National Aeronautics
and Space Administration

NASA EARTH SCIENCE

APPLIED SCIENCES PROGRAM

WATER RESOURCES

2017

Water Resources: 2017 Annual Summary

Table of Contents

I. INTRODUCTION

The ESD Applied Sciences Program promotes efforts to discover and demonstrate innovative and practical uses of Earth observations. The Program funds applied science research and applications projects to enable near-term uses of Earth observations, formulate new applications, integrate Earth observations and related products in practitioners' decision-making, and transfer the applications. The projects are carried out in partnership with public- and private-sector organizations to achieve sustained use and sustained benefits from the Earth observations.

The Applied Sciences Program's applications themes are currently focused on four of the nine Societal Benefit Areas of the interagency Group on Earth Observations: Health (including Air Quality), Disasters, Ecological Forecasting, and Water Resources.[1] The Program includes climate-related influences and impacts within each of these themes and has cross-cutting elements such as Wildfires and Capacity Building.

The Applied Sciences Water Resources Applications area supports the integration of NASA Earth observations and technologies into management tools for the water resources management community. The Water Resources Applications 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, and climatic and ecological impacts on water resources.

NASA's free and open exchange of Earth observation data helps engage and improve integrated observation networks and enables national and multinational regional water cycle research and applications. Satellite and airborne observations and hydrometeorological models can be applied to enhance information from surface observation networks, and they play a critical role in providing information on water resources, especially in data-sparse regions.

NASA satellite and modeling products provide a huge volume of valuable water resources information extending back more than 50 years across a broad range of spatial (local to global) and temporal (hourly to decadal) scales. Many of these products are also available in near real-time (see *https://earthdata.nasa.gov*).

The primary objective of NASA's Water Resources Applications area is to discover, demonstrate, and transfer innovative uses and practical benefits of NASA's Earth science observations, research, and technologies for improved water management to the water resources management community. To accomplish this objective, NASA partners with a diverse range of organizations (e.g. federal agencies, universities, NGOs, and industry) in the United

[1] The nine USGEO SBAs are Agriculture, Climate, Disasters, Ecological Forecasting, Energy, Health, Oceans, Water Resources, and Weather.

States and internationally to ensure cost-effective and beneficial solutions are provided to water resources managers.

II. OVERVIEW OF 2017

The Water Resources Applications Area, team, and community continued to make strides in addressing critical water resources challenges in the U.S. and globally. In addition to supporting a portfolio of 17 ROSES projects spanning topics such as drought, climate impacts on water resources, water quality and streamflow forecasting/flood monitoring, the Water Resources Applications Area integrated the Western Water Applications Office (WWAO) into its program of activities. WWAO addresses water management issues with an innovative program focused on stakeholder engagement and dynamic response to water management challenges in the western U.S. The Water Resources Applications Area also was very active in engaging the water resources community in the U.S. (Western States Water Council, National Drought Resilience Partnership, National Integrated Drought Information System, Transboundary Water ad-hoc team) and internationally (GEOGLOWs International Workshop, World Water Forum). In addition, we provided leadership in the establishment of the Group on Earth Observations GLOBAL WATER SUSTAINABILITY (GEOGLOWS) Initiative for interagency coordination on water security activities, the Committee on Earth Observation Satellites Ad-hoc Working Group, and a USAID Partnerships for Enhanced Engagement in Research (PEER).

III. ASSESSMENT

Calendar year 2017 was very productive, including the completion of six projects, and the selection of eight new projects (bringing the total portfolio to 17 at the end of 2017) from the A37 solicitation. The new projects funded under the A37 solicitation are focused on the development of applications with operational partners to address management challenges related to water quality and agriculture water use. In addition, three impact assessments continued work to quantify the impacts of projects on stakeholder decisions.

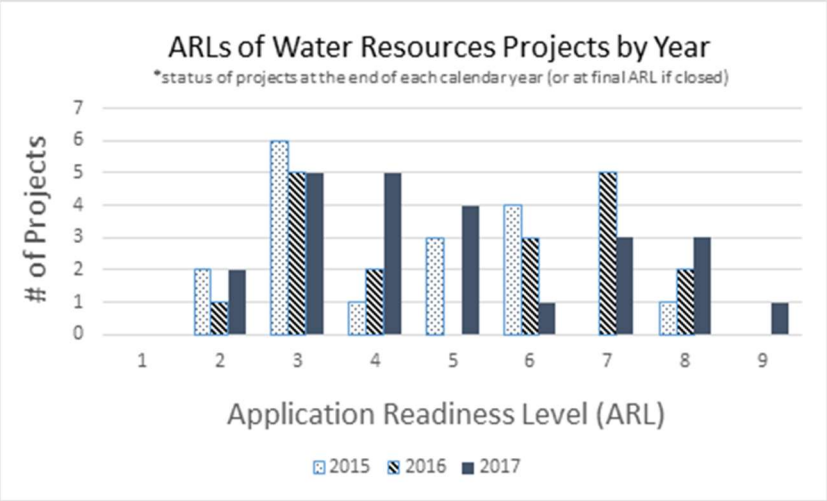
The Water Resources team was highly active in engaging with the operational, policy, and practitioner communities as well as Earth science communities, attending more than 20 meetings and conferences (multiple practitioner meetings such as National Council on Science and the Environment Conference, National Water Quality Monitoring Conference, NOAA National Water Center-PI meeting, USGS-NASA Coordination meeting, Western States Water Council Annual Meeting, U.S. Water Global Water Security Summit, American Society of Engineers World Environmental and Water Resources Congress, Water and Long Term Value Conference, National Academy of Science Arab American Frontiers Symposium, and the Water Funders Initiative, among others).

IV. PROJECT PORTFOLIO

The portfolio currently has 17 active projects, excluding the Western Water Applications Office (WWAO) projects. Nine projects were selected from the A.45 solicitation to develop improved forecasts of water supply anomalies in the mid-term (30-180 day outlooks), and eight projects were selected from the ROSES 2016 A.37 solicitation focused on water quality and agricultural water use and awarded in 2017. Descriptions of these projects are included in Appendix (1).

The table below summarizes the distribution of Application Readiness Levels (ARLs) of the 24 projects that were active during 2017 calendar year, and the final ARLs achieved by the projects completed during 2017. Approximately one-third of projects were selected in 2017 and one-third of the projects closed in 2017. This is reflected in the distribution of project ARLs evenly in the full ARL range shown in the graph below. During 2017, 15 projects advanced one or more ARL.

ARL Levels of all 24 Water Resources Projects in 2017		
ARL	# of active projects at the end of 2017	# of projects that closed in 2017
9	0	1
8	1	2
7	0	3
6	0	1
5	4	0
4	5	0
3	5	0
2	2	0
1	0	0
TOTAL	17	7



V. WESTERN WATER APPLICATIONS OFFICE

Major Accomplishments

The Western Water Applications Office (WWAO) is a multi-NASA-center effort that is based at the Jet Propulsion Laboratory in Pasadena, Calif. The mission of WWAO is to address western U.S. water-resource management concerns through more effective application of NASA assets, capabilities, and expertise.

CY 2017 was a busy year for WWAO as it expanded and matured its program activities in a number of ways. The WWAO project portfolio grew to include a total of seven projects in formulation phase. WWAO published its first Rapid Needs Assessment summarizing the needs

of western water managers and completed a market survey of water stakeholders in the Colorado River Basin. Cross-agency Stakeholder Engagement and Capabilities Working Groups were established to help shape the Stakeholder Engagement and Project Formulation activities. These groups comprise members at Jet Propulsion Laboratory, Goddard Space Flight Center and Ames Research Center with a diversity of experience and perspectives in western water.

In addition, WWAO conducted its first application-transition viability study for one of its projects, and embarked on a focused program of strategic communication. CY 2017 saw the office begin work on implementing an impact assessment framework, partly in collaboration with the new Consortium for the Valuation of Application Benefits Linked with Earth Science (VALUABLES), a cooperative program between NASA and Resources for the Future. WWAO held its first annual strategic retreat where the team reviewed its objectives and strategy, and solidified plans and schedules for FY 2018 and beyond.

Project Portfolio

WWAO's vision is to equip water decision-makers in the western U.S. with useful, accessible and sustained remote-sensing-based information. To realize this vision, the office adopts a two-pronged approach: getting NASA data and expertise into the hands of water stakeholders (a capability-driven "push") and building WWAO into a "go-to" organization for western decision-makers who have water-related issues (a needs-driven "pull").

To help maximize potential decision-support, WWAO applies a tailored approach to all of its projects with the help of three subteams. The multi-center Capabilities Working Group (CWG) maintains awareness of NASA's technical, scientific, and applications capabilities relevant to western-water needs, offering WWAO a deep reach into a broad range of NASA capabilities and informing proposal opportunities and WWAO project development. The multi-center Stakeholder Engagement Working Group (SEWG) works to ensure all projects have a meaningful stakeholder-driven component that meets end-user needs. In tandem, WWAO's Applications Transition team helps define products, customer requirements and plans for transitioning each application into a long-term solution or into an operational status.

2017 saw WWAO fund seven promising application projects that advance water-resource decision-support. Projects were advanced from proposal to formulation phase following a 12-week proposal development process. Each will undergo review for consideration to advance to implementation phase in early CY 2018. See appendix A (2) for the seven WWAO project highlights.

Community Building

During 2017, WWAO undertook a wide range of Stakeholder Engagement activities that focused on identifying, prioritizing and developing relationships with water stakeholders in the west. Around 40 meetings were held with federal and state agencies, boundary organizations, academic institutes, NASA centers and private sector groups. In addition to

cultivating diverse partnerships and raising awareness of WWAO, an integral part of the 2017 Stakeholder Engagement program was to provide key support to WWAO's water-application project leads to help them develop effective stakeholder-engagement plans.

In December 2017, working with the NASA Applied Science Program's Capacity Building Program, the WWAO Stakeholder Engagement Strategic Lead co-chaired a capacity-building panel at the American Geophysical Union meeting. WWAO brought in Sara Larsen, Program Manager of the Western States Water Council, and David Wegner, Former Senior Staff, Water & Energy Committee, U. S. House of Representatives, to participate.

Towards the end of CY 2017, WWAO made plans to host a joint workshop with the Western States Water Council on Water Information Management Systems in early CY 2018, at the Jet Propulsion Laboratory. It will involve over 70 in-person and online attendees representing 12 western states, 3 NASA centers, the U.S. Geological Survey, the private sector, NGOs and academia. The meeting will focus on IT-related water topics including the use of cloud computing, remote-sensing applications, visualization and open water-data platforms and trends. WWAO's goal is to glean insights into the state of the field, to identify best practices in this arena, and to seed ideas on a roadmap for shared and/or valuable water-data frameworks.

Rapid Needs Assessment

WWAO published its first Rapid Needs Assessment (RNA) for Western Water Management, a summary of high-priority science and management needs in western water management, and used this to guide the strategic investment of time and resources. The objectives of the RNA were to assemble a preliminary catalog of needs that can be shared with interested NASA and non-NASA scientists and engineers; establish the basis from which projects for prioritized areas will be developed in the near-term; and to provide guidance for the development of strategies that address high-impact long-term needs. The RNA focused on water supply and availability, and consumptive water use.

