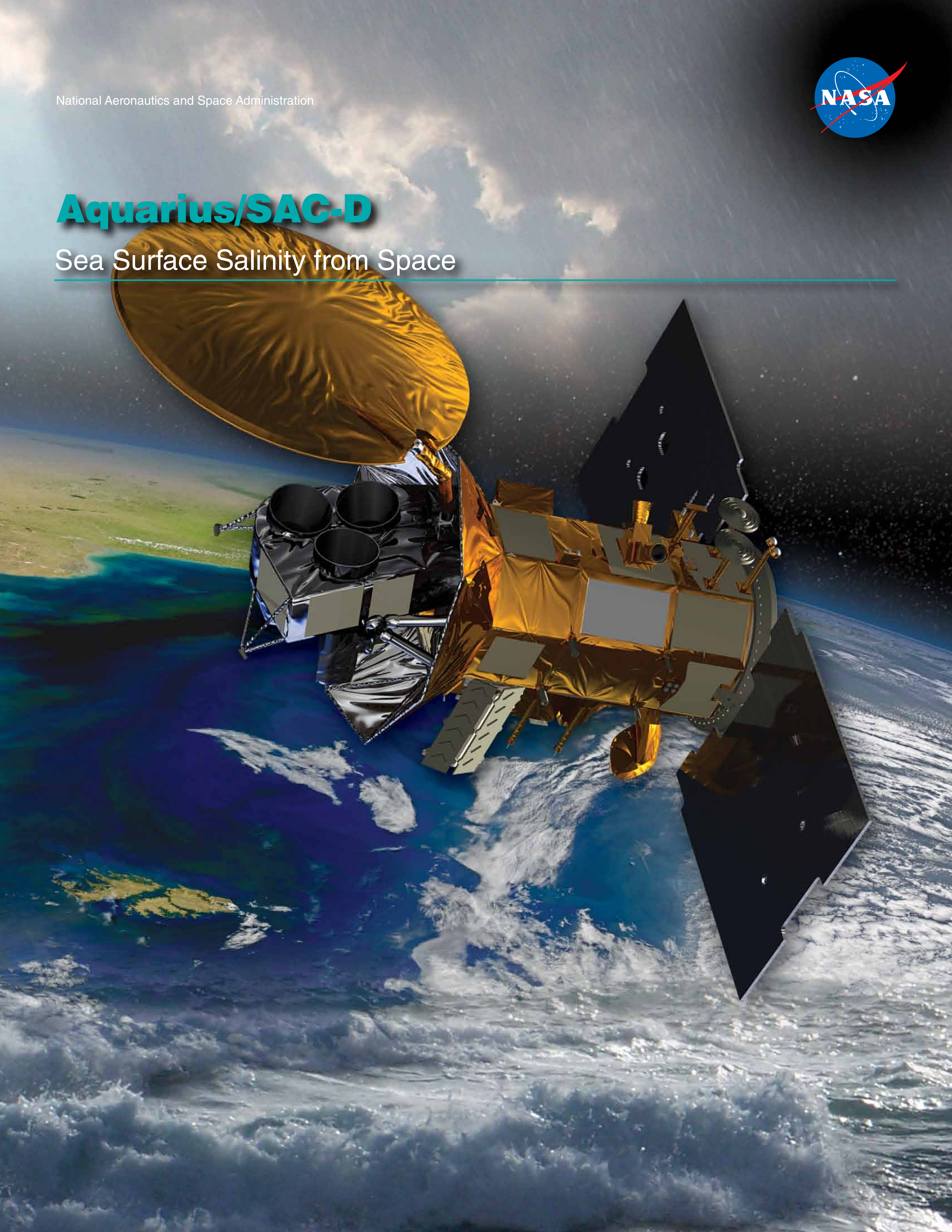
National Aeronautics and Space Administration

Aquarius/SAC-D

Sea Surface Salinity from Space



Acknowledgments

Aquarius Web site
http://aquarius.nasa.gov/

Special thanks to the Aquarius Science Team for making this publication possible.

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Cover image: The Aquarius/SAC-D satellite observatory is shown in orbit off the coast of South America. The NASA Aquarius instrument will measure sea surface salinity, a key tracer for understanding ocean circulation and global freshwater balance.

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Aquarius/SAC-D: Sea Surface Salinity from Space

Aquarius is a new Earth orbiting mission sponsored by NASA's Earth System Science Pathfinder (ESSP) Program. After launch in 2011, Aquarius will employ advanced technologies to make NASA's first space-based measurements of ocean salinity across the globe—an important observation for ocean and climate studies. Aquarius will detect changes in ocean salinity as small as the equivalent of a "pinch" (about 1/8 teaspoon) of salt in a gallon of water, or about 0.2 grams salt per kilogram seawater.

