Simmons, (1975). A multi-layer spectral model and the semi-implicit method, *Quarterly Journal of the Royal Meteorological Society*, 101, pp. 637–655.

Lunkeit, F., M. Böttinger, K. Fraedrich, H. Jansen, E. Kirk, A. Kleidon, U. Luksch, (2007). Planet Simulator Reference Manual Version 15.0. Available at http://www.mi.uni-hamburg.de/fileadmin/files/forschung/theomet/planet_simulator/downloads/PS_ReferenceGuide.pdf.

Orszag, S. A. (1970). Transform method for calculation of vector coupled sums, *Journal of the Atmospheric Sciences,* 27, pp. 890–895.

Robert, A. J. (1981). A stable numerical integration scheme for the primitive meteorological equations, *Atmos. Ocean* 19, pp. 35–46.

Roeckner, E., K. Arpe, L. Bengtsson, (992). Simulation of present-day climate with the ECHAM model: Impact of model physics and resolution, *Technical Report* 93, Max-Planck-Institut.

Simmons, A. J., B. Hoskins, D. Burrdidge, (1978). Stability of the semi-implicit method of time integration, *Monthly Weather Review*, 106, pp. 405–412.

## Biography

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1984: PhD at the University of Cologne (major: Meteorology, minor: Computer Science).
1985–today: Scientist at the University of Hamburg with emphasis on:
1985–1991: Development team member of the first German climate model ECHAM.
1992–1999: Work on short-term forecasts and simple GCMs (PUMA).
2000–today: Development team member of the “Planet Simulator”.

# Forecasting the Effects of Climate Change on Biodiversity: Visualizing Change to Inspire Public Action

Lindsay Irving and Healy Hamilton

## Abstract

Climate change impacts to the species and ecosystems upon which human economic and ecological well-being depends receive relatively little attention from the media and the general public. Ecological forecasts of future climate impacts on the geographic ranges of iconic species produce models depicting alternative scenarios that vary dramatically in their degree of projected changes. Using the IPCC's latest climate model outputs and greenhouse gas emissions scenarios, scientists and science visualization specialists from the California Academy of Sciences are creating multimedia presentations that convey two different trajectories for Earth (and our) future, told through the lens of wildlife icons such as the jaguar and wolverine. These science-based results translate into educational 'global change vignettes' that introduce the public to alternative potential futures for the species and landscapes to which they are connected. In this way, the diffuse issue of global climate change becomes more personal, and the viewer may be motivated to become part of the solution that creates the more positive outcome.

## Introduction

The majority of media and public attention regarding potential climate change impacts is focused on extreme weather events such as droughts, floods, and fires, and public health consequences such as disease and food security. While acknowledged, relatively less awareness surrounds potential climate impacts to biological diversity and ecosystem function. This reflects a general under-appreciation by the media and the public of the critical role intact natural systems play as the economic and ecological foundation to human well being. Despite the fact that climate change is becoming a more popularized issue, many people perceive it as a distant problem in both time and space (Maibach et al., 2009). In order to engage a wide ranging public from diverse backgrounds and with disparate value systems, scientists are challenged to translate the global impacts of climate change on Earth's ecological systems into a more familiar, personal, and regional context. Here, we propose that compelling educational media about climate impacts to biodiversity can be derived from research approaches that use downscaled global climate models to forecast climate impacts at the scale at which plants and animals experience and respond to climate. Ecological forecasts based on downscaled climate models under alternative greenhouse gas emissions scenarios can establish a deeply immediate impact on personal awareness of climate change.

This essay will briefly discuss examples of ecological forecasting with downscaled climate models for two iconic conservation target species, the Jaguar (*Pantera onca*) and the Wolverine (*Gulo gulo*), being conducted at the Center for Applied Biodiversity Informatics of the California Academy of Sciences. We will discuss the challenges and opportunities of visualizing these research results as climate change educational media for our diverse public audiences. By demonstrating the impacts of climate change on the future distribution of plants, animals and ecosystems that people are familiar with, the effects of global climate change are conveyed at a personal level, and may inspire people to think creatively and actively about solutions.

## Biodiversity, Climate Change and Natural History Museums

Natural history museums maintain specimen collections which represent the most extensive and verified record of what life was like on the planet when the climate was considered "normal". The result of several hundred years of research and exploration, biological specimen collections contain essential information about the past and present distribution of species. Recent advances in biodiversity informatics and collaborative digitization efforts have "unlocked" specimen data and made them freely available online through initiatives like the Global Biodiversity Information Facility (www.gbif.org). Researchers can access GBIF integrated databases and apply these collections data to analyses of patterns of biodiversity under alternative climate scenarios. Museums require continued investment in digitizing and georeferencing their historic collections, as much of their legacy data are not yet available for climate change research applications. Natural history museums play complementary roles as both sources of biodiversity research as well as sources of biodiversity education that present interesting opportunities for the visualization community. At the Academy, the opportunity exists to explore research results with advanced science visualization techniques in collaboration with the Morrison Planetarium. (see Figure 1). Through cross-cutting programming, exhibits, and research, the Academy is both a place for innovation and education.

Figure 1. California Academy of Sciences in Golden Gate Park, San Francisco, California. Newly re-designed, the Academy contains a natural history museum, aquarium, planetarium, 23 million biological specimen collections, research and education programs under a living roof.

The Center for Applied Biodiversity Informatics (CABI) focuses on developing strategies for forecasting target species geographic range shifts under a large ensemble of downscaled climate models run under alternative greenhouse gas emissions scenarios. The results of these research efforts produce bioclimactic range maps (see Figure 2) for a target species decade by decade through 2100 under optimistic and pessimistic scenarios of future greenhouse gas emissions (SRES B1 and A2 scenarios, respectively).

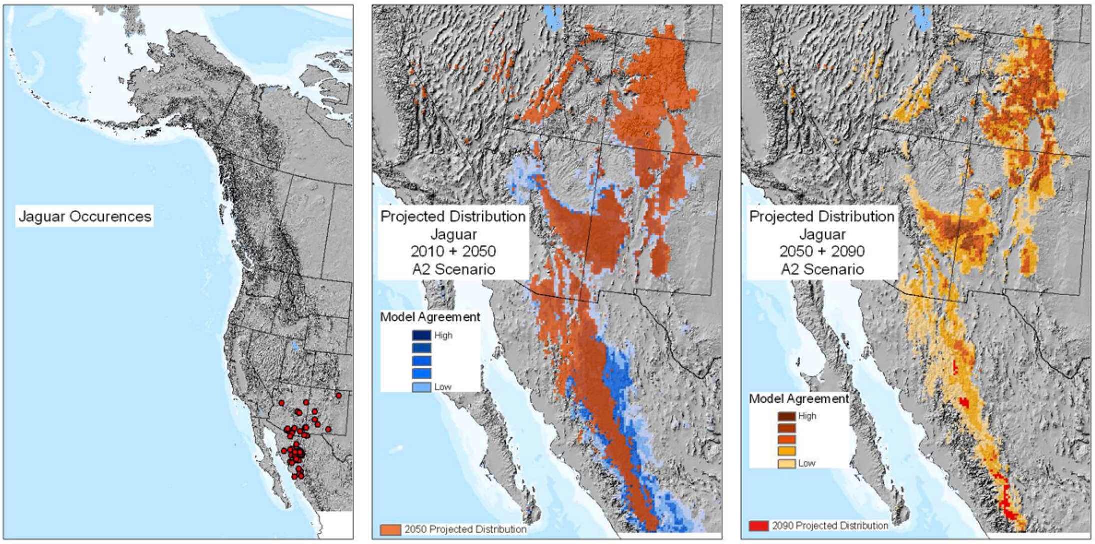


Figure 2a. Current distribution of Jaguar (*Panthera onca*) based on occurrence data from museum collections and field observations and future projected distribution of Jaguar for 2010, 2050, and 2090 under A2 emission scenario. Figures represent preliminary results and are for demonstration purposes only.

