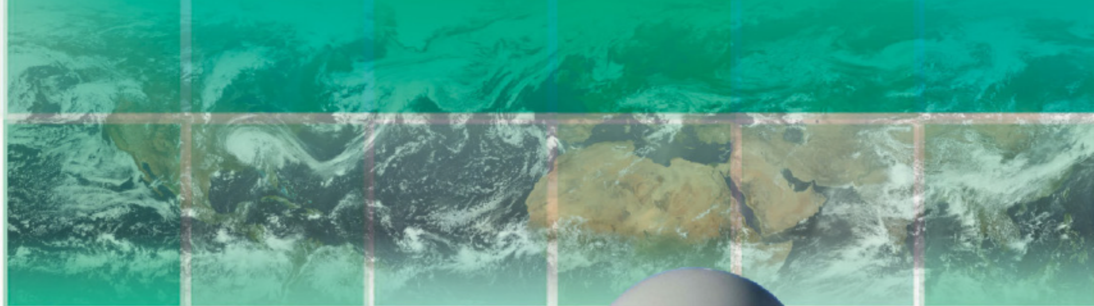
National Aeronautics and Space Administration

PROFILES OF NASA EARTH SCIENCE DATA USERS

2018 YEAR BOOK



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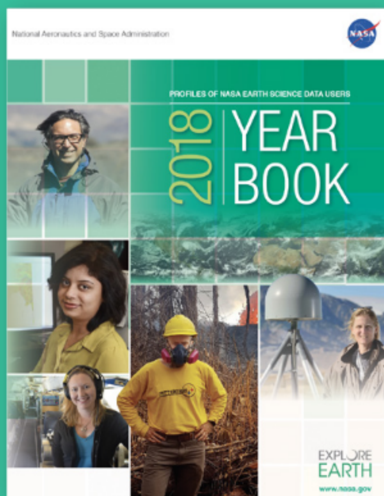

COVER: (Counterclockwise from upper left) Dr. Santiago Gassó, Dr. Pinki Mondal, Dr. Róisín Commane, Dr. Michael Ramsey, and Dr. Kristine M. Larson.

NASA's Earth Observing System Data and Information System (EOSDIS) is pleased to present the 2018 EOSDIS Data User Profile Yearbook. The 12 data users you'll read about this year are using Earth science data in the EOSDIS collection for improving severe storm forecasting, analyzing chemicals in the atmosphere and the transport of these chemicals, developing new ways of using GPS technology, helping emergency managers respond to volcanic eruptions, and much more. 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, fully and without restriction.

EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from satellites, aircraft, field measurements, and various other programs. These data are managed, archived, and distributed by discipline-specific Distributed Active Archive Centers (DAACs) to a diverse worldwide user community.

Table of Contents

All profiles written by Josh Blumenfeld, NASA EOSDIS Science Writer

Who Uses Earth Science Data?

Dr. Piyush Agram, for developing Synthetic Aperture Radar (SAR) data products.

Dr. Agram in his JPL office. On his computer screen is an interferogram created from Synthetic Aperture Radar (SAR) imagery showing changes in land elevation following earthquakes that occurred on April 14 and 16, 2016, at the southern tip of Japan. Each colored fringe in the image represents a change in elevation between April 8 (pre-earthquake) and April 20, 2016 (post-earthquake). Screen image uses Copernicus Sentinel data 2016, processed by the European Space Agency (ESA).

Dr. Piyush Agram

Signal Analyst,
Radar Algorithms and Processing Group, Radar Science and Engineering Section, NASA's Jet Propulsion Laboratory (JPL), Pasadena, CA

Research interests: Developing algorithms for processing data from the upcoming joint NASA/Indian Space Research Organization (ISRO) NISAR mission; developing new techniques for using and interpreting Synthetic Aperture Radar (SAR) and Interferometric SAR (InSAR) imagery.

Research highlights: Synthetic Aperture Radar (SAR) is an amazing remote sensing technology. It can create high-resolution images 24/7 regardless of weather and can penetrate through dense forest canopy to reveal underlying ground features. Plus, it can be used to precisely measure changes in land elevation, such as after an earthquake or volcanic eruption. For detailed environmental monitoring and resource mapping, SAR is an instrument of choice.

NASA put the first civilian SAR in space with the launch of Seasat in 1978. Now, NASA, in collaboration with the Indian Space Research Organization (ISRO), is preparing for one of the most sophisticated SAR missions ever to orbit Earth: the joint NASA/ISRO SAR, or NISAR, mission. The vast array of science data products created from NISAR mission data will be thanks, in part, to the work and contributions of Dr. Piyush Agram and his colleagues in the Radar Algorithms and Processing Group at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA.

NISAR is tentatively scheduled to launch in late-2021 and will put into Earth orbit two powerful SAR systems designed to collect data about natural hazards and global environmental change. The volume of data collected by NISAR is expected to be greater than any previous NASA Earth observing mission—as much as 85 terabytes (TB) of data each day (for perspective, the Hubble Space Telescope generates roughly 10 TB of new data ***each year***, according to NASA). The total volume of data generated by NISAR over its planned three-years of science operations could be as high as 140 petabytes (PB). For a sense of how much data this represents, NASA's Earth Observing System Data and Information System (EOSDIS), which is responsible for Earth observing data in the NASA collection, currently has a total archive volume of a bit more than 26 PB. (For a look at how NASA's Earth Science Data and Information System [ESDIS] Project, which manages the data in the EOSDIS collection, is preparing to handle NISAR data, please see *Getting Ready for NISAR—and for Managing Big Data in the Commercial Cloud* on the Earthdata website.)

NISAR data, though, will be merely strings of numbers unless they can be turned into standard data products with the quality assurance, validation, and processing required for use in scientific research. This is where Dr. Agram and his colleagues come in.

Dr. Agram is part of the NISAR Algorithm Development Team (ADT), which is responsible for developing and validating algorithms that will be used to process data from NISAR's L-band SAR, which is being developed by NASA. The second SAR system aboard the spacecraft is an S-band SAR that is being developed by ISRO. Having two SARs operating at two different wavelength bands (L-band and S-band) will facilitate in-depth studies of natural processes ranging from flow rates of glaciers and ice sheets to landform changes caused by earthquakes, volcanoes, and human action. And SAR is a technology perfectly suited to this task.

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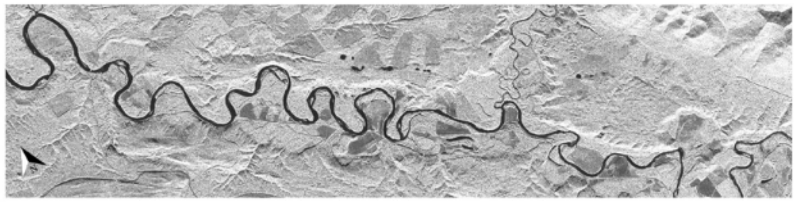
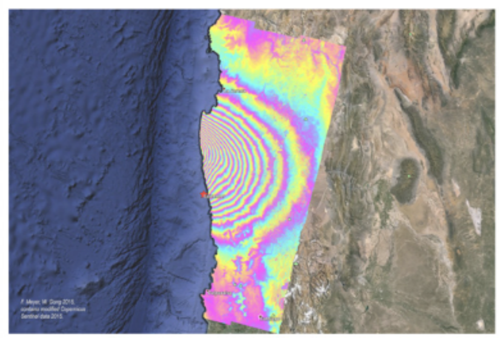


SAR image of the Fraser River in British Columbia, Canada. This image was acquired during NASA's Shuttle Imaging Radar-C (SIR-C) mission conducted in 1994. NASA's home for SAR data and imagery is the Alaska Satellite Facility (ASF) Distributed Active Archive Center (DAAC).

SAR is an "active" radar system, and collects data by bouncing a microwave radar signal 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). 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.

The SAR radar wavelength determines the penetration depth of the transmitted signal; the longer the wavelength, the deeper the penetration. The 24-cm wavelength of NISAR's NASA-provided L-band SAR can penetrate soil, ice, and dense tree canopies. The 12-cm wavelength of NISAR's ISRO-provided S-band SAR can penetrate light vegetation, but is unable to penetrate as far as L-band. As noted in the *NISAR Science Users' Handbook,* while the L-band SAR will be used for global radar imaging, the S-band SAR will be used for more targeted radar imaging, primarily over India. In addition, NISAR's L-band and S-band systems can be operated simultaneously.



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

One NISAR science objective is to study minute (mm- to cm-scale) changes in landforms caused by natural events (such as the rise or fall of land following earthquakes or volcanic eruptions) or human actions (such as land subsidence due to agricultural drawdown of water from aquifers). By looking at multiple SAR images of the same area captured days, weeks, months, or even years apart, precise elevation changes can be mapped and calculated. This technique, called *interferometry*, uses interferometric SAR (InSAR) images to depict land elevation changes as colored fringes in an image called an *interferogram*. An interferogram shows where land elevation is changing and the amount of elevation change.

NISAR is the continuation of civilian space-based SAR observations that began with the launch of NASA's Seasat satellite in 1978 (which carried a L-band sensor). NASA built upon Seasat with a series of SAR missions aboard early flights of the Space Shuttle. These were designated Shuttle Imaging Radar, or SIR, missions, and flew aboard the Space Shuttle in 1981, 1984, and 1994 (two missions). In 2000, NASA and the National Geospatial-Intelligence Agency participated in the international Shuttle Radar Topography Mission (SRTM), which included a C-band (5.6-cm wavelength) SAR (which was operated by JPL) and a X-band (3.1-cm wavelength) SAR (which was operated by the German and Italian space agencies). SRTM data were used to produce extremely accurate digital elevation maps covering nearly 80 percent of the planet.

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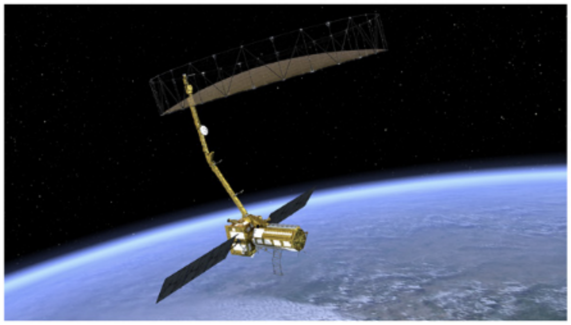
Dr. Agram notes that almost all the SAR data he works with are distributed by NASA, primarily through NASA's Alaska Satellite Facility (ASF) Distributed Active Archive Center (DAAC). ASF DAAC is responsible for SAR data in NASA's collection, which includes data from NASA orbital missions such as Seasat as well as airborne SAR missions such as the Airborne Synthetic Aperture Radar (AirSAR) mission (operational 1990 to 2004). ASF DAAC also has agreements to distribute SAR data from international missions including the European Space Agency's Sentinel-1 mission, the Japan Aerospace Exploration Agency's Advanced Land Observing Satellite-1 (ALOS) mission, and the Canadian Space Agency's Radarsat-1 mission. ASF DAAC eventually will archive and distribute NISAR data.

To prepare for the enormous influx of data from NISAR, ASF DAAC is working in collaboration with JPL on a project called Getting Ready for NISAR (GRFN). Dr. Agram supports GRFN through his work creating sample interferometric products as part of JPL's Advanced Rapid Imaging and Analysis (ARIA) Project for Natural Hazards. These sample InSAR products are designed to help the science community prepare for working with similar products from NISAR.



Artist's rendering of the NISAR spacecraft. The large circular object on the boom above the main satellite bus is the radar antenna reflector. NISAR will have an approximately 464-mile orbital altitude and provide repeat global coverage every 12 days. NASA JPL-Caltech image.

Dr. Agram's NISAR support also includes his work as part of the team that developed the InSAR Scientific Computing Environment (ISCE) software, which will become the processing software for NISAR. In addition, Dr. Agram developed the Generic InSAR Analysis Toolbox (GIAnT), which will be used to generate NISAR Level-3 Solid Earth Deformation Time-series products.

As Dr. Agram observes, his work enables work by other scientists. The algorithms he is developing and testing for NISAR, along with his work preparing the science community to use NISAR data, will contribute greatly to the research conducted using data from one of the most advanced radar systems ever put into Earth orbit.

Representative data products used:

- SAR data available through ASF DAAC using the ASF Vertex data portal:
  - Uninhabited Aerial Vehicle SAR (UAVSAR), L-band products
  - Various Sentinel-1, Level 1 Single Look Complex (SLC) data (NASA's provision of the complete ESA Sentinel-1 SAR data archive through ASF DAAC is by agreement between the U.S. State Department and the European Commission)
  - Advanced Land Observing Satellite-1 (ALOS) Phased Array-type L-band Synthetic Aperture Radar (PALSAR), Level 0 and Level 1 SLC data (the Japan Aerospace Exploration Agency [JAXA]/ Japanese Ministry of Economy, Trade, and Industry [METI] is the source for ALOS PALSAR data distributed by ASF DAAC; all ALOS PALSAR imagery and data are © JAXA/METI)

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- Shuttle Radar Topography Mission (SRTM) data; available through NASA's Land Processes DAAC (LP DAAC):
  - SRTM v3 (1 arcsec) [DOI: 10.5067/MEaSUREs/SRTM/SRTMGL1.003]
  - SRTM v3 (3 arcsec) [DOI: 10.5067/MEaSUREs/SRTM/SRTMGL3.003]
  - SRTM v3 (land/water mask) [DOI: 10.5067/MEaSUREs/SRTM/SRTMSWBD.003]
- NASA Digital Elevation Model (NASADEM), provisional products; available through LP DAAC
- SAR data from various ESA missions; available through the Western North America InSAR (WInSAR) Consortium archive hosted at UNAVCO

Read about the research:

Fattahi, H., **Agram, P.** & Simons, M. (2017). "A network-based enhanced spectral diversity approach for TOPS time-series analysis." *IEEE Transactions on Geoscience and Remote Sensing,* 55(2): 777-786 [doi: 10.1109/tgrs.2016.2614925].

Fattahi, H., Simons, M. & **Agram, P.** (2017). "InSAR Time-Series Estimation of the Ionospheric Phase Delay: An Extension of the Split Range-Spectrum Technique." *IEEE Transactions on Geoscience and Remote Sensing,* 55(10): 5984-5996 [doi: 10.1109/tgrs.2017.2718566].

Podest, E. (2017). "Basics of Synthetic Aperture Radar (SAR)." NASA Applied Remote Sensing Training (ARSET). PowerPoint presentation, November 29, 2017. Available online at https://arset.gsfc.nasa.gov/sites/default/files/water/Brazil_2017/Day1/S1P2.pdf.

Agram, P. & Simons, M. (2015). "A noise model for InSAR time series." *Journal of Geophysical Research: Solid Earth,* 120(4): 2752-2771 [doi: 10.1002/2014jb011271].

Rosen, P.A., Gurrola, E., Sacco, G.F., Zebker, H. (2012). "The InSAR scientific computing environment." Presentation at EUSAR 2012; 9th European Conference on Synthetic Aperture Radar, April 23-26, 2012, Nuremberg, Germany. Available online at https://ieeexplore.ieee.org/document/6217174/authors.

Dr. Emily Berndt, to improve short-term forecasts of high-impact weather.

Dr. Emily Berndt in the NASA SPoRT Visualization and Collaboration Lab. Behind her is a water vapor image of Hurricane Matthew coupled with CrIS/ATMS soundings. NASA photograph by Emmett Given, NASA's Marshall Space Flight Center.

Dr. Emily Berndt

Research Scientist, Short-term Prediction Research and Transition Center (SPoRT),NASA's Marshall Space Flight Center,Huntsville, AL

Research interests: Using satellite data to better understand the atmospheric processes leading to strong storms and using this knowledge to develop new forecasting products and new capabilities to display storm data.

Research highlights: A ripple in the atmosphere off the northern coast of Africa on September 22, 2016, caught the attention of the U.S. National Hurricane Center. Using data from Earth observing satellites, aircraft, and ocean buoys, forecasters watched the disturbance churn westward across the Atlantic, absorbing warm, moist air as it slowly intensified. By the time the storm approached Barbados on September 28, it was packing sustained winds of 39 to 73 mph and had developed a closed circulation. It was now a tropical storm, and given the name Matthew. Tropical Storm Matthew became Hurricane Matthew on September 29 as sustained winds increased to 74 mph. Suddenly, over a 24-hour period, the pressure inside the hurricane dropped rapidly, increasing the storm's sustained winds from 80 mph to 165 mph. In the span of a day, Matthew became a Category 5 hurricane, the strongest storm possible on the 1-5 Category Saffir-Simpson Hurricane Wind Scale—a rate of intensification that rarely has been observed.

