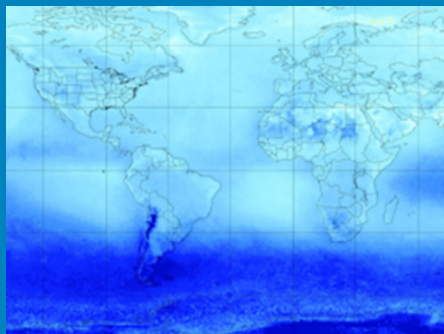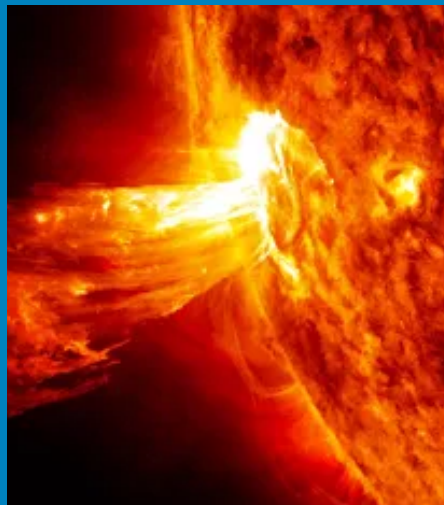# 2024 NESDIS Impacts Briefings

Hightlighting the Hot Spots

NOAA's Urban Heat Island Mapping and VR Heat-Mapping Experience

Our summers are getting hotter and more deadly—extreme heat is one of the leading weather-related hazards in the U.S. Most years, heat kills more people than hurricanes, floods, and tornadoes combined. However, heat impacts tend to affect certain areas more than others. These areas are known as heat islands.

> *Heat islands are usually in highly developed urban areas, where mid-afternoon temperatures can be 15° to 20°F warmer than other areas within the same city, with little cooling occurring overnight.*

Heat islands happen in places with a high concentration of buildings, roads, and other infrastructure that absorb and re-emit the sun's warmth more than natural landscapes like forests and bodies of water. This is why cities become hotter than surrounding suburbs and nature reserves. Heat islands are often linked to demographic factors such as income and race, with historic redlining cited as a contributing factor.

To address this problem, NOAA has been working with citizen scientists in urban areas to map heat islands. This effort is part of a larger campaign launched in 2017 by the National Integrated Heat Health Information System (NIHHIS) and managed by the Climate Program Office (CPO) under NOAA Oceanic and Atmospheric Research (OAR).

This project relies on volunteer community scientists who travel around the city along a predetermined route during the morning, afternoon, and evening of a single day. The volunteers typically conduct these rides on one of the hottest days of the year, and communities work with their local weather forecast offices to pinpoint a day that will have no precipitation and little cloud cover. Sensors mounted on volunteers' cars or bicycles capture air temperature and humidity data, and these data are used to construct reports that identify hot spots within the city.
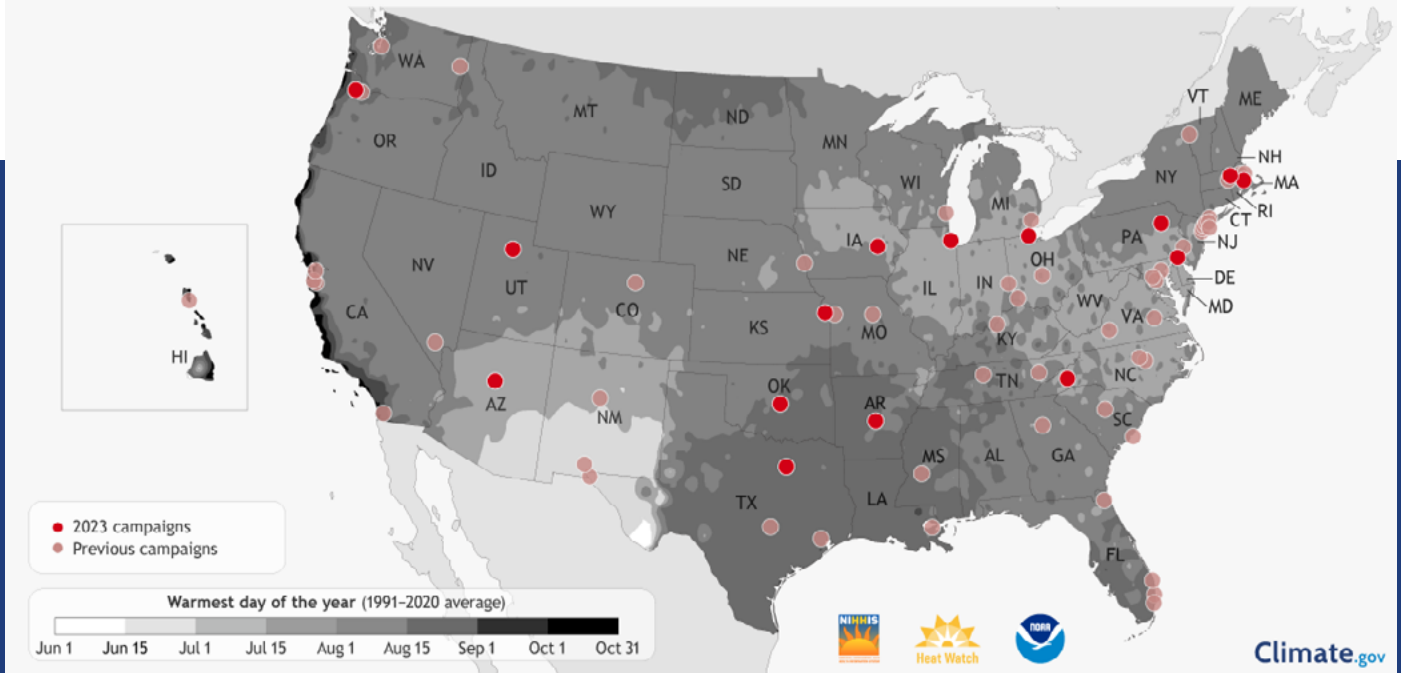
"I love to learn about communities and how the federal government can support them," says Morgan Zabow, MPH, who joined the NOAA's Climate Program Office in 2021. "We help connect communities, and we help them share best practices in implementing solutions." Zabow uses her background in community public health to develop and grow NOAA's heat mapping efforts in concert with community partners.

Morgan Zabow of NOAA CPO and Nicholas Mullenix put a sensor on a car before conducting a data ride in Montgomery County, MD. on August 7, 2022.

These mapping campaigns take place each summer, and approximately 10 to 15 communities are selected every year based on an application process that opens in the fall. During the 2022 urban heat island campaigns, 782 citizen scientists collected over one million measurements in 15 U.S. communities.

NOAA Urban Heat Island Mapping Campaigns: All Locations, 2017-2023

- 2023 campaigns
- Previous campaigns

Warmest day of the year (1991–2020 average)

Jun 1   Jun 15   Jul 1   Jul 15   Aug 1   Aug 15   Sep 1   Oct 1   Oct 31

This NOAA mapping effort is instrumental in identifying the hottest neighborhoods in cities across the nation. The data helps city planners in these communities understand how and why different neighborhoods are hotter and encourages the development of cooling solutions.

"Asheville, NC is known as a 'climate refuge,'" Nicole McNeill, a Heat Mapping Project Manager for Asheville GreenWorks explained, "But urban trees are under particular threat from development." So McNeil, along with the GreenWorks community, have collected detailed heat data in order to target new tree-planting efforts in the places that can most benefit from them—and identify where it's imperative to protect existing trees.

McNeill and her team of volunteers completed a heat data collection day in 2023. She hopes their work will help residents understand the connection between heat and their homes, their health, and their future as well as foster better awareness and understanding of heat disparities to develop solutions.

"The choices we all make right now will create the future we experience. Right now, we have the chance, and the responsibility, to choose to thrive."

Asheville GreenWorks Interim Executive Director Eric Bradford and Interim Operations Director Chelsea Adams teach heat campaign volunteers how to use the sensors during data collection day on July 24, 2023.

The heat-mapping project allows communities to develop hyper-local descriptions of heat and to strategize about solutions specific to each community and its needs. Many cities have already taken action based on this data. Honolulu, HI and Cincinnati, OH have embarked on tree-planting campaigns. Las Vegas, NV is constructing shading stations at bus stops in

hotter areas to provide relief to bus riders. Raleigh, NC is adding titanium dioxide (a material that imparts bio-cidal, self-cleaning, and smog-abating functionalities) to its concrete surfaces to reduce the amount of heat absorbed by roadways. Many communities have used the data to develop extreme heat action plans, educate residents and policymakers, and inform new research. All data from the UHI campaigns are open access and available on the federal website Heat.gov.

"The most surprising data from the campaign was that in certain areas of the city, there can be as much as a 17-degree variance in temperature," said Denise Castil-lo-Gonzalez, a Sustainability Specialist with the City of Albuquerque, NM. She supports heat island mapping projects as a first step in helping to develop both short-and long-term strategies. "Helping us identify where immediate mitigation is needed is very impactful."

Castillo-Gonzalez is working with her city to establish the New Mexico Urban Heat Cohort, the first effort in the state to bring together various community-based organizations, academia, as well as local, regional, and state government departments and agencies to develop strategies that protect the most vulnerable communities during extreme heat events.

The NOAA Visualization Laboratory (VizLab) within NESDIS has made these city UHI datasets available as public geospatial services on ArcGIS servers, enabling users to quickly add this data to their web map appli-cations and information products. In collaboration with the NOAA Global Systems Laboratory, the VizLab used this data to develop the Urban Heat Island of Washing-ton DC Virtual Reality (VR) Experience. This immersive experience provides a realistic representation of the UHI phenomenon, and aims to raise public awareness about the importance of addressing UHIs in cities as well as the impact of heat inequities. It also provides an example of how NOAA data can be used in innovative ways to educate and inform the general public.

This project used new software that allows gaming en-gines to access and display GIS map layers and data. This is one of the first practical examples developed using this novel technology, which uses storytelling to explain the information and create an engaging and eye-opening experience for users. This project was recognized by the American Council for Technology and Industry Advisory

Council ACT-AIC with the 2023 Innovation Champion Award (the organization's highest honor).

Juan Pablo Hurtado from the NOAA Visualization Laboratory shows a user how to navigate the Urban Heat Island of Washington DC Virtual Reality (VR) Experience

The VizLab worked closely with community leaders in developing the VR experience. In 2022, the VizLab's Juan Pablo Hurtado visited the Faunteroy Commu-nity Enrichment Center (FCEC) in D.C.'s Deanwood neighborhood during their Juneteenth celebration and demonstrated a simple geoplatform app showing temperatures in Washington, D.C. vs. satellite images. Community members wanted something even more in-teractive and immersive, so over the next year, Hurtado and his colleagues developed the VR experience based on their feedback. Hurtado returned to the FCEC for their 2023 Juneteenth celebration and demonstrated the new VR product to rave reviews. NOAA awarded a

grant to the FCEC to support a new Resilience Hub for the community. This project will increase the resiliency and preparedness of the community in facing climate change effects, such as heat waves and the urban heat island effect by providing a bird's eye view of their neighborhood and how it compares to the rest of the city.

NOAA's heat island mapping program is part of the Justice40 initiative, a whole-of-government effort to ensure that federal agencies work with states and local communities to deliver 40% of benefits from federal investment in climate and clean energy to disadvantaged communities. The program is also part of America the Beautiful Initiative, as urban heat islands are areas in great need of more access to nature and its health and cooling benefits.

> *"The burden of heat is not shared equally in our urban areas. Gathering this type of environmental intelligence helps communities measure their hottest places so they can develop strategies to reduce the dangerous effects of heat. Community by community, we're working to create a Climate-Ready Nation that is resilient in a changing world."*
>
> *—NOAA Administrator, Dr. Rick Spinrad*

Dr. Rick Spinrad, NOAA Administrator, navigates the Urban Heat Island Virtual Reality Experience at a NOAA exhibit.

NOAA Satellites Track Trends in Greenhouse Gases

From Both Human and Natural Sources

Earth science settled the question of whether and how greenhouse gases (GHGs) trapped in our planet's atmosphere are warming the planet. Science shows that human activities, such as deforestation and burning fossil fuels, contribute to the concentration of GHGs in the atmosphere. Earth science discoveries of the last two decades tell us that increasing GHGs in the atmosphere is driving other changes in our Earth system, such as increasing surface temperatures, rising sea levels, loss of polar sea and land ice, more frequent and more severe weather, and shifts in ecosystems and habitats.

To inform strategies for reducing GHGs, such as carbon dioxide (CO_2) and methane (CH_4), decision-makers need tools to track and monitor them. Since the greenhouse gas effect is a global phenomenon, those decisions are often made at the global level. For instance, the Paris Agreement adopted by 196 parties on Dec. 12, 2015, is an international treaty on climate change with the goal of limiting the temperature increase.

NOAA's CarbonTracker tool monitors global GHG concentrations using a measurement and modeling system that tracks sources (when carbon dioxide is emitted into the atmosphere) and sinks (when carbon dioxide is removed from the atmosphere). While NOAA developed CarbonTracker, its observations depend on a network of collaborators and a variety of sensors, from ground monitoring to NOAA's satellite systems.

While ground-based sensors provide the most accurate measurements of GHGs, NOAA's Joint Polar Satellite System (JPSS) contributes to our understanding of how these gases are distributed across the globe. The JPSS sensors measure concentrations of GHGs like methane at different levels of the atmosphere, and can also detect and monitor what's contributing to GHGs, such as wildfires and agricultural burns.

NOAA's JPSS mission carries an instrument called the Cross-track Infrared Sounder (CrIS) that measures methane in the mid-to-upper troposphere—or about the midpoint of the atmosphere. CrIS continues the
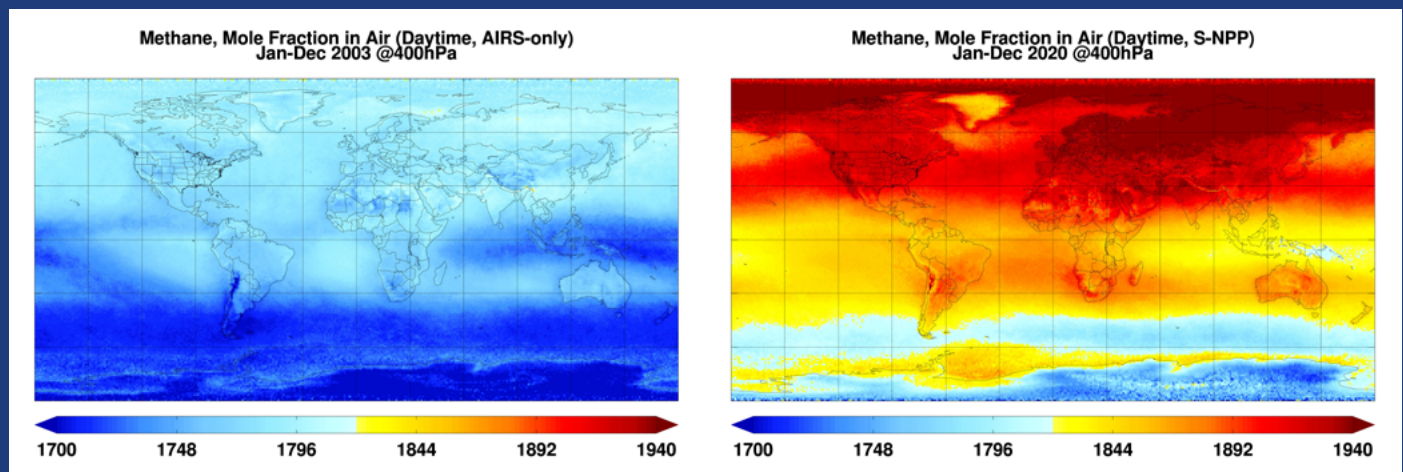
The image on the left shows annual mean methane (CH_4) concentrations in 2003, as measured by NASA's AIRS sensor on the Aqua satellite. The image on the right shows the concentrations in 2020 as computed by the CrIS sensor onboard the S-NPP satellite. There is a significant increase in CH_4 in the atmosphere over this period of time.

legacy of measurements by a similar, earlier NASA instrument called the Atmospheric Infra-Red Sounder (AIRS). Figure 1 shows a side-by-side comparison of methane measured by AIRS in 2003 and by CrIS in 2020; there is a significant increase in methane in the atmosphere over this period of time.
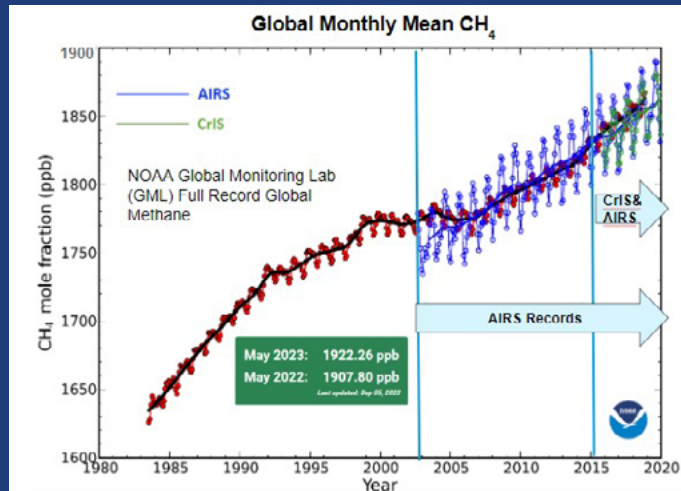
The red lines and circles are globally averaged monthly mean atmospheric CH_4 abundance determined from marine surface sites by NOAA Global Monitoring Lab. Monthly data transformed to 12-month running mean are shown with the black curve. The blue dots show CH_4 concentrations in units of parts per billion for 400 millibars in the atmosphere and the green dots are CH_4 concentrations from CrIS, also for 400 millibars in the atmosphere..

