AOML Keynotes

NOAA'S ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORY

January-March 2023

AOML is an environmental laboratory of NOAA's Office of Oceanic and Atmospheric Research located on Virginia Key in Miami, Florida

In This Issue

AOML Celebrates 50 Years of Groundbreaking Research

AOML founder and first director Dr. Harris B. Stewart at the podium during AOML's inauguration ceremony on February 9, 1973. Photo Credit: AOML Archive.

NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) on Virginia Key in Miami, Florida officially opened on February 9, 1973. Since then, the lab has been a leader in Earth system research, providing trusted scientific data and knowledge to predict changes in weather, climate, the oceans, and marine ecosystems. From entering measurements on keypunch cards to the recent premier of a state-of-the-art data center, AOML continues to build on 50 years of experience and discoveries, fueling cutting-edge research and technological advancements.

The roots of AOML, however, stretch farther back than five decades. They began with the founding of the Environmental Science Services Administration (ESSA) in July 1965, a new federal agency housed within the Department of Commerce. Soon thereafter, ESSA created an Institute of Oceanography with Dr. Harris B. Stewart, the chief oceanographer of the Coast and Geodetic Survey, as its new director.

Stewart was appointed as chairman of ESSA's Site Evaluation Committee after a 1966 notice in *Commerce Business Daily* asserted the agency's intention to build an oceanographic research laboratory and ship base along the eastern seaboard. The announcement sparked widespread interest, as local officials from Maine to Florida, even the Virgin Islands, competed for the chance to showcase their community.

Throughout 1966 and into 1967, Stewart and his team visited more than 115 potential sites, including several locations in Florida—Jacksonville, Port Canaveral, Fort Pierce, Port Everglades, and Miami. Miami's Dade County delegation wooed the committee by offering Miami Beach, Fisher Island, Watson Island, Dodge Island, and Virginia Key as possible sites for the new facilities. **cont. page 2** *continued from page 1*

In April 1967 the committee chose Virginia Key as the site for the new lab, with Dodge Island as its accompanying ship base. A few months later, more than 100 scientists, technicians, and administrative staff from the Institute of Oceanography in Silver Spring, Maryland moved to Miami with Stewart to be part of the new lab, working out of rented office space on South Miami Avenue.

The "Institute" level of organization was abolished shortly after their arrival, and the name of the Miami-based group changed to the Atlantic Oceanographic Laboratories or AOL. The reorganization into AOL of two local meteorological groups in 1968—the National Hurricane Research Laboratory and the Experimental Meteorology Laboratory—necessitated a name change to the Atlantic Oceanographic and Meteorological Laboratories. These groups were later transferred out of AOML, but staff with the National Hurricane Research Laboratory returned in 1983 as the Hurricane Research Division.

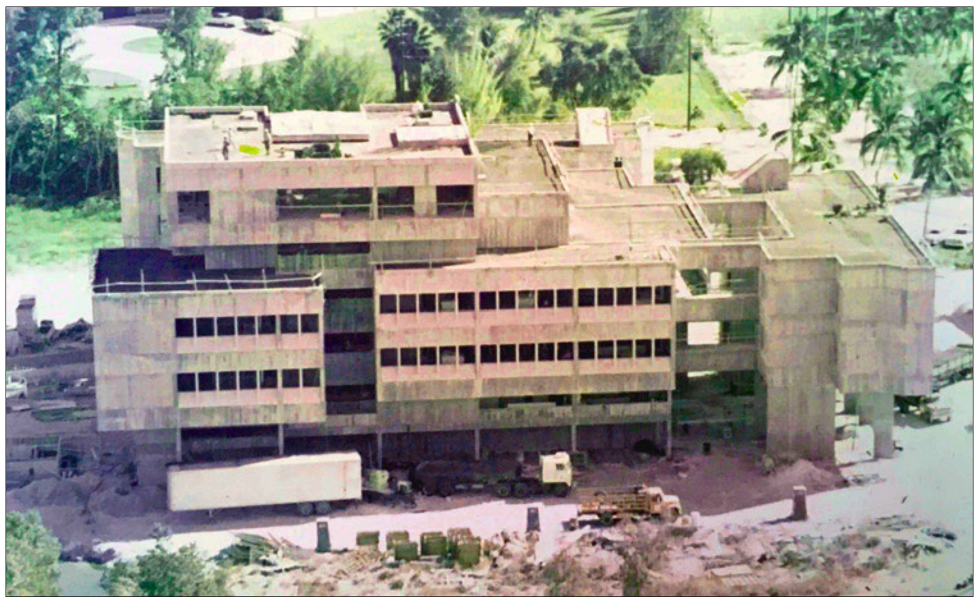
Groundbreaking ceremonies kicked off in October 1970, just 2 weeks after a new federal agency called the National Oceanic and Atmospheric Administration replaced ESSA. Dedication ceremonies for the AOML facility were held 3 years later, heralding the start of a new era.

AOML's early research focused on studies of physical oceanography, sea-air interactions, and ocean remote sensing. The lab's science portfolio was also augmented by marine geology, marine geophysics, and seafloor sedimentation studies that contributed to a better understanding of continental drift, plate tectonics, and seafloor spreading. Marine geologists at AOML additionally led the expedition that discovered deep sea "black smokers," or hydrothermal vents, along the Mid-Atlantic Ridge and the life forms that thrived in total darkness and heated water.

Marine geology and geophysics transitioned to research still ongoing today on the large-scale physics and chemistry of the ocean related to climate variations and global change, as well as studies on the nature and mechanisms of tropical cyclones.

AOML's current research focuses on the Atlantic Ocean region to inform the accurate forecasting of extreme weather and ocean phenomena, the management of marine resources, and an understanding of climate change and its associated impacts, improving ocean and weather services for Florida, the nation, and the world.

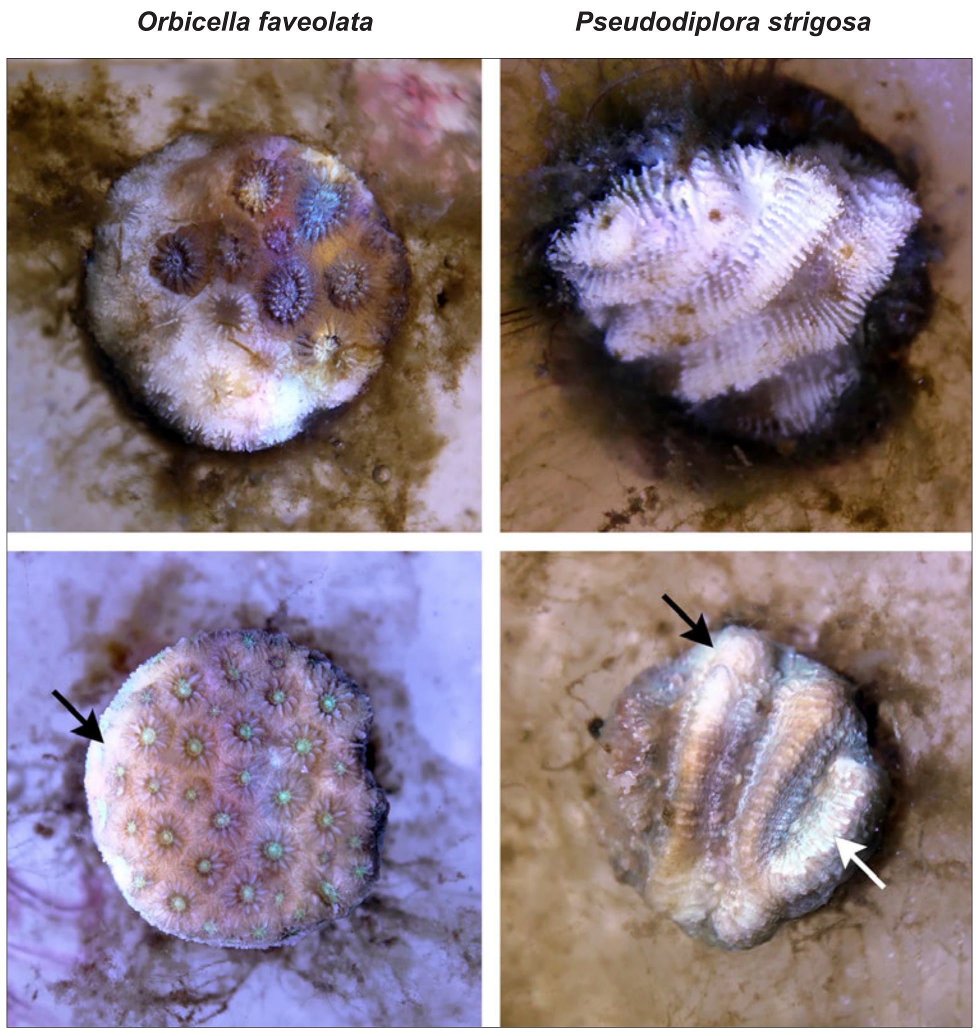
WPLG Channel 10 reporter Molly Turner interviews Harris Stewart in October 1970 following groundbreaking ceremonies for construction of the new AOML facility. Photo credit: AOML archive.