The explosive growth of Hurricane Matthew is one example of *cyclogenesis*. Cyclogenesis refers to the general development or strengthening of a cyclonic system, such as a hurricane or other area of low pressure. Developing ways to use data from Earth observing satellites to better understand the atmospheric factors behind cyclogenesis and the rapid intensification of storms like Hurricane Matthew is one responsibility of NASA's Short-term Prediction Research and Transition Center (SPoRT). It also is a key element of Dr. Emily Berndt's research as a member of the SPoRT team.

SPoRT, which is located at NASA's Marshall Space Flight Center in Huntsville, AL, develops ways for the operational weather community to use satellite observations and research capabilities to improve short-term regional and local weather forecasts, and is jointly-funded by NASA and the National Oceanic and Atmospheric Administration (NOAA). From using data from NASA Earth observing satellites to improve soil moisture models in NASA's Land Information System to providing real-time lightning and storm data, SPoRT work and research encompass a wide range of activities. In her SPoRT research, Dr. Berndt relies on data from instruments aboard numerous Earth observing satellites, especially hyperspectral infrared sounders that detect radiated infrared energy.

While humans can detect light in the visible band of the electromagnetic spectrum (human light sensitivity ranges from wavelengths of about 430 nanometers [violet] to about 770 nanometers [red]), hyperspectral infrared sounders detect radiated energy in hundreds to thousands of narrow bands across the infrared portion of the electromagnetic spectrum. One key hyperspectral sounder Dr. Berndt relies on is the Atmospheric Infrared Sounder (AIRS) aboard NASA's Aqua satellite. The AIRS instrument by itself is best used in clear conditions, but when paired with the Advanced Microwave Sounding Unit (AMSU-A), which also is aboard Aqua, the combined instruments can be used to detect atmospheric variables in partly cloudy regions. Since clouds are mostly opaque in the infrared part of the electromagnetic spectrum and are largely transparent at microwave frequencies, the infrared + microwave AIRS/AMSU system provides data over a broad range of atmospheric conditions.

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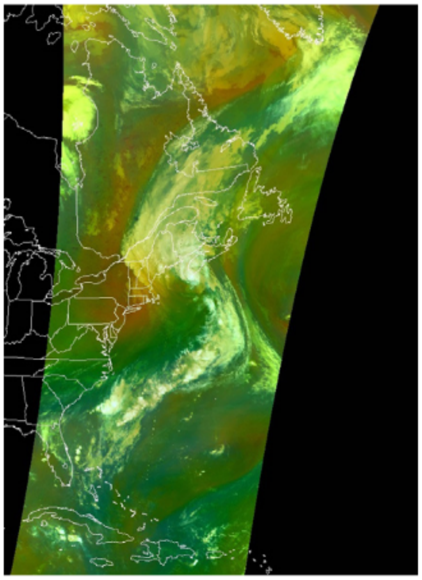
In an early research project, Dr. Berndt used AIRS/AMSU atmospheric soundings of temperature, moisture, and ozone to investigate rapid cyclogenesis and the development of high-impact winds associated with intense low pressure systems developing in the North Atlantic Ocean. Her research was tied to understanding how AIRS/AMSU data can be used by forecasters at NOAA's Ocean Prediction Center (OPC) to anticipate and more accurately forecast high winds with these events.

NASA-funded research has shown that changes in atmospheric ozone levels are closely related to changes in storm intensity and the development of high winds that can threaten maritime activity. These ozone changes can be sensed by satellite-borne instruments in near real-time, meaning that ozone observations are available several times a day and can be tracked by forecasters. Building on this research, Dr. Berndt and her SPoRT colleagues developed an AIRS/AMSU total column ozone product that OPC forecasters can view using the National Centers for Environmental Prediction (NCEP) Advanced Weather Interactive Processing System (N-AWIPS). The AIRS/AMSU total ozone product evolved into an ozone anomaly product to give forecasters more certainty for identifying areas of ozone-rich air in the stratosphere that can drive rapid cyclogenesis and high wind events.

Another forecasting product used by Dr. Berndt and her SPoRT colleagues in their product development is the Air Mass Red, Green, Blue (Air Mass RGB) composite. Derived from data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Aqua and Terra satellites, the Air Mass RGB composite uses four MODIS infrared channels to characterize temperature, moisture, cloud cover, and large-scale features associated with air masses. The composite improves the detection of rapid cyclogenesis, localized areas of very fast moving air embedded in the jet stream (called jet streaks), and areas in the atmosphere that could impart spin on air masses and contribute to the development of cyclonic systems. Dr. Berndt used the Air Mass RGB and AIRS/AMSU products, along with water vapor imagery, to study the evolution of Hurricane Sandy (2012) and the processes controlling the storm's movement out of the tropics and along the U.S. East Coast.



An Aqua MODIS Air Mass RGB image created during Hurricane Arthur on July 5, 2014. Regions of warm, dry, ozone-rich air that can be drawn into a storm and impact storm intensity are represented in orange (seen on left side of image). Image created at NASA's Marshall Space Flight Center by SPoRT using MODIS data from LANCE.

With the launch of the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi-NPP) satellite in October 2011, Dr. Berndt and her colleagues were able to start using hyperspectral sounding data from the Cross-track Infrared Sounder (CrIS), which produces high-resolution, three-dimensional temperature, moisture, and trace gas profiles. Like the AIRS/AMSU instrument combination, CrIS can be paired with Suomi-NPP's Advanced Technology Microwave Sounder (ATMS) (which creates global temperature and moisture profiles) to more accurately detect atmospheric features in partly cloudy regions. The use of data from both the AIRS/AMSU and CrIS/ATMS instrument combinations provides not only more sensor overpasses to study high-impact weather events, but also additional data to forecasters.

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Dr. Berndt and her SPoRT colleagues applied lessons-learned from studying high-impact events (such as Hurricane Matthew) and storms like Hurricane Sandy to understand how hyperspectral infrared sounder data can be used to anticipate changes in hurricane intensity, which can occur when a hurricane moves out of the tropics and becomes an extratropical storm. Notable events such as Hurricane Sandy, Hurricane Arthur (2014), and Super Typhoon Atsani (2015) were studied to understand how hyperspectral infrared sounding data can be used to identify intrusions of dry air from upper levels of the atmosphere into a hurricane or typhoon, which can decrease storm intensity. The SPoRT team developed a tropopause-level product to allow forecasters to quickly and easily identify these dry air intrusions.

Dr. Berndt currently is investigating whether CrIS/ATMS soundings can be of value to better forecast complex winter weather events, such as bands of heavy snow, areas of mixed precipitation, or lake effect snow. She also is collaborating with forecasters and other researchers to develop better ways of using satellite data to forecast areas of cold air aloft (CAA). In CAA events, temperatures can drop as low as -65˚C (-85˚F). These extremely cold temperatures regularly occur at flight levels in the Arctic, and can freeze aviation fuel. The use of satellite observations enables forecasters to observe the horizontal and vertical extent of CAA in real-time and advise air traffic controllers how they can safely re-route aircraft around these areas. This is a great asset in data-sparse regions such as Alaska, which now have a reliable source for identifying CAA over vast areas that lack conventional observations.

And what about Hurricane Matthew? After roaring through Haiti as a Category 4 hurricane with winds of 150 mph, Matthew hit eastern Cuba before tracking up the east coast of Florida as a Category 3 storm with winds between 111-129 mph. Matthew finally weakened to an extratropical cyclone off Cape Hatteras, NC, before being absorbed by a cold front and carried out over the North Atlantic. Thanks to the work of Dr. Berndt and her SPoRT colleagues, meteorologists, emergency managers, and the general public have more resources at their disposal to track these severe storms, a better understanding of their causes, and the ability to create more accurate forecasts to know where and when these storms may hit.

Representative data products used:

- AIRS/Aqua L2 Support Retrieval (AIRS+AMSU) V006 (AIRX2SUP; DOI: 10.5067/Aqua/AIRS/DATA207); available through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC)
- Various near real-time MODIS data products; available through NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) system
- Suomi-NPP data from NOAA's Comprehensive Large Array-data Stewardship System (CLASS):
    - CrIS/ATMS L2 NOAA Unique Combined Atmospheric Processing System (NUCAPS) temperature, moisture, and ozone soundings; Joint Polar Satellite System Sounder Products (JPSS_SND)
    - Various data products created from data collected by the Visible Infrared Imaging Radiometer Suite (VIIRS)

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Read about the research:

Berndt, E.B., Harkema, S. & Folmer, M. (2018). "Anticipating Winter Weather with Next-Generation Satellite Sensors." 14th Annual Symposium on New Generation Operational Environmental Satellite Systems; American Meteorological Society, 98th Annual Meeting, Austin, TX, January 7-11, 2018. GOES-R/JPSS Poster Session I: https://ams.confex.com/ams/98Annual/webprogram/Paper327502.html.

Berndt, E.B. & Folmer, M. (2018). "Utility of CrIS/ATMS profiles to diagnose extratropical transition." *Results in Physics,* 8: 184-185 [doi: 10.1016/j.rinp.2017.12.006].

Berndt, E.B., Smith, N., White, K. & Zavodsky, B. (2017). "Development and Application of Gridded NUCAPS for Operational Forecasting Challenges." JPSS Science Seminar, October 23, 2017. PowerPoint Presentation.

Berndt, E.B., Folmer, M., Halverson, J. & Dunion, J. (2017). "Utility of NUCAPS Retrieved Profiles to Diagnose Extratropical Transition." 13th Annual Symposium on New Generation Operational Environmental Satellite Systems; American Meteorological Society, 97th Annual Meeting, Seattle, WA, January 22-26, 2017. Recorded Presentation.

Berndt, E.B., Zavodsky, B.T. & Folmer, M.J. (2015). "Development and Application of Atmospheric Infrared Sounder Ozone Retrieval Products for Operational Meteorology." *IEEE Transactions on Geoscience and Remote Sensing,* 54(2): 958-967 [doi: 10.1109/TGRS.2015.2471259].

Berndt, E.B., Folmer, M.J. & Dunion, J. (2014). "A Comparison of the Red Green Blue (RGB) Air Mass Imagery and Hyperspectral Infrared Retrieved Profiles and NOAA G-IV Dropsondes." 10th Annual Symposium on New Generation Operational Environmental Satellite Systems; American Meteorological Society, 94th Annual Meeting, Atlanta, GA, February 2-6, 2014. Poster.

Who Uses Earth Science Data?

Dr. Laura Bourgeau-Chavez, for studying wetlands and wildfire.

Dr. Laura Bourgeau-Chavez using a handheld water content reflectometer to measure soil moisture at a field site in Delta Junction, Alaska. Image courtesy of Dr. Bourgeau-Chavez.

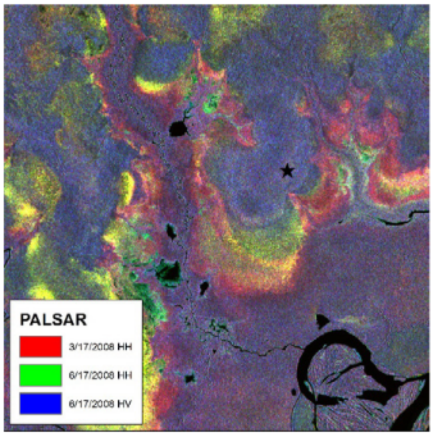
Dr. Laura Bourgeau-Chavez

Senior Research Scientist/ Adjunct Associate Professor,
Department of Geosciences and Director, Boise Center Aerospace Laboratory (BCAL), Boise State University, Boise, ID

Research interests: Using field and remote sensing data for mapping and monitoring wetlands in tropical, temperate, and boreal ecozones; evaluating the potential for wildfire; and assessing the effects of wildfire in boreal-arctic regions.

Research highlights: From the jungle to the tundra to isolated lakes in the U.S. Upper Midwest, remotely-sensed data enable scientific investigations in areas that are difficult—sometimes impossible—to access. However, investigations using remotely-sensed data can benefit from boots on the ground. These field campaigns allow scientists to connect remotely-sensed data with real-world processes and improve sensor algorithms to create more accurate data products. For example, the recent Soil Moisture Active Passive Validation Experiment (SMAPVEX16) in the farmlands of Iowa and Manitoba helped improve algorithms used to process NASA Soil Moisture Active Passive (SMAP) mission data. Using field investigations to connect ground observations with remotely-sensed data and to improve sensor data algorithms are also important elements of Dr. Laura Bourgeau-Chavez' investigations into wildfire, soil moisture monitoring, and wetlands.

A key remote sensing technology used by Dr. Bourgeau-Chavez is synthetic aperture radar, or SAR, which is well-suited for her work in remote areas that include the Great Lakes, Alaska, Canada, and South America. SAR is an "active" radar system, and creates an image by bouncing a microwave radar signal off Earth's surface to detect physical properties ("passive" radar, such as a radiometer, do not send out a radar pulse and sense energy radiated from Earth). Since SAR relies on reflected microwaves to create an image, it does not need illumination from an outside source. In addition, the wavelengths used for creating SAR imagery penetrate clouds, smoke, and even tree canopies. This allows SAR imagery to be created day or night, rain or shine.



Example of a three-date false color composite of Phased Array-type L-band SAR (PALSAR) imagery over the lowlands of Peru. The yellow, pink, and green colors in this derived product represent different hydrological conditions on the various dates and highlight different wetland types. Image © JAXA/METI 2008 and courtesy Michigan Technological University.

SAR sensors most commonly use L-band (24 cm wavelength), C-band (6 cm wavelength), or X-band (3 cm wavelength) radar. The sensor wavelength determines the penetration depth of the transmitted signal; the longer the wavelength, the deeper the penetration. For Dr. Bourgeau-Chavez' wetland research, L-band SAR can peer through tree canopies and other dense vegetation to reveal standing water underneath. NASA's home for SAR data is the Alaska Satellite Facility (ASF) Distributed Active Archive Center (DAAC), and Dr. Bourgeau-Chavez utilizes ASF DAAC SAR data from several U.S. and international missions in her research.

Currently, Dr. Bourgeau-Chavez is working on two wildfire projects in the boreal-Arctic regions of Alaska and western Canada. One project focuses on developing satellite data products to monitor drought conditions to better predict wildfire danger and wildfire

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behavior. Using both active and passive radar, Dr. Bourgeau-Chavez and her colleagues are developing fuel moisture algorithms to augment existing weather-based systems used to predict wildfire danger. Fuel moisture is a measure of the amount of water in a fuel source (such as organic soil or ground layers) that is available to a fire. Higher amounts of moisture in organic soil layers and vegetation can make it more difficult for the fuel source to heat to its combustion temperature.

Her second boreal-Arctic project is part of NASA's Arctic Boreal Vulnerability Experiment (ABoVE) field campaign. ABoVE is a large-scale study in Alaska and western Canada that connects environmental change and its implications for socio-ecological systems in this region. Dr. Bourgeau-Chavez' ABoVE work examines the vulnerability of boreal and Arctic ecosystems to wildfire, emphasizing peatlands. Noting that the effects of wildfire in peatlands are largely unknown, she points out that two variables contributing to post-fire plant succession in peatlands are burn severity in the canopy and ground layers along with post-fire soil moisture. She and her colleagues are using radar and optical data along with data from the joint NASA/U.S. Geological Survey (USGS) Landsat missions to develop remote sensing algorithms to map peatland types and ground burn severity, as well as to monitor peatland soil moisture and drought. Data from extensive field sampling can train the algorithms to more accurately reflect sensor data and provide a better understanding of post-fire vegetation ecology.

Remotely-sensed data are a valuable addition to field data, especially for research in remote areas. This image was taken by Dr. Bourgeau-Chavez from a float plane east of Yellowknife NWT, Canada, and shows areas where she is collecting field data as part of a wildfire study. At least one active wildfire can be seen ahead of the wing strut as a wisp of white smoke; burned areas are darker areas. Image courtesy of Dr. Bourgeau-Chavez.

Dr. Bourgeau-Chavez also evaluates using the SMAP radiometer for monitoring fuel moisture for fire danger prediction. She found that while SMAP soil moisture products adequately reflect fuel moisture across boreal North America, these fuel moisture estimates can likely be improved and applied to smaller-scale areas by merging the passive SMAP radiometer data with active radar data.