The RNA pointed to the following high-level needs of western water stakeholders:

- Understanding and characterizing the transient nature of basin-scale hydrology and water balance, including interannual and long-term, climate-change driven variations;
- Improving accessibility of NASA water observations and related data, in usable formats;
- Integrating wide-area satellite and aircraft observations with local- and basin-scale observations;
- Developing and maintaining a collaborative space in which to address these challenges with colleagues from other agencies.

More specific needs were also identified, including:

- Characterizing changing rain/snow transitions and high-elevation snow water content;
- Improved evaporation and evapotranspiration information products;
- Real-time soil-moisture monitoring;
- Groundwater inventories, capacity, inflow/outflow measurements;

- Improved precipitation forecasting, including for atmospheric rivers.

Market Survey – Colorado River Basin

In 2017, WWAO produced its first market survey identifying and characterizing water managers in the Colorado River Basin, the seventh largest drainage basin in the U.S. Approximately 40 million Americans (roughly 1 in 10) rely on the Colorado River and its tributaries to provide some, if not all, of their municipal water needs. The survey, conducted by Arcadis, Inc., pointed to the need for stakeholders to work together to find common ground in addressing basin-wide issues; to the importance of providing stakeholders with concrete examples of ways in which remote sensing solves water-resource issues; and of the need to reach out to both agriculture and industry.

Looking Ahead for WWAO

WWAO looks ahead to CY 2018 as a year of growth, expansion, and implementation of impact analysis and innovative projects. Through a second Needs Assessment to be held in mid-2018, the western water-resource community will help to directly generate leads for a new round of needs-driven applied research projects that WWAO will fund starting in FY 2019. WWAO's hands-on project formulation process will be applied to ensure that the projects meet pressing and timely needs of the water community while maximizing societal benefit and offering potential for sustainable, operational use of NASA's water data, tools and expertise.

VI. PROGRAM MANAGEMENT

The Water Resources Applications Area program activities focused on integrating WWAO into the overall program management team, expanding the stakeholder framework for the applications area, and assessing gaps in the portfolio.

Global Water Strategy

The Water Resources Program contributed to the US Global Water Strategy. The Global Water Strategy is a plan mandated by the Senator Paul Simon Water for the World Act of 2014, and required vetting and approval by the NASA administrator, the USAID administrator, and Secretary of State. More than 17 U.S. government agencies and departments contributed to the development of this Strategy, which will be coordinated in Washington, D.C., through the Department of State Interagency Water Working Group, and in the host countries through U.S. Missions. It was transmitted to Congress and high priority posts and environmental hubs on November 13, 2017.

2017 Water Resources Team Meeting

The annual NASA Water Resources team meeting was held at the California Institute of Technology on July 18-19, 2017, with more than 65 participants. The overarching purpose of the meeting was to provide a forum for the NASA-supported water resources community of principal investigators (PIs), water resources partners and stakeholders to exchange

information, share updates and collaborate on remote-sensing applications for water resources management.

The meeting also brought together NASA partners and stakeholders from the U.S. western states in an effort to leverage activities across the newly launched NASA Western Water Applications Office, led by the NASA Jet Propulsion Lab in Pasadena, California, with team members located at other NASA Centers, such as Ames Research Center and Goddard Space Flight Center. As a result, the meeting included project overviews that focused on progress related to development of remote-sensing applications, partner engagement and transition to operations, as well as panel discussions that highlighted the importance of impact assessment, stakeholder communications, lessons learned and emerging topics and priorities for the water resources management community.

NASA Water Resources Program Manager Dr. Brad Doorn opened the meeting with an introduction that highlighted the vision and strategic direction of the program, which was then followed by a series of PI presentations from the NASA Applied Sciences Water Resources portfolio on addressing water resource issues across the U.S. These presentations included improving estimates of crop water demand to support irrigation and agricultural applications, snowmelt-streamflow estimates for water supply forecasting and flood assessments and water quality applications including detection and mapping of harmful algal blooms and modeling of nutrient loading.

VII. COMMUNITY LEADERSHIP

Transboundary Water Workshop

To advance knowledge on the current U.S. Government (USG) and partners' technical information needs and gaps to support national security interests in relation to transboundary water, the workshop "Transboundary Water: Improving Methodologies and Developing Integrated Tools to Support Global Water Security", was held on August 15-16 in Silver Spring, Md, attended by the Program Manager, Program Associate Managers, and members of WWAO. Based on key findings from the workshop the following set of recommendations and a path forward were identified.

It was found that many existing science and technology capabilities are already available that can address the operational information needs of decision-makers on transboundary water, but the resources are often disjointed and not directly connected to end-user communities. There is also a lack of tools available that enable the translation and dissemination of the science and technology capabilities to decision-making processes. Overall, the U.S. intelligence, defense, and foreign policy communities need to have a more comprehensive understanding of the role that water plays in specific current and future security scenarios. Finally, the lack of an operational center with a hydrologic forecasting requirement for global water resources and transboundary water presents a steep barrier for transitioning research

and development activities to operations. The findings motivated detailed recommendations and a path forward surrounding the following outline: Prioritize Needs, Alignment of Needs and Capabilities, Technical Cooperation, Capacity Development, and Develop a Dissemination Framework.

American Water Resources Association Meeting

The annual American Water Resources Association – National Capital Region Section meeting was held on April 7, 2017 in Washington, D.C., and brought together more than 125 National Capital Region water-resources professionals from governmental agencies, academia, the private sector, and non-governmental organizations. The program included a keynote by John Bolten with invited panelists and breakout sessions featuring submitted oral and poster presentations. The theme of the 2017 Water Resources Symposium was 'Applications of Remote Sensing and Space Technologies in Water Resources Management'. The meeting featured several lively discussions and presentations on the synergistic application of remote sensing and modeling for improving water resource management. Sessions included, 'Remote Sensing of Rivers and Surface Water Bodies', 'Stormwater and Flood Management', and 'Innovative Techniques for Water Management'.

2017 World Water Week

The NASA Applied Sciences Water Resources team partnered with UNESCO's International Hydrological Programme, the International Institute for Applied Systems Analysis (IIASA), and Ericsson to develop a session at the World Water Week in Stockholm, Sweden in August, 2017. The session, which was sponsored by NASA, brought together experts in remote sensing, big data processing, information and communications technologies, Internet of Things platforms, water policy, scenario development, innovative water management strategies, and monitoring technologies. An estimated 60 participants attended the session and engaged in the discussions following four presentations. The presentations and discussion were supportive of the often-repeated observation, "if you can't measure water, you can't manage water." The panel discussion addressed some of the challenges and opportunities around the application of Earth observations to water resources projects. The emerging COMPASS (Comprehensive Assessment of Water Resources Systems) initiative of the Sustainable Water Futures Programme was introduced. It calls for an integrated approach from data capturing to modeling and management optimization, which was highlighted during the session.

2017 American Society of Civil Engineers (ASCE) World Environmental and Water Resources Congress

The Western Water Applications Office (WWAO) and the NASA Applied Sciences Water Resources Applications Area organized a training workshop at the 2017 ASCE Environmental and Water Resources Congress on May 21-25, in Sacramento, Calif. The training workshop provided an introduction to WWAO and training on applications of remote-sensing data for monitoring land subsidence, snow water resources, and crop water requirements. The training was attended by more than 50 water resources and engineering professionals and

emphasized ongoing applied research and tools being developing with support from WWAO and the Water Resources Applications area. Associate Program Managers and WWAO staff also presented posters and talks at the Congress on WWAO activities as part of WWAO and ASP outreach to the ASCE water resources engineering community. Associate Program Manager Forrest Melton also attended the ASCE technical committee meeting on remote sensing of evapotranspiration.

2017 Fall Meeting of the American Geophysical Union

The NASA Applied Sciences Water Resources team organized four sessions at the 2017 Fall American Geophysical Union (AGU) Meeting on the topic of Remote-Sensing Applications for Water Resources Management, Including, Droughts, Floods, and Water Cycle Extremes. The three consecutive oral sessions each had completely full agendas with eight presentations each and more than 100 attendees at each session. The poster session was also very well attended. The sessions covered both national and international applications of remote sensing for monitoring and management of precipitation, irrigation, drought, flooding, groundwater, soil moisture, evapotranspiration, runoff, and water quality. These sessions provided an opportunity for the NASA Applied Sciences Water Resources community to interact, share ideas, and foster new collaborations across science teams. Associate Program Manager John Bolten also gave an Ignite Talk and a Hyperwall Talk on NASA Earth Observations for Global Water Knowledge at the conference which was held December 11-15, 2017, in New Orleans, La.

VIII. MAJOR ACCOMPLISHMENTS

Project: Satellite-based Water Management in South Asia

PI: Faisal Hossain, University of Washington

South Asian nations face challenges in managing their water resources due to: a) transboundary issues; b) extreme availability or (lack) of water due to Monsoon; and, c) increasing unilateral river impoundments by upstream nations. NASA satellites and models—with their unique vantage in space and all-weather capability—are the only cost-effective way to resolve many of the increasingly difficult challenges to water management, and consequently empower the national water-management agencies in Pakistan and India.

- **NASA Satellites Empowering Pakistan Water Agency to sustainably manage its groundwater resources (*started in 2016; reached sustainable state in 2017).*** In Pakistan, close to 100 million people live inside the world's largest irrigation system—called the 'Indus Basin Irrigation System' (IBIS)—built by the British in colonial times for single-crop intensity. Groundwater resources of the Indus in Pakistan are systematically declining in many places due to uncoordinated groundwater use to supplement water demand for double-cropping intensity. On the other hand, major floods are known to significantly recharge groundwater stocks. The national agency with the mandate for

providing policy and planning guidance to the nation, Pakistan Council for Research on Water Resources (PCRWR), had been unable to carry out frequent monitoring of groundwater-stock changes before and after Monsoon season due to lack of adequate in-situ instrumentation, manpower, and difficult to access regions. An in-situ piezo network for a single province (Punjab) took 10 years to set up and provides only twice a year readings. NASA's Gravity Recovery and Climate Experiment (GRACE) twin satellite sensors, in conjunction with NASA Global Precipitation Measurement (GPM) precipitation, has been operationalized for PCRWR since February 2016 such that the agency is now able to independently monitor groundwater stock changes every two-to-three months. This allows the agency to make linear projections up to 60 days into the future of likely deficits and surplus at district-scale that consequently drive inter-seasonal management of groundwater and agricultural decisions (see figure above).

- **NASA Satellites Empowering 15,000 Pakistani Farmers to Make Better Decisions for Irrigating and Managing their Crops *(started in 2016; expanded in 2017 and reached 100-percent sustainability in 2017)*** In an allied effort aligned with the NASA ASP project's GRACE-based groundwater management, PI Hossain has been successful in having a sustainable and operational irrigation advisory system in Pakistan that is now owned and maintained by the Pakistan Government. This irrigation advisory service serves 15,000 farmers as of February 2018 (it started as 700 farmers in 2016; 10,000 farmers in 2017 and 15,000 farmers in 2018). Farmers get weekly irrigation advisory in the form of nowcast and forecast (up to seven days' lead time) of crop-water demand, expected precipitation (calibrated to GPM IMERG data), temperature (for heat waves), wind (for crop protection)—all of which are then compiled to create an advisory on how best to manage the farmers' crop and how much to irrigate. Full technology transfer has been achieved, with the system now entirely mirrored and paid for by the Pakistan Government as a permanent budget line. The irrigation advisory is designed to operate in tandem with the Pakistan Government's GRACE-based groundwater storage change monitoring where 60-day linear projections are made each season to understand the rate of groundwater depletion or recharge. Quantitative impact evaluation has revealed that the Earth-observation-based irrigation advisory is able to double crop-yield (and farmer income) in some cases, saving about 25-km^3 of groundwater per million of farmers, and achieve an 80-percent usage rate. Currently, this advisory has led to another spin-off advisory system designed for marginal farmers that uses affordable ground sensors and a Low-Power Wide-Area Network (LPWAN), and is undergoing piloting in Uttar Pradesh of India from March to November 2018.

