EARTH SCIENCE
APPLIED SCIENCES

2020 ANNUAL SUMMARY

WATER RESOURCES

NASA Earth Science
Applied Sciences Program

2020 Annual Summary for the Applied Sciences Program Water Resources Application Area

Table of Contents

ACRONYM LIST

AGU	American Geophysical Union
AIRS	Atmospheric Infrared Sounder
ARL	Application Readiness Levels
ASCE	American Society of Civil Engineers
ASO	Airborne Snow Observatory
AWRA	American Water Resources Association
AWWA	American Water Works Association
CA-DWR	California Department of Water Resources
CASMA	Crop Condition and Soil Moisture Analytics
CDWR	California Department of Water Resources
CEOS	Committee on Earth Observation Satellites
CRB	Columbia River Basin
DRI	Desert Research Institute
DSET	Drought Severity Evaluation Tool
DWR	Department of Water Resources
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment On Space Station
EO	Earth observations
EPA	Environmental Protection Agency
ESI	Evaporative Stress Index
ETD	Evapotranspiration Data
EWRI	Environmental Water Resources Institute
FAS	Foreign Agricultural Service
FINESST	Future Investigators In NASA Earth and Space Science and Technology
GCOS	Global Climate Observing System
GEO	Group On Earth Observations
GEOGLAM	Group on Earth Observations Global Agricultural Monitoring
GEOGloWS	Group On Earth Observations Global Water Sustainability
GIS	Geographic Information System
GPM	Global Precipitation Measurement
GRACE-FO	Gravity Recovery And Climate Experiment Follow-On
GREALM	Global Reservoirs and Lakes Monitor
ICESAT-2	Ice, Cloud and land Elevation Satellite-2
IMERG	Integrated Multi-satellitE Retrievals for GPM
ISAT	IWWG Science And Applications Team
ISRO	Indian Space Research Organisation
IWWG	Interagency Water Working Group
JAWRA	Journal of American Water Resources Association
JPL	Jet Propulsion Laboratory
LIS	Land Information System

LST	Land Surface Temperature
MERRA	Modern-Era Retrospective analysis for Research and Applications
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
NIDIS	National Integrated Drought Information System
NISAR	NASA-ISRO Synthetic Aperture Radar
NLDAS	North American Land Data Assimilation System
NNDWR	Nation Department of Water Resources
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PI	Principal Investigator
R2O	Research to Operations
ROSES	Research Opportunities in Space and Earth Sciences
SBG	Surface Biology and Geology
SESR	Standardized Evaporative Stress Ratio
SMAP	Soil Moisture Active Passive
SWE	Snow Water Equivalent
SWOT	Surface Water and Ocean Topography
TIR+MW	Thermal Infrared and Microwave
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	United States Geological Survey
WGCV	Working Group on Calibration & Validation
WRP	Water Resources Program
WWAO	Western Water Applications Office

I. INTRODUCTION

The Earth Science Division's 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 to stakeholders. The projects are carried out in partnership with public- and private-sector organizations to achieve sustained use and sustained benefits from Earth observations.

The Applied Sciences Program's applications themes are currently focused on five of the eight Societal Benefit Areas (SBAs) of the interagency Group on Earth Observations (GEO): Agriculture Disasters, Ecological Forecasting, Health (including Air Quality), and Water Resources.[1] The program assesses climate-related influences and impacts within each of these themes and includes crosscutting elements such as Capacity Building.

This annual summary highlights the accomplishments and management of the Water Resources application area throughout 2020.

Water Resources

The Applied Sciences Water Resources application area works to address the world's water management challenges. These water management challenges of today and tomorrow cannot be solved solely by Earth observations; however, Earth observations are essential to develop strategies to resolve these issues. NASA's leadership and expertise provide the unique ability to deliver Earth observations and the resulting Earth systems knowledge to water resource managers in the U.S. and across the globe.

The Water Resources application area currently supports a diverse range of projects addressing topics such as 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-observing 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

[1] The eight USGEO SBAs are Agriculture, Disasters, Ecosystems, Energy, Health, Infrastructure & Transportation, Urban Sustainability, and Water.

observation networks, and the resulting models 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, non-governmental organizations [NGOs], and industry) in the United States and internationally to ensure cost-effective and beneficial solutions are provided to water resources managers.

Western Water Applications Office (WWAO)

The Applied Science Program's Water Resources application area includes the Western Water Applications Office (WWAO)—a NASA program based at the Jet Propulsion Laboratory in Pasadena, California. WWAO's mission is to get NASA data, tools, and technology into the hands of water managers and decision-makers in the western U.S. It identifies what water managers in the west need, matches high-priority needs to NASA capabilities and technology, and builds applied science projects that translate NASA's power of perspective into action on 21st-century water issues. WWAO delivers operational tools that offer the power of NASA's remote sensing and data to water managers.