In the Great Lakes, Dr. Bourgeau-Chavez is working with ecosystem modelers, wetland managers, and other stakeholders to develop a strategic management plan to control the spread of the invasive variety of the common reed (*Phragmites australis*). Non-native *P. australis* is of European origin, and may have arrived in ballast water dumped from ships in U.S. harbors. This non-native variety began to expand rapidly across the U.S. starting in the mid-1800s due to increased habitat disturbance and nutrient loading. Today, *P. australis* and its hybrids are considered a noxious weed, which means the presence of this plant can be harmful to agriculture, natural habitats, ecosystems, humans, and livestock. In fact, *P. australis* has spread across marshes and wetlands in the continental U.S. and throughout southern Canada. Using a combination of PALSAR and Landsat imagery coupled with field training data from over 1,600 wetland locations, Dr. Bourgeau-Chavez has mapped the distribution of *P. australis*, as well as other wetland types (e.g., emergent wetland, shrub peatland, etc.), along the entire Great Lakes coastline and throughout the state of Michigan (http://geodjango.mtri.org/coastal-wetlands). She and her team have just completed field collection at more than 540 locations in the southern Great Lakes to update the *P. australis* distribution map. This updated map will document the

(Continued)

expansion or control of *P. australis* in this highly-invaded region, and is expected to be available this summer. Dr. Bourgeau-Chavez' *P. australis* and wetland mapping work are described in more detail in the 2016 *Sensing Our Planet* article "Where the Wetlands Are."

Dr. Bourgeau-Chavez' multi-institutional (Michigan State University, University of Michigan, and Michigan Technological University) and interdisciplinary research team has shown that increases in nitrogen in coastal zones along the Great Lakes trigger the spread of *P. australis*. Control of the plant requires a holistic watershed approach to reduce nitrogen loading while simultaneously treating invaded wetlands with a combination of herbicide and removing *P. australis* biomass through mowing and burning. Monitoring and mapping the effects of this management approach requires an integration of field data with data collected using unmanned aerial vehicles (UAVs), aircraft, and satellites. For wetland mapping, Dr. Bourgeau-Chavez and her colleagues found that L-band and C-band SAR data, combined with optical imagery from multiple seasons, can produce maps with individual wetland class (e.g., emergent, wooded bog, or wetland shrub) accuracies of 80 percent or higher.

Finally, in what she calls one of her favorite projects, Dr. Bourgeau-Chavez and her colleagues developed methods using Light Detection and Ranging (LIDAR) digital elevation models and seasonal L-band radar data to detect and map woodland vernal pools in Michigan. Vernal pools are small (typically less than 1 hectare/2.47 acres in size), shallow, isolated, temporary wetlands that are important for maintaining healthy forest ecosystems. Their chief characteristic is that they are ephemeral—they exist for variable periods from winter to spring, but may be completely dry for most of the summer and fall. Vernal pools provide critical breeding habitats for amphibians and invertebrates, including a number of rare and declining plant and animal species as well as obligate species that rely on or are restricted to vernal pools to complete their life cycle. Due to their small size and temporary nature, these fragile ecosystems are easily disturbed. In collaboration with the Michigan Natural Features Inventory, Dr. Bourgeau-Chavez and her colleagues are working on a database of Michigan's vernal pools to better conserve and protect these ecologically sensitive areas.

For Dr. Bourgeau-Chavez, the integration of field research and remotely-sensed data improve sensor algorithms and help produce a deeper understanding of the ecological aspects of the areas in which she and her colleagues conduct research. These boots on the ground provide a critical link between real-world processes and data sampled from high above Earth.

Representative data products used:

- SAR data; available through ASF DAAC:
  - L-Band:
    - Advanced Land Observing Satellite-1 Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR); © Japan Aerospace Exploration Agency/Ministry of Economy, Trade, and Industry [JAXA/METI])
  - C-Band:
    - European Remote Sensing Satellite-1 (ERS-1) and ERS-2 (© European Space Agency [ESA])
    - RADARSAT-1 (© Canadian Space Agency [CSA])

(Continued)

    - Sentinel-1 (processed by ESA and also acquired through ESA's Copernicus Open Access Hub); NASA's provision of the complete ESA Sentinel-1 SAR data archive through ASF DAAC is by agreement between the U.S. State Department and the European Commission
- Soil Moisture Active Passive (SMAP) data; available through ASF DAAC and NASA's National Snow and Ice Data Center (NSIDC) DAAC
- Landsat data; available through the USGS Earth Explorer data discovery and access application
- ABoVE: Burn Severity, Fire Progression, Landcover and Field Data, NWT, Canada, 2014 [DOI: 10.3334/ORNLDAAC/1307]; available through NASA's Oak Ridge National Laboratory (ORNL) DAAC
- North American Carbon Program (NACP) Peatland Landcover Type and Wildfire Burn Severity Maps, Alberta, Canada [DOI: 10.3334/ORNLDAAC/1283]; available through ORNL DAAC
- RADARSAT-2 data; © CSA and acquired through CSA's Science and Operational Applications Research (SOAR) for Radarsat-2 and collected and processed by SOAR as part of a research grant awarded to Dr. Bourgeau-Chavez
- Envisat data; © ESA and acquired through ESA's Earth Observation Link (EOLi) as part of a research grant awarded to Dr. Bourgeau-Chavez
- PALSAR-2 data; © JAXA/METI and acquired from JAXA/METI through a data grant awarded to Dr. Bourgeau-Chavez

Read about the work:

Bourgeau-Chavez, L.L., Endres, S., Powell, R. Battaglia, M.J., Benscoter, B., Turetsky, M., Kasischke, E.S. & Banda, E. (2017). "Mapping boreal peatland ecosystem types from multitemporal radar and optical satellite imagery." *Canadian Journal of Forest Research*, 47(4): 545-559 [doi: 10.1139/cjfr-2016-0192].

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Bourgeau-Chavez, L.L., Kowalski, K.P., Carlson Mazur, M.L., Scarbrough, K.A., Powell, R.B., Brooks, C.N., … Riordan, K. (2013). "Mapping invasive *Phragmites australis* in the coastal Great Lakes with ALOS PALSAR satellite imagery for decision support." *Journal of Great Lakes Research*, 39:65–77 [doi: 10.1016/j.jglr.2012.11.001].

Bourgeau-Chavez, L.L., Leblon, B., Charbonneau, F. & Buckley, J.R. (2013). "Evaluation of Polarimetric Radarsat-2 SAR Data for Development of Soil Moisture Retrieval Algorithms over a Chronosequence of Black Spruce Boreal Forests." *Remote Sensing of Environment*, 132: 71-85 [doi: 10.1016/j.rse.2013.01.006].

Dr. Róisín Commane, to examine the effects of terrestrial pollution on the atmosphere's chemical composition.

Dr. Commane aboard NASA's DC-8 research aircraft during ATom. Each ATom deployment followed similar flight tracks in a counter-clockwise direction: from Alaska south over the Pacific Ocean to New Zealand, east across the southern tip of South America, north over the Atlantic Ocean to Greenland, then west over the Arctic Ocean back to Alaska. Dr. Commane notes that the counter-clockwise direction of travel makes use of tailwinds on the long flight from New Zealand to Chile. Photo by Dr. Bernadett Weinzierl, Univ. of Vienna, and courtesy of Dr. Commane.

Dr. Róisín Commane

Assistant Professor, Columbia University, New York, NY, and affiliated with Columbia University's Lamont-Doherty Earth Observatory

Research interests: Using airborne gas concentration data, atmospheric transport models, and ecosystem models to understand surface processes affecting atmospheric chemistry. This includes measuring carbon dioxide (CO_2) and methane (CH_4) from Arctic ecosystems and measuring continental pollution (from, for example, fires and aerosols) over remote oceans.

Research highlights: Dr. Róisín Commane likely has more frequent flyer miles than you. As part of the joint NASA/Harvard University Atmospheric Tomography Mission (ATom), Dr. Commane just completed her fourth series of global flights aboard NASA's four-engine DC-8 research aircraft. Flying as high as 40,000 feet to skimming the surface at 500 feet (check out the amazing videos of low-level flights over Arctic sea ice and the open ocean on the ATom Twitter feed), ATom instruments collected data about chemical components of the atmosphere between 85° north and south latitude.

To say these flights were frill-free might be an understatement. Flights often lasted 10 hours or longer and the aircraft, which was built in 1969 and acquired by NASA in 1985, is a flying laboratory with instruments receiving priority over people (or soundproofing—headsets are recommended to "save your ears," according to the ATom daily schedule mission planning page). A typical "day" for Dr. Commane during the recently-completed fourth and final ATom deployment might begin well before local sunrise for flight preparations and end after sunset several time zones later, a schedule that was repeated throughout the almost one-month series of flights conducted between April 24 and May 21, 2018.

The "Tom" in "ATom" stands for *tomography*. Tomography is a technique for imaging by sections or sectioning using any kind of penetrating wave (magnetic resonance imaging, or MRI, is a type of tomography that uses strong magnetic fields and radio waves to create high resolution images of soft tissue in the human body that can be looked at slice by slice). ATom uses 24 aircraft-mounted instruments to sample slices of the atmosphere and analyze the chemical composition of these slices. These data are used to study the impact of human-produced air pollution on greenhouse gasses and on chemically reactive gasses in the atmosphere, especially over remote ocean areas. Data from ATom are helping to validate and improve satellite and model atmospheric data as well as the algorithms used to produce these data. Between the summer of 2016 and this past spring, Dr. Commane participated in ATom flights that sampled the atmosphere in all seasons.

Dr. Commane is a co-investigator for the Harvard University-developed Quantum Cascade Laser System (QCLS) instrument. The QCLS measures atmospheric concentrations of carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). She uses a range of tools, including airborne gas concentration data, atmospheric transport models, and ecosystem models, to develop a better understanding of processes occurring on Earth's surface that affect atmospheric chemistry. She is particularly interested in the different chemical signatures created by fires occurring in Africa and how these fires affect the chemical composition of the atmosphere over the Atlantic Ocean. She also is examining how clouds in the Arctic can hide the chemical signature of fires and make them more difficult to detect.

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ATom is closely linked to satellite missions designed to measure atmospheric chemistry, and provides unique complementary data for missions including NASA's Orbiting Carbon Observatory-2 (OCO-2); launched in 2014), the Global Ozone Monitoring Experiment–2 (GOME-2) instrument aboard the European Space Agency's (ESA) MetOp-A and MetOp-B satellites, the Tropospheric Monitoring Instrument (TROPOMI) aboard the ESA's Copernicus Sentinel-5 Precursor satellite, and the Japan Aerospace Exploration Agency's Greenhouse Gases Observing Satellite (GOSAT).

ATom researchers, in turn, use satellite data to extend the data collected from their airborne observations to a global scale and deliver a single, large-scale, contiguous *in situ* dataset that can be used for evaluating and improving computer models designed to forecast atmospheric conditions. One such model is NASA's Goddard Earth Observing System Model, Version 5 (GEOS-5), which is located at NASA's Goddard Space Flight Center in Greenbelt, MD.

Much of the ATom data collected by Dr. Commane and her colleagues are being archived at the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC). ORNL DAAC is the Earth Observing System Data and Information System (EOSDIS) DAAC responsible for archiving and distributing NASA Earth observing data related to biogeochemical dynamics, ecology, and environmental processes.

While Dr. Commane and her ATom research colleagues are still finalizing mission data and digging into science questions, she notes that they have been really impressed at how well the GEOS-5 atmospheric forecast has predicted pollution. In looking specifically at comparisons between GEOS-5 model predictions and observed concentrations of atmospheric CO, for example, she points out that some events, like Siberian forest fires, were completely missed by the model due to Arctic clouds masking the fires. Overall, though, she and her colleagues found that the model accurately predicted both the location and magnitude of atmospheric pollution plumes.

The real strength of ATom, observes Dr. Commane, will be when all the mission data are final and complete, giving the research community data representing all four seasons that can be used to evaluate and improve atmospheric chemistry models on a global scale. For a frequent flyer like Dr. Commane, these data are a price worth paying for her long days in the air.

Representative data products used:

- Data from the ORNL DAAC:
  - Atmospheric Tomography Mission main dataset page
    - ATom: Merged Atmospheric Chemistry, Trace Gases, and Aerosols (DOI: 10.3334/ORNLDAAC/1581); Dr. Commane contributed CO_2, CH_4, CO, and N_2O data for this collection
    - ATom: Observed and GEOS-5 Simulated CO Concentrations with Tagged Tracers for ATom-1 (DOI: 10.3334/ORNLDAAC/1604); Dr. Commane contributed CO data for this collection
  - Level 2 Atmospheric CO_2, CO, and CH_4 Concentrations (DOI: 10.3334/ORNLDAAC/1419) from the Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE); Dr. Commane contributed airborne platform CO_2, CH_4, and CO data for this collection
  - CARVE Level 4 Gridded Footprints from the Weather Research and Forecasting (WRF) Stochastic Time-Inverted Lagrangian Transport (STILT) model (DOI: 10.3334/ORNLDAAC/1431)

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- Arctic-Boreal Vulnerability Experiment (ABoVE) airborne CO_2 and CH_4 concentrations

- Moderate Resolution Imaging Spectroradiometer (MODIS) Snow Cover 8-Day Level 3 Global 500m Grid, Version 6 from NASA's Aqua (MYD10A2; DOI: 10.5067/MODIS/MYD10A2.006) and Terra (MOD10A2; DOI: 10.5067/MODIS/MOD10A2.006) Earth observing satellites; available through NASA's National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)
- CO total column Measurements Of Pollution In The Troposphere (MOPITT) data; available through NASA's Atmospheric Science Data Center (ASDC).
- GEOS-5 model Forward Processing (FP) CO fields; available through NASA's Global Modeling and Assimilation Office (GMAO) at NASA's Goddard Space Flight Center

Read about the research:

NASA ATom website: https://www.nasa.gov/content/earth-expeditions-atom

Strode, S.A., Liu, J., Lait, L., **Commane, R.,** Daube, B., Wofsy, S., Conaty, A., Newman, P. & Prather, M. (2018). "Forecasting Carbon Monoxide on a Global Scale for the ATom-1 Aircraft Mission: Insights from Airborne and Satellite Observations and Modeling." *Atmospheric Chemistry and Physics,* Discussion Papers [doi: 10.5194/acp-2018-150].

Commane, R., Lindaas, J., Benmergui, J., Luus, K.A., Chang, R.Y.-W., Daube, B.C., Euskirchen, E.S., Henderson, J.M., Karion, A., Miller, J.B., Miller, S.M., Parazoo, N.C., Randerson, J.T., Sweeney, C., Tans, P., Thoning, K., Veraverbeke, S., Miller, C.E. & Wofsy, S.C. (2017). "Carbon dioxide sources from Alaska driven by increasing early winter respiration from Arctic tundra." *Proceedings of the National Academy of Sciences,* 114(21): 5361-5366 [doi: 10.1073/pnas.1618567114].

Who Uses Earth Science Data?

Dr. Santiago Gassó, to study the concentration and global movement of dust.

Dr. Santiago Gassó

Dr. Santiago Gassó, Associate Research Scientist,
Goddard Earth Sciences Technology And Research (GESTAR) program, Greenbelt, MD/Morgan State University, Baltimore, MD

Research interests: Detection of smoke, dust, and other particles from space and the development of algorithms to derive pollution quantities from remotely-sensed imagery; dust transport at high latitudes and the interaction of volcanic emissions with clouds.

Research highlights: Our planet is a dusty place. One estimate provided by the National Oceanic and Atmospheric Administration (NOAA) indicates that about 20 teragrams (Tg) of dust are aloft in our planet's atmosphere at any given time. To put this into perspective, 1 Tg is equal to 1 trillion grams (that's about 2.2 *billion* pounds). For comparison, a fully-fueled NASA Saturn-V rocket, the one that took U.S. astronauts to the moon, weighed 6.2 million pounds at launch.

Of course, this dust does not simply sit in place. It is constantly in motion and can easily be carried long distances. Depending on the particle size and its height in the atmosphere, dust can remain suspended for several days or even weeks before settling. Developing algorithms to enable satellite-borne instruments to automatically identify, measure, and track atmospheric dust is one element of the research conducted by Dr. Santiago Gassó at NASA's Goddard Space Flight Center in Greenbelt, MD.

In fact, "dust" is a generic term describing particulate matter such as small grains of sand, clays, glacier silt, volcanic ash, and organic debris. It is the single largest component of suspended particles in Earth's atmosphere. Atmospheric dust also is a type of *aerosol*, which refers to any collection of suspended particles (such as water droplets, dust, ash, or pollen) in a gas. The amount and type of aerosols flowing in and out of a region or settling in a region can affect a wide range of environmental and physiological processes, including storm development and severity, climate, and human health.

