

# SPECTRA

THE MAGAZINE OF THE  
NAVY'S CORPORATE  
LABORATORY

# 7000



**SMART  
SEA GLIDERS**

Creating the  
Next Generation  
**ENVIRONMENTAL  
PREDICTION SYSTEM**

Ocean Acoustics  
in the Evolving  
**ARCTIC ENVIRONMENT**

**GROUND-TRUTHING**  
Remote Sensing  
Measurements of  
the Sea Ice

**U.S. NAVAL  
RESEARCH  
LABORATORY**



## From the Associate Director

### **DOUGLAS G. TODOROFF, Ph.D.**

Associate Director of Research for Ocean  
and Atmospheric Science and Technology

As the head of the Ocean and Atmospheric Science & Technology directorate, it's my pleasure to welcome you to this edition of the U.S. Naval Research Laboratory's Spectra magazine.

The work of the directorate's five divisions highlighted in this issue represents only the tip of the iceberg. Our world-class national defense scientists and engineers provide unique capabilities to the Navy and Marine Corps, helping the services better understand the environments in which they operate.

Our current research stresses two major themes: The advancement and creation of sophisticated models to predict the behavior of the environment, and the collection and analysis of data used to support and refine the skill-level of these models.

The models we create not only predict the behavior of Earth's atmospheric weather, but also the ocean, the sea floor, polar ice coverage, and the ionosphere. Because we know each of these environments are interconnected, our work is increasingly focused on coupling the models together. Our goal is to be able to accurately predict the interactions between the models, improve their spatial resolution and range in time, so that our naval forces have the information they need to operate in various climates and tactical situations.

To create these robust models, we need good data from the source. Our people are frequently in the field collecting observations and measurements or using remote sensing to continually improve quality and availability of inputs. We're finding new ways to collect and assimilate data, using artificial intelligence and machine learning techniques. This is truly an exciting time to be working in this field.

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Andrei Abelev, Ph.D.,  
a U.S. Naval Research  
Laboratory remote  
sensing division  
researcher, conducts  
ground-truth ice core  
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(U.S. Navy photo)

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# SMART SEA GLIDERS

Improving Ocean Observation and Prediction

DANIEL PARRY, NRL CORPORATE COMMUNICATIONS



*The U.S. Navy maintains a large fleet of sea gliders for environmental measurement. Sea gliders are slow-moving, long-endurance, underwater vehicles that gather data as they travel through the ocean's interior using high-efficiency buoyancy engines. (U.S. Naval Research Laboratory photo)*

Scientists from the U.S. Naval Research Laboratory's Ocean Sciences Division are optimizing the placement of sea gliders and the usage of glider data to improve the Navy's ability to predict ocean conditions.

Researchers frequently use gliders – slow-moving, long-endurance underwater vehicles – to collect data on ocean conditions such as temperature, depth, and salinity; in effect, observing the ocean's weather.

"Predicting the ocean's interior weather is challenging, yet it has important implications for all those who sail and operate on its waters," said Jeffrey Book, Ph.D., an NRL oceanographer. "To help mitigate this problem, the ocean observing community has been developing new techniques for autonomously measuring the ocean's interior and reporting data back in real time."

Because of the ocean's vast volume, efficiently placing a relatively small number of gliders to capture observations of a dynamic environment can be tricky.

Recently, NRL researchers have been looking at ways to optimize glider placement, including using them in teams.

## The Benefit of Teams

The current paradigm in deploying sea gliders calls for placing them far away from each other to maximize their limited spatial coverage.

However, Book said a slowly moving, single glider by itself cannot tell the difference between a stationary, kilometers-long ocean feature and a traveling ocean feature that oscillates over several hours. On the other hand, a team of gliders working together can provide spatial context and potentially help resolve this issue.

Placing gliders in teams required a change in piloting techniques, adding complexity to the project. To enable piloting gliders together, researchers built on an existing automated piloting tool developed by NRL called Guidance for Heterogeneous Observation Systems or GHOST.

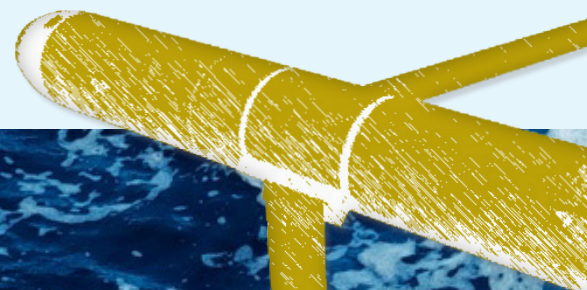
GHOST had the ability to optimize single glider use with user-defined conditions. For example, users could specify ocean areas to avoid and GHOST would provide reasonable paths under these restrictions.

Book and the research team adjusted GHOST to employ glider teams by adding two rules.

"The first rule was gliders should not be too close together, because current models can't use data collected too close to each other," said Charlie Barron, Ph.D., head of NRL Ocean Data Assimilation and Probabilistic Prediction group. "The second rule was they shouldn't be too far apart. This is because an individual glider moves too slowly to correctly identify and measure most major ocean features, and a team of gliders is needed to provide enough data for the model to correctly initialize features such as eddies, filaments, and fronts."

**We know the equations of motions for geophysical fluids quite well, so why is the task of predicting the weather on or in the ocean so difficult?**

Over land, meteorological services around the world, have established a worldwide network of weather stations and satellite systems that provide the needed data for fairly accurate four-day weather forecasts. However, in the ocean, satellite systems can only observe the ocean's surface, and coverage from sea-borne instruments for measuring the ocean's interior is very sparse.



## Taking Glider Teams Into the Field, But Where?

With GHOST upgraded, Book and the team took to the field to test the teaming concept.

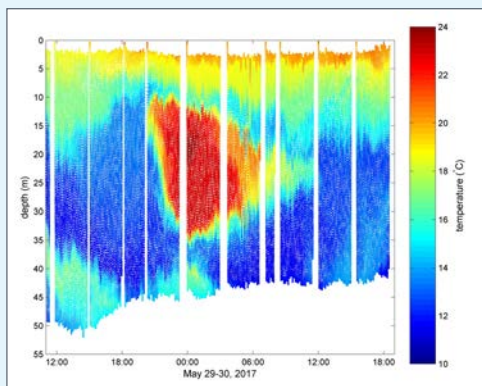
A first big decision was location, and the team decided to go to North Carolina.

"Because of the complicated ocean circulation in the area, it's an interesting place to test our ability to observe and predict the ocean environment," Book said. "The warm transport of tropical water northeastward along the continental shelf break by the Gulf Stream current creates some complex structures."

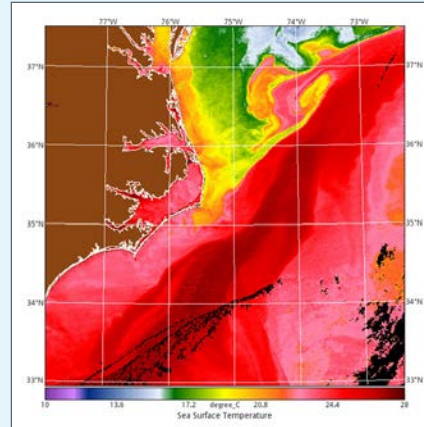
Book explained the additional dynamic of how some Gulf Stream water spins off the main stream onto the shelf where it can sink below coastal water. Even though Gulf Stream water is warmer, its salinity makes it denser than the fresher but colder shelf water. Sea gliders provide vital measurements in these conditions because the colder waters above mask the warmer waters below.

Finding and predicting such features can be important to many different types of naval operations.

In example below, the warm salty waters create a subsurface pocket with very different acoustic properties, which can create acoustic shadows.



Red colors show a warm and salty pocket of submerged Gulf Stream water on the North Carolina shelf as measured by an U.S. Naval Research Laboratory glider on May 29-30, 2017. The dots, which make up the graph composite, are individual temperature measurements taken as the glider descends and climbs in depth. The gaps in measurement occur when the glider is on the surface transmitting recent measurements back to Stennis Space Center for use in correcting the forecast model for this region. (NRL image)



Satellite measured sea-surface temperature offshore of North Carolina at the start of the U.S. Naval Research Laboratory experiment. The deep red colors (28°C / 82°F) mark the location of the Gulf Stream, while the yellow and green boundaries mark out swirling eddies and filaments that move Gulf Stream waters and cooler coastal surface waters around. Black streaks are clouds that block the satellite measurement. (NRL image)

## Grading the Glider Teams

For 18 days off the coast of North Carolina, NRL researchers tested six gliders in different team configurations near the Gulf Stream.

Overall, the gliders collected more than 13,000 conductivity, temperature and depth profiles used in two ocean forecast models.

Because of the volume of closely spaced glider data collected, Book's team also created and tested new ways to use the data in ocean forecast models. Prior assumptions based on the idea of single gliders collecting data far apart from each other had to be relaxed or removed before the models could begin to use glider team data effectively.

"We found that there is little to no benefit in using teams without improving the way you assimilate the data," said Book "There was some benefit to just improving the assimilation method for the models, but this benefit was greatly increased if we used glider teams instead of single gliders. What we saw overall was that it is important to do both." The overall improvement Book's team observed was 9 to 12 percent, a measurement of improved accuracy of the ocean weather models.

This effort was completed through base program funding provided by the Office of Naval Research in collaboration with the National Science Foundation. The intense level of field effort was made possible by a team of 12 researchers and technicians from NRL's Ocean Sciences Division, two reservists from the ONR Reserve Component program for support on meteorology and oceanography related projects, as well as collaborative help from a postdoctoral scientist, technicians, and students representing five separate academic institutions. □

Creating the  
NEXT GENERATION

# ENVIRONMENTAL Prediction System

NRL CORPORATE COMMUNICATIONS

## The Earth System Prediction Capability

*Long-range mission planning is vital to Naval operations and often performed months in advance. Knowing the environment where ships, aircraft, Sailors and Marines will be operating is crucial information. Historically, planners have had to rely only on climatological conditions, but climatology only provides the average conditions of the environment and can be far different from reality. The U.S. Naval Research Laboratory is creating a long-range environmental prediction system.*

### Sometimes Knowing the Weather Forecast Isn't Enough

In the environments the Navy and Marine Corps operate, Sailors and Marines also have to navigate in the ocean, deal with waves, and in the era of a "Great Power Competition," grow their ability to work in and around sea ice.

This need to know what to expect in the total environment is why researchers at the NRL are working on extending the limits of environmental prediction by developing a globally-coupled model called the Earth System Prediction Capability, or ESPC.

"ESPC is probably the biggest project I've worked on," said Carolyn Reynolds, Ph.D., a meteorologist at NRL's Marine Meteorology Division in Monterey, California. "It's the longest project. It could be the project with the most impact. I'm very excited."

Reynolds coordinates her division's work on the atmospheric component of the ESPC.

"It's exciting because it's a new opportunity for us, as the Navy has never had atmospheric forecasts beyond 16 days or ocean forecasts beyond seven days. Now we're going to have forecasts to 45 days," Reynolds said. "We're not the first to couple models, but what makes us unique is that we have very high horizontal resolution in the ocean and sea ice components of the system."

NRL scientists have been working on this project for more than four years now, and the effort relies on the expertise of researchers from a variety of disciplines: ocean modelers, atmospheric modelers, sea ice modelers, wave modelers, data assimilation experts and computer scientists.

In Monterey, NRL's meteorologists contribute the atmospheric component for ESPC, while at Stennis Space Center in Mississippi, NRL's Ocean Sciences Division provides the ocean, sea ice, and wave components.

NRL already has models for each of ESPC's individual components, and pieces of ESPC are already in use.

For example, the U.S. National Ice Center (NIC) is already using pre-operational 45-day sea ice forecasts from ESPC to support Arctic and Antarctic exercises and resupply missions.

"It's the coupling of the individual components that creates the interdependency of ESPC," said Joe Metzger, oceanography lead at Stennis Space Center. "We're working hard to stitch them all together and then shepherd them through the transition process from research and development to operations at the Navy's Fleet Numerical Meteorology and Oceanography Center."

### Pulling the Pieces Together

Historically, meteorologists and oceanographers designed and employed discrete models of Earth systems to produce individual forecasts: ocean models to predict the ocean circulation; atmospheric models for the weather; sea ice models to predict the cryosphere; and wave models for the ocean surface.

Researchers knew the Earth's environmental conditions were linked even though the models were seldom interdependent.

"We've realized for some time that these processes are all coupled," said James Doyle, Ph.D., a senior scientist with Marine Meteorology Division. "The atmosphere is exchanging information with the ocean in terms of temperature and moisture, and even the currents can affect the winds in the low levels to some degree."

Metzger said wind stress and heat exchanges at the ocean surface can impact ocean currents, waves, the sea ice cover as well as the entire ocean thermal structure.

“Things like El Niño, for example – they’re inherently coupled phenomena. They come about because of the way the ocean and the atmosphere talk to each other,” Reynolds said. “We’re coupling all these systems together with the hope—and I think we have evidence that it’s working — that we’ll be able to capture some of these coupled phenomena that have predictability on longer time ranges.”

## Four Years? Why is it Taking so Long?

Each model has its own grid of the Earth, a massive set of data points. Imagine the latitude and longitude lines crisscrossing a globe. Each intersection of the lines marks a grid point where the model equations are solved over and over again from the top of the atmosphere to the bottom of the ocean.

Each model’s grid is different, and the grids inside individual models can also vary.

For example, the distance between grid points for HYCOM, the ocean model, is only about four kilometers near the Equator, but this narrows to less than two kilometers near the North Pole. Imagine a grid spanning the entire Earth with points less than four kilometers apart — that’s an exceptionally large number of grid points and makes ESPC computationally expensive to run.

To enable the models to interact with each other, NRL scientists work with scientists from the National Oceanic and Atmospheric Administration, NASA, universities and research laboratories to develop the Earth System Modeling Framework. It’s essentially a coupler to allow the different model grids to exchange information.

And though the models themselves work well on their own, they don’t necessarily work well when they start talking to each other. They have to cooperate. So much of their work in model development involves adjusting the models themselves.

“It’s a relatively easy engineering problem to wire the models together, but the real science comes in the research to make sure the physics of each model have the proper feedbacks when exchanging information,” said Metzger.

“It took us quite a bit of time to get our models improved -- at least for the atmospheric model,” Reynolds said. “We spent a lot of time modifying the model so that it would behave well in a coupled system.”

Four years into system development is atypical, Reynolds said. From conception to deployment, it can take on the order of 10 years or so to construct these systems. It’s taking less time to develop ESPC because they’re building the coupled system from preexisting component systems. ▣



Deployment of a radiosonde to record temperature, humidity, and pressure during the oceanographic cruise aboard R/V Sally Ride in the Bay of Bengal. (U.S. Navy photo)

After the ESPC debuts, researchers will continue refining and improving the system. The system’s final operating capability is scheduled for fiscal year 2022.

Every day, environmental observations come from weather balloons launched twice a day all over the Earth, surface weather stations, ocean buoys, ships, aircraft, and even from sensors attached to marine mammals.

Additionally, millions of observational data points come from satellites, providing temperature, moisture levels, and winds in the atmosphere, sea surface height, sea surface temperature and sea ice concentration.

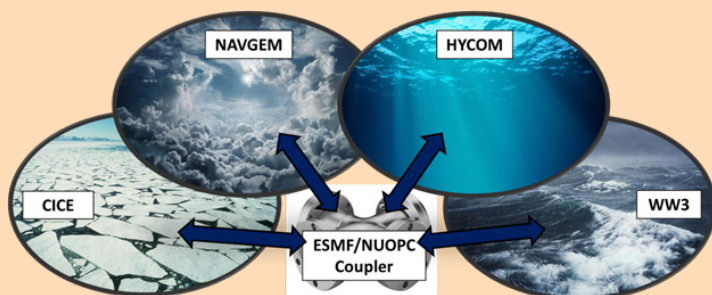
All of these observations are fed into creating the initial states of the models that comprise the Earth System.

The initial states are critical in a model because researchers never know with perfect accuracy the initial state of the atmosphere, ocean or cryosphere — the conditions from which a coupled Earth system starts. Over time, small errors in the initial state will propagate, grow and degrade the forecast.

Forecasts also become less accurate the longer researchers extend them in time and the upper limits of skillful predictability are different for the atmosphere, ocean and sea ice. ▣

## What is ESPC, how does it fit in?

The observational data driving ESPC is the same data used by the existing operational stand-alone forecast systems.



The various model components that make up the Earth System Prediction Capability (ESPC): The Navy Global Environmental Model (NAVEM) for the atmosphere, the Hybrid Coordinate Ocean Model (HYCOM) for the ocean, the Community Ice Code (CICE) for the cryosphere, and WAVEWATCH III® (WW3) for waves. The individual models exchange information with each other via a coupling layer using tools from the Earth System Modeling Framework (ESMF) and the National Unified Operational Prediction Capability (NUOPC).