II. OVERVIEW AND ASSESSMENT OF 2020

The Water Resources team continued to make strides in addressing critical water challenges in the U.S. and globally throughout 2020. The application area supports a portfolio of research projects; educates the community on the benefits of using Earth observations in natural resources management; provides leadership by contributing to international, interagency, and regional working groups; and actively advances relevant technology and capabilities through various program initiatives for the betterment of society.

Overview of 2020

The Water Resources application area including WWAO oversaw a portfolio of thirty-eight applied projects, five of which were completed in 2020. The Water Resources application team is proud to have supported many applications in 2020 that have achieved, or are working towards, successful integration into decision-making processes for improved water resource management. For example, the OpenET platform (a web-based platform that provides easily accessible satellite-based estimates of evapotranspiration (ET) for improved water management) had a soft launch in September 2020, making evapotranspiration data available to water managers and agricultural producers in the western United States, and the Cyanobacteria Assessment Network (CyAN) broadened its reach and value in 2020 by enabling additional state agencies to access cyanobacteria index metrics and information.

In addition to supporting funded projects spanning topics such as drought, climate impacts on water resources, water quality, and streamflow forecasting/flood monitoring, the Water Resources application area was also very active in national and regional water resources community groups in the U.S. and internationally. The team engaged with the operational, policy, and practitioner communities as well as Earth-science communities, attending multiple practitioner meetings and conferences such as the American Geophysical Union's Fall Meeting, the American Meteorological Society's Annual Meeting, Western States Water Council meetings, the American Water Works Association's meetings, National Soil Moisture meetings, and Committee On Earth Observation Satellites meetings, among others. In addition, WWAO staff gave a keynote talk at the Southwestern Extreme Precipitation Symposium, and are exploring opportunities for collaboration with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service.

Throughout 2020 the team strengthened ongoing partnerships and worked with new partners to bring the value of Earth observations to the water resources community. The Applied Sciences Program facilitated conversations and collaborations across professional societies, including American Water Resources Association, the American Water Works Association, and the American Society of Civil Engineers, as well as with non-profit and NGOs such as the Walton Family Foundation and the Gates Foundation.

Assessment

2020 was a challenging year. In some cases, the impacts of COVID affected science advancements and research. Water Resources project team members experienced work delays, shifting responsibilities at work and at home, and even the illness of themselves, family, and colleagues.

In the face of challenging times, this community demonstrated incredible strength and resilience. Many projects adjusted to the new environment. Project teams adopted

innovative ways of communicating and collaborating virtually, conducting training sessions and engagements with stakeholders remotely, and stakeholders stepped up to deliver ground data at sites that project teams could no longer access.

In this way, the Principal Investigators (PIs), the science and applied science communities, and project teams set the precedent for the Water Resources application area management team. It was their drive and ingenuity that inspired the management team to be flexible and innovative. The Water Resources application area hosted the 2020 Annual Meeting remotely and conducted all quarterly project meetings virtually. The team extended deadlines as needed and shared NASA resources that could help support research impacted by COVID. Given WWAO's NASA-wide team and distributed network of water partners, WWAO was able to pivot quickly to remote operations and continue growing the portfolio and program activities.

While the program continued to support research and activities through the adversities of COVID, some projects did face challenges that halted or significantly delayed project progress. Projects that were transitioning capabilities to the resource agencies could no longer enter agency buildings and could not conduct the planned training, testing, and/or field work. Some field sites became inaccessible, including a village in Alaska that was not allowing anyone to fly in or out, yet was the only access point to a stream gauge needed for validation. Other projects experienced delays due to team bandwidth as work hours reduced. Many of these projects have requested or will request a no cost extension to continue the work into 2021 and 2022.

For WWAO, the main impact of COVID was on in-person interactions that had been planned for 2020 – primarily capacity-building workshops for mature projects, WWAO's second interagency Research to Operations Workshop, and technical interchanges with WWAO's Water Alliance partners. Some workshops and conferences were held virtually, and in many cases WWAO was able to reach a broader-than-usual audience. Capacity- and partnership-building were achieved virtually, as was WWAO's private-sector needs assessment.

Lastly, the pandemic also spurred the scenarios of new demands from our stakeholders for information due to lost ability to acquire ground information and an inability to meet these demands due to lost resources and restrictions. In some cases, projects supported by the Water Resources application area were able to help stakeholders. For example, many state partners were no longer able to conduct routine water quality testing and surveys to test for cyanobacteria and associated toxins due to budget reallocations as well as safety concerns. State partners indicated that the data products from Cyanobacteria Assessment Network (CyAN) Project CyAN, derived from satellite remote sensing, would provide the only insight into the state of harmful algae blooms in the reservoirs and water bodies they managed. For the western communities, WWAO's Navajo Nation Drought Severity Evaluation Tool (DSET) and the Airborne Snow Observatory helped fill the gaps in drought reports and snow surveys, respectively, when COVID hampered partners' ability to collect

crucial ground-based data. As we leave 2020, we can and will find new pathways to meet these demands in collaboration with our scientists and our partners.