Remote-sensing observations confirm that atmospheric CH_4 resumed an increase after 2007 and has continued to increase since 2014. Our hyperspectral sounders provide high vertical resolution atmospheric information that can improve forecasts in numerical weather pre-diction (NWP) models. While in orbit the hyperspectral sounder can monitor atmospheric CH_4, but ground-level emissions are harder to detect from space.

Greenhouse gases are not all the same, and they have markedly different impacts on the atmosphere. Although atmospheric CH_4 is lower than CO_2, it is 25 times more potent than CO_2 because of its higher global warming potential, and it has a much shorter atmospheric lifetime (about a decade) than CO_2 (longer than a century).

Tools like CarbonTracker need the continuous mon-itoring of greenhouse gas emissions from sources like biomass (i.e. vegetation) burning—to accurately

simulate the various greenhouse gas sources and sinks. In partnership with NASA, NOAA has been accumulating records of biomass burning since the 1999 launch of the Terra satellite carrying the Moderate Resolution imaging Spectroradiometer (MODIS). Today, NESDIS is capturing measurements with the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on NOAA's JPSS series and the NASA-NOAA pathfinder Suomi National Polar Partnership.

Measurements collected by NOAA's Earth observation satellites provide critical data and information to policy-makers and decisionmakers. In 2020, NOAA estimated that global biomass burning released 7.9 gigatonnes of carbon, compared to 31.5 gigatonnes from burning of fossil fuels. In places like the western U.S., emissions from biomass burning are increasing at a rate of 214 teragrams per year—or more than 470 billion pounds—undoing years of air quality benefits the nation is experi-encing from the Clean Air Act and regulations enforced by the Environmental Protection Agency.
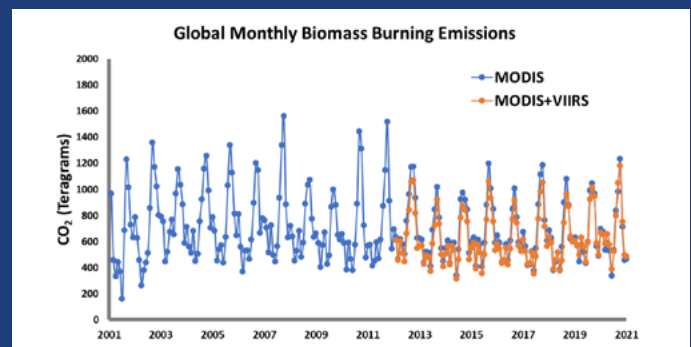
Time series of CO_2 released into the atmosphere from biomass burning. Each data point is an annual total CO_2 for Canada. Terra and Aqua MODIS fire products were obtained from NASA, and NOAA's Global Biomass Burning Emissions algorithm was run on the data to calculate CO_2 emissions. Anthropogenic CO_2 emissions data was obtained from iea.org. Note Canadian anthropogenic CO_2 emissions data are not yet available for 2021-2023.

With the use of these greenhouse gas monitoring instruments and systems, NESDIS has provided a crucial contribution to the U.S. Climate Resilience Toolkit, a framework that helps agencies and individuals docu-ment climate hazards in near-real time. With continued research and innovation, NESDIS tools are vital to policy-makers and communities in finding workable solutions to reduce climate-related risks now and in the future.

Monitoring Water and Air Pollution

From the Depths of the Ocean to the Outer Atmosphere

People, animals, marine life, and plant life on our planet need clean air and clean water to survive. With a long legacy of monitoring and studying pollution in both the ocean and the atmosphere, NESDIS scientists are committed to helping protect what is becoming increasingly valuable on a planet undergoing significant climate change.

Addressing Microplastic Pollution in Earth's Ocean and Lakes

Plastic is the most common type of marine pollution, and it can break down into very small particles. Pieces of plastic that are smaller than 5 mm are known as microplastics, and they are found throughout the world's ocean. Scientists are working to better understand marine microplastics, and their impact on coastal communities, marine ecosystems, and human health.

The National Center for Environmental Information (NCEI) at NESDIS is an open, accessible archive of data and information for people, businesses, and public entities to make informed, data-driven decisions about managing and mitigating microplastic pollution.

In collaboration with the Northern Gulf Institute, NCEI developed the global NCEI Marine Microplastic database and web portal, a treasure trove of accessible, large-scale and long-term data. People can also access an NCEI-developed geoportal and interactive GIS map of the microplastic data. These tools offer a global view of microplastics and their impact to scientists, environmental managers, policy makers, and the general public.

NCEI is working with several international science groups to establish best practices for collecting, analyzing, and reporting on microplastic ocean pollution. Key partners include the European Union's European Marine Observation and Data Network (EMODnet) marine litter database and the Ministry of the Environment Japan (MOEJ).

NCEI, the NOAA Marine Debris Program, and NOAA Gulf of Mexico Sea Grant work together to communicate information about this pollutant to stakeholders beyond the scientific community, to inform the general public on the effects of microplastics on marine ecosystems.

NCEI goes beyond the published scientific data by incorporating community-based scientific data. For instance, in April 2023, NCEI partnered with the non-profit Oceaneye to expand the NCEI marine microplastic database. Oceaneye trains boat captains to collect water samples for study, and promotes community science initiatives to raise awareness about plastic pollution in the ocean.

Most of the data on microplastics is collected from those floating on the ocean surface, but microplastic also ends up on beaches and in ocean sediments. so NCEI is expanding its efforts to add this information to its database. Partnering with Nurdlepatrol.org, an organization operated by the Mission-Aransas National Estuarine Research Reserve at the University of Texas Marine Science Institute, NCEI aims to train people to collect microplastics on beaches.
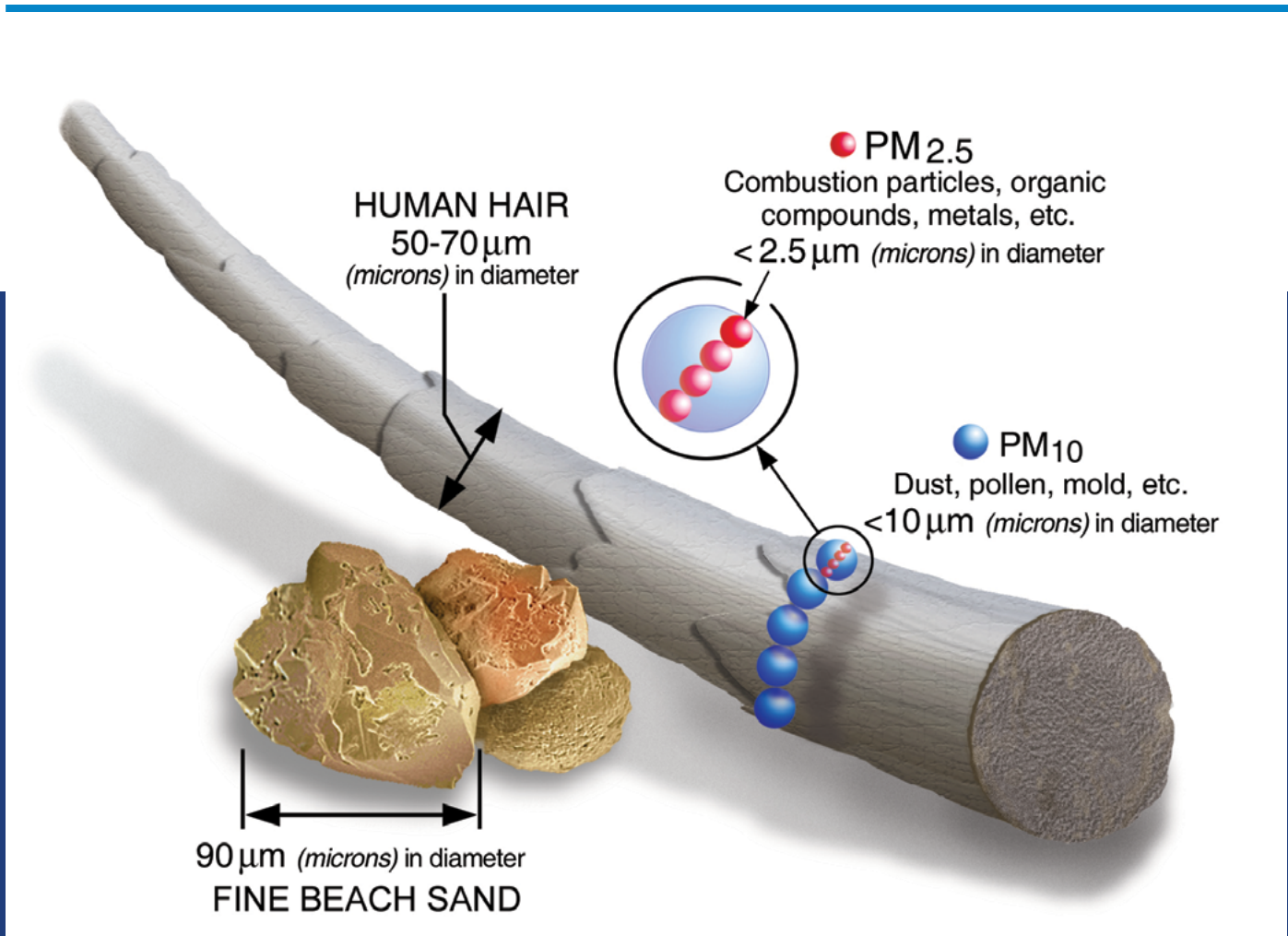
Filling In The Gaps In Monitoring Air Pollution

Both natural and human sources contribute to air pollution. Exhaust from vehicles, power plants, industrial processes, prescribed and natural fires, and dust storms—among many other sources—release particles into the atmosphere. These particles are incredibly small—20 to 30 times smaller than the thickness of a human hair (see diagram). Once airborne, they can easily be inhaled and can penetrate the lungs and enter bloodstreams. This can lead to harmful health effects including premature death. More than 100,000 people die each year in the United States alone due to poor air quality.

The United States Environmental Protection Agency (EPA) regulates fine particulate pollution as a pollutant

HUMAN HAIR
50-70 μm
(microns) in diameter

● PM 2.5
Combustion particles, organic
compounds, metals, etc.
< 2.5 μm (microns) in diameter

● PM 10
Dust, pollen, mold, etc.
<10 μm (microns) in diameter

90 μm (microns) in diameter
FINE BEACH SAND

Size comparisons of particulate matter, beach sand, and dust, pollen and other airborne matter. Source: EPA

under the Clean Air Act. Levels of fine particulate pollution are expressed as $PM_{2.5}$ (that is, particles with a diameter of 2.5 micrometers or smaller).

To assess trends in air quality and monitor airborne particle pollution, the EPA uses local air pollution monitors. While highly effective, EPA monitors have limited coverage; more than 67 percent of U.S. counties did not have a regulatory monitor in 2019. To fill this coverage gap, NOAA uses satellite data and algorithm formulas to provide vital measurements and information to air quality forecasters, urban leaders, and public health policymakers.

Efforts by state, local, and tribal agencies over the last two decades to meet the EPA health standards are working. However, research also shows that in some areas, fine particulate pollution from wildfires is countering those promising trends. This is especially true in non-urban regions that would otherwise not experience high particulate matter.

Though fire emissions vary from year to year, a warming and drying climate in the western U.S. is increasing fire activity, and increasing $PM_{2.5}$ trends. For example, in California, Oregon, and Washington, NOAA's satellite fire detections show emissions of $PM_{2.5}$ increasing at a rate of 214 gigagrams (Gg) per year—or the equivalent in weight of what would require approximately 16,850 dump trucks to carry.

Breathing in fine particulates in the air that are 2.5 micrometers or smaller can be harmful to our health, raising the risk of asthma, heart disease, and other ailments. High levels of $PM_{2.5}$ can also make the air hazy, reducing visibility. According to NOAA's satellite fire detection readings, the emissions of $PM_{2.5}$ are increasing by roughly half a pound per year.
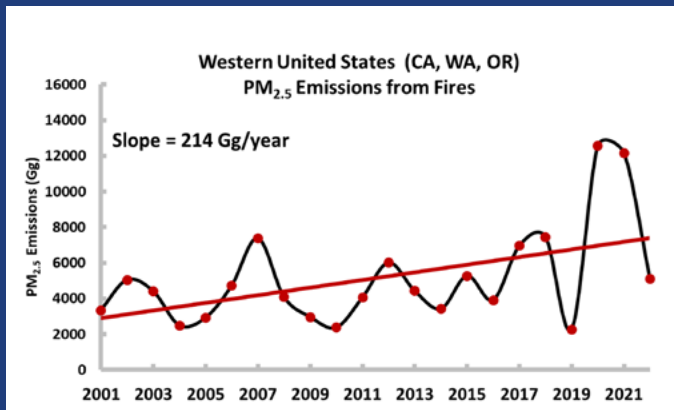
Trends in PM$_{2.5}$ emissions for the western United States derived by running NOAA's global biomass burning emissions algorithm on NASA's Aqua and Terra Moderate Imaging Spectrometer fire detections.
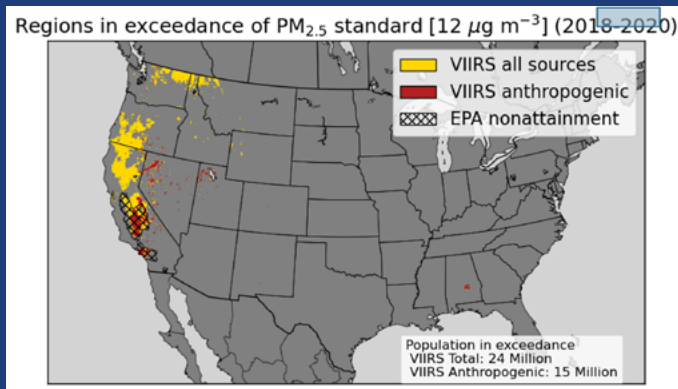
This figure shows that EPA regulations have worked in decreasing PM$_{2.5}$; most of the United States except parts of California, shown in black meshed markings in the map, are in attainment.

Under EPA regional standards, the NOAA data shows that central California is not attaining PM$_{2.5}$ air quality goals of less than 12 micrograms per cubic meter. Other sources of pollution, such as vehicle exhaust, agriculture and smoke (shown in yellow on the map), prevent Oregon, Washington and other parts of California from attaining EPA standards.

