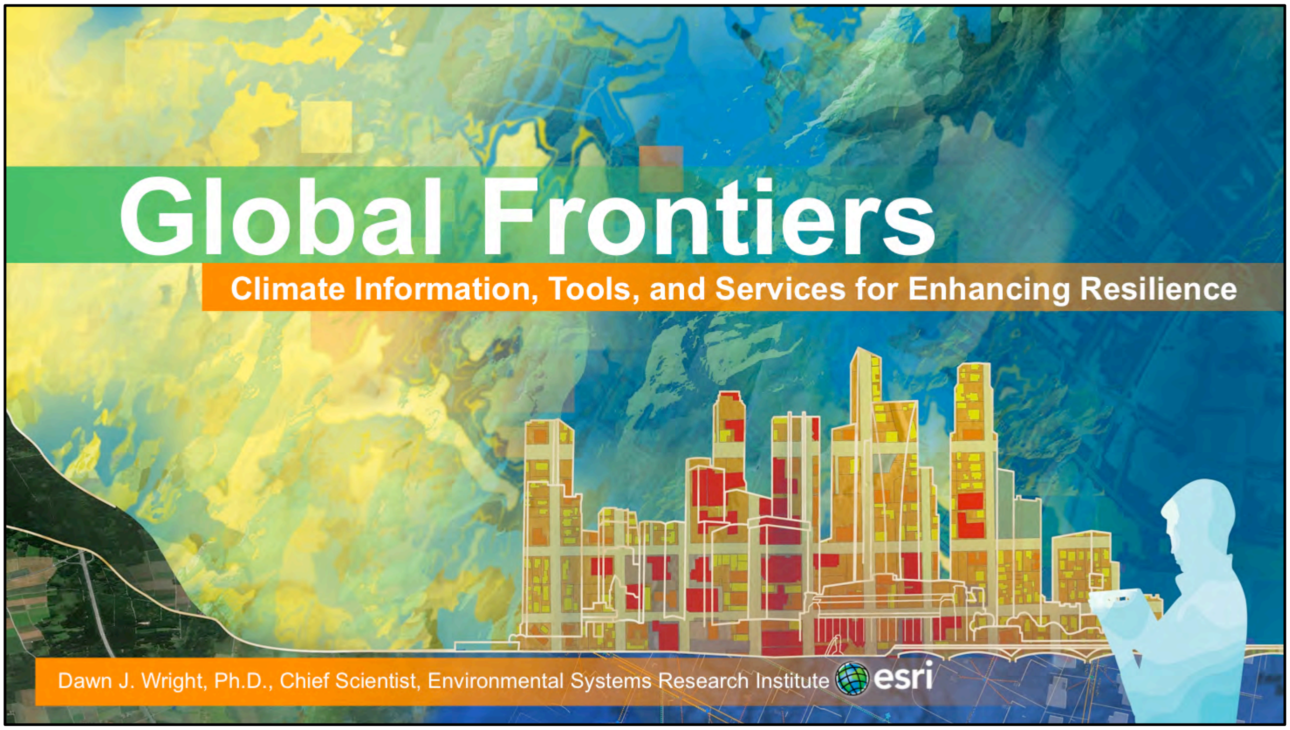
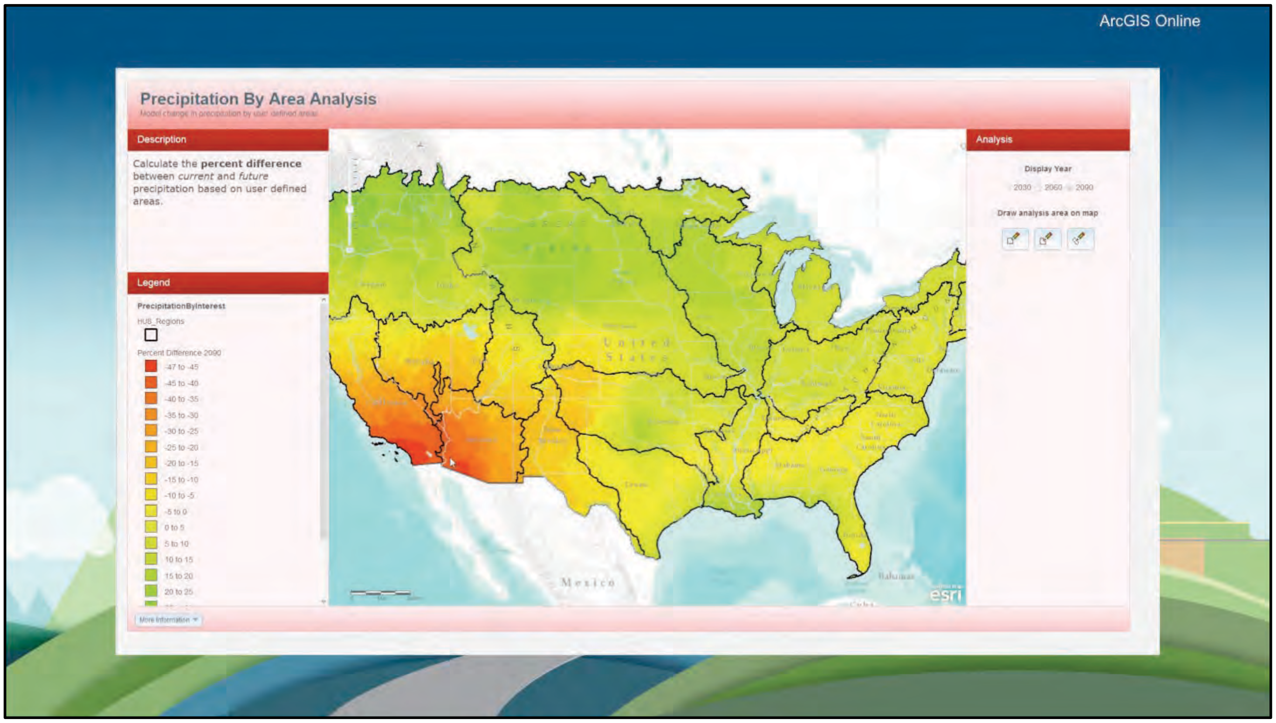


It's a pleasure and honor kick off this session on Climate Information, Tools, and Services for Enhancing Resilience

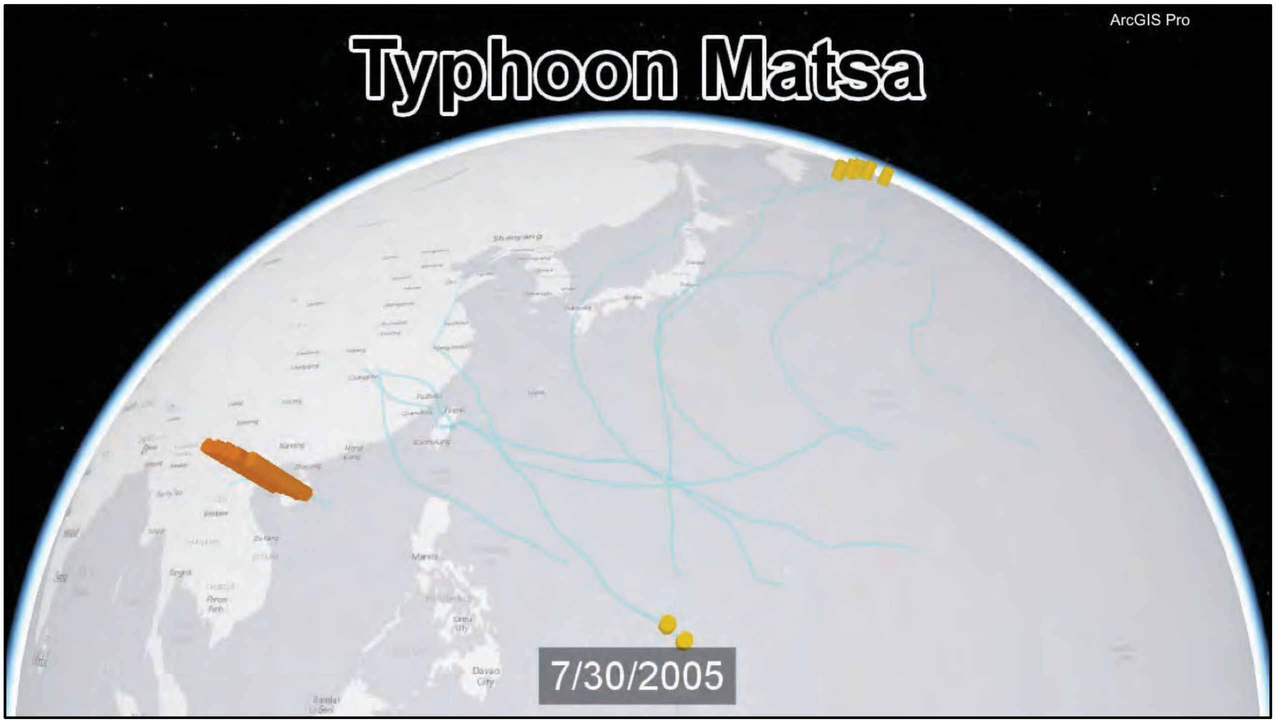
The White House Frontiers Conference, http://frontiersconference.org
October 13, 2016
On the campuses of the University of Pittsburgh and Carnegie Mellon University

I want to start off with a "story of the fourth" as many believe we are now in a **Fourth Paradigm, where scientific discovery can now go beyond the existing 3 paradigms of EMPIRICISM, ANALYSIS, and SIMULATION to a 4th where insight is discovered through the manipulation and exploration of large data sets.**

