A GLOBAL CAPACITY BUILDING VISION FOR SOCIETAL APPLICATIONS OF EARTH OBSERVING SYSTEMS AND DATA

Key Questions and Recommendations

by Faisal Hossain, Aleix Serrat-Capdevila, Stephanie Granger, Amy Thomas, David Saah, David Ganz, Robinson Mugo, M. S. R. Murthy, Victor Hugo Ramos, Carolyn Fonseca, Eric Anderson, Guy Schumann, Rebecca Lewison, Dalia Kirschbaum, Vanessa Escobar, Margaret Srinivasan, Christine Lee, Naveed Iqbal, Elliot Levine, Nancy Searby, Lawrence Friedl, Africa Flores, Dauna Coulter, Dan Irwin, Ashutosh Limaye, Tim Stough, Jay Skiles, Sue Estes, Bill Crosson, and Ali S. Akanda

Capacity building using Earth observing (EO) systems and data (i.e., from orbital and nonorbital platforms) to enable societal applications includes the network of human, nonhuman, technical, nontechnical, hardware, and software dimensions that are necessary to successfully cross the valley [of death; see NRC (2001)] between science and research (port of departure) and societal application (port of arrival). In many parts of the world (especially where ground-based measurements are scarce or insufficient), applications of EO data still struggle for longevity or continuity for a variety of reasons, foremost among them being the lack of resilient capacity. An organization is said to have resilient capacity when it can retain and continue to build capacity in the face of unexpected shocks or stresses. Stresses can include intermittent power and limited Internet bandwidth, constant need for education on ever-increasing complexity of EO systems and data, communication challenges between the ports of departure and arrival (especially across time zones), and financial limitations and instability. Shocks may also include extreme events such as disasters and losing key staff with technical and institutional knowledge.

GLOBALIZING SOCIETAL APPLICATION OF SCIENTIFIC RESEARCH AND OBSERVATIONS FROM REMOTE SENSING: THE PATH FORWARD

What: Recognizing that capacity building is key to globalizing societal applications of Earth observing systems and data, a community of Earth scientists who develop applications or solutions, and the stakeholders who need them, provided consensus-based input on key questions and recommendations to achieve a vision for global and resilient societal applications of Earth observations.

When: 23–25 June 2015

Where: Tacoma, Washington

The combined observational power of the multiple EO satellites and nonorbital platforms has untapped potential waiting to be harnessed to produce more durable societal benefits around the world (Hossain 2015). The community comprising scientists and stakeholders now needs to be ready to take complete advantage of the prolific amount of scientific output and remote sensing data that are emerging rapidly from satellite EO missions and convert them efficiently into products that can support decision-making for end users. So how do we take full advantage of Earth observational capability for a more sustainable, happier, and safer future in the coming decades?

To address this key question and strengthen the voice of the global societal applications and capacity building community, a three-day workshop was convened to debate issues and formulate a vision and path forward. Such a roadmap that relies on the use of EO data is expected to enable more widespread societal applications in fields such as water resources, disaster management, food and agriculture, public health, and ecosystem services around the world.

There were 27 in-person attendees at the workshop, including experts from the applied sciences community already engaged in EO-based capacity building across various themes for the stakeholder community and from the satellite EO data community, as well as several international stakeholder agencies with a need for real-world application of EO systems and data. Participants were selected by invitation to represent as much breadth in various themes (such as water, health, ecosystem function, agriculture, and disasters) as possible, as well as geographic relevance (Asia, Africa, and the Americas). Numerous and compounding issues needed to be explored, including uncertainty, end-user perception, location-specific technical and nontechnical operating constraints, human resources, data latency, scalability of solutions, widely varying social and cultural boundary conditions for scientific applications, and exploring business models appropriate for the coming decade. The key discussion point of the workshop throughout the three days was "What do we need to do now as a community that will enable greater and more successful societal application of Earth observations from space?"

