Using Earth Observations to Enhance Water Resources Decision-making and Disaster Assessment Processes in the United States and the Developing World

An overview of water-related projects within the NASA Applied Sciences Program

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***Abstract*—This paper provides an overview and discussion of water-related Applied Sciences Program (ASP) activities within the National Aeronautics and Space Administration (NASA) Earth Science Division. These activities seek to enhance decision-making processes that relate to water resources and disaster assessment in the United States (U.S.) and abroad. We evaluate the various approaches that are employed to improve the utility of and access to Earth observations in decision support for water challenges; in particular, we consider the development of applications and activities that strengthen capacity to use these applications. Applications include products like maps, decision support system improvements and tools, and related services. This paper also identifies potential next steps for continuing to facilitate a coordinated water strategy amongst the Applied Sciences Applications Areas and the ASP Capacity Building Program.**

Keywords— applied sciences, capacity building, decision-making, disasters, Earth observation, end users, flooding, NASA, remote sensing, satellite, water resources

I. INTRODUCTION

The NASA Applied Sciences Program (ASP) sponsors numerous activities that aim to strengthen the capacity of end users to utilize Earth observations-based tools in decision support or analysis of management practices. These activities are typically based within specific ASP applications areas, such as the Water Resources Program and the Disasters Program. Generally, projects that are based within an Application Area (AA) trend towards developing an application based on end user needs identified by the specific project Principal Investigator (PI), with the ultimate goal of transitioning that application to the end user. The Capacity Building Program, which is another component of the NASA ASP, supports activities that focus on improving the capacity to use Earth observation tools as a first tier priority, and includes applications-based projects that co-develop science applications with developing country partners. The Capacity Building Program also includes projects that target and engage end users in the U.S. through various mechanisms to be discussed.

This paper characterizes the ASP approach to addressing water resource management and disaster assessment challenges by examining a subset of projects from within the Water Resources, Disasters, and Capacity Building Program portfolios (Fig. 1). The common theme across this cross-section will be water, and this paper will also discuss water as a domestic and global challenge. The Applied Sciences Program addresses multiple water-related challenges by supporting and engaging projects through various program areas.

II. WATER-RELATED PROJECT PORTFOLIOS WITHIN THE NASA APPLIED SCIENCES PROGRAM

A. NASA ASP, Water Resources Applications Area

The Water Resources (WR) Portfolio consists primarily of project teams teams competitively selected through the NASA Research Opportunities in Space and Earth Science (ROSES) proces. The portfolio is focused on developing applications with a single partner and is primarily based in the U.S. However, the program has supported some projects that have a global or international geographic extent, often as a piece of a larger, interagency, or multilateral activity. The most common subthemes within the WR program are groundwater monitoring, agriculture, drought, and snow/runoff assessment.

B. NASA ASP, Disasters Applications Area

The Disasters Portfolio also consists largely of projects that develop applications, with many of them being based in the U.S. The Disasters Portfolio spans numerous extreme hazards, including floods, fires, volcanic eruptions, and landslides. In keeping with the water theme of this discussion, we focus on flood impacts analysis and flood forecasting.

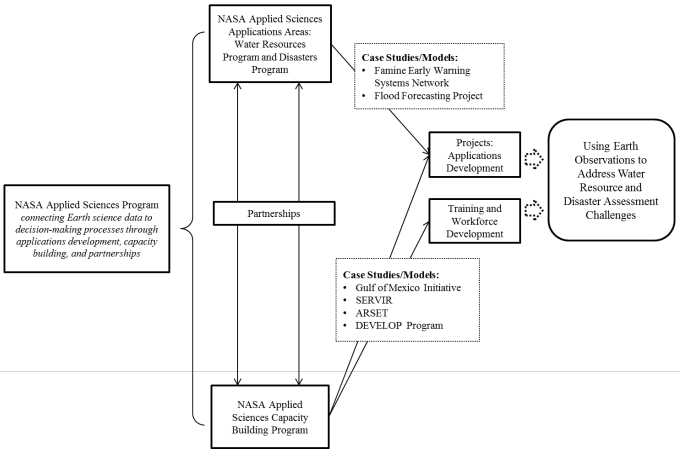

Fig. 1. The NASA Applied Sciences Program organization, with respect to the "water" societal benefit area.

