



CASE REPORT

# Knowledge mobilization for community resilience: perspectives from data, informatics, and information science

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## Abstract

This paper presents the perspectives of data, informatics, and information scientists and practitioners regarding how data solutions can be developed for place-based community resilience. Data were collected from participants at an Earth Science Information Partners (ESIP) meeting in 2015. Results show that to develop such data solutions, terminology related to community resilience must be further clarified to coordinate better with data and informatics systems, and institutional support of place-based community resilience must be prioritized. In addition, accessibility and usability of developed data solutions are crucial, and gaps along the information pathway must be filled to better connect data practitioners and community resilience practitioners.

**Keywords** Data science · Informatics · Community resilience · Information pathways · Knowledge mobilization

## Introduction

Place-based community resilience has emerged as a US national and global priority with the expectation that it can improve human livelihoods, address environmental change, and prepare communities and households to cope with hazards and disasters (Cutter et al. 2013; NSTC 2014; PCAST 2011). Efforts to facilitate the application of science to enhance place-based community resilience for human systems have been hampered by the lack of effective metrics, assessment tools, and supporting information pathways (Arbon 2014; Burton 2015; Altaweel et al. 2016). To improve the availability of analytical tools and access to information in communities, we are conducting an ongoing series of studies to develop frameworks and data-driven tools for residents, community planners, and disaster relief

organizations to support their efforts to enhance resilience in their communities. As one component of this work, we present the results of a workshop held during a 2015 Earth Science Information Partners (ESIP) summer meeting that summarize the perspectives of “science, data and information technology practitioners” (ESIP 2018) and their potential contributions for developing data solutions that help to support place-based community resilience efforts.

## Background

This section is divided into four subsections that provide background information. The first subsection presents a cursory overview of community resilience. The second subsection describes data, information, and knowledge sources relevant for enhancing community resilience. These sources include the US agencies and federally funded research and development centers like the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), US Department of Agriculture (USDA), US Geological Survey (USGS), and the National Center for Atmospheric Research (NCAR). In the third subsection, we discuss the concept of knowledge mobilization and its relevance to this study. The fourth subsection provides an overview of the ways communities of professionals interested in supporting

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such knowledge mobilization exchange ideas; prime amongst these is by participating in ESIP and its biannual meetings.

## Community resilience

Resilience studies have spanned the gamut from examinations of the individual in the context of children, family therapy, and development of maladaptive strategies (Rutter 2015) to understanding both the social and biophysical aspects of community resilience (Aldrich and Meyer 2015; Kelly et al. 2015) by emphasizing sustainable development (Collier et al. 2013; Luederitz et al. 2013), urban development, planning, and management (Desouza and Flanery 2013), and disaster risk reduction (Matyas and Pelling 2015). As an emerging transdisciplinary field, community resilience overall still lacks clear definitions, metrics, and analytical tools (Arbon 2014; Burton 2015; Altaweel et al. 2016). While such vagueness presents opportunities for creative development of a new field, it also presents a challenge as to how resilience can be applied and operationalized in practice (Kharrazi et al. 2016).

For the purposes of this paper, we define community resilience as “the capability [of a place-based community] to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change” (Community and Regional Institute 2013). Community is defined broadly, ranging from very small, sparsely populated areas to very large urban areas. Resilience can pertain to such cases as indigenous coastal communities endeavoring to cope with sea-level rise and loss of sea ice upon which to hunt (Brinkman et al. 2016; Himes-Cornell and Kasperski 2015). Another example of a small-scale community is the capacity of a mountain community to recover from a flash flood that destroys the only road through town (Mitchell 2013) or compromises the town’s water supply (Rael 2013). At the other end of the size scale, community resilience includes the capacity of metropolitan regions to prepare for rising sea levels (Upton 2014), adequately plan water and sewer facilities and their maintenance (Blue Water Baltimore 2018), and plan for and recover from disasters such as hurricanes (Kapucu 2008).

