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

Key Questions and Recommendations

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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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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

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.

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.

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.

REFERENCES

Hossain, F. 2015: Data for all: Using satellite observations for social good. *Eos, Trans. Amer. Geophys. Union*, **96**, doi:10.1029/2015EO037319.

National Research Council, 2001: *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley Of Death*. National Academies Press, 80 pp. [Available online at www.nap.edu/openbook.php?isbn=0309069416.]

United Nations, 2016: Open Working Group proposal for Sustainable Development Goals. [Available online at https://sustainabledevelopment.un.org/sdgsproposal.]

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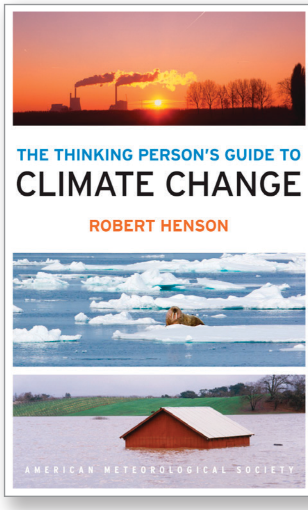

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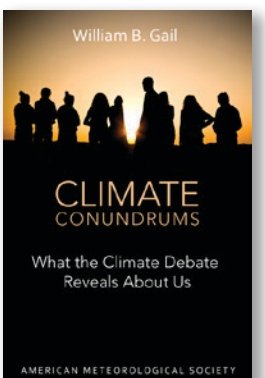

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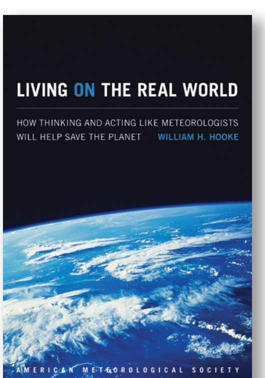

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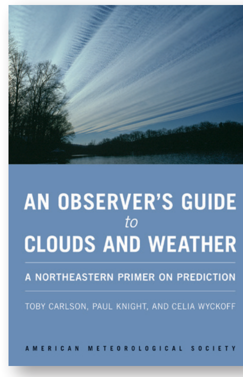

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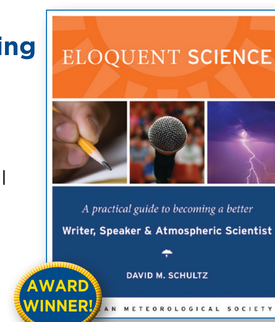

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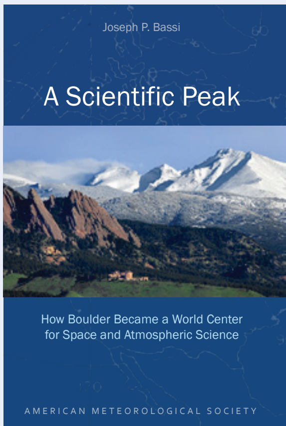

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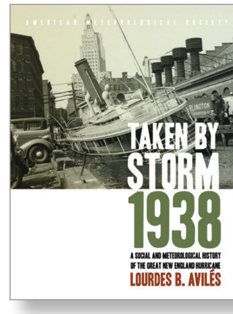

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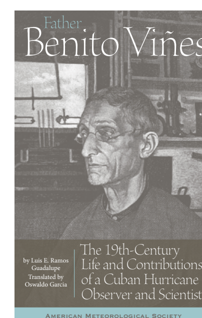

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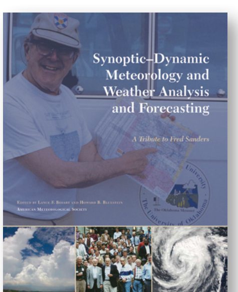

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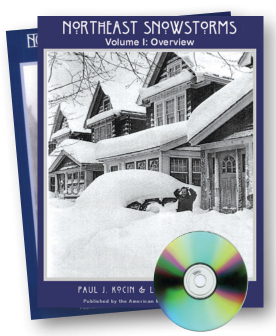

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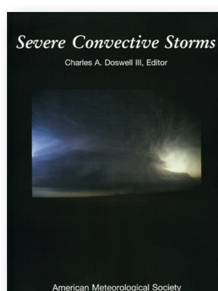

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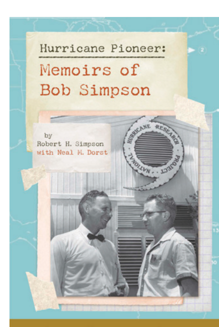

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