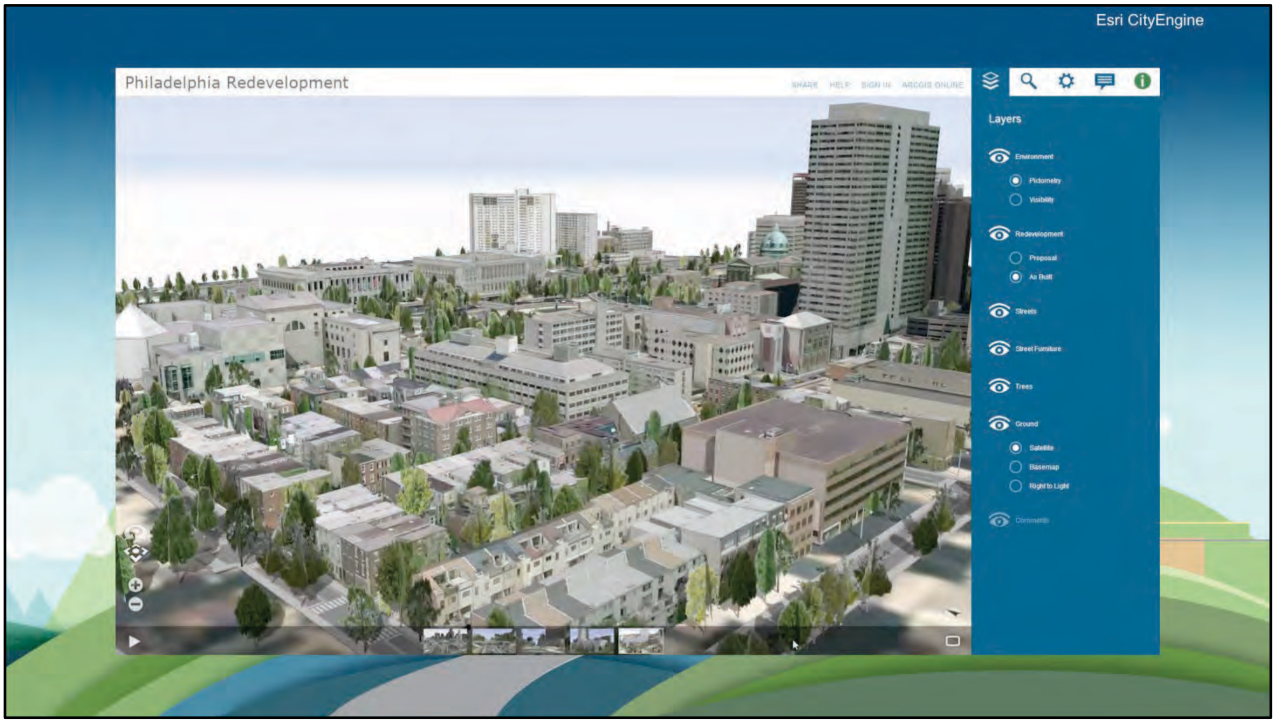
And we are also in a time where Information can be thought of a FOURTH pillar of governance as strategize for the future.



Indeed as we govern and manage, there are some wonderful existing climate datasets and associated tools to help citizens and govts prepare for and adapt to climate change. Here we are using open climate data in a GIS to calculate the percent difference between current and future precipitation. For California where I live, we are looking at a 44% reduction in precip in this region by the year 2090 – huge for a region in crisis already.



There are all manner of amazing visualization tools that heighten our understanding of how dangerous the Earth can be. We are in Hurricane season and recovering from the ravages of Matthew. This visualization showcases a new way to visualize the major typhoons that raged throughout the Western Pacific in August 2005, along with the variation in their intensity and thus danger to human life.



For the built environment, we can transform 2D data into smart 3D city models, to plan, assess, and make quality decisions about future development scenarios even according to changing climate scenarios (e.g., sun angle, best green spaces, heat indices from impervious surfaces, etc). We can compare designs with swipes and comments to arrive at the optimum urban plan.

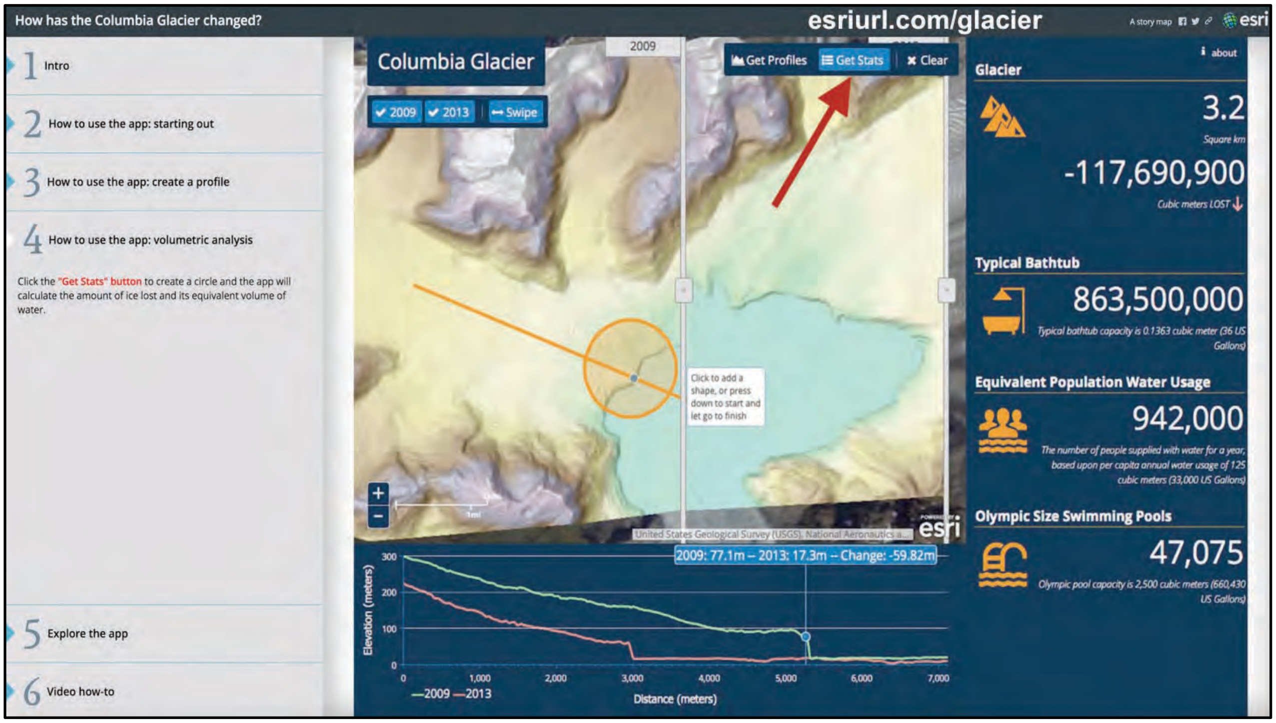
In these examples we are aiming for climate resilience, community resilience, perhaps even personal resilience. But how about DIGITAL resilience? How can we ensure that the data, information and tools that we work so hard to collect, build, and curate are really used, and used effectively on the ground for climate resilience?

Let me quickly posit 5 ideas.

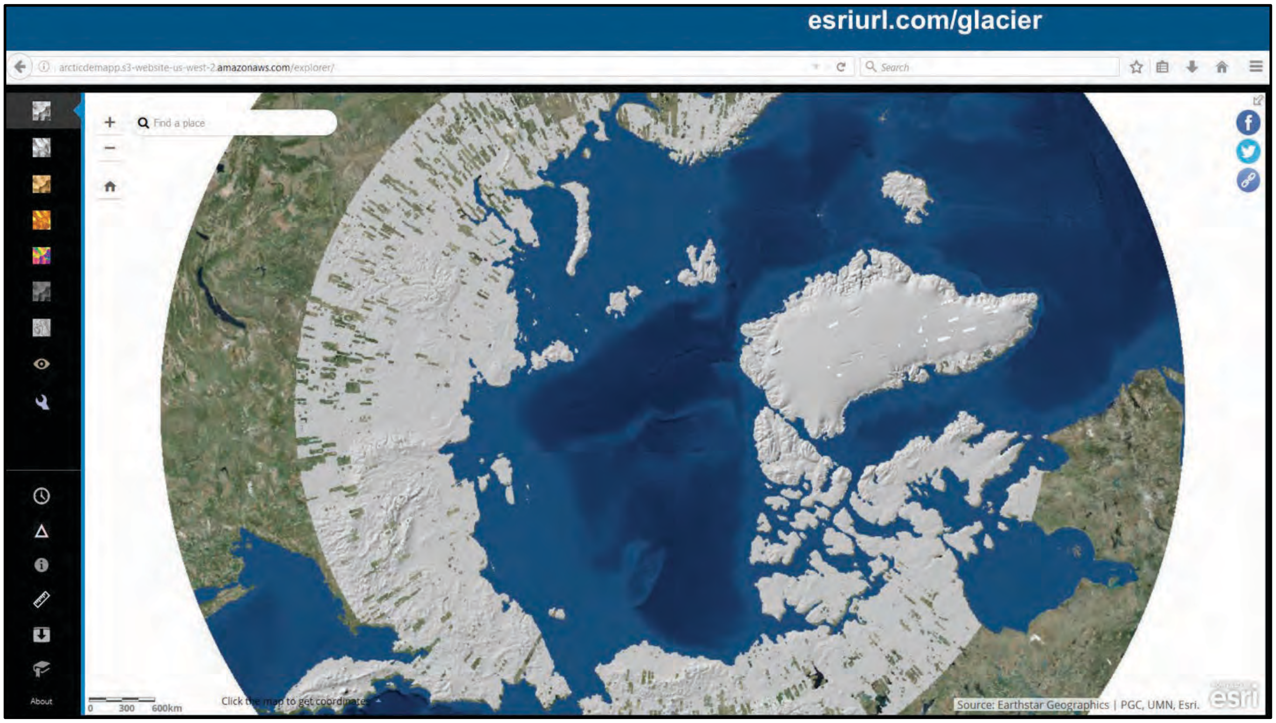
First is to empower everyone with apps which is already happening but we want to be able to do this EFFECTIVELY on any device, at anywhere, any time.