- **NASA Satellites and Satellite-assimilated General Circulation Models Assisting South Asian Nations to Assess Skill of Seasonal Water-supply Forecasting *(started in 2017; sustainability being explored by agencies in 2018)*** The ASP project has also led to the creation of a test bed platform called "South Asian Surface Water Modeling System (SASWMS)". In this platform, seasonal projections of weather from global models are integrated to provide routine and six monthly forecasts of streamflow

(http://depts.washington.edu/saswe). Streamflow is simulated using a hydrologic model that is set up using MODIS vegetation data and forced with daily precipitation (GPM IMERG) and temperature data (from GFS). The global models pertain to North American Multi-Model Ensemble of GCMs where NASA satellite data is assimilated from GPM, MODIS, and other environmental sensors. Currently, Bangladesh and nations in the Lower Mekong region are assessing the skill of this forecast that was previously not available to them.

- **NASA Satellites of JASON-3, MODIS and LANDSAT Being Used to Monitor Reservoir Storage Change, Outflow and Rule Curves by Vietnam *(started in 2017; independent operation skill demonstrated in late 2017)*** As part of the ASP project, the PI's team has focused on building tools that can monitor reservoirs that are transboundary and thereby use the vantage of space to empower downstream nations to perform better water management planning. PI has developed one particular technique based on hydrologic models (forced with GPM IMERG), MODIS and LANDSAT to estimate reservoir area, JASON-3 to estimate reservoir height (and storage change). The combination of these essential water variables then provides an estimate of the reservoir rule curve. Recently (in November 2017), the Vietnam Ministry of Water Resources demonstrated full proficiency in replicating the technique independently. In June of 2018, the PI's team will travel to Vietnam to operationalize an automated reservoir monitoring tool for Vietnamese Government for transboundary reservoirs in Red River basin.

Project: Cyanobacteria Assessment Network (CyAN)
PI: Blake Schaeffer, USEPA

Freshwater cyanobacterial harmful algal blooms occur worldwide and are associated with food-web alterations, hypoxia, human respiratory irritation, and foul taste and odor of potable water as a result of ingestion or skin exposure during recreational activities. Rapid detection of potentially harmful blooms is essential to protect humans and animals from exposure. Information about potential for exposure—such as bloom duration, frequency, and extent—is critical for management-decisions during periods of limited resources and funding. Successful assessment by satellites may provide a first-line of defense indicator for human and ecological health protection.

CyAN is a multi-agency project among NASA, NOAA, U.S. Environmental Protection Agency, and the U.S. Geological Survey, to develop an early warning indicator system for algal bloom detection in U.S. freshwater systems. This research is utilizing historical and current satellite data, and supporting federal, state, and local partners in their monitoring efforts to assess water quality to protect aquatic and human health.

Project objectives include: 1) creation of a standard approach for early identification of algal blooms that is useful and accessible to stakeholders of freshwater systems—remote-sensing assets that would include: ESA Envisat, Sentinel-3, and Sentinel-2 missions, and NASA's

Landsat satellite missions; 2) develop an information dissemination system for expedient public health advisory postings; and, 3) understand connections between health, economic, and environmental conditions to cyanobacterial and phytoplankton blooms. This project began October 1, 2015 and is providing continental U.S. coverage from 2002-2012 using Envisat archives which, along with initial Sentinel-3 Ocean and Land Color Imager data, will be made available to collaborators for review and validation.

The CyAN project hit numerous project achievements in 2017, including direct use of CyAN products in harmful algal bloom (HAB) management efforts, capacity building and exposure of CyAN products to state agencies and EPA regional offices, and numerous publications that establish the CyAN methodology for satellite based algorithms for HAB monitoring. Some of these examples are described below:

- **Utah Department of Environmental Quality (DEQ).** On June 30, 2017, the Utah DEQ released a statement describing the status of Provo Bay. In this statement, they noted that numerous warning signs had to be posted to warn visitors of the conditions of the Bay that represented a potential health risk from algal blooms that may produce toxins. This document also states that the location of these warning signs were informed by satellite imagery, which showed the bloom in proximity to Provo Bay Marina. The statement also refers to use of the satellite images to study the evolution of the bloom "expanding toward the northern shoreline of the lake." In addition to posting warning signs, the Utah DEQ, County Health, and State Parks used satellite imagery to support follow up sampling locations to better understand algal counts.

- **Trainings.** The project team conducted a number of trainings and seminars to begin introducing CyAN products and related tools to the broader user community, including state monitoring agencies as well as EPA regional offices. These included an introduction to SeaDAS (January 26, February 8), RSTools introduction and training webinar (March 14); EPA Tools and Resources/CyAN webinar (November 15).

- **Technical Highlights on HAB monitoring methodology.**
    - Clark, Schaeffer et al. published *Satellite monitoring of cyanobacterial harmful algal bloom frequency in recreational waters and drinking water sources* in *Ecological Indicators* this year. This paper documented the methodology for assessing frequency of bloom occurrence in water bodies in the U.S. and also developed an approach to evaluate recreational/drinking water sources by frequency of occurrence. This method also indicated that only 5.6 percent of waterbodies in the continental U.S. were resolvable with a 300-m single pixel resolution sensor and 0.7 percent were resolvable when utilizing a 3x3 pixel array.
    - Urqhart, Schaeffer et al. published *A method for examining temporal changes in cyanobacterial harmful algal bloom spatial extent using satellite remote sensing* in *Harmful Algae* in 2017. This was the most downloaded article from this

journal in 2017. This manuscript covers the methodology for quantifying cyanobacterial extent, and evaluated how this extent has changed over time for inland water bodies and was conducted using MERIS. The manuscript also binned water bodies based on three risk categories (low, moderate, high-risk bloom area). The study found that California, overall, experienced a less HAB extent; that Ohio (excluding Lake Erie) exhibited no significant change; and that Florida exhibited an increase in cyanobacterial extent.

Project: Integration of Precision NASA Snow Products with the Operations of the Colorado Basin River Forecast Center to Improve Decision Making under Drought Conditions
PI: Tom Painter, JPL

Runoff from melting snow in the Rocky Mountains is a critical source of water for 33 million people across seven western states, and is also an important source of water for irrigation across millions of acres of farmland. The Colorado Basin River Forecast Center (CBRFC) uses hydrologic models to provide forecasts of runoff from Colorado Basin, and these forecasts play an important role in managing water resources for agriculture, communities, hydropower production, ecosystems and recreation. Accurate forecasts are essential to water managers working to balance the goals of maximizing water storage to meet these demands while also minimizing flood risk across the Basin. Previous research has shown that dust accumulation on the surface of the snowpack plays a strong role in the rate and timing of snowmelt, and demonstrated the feasibility of using satellite data from the MODIS instrument onboard the Terra and Aqua satellites to accurately measure both the snow-covered area and dust radiative forcing. Led by Dr. Tom Painter, a collaboration between the NASA Jet Propulsion Lab and the CBRFC has successfully integrated these remote-sensing data products into the hydrologic modeling framework used by the CBRFC.

The joint effort focused on the integration of two remote-sensing data products generated by Dr. Painter and his team at JPL, the MODIS Snow Covered Area and Grain size (MODSCAG), which measures the extent of the snowpack, and the MODIS Dust Radiative Forcing in Snow (MODDRFS), which measure the snow albedo and estimates the solar energy absorbed by snow. Working with collaborators at the CBRFC, the team demonstrated that integration of these data products into the CBRFC hydrologic models could reduce forecast error by up to 70 percent in some basins. This reduction in forecast error has important benefits for water managers, increasing their confidence in information they use to guide reservoir operations and inform decisions about when to store water for irrigation, or release water for instream flows or to increase storage capacity for flood protection.

"We know how crucial water is to farmers and communities," says David Kanzer, a deputy chief engineer for Colorado River District in Glenwood Springs, Colo. "At the same time, without enough water flowing through the rivers, entire generations of endangered fishes could be put at risk. The more accurate the forecasts are, the better equipped we are to strike that balance."

In 2017, the project completed with the successful transition to operations of use of the MODSCAG and MODDRFS data products at CBRFC. This highly successful project demonstrates the value of satellite data for improving water management across the Colorado River Basin, improving the sustainability of water supplies for 33 million people in the U.S.

Participating in the 2017 Decadal Survey for Earth Science and Applications from Space. The Water Resources Team was represented on the 2017 Decadal Survey Global Hydrology panel, and also assisted in the planning and reporting of applications within the survey. Strategic planning of future applications of Earth observations is being assessed based on potential societal benefits, scientific discovery, and progress.

Participating in the U.S. Water Partnership All Partners Meeting. The Water Resources Team participated in the U.S. Water Partnership All Partners Meeting, an opportunity to connect with several agencies and NGOs dealing with water security, disaster monitoring and forecasting, and water and big data in the developing world. Topics included transboundary basins and the water security strategy process. Participants included representatives from General Mills, the Water Council, The Stimson Center, and the Global Environment and Technology Foundation.

Participating in the Water and Long-Term Value Conference. The Water Resources team participated in this conference during October 23-24, 2017 in San Francisco, Calif., and presented an overview of NASA-supported applications of remote sensing to enhance the monitoring and management of water resources. The conference was attended by more than 100 participants from the commercial sector, including representatives from Nestle, Facebook, Levi Strauss, and Coca-Cola, and provided an important opportunity for the Water Resources Team to engage with the commercial sector and explore new opportunities to apply NASA technologies to support the sustainability of water supplies in the U.S. and around the world.

Supporting the NASA Capacity Building Workshop on Globalizing Societal Application of Scientific Research and Observations from Remote Sensing: The Path Forward. The Water Resources team participated in this workshop; providing input and case examples for use of remote sensing of water resources applications and societal benefit. The team is also contributing to a book chapter that will be one of the outputs from this workshop.

Notable publications for Water Resources Applications Team program activities
The Water Resources Team contributed to three NRC Decadal Survey white papers in response to the first Request for Information—two about Evapotranspiration and one about Coastal and Inland Aquatic Ecosystems:

Bolten, J. D., et al., 2018. "Global Hydrological Cycles and Water Resources." National Academies of Sciences, Engineering, and Medicine. 2018. Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space, Washington, DC: The National Academies Press [10.17226/24938]

Fisher, J.B., Melton, F.S., Middleton, E., Hain, C., Anderson, M., Allen, R., Mcabe, M., Hook, S., et al., 2017. The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources. Water Resources Research, 53(4), pp. 2618-2626.

- The Water Resources team contributed to this community report on remote sensing of evapotranspiration, highlighting both current applications and future opportunities. This synthesis report identified key future observation needs and requirements for remotely sensed measurements of evapotranspiration in the context of applications for agriculture, water management, ecosystem functioning and carbon modeling. The paper was one of the most highly downloaded papers from Water Resources Research in 2017.

