National Aeronautics and Space Administration

PROFILES OF NASA EARTH SCIENCE DATA USERS

2019 YEAR BOOK

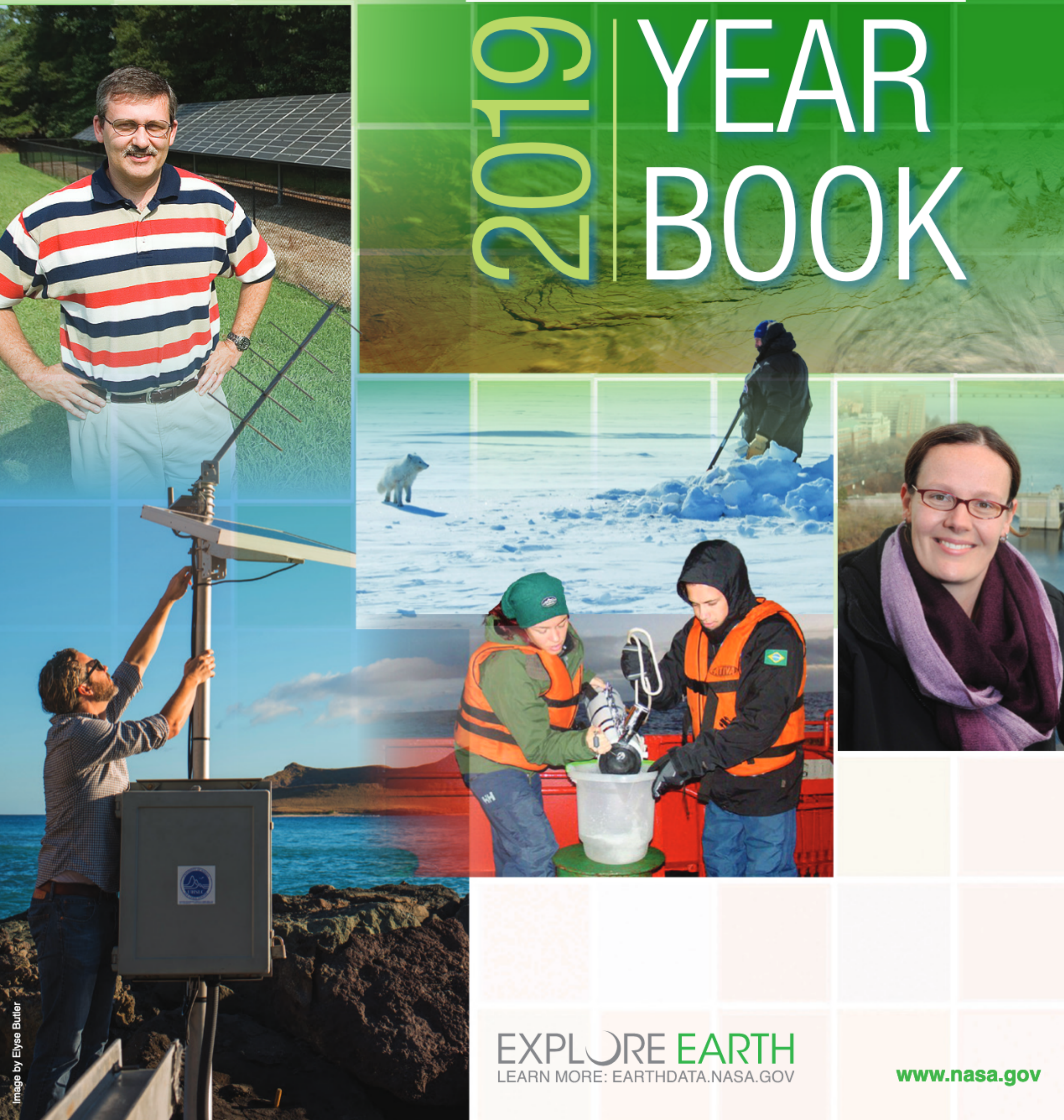

Image by Elyse Butler

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COVER: (Clockwise from upper left) Dr. Paul Stackhouse, Dr. Ludovic Brucker, Dr. Lucy Hutrya, Dr. Priscila Kienteca Lange, and Dr. Philip Thompson

NASA's Earth Observing System Data and Information System (EOSDIS) is pleased to present the *2019 EOSDIS Data User Profile Yearbook*. The 11 data users you'll read about in this year's edition are using Earth science data in the EOSDIS collection for many applications, including studying global phytoplankton biomass and distribution, exploring the impacts of urbanization, developing systems to assess global energy demands, creating innovative platforms for collaboratively sharing NASA data during natural disasters, and, along the way, solving a few mysteries (such as the reasons behind the sudden death of caribou on a remote island in the Canadian Arctic).

The EOSDIS Data User Profile series showcases these scientists, researchers, managers, and educators along with the data products that make their work possible. Our *Data User Profile Yearbook* gives you a taste of the breadth of research enabled by the vast NASA EOSDIS data collection—a collection that is yours to use freely and without restriction.

For more than 30 years, NASA's EOSDIS has provided long-term measurements of our dynamic planet. The thousands of unique data products in the EOSDIS collection come from a variety of sources including the International Space Station, satellites, airborne campaigns, field campaigns, in situ instruments, and model outputs. These data are managed by NASA's Earth Science Data and Information System (ESDIS) Project, and are archived at and distributed by discipline-specific Distributed Active Archive Centers (DAACs) to a diverse worldwide user community.

We hope the following examples of the work being done using data in NASA's EOSDIS collection will stimulate your own investigations into our dynamic planet.

Table of Contents

All profiles written by Josh Blumenfeld, NASA EOSDIS Science Writer

Who Uses Earth Science Data?

Dr. Ludovic Brucker uses NASA Earth observing data to explore climate-related changes in the cryosphere. He also used these data to investigate the mysterious death of caribou in the High Arctic.

An Arctic fox assesses Dr. Ludovic Brucker's snow measurements during a 2015 expedition to Cambridge Bay, Nunavut, Canada. Image by Dr. A. Roy, University of Sherbrooke, Canada.

Dr. Ludovic Brucker

Universities Space Research Association (USRA)/Goddard Earth Sciences Technology And Research (GESTAR) program; **Manager and Senior Scientist**, Cryospheric Sciences Laboratory, NASA's Goddard Space Flight Center, Greenbelt, MD

Research interests: Investigating climate-related changes to ice sheets, snow, and sea ice using microwave instrument observations from Earth observing satellites and aircraft coupled with measurements collected during field expeditions.

Research highlights: Prince Charles Island sits just north of the Arctic Circle off the west coast of Baffin Island in the Qikiqtaaluk Region of Nunavut, Canada. While the island was likely known to native Inuit peoples, it is so remote that it did not appear on published maps until the mid-20th century.

In the summer of 2016, Canadian scientists flying over the island came across a grisly scene—dead caribou, as many as 50, covering the ground. It appeared, according to one scientist, as if the animals had simply dropped where they were standing. The reason for the mass die-off was a mystery. Research by Dr. Ludovic Brucker, in collaboration with colleagues from the University of Sherbrooke in Quebec, helped provide an answer.

Dr. Brucker's research area is the cryosphere, which includes frozen ground, snow, ice sheets and ice shelves, sea ice, glaciers, and river and lake ice. Due to the sensitivity of snow and ice to temperature increases, the cryosphere is an area where indications of climate variability often are first observed.

Before the advent of airborne and satellite-borne instruments, the acquisition of cryospheric data required expeditions into some of the most extreme environments on Earth. Vast areas of the Arctic and Antarctic remained unexplored until the 20th century. Today, data from airborne missions, such as NASA's Operation IceBridge (operational 2009 to present), and satellite missions, such as NASA's Ice, Cloud, and land Elevation Satellite (ICESat, 2003 to 2009) and the recently-launched ICESat-2 (2018 to present), are helping to show how a changing global climate is affecting these remote regions.

Dr. Brucker uses a combination of satellite data and field investigations for his studies of ice sheets, snow, and sea ice. Remotely-sensed data are a key component of his work developing algorithms used to produce numerous cryospheric data products. Seven data products co-produced by Dr. Brucker are available through NASA's National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC). NSIDC DAAC archives and distributes NASA Earth observing data related to snow and ice processes, particularly interactions among snow, ice, atmosphere, and ocean, in support of research related to global change detection and model validation.

Monitoring snow and ice from space requires sensors that can collect data without the need for outside illumination (such as during the polar winter) and that can collect data through clouds, haze, and other atmospheric obstructions. Microwave radiometers fill these needs by detecting microwaves radiated from Earth without actively sending out a signal (like radar).

One example of an orbital microwave instrument is the Aquarius sensor, which was built by NASA and carried aboard the Argentine-built Satélite de Aplicaciones Científicas (SAC)-D spacecraft (operational 2011 to 2015). While its primary mission was to collect data on global ocean salinity, Dr. Brucker and his colleagues were able to use Aquarius data to study the cryosphere and to produce several data products for the NSIDC DAAC.

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Who Uses Earth Science Data?

In order to ensure that data acquired by an instrument aboard an aircraft or satellite are accurately representing ground conditions, they have to be validated. One way to accomplish this is through field campaigns that collect data at ground-level that are compared with remotely-sensed data. Dr. Brucker has participated in more than a dozen field campaigns, including polar deployments in both hemispheres. In addition, he led ground-based remote sensing activities in Colorado as part of NASA's ongoing multi-year Snow Experiment (SnowEx) campaign. The primary objective of SnowEx is to develop algorithms to aid in the remote sensing of seasonal terrestrial snow and gain a better understanding of how much water can be expected as this snow melts in the spring (SnowEx data are available through NSIDC DAAC). This is vital information for regions that depend on snowmelt for drinking water and irrigation, such as the Western U.S.

Combining ground-based meteorological data with microwave satellite data helped solve the riddle of the caribou deaths on Prince Charles Island: The deaths were a matter of bad timing.

While early-winter storms can lead to a crust on the ground that can prevent access to forage, caribou generally have the energy reserves at this time to move to other locations to feed. During the winter of 2015 and 2016, however, meteorological data indicate that major storms occurred in April—late in the season and a time when caribou energy reserves are generally at their lowest. Wind and snow from these storms created an unusually dense snowpack, which could be detected by orbiting microwave sensors. Using meteorological and satellite data, Dr. Brucker and his colleagues determined that the caribou starved to death when they were unable to break through the dense snow and ice layer to reach the nourishment they needed.

Dr. Brucker continues to explore the impacts of a changing climate on the cryosphere, and is preparing for another season of field work, including a campaign to the Canadian High Arctic Research Station in Cambridge Bay, Nunavut. The riddles remain, but the combination of remotely-sensed data and field observations are helping Dr. Brucker and his colleagues remove some of the mysteries from these remote regions.

Data products co-produced by Dr. Brucker. All are available through NASA's NSIDC DAAC:

- SnowEx17 data products:
  - Roy, A., Langlois, A. & **Brucker, L.** (2019). *SnowEx17 Radiometrics Surface-Based Radiometer Brightness Temperatures* (doi: 10.5067/JWONK1ZTSBXX).
  - **Brucker, L.,** Hiemstra, C., Marshall, H. & Elder, K. (2018). *SnowEx17 Community Snow Depth Probe Measurements* (doi: 10.5067/WKC6VFMT7JTF).
  - Elder, K., **Brucker, L.,** Hiemstra, C. & Marshall, H. (2018). *SnowEx17 Community Snow Pit Measurements* (doi: 10.5067/Q0310G1XULZS).
- Aquarius data products:
  - Roy, A., **Brucker, L.,** Prince, M., Royer, A. & Derksen, C. (2018). *Level 3 Weekly Polar-Gridded Landscape Freeze/Thaw* (doi: 10.5067/OV4R18NL3BQR).
  - **Brucker, L.,** Dinnat, E. & Koenig, L. (2015):
    - *Aquarius Level 3 Weekly Polar-Gridded Brightness Temperature and Sea Surface Salinity* (doi: 10.5067/Aquarius/AQ3_TB.005).

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- *Aquarius Level 3 Weekly Polar-Gridded Normalized Radar Cross Section* (doi: 10.5067/Aquarius/AQ3_NRCS.005).
- *Aquarius Level 3 Weekly Polar-Gridded Sea Surface Salinity* (doi: 10.5067/Aquarius/AQ3_SSS.005).

Read about the research:

Dolant, C., Montpetit, B., Langlois, A., **Brucker, L.,** Zolina, O., Johnson, C.A., Royer, A. & Smith, P. (2018). "Assessment of the barren ground caribou die-off during winter 2015-2016 using passive microwave observations." *Geophysical Research Letters,* 45(10): 4908-4916 [doi: 10.1029/2017GL076752].

Dinnat, E. & **Brucker, L.** (2017). "Improved Sea Ice Fraction Characterization for L-band Observations by the Aquarius Radiometers." *IEEE Transactions on Geoscience & Remote Sensing,* 55(3): 1285-1304 [doi: 10.1109/TGRS.2016.2622011].

Garcia-Eidell, C., Comiso, J., Dinnat, E. & **Brucker, L.** (2017). "Satellite Observed Salinity Distributions at High Latitudes in the Northern Hemisphere: A Comparison of Four Products." *Journal of Geophysical Research: Oceans,* 122(9): 7717-7736 [doi: 10.1002/2017JC013184].

Bokhorst, S., Pedersen, S.H., **Brucker, L.,** et al. (2016). "Changing Arctic snow cover: a review of recent developments and assessment of future needs for observations, modelling and impacts." *Ambio,* 45(5): 516-537 [doi: 10.1007/s13280-016-0770-0].

Miège, C., Forster, R., **Brucker, L.,** Koenig, L., Solomon, D.K., Paden, J., Box, J., Burgess, E., Miller, J., McNerney, L., Brautigam, N., Fausto, R. & Gogineni, S.P. (2016). "Spatial extent and temporal variability of Greenland firn aquifers detected by ground and airborne radars." *Journal of Geophysical Research: Earth Surface,* 121(12): 2381-2398 [doi: 10.1002/2016JF003869].

Who Uses Earth Science Data?

Atmospheric CO_2 is increasing. Dr. Lucy Hutyra uses NASA Earth observing data to explore how this affects urban environments.

Photograph of Dr. Lucy Hutyra by Kalman Zabarsky for Boston University Photography.

Dr. Lucy Hutyra

Associate Professor of Earth and Environment, Boston University; Director, Hutyra Research Lab, Boston University, Boston, MA

Research interests: Using Earth observing data to improve our understanding of the carbon cycle, particularly how changes in vegetation and land use affect flows of carbon between the biosphere and the atmosphere.