Since these airborne particles absorb and reflect light, they can be detected and tracked by instruments aboard Earth observing satellites. Two satellite-borne instruments used by Dr. Gassó in his dust research are the Ozone Monitoring Instrument (OMI) aboard NASA's Aura satellite (launched in 2004) and the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra (launched in 1999) and Aqua (launched in 2002) satellites.

However, tracking dust is tricky. In visible satellite imagery, it can be difficult or impossible to see dust against bright backgrounds (such as clouds or snow) or at high latitudes (due to instrument viewing angles or the lack of adequate light, such as during the polar winter). To make dust easier to see, scientists often use combinations of spectral observing bands to identify dust in false colors.

For example, the OMI Aerosol Index is a science parameter of the OMI Level-2 near ultraviolet (UV) aerosol data product (OMAERUV; DOI: 10.5067/Aura/OMI/DATA2004), and uses processing algorithms to highlight areas of higher aerosol concentrations in yellow and red. Dr. Gassó often begins his observations by looking at MODIS imagery using NASA's Earth Observing System Data and Information System (EOSDIS) Worldview data visualization application, then retrieves OMI data for his areas of interest.

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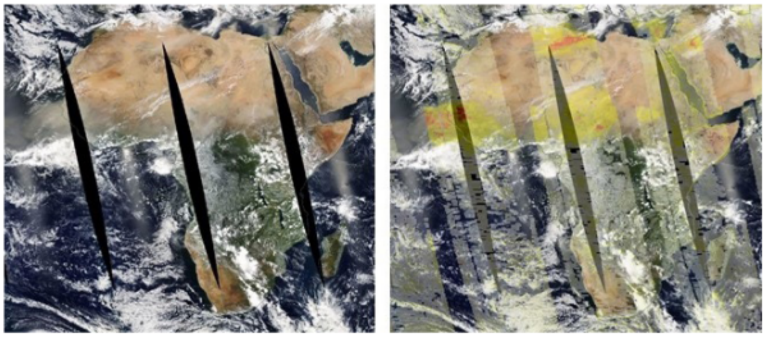
He points out that it can be challenging to use these images to estimate aerosol mass since there is no direct relationship between dust concentrations and the optical signals detected by satellite instruments. As a result, complex algorithms are needed to process this information, which results in a parameter called the ambient aerosol optical depth (AOD) that can be compared with model outputs. Much of Dr. Gassó's work involves creating these processing algorithms and interpreting the data produced by them, such as the effects dust and other aerosols have on clouds or in marine ecosystems. This information is essential for climate modelers, and also is used in air quality studies and forecasts.



Left image is a Worldview Aqua MODIS True Color image from March 25, 2018 (go.nasa.gov/2uD7YaZ). Dust mixed with smoke can be observed blowing off the west coast of Africa and south of the Sahara Desert, while a thick dust cloud is visible at the top of the image near the Mediterranean Sea. Right image is the same image with an overlay of OMI Aerosol Index data (go.nasa.gov/2GsnYCj). Yellow and red colors indicate areas with higher concentrations of aerosols, which make these areas easier to detect. Both images courtesy of NASA EOSDIS Worldview.

While instruments aboard Earth observing satellites do a good job identifying aerosol concentrations in the mid-latitudes, these instruments often underestimate—and in some instances are unable to detect—high-latitude dust concentrations (such as dust coming from Alaska, Greenland, Iceland, New Zealand, and Patagonia). Looking specifically at dust from the Patagonian region at the southern tip of South America, Dr. Gassó and his colleagues found that the MODIS and OMI instruments have difficulty automatically detecting dust in the cloudy conditions that often accompany dust storms and similar events. Even in clear conditions, the short-lived nature of Patagonian dust storms causes aerosol concentrations to be diluted, leading to weaker signals for the satellite instruments to detect. The result is an underestimation of aerosol concentrations over this region. This research found that the use of a single instrument (such as MODIS or OMI) is not sufficient for tracking dust at high latitudes. Rather, an integrated approach using multiple instruments and modeling tools (such as NOAA's Hybrid Single Particle Lagrangian Integrated Trajectory [HYSPLIT] model) can provide more consistent high-latitude dust observations.

High-latitude dust can also impact the melt rates of nearby glaciers and snowpack by darkening the surface and lowering the surface's albedo. Albedo is a measurement of the reflectivity of an object. Fresh, bright white snow has a high albedo and does a good job reflecting solar radiation. Dark snow, on the other hand, has a much lower albedo and absorbs more solar radiation. As dust settles onto snow and glaciers, it can darken the surface and contribute to an increase in absorbed solar radiation. This absorbed energy is returned to the environment in the form of heat, which leads to higher melt rates. Dr. Gassó points out that data for these high-latitude dust studies are limited due to the scarcity of year-round observations and remote sensing data.

Dr. Gassó also is studying the role atmospheric volcanic particles play in cloud longevity and evolution. Dust storms, volcanic ash, and pollen are all surfaces on which water vapor can condense to form cloud droplets, which are the basis for cloud drop and rain formation. An increase in particles, such as from a volcanic eruption, generally leads to an increase in surfaces onto which water vapor can condense. Since more cloud droplets in a given space are now competing for a limited amount of water vapor, the cloud droplets tend to remain smaller in size when compared with clouds forming in air with fewer particles. In addition, thin clouds

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made of smaller droplets tend to be brighter than thicker clouds that form from large droplets. These brighter clouds reflect more incoming solar radiation back into space, which can hinder biological processes (such as photosynthesis) at the surface and disrupt the temperature distribution in the atmosphere. Finally, it takes more time for smaller droplets to become large enough to fall, resulting in reduced precipitation and longer-lived clouds. Dr. Gassó's studies indicate that aerosols from passive or weakly active volcanoes (which often do not receive as much attention from volcano monitoring networks) can disrupt an area's precipitation and cloud cover by changing how long a cloud persists and how long these clouds are able to reflect solar radiation back to space.

While our planet will always have natural and human-created dust swirling throughout the atmosphere, the work of Dr. Gassó and his fellow researchers is helping scientists, health officials, and climate modelers develop a better understanding of where this dust is coming from and where it is going. The result is better knowledge about how our planet works along with more effective dust detection and tracking by instruments aboard Earth observing satellites.

Representative data products and visualization applications used:

- OMI/Aura Level 2 Near UV aerosol data product (OMAERUV; DOI: 10.5067/Aura/OMI/DATA2004); available through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC)
- Aqua/MODIS Atmosphere Level 2 Aerosol Product (MYD04; DOI: 10.5067/MODIS/MYD04_L2.006); available through NASA's Level 1 and Atmosphere Archive and Distribution System (LAADS) Distributed Active Archive Center (DAAC)
- EOSDIS Worldview data visualization application
- Aerosol optical depth data from the Aerosol Robotic Network (AERONET) at NASA's Goddard Space Flight Center
- CALIOP LiDAR data from the joint NASA/French Space Agency (CNES) Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) mission; available through NASA's Atmospheric Science Data Center (ASDC) in Hampton, VA.
- HYSPLIT model data; available through the NOAA Air Resources Laboratory
- Data products from the Japan Aerospace Exploration Agency (JAXA) Greenhouse gases Observing Satellite "Ibuki" (GOSAT)

Read about the research:

Bullard, J.E., Baddock, M., Bradwell, T., Crusius, J., Darlington, E., Gaiero, D., **Gassó, S.,** Gisladottir, G., Hodgkins, R., McCulloch, R., McKenna-Neuman, C., Mockford, T., Stewart, H. & Thorsteinsson, T. (2016). "High Latitude Dust in the Earth System." *Reviews of Geophysics*, 54(2): 447-485 [doi: 10.1002/2016RG000518].

Gassó, S. & Torres, O. (2016). "The role of cloud contamination, aerosol layer height and aerosol model in the assessment of the OMI near-UV retrievals over the ocean." *Atmospheric Measurement Techniques*, 9(7): 3031-3052 [doi: 10.5194/amt-9-3031-2016].

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Dr. Kristine M. Larson in front of her favorite GPS site (P041) near Boulder, Colorado. The gray object next to Dr. Larson is a GPS receiver antenna. Photograph by Glenn Asakawa, University of Colorado.

Dr. Kristine M. Larson

Professor of Aerospace Engineering Sciences, University of Colorado, Boulder, CO

Research interests: Plate tectonics and geodesy, with work developing new ways of using the Global Positioning System (GPS) to study Earth and the water cycle.

Research highlights: For many, GPS is a box that guides them around town or across the country. Thinking outside the GPS box, however, opens up this technology to innovative and extremely useful applications. The groundbreaking GPS research by Dr. Kristine M. Larson provides a good example of how a technology like GPS can be used for applications beyond its original intent.

Of course, like many serendipitous research discoveries, Dr. Larson's work developing a technique called GPS Interferometric Reflectometry, or GPS-IR, began with her efforts to deal with unwanted GPS signal noise interfering with her research into plate tectonics and ground movement during earthquakes.

GPS is an excellent technology for measuring minute changes in elevation or distance, such as displacement caused by an earthquake or the continuous shifting of tectonic plates as they imperceptibly slide across Earth's surface. GPS is the U.S. version of a Global Navigation Satellite System (GNSS). Other countries maintain similar systems, such as the European Galileo GNSS and the Russian Federation's GLObal NAvigation Satellite System (GLONASS). NASA's home for GNSS data is the Crustal Dynamics Data Information System (CDDIS) at NASA's Goddard Space Flight Center in Greenbelt, MD.

A GNSS system like GPS has three components: satellites in well-known orbits with synchronized clocks, ground controllers, and a ground segment providing data to users. As of October 18, 2018, the U.S. GPS constellation comprises 31 operational satellites orbiting more than 20,000 km above Earth, according to the federal GPS.gov website. Each satellite completes two orbits every day and sends out a unique one-way signal. Ground controllers keep track of satellite orbits and ensure that the clocks aboard each satellite are synchronized (the U.S. Air Force develops, maintains, and operates GPS space and ground control segments). Satellite signals are collected by a global network of receivers that detect, decode, and process these signals. Using signals from four satellites, a precise location in three-dimensions (within millimeters or less) along with precise time can be determined. By comparing measurements over time, minute elevation and distance changes at a station can be calculated. This is where Dr. Larson's work started.

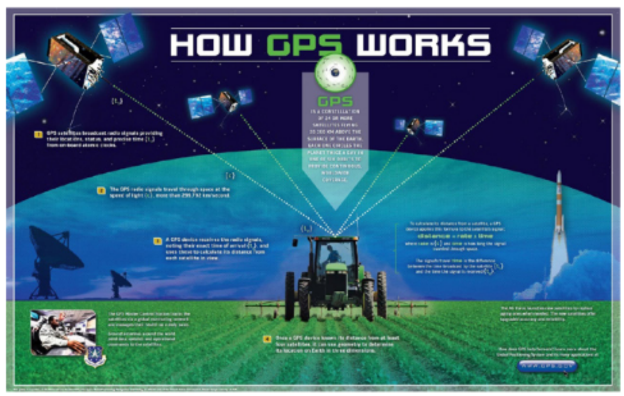

Image from GPS.gov and available for download at https://www.gps.gov/multimedia/poster/poster-web.pdf.

By training, Dr. Larson is a geodesist, which is the name given to scientists who measure and monitor Earth to determine the exact coordinates of any point (the overall field of study is called *geodesy*). She initially used GPS data to measure deformation caused by plate tectonics,

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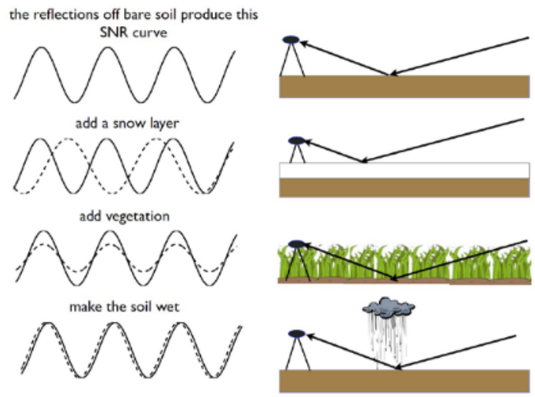
then began using GPS to study more dynamic signals, such as ground motions caused by earthquakes. While examining GPS seismic data, she noticed numerous errors caused by the GPS signals as they bounced on the ground before arriving at her scientific instruments. Erroneous signals outside the data being collected are called *noise*; for Dr. Larson, these erroneous GPS signals created an interference pattern that could be accounted for when analyzing her data. Still, this GPS noise was frustrating.

When Dr. Larson and her colleagues looked more closely at the GPS noise, though, they realized that the interference patterns they observed with ordinary GPS instruments correlated with the water content of the reflecting surface in the vicinity of the receiving antenna. By reverse-engineering the GPS reflections, Dr. Larson and her co-investigators were able to calculate a wide range of water cycle measurements, including soil moisture, vegetation water content, snow depth, and snow water equivallent (SWE). The technique they developed for using reflected GPS signals as a source for environmental data is called GPS Interferometric Reflectometry (GPS-IR).



This image by Dr. Larson illustrates how water can affect GPS signals to create noise (the signal to noise ratio or SNR). GPS signals reflecting off bare soil generate a "clean" signal with a SNR curve having a known frequency, phase, and amplitude (top image). If the GPS signal bounces off a snow layer (second image), the signal frequency changes (dashed line). If the GPS signal reflects off a vegetated surface (third image), particularly vegetation with water in it, the frequency doesn't change much, but the amplitude can change a lot. The hardest signal to see is soil moisture changes during precipitation events (final image), which causes a very small, but noticeable, phase shift in the SNR data. Image reproduced courtesy of Dr. Larson and UNAVCO.

Fortuitously, the development of GPS-IR coincided with the installation of the EarthScope Plate Boundary Observatory (PBO). EarthScope is a National Science Foundation (NSF) initiative to study the structure and evolution of the North American continent and the processes that cause earthquakes and volcanic eruptions. The PBO is a component of EarthScope that uses a large GPS network to precisely measure Earth deformation resulting from the constant motion of the Pacific and North American tectonic plates in the western U.S. Dr. Larson and her colleagues use PBO GPS data to measure shallow soil moisture variations, snow depth, vegetation water content, and water loading in a project called PBO H2O. PBO H2O soil moisture data were used to help validate sensor data from NASA's Soil Moisture Active Passive (SMAP) mission, and PBO H2O snow data are archived at NASA's National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC).

Building on their initial work, Dr. Larson and her colleagues used GPS-IR to measure water levels by seeing if a GPS receiver could be used as a tidal gauge. In an experiment conducted in Kachemak Bay, Alaska, the research team compared tidal coefficients acquired using GPS with tidal coefficients estimated from records acquired using a traditional tide gauge about 30 km away. Data from the two sources showed an agreement of 2.3 cm, indicating that GPS can be used to measure long-term sea-level changes. This water level methodology is now being used by geoscientists around the world.

Dr. Larson notes that one great benefit of her GPS reflection studies is that they use existing GPS instrumentation and infrastructure. This global infrastructure currently includes a network of more than 12,000 continuously-operating GPS systems in every biome. In some cases, Dr. Larson has been able to use GPS data that have been archived for more than a decade and turn these data into new environmental products.

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Who Uses Earth Science Data?

Dr. Larson receiving the Prince Sultan Bin Abdulaziz International Creativity Prize for Water from HRH King Salman in Riyadh, Saudi Arabia, on December 15, 2014. Image courtesy of Dr. Larson.

GPS-IR is now being used on every continent on Earth, including Antarctica, where it is being used to measure both snow accumulation and tides. In recognition of the significance of this work, the GPS Reflections Group led by Dr. Larson shared the 2014 Prince Sultan bin Abdulaziz International Prize for Water (PSIPW), Creativity Prize. The Creativity Prize is one of five biennial awards that are part of the PSIPW, and recognized the GPS Reflections Group for their "development of a new, unexpected, and cost-effective technique . . . to measure soil moisture, snow depth, and vegetation water content."

Along with being a means of navigating from point to point, the innovative GPS and GNSS work and research by Dr. Larson and her colleagues broadens the use of this technology in ways far beyond those originally envisioned. What was once "noise" to Dr. Larson has now become a harmonious new way of assessing Earth's water resources.