After the inaugural session, the following themes were addressed in order:

1) public health and air quality
2) disaster management
3) ecosystems function
4) water resources
5) food and agriculture

The discussion period during each session focused on capacity building and globalizing EO-based societal applications. During each discussion period, international participants were asked to voice viewpoints, ideas, and questions from their regions, keeping the critical issue of building resilient capacity in mind. To capture as many important themes as possible, particularly those that are cross-cutting (water–food, health–water, water–disaster, and energy–water) with important societal applications, the last session on the second day included an extended discussion period for miscellaneous items.

To target the discussions and elicit a vision for the future, five key questions were provided to all participants for consideration:

1) What types of value-added products/information should we provide for resource-constrained public and national stakeholder communities and agencies?
2) What types of industry or private-sector partnerships will most benefit the scientific research needed to meet societal needs?
3) How can we leverage the combined observational power of our many Earth observing satellite missions (current and future) in a synergistic manner to rapidly multiply societal applications?

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DOI:10.1175/BAMS-D-15-00198.1

A supplement to this article is available online (10.1175/BAMS-D-15-00198.2)

In final form 7 February 2016

4) How do we make the scientific innovation from satellite remote sensing data trigger durable and robust applications that do not require long-term incubation or external support?
5) From an economic standpoint, what should be the optimal business model between scientific communities and the stakeholders to support a sustainable partnership?

DEVELOPING THE GLOBAL CAPACITY BUILDING VISION. Moving forward in the coming decade, the capacity building community that is reliant on EO data will play a pivotal role through satellite and nonorbital EO systems in solving three grand challenges facing humanity. These challenges are 1) food security, 2) water access and availability, and 3) disaster risk reduction. The capacity building community also needs to help the world achieve the 17 Sustainable Development Goals set by the United Nations (2016). For example, is the world ready to feed nine billion people by 2050, most of whom will be living in megacities with a different set of constraints on demands for water, energy, and health? How can the global capacity building community using EO data play a leadership role as one of the many stewards of the planet to help achieve more sustainable living? The workshop participants noted that it was time for the EO-based capacity building community to broaden the focus of current EO application programs [such as the National Aeronautics and Space Administration's (NASA) Applied Sciences program] to tackle these issues that are existential to planet Earth and can be addressed through the application of EO-based science.

The participants noted that the community must also recognize the need to build capacity in the human (ergonomic) dimension for the following entities: 1) space observation agency scientists–trainers who work at the root level of EO data production, 2) the future workforce from across the board who will need to interact with EO data, 3) government and professional end users, and 4) stakeholder agencies with their scientific capacity. In addition, there is a need to build technology capacity to address different needs, abilities, and practices adopted by end users. For example, as a vision for where the global capacity building program could be in 2027 for water resources, the following was put forward at the workshop:

1) Using the combined suite of Earth observations available from space agencies around the world (e.g., the United States, France, the European Union, Japan, India, etc.), enable all people to know where the nearest safe water to drink is that day, the next season, the next year, and for the next 5, 10, 25, and 50 years.
2) Develop applications in collaboration with decision-makers responsible for populations most vulnerable to water stress.
3) Build institutional skills around the world to sustainably manage water resources over the long term.
4) Facilitate successful and widespread use of Earth observations in water management decisions by ministries of water, natural resources, agriculture, and energy around the world.

General recommendations for globalization of EO-based applications and capacity building. Workshop participants made the following recommendations for globalization of applications and capacity building efforts:

1) Societal applications should continue to expand and be the primary focus of new satellites and sensors, with support from airborne sensors and models.
2) The community needs to take advantage of the combined observational power of multiple platforms and Earth observing systems, with a focus on cross-cutting themes such as water–food, water–energy, or water–disaster.
3) New Earth observing satellites must provide timely data at the appropriate resolution to support country-level application requirements.
4) Space agencies need to find a balance between research products and real-time products. It is often the real-time products that tell compelling stories about the societal value of operations or nowcasting for prime-time news. Together with stories generated from research-grade products, such media exposure helps with the public's understanding of a satellite mission's societal value. Research products should ultimately advance the quality and timeliness of future real-time products.
5) There should be increased consideration/use of nanosatellites and other innovations for applications as appropriate.