Research highlights: Since colonial days, Boston, MA, has remained one of the largest U.S. cities, and the population of this metropolis is poised to surpass 700,000 residents, according to the U.S. Census (the city last hit this milestone in the 1920s). One consequence of this large population, though, is the production of high carbon emissions.

According to 2015 figures from the Massachusetts Department of Transportation, the entire Boston Central Artery/Tunnel project processes more than 530,000 vehicles per weekday and the Massachusetts Bay Transportation Authority (MBTA) that services the Boston region logs nearly 1.3 million daily trips on its subway, bus, and commuter rail system. While not all of these vehicles use fossil fuel-burning internal combustion engines, those that do create about 8.8 kilograms of carbon dioxide (CO_2) for every gallon of gasoline burned, according to the U.S. Environmental Protection Agency, and the average passenger vehicle equipped with an internal combustion engine emits roughly 4.6 metric tons of CO_2 per year. All this carbon adds up, especially in urban areas like Boston. And these urban areas are expected to grow dramatically over the next decade.

In fact, by 2030 "urban areas are projected to house 60 percent of people globally and one in every three people will live in cities with at least half a million inhabitants," according to a United Nations report. As Dr. Lucy Hutyra observes, the anticipated growth in urban areas over the next decade is "more urban land expansion than in all of history."

Dr. Hutyra's research focuses on developing a better understanding of how fossil fuel emissions of CO_2 coupled with biological activity in urban environments influences atmospheric CO_2 concentrations. Much of her work is conducted out of the Hutyra Research Lab at Boston University and spans urban-to-rural gradients. NASA remotely-sensed atmospheric data enable her to scale her ground-level carbon investigations across much larger regions. This is critical, given the impact carbon has on life on Earth.

Carbon is the fourth most abundant element in the universe by mass, and exists in gaseous forms that include carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO). Carbon constantly cycles in and out of the atmosphere, with CO_2 being the most abundant atmospheric carbon-bearing gas. In the absence of external inputs, the carbon cycle stays in balance, with natural CO_2 inputs from sources such as animals and forest fires roughly equaling natural sinks that take CO_2 out of the atmosphere, like oceans and the process of photosynthesis.

Human activities, including urban growth, deforestation, and the burning of fossil fuels, have led to an increase in atmospheric CO_2 beyond what would be expected from natural sources. In 2017 alone, more than 41 billion tons of CO_2 were emitted to the atmosphere from anthropogenic sources including land use change and the burning of coal, oil, and gas, according to the 2018 Global Carbon Budget report created by the international Global Carbon Project. This excess atmospheric CO_2 helps trap radiated heat, much as the glass of

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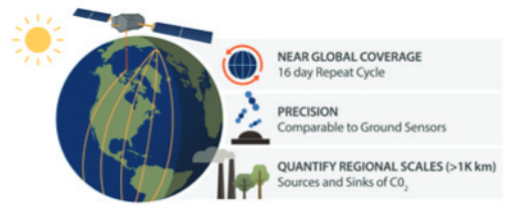
a greenhouse prevents the escape of solar radiation. Thanks to instruments aboard Earth observing satellites, atmospheric CO_2 can be measured and tracked 24/7.

One orbiting data source used by Dr. Hutyra is NASA's Orbiting Carbon Observatory-2 (OCO-2). Launched in 2014, OCO-2 is a re-flight of the original OCO mission, which failed on launch. OCO-2's primary science objective is to collect measurements of atmospheric CO_2 with the precision, resolution, and coverage needed to characterize its sources and sinks and to quantify the variability of CO_2 over seasonal cycles. OCO-2 provides roughly 100,000 global CO_2 measurements every day. Originally intended for a three-year mission, OCO-2 is still sending back valuable data.



Highlights of the OCO-2 mission. OCO-2 orbits Earth in a 705-km sun-synchronous polar orbit that provides observations over the same location at nearly the same time every day. NASA image.

OCO-2 data soon will be complemented with data from OCO-3, which successfully launched on May 4, 2019, and was installed on the International Space Station (ISS) on May 6. OCO-3's location on the ISS provides a number of advantages, such as the ISS' lower orbital altitude. While OCO-2 circles Earth in a 705-km polar orbit, the ISS orbits Earth between 52° north and south latitude at an altitude ranging from 330 to 435 km. This lower orbit enables OCO-3 to collect denser data than OCO-2 over high-carbon regions, such as the Amazon. More importantly, OCO-3 will pass over major cities and urban areas at different times of day, enabling it to collect data spanning all sunlit hours and provide a more precise picture of urban CO_2 changes throughout the day.

As Dr. Hutyra notes, individual cities have taken the lead in U.S. efforts to reduce greenhouse gas emissions. In a recent paper looking at a model for assessing CO_2 concentrations in Boston, Dr. Hutyra and her colleagues observe that a detailed representation of urban biological fluxes combined with a knowledge of the spatial and temporal distribution of emissions is essential for accurate modeling of annual CO_2 emissions. These data, covering all daylight hours over urban areas, soon will be available through OCO-3.

Another remotely-sensed variable used by Dr. Hutyra in her research is a nearly invisible fluorescent glow created by chlorophyll in plants that can be detected by sensors like those aboard the OCO satellites. This "vegetative fluorescence" provides valuable information about the productivity of terrestrial vegetation and enables scientists to estimate the rates of photosynthesis across large areas. If fluorescence decreases, this is an indication that plants are not as productive. Since plants play a key role in removing CO_2 from the atmosphere, less productive plants mean less CO_2 being removed. Conversely, as plants die and decay, they release CO_2 back into the atmosphere and become a carbon source rather than a carbon sink. In addition, fluorescence data help resolve some uncertainties about the uptake of CO_2 by plants in climate models.

One final NASA asset used by Dr. Hutyra and her colleagues is NASA's Carbon Monitoring System (CMS). Since its establishment in 2010, the CMS has served as a collaborative platform for incorporating remotely-sensed carbon data and measurements into a wide range of products and datasets designed "to support stakeholder needs for Monitoring, Reporting, and Verification (MRV) of carbon stocks and fluxes." Dr. Hutyra has participated as a co-investigator on several CMS projects and is a member of numerous CMS Groups. As noted in a recent article about the CMS, Dr. Hutyra was part of a team that used a CMS grant to develop

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methods "for detecting and attributing methane leaks from urban natural gas pipelines," which contributed to changes in how Boston and the state of Massachusetts regulate gas leak repairs.

As urban areas continue to expand in area and population, the need to understand the carbon contributions of these metropolises becomes ever more important. Through remotely-sensed data and ground observations, Dr. Lucy Hutyra and her colleagues are developing a better understanding of the effects of urban carbon emissions and their impacts—not just for Boston, but for urban areas around the world.

Representative data products used:

- NASA's Carbon Monitoring System (CMS): CO_2 Emissions from Fossil Fuels Combustion, Anthropogenic Carbon Emissions System (ACES) Inventory for Northeastern USA (doi: 10.3334/ORNLDAAC/1501); available through NASA's Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC)
- MODIS Collection 6 Land Product Subsets Web Service (doi: 10.3334/ORNLDAAC/1557); available through the ORNL DAAC
- OCO-2 Level 2 bias-corrected solar-induced fluorescence and other select fields from the IMAP-DOAS algorithm aggregated as daily files, Retrospective processing V8r (Shortname: OCO2_L2_Lite_SIF; doi: 10.5067/AJMZO5O3TGUR); available through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC)

Read about the research:

Popkin, G. (2019). "New Budget Bill Rescues NASA's Carbon Monitoring System." *EOS*, 100; published on 28 February 2019 [doi: 10.1029/2019EO117385].

Sargent, M., Barrera, Y., Nehrkorn, T., **Hutyra, L.R.,** Gately, C.K., Jones, T., McKain, K., Sweeney, C., Hegarty, J., Hardiman, B., Wang, J.A. & Wofsy, S.C. (2018). "Anthropogenic and biogenic CO_2 fluxes in the Boston urban region." *Proceedings of the National Academy of Sciences of the United States of America,* 115: 7491-7496 [doi: 10.1073/pnas.1803715115].

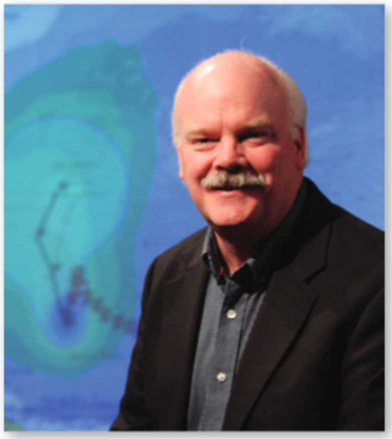
Smith, I.A., **Hutyra, L.R.,** Reinmann, A.B., Marrs, J.K. & Thompson, J. (2018). "Piecing together the fragments: Elucidating edge effects on forest carbon dynamics." *Frontiers in Ecology and Environment,* 16(4): 213-221 [doi: 10.1002/fee.1793].

Hardiman, B., Wang, J., **Hutyra, L.R.,** Gately, C., Getson, J. & Friedl, M. (2017). "Accounting for urban biogenic fluxes in regional carbon budgets." *Science of the Total Environment,* 592: 366-372 [doi: 10.1016/j.scitotenv.2017.03.028].

Trlica, A., **Hutyra, L.R.,** Schaaf, C., Erb, A. & Wang, J. (2017). "Albedo, Land Cover, and Daytime Surface Temperature Variation Across an Urbanized Landscape." *Earth's Future,* 5: 1084-1101 [doi: 10.1002/2017EF000569].

Who Uses Earth Science Data?

NASA near real-time Earth observing data are vital to emergency response. Dave Jones develops systems and processes that enable these data to be used collaboratively in real time across platforms by emergency responders and managers.



Dave Jones

Founder, President, and CEO, StormCenter Communications, Inc., Halethorpe, MD

Research interests: Developing systems and applications to collaboratively share Earth observing and infrastructure data from multiple sources to improve situational awareness and decision-making between subject matter experts, emergency managers, and the public.

Research highlights: When disaster strikes due to a hurricane, earthquake, wildfire, flooding, or tornado, access to reliable data is a critical component of response and recovery. The most valuable data in these situations are those from trusted sources that provide responders with information in real-time and near real-time, and give them the ability to make rapid decisions as events unfold.

Along with the more than 10,000 standard data products in NASA's Earth Observing System Data and Information System (EOSDIS) collection that are designed for scientific research, more than 100 near real-time data products are available through NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) system. LANCE near real-time data are available generally three hours after a satellite observation (sometimes sooner) and are an integral resource for decision-makers needing rapid access to remotely-sensed Earth observing data.

Developing ways to integrate EOSDIS near real-time data with real-time, near real-time, and critical infrastructure data from other agencies and sources—and provide ways to rapidly evaluate the utility of these data during an emergency—is one focus of Dave Jones and his team at StormCenter Communications, a private company he founded and leads. As Jones observes, if subject matter experts can be placed on the same map and access the same data as decision-makers, whether on a mobile phone or a computer, this creates an environment where data can be shared collaboratively, understood in a timely manner, and actions can be taken to protect lives and property.

Providing the ability to collaboratively view and integrate NASA low-latency data products with data from other agencies and share this abundance of data and information through a common interface in real-time was the impetus behind Jones' work developing a NASA-funded system called GeoCollaborate.

The development of GeoCollaborate was originally funded under NASA's Small Business Innovation Research (SBIR) Program. The highly-competitive SBIR program, along with NASA's Small Business Technology Transfer (STTR) program, supports the research, development, and demonstration of innovative technologies that fulfill NASA needs and have significant potential for successful commercialization. GeoCollaborate is now an SBIR Phase III technology, which means it is ready for commercialization and can be sole-sourced by any government agency.

GeoCollaborate provides access to EOSDIS near real-time data along with data from multiple U.S. government agencies and even from other nations. These data are combined with Geographic Information System (GIS) web services and on-ground reporting. This

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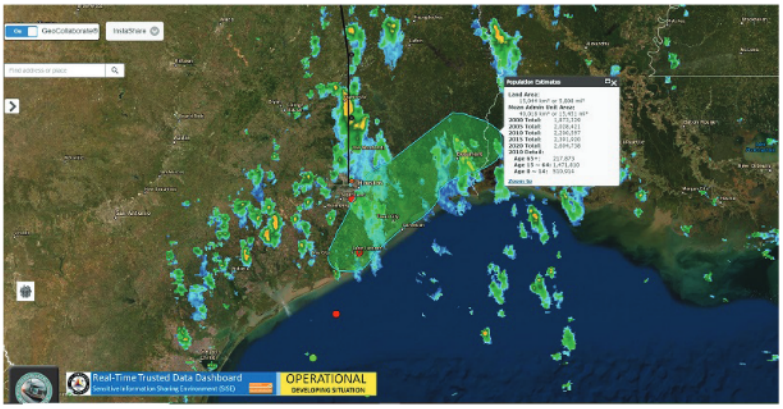
Who Uses Earth Science Data?

enables subscribers to the service to lead data-sharing sessions, connect with followers in real-time, and share data from multiple providers on any platform or device using a common dashboard interface.

Jones notes that the system has facilitated the collaborative use of NASA data during the response to numerous disasters. For example, following Hurricanes Harvey in 2017 and Florence in 2018, hundreds of utility company ‘bucket trucks’ caravanned across many states to join in recovery efforts. This equipment had to muster in remote locations before being dispatched into unknown neighborhoods, often with little guidance if local roads were flooded, on their way to being flooded, or impassable due to storm debris. Near real-time imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA’s Terra and Aqua Earth observing satellites were incorporated with USGS Landsat and stream gauge data, NOAA high resolution inundation modeling, and National Weather Service (NWS) radar to estimate when flooding would recede and utility trucks could safely enter impacted areas to restore power. More recently, NASA data were combined with data from the European Space Agency (ESA) to assess the extent of flooding in the Bahamas in the aftermath of Hurricane Dorian in September 2019.

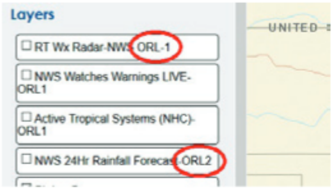
Along with near real-time data from MODIS and other sensors, Jones and his team recently incorporated population density information from NASA’s Socioeconomic Data and Applications Center (SEDAC) into the system. SEDAC is the EOSDIS Distributed Active Archive Center (DAAC) responsible for archiving and distributing NASA socioeconomic data, and serves as an “Information Gateway” between the socioeconomic and Earth science data and information domains. Using SEDAC’s Application Programming Interface (API), Jones and his design team configured GeoCollaborate to enable users to draw a polygon on a GeoCollaborate map that sends a real-time request to SEDAC’s database to display population information within the polygon. This population information is loaded immediately onto all other GeoCollaborate user dashboards or onto follower’s devices.