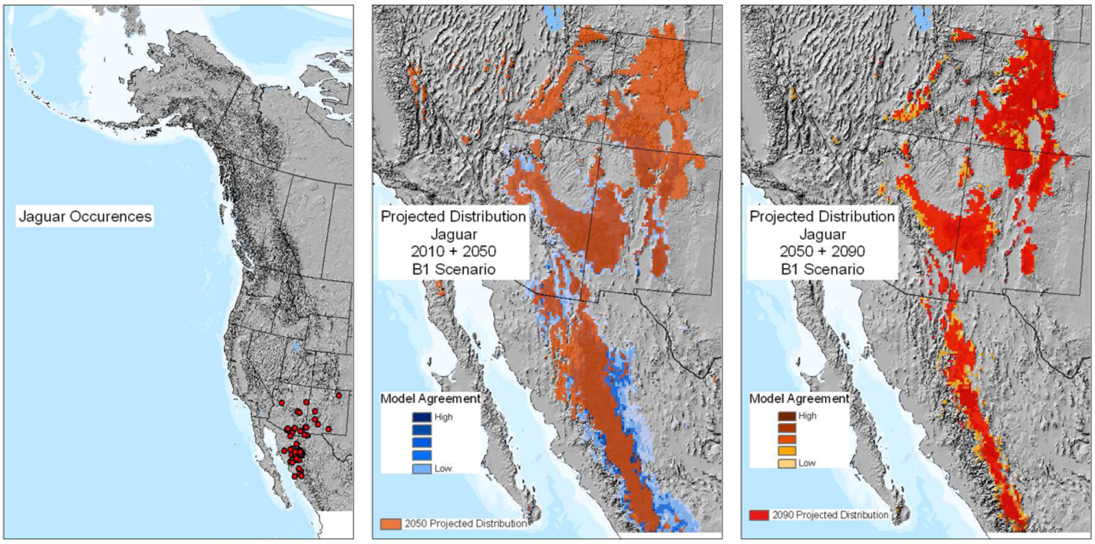


Figure 2b. Current distribution of Jaguar (*Panthera onca*) based on occurrence data from museum collections and field observations and future projected distribution of Jaguar for 2010, 2050, and 2090 under B2 emission scenario. Figures represent preliminary results and are for demonstration purposes only.

Recently, CABI is partnering with the production and outreach teams from the Morrison Planetarium to visualize original research results in multiple media productions for exhibits on the public floor and in the digital dome. The planetarium visualization staff produces feature productions and interactive presentations that are displayed in exhibits on the public floor, online, and in the planetarium. The opportunity to use immersive environments and associated visualization technologies to tell biodiversity and climate change stories is a unique opportunity for natural history museums to explore. By integrating research with visual productions, museums are placed in an active role in the dialogue for finding solutions to climate change and developing approaches that may motivate diverse audiences into action.

# Ecological Forecasting Eexamples, The Jaguar (Panthera onca) and the Wolverine (Gulo gulo)

Working with the visualization experts, CABI is translating climate model downscaling and ecological forecasting results into animations of projected range shifts, contractions, and expansions for species to which many people may experience emotional attachment. For example, the Jaguar (*Panthera onca*) is a charismatic top predator with a distribution that spans South and Central America and extends, though tenuously, to the southwest United States. It is considered a keystone species that plays a significant ecological role but with declining populations, the fate of this powerful feline is uncertain.

In a preliminary exercise, we integrated species distribution data from museum collections and observation data to model the future distribution of Jaguar under two emissions scenarios for the years 2010, 2050, and 2090 (see Figures 2.a. & 2.b.). Using an ensemble approach that combines the downscaled climate outputs of 17 GCM's and 5 different species distribution modeling algorithms, we can begin to see trends in the models that identify regions in the Jaguar's range where the species' suitable climate is projected to occur in the future.

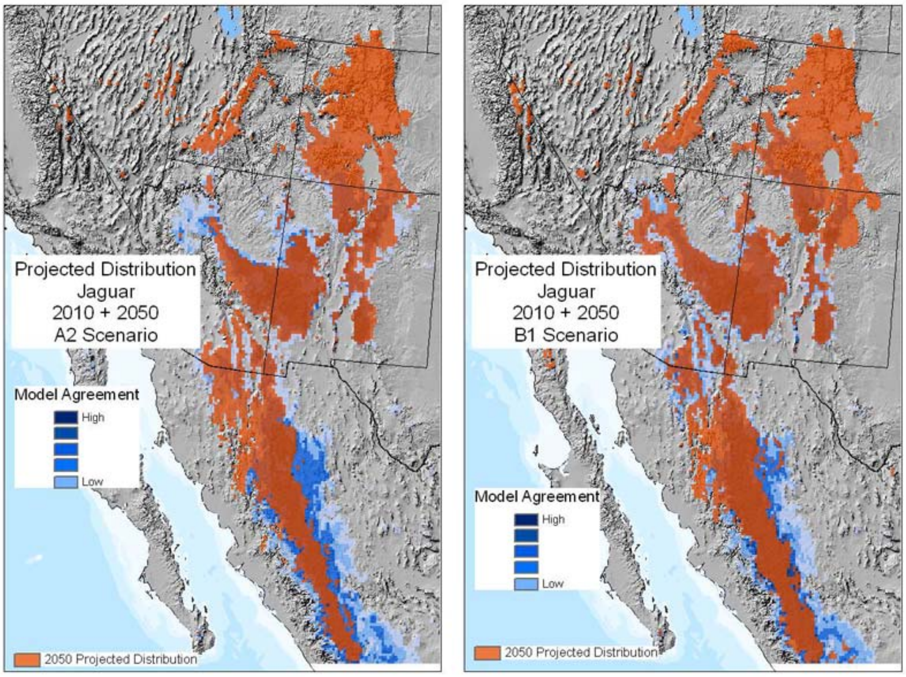


Figure 3. Projected distribution of Jaguar (*Panthera onca*) under the A2 (pessimistic) compared to the B1 (optimistic) emission scenario for 2010 (blue) and 2050 (orange). Figures represent preliminary results and are for demonstration purposes only.

In 2050 (see Figure 3), one can see a significant difference between the A2 (pessimistic) and the B1 (optimistic) emissions scenarios whereby Jaguar's range begins to contract. By 2090 (see Figure 4), the differences between emissions scenarios are drastic. The Jaguar is completely extirpated from the United States in the A2 scenario (if greenhouse gas emissions continue to rise near current rates), whereas in the B2 scenario the projected range of Jaguar remains in the United States and contracts to semi-contiguous, high elevation regions. In a similar exercise with Wolverine (*Gulo gulo*), another charismatic but highly threatened predator, our models demonstrate a stark contrast between the projected future ranges under the two opposing emissions scenarios (see Figure 5).