The EPA is preparing to lower the current PM$_{2.5}$ annual standard to 9-10 micrograms per cubic meter. The intent of this proposed regulation is to protect the health of people vulnerable to high levels of pollution, especially children, the elderly, and people with asthma. Scientists are carefully studying wildfires and their role in exposing large populations to harmful levels of

smoke, especially in the western U.S. Using satellite-derived data, NOAA estimates there could be a four-fold increase in the number of people exposed to air quality exceeding the new health standard.

Barron Henderson, Ph.D, is a physical scientist in the EPA's Office of Air Quality and Planning Standards. He is currently working with NOAA to add satellite PM$_{2.5}$ data into the EPA's tools for air quality managers. Henderson says, "NOAA's quantitative PM$_{2.5}$ and smoke identification can provide fast screening data that highlight days and locations with large air quality impacts from wildfires." Tools like this that estimate wildfire PM$_{2.5}$ contribution, will be helpful for the states to quantify the effects of fires on air quality.

From NOAA's "eyes in the sky" satellite systems measuring fires and fine particulates, to the sample collectors and researchers tracking seaborn microplastics, NOAA is working around the clock to protect lives and property by helping keep our air and water clean.

Tracking Wildfires and Smoke

How the View from the Sky Helps Fight Fires on the Ground

North America experienced a catastrophic wildfire season in 2023. In Canada, the total area burned by wildfires obliterated previous record highs—the fires consumed nearly 45 million acres. Heavy smoke from these fires descended over major metropolitan areas from the U.S. Midwest to the Mid-Atlantic, causing hazardous air quality conditions affecting millions of people.

NOAA plays a key role in detecting, monitoring, and fighting these kinds of devastating fires. NOAA's wildfire team includes experts from NESDIS, the National Weather Service (NWS), and NOAA Oceanic and Atmospheric Research (OAR). NOAA satellites provide critical, timely information on wildfires and smoke detection that is used by this team and by the National Interagency Fire Center (NIFC) which coordinates the nation's wildland fire management and suppression agencies.

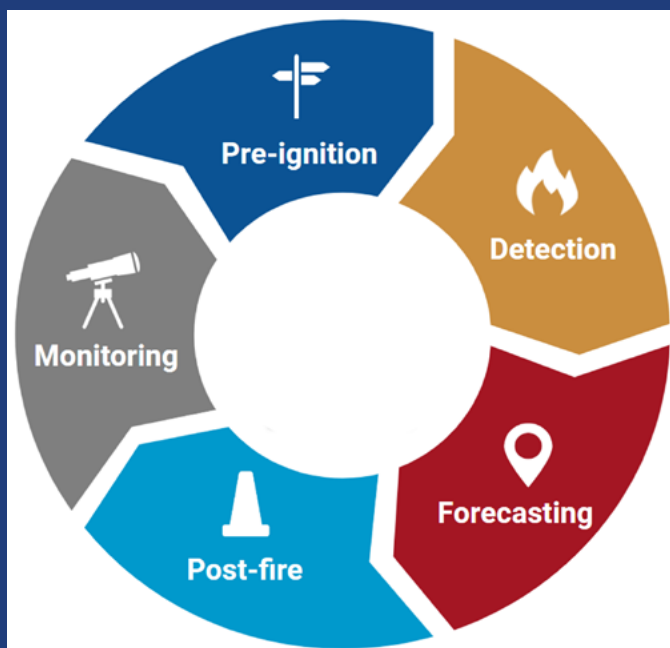*Fire life cycle from a NOAA science and service perspective.*

The NESDIS GOES and JPSS satellite missions supported Canadian wildfire monitoring efforts, and tracked the smoke that drifted across the Midwest and East Coast United States. From their positions in geosynchronous orbit over North America, GOES-East and GOES-West satellites observations tracking the heavy smoke from the Canadian wildfires allowed local communities to issue timely Air Quality Index alerts so vulnerable people, such as the elderly, or people with asthma, knew to stay indoors.

The VIIRS instruments on JPSS satellites provide data to help predict where wildfire smoke will affect air quality in the United States and the amount of particulates in the air. The data from JPSS are essential for running smoke models used by air quality forecasters to predict where smoke from wildfires will move. OAR developed a smoke forecasting capability and the NWS operated the model, increasing the accuracy of forecasts of wildfire smoke impacts on air quality.

While tracking the Canadian wildfires and smoke, NOAA satellites simultaneously monitored Alaska, the lower 48 and neighboring countries to the south for signs of burning. The satellite-derived data are generated routinely in near real time and accessible via interactive web-based mapping applications displaying detailed fire locations and smoke extent.

Forecasters at the National Interagency Fire Center (NIFC) use NOAA satellites and data to track the lifecycle of wildland fires beginning with monitoring and pre-ignition. This includes monitoring drought and dry conditions that inform land management agency assessments that a wildland fire may start.

Detection of wildfires by satellites has improved with the GOES-R Series, which is orbiting innovative instrument technology. The Advanced Baseline Imager (ABI) detects wildfire locations from more than 22,000 miles above the earth and within minutes of the wildfire
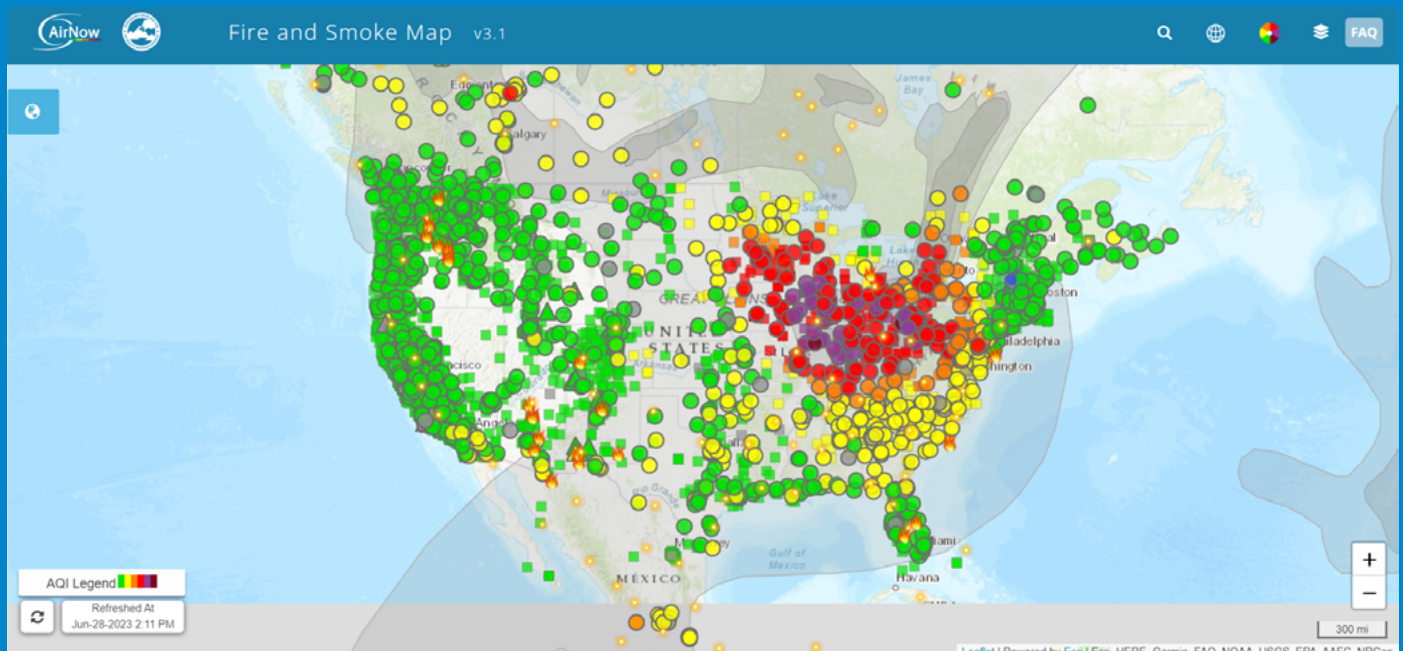
AirNow Fire and Smoke Map

Ron Evans serves as the US Environmental Protection Agency's (EPA) AirNow Fire and Smoke Map Coordinator, He notes, "The AirNow Fire and Smoke Map, a joint USEPA and USFS project, provides the NOAA smoke plume information to augment the air quality data which we provide in real time to the public. Users of the AirNow Fire and Smoke map have told us the smoke plume information helps them understand the sources of smoke in their area and any actions they need to take to protect their health."

—Ron Evans, EPA AirNow Fire and Smoke Map Coordinator, US Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality and Standards, Air Quality Assessment Division

The AirNow Fire and Smoke map provides real-time information on air quality, fire information, smoke plumes, and smoke outlooks.

being imaged. The Geostationary Lightning Mapper (GLM) assesses potential lightning that may ignite fires in remote and difficult-to-monitor locations.

NWS forecasters at field offices across the nation monitor satellite information and alert our partners in the wildfire and emergency management communities whenever they detect a "hot spot" or new fire start. Investments from the Supplemental Disaster Appropriations and Bipartisan Infrastructure Law will improve the use of ABI and GLM on GOES satellites for wildfire detection, tracking, and intensity classification through development of sophisticated algorithms and applications for decision making.

Real-time support of wildfire suppression crews requires specialized assistance—the kind provided by instruments on GOES-West and GOES-East (ABI and the GLM), and the JPSS satellites (Visible Infrared Imaging Radiometer Suite (VIIRS), which provide data 24 hours a day to all users.

Satellite images give crucial information, but firefighters might need specific information about wildfire and smoke. NOAA provides multi-faceted support to land management and fire agencies to aid decision making to better manage and suppress active fires. This support includes tailored, detailed weather forecasts provided by NWS Incident Meteorologists, and satellite imagery that fire behavior analysts can use to monitor trends in fire behavior. NOAA provides satellite-based analysis of smoke to the Environmental Protection Agency and is part of the EPA's AirNow fire and smoke mapping system. This allows forecasters to provide accurate hazard warnings to the public, so people can protect themselves.

"We use the satellites to inform decisions on where to stage assets across the country," said Brad Quayle of the Forest Service's Geospatial Technology and Applications Center, which plays a key role in providing remote-sensing data for active wildfire suppression. "When there's high competition for firefighters, tankers and aircraft, decisions have to be made on how to distribute those assets."

Forecasting and post-fire monitoring are an integral part of the year-round nature of managing wildfires. NOAA satellites provide data to help create products

and imagery that enable forecasters to better understand how landscapes previously impacted by fire are recovering. This is essential for identifying areas that are vulnerable to mudslides and flooding during the rainy season. NWS forecasters use these data as they prepare rainfall forecasts and consider the potential for deadly debris flows and mudslides.

Disaster Supplemental and BIL funds

Using investments from the Disaster Relief Supplemental Appropriations Act, 2022 (P.L 117-43), NESDIS has been refining its ABI-derived hotspot detection algorithm. This will assist land management agencies and other users in identifying new wildfires in a timely manner, enabling a more rapid response to wildfires that are a threat to life and property. The combination of ABI and GLM, along with the traditional and AI-based weather nowcasting provided by GOES satellites, improves decision making that protects the public, firefighters, and aviation assets during fire suppression operations.

Additionally, the BIL directed USDA and DOI to collaborate with NOAA on space-based wildfire detection work. This coordination is on-going.

Looking to the Future

As the planet's climate changes, the nation's wildfire community will need more tools and resources. NOAA is defining requirements now for our next generation satellites to continue and enhance its support of wildfire and smoke management. NOAA's next generation geostationary satellites, GeoXO, and polar-orbiting satellites, Near Earth Orbit Network (NEON), will include enhanced imaging and new capabilities for detecting wildfires and tracking smoke, building on the GOES and JPSS satellite mission legacy.

Monitoring Coral Bleaching Events

Nestled in the world's shallow tropical waters are some of the oldest, most diverse and ecologically important ecosystems on Earth: coral reefs. While coral reefs occupy a tiny fraction of the ocean floor, they contribute billions of dollars in economic, social, and cultural benefits. Those benefits include: habitat for a wide array of marine life; food for coastal and island communities; coastline buffering against erosion, waves, storms, and floods; and jobs and income from fishing, recreation, tourism, and other reef-ecosystem based businesses.

But coral reef ecosystems around the globe are at risk from soaring ocean temperatures and changing ocean chemistry.

> *Changes in conditions such as temperature and light can cause stress in corals and subsequently lead them to lose their vivid colors and turn pale or white via a process called bleaching. When many corals bleach over a large area of the reef (or multiple reefs), it is referred to as mass coral bleaching.*

Climate change and other human impacts are causing more frequent mass coral bleaching events and disease outbreaks. First observed in the early 1980s, mass coral bleaching is now one of the most visible consequences of steadily rising ocean temperatures.

NOAA Coral Reef Watch

The NOAA Coral Reef Watch (CRW) program, housed in the Center for Satellite Applications and Research (STAR) within the National Environmental Satellite, Data, and Information Service (NESDIS), provides essential environmental intelligence to a diverse community of users worldwide by delivering satellite and modeled products, and alerts, to help predict and monitor changes in the coral reef environment. Since it was established in 2000, CRW has provided the world's only global early-warning system for coral reef ecosystem heat stress.

From the vantage point of space, satellites can monitor coral reefs and their surroundings frequently and broadly. In the most remote regions on the Earth's surface, satellite data are key to ensuring that coastal and island communities around the world receive near real-time updates on changing reef conditions. This allows stakeholders to quickly and effectively implement actions to protect their reefs before and during periods of severe stress. CRW also uses in situ (or in place) data provided by local partners working on these reefs to help develop, calibrate, and validate its satellite-based products.
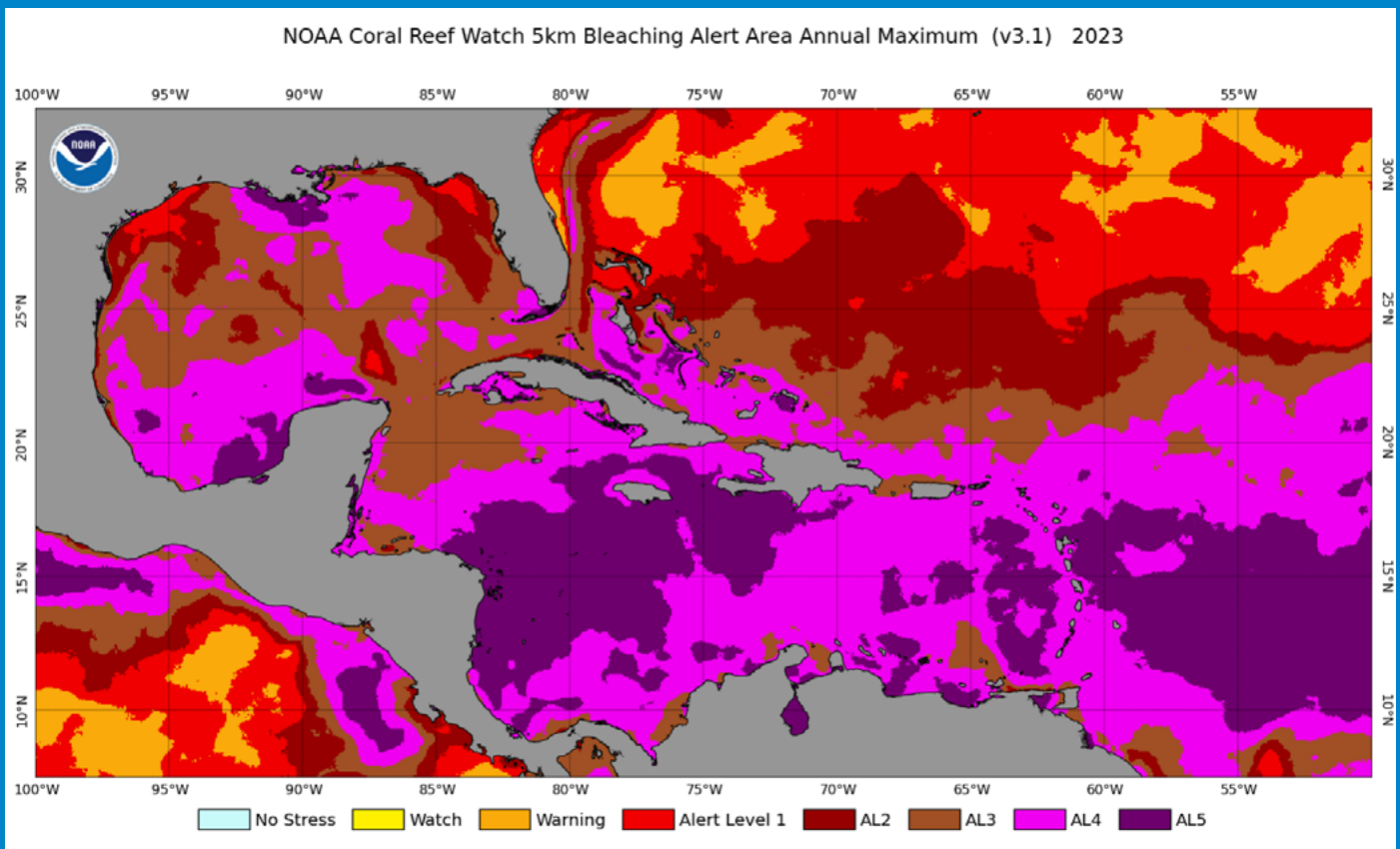
NOAA CRW offers a variety of satellite products, most of which are based on sea surface temperature (SST) measurements and are updated in near real-time. Examples include a suite of operational coral bleaching heat stress products; a daily global 5km Marine Heatwave Watch (MHW); Regional Virtual Stations; historical 5km Thermal History; Coral Disease Outbreak Risk (for Hawaii and the Great Barrier Reef, Australia); and Ocean Color Monitoring (for Puerto Rico and Hawaii coral reefs), among others. With their focus on current conditions, this satellite data helps users assess whether coral reefs are currently at risk for bleaching. With a near-future focus, NOAA CRW also provides modeled predictions, which incorporate satellite data as the observational feed, of potential heat stress up to four months in the future via the Four-Month Coral Bleaching Heat Stress Outlook. The Outlook is based on the second generation NOAA Climate Forecast System.