Screenshot acquired September 20, 2019, at 1:48 pm (EDT) showing scattered intense rainfall across southeast Texas (indicated in green and yellow) caused by Tropical Storm Imelda. Square box with text just right of center is a NASA SEDAC population esitmate for an area impacted by severe flooding (outlined by solid green polygon). Image: StormCenter Communications.

Of course, it’s not enough for emergency responders to have data for use during disaster recovery; responders also need the ability to quickly evaluate the utility of these data to ensure they are using best data for a given situation. This is where another component of Jones’ work comes in. As co-chair of the Earth Science Information Partners (ESIP) Federation Disaster Lifecycle Cluster, Jones is helping to evolve a process through which datasets can be assigned ‘trust levels’ for use in decision making. This work is resulting in a new standard called Operational Readiness Levels (ORLs) for data, which enable decision-makers to rapidly assess the quality of specific data products and their potential application during ongoing events.

ORLs range from 1 to 4. ORL 1 is the highest trust designation, and indicates data are available now for immediate situational awareness and decision making, among other criteria. ORL 4 is currently the lowest designation and indicates data that are “not likely to be immediately useful for operations, but are emerging datasets that should be ‘on the radar’.” ORLs also facilitate awareness of evolving research datasets moving toward operational use.



ORLs displayed with data products. Image: StormCenter Communications.

While NASA standard data products facilitate in-depth scientific research, NASA near real-time products and socioeconomic data are critical resources for tracking ongoing events and

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the number of residents that might be affected by these events. For Dave Jones, these data are integral components in his work developing new ways to provide public and private emergency managers and decision-makers with the information they need—at the right time and the right place—to make quick decisions for protecting lives and property using the best data available.

Representative data products used:

- Data from NASA's SEDAC:
  - U.S. Census Grids, Summary File 1, v1 (doi: 10.7927/H40Z716C)
  - Population Estimation Service, v3 (doi: 10.7927/H4DR2SK5)
- Various MODIS land data products from NASA's Terra and Aqua Earth observing satellites; available through NASA's Land Processes Distributed Active Archive Center (LP DAAC)
- MODIS and Visible Infrared Imaging Radiometer Suite (VIIRS) thermal anomaly data; available through NASA's Fire Information for Resource Management System (FIRMS):
  - MODIS Fire and Thermal Anomalies Product: MCD14DL (doi: 10.5067/FIRMS/MODIS/MCD14DL.NRT.006)
  - VIIRS I-band (375 m) Active Fire product: VNP14IMGTDL_NRT (doi: 10.5067/FIRMS/VIIRS/VNP14IMGT.NRT.001)
  - Various Landsat products; available through the USGS EarthExplorer application

Read about the work:

Jones, D. & Moe, K. (2018). "Operational Readiness Levels: Establishing Trusted Data to Improve Situational Awareness." Presentation at the ESIP Federation Summer Meeting, July 17-20, 2018. Available online at https://static.sched.com/hosted_files/2018esipsummermeeting/c5/DJones-Operational%20Readiness%20Levels20180717.pdf.

Robinson, E. (2014). "Member Highlight: StormCenter Communications, Inc." ESIP Federation, Partner Highlights, October 22, 2014. Available online at https://www.esipfed.org/member-highlights/member-highlight-stormcenter-communications-inc.

Coleman, D., editor. (2013). "Cloud-Based Data Sharing Connects Emergency Managers." *NASA Spinoff*, NASA Technology Transfer Program, pp. 76-77. Available online at https://spinoff.nasa.gov/Spinoff2013/pdf/Spinoff2013.pdf.

Schwerin, B., editor. (2012). "Collaborative Platforms Aid Emergency Decision Making." *NASA Spinoff*, NASA Technology Transfer Program, pp. 76-77. Available online at https://spinoff.nasa.gov/Spinoff2012/pdf/Spinoff2012.pdf.

Who Uses Earth Science Data?

Flooding is second only to heat as the leading cause of weather-related fatalities. Dr. Pierre Kirstetter uses NASA Earth science data to help communities be better prepared for this hazard.

Dr. Pierre Kirstetter

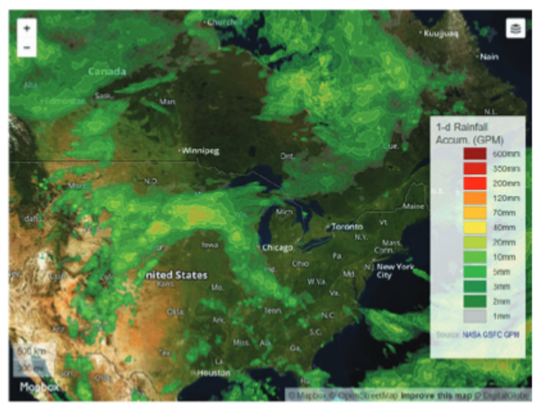
Associate Professor, the School of Meteorology and the School of Civil Engineering and Environmental Science, University of Oklahoma; Faculty Member, Advanced Radar Research Center, University of Oklahoma; Affiliate, National Severe Storms Laboratory, Norman, OK

Research interests: Radar and satellite remote sensing of precipitation, hydrometeorology, hydrology, severe weather, hydrologic hazard prediction with a focus on precipitation and related impacts, and the development of next-generation precipitation products.

Research highlights: On a calm, sunny day it's easy to underestimate the power of water. But when clouds build and precipitation begins, things start to change. Just six inches of fast-moving water is enough to knock over an adult, and 12 inches of rushing water can carry away most cars (with only two feet of water needed to carry away SUVs and trucks), according to the National Weather Service (NWS). And when persistent precipitation leads to flooding, the power of water can be devastating. Between 1989 and 2018, flooding was second only to heat as the leading cause of weather-related fatalities in the U.S., based on NWS statistics. Globally, floods accounted for almost half of all weather-related disasters from 1995 to 2015, affecting 2.3 billion people and killing 157,000, according to the United Nations Office of Disaster Risk Reduction (UNDRR).

Tracking precipitation and storms through their lifecycles is an undertaking perfectly suited for Earth observing satellites. These precipitation and storm data are an important part of NASA's Earth Observing System Data and Information System (EOSDIS) collection, and are an integral component of Dr. Pierre Kirstetter's work developing the next generation of products for studying hydrology and forecasting high precipitation events and flooding.

The primary source for the NASA precipitation data used by Dr. Kirstetter is the ongoing Global Precipitation Measurement (GPM) mission. The GPM mission began in 2014 with the launch of the joint NASA/Japan Aerospace Exploration Agency GPM Core Observatory. The Core Observatory acquires precipitation data from a constellation of orbiting international satellites to generate estimates of rain and snow as rapidly as every 30 minutes. As a member of NASA's Precipitation Measurement Missions (PMM) Science Team, Dr. Kirstetter helped develop algorithms for processing GPM precipitation data.



GPM Integrated Multi-satellitE Retrievals for GPM (IMERG) Late Run dataset image showing one day rainfall accumulation over North America for the period ending July 1, 2019. IMERG combines data from all passive microwave instruments in the GPM constellation of satellites. Image source: NASA's Goddard Space Flight Center (GSFC), GPM.

Of course, satellite-collected data need to be verified to ensure that they are accurately reflecting events at ground level. This is accomplished through ground validation campaigns that are vital components of any satellite mission. (Read more: Collecting Data from the Ground Up: NASA's Ground Validation Field Campaigns.) For GPM, these ground validation, or GV, campaigns have included the Olympic Mountain Experiment (OLYMPEX), the Mid-latitude Continental Convective Clouds Experiment (MC3E), the Integrated Precipitation and Hydrology Experiment (IPHEx), and the Iowa Flood Studies (IFloodS) experiment. Data from these GPM-GV

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campaigns are available through NASA's Global Hydrology Resource Center Distributed Active Archive Center (GHRC DAAC), which archives and distributes NASA Earth observing data focused on lightning, tropical cyclones, and storm-induced hazards.
Dr. Kirstetter co-developed datasets for the IPHEx and IFloodS campaigns that are available through the GHRC DAAC.

Under a NASA Research Opportunities in Earth and Space Science (ROSES) grant and GPM-GV support, Dr. Kirstetter is leading the development of a framework for integrating GPM sensor data with data from the Multi-Radar/Multi-Sensor (MRMS) system, which was developed by NOAA's National Severe Storms Laboratory (NSSL) and the University of Oklahoma. The MRMS system integrates data from radars, satellites, surface observations, upper air observations, lightning reports, rain gauges, and numerical weather prediction models into a suite of decision-support products every two minutes.

The framework developed under Dr. Kirstetter's leadership makes it easier to evaluate the consistency of ground- and space-based surface precipitation estimates at various scales and improves the retrieval of remotely-collected satellite precipitation data. This work further refines the convergence between satellite data and the MRMS system, and enables forecasters to more quickly diagnose severe weather. This, in turn, helps forecasters produce more accurate forecasts and issue more timely warnings. Along with fostering close collaboration between NASA and NOAA, Dr. Kirstetter points out that this work demonstrates that the NOAA meteorological radar network is highly useful for current and future NASA global precipitation missions.

NOAA NSSL image.

Dr. Kirstetter also is a co-developer of the Flooded Locations And Simulated Hydrographs (FLASH) Project. Coordinated through the NSSL, the primary goal of FLASH is to improve the accuracy, timing, and specificity of flash flood warnings in the U.S. FLASH was launched in 2012 largely in response to the successful demonstration and real-time availability of high-resolution, accurate MRMS rainfall observations. The FLASH Project uses MRMS rainfall data as input into a hydrologic model to produce flash-flooding forecasts up to six hours in advance of an event with a five-minute update cycle.

The work and research of Dr. Kirstetter, facilitated by data from NASA precipitation missions like GPM, is contributing to the development of more effective ways of forecasting floods and other high-precipitation events. The collaboration between NASA and NOAA on this work is not only helping to save lives and property, but providing a better understanding of one of the planet's leading weather-related hazards.

Representative data products co-developed or used:

- Datasets co-developed by Dr. Kirstetter and available at NASA's GHRC DAAC:
  - **Kirstetter, P.E.,** Petersen, W.A. & Gourley, J.J. (2018). *GPM Ground Validation Multi-Radar/Multi-Sensor (MRMS) Precipitation Reanalysis for Satellite Validation Product* (doi: 10.5067/GPMGV/MRMS/DATA101).
  - **Kirstetter, P.E.,** Gourley, J.J., Zhang, J. & Petersen, W.A. (2018). *GPM Ground Validation National Mosaic and Multi-Sensor QPE (NMQ) System IFloodS* (doi: 10.5067/GPMGV/IFLOODS/NMQ/DATA101).

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- **Kirstetter, P.E.,** Gourley, J.J., Zhang, J. & Petersen, W.A. (2018). *GPM Ground Validation National Mosaic and Multi-Sensor QPE (NMQ) System IPHEx* (doi: 10.5067/GPMGV/IPHEX/NMQ/DATA101).
- Gourley, J.J., **Kirstetter, P.E.,** Jorgensen, D. & Cifelli, R. (2018). *GPM Ground Validation NOAA X-band Polarimetric Radar (NOXP) IPHEx* (doi: 10.5067/GPMGV/IPHEX/NOXP/DATA101).

- Various GPM precipitation products; available through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC) and NASA's Precipitation Measurement Missions (PMM) website (GPM-GV data collections are available through NASA's GHRC DAAC)
- Various products from the joint NASA/NOAA GOES-16 satellite; available through NOAA's National Centers for Environmental Information (NCEI)

Read about the research:

Gebregiorgis, A., **Kirstetter, P.E.,** Hong, Y., Gourley, J.J., Huffman, G., Petersen, W., Xue, X. & Schwaller, M. (2018). "To what extent is the Day-1 IMERG satellite rainfall estimate improved as compared to TRMM TMPA-RT?" *Journal of Geophysical Research,* 123(3): 1694-1707 [doi: 10.1002/2017JD027606].

Carr, N., **Kirstetter, P.E.,** Gourley, J.J. & Hong, Y. (2017). "Polarimetric Signatures of Mid-Latitude Warm-Rain Precipitation Events." *Journal of Applied Meteorology and Climatology,* 56(3): 697-711 [doi: 10.1175/JAMC-D-16-0164.1].

Saharia, M., **Kirstetter, P.E.,** Vergara, H., Gourley, J.J. & Hong, Y. (2017). "Mapping Flash Flood Severity in the United States." *Journal of Hydrometeorology,* 18(2): 397-411 [doi: 10.1175/JHM-D-16-0082.1].

Smalley, M., **Kirstetter, P.E.** & L'Ecuyer, T. (2017). "How frequent is precipitation over the contiguous United States? Perspectives from ground-based and space-borne radars." *Journal of Hydrometeorology,* 18(6): 1657-1672 [doi: 10.1175/JHM-D-16-0242.1].

Kirstetter, P.E., Gourley, J.J., Hong, Y., Zhang, J., Moazamigoodarzi, S., Langston, C. & Arthur, A. (2015). "Probabilistic Precipitation Rate Estimates with Ground-based Radar Networks." *Water Resources Research,* 51(3): 1422-1442 [doi: 10.1002/2014WR015672].

Špitalar, M., Lutoff, C., Gourley, J.J., **Kirstetter, P.E.,** Brilly, M. & Carr, N. (2014). "Analysis of flash flood parameters and human impacts in the U.S. from 2006 to 2012." *Journal of Hydrology,* 519(A): 863-870 [doi: 10.1016/j.jhydrol.2014.07.004].

Who Uses Earth Science Data?

Life on Earth would not be possible without the help of phytoplankton. Dr. Priscila Kienteca Lange uses NASA ocean biology data to study the biomass and distribution of these microscopic organisms.

Dr. Lange (left) and Dr. Rafael Araujo (right, Technical University of Denmark, Kongens Lyngby (DTU)) collecting surface water samples with a Van Dorn bottle on board the Brazilian Research Ship Ary Rongel at the Bransfield Straight, Antarctic Peninsula, in February 2010. Image courtesy of Dr. Lange.

Dr. Priscila Kienteca Lange

NASA Post-Doctoral Fellow and Scientist (Universities Space Research Association), Ocean Ecology Laboratory, NASA's Goddard Space Flight Center, Greenbelt, MD

Research interests: Using satellite ocean color data to study how different types of phytoplankton influence marine life and biogeochemical cycles, and how they respond to physical and chemical processes.

Research highlights: When it comes to making life on Earth possible, microscopic phytoplankton are the big dogs on the block. These minute creatures are responsible for approximately half of Earth's primary production, not to mention at least half of Earth's oxygen. Since phytoplankton are the base of virtually all marine food webs, the presence and health of phytoplankton are vital to ocean productivity.