AOML under construction, circa September 1971. Photo credit: AOML archive.

Front view of AOML, circa October 2022. Photo credit: AOML.

Spread of Deadly Coral Disease Linked to Ship Ballast Water



Examples of disease lesions on *Orbicella faveolata* (left) and *Pseudodiplora strigosa* (right) fragments following contact with disease-exposed water. *O. faveolata* fragments typically exhibited a rapid onset of necrosis/tissue loss following initial exposure to SCTLD (top left) and/or paling/bleaching margins (bottom left, indicated by arrow). *P. strigosa* fragments demonstrated a rapid progression (<24 hours) of tissue loss once lesions were first observed (top right), with a less frequent occurrence of paling/bleaching lesions (bottom right, indicated by arrows) (from Studivan *et al.*, 2022).

Recent research suggests a deadly disease that has decimated coral reefs throughout Florida and the Caribbean may be spreading due to ballast water stored in the hulls of ships. As ships take on ballast water from one area and release the water into another to offset the transfer of cargo, they may be inadvertently transmitting the disease to distant locales. This finding may help to explain why the disease has surfaced on some isolated reefs.

Stony coral tissue loss disease, or SCTLD, first appeared in the coastal waters of Miami in 2014. Since then, it has spread unabated across Florida's 350-mile long coral reef tract and into the Caribbean, impacting reefs in Jamaica, St. Maarten, the Dominican Republic, US Virgin Islands, and Belize, among others.

The disease is characterized by the rapid onset of blotches or bands of bleached tissue that affect at least 22 species of reef-building corals. These lesions typically lead to tissue loss and colony mortality in a matter of days to weeks. Although the source of the disease has yet to be identified, a waterborne pathogen dispersed by ocean currents is considered the most likely culprit.

Scientists at AOML, the University of Miami's Cooperative Institute for Marine and Atmospheric Studies, and other partners conducted an experiment to evaluate the potential for the transmission of SCTLD by simulated ballast water. They also conducted an experiment to evaluate the effectiveness of an ultraviolet radiation treatment of water for its ability to prevent disease transmission.

Two reef-building coral species, *Orbicella faveolata* and *Pseudodiploria strigosa,* were subjected to disease-exposed, ultraviolet-treated disease-exposed, and non-disease-exposed simulated ballast water in aquaria housed in AOML's Experimental Reef Lab. The results of these experiments, published in *Scientific Reports,** revealed SCTLD can be transported through ballast water, without direct contact occurring between diseased and healthy corals.

"Outbreaks in very distant locations suggest that disease transport is aided by means other than just ocean currents, such as through ship ballast water," said Michael Studivan, PhD, a University of Miami-Cooperative Institute researcher at AOML and the lead author of the study. "The results of our experiments imply that ballast water may pose a threat to the continued persistence and spread of SCTLD throughout the Caribbean, and perhaps to coral reefs in the Indo-Pacific."

Although ultraviolet radiation reduced the number of corals exhibiting signs of SCTLD by 50 percent in both coral species, it failed to significantly reduce the risk of lesion formation. The experiments showed that the pathogens responsible for SCTLD can persist in both untreated and ultraviolet-treated ballast water and remain pathogenic.

Further study is warranted to develop additional ballast water treatment and pathogenic detection methods to mitigate the persistence and transmission of this deadly disease.

The study was funded through an Environmental Protection Agency agreement with the Naval Research Laboratory, NOAA's Coral Reef Conservation and 'Omics programs, the Louisiana Board of Regents Research Support Fund Research Competitiveness Subprogram, and the National Science Foundation's Ecology and Evolution of Infectious Disease program.

*Studivan, M.S., M. Baptist, V. Molina, S. Riley, M. First, N. Soderberg, E. Rubin, A. Rossin, D. Holstein, and I.C. Enochs, 2022: Transmission of stony coral tissue loss disease (SCTLD) in simulated ballast water confirms the potential for ship-borne spread. *Scientific Reports*, 12:19248, https://doi.org/10.1038/s41598-022-21868-z.

Four Decades of Coral Research Leads to Discovery for Tropical Pacific Reefs

Ana Palacio-Castro surveys a tropical eastern Pacific reef dominated by *Pocillopora* corals. Photo Credit: Viktor Brandtneris.

Global warming is causing the loss of coral reefs worldwide, as a result of heat-induced coral bleaching and subsequent mortality. Some coral reefs exposed to heat stress, however, develop a tolerance to bleaching events, possibly due to changes in their symbiotic algae communities.

Over the past 40 years, scientists with the University of Miami's Cooperative Institute for Marine and Atmospheric Studies, AOML, and partners have monitored reefs in the eastern tropical Pacific region, culminating in an interesting discovery. According to new research reported in the *Proceedings of the National Academy of Sciences**, a heat-tolerant algae found in some tropical Pacific corals can make reefs more resilient to heatwave events.

Researchers examined four decades of temperature, coral cover, bleaching, and mortality data from three mass bleaching events, along with symbiont community data from the last two events. They found that a symbiont algae helped corals better tolerate heat stress, increasing their resilience to warming ocean temperatures.

It became clear that reefs in this region had become less susceptible to heat stress after the 1982-1983 El Niño event, which caused catastrophic mortality. Following the more recent El Niño events of 1997-1998 and 2015-2016, the negative impacts on coral cover were relatively mild.

Using sea surface temperature data, researchers found that the heat stress levels the corals experienced during the three strong heat waves in 1982-1983, 1997-1998, and 2015-2016 were similar and, therefore, could not explain the lower coral mortality in the latter events. This discovery prompted scientists to wonder what changed between the first and second El Niño events that enabled corals to become more resilient.

To assess how different coral species responded to all three heat stress events, researchers collected coral bleaching and mortality data using health assessments of individual coral colonies before and during the heatwaves. They discovered that the most dominant reef-building coral in the region, *Pocillopora*, was among the most heat-susceptible corals during the 1982-1983 El Niño, but among the most heat resistant corals during the 1997-1998 and 2015-2016 heatwaves.

To learn why this coral genus was more resistant to heat stress, tissue samples were collected from tagged coral colonies before and after the last two heatwaves, and DNA analyses were used to study the types of symbiotic algae hosted in these corals. The analysis showed that one of the two *Pocillopora* coral species had increased thermal tolerant algal symbionts (*Durusdinium glynnii*) following the heat stress event in 2015-2016. This specific lineage of *Pocillopora* coral experienced less bleaching and less overall mortality compared to the other lineage that did not acquire *Durusdinium glynnii*.

Climate change projections were used to anticipate the amount of heat stress these reefs would experience in the coming decades. Using these projections, Ana Palacio-Castro, PhD, a University of Miami-Cooperative Institute scientist at AOML and primary author of the study, determined that some coral reefs in the eastern tropical Pacific could retain high coral cover through the 2060s.

"However, the time frame from now until the 2060s acts as a 'buffer' period where steps must be taken to reduce global emissions and improve our understanding of the climate change system," said Palacio-Castro. "Without any changes, these reefs will experience entirely new levels of heat stress they may not be equipped to tolerate."

The results of this study revealed a mechanism by which some reefs can become more resilient to ocean warming than previously thought. The accessibility of four decades of coral reef monitoring data provided researchers with the information they needed to make this groundbreaking discovery, demonstrating the importance of monitoring coral reef ecosystems over time and showing how long-term data can help scientists answer complex questions about the marine environment.

This research provides a glimmer of hope for the reefs of the eastern tropical Pacific, stimulating a continued commitment to reef conservation and climate action.