As an example, this is Esri's gallery of climate resilience maps and apps in support of President Obama's Climate Action Plan and Climate Data Initiative → Partnership for Resilience and Preparedness (PREP)

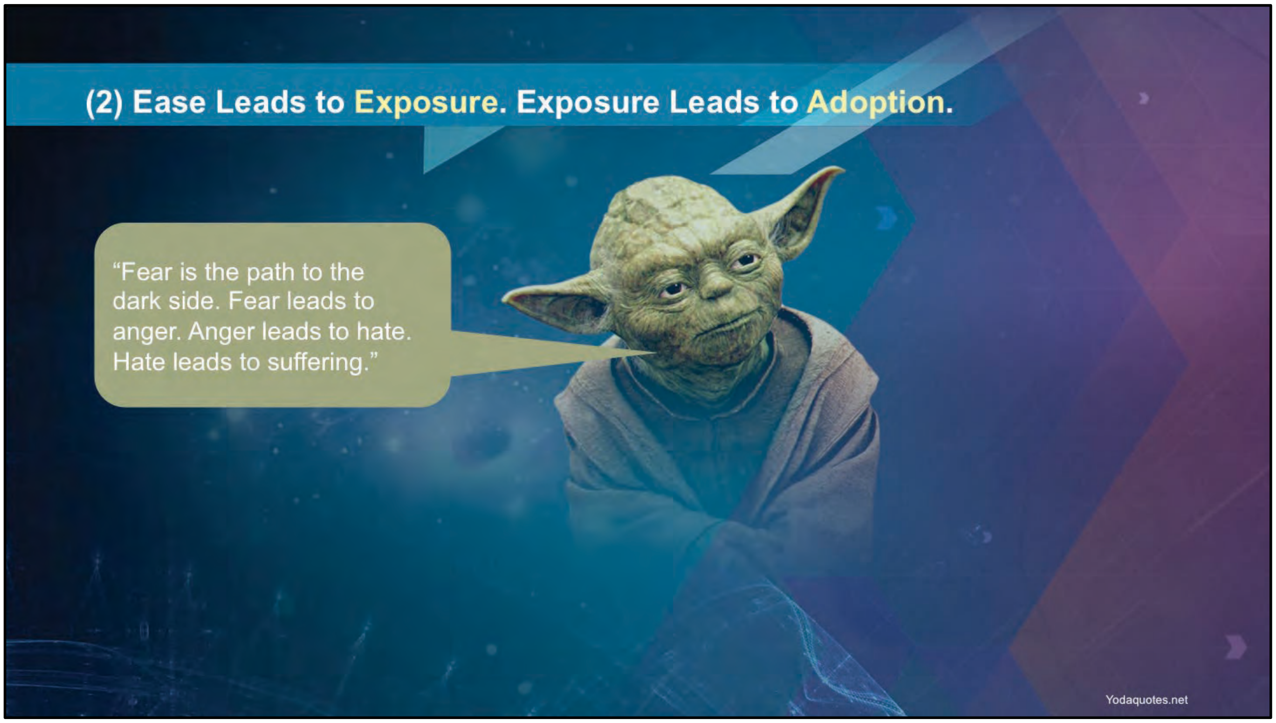
This is an ***open data site encouraging collaboration and open sharing of data and apps***



In honor of the recent Arctic Ministerial, I'd like to mention this free web app (all you need is a browser) that calculates the volume of water that has melted from the Columbia glacier between 2009 and 2013 based on some of the highest resolution elevation data available.



This is also coupled with new Arctic elevation data (hosted with Amazon web services) now available at over 100x the prior resolution for this part of the world, created in response to a 2015 **Presidential Executive Order** calling for enhanced coordination of national efforts in the Arctic



Next, allow me to channel Master Yoda for just a second. He has famously said: “Fear is the path to the dark side…. Anger leads to hate. Hate leads to suffering.” As a data Jedi, I say that ease leads to exposure and exposure leads to adoption.

(That is making it easy for people to use what we have built, and having used it to meet their needs they will hopefully adopt and go further.)

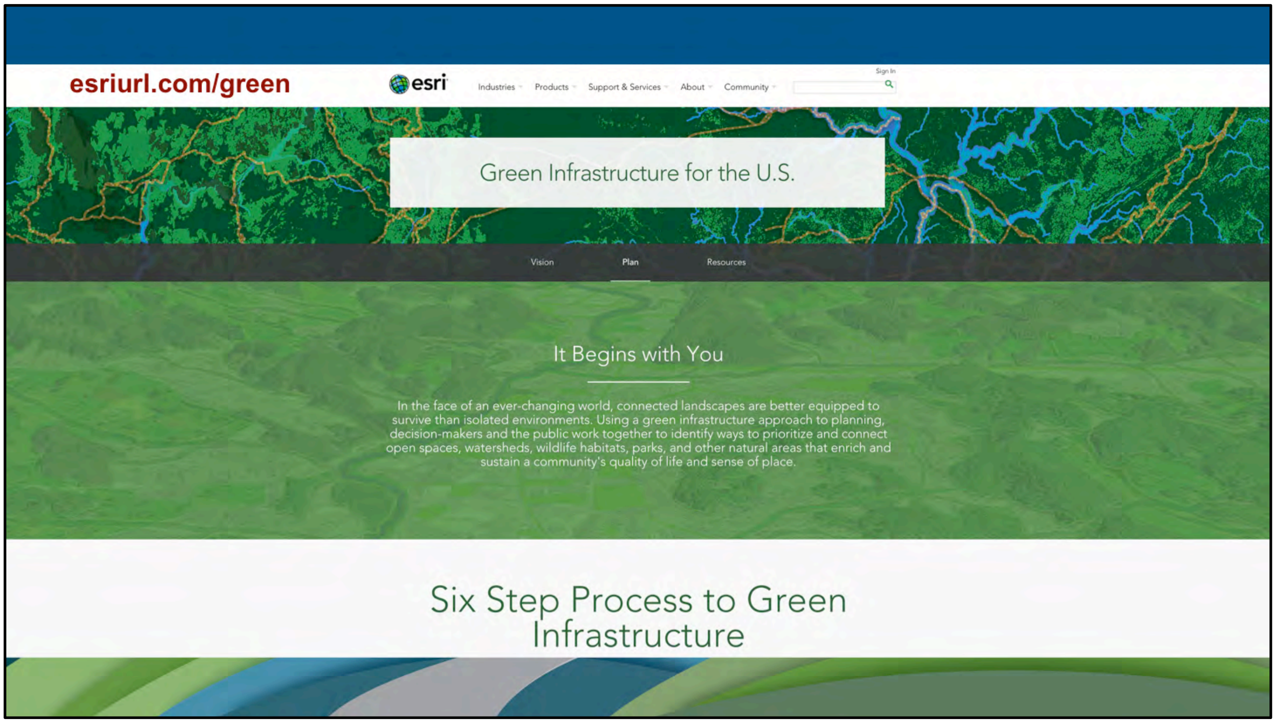
As an example, this is one way to make Landsat much, much easier for resource managers and planners to understand and access the entire catalog of 80,000 Landsat scenes. This web app with the click of an icon, takes them through the different band combinations and spectral profiles for anywhere in the world. And there is more information at the web addresses on the slide.

Each night Esri downloads and processes new Landsat scenes. These are not just cached images but are dynamic, high-performance image services that perform on-the-fly processing and dynamic mosaicking of Landsat's multi-spectral and multi-temporal imagery.

In terms of more advanced, complex scenarios and applications we need to do more than just make our data or our code available through a site or portal, even through GitHub. We need to be more open about what we DO with that dataset or piece of code.

This is about sharing WORKFLOWS

WORKFLOWS within a Culture of Sharing, Engagement, and Collaboration through PARTNERSHIPS that enable people to work together effectively, as exemplified so nicely here by NOAA's Digital Coast portal

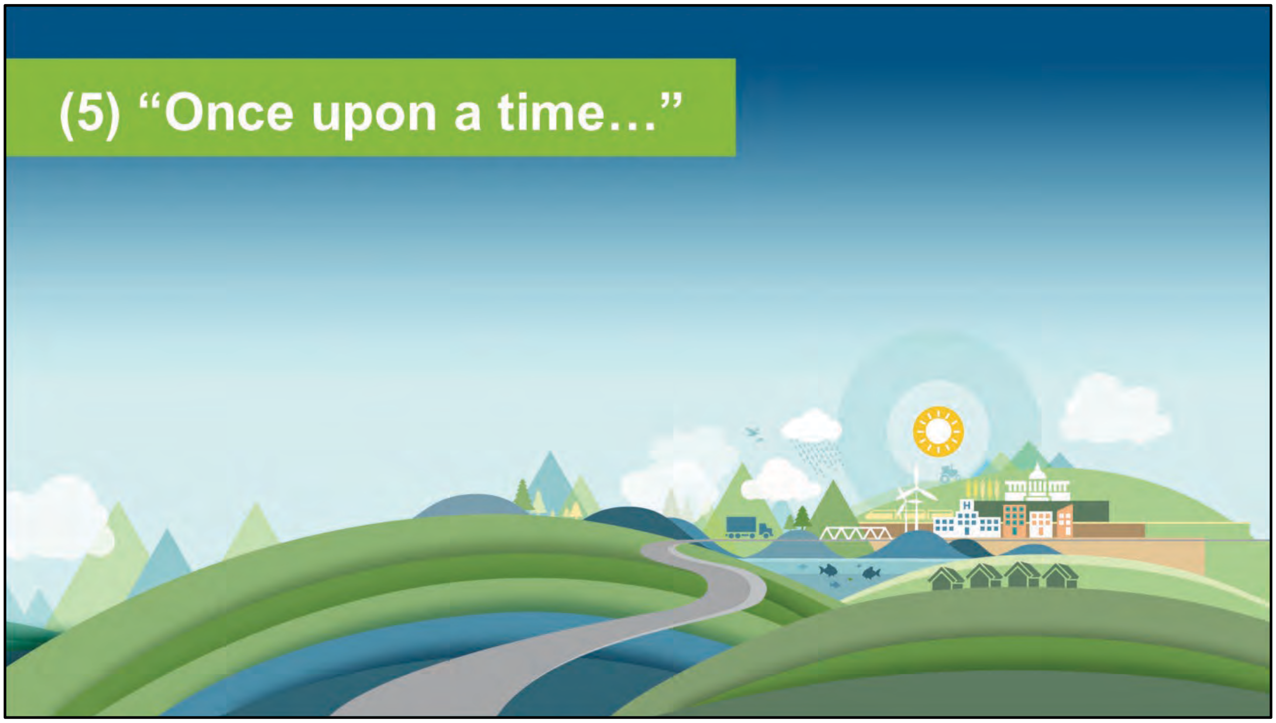


As well as Esri's extensive Green Infrastructure site with workflows to show what's possible in creating a comprehensive national "greenprint"