The resilience of many place-based communities is challenged by such factors as social and economic inequity, poor multi-scale connectivity (e.g., transportation, hydrological processes), ecosystem degradation, lack of preparedness for natural hazards, and poor adaptation to climate change (Ahern 2011; Leichenko 2011). To overcome these challenges, policy makers and planners must have the appropriate assessment tools and information to allow them to understand the integrative, interlinked biophysical and social aspects of a community, so they can

take action and make informed decisions (Jha et al. 2013). Communities are increasingly dependent on data and information to function, such as to manage transportation, energy usage, and infrastructure development (PCAST 2016). Therefore, a clear understanding about the information use and needs of diverse communities, and a streamlined information pathway between data generation and application are crucial for achieving a society that is well positioned to respond to complex social–environmental issues (Cash et al. 2006) and innovate accordingly (Tödtling and Trippel 2005). Sustainable community management calls for effective partnership between different stakeholders both within the community (Stringer et al. 2006) and in the larger world beyond (Kapucu et al. 2010), and this is often made possible by a shared readiness to form technologically supported knowledge networks (Stokols et al. 2008).

In recognition of these data and information needs, programs exist to help provide updated information and tools to support community resilience. Examples of programs include the US Climate Data Initiative, <https://www.data.gov/climate>; the US Climate resilience toolkit, <https://toolkit.climate.gov>; the Resilience Alliance assessment, <https://www.resalliance.org/assessment-resources>; the 100 Resilient Cities program, <http://www.100resilientcities.org>; and the United Nations Office for Disaster Risk Reduction, [www.unisdr.org/campaign/resilientcities](http://www.unisdr.org/campaign/resilientcities). According to Greg Guibert, the Chief Resilience Officer of the City of Boulder, Colorado, more support is needed to help close the gap between potentially useful information and its application at the individual, neighborhood, and city level. Managers of cities, land, and natural resources are asked to use the best available science to inform their decision-making for resilience (Sullivan et al. 2006), but the appropriate data generation and data management systems have yet to be developed to make that possible.

## Data, information, and knowledge sources

In the US, many important social and biophysical source data that are relevant to community resilience are publicly available from federal-, state-, and local-level government agencies. While the records of agencies like the US Census Bureau, the Bureau of Labor Statistics, and Bureau of Economic Analysis may spring readily to mind for high-level demographic and socioeconomic information, agencies like NASA, NOAA, USDA, and USGS also have important historical and current data that are necessary for understanding the biophysical and environmental contexts and trends at any given location. For example, NASA’s over-50-year history of satellite imagery is used in many applications, including wildfire threat assessments, detection and recovery management, and predicting and

assessing damage from disasters, such as earthquakes, floods, landslides, and tornadoes (NASA 2017). NOAA's satellite-, radar-, and aircraft-based weather forecasts from the National Hurricane Center are relied on by both US and international communities; their forecasts of 2017's record-breaking Hurricane Irma prompted one of the largest evacuations to date in modern US history (Holmes and agencies, 2017). Similarly, stream gauge information, coupled with geologic and elevation information from USGS, and historical temperature and precipitation records and weather forecasts from NOAA are useful for assessing the likelihood of such hazards as flash floods and debris flows (USGS 2017), and planning for their mitigation.

USDA's agricultural yield information (USDA 2017), Environmental Protection Agency's (EPA) water and air quality data (EPA 2017a, b), and federal and state Department of Transportation's (DOT) information on roads, bridges, and traffic (e.g., Colorado DOT, <https://www.codot.gov/travel>) are all other examples of the great breadth of datasets that are relevant and available to city managers and residents. For such data and information to be truly available, however, appropriate information systems must exist to ensure that data are presented in forms that are usable and understandable by a diversity of relevant audiences.

### Knowledge mobilization

Knowledge mobilization is a translation process that transforms the outputs of research into forms suitable for use by various audiences (Levin 2008). For many years, Earth Science data and informatics professionals have attempted to maximize the utility of collected data by endeavoring to understand the needs of relevant audiences, and developing data products and services targeted to each audience. For example, NASA and other agency Earth Science data products are categorized by data level (Space Studies Board 1986) for the purposes of enhancing knowledge mobilization; the higher the data level, the more aggregated and easily interpreted the data product is, thereby increasing its accessibility by broader, more numerous, and less specialized audiences. This has worked well in practice for satisfying the needs of the research communities that are core to these government agencies' missions. However, as Baker et al. (2015) have shown, even higher levels of interpretive data products, such as textual summaries written for a general audience with graphs, maps, and visualizations, may be necessary to satisfy the needs of broader audiences, such as the media, decision makers, and general public.

