AIA Earth Observation Report:

Knowing Our Home – Understanding Earth from Space

AEROSPACE INDUSTRIES ASSOCIATION

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The Aerospace Industries Association takes great pride in our member companies' work in support of the space-based Earth observations capabilities that NASA, NOAA, the U.S. Geological Survey, and other government agencies put to use on behalf of our nation and people worldwide. As with many things in science, you can often only truly understand something when you step back far enough to see it in full detail. Today, as this report details, space-based Earth observations are critical to saving lives in the event of natural disasters, improving the management of our resources and infrastructure, understanding our weather and supporting national security.

While some question whether NASA should be involved in Earth science, understanding the Earth from space, from the beginning of the Space Age, has been one of the space program's major achievements. In fact America's first satellite, Explorer 1, discovered in 1958 that Earth's magnetic field created the Van Allen radiation belts around our world, a phenomenon that still impacts the design of satellites.

We believe that a robust national Earth science from space program will continue to pay enormous dividends in the future, and is deserving of the support of our government. In order for this to happen, we as a nation need to continue to provide robust, balanced and predictable civil space budgets.

This report contains fascinating and unexpected examples demonstrating how everyone benefits from space observations of Earth. But as the report indicates, it barely scratches the surface of how Earth science research and observational capabilities save and improve lives. I appreciate your interest in this vital aerospace activity.

Sincerely,

David. F. Melcher
President & CEO Aerospace Industries Association

Executive Summary

For more than forty years, the space-based Earth observing assets and capabilities NASA has deployed in its Earth Science program and developed for NOAA and the U.S. Geological Survey (USGS) have gathered insights and information that have changed our understanding of the world and improved the lives of millions on Earth. The Aerospace Industry Association strongly supports Earth science budgets sufficient to sustain and enhance our nation's vital Earth science and operational environmental monitoring needs.

Beginning with NASA's founding in 1958, the agency's charter has directed it to use the unique vantage point of space to understand "phenomena in the atmosphere and space" and, since the Reagan Administration (1984)[1], "the Earth." Indeed, one of the first discoveries from space was the existence of the van Allen radiation belts in the Earth's magnetic field, which cause the aurorae visible in the skies above the polar regions of the world. This was just the first example of an avalanche of insights into our planet which have resulted from space observations of the Earth – from plate tectonic movements and oceanic currents to groundwater reserves deep below ground.

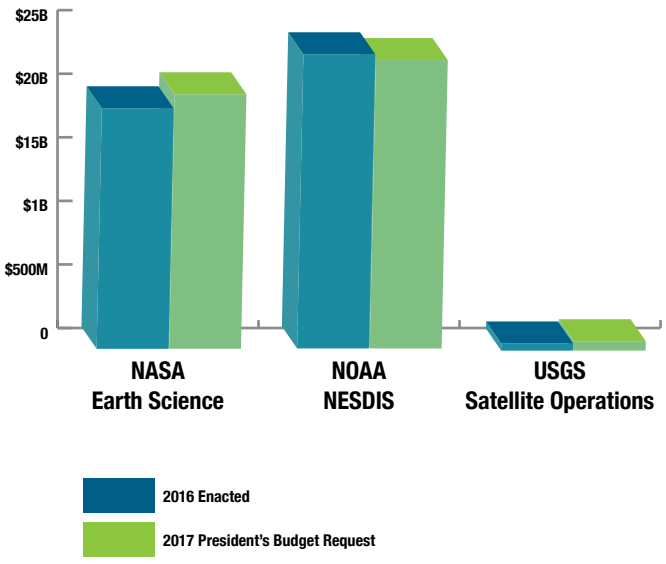
Continued support for space-based Earth observation capabilities is essential to saving lives, growing our economy and understanding our planet. Unfortunately, many of our nation's Earth observing spacecraft are aging and will need to be replaced before they fail in order to ensure observational continuity.

While responsibility for our Earth observation systems is divided among several government agencies, NASA has always had a significant role due to its unique capabilities. NASA has developed earth observing satellites for scientific purposes as well as research and technology development. They have also developed and launched weather and environmental satellites to support NOAA's forecasting mission. Similarly, the Landsat series of remote sensing satellites have been developed and launched by NASA in support of the USGS.

[1] Public Law 98-361, July 16, 1984, section 110(b) (98 Stat. 426)

Recommendations

AIA urges the United States Congress to continue its funding support for these groundbreaking Earth science research and observational capabilities; the rewards of these vital investments far exceed the costs. Specifically, AIA recommends support for the following budgets contained in the FY2017 Presidential budget request:



The NASA budget recommended here, an increase of $111 million or 5.8% above FY 2016 enacted, allows for the prompt development of a number of high-priority missions. These missions include Pre-Aerosol, Clouds, and Ocean Ecosystems (PACE) – which will help monitor oceanic weather, oil spills, and harmful algal blooms that impact coastal communities – as well as Surface Water and Ocean Topography (SWOT) – which will conduct a global survey of Earth's surface water to aid drought management, flood risk assessment, and help optimize military and commercial marine operations. The budget increase for NASA and the USGS also supports advancing the timeline of the launch of Landsat 9 from 2023 to 2021, ensuring continuity of critical Earth observations for to meet our economic and environmental needs.

The capabilities created by a strong Earth science program benefit American strength, security and prosperity in innumerable ways, of which just a few are described in the report to follow. Investing in these capabilities is critical to our understanding of climate, our ability to predict the weather, and our ability to mitigate the threats posed by national hazards. It is essential to our national interests that these Earth science programs be fully funded.

Earth observations from space are critical to our nation for a wide range of reasons, from saving lives to growing our economy. Although a complete list could fill a very large volume some salient examples include the following categories:

Observing Earth from Space

Saving lives and facilitating recovery

1. Weather forecasting has greatly improved thanks to space assets. In the past, communities suffered tremendous damage as storms unexpectedly hit coastal communities. For example, in 1900, around 8000 people died in Galveston, Texas. In 1928, 2000 people died in Palm Beach, Fla., and more than 500 died in a storm in Louisiana in 1957. Now, with accurate storm forecasts, evacuations are precisely targeted, greatly reducing casualties.