Fourth, in order to make things reproducible in keeping with solid science, let's make it virtual. By this I'm referring to emerging cataloging standards such as DOIs (digital object identifiers) and innovative new technologies such as CONTAINERS, where you can package together an operating system, a server, your database, a Hadoop or Spark big data store, and share that as a single executable that "just runs" for the user. This may be the future of data sharing and

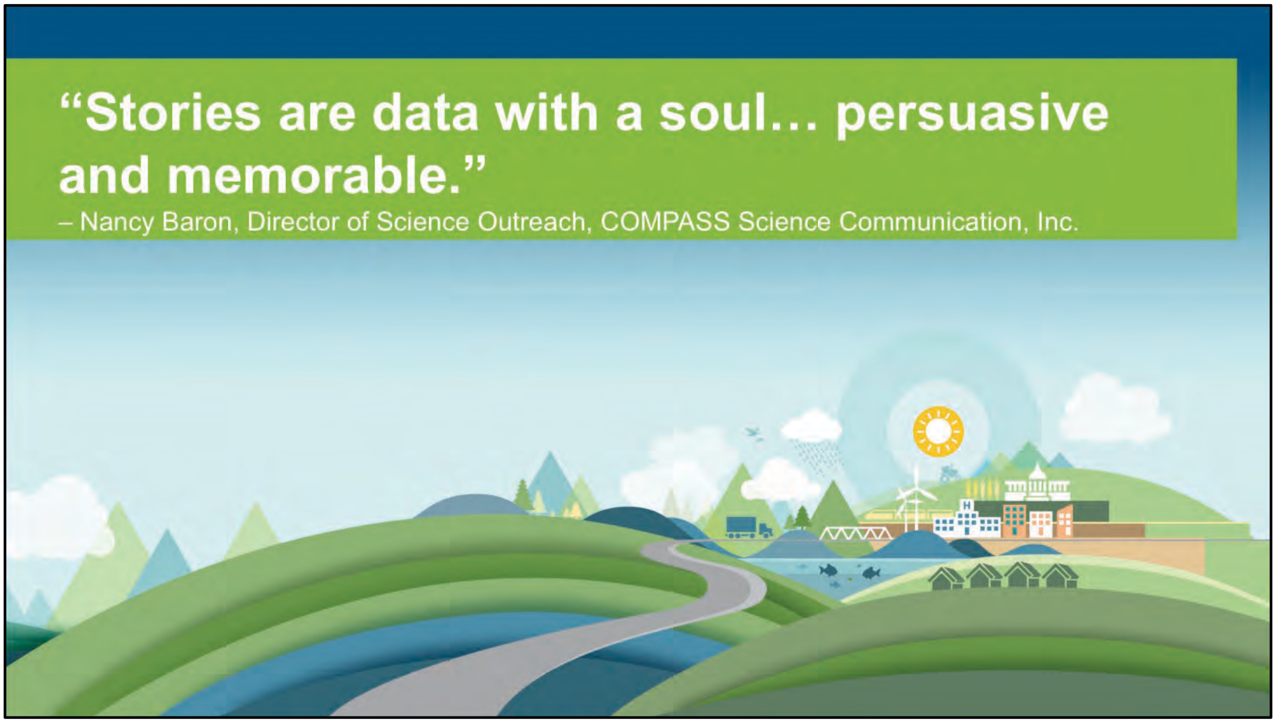
"living" reports and journals.

(Esri is experimenting with Docker and having great success. Ben Domenico of UCAR's idea at 2015 Digital Earth Symposium of being able to run code or analyses with actual data as we read the journal article.)



Fifth, We may get maps, we often DON’T get graphs, but we are absolutely hardwired to understand stories.

“People are moved by emotion. The best way to emotionally connect other people to our agenda begins with “Once upon a time…”



As such, to connect with communities and inspire action toward resilience, climate and data scientists MUST tell their STORY and the importance of that story

“STORIES ARE STICKY”
Every single scientific success (or challenge) is perfect fodder for a narrative structure

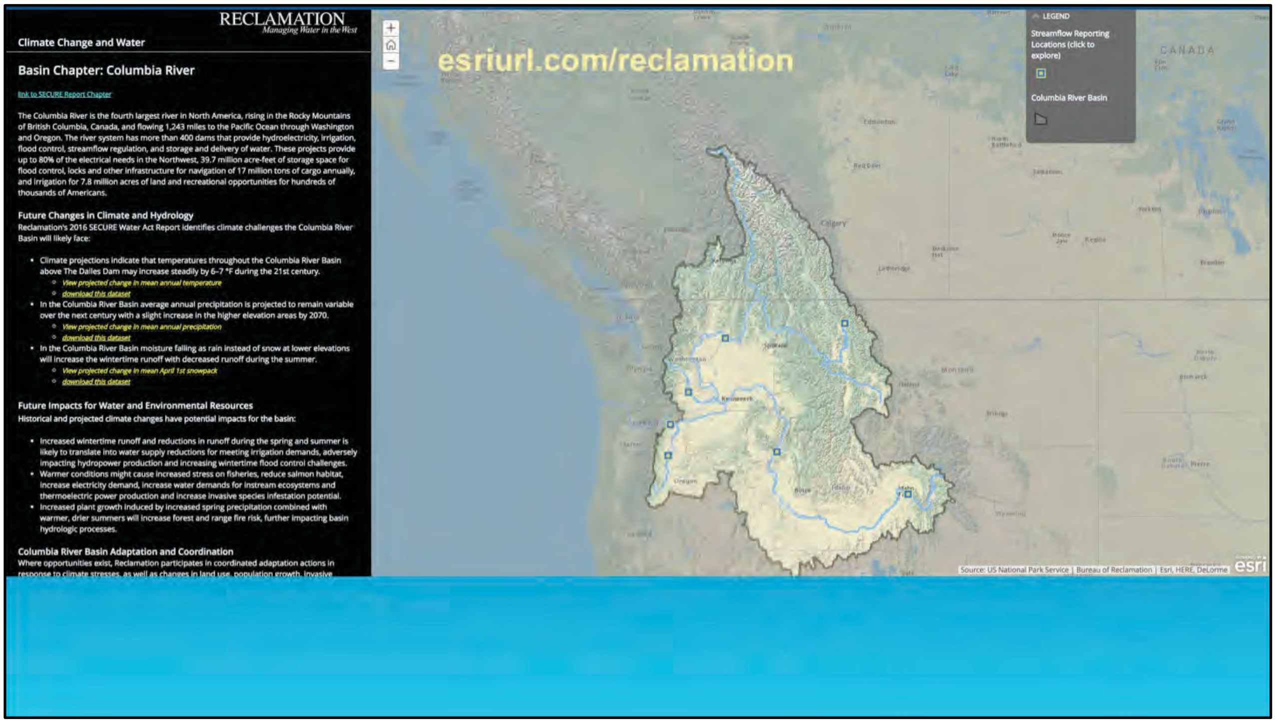
Science backs up the long-held belief that story is the most powerful means of communicating a message. Over the last several decades psychology has begun a serious study of how story affects the human mind. Results repeatedly show that our attitudes, fears, hopes, and values are strongly influenced by story. In fact, fiction seems to be more effective at changing beliefs than writing that is specifically designed to persuade through argument and evidence.”