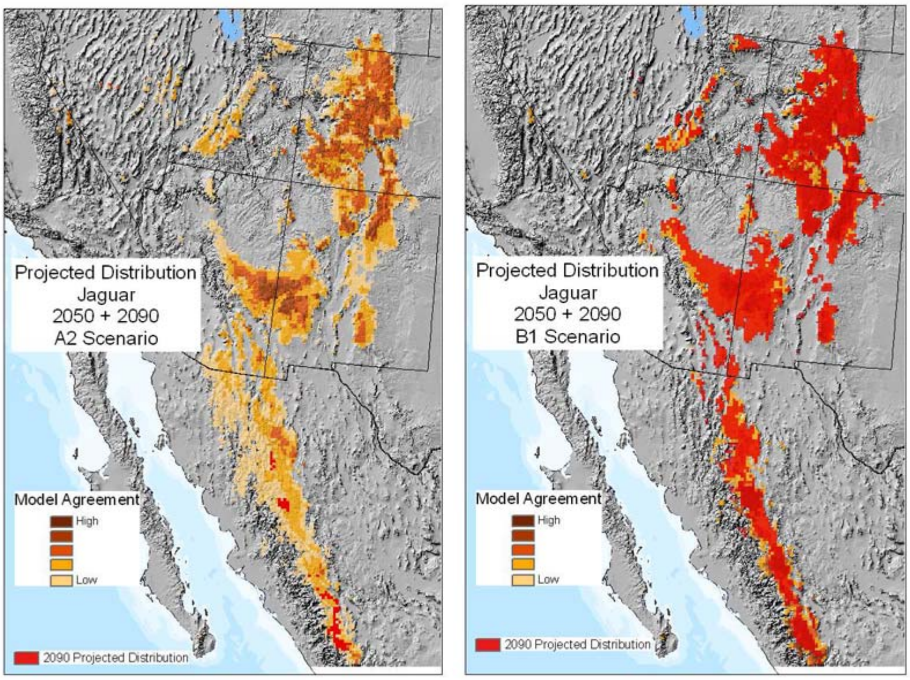


**Figure 4.** Projected distribution of Jaguar (*Panthera onca*) under the A2 (pessimistic) compared to the B1 (optimistic) emission scenario for 2050 (yellow) and 2090 (red). Figures represent preliminary results and are for demonstration purposes only.

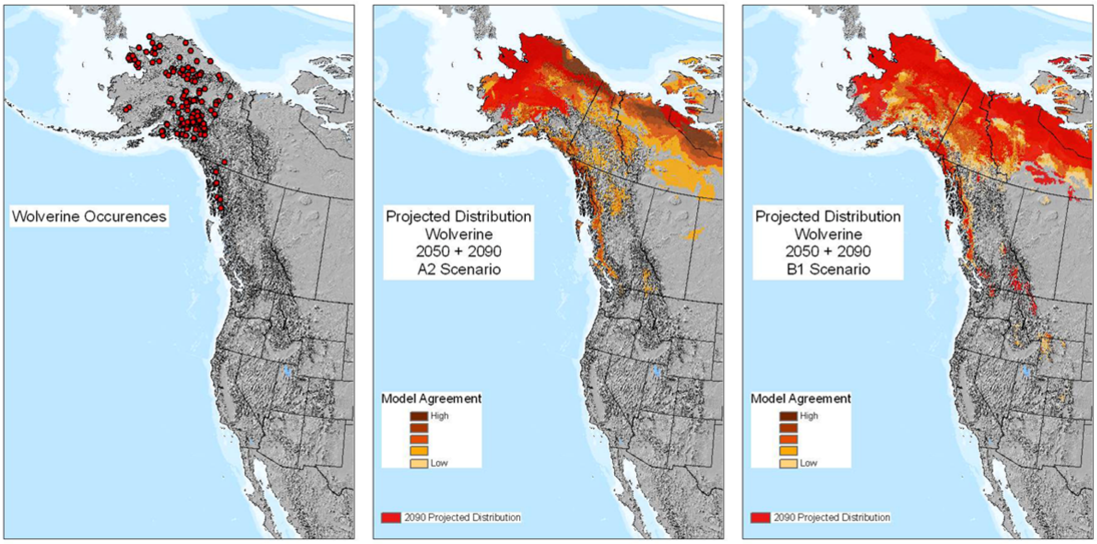


Figure 5. Current distribution of Wolverine (*Gulo gulo*) based on occurrence data from museum collections and field observations and future projected distribution of Wolverine for 2050 and 2090 under A2 compared to B1 emissions scenarios. Figures represent preliminary results and are for demonstration purposes only.

# Visualization Challenges and Opportunities

Current climate change visualization efforts at the Academy stemmed from research results that revealed two very stark but consistent alternative future scenarios across modeled species and our desire to share these results with the public. In both the Jaguar and Wolverine modeling exercises, species ranges contracted and became more fragmented as emissions levels continued to accumulate throughout our projected future time slices. By 2090 in the A2 (pessimistic) scenario, Jaguar species are projected to disappear from their historic ranges in the United States altogether.  We are compelled by the idea that these contrasting results connect the behaviors of individuals and societies today to future alternative outcomes for the species and landscapes to which we have personal attachment, providing a motivation to be part of the more optimistic outcome. A recent study conducted across the United States by the Yale School of Forestry found that none of the Americans surveyed are very confident that humans both can and will successfully reduce global warming (Maibach et al., 2009). It is our hope these powerful visualizations will inspire the public to get involved in the solutions that will lead to a more sustainable future, to choose the "optimistic" scenario.

The challenge will be to find the most effective way to visualize this data and develop approaches to evaluate audience responses. Interoperability issues between transferring geospatial and biodiversity data from Geographic Information Systems (GIS) to display platforms like UniView, Google Earth and others are significant stumbling blocks. Visualizing complicated ecological relationships and model results in clear ways is another challenge in terms of balancing data integrity with keeping the human dimension of the message. Opportunities to share these climate change visualizations across institutions and facilities are becoming more widespread due to simulcast web technologies and protocols like web map service (wms) keyhole markup language (kml). Establishing a network of professionals to share data, test programming, and evaluate audience responses are already underway and are further encouraged through symposia like the *Visualizing Climate Change* workshop.

## Conclusion

Although the data, models, and computational tools used in these preliminary analyses include significant uncertainties that must be continually evaluated and refined, it is already well- established that species are responding both spatially and temporally to the climate change we have already experienced, and further change is certain. Our challenge will be to develop methodologies and approaches of visualizing the outcomes of ecological forecasts that effectively engages diverse audiences about climate change issues and inspires them to change their actions and perceptions. We believe our ecological forecasting approach as briefly described using the Jaguar and the Wolverine as examples will provide a conceptual connection audiences need to think about how their actions today will affect the species and ecosystems they know and care about in the future. Scientists and visualization experts will need to reach beyond disciplinary, institutional, and cultural boundaries and collaborate with artists, designers, First Nations, and others to develop and test visualization and educational strategies. Natural history museums have a unique opportunity to act as creative incubators for fostering the integration of climate change research and visualization techniques while acting as venues of expression through their various public education programs, exhibits, and facilities.

## References

Maibach, E, Roser-Renouf, C. and A. Leiserowitz. (2009). "Global Warming's Six Americas 2009: An Audience Segmentation Analysis". Yale Project on Climate Change, Yale School of Forestry and Environmental Studies and George Mason University Center for Climate Change Communication.

## Biography

**Lindsay Irving** manages the Visualization & Outreach program at the Center for Applied Biodiversity Informatics. Her primary role is to integrate Academy research into digital media products and experiences that include maps, websites, multimedia productions, public

programs, and special events that are shared with audiences online and on the public floor. She has conducted natural resource mapping fieldwork in Panama and has curated exhibits and performances that highlight the collaborative works of artists and scientists.