Mladenova, I. E., J. D. Bolten, W. T. Crow, et al. 2017. "Intercomparison of Soil Moisture, Evaporative Stress, and Vegetation Indices for Estimating Corn and Soybean Yields Over the U.S.." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10 (4): 1328-1343 [10.1109/jstars.2016.2639338]

IX. INTERNATIONAL ACTIVITIES

GEO Global Water Sustainability (GEOGLOWS) Update.
GEOGLOWS is a Group on Earth Observations (GEO) initiative designed to support the development and sustainable use of the world's water resources by bringing those who need information to make better decisions together with those who can provide relevant and robust information. This process involves data, analysis, product development and distribution, and support for the use of data products and research results to explore new applications and solutions to existing and emerging needs.

At its first business meeting, which was held at NOAA's National Water Center in Tuscaloosa, Ala., in May 2017, GEOGLOWS confirmed its Steering Committee membership and established four Working Groups. The Steering Committee includes two NOAA managers while NASA experts chair the Science, Applications, Product Development, and Testing working group, and the Essential Water Variables and Observations Working Groups and NASA expertise is engaged in all of the working groups. The four Working Groups include: a) Socio-economic issues of the water crisis and policy linkages; b) Science, applications, product development, and testing; c) Essential Water Variables and observations; and, d) Data

dissemination, community portal, capacity building, and communication. Programmatically, GEOGLOWS is structured along six themes including:

1. Enhancing Global Water Sustainability;
2. Minimizing Basin and Regional Risk;
3. Essential Water Variable (EWV) Understanding;
4. Earth Observations, Integrated Data Products and Applications, and Tool Development;
5. Data Sharing, Dissemination of Data, Information, Products, and Knowledge; and
6. User Engagement and Capacity Building.

The GEOGLOWS framework builds upon its connections to the regional GEO programs, thereby providing a framework whereby NASA can make connections with stakeholders in all parts of the world. GEOGLOWS also connects with much of the work in which GEO has engaged, such as the GEOSS Water Strategy. The Applied Science Program also selected four GEOGLOWS projects from a competitive ROSES solicitation.

X. LOOKING AHEAD

The Water Resources Applications area looks ahead to 2018 as a year of growth, expansion, and strengthening of impact analysis across the program—with a plan to implement impact analysis activities and plan for the growth of the Western Water Applications Office (WWAO). The Water Resource portfolio will support existing projects, impact assessments, and anticipates selection and initiation of new projects focused on mitigating risks to water supplies and water quality through the ROSES 2018 solicitation. Also, WWAO will be adding more projects and initiating work on more western U.S. basins in 2018.

XI. APPENDIX

A. (1) Water Resources Project Highlights from 2017

Project: Advancing Drought Onset Detection and Seasonal Prediction Using a Composite of NASA Model and Satellite Data

Principal investigator: Amir AghaKouchak, University of California, Irvine

Project year: 2

Year-end ARL: 5

Description: The primary goal of this project is to improve drought monitoring and prediction in California through: (a) Using NASA's Atmospheric Infrared Sounder (AIRS) relative humidity and water vapor to improve drought early onset detection and prediction; (b) developing a

multivariate modeling framework for composite drought assessment; and, (c) developing a framework for quantitative and probabilistic assessment of drought by integrating satellite data into an analog-based drought prediction model. The project is being conducted in close collaboration between UC Irvine and investigators from the California Department of Water Resources (CDWR).

End users: CDWR

Data sources, models, technology: NASA Atmospheric Infrared Sounder, MODIS SST, VIIRS SST, land-atmosphere models, stochastic modeling techniques.

Major accomplishments in CY 2017:

- The team delivered the data processing and forecasting software toolkit to CDWR in May 2017 for implementation and review on CDWR compute resources.
- The project team delivered forecasts of seasonal precipitation anomalies to CDWR throughout 2017.
- The project team has published five peer-reviewed papers documenting the methodologies used within the different components of the project.

* * *

Project: Advancing Water Supply Forecasts in the Colorado River Basin for Improved Decision Making

Principal investigator: Gerald Day, RTI International

Project year: 2

Year-end ARL: 4

Description: This project is a collaboration among RTI International, the Colorado Basin River Forecast Center (CBRFC), Colorado State University, and Utah State University to couple advanced data assimilation techniques with distributed hydrologic modeling to provide improved water supply forecasts for the Colorado River basin. In addition, the project team is working with Denver Water and the Dolores Water Conservancy District to demonstrate how the probabilistic ensemble forecast information can be used to improve water management decision making.

End users: Colorado Basin River Forecasting Center, Denver Water, Dolores Water Conservancy District

Data sources, models, technology: NASA MODIS MODSCAG, MODDRFS, GPM, IMERG, NLDAS, Utah Energy Balance Snow Model, NWS Research Distributed Hydrologic Model, Community Hydrologic Prediction System, NASA Earth Exchange

Major accomplishments in CY 2017:

- During 2017, the project focused intensively on completing the integrated modeling and snow data assimilation framework.
- RTI completed the RDHM model calibration runs for 30 basins out of 32 pilot basins using high performance computing available through the NASA Earth Exchange. The multi-objective NSGA-II optimization scheme produced 40-120 pareto solutions for each basin.
- The project also built and tested a flexible ESP reforecasting framework that provides options to perform snow data assimilation (DA) at any timestep, perform reforecast at any timestep, and use SWE observations masked with MODSCAG, or SWE observations solely from SNOTEL. The project evaluated the ESP reforecast performance against CBRFC for one test basin (Animas) for 1990-2010 and is currently evaluating forecast performance for other basins.
- The project also developed a standardized approach for utilizing the ensembles and assessing the potential benefits of improved forecasts for end-users.

* * *

Project: Analysis of Agricultural Water Supply-Demand Imbalance During the Unprecedented California Drought Using NASA Satellite Data

Principal investigator: Noah Molotch, USDA Agricultural Research Service

Project year: 1

Year-end ARL: 4

Description: The overarching goal of the project is to characterize anomalies in water supply and demand using a combination of NASA satellite observations and NASA physically based land surface models. The annual water supply-demand imbalance is ingested into existing California Department of Water Resources (CDWR) operations and the jointly-produced information is distributed to multiple stakeholders across California. Additional project objectives include migration of remotely sensed SWE and ET analyses into the CDWR computational environment; and to conduct quantitative and qualitative assessment of the utility of the SIMS ET, and MODIS-based snowpack information to inform water resource decisions during drought.

End users: California Department of Water Resources, NASA-JPL, U.S. Fish and Wildlife Service, San Francisco Public Utilities Commission, Pacific Gas and Electric, Kings River Water Association, City of Bakersfield, Sacramento Municipal Utility District, Turlock Irrigation District,

U.S. Bureau of Reclamation, Merced Irrigation District, Kaweah Delta Water Conservation District, J.G. Boswell Company, Southern California Edison, Los Angeles Department of Water and Power, National Oceanic and Atmospheric Administration, National Park Service, University of California at Merced, and the Desert Research Institute.

Data sources, models, technology: The project is using MODIS-based snow water equivalent (SWE) estimates and Landsat and MODIS-based ET estimates from the NASA Satellite Irrigation Management Support project (SIMS) from 2000 through present.

Major accomplishments in CY 2017:

- The project delivered SWE estimates on a monthly basis to all project partners beginning in the fall of 2017 and continuing through the winter into 2018.
- The initial datasets assisted water managers in monitoring conditions in the Sierra Nevada as California was faced with a possible return to drought in 2018.
- The project team compiled historic MODIS SWE and SIMS ET data from 2010 to present for analysis of water supply-demand imbalances during the previous drought.
- The project team met with project stakeholders to review initial data products and discuss requirements for delivery of new data products being developed.

* * *

Project: Assessing Water Resources in Remote, Sparsely Gauged, Snow-Dominated Mountain Basins

Principal investigator: Jeff Dozier, University of California, Santa Barbara

Project year: 4

Year-end ARL: 6

Description: Utilizing MODIS data and GDAS/GLDAS assimilations, this project estimated seasonal snow volumes, relative to historical trends and extremes, in snow-dominated mountains that have emerging or enduring insecurity related to water resources, to support government operations and analysis for aid organizations. It identified, on regional and local bases, “crisis” and near-crisis events compared against historical data.

End users: U.S. Army Staff, U.S. Army Corps of Engineers, U.S. Embassy (Islamabad and Kabul), California Department of Water Resources (CDWR)

Data sources, models, technology: MODIS, VIIRS, SSM/I assimilations from GDAS and GLDAS.

Major accomplishments in CY 2017:

- Demonstrated that retrievals of SWE from passive microwave instruments have close correspondence to reconstructed SWE during drought conditions;
- Demonstrated that reconstructed SWE data matched data from the Airborne Snow Observatory, and showcasing the feasibility of using SWE estimates from satellite data to identify and forecast drought events at seasonal timescales;
- The project worked with USACE CRREL and USAF 14th Weather Squadron to develop a transition strategy and this work to advance toward operations will continue beyond the end of the NASA-supported effort.

* * *

Project: Cyanobacteria Assessment Network (CyAN)

Principal investigator: Blake Schaeffer, Environmental Protection Agency

Project year: 3

Year-end ARL: N/A

Description: The Cyanobacteria Assessment Network is a multi-agency project among the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, and U.S. Geological Survey to develop an early warning indicator system for algal bloom detection in U.S. freshwater systems. This research will utilize historical and current satellite data and supports federal, state, and local partners in their monitoring efforts to assess water quality to protect aquatic and human health.

End users: USEPA Regional Offices (10 in total), US Army Corps of Engineers, Environment Canada, State water / environmental management agencies, EPA Office of Water, State EPA agencies

Data sources, models, technology: Landsat, Sentinel-2 and Sentinel-3

Major accomplishments in CY 2017:

- Project demonstrated, through examples such as providing supporting satellite information to Utah DEQ, that CyAN products can be used for HAB monitoring/management and activities
- Published numerous papers, documenting the systematic methodology to evaluate HAB frequency and extent, with additional method papers in progress to evaluate severity and duration
- Continued to conduct validation/calibration efforts for HAB and related product algorithms

- Beta test stage of a mobile applications DSS with various users.

Plans or expectations for 2018:

- Evaluate linkages between in water constituents, such as disinfection by-products, with cyanobacteria concentrations
- Continued evaluation of various algorithms over increasing geographic extent (coverage become continental U.S.)
- Investigate various options for transition of production of data products

* * *

Project: Decision Support System to Enhance Water Quality Modeling and Monitoring using Remote Sensing Data

Principal investigator: Josh Weiss, Hazen and Sawyer

Project year: 3

Year-end ARL: 5

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The goal of this project is to develop a decision support system for partners that utilizes remote-sensing information to predict anomalies in source water quality, looking at parameters such as haloacetic acids, nutrients, and organic matter.