C. NASA ASP, Capacity Building (CB) Program

The CB Program supports multiple societal benefit areas as defined by the Group on Earth Observation's (GEO) Global Earth Observation System of Systems (GEOSS), including disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity. The CB Program supports activities that strengthen the use of Earth observations to address water challenges at the program level and within the four major program elements:

- **Applied Remote SEnsing Training (ARSET):** increases utility of NASA Earth science and model data by providing training to decision-makers and applied science professionals in water resources and air quality areas.

- **DEVELOP:** supports young and transitioning professionals in working on applied science projects with NASA science advisors and end users.

- **Gulf of Mexico Initiative (GOMI):** addresses coastal management issues to enhance the ecological and economic health of the Gulf region.

- **SERVIR:** provides Earth observation data and science applications to help developing regions improve their environmental decision-making through a partnership with the U.S. Agency for International Development (USAID).

III. Projects within the NASA Appled Sciences Program Areas

The NASA Applied Sciences Program (http://appliedsciences.nasa.gov) Areas have supported multiple efforts to improve water management decision-making and disaster assessment. This paper will consider six different models or activities that have been employed or supported in the NASA ASP and relate to water.

A. *Project 1. Developing an application to improve disasters management. "Global Flood and Landslide Monitoring/Forecasting" Project, PI Robert Adler, University of Maryland. NASA ASP Disasters Program.*

1) Project Description: The most prevalent and impactful of natural disasters on Earth are floods and rainfall-driven landslides. To improve the ability of humanitarian aid agencies to respond to such events, PI Robert Adler and his team developed a Global Hazard System (GHS) that provides improved global information about floods and landslides and their impacts on people and property [1, 2]. Remote sensing data are input into hydrological models that provide estimates and forecasts of floods and landslides on a global scale. The primary goal of this project was to improve GHS for use by USAID, in support of their disaster response and mitigation activities around the globe.

2) Geographic Extent: Africa, Central America, Bangladesh

3) End Users/Partners: USAID, with partners World Meteorological Organization and the International Consortium on Landslides

4) Decisions Targeted: This project targets decisions that relate to managing disaster response and mitigation on a global scale, as administered by USAID.

5) Satellite Data/Assets Used: Shuttle Radar Topography Mission (SRTM), Moderate Resolution Imaging Spectrophotometer (MODIS), Tropical Rainfall Measurement Mission (TRMM), TRMM Multi-satellite Precipitation Analysis (TMPA)

B. *Project 2. Supporting an international, multi-agency effort to improve humanitarian response. Famine Early Warning Systems Network (FEWS NET) and "A Land Data Assimilation System for Famine Early Warning" Project, PI James Verdin, US Geological Survey. NASA ASP Water Resources Program.*

1) Project Description: The purpose of this FEWS NET activity was to integrate seasonal climate forecasts with livelihood indicators to improve food security outlooks and projections. FEWS NET (www.fews.net) aims to build capacity and consensus among partners with deliverables that include food security briefs for 25 countries and other decision support documents. The NASA WR Program supported the international program manager of FEWS NET, PI Jim Verdin of the U.S. Geological Survey (USGS), who has contributed significantly to the integration of Land Information System,

Rainfall Estimates, and other remote-sensing based data products [3, 4] into food security projections.

2) Geographic Extent: Africa, Central America, Haiti, and Afghanistan.

3) End Users/Partners: The primary target end user of FEWS NET products is USAID, which uses the products to improve planning and implementation of interventions to avert famine crises. Other partners and supporters of the program include USGS, NOAA, Chemonics International, and U.S. Department of Agriculture (USDA).

4) Decisions Targeted: Decisions that have been informed by FEWS NET include the following interventions: (i) assessing food insecurity variables that are non-food based; (ii) addressing food insecurity despite food interventions, such as chronic malnutrition of children in specific regions; (iii) provision of sustained food interventions; and (iv) market-based interventions, particularly for those who are market-dependent households, agricultural households, pastoralists, and agropastoralists. Urban food insecurity interventions were also considered.