Coral Bleaching Alert Area Product

NOAA CRW's Satellite Coral Bleaching Alert Area product uses satellite-based data on accumulated ocean heat stress to provide alerts for coral reef areas globally that may be experiencing high enough heat stress to cause coral bleaching and death. NOTE: on December 15, 2023, CRW implemented a revised coral bleaching heat stress category system for its Bleaching Alert Area product. Extreme accumulations of marine heat stress in 2023, in multiple regions of the world, necessitated the introduction of additional Bleaching Alert Levels. This development is a refinement of the original system that only used Bleaching Alert Levels 1 and 2. The new Alert Levels 3-5 provide important, added detail, for when the magnitude of extreme heat stress exceeds the threshold of Bleaching Alert Level 2 conditions.

NOAA Coral Reef Watch 5km Bleaching Alert Area Annual Maximum (v3.1) 2023

Legend: No Stress | Watch | Warning | Alert Level 1 | AL2 | AL3 | AL4 | AL5

The dark red/brown areas on this map, which is focused on the Northwest Atlantic Ocean, Caribbean, and eastern tropical Pacific Ocean, show the heat stress capable of causing reef-wide bleaching with mortality of heat-sensitive corals. The light brown (Alert Level 3), pink (Alert Level 4), and dark purple (Alert Level 5) areas on the map indicate locations where the magnitude of extreme heat stress exceeds the Bleaching Alert Level 2 threshold and can lead to multi-species or near complete mortality on a coral reef.

These products and alerts enable coastal and island communities to:

1. Prepare for coral bleaching and disease outbreak events that may have significant, long-term impacts on coral reef ecosystem health and functioning,

2. Take actions (e.g., closing areas to fishing or scuba diving) to reduce additional, local stresses on the reef ecosystem,

3. Prioritize resources to protect key corals and reefs, especially during periods of high or prolonged heat stress (e.g., by rescuing native or rare corals to preserve genetic diversity and/or by shading/cooling key nursery reefs), and

4. Conduct restoration activities in times of no heat stress.

In addition to enabling resource managers and coastal/island communities to effectively monitor all the reefs in their jurisdiction and implement targeted conservation actions to help reduce stressors on and protect their coral reef ecosystems, CRW's satellite-based information allows NOAA to meet its users' needs and its missions, goals, and objectives.

> *"The importance of this effort relies on us being able to monitor the evolution of the heat stress in near real-time and to inform the ongoing impacts from the severe, prolonged marine heatwave. These efforts are key for decision-making processes as we continue coral recovery and conservation efforts during the current and future marine heatwave events."*
>
> *—Maria Vega-Rodriguez, Departamento Recursos Naturales Y Ambientades, Gobierno de Puerto Rico*

In response to the critical, user-defined need for remote prediction, monitoring, and assessment of the coral reef environment and coral health globally, CRW also engages heavily with its users and partners in research, development, and operations, and conducts extensive communication and outreach. As with previous major heat stress events in the region, CRW recently provided advance warning and near real-time satellite monitoring of the 2022 heat stress and subsequent mass coral bleaching event on the Great Barrier Reef in Australia. CRW collaborated directly with the Australian Government and other local stakeholders to coordinate information sharing and messaging to global media outlets.

2023: A Historically Hot Year for Reefs in the Florida Keys

In April 2023, CRW scientists observed and began communicating with local stakeholders about multiple marine heatwaves that were developing in the eastern tropical Pacific and in the Atlantic/Caribbean that had the potential to negatively impact corals in both regions. By July, in Florida, heat stress conditions had become so severe that Dr. Derek Manzello, the NOAA CRW Federal Coordinator, who had previously, for two decades, researched the impacts of ocean warming on reefs in the Florida Keys, dubbed the heat stress event "historically horrific." Using SST measurements from a satellite record dating back to 1985, Manzello pointed out that water temperatures were much higher and came much earlier in 2023 than any prior year.

During Florida's severe marine heatwave and prolonged mass bleaching event, CRW products were critical to a wide array of efforts including in-water monitoring, conservation, and rescue/relocation of coral colonies, as well as communication with decision makers, the press, and the public.

Single-pixel satellite Virtual Stations—a new addition to the NOAA CRW product portfolio—were created in response to an emergency need by coral reef stakeholders in Florida. The product enables users to compare current heat stress levels across sites, to assist with: prioritization of current efforts by location, communication among stakeholders, and subsequent relocation of coral colonies back into the water, once the heat stress subsides, for monitoring and restoration activities.

Florida Keys (Jan 1 1985 — 22 Jan 2024)
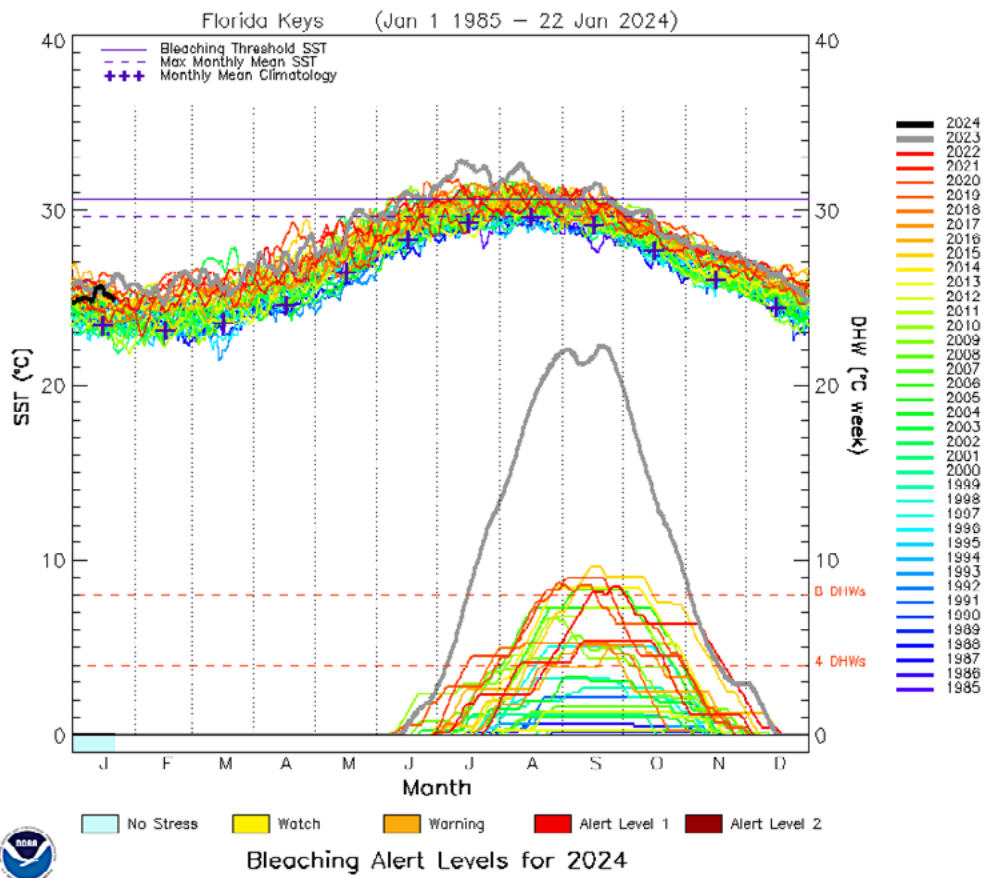
In the figure, the thick gray line represents 2023. Heat stress capable of causing coral bleaching, including mass bleaching and subsequent mortality, starts once the SSTs surpass the solid bluish-purple horizontal line.

NOAA/OAR/Atlantic Oceanographic & Meteorological Laboratory coral reef ecologist, Dr. Ian Enochs, surveys coral bleaching at Cheeca Rocks, Florida Keys in July 2023.

A piece of brain coral completely bleached.

The comments that follow help demonstrate how meaningful the Single-pixel satellite Virtual Stations were in understanding and meeting the needs of different stakeholders in different situations.

> *"The NOAA Coral Reef Watch single-pixel satellite virtual stations have been remarkably well received, and are actively being used by coral reef stakeholders all over the state, to help monitor environmental changes in near real-time and triage ongoing impacts from the severe, prolonged marine heatwave. These data will be of great use in the future, as we learn and adapt FKNMS's conservation and management efforts with ocean warming."*
>
> —Katey Lesneski, Mission: Iconic Reefs, Research and Monitoring Coordinator, Florida Keys National Marine Sanctuary

Working with local management partners, CRW also developed single-pixel satellite Virtual Stations for key restoration and nursery reef sites in Puerto Rico and the US Virgin Islands.

Anthropogenic climate change and human-induced hazards are putting the health of coral reef ecosystems in jeopardy globally. However, even as these ecosystems face mounting and severe threats, NOAA's satellite and modeled products continue helping user communities worldwide to prepare for coral bleaching and disease outbreak events; take action to limit stressors to coral reef ecosystems; and shape conservation, rescue, restoration, resilience, and communication efforts. Through the CRW program, ecosystem managers, scientific researchers, in-water monitoring networks, elected officials, and coastal/island communities in the US and around the world have critical tools to help them effectively manage, monitor,

research, and protect coral reef ecosystems in a rapidly warming world.

> *"Florida's coral reef community now has an enhanced decision-support-tool that provides data on which sites are experiencing the highest heat stress and require urgent intervention, such as coral rescue and relocation efforts aimed to preserve the genetic diversity of threatened staghorn and elkhorn corals. These data are still being used for prioritization of in-water efforts and resources, as well as a communication tool among Florida's coral reef stakeholders, the public, and the press."*
>
> —Jennifer Moore, Co-Lead, Mission: Iconic Reefs, National Marine Fisheries Service (NOAA)

Artificial Intelligence at NOAA

What comes to mind when you think of artificial intelligence? Does the term conjure a sci-fi movie plot? Or does it bring to mind a distant future where technology automates all of our dull, repetitive chores, freeing us to focus our human cognitive talents on solving more interesting challenges?

That future is now at NOAA's Center for Artificial Intelligence (NCAI). NOAA is leveraging the transformative technology of AI to help scientists understand the environment and our place in it. NESDIS is helping NOAA build a fully capable NCAI technology hub by accelerating the AI-readiness and public cloud accessibility of NOAA data, building a community of practice through public workshops, and collaborating with the research community to integrate ethical AI into NOAA's services.

NOAA has long been a pioneer in the use of AI. In the 1980s, NOAA was one of the first organizations to employ AI to analyze satellite data and improve weather forecasting models. In 2020, Congress passed the National AI Initiative Act, which codified the mandate for NOAA's pioneering coordination of AI application across climate, ocean, earth, and space sciences.

This story highlights just a few of the many AI projects at NOAA. Collectively, these projects span from the bottom of the ocean to the outer atmosphere.

Predicting Dangerous Currents

A relaxing day at the beach can quickly turn dangerous under the wrong conditions. Rip currents are responsible for 80 percent of beach rescues and approximately 100 deaths in the United States annually. They are as dangerous as they are difficult to detect.

Rip currents are powerful, narrow channels of fast-moving water that are prevalent along the coasts of the United States, as well as the shores of the Great Lakes. Panicked swimmers often try swimming straight back to shore, into the current, putting themselves at risk of drowning because of fatigue.

Today NOAA uses AI technology to more accurately predict the likelihood of hazardous rip currents, offering hourly predictions up to six days in advance.

The National Ocean Service and National Weather Service collaboratively developed and deployed a rip current model using the logistic regression machine learning technique, which uses wave and water level data to predict rip currents. Similar to predicting weather or precipitation, the model predicts the likelihood of dangerous currents on a scale, from 0–100 percent.
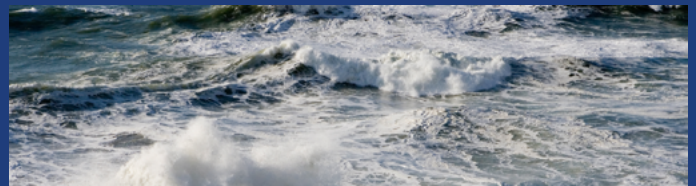
Mapping Urban Heat Islands

Summer promises longer days filled with outdoor activities. But dangerously high temperature and humidity can turn those summer days hazardous. Excessive heat is the leading weather-related killer in the United States, disproportionately affecting low-income people and communities of color.

Applying Artificial Intelligence to NOAA's Mission
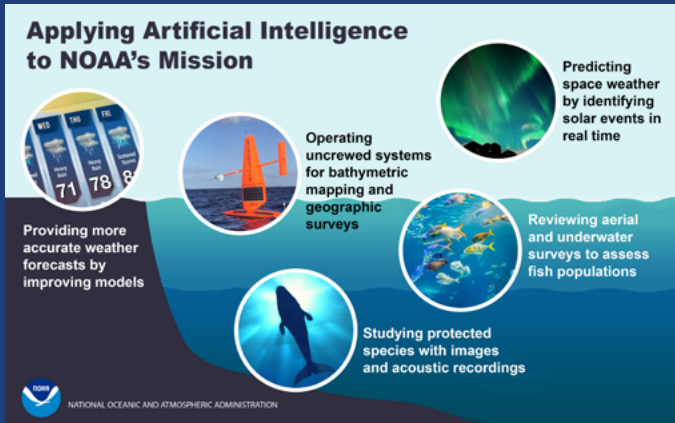
The NOAA Climate Program Office is working with the interagency National Integrated Heat Health Information System (NIHHIS) and partners to develop high-resolution air temperature and humidity data maps. A pilot effort by NESDIS NCAI is developing an AI-ready humidity dataset by blending measurements from ground stations and satellites using AI methods. The ultimate goal is to inform policy decisions by empowering communities researching heat health and developing applications with high resolution maps that combine environmental, land use, land cover and social economic information. For more information, see the NESDIS Impacts Brief Extreme Events story and AI at NOAA StoryMap.

Monitoring Tropical Cyclones

Tropical cyclones form in every tropical and subtropical oceanic region, with devastating impacts to vulnerable coastal areas (see also internal link here to the NESDIS Impacts Brief Extreme Events story). AI-ready and accessible benchmark satellite datasets are driving the future of tropical cyclone impact prediction–that is, the likelihood and severity of coastal flooding and other risks to people, businesses, and community infrastructure.

NOAA's Center for Satellite Applications and Research partnered with the Cooperative Institute for Atmospheric Research at Colorado State University to publish an AI-ready dataset for tropical cyclone research: the Tropical Cyclone PRecipitation, Infrared, Microwave, and Environmental Dataset (TC PRIMED).