**Dr. Healy Hamilton** is a biodiversity scientist at the California Academy of Sciences, and an adjunct professor in the Department of Geography at San Francisco State University. She is the founding director of the Center for Applied Biodiversity Informatics, a program that integrates biological and geospatial data for biodiversity research, conservation and education. Her lab's focus is on analyzing geographic patterns of biodiversity in the past, present, and future for science-based conservation planning.

# Climate Change Visualization: Using 3D Imagery of Local Places to Build Capacity and Inform Policy

Sarah Burch, Alison Shaw, Stephen Sheppard and David Flanders

## Abstract

Linking global science to locally significant places with visioning processes and visualizations represents a powerful tool for decision-making in the context of climate change responses. The Local Climate Change Visioning Project in British Columbia, Canada, builds on recent advances in backcasting and scenario-building to bridge the divide between predictive, quantitative approaches and narrative-based qualitative methods. The Visioning Project incorporates novel 3D visualization techniques with elements of participatory integrated assessment to explore visions of the future under climate change for the Lower Mainland community of Delta. This study illustrates that addressing climate change in a participatory way, with credible but easily accessible visuals, and at a scale that matters to people, may be critical in building capacity for climate change action. Furthermore, this project demonstrated that compelling 3D visualizations of local climate change scenarios can be developed defensibly, despite the multi-disciplinary data/modelling needs, complexity and uncertainty involved.

## Introduction

Climate change has recently emerged as a defining political, economic, and environmental issue as a result of increasing levels of awareness, mounting scientific evidence, and high profile instances of innovative political leadership. Nevertheless, climate change remains a complex issue characterized by deep uncertainty, and has failed to stimulate pervasive and transformative shifts in behavior and policy (Nicholson-Cole 2005).

The Intergovernmental Panel on Climate Change (IPCC) has been instrumental in framing the problem of climate change. Using global emissions scenarios, the IPCC has projected future impacts of climate change while also communicating various response strategies available to policymakers, primarily at the international and national scales (IPCC 2007a). The latter scenarios include ways to adapt to projected impacts and to reduce overall vulnerability to climate change via mitigation. With these goals driving the IPCC assessment process and becoming the foundation for its credibility in the policy sphere (Shaw, 2005), the IPCC has taken an approach that is targeted at an improved *understanding* of climate change.

Following the IPCC's lead, climate change is still largely addressed by an expert-driven process including the 'communication-as-transmission' concept – knowledge is best generated by scientists, and simply needs to be transmitted to decision-makers and the public for subsequent action (cf. Lubechenco 1998 p. 491). Despite substantive critique (e.g., Gibbons 1999), the concept seems to persist in the climate change discourse.

All three features of this approach to climate change, namely being global in focus, aiming at enhanced understanding, and being expert-driven, seem to be insufficient to anchor climate change *action* in regional and local contexts. Yet, a number of recent studies demonstrate new ways to holistically communicate climate science (cf. Moser and Dilling 2007). First, *contextualizing* climate change impacts on the regional and local level by means of iconic locations allows people to ‘encounter’ the possible impacts of climate change and make them more meaningful (Leiserowitz 2004; Balmford et al. 2004). Second, *visualization* seems to be a viable aid to link the understanding of climate change impacts to behavioral change and action, in some cases through emotional involvement (Nicholson-Cole, 2005; Sheppard, 2005a). Finally, studies on the science-policy interface have provided evidence that ownership and social robustness of problems and solutions requires co-production of knowledge (Gibbons 1999; Shackley and Deanwood 2002; Shaw 2005; Robinson and Tansey 2006). Engagement of non-academic stakeholders does not simply mean transferring information, but needs to occur through an iterative participatory process to create ownership, accountability, and a willingness to act (UKCIP 2009). In sum, progress towards climate change mitigation and adaptation seems to be more likely if credible information is localized, visualized, and co-constructed (Lorenzoni et al. 2007, Shaw et al. 2009).

The Local Climate Change Visioning Project in British Columbia, Canada, represents one approach that may assist local decision-making. Building on recent advances in backcasting and scenario-building to bridge the divide between predictive, quantitative approaches and narrative-based qualitative methods, the Visioning Project incorporates novel 3D visualization techniques with elements of participatory integrated assessment to explore visions of the future under climate change for the Lower Mainland community of Delta.

This paper provides a brief introduction to the methods used by the Local Climate Change Visioning Project, with a particular focus on the creation of 3D visualizations (as opposed to the participatory scenario development aspects of this project, for instance). These methods have been explored in greater detail elsewhere (Shaw et al. 2009), along with their impact on public awareness, decision-making, and behavioural intent.

## Methods and Approach

The Local Climate Change Visioning Project developed a methodology of translating the science of climate change into credible, ethical computer visualization imagery. It achieves this in a 3-step process:

i. Localize: translate or downscale global climate data to regional and local scales in a transparent, understandable manner for local policy makers and the public;

ii. Spatialize: describe the potential impacts of climate change in the landscapes where people live and work, and adaptation and mitigation options in these places, through spatial modelling and/or interpretive mapping at the local level;

iii. Visualize: communicate this information in an ethical, scientifically defensible, and dramatic manner (using 3D simulation of recognizable places) that not only educates viewers on the realities of climate change but also emotionally motivates behavioral change at the individual and community level (Conroy 2004; Sheppard 2005a).

We visualized the local scenarios based on decision rules and ethical standards (Sheppard, 2005b), addressing data availability, expert and local input, clear and compelling visual information, and fit with the local narratives. These visualizations were created to test whether defensible, compelling depictions of climate change and responses to it would add value to existing approaches to climate change communication and planning (Nicholson-Cole, 2005; Sheppard, 2005a). The scenarios were designed to be used in subsequent perception studies; therefore emphasis was placed on providing a range of common styles, levels of realism, and types of imagery that have been shown to be effective in previous participatory studies (eg. Tress & Tress 2003; Sheppard 2005b). A deliberate decision was made to reduce somewhat the realism of the developed areas in close-up views, in order to avoid possible adverse reactions from participants and potential legal repercussions around individually recognized property in the area (cf. Mendez 2008).

The first phase was the development of a conceptual framework which allowed for the organization of a plethora of qualitative and qualitative data, bridging from the global to the local level (Sheppard and Shaw 2007). Key biophysical and socioeconomic drivers were collated from the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios (Banuri et al. 2001; Nakicenovic and Swart 2000), the Millennium Ecosystem Assessment (Raskin 2005), and the scenarios of the Global Scenario Group (see for example Raskin et al. 2002). These scenarios were downscaled by integrating national, regional, and local impact assessment with climate-related policy information. The framework development also involved the use of a pre-existing socio-economic model, GB-QUEST (see for example: Robinson et al. 2006; Tansey et al. 2002), to match regional and global emission assumptions while maintaining internal consistency for socio-economic drivers (see Figure 1). Regional storylines and narratives were developed which utilized the combined data provided by global models, regional assessments, local expertise, and GHG emission assumptions (Shaw et al. 2009).

