Collaborative Data Collection in the Earth Science Community: What Lessons Can Philadelphia's Water Department Learn from UNAVCO's Plate Boundary Observatory?

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Abstract

As cities pursue innovative new policies to become more environmentally sustainable, they face a new challenge: how can they collect the data they need to understand natural processes in cities and to evaluate the effectiveness of new designs for development? Because of the complexity of cities' land ownership and development, and the mismatch between natural and jurisdictional boundaries, urban environments are difficult to study in a systematic way. How can cities collect the data they need to inform successful policies, and how can they collaborate with academic researchers to maximize their effectiveness?

One successful case of collaborative data collection that spans jurisdictional boundaries and individual research designs is UNAVCO's Plate Boundary Observatory. UNAVCO was founded in 1984 and as a nonprofit consortium of academic and government researchers in the earth sciences. One of UNAVCO's most notable projects is the Plate Boundary Observatory (PBO), constructed from 2003 to 2009, which was a comprehensive network of high-precision geodetic monitoring equipment (GPS monuments, borehole strainmeters, and seismometers) to collect ground deformation data throughout the United States in a coordinated way with shared data formats. This geodetic network provides open data to support a variety of research topics. Through projects like the PBO, UNAVCO successfully collects data across political jurisdictions that can be used for many different research objectives. This allows scientists to collect data in a comprehensive and efficient way over a large geographic area.

UNAVCO's successes that are most relevant to cities are:

- *Creating a nonprofit organization can foster collaboration between government agencies and academic researchers;*
- *Collaborating to collect data that can satisfy multiple research agendas;*
- *Collecting data on a large scale that spans political jurisdictions;*
- *Providing open data in standardized formats;*
- *And focusing on data stewardship as well as data collection.*

Introduction: Why study UNAVCO?

As cities pursue innovative new policies to become more environmentally sustainable, they face a new challenge: how can they collect the data they need to understand natural processes in cities and to evaluate the effectiveness of new designs and development? Evidence-based design in architecture and landscape architecture and adaptive management in environmental planning have become increasingly popular, but they require robust data to be successful. Because of the complexity of cities' land ownership and development, and the mismatch between natural and jurisdictional boundaries, urban environments are difficult to study in a systematic way. How can cities collect the data they need to inform successful policies, and how can they collaborate with academic researchers to maximize their effectiveness?

In Philadelphia, the Philadelphia Water Department (PWD) recognizes the need to collect data for monitoring and maintenance of stormwater management infrastructure, as well as evaluating the effectiveness of new designs. However, the PWD must find methods for building a data collection system that is effective and cost-efficient. This is an especially difficult question for the Water Department for two reasons: 1) assessing subsurface water conditions can be difficult and costly; and 2) implementation of the *Green City, Clean Waters* plan relies on the actions of many individuals and institutions, including private property owners and developers (Philadelphia Water Department, 2011 and 2012). How can the city ensure that these green infrastructure projects incorporate means to collect the data the city and other researchers will need to evaluate performance, enhance understanding of the urban hydrological system, and alert city staff when stormwater infrastructure requires maintenance?

Watersheds do not match political boundaries. Instead, watersheds in the Philadelphia area span multiple municipalities, with different governments with their own stormwater management policies. Even within one city, land in the watershed is owned and controlled by many different private landowners and institutions. Therefore, cities like Philadelphia face challenges in collecting the data they need to understand the hydrological system or to evaluate the effectiveness of existing drainage. Meanwhile, the Philadelphia area is home to several academic institutions, such as the University of Pennsylvania, which employ researchers in hydrology, ecology, civil engineering, and landscape architecture. These researchers are currently an underutilized resource for the city, but they could work collaboratively with the Philadelphia Water Department to collect data and study the city's hydrological system. UNAVCO, as a nonprofit that successfully coordinates data collection for diverse academic and government research purposes, is a promising case for Philadelphia and other cities.