This new dataset collocates and subsets LEO and GEO satellite imagery along with ancillary model informa-

tion to create a 22-yr period of tropical cyclone centric scenes. TC PRIMED is a new AI-ready and cloud-accessible dataset that enables the broader community to develop machine-learning applications and better understand tropical cyclones to improve the lead-time and accuracy of severe weather warnings for coastal communities.

Predicting Extreme Weather

Extreme weather and cascading hazards account for an increasing number of high-impact, Billion Dollar disasters. ProbSevere (shorthand for "probability of severe") is an application that uses machine learning and AI to distill massive volumes of environmental data into actionable information to improve lead-time and accuracy of severe weather warnings.
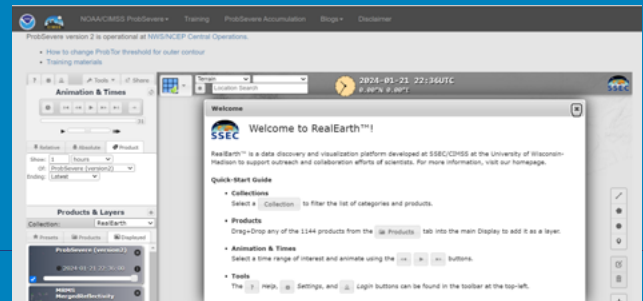

Mapping Fire Weather

Between January and September 2023, the United States experienced 18 weather and climate disasters that each caused upward of a billion dollars in damage. Devastating wildfires fanned by the winds from Hurricane Dora destroyed the historic town of Lahaina on the Maui Island of Hawaii. The fires killed 97 people and destroyed thousands of homes, vehicles and businesses. In response, NOAA is combining advanced satellite products, fuels, terrain, and fire weather data to train machine learning models that predict extreme fire behavior and will help improve wildland fire incident preparedness and response. For more information, see the NESDIS Impacts Brief Fire Weather story and the NESDIS Impacts Brief Extreme Events story.

Improving Navigation and Magnetic Field Forecasts

The Earth's geomagnetic field is an invisible shield that envelops the planet. This magnetic field prevents Earth from bombardement by harmful solar and cosmic radiation that would render our planet uninhabitable. This field is also crucial to the functioning of various navigation and technical devices such as antennas, satellites, and smartphones.

To better understand geomagnetism and improve our ability to forecast changes in the magnetic field, NOAA and the Cooperative Institute for Research in Environmental Sciences (CIRES) developed models of the geomagnetic field and maintain archives of geomagnetic data. In December 2020, NOAA partnered with NASA to launch a global crowdsourcing challenge called "MagNet: Model the Geomagnetic Field" to develop better models that can predict changes in the magnetic field in response to space weather.
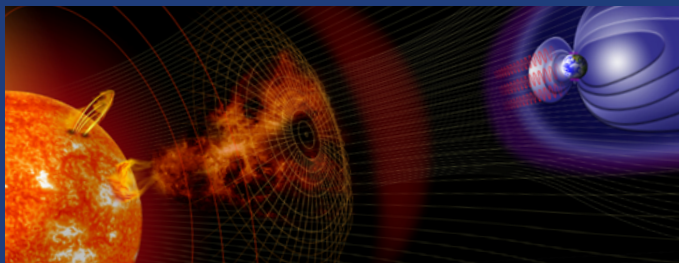
The competition challenged developers to create a forecast of the Disturbance Storm-Time Index (Dst), a measure of magnetic activity at the Earth's surface. More than 600 participants from across the world submitted more than 1,200 predictions based on a set of data that included solar wind speed and intensity, real-time Dst, and other factors. The challenge demonstrated that AI/ML models could outperform scientists in predicting the reaction of the Earth's magnetic field to space weather, even without detailed knowledge of the physics involved, effectively diversifying the community of potential solvers for NOAA's data science challenges.

Looking to the Future

NOAA and its partners are leveraging AI on a vast range of environmental and ecological issues, from monitoring and mitigating the effects of climate change to predicting and reducing harm from natural disasters. AI-powered sensors and monitoring systems will help track changes in air, water, and soil quality, while predictive algorithms will aid ecosystem management, reduce the risks of invasive species, and protect endangered wildlife. AI helps NOAA promote sustainable and responsible management of natural resources and ensure the protection and preservation of the environment for future generations.

> *"NOAA recognizes that AI–especially human-centered AI–is one of the most transformative technologies we've ever seen. The NOAA Center for AI is working to harvest the galaxy of AI possibilities to improve our ability to deliver critical products and services to all communities. The science of AI is dedicated to enabling machines to mimic human behavior, but the goal of AI is not to replace the human element, but rather for humans and machines to work together to improve our environment."*
>
> *—Dr. Robert Redmon, NOAA Center for AI Director*

NESDIS's Impact on Agriculture

From Outer Space to Our Plates

As the world's population grows, demand for food increases. Thanks to advances in technology, farming has transformed to a highly efficient, data-driven industry. NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) directly supports agriculture by providing essential data and tools that help us produce more food, enhance food security, and adapt to an ever-changing world.

Satellite and Ground-Based Monitoring

NESDIS operates a fleet of satellites that provide data vital to farmers: including crop health, soil moisture, weather, and climate. NESDIS satellites can spot crop diseases and pests early, predict yields, and guide decisions on water management, fertilization, and harvesting more efficiently. This technology allows farmers to make informed decisions and boost productivity, which benefits society as a whole.

Satellite data improves accuracy of weather forecasts, watches, and warnings, helping farmers anticipate weather patterns, monitor changes, and prepare for extreme weather events, such as hurricanes or droughts. Beyond individual farmers, NESDIS satellite and ground-based measurements contribute to sophisticated crop models and data products used by agronomists, economists, commodity traders, insurance companies, and both national and global food and relief organizations.

Data and Services

NESDIS satellite data plays a pivotal role in the development of precision agriculture techniques. By combining satellite imagery with ground-based measurements and GPS technology, farmers can obtain detailed maps of variations in soil composition, soil moisture levels, and crop health conditions. This can improve management practices, such as precision application of farm inputs like water, fertilizer and pesticide, reducing waste and environmental impact while improving efficiency.

"Water availability is a major issue facing agriculture in many parts of the globe today, and uncertainty in water supplies to support crops—both through rainfall and irrigation—will become even more volatile under changing climate conditions. We're using GOES data to monitor crop water availability and agricultural drought in the United States, and the thermal bands on GOES [satellites] in particular provide a very effective early warning signal of developing crop stress.

GOES is an excellent platform for regional monitoring, offering the necessary regional coverage and rapid temporal sampling required to quickly identify changes in water use and availability across the entire United States. Moreover, it provides much finer spatial detail (a couple of kilometers) than what can be attained with standard meteorological data."

—Martha Anderson, Research Physical Scientist, U.S. Department of Agriculture
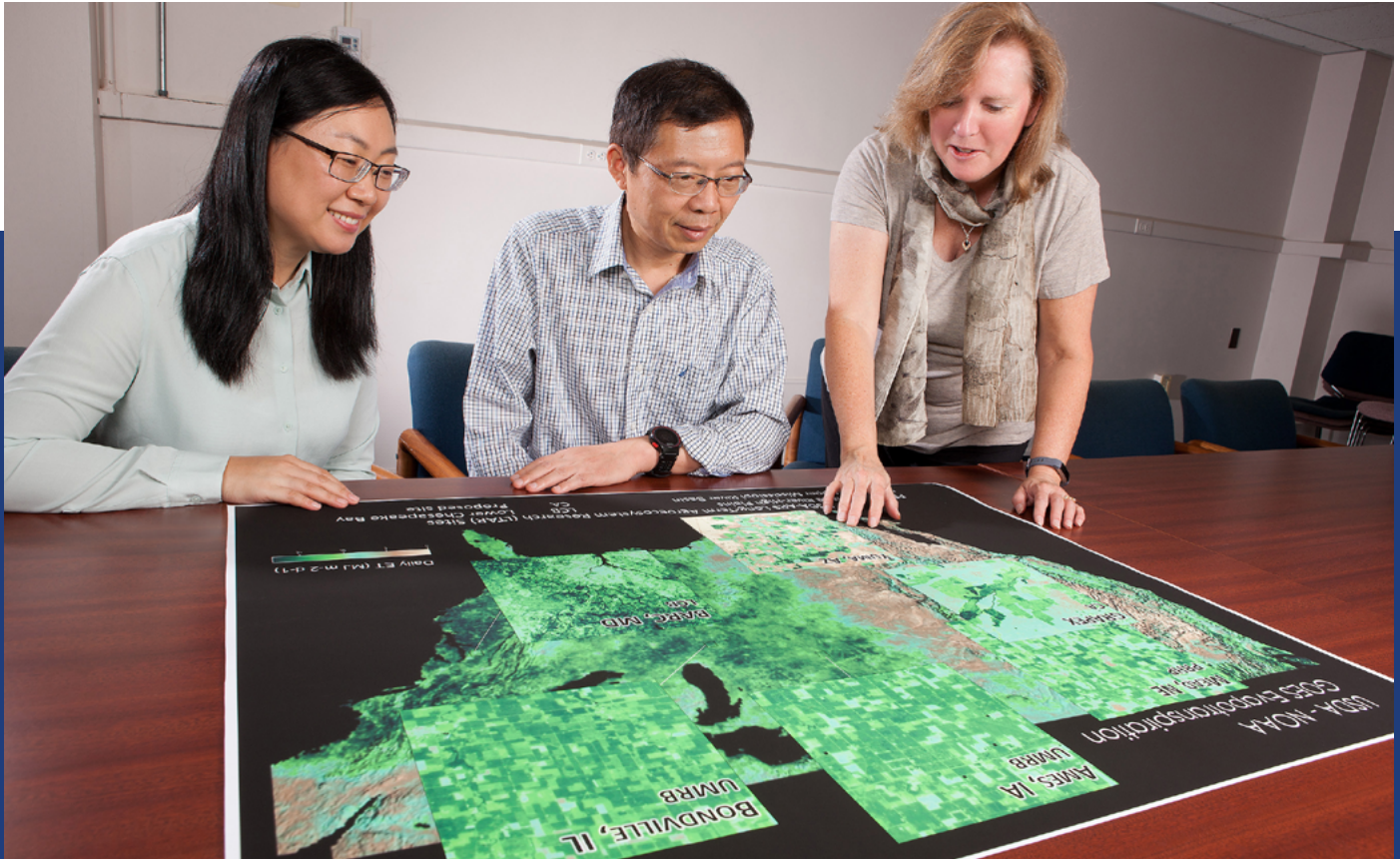
Scientists (left to right) Dr. Yun Yang, Dr. Feng Gao, and Dr. Martha Anderson from the USDA's Hydrology and Remote Sensing Laboratory view high-resolution maps of evapotranspiration (ET), or crop water use, over various agricultural landscapes in the United States. These detailed maps are generated using a combination of data sources, including land-surface temperature from NOAA's GOES satellites and leaf area index data from NASA's MODIS instrument. They will soon also incorporate data collected by the VIIRS instrument onboard NOAA's JPSS satellites. This information helps manage irrigation, estimate the effects of drought on yield, and map crop water productivity. Photo by Peggy Greb.

Additionally, NESDIS scientists from NCEI and STAR work closely with NOAA line offices and programs to deliver data and information to regions and underserved communities in the United States and around the globe where ground-based information on agricultural conditions or productivity is imprecise or uncollected.

Other federal agencies, such as the U.S. Department of Agriculture, rely on NESDIS satellite data and NESDIS scientists to support tools that farmers, commodity markets, and food-aid organizations rely on regularly. For example, NESDIS STAR scientists support the National Integrated Drought Information System with measurements from the VIIRS instrument aboard the Suomi-NPP satellite to monitor crop health over broad areas. This information helps farmers better predict yields, helps insurers analyze risk, and helps traders and food-relief organizations find pricing.

Disaster Management and Response

Natural disasters can devastate agricultural production. NESDIS satellite data helps monitor progression of a potential disaster, issue early warnings, and aid in response. For example, the evaporative stress index based on satellite evapotranspiration observations could provide a one-to-two-week early warning of a flash drought occurrence. Satellite data improves agricultural resiliency in the face of changing environmental and weather conditions.

Climate disasters, especially drought, can significantly reduce crop yield and livestock production. As drought-related crop losses intensify due to climate change, NOAA's Earth observation satellite data can improve efforts to prevent further loss of food production.

The U.S. Drought Monitor (USDM) is a map released weekly, showing the location and significance of drought across the United States and its territories using NESDIS satellite data on an array of land surface conditions. NESDIS has expanded the USDM to cover the U.S. Affiliated Pacific Islands, and as a result, Guam was able to apply for agricultural disaster assistance for the first time in history.

Weekly USDM publications are specifically used to determine Agriculture Disaster Declarations and deliver relief and aid to farmers. The USDM is also used to determine payouts from the USDA Livestock Forage Program (over $1B annually), the Emergency Haying Program, and the Dry and Nonfat Milk Program.

For more information on the USDM, please see: NESDIS Impacts Brief Article on Tropical Cyclone Algorithms and Droughts Definitions: Making an Impact on Extreme Events and Cascading Hazards.

Climate Change Adaptation

As the effects of climate change become increasingly evident, NESDIS data is becoming more important to farmers adapting to new challenges. Rising temperatures, shifting precipitation patterns, and more frequent extreme weather events pose significant risks to agriculture. NESDIS provides the data necessary for long-term climate analysis, helping farmers make strategic decisions about crop selection and management practices that are resilient to changing climate conditions.

Global Food Security

NESDIS's impact on agriculture extends beyond the United States. By collaborating with international partners and sharing data, NESDIS contributes to global food security efforts. Timely information about weather patterns, crop conditions, and food supply helps governments and organizations make informed decisions regarding food distribution, aid, and disaster relief in vulnerable regions worldwide.

"I'm a farmer in Columbus, Mississippi, and I have a healthy pine forest planted 25 years ago. Farming trees is a long-term investment, with returns coming decades after planting. If I lost my forest from wildfire, disease, or insect infestation, I would be financially devastated. Satellite data provides invaluable insights about the weather; precipitation patterns; and threats like droughts, floods, and wildfires; empowering me to make informed decisions to mitigate risks, manage resources, and protect my trees."

—Billy Cox, Cox Centennial Farm
Columbus, Mississippi

Vegetation Health Index
As of: Tuesday, March 21, 2023
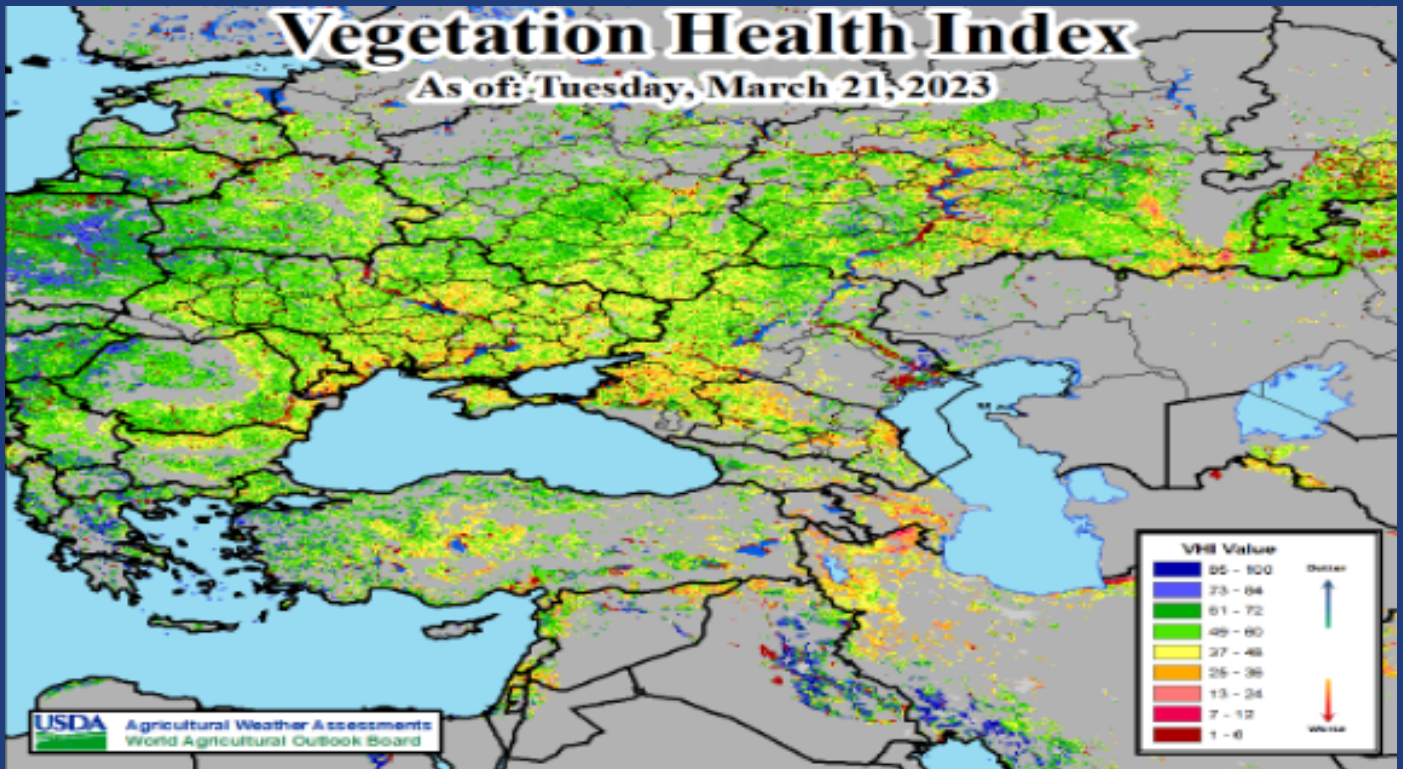
NESDIS In Action

NESDIS isn't just about satellites in space—it's about making a difference here on Earth.