The conceptual framework outlined four alternative global change scenarios based on GHG emissions and response options, from a 1990 baseline over the time steps 2020, 2050, to 2100. The first scenario entitled "Do Nothing" is a high emissions scenario with no effective adaptation or mitigation activities. The three other scenarios implement different proactive response strategies with different effects on emission profiles. The 'pure' adaptation scenario entitled "Adapt to Risk" still remains a high emissions scenario (no significant effect on emissions). The scenario entitled "Efficient Development" employs adaptation but also limited mitigation measures resulting in a moderate emissions profile. Finally, the fourth scenario entitled "Deep Sustainability" is based on the assumption that strong mitigation responses, coupled with adaptation, would significantly reduce the emissions trajectory over time (approximately 60% reduction by 2050, relative to 1990), and lead to stabilization of climate change.[1]

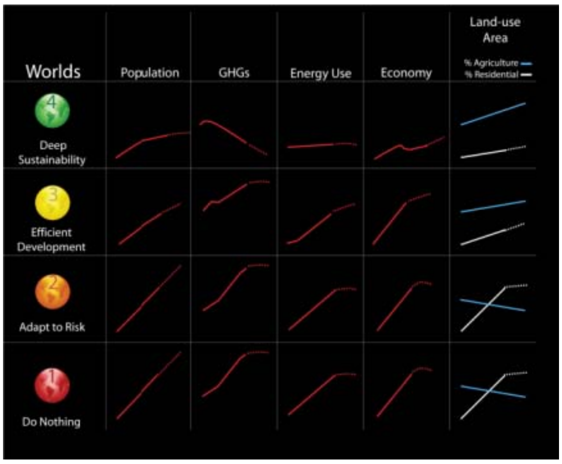

Figure 1. GB QUEST modelling input (GHG emissions) and outputs (drivers), combined with impacts (partly regionalized) and response adaptation and mitigation measures.

Two- and three-dimensional landscape visualizations were supported by Geographic Information Systems (GIS) and climate/environmental modeling. We applied visualization tools ranging from 2D photorealistic graphics editing (*Photoshop*) to 3D tools including *ArcSCENE*, *Google Earth*, *SketchUp*, and *Visual Nature Studio*. We processed a high-resolution 3D dataset (*LiDAR* data) for accurate visualization of the shorelines. The generated visuals were reviewed by the extended research team which included approximately a dozen scientists across a range of disciplines, levels of government and academia, as well as by the local working group composed of residents, practitioners and stakeholder group

1 Stabilization here refers to remaining under a 450 ppmv atmosphere CO2 concentration by 2100 (and subsequently remaining below a projected 2ºC global average surface temperature warming), considered the threshold of dangerous anthropogenic interference (IPCC, 2007b).

representatives. These were subsequently revised by the core research team, a smaller group of UBC researchers, in an iterative process. The visual material (which also included GIS mapping, charts, and photographs of precedent response options elsewhere) were finally combined with data and narratives to produce ‘visioning packages’. These were used in testing sessions in the second phase of this project, to establish local public reactions (cognitive, affective, and motivational) to the visioning presentations in community workshops.

Figure 2 illustrates the four scenarios in one well-known local neighbourhood, providing an understanding of what each of the four scenarios look like in one location. Figure 3 demonstrates the use of multiple spatial scales for contextualizing climate impacts while at the same time exploring detailed, localized adaptive and mitigative solutions.

Figure 2 a-d. (from top left to right, to bottom left to right) a. Scenario 1 illustrates more frequent flooding and abandonment of houses; b. Scenario 2 shows a berm as an adaptation strategy; c. Scenario 3 includes incremental retrofits of stilts and solar panels; d. Scenario 4 depicts a new urban design with low-carbon, energy and food producing clusters with integrated resilience to projected impacts. (Credit: David Flanders, CALP/DCS, UBC).

Figure 3 a-d (from top to bottom). Impacts and adaptations from Scenario 2 shown at a. Larger sub-regional scale with sprawling future sub-urban development into high-flood-risk agricultural areas; b. Neighbourhood scale demonstrating existing community risk to sea level rise; c. An "in-my-own-backyard" view of adaptive housing necessary due to the risk of a dike breach; d. A detailed depiction of sea-wall raising to the height sufficient for protecting homes under this climate scenario. (Credit: David Flanders, CALP/DCS, UBC).

## Preliminary Results and Discussion: The Influence of Visualizations in The Public and Policy-Making Realms

The Local Climate Change Visioning Project incorporated strong elements of public participation – from the development of the images in conjunction with staff and policymakers within the municipality, revision of the images with the help of local experts and stakeholders, and testing of these images with a public audience. Even among municipal experts, the mere provision of information was deemed unlikely to address concerns regarding the uncertainty of local climate futures, the portfolio of response options available, and effect of regional, provincial, and federal policies on local spaces. The project therefore went beyond conventional information provision, using visualization and an 'analytic deliberative process' (Stern and Fineberg 1996), which "combines sounds science and systematic uncertainty analysis with participatory deliberation by an appropriate representation of affected parties, policy-makers, and specialists" (Pidgeon et al. 2005). The project demonstrated that such a holistic process is workable and effective at the local community level. Compelling 3D visualizations of local climate change scenarios can be developed defensibly, despite the multi-disciplinary data/modelling needs, complexity and uncertainty involved.

This deliberative process of scenario and visualization design may be an important means of overcoming barriers to municipal climate change action (Burch 2009) for three reasons. First, communicative partnerships were forged between politicians, municipal staff and scientists. These partnerships may improve the legitimacy and effectiveness of the climate change response discourse in the municipality of Delta, and may lead to locally-specific and integrated adaptation and mitigation policies. Second, the development of four iconic, highly localized, and meaningful scenarios aided in the explicit incorporation of values into an alternative mode of deliberation – namely storytelling using visual media. These media provide a common language with which experts from disparate disciplines may communicate and express anticipated climate change impacts and desirable responses, and thus help to overcome the barrier of miscommunication. Finally, the Local Climate Change Visioning Project, through a series of iterative consultations with various municipal groups and advisors, provided a mechanism by which the fruits of the participatory visualization development process may be fed into decision-making procedures. Collaboration with the Project was officially endorsed by the Delta City Council, and the products of the process were presented to the Council upon completion. This served the purpose of allowing Delta's political leaders to explore the implications of future climate change impacts in their region, obtain valuable technical advice from their staff in a focused and highly effective manner, and explore linkages between climate change responses and other policy priorities.

Based on observational data of audience response recorded during the evaluation workshops, it is clear that the extensive use of realistic visualisations maintained a high level of engagement among the public participants over a long and intense visioning session (Sheppard et al. 2008). Credibility of the visualisation tools and effectiveness of the visioning process were rated generally as high, though some recommendations for enhanced or additional products were received. The research offers compelling evidence (see Shaw et al, 2009; Sheppard et al. 2008) to support the use of alternative climate change scenarios, downscaled climate information, and geomatics-based visualization technology to generate significant cognitive and affective responses in community participants, and increase behavioural intent to take action on climate change. Community members reported increased awareness of local climate change impacts and of the response options available to communities. Despite a fairly high prior knowledge of global climate change, many respondents' concern about the effects of climate change significantly increased. Some respondents noted that having information locally contextualized and visualized in alternative futures made the climate change information "hit home". The visioning material increased stated motivations for behaviour change and altered community participants' attitudes: there was, for example, a significant increase in the number of respondents who personally plan to do something about climate change (Sheppard et al. 2008).

It has not been possible in this initial study to measure actual behavioural changes, so the overall impact (if any) of the visioning process on action cannot be gauged. Discussions with the Municipalities are still continuing and impacts on policy remain possible. The Local Climate Change Visioning process has since been replicated in other Canadian communities and is the subject on ongoing research evaluation.