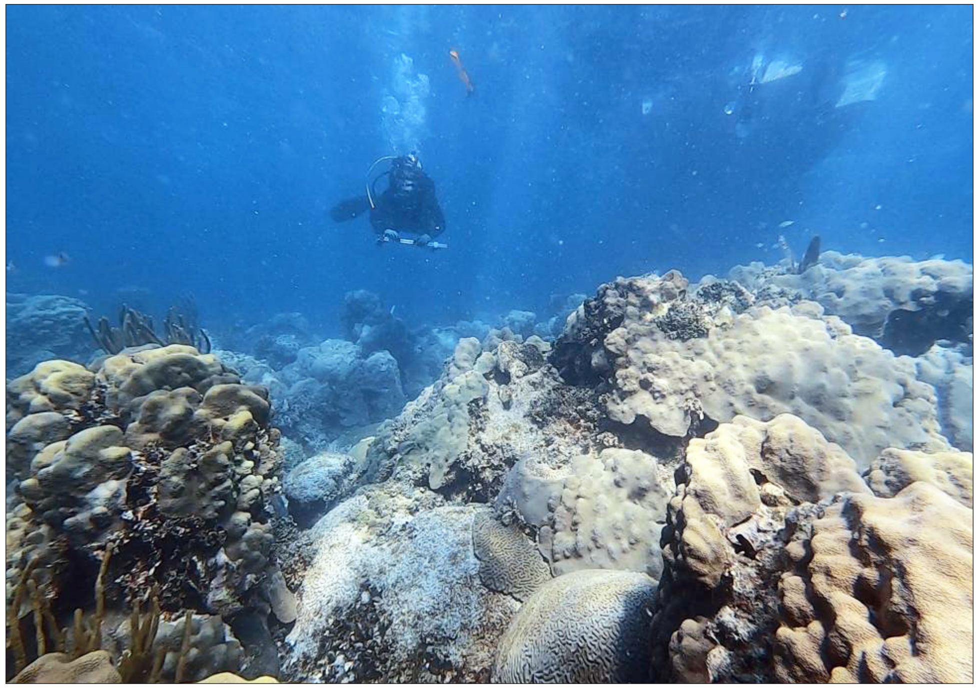
*Palacio-Castro, A.M., T.B. Smith, G.A. Snyder, V. Brandtneris, R. van Hooidonk, J.L. Maté, D. Manzello, P.W. Glynn, P. Fong, and A.C. Baker, 2023: Increased dominance of heat-tolerant symbionts creates resilient coral reefs in near-term ocean warming. *Proceedings of the National Academy of Science,* 120(8):e2202388120, https://www.pnas.org/doi/10.1073/pnas.2202388120.

Monitoring Framework Established for Evaluating Reef Persistence under Climate Change, Ocean Acidification

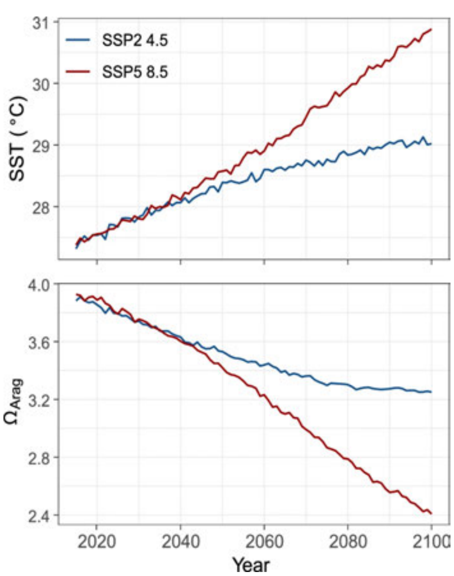
Coral scientists at AOML and the University of Miami-Cooperative Institute for Marine and Atmospheric Studies have developed a new modeling approach for evaluating coral reef persistence under climate change and ocean acidification scenarios. This new framework was created as a tool to assist coral reef scientists and managers in addressing the increasing vulnerability of these vital ecosystems.

A carbonate budget measures the net carbonate production of a given reef environment. Carbonate production is a vital tool that corals possess, as it essentially builds their internal skeleton, enabling corals to build entire reefs. Each coral polyp, which is an invertebrate organism, secretes this skeleton-forming material, known as calcium carbonate.

Calcium carbonate helps reefs survive and thrive, but it is also what is easily broken down by increasingly warm and acidic ocean conditions. Warmer waters cause the colorful symbiotic algae organisms known as zooxanthellae to be expelled from corals, leaving them looking white or bleached. Ocean acidification occurs primarily from increased amounts of carbon dioxide being absorbed by the oceans. This increased absorption of carbon is due to the burning of fossil fuels and lowers the pH of ocean water, making it more acidic. This acidity makes it harder for corals to form their calcium carbonate skeletons, limiting or halting the formation of reef-building corals.



An AOML Coral Program diver floats above a reef while collecting data at the Cheeca Rocks site in the Florida Keys. Photo credit: NOAA-AOML.



Two graphs show the relationship between sea surface temperature (SST) and aragonite saturation rate (Ω_{Arag}) under different emission scenarios. Aragonite saturation rate is the measure of calcium carbonate that corals need to form their skeletons. The blue line represents a highly ambitious but plausible scenario where emissions are reduced, often referred to as the "middle of the road scenario." The red line represents a high emissions scenario. In both graphs, SST rises and aragonite saturation rate decreases, making it difficult for reef-building corals to propagate (from Webb *et al.*, 2023).

This new approach, recently published in *Scientific Reports**, provides a technique behind a user-friendly tool for managers to explore the persistence of their reefs of interest and to evaluate the potential impact of local initiatives to mitigate the effects of ocean warming and acidification.

"We started this project because decision makers are limited by a lack of predictive tools used to assess regional responses under future climate change," said Alice Webb, a University of Miami-Cooperative Institute post-doctoral scientist at AOML and lead author of the study. "To address these challenges, we created a new tool for the successful management of coral restoration initiatives."

The new framework will enable scientists and conservationists to evaluate reef persistence under scenarios of ocean warming and ocean acidification, while exploring the outcomes of different restoration targets. It was first applied to Cheeca Rocks, an outlier reef in the Florida Keys in terms of high coral cover, carbonate production, and an abundance of the vulnerable mountainous star coral (*Orbicella faveolata*). The site is a National Coral Reef Monitoring Program sentinel site, as well as a reef targeted for the Mission: Iconic Reefs initiative.

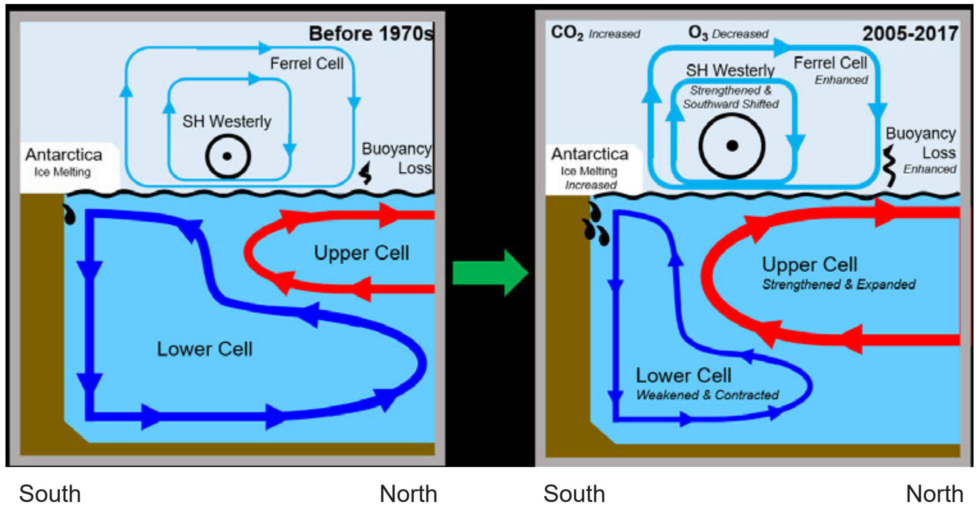
The effects of coral thermal adaptation in the context of climate change was also examined by increasing the bleaching threshold of corals. Results from this study show that regardless of coral restoration or adaptative capacity, net carbonate production at the Cheeca Rocks site declines once the threshold for annual severe bleaching is reached. Scientists believe that a combination of restoration efforts and coral thermal adaptation have the potential to delay the onset of mass bleaching mortalities at Cheeca Rocks, supplying the time needed until a low-carbon economy is implemented.

*Webb, A.E., I.C. Enochs, R. van Hooidonk, R.M. van Westen, N. Besemer, G. Kolodziej, T.S. Viehman, and D. Manzello, 2023: Restoration and coral adaptation delay, but do not prevent, climate-driven reef framework erosion of an inshore site in the Florida Keys. *Scientific Reports,* 13:258, https://doi.org/10.1038/s41598-022-26930-4.

