# Globalizing Societal Application of Scientific Research and Observations from Remote Sensing: The Path Forward

**NASA E2 Capacity Building Workshop for Decadal Survey 2017-2027**

June 23-25, 2015
Holiday Inn Express at Tacoma Downtown, Washington

**DRAFT WORKSHOP REPORT**
**Version 3.0**

**Prepared by**

Faisal Hossain
Department of Civil and Environmental Engineering
University of Washington

**With Contributions from:**
All workshop participants

**Submitted to:**
Nancy Searby
Program Manager
NASA Capacity Building Program

# Contents

# EXECUTIVE SUMMARY

Capacity building using Earth observing (EO) systems and data (i.e., from orbital and non-orbital platforms) to enable societal applications may be defined as the network of soft and hard components comprising human, non-human, technical, non-technical, hardware and software dimensions necessary to successfully cross the "valley of death" between science and research (port of departure) and societal application (port of arrival). The capacity building community of scientists and stakeholders need to be ready to take full and swift advantage of the rapidly emerging, abundant scientific output and remote sensing data from satellite missions by converting them into decision-making products for end users. However, our current application framework appears to lack the resilient capacity required to simultaneously handle scientific research and efficiently use the voluminous (petabyte-scale) satellite data to accelerate the growth of societal applications. 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. *So how do we change this course and take full advantage of our Earth observational capability towards a more sustainable, safer future in the coming decades*?

To address this key question and strengthen the global societal applications and capacity building community's voice, a three-day workshop was held in Tacoma (Washington) during June 23-25, 2015, in anticipation of the 2017-2027 NRC Decadal Survey. The workshop was sponsored by the NASA Applied Sciences Program as an E2 Topical Workshop, Symposium, and Conference (TWSC) event. It brought together experts from the applied sciences community already engaged in capacity building across various themes for the stakeholder community; NASA Applied Sciences and Capacity Building programmatic personnel; and several international stakeholder agencies with a history of using and a need for EO systems and data. The workshop aimed to debate issues to formulate a vision and a path forward for the NASA Applied Sciences and Capacity Building community.

The event recognized the numerous and compounding issues that need to be explored. Examples included data uncertainty, end user perception, location-specific technical and non-technical 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?'*

There were 27 in-person attendees at the workshop. Participants were selected by invitation with a view to represent as much breadth in various applied sciences themes (such as water, health, Ecosystem Function, and disaster) as well geographic relevance (Asia, Africa, Americas). Given the nature of the participant group, the format of 'theme first, region second' was adopted.

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
6. miscellaneous issues

The discussion period during each session focused on capacity building and globalizing applications. In each discussion period, international participants were asked to voice viewpoints, ideas, and questions from their regions, keeping the critical issue of building capacity in mind. To capture as many important themes as possible, particularly those that are cross-cutting (water-food, health-water, 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 partnership 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?*
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 CAPACITY BUILDING VISION FOR 2027

Moving forward in the coming decade, the capacity building community that is reliant on EO data will play a pivotal role through satellite and non-orbital EO system 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 9 billion people by 2050, most of whom will be living in megacities with different set of constraints on demand 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 NASA Applied Sciences program) to tackle these issues that are existential to planet Earth and can be addressed through 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) future workforce from across the board who will need to interact with EO data, (3) government and professional end-users, and (4) scientific capacity of stakeholder agencies. 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 of the world (e.g. US, France, 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 the next 5, 10, 25, 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 Capacity Building**

Workshop participants noted the following considerations in regard to a vision for globalization of 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 or water-energy.
3. New satellites must provide timely data at the appropriate resolution to support country-level application requirements.
4. EO data community needs to find a balance between research products and real-time products. It is the real-time products that tell compelling stories on societal impact and help with public understanding of an EO mission's societal value.
5. There should be increased consideration/use of nanosatellites and other innovations for applications as appropriate.

**International Perspectives on Capacity Building**

International participants provided perspectives on capacity building relevant to their region For the region of 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 were summarized as follows: (1) popularize and bring local flavor to dissemination systems; (2) identify and facilitate local institutional interface and uptake systems; (3) develop bigger canvas/tier of scientific, policy, and 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. 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. Unlike European countries, Southeast Asian countries have contrasting capacity for 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 accurate DEM (better than the 30 m SRTM) 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. And forest fires frequently lead to wildlife fleeing their natural habitats. EO data and systems have a major role to play toward understanding, predicting, and adapting to/mitigating extremes that have a direct impact on the regional economy.

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 of the Fire Urgency Estimator in Geosynchronous Orbit (FUEGO). Earth observation's role in disaster management in the region currently remains confined to post-disaster 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 institutional water management taking advantage of EO data from water-relevant Earth observing systems.

## THEMATIC QUESTIONS AND RECOMMENDATIONS FOR 2027 VISION

As the workshop progressed into individual themes such as health, water, agriculture, disaster management, participants prioritized the following key questions and recommendations through panel discussion concluded with a consensus-based ranking.

### Health and Air Quality

#### Key Questions

- *How can we better adapt to the impact of climate change on changing disease burden (for both vector and water borne) on vulnerable populations?*
- *If capacity to build Earth observing 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 Earth observing based decision-making tools?*
- *How can the use of small satellites, aerial campaigns, and crowd sourcing 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 Earth observing tools should we build to empower the health community?*

- *Recognizing the inherent water nexus of water-borne 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 water- borne 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 take advantage of 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 Earth observing 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 is the most effective way to use radar observing platforms for disaster response?*
- *How can space agencies partner with reinsurance market players towards identifying a sustainable business model for disaster response? What would be the implication of such a move for non-profit disaster response agencies like Red Cross or Mercy Corps that 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, EO data community should conduct and share results from action reviews to assess the effectiveness of individual response efforts, 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 non-profit missions like Red Cross or Mercy Corps provide around the world.
- Policies and 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 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.

**Ecosystem Function**

**Key Questions**

- *What type of Earth observing missions and data have been most useful in resource management? What are the categories of Earth observing data that fall into research, operational application or experimental observations?*
- *How can we use such classification 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 co-produced 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 MODIS but inclusive of more complex sensors that provide less intuitive information than the visible wavelength?*

**Key Recommendations**

- The EO data community should create structured data at finer resolution on land resources (vegetation, household, roadways structure) to enable wider application in Ecosystem Function and cross-cutting themes.
- Simple metrics of uncertainty that have monetary implications should be associated with Earth observations data used for resource management and Ecosystem Function.
- 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 Ecosystem Function 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 capacity of engineering private sectors 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 co-sponsors' 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, EO data community should engage in pre- and post-analysis 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 water drinking source, EO data community should engage in partnerships to build a one-stop data portal from Earth observing systems for water alone.
- Early adopter programs should evolve from a single-mission to a multi-mission format to take advantage of the combined observational power of EO satellites.
- Space agencies and 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 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 Earth observing-based agricultural management?*
- *How do we measure progress/success of applications of agricultural management, particularly in the developing world?*
- *How can Earth observing 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 inter-seasonal to inter-annual forecasting applications need to be explored involving water availability and food production and the necessary research to close the gaps in understanding use of Earth observing data should be promoted.

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

**Miscellaneous Items**

**Key recommendations**

- NASA should explore more efficient and outside the box approaches to seeking solicitations that encourage more capacity building projects for Earth observing systems and data. Such approaches could be:
    - Revive a program on energy applications of Earth observing systems given the increased and better awareness of renewable energy and energy markets
    - Create more cross-cutting programs such as food-water and water-energy where communities from different disciplines can converge to jointly address cross-disciplinary topics that require a steep learning curve. The payoff for such programs is expected to be great for society.
    - Early Adopter programs should consider multi-mission interactions of missions to enable the leveraging of combined observational power of Earth observing systems.

# INTRODUCTION

The study of planet Earth, its changing environmental conditions, and its natural resources, has been driven by the pursuit of a more sustainable, safe, and happier future. In the 21st century, the interplay between human activity and nature is one of the most dominant drivers of change. In an era where this interplay of human activity is happening on almost all continents and with rules set not just by nature, Earth Observing (EO) systems based on remote sensing from satellite and airborne platforms offer a unique and global observational capability for the pursuit of societal benefits that are not feasible using only conventional ground-based approaches. It is already well established that observations from visible, laser, infrared, and microwave satellite sensors can provide key information for societal applications on management of land, water, agriculture, energy, health, air quality disaster, and ecosystem services. During the last few decades, the applied sciences community has been quite successful in taking advantage of the science and observations afforded by satellites to make spectacular societal impacts. For example the 1976 Big Thompson Flood in Colorado killed 144, while the recent 2013 Boulder/Lyons Flood (also in Colorado) was managed with fewer casualties (thanks also to the improved forecasting and communication technology catalyzed by satellites; *Hamill, 2014*). Similarly, a cyclone off the coast of Bay of Bengal (Bangladesh) in 1991 took more than 138,000 lives and made 10 million homeless. In contrast, the more recent cyclone Aila (in 2009) killed a few hundred and rendered 1 million homeless. The differences in theses casualty rates were a result of a significantly improved warning system based on Earth observing satellites (*Chowdhury et al., 1993; Paul, 2009*).

Most of the spectacular impacts for society from space observations have a few limiting features. They usually need long gestation periods to transition to real impacts for stakeholders (sometimes over decades). They have thrived primarily in the developed world of Europe and North America. In the developing world (where ground-based measurements are largely absent), satellite-based applications have struggled for longevity or continuity for a variety of reasons, the foremost being a lack of resilient capacity. The combined observational power of multiple Earth observing satellites and non-orbital platforms is not currently harnessed holistically to produce maximum, enduring, global societal benefits. The applied sciences community of scientists and stakeholders that rely on EO data (*hereafter called 'EO capacity building community'*) is unable to take complete advantage of the prolific amount of scientific output and remote sensing data rapidly emerging from satellite missions and convert them quickly into decision-making products for end users. Our existing application framework lacks the absorption bandwidth required to handle scientific research and the voluminous (petabyte-scale) satellite data. *So how do we change this course and take full advantage of satellite observational capability for a more sustainable, safer future in the coming decades*?

To address this key question and strengthen the global societal applications and capacity building community's voice for the upcoming 2017-2027 NASA Decadal Survey, a three-day workshop was held in Tacoma (Washington) during June 23-25, 2015. The workshop was sponsored by the NASA Applied Sciences Program as an E2 Topical Workshop, Symposium and Conference (TWSC) event. The workshop brought together experts from the applied sciences community across various themes already engaged in capacity building for the stakeholder community; NASA Applied Science and capacity building programmatic personnel; and several international stakeholder agencies with a history of using and a need for EO systems and data. Figure 1 below visually captures the main essence of EO-based global capacity building for society. Holistic use of the combined observational power of multiple satellites may be considered analogous to the A-train concept, except that herein we are focused on an 'A-train' for applications. During the workshop, the term '*Compound Eye*' of EO systems (satellites) was used to capture the key question (posed in preceding paragraph) more succinctly.

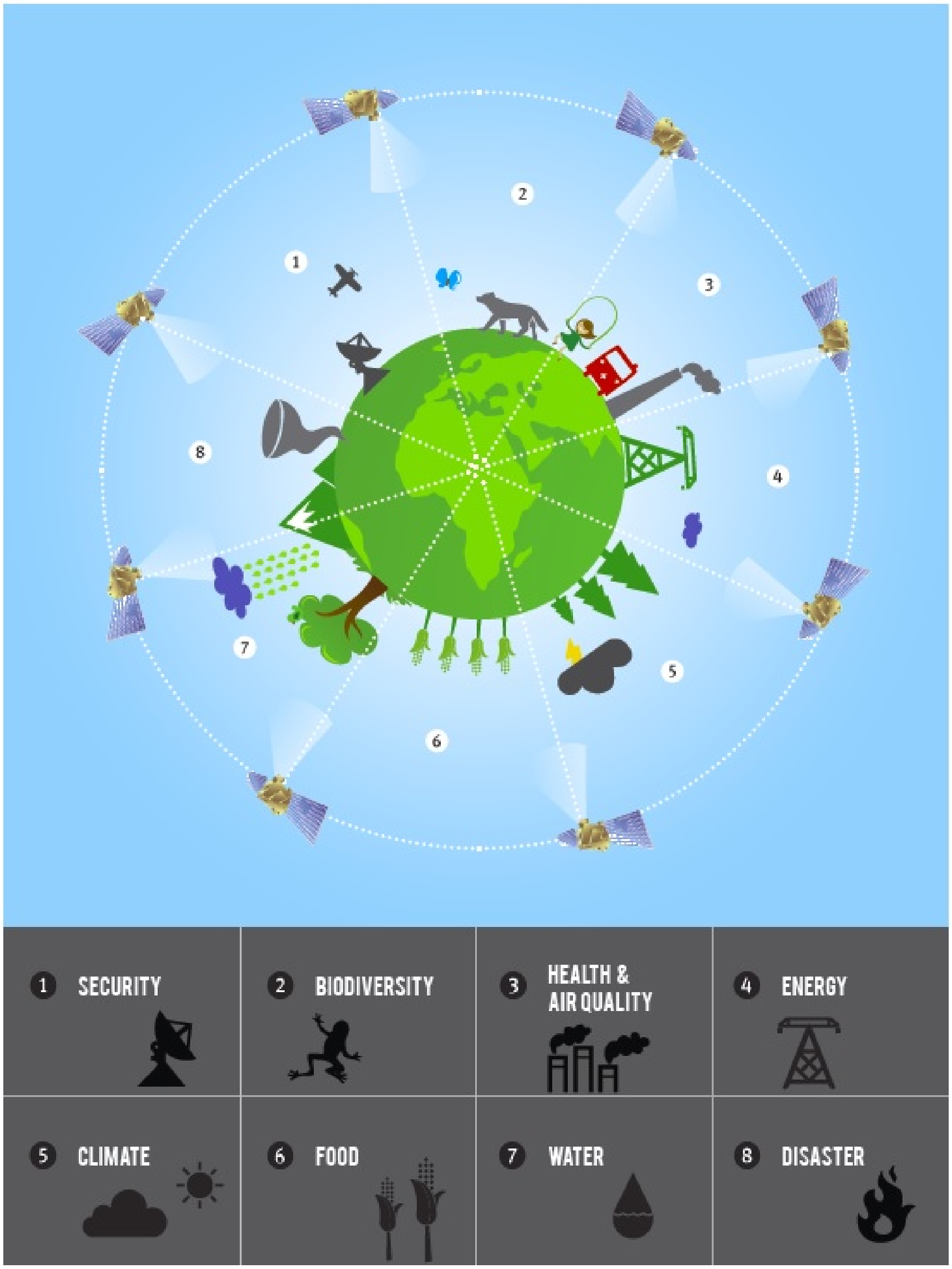


**Figure 1.** The Compound Eye of Satellites for Enhancing Societal Benefits. Note: the graphic was later modified based on input from the panel to make it communicate more clearly to the public the capacity building agenda of the NASA Applied Sciences program. [Copyright: University of Washington]

**What is Capacity Building in the Context of NASA Applied Sciences?**
EO-based capacity building (the overarching theme of this workshop) may be defined as *"the network of soft and hard components comprising human, non-human, technical, non-technical, hardware and software dimensions necessary to successfully cross the 'valley of death' between science and research (port of departure) and societal application (port of arrival)."*

## WORKSHOP OBJECTIVES

Recognizing that the answer to the question posed earlier (i.e., *How do we change this course and take full advantage of satellite observational capability for a more sustainable, happier and safer future in the coming decades*?) does not rest on expanding the use of satellite remote sensing alone, the workshop aimed to debate issues in order to formulate a path forward for the EO-based capacity building community in time for the NASA Decadal Survey expected to be completed in 2017. The workshop recognized the numerous and compounding issues that need to be explored. Issues included uncertainty, end user perception, location-specific technical and non-technical operating constraints, human resources, data latency, scalability (or the lack of) of solutions, widely varying social and cultural boundary conditions for scientific applications, and exploring business models appropriate for the coming decade. The workshop therefore connected the regional stakeholder community from the four SERVIR hubs in the developing world with the EO-based research community through in-person or remote participation. This connection allowed a meaningful and candid discussion, which has largely been uncoordinated or absent previously but was necessary to globalize and accelerate societal applications of satellite data in the future for the NASA Decadal Survey. The key discussion points of the workshop throughout the three days were '*What has worked and what hasn't?* and '*How do we fix what is not working while scaling up what is working well as a societal application?*' In other words, *'What do we need to do now as a community that will enable greater and more successful societal application of Earth observations from space?'*

**Specific Objectives**
In addition to the broader workshop objective of seeking answers, through in-person debating and discussions, to the questions posed so far, the workshop sought to achieve the following specific objectives:

1. Make the global capacity building and applied science community aware of critical importance of the NASA Decadal Survey 2017-2027.
2. Create a sustained atmosphere of meaningful interaction among scientific, stakeholder, and NASA programmatic communities after the workshop and in the lead up to 2017.
3. Create a series of wide-audience and peer-reviewed publication and media outreach products that can increase the visibility of the global capacity building community's voice for the Decadal Survey of 2017-2027 and other cross-cutting opportunities.
4. Identify a series of prioritized questions, potential solutions, and roadmap for each applied sciences theme, recognizing the cross-cutting (nexuses) and region-specific nuances critical for globalizing societal applications of Earth observations.