# Ocean Acoustics in the Evolving ARCTIC ENVIRONMENT

J. RAYNEL KOCH, NRL CORPORATE COMMUNICATIONS



*The U.S. Naval Research Laboratory-built Billboard Array is an acoustics instrument equipped with 64 receiver elements. It differentiates and amplifies sounds from different directions. The array provided remarkable acoustic data under both seasonal oceanographic and sea ice conditions during the multi-institutional Canadian Basin Acoustic Propagation Experiment (CANAPE) in the Beaufort and Chukchi seas. (U.S. Navy photo)*

U.S. Naval Research Laboratory scientists developed ice-tethered Acoustic Buoys to monitor the acoustic and oceanographic environment in the changing Arctic. The buoys provide critical oceanographic data to improve prediction capabilities of ocean and climate models.

These buoys validated the Arctic researchers sound propagation theories and will continue to guide and validate theoretical studies in the Beaufort Sea from March 2020 to 2021.

“Our job, in real time, does the tomography in the ocean with buoys,” said Altan Turgut, research physicist with NRL. “Every four hours they assimilate data into the ocean models.”

Ocean acoustic tomography is a technique that uses sound waves to image sections of ocean temperature and current.

The buoys are a practical alternative to more traditional acoustic and oceanographic measurements techniques, because they provide real-time monitoring and operational capability. Additionally, they enable under-ice acoustic communication and navigation capability for mobile platforms such as ocean gliders and underwater autonomous vehicles.

Turgut and his colleagues began to investigate the effects of changing ice characteristics in 2016 on mid-frequency sonar performance in the modern Arctic. Mid-frequency sonars have a frequency range similar to most common bird songs.

The researchers participated in several multi-institutional Arctic expeditions to assess the impact of changing sea ice on mid-frequency sonar performance.

Turgut and his team deployed several NRL-built acoustic and environmental mooring instruments during the multi-institutional Canadian Basin Acoustic Propagation Experiment (CANAPE) in the Beaufort and Chukchi seas on the northeast and northwest shores of Alaska.

Two source moorings transmitted mid-frequency signals every four hours for 40 minutes and one Billboard Array recorded acoustic data during the yearlong experiment.

The Billboard Array is an acoustics instrument equipped with 64 receiver elements lying in a seven meters by four meters vertical plane. It differentiates and amplifies sounds from different directions. The array provided remarkable acoustic data under both seasonal oceanographic and sea ice conditions.



"Results from CANAPE showed favorable sound transmissions are possible within a cold and fresher water layer at 100 to 200 meter depths," Turgut said. "The sounds were bounded by warm Pacific summer water from above and warm Atlantic water from below."

The researchers also developed the first mathematical model to simulate and predict sound propagation under the ice called the Arctic Parabolic Equation.

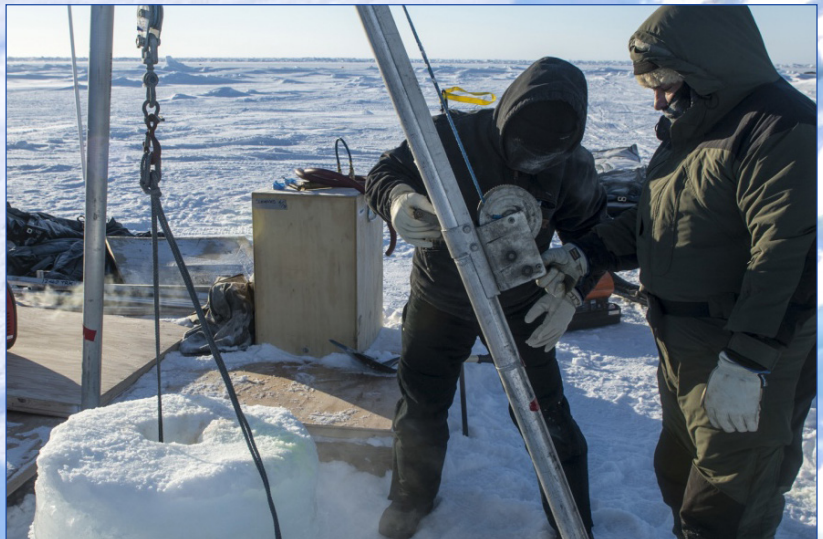
"This model accurately simulates the interaction of sound waves with the sea ice that has been a challenging numerical problem," said Michael Collins, NRL mathematician who developed the Arctic Parabolic Equation.

Scientific evidence indicates the character of the Arctic sea ice continues to change. The current sea ice composition is thinner, younger and declined at a rate of 13 percent in the summer and three percent in the winter per decade.

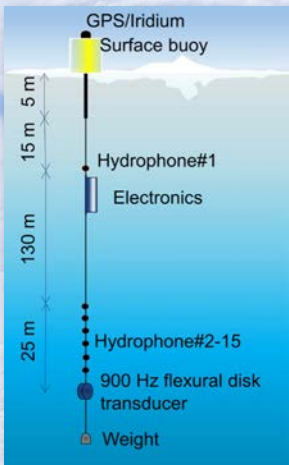
"Interaction between the ocean and atmosphere is increasing and becoming similar to those at lower latitudes with more open ocean and fragile thin ice conditions," Turgut said. "Therefore, acoustic measurements of new ice composition and near-surface hydrography would be essential for accurate ocean and climate model predictions in the Arctic." □



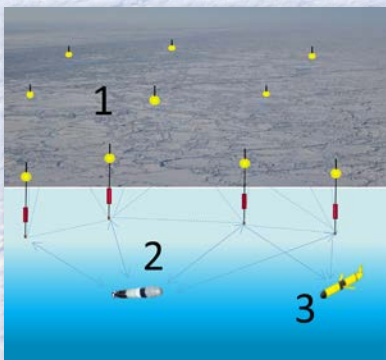
Arctic Circle - Rick Hagen and Joan Gardner, with the Naval Research Laboratory gather ice core samples in the Arctic Circle. The core samples will help the scientists measure salinity and density as part of an ongoing ice characterization research project, during Ice Exercise (ICEX) 2016. (U.S. Navy photo by Mass Communication Specialist 2nd Class Tyler N. Thompson)



Arctic Circle - Engineers with the Applied Physics Lab, create a hole in nine feet of ice to deploy divers during Ice Exercise (ICEX) 2016. They research, test, and evaluate operational capabilities in the region. (U.S. Navy photo by Mass Communication Specialist 2nd Class Tyler N. Thompson)



Components of the Ice-tethered Acoustic Buoy (ITAB). (U.S. Navy illustration)



An illustration of the U.S. Naval Research Laboratory, Ice-tethered Acoustic Buoys (ITAB) sending and receiving signals to underwater autonomous vehicles.

Use of ITAB in the Arctic:  
 1) Acoustic Tomography  
 2) Acoustic Navigation  
 3) Acoustic Communication  
 (U.S. Navy illustration)



First deployment of an earlier version of the Ice-tethered acoustic Buoy (ITAB), March 2017. (U.S. Navy photo)

# GROUND-TRUTHING:

## Remote Sensing Measurements of the Sea Ice

NRL CORPORATE COMMUNICATIONS

It wasn't Joan Gardner's first time seeing a polar bear. Over the years, while conducting research on floating ice in the Arctic, she had often spotted them wandering the outer periphery of her work site. Now it was 2016, and her team was outside the city of Barrow (Utqiagvik), in the Alaska North Slope. Her field of vision was restricted by goggles. She was looking down while sampling the ice and taking measurements.

When she looked up, she saw a huge polar bear just 100 feet away from her research group of 20 people, which included several Naval Academy students. It was her first time seeing a polar bear that close. In that moment, she was suddenly unable to appreciate the beauty of nature.

"It was beyond terrifying," she recalled. "Not until two or three days later, after somebody produced pictures, and I was like, 'Oh look how cute it is.' Right then, it was 990 pounds of cute that was hungry."

For the group, that spelled the end of their day on the ice. After they reported the incident to the U.S. Fish and Wildlife Service, the agency's personnel surveyed the area and discovered the bear's

den and cubs that were just a few months old. The researchers had inadvertently disturbed their habitat. They would have to find a different work site.

Gardner has been visiting the Arctic since she joined the U.S. Naval Research Laboratory in 1993, when she first began oceanographic work, studying the ocean character and sea floor character to improve navigation safety. Since 2011, she has been using data collected by satellites and aircraft to monitor the thickness and changing character of sea ice.

This year, she was again in the Arctic, this time tagging along with the Canadian military. During March, when the ice there is the thickest, they were working at an icy location outside of the town of Tuktoyaktuk in the Northwest Territories of Canada.

As a Royal Canadian Air Force plane flew overhead, collecting data with radar, Gardner and her team were on the floating ice below, determining the ice's thickness and hardness and measuring the depth of the snow. They were "ground-truthing" for the ICESat-2 Satellite, a NASA satellite that launched in 2018 on a mission to use laser pulses to measure elevation of ice sheets, glaciers and sea ice.

Gardner's goal that day was to collect on-the-ground data to compare to the satellite's data to gauge the accuracy of the satellite's measurements. To determine the thickness of the ice, her team drilled holes in it. To measure snow thickness, they used a magnaprobe, essentially a ski pole with a sensor and GPS functionality.

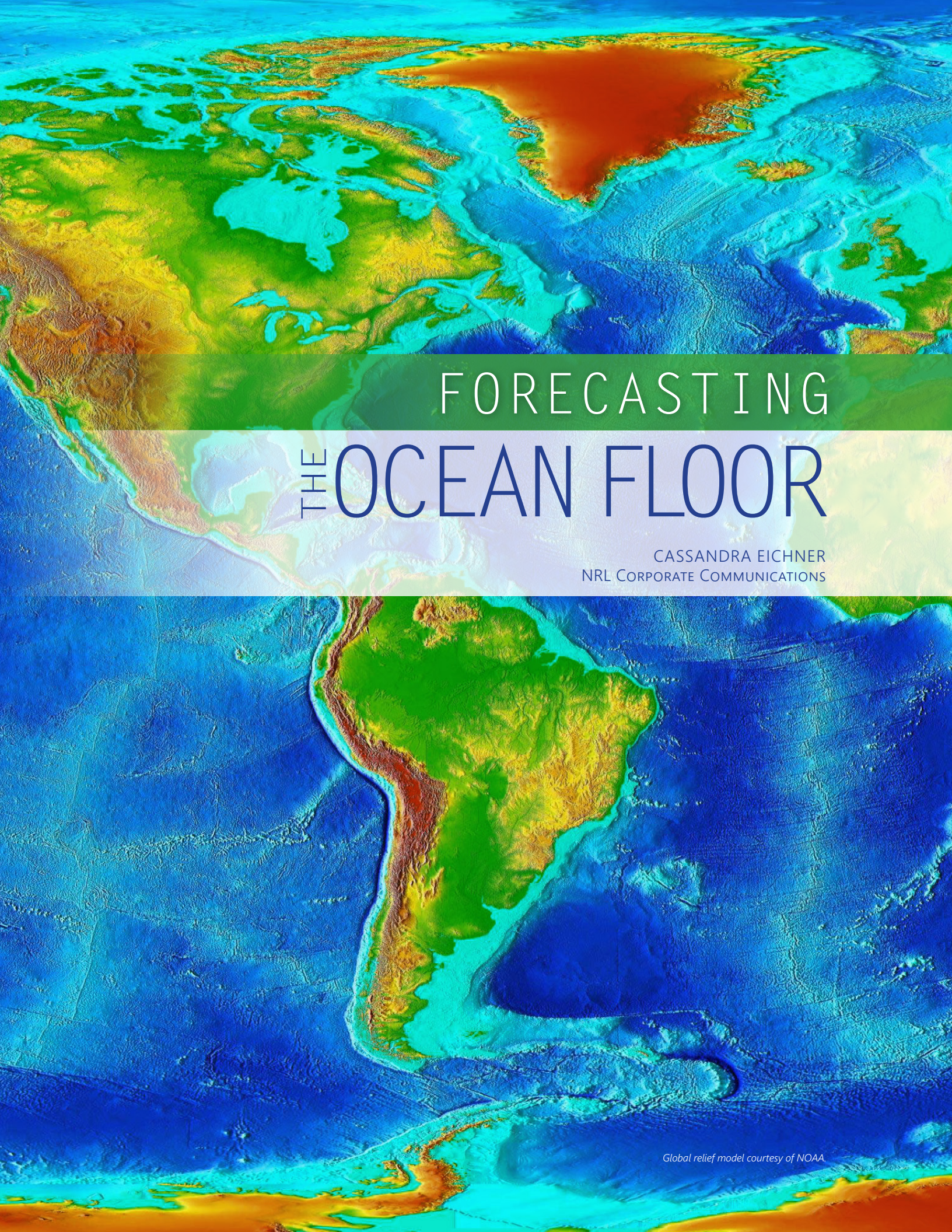
"You have to make these measurements while the satellite passes overhead," she explained. "It seems like simple work, but it's a harsh environment that presents many challenges. We're just one of many groups that do this kind of work. NASA pays people to do this."

That year Gardner's team was just one among the multitudes of scientists and research teams trekking to the top of the world to take measurements, deploy buoys, launch weather balloons and engage in a variety of other data-collecting efforts. Their work would inform our understanding of the Arctic, sea ice, the ocean and the Earth itself.

For the Navy and its partners, that data would be essential for ensuring safety of navigation for vessels and improved environmental forecast modeling. In particular, the Arctic is important in extended sub-seasonal to seasonal forecasts such as those to be produced by the future Earth System Prediction Capability (ESPC), NRL's cutting edge Earth systems model now in advanced stages of development. □

*Members of an Arctic research team in Tuktoyaktuk in the Northwest Territories of Canada. (Photo courtesy of Canadian Armed Forces – Joint Task Force (North) by Capt. Soomin Kim)*





# FORECASTING THE OCEAN FLOOR

CASSANDRA EICHNER  
NRL CORPORATE COMMUNICATIONS

*Global relief model courtesy of NOAA.*

## Mapping the Ocean Floor

The Navy is gaining a competitive edge over its adversaries by marshalling its knowledge of the material properties and processes affecting the ocean floor.

At the helm of this effort is U.S. Naval Research Laboratory geologist Warren Wood, whose team collaborated with the University of Sydney, the University of Colorado Boulder, and the U.S. Geological Survey on critical research for the development of a conceptual model that maps the ocean's seafloor features and predicts how the seafloor will change over time. The model is called the Global Predictive Seabed Model (GPSM).

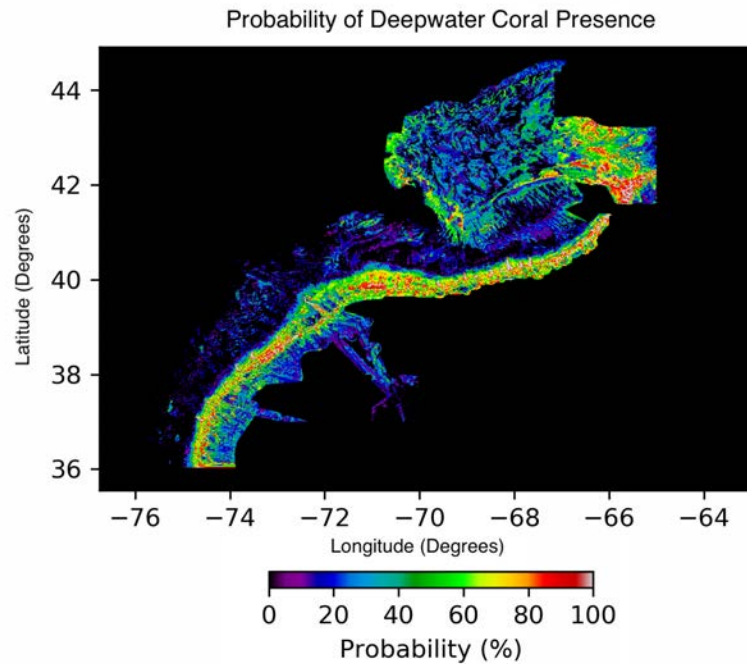
GPSM will provide Navy decision-makers the layout of the ocean floor, enabling a richer assessment of the ways in which sonar interact with the seafloor environment in a particular location. This insight could help the Navy determine the nature of sonar anomalies and define appropriate responses.

Understanding the physical structures of the seafloor and when, how and where they change is of great interest to the Navy. The Navy uses sonar to identify submarines and various objects under the water. Different objects respond differently to inputs from the physical environment around them. The makeup of the ocean floor is a factor in how sound propagates and, therefore, how sonar reacts.