### Data and information science landscape

The information pathway from data generation to end user for community resilience topics includes a wide variety of stakeholders. Data generation includes researchers, sensors, and platforms (e.g., ships, airplanes, satellites, buoys, surveys, etc.) that acquire data and conduct analyses to create derived data products. Data managers and curators organize data and derived or value-added data products, so they can be shared, aggregated, and used more easily (i.e., facilitating access to data). Software engineers, either at data repositories or in industry, create software that generates data products (e.g., hurricane forecast maps) for the purpose of fulfilling the needs of specific end user groups. These groups can span the gamut from city planners and policy makers to various segments of the residential community. As part of the process, data centers and repositories (e.g., NOAA's National Centers for Environmental Information) are key infrastructure that store, curate, and develop data products that are deemed important enough to be generated regularly (Mayernik 2015). These data centers and repositories often employ data generators, data managers, and software engineers to support specific topics that have been identified as vital issues for society.

The key to knowledge mobilization along an information pathway is to understand the major social groupings in a community, and the information needs of each group (Baker et al. 2015). It takes time and resources, however, to build relationships between these groups, and there are often fundamental mismatches in missions and available resources between individual communities, researchers, and data repositories. One way to maximize the use of scarce resources is to pool them, and this is the strategy behind the development of such initiatives as digital libraries and global collaborative research organizations (e.g., e-Science; Hey and Trefethen 2003). An increasingly common mechanism in practice is for agencies, researchers, and commercial entities to meet, share knowledge, and coordinate actions that advance the data, information, and knowledge community. The Earth Science Information Partners is one of the main such organizations for the Earth Sciences data and informatics in the United States (ESIP 2018).

Founded by NASA in 1998 (upon suggestion by the US National Research Council) and currently still funded by them, as well as by NOAA and USGS, ESIP today is an open community with about 150 partner institutions, including government agencies and research laboratories, research universities, modelers, education resource providers, technology developers, nonprofit organizations, and commercial enterprises. ESIP partners jointly seek to improve their ability to connect science, data, and users. As

a community-driven organization, ESIP provides a neutral space and intellectual commons through working groups, telecons, and biannual meetings.

Within this context, some members of the ESIP community are undertaking a series of activities that aim to identify the challenges and opportunities for bridging gaps and mobilizing knowledge along the information pathway for community resilience (Virapongse et al. 2018). These activities are intended to spur the development of resilience frameworks and data-driven tools that support resilience assessment across communities within the US. Such tools can help to translate complex data into useful information that supports the efforts of residents, planners, and disaster relief organizations to enhance resilience in their respective communities. Here, we report the results of a study that was conducted among attendees at the 2015 ESIP summer meeting. The goal of this study was to understand the perspectives of data, informatics, and information scientists and practitioners for developing data solutions for community resilience.

## Methods

### Data collection

The 2015 ESIP summer meeting in Pacific Grove, CA was attended by 317 individual attendees and remote participants. Participants represented the US government agencies [e.g., NASA, NOAA, EPA, USGS, and National Science Foundation (NSF)], academic, and private sector organizations (commercial and nonprofit) (Fowler 2015).

At the beginning of the first day, a 3-h morning plenary session with 7 presenters provided all meeting attendees with a variety of perspectives on community resilience. Bruce Goldstein (University of Colorado, Boulder) began the session by framing collaborative resilience in both place-based and virtual networks. Next, Kathleen Weathers of the Cary Institute of Ecosystem Studies described lessons learned from the Global Lake Ecological Observatory Network (GLEON). Then, Lauren Casey (USGS) discussed the dynamics of community resilience and the variety of expectations within a community. Lawrie Jordan of Esri talked about Esri's efforts to bridge the gap between Earth Science data and local-community resilience efforts. She was followed by Sangram Ganguly of NASA who spoke about the big data challenges in the context of the NASA Earth Exchange and OpenNEX initiatives. David Lubar of the Aerospace Corporation discussed the challenges of sharing weather satellite spectrum with terrestrial networks and the implications for weather and hazard prediction. Finally, Chris Waigl from the University of Alaska,

Fairbanks, Alaska discussed data usability in the context of Alaska wildfires.