**Relevance of Workshop to NASA**
NASA relies on the science community to identify and prioritize leading-edge scientific questions and the observations required to answer them. The National Research Council (NRC)

is a key mechanism by which NASA's Science Mission Directorate engages the science community in this task. The NRC conducts decadal-scale studies, known as Decadal Surveys, which provide a science community consensus on key questions posed by NASA and other U.S. Government agencies. NASA and its partners ask the NRC once each decade to look out ten or more years into the future and prioritize research areas, observations, and notional missions to make those observations. NASA has recently embarked on conducting its second Decadal Survey (2017-2027) as the first one (2007-2017) draws to a close.

The first (2007) Decadal Survey (DS) report recommended that "*The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth-observing systems and restore its leadership in Earth science and applications*." The workshop participants were briefed on this survey (2007-2017) report in order to map a set of recommendations for the 2017-2027 DS on globalizing societal applications of Earth observing systems while recognizing that NRC is expected to conduct its second Decadal Survey differently. Thus, the workshop provided feedback from the community on identifying the set of recommendations and a roadmap as targeted guidance materials that the 2017-2027 DS NRC committee is currently looking for.

## WORKSHOP PARTICIPANTS

There were 27 in-person attendees at the workshop. Participants were selected by invitation with a view to represent as much breadth as possible in various themes of applied science (such as water, health, Ecosystem Function and disaster) as well as geographic relevance (Asia, Africa, Americas). While every attempt was made to create a balanced composition of participants, schedules conflicted for many experts. Thus some thematic or geographic areas lacked adequate in-person representation. But with the option for remote participation made available and the continuation of discussions offline during the post-workshop phase, less focused aspects received due attention. The overall break down of participants was as follows (participants are pictured in Figure 2):

**From Applied Science Community (8):**

1. Faisal Hossain – University of Washington (UW) – Water
2. Guy Schumann – University of California, Los Angeles (UCLA)– Water
3. Stephanie Granger – JPL - Agricultural Management
4. Rebecca Lewison – San Diego State University - Ecosystem Function
5. Ali Akanda – University of Rhode Island – Health
6. David Saah – University of San Francisco – Geospatial Technologies
7. Aleix Serrat-Capdevila – University of Arizona – Water
8. Dalia Kirschbaum – Disaster

**From Stakeholder Community (5):**

1. Robinson Mugo – Regional Center for Mapping of Resources for Development, Kenya (RCMRD)
2. David Ganz – Asian Disaster Preparedness Center (ADPC), Thailand
3. Victor Hugo Ramos – CONAP/Wildlife Conservation Society, Guatemala
4. Naveed Iqbal – Pakistan Council for Research on Water Resources (PCRWR)
5. Elliot Levine – Mercy Corps (Portland)

**From EO-based Programmatic Areas (14):**

1. Lawrence Friedl – Director, NASA Applied Sciences (AS) Program
2. Nancy Searby – Program Manager, NASA Capacity Building Program
3. Dan Irwin – NASA SERVIR Program
4. Ashutosh Limaye – Technical Program Manager for Capacity Building
5. Christine Lee – Program Associate for NASA AS Water Resources Program
6. Jay Skiles – Program Associate for NASA AS Ecosystem Function Program
7. Tim Stough – Program Associate for NASA AS Disaster Management Program
8. Sue Estes – Program Associate for NASA Health and Air Quality Program
9. Margaret Srinivasan – NASA AS Applications Lead for several missions
10. Eric Anderson – NASA SERVIR Program
11. Africa Flores – NASA SERVIR Program
12. Bill Crosson – NASA SERVIR Program
13. Dauna Coulter – NASA SERVIR media specialist
14. Carolyn Fonseca – NASA SERVIR Monitoring and Evaluation specialist

**Remote Participants (6):**

1. Vanessa Escobar – NASA AS Early Adopter Program
2. Woody Turner – NASA AS Program Manager for Ecosystem Function
3. Ben Zaitchik – Johns Hopkins University – Water
4. Sharon Ray
5. Sabrina Delgrado Arias
6. MSR Murthy, International Center for Integrated Mountain Development (ICIMOD)

**Temporary Participants (stayed only during Inaugural Session)**

Dennis P. Lettenmaier, NAE and UCLA – Chair of Water Panel for 2007-2017 Decadal Survey
Greg Miller – Chair, Department of Civil and Environmental Engineering, UW
Joel Baker – Director, Center for Urban Waters, UW (Tacoma)


**Figure 2.** Left panel: Workshop participants during June 23-25, 2015; Right panel: Workshop panel set up to foster a candid atmosphere of interaction.

# WORKSHOP AGENDA

The workshop was organized into five sessions (three morning-AM and two afternoon-PM sessions). In the first AM session, an overview and introduction by workshop organizer (Faisal Hossain), welcome message, workshop objectives, introduction to NASA Decadal Survey 2017-2027, and NASA Applied Sciences programs were provided. The first AM session also provided introductions by regional stakeholder participants from around the world. The remaining sessions addressed two themes per session, while the last session on 3rd day was for prioritization and voting of issues discussed, conducting group exercises, and providing more direct feedback to the 2017-2027 NRC DS committee. The workshop was held in a medium-sized classroom environment with facing tables to evoke an intimate and candid atmosphere for sharing of ideas. The specific agenda followed during each session is outlined below. Copious amounts of notes were taken by multiple scribes during the workshop deliberations. These notes were compiled and used in writing this workshop report.

**FIRST DAY- June 23 (8.30AM-5.30PM)**

**8.30AM-8.45AM**
Greetings: *Why are we gathered here today?* – Faisal Hossain (10 min)
*Welcome Message from University of Washington* – Dr. Greg Miller, Chair of Civil Engineering, University of Washington (5 min)

**8.45AM-10.30AM**
What is the NRC Decadal Survey of 2017-2027? - Lawrence Friedl (30 min)
Overview of NASA Applied Sciences Program: Past, Present, Future – Lawrence Friedl (10 min)

- *Capacity Building Program* – Nancy Searby (10 min)
- *SERVIR Program: From Space to Village* – Dan Irwin (10 min)
- *Water Resources Program* – Christine Lee (10 min)
- *Health and Air Quality Program* – Sue Estes (10 min)
- *Ecosystem Function Program* – Jay Skiles (10 min)
- *Disaster Management Program* – Tim Stough (10 min)

*Refreshment Break: 10.30-10.45 AM*

**10.45AM-11.00AM**
Workshop Purpose: The Work Ahead of us the next 2.5 days- Faisal Hossain (15 min)

**11.00AM-12.00 NOON**
SERVIR Hub Perspective:

- *MesoAmerica* – Africa Flores/Victor Hugo Ramos (15 min)
- *Eastern/Southern Africa and RCMRD* – Robinson Mugo (15 min)
- *Hindu Kush Himalaya and ICIMOD*– Eric Anderson on behalf of Dr. Murthy- ICIMOD) (15 min)
- *Lower Mekong and the ADPC* – David Ganz (15 min)

*Lunch Break: 12.00 – 1.00PM* (Box lunch will be provided)

**1.00PM – 5.30PM**

**THEME – PUBLIC HEALTH AND AIR QUALITY: 1.00PM-3.30PM**
*Defining the Success in the Future for the Health and Air Quality Program* - Sue Estes, University of Alabama (10 min)
*Value of Satellite Observations in Cholera Early Warning: Institutional Challenges in South Asia*– Ali Akanda, University of Rhode Island (15 min)
*Health Applications of Satellite Remote Sensing Data and Challenges* **–** Bill Crosson, USRA (15 min).

**Open Discussions** (50 min) – Session Chair - Africa Flores
[Note: Capacity Building is the unifying theme]
- International Perspectives (10 min)
- Workshop Questions and Issues on Public Health and Air Quality (30 min)
  - Logistical challenges
  - Manpower/HR issues
  - Climate Change adaptation issues
  - Itemizing/listing questions and solutions for NRC panel
- Cartoon Graphic on Public Health for NRC panel uptake– suggestions (10 min)

***Refreshment Break and Breakout Session on PUBLIC HEALTH:*** *2.30PM-3.00PM*

**Wrap up on PUBLIC HEALTH** (10 min) – Session Chair – Africa Flores

**THEME- DISASTER MANAGEMENT: 3.10PM-5.30PM**
*Landslides and Floods: Institutional Challenges* – Dalia Kirschbaum, NASA (15 min)
*The Global Flood Modeling Challenge: African perspective* Guy Schumann, UCLA (15 min)
*The Nepal Earthquake Satellite Imagery: Lessons Learned by SERVIR* – Eric Anderson, NASA (15 min)

**Open Discussions** (50 mins) – Session Chair- Eric Anderson
[Note: Capacity Building is the unifying theme]
- International Perspectives (10 min)
- Workshop Questions and Issues on Disaster Management (30 min)
  - Logistical challenges
  - Manpower/HR issues
  - Climate Change adaptation issues
  - Itemizing/listing questions and solutions for NRC panel
- Cartoon Graphic on Disaster Management for NRC panel uptake (10 min)

***Refreshment Break and Breakout Session on DISASTER MANAGEMENT:*** *4.45PM-5.20PM*

**Wrap up on DISASTER MANAGEMENT** (10 minutes) – Session Chair – Eric Anderson

**SECOND DAY June 24 (8.30AM-5.30PM)**
**8.30AM-10.30AM**

**THEME- ECOSYSTEM FUNCTION**
*Remote Sensing Applications in Resource Management* - Rebecca Lewison – San Diego State University (15 min)
*Geospatial Information Technology and Remote Sensing* – David Saah - Spatial Informatics Group (15 min)
*Resource and Wildlife Conservation in Central America* **–** Victor Ramos, CONAP (15 min)

**Open Discussions** (45 min) – Session Chair – Africa Flores
[Note: Capacity Building is the unifying theme]
- International Perspectives (10 min)
- Workshop Questions and Issues on Ecosystem Function (25 min)
  - Logistical challenges
  - Manpower/HR issues
  - Climate Change adaptation issues
  - Itemizing/listing questions and solutions for NRC panel
- Cartoon Graphic on Ecosystem Function (10 min)

***Refreshment Break and Breakout Session on ECOSYSTEM FUNCTION**: 10.00AM-10.30AM*

**Wrap-up on ECOSYSTEM FUNCTION** (15 min) – Session Chair Africa Flores

**10.45AM-12.30PM**

**THEME- WATER RESOURCES**
*Satellite-assisted Water Management of the World's Water: A Developing World Perspective* – Faisal Hossain, University of Washington (15 min)
*Uncertainty, Challenges and Disconnects in Satellite Product Applications for Operational Hydrology: efforts in Africa*– Aleix Serrat Capdevila, The University of Arizona (15 min)

**Open Discussions** (45 min) – Session Chair – Faisal Hossain
[Note: Capacity Building is the unifying theme]
- International Perspectives from Hubs (15 min)
- Workshop Questions and Issues on Water Resources (25 min)
  - Logistical challenges
  - Manpower/HR issues
  - Climate Change adaptation issues
  - Itemizing/listing questions and solutions for NRC panel
- Cartoon Graphic on Water Resources (5 min)

***Breakout Session on WATER RESOURCES**: 12.00-12.30PM*

*Lunch Break: 12.30PM – 1.30PM* (Lunch Buffet provided in the room)
**1.30PM – 5.30PM**

**Wrap-up on WATER RESOURCES** (10 min) – Session Chair – Faisal Hossain

**THEME –AGRICULTURAL MANAGEMENT 1.40PM-3.30PM**
*Crop Water Modeling and Agricultural Management* – Stephanie Grainger (15 min)
*Groundwater Management Challenges in Pakistan* – Naveed Iqbal, Pakistan Council for Research on Water Resources (PCRWR) (15 min)

**Open Discussions** (50 min) – Session Chair – Ashutosh Limaye
[Note: Capacity Building is the unifying theme]
- International Perspectives (10 min)
- Workshop Questions and Issues on Agricultural Management (30 min)
    - Logistical challenges
    - Manpower/HR issues
    - Climate Change adaptation issues
    - Itemizing/listing questions and solutions for NRC panel
- Cartoon Graphic on Agricultural Management (10 min)

***Refreshment Break and Breakout Session on AGRICULTURAL MANAGEMENT**: 3.00 PM-3.30PM*

**Wrap-up on AGRICULTURAL MANAGEMENT** (10 min) – Session Chair – Ashutosh Limaye

**THEME- RECENT/FUTURE NASA MISSIONS & MISCELLANEOUS: 3.40PM-5.30PM**
*NASA Early Adopter Program for SMAP, ICESat-2 and SWOT Mission: Lessons Learned* – Margaret Srinivasan, JPL & Vanessa Escobar, NASA (15 min)
*GPM Applications: Current Status* – Dalia Kirschbaum, NASA (15 min)

**Open Discussions** (80 mins) – Session Chair – Faisal Hossain and Nancy Searby
- International Perspectives
- Other Applied Science themes (Energy, Carbon Management, Air Quality)
- Nexuses – Food-Water-Energy
- Student Fellowship and Young Investigator Programs (Encouraging young talent)
- Workshop Questions and Issues on Recent/Future Missions & Early Adopter
- Wrap-up (Finalize Questions/Issues)

**THIRD DAY (8.30AM-12.00 Noon)**

**Prioritization of Future Missions & Funding Breakdown** Session Chair-Lawrence Friedl
**Prioritization of Questions, Issues (and Proposed Solutions) on Capacity Building for each theme (45 min)** Session Chairs – Nancy Searby and Faisal Hossain

Meeting adjourned

*Lunch 11.00AM – 12.00 Noon*

## PROGRAMS, THEMES, AND REGIONS

Given the nature of the workshop participant group, the format of 'theme first, region second' was adopted, as is evident from the preceding workshop agenda. After the inaugural session, the following themes were addressed in order:

1. public health and air quality
2. disaster management
3. ecosystem function
4. water resources
5. food and agriculture
6. current and future mission's early adopter programs and miscellaneous issues

The discussion period during each session focused on capacity building and globalizing applications. In other words, as the title of the workshop suggests, all discussions were driven by the goal of accelerating and globalizing societal applications of EO systems and data. In each discussion period, international participants were asked to voice viewpoints, ideas, and questions of their regions, keeping the critical issue of building capacity in mind. Participants spoke freely, drawing from their experience of failures and successes on building capacity using Earth observing systems. Feedback from remote participants was sought as well and will continue to be sought through post-workshop online surveys. To capture as many important themes as possible, particularly those that are cross-cutting (water-food; health-water; energy-water) with important societal applications, the last session on the second day included an extended discussion period for miscellaneous items. To target the discussion and elicit feedback for 2017-2027 DS, a starting set of five key questions was provided to all participants for consideration (see next section).