While it is possible to study phytoplankton simply by dipping a net or bottle into the water and using a microscope to examine the collected critters, sensors aboard Earth observing satellites make it possible to study these organisms across huge distances using data collected over many years. Satellite-collected data combined with data collected by scientists aboard research vessels plying the world's seas are the foundation of Dr. Priscila Kienteca Lange's research into phytoplankton biomass and distribution.

The term "phytoplankton" refers to a diverse group of single-celled aquatic organisms that contain chlorophyll and produce energy through the process of photosynthesis. They can further be broken down into two types: single-celled algae known as protists, which includes the common diatoms that are found near coasts; and primitive photosynthetic bacteria (cyanobacteria), some of which are really, really tiny (about a micron across in size, which is 0.000039 of an inch). But don't let their size fool you—as Dr. Lange notes, cyanobacteria are the most abundant photosynthetic organisms in the sea.

OceanColor is the NASA OBPG website and a source for ocean biology data in NASA's EOSDIS collection. Tools for discovering and using these data also are available through the website.

Much of the satellite-collected data used by Dr. Lange come from NASA's Ocean Biology Processing Group (OBPG) located at NASA's Goddard Space Flight Center in Greenbelt, Maryland. These data are distributed through the Ocean Biology Distributed Active Archive Center (OB.DAAC), which is responsible for ocean biology data in NASA's Earth Observing System Data and Information System (EOSDIS) collection.

While sensors orbiting hundreds of miles above Earth can't "see" microscopic organisms, they can detect differences in water reflectance caused by their presence. Phytoplankton contain pigments, like chlorophyll, that absorb the energy from light that is used in the photosynthetic process. Different types of phytoplankton have unique combinations of pigments that change the reflectance of the water when they are present. Satellite-borne sensors can detect this reflectance as well as changes in this reflectance over time.

One specific measurement used by Dr. Lange is remote sensing reflectance, which is notated R_{rs}. R_{rs} is a powerful tool for quantifying the amount of phytoplankton chlorophyll in the surface ocean and in distinguishing key phytoplankton types. After calibration with shipboard-collected measurements, R_{rs}-based satellite observations of phytoplankton enable the assessment of large-scale ecosystem changes based on the distribution and amount of different phytoplankton types, and aid in the development and improvement of models used to estimate phytoplankton biomass.

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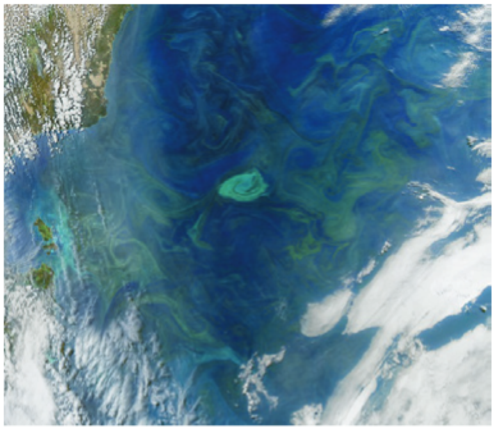
The R_{rs} data product used by Dr. Lange is available through NASA's OB.DAAC, and is produced from data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Aqua Earth observing satellite. Launched in May 2002 with six instruments to study Earth's water cycle, five of Aqua's instruments (including MODIS) are still collecting valuable data, including data related to phytoplankton and dissolved organic matter in the oceans.



Blooms of phytoplankton are clearly seen as blue/green swirls of color in this Aqua/MODIS image of the Tasman Sea off the south coast of Australia acquired on November 1, 2019. NASA image available through the NASA Ocean Color Image Gallery.

Along with Aqua MODIS R_{rs} data, other Aqua MODIS data products used by Dr. Lange (and available through NASA's OB.DAAC) include Sea Surface Temperature (SST), Photosynthetically Active Radiation (PAR, which measures the amount of light available for photosynthesis), chlorophyll concentration, and diffuse attenuation coefficient (which is abbreviated K_d and is a measurement of how the penetration of light dissipates with depth in a column of water).

For the past few years, Dr. Lange has concentrated her phytoplankton research in the largest ocean ecosystems: subtropical gyres. A gyre is a system of ocean currents that rotates clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. Five principal gyres extend across roughly 50 percent of Earth's ocean area: the North and South Pacific Subtropical Gyres, the Indian Ocean Subtropical Gyre, and the North and South Atlantic Subtropical Gyres (the Gulf Stream current along the U.S. East Coast forms the western boundary of the North Atlantic Gyre).

The nutrient-poor waters of these gyres are dominated by the smallest and most abundant photosynthetic organism on Earth: *Prochlorococcus*. The pigments within this cyanobacterium can change the color—and thereby the reflectance—of water, making it possible to study this organism across large distances using remotely-sensed data.

Previous studies have shown that the overall warming of the world's oceans is leading to an expansion of subtropical gyres. A recent study by Dr. Lange and her colleagues shows that this warming also is leading to changes in the distribution of *Prochlorococcus*. Using both ship-collected data and satellite-collected measurements, the research team found that distribution of *Prochlorococcus* within the gyres is expanding vertically, which is leading to a tremendous shift in phytoplankton biomass. Along with warming temperature of the water column within the gyres, the vertical distribution of *Prochlorococcus* also is closely linked to available light, so the biomass of phytoplankton under the ocean surface can be estimated based on satellite-collected measurements of how far light can penetrate into the water column.

As Dr. Lange and her colleagues observe, the warming of ocean surface layers within subtropical gyres enable *Prochlorococcus* to survive at greater depths. This, in turn, leads to a shift in phytoplankton biomass to lower levels of water within these gyres. As phytoplankton biomass moves to lower levels in the water column, this, in turn, removes phytoplankton biomass from upper levels of the water column and allows greater amounts of solar radiation to penetrate more deeply into the water column. Through this feedback loop, the gyres' waters continue to warm and phytoplankton continue to move to lower levels where the sunlight now penetrates. The research team notes that a decrease in the abundance of *Prochlorococcus* at the surface is compensated by an increase of *Prochlorococcus* at depth. Thus, while the biomass of *Prochlorococcus* biomass is decreasing at the surface, the overall biomass of this organism is actually increasing throughout the entire water column since it now exists at lower levels.

The distribution of phytoplankton, whether in subtropical gyres or in the highly productive waters of the Arctic and Antarctic, will continue to adjust to take advantage of changing ecological conditions. This shift in biomass that forms the base of the aquatic food pyramid will have significant impacts for the survival of animals that feed on the surface and those the feed farther

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below the surface. Instruments aboard Earth observing satellites are providing the data needed by Dr. Lange and her colleagues in their studies looking at how microscopic phytoplankton continue to be the big dogs on the block when it comes to facilitating life on Earth.

Representative data products used:

- NASA OB.DAAC Aqua/MODIS data products:
  - Sea surface temperature (SST; doi: 10.5067/AQUA/MODIS/L3M/SST/2014)
  - Remote sensing reflectance (R_{rs}; doi: 10.5067/AQUA/MODIS/L3M/RRS/2018)
  - Photosynthetically active radiation (PAR; doi: 10.5067/AQUA/MODIS/L3M/PAR/2018)
  - Chlorophyll concentration (CHL; doi: 10.5067/AQUA/MODIS/L3M/CHL/2018)
  - Diffuse attenuation coefficient (K_d; doi: 10.5067/AQUA/MODIS/L3M/KD/2018)
  - Various data products from the OB.DAAC SeaBASS data repository: https://seabass.gsfc.nasa.gov; SeaBASS is a publicly shared archive of in situ oceanographic and atmospheric data maintained by NASA's OBPG
- Various data products from the British Oceanographic Data Centre (BODC) data repository; available at https://www.bodc.ac.uk/data/

Read about the research:

Lange P.K., Brewin, R.J.W., Dall'Olmo, G., Tarran, G.A., Sathyendranath, S., Zubkov, M.V. & Bouman, H.A. (2018). "Scratching beneath the surface: a model to predict the vertical distribution of Prochlorococcus using remote sensing." *Remote Sensing*, 10(6): 847 [doi: 10.3390/rs10060847].

Brewin, R.J.W., Tilstone, G.H., Jackson, T., Cain, T., Miller, P.I., **Lange, P.K.**, Misra, A. & Airs, R.L. (2017). "Modelling size-fractionated primary production in the Atlantic Ocean from remote sensing." *Progress in Oceanography*, 158: 130-149 [doi: 10.1016/j.pocean.2017.02.002].

Lange, P.K., Tenenbaum, D.R., Tavano, V.M., Paranhos, R. & Campos, L.S. (2014). "Shifts in microphytoplankton species and cell size at Admiralty Bay, Antarctica." Antarctic Science, 27(3): 225-239 [doi: 10.1017/S0954102014000571].

When is a "flash drought" not a "flash drought"? NASA Earth science data helped David Mocko make this determination.

David Mocko

Senior Research Scientist
(Science Applications International Corporation [SAIC]) supporting the Hydrological Sciences Laboratory at NASA's Goddard Space Flight Center, Greenbelt, MD

Research interests: Using and evaluating land-surface models to study soil moisture, snow depth/cover, surface fluxes, and drought.

Research highlights: For Washington, D.C., the end of June and the first half of July in 2018 were bone dry, with only a trace of rain recorded at Ronald Reagan Washington National Airport. Slightly more rain was recorded north of Washington and at Dulles International Airport to the west, but not much more. An online *Washington Post* article published on July 12, 2018, raised the specter of a regional "flash drought."

"Flash drought" refers to a drought that develops much more rapidly than a typical drought. They typically exhibit sudden and relatively short periods of warm surface temperatures coupled with anomalously low and rapidly decreasing soil moisture. Precipitation certainly factors in, since a lack of available moisture exacerbates decreases in soil moisture. While the Washington region clearly was experiencing a lack of precipitation, was this really a flash drought?

David Mocko and his colleagues at NASA's Goddard Space Flight Center in Greenbelt, Maryland, were skeptical. They decided to take a closer look using land-surface models driven by meteorological observations. The truth, it turned out, was in the models.

Data about current water availability and soil moisture are acquired in a variety of ways and from many sources, including precipitation records from ground stations and in situ water monitors and gauges (such as calibrated airport rain gauges). Remotely-sensed data from Earth observing satellites also play an important role in providing these data, such as precipitation data from the joint NASA/Japan Aerospace Exploration Agency Global Precipitation Measurement (GPM) Core Observatory (launched in 2014) and soil moisture data from NASA's Soil Moisture Active Passive (SMAP) satellite (launched in 2015).

Along with providing information about ongoing events, these data (supplemented with historic records) serve as input to mathematical land-surface models that are used to produce representations of current environmental conditions (such as U.S. Drought Monitor maps) and forecast potential environmental conditions (such as seasonal climate predictions produced by the National Weather Service's Climate Prediction Center). These datasets also are used to verify land-surface models, or LSMs, to help ensure that the model simulations accurately represent real-world conditions.

As a Senior Research Scientist in the Hydrological Sciences Laboratory, David Mocko programs and uses software behind LSMs to run computer simulations for testing new LSMs and for exploring soil moisture, snow depth/cover, surface fluxes, and drought (both current and historic). He also is one of the core contributors to NASA's Land Information System (LIS) software framework, specifically as a member of the LSM team that incorporates different surface models into the LIS.

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LIS is a software suite comprising three modeling components: (1) the Land surface Data Toolkit (LDT), which handles the data-related requirements of LIS; (2) LIS, which is the actual modeling system that includes land-surface models, data assimilation algorithms, optimization and uncertainty estimation algorithms, and high performance computing support; and (3) the Land surface Verification Toolkit (LVT), which is a model verification and benchmarking environment that enables rapid prototyping and evaluation of model simulations by allowing users to compare model output against a comprehensive collection of in situ, remotely-sensed, and model and reanalysis data products. NASA's Dr. Sujay V. Kumar is the overall technical lead for LIS development.

Processing the enormous amount of data required for modeling the natural world is a task far beyond what any desktop computer can handle. Mocko's computing platform of choice is the "Discover" supercomputer located at NASA's Goddard Space Flight Center. To be more precise, Discover is not just a computer, it is a "90,000-core supercomputing cluster of multiple Linux scalable units built upon commodity components capable of nearly 3.5 petaflops, or 3,500 trillion floating-point operations per second [FLOPS]," to use the language of the NASA Center for Climate Simulation (NCCS). In other words, Discover uses a huge number of individual computers working in parallel to create fine-scale simulations of the atmosphere and oceans for short-term (months to years) climate predictions and long-range (decades to centuries) climate change projections. After programming and running job scripts on Discover, Mocko uses the simulation results for his scientific studies.

Mocko also is a co-Principal Investigator (PI) (along with lead PI Dr. Christa Peters-Lidard of NASA) for research on and development of the North American Land Data Assimilation System (NLDAS). NLDAS is a collaborative effort jointly led by the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction's (NCEP) Environmental Modeling Center (EMC) and by NASA's Goddard Space Flight Center. NLDAS uses the best available observations and model output to construct quality-controlled, spatially- and temporally-consistent LSM datasets to support modeling activities. This, in turn, helps reduce errors in the calculations of soil moisture and energy that often occur in numerical weather prediction models and helps improve the accuracy of these forecast models.

NLDAS datasets are used in a wide range of applications, including drought monitoring, land initialization for atmospheric weather and climate forecast models, streamflow and water quality studies, water and energy cycle studies, mosquito monitoring, and soil moisture studies. These datasets are available through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC), which is the Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Center (DAAC) responsible for NASA Earth science data related to global precipitation, atmospheric composition, atmospheric dynamics, hydrology, and solar irradiance.

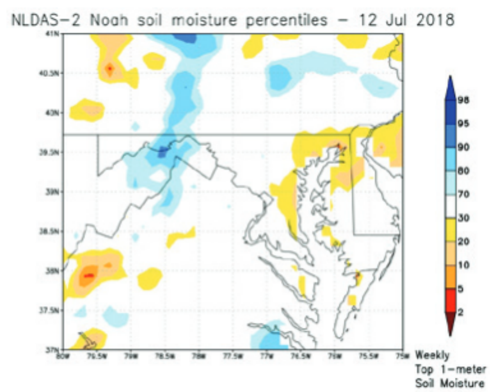
Mocko and his colleagues currently are working on adding the Noah-Multiparameterization (Noah-MP) LSM into NLDAS. Noah-MP includes an option to run a dynamic vegetation scheme that simulates vegetation based on evolving conditions. This is an important parameter in drought and soil moisture calculations since vegetation (both in extent and growth stage) can affect variables including soil moisture, transpiration, and water storage.