2. Disaster preparedness and emergency responses have also greatly improved; with more precise hurricane forecasts, the Red Cross, fire departments and utilities can preposition assets just outside the danger zone for more rapid recovery assistance.

3. Satellite imagery is used by the insurance industry to determine risk and speed insurance claim response after devastating weather events. Prompt response allows victims of natural disasters to get back on their feet much sooner. Imagery also prevents costly insurance fraud and is used to reach equitable judgments.

4. The World Food Program uses a sophisticated Famine Early Warning System (FEWS) for monitoring at-risk regions of the world. FEWS analysis relies on satellite observation to gauge rainfall, vegetation indices and water measurements to warn localities of impending famine conditions. FEWS has helped predict a number of recent famines, enabling a better response before the crisis peaked.

Growing our economy

1. Satellite observations assess natural resource availability and depletion – including the potential for energy exploration and extraction. Multispectral imagery from space can even be used to determine mineral availability below ground, before mining operations begin.

2. Land imaging from moderate-resolution Earth-observing satellites such as Landsat offers the critical capability to observe land use and land use change on large scales over time, which is critical to long-term economic planning. Landsat's space-based land measurements are essential to many areas of the economy since they provide repetitive, highly calibrated and synoptic observations across wide geographical areas and applications.

Supporting national security

1. NASA is primarily responsible for developing new space-based sensors and analytical capabilities to understand the Earth – capabilities that also support U.S. military, homeland security and law enforcement requirements.

2. Environmental intelligence about weather – including soil moisture, sea surface conditions, ocean currents and even humidity – provides a tremendous competitive advantage to U.S. forces. This information greatly facilitates combat operations as well as the movement of ships and aircraft – including during relief efforts in other nations.

3. The U.S. military needs precise intelligence on local weather conditions. For example, when the 1991 Gulf War's "Left Hook" maneuver was executed in the desert of Iraq, the U.S. military constantly monitored weather from space to ensure troops would not be endangered by an unexpected sand storm or other perilous desert conditions.

"Do we dare apply our capabilities to explore the mysteries of other worlds, and not also apply those capabilities to explore and understand the mysteries of our own world – mysteries which may have important implications for our future on this planet?"

– *Sally Ride*

NASA Leadership and America's Future in Space, August 1987

Understanding natural processes and the ecosystem

1. By taking global scientific measurements of environmental phenomena, satellite observations provide breakthrough insights into the Earth as a complex system. For example, in 2011, the NASA satellite Aquarius provided the first global surface salinity map for the entire ocean. Salinity significantly affects the environment, including ocean currents, sea level, sea ice, water cycles and climate. Prior to Aquarius, only 25 percent of ocean salinity had been measured. To date, more than 135 NASA Earth observation missions like Aquarius have provided invaluable data for a more complete and global understanding of how Earth works.

2. Satellite observations are also integral to understanding the land environment – observing deforestation, tracking invasive species, identifying diseased crops, monitoring wildlife parks and determining habitat losses.

NASA's vital leadership role in Earth observations from space-based assets and the capabilities NASA has developed for NOAA and the USGS have saved lives, improved our economy and helped assure our nation's security – while also giving us a revolutionary insight into the science of how our planet works. This remarkable capability to gather insights and information about our world will be at risk if federal Earth science programs are not adequately funded.

NASA's Earth Observing System

Jason-3 Joint Program between NASA, NOAA, France's Space Agency, CNES, and Europe's EUMETSAT to measure sea surface height.

DSCOVR Deep Space Climate Observatory, located at the stable Sun-Earth L1 Lagrange Point to monitor solar activity and Earth's radiation balance.

SMAP Soil Moisture Active Passive, radiometer mission measuring soil moisture and freeze-thaw state.

ISS-RapidScat Ocean wind speed-measuring scatterrometer (microwave radar), takes advantage of ISS infrastructure to cheaply and quickly replace NASA's QuickScat instrument.

CATS Cloud Aerosol Transport System, ISS-mounted laser ranging system to measure clouds, as well as dust and other particulates in the atmosphere.

Suomi NPP Suomi National Polar-orbiting Partnership, joint NASA, NOAA, and Department of Defense satellite for weather forecasting and climate measurement.

CloudSat radar satellite for cloud research.

CALIPSO Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations, joint NASA/CNES lidar and infrared imaging satellite studying clouds and aerosols.

OSTM/Jason-2 Ocean Surface Topography Mission, joint NASA/NOAA/CNES/EUMETSAT sea surface height measuring satellite.

"We shall not cease from exploration, and the end of all our exploring will be to arrive where we started and know the place for the first time."

T.S. Eliot's poem *Little Gidding,* 1942

Aura studies air composition and quality, climate, and the ozone layer.

SORCE Solar Radiation and Climate Experiment, measures solar output over a variety of wavelengths.

GRACE Gravity Recovery and Climate Experiment, joint NASA/German Aerospace Center mission to study variations in the Earth's gravitational field.

EO-1 Earth Observing-1, land imager and pathfinder for future earth observation missions.

QuickSCAT Ocean wind speed-measuring scatterometer (microwave radar).

Landsat 8 US Geological Survey (USGS) operated Earth imaging satellite.

Aqua Measures various processes in the water cycle.

Terra Multipurpose Earth observing satellite studying thermal emissions, clouds, pollution, and other factors.

Landsat 7 USGS-operated Earth imaging satellite.

OCO-2 Orbiting Carbon Observatory, measures carbon dioxide from human and natural sources and its effect on global climate.