NEDIS vegetation health index (VHI) data products have been used by USDA's World Agricultural Outlook Board to forecast crop yield since the 1990s. The VHI map in the right figure is used to feed USDA's crop models. The plot in the figure indicated that VHI data contributed to the sunflower production forecast significantly together with weather data. USDA uses near real time weekly VHI data from NEDIS delivered by NESDIS Vegetation Health Product team.

By providing farmers with essential data from satellite and ground-based observations, NESDIS is transforming agriculture, boosting food security, and helping us adapt to a changing world. As technology continues to advance, we can expect NESDIS to remain at the forefront of agricultural innovation, shaping the future of food production for generations to come.

Fostering the New Blue Economy

Charting a Course for a Sustainable Future

NESDIS plays a pivotal role in advancing our nation's New Blue Economy by collecting and providing data, technology, and insights to unlock the full potential of our coasts, oceans, and the Great Lakes. Operating Earth-observing satellite missions in orbit and data information systems on the ground, NESDIS data informs agencies, businesses, coastal communities, and other stakeholders to guide decisions and actions that have a far-reaching impact on our sustainable future.

Critical to the New Blue Economy are operations like this oyster aquaculture facility near the mouth of Mobile Bay, Alabama, in the Gulf of Mexico adjacent to vacation housing. In the background, gas platforms are being used for energy production. Credit: Navy Cove Oysters in Fort Morgan, Alabama

What is the New Blue Economy?

The Blue Economy describes the sustainable, equitable, and socially inclusive use of ocean and Great Lakes resources to benefit economies, livelihoods, and ocean ecosystem health. These include resources such as fisheries, renewable energy, tourism, and the preservation of marine ecosystems. The Blue Economy offers enormous potential for economic growth, job creation, and environmental conservation.

The New Blue Economy takes this concept a step further, looking to the sea for big-data and information. NOAA plays a crucial role in collecting, developing, and sharing ocean and coastal data. As a public service agency, NOAA is in a unique position to lead and accelerate the early development of the New Blue Economy by transforming how ocean data is applied across various industries. NOAA is dedicated to collecting the most reliable ocean data for building connections between healthy ocean ecosystems, economic benefits, and prosperous, resilient coastal communities.

Ocean Monitoring and Climate Studies

NESDIS's satellites and sensors monitor ocean temperatures, sea-level rise, the progression of climate change, and more. Coastal communities and marine industries depend on information from our satellites to prepare for immediate events like storms and flooding, but also to make informed decisions on long-term strategies and plans for adapting to environmental changes.

For example, certain environmental conditions encourage the growth of Harmful Algal Blooms (HABs), which can be toxic and disrupt seafood supplies, threaten human health, and impact economies. NOAA NESDIS collaborates with various partner agencies around the world to provide scientists with satellite data that helps them to better understand ways of reducing harmful impacts of HABs.

For example, NOAA's National Centers for Coastal Ocean Science's (NCCOS) Algal Bloom Monitoring System utilizes data from the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard NOAA's JPSS polar-orbiting satellites along with data from sensors onboard other NASA, European Space Agency, and EUMETSAT satellites.

A handful of young oyster spat ready to be stocked in underwater cages at an aquaculture facility. Credit: Navy Cove Oysters in Fort Morgan, Alabama.

This system provides real-time information on bloom intensity in both freshwater and marine areas, helping managers and researchers make informed decisions about water sampling, municipal drinking water systems, and other water-dependent activities. Public health officials also use the information to prepare for potential impacts of HABs.

NCCOS forecasts HABs using data and other inputs from the Sentinel missions—a constellation of European Space Agency and joint missions that share information with NOAA.

For anybody who loves a fresh-shucked oyster, rest assured that NESDIS satellites are the "sentinels in the sky" watching for events like a red tide—a HAB caused by Karenia brevis algae—which threatens both wild and cultivated oyster harvests. This is especially important as oyster landings in the north-central Gulf of Mexico continue to decline, and the seafood industry looks to oyster aquaculture to help bridge the gap in oyster production.

NOAA's National Centers for Environmental Information's (NCEI) Harmful Algal BloomS Observing System (HABSOS) receives HAB observations from monitoring agencies operated by states along the Gulf of Mexico. These observations are on a publicly accessible map almost instantly. Oyster farmers in the Gulf use these maps and data to adjust their harvest plans, helping them cover the cost of bloom-related closures. The public can also find HABSOS records of these observations dating back to 1953, available within the NCEI archive.

Fisheries Management

Without healthy oceans, we would not have sustainable fisheries and aquaculture—which provide a large supply of seafood. NESDIS collects data on sea surface temperatures, ocean currents, and plankton distribu-

tion, all information that fishery managers depend on to determine fishing quotas and protect endangered species.

NOAA Fisheries oversees 163 endangered and threatened marine species around the globe, but changing climate and oceans greatly affect not only the nation's marine life, ecosystems but also the human communities that rely on them.

Warming oceans, rising sea levels, increased floods and droughts, and ocean acidification are changing how we manage fisheries and protect habitats. Climate change threatens 1.7 million jobs and $253 billion in annual economic activity supported by fisheries in the United States. Coastal habitats also offer crucial services, including nurseries for fish, protection for people from storms, and support for protected species. NESDIS satellite information is helping people, communities and industries prepare for changing oceans and sustain the nation's valuable marine resources, fisheries, and coastal communities.

HABSOS Helps Manage Oyster Harvest

Dr. Chuck Wilson, Chief Science Officer of the Gulf of Mexico Research Initiative and contributor to the Gulf of Mexico Alliance co-owns the Navy Cove Oyster farm in Fort Morgan, Alabama He and his team have utilized HABSOS as a decision tool for harvest management when red tide blooms approach their farm, such as a particularly large one during the fall of 2018.

"HABSOS is a major addition to our water quality forecasting abilities," Dr. Wilson said. "When we see a HAB moving west along the Northern Gulf coast, it gives us an opportunity to harvest extra oysters in advance of a health department closure. This allows us to continue to meet market demand while our waters are closed."

Dr. Wilson also explained that knowledge about a HAB approaching their area allows his team to minimize stress on the oysters. "For example, when we know a bloom is approaching, we stop doing things like drying and grading oysters which can be stressful to them. When oysters experience too much stress it can affect their growth and even cause mortality."

Farm partners Chuck Wilson, George Allen, and John Supan at the Navy Cove Oyster farm. Credit: Navy Cove Oysters in Fort Morgan, Alabama.

NOAA's latest Argos DCS contribution was launched on Oct. 7, 2022: an Argos-4 payload provided by the French Space Agency (CNES) is hosted onboard the General Atomics' GAzelle satellite.

Innovation in satellite and instrument technology is providing new and improved means of tracking crucial environmental conditions and marine ecosystems. The only satellite capable of tracking very small surface transmitters on Earth is the Argos Data Collection System, which monitors and studies marine species. In a partnership with France's Space Agency, Centre National D'Etudes Spatiales (CNES), dating to the 1970's, NOAA/NESDIS currently contributes four of the nine active polar-orbiting satellites with Argos instruments onboard.

In 2024, CNES and its subsidiary companies, Collecte Localisation Satellites (CLS) and Kinéis, plan to launch 25 small-sats, enhancing the Argos program and significantly improving marine animal tracking capabilities.

An Argos tracker attached to a sea turtle. Credit: Collecte Localisation Satellites (CLS)

Ecosystem Conservation

Under the ocean's surface, but within reach of sunlight, thrive vast meadows of seagrass. More than 70 species of these aquatic plants are found on every continent except Antarctica, and while often confused with seaweed, are the only flowering plants living in the oceans.

Seagrass meadows are one of the most productive ecosystems in the world, providing important food sources and habitats for a diverse community of wildlife—from tiny invertebrates to large fish, crabs, turtles, marine mammals, and birds. In fact, some species of fish and shellfish are only found in seagrass meadows. Additionally, seagrass plants filter water, produce oxygen, and control erosion while acting as vital carbon sinks, storing carbon captured from the atmosphere. Thus, if properly managed, they could help rein in global carbon dioxide emissions responsible for climate change.

While we know the value of seagrass meadows, we are still understanding the extent of their reach on the globe—estimates vary from 150,000 to more than 4.3 million square kilometers.

Without precise information on seagrass coverage and density, efforts to manage human impacts, coastal development, and climate change adaptation are more challenging to implement. Traditional field observations are expensive and time-consuming, and legacy satellites haven't had the resolution needed to distinguish seagrasses from other underwater features.

However, thanks to recent advances in sensor technology, we now have sharper satellite imagery that can capture detailed views of coastal areas, mapping features as small as two meters. Working with partners in the Philippines and Indonesia, NESDIS is creating the first-ever large-scale maps of seagrass coverage and density along their coasts.

The Tropical Indo-Pacific global seagrass bioregion has the largest difference between expected and mapped seagrass areas. The NESDIS information on seagrass coverage and density will help our partners in the Philippines and Indonesia develop sustainable management plans. The NESDIS information will also refine global carbon budgets, giving a better understanding of blue carbon–carbon captured by the world's oceans and coastal areas. Without high-resolution satellite data, mapping the extent and density of these seagrass beds would be too difficult, hindering crucial management efforts.

The Future of Our Oceans

These are just a few examples of the work NESDIS conducts to preserve the future of our oceans and the New Blue Economy. By promoting a healthy and thriving New Blue Economy, NESDIS contributes to economic prosperity, and addresses challenges such as climate change, overfishing, and coastal erosion. NESDIS initiatives empower decision-makers, researchers, and local communities to make informed choices that protect the environment while promoting economic development.
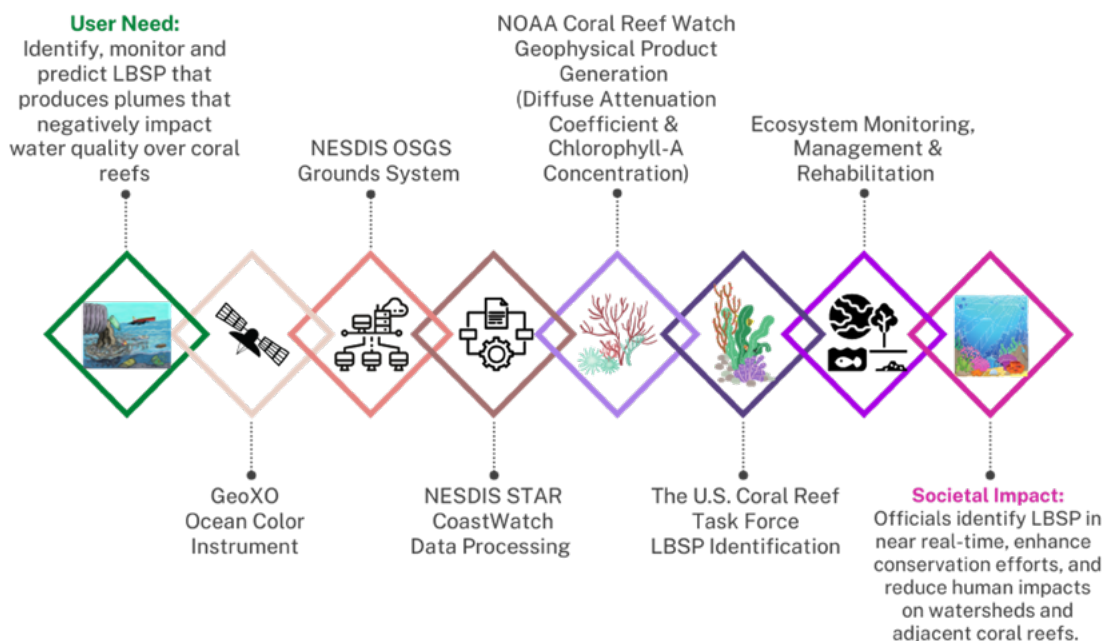
However, as our planet's climate changes, it's crucial for NOAA's environmental monitoring capabilities to evolve. Building on the legacies of the current geostationary GOES and polar-orbiting JPSS satellite missions, NOAA is currently developing the next generation of satellites that will take over for its current fleet as they near the end of their operational lifespans. Geostationary Extended Observations (GeoXO), NOAA's next series of geostationary satellites, and Near Earth Orbit Network (NEON), NOAA's next series of polar-orbiting satellites, will include enhanced imaging and new capabilities that will help monitor the health of our oceans.

For example, NOAA plans to include a new Ocean Color (OCX) instrument as part of the GeoXO satellite system. This tool will monitor various aspects of the ocean, such as its biology, chemistry, and ecology, and will offer more frequent and detailed information than current monitoring methods. OCX, positioned in geostationary orbit, will provide updates at least every three hours, a significant improvement over the once-per-day updates from current sensors in low-Earth orbit. This frequent, high-resolution data will enable NOAA to provide more accurate and timely forecasts and guidance to various agencies and industries, including ecological forecasters, marine resource managers, health departments, as well as the commerce, recreation, and tourism sectors.

NEON will launch small to medium-sized satellites with Earth-observing instruments more frequently. A resilient constellation of low earth orbiting satellites, which can be deployed quickly, will enhance our weather forecasting, disaster management, and understanding of the effects of global climate change.

By ensuring the responsible management of marine resources, these advancements pave the way for a sustainable future for generations to come.

GeoXO Ocean Color Data Value Chain

User Need: Identify, monitor and predict LBSP that produces plumes that negatively impact water quality over coral reefs

NESDIS OSGS Grounds System

NOAA Coral Reef Watch Geophysical Product Generation (Diffuse Attenuation Coefficient & Chlorophyll-A Concentration)

Ecosystem Monitoring, Management & Rehabilitation

GeoXO Ocean Color Instrument

NESDIS STAR CoastWatch Data Processing

The U.S. Coral Reef Task Force LBSP Identification

Societal Impact: Officials identify LBSP in near real-time, enhance conservation efforts, and reduce human impacts on watersheds and adjacent coral reefs.

Forecasting Space Weather

From here on Earth, the Sun seems like an evenly-shining orb, slowly rising and setting in a steady cadence. But closer looks at the Sun show an active, turbulent surface emitting electromagnetic radiation and spewing streams of gas and particles, two types of space weather, into the Solar System.