"We want to understand the seafloor the same way we understand the ocean and the atmosphere—with a global model," Wood said. "Many naval operations use sound propagation properties such as speed, density and acoustic attenuation of sound energy to estimate sonar performance. We have to know how sound is going to interact with the environment before we can understand how it reacts to an anomaly."

GPSM is designed to look at fundamental properties of the seabed and use that information to calculate the sound interaction with the seafloor. According to Wood, GPSM is capable of looking at the geology of the entire world, but his research today is focused on the ocean. To develop this global model, he started with what he calls a "nowcast."

The nowcast is a model used to inform a researcher of a present condition or something happening in the very near future. Nowcasts are very common in meteorology—you see them when checking the weather app on your smart phone. That information is fed into the predictive models, also known as forecasts, to improve those models' algorithms, resulting in increased accuracy.



*Predictive model of deepwater coral presence in U.S.-Canada Atlantic waters, produced using U.S. Naval Research Laboratory's Global Predictive Seafloor Model (GPSM). Hot colors are likely suitable habitats for deepwater corals, while cold colors are unsuitable for corals. Habitat maps like this one help with selecting ROV dive sites for Okeanos Explorer expeditions. (NRL image)*

That same concept can be applied to geology to identify what is there now, and eventually what will be there in the future.

"We're identifying what sediment currently exists in these areas all over the world and consolidating it into one system called a nowcast," Wood said. "Once we have the nowcast, we will move forward with the forecast."

Wood said the data currently used for the nowcast is collected from public sources, but the system can use data from any source. Included among the many data points it currently uses are sediment information on grain size, grain type, temperature, and porosity.

Field data such as sub-bottom profiles help researchers identify and characterize seafloor sediment from the sea surface. These data, acquired from a distance, are incredibly important for acoustic research because they help constrain characteristics such as the ratio of clay to the total solid materials.

Wood also collects data through lab research for use in his numerical predictions. At his lab within the Stennis Space Center in Mississippi, he conducts sediment physics tests that allow for careful, direct measurements of the interactions between sound and sediments.

"This is a new way of thinking about the seafloor, and it requires a community to support it."

— Warren Wood, U.S. Naval Research Laboratory geologist

Although Wood can learn a great deal from his own research, he also relies heavily on input from the global geophysical community to identify the location and types of sediment found throughout the world. Although operational security requires that some of the data remain classified, he hopes much of the research can be conducted in the public domain to facilitate knowledge sharing and collaboration.

“This is a new way of thinking about the seafloor, and it requires a community to support it,” Wood said. “We have to think about how to collect and ingest data from Navy survey vessels as well as commercial and academic groups. We need everyone on the same page to determine how acoustic measurements could be incorporated into the global model to make it more accurate.”

In addition to examining geophysical structures, GPSM will predict the likelihood of encountering a certain fraction of microorganisms. Wood and other researchers are developing a sediment system that will tell researchers whether sediment is terrigenous (material from the land) or biogenous (material from plants and animals).

“There are many aspects of the seafloor of interest to the geophysical community as well as to the Navy, and we want to build as comprehensive of a model as possible, which includes gravity and magnetics, bathymetry, total organic carbon, etc.,” Wood said.

## Geomorphic Processes that Shape the World’s Oceans

When studying and describing the ocean floor, scientists generally think of it as three different environments: the continental shelf, the continental slope and the abyssal plain (the deep ocean). Each area of the ocean floor boasts its own unique geological features that influence how sound propagates, features that undergo constant change due to a variety of geomorphic processes.

“We are looking into acoustic interaction with the seafloor,” Wood said. “Because of the change in temperature of water column with depth, the sound actually travels mostly horizontally, bending up and down in what is called a sound channel.

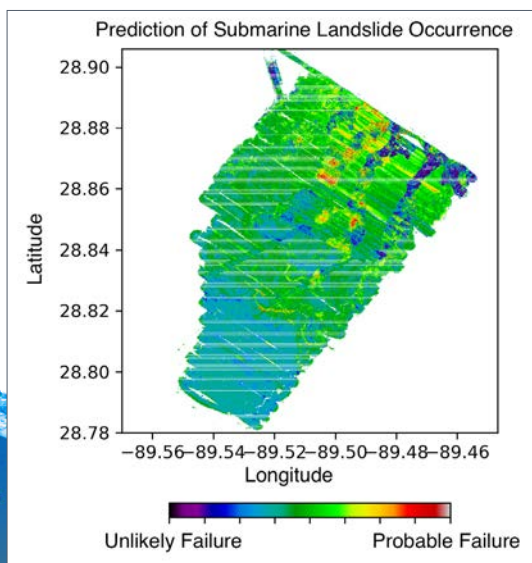
“Sometimes the sound interacts with the sea surface, and sometimes it interacts with the seafloor as it refracts through a sound channel. Greater interaction with the sea surface or seafloor generally results in greater loss of sound energy—important for knowing how far the sound will travel and how far away certain sounds can be detected.”

Wood operates under the hypothesis that if his team can predict the geology they will be able to predict the sound interaction and therefore the distance the sound will travel. The area he seeks to identify and forecast begins at the province of surfers, boaters, and other water enthusiasts—sea level—and extends all the way down to an abyss that hardly any of us are familiar with: the deep ocean.

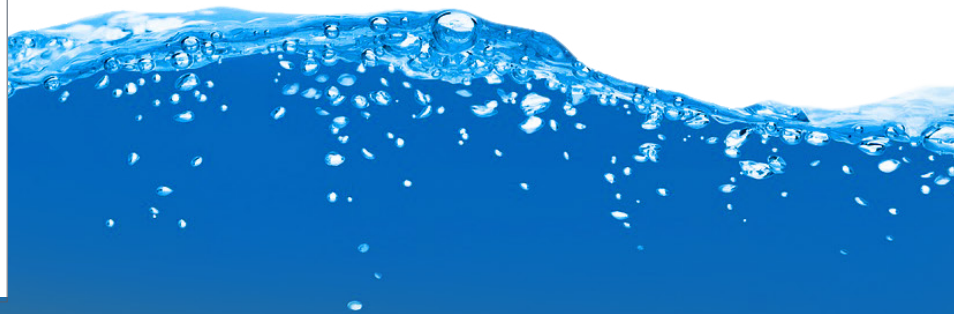
The depth of the continental shelf ranges from around 100 to 200 meters and includes beaches, estuaries and other coastal areas, which are made of varying types of sediment: loose sand, clay, silt and other soil particles. Created through soil erosion or from the decomposition of plants and animals, sediment ranges in size from microscopic clay particles to large boulders. Ocean currents and rivers carry sediment vast distances, which means that as currents and sea levels change, so do Earth’s distributions of sediment deposits.

Below the shelf is the continental slope, which extends from about 100 to 3,200 meters deep, ending with a gentle slope called the continental rise. While the shelf tends to be sandy, the continental slope tends to be rich in fine-grained sediment, including clay. The total rate of sedimentation slows on the slope, which means it contains larger accumulations of dead microorganisms, remnants often made of calcium carbonate or silicon.

Deep in the ocean and far from human view live a variety of microbial communities prospering in what for us would be an unforgiving environment. These communities feast on a variety of substances including buried organic matter, methane seeping from the sediments below and the remains of large marine life, such as dead whales. Just as on the slope, these living and deceased organisms, particularly the shells and skeletons they leave behind, impact the way sound interacts with the environment.



*Predictive model of submarine landslides on the Mississippi River Delta Front, Gulf of Mexico, generated using the U.S. Naval Research Laboratory’s Global Predictive Seafloor Model (GPSM). Submarine landslides are concentrated in mudflow gullies, depressions within the seafloor that resemble mud conveyor belts. (NRL image)*



Events hundreds or even thousands of kilometers away can change the composition of the sea bed. Volcanic eruptions create ash that is carried by wind and then dropped throughout the ocean. When the ash sinks, it creates layers on the seafloor that mix with microorganisms and clay. It is also common for clay to be carried from afar. Winds often carry clay thousands of kilometers, all the way from the Gobi Desert to the Pacific Ocean.

Today, the effects of these natural processes on the ocean are not tracked in real time on a global scale. GPSM seeks to be the first model to understand current conditions and eventually predict changes for all areas of the seabed.

## Artificial Intelligence Improves Environmental Best Predictions

Assimilating the millions of data inputs into a useable model will require extensive computing resources, Wood said. That is why he is turning to artificial intelligence for help.

"We are deeply involved in using artificial intelligence and machine learning to do predictive modeling," Wood said. "Using computer research in combination with geology and geophysics, we are able to make the best predictions we can about the environment."

Already, NRL researchers have demonstrated their ability to use artificial intelligence to predict seafloor properties on a global scale. Wood and a researcher on his team, Taylor Lee, recently published an article in the journal *Global Biogeochemical Cycles* in which they highlight their success measuring global total organic carbon. Their research details how recent machine learning techniques relying on geophysical and geochemical properties show promise for making comprehensive, statistically optimal predictions.

However, Wood and his collaborators continue to face a major challenge to their work: actual data collection. While land surveying can be accomplished using satellites, the ocean floor, of course, is not visible from space. Nevertheless, this challenge only fuels Wood's naturally curious and determined personality.

"It's a lot of fun figuring out how all this stuff works" Wood said. "We have several projects using this idea [the nowcast], and we are almost ready to develop the model. We are successfully nowcasting various aspects of the seafloor and trying to rapidly transition research findings to the fleet." □

# RUTH PRELLER

Superintendent  
Ocean Sciences Division



Ruth Preller, Ph.D., took the helm as superintendent of the U.S. Naval Research Laboratory's newly established Ocean Sciences Division at Stennis Space Center, Mississippi on July 7, 2019. The new division replaced NRL's Oceanography Division, previously led by Preller, and Marine Geosciences Division.

"The two divisions had a lot of synergy," said Preller. "Now that we have become one division it allows us to work together more easily to study complex science that reflects the interdisciplinary research in oceanography and marine geosciences."

The Ocean Sciences Division conducts a research development test & evaluation (RDT&E) program in biological, chemical, dynamical, and physical processes of the open ocean; coastal and littoral areas; marine boundary layers; and marine geology, geophysics, geoacoustics, and mapping, charting and geodesy.

According to Preller, the division will continue to provide sponsors the same quality research and development they have come to expect from NRL. She has kept the structure of the research branches the same, as well as the number of researchers. Preller has created the Center for Geospatial Sciences, from what was previously one of the four branches and a new Information Technology support group for the division.

"Under Dr. Preller's leadership, I see exciting opportunities that build on the natural synergies in combining oceanography and marine geosciences into the new Ocean Sciences Division," said Douglas Todoroff, Ph.D., associate director of research for Ocean and Atmospheric Science and Technology at NRL. "I look forward to the groundbreaking research that will come from the new division."

CASSANDRA EICHNER  
NRL CORPORATE COMMUNICATIONS

# Measurement and Analysis of GROUND CHARACTERISTICS IN AUSTRALIA

VICTOR CHEN  
NRL CORPORATE COMMUNICATIONS



*Physical scientists and engineers from the U.S. Naval Research Laboratory collect soil samples and conduct ground measurements with collaborators during a 2019 Australian field expedition to validate remote sensing techniques for terrain characterization. NRL's Remote Sensing Division uses multiple sensor modalities to understand geotechnical characteristics of the soil, such as soil type, composition, and strength. (U.S. Navy photo by Andrei Abelev)*

U.S. Naval Research Laboratory physical scientists, engineers, and principal investigator Andrei Abelev visited Australia in May 2019 to validate their techniques for terrain characterization.

Using multiple types of sensors to gain understanding of different soils, the team used the trip to see how their models performed with the soils Down Under, digging into the homes of some of the most dangerous animals in the world.

"We are proud of being a one-stop shop at NRL for remote sensing of terrain and its characterization," Abelev said. "It's a capability that no other organization has, and we are unique in our multi-sensor multi-modal approach."

Understanding ground characteristics is part of the science and the art of geotechnical engineering, which can be useful in multiple areas, including project management and planning.

Abelev said remote sensing technologies can aid many applications in civil, environmental, and hydrological engineering, as well as agriculture. For example, knowing specific soil properties can help to optimize locations for new buildings and roads, or lead to better understanding of the dangers in possible landslides or devise estimates of surface water erosion during rain events.

"The ability to survey soils remotely and on a large scale allows us to better understand the properties of these soils," Abelev said. "We have lots of global expertise in helping people understand the composition of soil, whether it is sand, silt, clay, or rock. We can help understand runoff, soil stability, and other characteristics."

To collect soil data, NRL researchers use multiple kinds of sophisticated sensors, also known as modalities, on the ground and in the air, including radar, hyperspectral instruments, and lidar – a laser-based detection and ranging sensor.

After the data is collected, the analysis can be lengthy and anything but trivial.

"Some of these sensors are capable of collecting gigabytes and even terabytes of data per hour, and each sensor type has its own unique set of data analysis and processing tools and algorithms," Abelev said. "Depending on what level of detail you are looking for, it can often take substantial amount of time to analyze it."

Abelev said the team uses several methods to analyze the data, including machine learning and neural nets, a form of computer-based analysis based on the human brain. □



# Predicting the Presence of OCEAN SWARMS

CASSANDRA EICHNER, NRL CORPORATE COMMUNICATIONS

## **Navy Gains a Competitive Edge with Research into Biological Ocean Swarms**

Tiny and frightening-looking creatures lurking freely throughout our world's oceans can wreak havoc on Navy tactical decision makers' ability to sense the environment or plan and chart a navigation course.

The simple presence of these animals, some the size of a pen tip, can affect Navy operations through attenuation of acoustic signals, bioluminescence, and ambient noise.

To help increase our understanding of these intermediate trophic level (ITL) organisms like plankton and jellyfish, researchers conducted a 14-day field campaign last year off the coast of Delaware. The campaign, led by U.S. Naval Research Laboratory oceanographer Brad Penta, Ph.D., collected information about the dynamics of ITL ecosystems near oceanfronts – areas that tend to be biologically active.



## Intermediate Tropic Level Organisms, Small but Mighty

All organisms within an ecosystem belong to a particular trophic level – essentially a label of where they fall in the food chain. ITL animals can range in size from tiny copepods to large jellyfish. They move throughout the ocean, and can form massive swarms.

Penta, who served as chief scientist for the campaign, said swarms around underwater acoustic equipment can render the equipment output unreliable. Swarms can be so dense that sound reflects and reverberates off of them, causing false readings and adding to ambient noise.

In addition to affecting sound, ITLs are known to flash.

“Many of these organisms emit light, called bioluminescence,” Penta said. “They do not light up all the time; usually it’s when they are mechanically stimulated or disturbed.”

## Eyes in the Sky

As part of the field campaign, up in the skies, an aircraft equipped with imagers and remote sensing experts aboard surveyed the ocean environment. It flew with cameras sensitive to visible, long and short infrared, and hyperspectral wavelengths.

The aircraft also had multiple lidar cameras. Lidars emit colored lasers to reveal profiles of a subject. In this case, lidar provided researchers information on what was going on under the water. Deric Gray, an oceanographer in NRL’s Remote Sensing division, operated and tested a new NRL-developed tool called MUlti Wavelength Lidar for the Environment (MUWLE).

Unlike traditional oceanic lidars which normally have a monochrome laser, Gray and his team designed MUWLE with interchangeable laser colors. The flexibility allowed Gray and his team to test and optimize different colors in multiple marine environments.

“Blue worked better in deep water,” Gray said. “Green worked well in algae rich areas, and yellow worked well in turbid bays with a lot of mud.”

Researchers designed MUWLE to pick up details in the water, knowing it would pick up a small amount of information about the atmosphere. But researchers were surprised to learn MUWLE could collect detailed information about the atmosphere.

“We saw aerosol layers that showed up more significantly than we thought they would,” Gray said. “The lidar also saw thin, broken clouds underneath the aircraft that we couldn’t otherwise see.”

## What’s in the Data?

Researchers now are actively sifting through their data. The ultimate goal of the study is to develop a model which can predict the presence of ITL organisms.

Before the models can use the data, however, the hoard of data must be processed.

Penta said he extracted more than 1.2 million images from just one tow with the ISiIS instrument. His team is using new techniques to sort through all the information and establish trends.

“We have begun to set up machine learning deep neural networks to use artificial intelligence to classify the organisms, but do not have results yet,” Penta said.

Deep neural networks (DNN) are sophisticated mathematical models used to process large amounts of data. Christopher Wood, an NRL computer scientist, is training a kind of DNN – a convolutional neural network (CNN) – to identify organisms in the ISiIS images.