## KEY QUESTIONS AND DELIVERABLES

To initiate the discussion process and the sharing of ideas as a community on how to move forward in strengthening global capacity for societal application of EO systems, the following five questions were outlined as a starting point:

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 partnership 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?*
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?*

All participants were provided with these five questions to ponder prior to the workshop. It was stressed to the participants that these questions were not cast in stone, but would be used as a starting point to keep the discussions focused in each session. A community effort in 2013 that focused on conservation biology developed highly useful recommendations *(Rose et al.2014*) that served as inspiration for this workshop. The discussions were not limited to EO systems from satellites only. Other platforms and observing systems (such as airborne and ground-based measurement activities that frequently aid in decision-making and improving applications) were given due attention. Microsatellites, which are becoming increasingly widespread along with the unmanned aerial vehicles (UAVs), were also considered to the extent possible with a view to breaking down the 'divide' within the scientific community along these activities/platforms for the greater benefit of stakeholders.

Specific outputs expected from the workshop during the post-workshop period up to 2016 are:

1. Wide-audience article in EOS (AGU) and Bulletin of American Meteorological Society (BAMS) summarizing the workshop and the key findings (Target date: August 2015).
2. A community-based review paper in American Geophysical Union (AGU) Reviews of Geophysics (RoG) (or equivalent) that outlines current state of art, key open questions, proposed solutions and an overarching capacity building framework for globalizing societal benefits of NASA data for the coming decade (Target date: December 2015).
3. A set of community-based graphics similar to Figure 1 that can be used for large-scale public education and dissemination of capacity building effort (Target date: December 2015).
4. A special collection of peer-reviewed chapters on application of satellite Earth observation in a Springer Edited Book titled "*Earth Science Applications: Current and Future Prospects*" (Target date: May 2016).

# OVERVIEW OF NASA APPLIED SCIENCES PROGRAM

## INTRODUCTION

Lawrence Friedl (LF), Director of NASA Applied Sciences Program, started the AM session of Day 1 with an overview of the Applied Sciences program and the 2017-2027 Decadal Survey. He stressed the need for a candid atmosphere where all participants would feel encouraged to share ideas and criticisms freely so that an actionable (and game changing) roadmap leading to successful results can be designed for the upcoming Decadal Survey.

In reminiscing where the Applied Sciences program was at the last Decadal Survey, LF noted that the 12 themes under Applied Sciences, including cross-cutting solutions, were essentially using a linear model for enabling applications (i.e., from research to application as a one way street) using traditional science solicitations. He also noted that, 10 years ago, there was minimum engagement with current or future NASA missions and their science teams. There were very limited examples of application success stories that were mostly confined to international arenas. Training programs for use of EO systems and their data were very nascent. He alerted the participants to a paper written almost 10 years ago by *Sarewitz and Pielke (2007)* ("*The neglected heart of science*') where the supply of science needed to be grounded in the real demand for it through empowerment and building durable capacity.

The Applied Sciences program has come a long way since 2007, as noted by LF with the following key milestones: (1) launching of Application Project Grants; (2) NASA DEVELOP program to train youth on building capacity to handle Earth observation data; (3) capacity building on a global scale (international) through SERVIR (where regional representation is increasing each day); (4) numerous training programs managed by Applied Sciences program; (5) Applied Sciences Teams; (6) Early Adopter program to build user demand during mission involvement; (7) active participation of Applied Sciences community in NASA science teams; and (8) Interagency Partnership expansion (such as with USAID for SERVIR). LF highlighted that the traditional linear (one way) model of making research/science serve society needed to be replaced with an iterative approach known as 'co-production' of knowledge, where end-users from demand and scientists from supply partner intimately in joint investigations to build capacity. He also alerted to the numerous documents calling for greater attention to human dimensions, informing decisions, and the integration of social and economic sciences with physical sciences. Moving forward, LF challenged and encouraged the community to think outside the box in doing business to enable societal applications differently. He suggested the consideration of ideas like (1) Idea Factory; (2) Matchmaking (analogous to match.com where scientists are paired up early with stakeholder agencies); (3) Applications "Shark Tank"; (4) Prizes & Contests; (5) Explore Foundation Funding and crowdfunding programs; and (6) Explore Political & Technical "Marriages" for the Applied Sciences program. Currently NASA Applied Sciences is much more deeply engaged with the community through strategic partnerships with entities like Mercy Corps, Zurich, Microsoft, and Google.

Moving forward in the coming decade, NASA Applied Sciences would like to play a pivotal role through NASA's EO system in solving the three grand challenges facing humanity- (1) food security; (2) water access and availability; and (3) disaster risk reduction -- and help the world achieve the 17 Sustainable Development Goals (SDG) set by the United Nations (UN). For example, *is the world ready to feed 9 billion people by 2050, most of whom will be living in megacities with different set of constraints on demand for water, energy, and health?* How can NASA Applied Sciences play a leadership role as one of the many stewards of the planet to help achieve more sustainable living? LF noted that it is time to broaden the intellectual horizon of Applied Sciences to tackle these issues that are existential to planet Earth and can be addressed only through application and not by science alone. Thus, the coming Decadal Survey must recognize the marriage and synergy between research and Applied Sciences if the future challenges of sustainable living are to be met through meaningful application of NASA's EO systems and data.

**The 2017-2027 Decadal Survey**
LF next provided an overview of the 2017-2027 Decadal Survey, defining it as an *"Opportunity for the wide array of fields within the Earth Science community to propose, discuss, debate, and reach consensus on priorities that aids Administration and Congress by having a documented consensus of scientific experts."* While the 2007 NRC Decadal Survey was divided into several panels, with one being 'Earth Science Applications and Societal Benefits', it was recognized (and also suggested by Dennis Lettenmaier – panel chair for 2007 Decadal Survey) that the Applied Sciences agenda would be better served if the Applied Sciences and Capacity Building theme permeated in all the science panels (e.g,. water, health, climate etc.) rather than having a panel of its own. LF asked the community to think of the following:

1. *What does Global Applications and Capacity Building Community want this 2017 Decadal Survey to say?*
2. *What guidance does the community want it to give?*
3. *What priorities to state or confirm?*

Finally, in noting the way the 2017-2027 Decadal survey will be managed, LF highlighted the following goals for the NRC panel this round:

Goal 1: Assess progress in addressing the major scientific and application challenges outlined in the 2007 Earth Science Decadal Survey.

Goal 2: Develop a prioritized list of top-level science and ***application*** objectives to guide space-based Earth observations over a 10-year period commencing approximately at the start of fiscal year 2018 (October 1, 2017).

Goal 3: Identify gaps and opportunities in the programs of record at NASA, NOAA, and USGS in pursuit of the top-level science and application challenges—including space-based opportunities that provide both sustained and experimental observations.

Goal 4: Recommend approaches to facilitate the development of a robust, resilient, and appropriately balanced U.S. program of Earth observations from space.

For NASA in particular, LF noted that the DS panel would *"pay particular attention to prioritizing and recommending balances among the full suite of Earth system science research,* *technology development, flight mission development and operation, and applications/capacity building development conducted in the Earth Science Division (ESD) of the Science Mission Directorate."*

In the same context, Dennis Lettenmaier (DL) (chair of last decadal survey water panel) shared his insights on ways to move forward with Applied Sciences program. He suggested that the mission focus not be taken away completely as the need to measure new variables (and how to measure them) to enable applications provides much more tangible guidance to NASA leadership. DL stressed that scientific panels engaged in basic research and development for new missions recognize that real societal applications generate the best public relations mileage, and therefore the Applied Sciences program has to be more proactive in partnering with them, even though a natural tension exists between science and application (the argument herein being that NASA missions have a research mandate). In response to LF's question on the best way to build alliances with NASA science missions, DL suggested that most new missions have an 'application working group' (for example the SWOT Application Working Group-SAWG), and that it would be best if the Applied Sciences community was deeply engaged in developing win-win partnerships with the scientific community. The early adopter program is also a good avenue for building alliances.

## CAPACITY BUILDING AS THE OVERARCHING PROGRAM: WHY IS IT IMPORTANT?

Nancy Searby (NS), Program Manager of NASA Capacity Building, provided an overview of why capacity building is important in globalizing societal application of EO systems and data. Recalling where NASA Applied Sciences was in 2007, she noted that 10 years ago, several factors limited how we could advance the application of Earth science research and observations in the public and private sectors. These factors included "(*1) inexperience in identifying the requirements of applied users of the data and information; (2) limited knowledge of how managers, policy and decision makers, and the public obtain and use data and information; and (3) limited understanding of the capacity of institutions and organizations to apply new types of data and information to traditional and ongoing processes and ways of doing business."* (Quoted from page 44 of 2007 NRC Survey report). Today, in 2015, NASA Capacity Building has come a long way (as also noted by LF) through programs such as (1) DEVELOP, (2) ARSET, and (3) SERVIR. In the current context, NS noted that Applied Sciences Capacity Building Program engages current and future decision makers in a spectrum of activities to improve skills and capabilities in the U.S. and developing countries to access and apply NASA Earth science. Earth observations benefit society every day to make better decisions related to agriculture, climate, disasters, Ecosystem Function, energy, health, oceans, water resources, and weather. Today, capacity building has a wide reach globally (see Figure 3).

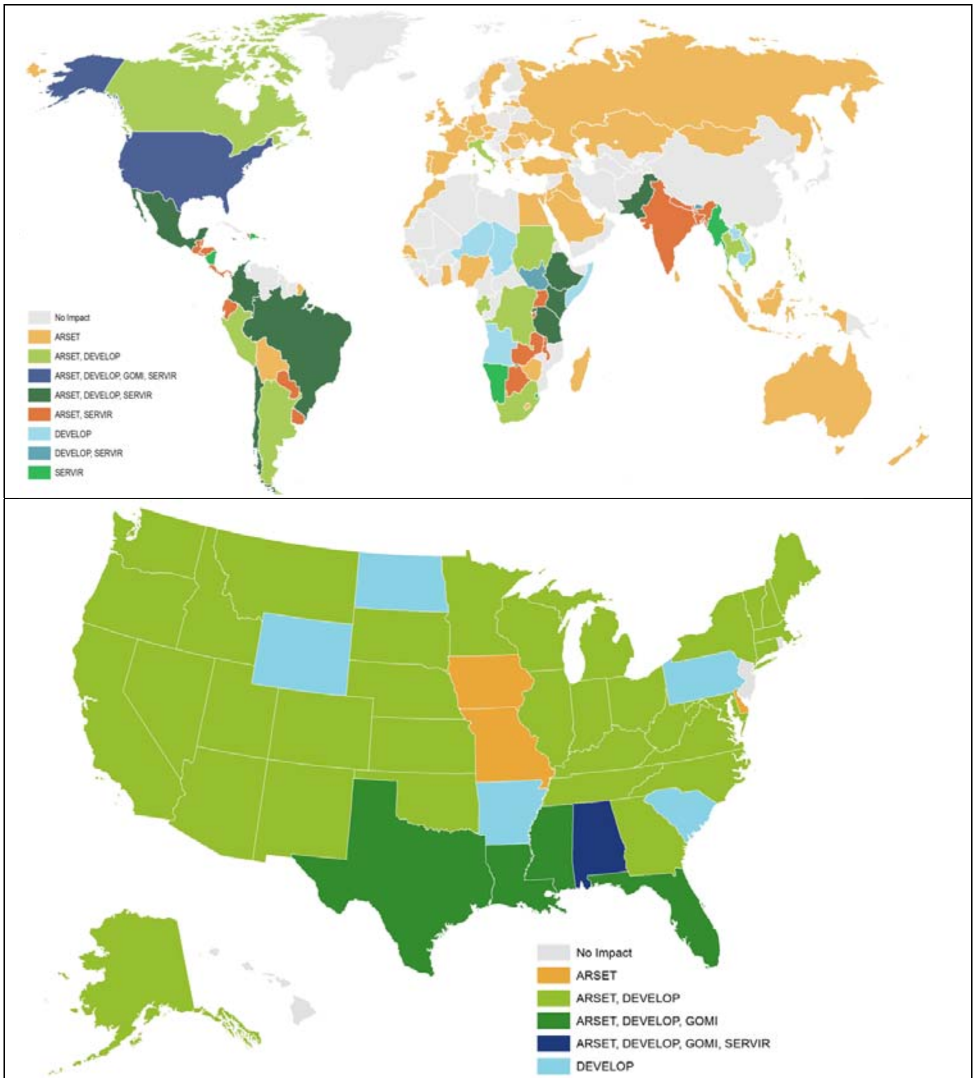


**Figure 3.** Current (2015) reach of NASA Capacity Building program. Since 2007, the program has witnessed significant growth with many success stories on enabling societally-relevant applications.

In noting lessons learned, NS noted that Capacity Building now recognizes the need to build capacity in the human dimension for the following entities: (1) NASA scientists-trainers, (2) future workforce, (3) government and professional end-users, and (4) scientific capacity. In addition, there is a need to build technology capacity to address different needs, abilities, and practices adopted by end users. Lastly, the building of organizational capacity was also underscored through long-term relationship, with regular site visits and on-going interactions being key to sustainable impact. NS stressed that more buy-in of societal applications of EO data is possible when end-users provides leveraged resources. Champions with a dual role of supply and demand can provide influence, vision, and long-term position to globalize societal applications.