III. PORTFOLIO OF RESEARCH PROJECTS

The Water Resources application area managed thirty-eight active projects in 2020, thirty-one of which were funded through NASA Research Opportunities in Space and Earth Sciences (ROSES) solicitations and seven of which were formulated and implemented through WWAO. Three projects were completed this year from the 2013 NASA A.45 ROSES solicitation led by the Water Resources element and two additional projects were transitioned to partners through WWAO.

Of the thirty-three projects that will continue in 2021, eight projects are from the ROSES 2016 A.37 solicitation focused on water quality and agricultural water use. Thirteen projects are from the 2018 A.36 ROSES solicitation focused on supporting applied research to monitor and assess local and regional water quality and quantity for improving water resource risk assessment, economic planning, investment planning, and policy making.

The Water Resources application area manages four international projects through Group on Earth Observations Global Water Sustainability (GEOGloWS), an element of the Group on Earth Observations solicitation sponsored by NASA's Applied Sciences Program. Two of the projects managed by the application area are funded through the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) solicitation. The team also manages a joint project on cyanobacteria with NASA's Research and Analysis Program, the Environmental Protection Agency (EPA), NOAA, and United States Geological Survey (USGS).

WWAO supported seven water projects in 2020 – two of which were transitioned to a partner entity during 2020. WWAO also initiated two new projects that address drought and evapotranspiration gaps in the Colorado River Basin.

Portfolio Performance

Projects report progress by advancing through Application Readiness Levels (ARLs). The ARL is intended to correspond with the maturity of Earth science applications projects and allows NASA to track integration of Earth science information into decision-making processes by articulating expected advancement along a continuum, from fundamental research to application and sustained operations. Twenty-seven of the thirty-eight projects within the portfolio report ARLs.

Table 1, at right, shows the ARL distribution of these projects at the end of the calendar year 2020, including the final ARL achieved by the three completed projects, and the status of the twenty-four ARL-tracked projects that will continue into 2021. Sixty-three percent of the projects (17 out of 27 projects) advanced at least one ARL during calendar year 2020.

Table 1: 2020 ARL advancements

ARL Levels of the 27 ARL-tracked projects managed by the Water Resources application area in 2019

ARL	# of projects at each ARL **Dec 2019**	# of projects at each ARL **Dec 2020**
9	0	0
8	0	3
7	0	3
6	5	7
5	5	3
4	8	6
3	6	3
2	3	2
1	0	0

Completed Projects

The following five projects (three from the Water Resources application area portfolio and two WWAO projects) were completed or transitioned in 2020:

- WWAO's Drought Severity Tool was transitioned to the Navajo Nation Department of Water Resources (NNDWR) for operational use, and a user guide was released. It remains a sustainable application with the support of the Desert Research Institute. Training and applications with other Navajo departments continue, funded by the S.D. Bechtel Jr. Foundation. Of the effort, Carlee McClellan (NNDWR) has said: "I'm full-blooded Navajo – I grew up on the Navajo Reservation. It is monumental to have an organization like NASA work with us to diversify and augment the water tools we have at our disposal."

- A project completed by Jay Day and Jonathan Quebemann (RTI International) attained the goal of a final ARL 6. The project, Advancing Water Supply Forecasts in the Colorado River Basin for Improved Decision Making, worked to couple advanced data assimilation techniques with distributed hydrologic modeling to provide improved water supply forecasts for the Colorado River basin. The project team also worked 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. The team used NASA data, products, and resources including NASA Moderate Resolution Imaging Spectroradiometer (MODIS), MODIS Snow-Covered Area and Grain size (MODSCAG), MODIS Dust Radiative Forcing in Snow (MODDRFS,) Global Precipitation Measurement (GPM), Integrated Multi-satellitE Retrievals for GPM (IMERG), North American Land Data Assimilation System (NLDAS), Utah Energy Balance Snow Model, National Weather Service's Research Distributed Hydrologic Model, Community Hydrologic Prediction System, and high-performance computing resources provided by the NASA Earth Exchange.

- PI Amir AghaKouchak, (University of California, Irvine) wrapped up his work with California Department of Water Resources (CDWR) at an ARL 5. The primary goal of this

project was to improve drought monitoring and prediction in California through: a) using NASA's Atmospheric Infrared Sounder (AIRS) relative humidity and water vapor measurements 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 made substantial technical progress on the development of probabilistic forecasting frameworks, but also highlighted challenges with sustaining these types of applications for operational use at state agencies.

- WWAO's support of the NASA Airborne Snow Observatory (ASO) Runoff Forecasts ended in 2020. WWAO's Airborne Snow Observatory Runoff Project established operational pathways for ASO data to improve forecasts at NOAA's Colorado River Basin Forecast Center. Seth Shanahan (Southern Nevada Water Authority) addressed the uptake of the data: "The product will be used by the Colorado Basin River Forecast Center and the Bureau of Reclamation to help improve streamflow forecasts and reservoir operations in the Colorado River Basin."