At lunch, meeting attendees were randomly assigned to different tables. Facilitators, who were ESIP leadership, data practitioners, and often long-time members of ESIP, led round table discussions (45-min long) using pre-prepared questions as a guide. A total of 17 tables with an average of 10 individuals per table ( $n = 170$  individuals) participated in the facilitated discussions.

All participants of the discussions were informed that their comments would contribute to a study, and that their input would be kept confidential and anonymous. Individuals could choose not to participate by not contributing to the discussion or sitting elsewhere. Participants were asked to define community resilience within their practice, identify the potential role of data and technology practitioners in building community resilience, and articulate challenges and potential solutions to bridge gaps between data and community resilience. Facilitators took notes of the discussion, and these notes were used as data for this study. Immediately following the facilitated round table discussions, the data were recorded into a Google document.

### Analysis

Later that day, a 4.5-h workshop co-organized by representatives from NASA, NOAA, CiviSparks, ESIP, and University of Idaho was held. For the first portion of the workshop, representatives from NASA; NOAA; the Santa Clara County Office of Sustainability and Climate, CA; Four Twenty-Seven, a market intelligence and advisory firm specializing in the economic risks of climate change; and Antioch University presented different ways that data and software tools were currently being used to address a variety of resilience issues. Following these talks, the data recorded earlier in the Google document were presented to about 30 workshop participants, who consisted of voluntary attendees at the ESIP conference representing the US government (e.g., NASA, NOAA, and State of California), academics (e.g., University of Colorado), NGOs (e.g., National Ecological Observatory Network) and the private sector (e.g., Climate Data Solutions), as well as the presenters. Workshop participants discussed the data and added comments to the Google document. Then, two breakout groups discussed potential data and informatics support for community resilience as it related more specifically to agriculture and climate, and the disaster lifecycle, which are topics of two existing working groups of ESIP. Notes taken from these discussions by the authors were used to help inform the recommendations presented here.

In a second phase of analysis, meaning was elicited from the data collected from the facilitated discussions by identifying, coding, and aggregating common themes to

identify the most recurrent patterns and agreement in the data set. To ensure trustworthy interpretations of the data, two of the co-authors were involved in the coding process, including iteratively sharing and discussing their interpretations of the data.

## Results and discussion

This section is organized around the resulting recommendations regarding how appropriate data systems for community resilience can be developed (summarized in Textbox 1). Many of the issues identified are, indeed, common across data science for any domain. This highlights the benefit of data science to be able to cross disciplines, as well as points out that the starting point for improved information mobilization between data generation and community resilience can be founded on lessons learned in other domains, such as geosciences (Richard et al. 2014) and health sciences (Murdoch and Detsky 2013).

### Textbox 1: Recommendations to improve information mobilization to enhance community resilience

#### Clarify the term “community resilience”, so that its data needs can be identified

- Identify community resilience questions, definitions, goals, best practices, scope, and metrics as they relate to data needs.
- Conduct systems analyses to understand relationships between events, issues, dependencies, and overlaps between different end goals for data collection and data systems.
- Conduct risk management by assessing the strengths and limitations of existing data systems and infrastructure, and identify opportunities.
- Differentiate resilience needs according to different governance scales, so that data solutions can be tailored to cross scales more easily.

#### Prioritize institutional support for community resilience

- Focus financial and strategic investments on developing data systems and infrastructures, and data practitioners that are specific to the needs of place-based community resilience.
- Develop institutional processes for improving engagement among groups in the information pathway for community resilience.

#### Ensure accessibility and usability of data solutions for community resilience

- Prioritize data accessibility, which is informed through consistent engagement with end users.
- Enforce best practices for data and data tools production that include prioritization of open source data, creation of community tools, production of decision-ready data products and tools, description of metadata, defined data standards, documentation, transparency, and an iterative review process of data products with end users and stakeholders of the information pathway.