http://www.fastcocreate.com/1680581/why-storytelling-is-the-ultimate-weapon

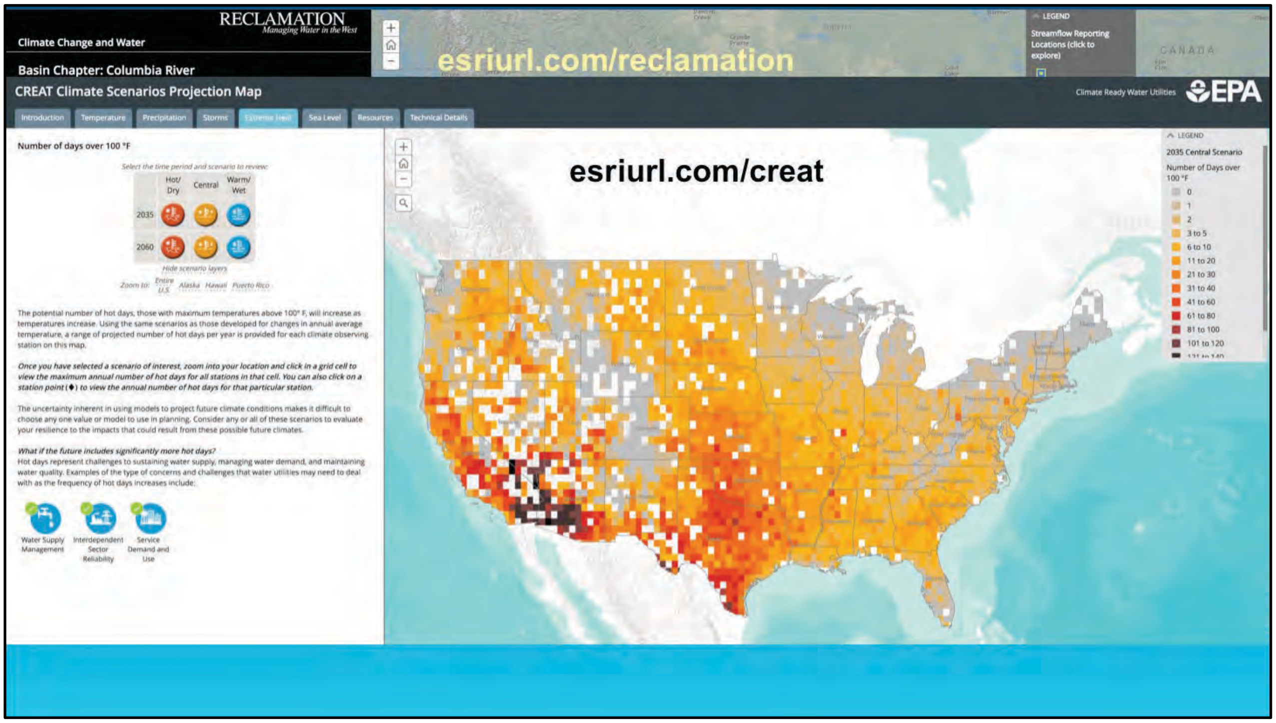
Scientists are often encouraged not to publish their work until it constitutes a complete story.
Why not combine BOTH, especially to take advantage of the power of maps and geography to educate, inform, and inspire people to action as well?
The story map is about using maps in new and innovative ways to get people excited and involved in the world.
Thanks to continuing changes in **the Internet, cloud computing, mobile and tablet platform**s, and to constant improvements in the software itself, we can now put the power of GIS into the hands of policy makers, managers, CEOs, reporters—*even school children*

Happily there are many free apps available to help us easily tell stories with data and maps, data-driven narratives if you will. This is one that Esri built to support the COP21 meeting in Paris. But we currently host about 50,000 of these in the cloud, built by users themselves.

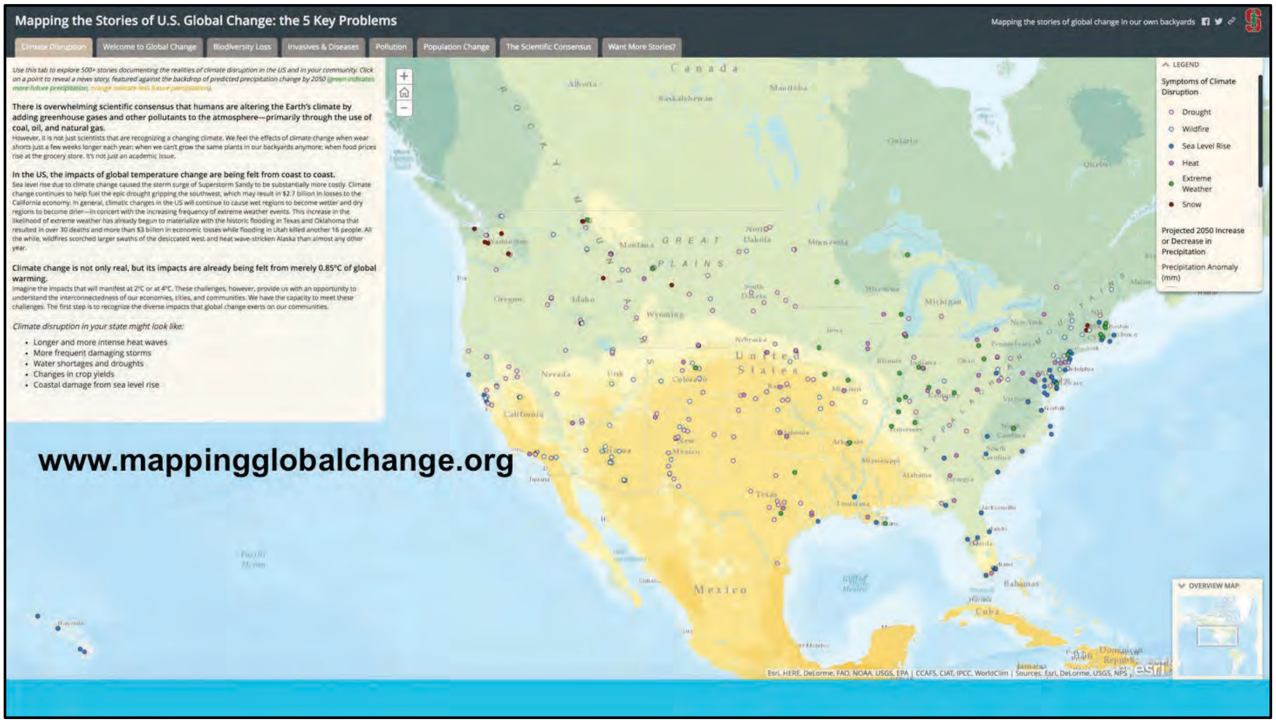
This new medium of story maps grew by 400% last year as our cloud platform hosted nearly 50,000 of these story maps with 7.4 million views.
In support of the UN Climate Summit (aka United Nations 21st Conference of the Parties, aka COP21, to call attention to the role of GIS in climate science and policy and to showcase valuable climate data in 5 categories).
Story map was for scientists, policy makers, planners, and activists to examine detailed spatial information critical for adapting to a warmer future.
Nov 2015 press release: http://www.esri.com/esri-news/releases/15-4qtr/story-map-navigates-cause-and-effects-of-climate-change
Excellent overview article: https://eos.org/editors-vox/after-the-climate-agreement-in-paris



Passionate users all around the world leveraging the **easy** and **repeatable** story map templates, such as **The Bureau of Reclamation,** providing major climate projections for major water basins throughout the US AND providing downloads to the data



The EPA providing national climate change scenarios (Climate Resilience Evaluation and Awareness Tool)



and

Stanford University mapping out the stories of the changing environment AS TOLD BY CITIZENS as part of a special course at Stanford.

So thank you for allowing me to share these ideas as a gateway to the excellent talks and discussions that will follow. You can access *my* talk at the URL on the screen.

5 ideas:
(1) Empower with apps;
(2) ease leads to exposure, exposure leads to adoption;
(3) just putting up your data, your code, and even the apps is not good enough – need to share WORKFLOWS as well;
(4) make it reproducible by making it virtual; and
(5) be willing to share what you do as a STORY, your data-driven narratives (and I shared the story map medium as one way to do this)

IF WE WANT A RESILIENT WORLD, WE NEED TO START WITH RESILIENT DATA

As we work to build our capacity to cope with global change, let's make sure the tools we're using can roll with the punches, too.

Illustration by Benjamin Currie

WRITER
Dawn Wright
@deepseadawn

Chief scientist, Esri

SHARE

REPUBLISH

February 4, 2016 — Editor's note: This Voices piece is published in collaboration with the academic journal Elementa. *It is based on* "Toward a digital resilience," *a peer-reviewed article published February 3 as part of Elementa's* Avoiding Collapse *special feature.*

If the bad news is that we're living in a world in which resilience is more critical to survival than ever, the good news is that technology is more than ever providing the tools we need to cultivate resilience. Exciting innovations in digital data collection, analysis and visualization now allow us to track and understand human impacts at global to local scales and identify big-picture patterns and processes in ways never before possible, from the National Science Foundation's Ocean Observatories Initiative, which measures physical, chemical, biological and geological variables throughout the depths of the ocean to the Global Earth Observation System of Systems, which provides petabytes of environmental data from space-borne, airborne and *in situ* sensors.

Indeed, we now find ourselves inhabiting a "Digital Earth" composed of technologies from satellites to wristwatches that monitor, map, model and manage virtually everything around us.

And it's not just data for data's sake. The same digital technologies we use to understand how the Earth works are also helping communities in very practical ways. These range from monitoring fire, drought or flooding to mapping the relevant insurance zones for such. They include tracking economic collapse or health epidemics, finding available drinking water, alerting us to temperature and precipitation changes, determining landscape vulnerability for land managers, monitoring air quality, even identifying the suitability of a position on one's roof for installing solar panels.

The information such programs produce is precisely what we need to be able to cope with global change. But in order to use it to that end, we need to ensure it's available to those who need it. In other words, we need to make sure the tools that allow us to gather and use this information are resilient, too. To that end, I propose a set of three principles that data generators should subscribe to and governments should adopt.

1. Share more than just data

To be of societal value, digital data must be tagged and analyzed, a practice commonly known as generating "metadata." It also must be made available in a format that matches the user's needs. We should not only share data openly, but also facilitate the use of data in a variety of ways. For example, temperature and precipitation data can be used not only to track or predict the effects of climate change but also to calculate how much energy is needed to cool a home or business in a specific region.

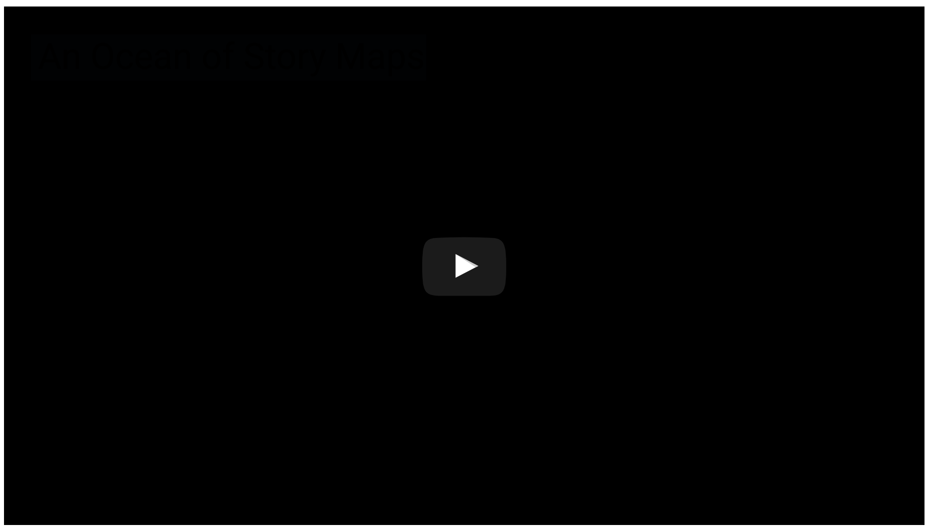
In making our data open to application by others, we need to be open about what we are doing with the data — the actual steps taken in an analysis or map preparation (aka "workflows") — so others can replicate and validate (or improve upon) our work.