- Using NASA's precipitation data and models, PI Mekonnen Gebremichael (University of California, Los Angeles) worked with Ethiopian partners to complete the project, Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts. This project improved 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. The project reached an ARL 7 when Mekonnen and the team carried out multiple training sessions with Ethiopian partners so they could effectively integrate NASA's data into the dam's management.

Notable Project Advancements

- On September 15, 2020, Applied Sciences announced the soft release of OpenET, a web-based platform that puts NASA Earth science data on water use into the hands of farmers, water managers, and conservation groups. Until PI Justin Huntington and his team created OpenET, there was no operational system for measuring and distributing daily evapotranspiration data on the scale of individual fields. Information on evapotranspiration—the process by which water leaves soil and plants—is crucial for farmers and other water managers. During this trial period, OpenET is available to more than 100 partners and state agencies for testing and use in case studies. OpenET is scheduled for a full public launch in summer 2021 and will supply evapotranspiration data across 17 western U.S. states.

- A project led by the University of Colorado, Boulder and the NASA Jet Propulsion Laboratory (JPL) (PI Noah Molotch) advanced to ARL 8 when the California Department

of Water Resources (DWR) integrated remotely sensed Snow Water Equivalent (SWE) estimates from the project into operational data reporting systems and bi-weekly updates on snow water resource conditions in the Sierra Nevada. Water allocation decisions, which heavily impact agriculture operations in California, are informed by forecasts of streamflow volume issued by the California Department of Water Resources (CA-DWR). Streamflow volume in parts of California are dependent on natural water storage in the form of the Sierra Nevada snowpack, which represents approximately 14 million acre-feet of water annually. SWE, a measurement of the amount of water contained within the snowpack, is a key influencing factor of these streamflow forecasts. Through a NASA Applied Water Resources grant, Noah Molotch and his team have shown that remotely sensed SWE measurements from sensors onboard NASA's Terra and Aqua satellites can significantly improve forecasts. The project team produces real-time SWE tables and maps, which have been integrated into the decision-making process by CA-DWR. This project advanced to an ARL 8 when CA-DWR dedicated funding to Moltoch's research team to produce the near-real-time SWE reports, tables, and modeled spatial output for water year 2020.

- In 2020, the Idaho Department of Environmental Quality added information from the Cyanobacteria Assessment Network (CyAN) as a layer to their geographic information system (GIS) maps. CyAN is a multi-agency project involving NASA, NOAA, the EPA, and the USGS to develop an early warning indicator system for algal bloom detection in U.S. freshwater systems. This project utilizes 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.

- A project titled, Maximizing Utility of Remote Sensing Data for Water Quality Monitoring and Resources Management in California's Water Systems, aims to operationalize the implementation of water quality algorithms to support water quality monitoring and management in California focusing on turbidity (a bulk indicator of water column scattering and absorption), chlorophyll-a (phytoplankton pigment), and temperature. These variables are all important to management of water quality and resources in California's water systems; turbidity and temperature are integral to water quality compliance measures, motivated by the need to minimize detrimental impacts on endangered species such as the Delta smelt. In 2020, the team presented their results on the temperature results as monitored by remote sensing. Partners from the Metropolitan Water District requested additional analyses utilize remote sensing derived water quality parameters. Project team members Christine Lee and Gregory Halverson also briefed the Lead Scientist from the California Department of Water Resources.

- WWAO's High-Resolution Soil Moisture App, Crop-CASMA (Crop Condition and Soil Moisture Analytics), was released for operational use by the USDA National Agricultural Statistics Service, giving farmers, researchers. and meteorologists access to higher-

resolution soil moisture data. WWAO's collaboration with the USDA forms part of a larger, recently signed Memorandum of Understanding between the USDA and NASA to strengthen agricultural and Earth science research. Rick Mueller, USDA National Agricultural Statistics Service (NASS) Spatial Analysis Research Lead, said of the transition: "We are very pleased to release … Crop-CASMA. These satellite-derived vegetation condition indices and soil moisture condition maps show firsthand the ever-changing face of U.S. agriculture. They contribute extensively to operations and research on various issues, including agricultural sustainability and extreme weather events, such as flooding and drought."

- In 2020, Google Earth Engine and NASA's Soil Moisture Active Passive (SMAP) mission were both leveraged to assess California's fire susceptibility. Satellite-based fire detections in Northern California in late 2020 have revealed unprecedented increases in fire activity. Satellite-based soil moisture observations can help better anticipate the potential impact of fire on soil water availability and crop production. In addition, satellite-based soil moisture observations can aid our understanding of the linkage between soil moisture and fire, and their combined impact on crop health and crop production. The cloud-based data enabled by a NASA - Google Earth Engine partnership demonstrate the value of concurrent satellite-based measurements for mapping, monitoring, and assessing regional fire potential impact and susceptibility. PIs John Bolten and Nazmus Sazib produced an analysis of satellite-based maps of soil moisture deviations from average conditions (anomalies) and observed fires over California. The analysis shows that a decrease in soil moisture is followed by a high occurrence of forest fires. The information and figures highlighting the linkage between soil moisture and susceptibility of wildfires can be seen in the article on the Disasters Program webpage.