“CNNs are geared toward image analysis,” said Wood. “A human being couldn’t process these images in a lifetime. The image reels are massive and some of the organisms are very small.”

Penta said he plans use the CNN to identify organisms, and match that information to the fronts and water masses. This will show how communities in the ocean changed over the two-week campaign.

Once fully synthesized, Penta said the information will create a comprehensive picture of the environment, which can then be applied to and tested against ecosystem models. □



*In situ ichthyoplankton imaging system (ISiIS), Remotely Operated Towed Vehicle. (Photo courtesy of Ocean Innovations)*

## HOW THEY DID IT

The coastal study incorporated a number of shipboard instruments and tools.

One of the study’s collaborators, the University of Mississippi, brought an In Situ Ichthyoplankton Imaging System (ISiIS). ISiIS provided multiple high-resolution images each second it was towed behind the ship.

During one of the tows, ISiIS passed a patch of marine life and falsely thought it had hit the bottom of the ocean. It turned out to be a swarm of veligers, a larval stage of mollusks.

“If you had enough of them [veligers], they could interfere with sonar or an optical instrument,” said Penta. “Their presence may change the depth the Navy needs to deploy equipment, such as the systems used to hunt for mines or for scouting.”

Researchers also attached tools to the back of ISiIS to measure temperature, salinity, chlorophyll-a, oxygen, and light attenuation. Pairing these tools with the ITLs identified by ISiIS enabled researchers to determine an exact environmental profile where particular organisms lived.

Throughout the cruise, researchers used nets for sampling, but also deployed a Wirewalker, a sampling device driven by currents. The Wirewalker was equipped with a variety of instruments to measure light, conductivity, temperature, depth, light and acoustic backscatter, and dissolved oxygen.

# PREDICTING TROPICAL CYCLONES

NRL CORPORATE COMMUNICATIONS

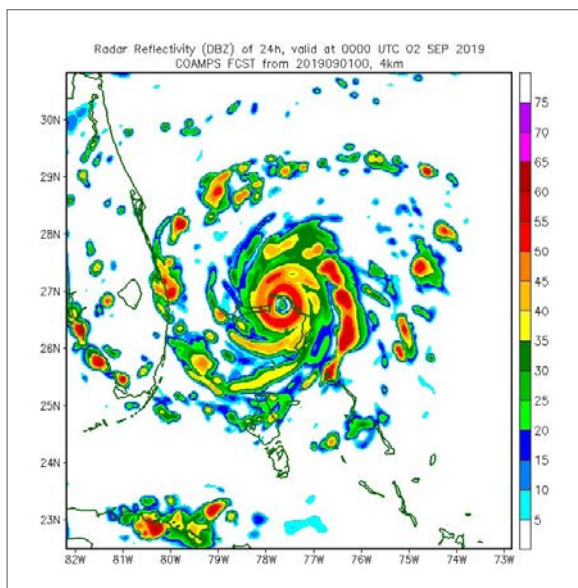
## Naval Research Laboratory's Tropical Cyclone Model: COAMPS-TC®

At the time, senior scientist Jim Doyle, Ph.D. was a little worried. Projections by his team's tropical cyclone model were deviating from those of the other major weather models, which were predicting Hurricane Dorian would make landfall in Florida. His own team's model showed the storm would curve northward along the coast.

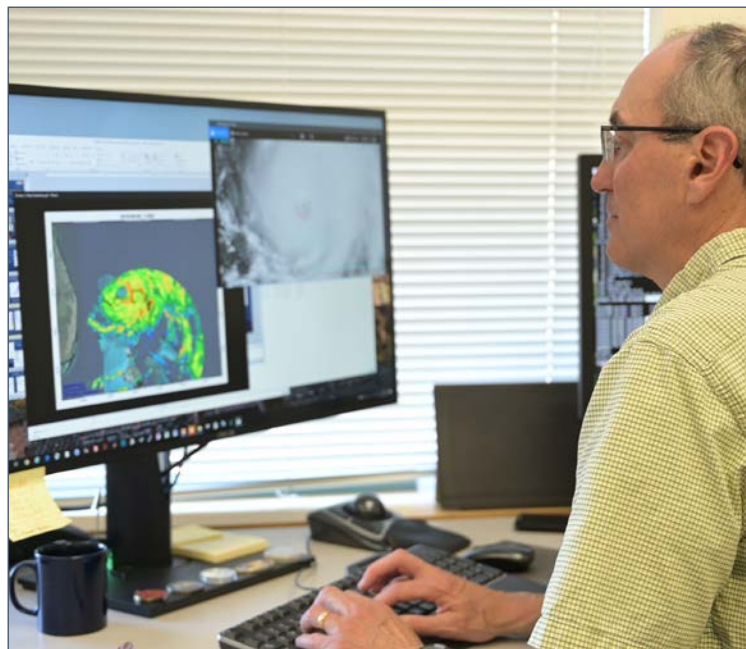
"You know, it's just human nature," said Doyle, whose team develops and runs the U.S. Naval Research Laboratory's Coupled Ocean-Atmosphere Mesoscale Prediction System-Tropical Cyclone model (COAMPS-TC®). "We were watching closely. I'll say that much. And we were a bit concerned, because we thought, well, maybe it's curving to the north a bit early."

It turned out that COAMPS-TC was one of the only models to indicate early on that the storm would curve to the north and not make landfall in Florida, according to Doyle and the National Hurricane Center. It was little consolation: the model performed well, but Dorian went on to bombard the northernmost islands of the Bahamas, where it wrought historic levels of destruction.

Making landfall Sept. 1, the Category 5 storm turned homes into rubble and flattened neighborhoods with winds reaching nearly 200 mph, leaving more than 75,000 in need of shelter and food assistance, 1,300 more missing and at least 67 dead. According to various Bahamian government reports, there is an estimated \$3.4 billion recovery cost as of late October.



U.S. Navy COAMPS-TC model (U.S. Naval Research Laboratory image by Jim Doyle, Jon Moskaitis, Yi Jin, Hao Jin, Will Komaromi, and the COAMPS-TC Team)



U.S. Naval Research Laboratory, senior scientist Jim Doyle leads a team of 10 researchers on the development and refinement of the Coupled Ocean-Atmosphere Mesoscale Prediction System-Tropical Cyclone model. (U.S. Navy photo by Leonard Pieton)

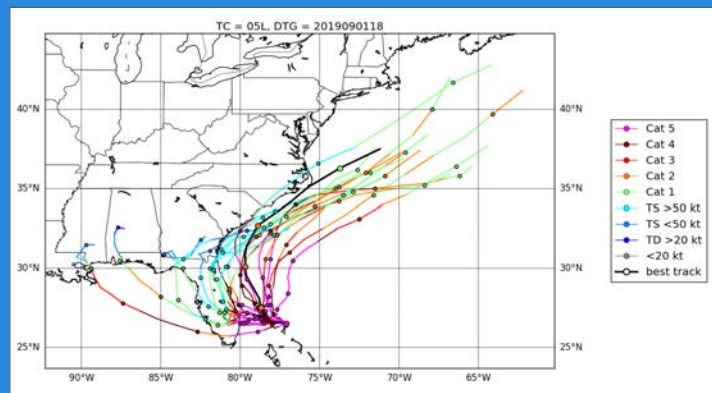
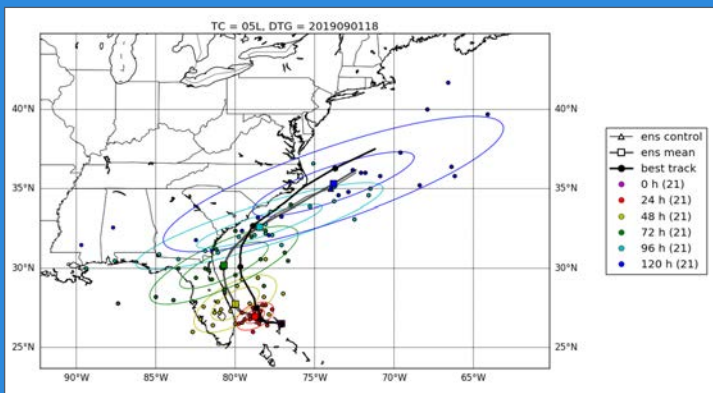
Although they often must think of tropical cyclones in abstract, computational terms when studying and modeling them, Doyle and his team are well aware of what transpires on the ground when people, property and infrastructure stand in the path of one.

"We watch the news, too, and it's devastating," Doyle admitted. "Nobody wants to see humans suffer and experience loss and death and destruction because of these storms. I think all meteorologists feel the same. It underscores the importance of what we do."

NRL's Marine Meteorology Division in Monterey, California, began developing the COAMPS-TC around 2010. COAMPS-TC became operational in 2013. It is a derivative of NRL's COAMPS computational weather model, which has supported Navy missions around the world for years.

Doyle's team of 10 researchers works on testing and further refining the COAMPS-TC annually. Those refinements can take years to implement operationally; sometimes, they take just one hurricane season. The most-recent COAMPS-TC version to go into operations transitioned in May 2019.

"Each season, we come up with new ideas on how to improve it," Doyle said. "Then we'll have to test it on many, many storms across multiple seasons to be able to get a statistical signal on whether it improves the system or not."



U.S. Navy COAMPS-TC model (U.S. Naval Research Laboratory image by Jim Doyle, Jon Moskaitis, Yi Jin, Hao Jin, Will Komaromi, and the COAMPS-TC Team)

## How Does COAMPS-TC<sup>®</sup> Work?

COAMPS-TC uses multiple nested grid meshes to follow tropical storms. Increasingly smaller grid cells on each mesh descend from the outermost mesh to the innermost. The innermost mesh uses a grid of cells, each measuring 4 square kilometers, to create high resolution representations of the hurricane, its inner core, and various aspects of its circulation.

“At each of these cells, 12 predictive equations are solved and information from the neighboring cells is shared frequently as the model runs,” Doyle said. “The outer mesh doesn’t cover the whole globe. It covers only part of the globe, and usually it’s an entire basin — for example the Western Pacific, along with other basins such as the Atlantic, Eastern and Central Pacific, and Indian Ocean.

“We have several different areas around the world for COAMPS-TC, where it has a basin-scale outer grid mesh. And then within that outer mesh, the two nested grids that follow the storm operate.”

And where does all the data for all those cells come from? Though the researchers are in the habit of referring to COAMPS-TC in the singular, today there are two versions of COAMPS-TC, each a limited area system coupled with a different global model that provides the large-scale conditions for its initial state. The data come from those two global models.

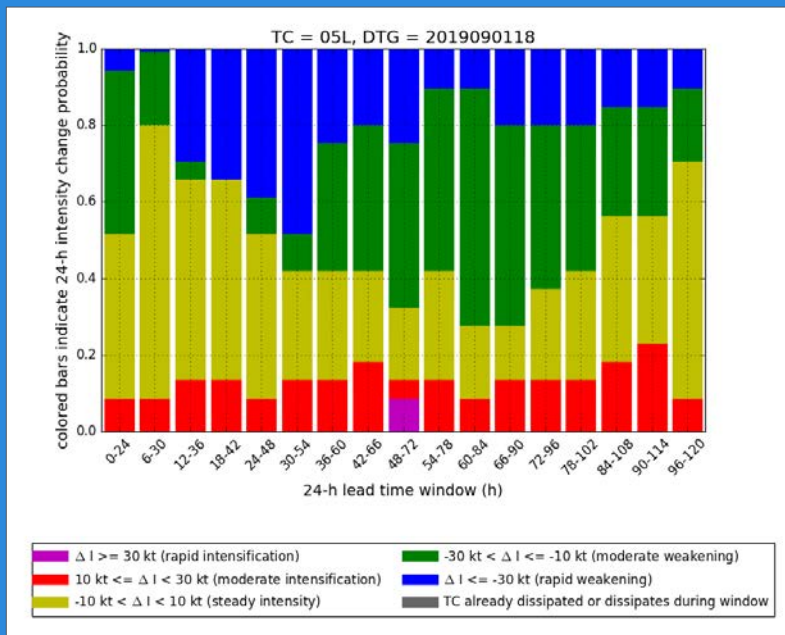
One version of COAMPS-TC begins with data from the Navy Global Environmental Modeling system. The other version of COAMPS-TC makes use of data from the National Oceanic and Atmospheric Administration’s Global Forecast System. Essentially, these global systems drive the limited area systems. The arrangement is called one-way coupling.

NAVGEN and GFS are both sophisticated numeric weather prediction models that employ data assimilation systems taking in observational data from every conceivable source. These include weather balloons, surface stations, aircraft, ships, and satellites that make up most of the observing system. The number of observations per day used in these systems are in the millions.

“The number of satellites is finite, and it’s smaller than the number of observations,” Doyle said. “But, of course, you can have one satellite sensor with hundreds of channels – these are hyperspectral satellites.

“The global models provide the initial state that COAMPS-TC is using, and we specify the hurricane vortex itself using the information directly from the forecasters about the intensity, position, and size. We insert the vortex based on that information into the COAMPS-TC initial model fields.”

Generally, the operational versions of COAMPS-TC run on a supercomputer at The Fleet Numerical Meteorology and Oceanography Center in Monterey, while U.S. Naval Research Laboratory Monterey runs test versions at the Department of Defense Supercomputer Resource Center at Stennis Space Center in Mississippi.



U.S. Navy COAMPS-TC model (U.S. Naval Research Laboratory image by Jim Doyle, Jon Moskaitis, Yi Jin, Hao Jin, Will Komaromi, and the COAMPS-TC Team)

## Further Refinements, Initiatives

Like all scientific disciplines, the meteorology community still grapples with its share of mysteries. Their models advance as their knowledge of the Earth, the oceans and the atmosphere advances. Among the phenomena that still puzzle them is that of rapid intensification, defined as the change in the intensity of a storm by at least 30 knots over a 24-hour period.

Scientists are still trying to understand exactly why some storms rapidly intensify and how to predict when it will happen. Not every storm undergoes rapid intensification, but the phenomenon is far from rare. Hurricane Dorian underwent not one, but two instances of rapid intensification with the first taking it from category 2 to category 3; the second from category 3 straight to category 5.

“Rapid intensification is really hard for the forecast models to capture,” Doyle said. “There’s a lot of subtle processes that we don’t understand yet that control this intensification. So, Dorian getting up to category 5 was a bit of a surprise.” Models, including COAMPS-TC, hinted that it could go to a strong category 4 in its forecasts, but the timing of that intensification was not particularly accurate.”

In an Office of Naval Research-sponsored research initiative, Doyle’s team and academic researchers are collaborating with scientists on a field project to learn more about rapid intensification. The project utilizes NOAA’s aircraft, including two Lockheed WP-3D Orion and a Gulfstream IV-SP jet, to drop instrumented packages called dropsondes into storms to collect profiles of wind, temperature and moisture.

“There are some pretty good theories on why rapid intensification happens, but I think understanding the details of when it happens in a particular storm’s life cycle is really challenging,” Doyle said. “We want to be able to predict when a storm just offshore will undergo rapid intensification like Hurricane Harvey did. Because that is critical for Navy and civilian decision makers.”