Reshaping of Meridional Overturning Circulation Detected in Southern Ocean

Scientists at AOML have shown that the Global Meridional Overturning Circulation (GMOC), commonly known as the global ocean conveyor belt, has changed significantly in the Southern Ocean since the mid-1970s, with a broadening and strengthening of the upper overturning cell and a contraction and weakening of the lower cell. These changes are attributed to human induced ozone depletion in the Southern Hemisphere stratosphere and to increased carbon dioxide in the atmosphere. The study in *Communications Earth & Environment** also shows that the changes in the Southern Ocean are slowly advancing into the South Atlantic and Indo-Pacific oceans.

Global Ocean Conveyor Belt is Reshaping from the Southern Ocean



Schematics of the Meridional Overturning Circulation in the Southern Ocean before the 1970s (left panel) and from 2005–2017 (right panel). Major changes in the GMOC and associated increases in the Southern Hemisphere (SH) Ferrel cell, westerly winds, and Antarctic meltwater discharge, as well as surface buoyancy flux changes, are also indicated in the right panel.

The GMOC is a system of ocean currents that moves heat, freshwater, nutrients, and carbon around the global ocean. As the ocean warms and polar ice sheets melt due to increasing levels of carbon in the atmosphere, near-surface stratification, the separation of a body of water into layers by density, is also increasing. This enhanced near-surface stratification inhibits the sinking of warm surface waters into the deep ocean.

As a result, the GMOC is expected to change significantly, posing a risk of disrupting the redistribution of heat, salt, nutrients, and carbon between the northern and southern hemispheres and across ocean basins. Human populations would be directly impacted by changes in coastal sea levels, marine ecosystems, extreme weather events, and shifts in regional weather and global climate.

Numerous studies based on repeated hydrographic observations have suggested that significant changes in the GMOC have already occurred during recent decades. However, unlike in the Atlantic Ocean where several observing systems are presently in place, it is not currently possible to directly measure the Meridional Overturning Circulation (MOC) spanning the entire Southern Ocean due to its large size and location. Additionally, the majority of the current climate and ocean models fail to accurately reproduce the mean state or long-term trends of the MOC in the Southern Ocean.

"We are still in the dark while significant shifts in the MOC, likely due to human activity, are currently in progress in the Southern Ocean and neighboring regions where there are no direct measurements and climate models are failing," said Sang-Ki Lee, PhD, an AOML scientist and lead author of the study.

Scientists from AOML, the Northern Gulf Institute, National Center for Atmospheric Research, and the University of Miami used a diagnostic ocean and sea-ice model to estimate changes to the GMOC since the mid-1950s that were consistent with historical hydrographic observations. They found that the Southern Ocean's upper overturning cell has strengthened its flow by 50-60 percent and expanded poleward into denser water.

These changes are largely due to ozone depletion in the Southern Hemisphere stratosphere and an associated increase in Southern Hemisphere westerly winds and a loss of surface buoyancy. The depletion of the ozone layer causes the stratosphere to cool, resulting in stronger westerly winds in the region.

Conversely, the lower overturning cell has weakened its flow by 10-20 percent and contracted during the same period, due to the increased melting of Antarctic ice sheets driven by increasing carbon dioxide (CO_2) in the atmosphere. When ice sheets melt into the ocean, surface waters are fresh and light instead of salty and dense. This fresh water is unable to sink into the deep ocean, which has led to a weakening of the lower cell.

These changes, summarized in the schematic images above, have important implications for the ocean's uptake of anthropogenic carbon. The strengthening and expansion of the upper cell may bring more natural carbon stored in the deep ocean for hundreds to thousands of years to the surface. When the concentration of dissolved carbon at the surface is too high, it is released into the atmosphere through a process known as CO_2 outgassing.

At the same time, the weakening and contraction of the lower cell may allow for less sinking of carbon dioxide into the deep ocean, leading to reduced anthropogenic carbon uptake. Both processes increase anthropogenic carbon concentrations in the atmosphere and thus accelerate global warming.

This is the first study to report, based on historical global hydrographic observations, that a significant reshaping of the GMOC has already emerged in the Southern Ocean due to human activity. Additionally, a large-scale readjustment of the GMOC seems to be underway in the South Atlantic and Indo-Pacific oceans during the most recent decade (2005-2017) in response to changes in the Southern Ocean.

*Lee, S.-K., R. Lumpkin, F. Gomez, S. Yeager, H. Lopez, F. Tagklis, S. Dong, W. Aguiar, D. Kim, and M. Baringer, 2023: Human-induced changes in the global meridional overturning circulation are emerging from the Southern Ocean. *Communications Earth & Environment*, 4:69, https://doi.org/10.1038/s43247-023-00727-3.

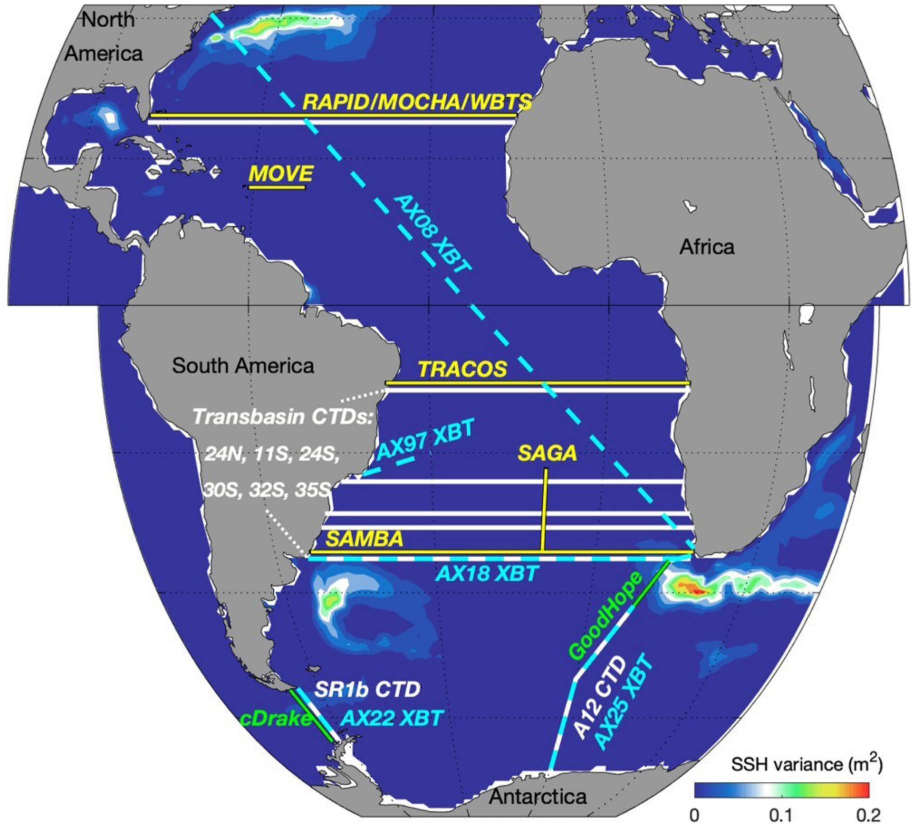
SAMOC Initiative Advances South Atlantic's Unique Role in Global Overturning Circulation, Push toward Inclusive Science

Since the inception of the international South Atlantic Meridional Overturning Circulation (SAMOC) initiative in 2007, substantial advances have been made in observing and understanding the South Atlantic component of the Atlantic Meridional Overturning Circulation or AMOC. In addition to these advances, major strides have also been made toward developing a more balanced and inclusive approach to science.

The SAMOC executive committee was created by four scientists, including Silvia Garzoli, PhD, a former director of AOML's Physical Oceanography Division. The committee was structured to provide equal participation from the northern and southern hemispheres and an equal representation of male and female scientists. As the initiative developed and grew, the committee added senior and mid-career scientists from all four continents that bound the Atlantic.

The AMOC plays a critical role in redistributing heat, salt, dissolved oxygen, nutrients, and carbon throughout the global climate system, and variations in its strength have been shown to have direct societal impacts on coastal sea levels, marine heat waves, extreme weather events, and shifts in regional weather and global climate.

The SAMOC network of internationally coordinated observations from long-term programs and newly-developed analysis techniques have shown the South Atlantic has warmed from its surface to the deep ocean, upper ocean salinity has increased, and that intermediate, deep water masses are freshening. It is the only ocean basin that transports heat toward the equator instead of toward the poles.



The SAMOC observing system, with links to AMOC-related observing systems in other ocean basins via inter-ocean exchanges. Moored transport arrays in the tropical and subtropical Atlantic appear as yellow solid lines. Past AMOC-related arrays in the Drake Passage (cDrake) and south of South Africa (GoodHope) appear as green solid lines. Repeat expendable bathythermograph (XBT) transects are denoted by dashed light blue lines, and repeated conductivity-temperature-depth (CTD) lines are denoted by white solid lines. Color shading indicates elevated regions of sea surface height (SSH) variance in units of m^2, i.e., regions with strong eddies and high mesoscale variability (from Chidichimo *et al.*, 2023, https://doi.org/10.1038/s43247-022-00644-x).