End users: NYC Department of Environmental Protection; Raleigh Public Utilities; Northern Colorado Water Conservancy, Lower Colorado River Authority; Bloomington Water Dept; Cary DWR

Data sources, models, technology: MODIS NDVI, EVI, GPP, LAI, Fpar; TRMM

Major accomplishments in CY 2017:

- Project addition of linear mixed effect statistical model approach yielding improved and promising results for their sites (particularly in TX and CO)
- Prototype DSS development underway
- Continued engagement with various utility stakeholders to establish correlations with in-situ monitoring data

Plans or expectations for 2017:

- Continued investigation of LME approach across all watershed sites in collaboration with utility partners
- Continued testing of prototype DSS which will enable users to retrieve and conduct tailored analyses within their watersheds

- Explore data sharing with other water quality projects

* * *

Project: Development of a Global Evaporative Stress Index Based on Thermal and Microwave LST towards Improved Monitoring of Agricultural Drought

Principal investigator: Christopher Hain, University of Maryland

Project year: 1

Year-end ARL: 4

Description: The project aims to develop a global agricultural monitoring tool, with a focus on providing early warning of developing vegetation stress for agricultural decision-makers and stakeholders at relatively high spatial resolution (5-km). This tool is based on remotely sensed estimates of evapotranspiration, retrieved via energy balance principals using observations of land surface temperature. The ESI-GDPS will serve the decision support needs of the three primary project stakeholders: the USDA Foreign Agricultural Service, the International Center for Biosaline Agriculture's MENA Regional Drought Management System and the G20 GEOGLAM Crop Monitor Initiative for the Agricultural Market Information System (AMIS) and for Early Warning.

End users: National Drought Mitigation Center, U.S. Drought Monitor, the Texas Water Development Board, the USDA National Agricultural Statistics Service, the USDA Foreign Agricultural Services, the NOAA Environmental Modeling Center, the NOAA Climate Prediction Center, and the G20 GEOGLAM Crop Monitor Initiative

Data sources, models, technology: MODIS/VIIRS (LST; LAI; Albedo; Emissivity; Landcover Type); Atmosphere Land Exchange Inverse (ALEXI) Two-Source Energy Balance Model; MERRA/CFS-R for meteorological inputs needed for ALEXI; GLDAS (SM/ET for intercomparison with ESI)

Major accomplishments in CY 2017:

- The thermal-only ESI is now being run in near-realtime at NASA SPoRT and providing weekly updates to project stakeholders.
- The TIR+MW ESI is being ported to NASA SPoRT and test processing began in Fall of 2017.
- The end users provided evaluations of the ESI datasets and aid in quantifying the potential impact of the products in each of their specific application areas.
- Transition of code to MSFC – prototype system has begun delivering TIR-only ESI in July 2017 to project stakeholders (see slide 10 for example of current Global ESI)
- Integration of IMERG Ka-band observations – will streamline processing of MW-LST for ESI-MW product – working on downscaling MW product to produce 0.05 MW LST data to be consistent with TIR-LST – near-real-time processing system to ingest, map and

generate MW LST is currently being transitioned into the global ESI system at NASA SPoRT). NRT MW ESI products are planned to become available in Spring of 2018.
- NASA Summer Faculty Fellow (Dr. Brent McRoberts) spent the summer at NASA SPoRT and completed several analyses related to global ESI and other global drought indicators – 2 manuscripts are in preparation.
- Global ESI product has been integrated into the Crop Monitor interface for use by GEOGLAM crop analysts in their monthly assessments that produces the GEOGLAM Crop Monitors

* * *

Project: Developing a Dynamic SPARROW Water Quality Decision Support System Using NASA Remotely-Sensed Products

Principal investigator: Richard Smith

Project year: 1

Year-end ARL: 2

Description: The goal of the proposed project is to enhance the USGS SPARROW (Spatially Referenced Regression on Watershed Attributes) water quality Decision Support System (DSS) with a remote sensing-driven seasonal dynamic SPARROW models to aid environmental managers to more effectively manage the waters, habitats and resources under their responsibility. This DSS will provide end users with a dynamic tool with which they can make near-real time decisions regarding distribution of resources, mitigation activities, land use restrictions, water quality alerts. End-users/stakeholders include Mobile Bay, Tampa Bay and Sarasota Bay National Estuary Programs; Weeks Bay and Winyah Bay National Estuarine Research Reserves; Southwest Florida Water Management District.

End users: Mobile Bay National Estuary Program, Tampa Bay National Estuary Program, Sarasota Bay National Estuary Program, Weeks Bay National Estuarine Research Reserve, North Inlet-Winyah Bay National Estuarine Research Reserve

Data sources, models, technology: MODIS, VIIRS, OMI, LIS, Landsat, Sentinel, SMAP, GRACE, NLCD

Major accomplishments in CY 2017:
- Finished building a test SPARROW data1 file and a working control file for a preliminary run of a total flow dynamic model for the PeeDee (Winyah Bay) River Basin for 2000-2004.
- The groundwater group (Ward, Wes, and Meredith) continued refining methods for filtering water table measurements from the larger NWIS database of all groundwater measurements.

- Various upgrades were made to RSPARROW, a USGS R-based software package that supports the estimation and visualization of static SPARROW models and predictions.
- USRA team members (Al-Hamdan, Crosson, Srikishen) have developed computer programs to process remotely-sensed products associated with nutrient and sediment sources and transport from watersheds and provided access to product files for SPARROW team.

Plans or expectations for 2018:

- Continued development and evaluation of model performance with in situ data
- Continued integration of groundwater module, including impacts at nearshore/coastal zones
- Evaluate catchment level seasonal remote sensing products in SPARROW model

* * *

Project: Eco-hydrological modeling using field-based and Earth Observations to assess water use efficiency and support agricultural water resources management

Principal investigator: Piere Guillevic, University of Maryland

Project year: 1

Year-end ARL: 3

Description: In this project, we propose to develop an integrated modeling platform using Earth Observations to simulate large-scale hydrological processes and food production in support of water use decision and agricultural policy. The decision tool will provide timely and relevant assessments of crop growth, agricultural water use and available water supply from local to regional scales, with the capability to predict the impact of different climate and water resources management scenarios on food production. The approach is based on the use of field and Earth observations to calibrate the APEX and SWAT eco-hydrological models, and climate simulations to forecast crop condition and yield through the crop season. The primary outcomes and results for stakeholders will be potential best water management practices to improve water use efficiency and prevent excessive losses of water and nitrogen to the environment.

End users: GEOGLAM, Different Ministries (Agriculture, Water), water management consortiums and farmers in Argentina, Tanzania and South Africa. Natural Resources Conservation Service, Bureau of Reclamation and farmers in the US.

Data sources, models, technology: MODIS, VIIRS, SWAT, MERRA, SMOS, Sentinal-1

Major accomplishments in CY 2017:

- Remote sensing (MODIS, VIIRS, HLS) and ground datasets for all 7 field sites were archived and processed at UMD and NASA GSFC
- Models (APEX and SWAT) have been implemented and a calibration process has been developed.
- All available Synthetic Aperture Radar (SAR) data in multi-polarization (VV and VH) derived from Sentinel-1 from 2015 to present for the seven study areas have been accessed and processed
- The PI visited field sites near Ames, IA, Tifton, GA, Argentina, and Bakers, CA to collect field data and meet with end users.

* * *

Project: Enhancing the USDA Global Crop Production Decision Support System with NASA Soil Moisture Active Passive (SMAP) Satellite Observations

Principal investigator: John Bolten, NASA Goddard Space Flight Center

Project year: 3

Year-end ARL: 5

Description: The primary goal of this project is to provide NASA products, tools, and information to the USDA Foreign Agricultural Service to advance agricultural productivity forecasting ability of the CADRE crop forecasting system.

End users: USDA FAS

Data sources, models, technology: SMAP, ASCAT, GPM, SMOS

Major accomplishments in CY 2017:

- Tested SMOS system rescaling algorithm and climatology analysis of SMAP surface soil moisture
- Operational data assimilation system was transferred to NASA Goddard Space Flight Center GIMMS system to meet USDA FAS delivery requirements
- SMAP- based system was vetted by stakeholders and full historical dataset of soil moisture-based products were provided for assessment.
- Thorough end-of-season yield analysis was completed using the integrated soil moisture product and other model- and satellite-based products

CY 2018 Plans

- Project finalizing where operational system will be hosted long term (had to move from USDA ARS to GSFC)

* * *

Project: Fallowed Area Mapping for Drought Impact Reporting and Decision Making

Principal investigator: James Verdin, U.S. Geological Survey

Project year: 4

Year-end ARL: 8

Description: Using MODIS and Landsat data, the project has demonstrated the utility and value of a remote-sensing fallowed-land monitoring service. This is a joint effort by USGS EROS, USDA NASS, CDWR, and NASA Ames Research Center to improve the timeliness of fallowed area information products to support within-season decision making on drought disaster declarations and proposed water transfers, and gauge impacts on local economies and employment.

End users: CDWR, U.S. Bureau of Reclamation, California Farm Water Coalition, Western Growers Association, National Integrated Drought Information System, the Nature Conservancy

Data sources, models, technology: MODIS 250m data, Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI, NASA Earth Exchange

Major accomplishments in CY 2017:

- Successfully sustained capability for within season mapping of idle acreage (advanced delivery of information >10 months).
- Monthly estimates generated by the project team for March – September 2017 and delivered to DWR within two weeks of end of month.
- Overall accuracy has been approx. +/- 15 percent or better in all months, exceeding CDWR specified targets for accuracy.
- Good agreement between USDA/NASA year-to-date idle estimates.
- During 2017, the State of California experienced heavy flooding and the project documented increases in winter land fallowing due to flooding and inability of growers to plant fields. In previous years (2015, 2016), data from the project was presented to Governor's Drought Task Force by CDWR and used as input to decision making for allocation of emergency drought relief funds to food banks and social service agencies in impacted counties.
- The project moved the core satellite data processing algorithms to Google Earth Engine to facilitate transition to CDWR, and also developed automated data processing workflows to process Earth Engine output into figures and graphs.
- In late 2017 the project, began work on transition to CDWR for sustained operations, and will continue the transition with trainings in early 2018.

- Expansion of project capabilities to Washington State and Nevada is ongoing with matching support from the Western Water Applications Office and the National Integrated Drought Information System.

* * *

Project: Integrating GRACE and GRACE Follow-On Data into Flood and Drought Forecasts for the Continental U.S.

Principal investigator: Matt Rodell, NASA GSFC

Project year: 3

Year-end ARL: 4

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The objective of the project is to build upon a current suite of soil moisture and groundwater wetness indicators employed by the project team and end users to develop 30-90 day, 0.125° gridded predictions of water storage conditions and runoff for the continental U.S. using GRACE and GRACE-FO and to test them as inputs to existing drought, river flow, and flood decision support systems at the NDMC, NWS/NCRFC, and USACE.

End users: National Drought Mitigation Center

Data sources, models, technology: GRACE, GRACE-FO, Catchment Land Surface Model, GEOS-5

Major accomplishments in CY 2017:

- Historical GEOS-5 seasonal forecasts are now being downscaled and used to drive the Catchment model retrospectively to produce 30-90 day drought/wetness hindcasts.
- Project partners at the National Drought Mitigation Center are reviewing current monitoring products and will apply the same approach for the hindcasts being produced, and the same for forecasts.
- Project team is working with our partners at the NOAA North Central River Forecast Center and US Army Corps of Engineers on the protocol for testing the value of our products in their operations.
- The project team is collaborating with Resources for the Future (RFF) on a quantitative impacts assessment project. It includes end user engagement and economic analyses that will lead to a value-of-information analysis.
- RFF has developed a framework for assessing the Value of Information resulting from our project, which was presented to the full team on a recent telecon.
- GSFC completed hindcasts with unaltered GEOS-5 forcing and continues to evaluate the resulting wetness/drought indicators; hindcasts with downscaled forcing begin 11/30/17.