5) Satellite Data/Assets Used: Landsat, TRMM, Advanced Very High Resolution Radiometer (AVHRR)/ National Oceanic and Atmospheric Administration (NOAA)-17, Special Sensor Microwave/Imager (SSM/I) on Defense Meteorological Satellites, and Advanced Microwave Sounding Unit (AMSU) on NOAA satellites.

C. *Project 3. Developing an application to improve water resources management in a southeastern coastal region. "The Use of Satellite Products to Improve Characterization, Delineation, and Mitigation of Drought" Project, PI Richard McNider, University of Alabama in Huntsville. NASA ASP Capacity Building Program, Gulf of Mexico Initiative, Lead: Curtis D. Armstrong.*

1) Project Description: As part of the Gulf of Mexico Initiative the project goal was to provide tools to improve the response and mitigation of drought in the Gulf of Mexico (GOM) Region, where row crop agriculture has been declining (http://gulfofmexicoinitiative.community.nasa.gov/home/asp-projects). This project used an array of satellite observations with improved spatial resolution to delineate the impacted area of drought and used gridded crop models to devise stress maps over time [5, 6] .

2) Geographic Extent: GOM/southeastern U.S. states

3) End Users/Partners: State Climatologists (Alabama, Florida), National Drought Mitigation Center, USDA National Agriculture Statistics Services, and USDA Natural Resources Conservation Service.

4) Decisions Targeted: Tracking crop evolution and drought impacts and expanding irrigation in the Southeastern U.S. sustainably.

5) Satellite Data/Assets Used: MODIS

D. *Project 4. Developing an application to improve flood forecasting in the developing world through SERVIR, a joint USAID and NASA project, in collaboration with regional partners. NASA ASP Capacity Building Program, SERVIR Project, Project Director and Scientist: Daniel Irwin and Ashutosh Limaye.*

1) Project Description: The SERVIR Project (www.servirglobal.net) is developing web-based tools based on science models like the Coupled Routing and Excess Storage (CREST) Model to assist developing countries in flood forecasting. The CREST Model was co-developed by NASA, the University of Oklahoma, the Regional Centre for Mapping of Resources for Development (RCMRD), and the International Centre for Integrated Mountain Development (ICIMOD). CREST helps visualize potential areas with high probability of flooding [7, 8], and this information can be used to help government ministries respond efficiently to these hazards.

2) Geographic Extent: East Africa and Bhutan

3) End Users/Partners: RCMRD and the SERVIR-Africa hub, the Kenya Department of Water Resources, and the Kenya Meteorological Department. ICIMOD and the SERVIR-Himalaya hub are working with the Department of Hydrometeorology in Bhutan, and SERVIR-Africa is working with the Namibian ministry to implement similar CREST-based systems in those regions. Related efforts supported by the USAID missions in East and South Africa may also benefit from the use of the CREST Model.

4) Decisions Targeted: CREST provides prediction for floods in East Africa to improve decision-making on water resources and food security with potential improved outlooks for agriculture, health, and ecosystems.

5) Satellite Data/Assets Used: MODIS, SRTM, TRMM.

E. *Project 5. Building capacity to use Earth observations through 10-week applied research projects. NASA ASP Capacity Building Program, DEVELOP Program, Lead: Michael Ruiz, NASA Langley Research Center (LaRC), with DEVELOP Mentors: James Favors, NASA LaRC, and Amber Kuss, NASA Ames Research Center (ARC).*

1) Project Description: The project entitled "Central Valley Water Resources: Downscaling Gravity Recovery and Climate Experiment (GRACE) data in the Central Valley Aquifer, California (CA)," conducted by the DEVELOP team (http://develop.larc.nasa.gov) at NASA ARC, focused on the application of NASA GRACE data to address water availability concerns in California's Central Valley [9]. Current management techniques do not include natural climate variability, such that water managers and farmers may be left unprepared for extended periods of drought. The team explored multiple methods of downscaling GRACE data and improvements to hydrological modeling, as well as methods to monitor change in groundwater availability due to natural variation (e.g., El Nino Southern Oscillation) to improve decision-making regarding total water storage monitoring.