International perspectives on EO-based capacity building. International participants provided perspectives on capacity building relevant to their region. For South Asia (e.g., Hindu Kush–Himalaya nations), the key issue noted in building durable applications was recognizing "indigenous" knowledge and explicitly using it in the design of decision-making systems that uptake Earth observations. The steps required to achieve this are summarized as follows: 1) popularize and bring local flavor to dissemination systems; 2) identify and facilitate local institutional interface and uptake systems; 3) develop a bigger canvas/tier of scientific, policy, and of the local user community; 4) develop a handful of facilitators and practitioners (transitioning science products to actionable products; awareness building over large and diverse users); and 5) enhance citizen understanding of web applications, gathering more feedback and citizen science information.

In Southeast Asia (e.g., the lower Mekong nations), participants noted that solutions built for disaster risk reduction using EO will have to be compatible with country-specific skills and human resource settings that represent wide variability in the region. Southeast Asian countries have contrasting capacities for the uptake and sustenance of Earth observations (a good example is Vietnam with strong capacity and neighboring Cambodia with weak capacity). Another issue noted was that, given the extensive nature of dam building in the Mekong River basin, having a vertically accurate digital elevation model (DEM) [better than the 30-m Shuttle Radar Topography Mission (SRTM) dataset] is now a key priority for building applications for resource management.

In the eastern and southern Africa region, high population growth and increasing demands on food and water are the two critical issues needing improved capacity building for EO data. Extreme weather, disasters, and their impacts on biodiversity are also key issues. Frost is becoming an increasingly common phenomenon, affecting Kenya's tea production. Forest fires, deforestation, land-use change and overappropriation of water resources in many basins are the main causes behind the progressive strangulation of wildlife sanctuaries and the destruction of natural habitat and ecosystem services. The EO data and systems have a major role to play in understanding and predicting the impacts of global change and helping manage mitigation and adaptation strategies for the benefit of regional livelihoods, disaster reduction, and environmental health.

Like many other regions, international workshop participants noted that resource management was a key decision-making need for Mesoamerica, with a clear demand of EO systems and data. The goal by 2027 for this region's stakeholders would be to evolve to a more "proactive" approach of mapping fires based on forecast or incidence probabilities by taking advantage, for example, of the Fire Urgency Estimator in Geosynchronous Orbit (FUEGO). Earth observation's role in disaster management in the region currently remains confined to postdisaster analysis. Future needs include a full-cycle "in house" capacity for disaster forecasting/prediction, mitigation, adaptation (risk reduction), and response/recovery through local institutions. In regard to water issues, the region lacks sustained capacity for water quality management. Future needs point toward more water management institutions taking advantage of EO data from relevant EO systems.

A SAMPLING OF THEMATIC QUESTIONS AND RECOMMENDATIONS FOR A 2027 VISION

As the workshop progressed into individual themes such as health, water, agriculture, ecosystems, and disaster management, participants prioritized the key questions and recommendations through panel discussions and concluded with a consensus-based ranking. The following is a sample of questions as well as (indirect) determinations representing each of the five themes. The complete list of key questions and recommendations is available as part of the online supplement to this article (more information can be found online http://dx.doi.org/10.1175/BAMS-D-15-00198.2).

Key Questions

- **Health**—How can we identify the most impactful intervention strategy for endemic and epidemic diseases in order to design EO-based decision-making tools?
- **Disaster management**—How is a "successful response" defined in order to maintain the EO-based capacity building community's ability to respond regularly to disasters in a sustainable manner?
- **Ecosystems**—What type of EO missions and data have been most useful in resource management? What are the categories of EO data that fall into research, operational application, or experimental observations?
- **Water**—How do we strengthen users' understanding of the utility and uncertainty of remote sensing information for water challenges?
- **Agriculture**—How can EO data be used to improve the resilience of agricultural systems to both gradual climate change and increased climatic variability and extremes?