IV. PROGRAM MANAGEMENT

In 2020, the Water Resources application area adopted a flexible management approach focused on the personal needs of the community, not just the science and research needs. The program chose to place the health, wellbeing, and safety of the staff and research teams as the foremost priority. The program implemented new and flexible practices and processes that could accommodate reduced work hours and shifting priorities of the larger team. This approach included deprioritizing anticipated 2020 staff tasks and extending deadlines for project reports. As did most of the world, the program began using virtual platforms to host meetings and events to stay engaged with partners, end-users, and project teams. Despite the challenges of 2020, the program still succeeded in reaching many of the year's goals.

Program Events

To connect researchers and stakeholders, the program hosted team meetings and events for community members. On July 20-23, the annual NASA Applied Sciences' Water Resources and WWAO team meeting highlighted achievements by 37 projects, NASA's Western Water Applications Office, and scores of user organizations, including the Bureau of Reclamation, the Navajo Nation, and the state of California. Each day over 85 people tuned in to seven sessions on hydrologic forecasting, water quality, evapotranspiration, groundwater monitoring, and more. The overarching purpose of the meeting was to provide a forum for the NASA-supported water resources community of PIs, water resources partners, and stakeholders to exchange information, share updates, and collaborate on remote-sensing applications for water resources management. NASA Water Resources Program Manager Dr. Bradley Doorn opened the meeting with an introduction highlighting the vision and strategic direction of the program. Next, PIs from the NASA Applied Sciences Water Resources portfolio gave a series of presentations addressing water resource issues across the U.S. These presentations covered topics such as: 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 of algal blooms and modeling of nutrient loading. Highlights included presentations from PIs on the technology transition process and their experiences leading applied science activities.

The program also hosted sessions on remote sensing for water resources at the American Water Works Association Annual Conference (AWWA ACE20) and the virtual American Geophysical Union (AGU) Fall Meeting. At the 2020 AGU Fall Meeting, the program convened two oral sessions and one poster session titled, "Remote Sensing Applications for Water Management." In total, the sessions included 40 presentations focusing on novel applications of satellite-based observations, including several presentations from program PIs, including Charon Birkett's presentation, "The Global Water Monitor: A New Phase in the Operational Monitoring of Lakes, Wetlands, and River Reaches for Resources Management and Hazard Observation;" and Wade Crow's presentation, "High-resolution monitoring of root-zone soil moisture for vineyard irrigation scheduling." WWAO also hosted a technical session at the virtual AGU 2020 Fall Meeting. The session titled, "Science to Action: Enabling Science- and Data-Driven Water Management," featured presentations from 30 key stakeholders in the field.

Partnerships

The Water Resources application area aims to be a leader in forging non-traditional partnerships with new organizations, including private and non-profit institutions. In 2020, this effort included participating in roundtables, and collaborating with entities like the Walton family Fund, the Gates Foundation, the American Water Resources Association, and Mercy Corps. While there is real interest in NASA from the private sector, partnerships with

private entities need to have a well-defined return on investment for the partner to justify their investment in NASA over other opportunities. Collaborations must offer a win-win proposition

Ongoing partnerships with the program's federal and state partners continue to thrive, including partnerships with the Group on Earth Observations Global Water Sustainability (GEOGloWS) support, Western Federal Advisory Support Team (WestFAST), the Department of State Interagency Water Working Group (IWWG), as well as bilateral agency collaborations. Through the IWWG, the program partnered with the U.S. Army Corps of Engineers and the U.S. Air Force to form the IWWG Science and Applications Team (ISAT). ISAT formalizes a nearly two-decade collaboration between the U.S. Army Corps of Engineers (USACE), NASA, and the U.S. Air Force aimed at improving and fielding science and engineering technology that bridges the gap between prediction of Earth global hydrologic cycle properties and decision-making processes in order to more thoroughly understand global food and water security challenges.

Coordination with other NASA programs

The Water Resources application area used 2020 as an opportunity to strengthen ties and increase coordination activities with other programs within NASA. The program participated in working groups and meetings pertaining to missions such as ECOSTRESS, Surface Water and Ocean Topography (SWOT), and Soil Moisture Active Passive (SMAP); participated in the Administration's Designated Observables work and contributed to the working groups for Mass Change and Surface Biology & Geology; collaborated with the Future Investigators in NASA Earth and Space Science and Technology (FINESST) program; and coordinated with other applied programs and the Terrestrial Hydrology focus area of the Research and Analysis Program.