#### Fill in gaps along the information pathway to increase interactions between data practitioners and community resilience practitioners

- Organize community engagement workshops and tutorials to help community resilience practitioners learn about accessing and using data and data tools.
- Teach collaboration, facilitation, leadership, management, and teamwork skills to data practitioners.
- Create roles for intermediaries, science and data interpreters, mediators, community engagement leaders, and storytellers to help mobilize knowledge along the information pathway.
- Link data practitioners with networks of community resilience practitioners; e.g., Urban Sustainability Directors Network, Local Governments for Sustainability (ICLEI), 100 Resilient Cities program of the Rockefeller Foundation, Climate Action Champions.
- Identify early adopter end user communities that are willing and ready to engage with data practitioners as a first target for collaboration and partnership, so that tools can be developed and used as examples to reach out to other communities.
- Convene joint meetings between data practitioners and community resilience practitioners to start building relationships between these groups, and propose pilot projects.
- Create fora for different stakeholders of the information pathway to engage regularly around specific community resilience topics (e.g., disasters, urban development).
- Work with bridge organizations to help facilitate communication between data practitioners and community resilience practitioners. ESIP, for example, has an existing organizational structure that has been successful for optimizing the sharing, trading, and seeding of ideas to find data solutions to real-world problems.



## Clarify the term “community resilience”

Participants interpreted community to be an open system that includes all the diverse groups involved in the information pathway (data production to end user), as well as the institutions and infrastructure of the community, and the resources found in the place-based community and beyond. Resilience was defined as a characteristic of a dynamic system with different components (e.g., infrastructure and economics) that interact through feedback cycles, and determines how well a system survives through change, prepares for a potential change, and adapts. Overall, study participants’ perception of resilience correlated closely with theoretical definitions of resilience science, demonstrating that resilience is a concept being used in their fields.

Participants assumed that data are needed to generate the knowledge needed to enhance resilience of a system. As such, resilience is specifically relevant to data producers and managers, as they must improve their own long-term strategies regarding the recording, storage, and sharing of data, thereby supporting the overall goals of place-based community resilience. For example, resilience is increasingly being prioritized by influential data generating and management organizations; NOAA and NCAR include resilience issues such as sea-level rise and flooding as part of their risk management plans.

It is necessary to identify definitions of terms, goals, best practices, data standards, assessment tools, metrics, and a baseline for community resilience that are shared and adhered to among stakeholders in the information pathway. By identifying and prioritizing these aspects of community resilience, efforts to develop data, data procedures, and data systems to support community resilience can be optimized. The City Resilience Index (CRI; Arup 2016), for example, is one assessment framework being promoted by the 100 Resilient Cities program of the Rockefeller Foundation. Most current community resilience assessments, however, use high-level metrics that allow for comparisons between cities, but do not offer much help for assessing the household-level resilience that is important within cities. Without such baseline information, it is still unclear what data and information aspects, including how to improve access, quality, and relevance of information, are needed to support place-based community resilience initiatives.

The development of semantic structures can also be helpful for organizing data sets (Walls et al. 2014) for community resilience. It is well known within the semantic web community that different communities share a common language, such as English, but use some terms differently. As an often-used example, a person from the

eastern part of the USA may use the term “soda”, while folks elsewhere in the country use the term “pop”. This concept holds true not just for different regions within a country, but also for individual scientific disciplines. In the context of this paper, these differences in terminology usage mean that information about data produced for a specific discipline may not be easily found or understood by other disciplines or the public. To help mitigate such problems, developing semantic structures that relate varying term definitions can be used. A classic but very simple example of semantics in action is a semantic search engine that knows that both “rain” and “snow” are types of “precipitation”. If a user enters a query for “precipitation”, the system will return not just data sets that mention “precipitation”, but also those that only use the terms “rain” or “snow”. Semantics can even be used to mediate between different conceptions of the world. For example, conceptions of sea ice vary between the captain of a sea going vessel, indigenous community members using ice as a hunting platform, and climate modelers (Duerr et al. 2015). However, for such semantic mediation to be effective, a deep understanding of the diverse ways that each community communicates is required to build the appropriate semantic structures, and this is typically a very time-consuming process.