As a vision and roadmap for where Capacity Building program could be in 2027, NS used water as an example to outline the following for the participants to start thinking about:

1. Roadmap: Identify essential measures of capacity built, standardize use, and measure impacts of capacity building methodologies across end user types and societal benefit areas (e.g., *to build skill to use an Earth observation application to predict floods, what project collaboration and/or training approach is best?)*
2. Vision: By 2027, using the combined suite of NASA Earth observations, enable all people to know where the nearest safe water to drink is that day, the next season, the next year, and the next 5, 10, 25, 50 years.
3. Roadmap: Develop applications in collaboration with decision-makers responsible for the most vulnerable populations.
4. Roadmap: Build skills to sustainably manage water resource over the long term.
5. Vision: By 2027, demonstrate sustained use of Earth observations in water management decisions by Ministries of Water in all SERVIR-supported countries.

## GLOBALIZATION OF NASA CAPACITY BUILDING EFFORTS (SERVIR PROJECT)

Dan Irwin (DI) presented an overview of the SERVIR project, which is responsible for building and globalizing capacity exclusively in overseas regions of the world. DI recalled that in 2007, SERVIR was mostly operating in Mesoamerica, demonstrating prototype applications of EO systems and data. These applications were limited to Wildfire Detection, Algal Blooms/Chlorophyll Concentration, Land Use and Land Cover Change, Cloud Forest Mapping and Post Disaster Assessments. SERVIR is now a fast growing and expansive network of scientists and end users in Eastern and Southern Africa, the Hindu Kush Himalayan region, the Lower Mekong region, and Mesoamerica. It is also engaged with strategic partners around the world. SERVIR has demonstrated operational use or uptake of 21 NASA Earth observational satellites for a variety of societal applications (see Table 1). It is also actively engaged in planning use of data from anticipated satellite missions such as SMAP, JASON-3 and ICESat-2.

In noting the vision for 2027 and the roadmap for SERVIR the coming decade, DI outlined the following:

1. Societal applications should continue to expand for SERVIR 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 (i.e., “Compound Eye” of applications) with a focus on cross-cutting themes such as water-food or water-energy (e.g., how can current microwave and visible satellites be used to make better decisions on water-energy nexus for an agency?)
3. New satellites must provide timely data at the appropriate resolution to support country-level application requirements.
4. NASA needs to find a balance between research products and real-time products. It is the real-time products that tell compelling stories on societal impact and help with public understanding of the value of a mission.

5. There should be increased consideration/use of nanosatellites and other innovations for applications as appropriate.

**Table 1.** Current use of Earth Observing Satellites, Systems and Data by SERVIR project to enable societal applications around the globe as of 2015. [Note:* Satellite/sensor no longer producing data. ** 5 Commercial Satellites in use through a unique data collection tasking agreement]

| Satellite/Sensor Name | Projects Using Data |
|---|---|
| ALOS (Japanese) (PALSAR data) * | 1* |
| AltiKa (French, Indian) | 1 |
| AMSR-E on Aqua * | 3* |
| ASAR (European) Envisat | 1 |
| ASTER | 3 |
| Digital Globe constellation** | 3 |
| EO-1 Visible Imagery, 30-m | 1 |
| GPM (Launched-2014) | 1 |
| GRACE | 2 |
| ICESat (GLAS)* | 1* |
| Jason-2 | 1 |
| LANDSAT 5* and 7 | 8 |
| LANDSAT 8 | 1 |
| Meteosat (European) | 2 |
| QuikSCAT * | 1* |
| Radarsat-2 ** | 3 |
| SMOS (European) | 1 |
| SRTM | 8 |
| Terra and Aqua- MODIS | 18 |
| TRMM | 10 |
| VIIRS | 8 |

## REGIONAL STAKEHOLDER PERSPECTIVES ON CAPACITY BUILDING

### Hindu Kush Himalaya (International Center for Integrated Mountain Development)

Eric Anderson of NASA SERVIR presented the South Asian perspective on behalf of the regional stakeholder entity (Dr. MSR Murthy. In South Asian nations sustained by the mountains of the Hindu Kush-Himalayan region, resource management, forest mapping and disaster prediction/mapping are the key societal needs that stand to benefit most from Earth observing systems. The International Center for Integrated Mountain Development (ICIMOD) has embraced a paradigm shift in its approach to enable durable applications through adopting a turnkey systems approach. Current decision-making needs of the region span agricultural monitoring (to map sowing area and drought), transhumance grazing management (rangeland phenology, sheep movement), and disaster management support in areas of forest fire, floods, landslide, and earthquake.

Key issues moving forward in building durable applications through ICIMOD engagement is to recognize the 'indigenous' knowledge and explicitly use it in the design of decision-making systems that uptake Earth observations. The steps required to achieve this can be itemized as follows: 1) popularize and bring local flavor to dissemination systems; 2) identify and facilitate local institutional interface and uptake systems; 3) develop bigger canvas/tier of scientific, policy, and local user community; 4) develop 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, gather more feedback and citizen science information. ICIMOD recognizes that the bridge (the bridge that we often term as '*valley of death*') between researchers and policy makers (end users) remains weak. Future efforts in the coming decade should involve greater involvement of regional expertise (rather than only global expertise), more face-to-face meetings (between demand and supply), development of products based only on clear and growing demand, and development of effective communication systems between Earth scientists and decision makers of Earth observation data.

### Southeast Asia (Lower Mekong and Asian Disaster Preparedness Center)

David Ganz (DG) next presented the Southeast Asian perspective on behalf of the regional stakeholder entity. The Asian Disaster Preparedness Center (ADPC) aims to build and institutionalize technical capacity of government decision makers and key civil society groups of the region to integrate geospatial analysis into their decision-making, planning, and communications. ADPC also aims to improve the sharing of user-tailored geospatial data, products, and services; and develop new high-quality user-tailored data, tools, applications, and models to address on-the-ground priorities. Given the focus on disasters, ADPC aims to build safer communities in the region through disaster risk reduction. This is where the use of Earth observing systems and data intersect with the mission of the regional stakeholders.

DG noted that many agencies of Southeast Asia are currently involved with collecting land use data but may not be cooperating on the integration of these datasets. For example, one agency may be collecting data on agricultural lands, another on forest areas, and a third on wetlands. For a unified dataset to be created, each agency needs to have clear definitions of what it is collecting, and ideally, the data should be collected in similar ways to help harmonize those datasets. If not feasible and/or politically sensitive, at the very least they'll need a better understanding of methods for merging data and resolving conflicts. This is where ADPC can provide a coordinating role through workshops between relevant agencies in each country to reach consensus on institutional arrangements for data collection, maintenance, monitoring change and data sharing. Through such coordination across borders, societal application of Earth observation data can be globalized in the region. Given the extensive nature of dam building in the Mekong River basin, having accurate DEM (better than the 30 m SRTM) is now a key priority for building applications for resource management. This demand is a reason why the future mission (Tier 3 in 2007 Decadal Survey), LIST, is likely to be ranked as a societally very relevant mission for the region. Solutions built for disaster risk reduction using EO will have to be cognizant of country-specific skills and human resource settings that represent wide variability in the region. Unlike Europe, Southeast Asian countries have contrasting capacities for uptake and sustenance of Earth observations (a good example is Vietnam with strong capacity and neighboring Cambodia with weak capacity). Thus, any early warning system developed for floods, cyclones, landslides to empower the institutions of the countries will have to be uniquely tailored, recognizing the boundary conditions of inherent institutional capacity (or limitations). Cambodia will likely be more challenging given the lack of in-situ records, which is why EO systems will likely have the biggest impact if the valley of death can be crossed for that country.

**East and Southern Africa (Regional Center for Mapping of Resources for Development)**
Robinson Mugo of RCMRD presented an overview of the East and Southern Africa perspective. High population growth and increasing demands on food and water are the two topmost issues facing the Eastern and Southern Africa region. Extreme weather, disasters, and their impacts on biodiversity are also key issues. Frost is becoming an increasingly common phenomenon, affecting Kenya’s tea production. And forest fires frequently lead to wildlife fleeing their natural habitats. EO data and systems have a major role to play towards understanding, predicting, and adapting to/mitigating extremes that have a direct impact on the regional economy. For example, weather monitoring through in-situ wireless sensors that work in tandem with space-borne platforms (such as MODIS on TERRA and AQUA) for predicting frost in tea gardens of Kenya have found wide acceptance due to the obvious implications of tea production economics. RCMRD also engages in building capacity for flood monitoring and water quality monitoring for shared water resources (such as Lake Victoria) among countries. South to south cooperation (i.e, cooperation between RCMRD of Africa and ICIMOD of South Asia) have proven valuable in capacity building. As a way forward, the region requires to transition towards creation of products that have more direct value in decision-making and impacting policy. For example, an EO based product on agricultural productivity is more useful than the NDVI of greenness of a region.

**Mesoamerica**
Africa Flores (AF) presented an overview, in coordination with Victor Hugo Ramos (VR) from Guatemala, of the Mesoamerican perspective. As in many other regions, resource management is a key decision-making need with clear demand of Earth observing systems and data. Today, forest cover in Mesoamerica is mapped roughly every 5 years at 30 m (Landsat) resolution to provide guidance to key stakeholder agencies. The future goal is to evolve to a more routine (annual) mapping with an estimate for biomass, carbon sequestration to support REDD activities. Forest fire mapping today in the region is based on MODIS quick look temperature products that

provide information on ‘active’ fire. 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 of Fire Urgency Estimator in Geosynchronous Orbit (FUEGO). Disaster management here currently remains confined to post-disaster analysis. The future needs are on a full-cycle ‘in-house’ capacity for disaster forecasting/prediction, mitigation, adaptation (risk reduction) and response/recovery through local institutions. On water issues, the region lacks sustained capacity for management that is currently confined to water quality issues. Future needs point towards more institutional water management taking advantage of Earth observing data from water relevant Earth observing systems (GPM, SWOT and SMAP).

In terms of the type of value-added products that need to be developed for the region, it is clear that products that can be ‘ingested’ in day-to-day operational framework would have the most value. Products that also recognize the local perspectives of decision makers are critical. The following suggestions were provided for building durable applications of EO data without the need for long-term incubation or external funding:

1. Promote the adoption of applications and the insertion of products and processes into institutional workflows
2. Promote the adoption and use of data in regulatory contexts
3. Promote the adoption and use of data in compliance and law enforcement

In terms of identifying the optimal business model and ideal mode of private-public partnership, there is no clear picture yet for this region on how to move forward. But evidence suggests that involving more than one institution per country could be the way forward. The same could be stated for taking advantage of the combined observational power of Earth observing systems.

# HEALTH AND AIR QUALITY (HAQ) PROGRAM

## CURRENT STATUS

In the first PM session of Day 1, Sue Estes (SE) presented an overview of the Health and Air Quality (HAQ) program. Recalling the 2007 Decadal Survey, the HAQ program was about "*targeted interventions to reduce vulnerability to health risks, and enhanced knowledge of human health-environment interactions.*" The focus was on transcontinental air pollution, impacts of climate change on human health, and the occurrence of extreme events, such as heat waves, earthquakes. The HAQ program began addressing the health impacts of climate change. Key question posed for HAQ was "*how will continuing economic development affect the production of air pollutants, and how these pollutants will be transported across oceans and continents.*" The key focus was on understanding if rare diseases would become common and on improving predictability of health epidemics.

The AQ component of the HAQ programs uses a variety of platforms at orbital (space) sub orbital/sub-orbital platforms (like airplane, ground radar). The current HAQ program supports the use of Earth observations in air quality management and public health, particularly regarding infectious disease and environmental health issues. It also promotes uses of EO data and models regarding implementation of air quality standards, policy, and regulations for economic and human welfare, in addition to understanding the effect of climate change on human health and air quality. The range of Earth observing systems used involve Terra/Aqua (MODIS: land surface); Landsat (TM/ETM+: land surface); TRMM/GPM (Precipitation Radar); SMAP (radar & radiometer: soil moisture); and AURA (ozone, air quality & climate). While CDC represents the key stakeholder agency of the HAQ program, agency interactions also occur currently with NOAA, EPA, DoD, US Global Change Research Program Health, Non-profit and For-profit sectors and GEO Health and Environment Community of Practice.

## FUTURE PLANS

In defining where the HAQ program aspires to be in 2027 in terms of global capacity, the following has been mapped as a vision statement for the next decade:

> *The program will examine Health "grand challenges" to the community:*
> <u>*Malaria*</u> *- Risk characterization models are currently deployed regionally. A unified dynamic malaria risk model would be a major achievement for end-users worldwide and would provide economic savings by scale and elimination of duplicative and competing models.*
> <u>*Vector-borne Diseases:*</u> *The World Health Organization and other health officials will now have access to global risk maps of infectious diseases associated with viral hemorrhagic fevers on a daily basis to aid health officials' preparedness.*
> <u>*Monitoring and Forecasting Harmful Cyanobacterial Blooms:*</u> *Cyanobacterial harmful algal blooms (CyanoHABs) are a concern for both drinking and recreational water supplies due to their potential to produce toxins in many lakes and estuaries. In cooperation with NOAA, new satellite derived products will be developed for the*

*issuance of daily HAB bulletins to pertinent end users in the Great Lakes, Chesapeake Bay, and the Gulf Coast.*

*The program will examine Air Quality "grand challenges" to the community: Accurate ground-level aerosol and constituent measurements from remotely-sensed columnar values. Ozone levels in the future is also a critical issue. Satellite observations for air quality will be increasingly vital in the coming years.*

*The HAQ program will have established strong relationships with federal, state, local, and international partners to identify unique applications of satellite observations and realize their operational use. These applications will provide critical components for integration with various forecasts, models, and decision support systems. NASA's participation in health and air quality applications research and related transition to operations activities currently performed with EPA, NOAA, CDC, and others will fill a significant niche in national capabilities and will be vital components in current and future domestic and international programs and plans.*

In other words, by 2027, the EO products developed under solicitations of HAQ program will be widespread, regularly accessed, and indispensable to the public and end users. The HAQ program will be known as the 'go to' program by 2027 for information about vector-borne and infectious disease risks, environmental health risks, and dangerous air pollution episodes. The program's international activities will include more leadership in the coordination of several international satellites that measure parameters relevant to global air quality and public health parameters. The recent or future generation of Earth observing systems that HAQ anticipates taking advantage of for achieving this decadal scale vision are SWOT, PACE, GEO-CAPE, PATH, HyspIRI, SMAP, and TEMPO.

**PANEL DISCUSSION**

Discussions started with views from regional stakeholders on health and air quality issues. The regional stakeholders mostly raised the issue of air quality as the more pressing need for use of EO data. In Mesoamerica (such as in Guatemala), air quality and smog in rapidly expanding cities is becoming an increasingly difficult problem to predict and solve. Similarly in East Africa cement factories that are springing up due to rapid development are contributing to poor air quality. In Nepal, where a lot of rebuilding will have to be done after the destruction from the Gorkha Earthquake, brick kilns that contribute to poor air quality are likely to become more widespread and operate with less regulation given the pressures of restoring housing and large infrastructure building.