We also need to provide use cases — scenarios showing how and why data were used for a particular analysis or map, with an emphasis on a practical, real-world outcome. For example, a use case might tell the story of the correct or most effective way of using a particular workflow (i.e., the actual steps taken in an analysis or preparation of a map from initiation to completion), including how the data may be used in a range of formats, devices and platforms. If the reader of the use case is able to understand what is going on behind the scenes that produced a certain map or output, this will engender trust in the workflow and hence the results

2. Tell stories

Decades of studies in psychology have repeatedly shown how story affects the human mind and influences attitudes, fears, hopes and values. Storytelling is a valuable tool for taking the knowledge developed within academia and transmitting it into mainstream society in ways that resonate and empower action.

Scientists tend to want to explain how the world works by way of copious background information, overview of prior studies, detailed methods, results and discussion before getting to the take-home message. But policy-makers, journalists and the general public want the take-home message first. Telling stories is one way scientists could meet this need.



In the realm of digital data and information, a relatively new medium called the "story map" offers valuable assistance in telling a specific and compelling story. A story map allows scientists to share not only data, but also photos, videos and even sounds, all within the framework of a digital map. Story maps are created with Web map applications that provide the user with sophisticated cartographic functionality that does not require advanced training in cartography or geographic information systems, usually coupled with data needed to tell the story. Users can also leverage their own data (including workflows and use cases) in new ways to inform, educate and inspire decision-makers on a wide variety of issues.

The illustration below shows the opening page of a Smithsonian Institution story map depicting human influence on our planet and innovations that are helping to promote sustainability.

3. Be open to partnerships

Climate science, resilience studies and ecology are squarely in the realm of academia and government agencies, but it's critical to partner with industry as well. The private sector is often looking to create and share knowledge toward solving environmental challenges in partnership with academia or government. Many companies are entering into a culture of resilience not only as part of their values or worldview, but also because it is good business.

Public–private partnerships are most successful when based on a holistic strategy that addresses specific community needs. For example, in June 2013, President Obama announced the Climate Data Initiative, which encourages innovators from the private sector and the general public to share data on climate change risks and impacts in compelling and useful ways that help citizens, businesses and communities make smart choices in the face of climate change. Similarly, NOAA has created cooperative research and development agreements with Amazon, Microsoft, Google, IBM and the Open Commons Consortium. These industry partners in turn share data with smaller companies such as AccuWeather, Esri (where I work) and PlanetOS to extend the public–private partnership even further. On a smaller scale, the new Research Data Alliance is fostering public-private partnerships to enhance data use, data quality and the adoption of data-sharing approaches and tools.

Communities around the world face increasing challenges from natural and manmade disasters. Whether they face drought or flooding, economic collapse or epidemic, communities need digital information technologies to prepare ahead of time, to operate effectively during events and to recover quickly. For digital technologies to meet this need, they too must be resilient. By sharing workflows and use cases, telling compelling stories, and building private-sector partnerships, we can help ensure that digital resources are able to provide the information we need to effectively respond to challenges wherever and whenever they arise.

Add Your Comments

Dr K Selvavinayagam
Feb. 7th, 2016

The science and art of data resilience is proven required technology as geosystems synthesis and analysis and needs huge spatial and aspatial data models to bring out a concrete solutions for problems identified in earth sphere. Therefore for all stakeholders and communities to get benefited the art of resilience in data concerne
important. Therefore this t
effectively used for Geosys
resilience measure for it's a

Dawn Wright
Feb. 9th, 2016

Agreed Dr. Selvavinayagan
This is where the importance of documentation, including workflows comes in, as mentioned in the article (i.e., the actual

ELEMENTA
Science of the Anthropocene

Toward a *digital* resilience

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Abstract

As we contend with human impacts on the biosphere, there is rightfully a great emphasis now on community adaptation and resilience to climate change. Recent innovations in information technologies and analyses are helping communities to become more resilient. However, not often discussed in this vein is a path toward *digital* resilience. If mapping and information tools are to help communities, it stands to reason that they must be resilient themselves, as well as the data that they are based on. In other words, digital tools can help make communities resilient by providing data, evidence-based advice on community decisions, etc., but the resilience of the tools themselves can also be an issue. Digital resilience means that to the greatest extent possible, data and tools should be freely accessible, interchangeable, operational, of high quality, and up-to-date so that they can help give rise to the resilience of communities or other entities using them. Given the speed at which humans are altering the biosphere, the usefulness and effectiveness of these technologies must keep pace. This article reviews and recommends three fundamental digital practices, particularly from the standpoint of geospatial data and for community resilience and policy-making. These are: (1) create and implement a culture that consistently shares not only data, but workflows and use cases with the data, especially within maps and geographic information systems or GIS; (2) use maps and other visuals to tell compelling stories that many different kinds of audiences will understand and remember; and (3) be more open to different kinds of partnerships to reduce project costs, yield better results, and foster public awareness and behavioral change.

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Avoiding collapse

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Introduction

Barnosky et al. (2015) point out that one of the grand challenges for both science and society, is solving six intertwined and vexing problems: human population growth and overconsumption, pollution, disease spillovers, human-caused climate disruption, ecosystem destruction, and extinction. *A Scientific Consensus Statement for Maintaining Humanity's Life Support Systems in the 21st Century* (Barnosky et al., 2014a, 2014b) identifies many applicable solutions, including working alongside the engineering community (e.g., civil and construction engineering, environmental engineering, energy resources engineering, materials science, mechanical, industrial, and manufacturing engineering, and the like). For example, these collaborations are leading to the creation and deployment of new solar, wind, and hydro fuel cells, new monitoring systems for drought, new mapping systems that alert citizens to climate-induced hazards, and more.

This paper focuses more on the digital realm of *software* engineering, within the broader world of information technology and its accompanying practices. The 2015 American Association for the Advancement of Science (AAAS) symposium "Avoiding Collapse: Human Impacts on the Biosphere" emphasized that various innovations in digital data collection, analysis, and visualization now allow for a synthesis of environmental information so that we may track and understand human impacts at global to local scales. Analysis of such data provides new ways to identify macro-scale patterns and processes through long time periods. Indeed we are surely living in an unprecedented era of regional to global scale observation and simulation of the Earth as exemplified by scientific observatories funded by the National Science Foundation, such as: the Critical Zone Observatories (http://criticalzone.org/national/) that look at fluxes of water, carbon, sediments, and nutrients across natural watershed and human land use boundaries; the EarthScope program (http://earthscope.org) that investigates the structure of the Earth's crust, the strain of earthquake faults, and the activity of volcanoes by way of a vast network of sensors scattered across the entire North American continent; the Ocean Observatories Initiative (http://oceanobservatories.org) which is deploying a similar network of sensors around the world to measure the physical, chemical, biological and geological variables throughout the depths of the ocean down to the seafloor; and the Global Earth Observation System of Systems (http://www.earthobservations.org/) with its focus on space-borne, airborne, and *in situ* sensors. All of these above-mentioned programs are constructing the appropriate data management architecture and decision-support systems in parallel. Indeed, we now find ourselves inhabiting a "Digital Earth" comprised of digital technologies from satellites to wristwatches that monitor, map, model, and manage (Annoni et al., 2011; Dobson, 2000; Foresman, 2008; Goodchild, 2007; Goodchild et al. 2012; National Research Council, 2010).

These big science programs produce the so-called "big data." Big data is defined in Gantz and Reinsel (2012) as "a new generation of technologies and architectures, designed to economically extract value from very large volumes of a wide variety of data by enabling high-velocity capture, discovery, and/or analysis." Big data, with the three main characteristics of volume, velocity, and variety, are in turn leading to a new science paradigm, a new data science that deals with, among many issues, the inundation of data from satellites, sensors, and other measuring systems and the issues associated with those large data sets (Seife, 2015; Wright A, 2014). Indeed we are seeing the fruition of ideas expressed by Hey et al. (2009), which posits a new paradigm of scientific discovery beyond the existing three paradigms of empiricism, analysis, and simulation, to a fourth where insight is discovered through the manipulation and exploration of large data sets (i.e., both volume and variety). The impediments to further development are not only technological but also conceptual. For example, the lack of complete understanding about the nature of data in both space *and* time (i.e., both velocity and variety) continues to obstruct solutions to its manipulation in digital forms. But with recent advances in mapping technologies such as geographic information systems or GIS (as an example), scientists are now able to apply high-resolution optical and acoustic imaging techniques that span an incredible range of mapping scales, from km to cm (e.g., Chase et al., 2012; Costa et al., 2014; Dick et al., 2014; Dolan and Lucieer, 2014; Ferrini et al., 2008; Galparsoro et al., 2010; Makowski et al., 2015; Sen et al., 2013).