Recent studies also suggest a reduction in the strength of the AMOC due to anthropogenic warming could lead to additional surface warming and salinification in the South Atlantic. Monitoring these water mass changes and how they are driven by spatially-varying AMOC changes is an ongoing priority for South Atlantic research.

The SAMOC initiative's observing programs are led by researchers from more than nine countries that span a wide range of career stages, including scientists at AOML who support the initiative's goals to monitor climatically relevant oceanic fluxes of mass, heat, and freshwater, provide observations to validate and improve numerical models and climate predictions, and understand the impacts of SAMOC on climate and weather.

What began as a grassroots effort to study the South Atlantic Ocean has also become a platform for the empowerment of women and international scientists. In addition to creating an inclusive and diverse environment, the SAMOC initiative community aims to build capacity in the marine sciences. Although there is still progress to be made, the program has created a unique space where scientists spanning several generations from different backgrounds and countries of origin work together toward achieving a shared research mission.

SAMOC Initiative members attended the fifth SAMOC Workshop in Buenos Aires, Argentina in December 2014 (from Perez *et al.*, 2023, https://rdcu.be/c3M2s).

Dropsonde Data Assessed for Impact on Hurricane Forecasts

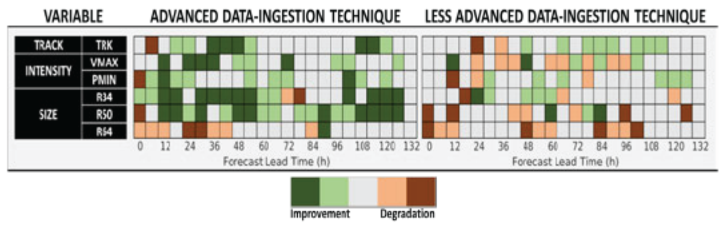
A regional hurricane model was used to conduct the most comprehensive assessment of the impact of dropsondes on tropical cyclone forecasts to date. Dropsonde data can improve many aspects of tropical cyclone forecasts if they are assimilated into forecast models with sufficiently advanced techniques. Particularly notable is the impact of dropsonde data on tropical cyclone significant-wind-radii forecasts, since improving those forecasts leads to more effective hazard forecasts.

Reconnaissance aircraft fly into and around tropical cyclones to collect data for hurricane specialists to better understand what is happening in the storm environment and for use in computer forecast models. One instrument, the Global Positioning Satellite (GPS) dropsonde, is a single-use instrument launched from Hurricane Hunter aircraft to record data like pressure, temperature, humidity, and wind velocity as they fall to the Earth's surface.

Dropsondes are valuable since they enable data collection in regions where it is too dangerous to fly, e.g., turbulent regions near the surface, and in areas that are not observed by satellites, e.g., within clouds and at the surface. Overall, previous research has generally found that dropsonde data improve tropical cyclone track and intensity forecasts in a wide variety of computer models.

Yet, a major shortcoming of those studies is that there are rarely enough forecasts to get a fully accurate picture of the impact of the dropsonde data, especially given differences that exist from year-to-year, tropical cyclone-to-tropical cyclone, and even forecast-to-forecast. To address these shortcomings, researchers with the University of Miami's Cooperative Institute for Marine and Atmospheric Studies and AOML assessed the overall impact of dropsonde data on tropical cyclone forecasts of track, intensity, and significant wind radii. In doing so, the study* represents the most comprehensive assessment of the impact of any airborne-observing system on tropical cyclone forecasts to date.

Two sets of computer forecasts were compared: one that ingested, and another that did not ingest, dropsonde observations. These experiments used an experimental version of NOAA's Hurricane Weather Research and Forecasting model and covered active North Atlantic basin periods during the 2017–2020 hurricane seasons.



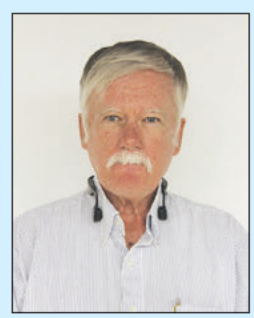
Impact of dropsonde data on tropical cyclone forecasts by forecast lead time for five variables: TRK (row 1, track); two measures of tropical cyclone intensity: maximum sustained wind speed at 10-m altitude (row 2, VMAX) and minimum sea level pressure (row 3, PMIN); and three significant surface wind-speed radii reported by the National Hurricane Center: 34-kt wind-speed radii (row 4, R34), 50-kt wind-speed radii (row 5, R50), and 64-kt wind-speed radii (row 6, R64). Shaded boxes indicate forecast lead times where results showed consistent improvement (green) or degradation (rust) (from Ditchek *et al.*, 2023: Best-track verification of tropical cyclones: A new metric to identify forecast consistency. *Weather and Forecasting*, https://doi.org/10.1175/WAF-D-22-0168.1).

As the only difference between these experiments was whether dropsonde data were ingested, differences in the forecasts highlighted their impact. The study demonstrates the importance of using a large, diverse sample of forecasts and closely examining the forecasts when evaluating the impact of observing systems, new modeling systems, or model upgrades on tropical cyclone forecast performance. Improving how observational data are ingested into forecast models and reducing limitations in observing systems will also likely enhance dropsonde data impacts.

While some consistent track and intensity improvements were found, the most consistent improvement from dropsonde data was to forecasts of the extent of the tropical-storm-force wind (34 kt) and storm-force wind (50 kt). This is notable since improving those forecasts leads to more effective tropical cyclone hazard forecasts. On the other hand, forecasts of the hurricane-force wind-speed radii (64 kt) were degraded by the dropsonde data if the area within 150 km of the tropical cyclone center was not adequately observed. These results suggests ways to improve how tropical cyclones are sampled by aircraft in the future.

*Ditchek S.D., J.A. Sippel, G.J. Alaka Jr., S.B. Goldenberg, and L. Cucurull, 2023: A systematic assessment of the overall dropsonde impact during the 2017-2020 hurricane seasons using the basin-scale HWRF. *Weather and Forecasting*, https://doi.org/10.1175/WAF-D-22-0102.1.

AOML Mourns the Loss of Hurricane Scientist Peter Dodge



AOML was saddened by the sudden and tragic loss of one of its longtime meteorologists, Peter Dodge, who died peacefully on March 3. Peter's research interest was in radar meteorology, especially observations of tropical cyclones. He had advanced expertise in radar technology and collaborated with the National Hurricane Center and Aircraft Operations Center on both land-based and airborne radar research.

Over his long and distinguished career, including celebrating 44 years of federal service on February 23, Peter was the recipient of a Department of Commerce Bronze Medal, two NOAA Administrator Awards, and the Army Corp of Engineers Patriotic Civilian Service Award. He additionally received a Department of Commerce Gold Medal as part of a Hurricane Research Division group award and an Interdepartmental Hurricane Conference Public Service Award for distinguished service to the state of Mississippi and the nation during the 1998 hurricane season.

Before becoming a meteorologist, Peter was a Peace Corp volunteer who taught math and science to students at a rural high school in Nepal. He began his meteorological career by working in a NOAA coopertive program at the Prototype Regional Observing and Forecasting System in Boulder, Colorado, subsequently earning an MS degree at the University of Washington. During hurricane seasons, Peter participated in hurricane aircraft missions, serving as the onboard radar scientist and conducting radar analyses, later becoming an expert in radar data processing. Despite his progressive visual limitations, Peter continued to play a role in the AOML's annual hurricane field program by designing flight modules for the Hurricanes at Landfall experiments and coordinating with research landfall teams to gather data with mobile weather platforms.

Peter was a friend to many at AOML and enjoyed discussions of current events, books, music, and radar technology. He will be dearly missed by those in the various work, aikido, bamboo, mindfulness and wellness, and blindness communities he cultivated.

Scientists Examine Hurricane Dorian's Track Forecast Uncertainties

Scientists at AOML and the University of Miami's Cooperative Institute for Marine and Atmospheric Studies analyzed the large spread in Hurricane Dorian's track forecasts to learn why some models performed better than others. The paper, published in *Monthly Weather Review**, examined a collection, or ensemble, of hurricane model runs for Dorian with two objectives: determine the usefulness of ensembles for understanding how hurricanes move; and review the atmospheric weather systems around Dorian to better understand their impact on the storm's path.