The team found, though, that the dynamic vegetation option in Noah-MP had difficulty simulating drought in the U.S. Central Plains, especially in regard to accurately representing soil moisture and transpiration. By incorporating leaf area index (LAI) data produced from Moderate Resolution Imaging Spectroradiometer

(MODIS) data, the team found that Noah-MP does a better job depicting drought, particularly in agricultural areas. Other recent studies done by the LIS and NLDAS teams show that assimilating soil moisture data (such as from SMAP), snow cover data (such as from MODIS), and terrestrial water storage data from the joint NASA/German Aerospace Center Gravity Recovery and Climate Experiment (GRACE, operational 2002 to 2017) also improves simulations of soil moisture, streamflow, and drought. These enhancements will be part of the next phase of NLDAS.

Which brings us back to the work by Mocko and his colleagues using LSMs as part of their examination of "flash drought" conditions in the Washington region during the summer of 2018. In a LIS blog post, the team observes that key flash drought criteria were not met in the region, specifically longevity of the drought (a mid-latitude location like Washington that doesn't have a very distinct rainy season requires a minimum drought length of at least four weeks to reach flash drought status) and the uniqueness of these conditions in space and time (it's not unique for the region to be hot and dry for periods of time in the middle of summer).

LSMs provide even more evidence to refute the flash drought claim. Using NLDAS soil moisture products, the team observed that root zone soil moisture (from the surface to one-meter deep) as of July 12, 2018, was generally still in the 'normal to moist' range for this time of year, and only a few areas east of Washington showed, at most, "abnormally dry" conditions. These data were supported by the July 10, 2018, U.S. Drought Monitor, which does not indicate even abnormally dry conditions south of New York state (abnormally dry conditions do appear over the region in the U.S. Drought Monitor map for July 17, 2018, but this is still above the threshold required for "drought" designation). In fact, NLDAS-2 Noah LSM top one-meter soil moisture data indicated that only about 20 percent of the region was "abnormally dry" by July 12. Based on their combination of model and observed data, the team noted that while dry conditions may have been developing in the Washington region in late-June and early-July, a two-week period without rain was not enough, by itself, to warrant the designation of "flash drought."



Soil moisture percentiles for the Washington region from the NLDAS Phase 2 Noah LSM for the top 1-meter of soil as of July 12, 2018. Colors indicate drought categories defined by the U.S. Drought Monitor, from abnormally dry (yellow) to exceptional drought (dark red). Abnormally moist areas on the same scale are shown in blue shades. Image and caption text from Hunt, et al., 2018.

Four days after the *Washington Post* "flash drought" article, storms dropped more than 2.7 inches of rain at Ronald Reagan Washington National Airport followed by four inches of rain on July 21. Despite the mid-summer dry period, the region never reached drought conditions before the torrential rain of mid-July. In fact, 2018 ended up being the wettest year ever recorded in Washington, D.C., according to the National Weather Service. For David Mocko and his colleagues, the truth was in the models.

Representative data products used:

- Data available through NASA's GES DISC:
  - NLDAS datasets
  - National Climate Assessment - Land Data Assimilation System (NCA-LDAS) (doi: 10.5067/ZQ7R3NHX28IO)

(Continued)

- SMAP soil moisture data; available through NASA's National Snow and Ice Data Center DAAC (NSIDC DAAC)
- MODIS snow cover and vegetation datasets from the Terra and Aqua Earth observing satellites; available through NASA's Land Processes DAAC (LP DAAC)
- GRACE water storage data; available through NASA's Physical Oceanography DAAC (PO.DAAC)

Read about the research:

Hunt, E., Santanello, J., Otkin, J., **Mocko, D.M.,** Kumar, S.V. & Lawston, P. (2018) "Was Washington DC really in a flash drought?" NASA LIS blog post published Thursday, July 19, 2018. Available online at https://lis.gsfc.nasa.gov/blog/was-washington-dc-really-flash-drought.

Kumar, S.V., Jasinski, M.F., **Mocko, D.M.,** Rodell, M., Borak, J.S., Li, B., Beaudoing, H.K. & Peters-Lidard, C.D. (2018). "NCA-LDAS land analysis: Development and performance of a multisensor, multivariate land data assimilation system for the National Climate Assessment." *Journal of Hydrometeorology*. Published online July 30, 2019 [doi: 10.1175/JHM-D-17-0125.1].

Mocko, D.M., Peters-Lidard, C.D., Wang, S., Kumar, S.V. & Xia, Y. (2018). "Drought Depiction in the Noah-MP (Multiphysics) Land Surface Model in the North American Land Data Assimilation System (NLDAS)." Presentation at the American Meteorological Society 98th Annual Meeting, Austin, TX, January 8, 2018. Link to recorded presentation.

Kumar, S.V., Wang, S., **Mocko, D.M.,** Peters-Lidard, C.D. & Xia, Y. (2017). "Similarity Assessment of Land Surface Model Outputs in the North American Land Data Assimilation System (NLDAS)." *Water Resources Research,* 53(11): 8941-8965 [doi: 10.1002/2017wr020635].

Xia, Y., **Mocko, D.M.,** Huang, M., Li, B., Rodell, M., Mitchell, K.E., Cai, X. & Ek, M.B. (2017). "Comparison and assessment of three advanced land surface models in simulating terrestrial water storage components over the United States." *Journal of Hydrometeorology,* 18(3): 625-649 [doi: 10.1175/jhm-d-16-0112.1].

Who Uses Earth Science Data?

Knowing where species live in a particular region is only one piece of an ecological puzzle. You also need to know why they live where they do. Dr. Monica Papeş uses NASA Earth science data to find out.

Dr. Monica Papeş

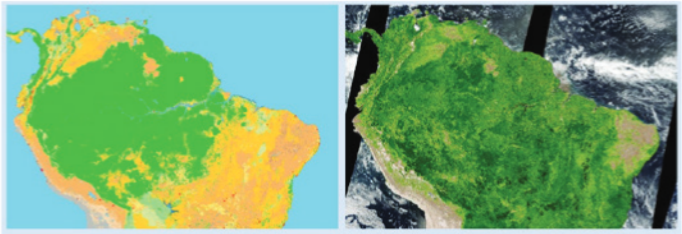
Assistant Professor, Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville

Research interests: Using remotely-sensed satellite data combined with ecological niche modeling techniques and GIS to study the geographic distributions of plant and animal species.

Research highlights: Pull up the range map of a plant or animal species and you'll see a shaded area indicating the general geographic region in which members of that species have been observed. This shaded area tells you *where* you can expect to find a particular species. A range map, however, won't tell you *why* a species lives where it does. Earth observing data in NASA's Earth Observing System Data and Information System (EOSDIS) collection help Dr. Monica Papeş answer this critical *why* question.

As Dr. Papeş observes, the geographic distribution of a specific plant or animal is deceptively simple (the shaded area on a range map), but is inadequately known in enough detail for most species to address real-world problems such as biodiversity conservation and impacts caused by invasive organisms and disease outbreaks. Despite the great advancements over the past two decades in forecasting biodiversity patterns, she notes that two shortcomings in this area include problems integrating remotely-sensed data into these studies along with the lack of a better understanding of the interrelationships between an organism's environment and how the organism lives in its environment, which is referred to as *ecophysiology*.

Dr. Papeş attempts to achieve three primary goals through her research: develop a better understanding of how species are distributed across broad spatial scales, derive local-scale ecological models that take into account seasonality and the effects of this seasonality on animal distributions, and integrate ecophysiological information into studies of geographic distribution. Remotely-sensed data have a number of attributes that make them a valuable tool in her investigations, including the ability to collect data continuously over spatial scales ranging from regional to continental and to examine the impacts of environmental change over time.



Two ways Dr. Papeş uses MODIS data to look at vegetation. ***Left image*** is combined Terra and Aqua MODIS Land Cover Type (MCD12Q1) with colors representing land cover type based on the International Geosphere-Biosphere Programme (IGBP) classification scheme (e.g., green represents broadleaf forest vegetation, yellow represents croplands, and red represents urban/built-up areas). ***Right image*** is a Terra MODIS Enhanced Vegetation Index (EVI; MOD13Q1) showing areas with high biomass (dark green areas) and areas with low biomass (brown areas). Both images show land cover type and vegetation as of January 1, 2018. NASA Worldview images.

Data related to vegetation structure characteristics are an important component of her work, especially data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Terra and Aqua Earth observing satellites. Specific MODIS data products used by Dr. Papeş include land cover type (which uses colors to differentiate among 18 global land cover types at yearly intervals), vegetation continuous fields (which provides estimates of vegetation type distribution), and vegetation index

(Continued)

products (which characterize the global range of vegetation states and processes). MODIS land cover products are available through NASA's Land Processes Distributed Active Archive Center (LP DAAC). LP DAAC is a partnership between NASA and the USGS, and provides tools and services for discovering and analyzing EOSDIS data related to land cover and land use.

Along with MODIS products, Dr. Papeş also utilizes hyperspectral imagery. While humans detect reflected light in the visible region of the electromagnetic spectrum (wavelengths of 0.45 µm [blue] to 0.67 µm [red]), hyperspectral instruments detect a much broader range of wavelengths. Since tree species have unique reflectance values, hyperspectral imagery can be used to identify cover type (e.g., broadleaf vs. conifer), vegetative health, and even individual species. The spectral response of vegetation also varies by season, such as early spring new growth vs. late-summer vegetation and changes in leaf pigments in autumn.

Dr. Papeş and her colleagues used hyperspectral imagery from the Hyperion imaging spectrometer instrument aboard NASA's Earth Observing-1 satellite (EO-1, operational 2000 to 2017) to identify tree species in a lowland forest in the Peruvian Amazon. The research team was able to differentiate the crowns of 42 individual trees in five distinct species and track their spectral changes over time, noting that this research method could be applied in larger studies of spectral-based multi-seasonal species mapping and ecosystem studies.

Model data derived from remotely-sensed data also are a component of Dr. Papeş' research. One example is the North American Land Data Assimilation System (NLDAS), which is a collection of quality-controlled, spatially and temporally consistent land surface model datasets. These data are available through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC), which is the EOSDIS DAAC responsible for global climate data related to the water and energy cycles, climate variability, atmospheric composition, and solar irradiance along with several land surface hydrology modelling datasets (like NLDAS). Dr. Papeş and her colleagues used NLDAS soil temperature data as one component in a study looking at the effects of life-history requirements on the distribution of the alligator snapping turtle.

Before weighing 200 pounds or more and growing to half as large as a six-foot man, alligator snapping turtles begin life as two-to-three-inch hatchlings. Whether a hatchling is male or female, though, depends on the incubation temperature of the nest in which the eggs are laid—embryos developing in warmer nests tend to develop into females; embryos developing in cooler nests tend to develop into males.

Using ecological models designed to examine turtle survival and reproduction, the research team determined that while low annual precipitation constrained the western distribution of alligator snapping turtles, soil temperature during embryonic development constrained the northern range of the species. The team also found that only a portion of the geographic range predicted to be suitable for alligator snapping turtle survival was estimated to be capable of supporting successful embryonic development. Dr. Papeş and her colleagues note that their research results "highlight the importance of considering [both] survival and reproduction when estimating species' ecological niches . . . and the benefits of incorporating physiological data when evaluating species' distributions."

From alligator snapping turtles to trees in Peru, each animal and plant species has a reason for living where they do. For Dr. Monica Papeş, remotely-sensed data from the EOSDIS collection greatly facilitate her explorations into the *why* behind these geographic distributions.

Representative data products used:

- Available through NASA's LP DAAC:
  - MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V006 (MOD13Q1; doi: 10.5067/MODIS/MOD13Q1.006)

(Continued)

- MODIS/Terra Vegetation Continuous Fields Yearly L3 Global 250m SIN Grid V006 (MOD44B; doi: 10.5067/MODIS/MOD44B.006)
- MODIS/Terra+Aqua Land Cover Type Yearly L3 Global 500m SIN Grid V006 (MCD12Q1; doi: 10.5067/MODIS/MCD12Q1.006)
- NASA Shuttle Radar Topography Mission (SRTM) Global 1 arc second elevation maps (doi: 10.5067/MEaSUREs/SRTM/SRTMGL1.003)

■ Available through NASA's GES DISC:

- NLDAS soil temperature data

■ Available through the USGS EarthExplorer:

- Hyperion hyperspectral imagery from NASA's EO-1 satellite
- Landsat Enhanced Thematic Mapper+ (ETM+) data

Read about the research:

Thompson, D., Ligon, D.B., Patton, J.C. & **Papeş, M.** (2017). "Effects of life-history requirements on the distribution of a threatened reptile." *Conservation Biology*, 31(2):427-436 [doi: 10.1111/cobi.12800].

Escobar, L.E., Peterson, A.T., **Papeş, M.**, Favi, M., Yung, V., Restif, O., Qiao, H. & Medina-Vogel, G. (2015). "Ecological approaches in veterinary epidemiology: mapping the risk of bat-borne rabies using vegetation indices and night-time light satellite imagery." *Veterinary Research*, 46(1) [doi: 10.1186/s13567-015-0235-7].

Papeş, M., Tupayachi, R., Martínez, P., Peterson, A.T., Asner, G.P. & Powell, G.V.N. (2013). "Seasonal variation in spectral signatures of five genera of rainforest trees." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (JSTARS)*, 6(2):339-350 [doi: 10.1109/jstars.2012.2228468].

Who Uses Earth Science Data?

Renewable energy has the potential to meet a large portion of global energy demands. It also is a key component of the POWER behind Dr. Paul Stackhouse's work.

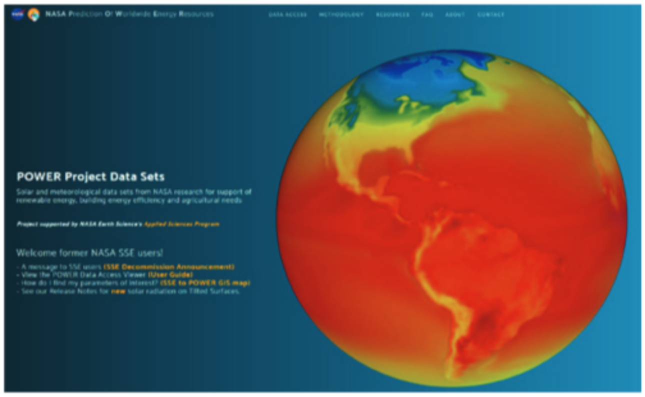
Dr. Paul Stackhouse

Senior Research Scientist, NASA's Langley Research Center, Science Directorate/ Climate Sciences Branch, Hampton, VA

Research interests: Using satellite observations of the Earth-atmosphere system from multiple sources to study Earth's global energy cycle, especially the processes that cause variability from global to regional scales. Dr. Stackhouse also develops new data products and data systems to help analyze these processes and more efficiently understand and use renewable energy sources.