Charged with electricity, these streaming particles, called the solar wind, can cause geomagnetic storms in Earth's atmosphere and magnetosphere—damaging the electrical grids that power our communities, interrupting radio and satellite communications, and causing our GPS navigation to fail. Predicting when and how much space weather could hit the Earth's atmosphere is important to protecting people and property. To improve the accuracy and reliability of space weather predictions, NOAA's Space Weather Observations (SWO) Office which falls under the National Environmental Satellite, Data, and Information Service (NESDIS), is set up to observe, track and understand space weather and the Sun's changing environment.

It is important to understand and monitor space weather because it threatens our economy, national security, and individual safety. Perhaps no part of U.S. infrastructure is more vulnerable to space weather than our nation's electrical generation and transmission system. The energy imparted from space weather events can ultimately generate unexpected currents in electric power transmission lines, risking the stability of those electrical grids. Protecting those grids by knowing when space weather is likely is critical. Accurate predictions of space weather can reduce or eliminate operational and service interruptions costs. Some studies estimate that extreme space weather-induced electricity blackouts could cost the U.S. more than $40 billion every day.

NOAA's space weather services, data management, and observations provide other societal and economic benefits across sectors including civil aviation, agriculture, satellite industry, communications, and navigation.


Space weather impacts aviation, auroras, electric power, emergency management, Global Positioning System (GPS), radio communications, satellites, and human space exploration.

To produce space weather forecasts similar to the weather forecasts predicting rain or snow here on Earth, NOAA uses real-time observations of the solar wind, space weather, and the Sun's surface. To collect these observations, NESDIS operates the Office of Space Weather Observations (SWO), which develops, deploys, and manages space weather satellite systems. NESDIS and SWO augment those observations with data from other federal science agencies, private sector companies, and our international partners.

The best way to measure space weather is from the vantage point of space. NOAA observes the Sun and space weather in the ultraviolet and x-ray spectrums from satellites carrying high-performance instruments.

Other NOAA instruments measure the solar wind, which interacts with Earth's magnetic field and can pose a danger to our near-Earth environment. Additionally, NESDIS gathers space weather data in the near-Earth environment that impacts technologies such as communications systems and GPS, and perturbs satellite orbits.
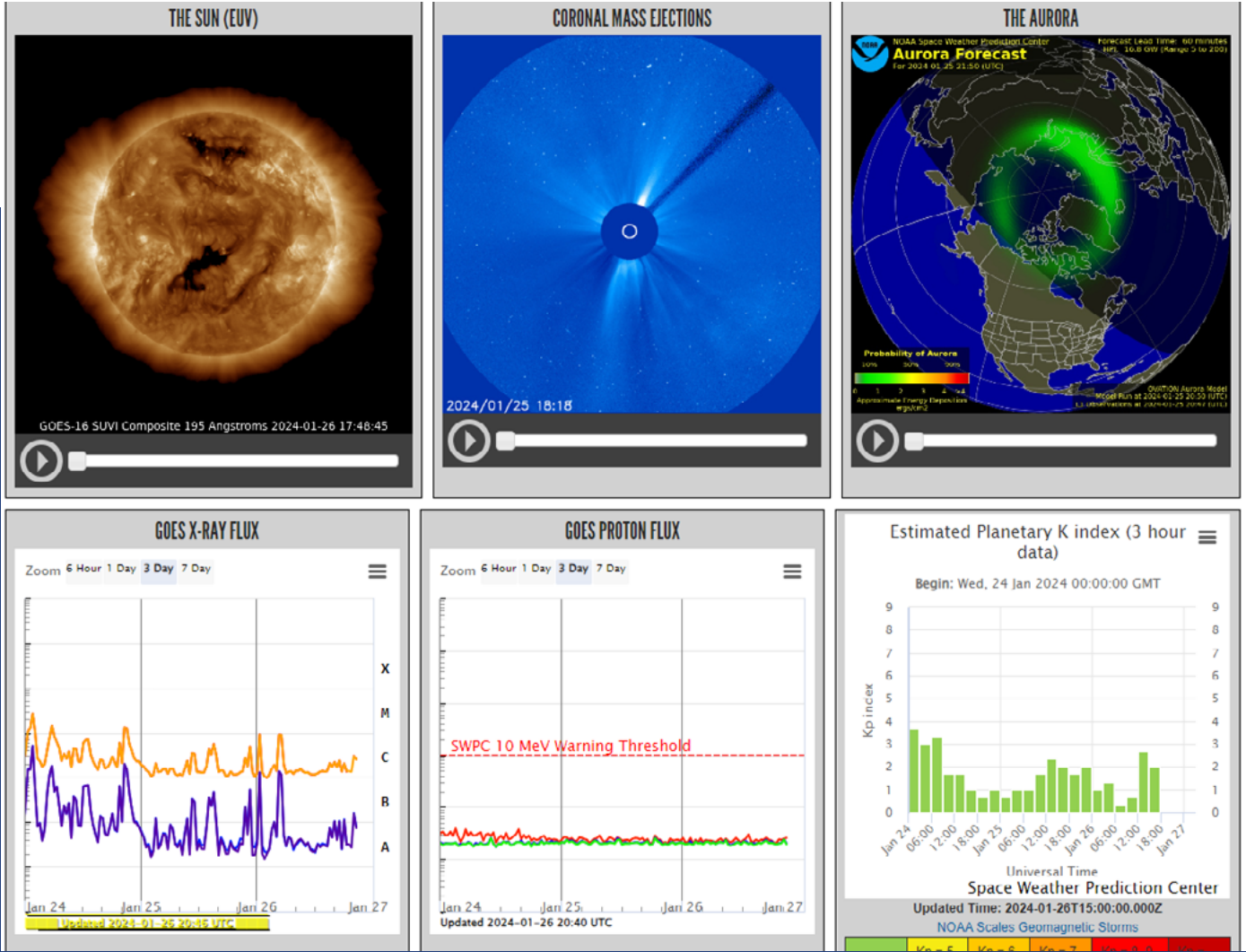
NOAA collects and provides space weather data to support agency decisions, forecasts, watches, warnings and alerts.

The data collected from platforms in various orbits is sent down to our antennas on Earth as soon as it is collected.The real-time data drive around-the-clock analysis and forecasting of space weather conditions that are then provided to the public and other government agencies by NOAA's Space Weather Prediction Center (SWPC). SWPC is the nation's official source of space weather data and information to support civil agency decisions, forecasts, watches, warnings, and alerts.

Once space weather data has been used in an alert or prediction, it is archived by NOAA's National Centers for Environmental Information (NCEI) to ensure data quality and continued access for ongoing scientific research.

How important are NOAA's space weather forecasts? Knowing of an incoming solar storm helps commercial

The Aurora Borealis is a visible manifestation of space weather. Chena Springs, Alaska.

airlines direct their pilots to avoid areas where solar wind could disrupt High Frequency (HF) communications, cause satellite navigation system errors, and risk radiation hazards to passengers and aircraft.

Solar weather also threatens the GPS used in our cell phones, the vehicles we drive, and any useful item that needs precision location measurements. Solar activity can change radio signal paths and create errors in GPS positioning information—essential to industries such as farming, construction, commercial shipping, and navigation.

When disasters such as hurricanes strike, communication is crucial. On September 6, 2017, as Puerto Rico braced for impact from Hurricane Irma, activity on the sun triggered a major coronal mass ejection--the largest solar flare detected by satellites in about a decade. A subsequent radio blackout disrupted high-frequency ground communication and aviation systems when emergency needs were critical. The outage caused a near-total communication blackout for most of that morning and early afternoon. French Civil Aviation Authority officials reported losing contact with an aircraft in the region for 90 minutes during the blackout. In situations like this, data and alerts from SWO and SWPC provide emergency response teams with information on potential space weather impacts. This gives the teams time to protect their communications equipment, to switch to alternate communications channels in order to stay in touch with each other, and to send emergency broadcasts to the public in order to save lives and protect property.

Accurate space weather data is also critical to military operations. This data can help the military determine if impacts they're experiencing are from the environment or an adversary and whether they need to leverage alternate methods of communication during the operation. SWO and SWPC are working closely with the Department of the Air Force on space weather forecast capability development to ensure that the national security sector has the data and models it needs to effectively execute its operations.

> *"Space weather is a serious threat to the Nation, and we need to continue to advance and improve our capabilities. Our attention to space weather research, observations, and services must evolve if we are to address, at the level we need to, the support necessary to protect critical national functions and security from space weather storms."*
>
> *—NOAA Administrator, Dr. Rick Spinrad*

Looking to the Future

As space commerce rapidly grows, with higher numbers of more sophisticated satellites going into orbit, so does the need for new observations and data to continually improve space weather forecasts. In 2022, 38 SpaceX Starlink satellites burned up after launch as a result of a period of prolonged, yet minor geomagnetic storm conditions. Smaller storms once unnoticed are now causing problems as we become more reliant on advanced technology and increase our activities in space, where that technology is more vulnerable to space weather.

Engineers integrate the nation's first coronagraph on the NOAA GOES-U satellite. Image Credit: Lockheed Martin

The 2024 launch of NOAA's GOES-U satellite will carry a NESDIS-developed coronagraph capable of taking images of the Sun's outer atmosphere, called the solar corona. This will help detect and characterize coronal mass ejections (CMEs) that expel plasma and accompanying magnetic field. These CMEs are potentially the most dangerous and impactful space weather events. This will be the nation's first operational coronagraph and will deliver CME imagery within 30 minutes of acquisition, an unprecedented level of monitoring that greatly exceeds the current data rate (often once in eight hours) from an aging ESA-NASA research satellite.

The SWFO team in front of the Consolidated Backup (CBU) Antenna after conducting Antenna Site Acceptance Testing (SAT). Image Credit: NASA

To ensure continuity of critical space weather data, in 2025 SWO's Space Weather Follow On (SWFO) program plans to launch a dedicated satellite to the Lagrange Point 1 position, also called L1, which is one million miles upstream of Earth. This will afford NOAA an uninterrupted view of the Sun and will provide early detection of dangerous conditions in the solar wind before it reaches Earth. To meet growing demand from users for additional space weather data and services to safeguard our nation, SWO's Space Weather Next program is developing instruments and spacecraft to collect observations from different vantage points near Earth and the Sun, in addition to expanding capabilities

to new orbits using new and improved instruments. Space Weather Next's first project will be to plan for the continuity of measurements at L1. This space weather satellite constellation will be called Space weather Observations at L1 or SOL for short. It signifies a milestone for continuity and resiliency of real-time solar imagery and solar wind measurements.

> *"NOAA is the space weather agency, just like NOAA is the ocean agency and the weather agency. NOAA embraces its mission 'from the surface of the Sun to the unknown impacts from the Sun that affect humans and our activities, the economy, and National Security.'"*
>
> *—Elsayed Talaat, NOAA Space Weather Observations Director*

SWO Director, Dr. Elsayed Talaat, views the annular solar eclipse during a NOAA-NASA-NSF joint event for the public in Albuquerque, New Mexico on October 4, 2023.

Fostering Coastal Resilience In a Changing Environment

NESDIS's Capabilities Help Communities Plan and Recover

Waves as high as 18-feet crashed into California beach towns between December 2023 and January 2024—the "king tides" strewing debris, sweeping beach sand back into the ocean, and powering ocean flood waters up into the communities. The coastal flooding damaged or destroyed homes, shops, restaurants, beach access roads, playgrounds and more. At least one person died.

At NESDIS, scientists and engineers are working to better understand how climate change-induced sea level rise threatens coastal communities, ecosystems, and natural habitats with flooding and inundation. The ability of a coastal community or ecosystem to absorb events, such as higher-than-normal "king waves," and still bounce back, is called coastal resilience. The work NESDIS does helps improve coastal resilience through a variety of environmental data, information tools, products and services that can inform decisions made at local, state, and national levels.

Observing the Surface Through Clouds With Synthetic Aperture Radar

Much of the work to provide coastal resilience begins with remote-sensing: observations collected by satellites either operated by NOAA or by NOAA partners.

Advances in technology are constantly improving our ability to collect measurements from space. Satellites with Synthetic Aperture Radar (SAR) are useful in coastal storm conditions because SAR is able to penetrate clouds, capturing data regardless of weather conditions.

NESDIS scientists use satellite data to compare images taken before and after floods to create flood extent maps, which help emergency responders and managers understand the scope of the impact.

Unlocking the Potential of Satellite Data

In many cases, NESDIS partners with other federal agencies, local and state governments, universities and others to collect data. Some data come from in-situ sources, like ground sensors, which can be sparse, localized, or otherwise restricted. Satellite data helps fill in the observational gaps, and in the case of coastal communities where the depth and shape of underwater terrain is a significant consideration, can provide wide coverage in shallow waters to enable more complete mapping of coastal terrain.

NESDIS Scientists at Work

Using data from SAR and optical satellites, as well as in-situ data, a NESDIS team of specialists builds digital elevation models (DEMs) to help coastal decisionmakers. Specializing in the development of flood inundation maps that help assess the impact of coastal flooding, the effort is led by a group of scientists within the Satellite Oceanography and Climatology Division, marine Ecosystems and Coastal Branch at the NESDIS Center for Satellite Applications and Research (STAR) and the Marine Geology and Geophysics Section at the National Centers for Environmental Information (NCEI).

Coastal states and communities rely on NESDIS maps, grids, and data to model where flooding and inundation might occur – informing leaders making decisions about resilience. But those maps, grids, data and information from NESDIS—critical for U.S. coastal communities monitoring and preparing for disruption—depend on the expertise, research and services of our NOAA scientists.

NESDIS digital elevation model maps the seafloor near coastal communities.

Resilience Toolkit Provides a Seamless Representation of The Ocean Floor

Accurate, high-resolution, three-dimensional coastal maps are essential to coastal flood modeling as the shape and depth of the ocean floor affect the speed and height of waves, and the coastal land topography primarily determines the inland extent of inundation. The NESDIS generated DEMs incorporate sonar data with high-resolution satellite lidar, satellite radar, and data from airborne campaigns map the seafloor near coastal communities.

Understanding coastal topography helps monitor for changes in coastline shape and stability, including low-lying areas susceptible to flooding and erosion. DEMs are used to create floodplain maps, which help identify and model areas prone to flooding during heavy rainfall, storm surges, or high tides such as the recent king tides that pummeled California's coastline.
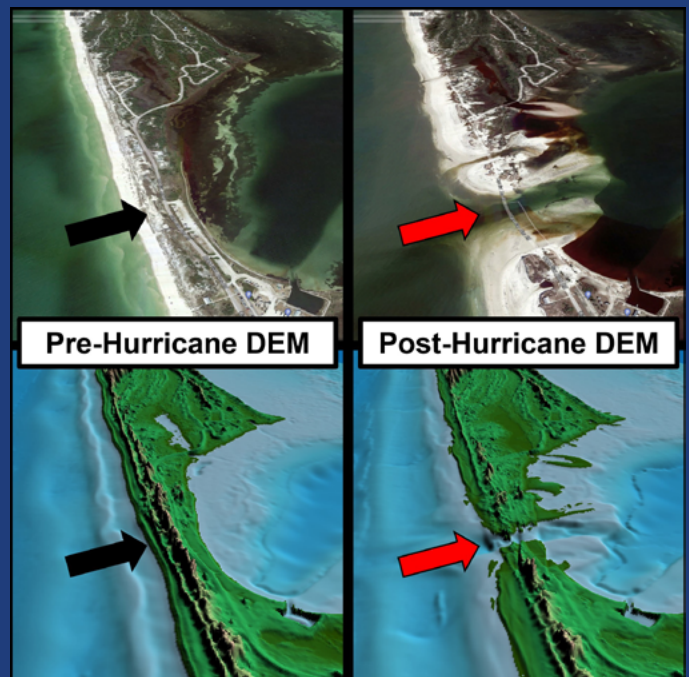
Comparison of Pre-Hurricane digital elevation map and Post-Hurricane digital elevation map

Potential Exposure to Inundation?

A first look with NOAA's Sea Level Rise Viewer

This viewer gives communities a preview of their exposure to inundation from coastal flooding and sea level rise. The DEMs that form the base maps are customized for mapping inundation and have been used in selected coastal resilience efforts and for storm surge modeling and mapping by the National Hurricane Center.

Bridging The Knowledge Gap

Technical information like digital elevation models are only as good as the capability of the people expected to use them—and given the wide range of users who rely on NESDIS data products and services (local government officials, nonprofits, and private sector companies), NESDIS is working to build capacity among the user community.