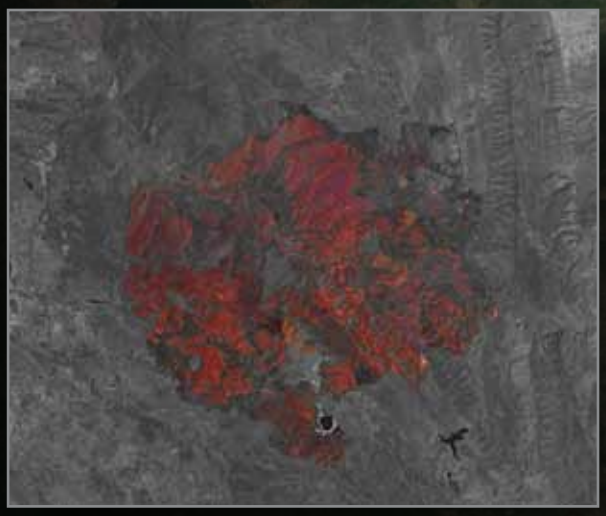
GPM Global Precipitation Measurement, joint NASA/JAXA (Japan's equivalent) mission to study global precipitation.

Tracking Hurricane Sandy

Weather on Earth is a complex system and a wide variety of factors from around the planet come together to drive specific – and sometimes deadly – outcomes. Having consistent access to a wide variety of simultaneous measurements across the globe is necessary to turn a chaotic system into a predictable one, saving lives in the process. Hurricane Sandy caused roughly 160 American deaths and more than $70 billion in damage, but without the data provided by Earth observation systems, the toll would have been far higher.

The Visible Infrared Imaging Radiometer Suite (VIIRS) system, built by Raytheon and launched aboard the Suomi National Polar-orbiting Partnership (Suomi NPP) spacecraft in 2011, provided visible and infrared imagery of the storm of unprecedented quality both day and night, aiding meteorologists in predicting its impact on the Atlantic coast. But it was only in conjunction with other data sources, like sea surface temperatures measured by other Earth observation instruments, that the lifesaving accuracy of Sandy's path prediction could be achieved.

VIIRS Day-Night Band Visible Imagery Combined with the Storm's Track and Sea Surface Temperature Data Provide Significant Insight into the Projected Path and Strength of the Storm



Forest Fire Risk and Response

Each year, wildfires tear across millions of acres of forest in the Western United States. These tragedies take human lives, burn homes and communities, and can seriously injure regional economies. Furthermore, the cost of suppressing and recovering from massive wildfires often measures in the hundreds of millions or even billions of dollars for each regional outburst. Thick smoke and dangerous conditions can prevent aircraft from observing fires and poor reconnaissance can threaten recovery efforts, putting the lives of firefighters at risk. Fortunately, NASA's Earth Observing System can observe fires across multiple wavelengths where aircraft and other systems can't, saving lives and preserving communities through support for fire prevention, suppression and recovery.

Prior to an outbreak, satellite imagery is used to predict fire risk by comparing new images with data collected over past decades to estimate the dryness of each section of forest. Alerts warning communities of extreme fire risk are issued when dry, fire-susceptible sections coincide with areas of low precipitation as determined by weather satellites.

Firefighting agencies also turn to NASA data in the midst of emergencies such as the Wallow Fire, which raged across nearly 900 square miles of the American Southwest. Responders used real-time fire mapping generated by the U.S. Forest Service from NASA data, which allowed for quick responses and appropriate allocation of funds, aircraft and firefighters.

This image, obtained through visible and infrared observations by NASA's Aqua satellite, shows clusters of forest fires (red outline) and smoke trails. ***Courtesy of NASA***

Images from space demonstrate the full extent of the fire and help observers understand behaviors of the wildfire that are not evident from the ground, such as using false color short wave infrared and near infrared images to locate fire fronts and hot spots that may not be readily apparent in visible imagery. In the aftermath of fires, local and state officials use satellite images to study burned regions so they can plan steps to protect water supplies and prevent erosion. The use of satellite images in fighting wildfires is a prime example of the immediate utility of NASA's Earth observation mission. Through its quest to observe and understand our home planet, NASA is preserving both lives and livelihoods in American communities.

NASA's SERVIR Partnership

NASA's SERVIR (Spanish for "to serve") program allows developing nations to access information from American Earth observing satellites. These partnerships help local leaders plan for disasters, manage water and land use, and maximize agricultural output.

On July 26, 2011, marine scientists making routine checks of SERVIR satellite data in El Salvador noticed the beginnings of a massive bloom of algae off the coast.[2] Blooms known as red tides are difficult to predict and commonly produce toxins that kill marine wildlife and endanger the lives of people who eat contaminated marine animals. Using data from Earth observation satellites, the team initiated on-the-ground tests for contaminated sea life and warned the country's leaders of the arrival of the red tide. These tides must dissipate naturally, so months-long monitoring campaigns are necessary to coordinate fishing bans and prohibitions on the harvesting of contaminated shellfish. Through this work, Earth observation satellites are enabling life-saving preparations while also stabilizing and growing the economies of developing nations.

Scientists in El Salvador review data from visible light and infrared observations made by NASA's Aqua and Terra satellites. ***Courtesy of NASA***

[2] "SERVIR detecting red tides in El Salvador." SERVIR Global, September 1, 2011. <https://www.servirglobal.net/Global/Articles/tabid/86/Article/1045/servir-detecting-red-tides-in-el-salvador.aspx>.

Ground Systems

Behind every space mission is a ground network. These towering antennae – like the smaller versions you see mounted on top of offices or homes – receive signals from spacecraft and pass that vital information to users. Antennae like those shown above are the crucial link between our national space assets and those who need to access Earth observation data on the ground.

While antennae for the Landsat program of the USGS stretch around the world, the heart of the operation is the Earth Resources Observation and Science (EROS) Center. Located in a rural area north of Sioux Falls, South Dakota, this facility (shown above) collects and processes signals from Landsat satellites. Currently the new Landsat-8 craft and an aging Landsat-7 are providing data to the EROS Center.