Systems analyses are needed to better understand relationships between events, issues, dependencies, and overlaps between different end goals for data and data systems. For example, data and data processes that exist today for other domains may also be appropriate for supporting specific community resilience needs. To increase adaptive capacity of data systems, there should be redundancy, duplication, and diversity of methods and tools, so that a single point of failure can be avoided. Systems do not function in isolation, so situational awareness, or awareness of changes occurring in the surrounding environment, is needed to ensure adaptiveness. Communities can also avoid isolation by connecting with broader networks of information. The movement towards “smart” cities that are instrumented to allow for real-time analysis of city life (Kitchin 2014) also emphasizes the vital role that data systems, infrastructures, and institutions will play in the future of community resilience. For such a future to exist, however, the strengths and limitations of existing data systems and infrastructure must be assessed to identify what changes are needed and what opportunities are available to support community resilience.

On the local scale, communities can build resilience by being more self-sustaining and less dependent on outside infrastructures. The local food movement and growth of renewable energy sources accompanied by local energy storage are two such resilience activities currently being adopted by both individuals and communities around the

world (100 Resilient Cities 2018). Community data that are more interoperable and easily sharable can also help a community be more resilient. One common method is, for a community, to maintain a local data warehouse that consolidates data currently held in disparate systems, such as departmental servers or consulting companies. Such a strategy is currently being explored by the City of Boulder, Colorado, according to Chris Trice, the City's Information Resources Manager. However, this solution also inhibits resilience if good data management practices are not followed. Such practices include local data backups, as well as ensuring that copies of the data are held sufficiently far from the community that they are unlikely to be affected by local disasters, and well testing the processes for restoring those copies (CCSDS 2012).

By addressing local-level processes, faster adaptation and decision-making can occur in response to disturbances (Wilson 2012). Information and data tools are often produced to address broad or generalized issues, so these efforts must be down-scaled to meet local-level needs. To be most effective, the data component of resilience strategies must be designed to cross scales by being both tailored to events that occur at local scales, while having capacity to adapt to potential larger scale events. Developing tools that allow local government to assist individual homeowners or neighborhood groups to develop resilient practices are essential for long-term place-based community resilience planning.

### **Prioritize institutional support for community resilience**

To enhance the resilience of data-related institutions and infrastructure, tools/structures, policy, and investments should be specifically aimed at increasing potential for adaptation. A desire for the data and informatics community to contribute toward community resilience is simply not enough. Institutional changes must occur on multiple governance scales. Appropriate rewards and motivation systems must be developed to complement any new goals, and leadership at all governance levels must demonstrate a focused strategic and financial investment to close gaps between data producers, data managers, software developers, and community resilience practitioners through bottom-up and top-down approaches.

Resilience planning depends on having access to the right type of data (e.g., diverse, long-term, interoperable), as well as addressing such issues as sustainability of the information pathway, data sharing protocols, and data standards. As data volume grows, better solutions for data management and preservation must be developed (Lynch 2008). While national data centers and new data policies aim to make data available for end users, such as by

emphasizing data sharing (e.g., NSF 2014; USGS 2015), institutional changes are still needed to create the resources (e.g., time and funding) and frameworks needed to ensure that the right type of data and data products are being produced to support and assess community resilience. Typical science projects, such as those funded by NSF, for example, are often too limited in scope (spatially and temporally) to address large scale, system-based research questions, such as resilience. With a typical project length of 2–3 years, such projects barely have time to develop the relationships needed to understand the issues of a single community or to develop systems based on those results (Redman et al. 2004).

To help address this limitation, funding opportunities for more coordinated, expansive, and long-term initiatives have been developed to produce the type of data needed to understand place-based resilience (e.g., Long-term Ecological Research projects, Robertson, 2008; Belmont Forum intergovernmental-funded research). As data are often generated in isolation from end user's needs, their potential use for broader social impact can be limited. Institutional incentives and support are also needed to create a culture for collaboration (Goring et al. 2014), which is often a motivation for data sharing (Borgman 2012), to help streamline information mobilization from data generation to user.