The Water Resources application area also works closely with mission teams. In 2020 the program participated in a series of technical interchanges with the NASA- Indian Space Research Organisation (ISRO) Synthetic Aperture Radar (NISAR); SWOT; Ice, Cloud and land Elevation Satellite-2 (ICESAT-2); Gravity Recovery and Climate Experiment Follow-on (GRACE-FO); Global Precipitation Measurement (GPM); and SMAP Earth missions. WWAO shared its online catalog of water management needs with missions in an effort to ensure needs are considered for Science and Applications Traceability Matrices and community assessments. WWAO examined the mission science-team projects for data products relevant to water stakeholder needs. In 2020, the NASA-CNES SWOT mission applications team led a four-day virtual hackathon where computer programmers and domain experts used pre-launch SWOT simulated data for real-world applications, such as improving flood forecasting over the Godvari basin in India.

Communications

2020 brought on a dramatic increase in the types of communications used to showcase the program's work. The Applied Sciences communications team highlighted significant application project milestones and also put a spotlight on some of the incredible team members moving this work forward. The personal stories published in 2020—including those of NASA Associate Program Manager Christine Lee, researcher Alberto Guzman, and partner Nikki Tulley from the Navajo Nation— showcased how the program engages and effects a wide breadth of individuals.

In addition to the articles on the Applied Sciences website, four stories highlighting the work supported by the Water Resources application area were posted on the NASA.gov website. These stories covered Rajat Bindlish's (NASA) work producing high resolution soil moisture for USDA; Bill Kustas's (USDA) work on improving water management for vineyards, *Raising a Glass in Wine Country to Better Water Management*; Blake Schaeffer's (EPA) work on detecting algae blooms with satellites, *Early Detection of Algae 'Blooms' by Satellite Yields Healthcare Savings*; and Justin Huntington's (Desert Research Institute) project on measuring Evapotranspiration, *Transforming Water Management in the U.S. West with NASA Data*.

The program's work was also shared through social media. There were 33 postings on NASA's Twitter accounts and 21 postings on NASA's Facebook accounts in 2020 that highlighted the work of the water resources application area.

The program has developed a communications plan for 2021 and 2022 to build on momentum already achieved in 2020 and continue to broadcast the program's successes and milestone achievements, and bring special attention to the phenomenal partners, researchers, and team members that make it all possible. In addition to utilizing the NASA websites, the program aims to collaborate with other entities to leverage their platforms to reach new audiences and educate them on the value of Earth observations for water resource management.

V. COMMUNITY LEADERSHIP

Water Resources application area team members are truly leaders in the field. The program staff represented the community at countless domestic and international conferences and events, enabling program scientists to advance research while simultaneously building bridges and channels of communications with potential partners and stakeholders.

The Water Resources team hosted sessions and events that allowed PIs and project teams to showcase their work and circulate their findings. In 2020, this effort included sessions at the American Geophysical Union's Fall meeting and at the annual conference of the American Water Works Association.

At the 2019 NASA Water Resources Annual Team Meeting, the WRP community provided feedback to the program on the importance of publishing applications and applied sciences research for career advancement and for documenting methodologies and work with stakeholders. As a result, the WRP team worked with the American Water Resources Association (AWRA) in 2020 to produce a forthcoming special issue on NASA water projects in the Journal of the American Water Resources Association (JAWRA). The issue received 15 submissions.

Committees and Boards

The program furthers the uptake of Earth observations (EO) for water by contributing to multiple regional and interagency boards and committees. The Water Resources application area staff represent NASA by participating in various committees, boards, and leadership organizations. These organizations range from international organizations and interagency working groups to regional/local committees. Some examples include the Western States Federal Agency Support Team (WestFAST), National Integrated Drought Information System (NIDIS) Interagency Working Group, National Coordinated Soil Moisture Monitoring Network, Interagency Water Working Group, National Drought Resiliency Partnership, the United Nations Framework Convention on Climate Change, the American Society of Civil Engineering Remote Sensing of Water Quality Technical Committee, the Committee on Earth Observation Satellites Land Product Validation, and the steering committee for Pecora.

This past year, program staff were asked to join new committees including the Freshwater Harmful Algae Blooms (FHABs) Technical Committee for the state of California and the Advisory Board of the Mekong Dam Monitor.

Water Management Needs

In 2020, WWAO published its assessment of public-sector water management needs in the U.S. Columbia River Basin (CRB). The report was the culmination of in-depth interviews and a workshop convened with a cross-section of over 20 CRB stakeholders including policy makers, planners, water management officials, and end-users. WWAO boiled down the 15 top-priority stakeholder needs from an initial set of 54, and documented obstacles to meeting those needs. Key areas of need in the CRB include water use (agricultural), water quality, water availability, and watershed health.

WWAO began water needs assessments in the Missouri and Rio Grande River Basins, following a similar approach to that developed for the Columbia and Colorado River Basins.