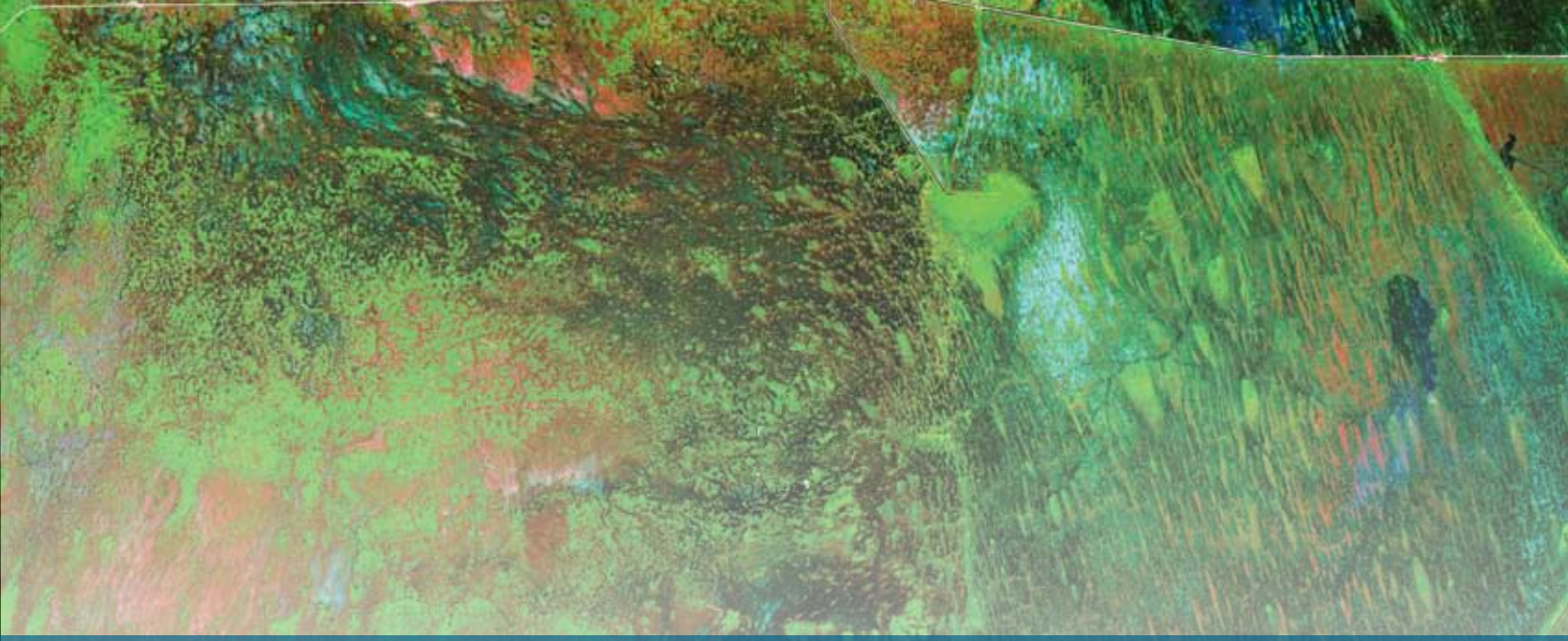
Since the first in the line of Landsat craft entered orbit in 1972, this satellite program has proven valuable to the economy of the United States. Landsat-8 carries instruments capable of making scientific quality images in visible and infrared light. The wavelengths of light collected are used to track and analyze landscape changes, water consumption for irrigation, deforestation trends and other Earth-based phenomena. By observing and understanding these events from space over periods of many years, scientists, policymakers and business leaders can create forward-looking strategies like agricultural plans that overcome droughts and logging guidelines that minimize soil erosion. Each year, these practical applications help grow the U.S. economy by billions of dollars.

Landsat 8: Operational Land Imager City and Resource Planning in a Changed World

The effects of wind and water currents, weather events, geologic processes and human activity mean that the surface of our planet is constantly changing. A shrinking lake, a river changing course, or a desert expanding can all have impacts on where we choose to build or what crops we choose to plant. As land use changes, cities grow and resource needs increase; it is critical that we understand these changes.

The Mississippi river delta, for instance, has been disappearing in most areas, but the comparison of this image from 1984 and the recent image in 2014 shows that land is being added in some areas. This is important for city planning in the delta and understanding the impacts of flooding on the cities in the delta.

Because the policy implications of a catastrophic change and a gradual change are very different, continuous observations are necessary in order to determine the rate at which terrain changes take place. A robust Earth observations system avoids coverage gaps in surface monitoring, which ensures that decision makers have accurate predictions on which to base policy.



Everglades Water Loss and Restoration

Graced by an abundance of subtropical plants and a diverse animal population, Everglades National Park is a unique national treasure. Unfortunately, the park's aquatic ecosystem is at serious risk from human activity and watershed redirection.