In Cambodia, Thailand, and Laos, managing transboundary air pollution is also becoming an issue. Forest fires in Thailand recently impacted cities in neighboring countries, dispelling the conventional notion in the region that most haze-related issues originate from Indonesia and impact mostly Singapore. Even Myanmar and Laos appear to be suffering from transboundary air pollution that is a relatively recent occurrence. All of this informs us is that there is a clear need for improved capacity to monitor, predict, and forecast air quality metrics and dynamics using EO systems and data in a regional manner by involving the regional institutions. Because this problem is not confined to a single country, SERVIR (or similar programs with a mandate to serve developing nations) is likely to be the key program to help in this issue in the coming decade, when more than 70% of the world population will live in cities and face greater air quality issues. Getting local authorities and government institutions to recognize this issue and act accordingly to build capacity will be an upcoming challenge for the coming years, particularly in East Africa where capacity for air quality monitoring seems to be trailing behind the rest of the world.

International stakeholders also raised the issue that there is currently a lot of interest in vector-borne diseases in Asian countries. Ambassadors of developing nations typically bring up health as a bilateral issue. So there is a lot of transboundary interest in health and air quality monitoring. In addition, institutions desire to understand the impact of deforestation on malnutrition - clearly a cross-cutting and inter-disciplinary 'nexus' theme among resource management, food, and health. Currently, there do not appear to be clear capacity building programs within the EO community that are tailored specifically to address such nexus challenges involving health. Perhaps the coming decade (2017-2027) is the time when such programs need to be created. Access to clean water is a challenge in many countries, a question for the capacity building community therefore (in line with capacity building vision set by NS) is "*How can we take advantage of the compound eye of Earth observing systems and guide institutions on the nearest safe water source*?" This clearly falls under a 'grand challenge' for the health and water cross-cutting theme of building capacity using satellites.

The panel started a discussion on the current impact of what the applied science community has been doing on health and air quality issues. A comment was made that '*who is paying attention to the models, peer-reviewed papers that demonstrate the value of Earth observation for improvement of health monitoring and prediction?*' This comment was phrased as a need to measure the impact in different ways – '*if capacity is indeed building up for better health monitoring through Earth observations, then shouldn't data on intervention or incidence indicate a declining trend, or should that not be the goal of the HAQ program?*' It was noted that members of the public health community are not necessarily trained as Earth scientists in their primary degrees. They usually have a medicine or public health degree. Therefore, the language they speak and understand and the way business is done is significantly different from that of Earth scientists engaged in using EO for health monitoring. Perhaps this gulf is the largest in the HAQ program compared to other Applied Sciences programs such as water resources, agriculture, or disaster management. It may be time to recognize a potential gulf in communication styles and rectify it.

The health community engages directly with people affected are more aligned towards intervention, vaccination, prevention, and better sanitation. Unless an Earth scientist also happens to be a doctor by training, it may be difficult for him/her to convey the message that it is indeed feasible to do actionable monitoring and forecasting of health epidemics that can then be used for intervention decision-making. While the HAQ program's engagement with CDC represents a trove of success stories, the experiences to learn from are limited to the Americas. For the broader international community, it appears that most health ministries do not recognize the value of Earth observation data in helping to become proactive in health epidemic response or policy. This lack of recognition results either from lack of capacity or from refusal to believe that satellites can indeed monitor health-sensitive environmental markers. For example, in

Bangladesh, the Health Ministry does not have a 'water cell' or a good liaison to interact with Water Ministry or water-resources related institutions. Thus, the Ministry's understanding of the implication of water availability on diarrhea (a water-borne disease) is severely limited. Certainly there appears to be a lot of education to be done on this issue of communication between two disparate communities. However, there exists a silver lining. SE of HAQ program indicated that any session on satellites at workshops or conferences on tropical medicine or public health tend to be full house. This indicates that the health community of doctors and public health officials indeed has always been eager to listen and take advantage of EO systems and data.

In response to building durable applications, the panel raised the question of '*whose capacity is the HAQ program aiming to build?*' Is it the science community or the stakeholder institutions? It might be worthwhile to pursue this question and find out who will be using the EO systems and data for health monitoring in their decision-making before deciding on the appropriate approach to build capacity. Country-level intervention strategy for health can be a complex problem. Often, for example, it is not known what the first and most impactful intervention for diarrheal diseases is. *Is it to control sanitation or address salt water intrusion or to predict floods?* Diarrheal research centers such as the International Center for Diarrheal Disease Research, Bangladesh (ICDDRB) have a diarrheal expert group, but do not have an in-house water expert.

For AQ monitoring, the panel noted the potential of using small/nano satellites (such as cube sats) in constellations for aerosols and trace gases. Crowd-sourced health outcomes and passive crowd-sourcing (e.g., prescription purchases and using social media) have value in building capacity. Although a heat warning system exists in US cities, heat warning systems producing a heat index at neighborhood (city block) scale in an urban environment remain unresolved. In terms of taking advantage of the combined observational power of multiple EO platforms, the panel noted that cholera monitoring can potentially benefit from GRACE, SWOT, and GPM missions working as an 'integrated system'' for the South Asian region. For malaria, visible and near-infrared sensors on LANDSAT and MODIS are already used frequently, and it may be worthwhile to explore how SWOT, SMAP, and GPM can be added to improve and refine the trajectory of malaria based on surface water mapping or modeling. In all this, the interpretation of some of the satellite data (such as GRACE) may involve a steep learning curve on the demand side. This is an issue that the Applied Sciences community must recognize before designing a system that is durable and can be independently owned.

Experts from the development realm noted that agencies (such as USAID) with a global development mandate desire health data but do not necessarily worry about where the data comes from. These agencies also have a tendency to put excessive faith in the data if satellite observing systems happen to be the data source (such as NASA satellite missions). Recalling an experience from a few years ago in engaging philanthropic foundations for strategic engagement in health, the Gates Foundation indicated that their priority was to invest in vaccination and not on monitoring and forecasting of environmental conditions using EO data. Obviously, when there is no overlap of priorities, capacity building of Earth observations through public-private partnerships can be difficult. Thus, in building durable capacity, it is important to know the partnering agency's interests first.

Attention was drawn to President's Malaria Initiative. If the EO-based capacity building community wants to build capacity of countries through this initiative, then there may be an opportunity to provide support for EO data and gain in-situ health records from nations in decision-making tool development. The panel suggested that because SERVIR has hubs in many continents, the Applied Sciences community could learn more about the key institutional capacity for health monitoring for local health institutions and then prioritize capacity building efforts to gain maximum societal impact from Earth observing systems and data. The panel noted that it might not be fair to the stakeholder institutions to 'dictate' what they need or need not do for decision-making. These institutions are front-line in any health related epidemic and know better what the ground zero reality is. For sustainable applications, the EO data community is better off making access to various data, products, and potential systems known to them so that the stakeholder agencies can decide how best those might improve their current decision-making process. As a counter, a panel member noted a lack of appreciation and belief of specific capabilities afforded by EO systems (such as predicting cholera incidence with 3-4 months' lead time). Thus, there needs to be more communication and trust building to make EO relevant for capacity building of health institutions. The panel also noted that in general, building an EO data based health monitoring system usually ends up being used in some fashion by end users. However, the real test of impact is whether the decisions enabled by such EO systems are truly improving or saving lives. This has historically been hard to track. The panel also noted that prioritization of health issues is difficult as they are all equally important (one cannot say diarrhea should take more precedence over malaria or Ebola). In terms of climate change adaptation, it appears that there is a lot of work to be done by the HAQ community. Model projections of temperature indicate that Mexico City will be very dengue susceptible by 2050. *What is the community doing to raise this awareness and get local institutions to build the capacity to adapt to the future forcings?*

## SUMMARY FOR DECADAL SURVEY

### Key Questions

- *How can we better adapt to the impact of climate change on changing disease burden (for both vector and water borne) on vulnerable populations?*
- *If capacity to build Earth observing 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 Earth observing based decision-making tools?*
- *How can the use of small satellites, aerial campaigns, and crowd sourcing programs (citizen science) assist in building and improving more relevant health and air quality monitoring tools that use conventional Earth observing satellites?*
- *How do we forecast air pollution in smog, fog, and haze prone regions using Earth observing systems?*
- *What type of disease-relevant and region-specific Earth observing tools should we build to empower the health community?*
- *Recognizing the inherent water nexus of water-borne disease, how can we facilitate greater interaction of technical experts on water with the health monitoring community?*

**Key Recommendations**

- The EO-based capacity building community should focus greater effort 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 water- borne diseases, water community technical experts that use Earth observing systems and data should partner more effectively with the traditional health community.
- There is a need for 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 Earth observing data for capacity building of health institutions around the world.
- In an effort to build durable capacity of Earth observing systems, the EO data agencies and capacity building community 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

## CURRENT STATUS

Tim Stough (TS) presented an overview of the NASA Disaster Management program. TS noted that in the last Decadal Survey report, the Disaster Management (DM), or Disasters was a fledgling program with several challenges highlighted, particularly those related to solid Earth. The program had responded to 2004 East Asian Tsunami using Earth observation imagery from EO-1, Landsat, and MODIS. It also responded to Hurricane Katrina with housing maps for logistics and environmental impact created from satellite imagery. The program also initiated a Hurricane Flood and Landslide Project using precipitation data from NASA EO systems to monitor the risk of tropical floods and landslides. The program partnered with NOAA to improve NOAA River Forecast systems.

Currently, the DM area promotes the use of Earth science data and information that enable decision-making for targeted end users. It provides observation and monitoring of hazards with a view to improving model-based forecasting and risk assessment for communities and infrastructure. It also guides preparedness, mitigation, and response and advances understanding of hazard processes that lead to disasters and disrupt our daily lives. The DM program has several inter-agency partnerships such as CENRS Subcommittee on Disaster Reduction, National Academy of Sciences – Disasters Roundtable, Interagency Remote Sensing Coordination Cell USGS, NOAA, FEMA, US Army Corps of Engineers (USACE), EPA, and Department of Defense. The EO satellites used, but not limited to, for disaster management are those with strengths in visible and near-infrared multi-spectral and hyperspectral imaging, such as LANDST, MODIS, Hyperion, and CALIPSO. Also, GPM and TRMM have found frequent use (in flood monitoring). In 2014, the DM program responded to 109 flood events globally and more recently in 2015, it focused a tremendous amount of effort on the Nepal Gorkha earthquake.

## FUTURE PLANS

Moving forward, the DM program envisions the coming decade  as one where there will be integration of NASA’s EO data with the satellite, airborne, and ground systems of other space agencies, public, private, and global, to obtain complete near-real-time situational awareness for disaster mapping and risk assessment. The program will strive to reduce latency, take a more ‘constellation’ approach, and automate tasking and disaster operations integrating SAR, optical and GPS sensing. In the coming decade (2017-2027), the program hopes to keep the following key questions at the forefront of its evolution for more effective disaster mitigation and response:

- *How do we best employ our science mission assets to support routine disaster monitoring as well as response and recovery?*
- *What is the best way to engage our international partners at other satellite agencies (e.g. JAXA, ESA, CSA, ASI)?*

- *How can we improve communication of needs and shared practices across different hazard communities (storms, floods, volcano, earthquakes, etc.) and across national boundaries?*
- *What are the common platforms for multi-hazard, primary or induced, visualization, mapping, and risk and vulnerability assessment?*

**PANEL DISCUSSION**

The panel initiated the discussion by reviewing the experience of disaster response to the Nepal Gorkha earthquake in 2015. A question was asked as to why the response was so successful in terms of speed of response, inter-agency cooperation, and helping the 'boots on the ground' compared to a lot of other recent disasters where response struggled. The question asked was if the synergy in response was due to a) the scale of the disaster or b) a change in the way NASA and other space agencies currently responds to disaster. Among other things, LF noted that the Nepal disaster was a successful response because there was a vast community of volunteers who were familiar with Nepal and had a deep bonding with the country, which was sufficient to tip over the capacity to overcome time-sensitive hurdles. The panel also noted that the size of the disaster brought various US and international agencies together. Also, NASA has significantly improved its own modus operandi (MO) of inter-agency engagement. In particular, the Marshall Space Flight Center (MSFC) where the SERVIR project is housed was able to play a pivotal role given SERVIR's presence in Nepal through ICIMOD. The panel also noted that there had been a series of preceding disasters (such as Fukushima) providing a learning curve that had helped NASA identify who to liase with and how to respond better in future.

A key point made on the Gorkha earthquake was that it was a very 'expensive' response and not sustainable for NASA to repeat such a response on a regular basis without a clear exit strategy and business model in place. The question that came up in response was '*when does DM program know when to stop and pass on the buck further downstream?'* This issue naturally led to the key question of what is a good business model. The panel noted that satellites do not last forever but disasters will keep happening. *So what is the best way to engage private sector (such as reinsurance – SwissRE) and demonstrated that the Earth observing data indeed has value in disaster mitigation and management so that they step forward to invest in such data?* The global flood partnership may be a good starting point to explore an effective business model that engages space agencies and EO data community with private and philanthropic sectors for more sustainable disaster response.

In the case of flood insurance, if using Earth observations from satellites can be shown to improve the business model for insurance companies, there is an opportunity for engagement with NASA. MODIS has had value in flood inundation mapping. However, the panel noted that a lot of insurance companies just want to take advantage of what's available for visualization as a 'free resource' without having to pay for it within their business models. Another issue to consider, as highlighted by the panel by drawing on references to floods and fires (Malibu fire in California), is that the very essence of the business model of insurance companies is profit driven by keeping the monopoly over information. If everyone had access to the same information, then insurance companies would not have the market share to sell their insurance products. The panel noted that when it comes to disasters, the private sector seems willing to invest in Earth observing data only if data is not made publicly available. Among Earth observing agencies, the panel noted that there is recent greater sharing of data for disasters such as from JAXA, NASA, and Chinese agencies. It appears that a business model for responding sustainably to disasters involving the private sectors might be elusive and a topic worthy of pursuit for the coming decade. Non-profit disaster response agencies such as Mercy Corps (and Red Cross) noted that they prefer working with EO data from NASA as it is free and they do not have a profit making agenda.

The panel finally noted that, to make a more compelling case, it is important for the community to demonstrate '*what could have happened*' if EO data had not been used in a real disaster response. In that effort, it is important to document what measurements were used for responding to the disaster. Discussion then transformed to the case of success stories for disaster management and how important they are for showcasing the value of EO systems. *Is the community keeping a good tab on success stories, because they certainly help scientists make their case on why a specific tool needs to be developed?*

## SUMMARY FOR DECADAL SURVEY

### Key Questions

- *What should be NASA's primary role in disaster response?*
- *How is a "successful response" defined in order to maintain ability of space agencies and EO data community to respond regularly to disasters in a sustainable manner?*
- *What is the most effective way to use radar observing platforms for disaster response?*
- *How can EO capacity building community partner with reinsurance market players towards identifying a sustainable business model for disaster response? What would be the implication of such a move for non-profit disaster response agencies like Red Cross or Mercy Corps that 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 keep an inventory of success stories and aggressively promote how Earth observations provide fundamental life-saving support to disaster response.
- The EO capacity building community should investigate ways to partner with private sector entities on disaster reinsurance without compromising the greater-good agenda that non-profit missions like Red Cross or Mercy Corps provide around the world.
- Policies and MOUs should be in place for greater inter-agency partnership for data sharing at low latency to make Earth observing systems more meaningful for disaster response.
- There should be a clear exit strategy in place for the engagement of EO data community in disaster response for large scale disaster events.