This is not only about a fourth paradigm of scientific discovery, but a fourth paradigm of government, where Pitroda (2013) predicts that the future of democratic governance lays not only in the pillars of the executive, legislative and judicial, but also in a fourth pillar of information. Indeed governments around the world are adopting principles of open data in government, in which data gathered at the taxpayers' expense is made freely available for both access and reuse, to help foster the transparency and accountability of government as it addresses a wide range of societal challenges, including adaptation and resilience to climate change (Publications Office of the European Union, 2015). These data include local, state, and national boundaries, information about land ownership, the heights and depths of land and water bodies, the paths of streams and drainage areas, and maps of all transportations corridors, urban and rural (witness the recent, bipartisan Geospatial Data Reform Act introduced in the US Senate; http://www.scribd.com/doc/259032993/Geospatial-Data-Reform-Act). In some cases, powerful interests actively seek to keep digital data and information technologies out of the reach of groups of people (Wright et al., 2009). This state of affairs suggests that we need to understand how spatial knowledge is shaped by identity, power, and socio-economic status, and how spatial data handling are socially and politically mediated, particularly with the emergence of crowd-sourcing and citizen science (Connors et al., 2011; Elwood, 2007; Goodchild, 2007).

A very positive circumstance, however, is that there exists an ever-growing catalog of data portals (i.e., single points of electronic access to data and the maps and tools that use them) along with information technology *tools* to monitor, track, and report events and day-to-day operations across a network of people within an organization (see for example the US federal government data portals Data.Gov and geoplatform.gov). A significant proportion of these are map-based, given the incredible power of maps to communicate, persuade, inspire, understand, and elicit action (e.g., Gale, 2013; Harrower, 2015; Wood, 1992). The demand for maps has never been greater; whether for finding directions, for looking at city services, deliveries, movements of people and vehicles, weather events, social events, and social media. We are clearly in a new digital world order. And in this new world order these same digital mapping technologies used for science (for understanding how the Earth works) are also helping communities in a more practical way to gain resilience against one or more of the six intertwined problems discussed in Barnosky et al. (2015). These range from monitoring fire, drought or flooding to mapping the relevant insurance zones for such. They include tracking economic collapse or health epidemics, finding available drinking water, alerting us to temperature and precipitation changes, determining landscape vulnerability for land managers, monitoring air quality monitoring, even the identifying the suitability of a position on one's roof for installing solar panels. However, often not discussed is a path toward *digital* resilience. If digital mapping and information tools are to help communities, it stands to reason that they must embody some resilience themselves if they are to continue to be effective.

Digital resilience

Resilience in general refers to the capacity to deal effectively with change and even threats, to recover quickly from challenges or difficulties, even to withstand stress and catastrophe. Holling (1996) lays out two distinct

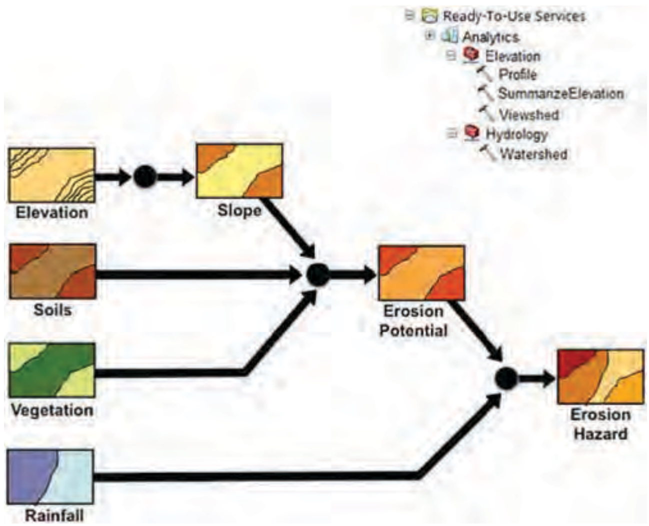

Figure 1

An example GIS workflow for an erosion hazard map.

This is an example of a simple GIS workflow, depicting data layers that will be used as input into GIS analytical functions of determining slope from a topography (elevation), erosion potential using soils and vegetation, all combined with rainfall to produce a final output map of erosion hazard. This workflow can be coded in the GIS or other computer platform using the Python scripting language so that it can be repeated with datasets for different study areas. Upper right: In ArcGIS as an example, the workflow can be shared as a "toolbox" within the desktop version of the software or as a "geoprocessing web service" (aka "Ready-to-Use Services"), an online toolbox that is shared in a data portal for users to select along with the appropriate data and metadata.

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definitions of resilience, further amplified in Walker and Salt (2006). The first involves the common conception of the ability to recover quickly to a prior desired state (aka "engineering resilience"). The second involves whether a system retains the capacity to recover to a prior desired state at all, including its capacity to absorb disturbance and still retail essentially the same (desired) structure and function (aka "ecological resilience"). I argue that these definitions of resilience can and should apply to digital data and systems as well, meaning that for the most part they should be free, accessible, interchangeable, operational, and up-to-date; hence resilient.

Investments in digital data continue to rise (especially with the emergence of the open data movement) and data portals have been proven to be effective in providing electronic access to data and information (e.g., Aditya and Kraak, 2006; Diamond, 2013; Mossbauer et al., 2012). Gantz and Reinsel (2012) predict that by 2020, a third of the data in the digital universe (more than 13 zetabytes, where one zetabyte is one million times the word count of books, monographs and journals in the world's largest library; Johnston, 2012; Kirk, 2012) will have tremendous societal value, but only if tagged and analyzed. As such there continue to be huge efforts in structuring and properly characterizing or tagging data, a practice commonly known as generating "metadata." However, there is more that can be considered. A first principle is that making data, metadata, and all manner of computer code "available" via portals is no longer good enough. Gahegan and Adams (2014) point out the very important difference between what data portals provide and what the user actually needs, especially if seeking to serve many categories of users. Indeed, it is not only a question of how the data are shared openly, but how to facilitate the reuse of data for a range of appropriate scenarios that make sense for the data in that context (e.g., temperature and precipitation data can also be used to derive cooling degree days mapped out as energy needed to cool a home or business in a specific region). Three recommendations toward a digital resilience are shared below. These recommendations, while far from exhaustive, are meant to engender initial thought and discussion, especially where resilience to the grand challenges of society discussed in Barnosky et al. (2015) is concerned.

Share not only data, but workflows and use cases

In making our data open to access, we need to be more open about we are doing with the data. In other words, we need to share more of the workflows done with the data (i.e., the actual steps taken in an analysis or preparation of a map from initiation to completion), and further amplify them in use cases (scenarios or vignettes showing behind the scenes how and why data were used for a particular analysis or map, with an emphasis on a practical, real-world outcome to achieve the user's goal). This is especially true if wishing to maintain scientific rigor where repeatability of an experiment or approach or algorithm is a hallmark. Can someone reconstruct and verify the rigor of an approach, and hence the correctness of a conclusion? Can someone replicate the workflow? In other words, can someone reconstruct and understand the scientific process that was undertaken? Garijo et al. (2014) define a workflow simply as a template defining the set of methods or tasks needed to carry out a scientific or computational experiment (Figure 1). Providing a workflow supports reimplementation or application by others, thus validating approaches and models (Börner and Scharnhorst, 2009; Weber et al., 2015). And given the provision of a workflow *within a data portal*, the best datasets, tools, and results are amplified not only for research and education, but also for practice by governments, non-profits, and other organizations seeking to solve societal problems. In addition, the long-term provenance and preservation of both the data and workflow are critically important for the life cycle

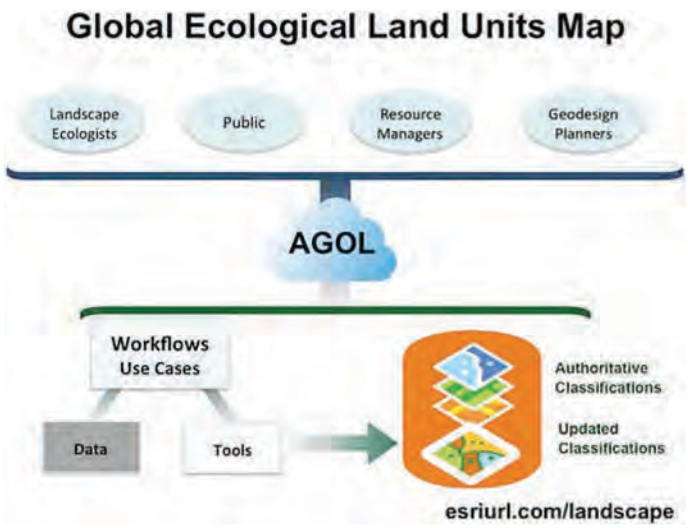

Figure 2

Dissemination strategy for a new global ecological land units map and its underlying data, aimed at landscape ecologists, resource managers, land use planners, and the general public.

The main portal for dissemination of this ecological land units (ELUs) map is ArcGIS Online (AGOL), a cloud-based geospatial content management system. By sharing workflows and use cases, in addition to receiving new ones from the scientific and resource management communities, new thematic maps depicting updated classifications of the land units can be derived from the original data. The aim is for a more repeatable form of landscape management for state and national governments around the world. The web address at the lower right takes the user to a story map describing the entire project.

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of the scientific process. On-the-fly, dynamic calculations and approaches have their import, but scientists often want and need to keep the data at each stage of a workflow.

Wright (2016a) provides an example scientific data workflow package that is being shared openly and freely within the global data and map portal known as ArcGIS Online (http://www.arcgis.com/home). In a similar vein, Wright (2016b) also contains Python scripts and documentation for building and configuring a workflow to handle imagery from the Landsat 8 satellite.

The workflow is brought to life as part of a use case that simply tells the story of the correct or most effective way of using that workflow (aka best practice). This includes how the data used by the workflow may interoperate (or be interchangeable) in a range of formats and on whatever devices or platforms are chosen, especially by way of international standards. This is not unlike how a file or program that works on both a personal computer running Windows and also on a Macintosh running OS, or a digital device that plugs into a home stereo but will also plug into and work in one's car, or how a smart phone can translate calls made from other places in the world in many different language. Also desirable in a use case is a discussion of interoperability in terms of modeling frameworks and how best to decouple data from models so that they may be used for multiple purposes (along the continuum from data to information to knowledge). The use case should also describe how the integration of the data and workflow might work with a host of additional scientific tools and libraries, or the workflow may "crosswalk" among several related approaches (e.g., Gallagher et al., 2015). In the scientific realm, but also for policy-makers and other non-specialists seeking to benefit from scientific data, well-written and complete use cases can be tremendously helpful. If the reader of the use case is able to understand what is happening (e.g., what is going on behind the scenes that produced a certain map or output), this will engender trust in the workflow and hence the results.