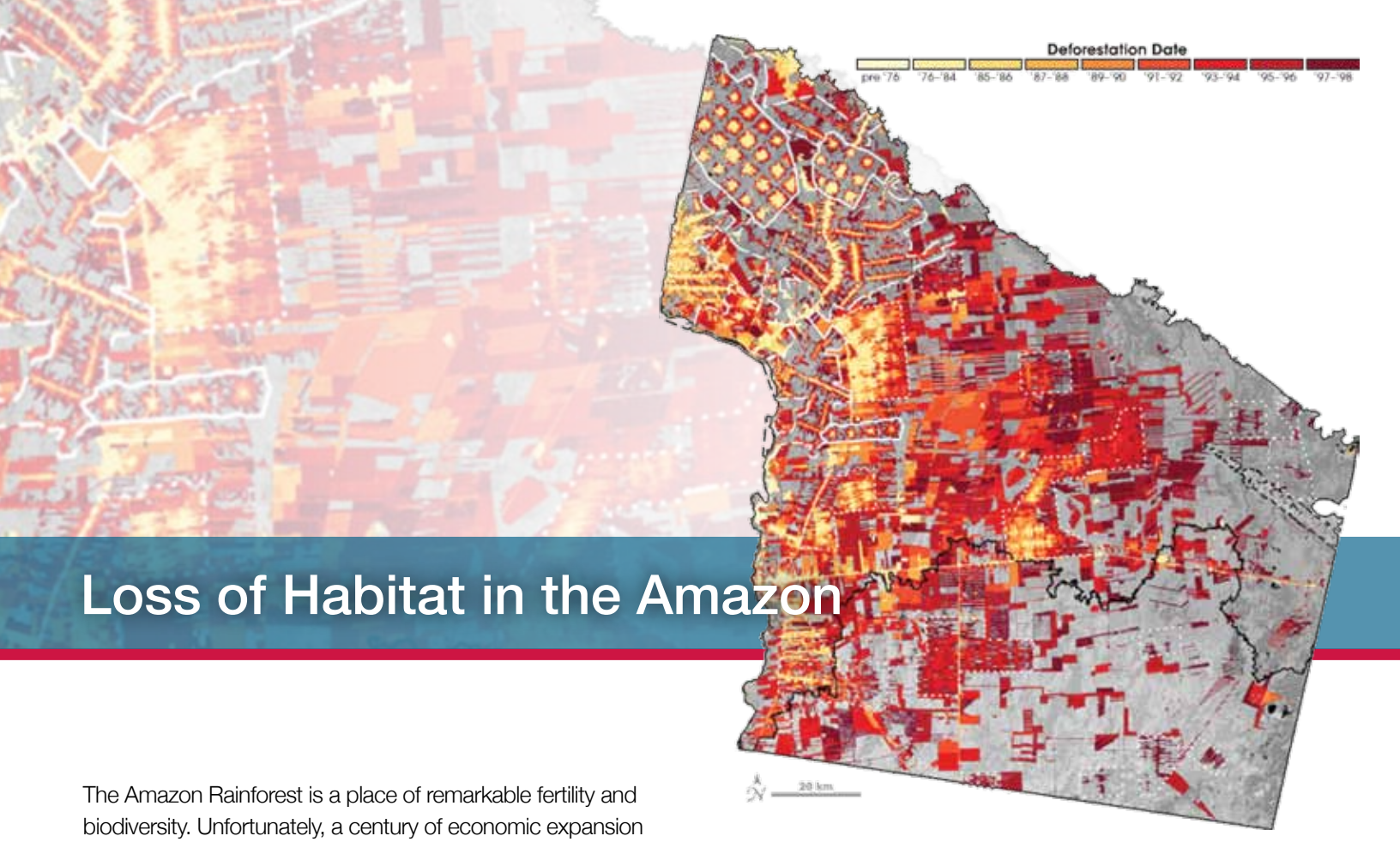
Apart from its cultural value, the Everglades and the nearby Florida Bay offer economic value as a source of tourism and as the basis for local commercial fisheries. Although many Floridians cherish this ecosystem today, historically the Everglades has been thought of as an impedance to agricultural and residential development in the state. As a result, an extensive set of levees and other water diversion projects attempted to alter the natural water cycles of the area. These water flow changes, as well as chemical runoff from agriculture and human habitation in the region, have damaged the biodiversity in the park and threaten its beauty and economic productivity in the immediate future.

Today, Earth observation data is playing a major role in monitoring and guiding restoration efforts in the Everglades. The above image from Landsat-7 melds infrared and visible light images into a stunning view of water flow across the Everglades.

Drought Mitigation in California

As of January 2016, California was beginning its fifth year of drought. The state's parched landscape is driving severe wildfires and bringing a future of severe residential and commercial water shortages into sharp focus. With shortages on the horizon, the governor declared a state of emergency in early 2015 with many cities moving to limit non-essential water use. Tracking and preparing for water shortages will allow the state to mitigate the drought's impact on agriculture. Without strong proactive measures, California stands to lose billions of dollars in agricultural productivity, leading to higher prices for produce across the country. The state's 39 million residents must also face an uncertain future marked by the specter of water rationing and other dramatic changes wrought by drought.

NASA's Gravity Recovery and Climate Experiment (GRACE) mission is providing surprising insights into water loss in California. This set of close-flying twin spacecraft observes slight changes in Earth's gravity as the pair flies overhead. While mountain ranges can certainly contribute to shifting gravity readings, hidden features like underground water reserves are also seen by GRACE. The above image shows the severe depletion of groundwater in California's Central Valley as a dark red zone overlain on a regional map. For the first time, scientists were also able to estimate the state's water deficit – 11 trillion gallons. Space-based assets like GRACE are now revealing major barometers of drought severity and are helping to estimate how much change in water use, rationing and snowfall must occur to rescue the state from its drought.



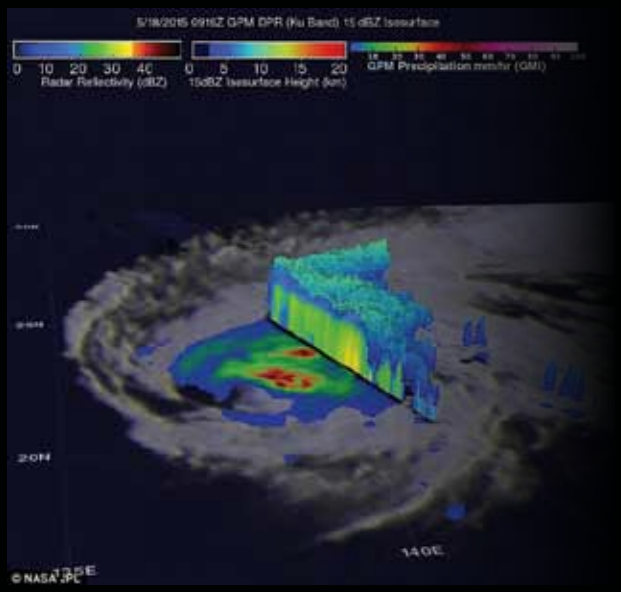
Loss of Habitat in the Amazon

The Amazon Rainforest is a place of remarkable fertility and biodiversity. Unfortunately, a century of economic expansion and industrialization has seen loggers, colonizers and others systematically eliminating huge swathes of the forest. By 2015, the Amazon had lost nearly a fifth of its original land area. Short-sighted forest destruction places immediate gain from logging and ranching over the long-term material contribution of the forest to the people of South America and to the world economy.