Key Recommendations

- **Health**—There needs to be greater investment in small satellites and stronger emphasis on citizen science programs (volunteered geographic information) for health monitoring.
- **Disaster management**—To encourage greater engagement from the broader disaster community, the EO data community should conduct and share results from action reviews to assess the effectiveness of individual response efforts and keep an inventory of success stories on how Earth observations provide fundamental life-saving support to disaster response.
- **Ecosystems**—Programs need to be fostered that bring the Earth science applications community into closer engagement with the business community through education partnerships with a view to identifying successful private–public business models for ecological forecasting and other cross-cutting themes.
- **Water**—The EO data community should engage in partnerships to build a one-stop data portal from EO systems for water alone with examples on potential utility and uncertainty of data.
- **Agriculture**—Effective ways to scale up interseasonal to interannual forecasting applications need to be explored involving water availability and food production. The necessary research to close the gaps in understanding the use of EO data for agricultural management should be promoted.

CONCLUSIONS. Sustainable livelihoods with human and economic development can only be made possible within a context of food security, water availability, and environmental health. Societal applications of Earth observations should be developed to monitor and support progress toward these goals. In developing regions of the world, easy access to safe water means reduced malnutrition, morbidity, and child mortality, as well as time and the opportunity for girls, and children in general, to attend school. Health and food security are dependent on water availability and ecosystem health, which in turn is highly influenced by local resource management strategies. Disaster risk is modulated by land-use cover and the ability of ecosystems to provide regulating and provisioning services. Because of the integrated nature of human–natural systems (and the need for environment–water–health–livelihoods sustainability/security), societal applications must draw on the combined observational power of different sensors and products at adequate resolutions in space and time. While research and retrospective products enable useful hindsight, operational real-time products are essential to support present decisions and strategies. Earth scientists must work with the practitioner and stakeholder communities to best tackle the challenges on the ground and develop innovative efforts using large missions, nanosatellites, and crowdsourcing feedbacks.

Given the above, the science community that is reliant on EO data for exploring Earth science has a responsibility to regularly update and prioritize societally relevant scientific questions and the Earth observations required to answer them. For the case of space agencies and their EO systems and data that various organizations maintain, a key mechanism by which the science community is engaged in such a task is through the National Research Council (NRC). The NRC conducts a review every 10 years, known as a decadal survey, that provides a science community consensus on key questions and recommendations. Recognizing that capacity building is key to globalizing societal applications of EO systems and data, the workshop held during 23–25 June 2015 in Tacoma provided one such consensus-based input on key questions and recommendations from a community comprising Earth scientists, stakeholder organizations, and end users. It is hoped that the workshop findings will initiate a sustained atmosphere of meaningful interaction within this community in the coming years to achieve the global capacity building vision for societal applications of Earth observations outlined previously.

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This document is a supplement to "A Global Capacity Building Vision for Societal Applications of Earth Observing Systems and Data: Key Questions and Recommendations," by Faisal Hossain, Aleix Serrat-Capdevila, Stephanie Granger, Amy Thomas, David Saah, David Ganz, Robinson Mugo, M. S. R. Murthy, Victor Hugo Ramos, Carolyn Fonseca, Eric Anderson, Guy Schumann, Rebecca Lewison, Dalia Kirschbaum, Vanessa Escobar, Margaret Srinivasan, Christine Lee, Naveed Iqbal, Elliot Levine, Nancy Searby, Lawrence Friedl, Africa Flores, Dauna Coulter, Dan Irwin, Ashutosh Limaye, Tim Stough, Jay Skiles, Sue Estes, Bill Crosson, and Ali S. Akanda (*Bull. Amer. Meteor. Soc.*, **97**, xxx–xxx) • ©2016 American Meteorological Society • *Corresponding author:* Faisal Hossain, Dept. of Civil and Environmental Engineering, University of Washington, 201 More Hall, Seattle, WA 98195, Meteorology Program, Department of Geography, Northern Illinois University, DeKalb, IL 60115 • E-mail: fhossain@uw.edu • DOI:10.1175/BAMS-D-15-00198.2