2) Geographic Extent: Central Valley, CA, U.S.

3) End Users/Partners: CA Department of Water Resources.

4) Decisions Targeted: The project played a critical role in improving the CA Department of Water Resource's understanding and potential application of GRACE data to groundwater planning, assessment, and management efforts, with project results and methodologies incorporated into the California Water Plan Update 2013.

5) Satellite Data/Assets Used: GRACE

F. Project 6. Training water managers and other practitioners to be better enabled to access and utilize Earth observations in their decision-making processes. NASA ASP Capacity Building Program, ARSET Project, Lead: Ana Prados, University of Maryland.

1) Project Description. The Applied Remote SEnsing Training (ARSET) Project provides training and other capacity building activities to improve the capacity of decision-makers to utilize NASA Earth science and model data [10]. ARSET provides multiple types of training (http://water.gsfc.nasa.gov), including training related to water resources management and flood monitoring/forecasting. Training activities are conducted in two tiers; the first tier is a series of webinars, or an online course, that is primarily focused on exposure/awareness-level training. The second tier is typically a multi-day, in-person training that is intended to provide more focused and tailored training to users who are intermediate or advanced, based on their interests and needs.

2) Online course example: The ARSET Flood and Drought Applications Course was presented as a live webinar for one hour every week for five weeks, with occasional 'homework' exercises assigned during or after each lecture [11]. The course instructors were based at NASA Goddard Space Flight Center in Greenbelt, Maryland. However, because the course was presented online, participants from all over the world were able to attend and engage in the course. Webinar series are developed for remote sensing beginners and are intended to provide a picture of how remote sensing-derived tools could potentially be used in water resources management or disaster assessment. The lecture topics included: Data requirements for flood and drought monitoring - overview of NASA data from satellites, atmosphere and land models; Introduction to rain, temperature, humidity, and wind data; Overview of web-based tools for data access and imaging; Evapotranspiration (ET) data; and Case studies of floods and droughts over the U.S., Asia, and Africa.

3) Hands-on workshop example: The ARSET National Weather Center (NWS) Workshop Course. The National Weather Center at the University of Oklahoma in Norman hosted an ARSET course for water resources managers. This training addressed extreme rain event monitoring and flood analysis using TRMM and model and meteorological data from Modern Era Retrospective-Analysis for Research and Applications (MERRA). The course included case studies specific to drought and flooding in Oklahoma using the TRMM Current Heavy Rain, Flood and Landslide tool (http://trmm.gsfc.nasa.gov/publications_dir/potential_flood_hydro.html), Atmospheric Infrared Sounder (AIRS)/MODIS cloud cover, North American Land Data Assimilation System (NLDAS) soil moisture, and MERRA winds and humidity products. Participants learned how to access, visualize, and analyze NASA data to detect extreme weather and seasonal to inter-annual rainfall variability and associated effects on large-scale soil moisture and evapotranspiration over Oklahoma. Among the participating organizations were the Association of Central Oklahoma Governments, Oklahoma Water Resources Board, Oklahoma Department of Environmental Quality, Chickasaw Nation, USGS, and University of Oklahoma Center for Spatial Analysis.

IV. Discussion: Observations and Next Steps

A. Activity types across the ASP Water Portfolio include capacity building activities (training, workforce development) and development of applications (data products, applications, decision support tools) (Fig. 2).

Conducting this very general mapping exercise of how projects and activities are distributed across the ASP Water Portfolio reflects a gradient of activity type based on the CB program element or Application Area (AA, e.g., Water Resources or Disasters Application Areas). However, even with the limitations of this qualitative scale, when taken as a whole for the ASP Water Portfolio, this graphic illustrates the existing complementarity of CB and AA project approaches in the area of Water Activities. One of the primary commonalities between the CB and the AA Programs is the emphasis on *User Engagement (UE), though the approach to conducting UE may vary depending on the program element.