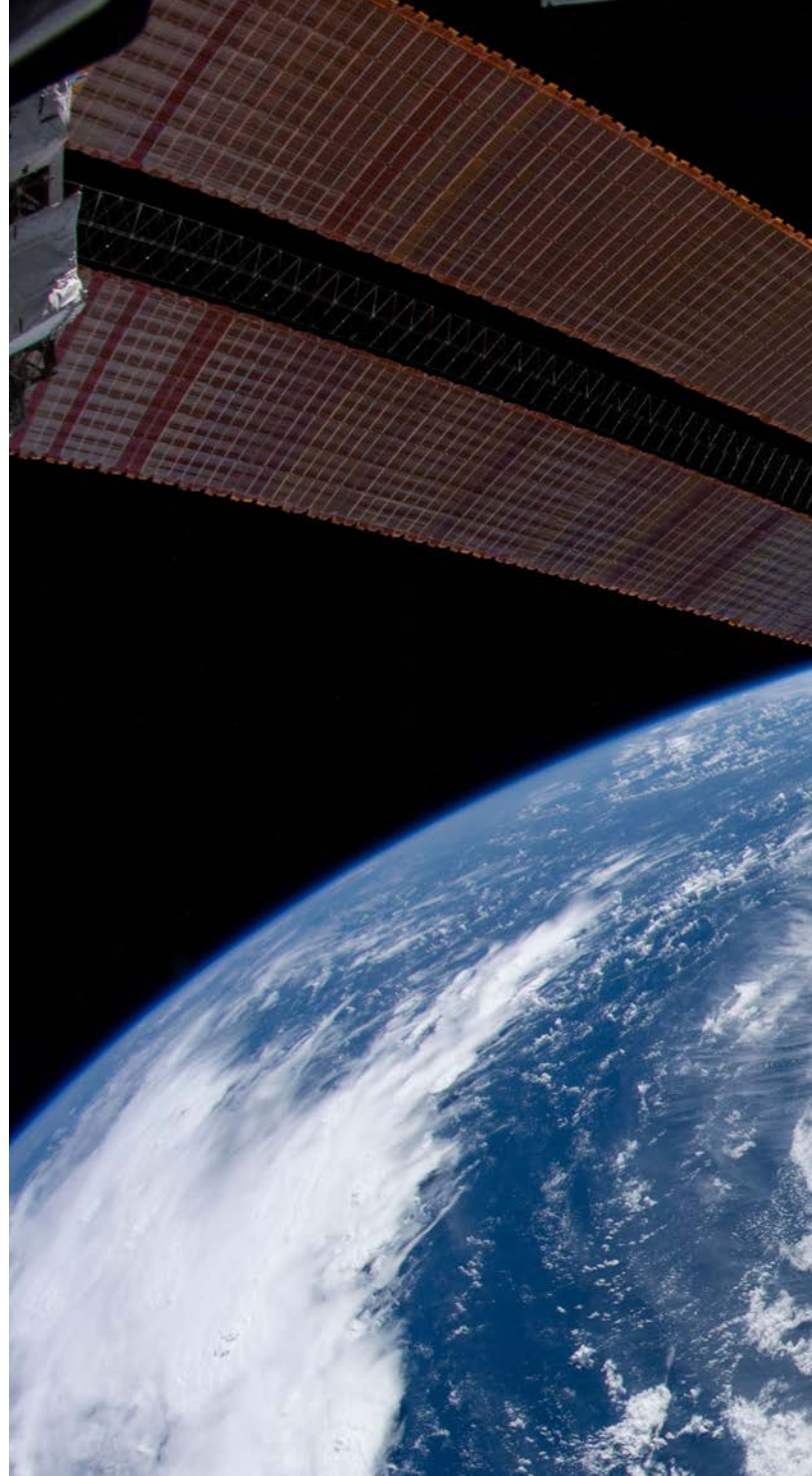
Meanwhile, Doyle’s team is already working on a new data assimilation initiative to initialize the COAMPS-TC model based on satellite radiances, the raw measurements that satellites take using solar-reflected and Earth-emitted radiation. Doing so should enable the model to produce more realistic representations of storms, according to Doyle.

“The best approach is to use the raw radiance information directly in the model data assimilation system,” he said. “At this point, we’re trying to demonstrate a new data assimilation capability using high-spatial and temporal resolution radiance measurements.”

With these and other efforts, the division has set a goal to improve forecasts for more advanced tropical cyclone warnings, and to track forecasts better, the storm size, and its intensity. Accomplishing these goals will help governments, the Department of Defense, emergency managers, and the public to prepare and, if necessary, get people and assets out of harm’s way in time.

“One of the decisions the Department of Defense needs to make, for example, in Norfolk [Virginia] is whether to send ships out to sea if a storm is coming close,” Doyle pointed out. “This is one of the applications of COAMPS-TC that’s really important. Prior to Dorian, the Navy made the decision to sortie the Hampton Roads-based ships and aircraft.

“We have a very dedicated team that’s trying to improve the forecast, because its impact is so front and center, not only for the DOD but of course for everyone whose lives and property will be affected.”



Expedition 60 flight engineer Christina Koch of NASA captured this image of Hurricane Dorian from the International Space Station on Sept. 2, 2019 as the storm churned over the northwestern Bahamas. (Photo courtesy of NASA)



New Orleans, Louisiana after Hurricane Katrina.



“We have a very dedicated team that’s trying to improve the forecast, because its impact is so front and center, not only for the DOD but, of course, for everyone whose lives and property will be affected.” – Jim Doyle

## From Dorian to Lorenzo

But for the most part, the process is automated, essentially a network of supercomputer servers interacting with one another. The servers used by the forecasters — in Dorian’s case that’s the National Hurricane Center — send out a signal every six hours alerting weather systems models that they have identified an investigation area (meteorologists call them “invest areas”) or a tropical cyclone and provides the location, intensity and size of the storm. That information is used to initialize the COAMPS-TC hurricane vortex.

“They initiate a message that has the information in a certain format through the Automated Tropical Cyclone Forecast system, and the models, like the NOAA models and our Navy models, look for that message,” Doyle said. “The software downloads the message, sorts through the different storms, and identifies which storms to run.”

Meanwhile, NOAA conducts special observations from their aircraft that help meteorologists gain a more thorough understanding of the circulation and other processes inside the tropical cyclone. The U.S. Air Force flies C-130s into the storm to get measurements of the peak winds, which tells forecasters about the storm’s current strength, size and location including the center of the circulation (if one can be found).

Doyle’s team of meteorologists conduct weekly meetings to discuss the development of the system, the storm’s track and intensity, according to COAMPS-TC’s projections and those of a half dozen other models that are also predicting the storm, including NOAA, the United Kingdom Meteorological Office and the European Centre for Medium-Range Weather Forecasts. □

# When a Speck INFLUENCES A STORM

CASSANDRA EICHNER  
NRL CORPORATE COMMUNICATIONS

*A crumbling old pier on the island of Corregidor. (Photo courtesy of CIA)*

## Studying the Role of Aerosol Particles in the Hydrological Cycle

U.S. Naval Research Laboratory meteorologist Jeffrey Reid, Ph.D., is at the forefront of research studying the role of aerosol particles, and the relationships between the particles with monsoon meteorology, clouds and the sun's radiation.

Aerosol particles floating through the environment harbor big mysteries to scientists globally. The particles range in size from bundles of molecules (10nm) to a grain of sand, and are capable of surfing through the air for thousands of miles. Small and seemingly insignificant on their own, the particles travel as inanimate swarms, influencing the earth's weather and climate in ways scientists do not yet fully understand.

Reid served as the mission scientist for the international field campaign, The Cloud, Aerosol and Monsoon Processes Philippines Experiment (CAMP<sup>2</sup>Ex), the largest airborne field campaign to date in Maritime Southeast Asia. The NASA-initiated campaign studied tropical weather and aerosols in the South East Asian Region last year from August to October.

As the mission scientist, Reid was responsible for managing the daily operations of the science and flight teams. His efforts ensured the team of more than 150 scientists efficiently and safely collected data despite extreme weather conditions and challenging geophysical features.

CAMP<sup>2</sup>Ex was a partnership with NASA, U.S. Naval Research Laboratory, the Manila Observatory, the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), and various academic organizations. Researchers on the campaign sought to collect data to answer three key questions:

- Do aerosol particles influence weather and precipitation in in tropical environments?
- Do these influences feed back into the aerosol lifecycle?
- How do the aerosol and cloud influence the radiation energy budget of the region?

Filipino scientists were especially interested in the ramifications of monsoonal meteorology on regional hydrology, oceanography and air quality.

With its unique geological features and annual weather extremes, the Philippine Archipelago is an ideal location for scientists to conduct this research. Sitting astride the Pacific Typhoon Belt, 20 to 21 cyclonic storms affect the Philippines annually, and five to six of these storms typically strike the string of islands. These storms have devastating local impacts, but are also an integral part of the meteorology of the Indian Ocean through the Pacific Ocean.

"Being able to predict [major weather events] with greater accuracy and lead time has obvious benefits, not the least of which is keeping people safe," said Hal Maring, NASA/CAMP<sup>2</sup>Ex program scientist.

"We want to get a better understanding of how aerosol particles produced by biomass affect the earth's radiation budget directly and indirectly, and how they interact with clouds relative to precipitation," he added. "If we are going to do climate prediction with greater fidelity, those processes need to be understood."

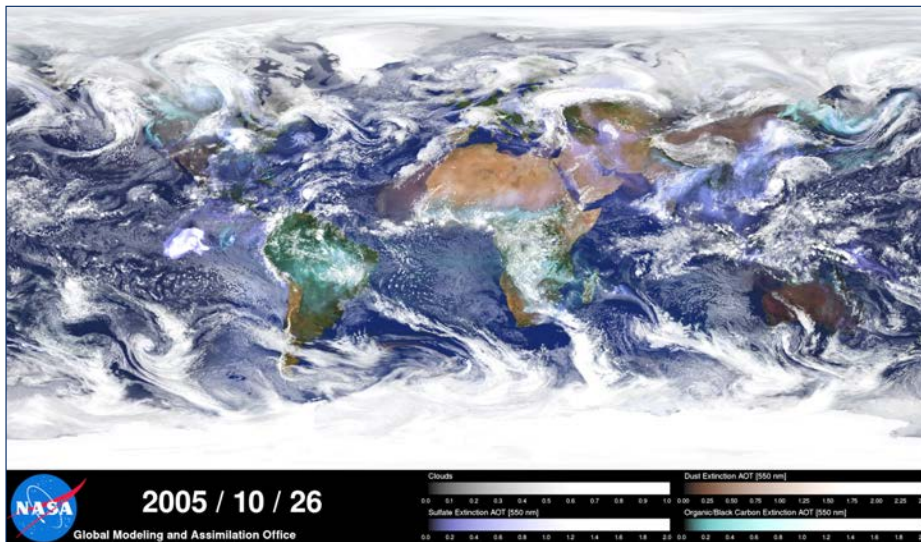
Their research has international implications for weather forecasting. According to Reid, the information collected from the Philippines could be used to develop models to predict major weather events around the world, including those in the United States. This capability would prove valuable for the Navy, which maintains a constant forward deployed presence.

## The Hydrological and Aerosol Cycles: How a Speck Creates a Storm

The hydrological cycle, more commonly known as the "water cycle," is a continuous process of evaporation and precipitation. According to Reid, aerosol particles are an important part of this cycle, because they serve as the nuclei for forming cloud droplets.

Aerosols are produced a variety of ways. Some are human-made pollution, such as car exhaust, biomass burning and industrial emissions. Others occur naturally, like those made up of dust from the Sahara or salt from the ocean.

Every cloud droplet has some airborne particle at its core, according to Reid. That means as the number of pollution particles in the atmosphere change, so too do the number



A simulation of the atmosphere that captured how winds transport aerosols around the world. This simulation, produced by the Goddard Earth Observing System Model Version 5 (GEOS -5), shows clouds (white), dust (brown shades), sulfates (purple shades), and organic black carbon (green shades) at 7-kilometer resolution from September 1, 2005 to December 31, 2005 (hourly). (Photo courtesy of NASA)

of cloud droplets -- as well as their radiative properties, how long they last, and, ultimately, precipitation.

"Chemical reactions happen within those cloud droplets," he said. "So the feedback between emissions, photochemistry, [affecting] how clouds are changed and how the clouds are changing these aerosol particles is complex. We roughly know general types of relationships, but we don't know specifics."

"Some particles get rained out, and some get dumped outside of the cloud. Then they are even bigger and more effective at making larger cloud droplets and it gets recycled back into the clouds. In some cases particles inhibit precipitation. In others they can intensify storms."

## International Collaboration for a Step Forward in Predicting Weather Events

A research campaign of this magnitude took extensive coordination between the U.S. and Philippine government and its public, private, and academic organizations. During the campaign, one of Reid's focuses was building collaboration between the researchers and their Philippine counterparts.

In the year leading up to the campaign, Reid and his meteorology and oceanography (METOC) forecasting team worked with the forecasting and flight teams to practice creating forecasts for flight planning. By the time the campaign kicked off, team members had experience producing forecasts and flight plans using actual meteorological data from the vicinity of the Philippines.

"[The forecasts] provided us legitimate proto-type plans for us to share with the Philippines to facilitate getting diplomatic clearance as well as basing and overflight permission," Maring said.

During the campaign, Reid, Maring and members of the METOC and flight teams met early in the morning to determine the best locations to fly NASA's P-3 Orion and SPEC Learjet for data collection. Preparing for science flights took hours.

"The ground crew prepped the plane, and we would double and triple-check the meteorology, and triple-check the flight plans," Maring said. "Some of the instruments took hours to warm up."

According to Maring, their Philippine colleagues led the air quality portion of the study, utilizing the instruments on the P-3 to characterize air quality, including suspended particulate matter.

"We were able to get a flight dedicated solely to collecting air quality data in and around the Manilla Megaplex which included measuring upwind and downwind," Maring said. "We were able to make measurements from near the surface, (approximately) 350 feet to over 20,000 feet."

Mission conditions were perfect for this kind of study, according to Reid, providing the wide variety of environments for which the science team was looking. Researchers observed massive smoke plumes from Borneo with megacity pollution alongside pristine air masses and developing tropical cyclones.

Meanwhile, researchers with the Office of Naval Research were also collecting climate data from their Sally Ride research vessel off the coast of the Philippines. For the past five years ONR and their collaborators have been monitoring how regional weather impacts weather across the globe as part of the Propagation of Intra-Seasonal Tropical Oscillations (PISTON) program.

"Southeast Asia is a boiling pot for evaporation and convection," Reid said. "Water vapor enters the atmosphere in Southeast Asia and can eventually work its way to the United States. We can pass the information collected here to a mission like PISTON that takes the data and looks at long-range transport and weather all over the Pacific Ocean. At the same time, PISTON observation and modeling efforts support the CAMP2Ex analysis. Ultimately, the science of both missions is tightly coupled."

Researchers, however, will have to wait for the results.

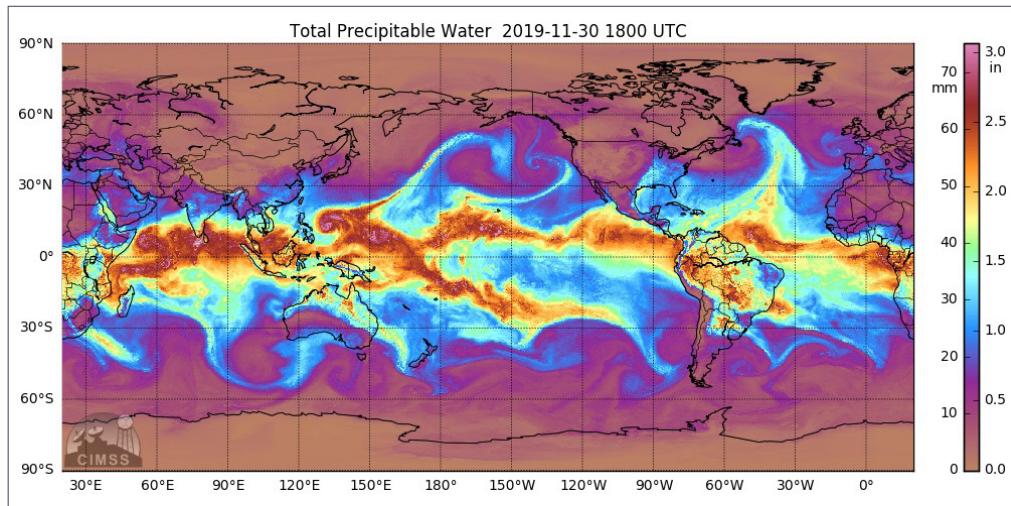
"The region is so complicated we will be analyzing the data for at least another five years," Reid said. "Ultimately we believe this data will stand the test of time." □



CAMP2Ex Group. (Photo courtesy of NASA)

# ATMOSPHERIC RIVERS

VICTOR CHEN  
NRL CORPORATE  
COMMUNICATIONS



Screen capture of the world's atmospheric rivers, which account for most of the horizontal moisture transport outside of the tropics. U.S. Naval Research Laboratory meteorologists plan to participate in a cooperative study in 2020 in the Eastern Pacific to improve their ability to forecast the rivers. (Image courtesy of the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin, Madison)

Meteorologists at the U.S. Naval Research Laboratory plan to take a harder look in 2020 at a prime, yet difficult to model, component of the global water cycle known as atmospheric rivers.

Rivers in the sky, sometimes known as the Maya or Pineapple Express, account for most of the horizontal moisture transported outside of the tropics – and even up into the Arctic.

Horizontal moisture transport is water moving from east to west or north to south, as opposed to moisture moving vertically from the ocean to the atmosphere.

“These narrow rivers move a significant amount of water through the air, even though they take up a relatively small area,” said Carolyn Reynolds, Ph.D., head of the Probabilistic Prediction Research Office at NRL. “Large atmospheric rivers can transport as much moisture as the Amazon.”

On average, just a few atmospheric river events are responsible for 30 to 50 percent of the annual rainfall on the West Coast, according to the National Oceanographic and Atmospheric Administration.

The significant moisture, high surface winds, and associated severe weather these planetary features bring makes being able to predict them important to the Navy and Marine Corps. For example, the 2010 Maya Express contributed to Washington, D.C.'s “Snowmageddon,” which dropped about 5 feet of snow in the area over approximately four days.