As part of WWAO's Water Alliance with the private sector, the team conducted an assessment to understand perceived needs in the water industry. Ten organizations took part in detailed interviews with WWAO. The inputs were published in an internal report. Organizations participating in the assessment included geospatial data providers (Esri, Quantum Spatial, Maxar Technologies); companies that supply infrastructure, treatment, and engineering services (Tetra Tech, Jacobs Engineering, Parsons, AECOM); a provider of water technology acceleration (Waterstart); a water utility (California Water Services Group); and a foundation focused on freshwater conservation and restoration (The Freshwater Trust). On the whole, interviewees responded positively about exploring collaboration and technology-transition opportunities with WWAO and expressed enthusiasm about how NASA might inform remote-sensing solutions for the water industry.

WWAO launched an online NASA Water Portal that catalogs the high-priority western water management needs it has identified and NASA capabilities that could be readily harnessed by stakeholders in the west. The portal is designed for use by water managers and researchers. Stakeholders can submit their own needs and capabilities and explore existing ones through an interactive map and interface. The Internet of Water invited WWAO to present its new Water Portal to its board. WWAO also launched a redesigned version of its website to support the new portal.

Setting the Standard

By supporting applications research and through direct participation by program staff, the Water Resources application area contributed to the creation and release of multiple internationally recognized, standard-setting documents. One example was the 2020 release of the Soil Moisture Product Validation Good Practices Document**.** The final community-accepted version was endorsed by the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration & Validation (WGCV). The Global Climate Observing System (GCOS) included soil moisture in its list of Essential Climate Variables (ECVs) to express the important role soil moisture plays in Earth's water, energy, and carbon cycle. Soil moisture has a major impact on agriculture, land surface hydrology, weather, and climate forecasting. This document is a community-based effort to provide recommendations on good practices for the validation of global to regional soil moisture products.

Technology Transition

WWAO is uniquely placed to help transition water technology from NASA to partners managing water in the western United States. Its focus on Research to Operations (R2O) carves paths to water decision-makers and boosts spinoff efforts. In 2020, WWAO staff co-wrote a paper on best practices for achieving R2O in the water sphere with the Western

States Water Council and U.S. Environmental Protection Agency. The paper's conclusions are consistent with results from WWAO's 2019 Technology Transition Workshop and ongoing work to boost federal R2O.

WWAO has worked with NASA's ASO since 2016 to transfer applications of remotely sensed snow data to western water managers. ASO can forecast snow water equivalent (SWE) with 98% accuracy and, in 2018, WWAO's business-case analysis determined that a commercial spinoff of ASO was viable. WWAO's snow projects from 2016 to 2020 established operational pathways that enabled ASO data to improve forecasts at the California Department of Water Resources and Colorado River Basin Forecast Center. Collectively, this work helped culminate in ASO spinning off to the private sector.

Although the ASO was fully transitioned from NASA to the commercial sector in 2019, WWAO continued to monitor ASO, Inc. and observed strong indicators of the value of ASO data for water management in the West. For example, in August 2020, the U.S. Senate and House of Representatives put forward bills to fund airborne snow surveys under a Snow Water Supply Forecasting Program run out of the Department of Interior/U.S. Bureau of Reclamation.

In 2020, WWAO also kicked off a market evaluation study to investigate the value of field-scale evapotranspiration data (ETD) within the private sector. This work will deliver to NASA a survey report with insights into the opportunities and challenges related to ETD products.

WWAO has delivered several successful technology transitions. The overriding finding is that transition requires dedicated program support from project outset. Transition of applied science into action is a challenge faced across federal (and non-federal) agencies. Even the most "successful" projects may need ongoing resources (e.g., for data maintenance or computational resources that cannot be sustained by the partner). WWAO can define and track project-transition requirements, as well as help project leads communicate to partners the potential impact of the NASA capability on water decisions, which can be crucial for uptake.

VI. INTERNATIONAL ACTIVITIES

The Water Resources application area contributed to many international activities throughout 2020. The application area continues to be an active participant in working groups, committees, and advisory groups of international and foreign activities. This effort includes working with other U.S. entities that have international interests.

For example, Associate Program Manager John Bolten represented the program by serving on the Advisory Board of the Mekong Dam Monitor. The Mekong Dam Monitor is an online platform that uses remote sensing, satellite imagery, and GIS analysis to provide near-real-time reporting and data downloads for numerous previously unreported indicators in the Mekong Basin.

In addition to the internationally directed projects under the GEOGloWS initiative (see below), applications supported by the Water Resources application area demonstrated global applications in 2020.

- PI Eric Hunt (Atmospheric and Environmental Research, Inc.) made advances in his project to develop a flash drought monitoring capability based on the Standardized Evaporative Stress Ratio (SESR) using four different global reanalysis data sets. In 2020, Dr. Hunt and his team completed a thorough case study of the Russia 2010 drought. This paper, “Flash drought development and cascading impacts associated with the 2010 Russian heat wave” is now published in Environmental Research Letters.