## Conclusion

Recent studies have paved a way to anchor climate change action in regional and local contexts. The scenario study presented here was a collaborative effort by the University of British Columbia, communities within Metro Vancouver, and numerous agencies and organisations, utilizing participatory methods of capacity building for climate change. Emphasis was placed on closing the gaps between global climate change on the one hand and local impacts and action on the other, by integrating global climate science, different scales of governance, local planning, and public engagement. A key component was to visualize climate change scenarios and response options at iconic local places, offering a new way of enhancing relevance to decision makers and community interests. This study illustrates that addressing climate change in a participatory way, with credible but easily accessible visuals, and at a scale that matters to people, may be critical in building capacity for climate change action. The effects of visualizations on increasing understanding, emotional engagement, and motivating behaviour change have been initially demonstrated with community members, and are the subject of a more in-depth analysis to be presented elsewhere.

Linking global science to locally significant places with visioning processes and visualizations represents a powerful tool for decision-making in the context of climate change responses. In the future, providing an integrated and concise assessment of the ways in which the results of the testing sessions could be built into concrete and effective climate change response policies represents the final link in closing the loop between municipal governance, scientific expertise, and public participation.

## References


Balmford, A., Manica, A., Airey, L., Birkin, L., Oliver, A., Schleicher, J. (2004). Hollywood, climate change and the public. *Science* 305, 1713.

Banuri, T., Weyant, J., Akumu, G., Najam, A., Pinguielli Rosa, L., Rayner, S., Sachs, W., Sharma, R. & Yohe, G. (2001). Setting the Stage: Climate Change and Sustainable Development. IN METZ, B., O. DAVIDSON, R. SWART, AND J. PAN (ed.) *Climate Change 2001: Mitigation, Report of Working Group III, Intergovernmental Panel on Climate Change.* Cambridge, Cambridge University Press.

Burch, S. (2009). In pursuit of resilient, low carbon communities: An examination of barriers to action in three Canadian cities. *Energy Policy* DOI: 10.1016/j.enpol.2009.06.070.

Conroy, M.M., S. I. Gordon (2004). Utility of interactive computer-based materials for enhancing public participation. *J. Environ. Planning Manage* 47, pp. 19–33.

Gibbons, M. (1999). Sciences new social contract with society. *Nature* 402, C81-C84.

IPCC (2007a). Climate Change 2007 – Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. M.L. Parry, O.F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (eds.). Cambridge University Press, Cambridge.

IPCC (2007b). Climate Change 2007 – Fourth Assessment Report. Synthesis Report. Cambridge, UK: Cambridge University Press.

Leiserowitz, A. (2004). Before and after “The Day After Tomorrow”: A U.S. study of climate risk perception. *Environment* 46, pp. 22–37.

Lorenzoni, I., Nicholson-Cole, S., Whitmarsh, L. (2007). Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global Environmental Change* 17, pp. 445–459.

Lubchenco, J. (1998). Entering the century of the environment: A new social contract for science. *Science* 279, pp. 491–497.

Méndez, R. (2008). Inmobiliarias acusan a Greenpeace de hundir los precios de La Manga. El Pais, June 10, 2008. Retrieved July 2008 from

http://www.elpais.com/articulo/espana/Inmobiliarias/acusan/Greenpeace/hundir/precios/Manga/elpepuesp/20080610elpepinac_11/Tes.

Moser, S. C., Dilling, L. (2007). Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change. Cambridge: Cambridge University Press.

Nakicenovic, N., Swart, R. (eds.) (2000). Special Report on Emissions Scenarios (SRES). A special report of Working Group III of the IPCC. Cambridge: Cambridge, UK: University Press.

NRCan (Natural Resources Canada) (2006). Climate Change Impacts and Adaptation: A Canadian Perspective (Coastal Zone Summary). Retrieved September 27, 2006 from http://adaptation.nrcan.gc.ca/perspective/toc_e.asp.

Nicholson-Cole, S.A. (2005). Representing climate change futures: a critique on the use of images for visual communication. *Computers, Environment and Urban Systems* 29, pp. 255–273.

Pidgeon, N. F., Poortinga, W., Rowe, G., Jones, T. H., Walls, J. & O'Riordan, T. (2005). Using surveys in public participation processes for risk decision-making: The case of the 2003 British GM Nation? public debate. *Risk Analysis*, 25**,** pp. 467–479.

Raskin, P., Banuri, T., Gallopin, G., Gutman, P., Hammon, A. (2002). Great Transition: the Promise and Lure of the Times Ahead. A report of the Global Scenario Group. Boston: Stockholm Environment Institute.

Raskin, P.D. (2005). Global scenarios: Background review for the Millennium Ecosystem Assessment. *Ecosystems* 8, pp. 133–142.

Robinson, J., & Tansey, J. (2006). Co-production, emergent properties and strong interactive social research: The Georgia Basin Futures Project. *Science and Public Policy* 33, pp. 151–160.

Robinson, J., Carmichael, J., Tansey, J. & Vanwynsberghe, R. (2006). Sustainability as a Problem of Design: Interactive Science in the Georgia Basin. *The Integrated Assessment Journal* 6**,** pp. 165–192.

Shackley, S., Deanwood, R. (2002). Stakeholder perceptions of climate change impacts at the regional scale: Implications for the effectiveness of regional and local responses. *Journal of Environmental Planning and Management* 45, pp. 381–402.

Shaw, A., Sheppard, S. R. J., Burch, S. Flanders, D., Weik, A., Carmichael, J., Robinson, J., Cohen, S. (2009). How futures matter – synthesizing, downscaling, and visualizing climate change scenarios for participatory capacity building. *Global Environmental Change*, In Press.

Shaw, A. (2005). Imbued Meaning: Science Policy Interactions in the IPCC. Dissertation Manuscript, University of British Columbia, Vancouver, B.C. Canada.

Sheppard, S. R. J. (2005a). Landscape visualisation and climate change: The potential for influencing perceptions and behaviour. *Environmental Science and Policy* 8, pp. 637–654.

Sheppard, S. R. J. (2005b). Validity, reliability, and ethics in visualization. In: Bishop, I. & Lange, E. (eds.) Visualization in Landscape and Environmental Planning: Technology and Applications. Taylor and Francis, London. Chapter 5, pp. 79–97.

Sheppard, S. R. J,, Shaw, A., Flanders, D., and Burch, S. 2008. Can visualization save the world? Lessons for Landscape Architects from visualizing local climate change. Conference Proceedings, Digital Design in Landscape Architecture 2008, 9th International Conf., Anhalt University of Applied Sciences Dessau/Bernburg, Germany.

Sheppard, S. & A. Shaw (2007). Future visioning of local climate change scenarios: Connecting the dots and painting pictures to aid Earth System Governance. Conference Proceedings, 2007 Amsterdam Conference on the Human Dimensions of Global Environmental Change "Earth System Governance: Theories and Strategies for Sustainability", 24-26th May 2007, Vrije Universiteit, Amsterdam. (12 p).

Stern, P. C. & Fineberg, H. V. (1996). Understanding Risk: Informing Decisions in a Democratic Society. National Research Council: Washington, D.C.

Tansey, J., Carmichael, J., Vanwynsberghe, R. & Robinson, J. (2002). The future is not what it used to be: Participatory integrated assessment in the Georgia Basin. *Global Environmental Change* 12, pp. 97–104.

Tress, B., Tress, G. (2003). Scenario visualisation for participatory landscape planning: A study from Denmark. *Landscape and Urban Planning* 64, pp. 161–178.

UKCIP (United Kingdom Climate Impacts Program) (2009). User Consultation. Retrieved on March 10, 2009 from

http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=256&Itemid=350.