“What makes them a little bit confounding to model is how dynamic they are,” Reynolds said. “They can last up to several days, they can pulse, and small details on their edges can have a big impact on how they evolve.”

Reynolds said current weather models can be off by hundreds of kilometers even for short forecasts of just a few days.

“There is a lot about them we still need to understand, especially the ocean and air interactions,” she said. “We have a basic knowledge, but still have to get to the details.”

Reynolds and James Doyle, Ph.D., senior scientist in NRL's Marine Meteorology Division use sophisticated methods called adjoints to discern how the forecasts of these rivers are very sensitive to small changes in the structure of the rivers.

Reynolds said the adjoint tools are not unique, but are among the most complete and highest fidelity in the world. The team's adjoints will be put to the test in 2020 when NRL will collaborate with other agencies to get live data on atmospheric rivers.

## Going for a River Cruise

In early 2020, U.S. Naval Research Laboratory is on track to participate in an Eastern Pacific field project, led by the Scripps Institute of Oceanography at the University of California, San Diego, to collect in situ observations of atmospheric rivers. Researchers sample in situ observations directly in the environment, vice using remote means such as satellites. U.S. Naval Research Laboratory participated in similar field programs in 2016, 2018 and 2019.

During the project, NRL's adjoint modeling system will be used to direct the U.S. Air Force's “Hurricane Hunter” WC-130J aircraft. The goal is to provide the optimal flight paths for the Hurricane Hunters to use their onboard sensors and deploy instrumented packages with parachutes known as dropsondes.



A U.S. Air Force “Hurricane Hunter” WC-130J aircraft from the 53rd Weather Reconnaissance Squadron taxis to a parking spot after completing its mission into Hurricane Dorian, Sep. 5, 2019, at Keesler Air Force Base, Mississippi. (U.S. Air Force photo by Tech. Sgt. Christopher Carranza)

In-situ observations are highly valuable. NRL meteorologists developed a technique, called the Forecast Sensitivity/Observation Impact, to measure each data point's impact on reducing forecast error and to better understand biases in their weather models.

“Direct observations of actual weather conditions in these atmospheric rivers can have an outsized impact on our forecasts,” Reynolds said. “In the past, we've shown that having at least two aircraft collecting observations can reduce our 24-hour forecast error as much as the entire North American radiosonde (weather balloon) network.”

NRL's work on atmospheric rivers is funded by its basic science program, and is scheduled to continue through 2022. ▣



# MONSOON OSCILLATIONS BAY OF BENGAL

DANIEL PARRY / CASSANDRA EICHNER  
NRL CORPORATE COMMUNICATIONS

Oceanographers and meteorologists with the U.S. Naval Research Laboratory concluded an ambitious field research program in collaboration with the U.S. Office of Naval Research aimed at understanding the role of the Indian Ocean on monsoon intra-seasonal oscillations (MISO), June 26.

The project seeks to understand this major weather phenomenon that impacts more than one billion people living in the Indian subcontinent and the Bay of Bengal rim nations.

“Monsoons bring not only much needed water resources, but also major disasters resulting from severe weather, flooding, and storm surges,” said Hemantha Wijesekera, Ph.D., research oceanographer and lead principal investigator. “The goal is to study and quantify oceanic processes that regulate the intensity and propagation of the MISO in the region.”

Several times a year from May to October a process called MISO occurs in the atmosphere over the Indian Ocean, the western tropical Pacific Ocean, and surrounding land areas. This weather event brings periods of extremely wet and extremely dry conditions to the area, significantly affecting the people and the economy of those areas. Researchers do not currently know the extent to which the Indian Ocean affects the intensity of this process.

Scientists from the NRL, University of Notre Dame, Army Research Laboratory, and National Aquatic Research and Resources Agency in



Researchers recover a large buoy housed to a velocity and temperature microstructure package during the oceanographic cruise aboard R/V Sally Ride in the Bay of Bengal. (U.S. Navy Photo)

Sri Lanka evaluated air and sea processes that contribute to monsoon intensity from May 26 to June 26. Researchers recovered five deep underwater moorings, and sampled and evaluated surrounding ocean temperatures, salinity, and wind to help understand how those variables may influence MISO.

Instruments connected to the deep underwater moorings collected a variety of data including temperature, salinity, pressure, dissipation of kinetic energy of turbulence (i.e., the rate at which the turbulence energy is absorbed by the breakdown of eddies into smaller and smaller eddies), and currents in the upper 600-1000 meters of the ocean for a period close to a year. Several deep and shallow ocean-sondes measured ocean currents, bio-optical profiles, and multi-beam bathymetry.

University of Notre Dame scientists collected atmospheric observations in collaboration with NRL meteorologists. They collected data on humidity, temperature, and flow fields from the atmospheric boundary layer—the lowest part of the troposphere, approximately a kilometer above Earth’s surface, and above. Near surface meteorological measurements were also collected.

Observations of currents and hydrographic fields (measuring and describing the physical features of bodies of water and the land adjacent to them) for the same purposes as this study are rare within the Bay of Bengal and Sri Lanka.

“This new set of long-term, high-resolution observations will help to quantify upper ocean processes including variability of upper ocean heat content, seasonal currents, eddies and internal waves,” Wijesekera said. “Results will tie in to quantify detailed air-sea coupled processes in the NRL air-sea coupling model, COAMPS, and will improve operational Navy forecast models, accurately predicting ocean circulation and monsoon formation over the Arabian Sea, Bay of Bengal, and South China Sea.” □

Hemantha Wijesekera, Ph.D., U.S. Naval Research Laboratory research oceanographer, led a team of scientists from the NRL, University of Notre Dame, Army Research Laboratory, and the National Aquatic Research and Resources Agency in Sri Lanka, evaluated air and sea processes that contribute to monsoon intensity, May 26 through June 26. (U.S. Navy Photo)



# FIRE-BREATHING CLOUDS

## PREDICTING Pyrocumulonimbus Clouds

CASSANDRA EICHNER  
NRL CORPORATE COMMUNICATIONS

Researchers at the U.S. Naval Research Laboratory advanced their ongoing work to understand and predict formation of pyrocumulonimbus (pyroCb) clouds in 2019 by collecting the most detailed sampling of the clouds in history.

PyroCbs are massive thunderstorm clouds created by heat and fire. Such clouds, which can reach heights of more than 8 kilometers, heave intense wind, thunderbolts, and smoke toward anything in their path—sometimes even igniting new fires.

Between July and September, NRL meteorologists took part in multi-agency studies of pyroCbs in the western and central United States.

### PyroCbs: Intense Storms Reaching Into the Stratosphere

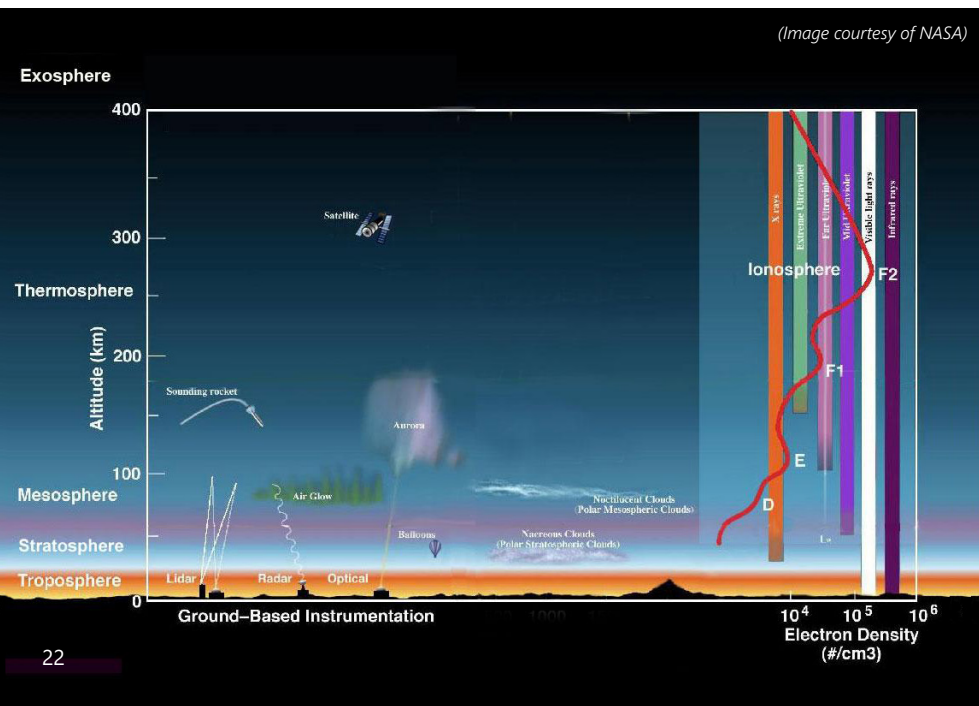
Fires leave little time to escape, and wreak mass destruction. It's no wonder NASA refers to the pyroCb as "the fire-breathing dragon of clouds."

But unlike threats posed by dragons, the devastating power of fire is all too real, and the implications of large fires don't stop on the ground. Large fires can extend their destructive force high into the atmosphere, drawing smoke and particulates.

"The pyroCbs act as giant chimneys, transporting smoke from the ground to high altitudes," said Dave Peterson, Ph.D., meteorologist at NRL. "Intense pyroCbs can inject smoke into the lower stratosphere, where it can persist for weeks or months."

Typically, smoke, ash and other pollutants produced by fires are contained within the troposphere, the lowest layer of the atmosphere, where they are removed quickly through normal weather processes like precipitation. When they reach the stratosphere, these substances block sunlight from reaching the Earth's surface, and become radiated by the sun, which can alter the altitude and chemical composition of the smoke plume.

Warm, dry environments here in the U.S. create ample opportunity for pyroCbs to thrive. In 2018, the Carr Fire burned for 164 days in California. It





# NRL Intern Braves Fire for NASA Campaign



U.S. Naval Research Laboratory Intern Melinda Berman steps off NASA's DC-8 aircraft in Boise, Ohio during her summer 2019 internship with NRL. Berman participated on the fire and weather forecasting team during the Fire Influence on Regional to Global Environments and Air Quality (FIREX-AQ) field campaign. (U.S. Navy photo by Christel Bennese)

Five college interns from the Naval Research Enterprise Internship Program (NREIP) accompanied U.S. Naval Research Laboratory meteorologists Dave Peterson, Ph.D. and Edward Hyer, Ph.D. to serve on the fire and weather forecasting team in support of FIREX-AQ, this summer.

Among those interns was Melinda Berman, a student from University of California, Los Angeles (UCLA). Hailing from the suburbs of Chicago, she knew she wanted to be a meteorologist ever since she witnessed a tornado around age 10. She was elated this March when she learned she would be participating in a NASA field campaign.

Her role on the team was to provide forecasting for the Twin Otter aircraft (one of four aircraft supporting the mission) and mobile lab support unit in Boise, Idaho. Early each morning, she would meet the team at Gowen Field, where they would put together the day's forecasting brief.

Together they would watch as the main research plane, NASA's DC-8 Flying Laboratory, gained momentum down a runway just barely big enough to support it. As it picked up speed, a massive dirt cloud would form around it, nearly covering the NASA logo on the side. Just before reaching the end of the runway, the plane would take off.

One highlight of the internship for Berman was when she flew on the DC-8 as researchers collected data over the Williams Flats Fire, Aug. 7.

"It gets hazier when you fly through the smoke," she said, recalling their flight over the fires below. "The sun turns red-orange because the smoke particles scatter the light more. It smells really smoky, almost like a wood-fired pizza or a barbecue. Being so close to the fire and seeing the instruments and data in real time was a different perspective."

Berman hopes to return next year and said she would recommend participating in the NREIP to other college students who are interested in the field of meteorology.

"I couldn't have asked for a better summer," she said. "This experience has opened my eyes to the research that is out there. I didn't know there was active meteorological fire research going on. I've become interested in doing research in this field." □

killed three, destroyed or damaged more than 1,800 structures, and charred approximately 229,651 acres. The destructive force of the Carr Fire did not stop on the ground — it was so strong it created a pyroCb, carrying smoke well above jet aircraft cruising altitudes.

The largest known pyroCb event occurred in British Columbia in 2017, and rivaled a moderate volcanic eruption, Peterson said.

Peterson detailed his research "Wildfire-driven thunderstorms cause a volcano-like stratospheric injection of smoke" in a 2018 paper published in *Npj Climate and Atmospheric Science*.

## A New Frontier in Meteorology

NRL has been a pioneer in the pyroCb research community since the late 90s, when researcher Mike Fromm and his partner, René Servranckx from the Canadian Meteorological Centre, first discovered the pyroCb phenomenon.

In 1998, Fromm and Servranckx ran analysis on clouds forming in the northern and southern hemispheres using NRL's Polar Oxone and Aerosol Measurement satellite (POAM III) and saw something puzzling.

"I started to see things that looked like polar stratospheric clouds," Fromm said. "But they were occurring in the summertime, not in winter."

Polar stratospheric clouds (PSCs) are clouds that develop in the extremely low temperatures of the polar stratosphere in winter. The clouds he observed existed in temperatures too warm to create a PSC.



“They looked like PSCs but could not be PSCs, so we had to look for another explanation,” he said. “I found almost immediately that people expected layers like this to be caused by volcanoes. So I explored the possibility of a volcano.”

According to Fromm, volcanoes were known to create aerosol layers that look similar to polar stratospheric clouds. Scientists generally assumed these layers occurred from volcanic eruptions, which was the only known way to get such a large amount of aerosols into the stratosphere. So dominant was this assumption that unreported volcanic eruptions were suspected even when none could be found.

“There was no volcano I could link,” From said. “So I was left with a puzzle.”

He traced the aerosol layers he saw back to a major wildfire. He continued to dig into decades of research and discovered several of the previously assumed volcanic eruptions were actually caused by pyroCb events.

Today, a growing number of researchers study pyroCbs in hopes of gaining a better understanding of how these storms impact climate over time. But the number of experts and data available are still relatively scarce; the science is still in its infancy.

## Collaborating with NASA, NOAA, and Academia

Peterson believes the key to improve our understanding of pyroCbs is to obtain detailed measurements of their outflow, a residual smoke layer or an “anvil ice cloud.”

“In the early stages of the pyroCb, an active thunderstorm updraft is present over the fire,” Peterson said. “The cloud flattens out as it pushes up against the tropopause [boundary between troposphere and stratosphere] forming an anvil cloud. Eventually, the pyroCb

updraft dissipates, the high-altitude anvil cloud drifts downwind and also dissipates, and you are left with a residual smoke layer in either the upper troposphere or lower stratosphere.”

To get outflow measurements, scientists must anticipate and track when and where a pyroCb may occur and have the appropriate aircraft with a variety of instruments (and the scientists to operate them) readily available to fly at just the right altitude to capture the data. It’s complicated, and requires extensive coordination.

Nevertheless, a joint NASA and NOAA venture, Fire Influence on Regional to Global Environments Experiment - Air Quality (FIREX-AQ), was able to do just that. Taking place July 23 to Aug. 18 in Boise, Idaho, and Aug. 20 to Sept. 5 in Salina, Kansas, it was one of the largest field experiments dedicated to the sampling and characterization of fires and their impacts from the point of emission.

Throughout the campaign, researchers investigated the impact on air quality and climate from wildfires and agricultural fires across the continental United States. Peterson served as the lead for the multidisciplinary fire and weather forecasting team and worked closely with Edward Hyer, a meteorologist at NRL, who also participated in the campaign.

Each morning Peterson and his team of more than 10 researchers and interns reviewed computer models, based on satellite observations and existing data about fire behavior, and delivered the fire and weather forecast to campaign participants. Those forecasts told researchers when and where to fly and drive to collect the most data at a given time. According to NOAA, researchers will eventually use FIREX-AQ’s data to make these models even more accurate.

The team began forecasting favorable conditions for pyroCb development in the Pacific Northwest, Aug. 5. Peterson hitched a ride on a NASA DC-8 airborne science laboratory to see a pyroCb for himself,

*Photo of a Pyroculonimbus cloud (pyroCb) taken over the Pacific Northwest on Aug. 8, 2019 during the FIREX-AQ field campaign from the cockpit of the NASA DC-8 aircraft. (U.S. Navy photo by David Peterson)*



for the first time, Aug. 8. With a camera in tow, he snapped the now famous photos of a pyroCb from the cockpit while flying over the Williams Flats Fire in Washington. This flight provided the most detailed sampling of pyroCb outflow in history.