Models for Urban Data Collection

There are several different potential approaches to urban data collection, which may be appropriate in different circumstances. They vary based on research design and collection mechanism. Directed research designs are those for which a researcher or research design committee determines what data must be collected to answer a set of research questions and designates a collection strategy to fulfill the project's data needs. In an opportunistic

data collection approach, researchers or organizations collect the data they are able to obtain, without the ability to direct what data they receive. Cities and organizations may collect data in a participatory manner, soliciting information from interested citizens, or they may direct data collection. Based on these criteria, the following are typical data collection models:

Crowd-Sourced Data

Cities have increasingly used crowd sourcing to collect data on constituent experiences, service and maintenance issues, and other citizen-observed phenomena. In crowdsourcing, cities provide a platform for interested citizens to submit information for analysis or action. Cities are increasingly collecting crowd-sourced data using GPS-enabled mobile phones. A few notable examples include the City of Boston's Citizens Connect (http://www.cityofboston.gov/doit/apps/citizensconnect.asp), which collects service requests and complaints, and Street Bump (http://www.cityofboston.gov/DoIT/apps/streetbump.asp), which uses the accelerometers in drivers' phones to detect potholes and sends the data to Boston's Department of Public Works. Boston's Mayor's Office of New Urban Mechanics, an office devoted to urban innovation and civic participation, developed both of these projects.

Crowdsourcing is an opportunistic, participatory model. Crowdsourcing's biggest strength is that it allows cities to harness the knowledge of its citizens, reducing its data-collection burden. It also gives citizens agency to participate in city data gathering. However, successful crowdsourcing requires a large enough population of citizens interested and willing to participate. Crowd-sourced data may have limited accuracy, and cities have no control over who collects data and where. Cities may find that citizen participation is biased, with certain neighborhoods or demographics more likely to submit data. Cities may also have difficulty maintaining citizens' interest over long time spans, which would undermine research projects that require consistent data over long time spans.

Regulatory-Driven Data

Regulatory-driven data collection is opportunistic but less participatory than crowdsourcing. In regulatory data collection, an agency with permitting authority may require the installation of data collection instruments for all new developments that meet or exceed certain criteria. An example of this model is Tokyo, which requires new buildings to install subsurface monitoring equipment (Spirn, 1984). This policy is opportunistic, collecting data as projects make it available rather than based on a set research agenda. However, the data collected may be more precise than that collected through crowdsourcing and is more likely to be in a standardized format, since regulators can specify data standards. After decades, Tokyo's policy has allowed the city to collect substantial data on its subsurface geology.

Research-Driven Data Collection

Research-driven data collection conforms most closely to the traditional model for scientific research, where a researcher or team determines what data they require to answer their research questions or test hypotheses, and they develop a strategy to collect the required data. This model is directed, rather than opportunistic, and it is usually not participatory, although some research may utilize volunteers for data collection. UNAVCO (www.unavco.org) is closest to the research-driven model for data collection. Within UNAVCO, research committees design networks to collect the data necessary to answer a set of research goals, and the organization builds its own systems that meet its standards. This allows the organization to control how data is collected and to manage its curation. However, the organization does not benefit from participatory collection, and researchers may face constraints on what data they can collect, especially on private land. Research-driven data collection projects such as UNAVCO's are most appropriate when an organization requires data with high precision or comprehensive coverage of a geographic area or other phenomenon.

What is UNAVCO?

UNAVCO is a nonprofit consortium of earth scientists that facilitates earth science and education using geodesy, or the measurement of the earth and gravitational fields (UNAVCO, 2012a). UNAVCO's mission statement is:

"We challenge ourselves to understanding the changing Earth by enabling the integration of innovative technologies, geodetic observations, and research, from pole to pole."

UNAVCO was founded in 1984 as the University NAVSTAR Consortium (UNAVCO), which was a partnership between the University of Colorado, Columbia University, and five other universities, funded by the National Science Foundation and housed at the University of Colorado. UNAVCO's goal was to advance the use of GPS technology, then cutting-edge, in academic research. UNAVCO continued to gain new members, and in 1992 it became part of the University Corporation for Atmospheric Research (UCAR). In 2001, UNAVCO incorporated as an independent 501(c)(3) with headquarters in Boulder, Colorado.

Today, UNAVCO has 183 member institutions, including over 100 academic institutions in the United States and international universities. Government members include agencies that engage in geoscience research, such as the U.S. Geological Survey (USGS), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA). Non-profit research institutions, such as the Woods Hole Oceanographic Institute and the Smithsonian, are also members.

UNAVCO has a multi-tiered governance structure, with a Board of Directors elected by members and several Standing Committees and Science Advisory Committees that recommend policies and data collection strategies to the Board. UNAVCO has offices in Boulder, CO, San Clemente, CA, Portland, OR, and Anchorage, AK, which carry out its day-to-day operations. UNAVCO's projects include building the infrastructure to collect geodetic data and collecting and curating remote sensing data about the earth's surface.