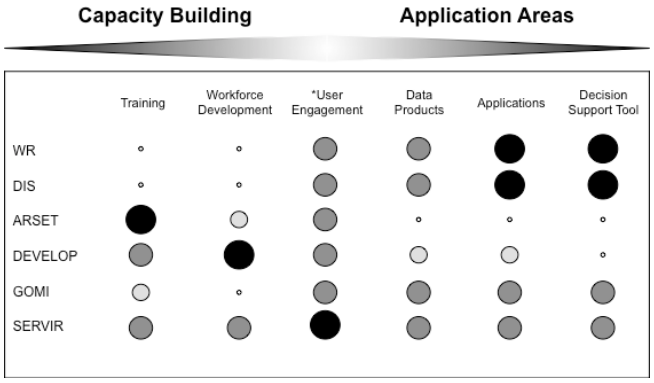

Fig. 2. Applied Sciences Program Water Activities comparison by program area: Water Resources (WR), Disasters (DIS), and the four main Capacity Building Program elements. Increased emphasis in a type of program activity is reflected by larger, darker circles. *Note that the approach to UE is not captured here, though the respective emphasis placed on UE activities is comparable.

B. *Geographic-focused Capacity Building Program elements emphasize end user needs and capacity to build and utilize EO, whereas Water Resources and Disasters Program projects are selected based on the best applied research to improve related decisions, with geography being a consideration.*

SERVIR, a Capacity Building Program element, focuses in international regions on needs identified by regional partner institutions in Central America, East Africa, and the Hindu Kush Himalayas. The Gulf of Mexico Initiative (GOMI) focuses in the Gulf region on needs identified by the five U.S. Gulf States. While not all the projects in the Water Resources and Disasters Programs were described here, each portfolio is supporting projects that address water-related issues and crises on a global scale, in the U.S., or within the developing world. We are working to overlay the geographic distribution of ASP Water Activities on top of the geographic regions SERVIR and GOMI support to continue identifying opportunities that would allow potential growth in the coastal and international Water Activities portfolio. These include, but are not limited to: (1) the opportunity to leverage existing in-country and State networks, and (2) the ability to expand to other target stakeholders. Analysis of the geographic locations of Water Resource and Disaster Program projects can identify possibilities for expanding end user engagement and reaching additional end users and partners.

C. *The Capacity Building Program elements DEVELOP and ARSET focus on developing workforce capacity.*

Unlike the other project examples, the objectives of DEVELOP and ARSET are to build awareness, provide training, and cultivate workforce capacity to use Earth observations for water-related analyses; here, applications development is an important but secondary emphasis. DEVELOP projects explore the feasibility of new types of analyses, pilot applications ideas, and commonly provide data products to end users, whereas ARSET provides training to access, visualize, and use water-related data and products. Each of these projects plays an important role in increasing awareness and capacity to use Earth observations within this and the next generation's workforce.

D. *Development of a cross-program water strategy that embodies and acknowledges the compounded challenge of working in a developing world context.*

A water strategy that continues to bridge relevant activities within the ASP Disasters, Water Resources, Capacity Building, and other program areas within the Earth Science Division would enhance and support the identification of synergistic efforts and opportunities in which the program can expand without duplicating efforts. The challenges associated with stakeholder and community engagement, project implementation, and resource limitations in the U.S. and in the developing world context underscore the potential benefit of continued improved coordination to address water-related stresses. As the strategy continues to evolve, the importance and added complexity of water nexus areas (energy, food, climate, and health) will be considered. Other ongoing activities to support this effort include mapping partners and boundary organizations, cultivating partnerships with entities that provide complementary expertise and skillsets, and investigating the possibility to develop joint programs with private sector and implementation-based organizations.