Locally, deforestation leads to soil erosion, which can permanently destroy the region's fertility. At the same time, indigenous peoples depend on the forest for survival and can be driven to conflict with loggers when their homes and means for survival are threatened. Globally, tropical rainfall and temperature patterns depend on forest cover. Tropic regions are predicted to get warmer and dryer as deforestation continues. Losses in the Amazon Rainforest may alter rainfall patterns as far away as the southern United States.[3]

Brazil's National Institute of Space Research (INPE) uses data from NASA's Terra satellite to analyze weekly changes to forest cover. High-resolution images from Landsat satellites are used for the Institute's annual evaluation of deforestation in the Amazon. Satellite data from the past 40 years can be retrieved and used to track rates of destruction and the impacts of deforestation. Through a robust Earth observation program, the United States is helping to ensure stable weather patterns and sustainable economic practices in the Western Hemisphere.

[3] http://www.earthobservatory.nasa.gov/Features/Deforestation/deforestation_update2.php



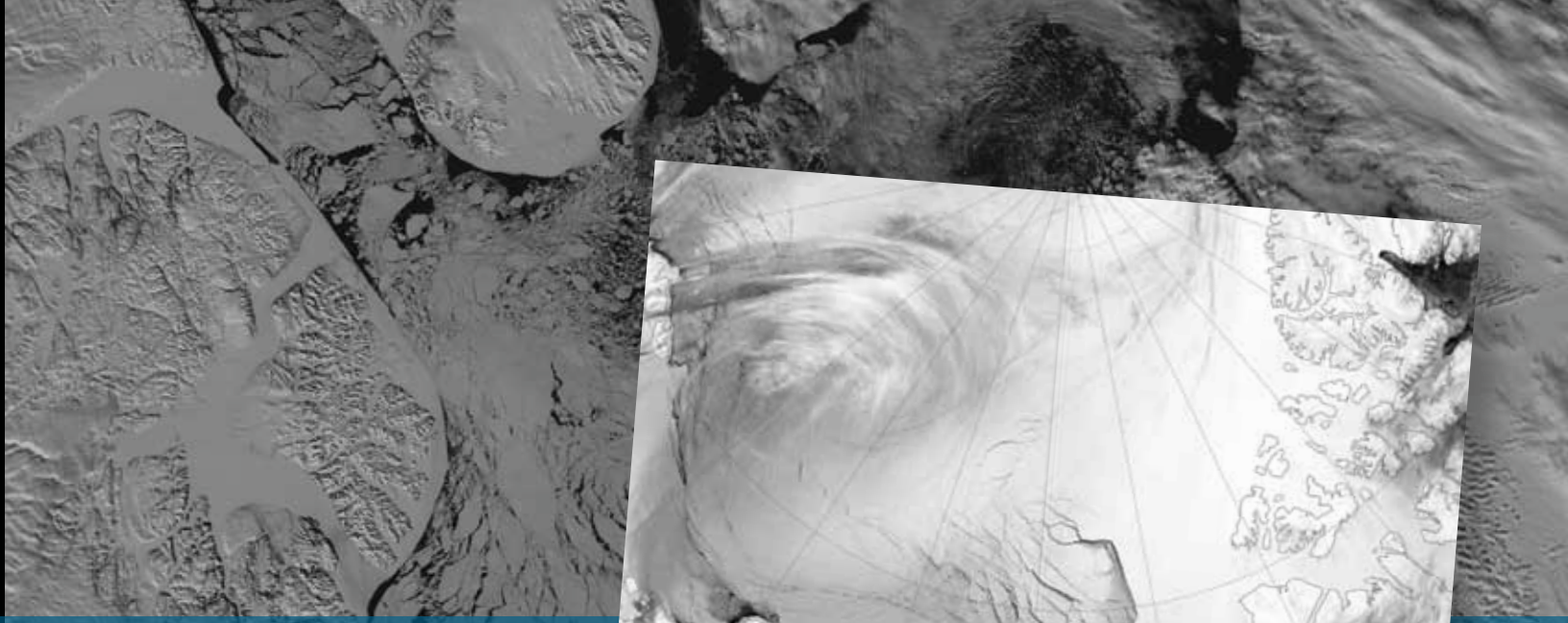
Global Precipitation Measurement

Microwave Imager Improving Severe Storm Forecasting

The Global Precipitation Measurement (GPM) mission is a joint activity between NASA and the Japanese space agency. NASA's Global Microwave Imager (GMI) instrument – designed and built by Ball Aerospace – aboard the GPM spacecraft produces valuable information about the movement of water through tropical storms. This allows more accurate predictions of their strength and enables estimation of expected rainfall levels that the storm will produce when it reaches land.

Because weather events follow no schedules, civilian populations and military operations must be constantly prepared to react to severe storms. In military scenarios, adverse weather conditions can seriously hamper a less prepared force's ability to conduct operations. Thus, the insights provided by NASA's GMI instrument on the GPM satellite provide a competitive advantage on the battlefield.