THEMATIC QUESTIONS AND RECOMMENDATIONS FOR A 2027 VISION. As the workshop on globalizing societal applications of scientific research and observations from remote sensing progressed into individual themes such as health, water, agriculture, ecosystems, and disaster management, participants prioritized the following key questions and recommendations through panel discussions and concluded with a consensus-based ranking. Note that the recommendations were not written to specifically answer the questions but rather to provide a broader perspective of the needs to build global capacity for societal applications of Earth observations.

HEALTH AND AIR QUALITY

Key questions

- How can we better adapt to the impact of climate change on changing disease burdens (from both vector and waterborne perspectives) on vulnerable populations using trends derived from Earth observation data?
- If capacity to build Earth observing (EO)–based health monitoring improves around the world, how do we measure the societal impact in terms of quality of life and lives saved?
- How can we identify the most impactful intervention strategy for endemic and epidemic diseases in order to design EO-based decision-making tools?

- How can the use of small satellites, aerial campaigns, and crowdsourcing programs (citizen science) assist in building and improving more relevant health and air quality monitoring tools that use conventional orbiting satellites?
- What type of disease-relevant and region-specific EO tools should we build to empower the health community?
- Recognizing the inherent water nexus of waterborne disease, how can we facilitate greater interaction of technical experts on water with the health monitoring community?

Key recommendations

- A greater focus is needed on understanding how EO systems can best address the impact of climate change on future disease burden.
- Recognizing the strong connections of water resources (availability) with waterborne diseases, water community technical experts that use EO systems and data should partner more effectively with the traditional health community.
- There needs to be greater investment in small satellites and stronger emphasis on citizen science programs (volunteered geographic information) for health monitoring.
- Programs need to be in place that facilitate clearer communication and trust building between the health stakeholder community and Earth scientists who use remote sensing data for capacity building of health institutions around the world.
- In an effort to build durable capacity of Earth observing systems, space agencies and other regional or global organizations should identify strategic partners from philanthropic and private-sector organizations with overlapping priorities that rely on monitoring of environmental and Earth science data in their day-to-day operations.

DISASTER MANAGEMENT

Key questions

- What should be the primary role in disaster response for space agencies and organizations that produce EO data?
- How is a "successful response" defined in order to maintain the EO-based capacity building community's ability to respond regularly to disasters in a sustainable manner?
- What are the most effective ways to use radar-observing platforms for disaster response?
- How can space agencies partner with reinsurance market players toward identifying a sustainable business model for humanitarian disaster response? What would be the implication of such a move for nonprofit disaster response agencies like the Red Cross, Mercy Corps, or the United Nations, which are often the first set of "boots on the ground" when a disaster happens?

Key recommendations

- To encourage greater engagement from the broader disaster community, the EO data community should conduct and share results from action reviews to assess the effectiveness of individual response efforts and keep an inventory of success stories on how Earth observations provide fundamental life-saving support to disaster response.
- The EO data community should investigate ways to partner with private-sector entities on disaster reinsurance without compromising the greater-good agenda that nonprofit missions like the Red Cross or Mercy Corps provide around the world.
- Policies and memorandums of understanding (MOUs) should be in place for greater inter-(space) agency partnership for data sharing at low latency to make Earth observing systems more meaningful for disaster response.
- More widespread use of radar observing platforms should be implemented for disaster response and hazard monitoring, and capacity to use and interpret radar-derived products should be built.
- Space agencies and EO data organizations should have clear definition of their scopes in place to define the appropriate levels and durations of response to large-scale disaster events. This will also help clarify the extent to which EO systems can address disaster management agencies' needs and expectations.