Case Study: UNAVCO's Plate Boundary Observatory

One of UNAVCO's most notable projects is the Plate Boundary Observatory (PBO), a large-scale, comprehensive network of geodetic equipment to measure plate boundary movements in the United States (PBO, 2011: http://pbo.unavco.org/). The network, which consists of 1,127 high-precision GPS monuments and 77 borehole strainmeters and seismometers, was built from 2003 to 2009 and funded by the National Science Foundation. The GPS monuments are permanent installations of high-precision GPS equipment powered by a solar panel and serviced with remote communications devices (Figure 1). These monuments provide measurements of ground position over time and, as a network, they depict relative ground movements due to plate tectonic shifts. The borehole strainmeters measure the vectors of stress and strain at depth, and the seismometers monitor ground shaking. The PBO, which UNAVCO built over a period of six years, provides a large-scale, comprehensive, open data set that researchers around the world can use for a range of studies. In this way, UNAVCO has successfully bridged local and state jurisdictions, as well as the confines of any individual research agenda.

Figure 1: PBO GPS monument at the Bumpass Hell overlook, Lassen Volcanic National Park.

Building the PBO required UNAVCO to complete the following tasks:

- *Network Design*
- *Reconnaissance*
- *Negotiation with landowners*
- *Permitting*
- *Construction*
- *Maintenance*
- *Data Sharing*

Siting committees designed the network to meet research goals for four different tectonic regimes that require different data collection strategies: magmatic, extension, subduction, and transform fault regions. The siting committees created maps showing preferred network sites with acceptable tolerance buffers. Within these buffers, UNAVCO engineers performed reconnaissance, searching for landowners with suitable sites who would be interested in hosting a monument. If no suitable site could be located within the buffer, engineers worked with the committee to find alternatives. In this way, the network design was a combination of research-driven and opportunistic; although the siting committee chose locations based on their research goals, the actual monitoring sites were constrained by the willingness of landowners within the buffer zone. This was especially challenging in urban areas, where land is more heavily developed and more valuable. In some cases, UNAVCO would alter its monument design by installing the GPS antennae on buildings. However, this still requires locating a willing building owner, and the building must be of stable enough construction that it would not move relative to the bedrock below.

This process required UNAVCO to build strong partner relationships with landowners who could allow UNAVCO to install monitoring equipment on their property. Many of UNAVCO's land partners were large government or institutional landowners, such as parks agencies, transportation departments, or large ranch owners. For some landowners, hosting a site had particular benefits. Because these monuments can increase real-time survey accuracy nearby, state and local transportation agencies often welcomed monuments in their rights of way. Parks and land management agencies often saw a public relations benefit to contributing to scientific research, and support for earth sciences aligned with their environmental stewardship goals. In some cases, parks agencies choose to highlight UNAVCO's monuments as part of their environmental education programs. In 2007-08, I worked as a planner for the Midpeninsula Regional Open Space District, a regional parks agency in the San Francisco Bay Area, which allowed UNAVCO to build four GPS monuments on District land for all of the reasons above (MROSD, 2008).

During negotiations with landowners, UNAVCO worked to address landowner concerns about maintenance, aesthetics, vandalism, and logistics. Although the basic design of the GPS monuments and borehole strainmeters was standardized, UNAVCO could paint them a variety of colors to suit their location. They would surround them with fencing if human vandalism or damage from grazing cows was a concern. UNAVCO also developed an

interpretive sign that they offered to install for monuments on public lands if a parks agency wanted to showcase the monument for visitors.

UNAVCO worked with landowners to find locations that met UNAVCO's research needs but also met the landowners' goals. One issue for parks agencies to decide was how visually compatible the monuments were with the experience of nature they provide; depending on one's point of view, these monuments could be an educational opportunity or an eyesore interrupting the natural experience. Some agencies chose to located monuments in prominent locations to highlight their role in geoscience research. For example, the National Parks Service located a monument at the Bumpass Hell overlook, at one of most visited spots in Lassen Volcanic National Park (Figure 1). Other parks agencies, such as the Midpeninsula Regional Open Space District, chose locations where monuments were not immediately visible from trails out of a desire to maintain a more wilderness experience for visitors. Many agencies may make this decision on a site-by-site basis, depending on context.

Figure 2: A UNAVCO engineer builds a GPS monument in Russian Ridge Open Space Preserve near La Honda, CA.

After finding a suitable location, UNAVCO staff managed permitting, construction, and long-term maintenance. Because the monuments themselves are standardized and have a small environmental footprint, permitting for individual monuments was relatively simple after completing programmatic environmental review for federal and state regulators. Construction of each monument typically took 1-2 days, with a crew of three people (Figure 2). The monument design includes radio communications equipment that notifies UNAVCO

staff of any problems, in which case they contact the landowner hosting a site to schedule maintenance. Because UNAVCO finished constructing the PBO network in 2009, the project is in its maintenance phase today.