### **Ensure accessibility and usability of data solutions for community resilience**

It is recommended that the data and informatics community takes a proactive role in ensuring that data streams and products meet the needs of end users and assist end users to use the data. Furthermore, the data and informatics community should provide better translation of the data being provided, so that useful data can be more easily identified, and end users can learn how to use and apply the data. Overall, data products and tools must be simple and easy to use. For example, NCAR recently learned from a series of focus groups that residents were more motivated by street-level imagery of their home under floodwater levels than by simply telling them the measured height of a storm surge (Aguilar 2017). Similarly, the National Snow and Ice Data Center (NSIDC) discovered that the public needed expert assessments of the sea ice situation, as well as graphs and imagery to make sense of the state of sea ice (Baker et al. 2015).

Data accessibility, such as by being open source and interoperable with other data and tools, should be prioritized. Metadata must be clearly described and documented. Processes for documentation, transparency, and iterative review of lineage/provenance are needed. Data standards must be well defined for all stakeholders involved in the

information pathway. Importantly, data products must be decision ready. Tools must be created in close communication with end users, as opposed to building individual and redundant tools that are developed in isolation. To ensure that the right data are being generated to support community resilience, usability and interfacing of data products and tools must be reviewed and vetted by end users and stakeholders of the information pathway.

Consistent communication along the information pathway, and particularly between data practitioners and end users, must be facilitated, so that tailored data solutions for community resilience can be produced. For data practitioners, a better understanding of the needs and practices of end users, such as community resilience practitioners, is direly needed to produce accessible data products. As a novel field that is still developing informative metrics (Arup 2016; Chang and Shinozuka 2004), resilience science should include data practitioners at an early stage of development to ensure that anticipated data needs will be met. Through engagement of the different stakeholder groups in the development and decision-making process, sustainable and effective change in the overall system is more likely to occur (Brugha and Varvasovszky 2000).

To help develop information solutions to support community resilience, conscious and targeted engagement and testing of data products and tools with end users is ideal for ensuring that products are easy and efficient to use. Data practitioners can increase the usability of data products through educational development and delivery of tutorials for end users (Turner et al. 2015). In the absence of access to end users, personas and user data sets such as those created by the collection of use cases can be used instead (Marshall et al. 2015). EarthCube (US NSF program) and the Research Data Alliance, for example, collect use cases to inform the development of data products that meet the needs of their end users.

### Fill in gaps along the information pathway

Better understanding of what place-based community resilience practitioners need in terms of data, data management, and tools would assist with closing the gap between data production and information use for community resilience, and determining priorities for action. To do this, stakeholder engagement, or the development of a relationship that supports two-way communication, is a critical need. Some relevant stakeholder groups along the information pathway for place-based community resilience are big platform developers, information technology specialists, community leaders, scientists, and potential consumers of data. Unfortunately, these groups are often isolated with a general lack of communication between them, as well as access to each other. Stakeholder analysis

is recommended as useful for understanding the short- and long-term expectations, and needs of stakeholders, so that the appropriate domain-specific data products and infrastructure can be developed.

Engagement with stakeholders must be a conscious and targeted process that builds connections and empowerment of diverse groups in the information pathway, so that they are included in the decision-making process, and feel some ownership and accountability of the end results. In addition, investments must be made to develop and sustain formal institutional processes for maintaining engagement. Appropriate communication infrastructure and mechanisms, and processes and space for distributing and sharing information must be in place for effective communication to occur. Overall, engagement mechanisms must be simple, easy to access, and inclusive.

Today, more skills are required of people working with science-based data, including among information professionals (Kouper 2013). While scientists must be capable of managing and using complex data sets (Hou 2015), data practitioners must often be competent in specific topic domains, for example, to address the data challenges of place-based community resilience. In addition, a multidimensional skill set, such as collaboration, leadership, management, and teamwork, is becoming increasingly more valued among science practitioners (Blickley et al. 2012; Cheruvilil et al. 2014). Likewise, such skills are highly useful for data practitioners, who are often expected to be well connected to broad networks and addressing end user needs. To identify, engage, and effectively communicate with diverse stakeholders, an open mind, inclusive attitude, and a shared vocabulary and knowledge base are needed.