- JHU developed pre-processing tools, based on NCAR's Generalized Analog Regression Downscaling (GARD) method, that allow comparison of the proposed downscaling methods prior to integration in LIS.
- JHU successfully downscaled historical GEOS-5 forecasts using the ClimDown algorithm with bias correction and spatial disaggregation (BCSD) tools provided by collaborators at MSFC and UC Santa Barbara.
- JHU is improving the modeling of anthropogenic impacts such as groundwater pumping due to irrigation.
- The GRACE DA wetness indicator product distribution webpage has been redesigned by NDMC, including a 2-date map comparison slider, and 1, 2, and 4-weekly change maps will soon be available. See http://nasagrace.unl.edu/.
- U. Texas has developed quick-look (low latency) GRACE hydrology fields for use in the DA runs, which will be more valuable when GRACE FO comes online.
- U. Texas developed and is evaluating (with GSFC) a daily GRACE swath product.
- NOAA/NCRFC is investigating the value of both GRACE hydrology fields and historical GRACE DA groundwater and SWE outputs for runoff/flood forecasting.

* * *

Project: Integration of Precision NASA Snow Products with the Operations of the Colorado Basin River Forecast Center to Improve Decision Making

Principal investigator: Thomas Painter, NASA Jet Propulsion Laboratory

Project year: 2

Year-end ARL: 8

Description: The project developed and delivered MODIS data products, which the Colorado Basin River Forecast Center (CBRFC) began integrating into its operations in 2013. CBRFC, which is run by the National Weather Service, generates daily and seasonal streamflow forecasts for the Colorado River Basin and eastern Great Basin.

End users: water managers, reservoir managers, government officials

Data sources, models, technology: MODSCAG, MODDRFS

Major accomplishments in CY 2017:
- Ongoing use and refinement of use of near real-time MODSCAG by CBRFC.
- Ongoing use of near real-time canopy-adjusted MODSCAG fractional snow covered area into CBRFC operations.
- Continuing use of near real-time MODDRFS dust radiative forcing to update snowmelt rates in CBRFC operations.

- Quantification of CBRFC SNOW-17 forecasting errors across Colorado River Basin relative to dust radiative forcing anomalies from near real-time MODDRFS, with demonstrated reduction in runoff forecast errors of up to 70%.
- Project was highlighted in a Phys.org article which described the project impacts and benefits to the CBRFC: https://phys.org/news/2017-01-nasa-colorado-river-basin.html
- Project is close to achieving ARL 9, pending final review and approval of integrated, operational system by CBRFC.

* * *

Project: Maximizing Utility of Remote Sensing on Water Quality Monitoring and Resource Management in California's Water Systems

Principal investigator: Christine Lee

Project year: 1

Year-end ARL: 2

Description: To advance the capability of multiple stakeholders in California's water resources to routinely access and utilize Earth observations-based water quality products to support operational or institutional decision-making related to water management practices. This will be achieved through the following objectives: (1) Water quality product development: strengthen existing algorithms across airborne and satellite platforms for three water supply resources in the CA State Water Project; (2) Make products accessible: develop / automate processing pipeline and make water quality data available on public portal; (3) Support testing / use of data: develop use cases with partners to test complementary remote sensing data in existing studies.

End users: Metropolitan Water District, California Department of Water Resources

Data sources, models, technology: Satellite: Landsat-8, MODIS, ASTER, Suomi NPP VIIRS, Sentinel 2/3 MSI and OLCI; Airborne: AVIRIS, PRISM

Major accomplishments in CY 2017:

- Turbidity and chlorophyll products processed for entire records for ESA Copernicus Sentinel 2 and Landsat-8 for SF Bay and Delta
- Initiated product development using AVIRIS-NG (turbidity, chlorophyll) and MASTER (water temp) with Landsat-8 for SF Bay and Delta, with DEVELOP team support
- Cruises planned for SF Bay and Delta, Oroville, San Luis Reservoir for
- Participated in a piggyback airborne campaigns extension
- Identified multiple use cases for integration into partner workspace, including turbidity model calibration / validation, constituent tracker

Plans or expectations for 2018:

- Multiple field campaigns, including capture of water year 2018 first flush storm event, to include in situ optical/radiometric data for evaluation of satellite products
- Continued evaluation of products through use case studies with partners

* * *

Project: Mitigation of Drought Impacts on Agriculture through Satellite Irrigation Monitoring and Management Support

Principal investigator: Forrest Melton, NASA ARC and California State University, Monterey Bay

Project year: 4

Year-end ARL: 8

Description: The Satellite Irrigation Management Support (SIMS) project is a NASA-supported effort to apply publicly available data from Earth-observing satellites to map crop cover, crop coefficients, and crop evapotranspiration. The project has developed information products and tools from satellite data to provide decision support for water managers and agricultural producers for agricultural water management and irrigation scheduling.

End users: California Department of Water Resources (CDWR), Western Growers Association, University of California Cooperative Extension, USDA Agricultural Research Service, Tanimura & Antle, Farming D Ranch, Pereira Bros. & Sons, Booth Ranches, Fresh Express, Ryan Palms Farms, Del Monte, Inc.; Constellation Wines, E. & J. Gallo, Dole, Inc., Driscoll's Farms, Meyer Farms, Huntington Farms, D'Arrigo Bros.

Data sources, models, technology: TOPS, MODIS, Landsat, Sentinel-2, NASA Earth Exchange

Major accomplishments in CY2017:

- The SIMS web interface was publicly available during 2017. Reports were generated on a weekly basis for partner growers, with combined management of more than 100,000 acres.
- The SIMS transition strategy was reviewed and approved by CDWR and work was initiated on transition of SIMS to operational use by CDWR. This work to complete the transition from ARL 8 to ARL 9 will continue with support from CDWR beyond the end of the NASA supported project.
- Four years of field studies have been conducted for vegetable crops in collaboration with USDA and UCCE to quantify the potential for reductions in applied water and associated changes in crop yields. Studies conducted to date demonstrate potential for reductions in applied water of 21-40 percent, without any statistically significant changes in yield. Field

trials conducted in 2017 also demonstrated that use of ET-based irrigation could also support substantial reductions in nitrate leaching.
- In partnership with CDWR and UC Berkeley, the project team completed a survey to be distributed to users of CIMIS to quantify the benefits of using ET-data to manage irrigation. A test version of the survey was distributed in 2017, and the full survey will be completed in early 2018.

* * *

Project: Monitoring Vineyard Water Use and Vine Water Status with Land Surface Temperature for Improved and Sustainable Water Management from Field to Regional Scales

Principal investigator: William Kustas, USDA Agricultural Research Service

Project year: 1

Year-end ARL: 3

Description: This project is developing a multi-scale remote sensing toolkit for mapping crop water use and crop stress for improved irrigation scheduling and water management in vineyards in the Central Valley of California. The toolkit will be available to winegrape growers and agricultural producers growing high value tree crops (e.g., almonds, walnuts) to improve water management and irrigation scheduling. The project is applying a thermal-based multi-spatial and temporal energy balance model developed to use multiple operational satellite systems in an integrative/data fusion methodology. The approach employed by the modeling system provides evpotranspiration monitoring at daily time scales from field to regional and continental scales. This modeling system is being applied and refined for vineyards and orchards, which have highly structured and unique canopy systems

End users: E. & J. Gallo, California winegrape growers, California Almond Board, USDA

Data sources, models, technology: Landsat, MODIS, VIIRS, GOES, ALEXI, DisALEXI, UAV thermal and mutlispectral data

Major accomplishments in CY 2017:
- The project successfully completed a major field campaign in collaboration with E. & J. Gallo to quantify the accuracy of the ET modeling approach.
- Results from the field campaign are documented in ten peer-reviewed publications that have been submitted for a special issue of Irrigation Science.
- The project team also made significant progress made n developing a VIIRS ET product. The processing of V2 of the 375-m VIIRS ET product for the period of 2014-2016 is was completed. Transition of the 375-m VIIRS ET product into near-real-time processing at NASA SPoRT – NRT production is underway.

- The project worked with E. & J. Gallo to define requirements for the operational system and initiate work on development of an ET toolkit for winegrape growers.

* * *

Project: Operational Remote Sensing of Agricultural Water Use in Cooperation with Western State Water Resource Agencies for Improved Water Management

Principal investigator: Justin Huntington, Desert Research Institute

Project year: 1

Year-end ARL: 4

Description: A remote sensing based ET framework is being developed, tested, and applied in collaboration with co-investigators in high-priority study areas of five western states: Central Valley and Paso Robles coastal groundwater basin, CA; Bear River Basin, ID/UT; Truckee, Carson, Walker River Basins, NV/CA; and Malheur Lake Basin, OR. The project is using Earth observation datasets combined with well-established ET models (e.g. METRIC, SIMS) that have been developed in cooperation with western state and federal agencies, and have been used for wide-area mapping of crop water. The ET framework and products are being tested and transitioned for in-house use by water agency co-Investigators for day-to-day operations and special studies to improve water management decisions related to irrigated agriculture, groundwater management, surface and groundwater rights accounting, and improved understanding of water availability and security through enhanced knowledge of historical and current consumptive use and hydrologic budgets.

End users: Nevada Division of Water Resources; Utah Division of Water Rights; Idaho Department of Water Resources; Oregon Water Resource Department; California State Water Resource Control Board

Data sources, models, technology: MODIS, Landsat, Sentinel-2, VIIRS, METRIC, SIMS, NASA Earth Exchange

Major accomplishments in CY 2017:

- During the first year, the project made substantial progress on the ET framework software development and testing within the Google Earth Engine Python API. Initial function development and testing of time integration and ET functions are ahead of schedule.
- The project held a training workshop for staff from partner water management agencies at DRI. The workshop was attended by collaborators from water management agencies in eight western states and provided hands-on training on use of METRIC, SIMS and Earth Engine to quantify and map ET across irrigated agricultural lands.

- During the training workshop, the project also identified user requirements for the operational system from state agency partners.

* * *

Project: Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts

Principal investigator: Mekonnen Gebremichael, UCLA

Project year: 3

Year-end ARL: 5.5

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. This project aims to improve reservoir operations for hydropower production for multiple utilities in East Africa by utilizing remote-sensing data and seasonal climate forecasts in respective Decision Support Systems.

End users: Ethiopian Electric Power Corporation; Ethiopian Water WOrks COnstruction Enterprise; Tanzania Electricity Company, National Meteorological Agency of Ethiopia

Data sources, models, technology: Satellite precipitation estimates: TMPA 3B42RT (to be replaced by GPM/IMERG); THORPEX Interactive Grand Global Ensemble (TIGGE) ensemble weather forecasts from 8 global centers; G-REALM altimetry lake height monitoring; DFO lake surface area monitoring; NASA-Unified WRF (NU-WRF) model

Major accomplishments in CY 2017

- NMME used to optimize climate forecast estimates for Obo-Gibe Basin
- Streamflow/surface water estimates optimized using NMME inputs, ET, and soil moisture, run through NASA LIS
- Optimization scheme is starting to be tested, found in preliminary retrospective evaluations that considerably more hydropower could be generated if this tool were available to inform operations

Plans or expectations for 2018:

- Continue partner engagement and training: PI speaks frequently with stakeholders but also travels to meet stakeholders in person. Series of training workshops set up.
- Engage SERVIR to discuss potential collaborations

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Project: Predicting Middle Eastern and African Season Water Deficits using NASA Data and Models

Principal investigator: Christa D. Peters-Lidard, Goddard Space Flight Center

Project year: 3

Year-end ARL: 5

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The objective of this work is to develop a season water deficit forecasting system that is relevant for USAID and U.S. Army Corps of Engineers in the Middle East and Africa. These activities will be based on existing/mature NASA and NOAA Earth science capabilities. The primary work has two goals: 1) align and improve the USAID's Famine Early Warning Systems Network (FEWS NET); and, 2) describe water supply and water supply anomalies in the region of interest through a suite of indicators.