Research highlights: The U.S. state of Arizona receives a lot of sunshine. According to data available through NOAA's National Centers for Environmental Information, Phoenix receives an average of 85 percent of possible sunshine each year when compared with other U.S. cities (such as Detroit, Michigan, which receives an average of 54 percent of possible annual sunshine). This surplus of sunshine makes Arizona is an ideal location for using solar power.

Solar power is one example of a renewable energy resource. Other examples include wind power, geothermal power, and hydroelectric power. The Renewable Electricity Futures Study by the Department of Energy's National Renewable Energy Laboratory found that "renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80 percent of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the United States."



The POWER project is supported by NASA's Applied Sciences Program. The Applied Sciences Program funds projects that enable innovative uses of NASA Earth science data in organizations' policy, business, and management decisions.

NASA provides ongoing support to the solar energy, energy-efficient building, and agriculture industries through its development of environmental datasets created from data collected by instruments aboard Earth observing satellites. Additional datasets are created from data derived from environmental models that simulate natural processes under future environmental conditions. Dr. Paul Stackhouse leads several NASA initiatives to create and enhance these data products and develop systems to provide these data to a global user community.

A principal effort led by Dr. Stackhouse is the Prediction of Worldwide renewable Energy Resources (POWER) applied science project. The purpose of POWER is to improve existing renewable energy datasets and create datasets using data from new and existing satellite missions. POWER is a geographic information system (GIS)-enabled interactive web portal that provides data products customized to three primary user communities: Renewable Energy, Sustainable Buildings, and Agroclimatology. These products are available from daily up to multiple-year averages.

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To the Renewable Energy community, POWER provides access to parameters specifically tailored to assist in the design of solar and wind-powered renewable energy systems. For the Sustainable Buildings community, POWER provides access to industry-friendly parameters important for building-system optimization. Finally, POWER provides the Agroclimatology community web-based access to parameters formatted for input to crop models contained within agricultural decision support systems.

POWER utilizes data products from two other projects led by Dr. Stackhouse: the World Climate Research Programme (WCRP) Global Energy and Water Exchange (GEWEX) Surface Radiation Budget (SRB) project and the Clouds and the Earth's Radiant Energy System (CERES) Fast Longwave and Shortwave Radiative Fluxes (FLASHFlux) project. "Radiation budget" refers to the difference between the absorbed solar radiation hitting Earth and the net infrared energy radiated from the surface, regulated by the atmosphere, and ultimately radiated back into space. These energy interactions control Earth's temperature and rainfall, and take into account the sum of all radiation, transferred in all directions, through Earth's atmosphere and to-and-from space.

The GEWEX SRB project seeks to determine the radiation budget and its components, including solar energy fluxes, at Earth's surface and exiting into space spanning from the early 1980's through near-present time. This information helps us better understand how this energy affects Earth's overall energy and water cycles over long time scales. Data for the GEWEX SRB project come from the International Satellite Cloud Climatology Project (ISCCP) along with a number of ancillary sources, including data products from models produced by NASA's Global Modeling and Assimilation Office (GMAO) at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

FLASHFlux, which was initiated by NASA's Langley Research Center in Hampton, Virginia, meets the needs of the science community for global near real-time surface and Top-Of-Atmosphere (TOA) radiative flux data. By speeding up the processing of TOA observations by the CERES and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments aboard NASA's Terra and Aqua satellites, these data are available about a week after they are collected and provide a first look for global solar and thermal infrared fluxes.

GEWEX SRB and FLASHFlux data are available through NASA's Atmospheric Science Data Center (ASDC) located at NASA's Langley Research Center. ASDC is NASA's Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Center (DAAC) responsible for NASA data related to the radiation budget, clouds, aerosols, and tropospheric composition. Data in the GWEX SRB and FLASHFlux collection provide a wide range of information. For instance, SRB and FLASHFlux surface solar energy data products are prepared in customized time series, together with other surface meteorological parameters, to support the solar power industry and for modeling the energy performance of buildings through the POWER web services tool (which also is hosted by ASDC). Current, near real-time data from these projects help systems engineers evaluate the energy performance of solar systems (whether these systems are stand-alone or integrated into buildings), while data related to long-term averages and the variability of solar and surface meteorological information aid in the optimization of building-installed systems for a building's specific location.

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All of these data are available quickly through the POWER web portal. The portal includes multiple data access methods, including an interactive data access viewer, web services, and a full-service POWER Application Program Interface (API). The API capability allows users to access POWER data through their own custom scripts and scalable applications. A great place to start for those new to the POWER portal is the POWER User Guide.

Screenshot of the POWER Data Access Viewer with an overlay of the 22-year climatological average insolation for Mexico, the U.S., and Canada. Orange and yellow hues indicate areas receiving higher amounts of solar radiation (such as over Arizona, which is highlighted); green areas receive lower amounts of solar radiation.

How can these data be used? One example is a recent analysis by Dr. Stackhouse and his colleagues on the contribution of solar brightening to the trend in higher U.S. maize yield. As the research team notes, many researchers attribute the increasing maize yield in the U.S. Corn Belt to advances in technology. However, environmental data point to decadal-scale global increases in the amount of incoming solar radiation ("solar brightening") since the 1980s. The research by Dr. Stackhouse and his colleagues shows that "accumulated solar brightening during the post-flowering phase of development of maize increased during the past three decades, causing the yield increase that previously had been attributed to agricultural technology." One implication of this research is that historical trend data might not be an accurate representation of future crop yields as the global climate continues to change. POWER provides a unified source for these radiation data.

Dr. Stackhouse and his teams are working on a number of project improvements. The SRB team is reprocessing the entirety of the GEWEX SRB dataset to produce a 30-plus year record of surface and TOA solar and thermal infrared radiative fluxes that show improved agreement with surface measurements. The CERES FLASHFlux team is preparing to update its algorithm to an improved version with newer CERES instrument calibration and with data parameters and formats more consistent with the CERES Edition 4 climate data products. Finally, the POWER team is working to enhance its current web portal capabilities by providing variability information for parameters related to building energy efficiency.

The efforts of Dr. Stackhouse and his colleagues are bringing new radiation data and data products from NASA Earth observing missions and models to support work in a wide range of fields. From the sustainable building industry to agriculture, the projects managed and led by Dr. Stackhouse provide a wealth of information for using renewable energy in a changing environment.

Representative data products used. All are available through NASA's ASDC:

- GEWEX SRB data and data products:
  - LW monthly data in 1x1 Degree NetCDF Format (doi: 10.5067/SRB/REL3.1_LW_MONTHLY_NC_L2)
  - SW Monthly UTC Data in 1x1 Degree NetCDF Format (doi: 10.5067/SRB/REL3.0_SW_MONTHLY_UTC_NC_L3)
- CERES FLASHFlux data (doi: 10.5067/TERRA+AQUA/CERES/FLASH_TISA_L3.003C)
- Various POWER datasets

(Continued)

Read about the research:

Zhang, T., **Stackhouse, Jr., P.W.,** Cox, S.J., Mikovitz, M.J. & Long, C.N. (2019). "Clear-sky Shortwave Downward Flux at the Earth's Surface: Ground-Based Data vs. Satellite-Based Data." *Journal of Quantitative Spectroscopy and Radiative Transfer*, 224: 247-260 [doi: 10.1016/j.jqsrt.2018.11.015].

Wong, T., Kratz, D.P., **Stackhouse, Jr., P.W.,** Sawaengphokai, P., Wilber, A.C., Gupta, S.K. & Loeb, N.G. (2018). "Earth Radiation Budget at Top-of-Atmosphere" [in "State of the Climate in 2017"]. *Bulletin of the American Meteorological Society*, 99(8): S45-S46 [doi: 10.1175/2018BAMSStateoftheClimate.1].

Yu, L., Jin, X., Kato, S., Loeb, N.G., **Stackhouse, Jr., P.W.,** Weller, R.A. & Wilber, A.C. (2018). "Global ocean heat, freshwater, and momentum fluxes" [in "State of the Climate in 2017"]. *Bulletin of the American Meteorological Society*, 99(8): S81-S84 [doi: 10.1175/2018BAMSStateoftheClimate.1].

Tollenaar, M., Fridgen, J., Tyagi, P., **Stackhouse, Jr., P.W.** & Kumudini, S. (2017). "The Contribution of Solar Brightening to the US Maize Yield Trend." *Nature Climate Change,* 7(4): 275-278 [doi: 10.1038/nclimate3234].

Who Uses Earth Science Data?

Remotely-sensed satellite data enable researchers to explore every corner of Earth. For economist Dr. Adam Storeygard, these data are an integral component of his research into city growth in sub-Saharan Africa.

Photograph of Dr. Adam Storeygard by Stephanie Alvarez Ewens for Brown University.

Dr. Adam Storeygard

Associate Professor of Economics, Tufts University, Medford, MA

Research interests: Urbanization, transportation, and the economic geography of the developing world, including research to explain city growth in sub-Saharan Africa.

Research highlights: The Greek word *oikos* means "house." But the concept of *oikos* extends beyond a mere building. It also can refer to a family or any dwelling area, such as a community or even a nation. When combined with Greek suffixes, *oikos* becomes an even more encompassing—and interesting—word.

Adding the Greek suffix *-logia*, which can be defined as "the study of," to *oikos* creates a word meaning "the study of the house"—what we more commonly recognize as the contemporary word *ecology*. Adding the Greek suffix *-nomos*, which can be translated as "law, custom, or management," gives us the contemporary word *economy*. The study of the house (*ecology*) and the management of the house (*economy*) are intertwined, and the connection is much more than mere etymology.

In fact, NASA's Earth Observing System Data and Information System (EOSDIS) maintains a large socioeconomic data collection that is archived at and distributed by NASA's Socioeconomic Data and Applications Center (SEDAC), which is one of the EOSDIS' discipline-specific Distributed Active Archive Centers, or DAACs. Hosted by the Center for International Earth Science Information Network (CIESIN) at Columbia University, SEDAC serves as an "Information Gateway" between the socioeconomic and Earth science data and information domains, and synthesizes Earth science and socioeconomic data and information in ways useful to a wide range of decision-makers and other applied users. Dr. Adam Storeygard is one of these applied users.

Remotely-sensed data from orbiting sensors designed to study our home planet are integral components of Dr. Storeygard's economic research into urbanization, transportation, and the developing world. The data collected by these satellite-borne instruments, particularly nighttime lights data, help him analyze economic development in remote or developing areas.

Dr. Storeygard's specific research focus is sub-Saharan Africa, a vast region that encompasses all African nations partially or fully located south of the Sahara Desert. The roughly one billion residents of this region have a life expectancy of about 61 years (up from 40 years in 1960) and 41 percent live in extreme poverty, according to the United Nations Development Programme. Relying on traditional economic measurements for research into the productivity and development of this region brings a unique set of challenges.

For example, one foundational economic measurement is a country's Gross Domestic Product, or GDP. GDP is the total value of goods produced and services provided in a country during one year. However, tracking economic activity in developing countries or remote regions is difficult. As noted by the World Bank, "Many statistical offices, especially those in developing countries, face severe limitations in the resources, time, training, and budgets required to produce reliable and comprehensive series of national accounts statistics." A key difficulty is the inability to account for unreported economic activity, such as informal transactions or agricultural production that is consumed rather than marketed.

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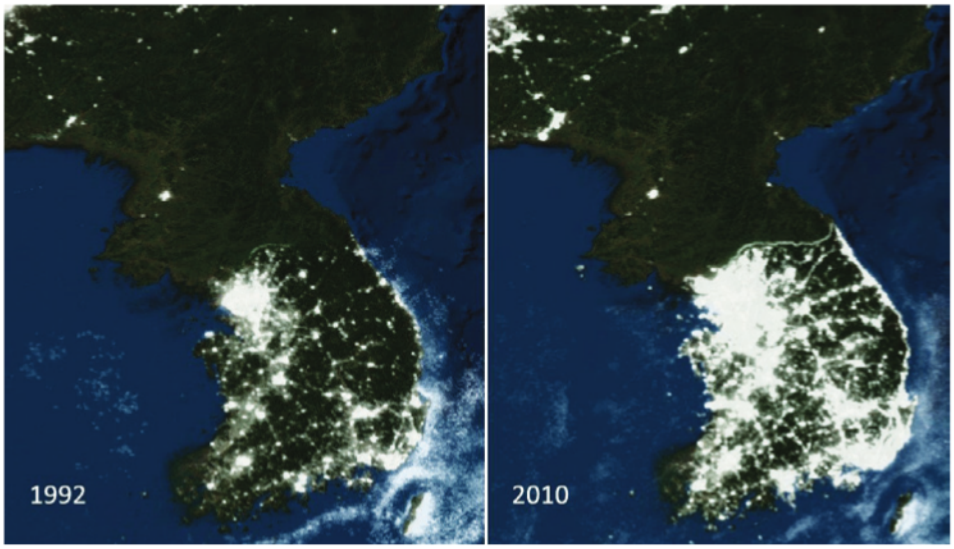
These "hidden" transactions likely represent a larger share of the economy in many developing countries. For Dr. Storeygard, getting accurate GDP metrics for sub-Saharan Africa requires a different approach.

Dr. Storeygard uses remotely-sensed nighttime lights data as a proxy for economic activity, and notes that nighttime lights data address two problems with GDP. For one, nighttime lights data are globally consistent, which enables them to be combined with more traditional sources of economic data to provide improved estimates of economic growth for countries with weak statistical systems. Secondly, traditional measures of economic activity are often unavailable for sub-regions within countries in the developing world (such as states, municipalities, or counties).



Example of how nighttime lights imagery can be used to study growth over time and space. Both images were created from data collected by the DMSP-OLS series of satellites and show the Korean Peninsula. Note the high concentration of nighttime lights in South Korea vs. North Korea as well as the spread of lights over 18 years. The thin line stretching across the peninsula just north of the bright lights of Seoul, South Korea, is the Demilitarized Zone (DMZ) separating North Korea from South Korea. Lights over water are lights from fishing vessels, bioluminescence from ocean organisms, or off-gassing from oil wells. Both images: NOAA DMSP OLS Global Composites Version 4, National Centers for Environmental Information.

His primary source for nighttime lights data is the Defense Meteorological Satellite Program (DMSP) series of satellites. The first DMSP satellite was launched in 1962, and the program is jointly run by NOAA and the U.S. Air Force. The primary weather sensor on the spacecraft is the Operational Linescan System (OLS), which provides the nighttime lights data used by Dr. Storeygard. First flown on DMSP satellites in 1976, the OLS is an oscillating scan radiometer with low-light visible and thermal infrared (TIR) imaging capabilities.