Representative data products used:

- Various GNSS data and orbit products; available through CDDIS
- Daily Snow Depth and SWE from GPS Signal-to-Noise Ratios, Version 1 [DOI: 10.5067/Z02Y1HGNFXCH]; available through NSIDC DAAC
- Data from the North American Land Data Assimilation System (NLDAS) Forcing Dataset; available through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC)
- GPS data archived at UNAVCO, a non-profit university-governed consortium that facilitates geoscience research and education using geodesy
- Data from the PBO H2O project; available through the PBO H2O Data Portal

Read about the research:

Larson, K.M. (2016). "GPS Interferometric Reflectometry: Applications to Surface Soil Moisture, Snow Depth, and Vegetation Water Content in the Western United States." *Wiley Interdisciplinary Reviews: Water (WIREs Water),* 3(6): 775-787 [doi: 10.1002/wat2.1167].

Larson, K.M., Wahr, J. & Kuipers Munneke, P. (2015). "Constraints on Snow Accumulation and Firn Density in Greenland Using GPS Receivers." *Journal of Glaciology,* 61(225) [doi: 10.3189/2015JoG14J130].

Larson, K.M., Ray, R.D., Nievinski, F.G. & Freymueller, J.T. (2013). "The Accidental Tide Gauge: A Case Study of GPS Reflections from Kachemak Bay, Alaska." *IEEE Geoscience and Remote Sensing Letters,* 10(5): 1200-1204 [doi: 10.1109/LGRS.2012.2236075].

Who Uses Earth Science Data?

Dr. Pinki Mondal, to study the effects of climate change on agricultural systems and communities.

Dr. Pinki Mondal at CIESIN. On the computer screen is a map showing trends in MODIS Normalized Difference Vegetation Index (NDVI) for the 2000-2016 wet season/monsoon in South Asia/India. Image by Dr. Chandranath Basak.

Dr. Pinki Mondal

Assistant Professor,
Department of Geography,
University of Delaware,
Newark, DE

Research interests: Human-environment interactions with a specific focus on the sustainability of agricultural ecosystems, agricultural sensitivity to climate variability, adaptation strategies for smallholder farms, and the effects of national-level policies on forestry and conservation.

Research highlights: Counting the residents of the second most populous nation in the world is a daunting task, but one India has undertaken every 10 years since the late 1800s (as a British colony until 1947, then as an independent nation). The numbers from the 2011 Indian census reveal that almost 70 percent of the nation's more than 1.2 billion inhabitants live in rural areas, with a majority of these rural residents engaged in agriculture.

While the Census of India collects data at ground level showing where the population lives, instruments aboard Earth observing satellites constantly collect data showing how land is used. These remotely-sensed data are a foundation of Dr. Pinki Mondal's studies into the sustainability of agricultural systems and the impacts of climate variability on agriculture in South Asia. One source for the socioeconomic data Dr. Mondal uses is NASA's Socioeconomic Data and Applications Center (SEDAC), which is located at the Center for International Earth Science Information Network (CIESIN) at Columbia University. SEDAC is an Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Center (DAAC), and supports the integration of socioeconomic and Earth science data in order to serve as an information gateway between the Earth sciences and social sciences.

Satellite data can reveal a lot about the socioeconomic impacts of urbanization and environmental change, and help researchers more easily identify changes in landscape patterns across a wide range of spatial (local, regional, or continental) and temporal (week, month, or year) scales. For example, nighttime lights imagery from the Visible Infrared Imaging Radiometer Suite (VIIRS) make it easy to see the spread of urbanization into previously rural areas through changes in the density of human-added lights. Vegetation indices created from data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra and Aqua satellites and by instruments aboard the joint NASA/U.S. Geological Survey's (USGS) Landsat series of satellites enable researchers to more easily analyze changes in vegetation and spot patterns across entire continents. As Dr. Mondal notes, her research would be impossible without NASA Earth science data.

Dr. Mondal's current research focuses on developing geospatial methods for monitoring smallholder agricultural systems in tropical countries. A "smallholder farm" generally is defined by both its physical size and its economic production, both of which are often small relative to other farms in a similar region. As a result, smallholder farmers can be impacted more significantly by changes in production caused by environmental factors including drought, flooding, and invasive species or by social factors like urbanization or state policies. In her research, Dr. Mondal uses microwave satellite data, Synthetic Aperture Radar (SAR) data (such as data from the European Space Agency's Sentinel satellites), and high-resolution optical satellite data (such as from Landsat and Sentinel-2).

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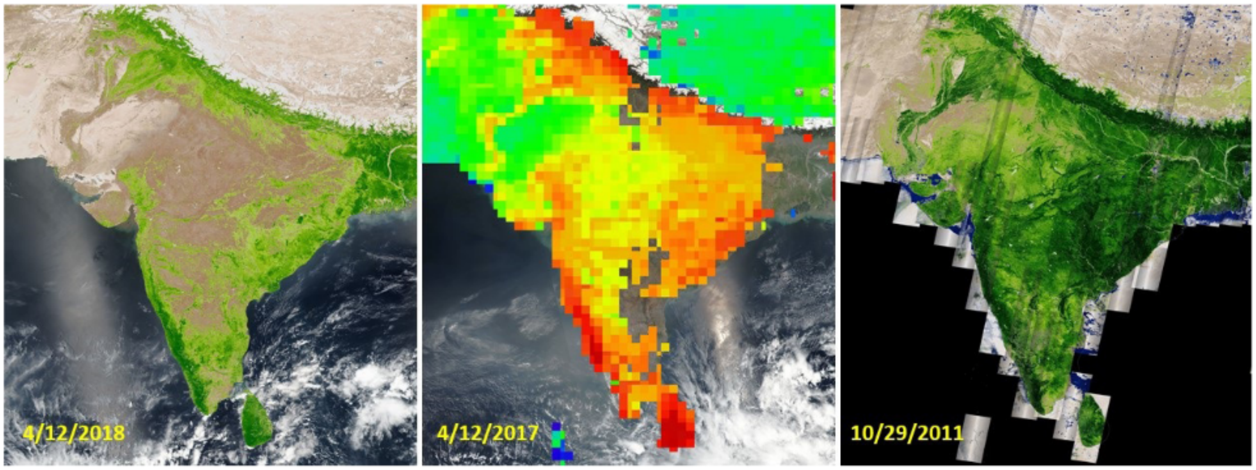

Three ways of looking at vegetation in India using Normalized Difference Vegetation Index (NDVI) data. NDVI is a measure of the greenness and health of vegetation. Left image: Terra/MODIS (go.nasa.gov/2GZJCtT). Center image: Terra/Multi-angle Imaging SpectroRadiometer (MISR) (go.nasa.gov/2GZSRdg). Right image: Combined Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 5 Thematic Mapper (TM) instrument data produced by the Web Enabled Landsat Data (WELD) project (go.nasa.gov/2JlhyNd). Darker green colors (MODIS and Landsat images) and yellow/red pixels (MISR image) indicate areas of healthier, more dense vegetation. Images courtesy of NASA EOSDIS Worldview.

As Dr. Mondal notes, climate changes are expected to lead to significant fluctuations in crop yields and contribute to concerns about food security of the growing Indian population. She uses multi-platform satellite time-series data from MODIS, Landsat, and the joint NASA/Japan Aerospace Exploration Agency Tropical Rainfall Measuring Mission (TRMM), operational 1997-2015, along with district-level Indian census data for irrigation, dominant crop type, crop yield, and socioeconomic status to explore factors associated with changing crop covers.

Dr. Mondal also is interested in developing machine-learning algorithms that can convert socioeconomic and environmental data into geographic information system (GIS)-ready formats. The socioeconomic data used by Dr. Mondal are often obtained from national census or large-scale surveys and have millions of records at the finest administrative levels that require big data analysis. She integrates these data with satellite imagery to understand potential adaptation strategies of agricultural systems to climate change.

Her collaborative research on agricultural sensitivity to weather and climate variability in India has led to several interesting research findings. Along with the critical importance of daytime temperature to winter crops, she found that the sensitivity of crop productivity to climate variability is location-specific, and due primarily to differences in cropping practices throughout the year and irrigation access during the dry season. In addition, the sensitivity of crop productivity to precipitation depends on the irrigation source. For example, a longer wet season (monsoon) followed by higher temperatures in winter or a late and dry monsoon can severely limit the water available through surface irrigation, such as canals. These canals are a common irrigation source in Indian smallholder agricultural systems, so impacts to the water in these canals through changes in monsoon intensity or timing can significantly impact smallholder agricultural production.

Dr. Mondal points out that winter wheat, a staple and an important winter crop in India, requires timely irrigation. In research looking at strategies smallholder farmers can consider in dealing with the impacts of water and climate variability on the production of winter wheat and other winter crops, Dr. Mondal and her colleagues found that *pulses,* that is, crops harvested solely for their dry seed (such as dried beans, chickpeas,

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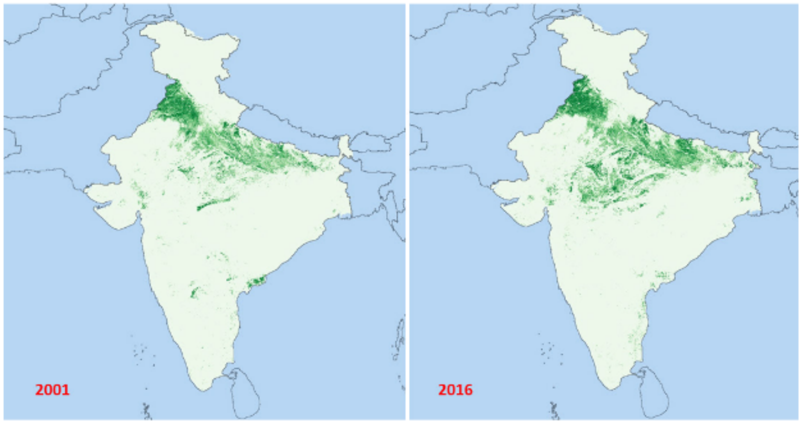
lentils, and peas), can be a potential alternative winter crop in the right type of soil. Other adaptation strategies include switching to crops less sensitive to heat, shifting the planting date for winter crops to avoid higher temperatures during the late-season grain maturing stage, and investing in research to develop early-maturing varieties of winter crops.



Changes in annual winter cropped area in India from 2001 (left image) and 2016 (right image). Darker green indicates a higher percentage of winter cropped area. Image credit: Jain, M., Mondal, P., Galford, G.L., Fiske, G. & DeFries, R.S. (2017). India Annual Winter Cropped Area, 2001-2016. Palisades, NY: NASA SEDAC [DOI: 10.7927/H47D2S3W]. Accessed April 13, 2018.

The combination of remotely-sensed data with census data provides a powerful tool for socioeconomic research and the application of this research to regions and economies that can be sensitive to climate variability. The research by Dr. Mondal and her colleagues seeks to provide a range of agricultural strategies so that the residents of these vulnerable areas can best prepare for potential future climate and environmental changes.

Representative data products used:

- Various SEDAC data sets:
  - India Data Collection; co-developed by Dr. Mondal
  - Global Summer Land Surface Temperature (LST) Grids, v1 (2013) (DOI: 10.7927/H408638T); developed by Dr. Mondal
  - Global Urban Heat Island (UHI) Data Set, v1 (2013) (DOI: 10.7927/H4H70CRF); co-developed by Dr. Mondal
  - Global Reservoir and Dam (GRanD-v1), Dams v1.01 (2011) (DOI: 10.7927/H4N877QK)
  - Global Rural-Urban Mapping Project (GRUMP-v1), Urban Extents Grid, v1 (1995) (DOI: 10.7927/H4GH9FVG)
- MODIS land data products; available through NASA's Land Processes Distributed Active Archive Center (LP DAAC):
  - Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) from Terra (MOD13Q1; DOI: 10.5067/MODIS/MOD13Q1.006) and Aqua (MYD13Q1; DOI: 10.5067/MODIS/MYD13Q1.006)
  - Terra Land Surface Temperature (LST) (MOD11A2; DOI: 10.5067/MODIS/MOD11A2.006)
- TRMM daily precipitation product (TRMM_3B42RT_Daily; DOI: 10.5067/TRMM/TMPA/DAY-E/7); available through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC)

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- Sentinel-1 SAR Level 1 Ground Range Detected (GRD) imagery; available through NASA's Alaska Satellite Facility (ASF) DAAC; NASA's provision of the complete ESA Sentinel-1 SAR data archive through ASF DAAC is by agreement between the U.S. State Department and the European Commission
- Landsat Tier-1 Precision Terrain (L1TP) products; available through the USGS

Read about the research:

Mondal, P., Trzaska, S. & de Sherbinin, A. (2018). "Landsat-derived estimates of mangroves in the Sierra Leone Coastal Landscape Complex during 1990-2016." *Sensors,* 18(1): 12 [doi: 10.3390/s18010012].

Jain, M., **Mondal, P.,** Galford, G., Fiske, G. & DeFries, R. (2017). "An Automated Approach to Map Winter Cropped Area of Smallholder Farms across Large Scales Using MODIS Imagery." *Remote Sensing,* 9(6): 566 [doi: 10.3390/rs9060566].

Mondal, P., Jain, M., Zukowski, M., Galford, G. & DeFries, R. (2016). "Quantifying fluctuations in winter cropped area in the Central Indian Highlands." *Regional Environmental Change,* 16: 69-82 [doi: 10.1007/s10113-016-0946-y].

Mondal, P., Jain, M., DeFries, R., Galford, G. & Small, C. (2015). "Sensitivity of crop cover to climate variability: Insights from two Indian agro-ecoregions." *Journal of Environmental Management,* 148: 21-30 [doi: 10.1016/j.jenvman.2014.02.026].

Mondal, P., Jain, M., Robertson, A., Galford, G., Small, C. & DeFries, R. (2014). "Winter crop sensitivity to inter-annual climate variability in central India." *Climatic Change,* 126: 61-76 [doi: 10.1007/s10584-014-1216-y].

Dr. Larry O'Neill, to explore the effects of air-sea interactions on weather, ocean circulation, and climate.

Dr. Larry O'Neill at Vernal Falls in Yosemite National Park, CA. Dr. O'Neill uses a wide range of Earth science data to investigate the impact of air-sea interactions on fresh water. Image courtesy of Dr. O'Neill.

Dr. Larry O'Neill

Assistant Professor,
College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR

Research interests: Air-sea interactions, specifically how ocean temperature affects weather and how weather affects ocean temperature and circulation.

Research highlights: Water is the dominant feature of our planet, and the circulation of water through the ocean and the atmosphere are vital cycles that enable life to exist. However, the amount of water is finite, and only a small percentage of this precious resource is available at a given time as fresh water. One key source of fresh water is precipitation from storms. Knowing why rain falls where it does and how changes in the strength or intensity of ocean currents can impact the distribution of precipitation are two key questions Dr. Larry O'Neill's research seeks to answer.

As Dr. O'Neill points out, interactions between the ocean and the atmosphere can affect circulation patterns in both sea and sky. These circulation patterns also can shift over time in response to changes in global climate. This, in turn, can impact storm formation, storm movement, and precipitation patterns. Given the small amount of fresh water available at any one time, having a better understanding of these air-sea interactions and their effect on weather is critical.

The U.S. Geological Survey estimates that there are over 332,500,000 cubic miles of water on the planet. Most of this water—about 97 percent—is saline ocean water (about 321,000,000 cubic miles), according to the National Oceanic and Atmospheric Administration. Of the remaining three percent of Earth's water, only about one percent is readily available fresh water on the surface and not locked up in ice or underground. This fresh water is found in lakes, rivers, and wetland areas or is transported through the atmosphere as water vapor, clouds, and precipitation. As a result, changes in atmospheric and oceanic circulation patterns can impact the formation and track of storms globally, while influencing the amount of fresh water delivered by storms locally.

These air-sea interactions continuously occur through near-surface winds, clouds, rainfall patterns, evaporation, storms, surface waves, and changes in ocean depth. Much of Dr. O'Neill's work centers on regions where these air-sea interactions coincide with very strong and large ocean currents, such as off the U.S. East Coast (the Gulf Stream), the Southern Ocean (the Antarctic Circumpolar Current), and off the east coast of Asia (the Kuroshio Current). Ocean currents in these dynamic regions can be very fast (NASA satellite data indicate that the Kuroshio Current carries warm water northeastward at speeds greater than 4 mph) and the temperature contrast between the core of these currents and nearby surrounding water can be as great as 15 degrees Fahrenheit.