# ECOSYSTEM FUNCTION

## CURRENT STATUS

Ecology deals with the science of relationships between organisms and their environments. The Ecosystem Function program deals with the use of historic and current EO data to detect future trends of how this relationship may be evolving, particularly under climate change. It provides the tools needed for planning the management of ecosystems and preserving biodiversity while providing societal benefits. Ecosystem Function was addressed in the 2007 Decadal Survey under the chapter "Land-Use Change, Ecosystem Dynamics, and Biodiversity," and also in chapter of "Human Health and Security." It was recognized that ecosystems are affected by and influence all topical areas covered in Decadal Survey. Almost all missions proposed in 2007 had some relevance to understanding and managing ecosystems and natural resources. EO missions of particular relevance included HyspIRI, DESDynI, SMAP, GEO-CAPE, and ACE. The program engages with a wide range of agencies and partnerships, such as NSF, USGS, US Fish and Wildlife, US Global Change Research Program on Biodiversity and Ecosystems cluster.

## FUTURE PLANS

Recently, the Ecosystem Function community converged to identify needs and formulate plans for the future use of EO systems and data. An Ecosystem Function funded workshop resulted in a 2014 paper in Conservation Biology; the paper identified *"Ten Ways Remote Sensing Can Contribute to Conservation."* The future points to needed improvements in spatial, temporal, and spectral capabilities of remote sensing to enable ecosystem understanding on space and time scales relevant to managers. More robust Ecosystem Function requires integration of global datasets of ecosystem structure (3-dimensional vegetation structure from lidars/radars) with ecosystem composition and function (hyperspectral systems operating from the VSWIR to TIR). In addition, integration of satellite, airborne, and in situ (e.g., camera traps, acoustic devices, small drones, etc.) sensor data is required to take the next step in Ecosystem Function. In the future, citizen science and other crowdsourcing technologies will need to be stressed to expedite the sharing and validation of information on ecosystem services.

## PANEL DISCUSSION

The panel first discussed remote sensing applications for dynamic ocean management as a form of resource management for fisheries. The balancing act between ecological sustainability and economic viability was presented as an unstructured problem. There have been tremendous advances in ocean remote sensing technology. From a marine resource management perspective, data collection and data applications are often disconnected. The panel noted that EO data from satellites has tremendous potential for dynamic ocean resource management where management needs change in space and time due to the changing nature of the ocean and the end users. *EcoCast* was noted as a successful example of a co-production model of an application between scientists and stakeholder agencies. LF asked if this successful co-production model could be transferred to other applications beyond Ecosystem Function, for example, to malaria. The panel discussed ways to do that, recognizing the value of visible imagery for resource management and its cross-cutting relevance to disasters like fires and floods that damage ecosystems and land cover. The issue of uncertainty quantification in projecting impacts on ecosystems was deemed critical. Some members of the panel thought that to enable meaningful capacity building, too much emphasis on uncertainty could undermine the value of the application, while others suggested that uncertainty has value only if it is tied to economics and monetary decision-making It was suggested that simple metrics of uncertainty (e.g., high, medium, low) that are intuitive to decision-making should be pursued.

Given the long-term nature of resource conservation and monitoring in Ecosystem Function, the panel raised the question about which specific types of Earth observing systems and types of measurements should be maintained for longevity. The pursuit of this question represents a natural marriage between the conservation community and Earth scientists using remote sensing. LF suggested that it might be prudent to ask the USAID missions about which types of Earth observing missions and data were really useful in resource management. For the decadal survey, a peer review of such work would be timely. The community should identify categories of satellite products that fall into research, operational application (e.g., an operational MODIS), or experimental observations. Using this classification, the community should explore what percentage of the data NASA should fund for each category, which ones should remain free and funded by government, and which should be funded through some public-private partnership or through contributions from other countries that stand to benefit tremendously from the data.

The panel felt that drawing the attention to finer scale information on the world's resources and ecosystem services would be timely for the next decade. When discussing the role of governments in supporting the application of Earth observing systems, the panel felt that while the private sector could have a future role to play, resource mapping and conservation (and Ecosystem Function) should remain an essentially government (or national) 'service' provided for the greater good. Thus NASA and other space agencies should continue to invest in such Earth observing systems for sustained observations for public services. The panel also wondered if the domain of Ecosystem Function was crowded with too many agency players who could benefit from Earth observations. For example, *what is the role of IPCC in resource mapping?* It was argued that the domain is actually not as crowded, particularly on the use of satellite data, and that only when resource mapping and its conservation made economic sense was the societal use of Earth observations triggered. In that regard, it may be worthwhile to consider how best to develop economic (or business models) for application of Earth observation for ecosystem services using current training programs such as DEVELOP under the capacity building umbrella. Another suggestion made was to hold 'matchmaking' workshops that bring economists and business community together with the Earth science community – an effort that probably has not happened yet. **This whole economic model discussion applies to all themes and is not limited to Ecosystem Function.**

The panel discussed the fundamental reasons for LANDSAT having become a great success for the resource conservation and Ecosystem Function community compared to other Earth observing systems (like SAR). The key attribute is that optical imagery (hyperspectral or multispectral) is much easier to visualize, and more intuitive than radar backscatter to the average user community. The question therefore posed is *how do we build capacity in applications that can be as popular as LANDSAT but based on more complex sensors that* *provide less intuitive information?* The applied sciences community hasn't yet wrapped its head around this issue, and a lot of work needs to be done. Speaking from experience on the use of radar nadir altimetry for flood forecasting, the way radar backscatter (in units of dB) was made relevant to agencies was by converting it to water elevations relative to the local datum and providing a 3-D visual map of heights. A similar approach could work for making less intuitive sensor data (non-optical) meaningful for stakeholders.

The panel noted that small satellites, UAVs, and aerial platforms have unique value in Ecosystem Function moving forward to address new challenges and should receive greater attention in the upcoming decadal survey. These time-limited platforms provide a unique perspective, ground validation opportunities, and insights on fast-changing processes that otherwise could be missed by the long repeat time of orbital platforms. Lastly, on international perspectives and regionalization of applications, the panel pondered whether the approach that has been so successful in engaging the fisheries industry to use Earth observations (and avoid no-fishing zones) could be replicated for preventing poaching of endangered animals in Africa. It appeared that the same model of co-production that EcoCast uses could apply for preventing poaching.

## SUMMARY FOR DECADAL SURVEY

### Key Questions

- *What type of Earth observing missions and data have been most useful in resource management? What are the categories of Earth observing data that fall into research, operational application or experimental observations?*
- *How can we use such classification of data to identify the percentage of the EO 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 co-produced 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 but inclusive of more complex sensors that provide less intuitive information?*

### Key Recommendations

- The EO data community should create structured data at finer resolution on land resources (vegetation, household, roadways structure) to enable wider application in Ecosystem Function and cross-cutting themes.
- Simple metrics of uncertainty that have monetary implications should be associated with Earth observations data used for resource management and Ecosystem Function.
- The EO 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 that bring the Earth science applications community into closer engagement with the business community through education partnerships should be fostered with a view to identifying successful private-public business models for Ecosystem Function and other cross-cutting themes.

# WATER RESOURCES

## CURRENT STATUS

In the last Decadal Survey, water resources received ample coverage. Water Cycle Observations for water resources applications were important elements of that survey. There existed a distinct panel on ‘water resources and global hydrologic cycle’. That panel addressed freshwater availability and drought (and wildfires) impacts around the world and explored the importance of nexuses such as water-health, water-climate and water-food issues. Several water missions received priority (such as SMAP, IceSat-2, DESDynl (NISAR), HyspIRI, SWOT, GEO-CAPE, PACE, GRACE-FO, LIST, and GPSR). In the earlier decade, notable application examples of Earth observing data were (1) reservoir heights from radar and laser Altimetry; (2) Famine Early Warning System (USAID) support; (3) U.S. Drought Monitor; and (4) EPA Basins. Key NASA satellites that were demonstrated to have impact on water resources were (1) Landsat 5 (+20 years old); (2) Landsat 7 (Scan-line detector defect); (3) MODIS (on Terra and Aqua); (4) TOPEX/Poseidon; (5) AMSR-E; and (6) TRMM.

Currently, the NASA Applied Sciences Program Water Resources application area supports the integration of NASA Earth observations and technologies into management tools for the water resources management community. The Water Resources application area currently supports a diverse range of projects in its portfolio, addressing topics including drought monitoring and mitigation, snow monitoring and runoff forecasting, water quality, soil moisture, groundwater change, agricultural applications, and climate and ecological impacts on water resources. The program has experienced multiple successful inter-agency interactions with World Bank, WHO, USGS, USAID, USDA, NOAA and USACE. The key questions/challenges that the program currently addresses are

Drought (*How do droughts affect water and food security from local to regional to continental scales?)*

Agriculture (*What are the feedbacks between agricultural management practices and regional hydrology? What factors determine resiliency to climate extremes?)*

Water Availability (*What are the water requirements for uses – such as agricultural, urban, residential, energy, and ecosystems?*)

Water-related Extremes (*What are the impacts of floods on water resources? What spatial and temporal scales are needed to support post-flood assessments?)*

Water Quality (*How does water quality limit water availability? How do we effectively track (and mitigate/minimize) water pollutant impacts on source water, environment, and health?*)

Climate and Water (*How will climate impact water availability for societal needs and how do we plan accordingly?)*

## FUTURE PLANS

In the coming decade, the water resources program aspires to address the following challenges in various water related sectors:

Agriculture: By 2027, the program will be able to give guidance on topics of societal relevance include monitoring water use, water resource quantity and quality, monitoring crop water and nutrient stresses, supporting decision-making associated with allocation of water resources to competing uses, and increasing resiliency to climate stresses.

Floods: By 2027, the program hopes to improve the precision of information on flow, stage, and timing of the peak and length of the recession limb for streamflow hydrographs significantly better than what is possible today. The cost of a false warning versus the cost of no warning will be better understood from an economic standpoint.

Water Quality: By 2027, the water resources program will be able to provide guidance on the protection of ecosystems and better manage water availability and water quality, given changes to the water cycle caused by human activities and climate trends. The program will have built advanced capabilities to monitor, predict, and constrain changes in water quality and availability

## PANEL DISCUSSION

The panel started by discussing the changing dynamics of water availability (surface water) that is mostly dictated by human decisions to rapidly develop a region. The developing world is currently seeing an increasing rate of construction of surface water regulation structures in the developing world, with implications on energy, agriculture, flood control, water supply, and ecosystem function (often negative due to reduced river connectivity). In particular, current evidence seems to indicate that Southeast Asia and East Africa are the two regions that will witness the most make over by human activity in water availability and impact on other sectors. The strong pressure to economically develop a region in the less developed world renders physical models simulating the natural movement of water inadequate. Models must assimilate Earth observations on how water is moving due to decisions made by humans and national priorities. The panel was alerted to a rapidly changing situation in the 21$^{st}$ century where such observations from space on water cycle will become increasingly valuable for decision-making involving water resources development.

It was noted that in East Africa, where predicting water availability is key for increasing agriculture and irrigated lands, capacity building using Earth observations can benefit from asking stakeholders to identify the top three water-related decisions they need to make. In addition, asking stakeholders to identify the precision of information required and the approach currently in use helps in contextualizing the societal applications. It has been noted that asking such questions helps prioritize how capacity building tools should be developed in co-production with water agencies. The panel noted that clear communication between supply and demand requires simplification of technical terms and speaking a language of decisions and impacts of using Earth observations. For example, in developing regions, information on uncertainty and probabilities often needs a 'watered down' approach and the level of technical information provided depends on the inherent skill set and education level of the end user. It appears that the community has not quite figured out the best way to engage engineering consulting firms that often deal with water in capacity building of Earth observations. It may be worthwhile to draw from successful applications of engagement with western US agricultural private sector stakeholders (PI Forrest Melton) and explore ways to globalize the model. Although building trust and personal relationships is an issue that applies to almost any theme, the panel noted that it is key to enabling societal applications with Earth observations, particularly in relation to water, which cross-cuts many themes (food, energy, ecosystem services).

To build better capacity internationally, the panel suggested that it is worthwhile to use a basin approach to understand how stakeholders view water quantity and quality. Showing the change a basin has undergone in water availability (e.g., 20 years ago and present, say for the size of a lake or river network) presents a very compelling story to stakeholders and brings them on board to use EO data to identify drivers of change. This consequently opens the way for buy-in and co-produced capacity building tools. The panel noted that, in regions such as Africa, it is worthwhile to understand the cumulative impact of past, current, and future decisions. For example, demonstrating the aggregate impact on water demand of 200 farmers practicing diverse crop growing practices is more convincing to a community than showing the stand-alone effect of individual practices. The capacity building community needs to find ways to convey this information effectively to emphasize the value of Earth observations.

The panel also discussed the best ways to achieve NS's 2027 vision of Capacity Building program, using water as an example ('by 2027, users should know the nearest source to safe drinking water'). For example, *how can the suite of recent and anticipated water missions (SMAP, SWOT, GPM) be brought into action to address this grand challenge vision of capacity building?* The panel noted that the NASA Applied Sciences early adopter program was key to achieving this vision. Currently the early adopter programs are single-mission oriented. It may be worthwhile for the community to explore multi-mission early adopter programs that address mission interactions or the 'compound eye,' taking advantage of the combined observational power of satellites. Speaking of the compound eye, the panel felt that the best starting point for an Earth observing data platform for all things water could be GIOVANNI (version 4.0), which is maintained at NASA Goddard. In closure, the panel noted that almost all philanthropic foundations have water as a cross-cutting theme as 'water is life'. *So how can NASA engage with them better to have a multiplier effect on the use of Earth observing data using water as the underlying theme?*

## SUMMARY FOR DECADAL SURVEY

### Key Questions

- *How do we bring greater awareness of Earth observations value/products to the water management community?*
- *How do we strengthen capacity of engineering private sectors 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 co-sponsors' 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 capacity building community should engage in pre- and post-analysis of water availability for shared water resources around the world in order to help users understand the value of Earth observations.
- The EO data community should support studies that explore the cumulative impact of various human decisions and sectoral communities (agriculture, energy, climate) on water availability using the combined observational power of satellites.
- To address the grand challenge of informing users on the nearest safe water drinking source, NASA should engage in partnerships with other space agencies and EO data organizations to build a one-stop data portal from Earth observing systems for water alone.
- Early adopter programs should evolve from a single-mission to a multi-mission format to take advantage of the combined observational power of EO satellites.
- The EO capacity building community should take advantage of water as the common underlying theme of many philanthropic organizations to engage in public-private partnerships to address water grand challenges of the future.

# AGRICULTURAL MANAGEMENT

## PANEL DISCUSSION

[Note: This session started directly with panel discussion as there is no agriculture management program per se under NASA Applied Sciences Directorate.]