Now that the campaign is complete, scientists are eager to review the data collected to answer a variety of questions. The detailed observations of the chemistry within pyroCb smoke plumes at high altitudes can contribute to initializing modeling studies that aim to understand the role of pyroCb in the climate system, Peterson said.

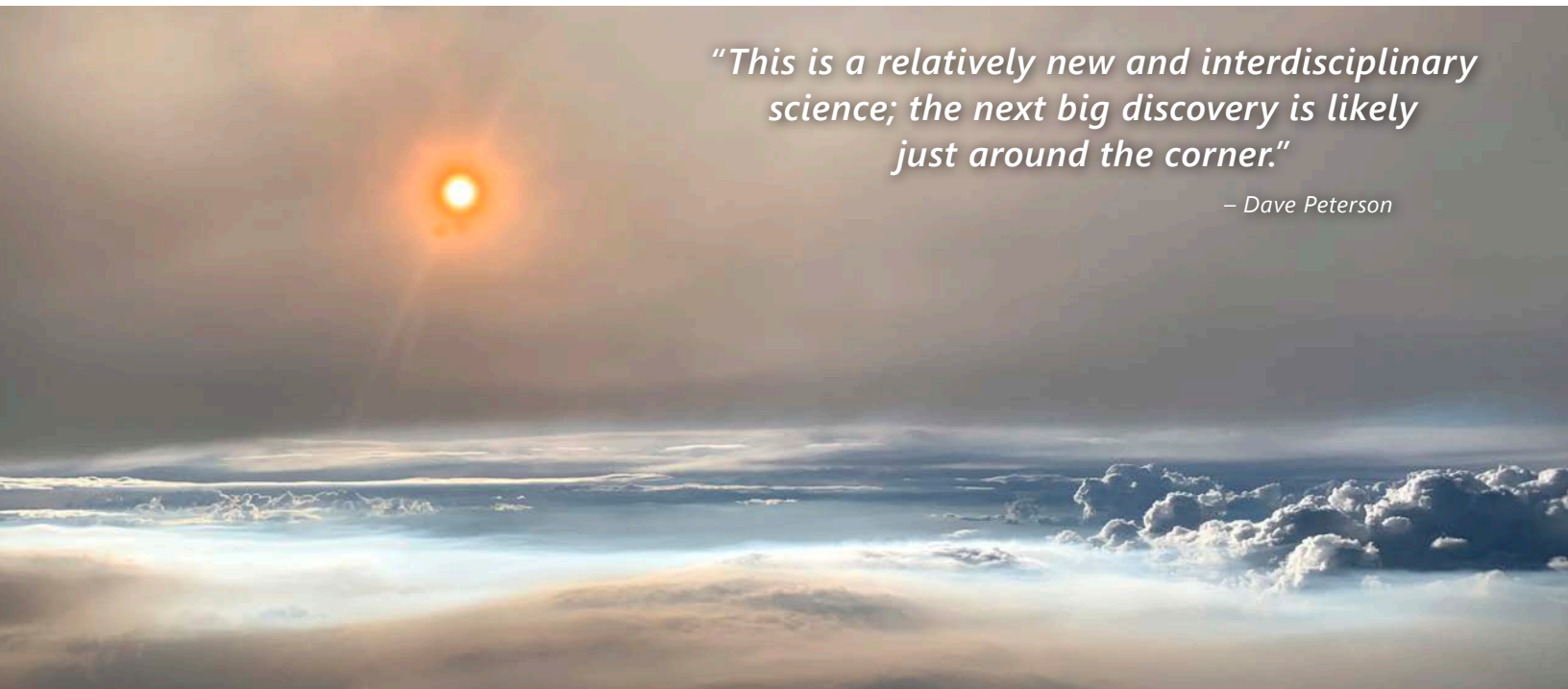
“Observations from within the pyroCb ice cloud [anvil] can be used to understand how cloud water droplets and ice particles change in the presence of smoke,” he said. “Remote sensing observations of the contributing fire [Williams Flats] can be used to understand what fire characteristics are required for pyroCb development, such as the overall size of the fire, the dimensions of the flaming region, and how these characteristics evolve prior to pyroCb development.”

Researchers believe they are on the right track to demystify pyroCbs.

“This is a relatively new and interdisciplinary science,” Peterson said. “The next big discovery is likely just around the corner.” ◻

*“This is a relatively new and interdisciplinary science; the next big discovery is likely just around the corner.”*

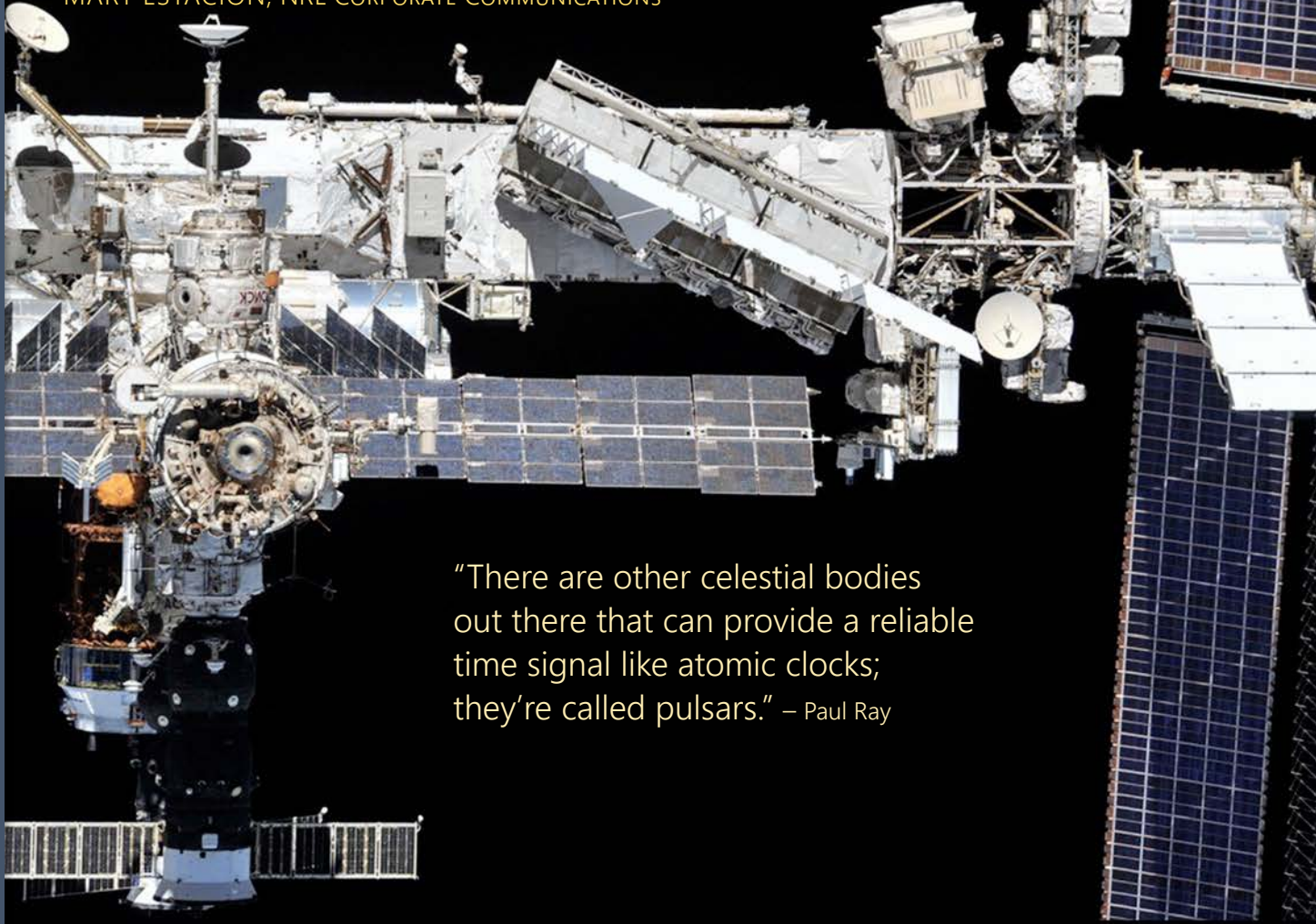
*– Dave Peterson*



# PULSAR-BASED NAVIGATION

TECH DEMONSTRATION

MARY ESTACION, NRL CORPORATE COMMUNICATIONS



“There are other celestial bodies out there that can provide a reliable time signal like atomic clocks; they’re called pulsars.” – Paul Ray

For thousands of years, humanity looked to the sky for help with navigation. Before the advent of modern technology, travelers used the sun and the stars as points of reference.

About 30 years ago, human-made systems such as the Global Positioning System (GPS), built on the U.S. Naval Research Laboratory’s TIMATION research, have largely replaced ancient navigation methods.

However, explorers looking to the stars as the next frontier will need a way to navigate in deep space without the Earth-centric GPS.

Researchers with NRL’s Space Science division are currently testing patented technologies to meet this need.

“TIMATION showed how a system of atomic clocks and time differences could be used to navigate -- that’s what became traditional GPS,” said Paul Ray, Ph.D., a researcher with Naval Research Laboratory’s Space Science Division. “There are other celestial bodies out there that can provide a reliable time signal like atomic clocks, they’re called pulsars.”

## Say HELLO to Pulsars

A pulsar forms when a massive star depletes the fuel in its core and collapses in on itself, resulting in a supernova. The remnant can be a rapidly rotating neutron star emitting powerful broad spectrum radiation, sweeping around like cosmic lighthouses, creating pulses.

The period between a pulsar’s sweeps can range from seconds to milliseconds. According to Ray, the fastest spinning “millisecond pulsars” – which spin faster than a kitchen blender – can provide a signal more regular and stable than man-made atomic clocks used in traditional GPS networks.

Partnering with NASA, U.S. Naval Research Laboratory was part of the NICER (Neutron Star Interior Composition Explorer) team, which was installed aboard the International Space Station in June 2017. Included with NICER is a deep space navigation technology demonstration called SEXTANT. (Photo courtesy of NASA)

Additionally, millisecond pulsars are steady and can be predicted to an accuracy of a microsecond over a year.

Ray's team at NRL has already tested the concept with the first spacecraft-installed navigation system.

Working with NASA, Ray's group was part of the NICER (Neutron Star Interior Composition Explorer) team, which was installed aboard the International Space Station in June 2017 to study the physics of neutron stars.

Included with NICER is a deep space navigation technology demonstration called SEXTANT (Station Explorer for X-ray Timing and Navigation Technology), which uses X-ray radiation from pulsars as substitutes for the atomic clocks GPS uses today.

NICER uses 52 telescopes to detect X-ray photons from pulsars and measures their arrival times. Its software algorithms process the very slight arrival time differences to determine the position of the NICER/SEXTANT receiver.

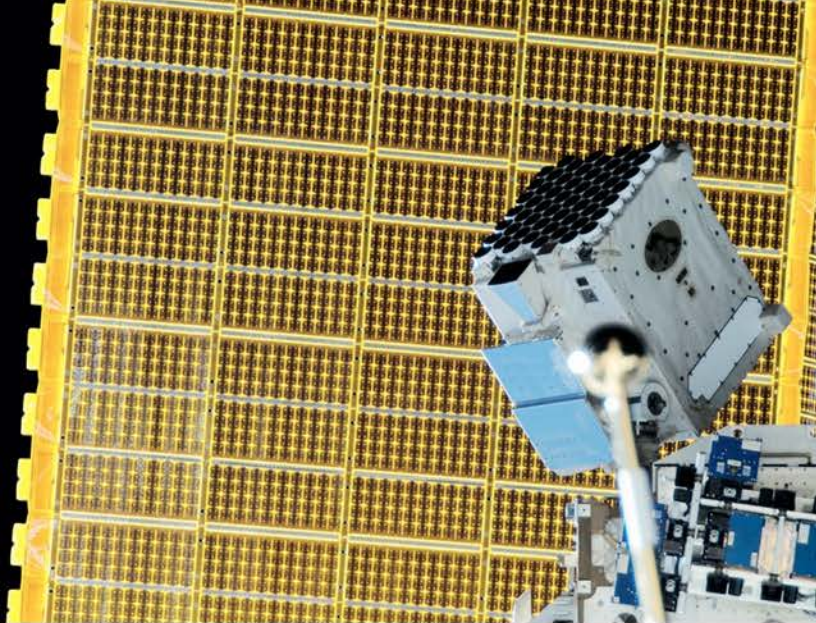
So far, Ray and his team determined the accuracy of the pulsar technique to be better than 10 kilometers, and up to one kilometer for periods of time.

"While it doesn't yet approach the accuracy of GPS, it works in many regimes where GPS is not available," Ray said. "Using pulsars can provide autonomous navigation and timekeeping for months or years without requiring any updates from the ground."

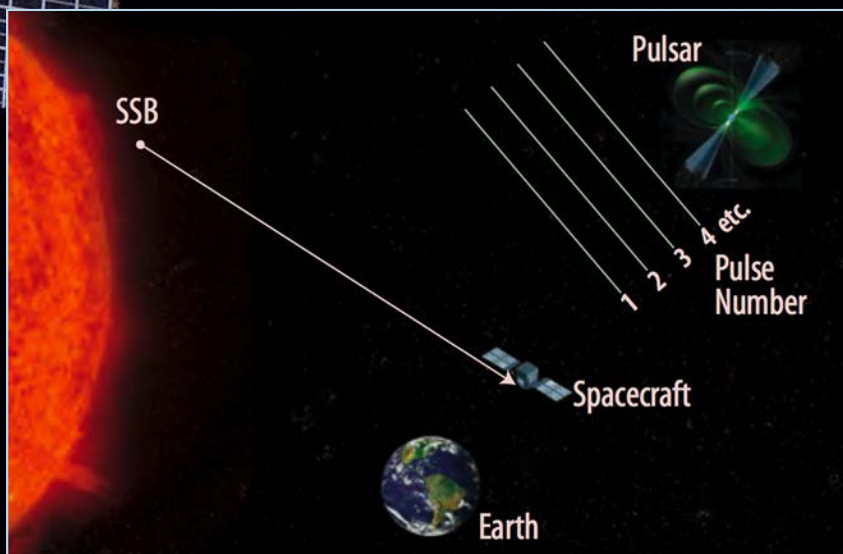
## Continuing Research

Funded by NASA's Science Mission Directorate, NICER has since completed its prime mission and has been extended by the recommendation of NASA's Senior Review for three more years, according to Eric Grove, head of the Space Science Division's High Energy Space Environment Branch.

"With its demonstration successfully completed, we are looking for new sponsors that need this technology," Grove said. "For users who require very high reliability, for example, [for] human spaceflight or critical military satellites, pulsar-based navigation may be an attractive backup to GPS."



Researchers from the Space Science Division of the U.S. Naval Research Laboratory are working on ways to use signals from pulsars to develop a space navigation system using NICER and SEXTANT; the NICER experiment is an externally-mounted payload on the International Space Station. It is on Express Logistics Carrier 2 on the zenith side of the ISS. (Photo courtesy of NASA)



Schematic of the geometry for determining a spacecraft's position using pulsars. The arrival times of pulses at the Solar System Barycenter (SSB), the stationary center of the solar system, can be predicted to high accuracy, so a measurement of the arrival time at a spacecraft gives the distance from the SSB to the spacecraft along the direction to the pulsar. (U.S. Naval Research Laboratory graphic)

Astronomers are on the hunt for more candidates to include in the pulsar navigation catalog. The Fermi Gamma Ray Space Telescope has been successful in discovering new pulsars that are then characterized with large radio telescopes on the ground. Once a promising candidate is discovered, it is then observed with X-ray telescopes to determine whether it is bright and stable enough to serve as a navigation beacon.

NRL's researchers also noted current limitations of detection and processing technology, as it takes up to 30 minutes to make a pulse arrival time measurement. Ray expects that over time, advances in optics technologies and new detectors will reduce the size and power requirements of the system but as far as demonstrating the concept, Ray said the future is now.

"We have the flight software and not just theoretically," he said. "It's built into GEONS [GPS-Enhanced Onboard Navigation System], which is [NASA] Goddard's navigation package. It actually works, and it can work in a hybrid system." □

# WISPR Wide-field Imager for Parker Solar Probe

NRL CORPORATE COMMUNICATIONS

## NRL, NASA Combine to Produce Sun Imagery with Unprecedented Clarity

Early returns from the U.S. Naval Research Laboratory's camera on NASA's latest mission to study the Sun's corona revealed on Dec. 4 a star more complex than ever imagined.

NRL's Wide-field Imager for Parker Solar Probe, or WISPR, the only imaging instrument aboard the NASA Parker Solar Probe mission, is now 84 percent of the way to the Sun.