New data practitioners and intermediary roles must be trained to address the complex nature of place-based community resilience, particularly as “smart” cities continue to grow (PCAST 2016). Adaptive learning cycles are needed to allow knowledge to evolve and adapt to new challenges. Capacity for learning can be built through greater attention to skill sets, incentive structures, safety nets and risk management, and development of relationships among the actors (Armitage et al. 2008).

To help fill some of the gaps that may exist in human resources among the data community, the development of new roles in the information pathway is needed. Some specific roles include:

- Intermediaries that act as liaisons between stakeholder groups to translate and drill through surface issues to identify underlying problems and potential solutions. These intermediaries can be individuals who work between scientists and end users, and organizations that act as bridges (e.g., ESIP).



- Science and data interpreters.
- Mediators to help groups find a common language and vocabulary to improve communication.
- Leaders within communities that push forward engagement between communities.
- Storytellers that share case studies and examples of successes and failures for broader reach and communication across stakeholders.
- Community managers, who can mediate relationships and collaborations between and within scientific groups in the context of information and data sciences (AAAS 2016).

More investments must be focused on retaining and training the next generation to meet the new needs of today. Intermediary individuals and communities, and networks that already have the existing relationships with different stakeholders in the information pathway can help to build relationships between stakeholders. Open networked communities of scientists and practitioners, such as ESIP, are particularly well suited for acting as an intermediary between different communities and providing a venue for face-to-face meetings, which are keys for building collaborations (Hampton and Parker 2011). Such a bridge organization can act by:

- Sending data science/practitioner representatives to end user events to represent the data science field.
- Hosting face-to-face meetings with different stakeholders along the information pathway.
- Hosting events, such as hackathons, to address specific data problems posed by end users.
- Creating a task force that specifically addresses end user needs.
- Developing an open forum or network of scientists that are available to interpret data and work directly with end users.
- Facilitating stakeholder analysis of end users to understand their data needs.
- Organizing education and training initiatives to (i) develop human resources, (ii) improve knowledge of domain topics to data scientists, and (iii) improve knowledge of data management for end users.

## Conclusion

This study is part of a larger series of activities that seek to spur development of frameworks and data-driven tools that support simple, scalable, and context-specific assessments of community resilience for residents and planners (ESIP 2018). Here, we presented the obstacles and recommendations for mobilizing knowledge and streamlining the

information pathway for place-based community resilience from the perspective of data and informatics practitioners. Our study shows that increased participation of data and informatics practitioners in resilience efforts could potentially help to improve the availability and quality of information needed to support better decision-making for community resilience. Some potential community resilience goals that data solutions could assist with include improved household-level response and decision-making during disaster events (e.g., floods) and building of social capital (e.g., through social networks that help people understand the needs and available resources of their neighbors).

In a subsequent study to the one reported here, we found that a top priority of city planners in Boulder, CO, which has a progressive urban resilience program (City of Boulder 2016) due to their strong grassroots base and early funding from Rockefeller Foundation's 100 Resilient Cities program, is to conduct an inventory of accessible data sets as a basis for a city-wide data management system. Recognizing that such data needs are common to many cities, the Environmental Systems Research Institute (ESRI), for example, has developed a GIS-based system that aims to help cities organize their data, and their first prototype was launched for Los Angeles (<http://geohub.lacity.org>). These examples show that new types of tools, data management systems, and personnel are needed to support the specific and unique needs of place-based community resilience initiatives. Many place-based resilience initiatives seek to use a systems' approach to integrate social and environmental components of their community, govern and monitor their community through both grassroots and top-down processes, and monitor their resilience progress through a streamlined data-rich system. Data and informatics scientists can offer invaluable skills and creative problem-solving to help support such goals.

Overall, data and informatics science must take a proactive role to ensure that data streams are accessible and useful for end users, such as by coordinating their goals and actions with other stakeholders in the information pathway. At the same time, it is of great benefit for community resilience practitioners to take advantage of established networks of data and informatics scientists as a resource to find solutions to their data needs. As community resilience becomes increasingly important to ensure the sustainability of place-based communities within the context of a changing environment, effective data systems and knowledge mobilization are keys to providing the information needed to quickly act and make informed decisions to safeguard our communities.

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