As these currents shift warm water from tropical regions toward the poles, they create their own weather patterns through their impact on evaporation and the resulting storm and cloud development. In fact, Dr. O'Neill and his colleagues found that the temperature of the Gulf Stream influences the generation and strength of intermittent storms, creating rain in bursts rather than continuously generating clouds and light rain.

While ocean buoys collect *in situ* data at specific locations, the ocean is simply too vast for large-scale data collection using conventional measuring devices. Earth observing satellites maintained by NASA and other space agencies provide the large spatial (ocean-wide) and temporal (many years) data that help enable Dr. O'Neill's research.

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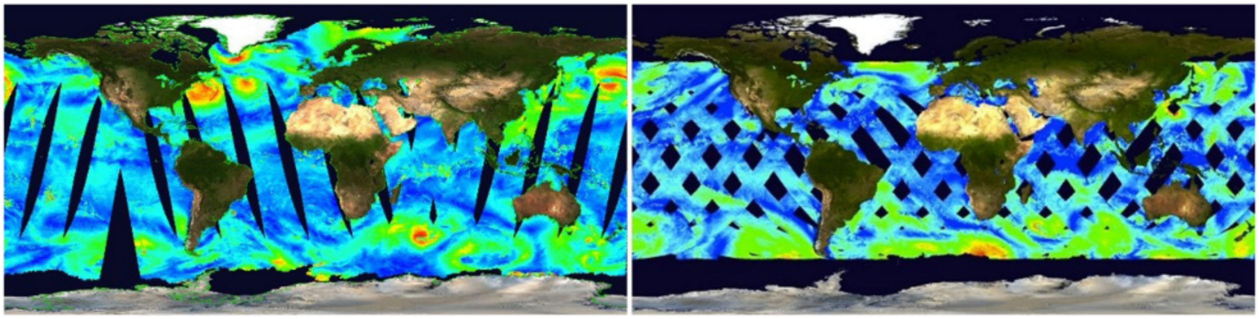
Of particular use is scatterometer data. A scatterometer is a microwave radar sensor that measures the reflection or scattering of radar waves by wind. Scatterometers are the best remote-sensing system for providing accurate, frequent, high-resolution measurements of ocean-surface wind speed and direction in most weather and cloud conditions and can be mounted aboard aircraft or on space-based platforms (such as a satellite or the International Space Station). Two sources of scatterometer data used by Dr. O'Neill are the SeaWinds instrument aboard NASA's Quick Scatterometer (QuikSCAT) satellite (operational 1999 to 2009) and the RapidScat instrument installed aboard the International Space Station (ISS-RapidScat, operational 2014 to 2016). Data from these instruments are available from NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC).



Comparison of QuikSCAT (left, January 1, 2009) and RapidScat (right, October 4, 2014) imagery showing global ocean surface wind speed. Lower speed is indicated by blue and green colors; higher speed is indicated by yellow and red colors. Black areas indicate an absence of data. Due to its mounting on the ISS, RapidScat flew at roughly half the altitude as QuikSCAT and had a low inclination angle that restricted data coverage to the tropics and mid-latitude regions. Images credit: JPL/PO.DAAC.

For measuring other ocean data, such as sea surface temperature, humidity, and precipitation, an important resource for Dr. O'Neill is the Advanced Microwave Scanning Radiometer (AMSR) series of instruments (AMSR, operational 2002 to 2003; AMSR-E, operational 2002 to 2011; and AMSR2, operational 2012 to present). AMSR instruments are passive microwave radiometers that sense energy radiated from Earth, and their near-polar orbits provide frequent sampling of a given location. A key feature of the AMSR instruments is their ability to "see" through clouds, which allows for continuous collection of ocean data. AMSR instrument data also are available from NASA's PO.DAAC and are processed to create ocean measurement products including sea surface temperature, surface wind speeds, atmospheric water vapor, cloud liquid water content, and rain rate.

Using a combination of scatterometer and AMSR data supplemented with computer models, Dr. O'Neill and his colleagues found that surface winds are affected by contrasts in sea surface temperature and that these surface winds can, in turn, set up a feedback loop that continues to strengthen sea surface temperature contrasts. These surface temperature contrasts contribute to areas of surface convergence and uplift that can result in storm formation. Further research by Dr. O'Neill shows that these storms can impact the mean mid-latitude atmospheric circulation and affect the overall transport of water vapor.

Through his research into air-sea interactions, Dr. O'Neill is helping to shed light on the complex relationships between ocean and atmospheric circulation and the resulting transport of water that drives our planet. The precipitation that results from these processes helps provide the life-sustaining fresh water necessary for survival. Having a better understanding of where and when this rain might fall is critical information Dr. O'Neill's work attempts to provide.

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Representative data products used:

- Data products available through PO.DAAC:
  - QuikSCAT ocean surface winds (DOI: 10.5067/QSX12-L2B01)
  - ISS-RapidScat ocean surface winds (DOI: 10.5067/RSX12-L2C11)
  - AMSR instrument sea surface temperature, clouds, humidity, ice extent, and rain data products from multiple satellites:
    - AMSR, aboard the Japan Aerospace Exploration Agency (JAXA), NASA, and French Centre Nationale d'Etudes Spatiales (CNES) Advanced Earth Observing Satellite-2 (ADEOS-II/SeaWinds)
    - AMSR-E aboard NASA's Aqua Earth observing satellite
    - AMSR2 aboard the JAXA Global Change Observation Mission-Water (GCOM-W1) satellite
  - Sea surface temperature, clouds, humidity, ice extent, and rain data products from the Global Precipitation Measurement (GPM) Microwave Imager (GMI) aboard the joint NASA/JAXA GPM Core Observatory; GMI data are available through PO.DAAC as well as through NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC)
  - Sea surface height data from the joint NASA/CNES Jason series of missions
- GPM and Tropical Rainfall Measuring Mission (TRMM) precipitation data; available through GES DISC
- COAMPS[*] atmospheric model data; available through the Naval Research Laboratory

Read about the research:

O'Neill, L.W., Haack, T., Chelton, D.B. & Skyllingstad, E. (2017). "The Gulf Stream Convergence Zone in the time-mean winds." *Journal of Atmospheric Sciences,* 74(7): 2383-2412 [doi: 10.1175/JAS-D-16-0213.1].

Wentz, F.J., Ricciardulli, L., Rodriguez, E., Stiles, B., Bourassa, M., Long, D., Hoffman, R., Stoffelen, A., Verhoef, A., **O'Neill, L.W.,** Farrar, T., Vandemark, D., Fore, A., Hristova-Veleva, S., Turk, J., Gaston, R. & Tyler, D. (2017). "Evaluating and Extending the Ocean Wind Climate Data Record." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 10(5): 2165 - 2185 [doi: 10.1109/JSTARS.2016.2643641].

Gaube, P., Chelton, D.B., Samelson, R.M., Schlax, M.G. & **O'Neill, L.W.** (2015). "Satellite Observations of Mesoscale Eddy-Induced Ekman Pumping." *Journal of Physical Oceanography,* 45: 104–132 [doi: 10.1175/JPO-D-14-0032.1].

O'Neill, L.W., Haack, T. & Durland, T. (2015). "Estimation of time-averaged surface divergence and vorticity from satellite ocean vector winds." *Journal of Climate,* 28: 7596–7620 [doi: 10.1175/JCLI-D-15-0119.1].

O'Neill, L.W. (2012). "Wind speed and stability effects on the coupling between surface wind stress and SST observed from buoys and satellite." *Journal of Climate,* 25(5): 1544-1569 [doi: 10.1175/JCLI-D-11-00121.11].

Who Uses Earth Science Data?

Lela Prashad, for exploring how people live in and experience urban environments.

Lela Prashad at her workstation. On the screen behind her is an image of ASTER normalized difference vegetation index (NDVI) and surface temperature data for Phoenix, AZ.

Lela Prashad

CEO and Co-Founder of NiJeL, a data science company focused on environmental and social sustainability, Phoenix, AZ; former director (2006-2011) of the NASA-funded 100 Cities Project at Arizona State University's School of Earth and Space Exploration

Research interests: Connecting satellite remote sensing data with ground-based monitors to build a more complete picture of urban environments and how people locally experience these environments.

Research highlights: The end of June and beginning of July in New York City this past summer were sizzling, with temperatures in Central Park soaring into the 90s four straight days. Meanwhile, the temperature in Islip, NY, 53 miles away on Long Island, reached the 90s only one time during this same period. While Islip's location closer to the Atlantic Ocean likely helped mitigate the high temperatures experienced in New York City, another factor in Islip's favor may have been that it lacks the extremely high density of people and pavement found in The Big Apple.

Temperature data measured by instruments aboard Earth observing satellites and at ground level show that urban areas tend to have higher average temperatures than the more rural areas around them. These warmer urban areas are called "urban heat islands." When temperature data are combined with socioeconomic data (such as census data), population clusters that may be affected by higher urban temperatures are easy to identify.

The ability to combine remotely sensed satellite data with socioeconomic and other demographic data is a powerful tool for exploring the impact humans have on Earth. This combination of satellite and ground-based data also is a key component of Lela Prashad's research into how people live in and experience urban environments.

Much of Ms. Prashad's research centers on exploring the impact of urban heat islands. The increased heat seen in urban areas is caused by numerous factors, including high amounts of concrete and asphalt (which retain and slowly dissipate heat) and higher concentrations of vehicles with internal combustion engines (which produce greenhouse gasses that trap heat). According to the U.S. Environmental Protection Agency, impacts of urban heat islands include:

- Increased energy consumption;
- Elevated emissions of air pollutants and greenhouse gases;
- Compromised human health and comfort; and
- Impaired water quality

As Ms. Prashad notes, NASA data are the foundation for her work on cities and provide numerous advantages in her studies. Satellite data and imagery allow her to study a complete region at multiple scales and resolutions, provide repeatable coverage at known times, and enable her to acquire data across political boundaries.

An important satellite data source for Ms. Prashad is the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). ASTER is one of five instruments aboard NASA's Terra Earth observing satellite (launched in 1999), and is a partnership between NASA, Japan's Ministry of Economy, Trade and Industry (METI), the National Institute of Advanced Industrial Science and Technology (AIST) in Japan, and Japan Space Systems (J-spacesystems). ASTER collects data in 14 different wavelengths

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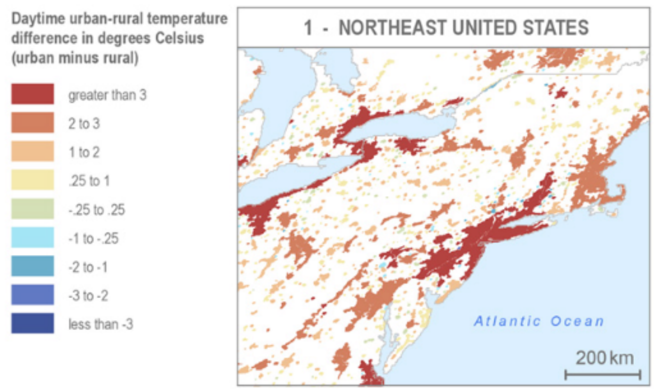
(ranging from visible to thermal infrared) that are used to create detailed maps of land surface temperature, emissivity (a measure of the ability of an object to radiate energy), reflectance (a measure of how well a surface is able to reflect light or other radiation striking the surface), and elevation. Ms. Prashad supplements ASTER data with data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Terra and Aqua satellites (primarily land surface temperature and emissivity products) along with imagery from the joint NASA/U.S. Geological Survey (USGS) Landsat series of satellites.

For socioeconomic data, Ms. Prashad relies on data products from NASA's Socioeconomic Data and Applications Center (SEDAC). SEDAC serves as an "Information Gateway" between the Earth sciences and social sciences, and is the NASA Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Center (DAAC) responsible for developing and operating applications supporting the human dimensions of Earth science. For example, SEDAC's Global Urban Heat Island (UHI) Data Set comprises four maps showing estimates of land surface temperature within urban areas as well as temperature differences between these urban areas and surrounding rural areas, which are defined as a 10 kilometer buffer around the urban area.



Map from the SEDAC Urban Heat Island (UHI) Data Set, 2013, showing summer daytime urban-rural temperature difference for the Northeast U.S. Image and data: Center for International Earth Science Information Network - CIESIN - Columbia University. 2016. Global Urban Heat Island (UHI) Data Set, 2013. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4H70CRF. Accessed August 23, 2018.

Along with her urban heat island research, Ms. Prashad also is the former director of an innovative NASA-funded effort called the 100 Cities Project, which used satellite-based remote sensing data to support socioeconomic and biogeographic comparisons of 100 worldwide cities. An underlying goal of the program was to discover the inherent taxonomy of cities through the measurement and classification of many urban sites in order to better inform city planners, managers, and government agencies about sustainable development options.

In order to provide the public, decision makers, and researchers with a simple tool to help them view, combine, and analyze NASA Earth observing data and ancillary data sets, Ms. Prashad and her colleagues created a toolset called JMARS for Earth (J-Earth). J-Earth was created from the Java Mission-planning and Analysis for Remote Sensing (JMARS) open-source geospatial information system (GIS) platform developed by the Mars Space Flight Facility at Arizona State University to provide tools for Mars mission planning and data-analysis. JMARS provides access to more than a terabyte of NASA satellite data and has basic image and vector processing features to compare, plot, and blend data. Using the JMARS platform, J-Earth provides access to ASTER and MODIS multispectral imaging products along with topography data.

Ms. Prashad's research shows that surface temperature and vegetation data derived from ASTER, MODIS, and Landsat imagery can represent ground conditions accurately enough to enable reliable comparisons of local conditions across different cities. These comparisons, in turn, can be used in studies of the heat-related stresses people in these cities might experience, such as higher temperatures and poor air quality. Further,

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emissivity and land surface temperature data sensed by instruments aboard Earth observing satellites show the extent to which concrete and asphalt can absorb and retain heat during the day and radiate this heat at night, raising nighttime minimum temperatures. Finally, she has found that while areas of asphalt and concrete can increase the urban heat island effect, patterns of parks, yards, and other green spaces in a city can help reduce the impact of these areas by providing areas of shade and through the cooling effects of evapotranspiration.

By combining remotely-sensed satellite data with socioeconomic data, Ms. Prashad and her colleagues are building a better picture of who may be most vulnerable to heat stress in a city. The results of her work and research give local governments, policy makers, and city planners around the world additional tools they can use to measure urban heat island impacts and develop ways to mitigate and reduce the stresses experienced by people living in these urban areas.

Representative data products used:

- Data sets from the following SEDAC collections:
  - Global Urban Heat Island (UHI) Data Set, v1 (2013)
  - Global Urban Rural Mapping Project (GRUMP), v1
  - Gridded Population of the World (GPW), v4
- ASTER data; available through the Land Processes Distributed Active Archive Center (LP DAAC):
  - Surface Emissivity (AST_05; DOI: 10.5067/ASTER/AST_05.003)
  - Surface Reflectance VNIR & Crosstalk Corrected SWIR (AST_07XT; DOI: 10.5067/ASTER/AST_07XT.003)
  - Surface Kinetic Temperature (AST_08; DOI: 10.5067/ASTER/AST_08.003)
  - Digital Elevation Model (AST14DEM; DOI: 10.5067/ASTER/AST14DEM.003)
  - Radiance at Sensor—Orthorectified (AST14OTH; DOI: 10.5067/ASTER/AST14OTH.003)
  - Global Digital Elevation Model (ASTGTM; DOI: 10.5067/ASTER/ASTGTM.002)
- MODIS Land Surface Temperature and Emissivity products (MOD11 and MYD11); available through the LP DAAC
- Landsat Level 1 data; available through the USGS EarthExplorer data exploration tool

Read about the research:

Prashad, L. (2014) "The People Within the Pixels," in *Sensors and Journalism,* Fergus Pitt, ed. (Columbia Journalism School, Tow Center for Digital Journalism; Tow/Knight Report, 2014), pp. 220-228. Available online at www.towcenter.org/wp-content/uploads/2014/05/Tow-Center-Sensors-and-Journalism.pdf.

Prashad, L., Dickenshied, S., Cheeseman, S. & Christensen, P. (2012). "Building Stakeholder Collaborations through Innovative Data Sharing: The J-Earth Project." *UGEC Viewpoints,* 7 (2012): 12-14. Available online at https://ugecviewpoints.files.wordpress.com/2015/01/ugec-viewpoints-7.pdf.