ECOSYSTEMS FUNCTION

Key questions

- What type of EO missions and data have been most useful in resource management? What are the categories of EO data that fall into research, operational application, or experimental observations?
- How can we use such classifications of data to identify the percentage of the data that should be funded for each category, which ones should remain free and funded by government, and which should be funded through some public–private partnership for resource management?
- How can we tailor a successful model of coproduced ecological applications of remote sensing in one area (such as fisheries) to another area (such as prevention of poaching)?
- How do we build capacity in applications that can be as popular as Landsat- or Moderate Resolution Imaging Spectroradiometer (MODIS)–derived but inclusive of more complex sensors that provide less intuitive information than multispectral data (e.g., hyperspectral, radar)?

Key recommendations

- The EO data community should create structured data at finer resolution on land resources (e.g., vegetation, household, and roadway structures) to enable wider application in ecological forecasting and cross-cutting themes.
- Simple metrics of uncertainty that have monetary implications should be associated with Earth observations data used for resource management and ecological forecasting.
- The EO data community should create programs and tools that help complex and less intuitive data structures/format (such as radar backscatter or spherical harmonic coefficients) become more intuitive and visualization friendly for end users to enable greater application of such data for resource mapping. Appropriate capacity should be built in the coming decade to make such complex Earth observing data directly useable to stakeholder agencies.
- Programs need to be fostered that bring the Earth science applications community into closer engagement with the business community through education partnerships with a view to identifying successful private–public business models for ecological forecasting and other cross-cutting themes.

WATER RESOURCES

Key questions

- How do we bring greater awareness of Earth observations value/products to the water management community?
- How do we strengthen the capacity of private-sector engineering to access data and help build products for their partners/clients? Can successful examples of private-sector partnership on water be replicated internationally?
- How do we strengthen cosponsors' and users' understanding of the utility and uncertainty of remote sensing information for water challenges?
- How do we work with water resources practitioners to invest in building their technical capacity around remote sensing and data processing skills?
- What is the optimal way of communicating uncertainty of EO-based water products and at the same time engaging rather than hindering capacity building for water management?

Key recommendations

- Given that many satellite Earth observing systems have a long heritage that exceeds decades, the EO data community should engage in pre- and postanalysis of water availability for shared water resources around the world in order to help users understand the value of Earth observations.
- Space agencies should support studies that explore the cumulative impact of various human decisions and sectoral communities (agriculture, energy, and climate) on water availability using the combined observational power of satellites.
- To address the grand challenge of informing users on the nearest safe drinking water source, the EO data community should engage in partnerships to build a one-stop data portal from EO systems for water alone.
- Early adopter programs should evolve from a single-mission to a multimission format to take advantage of the combined observational power of EO satellites.
- Space agencies and the EO data community should take advantage of water as the common underlying theme of many philanthropic organizations to engage in public–private partnerships to address water-related grand challenges of the future.

FOOD AND AGRICULTURE

Key questions

- What are the trends in agricultural management that take into account water scarcity and environmental sustainability (e.g., systems approach)?
- What is the integrating source, what are the standards to achieve integration, and are there common frameworks for EO-based agricultural management?
- How do we measure progress/success of applications of agricultural management, particularly in the developing world?
- How can EO data be used to improve the resilience of agricultural systems to both gradual climate change and increased climatic variability and extremes?
- What are the impacts of future climate change on agricultural management and yield?
- How can we predict food and water issues jointly with enough lead time to take actions recognizing the nexus that exists between them?

Key recommendations

- Effective ways to scale up interseasonal to interannual forecasting applications need to be explored involving water availability and food production. The necessary research to close the gaps in understanding the use of EO data for agricultural management should be promoted.

- The EO data community should facilitate programs that can forecast agriculture growth to enable better food supply management.
- Fundamental research is required on the utility of Earth observations for predicting pest prevalence and guiding the production of climate change resilient seeds.
- Investigations into the impact of agricultural expansion on climate have been a missing piece that should now be explored for future adaptation policies.
- The EO data community and space agencies should foster greater strategic collaboration with regional and global research laboratories around the world toward building better capacity for agricultural management using Earth observations.