End users: managers at the U.S. Agency for International Development, U.S. Army Corps of Engineers, and International Center for Biosaline Agriculture

Data sources, models, technology: GEOS-5, CFS seasonal forecasts, LIS, AMSR-E, ASCAT, SMOS, SMAP, GRACE, LDAS, DSSAT

Major accomplishments in CY 2017:

- Evaluated and demonstrated the forecasting system for crop production estimates
- The forecasting and data assimilation components were tested and demonstrated added value from the bias-corrected seasonal climate forecasts over the ESP benchmark forecast (climatology forecast).
- Our end-user partners began to ingest trial versions of the FAME Drought Forecasting system into their decision support tools, like ICBA's RDMS Composite Drought Indicator maps.
- The FAME drought forecasting prototype system had several of its components put into automated scripts to generate the required input files to run the main parts of the system.
- The data assimilation components were tested and used to initialize the seasonal climate forecasts.
- Several historic forecast or hindcast experiments have been generated and evaluated with independent observations, including streamflow and remotely sensed products. The drought forecast results are showing improvement over the benchmark climatology-based forecasts. Also, the system is able to capture realistically severe drought conditions in both monitoring and hindcast modes.
- Prototype drought forecasting systems for Africa were demonstrated for FEWS NET (e.g., Shukla et al., 2014);

- Demonstrated the ability of detecting drought conditions in the forecast system and improvement over the forecast benchmark.
- The GRACE terrestrial water storage (TWS) data assimilation component is contributing to improved results in the ability to detect drought, especially when evaluated with streamflow measurements. The system's ability and improved results have been presented to many of our end-user partners, currently being documented for papers and presented at major conferences.

* * *

Project: Satellite Enhanced Snowmelt Flood Predictions in the Red River of the North Basin

Principal investigator: Jennifer Jacobs, University of New Hampshire

Project year: 3

Year-end ARL: 4

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The objective of the project is to improve the NCRFC's operational flood prediction in the Red River Basin by using NASA products to update the NWS's operational forecasting models (SNOW17 model and Sacramento Sac-SMA) with spatially distributed estimates of state variables, including snow water equivalent, snow melt phase, snow-covered area, and meltwater partitioning parameters based on antecedent soil moisture. Once proven on the RRB, the same techniques will be available for use elsewhere within the NCRFC area of responsibility and at the remaining 12 RFCs.

End users: North Central River Forecast Center

Data sources, models, technology: SMM/I, AMSR-E, AMSR2, SMOS, SMAP, MODIS, SNODAS,

Major accomplishments in CY 2017:
- Satellite snow water equivalent (SWE) maps and times series distributed to NCRFC on a weekly basis during winter 2017 for use during forecasting
- Results from a strictly physically-based SWE algorithm distributed to NCRFC on a daily basis during the winter 2017 for use during operational forecasting.
- Results from winter season 2017 compiled and shared with NCRFC.
- Developed strategy to compare snow observations from traditional airborne gamma, USACE snow surveys, and ground sites to satellite observations
- Complete Detailed Characterization of User Decision-Making Process
- Demonstrated viability of microwave snow and soil moisture products in Red River of the North Basin

- Satellite snow water equivalent (SWE) maps and times series (including satellite and in situ measurements) created on a weekly basis November 1st 2016 – Apr 5th 2017 and distributed to NCRFC for use during operational forecasting
- Coordination meeting held on January 19, 2017 between four NASA projects that overlap in the Red River basin, meeting minutes shared with NASA project coordinator
- A new, physically-based SWE detection algorithm developed and tested to improve satellite SWE estimates and expand information content; data distributed to NCRFC on a daily basis during the winter 2017 for use during operational forecasting
- Coordinated GLISTIN-A airborne radar observation of the Buffalo Basin and Grand Forks flight lines; baseline lines flown on March 7, 2017
- Performed Intercomparison study to characterize differences in gridded SWE observations
- Satellite products (AMSR, UNH, SSM/I) provide a consistent record of peak SWE across the entire basin
- The satellite and model estimates provide consistent information in the south but differ in the north
- New satellite snow water equivalent (SWE) maps and times series created on a weekly basis for winter 2018; in distribution to NCRFC for integration into the decision support system
- Remaining technical issues of data integration into the decision support system are currently addressed and will conclude in the weeks ahead.

* * *

Project: The Global Reservoir and Lake Monitor (G-REALM): Sustained water level monitoring for Agriculture, Regional Security, and Inland Fisheries

Principal investigator: Charon Birkett, University of Maryland

Project year: 1

Year-end ARL: 2

Description: The objective of this project is to provide lake level products in a near real time framework. It will expand the current time line of merged products via integration of historical and future data sets. This includes the historical ESA ERS/Envisat dataset, and the NRL dataset. It also includes the future ISRO/SARAL, ESA/Sentinel-3 and NASA/NOAA Jason-3 data sets.

End users: USDA Foreign Agricultural Service (FAS)

Data sources, models, technology: Jason-1, Jason-2/OSTM, TOPEX/Poseidon, Sentinel-3 SARAL GDR

Major accomplishments in CY 2017:

- Extended the Jason-2/Jason-3 surface water level product series for 202 lakes and reservoirs with historical Topex/Poseidon and Jason-1 data. The resulting extended products, which now span the 1992-2017 period, are currently undergoing revision prior to delivery.
- Near real time products based on the SARAL, Jason-3 and Sentinel-3 missions. (Completed for the Jason-3 mission. Archive only SARAL products released in early 2017)
- The onboard altimeter on Sentinal was enhanced, providing higher spatial resolution in the along-track direction. The resulting surface water elevations will be provided at a new, 27-day resolution.
- New DEM was tweaked with CNES collaboration to correct errors in JASON 3 dataset. New dataset enables monitoring of very narrow lakes.

* * *

Project: The Quick Drought Response Index (QuickDRI): An Integrated Approach for Rapid Responses Agricultural Drought

Principal investigator: Brian Wardlow, University of Nebraska at Lincoln

Project year: 4

Year-end ARL: 9

Description: The project has developed a rapid-response drought monitoring tool called the Quick Drought Response Index (QuickDRI) that integrates satellite-based vegetation, evapotranspiration, and soil moisture data with climate index and biophysical data. QuickDRI is designed to map and monitor early-stage and rapid-onset vegetation flash drought stress, which is critical information needed to enhance the U.S. Drought Monitor (USDM) and associated key decision-making activities such as the multimillion-dollar USDA Livestock Forage Disaster Program that use the USDM.

End users: USDA Farm Service Agency, Livestock Forage Disaster Program, NOAA National Weather Service

Data sources, models, technology: Multiple NASA Earth science products characterizing key components of the hydrologic cycles affecting vegetation drought stress have been integrated into QuickDRI, including MODIS vegetation index data, GRACE and NLDAS soil moisture anomalies, and a *GOES*-based Evaporative Stress Index (ESI). Models are subsequently applied to gridded data to generate maps of short-term vegetation stress patterns across the continental United States.

Major accomplishments in CY 2017:

- This project was successfully transitioned to operations in 2017 at the National Drought Mitigation Center, achieving ARL 9.
- The QuickDRI maps were available through the USDM in 2017, and delivered to USDM authors and used in the development of drought maps that are the basis for drought reporting and eligibility for agriculture insurance payments across the U.S.

* * *

Project: Towards Operational Water Resources Management in South Asia Exploiting Satellite Geodetic and Remote Sensing Technologies

Principal investigator: Faisal Hossain, University of Washington

Project year: 3

Year-end ARL: 7.25

Description: In 2014, this project was selected for four-year funding as part of the A.45 Water Resources solicitation. The objectives of this project are to develop and transition multiple tools to respective end users. These tools include: (1) Satellite Precipitation and GCM-based forecasting of anomalies of water availability using hydrologic model for Ganges-Brahmaputra and Indus basins for IRSA and IWM-WRP; (2) GRACE and Altimetry (JASON-2/3, AltiKa, Cryosat-2, Sentinel-3, ICESat-2), ERA-Interim/MODIS based monitoring of glacier mass balance, elevation change for selected glacier and snow extent/depth change; (3) Satellite Altimetry based monthly-to-3-monthly monitoring of storage anomalies of surface water artificial reservoirs for IRSA; (4) GRACE-based monthly to seasonal monitoring of groundwater storage anomalies with sub-monthly frequency of updating for PCRWR and IWM-WRP; and, (5) Satellite Altimetry-based river level forecasting in the Ganges, Brahmaputra and Indus basins in near real-time made available at a web portal.

End users: Department of Hydrology and Meteorology (DHM-Nepal), Department of Hydromet Services (DHMS-Bhutan), Pakistan Council for Research on Water Resources (PCR WR-Pakistan), Indus River System Authority (IRSA-Pakistan), Institute of Water Modeling-Water Resources and Planning (IWM-WRP-Bangladesh), Flood Forecasting and Warning Center (FFWC-Bangladesh)

Data sources, models, technology: GRACE, JASON-2/3, AltiKa, Cryosat-2, Sentinel-3, MODIS, GCMs

Major accomplishments in CY 2017:

- GRACE SHC data is now operationally taken up by PCRWR for monthly groundwater storage change monitoring for Indus. PCRWR can now make linear ground water storage projections up to 60 days. (ARL 9)

- VIC based surface water nowcast, hindcast and FORECAST now available for South Asian stakeholders at http://depts.washington.edu/saswe (many agencies of Pakistan, Nepal, Vietnam and Bangladesh are using this operationally). Seasonal forecast component ADDED using SWAT model and NMME in Nov 2017. (ARL 5) Mangla Dam transboundary (Jhelum River basin) flooding for Pakistan Government. Satellite-based SMS system for improving water conservation and improving yield for Pakistan farmers expanded to 10,000 farmers. This is a volunteer effort (outside the project objectives) sustained with PCRWR budget. All scripts/tools transferred to PCRWR's new server on Nov 2017 (ARL 9 – this product was added later, but is already at 9)
- Nepal ARL is at 6 for GRACE/MODIS operationalization for snow/glacier monitoring.
- Additional activity: developed a crop water demand irrigation advisory, now being operationally delivered to 15,000 Pakistani Farmers. An impact assessment found an improved water savings AND crop yield.