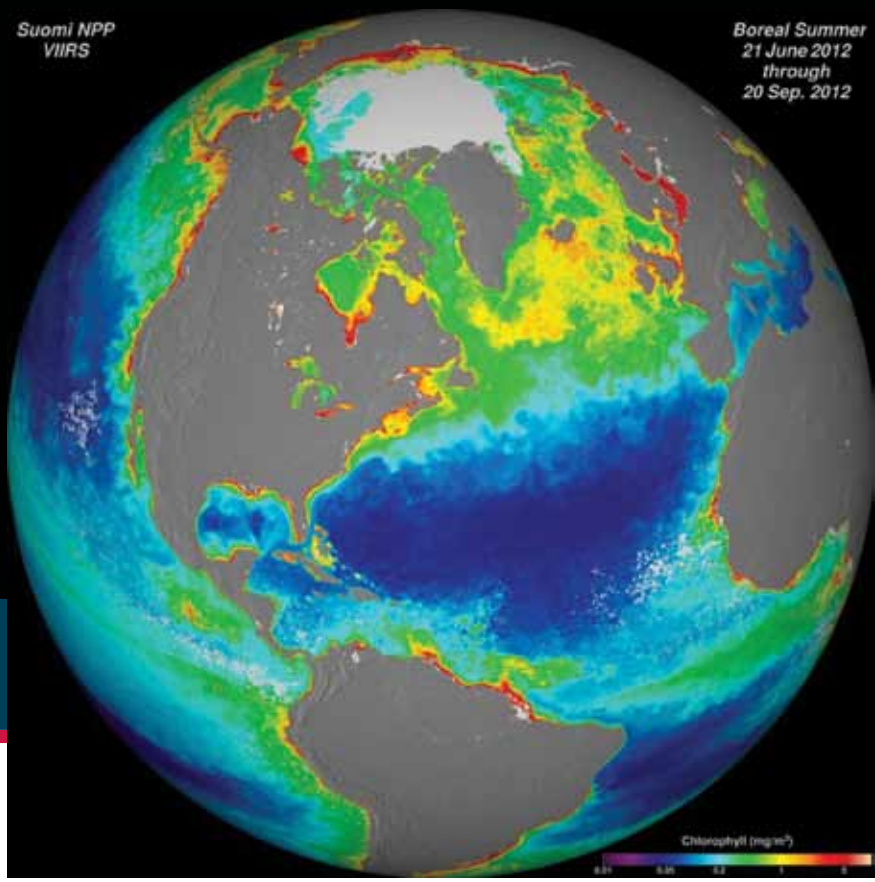
In civil defense scenarios as well, the importance of this data cannot be overstated. Predicting rainfall prepares civilian authorities for the severity of flooding that a storm can bring, allowing for the orderly evacuation of at-risk populations and the protection of infrastructure that could be damaged by the storm. As with all lifesaving Earth observation capabilities, it is crucial that continuous, global coverage be maintained and a healthy fleet supported to avoid gaps.



Ice Fracturing

Ocean currents, winds, temperature and other conditions shape the surface of the sea ice off the coast of Alaska and Canada. Ice on one end of a sheet can flow, shift and fracture as a result of forces on ice on another end of the sheet hundreds of miles away. Ice fracturing can impact the navigability of America's northernmost waters, the seasonal movement of animals and other aspects of life in the far north. Studying the evolution of these massive structures over time from the vantage point of space is crucial to understanding the Arctic, which has come to play an ever larger role in the American economy.

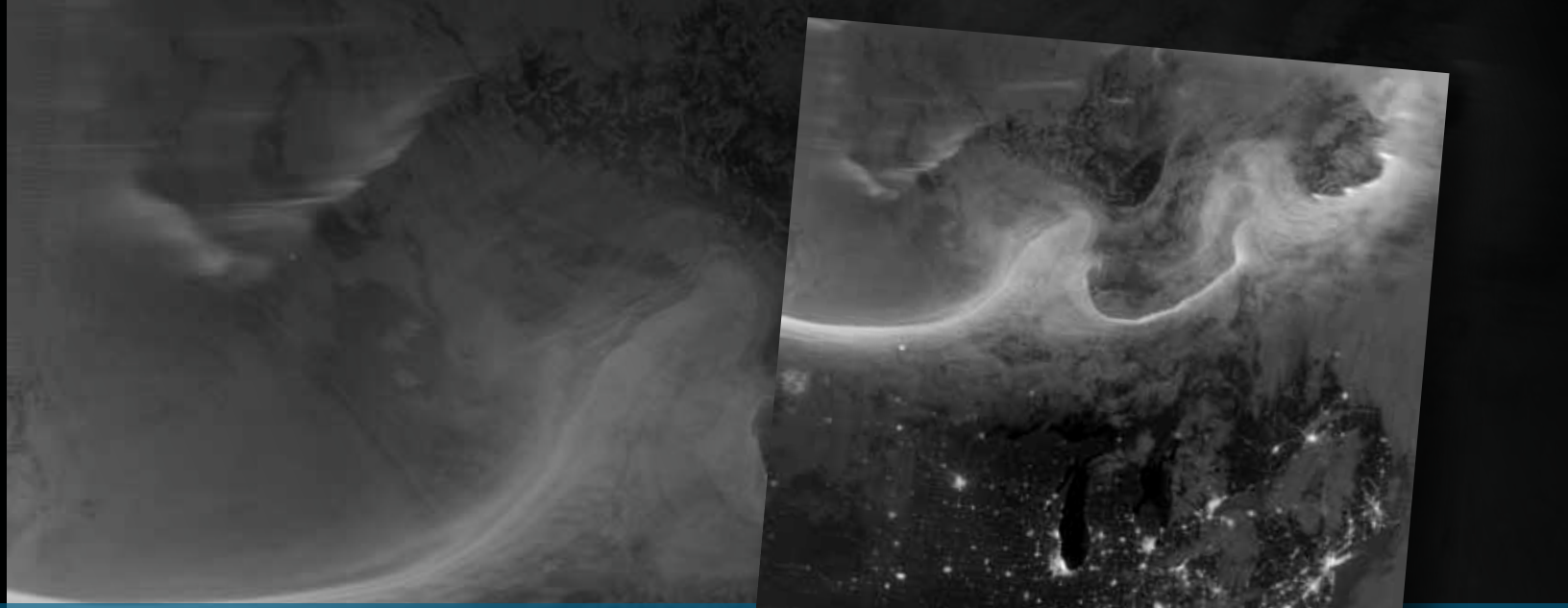
Earth observation spacecraft in polar orbits – like the Suomi NPP satellite – are central to this effort. Using its VIIRS infrared imaging instrument, the satellite can determine the thickness and temperature of the ice and the surrounding sea surface, aiding researchers in predicting where fractures are likely to occur and helping to understand seasonal and long-term patterns in the expansion and loss of sea ice. Maintaining a robust fleet of polar Earth observation spacecraft is critical to understanding the dynamics of this important region.