On international perspectives, the panel noted that most African national ministries with a mandate for agriculture management insist on having uncertainty information associated with outputs on crop yield or productivity enabled through Earth observations. Furthermore, crop yield is a more preferred metric than productivity for decision-making. The panel was provided with an alternate definition of capacity building as follows: "*process of developing and strengthening the skills, instincts, abilities, processes and resources that organizations and communities need to survive, adapt, and thrive in the fast-changing world (Philbin, 1996*)." In Africa, the challenges to agricultural management can be summarized into two broad categories: (1) diversity of agriculture; and (2) lack of ground-truth information on crop yields to calibrate Earth observing based systems. Most farms tend to be 10 hectares or less with poorly demarcated fields and mixed crop growing practices. This makes it difficult to distinguish between various cultivated crops using Earth observing data. In South Asia, use of gravimetry-based Earth observing systems for groundwater monitoring appears to be ripe for capacity building due to overuse and long time periods required to survey groundwater resources. For example, in the Indus river basin, it can take up to 10 years for the Pakistani Government to build a ground network for monitoring groundwater levels and assess available stock, and then use the system in decision-making for agricultural management. As a result, the Pakistani Government has found GRACE as an effective platform for cost-effective decision-making on changing patterns of groundwater stocks. In some places, there are success stories of improved agricultural management through sustained (decadal scale) external support provided. For example in the food insecure regions of northern Ethiopia, soil and water conservation methods across basins have resulted in re-greening, rise of water tables, reduced sediment load in rivers, and increased agricultural productivity – many of which were enabled through the use of remote sensing data.

The panel pondered how to leverage the intimate capacity building overlap between water and agriculture sectors given that water is essential to growing crops. Thus a nexus approach to capacity building (engaging in capacity building of water and agriculture together) should have a multiplier effect with huge human dimensions. In fact, the NASA water program engages in such a nexus-approach with limited foot print in the United States. The panel noted that a study on the cumulative impact of forecasting flooding on agricultural yield would help build better capacity across themes. It is not yet clear how stakeholder agencies perceive this food-water nexus and identify gaps in observation and capacity to explore the implications of one resource on the other. The panel noted that agricultural management decisions are made on longer timescales (monthly to seasonal for planning; decadal for food security). Thus longevity in mission continuity is considered essential (for example with GRACE and GRACE-FO). LF noted that since the exploration of this nexus issue (on the cumulative impact of water availability forecasting on food production) has great potential humanitarian benefit, the scientific community should suggest this as a research problem. The panel noted that before determining entry points for promoting Earth observations for capacity building, it is important to (1) identify the specific type of agricultural system (industrial, urban, or community agriculture) and (2) understand existing capacity in regard to that system. Each type of agricultural system has unique management practices that must be taken into account before attempting to raise capacity for ingesting EO data. Recent work has shed light on the food and water nexus from a conventional (non-Earth observing system) standpoint that is worth exploring (such as outlined in the book *Water for Food, Water for Life*, compiled by David Molden currently Director General of International Center for Integrated Mountain Development-ICIMOD).

One capacity building gap the panel identified for agricultural management is the understanding of tradeoffs between agriculture and carbon management. *How do agricultural and forest management decisions to produce food (under pressure or under normal development stress) impact carbon management?* The panel noted that agriculture often gives way to rising urbanization, thus changing the regional food distribution network. The panel also identified engagement with seed production community as a weak link and stated that the EO community could guide provide guidance in producing more drought-resistant seeds. How can the implications of climate change on food production be better communicated to the seed production community to enable better adaptation? Agencies like IRRI (International Rice Research Institute) have been engaged in developing a wide variety of seeds resilient to changing climatic and local environmental conditions; this has consequently helped address the growing food demand. The panel asked if remote sensing could potentially detect or inform stakeholders on pest prevalence in crops, a common development issue in many countries. It was noted that a better outreach program to engage entomologists and collaborate accordingly would be a good strategy. In addition, hyperspectral data from HysPIRI could potentially address pest prevalence in agricultural lands. The CGIAR labs around the world that engage in seminal research on food should be more closely engaged with the community of Earth scientists. A good example is the International Food Policy Research Institute.

## SUMMARY FOR DECADAL SURVEY

### 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 Earth observing-based agricultural management?*
- *How do we measure progress/success of applications of agricultural management, particularly in the developing world?*
- *How can Earth observing 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

- The EO capacity building community should explore effective ways to scale up inter-seasonal to inter-annual forecasting applications involving water availability and food production and promote the necessary research to close the gaps in understanding use of Earth observing data.

- The EO data community should create programs that can forecast agriculture growth before it happens and enable better proactive decisions on necessary infrastructure required to support the anticipated growth.
- Fundamental research is required on the utility of Earth observations for predicting pest prevalence and guiding the production of climate change resilient seeds.
- Investigations on the impact of agricultural expansion on climate has been a missing piece that should now be explored for future adaptation policies.
- NASA and other EO data organizations should foster greater strategic collaboration with regional and global research laboratories towards building better capacity for agricultural management using Earth observations.

# EARLY ADOPTER PROGRAM AND MISCELLANEOUS ISSUES

## PANEL DISCUSSION

The panel witnessed an introduction to the NASA Early Adopter Program and the lessons learned from two recent Earth observing missions (SMAP and ICESat-2) by Vanessa Escobar (VE). The Early Adopters are a subset of the mission user community. The goal of the Early Adopter Program is to provide specific support to Early Adopters in pre-launch applied research to facilitate feedback on mission products pre-launch, and accelerate the *societal use* of mission products post-launch in a written, signed Summary of Activities (SOA). Figure 4 below represents the EA concept in principle.

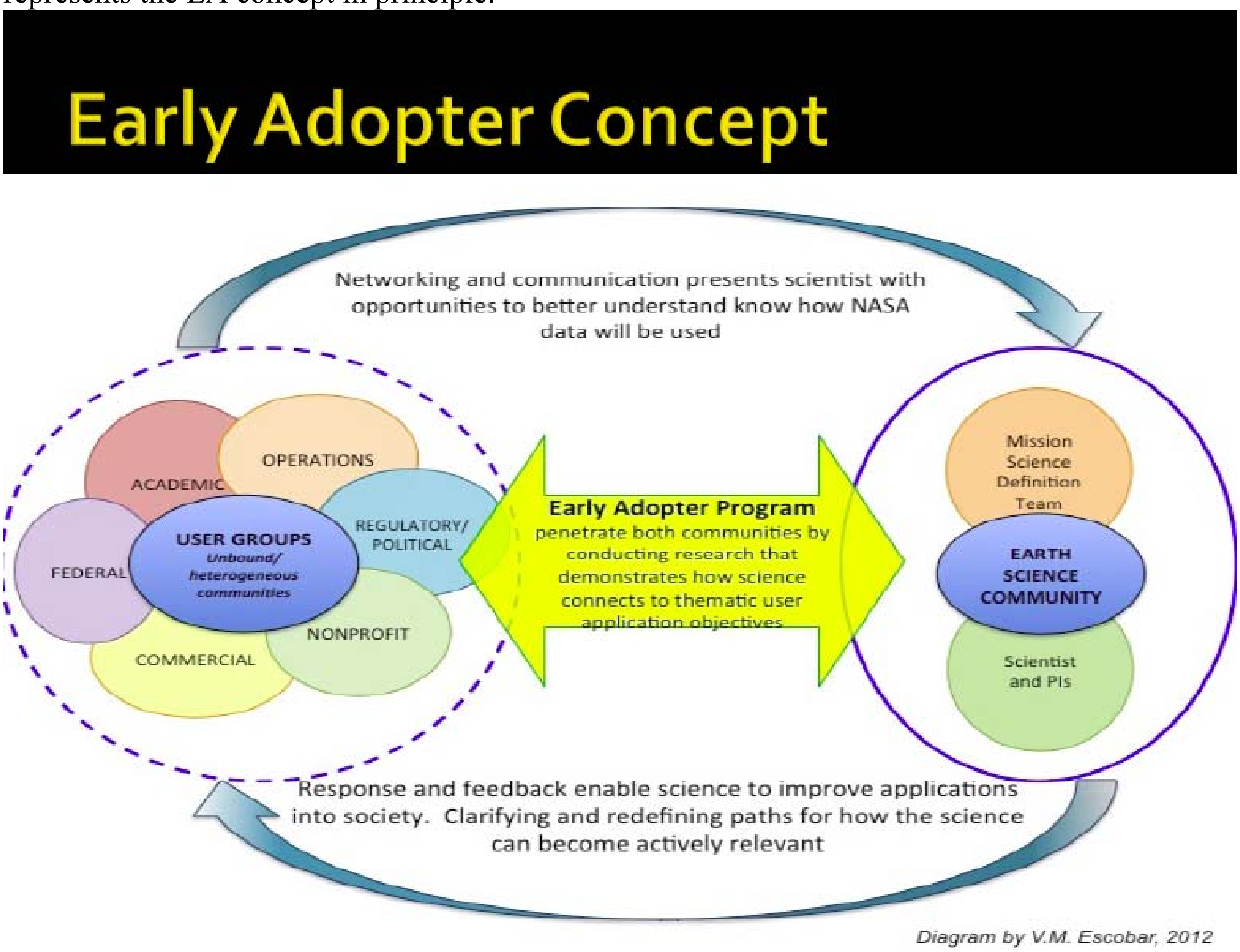


**Figure 4.** Interactions between science and application community through the early adopter program

As work statement, Early Adopters are responsible for the following functions

1. Engage in pre-launch research that will enable integration of mission data after launch in their application.
2. Complete the project with quantitative metrics prior to launch.

3. Join the Applications Team to participate in discussions of mission data products related to application needs.
4. Participate in the implementation of the Applications Plan by taking lead roles in applications research, meetings, workshops, and related activities.

In turn, the Project for the Earth observing mission provides the following functions:
1. Incorporate the Early Adopter contributions into the Applications Plan.
2. Provide Early Adopters with simulated data products via the SMAP Science Data System (SDS) Testbed.
3. and/or
4. Provide Early Adopters with planned pre-launch calibration and validation (cal/val) data from field campaigns, modeling, and synergistic studies.

To date two EA programs – SMAP and ICESat-2 – have kicked off for NASA AS, with SMAP having 54 early adopters. The feedback received has already impacted mission product science. Applications range from flooding, drought, and water management in the case of SMAP. For ICESat-2, there are 14 early adopters engaged in applications related to vegetation height, inland water detection, and monitoring of sea and ice. A key lesson learned from these EA programs was that future missions should limit early adopters to under 30 and engage in frequent quarterly exchanges of information. The panel raised the question about what is appropriate timing to launch an EA program for a future mission given that too early might lose stakeholder interest and right before launch might be too late to have a meaningful impact on data science issues. A good time for starting an EA program appears to be when the mission project has pre-beta or simulated datasets and a fairly clear idea on the range and possible structure of products. On the GPM application workshop (in post-launch phase), it has become clear that there is a need for a long, consistent precipitation record to bridge between precursor missions for many societal applications. The applications community for precipitation data has varying latency requirements and therefore early, late, and final (science-quality) products are useful.

**Miscellaneous Discussion Items**

The panel started a session wherein any important items left over from previous sessions were discussed. The discussion started with the topic of prioritizing the Tier 3 (from previous Decadal Survey) missions (see next chapter on ‘Group Activities’). The panel noted that it there is always a trade-off between the need to continue with new research and the need for making new observations. The panel recognized the need to prioritize several cross-cutting themes for capacity building, with “water and food” taking priority. Even though cross- disciplinary capacity building may require a steep learning curve, the panel recognized that it is worthwhile in the long run to making a lasting impact on society.

**World Energy Issues**

Sometimes the scale of relevance may help prioritize how to design capacity building approaches. For example, energy dependence (fossil fuel) is a global issue while water dependence is a local issue. Thus a question was raised about whether NASA has a capacity building role to play using Earth observations for energy markets. The private sector company called 3Tier (recent bought over by Vaisala) engages in the use of models and Earth observations for green energy production. Currently, there appears to be no activity within NASA that addresses the energy grand challenge. Recognizing that energy has cross-cutting implications (hydropower, burning of charcoal for cooking leading to deforestation), it appears that energy-relevant activities should be considered for the next decadal survey. LF noted that NASA Applied Sciences once did have an energy program several years ago but that it was decommissioned due to lack of sufficient proposals and expertise. It may be time to revisit the program and revive it for the coming decade.

**New ways of Soliciting Capacity Building Proposals for NASA**
The panel engaged in a very lively discussion on new and more efficient ways to solicit game changing ideas on capacity building through Earth observing systems. Although the traditional NASA ROSES solicitation is unlikely to be changed anytime soon, the panel asked if proposals could actually be developed in a co-production mode with stakeholders as accompanying PIs rather than just providing a simple support letter. The current PEER process managed by the National Academies does not necessarily enable this idea. LF encouraged the community to suggest new ideas for testing (for example, *SharkTank*, *applicationmatch.com*, or the *Apprentice* (the TV show). The decadal survey could benefit from having a recommendation on trying out newer approaches for proposal solicitation to globalize capacity building of EO systems and data.

The panel suggested that NASA could learn from some approaches that allow a 'preproposal' test with modest funding to manage risks in the initial stages. The USAID DiV program engages in such a tiered approach where the first tier does not require a detailed proposal. The panel also noted that proposals should be sponsored such that not everything has to be 'figured out' early on; there should be a process to 'learn as you go' or 'exit as you fail' while executing capacity building proposals. This 'learn as you go' approach could reduce overhead, precious funding, and paperwork in managing solicitations and making dynamic management decisions based on 'real-time' project conditions. NASA could also emulate the Gates Foundation model which, in line with the USAID DiV program, has its highest risk tier (the first tier) of proposal requiring only 2 pages of write up in a blind carbon copied manner. The proposal receives a call for greater information in writing or interview if any one of the four reviewers finds the ideas game changing enough to warrant more details.

The panel mentioned the NSF approach of soliciting proposals on nexuses. Examples include Coupled, Natural and Human (CNH), Water Sustainability Climate (WSC), and Sustainability Research Network (SRN) calls. There was no convincing argument on why or how that would be a good model for NASA to follow as capacity building was the focus. An approach suggested by the panel was to develop a venture that builds a nexus and brings experts from diverse and cross-cutting disciplines together. This group would then be invited to meet and develop a joint concept leading to a proposal. The funding provided would be for travel and not for labor.

**Encouraging New and Young Talent**
A discussion was started on how the community could make the career of pursuing capacity building through Earth observing systems an attractive choice early on as a profession. The panel recognized that it was important to reduce turn over and increase production of young talent who can carry on the work more effectively as future leaders. NASA Applied Sciences has encouraged fellowships under Earth science and expanded it in past few years, but it has not

been a broad scale program. Currently there appears to be no equivalent to the NASA New Investigator Program (NIP) tailored exclusively for applied sciences and capacity building for young academic professionals. On the other hand, there are several short term opportunities for student internship and trainings co-funded by NASA, including by SERVIR. It was noted that it is likely to become easier to involve youth as regional hubs for the SERVIR project move into a 5-year USAID funding cycle. Some panel members noted that the key to development of future leaders is collaborating with universities and involving professors (young faculty) who are developing curricula. Google appears to be replicating the USAID model (used in lower Mekong) of providing young faculty with curriculum and training them how to teach it. The Department of Education has Graduate Assistance in Areas of National Need (GAANN), a program in place for many years that funds the creation of a cohort of PhD students working as a team on a topic of 'national need'. The goal is to produce not just outstanding scientists but also educators who can train the next generation workforce based on demands of the economy and challenges. Such a model is worth investigating by NASA Applied Sciences.