# Biography

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# Visualizing *An Inconvenient Truth*

Jim Sweitzer

Since its release in 2006, the award winning documentary film **An Inconvenient Truth** (AIT) has created a sea change in public awareness of the threat posed by global warming. It is based upon a slide show that former Vice President Al Gore had shown nearly a thousand times. After the film opened, increasing demand for live presentations of the slide show inspired him to found The Climate Project in 2007. I was privileged to become an early member of The Climate Project (www.theclimateproject.org).

Because my planetarium consulting and production work often involve the use of scientific visualization, I thought it would be worth posing the questions: "What types of visualizations might one want to accompany **An Inconvenient Truth**? And, in particular, what might we learn that would help in the creation of full-dome digital theater visualizations?" This short paper is a thought experiment that begins to address these questions based upon my experience presenting Al Gore's slide show to the public. I don't intend the exercise to simply augment AIT: rather, I hope it will be useful for content producers and educators who wish to visualize climate change topics for digital theaters.

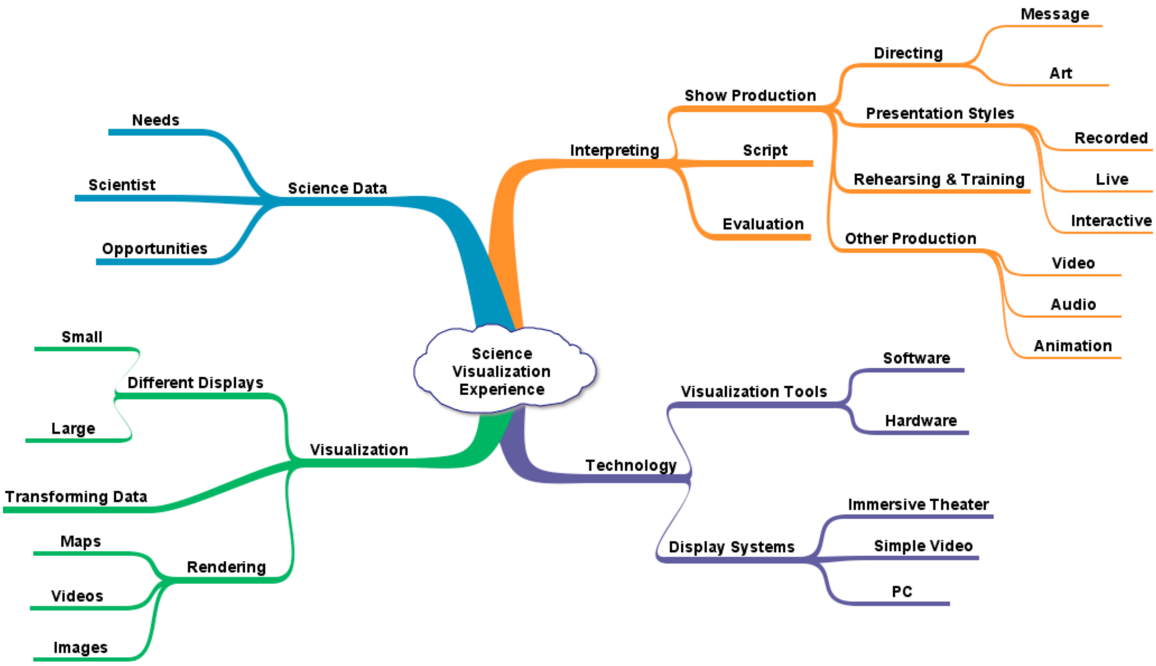



Figure 1. The Science Visualization Experience.

Of course creating programs based upon science visualization involves numerous steps and is a multi-faceted enterprise (see fig 1). This chart maps the extent of the task producers face when developing effective science visualization experiences. The two areas most important for answering my questions about visualizing AIT are located in the Interpreting and Science Data branches of the diagram. If one selects meaningful science data, interprets it properly, and makes it easy to access by display systems, then a knowledgeable presenter could amplify the AIT slide show in unique ways. They might help the audience with a more immediate experience of global hot spots and local impacts. The presenter would also have engaging visual tools to lead audience discussions about questions raised in the film.

Focusing on the questions audiences have posed about this film is the first step to understanding how to engage people in future discussions. I decided to use my experience as a member of The Climate Project as *informal data* to anticipate audience reactions to climate change visualizations. Twenty thousand presentations have been given by 1,200 volunteers like myself in the United States alone. This group effort has reached audiences of over 2 million in the past two years. Based upon my own AIT presentations as well as numerous discussions with and presentations by my Climate Project peers, I have found that some parts of the film's content are much more likely to be addressed than others.

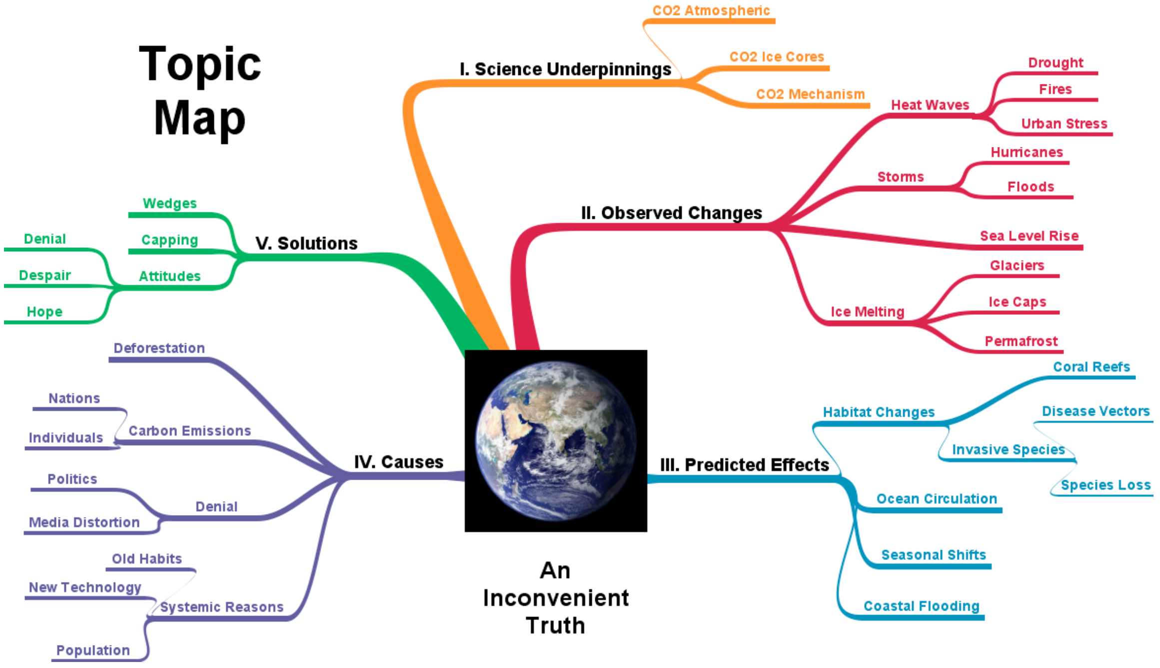



Figure 2. Topic Map of 'An Inconvenient Truth'.

Figure 2 shows how **An Inconvenient Truth** is organized. It is a documentary film with a large amount of information. Personally, I have been amazed that a film based upon a one-hour lecture could be so popular. The film version is, however, actually the short version of Gore's presentation. The complete Keynote slide show package currently includes over 400 of Mr. Gore's slides! Of course no audience could withstand such a long program, even though I've seen Al Gore deliver a six-hour presentation of it with only a couple short breaks! All presenters cull the base set of slides extensively.