While previous work outside of economics noted correlations between the amount of light emitted by countries and traditional measures of their economic activity (such as GDP) in a given year or two, the research by Dr. Storeygard and his colleagues was the first to consider the relationship in changes in emitted light vs. GDP growth over time and analyze it in a formal statistical model. Having established the value of using nighttime lights data for quantitative economic analysis, Dr. Storeygard has used these data in numerous studies of urbanization and urban economic growth in sub-Saharan Africa, including studies into impacts of transport costs on a city's economic growth and the effects of climate change on urbanization.

In a [recent research project](), Dr. Storeygard and his colleagues use nighttime lights data to help examine how attributes of physical geography, such as climate, topography, and proximity to coasts and navigable rivers, shape the location and density of human settlements worldwide. The research team notes that attributes related to agricultural productivity (such as a favorable climate and level terrain) are relatively more powerful in predicting settlement patterns within rich countries than attributes associated with trade access (such as proximity to

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water), which are relatively more predictive of settlement location within poor countries. This is somewhat surprising, Dr. Storeygard observes, because agriculture represents a much smaller share of overall employment and income in rich countries. It is, however, consistent with models representing how today's rich, developed countries achieved the improvements in agricultural productivity prior to the 20th century that allowed them to urbanize at a time when transport costs were high.

Dr. Storeygard and his colleagues summarize that city sizes were limited by the ability of food to be transported to them, which, in turn, led to the development of a dispersed network of cities. By the time today's poor countries began to urbanize rapidly in the mid- to late-20th century, transportation costs had fallen substantially, so their urban populations concentrated in a smaller set of cities in locations along coasts and navigable rivers. This research raises an intriguing speculative policy implication that cities of the developing world may be better located to thrive in today's economy than if they had become organized much earlier into more dispersed city systems similar to those in richer regions like Europe and North America.

The integration of remotely-sensed satellite data with measurements of GDP and other traditional economic metrics was not on the minds of the ancient Greeks when they developed their concept of *oikos*. For Dr. Adam Storeygard, nighttime lights data, captured by sensors orbiting hundreds of kilometers above Earth, give him a unique resource to supplement traditional economic measurements—ecology being used for economy.

Representative data products used:

- Gridded Population of the World (GPW), v4 (doi: 10.7927/H45Q4T5F); available through NASA's SEDAC
- DMSP data download; available through the Earth Observation Group at NOAA's National Centers for Environmental Information

Daily nighttime lights data available through NASA:

- Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB), Enhanced Near Constant Contrast; daily global imagery available through NASA's Global Imagery Browse Services (GIBS) for viewing using NASA's Worldview interactive data visualization application and similar applications

Read about the research:

Henderson, J.V., Squires, T., **Storeygard, A.** & Weil, D. (2017). "The Global Distribution of Economic Activity: Nature, History, and the Role of Trade." *The Quarterly Journal of Economics,* 133(1): 357-406 [doi: 10.1093/qje/qjx030].

Henderson, J.V., **Storeygard, A.** & Deichmann, U. (2017). "Has climate change driven urbanization in Africa?" *Journal of Development Economics,* 124: 60-82 [doi: 10.1016/j.jdeveco.2016.09.001].

Storeygard, A. (2016). "Farther on down the Road: Transport Costs, Trade, and Urban Growth in Sub-Saharan Africa." *The Review of Economic Studies,* 83(3): 1263-1295 [doi: 10.1093/restud/rdw020].

Henderson, J.V., **Storeygard, A.** & Weil, D.N. (2012). "Measuring Economic Growth from Outer Space." *American Economic Review,* 102(2): 994-1028 [doi: 10.1257/aer.102.2.994].

Who Uses Earth Science Data?

The global average sea level is rising. Dr. Philip Thompson uses NASA Earth science data to explore how—and when—this will affect vulnerable communities.

Dr. Philip Thompson checks a tide gauge solar panel mount on Makai Pier, Oahu, Hawai'i. Image by Elyse Butler.

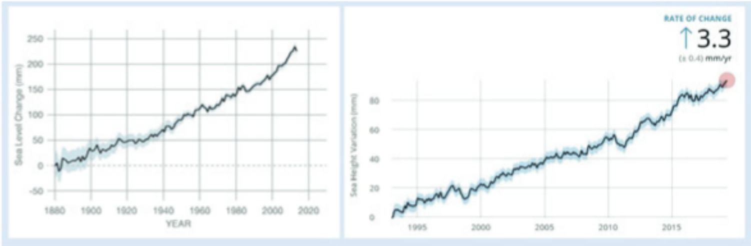
Dr. Philip Thompson

Assistant Professor, Department of Oceanography, School of Ocean and Earth Science and Technology, University of Hawai'i at Mānoa; Director, University of Hawai'i Sea Level Center, Honolulu, HI

Research interests: Studying the drivers and impacts of sea level variability along with the impact of future sea level rise on the frequency of high-tide flooding events and water level extremes.

Research highlights: According to the World Meteorological Organization (WMO), July 2019 was the warmest month ever recorded on Earth since official record-keeping began more than 100 years ago. This historic heat has consequences. As noted in an online *Washington Post* article published on August 3, 2019, data from the Danish Meteorological Institute indicate that during July the melting Greenland ice sheet added 197 billion tons of water into the Atlantic Ocean. The article quotes a researcher at the Institute observing that "this is enough to raise sea levels by 0.5 millimeters, or 0.02 inches, in a one-month time frame."

The melting did not just begin, however. Data collected by coastal tide gauges and instruments aboard Earth observing satellites, and available through NASA's Sea Level Change Portal, show that the global average sea level rose almost seven inches (178 mm) over the past century alone. Looking back to the late-19th century, the data are clear: Earth's average sea level is rising, and the rate of rise has increased since the mid-20th century.



Left graph is sea level change measured by coastal tide gauges between 1880 and 2013. Credit: Commonwealth Scientific and Industrial Research Organisation (CSIRO). **Right graph** is sea height variation as measured by altimeters aboard Earth observing satellites from 1993 to present. Red dot at upper right tip of graph indicates data as of April 27, 2019. Credit: NASA's Goddard Space Flight Center/NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC). Both graphs available at NASA's Sea Level Change Portal.

Identifying the many drivers of sea level change—including the reasons why some regions are seeing sea levels rise while other regions are seeing sea levels fall—is one focus of Dr. Philip Thompson's research. As director of the University of Hawai'i Sea Level Center, Dr. Thompson oversees a global network of more than 80 tide gauges and curates internationally-sourced tide gauge sea level datasets. He also develops products to help inform decision-makers in vulnerable communities about the impacts of sea level change, impacts that are expected to increase in severity as average global temperatures continue to rise.

First, a little background. Global average sea levels are influenced by two primary factors, both of which relate to increasing average global temperatures. One factor is water added to oceans from melting ice sheets and glaciers, particularly from areas near the poles. A second factor is the expansion of seawater as it warms. Since greenhouse gasses trap heat in Earth's atmosphere and oceans absorb more than 90 percent of this heat, thermal expansion is a significant contributor to global sea level rise.

Along with global sea level changes, sea levels also fluctuate regionally. These regional sea level variations are more complex, and involve factors including wind blowing over the ocean leading to uneven warming of the ocean surface and the uneven transport of ocean heat,

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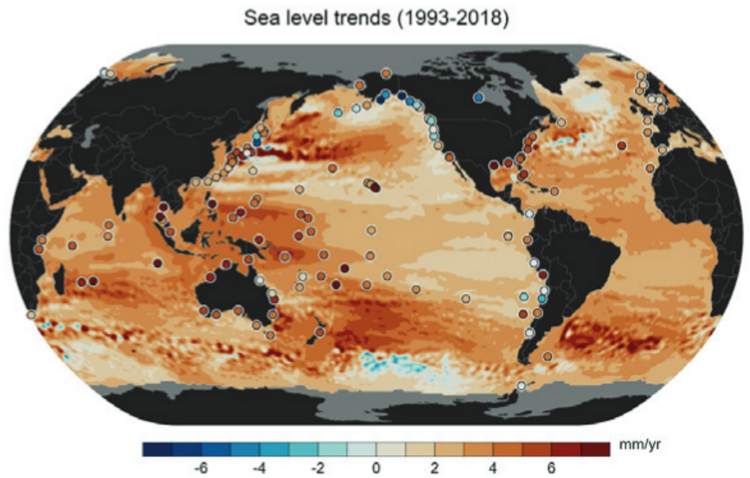
changes in gravity and Earth's rotation caused by the loss of huge quantities of ice from continents (more about this below), uplift from earthquakes, and localized precipitation. The result is that even while the global average sea level is rising, some regions are experiencing falling sea levels while others are seeing sea levels rise faster than average. To better understand the drivers behind these changes, Dr. Thompson relies on data from tide gauges and satellite-borne instruments, both of which complement each other.

The orbiting satellites providing the sea height data used by Dr. Thompson sample about 95 percent of the ice-free global ocean. However, they have a 10-day repeat cycle and might miss short-duration, high-impact changes in water level caused by events like tsunamis and storm surges. Fixed tide gauges, on the other hand, do not have the spatial coverage of a satellite instrument, but are better able to capture short-duration changes in sea level caused by localized high-impact events. As a result, both tide gauges and remotely-sensed satellite data are essential for comprehensive studies of the drivers and impacts of sea level change, with tide gauges also being vital for validating satellite-collected data.



Differences between global sea height change detected by satellite altimeters and regional sea level change measured by tide gauges is easily seen in this University of Hawai'i Sea Level Center (UHSLC) map showing overall sea level trends from the start of satellite-collected ocean height measurements in 1993. Colored contours indicate sea level trends derived from joint NASA/CNES satellite altimetry missions. Colored circles are sea level trends from fixed tide gauges. Trends were calculated using tide gauge data from the UHSLC Fast-Delivery database and Ssalto/Duacs altimeter products produced and distributed by the European Union Copernicus Marine and Environment Monitoring Service (CMEMS). Image reproduced courtesy of UHSLC.

The satellite data used by Dr. Thompson come from several ocean surface topography missions designed to measure ocean height using altimeters. These altimetry missions include the joint NASA/French Space Agency (CNES) Ocean Surface Topography Experiment (TOPEX)/Poseidon, Jason-1, and Ocean Surface Topography Mission (OSTM)/Jason-2. Data from these missions are available through NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC), which archives and distributes data in NASA's EOSDIS collection related to the physical processes and conditions of the global oceans.

As noted above, changes in sea level are associated with variations in Earth's gravity field. As ice sheets melt, a tremendous amount of ice mass packed into small continental areas gets redistributed in liquid form evenly around the global ocean (such as the melting in Greenland in July 2019 that converted billions of tons of ice sheet mass into liquid water that flowed into the Atlantic Ocean). The changes in gravity associated with ice melt can be tracked using data from the joint NASA/German Space Agency (DLR) Gravity Recovery and Climate Experiment (GRACE, operational 2002 to 2017) and GRACE Follow-On (GRACE-FO, launched in 2018) missions, which precisely map Earth's gravity field (Dr. Thompson currently uses GRACE data in his research, but not data from GRACE-FO).

The movement of water mass from continents to ocean not only alters Earth's gravitational field, it also produces specific patterns of sea level change that are unique to each melt source. Given the unique nature of these sea level change patterns, they have been called "ice melt fingerprints." Research by Dr. Thompson and

(Continued)

his colleagues explored the impact of these ice melt fingerprints on historical sea level trends measured by tide gauges and found that the fingerprints can have a substantial effect on estimates of sea level rise over the last century.

Even a partial melting of the Greenland ice sheet could raise sea level one meter (approximately three feet). If it melted completely, the Greenland ice sheet contains enough water to raise global sea level by five to seven meters (16 to 23 feet). **Left image** is the potential effect of a one-meter rise in sea level on Florida, the Northern Caribbean, and the U.S. Gulf Coast. **Right image** is the potential effect of a six-meter sea level rise. Red indicates land that would be covered by water. Images available through NASA's Global Climate Change website and created by the Center for Remote Sensing of Ice Sheets (CReSIS).

As the world continues to warm, the impacts of sea level rise are shifting from questions of "if" this rise will impact coastal regions to "how much" of an impact this will have. According to a 2018 report by the Intergovernmental Panel on Climate Change (IPCC), the average global temperature is likely to rise 1.5°C between 2030 and 2052 if it continues to increase at the current rate (some regions already have reached or passed this critical threshold). Looking at the impacts of this on global sea level, the IPCC concludes that "Increasing warming amplifies the exposure of small islands, low-lying coastal areas and deltas to the risks associated with sea level rise for many human and ecological systems, including increased saltwater intrusion, flooding and damage to infrastructure (*high confidence*)."

Dr. Thompson is involved with numerous research efforts to better understand and help prepare for these expected impacts. As a member of NASA's Sea Level Change Science Team, he is leading a study to quantify the impact of future sea level rise on the frequency of high-tide flooding along U.S. coastlines, including U.S. island territories. The results of this work will be incorporated into a dynamic, web-based tool hosted on NASA's Sea Level Change portal designed to support decision-makers.

Closer to home, he and his students recently examined the factors that led to an unprecedented number of high-tide flooding events around Hawai'i during the summer of 2017. Using satellite altimetry data, one of his graduate students documented how ocean eddies and the 2015 to 2016 El Niño event elevated sea levels to record heights and contributed to local flooding of roads and repeated over-wash of Waikiki beach in Oahu. These events led to further research into how the frequency of high tide flooding will evolve in Honolulu in coming decades and identified the potential for a four-fold increase in the number of flooding events in the 2030s to the 2040s.

Meanwhile, historic ice loss continues on the Greenland ice sheet. New data indicate that the ice sheet lost 12.5 billion tons of ice on August 1, 2019—the largest single-day ice loss by volume from the ice sheet ever recorded. The bottom line is that global average sea levels are rising, and more and more communities, regions, and nations will be impacted by this process. Thanks to the work and research of Dr. Thompson, his colleagues, and his students—aided by data collected by instruments aboard Earth observing satellites—the world will be better prepared to respond.

Representative data products used:

- Available through NASA's PO.DAAC:
  - NASA Making Earth Science Data Records for Use in Research Environments (MEaSUREs) Gridded Sea Surface Height Anomalies Version 1812 (doi: 10.5067/SLREF-CDRV2)

(Continued)

- Global Mean Sea Level Trend from Integrated Multi-Mission Ocean Altimeters TOPEX/Poseidon, Jason-1, and OSTM/Jason-2 Version 4.2 (doi: 10.5067/GMSLM-TJ142)
- JPL GRACE Mascon Ocean, Ice, and Hydrology Equivalent Water Height JPL Release 06 Version 1 (doi: 10.5067/TEMSC-3MJ06)

■ Available through the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information:

- Sea level measured by tide gauges from global oceans as part of the Joint Archive for Sea Level (JASL) since 1846 (doi: 10.7289/V5V40S7W)

Read about the research:

Thompson, P.R., Widlansky, M.J., Merrifield, M.A., Becker, J.M. & Marra, J.J. (2019). "A Statistical Model for Frequency of Coastal Flooding in Honolulu, Hawai'i, During the 21st Century." *Journal of Geophysical Research: Oceans,* 124(4): 2787-2802 [doi: 10.1029/2018JC014741].