One of the most valuable aspects of the PBO is its open data program. All of the location data from the PBO monuments is online in standardized data formats for use in earth science research. Access to the data is free, and the interface for download is simple to use (Figure 3). This allows many different researchers, with different agendas, to use data from this network. Some researchers have even used this data in unexpected ways. For example, in 2012 researchers from the University of Colorado used the "noise" in winter GPS data to reconstruct snow levels – not a typical use of data collected to study plate tectonic movements (UNAVCO, 2012b).

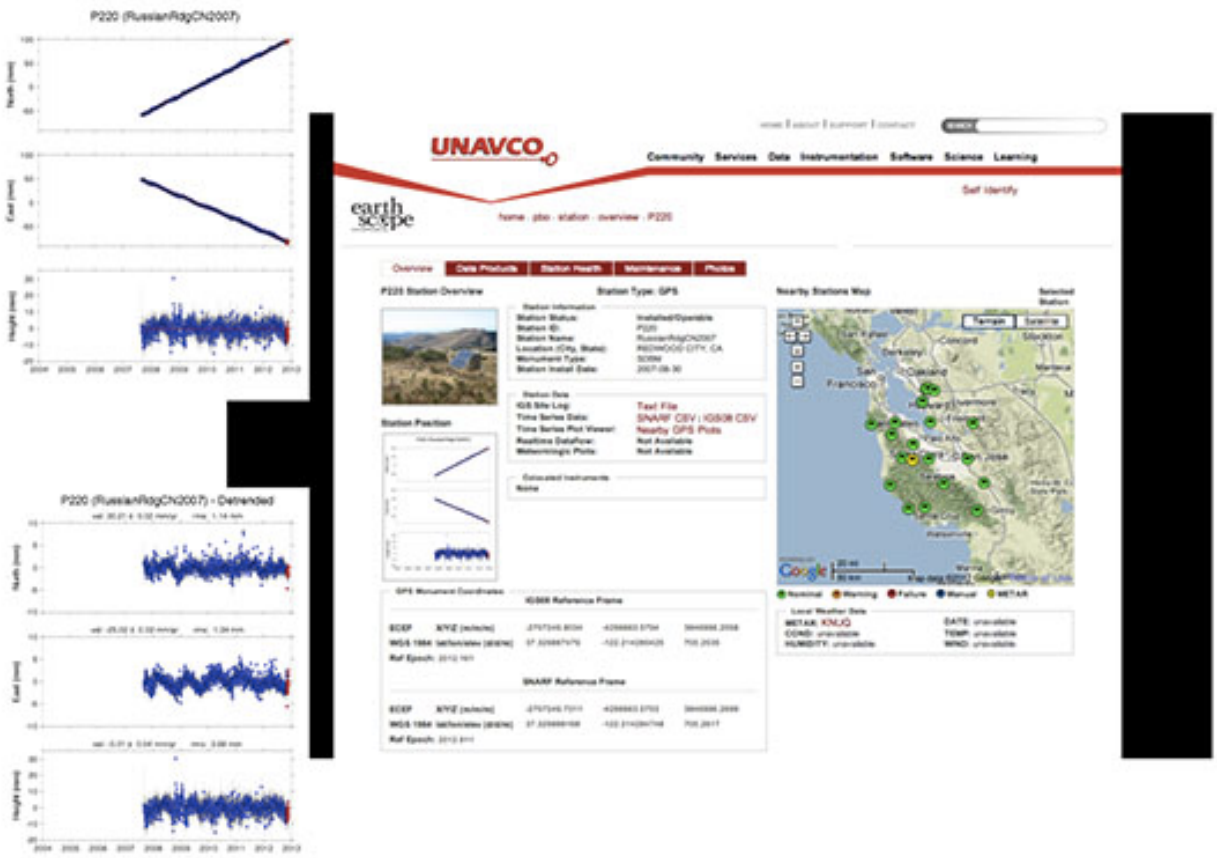

Figure 3: Screenshots of the PBO website data portal, showing the data overview page for a GPS monument, as well as the location data products available for download. (PBO, 2012: http://pbo.unavco.org/station/overview/P220/).