Capacity-building fosters collaboration and coordination, as well as capability to use NESDIS information and products.

NESDIS-run workshops on digital elevation models give local scientists and emergency managers the knowledge required to develop and update DEMs used in modeling and planning for a resilient community.

"These elevation models are crucial for assessing coastal and river water level risks from storm surges, tsunamis, and atmospheric river events and it will become even more valuable as climate change progresses with increasing sea level rise."

—Sean Mullen, Ocean Networks Canada

"The communities of Santa Cruz County are on the front lines of climate change impacts. The ability to forecast risk hazards such as tidal surges combined with extreme waves, winter rain storms, and wildfires are absolutely crucial for us. We use NOAA data to help us prepare for events, warn residents and businesses of possible dangers, and help build community resilience for future events. We've had NOAA staff embedded with us in our emergency operations center during storm events and other disasters. We rely on NOAA's expertise to help us safeguard lives, protect property, and care for our environment."

—David Reid, Director, Office of Response, Recovery, and Resilience (O3R), County of Santa Cruz, CA

Making an Impact on Extreme Events and Cascading Hazards

Tracking Tropical Cyclones and Monitoring Droughts

The United States has experienced extreme weather and climate events in the past, but they have been getting worse in recent years. With climate change, these events are expected to increase even more in frequency, intensity and duration in the coming decades. Many strike like fast-moving wrecking balls, imposing considerable damage and disruption to life, property and our natural resources.

When environmental extremes strike—such as persistent heatwaves, unusually severe, or long-lasting drought, or atmospheric rivers that trigger flooding and mudslides—NESDIS and our skilled employees are ready. NESDIS provides state-of-the-art observations, long-term data records, and information used by communities around the world in the face of extreme weather events. The following are two key areas where NESDIS scientists are making an impact.

Predicting the Birth of a Storm with the NESDIS Tropical Cyclone Formation Product

Tropical cyclones form in every tropical and subtropical oceanic region. A natural occurrence, cyclones bring many hazards to both coastal and inland areas, including heavy rain, strong winds, and floods. All can disrupt human and natural systems, including transportation and energy transmission infrastructure, coastal ecosystems, ocean commerce, and marine operations, as well as health and well-being. Nearly two billion people worldwide have been exposed to hazardous cyclone weather in coastal regions. With coastal populations growing and sea level rising, more people are at risk.

Between 80 and 100 cyclones form in a given year over vast ocean regions with sea surface temperatures greater than 26°C (~30 million square miles). Cyclones typically intensify to hurricane strength within 72 hours of formation.

Public attention is often captured quickly, as weather forecasts of future movement and intensity changes begin once a tropical cyclone forms. NOAA works with the Department of Defense (DoD) and international organizations to forecast global tropical cyclone activity—crucial to coastal warnings, preparedness, and mitigation.

Updates, Improvements, and Cloud Implementation

NESDIS scientists Dr. Christopher Slocum and Dr. John Knaff are working to improve the global prediction of the genesis of tropical cyclones. The pair developed an algorithm leveraging three elements:

- Environmental conditions, such as winds with altitude and the amount of energy available to develop and strengthen cyclones;

- Satellite observations of thunderstorm activity; and

- Locations of current tropical cyclones (existence of which prevents tropical cyclones from forming nearby).

A specialist in tropical cyclone dynamics, applications from geostationary platforms, and machine learning, Slocum updated a legacy tropical cyclone formation product using several machine learning algorithms to improve both calibration and forecast performance. Knaff, whose research centers on the observational aspects of hurricane structure and intensity variations and prediction, managed the project. They were supported by NESDIS IT specialists who readied the algorithm for operations on the NOAA Common Cloud Framework, bringing it over the finish line.

Outputs from the algorithm are displayed in real-time, archived for future use, and provided to NOAA, the
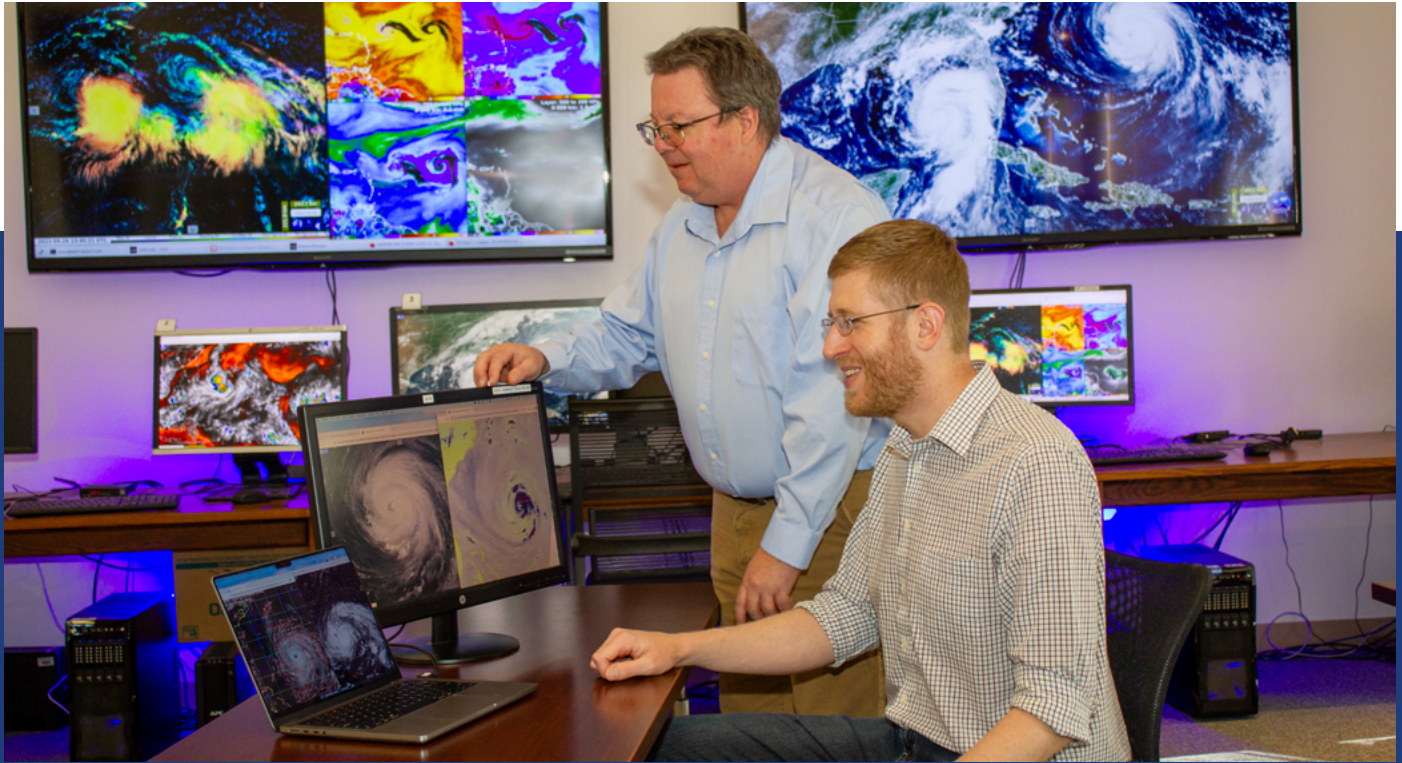
Dr. John Knaff and Dr. Chris Slocum used machine learning to develop an algorithm to predict tropical cyclone formation probabilities.

DoD, and other users, offering insight into current conditions and seasonal activity.

The algorithm combines satellite observations of real-time thunderstorm activity with global models of environmental conditions to predict 0-to-48 hour tropical cyclone formation probabilities. Slocum and Knaff's work suggests that machine learning can significantly improve storm forecasting. Higher quality data can provide more accuracy, greater temporal resolution, certainty, and precision.

Slocum and Knaff anticipate using a combination of machine learning and synthetic satellite information to extend formation probability to longer lead times (5–7 days).

Helping Tackle the Many Dimensions of Drought

One of the most pervasive and devastating climate-related disasters is drought. Climate change is driving the severity, duration, and frequency of drought. According to NOAA's Global Drought report, at the end of July 2023, drought was affecting every continent of the globe, including 63 percent of Europe, 27 percent of North America, and 19 percent of Africa.

Drought is a deficiency of precipitation over an extended period of time. It has plagued society for thousands of years, even potentially contributing to the collapse of some early civilizations. Drought affects every sector of society, including recreation, transportation, city water supply, power generation, agriculture, and national security.

In the U.S., drought has most notably affected the arid lands of the western U.S. that depend on melted mountain snowpack to meet summer water demand. That's changing as warmer temperatures cause more of the winter precipitation to fall as rain instead of snow, reducing winter snowpack, and consequently, the summer water supply. The combination of declining snowpack and prolonged dry and hot periods is creating "mega-droughts" —droughts that last not years, but decades.

NOAA scientists play a key role in monitoring the nation's drought conditions. Scientists such as Richard Heim and other drought experts at NESDIS are working to solve the toughest drought-related challenges. Heim's projects include refining drought monitoring tools, and writing the monthly State of the

Effects of Drought on our Environment

The summer of 2023 was especially dry and hot across the United States, from the Upper Midwest down through the southern Plains and the Lower Mississippi Valley. Louisiana saw its driest and hottest August. Mississippi had its hottest August. Minnesota and Wisconsin had their fourth-driest stretch from May through August. Soils were parched, crops withered, and lakes, rivers, and ponds dried up.

Drought is reducing yields and increasing costs on U.S. agriculture. The USDA's Livestock Forage Disaster Program (LFP) provides payments to eligible livestock owners and contract growers who have suffered a loss of grazed forage due to a qualifying drought during the normal grazing period for their county. Payouts under LFP from 2008–2023 have totaled $11.11B.

Dry stock pond in Texas, September 2023. Source: National Drought Mitigation Center Condition Monitoring Observer Reports.

Livestock Forage Disaster Program (LFP) payouts in millions of dollars, each year from 2008-2023 (2023 totals are incomplete). Source: U.S. Department of Agriculture.
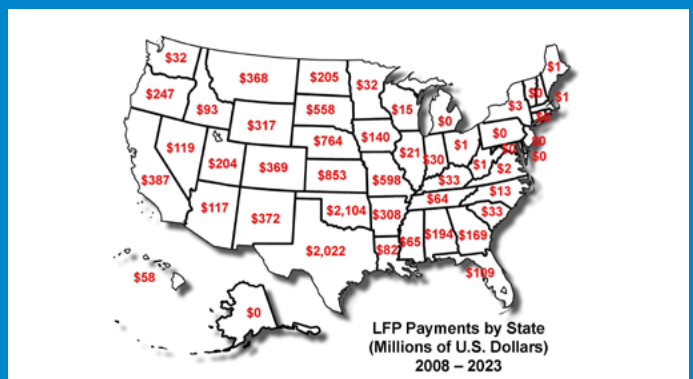
Livestock Forage Disaster Program (LFP) payments by state, in millions of dollars, totals for 2008-2023. Source: U.S. Department of Agriculture.

Climate Drought report for the National Centers for Environmental Information (NCEI). Heim is also a lead author of a journal article summarizing domestic and international user engagement workshops that helped define drought monitoring parameters and needs in the diverse climates of North America.

Drought poses other challenges, as a slow-moving and largely unseen phenomenon. To illustrate this, Heim compared droughts to hurricanes.

> *"You can see a hurricane coming—its wind speed, size, speed, and direction of movement can all be calculated and prepared for in real-time", Heim said. "Drought, however, is the absence of something, specifically precipitation. It develops slowly, from the lack of rain, or as the reduction of precipitation builds up deficits from what normally occurs over time and, at some point, impacts begin to be felt."*
>
> *—Richard Heim*

Since January 2000, NOAA, the United States Department of Agriculture (USDA), and the National Drought Mitigation Center have collaborated with hundreds of local experts across the 50 states and U.S. territories to produce a weekly drought map and narrative known as the U.S. Drought Monitor (USDM). Heim and his NESDIS colleague, Rocky Bilotta, contribute as authors to the USDM. NCEI led the development of a data platform that supports the USDM in the U.S.- Affiliated Pacific Islands, and hosts the National Integrated Drought Information System (NIDIS) drought.gov web platform, a multi-agency effort. Led by NOAA, NIDIS coordinates drought monitoring, forecasting, planning, and information at national, tribal, state, and local levels. NIDIS enables communities to better prepare for, respond to, and recover from drought.
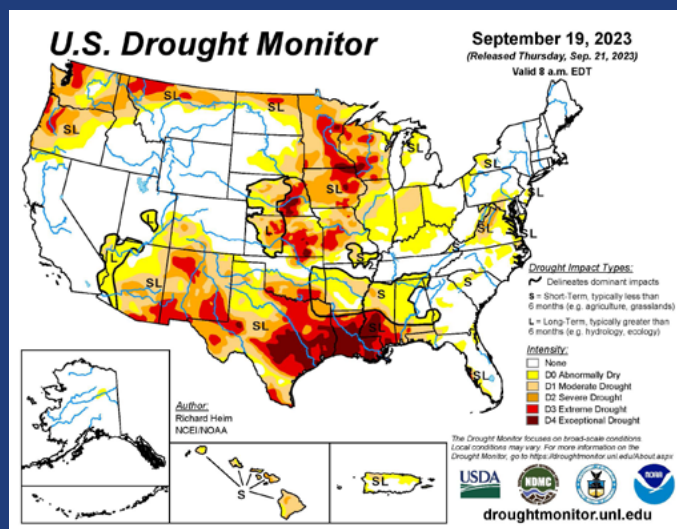
U.S. Drought Monitor map for September 19, 2023. The map shows the occurrences of the most extreme drought: the southern Plains to Lower Mississippi Valley, central Plains, and Upper Mississippi Valley. Source: National Drought Mitigation Center.

In 2002, NCEI led the expansion of drought monitoring across North America with the development of the monthly North American Drought Monitor (NADM), prepared from the corresponding USDM, Mexican Drought Monitor, and Canadian Drought Monitor and produced collaboratively by agencies from all three countries. NOAA/NESDIS also developed and hosts the Global Drought Information System (GDIS) and its Global Drought Monitor, which includes global drought maps updated each month, and a Global Drought Narrative, which discusses drought conditions on each continent.

Our changing climate means more extreme weather events such as cyclones and increased likelihood of hazards such as droughts. NOAA is responding to these challenges by providing both the technology and brainpower to help those both in the U.S. and around the world predict, endure, and recover from extreme events and hazards.

Acknowledgements and References

NESDIS's Impact on Agriculture

From Outer Space to Our Plates

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Fostering the New Blue Economy

Charting a Course for a Sustainable Future

Paul DiGiacomo (NOAA/NESDIS/STAR)
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Forecasting Space Weather

Space Weather Impacts Our Nation and the World

Irfan Azeem (NOAA/NESDIS/SWO)
Daniele Heiny (NOAA/NESDIS/SWO)
Susan Jacobs (NOAA/NESDIS/SWO)
Laurel Rachmeler (NOAA/NESDIS/NCEI)
Jim Spann (NOAA/NESDIS/SWO)
Jim Silva (NOAA/NESDIS/SWO)
Elsayed Talaat (NOAA/NESDIS/SWO)

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NESDIS's Capabilities Help Communities Plan and Recover

Sean Helfrich (NOAA/NESDIS/STAR)
Sean Mullen (Ocean Networks Canada)
David Reid (Office of Response, Recovery, and Resilience, County of Santa Cruz, CA)
Kelly Stroker (NOAA/NESDIS/NCEI/Marine Geology and Geophysics Section)
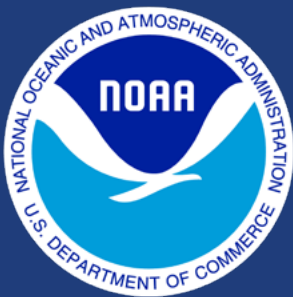
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Making an Impact on Extreme Events and Cascading Hazards

Tracking Tropical Cyclones and Algorithms and Monitoring Droughts

Marshall Baldwin (Hollins Scholar, Summer of 2022)
Richard Heim (NESDIS/NCEI)
John Knaff (NESDIS/STAR)
Chris Slocum (NESDIS/STAR)