Figure 2 depicts the sharing of both workflows and use cases as part of dissemination strategy for a new global ecological land units (ELU) map, aimed at landscape ecologists, resource managers, land use planners, and the general public. The project is ongoing as a public-private partnership between the Environmental Systems Research and the US Geological Survey, and was officially commissioned by the Group on Earth Observations (GEO) and its Global Earth Observation System of Systems (GEOSS) Task EC-01-C1, as key outcomes of the GEO Biodiversity Observation Network and the GEO Ecosystems Initiative (Group on Earth Observations, 2005; Sayre et al., 2007). A global ecological marine units (EMU) map (in progress, Sayre et al., 2015) and a global ecological freshwater units map have also been commissioned. The ELU is a massive biophysical stratification of the planet at a finest yet-attempted spatial resolution (250 m) to produce a first ever map of distinct physical environments and their associated land cover, in a delineation of ecologically meaningful regions that is both classification-neutral and data-driven (Sayre et al., 2014; Stockton, 2015). The intent is to provide scientific support for planning and management (including as an important variable for GIS geodesign models and apps), to enable understanding of impacts to ecosystems from climate change and other disturbances, and for the valuation of ecosystem services. In this way, it offers fulfillment of one of the main recommendations of the White House President's Council of Advisors on Science and Technology report on sustainable environmental capital (Executive Office of the President of the United States of America, 2011). A new ELU white paper (Frye et al., 2015) provides further guidance to use case testers throughout the academic community (i.e., anyone—researchers, students, resource managers, park rangers, Congressional staffers, etc.—wishing to work with a local or regional subset of the ELU map to assess its effectiveness in that region), offering the associated conceptual and technical support pro bono as they download the data, the workflow, the initial use cases, and prepare their own.

Be willing to tell stories, and of many kinds

Barnosky et al. (2015) point out an important two-pronged challenge in academia. The first is in training environmental and physical scientists to communicate issues in ways that truly resonate (especially in concert with, and learning from colleagues in the social sciences and humanities). As Caldas et al. (2015) point out, this is largely a matter of culture, "both a property of the individual, and a property of the social context in which individuals exist… but still an important variable mediating the relationship between humans and the natural environment." The second challenge is in taking the knowledge developed within academia writ large and transmitting it into mainstream society in ways that elicit significant action. One way to accomplish both is through the medium of storytelling.

Gottschall (2012) contends that the last several decades of studies in psychology have shown repeatedly how story affects the human mind, and how attitudes, fears, hopes, and values are strongly influenced by story. Scientists are often encouraged not to publish their work until it constitutes a complete "story." In the prior section a use case was categorized as a type of story, a "story" of best practice. However, there are different modes of story and storytelling. Scientists need to invert their mode and progression of communication to modes that a policy maker (or journalist) will receive well or understand (for a complete treatment of the concept and method see Baron, 2010). Scientists want to explain how the world works, by way of copious background information, overview of prior studies, detailed methods, results, and discussion before getting to the final take-home message. But policy-makers need this inverted, and thus need scientists to inform what decision they need to make (e.g., whether or not to establish a new protected area in their jurisdiction or specifically which ecosystem service to consider for a new management plan or regulation in that jurisdiction), sometimes in near real-time. A scientist may inform their decision by telling them a viable story. As we know, journalists are always in search of a good "story."

Returning to the realm of digital data and information, there is a relatively new medium called the "story map." The story map is a new medium for the sharing not only data, but photos, videos, even sounds, all within the framework of a digital map, and for telling a specific and compelling story by way of that map. Story maps are created via web map applications that provide the user with sophisticated cartographic functionality that does not require advanced training in cartography or GIS, and are usually coupled with web-accessible data needed to tell the story. They also allows the user to leverage their own data (including their workflows and use cases) in new ways to inform, educate, and inspire decision-makers on a wide variety of issues (Wright DJ, 2014, 2015a). Barnosky et al. (2015) provide the example of a story map focusing on how threats to human life support systems currently play out across the United States. Figure 3 shows the opening page of a story map featured in Esri and Jaggard (2014) for the Smithsonian Institution that "reveals the scope of humanity's influence on Earth—and the innovations aiming to create a more sustainable future." Other examples specifically for scientific, resource management and governance applications, including climate resilience, are described in Wright DJ (2014) and Wolfe (2015). A video within Wright (2016c) provides an instructional resource to aid in designing and deploying story maps. It provides further explanation about what story maps are, how a map becomes a story through its layers of data and information, and step-by-step instructions for constructing them.

Figure 3

The opening page of a story map about the Anthropocene.

This story map draws upon an electronic atlas of the Anthropocene, available with descriptive metadata at http://arcg.is/1S7Nw1z. Resources for creating one's own story map are at http://storymaps.arcgis.com.

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Be continually open to partnerships

Climate science, resilience studies, and ecology are squarely in the realm of academia and government agencies, but it will be critical to partner with industry as well. The private sector is already working on solving the six intertwined problems discussed in Barnosky et al. (2015), and is often looking to create and share knowledge toward effective action and in partnership with academia or government. Many are entering into a "culture of resilience" not only as part of the values or worldview of a particular company, but because it is also good business. To quote former Maryland Governor Martin O'Malley and many, many others: "cooperation is the new competition" (see also Lowery, 2014; Lowitt, 2013). Hence, academics in particular should not be afraid to investigate partnerships with the private sector.

Such *public-private partnerships* are successful when based upon a holistic strategy that addresses specific community or social needs in the context of sustainable socio-ecological systems (Hoegh-Guldberg et al., 2013). For example, in June 2013, President Obama announced the Climate Action Plan and within that the Climate Data Initiative, which encourages innovators from the private sector and the general public to convey data on climate change risks and impacts in compelling and useful ways that help citizens, businesses, and communities make smart choices in the face of climate change (Wright, 2015a). Similarly, NOAA, in an attempt to explore more sustainable models for increasing the amount of open data made available via the cloud, while minimizing the great cost in doing so, has created cooperative research and development agreements with Amazon, Microsoft, Google, IBM, and the Open Cloud Consortium (https://data-alliance.noaa.gov). These industry partners have in turn formed data alliances with smaller companies such as AccuWeather, Esri, and PlanetOS to extend the public-private partnership even further. The current strategy in part mirrors the recommendation of Hoegh-Guldberg et al. (2013) to "optimize the yield of common goods utilized, minimize the cost to the public of the activity through the leveraging of opportunities and assets and, incentivize responsible behavior in a transparent and synergistic fashion such that it results in long-term sustainability." On a much smaller scale, the new Research Data Alliance (https://rd-alliance.org) is fostering public-private partnerships focusing on data use, data quality, and the adoption of data sharing approaches and tools, with the aim that such a focus will lead to these resources being around and helpful for a longer period of time.

These are examples of free and open data stimulating new businesses and new research directions. A sample research issue: how best to keep the data free, of high quality, accessible, interchangeable, operational, up-to-date, and hence resilient, while keeping the businesses that generated the data sustained as well? A challenge will be engaging the rest of the private sector to participate in partnerships such as these, with the knowledge that they can, in fact, market these approaches, while still benefiting society at large and serving a public good.

Conclusion

Communities around the world are facing increasing challenges from natural and man-made disasters. Leaders of these communities seek to anticipate future trends and enact policies that will support rapid response during times of need. Whether they face challenges such as drought or flooding, economic collapse, or a health epidemics, communities that are resilient are using digital information technologies (such as GIS) to prepare ahead of time, to operate effectively during events, and to recover quickly.

While such digital information technologies can provide innovations that better connect cities, governments, and private organizations together in assessing their risk exposure and increasing their overall resilience, the emphasis of this article has been to lay out three major recommendations for ensuring the resilience of the digital resources themselves. Given the speed at which humans are altering the biosphere, we need such a digital resilience so as not to miss the opportunities for forecasting detrimental outcomes in time to avoid them. Global data needs will continue to grow, and will be met as the "digital Earth" expands, especially by way of real-time sensors. As such, data portals will continue to proliferate.

But this is not just about eyeballs on a map or on a series of numbers, but about coupling of the appropriate data, with workflows and use cases to make the data useful for the right audience (Wright, 2015b). The concepts of workflows and use cases are hardly new, but explicitly sharing these resources within data portals, even from the standpoint of digital objects that can be characterized with metadata, downloaded just like datasets, or even mapped out spatially, is the point of emphasis of here. It is also about telling compelling stories to effectively communicate the scientific results and to transform scientific data into actionable information that people can use in their decision cycles. To use the example of extreme weather (Wright, 2015b), this can be critical for short-term decisions (e.g., get in storm shelter now), medium term (e.g., evacuate), or long term (e.g., infrastructure planning as communities recover from a hurricane or tornado).

As emphasized in the AAAS symposium that prompted this *Elementa* Special Feature the time is now for governments, communities, non-profits, the private sector, and universities to go beyond just an exploration and discussion of ideas, to actually using these technological tools in an approach that is digitally resilient. This with an aim toward rapidly prototyping and delivering repeatable solutions that all can use to help guide the planet towards a more resilient future… before time runs out.

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Competing interests

The author has declared that no competing interests exist.

Data accessibility statement

The following datasets are freely available with this article and listed in the reference section.

- Example computer code package, documentation, and sample data for selected scientific workflows (Wright, 2016a);
- Example computer code package for building and configuring a workflow to handle imagery from the Landsat 8 satellite (Wright, 2016b);
- Story map instructional webinar video (Wright, 2016c).