Hartz, D., **Prashad, L.,** Hedquist, B., Golden, J. & Brazel, A. (2006). "Linking satellite images and hand-held infrared thermography to observed neighborhood climate conditions." *Remote Sensing of Environment,* 104: 190-200 [doi: 10.1016/j.rse.2005.12.019].

Who Uses Earth Science Data?

Dr. Mike Ramsey, for developing new ways to study active volcanoes and to provide data to support emergency response.

Dr. Mike Ramsey collecting thermal infrared data at a vent in the Leilani Estates subdivision near the eastern tip of the island of Hawaii in early June. The subdivision is located over part of the lower East Rift Zone of Kilauea. More than 27 homes in the subdivision have been destroyed as a result of eruptions that began this past May.

Dr. Mike Ramsey

Professor of Volcanology and Planetary Science,
Department of Geology and Environmental Science, University of Pittsburgh, Pittsburgh, PA

Research interests: Thermal infrared spectroscopy and remote sensing applied to a variety of Earth and planetary surface processes, especially the study of active volcanoes using ASTER data.

Research highlights: According to legend, the Hawaiian goddess of fire, Pele, lives in the Halemaumau Crater at the summit of Kilauea Volcano on the Big Island of Hawaii. She is reported to take many forms, sometimes appearing as a white dog, an old woman, or a beautiful young woman. Her most common form, though, is that of lava pouring across the ground.

Like Pele, lava, too, takes different forms, including smooth, ropy pahoehoe ("pa-hoy-hoy") and lumpy, rough a'a ("ah-ah"). Whether smooth or lumpy, all lava has one element in common—it is made from molten rock that can be hotter than 2,000 degrees Fahrenheit, according to the U.S. Geological Survey (USGS). This intense heat can be detected by instruments aboard Earth observing satellites. For volcanologist Dr. Mike Ramsey, these thermal data are a cornerstone of his work using infrared spectroscopy and remote sensing data in his studies of active volcanoes. He and his students currently are working at volcanoes in Guatemala (Fuego, Pacaya), Russia (Tolbachik), Hawaii (Kilauea), Italy (Etna, Stromboli), and Reunion Island (Piton de la Fournaise).

Dr. Ramsey collecting night time thermal data at the Kilauea lava lake in January 2017.

His current research focuses on understanding the spectral emissivity of volcanic products like lava. Emissivity is a unitless term that varies with wavelength between 0 and 1 and is based on the composition of an object. An object with high emissivity (closer to 1) is better able to radiate energy than an object with lower emissivity. The emissivity spectrum of a surface or a lava plume allows Dr. Ramsey to map its composition, particle size, and even micron scale roughness. He is particularly interested in the unique changes in emissivity from molten surfaces compared to their solidified counterparts. These changes reveal fundamental information about lava's molecular structure and govern its radiant cooling. This information, in turn, can be used to improve eruption forecasting and for developing models that predict the path of a lava flow.

A primary source of satellite-based instrument data used by Dr. Ramsey is the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). ASTER is a partnership between NASA, Japan's Ministry of Economy, Trade and Industry (METI), the National Institute of Advanced Industrial Science and

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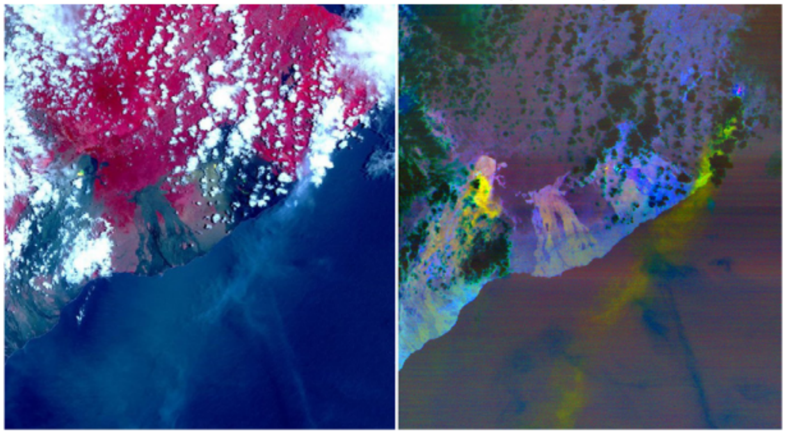
Technology (AIST) in Japan, and Japan Space Systems (J-spacesystems), and is aboard NASA's Terra Earth observing satellite (launched in 1999). The instrument obtains high-resolution images of Earth in 14 different wavelengths ranging from visible to thermal infrared. These data are used to create detailed maps of land surface temperature, emissivity, reflectance, and elevation. Dr. Ramsey is a member of the ASTER science team and uses ASTER's unique moderately high spatial and spectral resolution in the instrument's five thermal infrared (TIR) wavelength bands in his studies of active volcanoes. As of 2016, all ASTER data are available at no charge through NASA's Land Processes Distributed Active Archive Center (LP DAAC).

A unique feature of ASTER is that the instrument's telescopes can be pointed to collect imagery and data at specific locations. Dr. Ramsey utilized this feature to create the ASTER Urgent Request Protocol (URP) system. The URP is a sensor web designed to rapidly detect new thermal activity and target ASTER to collect data of that activity. This sensor web uses satellite-based instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Very High Resolution Radiometer (AVHRR) coupled with ground-based sensors to detect areas of high thermal activity. When new activity is detected, this triggers a request for ASTER data collection at the location of the detected activity. The program was established in 2004 and has been fully functional in its current state since 2011. It now results in nearly one new ASTER image per day of global eruptive activity.

The URP system was used extensively during the recent eruption of Kilauea in Hawaii. As Dr. Ramsey notes, the triggering for ASTER imagery was almost immediate due to the intense thermal signature given off by the first presence of new lava from the eruption. Daily thermal alerts continued as lava was flowing from the volcano, and ASTER was targeted to acquire data at every possible opportunity. Because the lava radiance is so intense, a special request for off-axis pointing of ASTER's Visible Near-Infrared (VNIR) subsystem also was used to increase the number of observations and to collect data at night. An analysis of these data by Dr. Ramsey and Dr. Vincent Realmuto at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA, shows that the sulfur dioxide (SO_2) plume from the volcano is easily detected in the ASTER TIR data.



Two images of the recent Hawaiian eruptions acquired by ASTER on May 6, 2018. Left image is a color composite showing vegetation in red and old lava flows in black and gray. Note the small yellow spots in the upper right and just left of center, which are areas of high thermal activity caused by flowing lava. Right image is from ASTER's multiple thermal bands and shows plumes of sulfur dioxide (SO2) in yellow and yellow-green. The brighter, thicker SO2 plume on the left of the image is coming from Kilauea. The prevailing trade winds blow the plumes to the southwest over the ocean. Images credit: NASA/METI/AIST/Japan Space Systems, and U.S./Japan ASTER Science Team.

Dr. Ramsey also is using ASTER data to create continually updated thermal maps of the Kilauea eruption for scientists at the Hawaiian Volcano Observatory (HVO), which is part of the USGS Volcano Hazards Program. HVO scientists supplement ASTER observations with ground-based high resolution thermal video data collected through periodic helicopter flights over the lava flows. ASTER data are being compared with ground

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and helicopter-based multispectral TIR data from a new instrument developed by Dr. Ramsey to provide a better understanding of how the lava flow channels develop and to track the emissivity changes with time as the lava channels cool.

Through the use of ASTER data coupled with ground-based observations, Dr. Ramsey and his colleagues are gaining a better understanding of the physical processes governing molten rock. This knowledge is being applied to the development of better tools and instruments that enable scientists and public officials to deal more effectively with volcanic activity and allow homeowners to live more safely in these areas.

End of the road: Panoramic view of lava fields in the Leilani Estates subdivision taken by Dr. Ramsey in June 2018. Note the orange ongoing eruption in the distance just right of center.

Representative data products used:

- ASTER data available through LP DAAC:
  - Level 1BE Expedited Data Sets (EDS) produced as part of the URP Project
  - Level 2 products for retrospective analysis:
    - AST_05: ASTER Surface Emissivity V003 (DOI: 10.5067/ASTER/AST_05.003)
    - AST_07: ASTER Surface Reflectance VNIR and SWIR V003 (DOI: 10.5067/ASTER/AST_07.003)
    - AST_07XT: ASTER Surface Reflectance VNIR and Crosstalk Corrected SWIR V003 (DOI: 10.5067/ASTER/AST_07XT.003)
    - AST_08: ASTER Surface Kinetic Temperature V003 (DOI: 10.5067/ASTER/AST_08.003)
    - AST_09: ASTER Surface Radiance VNIR and SWIR V003 (DOI: 10.5067/ASTER/AST_09.003)
    - AST_09T: ASTER Surface Radiance TIR V003 (DOI: 10.5067/ASTER/AST_09T.003)
    - AST_09XT: ASTER Surface Radiance VNIR and Crosstalk Corrected SWIR V003 (DOI: 10.5067/ASTER/AST_09XT.003)

Read about the research:

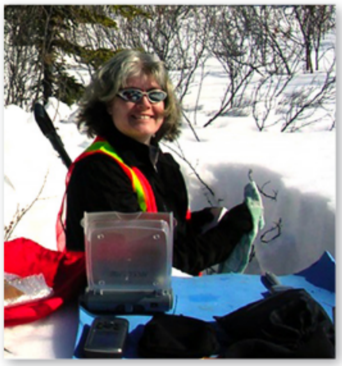
Reath, K.A., **Ramsey, M.S.**, Dehn, J. & Webley, P.W. (2016). “Predicting eruptions from precursory activity using remote sensing data hybridization.” *Journal of Volcanology and Geothermal Research,* 321: 18-30 [doi: 10.1016/j.jvolgeores.2016.04.027].

Ramsey, M.S. (2016). “Synergistic use of satellite thermal detection and science: A decadal perspective using ASTER.” In Harris, A.J.L., De Groeve, T., Garel, F. & Carn, S.A. (eds.), *Detecting, Modelling and Responding to Effusive Eruptions,* Geological Society, London, Special Publications, 426: 115-136 [doi: 10.1144/SP426.23].

Ramsey, M.S., Harris, A.J.L. & Crown, D.A. (2016). “What can thermal infrared remote sensing of terrestrial volcanoes tell us about processes past and present on Mars?” *Journal of Volcanology and Geothermal Research,* 311: 198-216 [doi: 10.1016/j.jvolgeores.2016.01.012].

Who Uses Earth Science Data?

Dr. Joan Ramage, to study glaciers and snowmelt.



Dr. Joan Ramage collecting data from a snow pit near the town of Faro in the Yukon Territory, Canada. Image courtesy of Dr. Ramage.

Dr. Joan Ramage

Associate Professor of Earth and Environmental Science, Lehigh University, Bethlehem, PA

Research interests: Past glaciations and their impacts in North and South America, the distribution and change of modern glaciers around the world, and hydrologic impacts of snowmelt.

Research highlights: Severnaya Zemlya is a forbidding place in which to conduct research. Located in the Russian High Arctic north of Siberia's Taymyr Peninsula, it has a large population of collared lemmings (*Dicrostonyx torquatus*), no permanent human population, and a mean annual temperature of 5.4 degrees Fahrenheit. It does, however, have glaciers. More than 20 significant glaciers cover the four main islands making up this archipelago. For Dr. Joan Ramage, these glaciers are an important part of her studies into the distribution of glaciers and the impacts of environmental changes to glaciers, snowpack, and the cryosphere.

The term *cryosphere* refers to any place on Earth where water is in its solid form, and includes snow, river, and lake ice; sea ice; ice sheets, ice shelves, glaciers, and ice caps; and frozen ground (such as permafrost). According to data from the Intergovernmental Panel on Climate Change (IPCC), the cryosphere covers 52-55 percent of Earth's land surface. While glaciers represent only 0.5 percent of this total, seasonal snow cover, which is variable, can represent up to 30 percent of this total in the Northern Hemisphere alone, according to the IPCC.

Dr. Ramage's research concentrates on measuring when and where glaciers and seasonal snow are melting, and the impacts of this on mountain hydrology, glacier mass balance, and glacier dynamics. Along with Severnaya Zemlya, her research has taken her to the Andes in South America, mountainous areas in Asia, and the Yukon River basin in Northwest Canada and Central Alaska.

While Dr. Ramage conducts field research and observations, these research sites are often at high latitudes and/or high elevations and in conditions that are, to say the least, challenging. Data collected by instruments aboard Earth observing satellites are an important source of additional research data and a key resource for observing large-scale changes spanning great distances or long periods of time.

Satellite observations, however, come with their own set of challenges. For instance, visual and near infrared observations often are limited by cloudy conditions and the perennial darkness of the Arctic and Antarctic winters. As a result, Dr. Ramage uses data from a variety of satellites, especially data collected by passive and active microwave sensors. Unlike instruments that require illumination from the sun or clear conditions to create images, microwave instruments sense radiated energy and are able to acquire images in cloudy and dark conditions. This gives Dr. Ramage and her colleagues the ability to collect data throughout the winter season, during storms, and at night.

As Dr. Ramage points out, tracking glacier movement and surface snowmelt often requires multiple observations using data from several orbiting microwave instruments. One suite of instruments Dr. Ramage uses comprises the Special Sensor Microwave/Imager (SSM/I) and Special Sensor Microwave Imager/Sounder (SSMIS) aboard the Defense Meteorological Satellite Program (DMSP) series of satellites, the Advanced Microwave Scanning Radiometer

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- Earth Observing System (AMSR-E) aboard NASA's Aqua Earth observing satellite, and the Advanced Microwave Scanning Radiometer 2 (AMSR 2) aboard the Japan Aerospace Exploration Agency's Global Change Observation Mission-Water 1 (GCOM-W1) satellite. The daily data from these instruments are particularly useful in her studies tracking hydrological responses to snowpack melting.

In research conducted at Severnaya Zemlya and other locations in the Russian High Arctic using a combination of field observations and data from multiple satellites, Dr. Ramage and her colleagues examined how rising air temperatures are affecting glaciers and snowmelt. One result of these higher temperatures is that areas in the Arctic and sub-Arctic are experiencing earlier snowmelt onset and a higher number of total melt days. This earlier snowpack melting and increased number of melt days has a significant impact on regional glaciers, which lose mass as they melt. This glacier melting also results in a large influx of fresh water into the surrounding seas that, in turn, impacts regional sea levels. In addition, while fresh, white snowpack reflects a great deal of incoming solar radiation, as the snowpack melts, the ground darkens and absorbs more solar radiation. This, in turn, increases the land temperature and leads to additional melting. Data collected by the research team indicate a link between land ice snowmelt dynamics and regional sea ice extent variations.

NASA Terra/MODIS image of Severnaya Zemlya acquired July 6, 2001. Glaciers appear as bright white circular objects against the bare brown land surface; puffy white areas are clouds; white/bluish-white areas surrounding the islands are sea ice. Credit: Jacques Descloitres, MODIS Land Rapid Response Team.

In fact, as Dr. Ramage and her colleagues note in research exploring early snowmelt events in the Yukon River basin, "high latitude drainage basins are experiencing higher average temperatures, earlier snowmelt onset in spring, and an increase in rain on snow events in winter." In this Yukon River basin work, the research team used meteorological and hydrological data from ground stations combined with passive microwave AMSR-E data and active microwave data from the SeaWinds instrument aboard NASA's Quick Scatterometer (QuikSCAT) satellite to study melt onset. The team found that all melt events in the study area coincided with above freezing temperatures; a limited number of melt events corresponded to rain on snow events and a majority of melt events were linked to fog. The research team notes that the results of this study show the influence of warm air intrusions on snowmelt in some areas and indicate that there is a large variability in snowmelt across years and regions.

Dr. Ramage also combines satellite data with models to simulate snowmelt runoff or test the effects of potential environmental changes. In another study conducted in the Yukon River basin, she used AMSR-E snowmelt timing and snow water equivalent (SWE) data as inputs into a model called SWEHydro to reconstruct snowmelt runoff. This model, which was co-developed by Dr. Ramage, is designed to quantitatively determine the relationship between snow distribution on the landscape, snowmelt timing, and spring stream runoff in high-latitude and high-altitude basins.

Using AMSR-E brightness temperature (which is the fundamental parameter measured by passive microwave radiometers like AMSR-E) and diurnal amplitude variations (DAV, which are the differences between the early-morning [usually minimum] and late-afternoon [usually maximum] brightness temperature observations), the research team was able to determine the timing of melt onset and snow saturation. Runoff was calculated using pre-melt SWE data combined with terrain information and melt rate estimates. As Dr.