Algal Blooms

Oceanic algae, or phytoplankton, produce approximately 50 percent of the Earth's oxygen. At normal concentrations, these algae are vital to the health of the oceans and the life forms they support – including humans – both at sea and on land. However, certain algae naturally produce neurotoxic chemicals that can injure or kill sea life at high concentrations – a phenomenon sometimes known as "red tide" – that can devastate fisheries and hospitalize human swimmers.

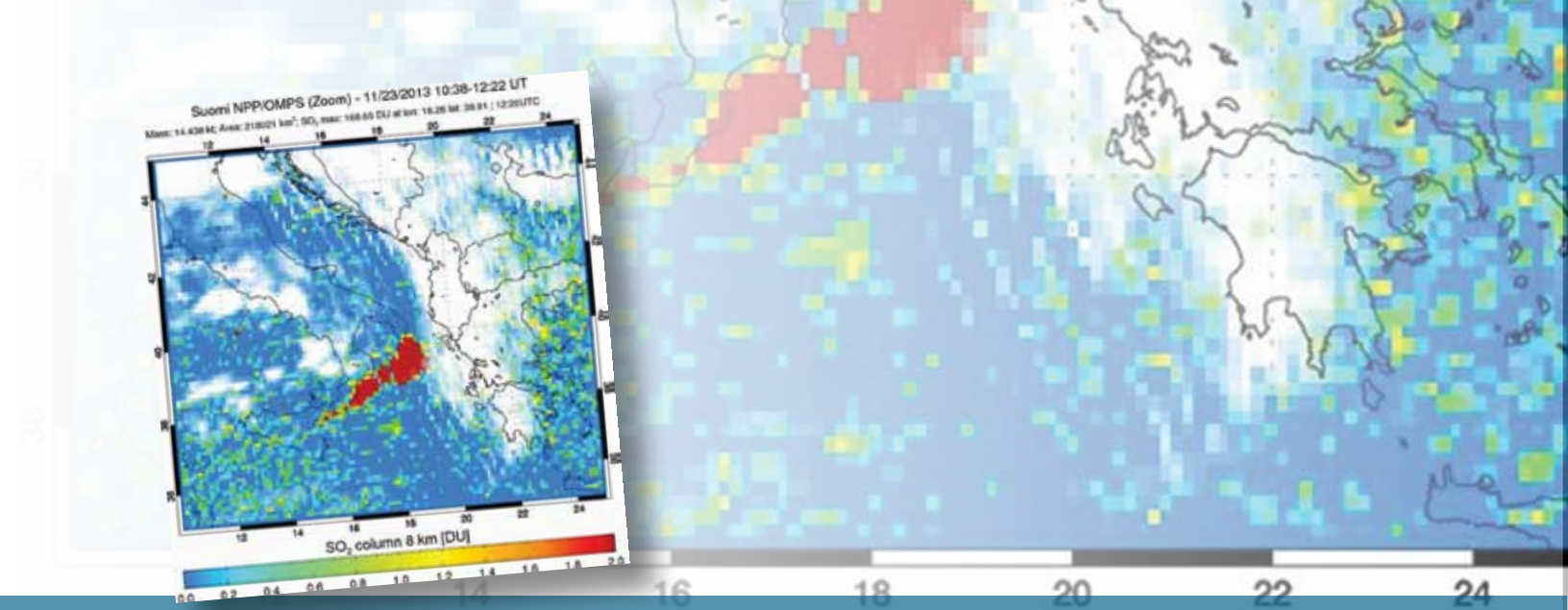
Predicting and identifying harmful algal blooms is crucial to preparation, response and recovery efforts, and instruments aboard NASA and NOAA spacecraft play vital roles in this effort. Continuous measurements of ocean temperature and color can help scientists better predict which areas are at risk of a harmful algal bloom. The VIIRS infrared imager on the Suomi NPP spacecraft is especially valuable, as it allows researchers to measure levels of chlorophyll – a chemical found in plants and algae – at the ocean's surface. Abnormally rising chlorophyll levels can indicate when an algal bloom is beginning and document where it spreads. Continuous coverage of chlorophyll levels through satellite monitoring can give coastal communities time to prepare for economic disruptions that an algal bloom could cause.



Observing Auroras

The image above depicting the energy produced by an aurora in 2012 was made by the VIIRS imaging instrument aboard the Suomi NPP spacecraft. Auroras are a manifestation of the impact the solar wind has on the Earth's magnetic field and atmosphere. They produce a stunning glow and haunting patterns, but they can also serve as indicators of much more dire effects. The geomagnetic storms that create auroras can also damage power grids, interrupt radio communications and slightly increase radiation doses for astronauts and airline passengers.

Observing the dynamics of auroras helps scientists to better predict how solar storms will interact with the Earth's atmosphere and surface, informing efforts to protect the country's citizens and assets from the harmful effects of the solar wind. The VIIRS instrument provides data that is crucial to understanding these beautiful and dangerous phenomena and their impact on our world, complementing data gained from spacecraft monitoring the sun in a way that would not be possible without robust investments in Earth observation.



Civil Aviation Flight Paths

The Ozone Mapping and Profiling Suite (OMPS) that flies on the Suomi NPP spacecraft measures more than just ozone concentration. This Ball Aerospace-built sensor is useful for tracking dust and sulfur dioxide from volcanic eruptions.

On average, 10 volcanic eruptions each year produce ash clouds that reach flight level on major flight routes.[4] Ash and trace gases from these eruptions present a significant risk to aviation, corroding aircraft material, interfering with sensors and damaging engines. However, these ash clouds may not always be visible to pilots and are not detected by radar.

The European Space Agency's Support for Aviation Control Service (SACS) provides data for the Volcanic Ash Advisory Centres. SACS uses OMPS data, along with other satellite information, in near real timeto monitor ash clouds from volcanic eruptions and determine optimal flight routes around the hazard.

[4] http://sacs.aeronomie.be/aviation.php

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