Yoon, H., Widlansky, M.J. & **Thompson, P.R.** (2018). "Nu'a Kai: Flooding in Hawai'i caused by a "stack" of oceanographic processes" [in "State of the Climate in 2017"]. *Bulletin of the American Meteorological Society,* 99(8): S88-S89 [doi: 10.1175/2018BAMSStateoftheClimate.1].

Thompson, P.R., Hamlington, B.D., Landerer, F.W. & Adhikari, S. (2016). "Are long tide gauge records in the wrong place to measure global mean sea level rise?" *Geophysical Research Letters,* 43(19): 10,403-10,411 [doi: 10.1002/2016GL070552].

Thompson, P.R., Piecuch, C.G., Merrifield, M.A., McCreary, J.P. & Firing, E. (2016). "Forcing of recent decadal variability in the Equatorial and North Indian Ocean." *Journal of Geophysical Research: Oceans,* 121(9): 6762-6778 [doi: 10.1002/2016JC012132].

Who Uses Earth Science Data?

More than half of Earth's population lives in urban environments. NASA Earth science data help Dr. Kristy Tiampo explore the hazards that can impact these areas.

Dr. Kristy Tiampo

Director,
Earth Science & Observation Center, Cooperative Institute for Research in Environmental Sciences (CIRES) and Professor, Geological Sciences, University of Colorado, Boulder, CO

Research interests: Using high-resolution satellite data and imagery to study natural (and human-created) hazards in order to help mitigate and respond to events caused by these hazards.

Research highlights: Ancient Romans considered Lake Avernus to be the entrance to the underworld and the home of Vulcan, the Roman god of fire. And no wonder. This volcanic crater lake just west of present-day Naples, Italy, is located near the Phlegraean Fields (*Campi Flegrei*, or "Fiery Fields," in Italian), which is one of the world's largest volcanically active regions. Steaming vents and boiling pools of mud surround this supervolcano—as do nearly three million residents of Naples, almost one million of whom live within the Campi Flegrei caldera. As Dr. Kristy Tiampo observes, this high urban concentration makes the caldera one of the most hazardous volcanic areas in the world.

Image of the Campi Flegrei caldera cluster acquired July 9, 2012, by the Advanced Land Imager (ALI) aboard NASA's Earth Observing-1 (EO-1) satellite. 1 = Lake Avernus; 2 = Campi Flegrei caldera; 3 = Naples, Italy. NASA Earth Observatory image by Jesse Allen and Robert Simmon.

Natural hazards represent a significant risk to the people and economy of every country, notes Dr. Tiampo, and are most often a future liability that is difficult to quantify or predict. Using a combination of remotely-sensed satellite data available through NASA's Earth Observing System Data and Information System (EOSDIS) and ground-based observations, her research seeks to provide a better understanding of the natural (and human-created) hazards affecting urban areas and how these areas might be impacted during a disaster. While hazards such as volcanic eruptions, earthquakes, tsunamis, and landslides haven't changed, the number of people living in areas susceptible to these hazards has.

According to the United Nations Department of Economic and Social Affairs (UN DESA), more than half (55 percent) of the world's population now lives in urban areas; this proportion is expected to increase to 68 percent by 2050. In fact, more than 30 cities currently have populations of 10 million or more and are considered "megacities," according to the World Economic Forum. By 2030, the World Economic Forum expects six new cities to be added to this list: Chicago, Illinois; Bogota, Columbia; Luanda, Angola; Chennai, India; Baghdad, Iraq; and Dar es Salaam, Tanzania. With the exception of Chicago, a critical point to note is that the remaining five cities are all in developing countries and may have significant difficulties dealing with natural hazards and the potential infrastructure impacts caused by these hazards. This is especially true for megacities and other urban areas located on or near coasts. This extreme growth is often coupled with unplanned urbanization and sprawl that has critical effects on coastlines, demographics, and ecosystems.

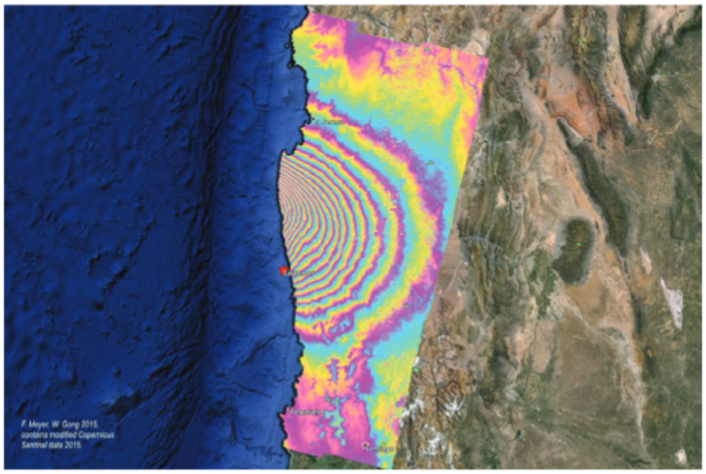
(Continued)

Who Uses Earth Science Data?

Dr. Tiampo relies on high-resolution satellite data and imagery in her studies. A key technology she uses is synthetic aperture radar (SAR). SAR is an "active" radar system, and collects data by sending out a radar pulse that bounces off a surface to detect physical properties ("passive" radar systems, such as a radiometer, sense radiated energy and do not send out a radar pulse). Since SAR relies on reflected microwaves to create imagery, it does not need illumination from an outside source (such as the Sun) to create an image. In addition, the wavelengths used for creating SAR imagery can penetrate clouds, smoke, soil, ice, and tree canopies. This allows high-relief SAR imagery to be created day or night, rain or shine across all biomes.

NASA's EOSDIS maintains a large collection of SAR data and imagery, which is available through NASA's Alaska Satellite Facility Distributed Active Archive Center (ASF DAAC). Along with data from NASA SAR missions, the ASF DAAC distributes data from numerous international SAR missions, including the European Space Agency (ESA) Sentinel-1A/B missions and the Japan Aerospace Exploration Agency Advanced Land Observing Satellite (ALOS) Phased Array type L-band SAR (PALSAR) mission.

By comparing two SAR images acquired at different dates from the same vantage point in space, changes in topography and elevation can be observed and mapped. These changes can be depicted as multi-colored "fringes," with the distance between fringes of the same color indicating the precise amount of elevation change. Thanks to the high relief of SAR imagery, these elevation changes can be mapped to a few centimeters or less. This technique is called differential interferometric synthetic aperture radar (DInSAR or InSAR), and images created using this technique are called "interferograms."



NASA ASF DAAC scientists used SAR data acquired from the European Space Agency (ESA) Sentinel-1A mission to create this interferogram showing land displacement following a September 16, 2015, earthquake in Chile. One complete color cycle represents a relative line-of-sight motion of 8.5 cm. NASA's ASF DAAC distributes the complete historical archive of ESA-processed Sentinel-1A SAR data by agreement between the U.S. State Department and the European Commission. This image is combined with a Landsat image in Google Earth (© 2015 Google). Image: F. Meyer, W. Gong 2015; contains modified Copernicus Sentinel data 2015.

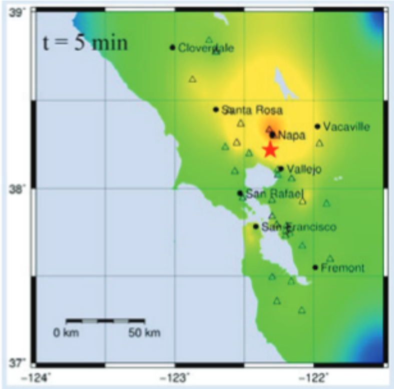
Dr. Tiampo and her colleagues applied advanced InSAR time series analysis at Campi Flegrei to study vertical and horizontal components of ground deformation at very fine spatial and temporal resolutions over a 20-year time period. The research team found that while the area underwent continuous slow subsidence from 1993 through 1999, moderate uplift began in 2010 and substantially increased through 2012, reaching approximately 13 cm by 2013. This suggests that new magma injected at shallow depths presents increased risk to the local and regional population. While this research was not intended to examine the probability of an eruption, it does indicate that the area warrants watching.

Along with InSAR imagery, Dr. Tiampo also uses Global Navigation Satellite System (GNSS) data to characterize long-term surface motions. GNSS data in NASA's EOSDIS collection are available through the Crustal Dynamics Data Information System (CDDIS), which is the EOSDIS DAAC responsible for geodetic data. A GNSS system has three components: satellites in well-known orbits with synchronized clocks, ground controllers, and a ground segment providing data to users. Using signals from four satellites, a precise location in three-dimensions (within millimeters or less) along with precise time can be determined. By

(Continued)

comparing measurements over time, minute elevation and distance changes at a station can be calculated. Dr. Tiampo integrates these GNSS data with extremely precise terrain data from the international Shuttle Radar Topography Mission (SRTM) for georeferencing and height corrections.

In a study published in 2017 investigating earthquake intensity, Dr. Tiampo and her colleagues made use of a more common data source—Twitter feeds. Since earthquake intensity is one of the key components in the decision-making process for disaster response and emergency services, the research team used advanced Big Data analytics to process Twitter social media feeds along with data from physical sensors (seismographs) to jointly estimate the ground shaking in near real-time from a magnitude 6.0 earthquake that occurred August 24, 2014, in South Napa, CA. The team showed that in the minutes after the event, the joint analysis of social media and data from physical sensors provided better estimates of the location and magnitude of ground shaking than using data from either source alone.



Ground shaking intensity (Modified Mercalli scale) derived from joint processing of Twitter and seismic records five minutes after the 2014 Napa Valley earthquake. Red star represents the epicenter location. Triangles represent seismic station locations. Image provided by Dr. Tiampo and appears in a, Y., et al. (2017; doi: 10.1007/s00024-016-1417-6).

Along with naturally-occurring earthquakes, research by Dr. Tiampo shows that human-induced earthquakes also are possible, especially in areas with heavy oil and gas exploration. Anthropogenic earthquakes caused by wastewater injection and the process of fracking have become more common in central North America. In fracking, high-pressure liquid is injected into subterranean rocks, boreholes, and similar features to force open existing fissures to extract oil or gas. One consequence of wastewater injection and fracking is the triggering of seismic activity in areas that have not historically experienced earthquakes and that are relatively unprepared for the associated ground shaking. Dr. Tiampo and her colleagues identified the first earthquakes in North America that were induced through the process of fracking. The research team followed these results by using InSAR for detailed studies of ground deformation associated with a series of human-induced earthquakes in Oklahoma, noting "the potential for InSAR to facilitate rapid response efforts for shallow, moderate-sized earthquakes, especially in poorly seismically-instrumented areas."

Meanwhile, rumbles continue under the Campi Flegrei, where the last known eruption occurred in 1538 and Naples had a population of about 200,000. Today, Naples is one of the most populated metropolitan areas in Italy, with classic Italian red-roofed buildings nestled along the verdant cliffs of the caldera. Far below, magma courses through ancient vents. With the aid of Earth observing data, Dr. Kristy Tiampo is helping a growing global population monitor and be better prepared for the potential hazards of living in urban environments—including the three million neighbors of Vulcan's home.

Representative data products used:

- SAR data and imagery distributed by NASA's ASF DAAC:
  - ESA Sentinel-1A/B; NASA's provision of the complete ESA Sentinel-1 SAR data archive through the ASF DAAC is by agreement between the U.S. State Department and the European Commission
  - Japan Aerospace Exploration Agency (JAXA) ALOS PALSAR; all PALSAR data and imagery © JAXA/METI

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- ESA European Remote Sensing satellites (ERS-1 and ERS-2); NASA's provision the ERS-1 and ERS-2 SAR data archive via the ASF DAAC is by agreement between NASA and ESA
- NASA Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR)

- GNSS data; available through NASA's CDDIS
- SRTM terrain data; available through NASA's Land Processes DAAC (LP DAAC)
- NASA/JAXA Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) Core Observatory precipitation data related to landslide triggering and flooding; available through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC)

Read about the research:

Barba-Sevilla, M., Baird, B.W., Liel, A.B. & **Tiampo, K.F.** (2018). "Hazard Implications of the 2016 Mw 5.0 Cushing, OK Earthquake from a Joint Analysis of Damage and InSAR Data." *Remote Sensing,* 10(11), 1715 [doi: 10.3390/rs10111715].

Kropivnitskaya, Y., **Tiampo, K.F.,** Qin, J.H. & Bauer, M.A. (2017). "Real-Time Earthquake Intensity Estimation Using Streaming Data Analysis of Social and Physical Sensors." *Pure and Applied Geophysics,* 174(6): 2331–2349 [doi: 10.1007/s00024-016-1417-6].

Tiampo, K.F., Gonzalez, P.J., Samsonov, S., Fernandez, J. & Camacho, A. (2017). "Principal component analysis of MSBAS DInSAR time series from Campi Flegrei, Italy." *Journal of Volcanology and Geothermal Research,* 344(15): 139-153 [doi: 10.1016/j.jvolgeores.2017.03.004].

Notes

Who Uses Earth Science Data?

Notes

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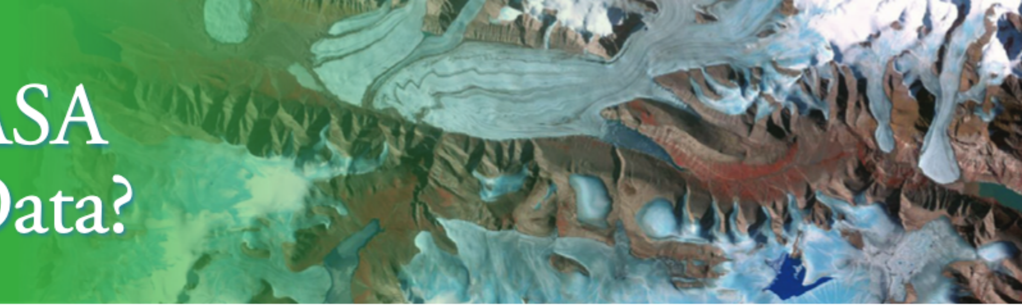

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Produced by:
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Code 423
Goddard Space Flight Center
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NP-2019-11-454-GSFC