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Ramage observes, once snowmelt begins, there is a transition period characterized by daytime melting and overnight refreezing, resulting in high variations in brightness temperature and high DAV. Using the snowmelt rate during and after melt transition and the snowmelt flow during and after melt transition, the SWEHydro model was able to effectively simulate the increase in water flow from melting snow, peak timing and magnitude of this flow, and the volume of this flow. This shows that the SWEHydro model may be effective for quantifying spring snowmelt in remote areas lacking sufficient meteorological measurements.

Dr. Ramage's use of data from multiple satellites is an effective technique in her glacier and snow cover change studies in high-latitude regions and some mountainous areas. Currently, using a newly developed multi-satellite high-resolution brightness temperature data set available through NASA's National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC), she is looking at smaller glaciers with higher relief and in more temperate environments. One somewhat elusive quantity she would like to be able to quantify is how much snow is melting in very remote places. Current satellite-borne instruments enable her to detect moisture in the near surface snowpack, but she and her colleagues find it difficult to turn this remotely-sensed presence of melt into a rate or volume. She hopes to rectify this gap through the development of additional datasets and further snowpack hydrology modeling.

Thanks to the ability of Earth observing satellites to peer into every corner of the globe 24 hours a day and acquire imagery in a wide range of weather conditions, Dr. Ramage and her colleagues are able to access an ever-increasing trove of remotely-sensed data to supplement their field investigations and modeling of remote, frozen environments.

Representative data products used:

- MEaSUREs Calibrated Enhanced-Resolution Passive Microwave Daily EASE-Grid 2.0 Brightness Temperature Earth System Data Record (ESDR), Version 1 [DOI: 10.5067/MEASURES/CRYOSPHERE/NSIDC-0630.001]; this data set is part of NASA's Making Earth System Data Records for Use in Research Environments (MEAsUREs) program and available at NSIDC DAAC
- Brightness Temperature products available at NSIDC DAAC:
  - AMSR-E; DOIs:
    - 10.5067/AMSR-E/AE_SI12.003
    - 10.5067/AMSR-E/AE_SI25.003
    - 10.5067/AMSR-E/AE_SI6.003
    - 10.5067/XIMNXRTQVMOX
    - 10.5067/RRR4WWORG070
  - SSM/I and SSMIS; DOIs:
    - 10.5067/MES22DNFS3O8
    - 10.5067/3EX2U1DV3434
    - 10.5067/AN9AI8EO7PX0
    - 10.5067/BBQSXI3ERWWY

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- SeaWinds radar backscatter (Sigma-0) data products; available at NASA's Physical Oceanography DAAC (PO.DAAC)
- Various Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data products; available through NASA's Land Processes DAAC (LP DAAC)
- Various Landsat products; available through the U.S. Geological Survey (USGS) EarthExplorer data search and discovery application (search using keyword "Landsat")
- Light Detecting and Ranging (LiDAR) data from the Pennsylvania Geospatial Data Clearinghouse

Read about the research:

Pfeffer, W., Arendt, A., Bliss, A., Bolch, T., Cogley, J., Gardner, A., . . . Sharp, M. (2014). "The Randolph Glacier Inventory: A globally complete inventory of glaciers." *Journal of Glaciology*, 60(221): 537-552 [doi: 10.3189/2014JoG13J176].

Zhao, M., **Ramage, J.**, Semmens, K.A., Obleitner, F. (2014). "Recent ice cap snowmelt in Russian High Arctic and anti-correlation with late summer sea ice extent." *Environmental Research Letters* (Special Issue: Focus on Northern Eurasia in the Global Earth System: Changes and Interactions), 9(4) [doi: 10.1088/1748-9326/9/4/045009].

Semmens, K.A., **Ramage, J.,** Liston, G. & Bartsch, A. (2013). "Early snowmelt events: detection, distribution, and significance in a major sub-arctic watershed." *Environmental Research Letters,* 8(1) [doi: 10.1088/1748-9326/8/1/014020].

Vaughan, D.G., Comiso, J.C., Allison, I., Carrasco, J., Kaser, G., Kwok, R., Mote, P., Murray, T., Paul, F., Ren, J., Rignot, E., Solomina, O., Steffen, K. & Zhang, T. (2013). "Observations: Cryosphere." In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. & Midgley, P.M. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available online at http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter04_FINAL.pdf.

Ramage, J. & Semmens, K.A. (2012). "Reconstructing Snowmelt Runoff in the Yukon River Basin Using the SWEHydro Model and AMSR-E Observations." *Hydrological Processes* (Eastern Snow Conference special issue), 26(17): 2563-2572 [doi: 10.1002/hyp.9226].

Yan, F., **Ramage, J.** & McKenney, R. (2009). "Modeling of high-latitude spring freshet from AMSR-E passive microwave observations." *Water Resources Research*, 45(11) [doi: 10.1029/2008wr007370].

Who Uses Earth Science Data?

Dr. Bridget Seegers, for developing new ways to study water quality and track harmful algal blooms.

Dr. Bridget Seegers conducting a ballast check on a glider (yellow, airplane-looking object in water) during a West Coast project to better understand the initiation of harmful algal blooms (HABs).

Dr. Bridget Seegers

Scientist (Oceanographer with the Universities Space Research Association [USRA]), Ocean Ecology Laboratory, NASA's Goddard Space Flight Center, Greenbelt, MD

Research interests: Using remotely-sensed satellite data for assessing water quality and harmful algal blooms (HABs) in fresh and salt water.

Research highlights: Dr. Bridget Seegers is searching for a killer. While the killer can't be seen with the naked eye, it leaves a trail of death and illness that can easily be tracked; it can run, but it can't hide from the ever-watchful instruments aboard Earth observing satellites. The killer Dr. Seegers seeks is cyanobacteria.

Cyanobacteria are microscopic single-celled organisms that live in lakes, streams, oceans, damp soil, and other wet environments. They are photosynthetic, meaning that they are able to use sunlight to produce energy and food. During this process, they release oxygen into the atmosphere. In fact, Earth as we know it today is partly courtesy of the massive amounts of atmospheric oxygen produced by cyanobacteria starting about 3.5 billion years ago (based on the fossil record).

Given the right conditions of water, sunlight, and nutrients, cyanobacteria can multiply rapidly and form extensive "blooms." These blooms can turn water surfaces a variety of colors depending on the species of cyanobacteria, including green, blue, red, or brown. Cyanobacteria are even capable of moving through layers of water, spending days near the surface collecting sunlight and producing energy then moving deeper at night for nutrients.

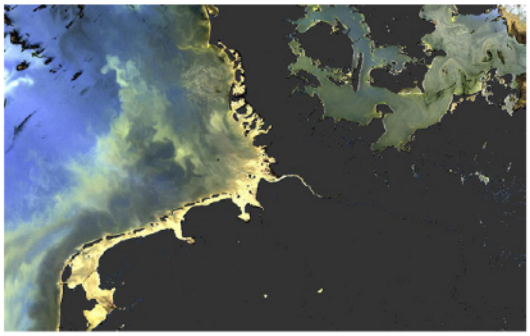

Image of blooms in the Baltic Sea acquired July 20, 2016, by the Ocean and Land Colour Instrument (OLCI) aboard the European Space Agency (ESA) Sentinel-3A spacecraft. Blooms appear as swirls of blue/green and yellow; black areas are land. ESA Copernicus Sentinel-3 image.

Some species of cyanobacteria also have the ability to produce toxins that can affect the central nervous system (neurotoxins), the liver (hepatotoxins), and other systems. When these species bloom and produce toxins, they create large areas of "harmful algal blooms" or HABs. HABs can be deadly to aquatic life by producing toxins and by the decaying blooms using up oxygen in the water. These actions can impact the well-being of a wide range of non-aquatic species, as well, by leading to foul odors and contributing to numerous health impacts. In humans, these impacts can include breathing difficulties, rashes, and intestinal problems.

While individual cyanobacteria are microscopic, cyanobacterial blooms can grow large enough and be colorful enough to be detected and tracked using instruments aboard Earth observing satellites. NASA ocean color data are the responsibility of NASA's Ocean Biology Processing Group (OBPG), which supports the collection, processing, calibration, validation, archiving, and distribution of ocean biology-related data products from a number of Earth observing missions. These data are available through NASA"s Ocean Biology Distributed Active Archive Center (OB.DAAC), which is NASA's Earth Observing System Data and Information System (EOSDIS) DAAC responsible for archiving and distributing ocean biology data.

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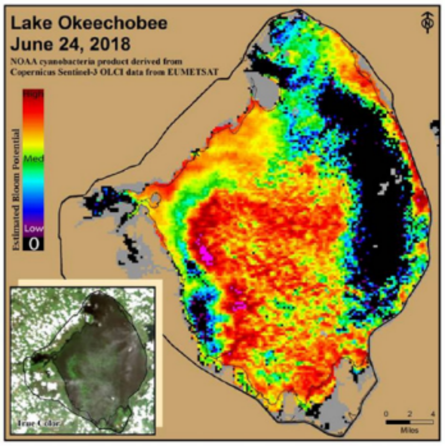
Dr. Seegers is part of a multi-agency effort called the Cyanobacteria Assessment Network (CyAN) Project. A joint undertaking of NASA, the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS), the CyAN Project uses historic and current satellite data to detect algal blooms in U.S. freshwater systems. These data are being developed into products designed to create an "early warning system" for detecting cyanobacteria blooms and related water quality issues that threaten ecosystem function, public health, recreational opportunities, and water supplies across the contiguous U.S.

An important aspect of the CyAN Project is its interdisciplinary approach. Along with Dr. Seegers (an oceanographer in NASA's Ocean Ecology Laboratory), the team includes ecologists, public health experts, economists, and remote sensing scientists. The project currently provides weekly estimates of cyanobacteria concentrations for more than 2,000 lakes in the continental U.S. that are large enough to be identified by instruments aboard Earth-orbiting satellites.

Dr. Seegers uses data derived from two primary satellite-based instruments to estimate cyanobacteria concentrations: the Medium Resolution Imaging Spectrometer (MERIS), operational 2002 to 2012 aboard the European Space Agency's (ESA) Envisat spacecraft; and the Ocean and Land Colour Instrument (OLCI), which is the successor to MERIS and is aboard ESA's Sentinel-3A spacecraft (launched in February 2016 and currently operational). Use of ESA Copernicus Sentinel data is under agreement between the OB.DAAC and European Commission partners.

Using a NOAA-developed algorithm, NASA's OBPG processes MERIS and OLCI data into a derived product called the Cyanobacteria Index (CI), which shows the concentration of cyanobacteria in fresh water bodies and estuaries. This product is provided to the EPA, the USGS, and other end-users. Since the MERIS and OLCI sensor band sets are similar to the sensor band sets on NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Terra and Aqua Earth observing satellites, the algorithm can be used to generate similar cyanobacteria concentration products using MODIS data when MERIS and OLCI data are unavailable (as was the case between the end of the Envisat mission in 2012 and the start of Sentinel-3A in 2016). MODIS ocean color data from both Terra and Aqua are available through OB.DAAC.



Combined OLCI and CI image showing potential HABs in Lake Okeechobee, FL. Red indicates areas of high bloom potential; blue/purple areas have lower bloom potential. Image courtesy of NOAA and derived from ESA Copernicus Sentinel-3 OLCI EUMETSAT data.

Water managers across the country are using the CI product to help monitor HABs and provide early indication of potential HAB events, and Dr. Seegers points to a few recent success stories. In Oregon, CI data were used to help identify drinking water sources that were potentially susceptible to cyanobacteria blooms, which led to increased monitoring of these areas to help minimize risk to public drinking water supplies. Wyoming issued a recreational use advisory after CI data made managers aware of a cyanobacteria bloom, and Utah's Department of Environmental Quality routinely uses the product to help monitor the health of state lakes. Twenty-four other states currently are working with the CyAN Project. Any state regulatory agency or health department is welcome to reach out to the CyAN Project to become a

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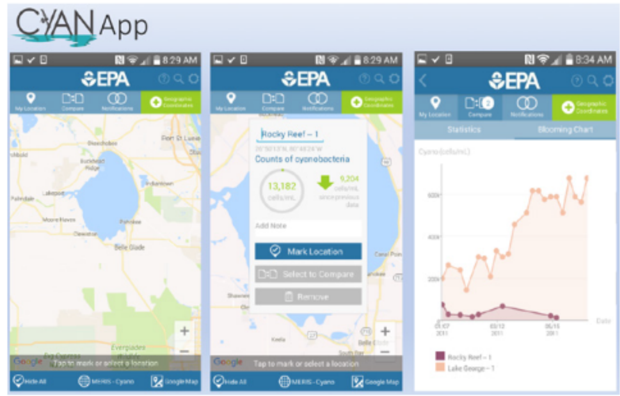
collaborator and gain access to CyAN Project data by contacting Dr. Blake Schaeffer at the EPA (schaeffer.blake@epa.gov).



Screenshots from the CyAN app. For more information about this app, please see the Schaeffer, et al. (2018) citation in the Read about the Research section (below).

Another way CyAN Project data are getting into the hands of state health agencies and managers is the CyAN app. Using MERIS and OLCI data coupled with USGS Landsat data, the app enables users to easily make initial water quality assessments and quickly alerts managers to potential problems and emerging threats. The app also includes a data archive that allows users to look back two-to-three years to track changes in cyanobacteria concentrations. While the app currently is available only to U.S. health departments and state environmental departments upon request to the EPA, it will be available to the general public in the future.

Dr. Seegers was instrumental in a recent effort to get NASA Earth science, HAB, and CyAN Project information to the public called "Sippin' On Science." These free informal presentations, funded by the Universities Space Research Association (USRA), were conducted at bars and breweries in small towns across Wisconsin and Minnesota over the summer. Along with hands-on science, trivia contests, a demonstration of the CyAN app, and information about lakes, algae, research robots, and satellite science, Dr. Seegers brought along a microscope where participants could see samples of microorganisms living in a drop of water from their local lake or river. As Dr. Seegers observes, Sippin' On Science broke down boundaries to create opportunities for the public to learn more about HABs, become better aware of the impact HABs have in their local waterways, and talk with a NASA scientist.

While individual cyanobacteria may be too small to be seen with the naked eye, their blooms can't hide from instruments aboard Earth observing satellites. Through the use of satellite-based instrument data, Dr. Bridget Seegers and her CyAN Project colleagues are giving health officials, environmental managers, and the general public the timely, accurate information they need to deal with the potentially deadly threat from this microscopic menace.

Representative data products used:

- Data available through OB.DAAC (the use of ESA Copernicus Sentinel data is under agreement between OB.DAAC and European Commission partners):
  - Various MERIS data products
  - Various OLCI data products
- Landsat Level-2 Surface Temperature Science Product [DOI: 10.5066/F7J38RTH]; available through the USGS

(Continued)

Read about the research:

Schaeffer, B., Bailey, S., Conmy, R., Galvin, M., Ignatius, A., Johnson, J., Keith, D., Lunetta, R., Parmar, R., Stumpf, R., Urquhart, E., Werdell, P. & Wolfe, K. (2018). "Mobile device application for monitoring cyanobacteria harmful algal blooms using Sentinel-3 satellite Ocean and Land Colour Instruments." *Environmental Modelling & Software,* 109(2018): 93-103 [doi: 10.1016/j.envsoft.2018.08.015].

Schaeffer, B., Liames, J., Dwyer, J., Urquhart, E., Salls, W., Rover, J. & **Seegers, B.** (2018). "An initial validation of Landsat 5 and 7 derived surface water temperature for U.S. lakes, reservoirs, and estuaries." *International Journal of Remote Sensing,* 2018 [doi: 10.1080/01431161.2018.147545].

Seegers, B., Stumpf, R., Schaeffer, B., Loftin, K. & Werdell, P. (2018). "Performance metrics for the assessment of satellite data products: an ocean color case study." *Optics Express,* 26(6): 7404 [doi: 10.1364/oe.26.007404].

Clark, J., Schaeffer, B., Darling, J., Urquhart, E., Johnston, J., Ignatius, A., Myer, M., Loftin, K., Werdell, J. & Stumpf, R. (2017). "Satellite monitoring of cyanobacterial harmful algal bloom frequency in recreational waters and drinking water sources." *Ecological Indicators,* 80(2017): 84-95. [doi: 10.1016/j.ecolind.2017.04.046].

Notes

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Produced by:
Earth Science Data and Information System (ESDIS) Project
Code 423
Goddard Space Flight Center
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NP-2018-11-299-GSFC