- PI Nazmus Sazib (NASA Goddard Space Flight Center) advanced the NASA-USDA global soil moisture product by transitioning the data assimilation system to integrate NASA Land Information System (LIS) atmospheric forcing data to the U.S. Air Force 557 Weather Wing. The resulting surface and root-zone global soil moisture products are available at 10km resolution and with full global coverage every three days and are being operationally applied by the USDA Foreign Agricultural Service (FAS), NASA Harvest, and the Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) to help inform international agriculture monitoring and forecasting. Other users include the NASA Disasters Portal and thousands of users through Google Earth Engine.

- PI Charon Birkett made progress with her project titled, “Global Reservoir and Lake Monitoring- Sustained Water Level Monitoring for Agriculture Regional Security, and Inland Fisheries.” This project refines, tests, and implements an inland water monitoring system that delivers archival and operational surface water level products for science and applied science projects that focus on lakes/reservoirs/wetlands and river reaches. In 2020, Dr. Birkett and her team developed a test case of wetland regions as part of an extension to the Global Reservoirs and Lakes Monitor (GREALM). The team is also partnering with PI Jack Eggleston (USGS) on his project titled, “River Discharge determination for Alaska,” by providing altimetric water level products for Alaskan river reaches."

- PI Chris Hain (NASA Marshall Space Flight Center) neared an operational level ARL with his project titled, “Development of a Global Evaporative Stress Index (ESI) Based on Thermal and Microwave Land Surface Temperature (LST) towards Improved Monitoring

of Agricultural Drought," in 2020. The project is developing a global agricultural monitoring tool with a focus on providing early warning of developing vegetation stress to agricultural decision-makers and stakeholders at relatively high spatial resolution (5 km). The team has developed a thermal-only ESI (ARL ~ 8) now being run in near-real-time at NASA Short-term Prediction Research and Transition Center (SPoRT) and providing weekly updates to project stakeholders. The thermal infrared and microwave (TIR+MW) ESI (ARL ~6) is being ported to NASA SPoRT and has begun evaluation with project partners.

Group on Earth Observations Global Water Sustainability (GEOGloWS)

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 together those who need information to make better decisions 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.

The Applied Sciences Program is managing four GEOGloWS projects from a competitive ROSES solicitation (see project summaries and 2020 highlights in Appendix A):

- "AmeriGEOSS Cloud-based Platform for Deployment of GEOGloWS," PI-Daniel Ames, Brigham Young University
- "Optimizing the Indus Basin Irrigation System," PI-Karl Rittger, University of Colorado
- "Risk and Capacity Development for Two Indian River Basins," PI-Venkat Lakshmi, University of Virginia
- "Surface Water Changes over the Lower Mekong," PI-Hongki Lee, University of Houston

VII. LOOKING AHEAD

The Water Resources application area looks to 2021 as a year of growth, expansion, and an opportunity to strengthen application impacts. The team is committed to creating and encouraging a diverse and inclusive work environment. The program will use 2021 as a planning year, establishing a strategy for the Water Resources application area that aligns to the Applied Sciences Program strategy. In addition, the application area is planning to roll out a communications plan to better share the stories and successes of the applications of NASA data for water resources management. Combined, these plans will be the catalysts to engage new

audiences, encourage the use of NASA data, and increase the breadth and reach of the application area.

The application area will continue to support ongoing applied water resources projects and also looks forward to selecting additional projects through the 2021 ROSES solicitation to grow the application area's portfolio of projects.

In 2021, the Water Resources application area will host multiple events to provide the community with opportunities to learn about EO for water resources. The team will host an annual meeting in October where all PIs will present their projects. The team will also host sessions at conferences such as the American Geophysical Union's Fall Meeting and a remote sensing water quality workshop at the meeting of the American Society of Civil Engineers Environmental Water Resources Institute (ASCE EWRI). The expected 2021 release of the special issue on remote sensing from the Journal of the American Water Resources Association will highlight many applications of NASA data for water resource management.

At the start of 2021, WWAO will issue a Request for Information to water stakeholders to seed new projects in the Columbia River Basin, which will be launched later in the year. Three existing projects will transition technology to their partners (USDA NASS, New Mexico Office of the State Engineer, University of California Cooperative Extension, and farmers in the west). On the water-management needs front, WWAO will complete its assessments underway in the Missouri and Rio Grande River Basins, which will add to the catalog of needs in WWAO's NASA Water Portal. Assuming COVID-19 shutdowns are largely lifted by late spring, WWAO plans to hold face-to-face needs assessments and a Research to Operations workshop in 2021.

Beyond water needs and projects, WWAO will continue to build strategic partnerships with stakeholders and deepen relationships with NASA missions and researchers. WWAO's NASA Water Portal and newsletter will aid strategic engagement, as will involvement in NASA's space-to-farm communications campaign. WWAO will release Project Impact Briefs and highlights and publish papers to underscore the power of remote sensing in decision-making and explain how best to bring NASA technology to bear on 21st-century water issues.