Hurricane Dorian made landfall in the Bahamas as a Category-5 hurricane with maximum sustained winds of 185 mph in September 2019. The largest period of uncertainty in its track occurred as the catastrophic storm slowly approached the Bahamas and east coast of Florida. Some early forecasts showed Dorian moving directly into or across Florida, while other forecasts correctly showed Dorian stalling over the Bahamas and then making a turn to the north.

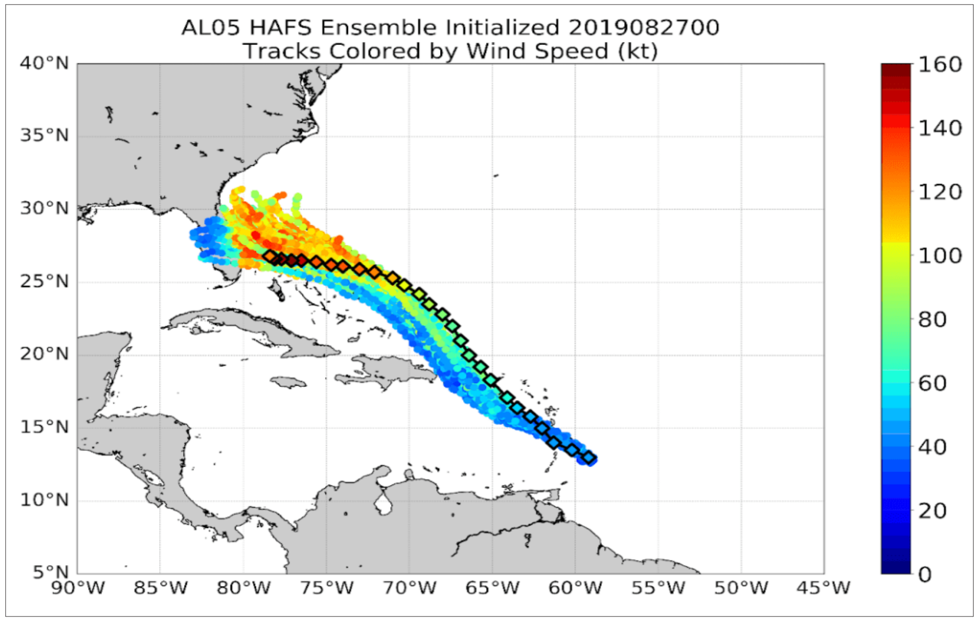
To better understand these forecast uncertainties, a set of 80 ensemble forecasts were produced using the new Hurricane Analysis and Forecast System model (see image, top right). Since it isn't possible to measure what is happening everywhere in the atmosphere, each ensemble member was programmed to start at the same time but with slightly different weather conditions.

Atmospheric weather features such as high- and low-pressure systems determine where hurricanes travel (see images below). The study reviewed the differences between ensemble members to determine which ones caused Dorian's track to differ. While some ensemble members correctly predicted where Dorian would move, others did not due a failure to accurately account for the large-scale weather features at play.

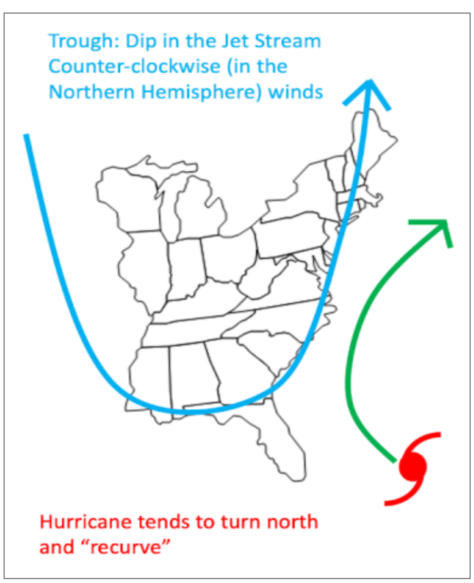
"This study shows how the Hurricane Analysis and Forecast System model can be used as a research tool to understand the complexities involved with hurricane forecasting," said Andrew Hazelton, lead author of the study and a Cooperative Institute scientist at AOML. "It also shows the power of large ensembles to predict and understand the large-scale weather patterns that steer hurricanes."

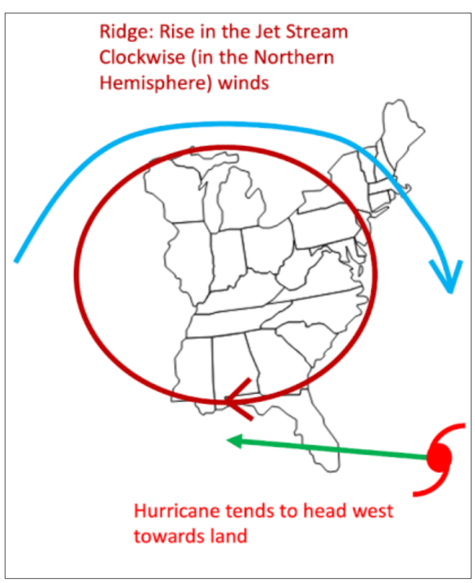
A special sensitivity analysis applied to the 80-member ensemble helped determine which large-scale weather features at different time periods in the forecast were the most critical to Dorian's track. It showed that the strength of a ridge of high pressure over the western Atlantic to the north of Dorian, as well as an upper-level trough of low pressure over the eastern US, both played a role in steering Dorian over the Bahamas. These two features were better forecast by the ensemble members that correctly showed Dorian would stall and turn northward.

Accurate track modeling over 5- to 7-day periods provides vital information to researchers, decision makers, and the public. This study demonstrated the effectiveness of ensemble datasets for studying tropical cyclone track forecasts, as well as the importance of accounting for large- and small-scale steering features to better predict the track of tropical cyclones.



Model runs of Hurricane Dorian's track for all 80 HAFS ensemble members, with colors denoting Dorian's maximum sustained wind speed. The diamonds represent Dorian's observed track and intensity (from Hazelton *et al.*, 2022).





Tropical cyclones are steered or pushed by the atmospheric flow around them. These schematic images show how troughs and ridges affect where they will travel. Image credit: NOAA-AOML.

*Hazelton, A., G.J. Alaka Jr., M. Fischer, R. Torn, and S. Gopalakrishnan, 2022: Factors influencing the track of Hurricane Dorian (2019) in the west Atlantic: Analysis of a HAFS ensemble. *Monthly Weather Review,* 151(1):175-192, https://doi.org/10.1175/MWR-D-22-0112.1.

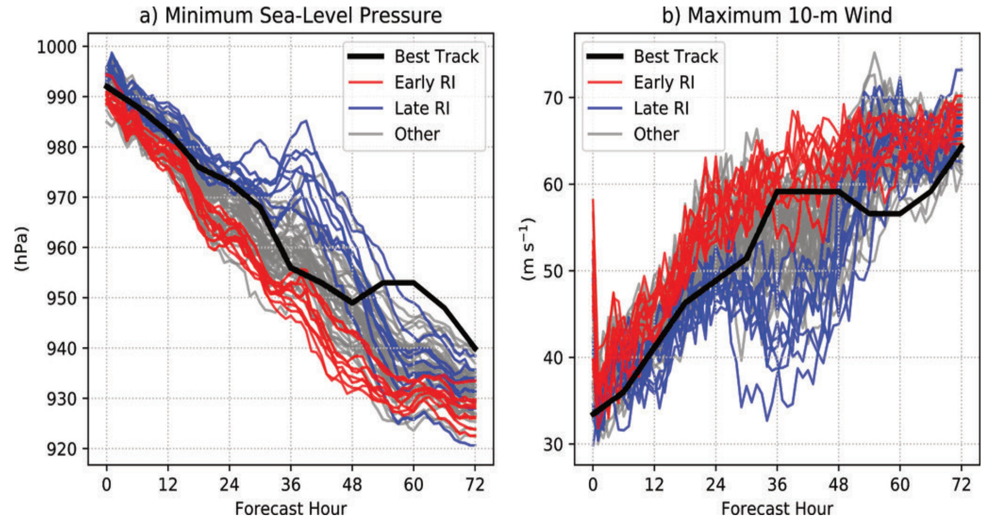
Study Explores Vertical Wind Shear's Impact on Tropical Cyclone Intensity Change

A study published in *Monthly Weather Review** examined the challenges of accurately predicting when a tropical cyclone will undergo rapid intensification, or RI, a quick and sudden increase in intensity. Scientists at AOML, the Cooperative Institute for Marine and Atmospheric Studies, Northern Gulf Institute, and State University of New York analyzed a group, or ensemble, of computer model forecasts during an actual rapid intensification event to better understand the process.