WISPR produced multiple scientifically relevant photos, capturing the beginning of a dust-free zone around the Sun, detailed plasma eruptions, magnetic flux ropes, and the first image of a magnetic island around the Sun, a small region of space with a circulating magnetic field.

"The images help in the modeling of the behavior and the transport of the solar wind to Earth," said Russ Howard, Ph.D., an NRL astrophysicist and principal WISPR investigator. "They allow us to develop more accurate models by putting proper physics in the models."

Understanding how the solar wind behaves is important to the Navy and Marine Corps because when the winds reach Earth, they can impact GPS, spacecraft operations, and ground-based power grids.

WISPR, designed, developed and led by NRL, records visible-light images of the solar corona and solar outflow in two overlapping cameras, which together cover more than 100-degrees angular width from the Sun.

The findings just released stem from Parker Solar Probe's most recent approach to the Sun during a quiet part of the solar cycle, and set the stage for discoveries when the Sun is more active.

"Parker is going to swoop past the sun three or four times a year for the next few years, getting successively closer each time," said Karl Battams, Ph.D., a computational scientist at NRL. "Every encounter is going to give us a view that humankind has never seen, and along with that a lot of new questions – and hopefully quite a few answers – about what we are seeing."

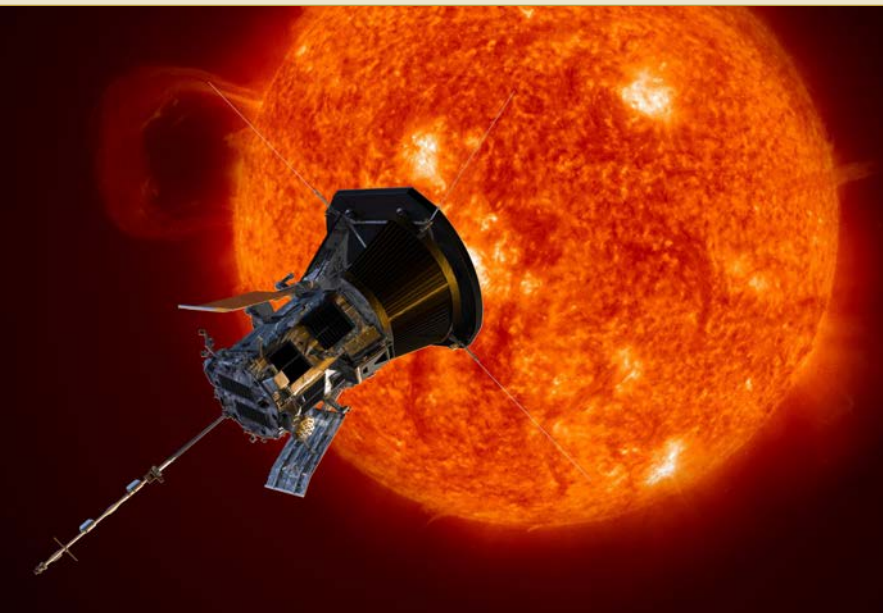
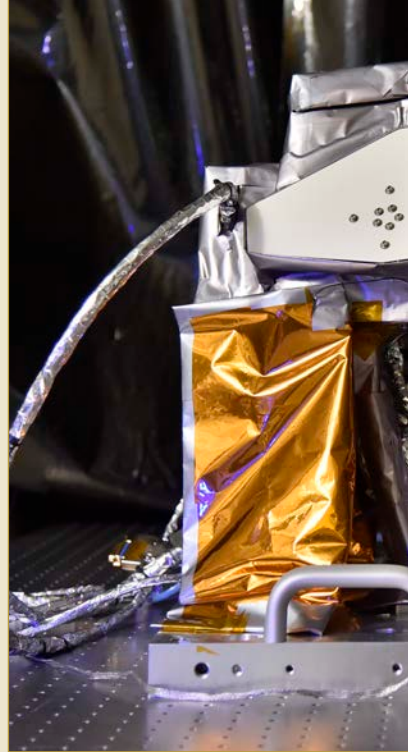
Parker Solar Probe recently completed its third perihelion, or closest approach to the Sun. By the end of its 7-year-long mission, the spacecraft will have circled the Sun a total of 24 times. In 2024, the Parker Solar Probe is expected to have traveled 96 percent of the distance to the Sun.

"We're explorers and we're getting in closer and closer until we're finally at the Sun," Howard said. "It's mindboggling because you're going to see things that we can't even imagine."

The Parker Solar Probe is a robotic spacecraft NASA launched in August 2018, whose mission is repeatedly probing and making observations of the outer corona of the Sun. WISPR is one of four instruments on Parker Solar Probe. □

MORE INFORMATION ON WISPR  
CAN BE FOUND AT  
<https://wispr.nrl.navy.mil>

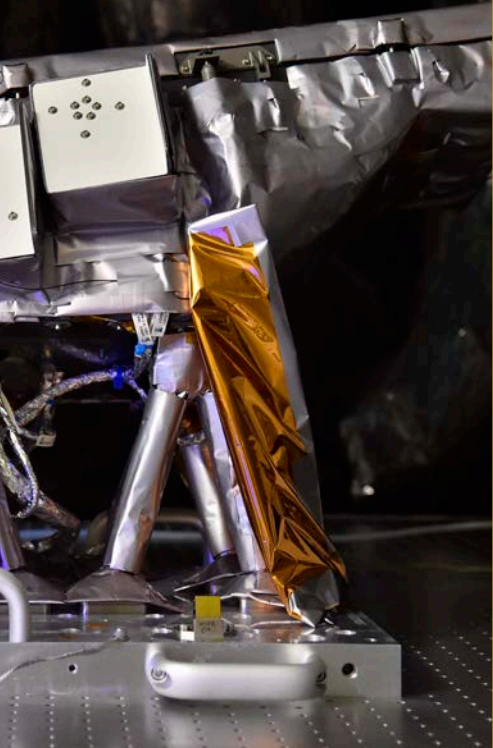
*The United Launch Alliance Delta IV Heavy rocket launches NASA's Parker Solar Probe on its voyage to the Sun, Aug. 12, 2018, from Launch Complex 37 at Cape Canaveral Air Force Station, Florida. Parker Solar Probe is humanity's first-ever mission into the Sun's atmosphere, called the corona. Here it will directly explore solar processes that are key to understanding and forecasting space weather events that can impact life on Earth. (Photo courtesy of NASA by Bill Ingalls)*



*Launch of Naval Research Laboratory's Wide-Field Imager for Solar Probe (WISPR) instrument on the NASA's Parker Solar Probe, a revolutionary mission to go deep in the heart of the sun's corona. WISPR was designed to analyze evolving solar wind structures close to the Sun and derive the three-dimensional structure of the solar corona to determine the sources of the solar wind. (Image courtesy of NASA/Johns Hopkins APL by Steve Gribben)*







U. S. Naval Research Laboratory's WISPR (Widefield Imager for Solar Probe) designed to observe the detailed structure of the corona from within the solar corona. (U.S. Navy Photo by Jonathan Steffen)



# RUSSELL HOWARD

2019 AGU Fellow  
Discusses His 50 Year  
Space Science Career



*Russell Howard, Ph.D., head of the Flight Projects Section in the U.S. Naval Research Laboratory's Solar and Heliospheric Physics Branch, received recognition as an American Geophysical Union Fellow in 2019 in commemoration of his more than 50 years of service and many contributions to the scientific community.*

*Howard has broad responsibility to conduct research in solar physics, solar-terrestrial physics and related areas at NRL. Most recently, he formed an international team to respond to NASA's proposal opportunity for the Solar Probe Plus mission, renamed the Parker Solar Probe in 2017. In September 2010, NASA accepted his team's proposal for the Wide Field Imager (WISPR) instrument for the mission, which launched in 2018.*

*Looking back at the past five decades, Howard cited his passion for physics and engineering as the foundation of his success and contributions to the field of astrophysics. With plans to retire soon, he reflected fondly on his career at NRL, which stretches all the way back to 1969, the tail end of the space race.*

**Q How do you feel about receiving this award?**

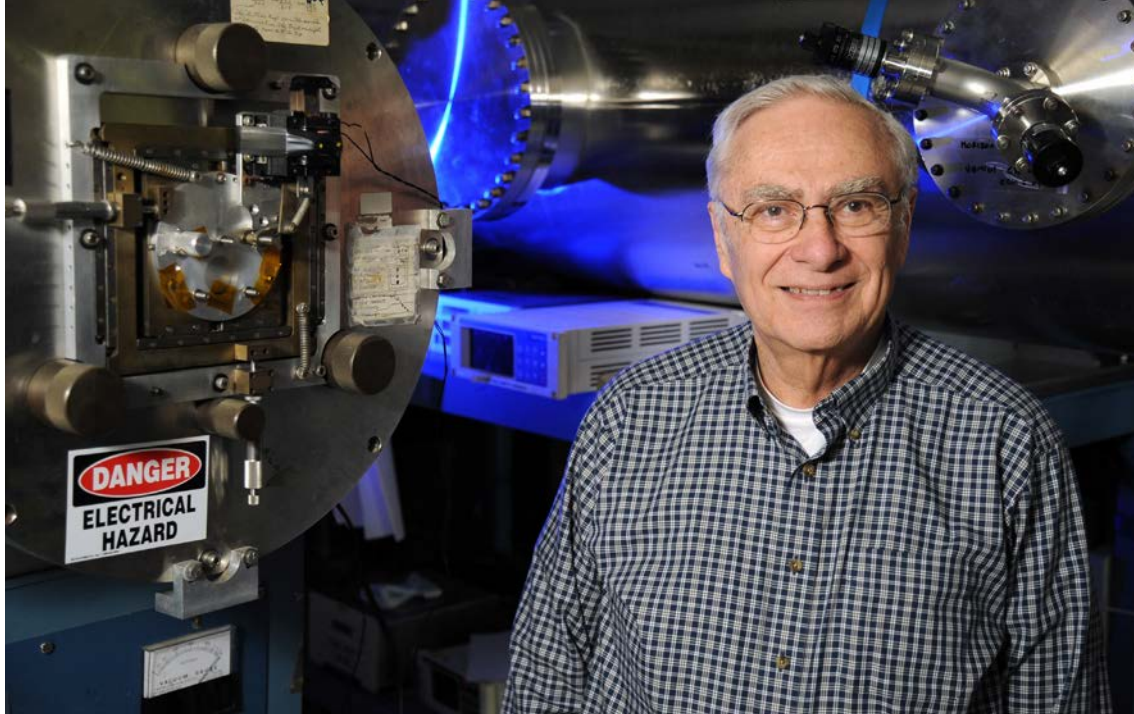
This is an award that's coming from the community, which is really nice. It's sort of an affirmation that you've done something right. It's an affirmation of this internal feeling that, "Well, I've done good here."

**Q Do you often reflect on your career and how far science and technology have advanced?**

It's just amazing how technology has really changed. On our first mission, we didn't even have computers that displayed the image. We had to print out the image on a piece of paper then color and draw isophotes around the image. We did develop a display system, which built up an image on a Polaroid camera. We still have some of those pictures. Then the idea of the displays came out and it became much easier. Who knows what it's going to be like in 10 years.

**Q Did you ever imagine you would be at NRL for 50 years?**

No way, especially compared to the younger generation now. Kids change employers every few years, and my own kids have done that. But at NRL over the years I've kept doing different things that are really exciting. The science is always different, and I'm not doing exactly the same thing I did 50 years ago. You're changing, you're evolving—and that's what NRL has enabled us to do. It's been very exciting and rewarding.



Russell Howard in working environment at U.S. Naval Research Laboratory. (U.S. Navy Photo by Jamie Hartman)

**Q** *What did you end up doing at NRL once you joined?*

Toward the end of my postdoc at NRL, I was asked to join a spacecraft group that was launching a new mission. Now, the NRL experiment on this mission had a photoelectric detector to image the solar corona, and they needed somebody to help out. The satellite launched at the end of September in 1971. In December of that year, they observed an eruption from the sun. That turned out to be what we now call a coronal mass ejection. It was a totally unknown phenomenon at that time and has become extremely important to the Navy. We then proposed a mission to fly the flight spare of that coronagraph, which had been a NASA mission, having reentered the earth's atmosphere in 1974. We proposed to fly it on the DOD [Department of Defense] Space Test Program.

**Q** *Was that second experiment just as successful as the first?*

This second experiment we conducted was called SOLWIND, and it was a satellite launched by the DOD Space Test Program. It launched from Vandenberg Air Force Base in California in 1979. With that experiment we saw a number of really important things for the first time. We observed and tracked a coronal mass ejection as it headed toward the earth. That showed us that these things are not just planar structures. They are really large things, and that had not been thought of or predicted. We modeled it as an ice cream cone. We were also able to establish the relationship between these coronal mass ejections and space weather events.

**Q** *What's been your secret to success?*

Just not accepting the general opinion about something. Just saying, "Well, this doesn't make sense. Let me explore this a little bit more." With the coronal mass ejection, there were theories saying it was due to an impulse in the corona, and that all we were seeing was an impulse of a wave being generated. We didn't think that was right. It probably was an impulse, but the main characteristic wasn't simply a result of an impulse to this complex corona but was real mass being thrown out from the sun.

**Q** *Now that you plan on retiring next year, are you trying to wrap up any long-term projects?*

It's time for others take over. I'm not retiring from science, but I do feel that I have to step down as the principal investigator for all these different instruments and let somebody else take over. But there is one project I'm still following. The LASCO [Large Angle and Spectrometric Coronagraph] experiment on the SOHO research satellite, which has become the de-facto instrument that NOAA [the National Oceanic and Atmospheric Administration] uses to observe coronal mass ejections and predict their geomagnetic impact.

**Q** *What's happening with LASCO?*

Well, what LASCO does is tell us when there's an event on the sun that's going to impact Earth. But now NOAA has finally been approved to put up a replacement mission for LASCO, which was launched in 1995, and they're building it here at NRL. It's called CCOR, which stands for Compact Coronagraph. This fall I'm going to Europe for some meetings to talk to people about collaborating on a new mission located 60 degrees off the sun-earth line. The experiment probably won't get launched until 2025 or 2026.

**Q** *What words of advice would you give to the next generation of science talent in terms of finding their way into the workforce?*

When I graduated from college, there were not many jobs available in the same discipline. But if you waited a little bit, one would come. Nowadays I don't know if it is so easy. I know that some people, if nothing was available, they would go back to school so they didn't have to change their field. I didn't even consider a job when I graduated and went straight to graduate school. With that being said, depending on your situation, be motivated by enjoying what you do in your career – do what is interesting and fun. ■

SAMINA MONDAL  
NRL CORPORATE COMMUNICATIONS

This issue of Spectra is dedicated  
in memory of



## **Herbert Charles Eppert, Jr.,**

Former Superintendent and Head of the Marine Geosciences Division,  
U.S. Naval Research Laboratory, at Stennis Space Center, Mississippi

Eppert held a doctorate in geology from Tulane University, started his federal career in 1973 as the director of the Ocean Floor Analysis Division at the Naval Oceanographic Office, and was responsible for basic and applied research in marine geology, geophysics and geochemistry in support of Navy operational oceanography program. In 1982, Eppert was appointed to be a senior executive service, leading the Ocean Science and Technology Laboratory, Naval Ocean Research and Development Activity. In 1992, he was appointed superintendent of the Marine Geosciences Division, a position he maintained until his retirement in 2018. In this role, Eppert directed a broadly based, multidisciplinary program of scientific research, advanced technology development and applied research in marine geosciences, geodesy, geospatial information and systems, and related technologies directed towards Naval, defense, and other national applications.

Eppert's passionate curiosity fueled his insatiable quest for better science for a better Navy and Marine Corps. "It's important for researchers to understand who they work for," Eppert said in 2016. "They work for the Navy. Our interaction with the young Sailors, the young aerographer's mates and team operators . . . we're not trying to teach them to be physicists, we're trying to help them understand the environment, what comes out of R&D and how they can use it."

**"If we ever build a Mt. Rushmore on the seafloor,  
you will surely find Dr. Eppert there."**

- Rear Adm. Jon White, former Commander of  
Naval Meteorology and Oceanography

## About the U.S. Naval Research Laboratory

NRL is a scientific and engineering command dedicated to research that drives innovative advances for the Navy and Marine Corps from the seafloor to space and in the information domain. NRL headquarters is located in Washington, D.C., with major field sites in Stennis Space Center, Mississippi; Key West, Florida; and Monterey, California, and employs approximately 2,500 civilian scientists, engineers and support personnel.



*A field expedition crew with Arctic Submarine Lab, loads a Bell 212 helicopter and prepares to return to Ice Camp Sargo during Ice Exercise (ICEX). (U.S. Navy photo by Aerographer's Mate 2nd Class Zachary Yanez)*

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