The panel highlighted the Mesoamerica experience, such as in Guatemala, where students, have to complete 'apprenticeships' in the real world before completing a thesis for graduation. This is analogous to many engineering programs in the US and abroad requiring a Co-Op or doctors requiring residency. Such real-world exposure while the student seeks a degree makes knowledge on Earth observations societally more relevant than what a 10 week or short-term internship program can afford. Many members of the panel noted that the numerous outreach and training workshops for youth organized by NASA did indeed have a lasting impact on choosing the pursuit of capacity building through Earth observation as a profession. Another idea suggested by LF with a view to developing business models was to create degree programs sponsored by NASA where student fellows are required to spend a certain number of credit hours in a business school learning the art of designing business models.

## SUMMARY FOR DECADAL SURVEY

### Key recommendations

- NASA should explore more efficient and outside the box approaches to seeking solicitations that encourage more capacity building projects for Earth observing systems and data. Such approaches could be
    - Degree-seeking student fellowships with business schools
    - NIP equivalent for young faculty wishing to invest more effort in applications
    - GAANN equivalent for building a cohort of PhD students who will become master educators and researchers in academia with a strong sense of building applications
    - Tiered approach to risk management in proposal execution (like USAID DiV), where all the details don't have to be known before proposal, and continuation of a project is based on dynamic management of project outcomes
- Given the increased awareness of renewable energy and energy markets, NASA should revive a program on energy applications of Earth observing systems.

- NASA should create more cross-cutting programs such as food-water and water-energy where communities from different disciplines can converge to jointly address cross-disciplinary topics that require a steep learning curve. The payoff for such programs is expected to be great for society.

- Early Adopter programs should consider multi-mission interactions to enable the leveraging of combined observational power of Earth observing systems.

# GROUP ACTIVITIES FOR DECADAL SURVEY 2017-2027

## PRIORITIZATION OF FUTURE MISSIONS (TIER 3 OF 2007 DECADAL SURVEY)

LF initiated a prioritization effort of Tier 3 missions that had not yet been planned in the 2007-2017 timeframe. The entire panel was involved in a voting process based on (a) initial selection of Tier 3 missions considered important; (b) hearing feedback from members on their most important missions; and (c) re-prioritization of the Tier 3 missions based on feedback received from (b). This exercise was designed to assist the NRC Decadal Survey 2017-2027 panel in deciding the important left-over missions that would need to be implemented during the 2017-2027 time period. The underlying theme for prioritization was societal applications.

The list below provides the ranked missions in Tier 3 in order of highest priority in terms of highest number of panel votes.

| | |
|---|---|
| HyspIRI | 18 |
| LIST | 15 |
| PATH | 12 |
| GRACE-II | 11 |
| ACE | 8 |
| GEOCAPE | 8 |
| SCLP | 5 |
| ASCENDS | 4 |
| GACM | 1 |
| XOVWM | 1 |
| 3D Winds | 0 |

HyspIRI was clearly a popular choice given its game changing ability while maintaining continuity of Earth observations for land and resource management in addition to LANDSAT. LIST was next most important as the panel recognized the need to upgrade the currently 15 year old SRTM DEM model that does not suffice for many societal applications. GRACE-II, with its clear societal application for groundwater, surface water, glacier mass balance and the availability of GRACE-FO, was ranked closely with PATH. The panel recognized the unique value of PATH in providing more accurate and 24/7 precipitation and weather information through new technology development that allows the use of microwave sensors in geostationary orbit.

## PRIORITIZATION OF FUNDING BREAKDOWN FOR NASA

Another group activity led by LF was on panel feedback (vote) on the percentage breakdown of budget allocation for flight and non-flight activities. The panel also provided feedback on the percentage break down for new and continuation missions, technology development, research and analysis and applied science programs. The table below provides the summary of panel input where a significant jump in applied sciences share for NASA budget can be observed.

| | Flight | | Non-Flight | | |
|---|---|---|---|---|---|
| Average | 56.63 | | 43.89 | | |
| Std Dev | 13.98 | | 15.00 | | |
| Min | 30 | | 20 | | |
| Max | 80 | | 70 | | |
| | New | Continuation | Technology | R&A | App Sci |
| Average | 41.53 | 58.47 | 28.84 | 37.84 | 33.32 |
| Std Dev | 16.10 | 16.10 | 9.00 | 11.60 | 10.14 |
| True Fractions | 23.52 | 33.11 | 12.66 | 16.61 | 14.62 |

## FUTURE PRESS RELEASE WISH LIST FOR 2017

The last group activity conducted at the workshop was on soliciting panel feedback on the top three items participants would like to see explicitly mentioned in the 2017 Decadal Survey Report. The first entry below is a sample press release listing possible items for mention. Other suggestions by workshops participants follow.

--------------------

*July 24, 2017*
*Washington, DC*

*Today, the National Academy of Sciences released the 2$^{nd}$ Earth Science Decadal Survey. Key highlights reflecting consensus priorities of the community include*

1. *Improving knowledge and skill on water consumptive use globally to locally provide a key research objective by 2027 with concomitant benefits for freshwater availability and water resources management.*
2. *By 2027, skill in local to regional forecasts of vector-borne and water-borne diseases, such as cholera and malaria are top priority to blend climate projections with near real-time health management practices incorporating research advances and major societal benefits.*
3. *Non-flight portion of ESD should emphasize grater basic research focus within R&A as well as higher percentage budget for Applied Sciences, especially to expand the applications portfolio to include energy management, agriculture, transportation, national security, and carbon management. Capacity building is a key way for US to achieve humanitarian benefits in these areas and enable international contributions and in-situ data to global Earth science research.*

------------------------

*Earth observing data products need to have wider outreach to diverse communities in order to accelerate cross-cutting application studies.*

---------------------------

*The SERVIR project must be sustained to enable health management around the world.*
*Better coordination among agencies is required for disaster management.*
*NASA should build capability to respond quickly but with clearly defined exit strategy for disasters based on immediate humanitarian needs.*

-----------------------

*Water-borne diseases should have more emphasis. NASA Applied Science needs to move away from the bias in vector-borne disease.*

*Freshwater access directly affects water and sanitation and human health. That emphasis should reflect in not just health but in freshwater text as well,*

*Public health should be more cross-cutting among the three themes – water, health, and disasters.*

-----------------------

*Community needs to develop clear linkages between environmental conditions and human health,*

*Applied Sciences program should transition from a data collection to an application enabling framework.*

*There needs to be greater support structure to foster co-production of societally relevant applications jointly by science and stakeholder communities.*

-----------------------

*Monitoring needs to be linked to a chain of actions and decisions in Applied Sciences.*
*Disasters: Early warning vs post disaster management. Operational satellites should be for post disaster management and to support applications.*

*Applications should be paired up with decision needs and monitoring requirements.*

-----------------------

*NASA should maintain satellite observations that support research and observations to address climate change adaptation (such as preparing for extreme heat events).*
*NASA should develop incentives to motivate the private sector (commercial interests) to develop applications and maintain satellite operations.*
*NASA should ensure that application development addresses end user needs and has a measurable impact on society.*

-------------------------

*Freshwater should be a priority issue for NASA in the coming decade greater resources need to be allocated to ensure its accessibility worldwide.*
*NASA should pursue a constellation approach to take advantage of the combined observational power of multiple platforms.*

*Matchmaking between supply side of Earth scientists and demand side of stakeholder entities must be facilitated through NASA efforts to make Earth observations more meaningful.*

--------------------------

*What are the impacts of a changing climate on health and air quality?*
*What are the strategies to address sustainability of observations?*
*What enabling technologies are on the horizon and how can they be prioritized?*

-------------------------

*Introducing graphical things to reach the layman user.*
*Discussion about who will be the beneficiaries of NASA missions or who will be the key contributor.*
*Greater application of remote sensing in the health sector.*

------------------------

*NASA should streamline NRT data delivery.*
*NASA should address multi-scale, multi-temporal information availability for applications.*
*NASA should assess the real impact of mission data for disaster response.*

-----------------------

*Health and Air quality topics are of great importance.*
*Health has implications on several key societal needs.*
*Disasters are multifaceted and there is a need for a variety of Earth observations. Radars and microwave should now play a greater role in disaster response.*

-----------------------

*Applications for societal benefits should have a renewed interest in the Decadal Survey.*
*There should be a balance between application-focused and research-focused satellites.*
*Operational application missions should have long term sustainability.*

---------------------

*MODIS should have a continuity mission.*
*Health applications should get to the people that implements health policies and actions.*
*What types of disasters will have a different treatment from NASA in terms of agility of response needs to be identified a priori so that first responders know what to expect from NASA.*

-------------------

*NASA requires the SAR equivalent of LANDSAT with global, consistent and repeat coverage for detecting land deformation on a routine basis.*
*Resolve aerosols at urban and transnational scales through fusion of geostationary sensors.*
------------------

*NASA needs to facilitate data sharing agreements and activities among agencies as part of disaster response.*
*NASA needs to partner with 'boots on the ground' agencies to support public health challenges. (Boots on the ground – NIH, USAID, Red Cross).*
*Important variables for water/public health/disasters include good water quality products.*
--------------------

*How can we leverage NASA Earth observing systems to address UN Sustainable Development Goals (SDG)?*

*How are we improving the quality of life by using NASA satellite data?*
-------------------------

*NASA should develop missions to better characterize aerosol constituents.*
*NASA should develop missions to better characterize urban scale (~ 100 m) land surface and air temperatures for supporting public health warnings related to excessive heat.*
*NASA missions should provide surveillance of hydrologic systems for flood warnings.*
-------------------------

*The Health community should focus on providing risk/vulnerability maps for infectious and vector borne disease driven by climatic change from seasonal to decadal time series*

*The role of NASA in addressing disasters needs to be clearly defined. How is the capacity that is being built for disaster response enabling better response in future?*
*The disaster community should prepare risk/vulnerability maps for each disaster driven by climate change from seasonal to decadal time series.*
-----------------------------------

*What is the role of NASA in responding to disasters? When is the response 'enough'?*
*How are indicators of health delated to each other?*
*What are the opposite scales or data that responders need to make decisions?*
----------------------------------

*Is there a place for applications missions and flight missions with applications as their primary goal?*
*Constellations for quicker revisits.*

-------------------------------

*NASA should emphasize the need for international collaboration and coordination among missions.*

*NASA should consult application communities during mission development/formulation to define latency requirements.*
*NASA should foster capacity building bridge to scientists needs and should elevate the importance of capacity building to the science community.*

---------------------------------

*NASA should focus on sustainable development goals, data formats and geospatial technologies for final information products.*
*NASA should leverage existing resources and build on existing efforts.*
*NASA should focus on building long-term time series of environmental and geophysical conditions.*

-------------------------------

*NASA should focus greater attention on floods and Earthquakes.*
*There needs to be more capacity building in developing countries.*
*SAR data should become freely available and new satellites should be built accordingly.*

------------------------------

# BIBLIOGRAPHY


Chowdhury, A. M. R., Bhuyia, A. U., Choudhury, A. Y. and Sen, R. (1993). The Bangladesh Cyclone of 1991: Why So Many People Died. *Disasters*, 17, 291–304. (doi: 10.1111/j.1467-7717.1993.tb00503.x)

Daniel Sarewitz, Roger A. Pielke Jr. (2007). The neglected heart of science policy: reconciling supply of and demand for science. *Environmental Science & Policy*, 10, Issue 1, February 2007, pp. 5-16.

Hamill, T.M. (2014). Performance of Operational Model Precipitation Forecast Guidance during the 2013 Colorado Front-Range Floods. *Mon. Wea. Rev.*, 142, 2609–2618. (doi: http://dx.doi.org/10.1175/MWR-D-14-00007.1).

Hossain, F. (2015). Science, science everywhere, nor any drop to drink, *IEEE Earthzine,* Op-Ed (February 10). (available online: http://Earthzine.org/2015/02/10/science-science-everywhere-nor-any-drop-to-drink-three-solutions-for-an-outdated-system/; last accessed June 10, 2015)

Maswood, M., F. Hossain (2015). Advancing River Modeling in Ungauged River Basins using Remote Sensing: The Case of Ganges-Brahmaputra-Meghna Basins. *Journal of River Basin Management*, (In press).

Morens et al. (2004) *Nature paper on disease*

Hossain, F. (2012). Do Satellite Data Portals Today Reach Out To Diverse End Users around the World? *Bulletin of American Meteorological Society* Nowcast Article, (doi: 10.1175/BAMS D-12-00035.1).

Paul, B.K (2009). Why relatively fewer people died? The case of Bangladesh's Cyclone Sidr, *Natural Hazards,* 50(7), 289-304.

Philbin, A. (1996) Capacity Building in Social Justice Organizations. Ford Foundation, New York, New York; 1996. *Capacity Building in Social Justice Organizations*

Rose, R.A. et al. (2014) Ten Ways Remote Sensing Can Contribute to Conservation, *Conservation Biology*, (doi: 10.1111/cobi.12397).

Wood, E. F., et al. (2011). Hyperresolution global land surface modeling: Meeting a grand challenge for monitoring Earth's terrestrial water, *Water Resour. Res.*, 47, W05301, (doi:10.1029/2010WR010090).

# APPENDIX – PANEL INPUT ON DECADAL SURVEY GRAPHICS

**Health and Air Quality**

- A girl skipping is not as representative of the mission and vision of the HAQ program. The panel suggested that a hospital (with cross and crescent sign), ambulance and the standard be shown on the general graphic.
- Showing smoke (black smog) and cloud as well as different colored atmosphere would also represent the air quality aspect of the HAQ program.
- Showing also some microbial presence could help the public form a better understanding of what exactly the HAQ program is about
- For the technical graphic SE (Sue Estes) and Bill Crosson's presentation has several ideas that could be used as starting points to show the 'Compound Eye' concept to a visionary (2027) approach to where the HAQ program wants to be.

**Disaster Management**

- Add a building collapsing under the wave
- Whale shouldn't be in the picture on disasters (whale could be made smaller for Ecosystem Function).
- Add a volcano or something dynamic showing a disaster in progress (such as a burning building).
- The graphic should show people who need information for disaster management
- The shape of a gear under water should be taken out.
- Add a question – what theme might satellites also be useful for, e.g. terrorism, conflict?
- For technical graphic –a suggestion is to show a suite of satellites in one column, a suite disaster type in the middle column and a suite of scales on the far right column – all integrated in the form of a neural network looking structure. Another suggestion is to show how the different satellites and other Earth observing systems (from other agencies) 'came together' in responding to Nepal Earthquake.

**Ecosystem Function** – start from graphics available in presentations in that session

**Water Resources:**

- Show mountains with snowpack, rivers, lakes and a dam on the water pie of the slogan graphic
- For a cross-cutting theme on how multi-platform satellites can help in agriculture and water resources, an infographic showing how satellites help in quantifying consumptive water use for irrigated agriculture was shown.

**Agricultural Management**

- Feedback was provided on a technical infographic on agriculture-water nexus showing how different EO systems work in tandem as Compound Eye