An important factor that controls how intense a tropical cyclone will become is vertical wind shear, or the difference in wind velocity between the top and bottom levels of a storm. High wind shear limits the ability of thunderstorms to organize around the tropical cyclone center, which hinders intensification. Moderate wind shear can allow a tropical cyclone to intensify, sometimes rapidly, but it may also weaken a tropical cyclone, making these storms difficult to forecast.

To better understand why some tropical cyclones experience rapid intensification in environments of moderate wind shear, researchers analyzed an ensemble of 60 computer model forecasts of Hurricane Gonzalo (2014), an Atlantic tropical cyclone that struck the island of Bermuda in October 2014. Gonzalo rapidly intensifed from a tropical storm to a major hurricane with winds above 110 mph.

"This project began as the last part of my PhD thesis in 2018 at the University at Albany," said Michael Fischer, PhD, lead author of the study and a University of Miami-Cooperative Institute Assistant Scientist at AOML. "Once I started working at AOML after graduate school, this study significantly benefited from new analyses performed in collaboration with my AOML coauthors, as we were able to perform a multifaceted examination of how vertical wind shear influences tropical cyclone intensity change."



Forecast intensity plots for Hurricane Gonzalo from all 60 ensemble members. Panel a) shows minimum sea-level pressure, while panel b) shows the maximum sustained wind at 10 m above the ocean surface. Forecasts from ensemble members that underwent rapid intensification early in the period (Early RI) are shown in red and those that underwent rapid intensification later in the period (Late RI) are in blue. The observed intensity of Hurricane Gonzalo is shown by the thick black line (from Fischer *et al*., 2023).

To accurately forecast tropical cyclone intensity change and when rapid intensification might begin, it is critical that computer models start with the correct intensity and storm structure so that a tropical cyclone's interaction with its environment is properly predicted.

Since scientists are unable to measure the precise values of temperature, pressure, moisture, and wind velocity everywhere in the atmosphere, they made small tweaks to the initial structure of Gonzalo and its environment in each ensemble member that were of the same scale as the uncertainty in the observations.

To identify why the spread in forecast intensity was so large for Hurricane Gonzalo, the study compared the characteristics of two groups of simulations to learn why the differences occurred. The first group, called "early-RI" (red lines in images above), immediately experienced rapid intensification, so Gonzalo remained very intense. The second group, called "late-RI" (blue lines in images above), intensified Gonzalo gradually and experienced a brief period of weakening due to dry air before rapidly intensifying.

The key difference between early- and late-RI groups was traced to differences in the initial intensity and structure of Gonzalo. At the beginning of the forecasts, storms in the early-RI group were programmed to be slightly more intense and had circulating winds that were more vertically aligned than storms in the late-RI group. These differences grew with time, ultimately resulting in significantly different forecasts.

Despite recent advances, hurricane specialists struggle to accurately predict rapid intensification events. This study showed that ensemble forecasts are helpful in demonstrating the range of potential intensity outcomes for tropical cyclones. These ensemble forecasts also provided valuable insight into the processes through which environmental wind shear and dry air interact with tropical cyclones to impact their intensity.

Visit the Hurricane Modeling and Prediction Program website to learn more about AOML's efforts to develop and advance NOAA's hurricane research and forecast modeling systems, as well as the prediction of rapid intensification events:

https://www.aoml.noaa.gov/hurricane-modeling-prediction/

Visit the AOML Hurricane Model Viewer for experimental and tropical cyclone model guidance from the Hurricane Analysis and Forecast System, Hurricane Weather Research and Forecasting, and other numerical weather prediction models:

https://storm.aoml.noaa.gov/viewer/

*Fischer, M.S., P.D. Reasor, B.H. Tang, K.L. Corbosiero, R.D. Torn, and X. Chen, 2023: A tale of two vortex evolutions: Using a high-resolution ensemble to assess the impacts of ventilation on a tropical cyclone rapid intensification event. *Monthly Weather Review*, 151(1): 297-320, https://doi.org/10.1175/MWR-D-22-0037.1.

AOML Hosts Top Leaders from NOAA's Office of Oceanic and Atmospheric Research

Dr. Steven Thur, the new Assistant Administrator for NOAA's Office of Oceanic and Atmospheric Research (OAR), and Dr. Gary Matlock, OAR's Deputy Assistant Administrator, visited AOML on March 8-10 to meet with AOML leaders and become better acquainted with the lab's research. A full, 3-day agenda provided them the opportunity to also become better acquainted with how AOML collaborates with Miami's other NOAA line offices, as well as the Virginia Key science community, on research that benefits South Florida, the nation, and the world.

AOML Director John Cortinas and Deputy Director Molly Baringer welcomed Drs. Thur and Matlock to the lab on March 8. Following introductions and an overview of the lab, they met with leaders from NOAA's Southeast Fisheries Science Center to discuss coastal and marine ecosystem studies conducted in partnership with AOML. They then attended an AOML Diversity Inclusion & You meeting, as well as met with early career scientists.

In the afternoon, a tour of AOML's Experimental Reef Lab on the grounds of the University of Miami's Rosenstiel School enabled them to learn about research focused on the molecular mechanisms of coral resiliency and studies to better understand how coral species are responding and adapting to climate change. A meeting with leaders from the University of Miami and its Cooperative Institute for Marine and Atmospheric Studies highlighted AOML's long term, successful collaboration with its academic partners.

Day two featured a tour of the AOML facility. Stops along the tour highlighted the broad array of innovative research performed at AOML to better document the changing physical, chemical, and biological properties of the ocean, as well as how these changes impact weather, climate,and marine ecosystems. An afternoon all-hands meeting in the Rosenstiel School auditorium enabled Drs. Thur and Matlock to address the AOML community, discuss a variety of topics, and answer questions, as well as hear from AOML's leaders. A poster session and informal reception followed.

Day three featured a tour of the National Hurricane Center and the William M. Lapenta Laboratory, which provides a meeting place for meteorologists and forecasters, as well as oceanographers, to collaborate in transitioning the latest research into operational products through the Hurricane and Ocean Testbed. Drs. Thur and Matlock attended an AOML research-to-operations transitions meeting, as well as met with leaders of the National Hurricane Center. They additionally met with members of AOML's Hurricane Research Division to discuss advances in hurricane modeling, tropical cyclone research, and their continued efforts to improve tropical cyclone forecasts.

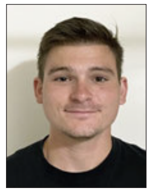
1. Rik Wanninkhof (far right) discusses carbon cycle research at AOML.

2. Rick Lumpkin (center) highlights an assortment of instruments AOML uses to monitor the ocean.

3. AOML staff gather in the auditorium of the University of Miami's Rosenstiel School for an all-hands meeting with Drs. Thur, Matlock, and AOML leaders.

4. Members of AOML's Hurricane Research Division meet with Drs. Thur and Matlock at the National Hurricane Center.

Welcome Aboard



Robert Bremer joined AOML's Ocean Chemistry and Ecosystems Division in February as a University of Miami-Cooperative Institute Research Associate. Rob will work with the Molecular and Environmental Microbiology group as a laboratory and field technician. He will assist with multiple environmental microbiology projects but will focus primarily on the molecular characterization and tracking of microbial contaminants from urbanized watersheds to the South Florida coastal zone, particularly the Biscayne Bay watershed. Rob recently graduated from the University of Miami's Rosenstiel School of Marine, Atmospheric, and Earth Science with a MS degree in Marine Biology and Ecology. He has a research background in molecular genetic studies of corals and their symbionts, as well as experience with field work, research diving, and operating small boats.

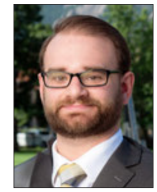
Sterling Butler joined AOML's Ocean Chemistry and Ecosystems Division in January as a University of Miami-Rosenstiel School of Marine, Atmospheric, and Earth Science student intern. Sterling will work with Dr. Stephanie Rosales on a project to develop a qPCR assay for tracking potentially parasitic bacteria in coral. He is a Rosenstiel School MPS graduate student in the Tropical Marine Ecosystem Management track, with a focus on coral reefs.

Autumn Dellorso joined AOML's Ocean Chemistry and Ecosystems Division in January as a University of Miami-Rosenstiel School of Marine, Atmospheric, and Earth Science student intern. Autumn will work with Drs. Stephanie Rosales and Nick MacKnight on a stony coral tissue loss disease microbiome study. She is a Rosenstiel School MPS graduate student in the Tropical Marine Ecosystem Management track, with a focus on microbial ecology.