Plans or expectations for 2018:

- Continue strong engagement with all end user agencies
- Fully operationalize use of GRACE data for snow/glacier monitoring via a web portal
- Increase satellite-based SMS system for monitoring farm conditions from 700 to 14000 farmers
- Integrate seasonal forecast component to surface water nowcast/hindcast tool

A. (2) WWAO Project Highlights from 2017

Project 1: Operational Analysis and Modeling with NASA's Airborne Snow Observatory

Project lead: Tom Painter, Jet Propulsion Laboratory

Description: The Airborne Snow Observatory (ASO) is a NASA airborne mission that provides water managers with the first ever estimates of basin-wide snow water equivalent, snow depth, and snow albedo. ASO began in 2012 as a cooperative effort between the California Department of Water Resources and NASA Terrestrial Hydrology, with flights over the Sierra Nevada and Colorado Rocky Mountains starting in 2013 and continuing to the present day. The objective of this project is to incorporate ASO data into precipitation runoff models in order to improve predictions of runoff throughout the Sierra Nevada. Decision makers will potentially use the information to inform decisions about water allocation and reservoir operation, including hydroelectric generation and flood management.

End users/decision-makers: California Department of Water Resources, U.S. Department of Agriculture Agricultural Research Service, San Francisco Public Utilities Commission, irrigation districts.

Data sources, models, technology: ASO measurements of snow depth, snow water equivalent and albedo.

* * *

Project 2: Satellite Mapping of Fallowed Agricultural Land for Drought Assessment

Project lead: Forrest Melton, Ames Research Center Cooperative Agreement for Research in Earth Science and Technology

Description: Scientists at NASA Ames Research Center working with the California Department of Water Resources, U.S. Geological Survey, U.S. Department of Agriculture, and California State University, Monterey Bay have shown it is feasible to use satellite imagery to track the extent of fallowed land in the Central Valley of California on a monthly basis. In direct response to state agency requests to extend this capability beyond California to other western states, NASA WWAO supported this Fallowed Area Mapping capability project during 2017. The data will be used to monitor the impact of drought on agricultural-land fallowing in near-real-time, and to help drought planning and response, particularly as part of the National Integrated Drought Information System Drought Early Warning System. Information about drought impacts will be shared with the public and state agency personnel working to mitigate the impact of drought on affected communities.

End users/decision-makers: Washington Department of Ecology, Washington Department of Agriculture, Nevada State Engineer's Office.

Data sources, models, technology: Landsat, MODIS, Sentinel-2A, NAIP, NASA Earth Exchange (NEX).

* * *

Project 3: A Land Information System that Improves Distribution of NASA Water Data

Project leads: Christa Peters-Lidard & Matt Rodell, Goddard Space Flight Center; Jay Famiglietti, Jet Propulsion Laboratory

Description: The goal of this project is to build a Land Information System that offers decision makers NASA's best assessment of water availability. This is done with a view to supporting California's recent Sustainable Groundwater Management Act of 2014, as well as the 200-300 emerging Groundwater Sustainability Agencies that must ensure compliance. This project leverages existing NASA land-surface modeling and satellite-data assimilation capabilities in a configuration optimized for the western U.S. The data will provide improved estimates of groundwater depletion as well as of the impact of drought on water quality.

End users/decision-makers: California State Water Resources Control Board, California Department of Water Resources, California Department of Food and Agriculture, Groundwater Sustainability Agencies.

Data sources, models, technology: SMAP, GRACE, MODIS/VIIRS, ASO, land-surface models.

* * *

Project 4: Operational Evapotranspiration for the State of New Mexico

Project leads: Joshua Fisher, Jet Propulsion Laboratory

Description: New Mexico is among the most arid states in the U.S. and consistently suffers from drought conditions that make agriculture, ranching, grazing, fire response, and other water-related activities difficult to manage. This project is working to deliver to the New Mexico Office of the State Engineer remote-sensing-based information that it can use to assess agricultural water use and drought conditions across the state, and improve water planning particularly during droughts.

End users/decision-makers: New Mexico Office of the State Engineer, U.S. Bureau of Reclamation, New Mexico State Forestry, New Mexico Department of Agriculture, New Mexico Fish and Game, U.S. Geological Survey.

Data sources, models, technology: Evapotranspiration, potential evapotranspiration, evaporative stress index, normalized difference vegetation index, albedo, land surface temperature, MODIS.

* * *

Project 5: Improving Crop Management and Decision Support

Project leads: Alberto Guzman, Ames Research Center Cooperative Agreement for Research in Earth Science and Technology

Description: The goal of this project to help growers and water managers in the western U.S. make more informed and efficient decisions about the amount of water and fertilizer to apply to crops. By combining two existing online tools (NASA's Satellite Irrigation Management system and CropManage), satellite, weather and soil data can be used to help growers tailor irrigation times and nutrient application to the specific needs of crops like lettuce, strawberries, broccoli and cabbage. NASA's Satellite Irrigation Management system provides detailed maps and trends of crop canopy conditions and irrigation demand, while CropManage is an app that helps growers and water managers make water and nitrogen-fertilizer decisions at the field level. Results suggest that water use can be significantly reduced with no loss of crop yield or

quality. The combined system is also expected to lower the cost of planning, water budgeting and reporting for compliance with California's Sustainable Groundwater Management Act.

End users/decision-makers: Commercial growers / shippers, agricultural water managers including farmers primarily on the California Central Coast, crop consultants, irrigation districts, groundwater sustainability agencies, state agencies. Initial focus is on California with potential expansion to stakeholders in the greater western U.S.

Data sources, models, technology: Landsat, MODIS, Sentinel-2, Satellite Irrigation Management system, CropManage app, remote-sensing-based vegetation indices, green fractional-crop cover, basal crop coefficients.

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Project 6: Satellite-Based Drought Reports for the Navajo Nation

Project leads: Amber McCullum, Ames Research Center

Description: The Navajo Nation is the largest federally-recognized Native American tribe in the U.S. in terms of land area, covering over 70,000 km^2 and occupying parts of northeastern Arizona, southeastern Utah, Southern Colorado, and northwestern New Mexico. With a population of over 200,000, the Navajo Nation is prone to frequent and pervasive droughts, and suffers from poor water-supply reliability. Over 40% of homes do not have direct access to potable water and must rely on water haulers. The goal of this project is to help improve the Navajo Nation Department of Water Resources Drought Report, which is presented to emergency managers and used to allocate drought-relief dollars throughout the community. Drought-relief funds, which are around $25 million, are currently disseminated throughout the Navajo Nation evenly among all agencies. A more informed Drought Report would help funds to be allocated in proportion to drought severity and needs.

End users/decision-makers: Navajo Nation Department of Water Resources, Navajo Nation Department of Emergency Management.

Data sources, models, technology: Navajo Nation rain-gauge data, multi-satellite precipitation product from TRMM and GPM, integrated multi-satellite retrievals for GPM, Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) (a quasi-global rainfall dataset), Drought Severity Evaluation Tool.

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Project 7: High-Resolution Soil Moisture Data for Monitoring Crop Conditions

Project leads: Rajat Bindlish, Goddard Space Flight Center

Description: Operational agencies like the U.S. Department of Agriculture's National Agriculture Statistics Service (NASS) provide agricultural forecasts and assessments that rely on best estimates of soil moisture. Currently these are created using ground input from farmers or field offices, which is an expensive approach that offers only sparse observations across different counties. For better forecasts, they need estimates that track changes in soil moisture with fine resolution over both space and time. This WWAO-funded project is working to explore the feasibility of using soil-moisture data from satellites to improve measures of soil moisture at both ground-level and in the root-zone for NASS, and to satisfy its operational data needs. The information will be helpful for the NASS Crop Weather report, crop grower associations and other agricultural groups.

End users/decision-makers: U.S. Department of Agriculture's National Agriculture Statistics Service (NASS) (Pacific and Northern Plains Regions), crop grower associations such as the Almond Board, agricultural extension groups and university contacts.

Data sources, models, technology: SMAP, SMOS, SMAP-Sentinel product.

Notably, in 2017, WWAO's Applications Transition team worked to develop a business case for transitioning WWAO's ASO-related pilot project into a potential operational forecasting resource. This effort included an analysis of comparable offerings in the current market and potential revenues that could be generated, and a report on the market viability of the capability. WWAO continues to work on developing and executing an implementation plan for the transition of this project, as well as others in the pipeline.

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B. Abbreviations & Acronyms

AGU: American Geophysical Union
AMIS: Agricultural Market Information System
AMSR-E: Advanced Microwave Scanning Radiometer - Earth Observing System
ARC: Ames Research Center
ARL: Application Readiness Level
ASCAT: Advanced SCATterometer
CADRE: Crop Condition Data Retrieval and Evaluation
CBRFC: Colorado Basin River Forecast Center
CDWR: California Department of Water Resources
CFS: Climate Forecast System
CONUS: Contiguous United States
CY: Calendar Year
DSS: Decision Support System
DSSAT: Decision Support System for Agrotechnology Transfer

Envisat: Environmental Satellite
EPA: U.S. Environmental Protection Agency
EROS: Earth Resources Observation and Science
ESA: European Space Agency
ESD: Earth Science Division
ESI: Evaporative Stress Index
ETM+: Enhanced Thematic Mapper Plus
FAS: Foreign Agricultural Service
FEWS NET: Famine Early Warning System Network
G-REALM: Global Reservoir and Lake Monitor
G20: Group of 20
GDAS: Global Data Assimilation System
GEO: Group on Earth Observations
GEOGLAM: GEO Global Agricultural Monitoring
GEOGLOWS: GEO Global Water Sustainability
GEOS-5: Goddard Earth Observing System Model, version 5
GEOSS: Global Earth Observation System of Systems
GLDAS: Global Land Data Assimilation System
GOES: Geostationary Operational Environmental Satellite
GPM: Global Precipitation Measurement Mission
GRACE: Gravity Recovery and Climate Experiment
GSFC: Goddard Space Flight Center
JPL: Jet Propulsion Laboratory
LIS: Land Information System
MERIS: MEdium Resolution Imaging Spectrometer
MODDRFS: MODIS Dust Radiative Forcing in Snow
MODIS: Moderate Resolution Imaging Spectroradiometer
MODSCAG: MODIS Snow Covered Area and Grain size
NASA: National Aeronautics and Space Administration
NASS: National Agricultural Statistics Service
NCRFC: North Central River Forecast Center
NDMC: National Drought Mitigation Center
NGO: Non-Governmental Organization
NLDAS: North American Land Data Assimilation System
NOAA: National Oceanic and Atmospheric Administration
NRL: U.S. Naval Research Laboratory
OLI: Operational Land Imager
OSTM: Ocean Surface Topography Mission
PEER: Partnerships for Enhanced Engagement in Research
PI: Project Investigator
Sac-SMA: Sacramento Soil Moisture Accounting
SeaDAS: SeaWiFS Data Analysis System
SIMS: Satellite Irrigation Management Support

SMAP: Soil Moisture Active Passive
SMOS: Soil Moisture and Ocean Salinity
SNODAS: Snow Data Assimilation System
SSM/I: Special Sensor Microwave Imager
SWAT: Soil and Water Assessment Tool
SWE: snow water equivalent
TM: Thematic Mapper
TMPA: TRMM Multi-satellite Precipitation Analysis
TOPEX: Topography Experiment
TRMM: Tropical Rainfall Measuring Mission
UN: United Nations
USACE: United States Army Corps of Engineers
USAID: United States Agency for International Development
USDA: United States Department of Agriculture
USGS: United States Geological Survey
VIC: Variable Infiltration Capacity
VIIRS: Visible Infrared Imaging Radiometer Suite
WWAO: Western Water Applications Office

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