If I wanted to use real-time science visualizations in a dome show immediately after the AIT slide show, I would still want to shorten my typical slide talk. I would tend to focus the AIT slides on Topic Map branches I and II. Topic areas II and III (Observed Changes and Predicted Effects) might be the best areas to mine for additional visualizations. Before suggesting an organization for these visuals, I first investigated what has actually been done to add visualizations using Google Earth.

The Climate Project and Google funded student interns at the Pew Center for Climate Change to develop visualizations for Google Earth. Google actively works with The Climate Project. It sends representatives to our summits, and Al Gore serves as a senior advisor to Google. At: sites.google.com/a/theclimateproject.org/google-earth-internship, one can find kml data for these visualizations:

- Global Air Surface Temperature A1B Scenario
- Global Carbon Emissions
- US Carbon Emissions
- Global Oil Consumption
- Global Solar Irradiation
- US Solar Irradiation
- US $CO_2$ Emissions and Tree Populations

Google Outreach is encouraging projects like this and could be a source of grants: http://earth.google.com/outreach. One of my hopes is that they make a plug-in that will allow viewing of Google Earth in domed theaters.

Although these student kml efforts are useful and interesting, they might not be exactly the visualizations that would be the most useful in a discussion after delivering the AIT slide shows. In my opinion, some of them are also not as highly rendered or developed as one would need for a high-resolution digital planetarium either.

Since visualizations are only the props to be used in a discussion, it is useful to learn what Climate Project presenters have experienced during discussions. We know that audiences can become quite animated. Most want a positive conversation that does not drift into either pessimism or denial. **An Inconvenient Truth** paints the big picture challenge rather well, but question and answer periods usually drift into conversations about local impacts. Specific visualizations will require new and frequently updated visualizations.

Although local concerns are a focus, whenever I have shown people their cosmic (astronomical) context, they say they feel motivated by understanding how they are part of the larger story of planet earth. It's natural for me as an astronomer to want to do this, but I've honestly been surprised at how popular adding this level of meaning has been. I have used Uniview to accomplish this perspective a couple of times. In my mind I have extended the usual environmental dictum from "Think Globally, Act Locally" to "Think Globally, Act Locally, Reflect Cosmically."

More specific questions in these talks touch on topics like water resources and drought. I know that many in my audiences are concerned for wildlife both in the oceans and on land. So, it seems to me that data sets that show species and water resource information at local levels would be interesting. For one talk, I incorporated some of California Academy of Sciences data on the future habitat range of the Canadian Lynx under different carbon emission scenarios. The Lynx requires snow because it prefers to hunt Snowshoe Hares. As a result, changes in the yearly distribution of snow pack will have an impact on the Lynx. Displayed in Google Earth, these data made the effects of climate change on this extraordinary North American wild cat apparent.

Finally, in my AIT audience discussions, I've found that people enjoy being able to add their own knowledge and opinions. They also have generally been interested in knowing what specific actions they might take to lower their carbon footprints – down to what type of water heater to buy!

Of course visualizing water heaters is not what I mean by visualizations that will serve AIT discussions. I think, however, the following structure might could serve as a useful data tree for visualizations:

- Current Data
    - **Global Data**
        - Biosphere
        - Cryosphere
        - Hydrosphere
        - Atmosphere
        - Technosphere (the constructed world of humans)
    - **Local/Regional Data** (A couple examples are listed here. These data should be specific and meaningful for the region where the program is presented.)
        - Water resources
        - Species habitats

- Future Data: Climate Model Predictions
    - **Global Data**
        - IPCC Emission Scenarios
    - **Local/Regional Data**
        - "Migrating Climates" (www.ucsusa.org/greatlakes/glimpactmigrating.html)
        - Species habitat changes
        - Local sea level rise

Data visualized for the above scheme must be platform and application software independent too. Kml format and wms servers would be one way to start. This will allow presenters to include them in versions that can run on anything from a laptop up to large immersive theaters and even pre-rendered production segments. Because theater time with audiences will be limited, giving them the ability to explore more on their own later will be welcomed.

There is one more dimension to productions on this topic that I would like to discuss. Helping audiences understand the topic of climate change is more than simply data and scientific explanations. It is important to help the audience deal with their emotional reactions to the threat. One always wants to move the audience beyond fear, denial, and angst towards hopeful action. They need to feel that they can make a difference. Pollsters have learned in the past two years that many more Americans accept the fact of global warming than they did a couple years ago. The problem for American audiences, at least, is that they don't feel it is an urgent priority to address. (See: people-press.org/report/485/economy-top-policy-priority) This is a major roadblock to solving this global challenge. Moving people to take action will require producers to be mindful of the emotional "frames" that the public associates with addressing the problem of climate change.

In recent years, the popular media have knowingly or unknowingly encouraged imposing contextual "frames" around the discussion of global warming. These include associating it with *pollution, scientific uncertainty,* and *economic consequences*. These are negative frames, some of which have been constructed by groups or stakeholders who stand to suffer if legislation were to be adopted that would seek to control the consumption of carbon-based fuels. Once associations like these become widespread, it is hard for educators or other communicators to prevent audiences from seeing the challenges only through one of these filters. Educators who work with visualizing climate content will want to work to establish more positive frames.

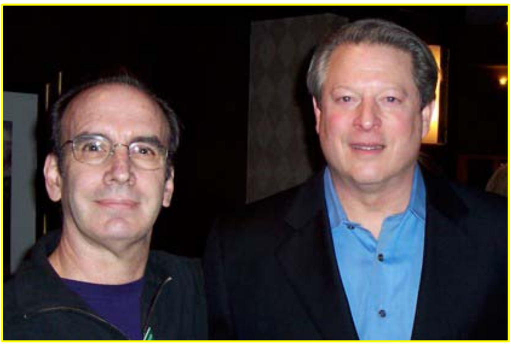
Examples of more promising frames have appeared lately through the Repower America program. These might not work in other countries, but they have been tested and are worth considering when establishing a context for dealing with climate change. These frames include positioning action on curbing green house gasses as fostering: *innovation*, *prosperity*, *health* and *stewardship*.

Some of these positive frames might not work well or be appropriate in a full-dome digital theater program. I have, however, had promising reactions to a positive frame similar to that of *stewardship*. I would call it the *cosmic context* frame. I sometimes have a short section in my talks, called **The Cosmic Carbon Story**, which traces the origin of carbon in long-dead generations of stars to earth's present atmosphere and its carbon-based life. The audience is thereby made to feel part of this universally-scaled drama. It is easier for them to realize that how the next act unfolds is at least in part up to them, or as the script of Yann Arthus-Bertrand's film **Home** ends: "It's up to us to write what happens next – together." This approach helps them take action by making them feel part of something much bigger and more meaningful than they might have previously believed.

This short paper is my way of exploring the question of how one might approach adding full-dome visualizations for an audience discussion following the presentation of **An Inconvenient Truth.** Although based upon experiences with that film's slide show, the thoughts presented here needn't be confined to accompanying only AIT. Rather, the experience of educating with that film should be regarded as data to help us know where to begin our visualizations and productions.

We should keep in mind too that what we may well be aiming for is a program that goes beyond simply presenting scientific truth. It is also not merely a story about how we know what we know, either. Our climate programs deal with a moral question: Given what we now know, how should we act? Presenting such programs offers us a new, important, and possibly uncomfortable role as planetarians. We are no longer simply helping people understand our planet among others as if humans were merely along for the ride. We now have the knowledge that we are a force of nature and determining the fate of our planet. The stakes have just been raised, but if any profession is equipped to ascend to that new level of responsibility, I can't think of a better one than our own that has always aimed for the stars.

## Biography



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