Taylor Gill joined AOML's Ocean Chemistry and Ecosystems Division in March as a University of Miami-Cooperative Institute Research Associate. Taylor will assist with field and laboratory projects during a year-long internship with the Coral Program, with a focus on climate monitoring and 'omics research in support of the National Coral Reef Monitoring Program. She holds a BS degree in Marine and Atmospheric Science from the University of Miami's Rosenstiel School of Marine, Atmospheric, and Earth Science.

Dr. Jakir Hossen joined AOML's Hurricane Research Division in March as a University Corporation for Atmospheric Research (UCAR) Project Scientist. Jakir will support NOAA's Quantitative Observing System and Assessment Program (QOSAP) under the guidance of Dr. Lidia Cucurull, with research focused on assessing the impact of current and proposed observations in ocean prediction. Prior to joining AOML, Jakir worked as a Physical Scientist at Lynker in support of NOAA's Environmental Modeling Center. He holds a PhD in Earth Sciences from the Australian National University.

Daryin Medley joined AOML's Ocean Chemistry and Ecosystems Division in January as a federal oceanographer. Daryin will work with Dr. Denis Pierrot and members of the Ocean Carbon Cycle Group to install, maintain, and troubleshoot *p*CO_2 instruments onboard the group's many volunteer ships of opportunity. He will also be involved in the retrieval, processing, and dissemination of the data collected on these ships. Daryin recently earned an MS degree in Environmental Science from Florida A&M University.

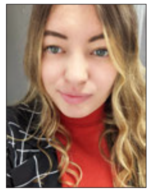


Dr. Connor Nelson joined AOML's Hurricane Research Division in January as a University Corporation for Atmospheric Research (UCAR) Project Scientist. Connor will support NOAA's Quantitative Observing System and Assessment Program (QOSAP) under the guidance of Dr. Lidia Cucurull by assessing the impact of current and proposed observations to improve hurricane prediction. Prior to joining AOML, Connor was a Research Scientist with the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University. He holds a PhD in Atmospheric Sciences from the State University of New York at Albany.

Dr. Christopher Riedel joined AOML's Hurricane Research Division in January as a University Corporation for Atmospheric Research (UCAR) Project Scientist. Chris will support NOAA's Quantitative Observing System and Assessment Program (QOSAP) under the guidance of Dr. Lidia Cucurull by quantifying and optimizing the benefits of radio occultation observations to improve global weather forecast skill. Prior to joining AOML, he was a National Center for Atmospheric Research-Advanced Study Program post-doctoral fellow. Chris holds a PhD in Meteorology from the University of Oklahoma.

Dr. Katherine Silliman joined AOML's Ocean Chemistry and Ecosystems Division in February as a Research Scientist with the Northern Gulf Institute. Katherine received her PhD in Evolutionary Biology from the University of Chicago, where she used reduced-representation sequencing, transcriptomics, and mesocosm experiments to study the population structure of the Olympia oyster (*Ostrea lurida*) and assess its adaptive potential in response to ocean acidification. Katherine will work with Dr. Luke Thompson to create bioinformatics workflows, analyze marine environmetal DNA and microbiome datasets, and develop NOAA's bioinformatics capacity and workforce. Her studies will involve significant use and development of NOAA and Northern Gulf Institute high performance computing resources, including Mississippi State's Orion supercomputer. Prior to joining AOML, Katherine completed a post-doctoral position at Georgia Tech, where she developed a bioinformatics pipeline for predicting the RNA secondary structure in roundworms (*C. elegans*), as well as at Auburn University, where she estimated the hybridization and population structure in black basses (*Micropterus spp*.) of the southeastern United States.

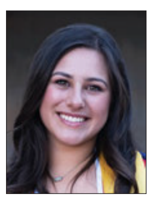
Welcome Aboard (*continued*)



Rachael Storo joined AOML's Ocean Chemistry and Ecosystems Division in February as a Northern Gulf Institute Research Program Manager. Rachel will work with Dr. Luke Thompson and members of the 'Omics group to develop bioinformatics workflows, analyze and visualize 'omics datasets, and encourage open, FAIR, i.e., findable, accessible, interoperable, reusable, data practices within AOML's 'omics program and across the Office of Oceanic and Atmospheric Research and NOAA. Prior to joining AOML, Rachael was an 'omics research and development technician and the head of the Molecular Department at a small biotech startup in Athens, Georgia. She holds an MS degree in Marine Science from Nova Southeastern University.

Briana Yancy joined AOML's Office of the Director in February as the lab's first ever Knauss Fellow intern. Briana will work remotely throughout 2023 from NOAA Headquarters in Silver Spring, Maryland with Annette Hollingshead on research and development transition planning and management. Her research interests focus on the practical use and conservation of coastal, marine, and Great Lakes resources to create a sustainable economy and environment. Briana's background includes research at the intersection of conservation and social sciences with a focus on coastal ecosystems, as well as time with the US Environmental Protection Agency's Chesapeake Bay Program and the Maryland Department of Natural Resources. She holds a MS degree in Biology from Miami University in Oxford, Ohio.

Farewell



Morgan Chakraborty, a University of Miami graduate student with AOML's Ocean Chemistry and Ecosystems Division, completed her year-long internship with AOML's Coral Program in March. Morgan spent the past year supporting the National Coral Reef Monitoring Program's field sampling efforts and research projects. She has returned to the University of Miami's Rosenstiel School of Marine, Atmospheric, and Earth Science as a doctoral student studying Marine Geosciences.

Dr. Heidi Hirsh, a University of Miami-Cooperative Institute post-doctoral researcher with AOML's Ocean Chemistry and Ecosystems Division, completed her 2-year appointment and resigned in January. Heidi has accepted a Systems Engineering position with the Aircraft Center for Earth Studies at the University of Miami's Rosenstiel School of Marine, Atmospheric, and Earth Science. During Heidi's time at AOML, she worked to develop statistical models to describe and predict carbonate chemistry variability on coral reefs in Guam and the Florida Keys. This work used estimated nearshore residence times and records of in situ carbonate chemistry and benthic composition to better describe the environmental and ecological drivers of reef-scale processes that modified the local biogeochemistry.

Farewell (*continued*)

Paul Leighton, an Information Technology Specialist with AOML's Hurricane Research Division, retired in January after 40 years of federal service. Paul served as the system administrator for the Hurricane Research Division's Mac computers. Over the years, he assisted scientists with computer software to process hurricane observations, including sending radar imagery via the Aircraft Satellite Data Link as far back as 1985, maintaining the Dropsonde Editsonde software and its transition to ASPEN, development of the G-IV Synoptic Targeting software, improvements to the SHIPS Rapid Intensification Index and, most recently, contributions to the Tropical Cyclone Genesis Index. Paul also participated in numerous P-3 Hurricane Hunter research flights by serving as the dropsonde and radar scientist, flying into 48 named storms and accumulating 371 hurricane eye penetrations.

Paulo Paz, a University of Miami-Cooperative Institute Software Engineer with AOML's Hurricane Research Division, resigned in March to accept a Software Engineering position with the financial industry in New York City. Paulo began at AOML in 2019 to work with the Observing System Assessment team under the direction of Lidia Cucurull. He supported observing system simulation experiment research capabilities for the group, providing access to nature runs for use in conducting numerical weather prediction experiments. He also migrated the Global Forecast System workflow to Amazon Web Services and developed infrastructure to support observing system simulation experiments on the Cloud.

Diego Ugaz, a University of Miami-Cooperative Institute Electrical Engineer with AOML's Physical Oceanography Division, resigned in February to accept a position with Neocis as an electrical engineer for dental robotics. During Diego's 5+ years at AOML, he was a member of the Engineering team who developed a number of prototype systems and sensors for ocean-observing instruments. He also deployed, operated, and recovered hurricane gliders and was seagoing participant on an extensive list of research cruises, as well as onboard merchant ships to collect scientific observations.

Congratulations

Nicole Besemer, an oceanographer with AOML's Ocean Chemistry and Ecosystems Division, was named as NOAA's February 2023 Employee of the Month. Nicole serves as the National Coral Reef Monitoring Program's Caribbean Climate Operations Coordinator. In 2022, despite numerous complexities and travel risks due to the pandemic, Nicole successfully orchestrated and served as the chief scientist for field missions in the Florida Keys, Dry Tortugas, St. Croix, and Flower Garden Banks following a widespread coral disease outbreak. Nicole worked closely with colleagues at the Flower Garden Banks National Marine Sanctuary and the crew of the RV *Manta* to complete all diving operations and ensure the data were safely collected.

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Keynotes is published quarterly to highlight AOML's recent research activities and staff accomplishments.

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Recent Publications *(AOML authors are denoted by bolded capital letters)*

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