Although UNAVCO's open data platform is very effective for sharing valuable data with its audience – earth scientists – it is worth asking whether they could do more to share and interpret this data for a non-specialist audience. In its strategic plan and in a recent workshop to consider future directions for geodetic research, UNAVCO recognized the need to emphasize education and outreach to a wider audience (UNAVCO, 2008 and 2001; Davis

et al, 2012). One way to do this would be to create tools or data visualizations that non-scientists could learn from and explore. A recent successful example of public data visualization that could be an inspiration is the Boston-area Metropolitan Area Planning Council's (MAPC's) Hubway Data Visualization Challenge (MAPC, 2012: http://hubwaydatachallenge.org/). For this challenge, the MAPC released a rich set of data about the Boston area's new bikeshare, and they invited teams of artists, designers, data analysts, and programmers to create unique and accessible visualizations.

A contest like this, or an artist-in-residence-like program, for public-facing data interpretation, could help UNAVCO reach out to a wider audience of policy makers who need to understand earth science research, as well as the general public. It may also be a way to give back to the landowners who allow UNAVCO to build monitoring equipment on their properties, if they can see what data their monuments have produced in a fun and compelling way.

What is next for UNAVCO?

The construction phase of the Plate Boundary Observatory ended in 2009, but UNAVCO's work is not done. UNAVCO staff continues to maintain the network. In addition, the task of collecting and preserving all of the data from the network is not trivial; at this point, UNAVCO has collected and archived over 22 terabytes of data from the PBO network (PBO, 2011).

In addition to maintaining the PBO network, UNAVCO has expanded other data collection projects. As an organization whose mission is to support scientific research, UNAVCO needs to remain on the cutting edge of technology and research topics, so their work cannot become static. In the past few years, they have expanded their collection and curation of other types of data, such as high-precision Light Detection and Ranging (LiDAR) data of active fault zones in the United States (UNAVCO, 2012). This data, available for free online, can be used to study ground deformation along faults, landslides, and hydrology. Because UNAVCO provides the first-return data, which shows trees and infrastructure, as well as bare earth data, this imagery can also be used to analyze tree cover and other planning questions. UNAVCO also has become a repository for Inferometric Satellite Aperture Radar (InSAR) data, which shows changes of elevation over time. Scientists have traditionally used this data to study faults and volcanic ground deformation, but InSAR data can also be used to understand urban ground subsidence or glacial retreat.

In *A Foundation for Innovation: Grand Challenges in Geodesy*, Davis et al (2012) explore how the kinds of data UNAVCO collects can be applied to some of today's most important environmental questions, such as hydrological processes, the future of water supplies, climate change, and glacial retreat. They recognize that geodetic data has applications beyond the traditional focus on plate tectonics, and that UNAVCO should reach out to other science and policy communities to magnify the benefit their data can provide.

Conclusion

UNAVCO has been very successful as a nonprofit organization that facilitates shared data collection for multiple research agendas, and it has provided a forum for government and academic researchers to collaborate. In this way, they may be an inspirational case for cities that want to study problems that cross jurisdictional boundaries, such as watershed hydrology, and for cities that want to leverage the knowledge resources that local universities can provide.

UNAVCO's institutional innovations are:

- *A governance model for collaborative data gathering;*
- *Universal data standards;*
- *A focus on data stewardship and open data access;*
- *And a large geographic scope.*

However, UNAVCO does face challenges, such as:

- *The need for secure, diversified funding for maintenance, construction and data preservation;*
- *A desire to expand the focus of data applications to include important global topics, such as climate change;*
- *The need to reach a wider, non-specialist audience;*
- *And the need to communicate with policy makers and other potential users about UNAVCO data and research.*

Overall, the non-profit consortium is a promising model for cooperation between government and academic researchers. UNAVCO's Plate Boundary Observatory shows how large-scale earth science monitoring projects can successfully bridge political boundaries as well as individual research designs. UNAVCO's provision of open data in standardized, easy-to-use formats is important for the success of collaborative research. However, there is great potential to improve UNAVCO's impact by reaching out to the non-scientific community, so that more people understand the implications of the data they collect.

These lessons from UNAVCO should be valuable for cities as they assess the data they need to successfully understand natural processes and urban sustainability. Data-driven design and policy requires adequate data, which cities rarely have the resources or authority to collect by themselves. Creating a regional consortium with other cities and regional agencies, as well as researchers from local universities, may be a successful strategy for collecting more and better data than cities can collect alone, and it may help cities leverage the knowledge and expertise of many different researchers who can use the data in new and unexpected ways. Although the types of data an agency like the Philadelphia Water Department needs to collect may differ, as may the methods for collection, UNAVCO's institutional structure shows that organizations can be ambitious and fill a need for knowledge that currently seems daunting.

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