V. Conclusions

This paper provides a high-level assessment of the Water Activities Portfolio (projects that address water challenges through applications development and/or capacity building) within the NASA Applied Sciences Program. In doing this examination, we were able to visualize how the ASP Water Portfolio, comprised of the Capacity Building Program and the Water Resources and Disasters Application Areas, has a considerable distribution of activities, and that the CB and AA are highly complementary. For example, the CB Program's focus on capacity building activities (training, workforce development, long-term investments by geographic region) balances the AA approach that is more focused on building applications with and for specific end users. When taken as a complex whole (as the Water Activities Portfolio rather than as individual Programs, e.g., Water Resources vs. Disasters vs. Capacity Building), the reach and the approach of the Water Activities Portfolio for cultivating the capacity to use and the use of Earth observations for water-related decision support is extensive. These activities produce results that are intended to improve decisions related to managing water resources and predicting and responding to floods. An adaptable, coordinated water strategy could continue to strengthen our ability to address water issues in the U.S. and in developing nations using NASA's open and freely available Earth science data (https://earthdata.nasa.gov).

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References

[1] Y. Hong, R.F. Adler, F. Hossain, S. Curtis, and G.J. Huffman, "A first approach to global runoff simulation using satellite rainfall estimation," Water Resources Research , vol. 43(8), doi:10.1029/2006WR005739, 2007.

[2] W. Huan, R.F. Adler, Y. Hong, Y. Tian, and F. Policelli, "Evaluation of Global Flood Detection Using Satellite-Based Rainfall and a Hydrologic Model," Journal of Hydrometeorology, vol. 13(4), p. 1268, 2012.

[3] J. Verdin, C. Funk, G. Senay, and R. Choularton, "Climate science and famine early warning," Phil. Trans. R. Soc. B., vol. 360(1463), pp. 2155–2168, doi:10.1098/rstb.2005.1754, November 2005.

[4] J. Rowland, J. Verdin, A. Adoum, and G. Senay, "Drought Monitoring Techniques for Famine Early Warning Systems in Africa" in Monitoring and Predicting Agricultural Drought: A Global Study, Oxford UP, 2005, 496 pages.

[5] R.T. McNider, J. Christy, and J. Hairston, "Bringing agriculture back to water - a solution for the 21st century," Proc. AMS Forum: Living with a Limited Water Supply, Ann. Meet. AMS, 2005.

[6] R.T. McNider, J.R. Christy, D. Moss, K. Doty, C. Handyside, A. Limaye, A.G. Garcia, and G. Hoogenboom, "A Real-Time Gridded Crop Model for Assessing Spatial Drought Stress on Crops in the Southeastern United States," J. Appl. Meteorol. (JAM), vol. 50(7), pp. 1459–1475, doi:10.1175/2011JAMC2476.1, 2011.

[7] J. Wang, Y. Hong, L. Li , J.J. Gourley, K. Sadiq I., K.K. Yilmaz, R.F. Adler, F.S. Policelli, S. Habib, D. Irwin, A.S. Limaye, T. Korme, and L. Okello, "The coupled routing and excess storage (CREST) distributed hydrological model," Hydrological Sciences Journal, vol. 56(1), pp. 84–98, 2011.

[8] L. Li, Y. Hong, J. Wang, R. Adler, F. Policelli, S. Habib, S., D. Irwin, T. Korme, and L. Okello, "Evaluation of the Real-time TRMM-based Multi-satellite Precipitation Analysis for an Operational Flood Prediction System in Nzoia Basin, Lake Victoria, Africa," J. Natural Hazards, 2009.

[9] A. Kuss, W.T. Brandt, J. Randall, B. Floyd, A. Bourai, M. Newcomer, C. Schmidt, and J.W. Skiles, "Comparison of changes in groundwater storage using GRACE data and a hydrological model in California's Central Valley," ASPRS Ann. Conf., Sacramento, CA, March 2012.

[10] "Project Description," Applied Remote Sensing Training: Water Resource Management webpage, Goddard Space Flight Center website. Available online at: http://water.gsfc.nasa.gov/index.php?section=7

[11] "Workshops: The National Weather Center, Norman, OK, June 19-20, 2012," Applied Remote Sensing Training: Water Resource Management webpage, Goddard Space Flight Center website. Available online at: http://water.gsfc.nasa.gov/index.php?section=9