Sea Surface Salinity

A trip to the beach fills your nostrils with the smell of salt from the ocean; accidentally swallow some water during a swim there and you can taste just how salty the ocean is. Processes that took place throughout Earth's history, such as the weathering of rocks, evaporation of ocean water, and the formation of sea ice, have made the ocean salty. Those same processes are still at work today, and are counterbalanced by processes that decrease the salt in the ocean, like freshwater input from rivers, the precipitation of rain and snow, and the melting of ice. The result is an ocean surface where the salinity—the concentration of salt—changes, and these changes, miniscule as they may be, have large-scale effects on Earth's water cycle and ocean circulation.

From 1872 to 1876, the H.M.S. Challenger sampled the global ocean—including salinity measurements at depth—heralding the beginning of oceanography as a science discipline

Although sea surface salinity has been measured for centuries from ships and buoys, within its first several months after launch, Aquarius will collect as many sea surface salinity measurements as are in the entire historical record.

Sea Surface Salinity - Key Facts

Absolute salinity is defined as the concentration of dissolved salts in seawater, historically expressed in grams per kilogram, or parts per thousand.

Modern oceanography uses the Practical Salinity Scale (PSS) to derive salinity from precise instrument measurements of seawater electrical conductivity, temperature and pressure (depth).

The ocean average of sea surface salinity is about 35 PSS (or about 3.5% salt). Over the globe, sea surface salinity ranges from 32 to 37 PSS.

The Aquarius sensor can detect subtle changes in the ocean's microwave emission that are caused by salinity.

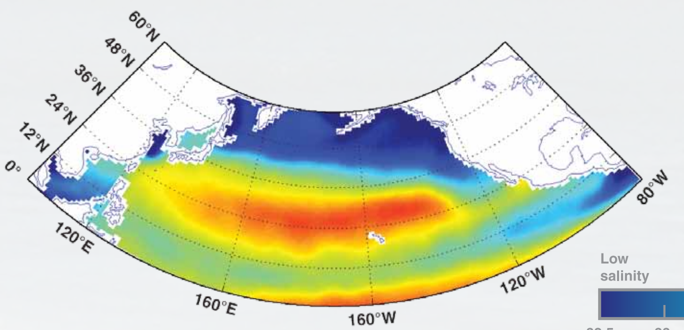
Each month, Aquarius will measure salinity changes of 0.2 PSS, equivalent to about 2 parts in 10,000.

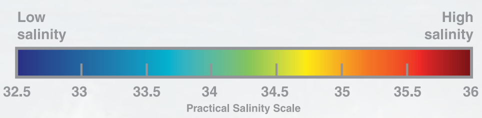
Mission Overview

The mission is a collaboration between NASA and Argentina's space agency, Comisión Nacional de Actividades Espaciales (CONAE). NASA's Aquarius sensors will be carried into space by the Argentine-built spacecraft, Satélite de Aplicaciones Científicas (SAC)-D, to provide scientists with long-term, global-scale salinity data critical to our understanding of the water cycle, ocean circulation, and climate.

Aquarius/SAC-D will begin its three-year baseline mission by launching onboard a Delta II rocket from Vandenberg Air Force Base in California in 2011. After its launch, it will fly 657 kilometers (408 miles) above Earth in a sun-synchronous polar orbit that repeats every seven days, providing NASA's first global observations of sea surface salinity. Aquarius data will be used to make monthly maps of sea surface salinity with a spatial resolution of 150 km (93 miles) over the mission's lifetime. These maps will allow scientists to resolve global salinity changes from month-to-month, season-to-season, and year-to-year.

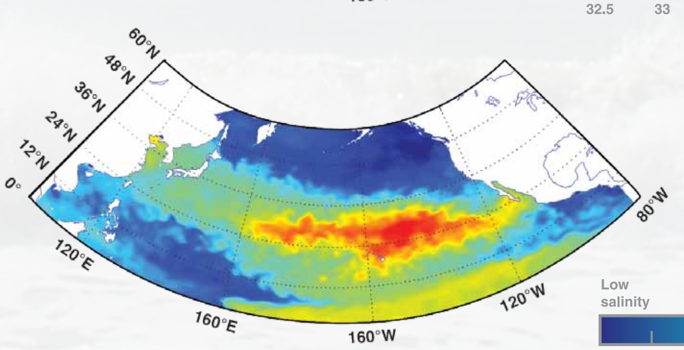
Overall mission design has been developed collaboratively between NASA and CONAE to best meet the goals of each agency while giving priority to salinity measurements. CONAE built complementary sensors to detect rain, sea ice, and wind speed, plus sea surface temperature sampling. CONAE-sponsored instruments—including sensors from the French Space Agency (Centre National d'Etudes Spatiales, CNES) and another from the Italian Space Agency (Agenzia Spaziale Italiana, ASI)—will provide environmental data for a wide range of applications, including natural hazards, land processes, epidemiological studies, and air quality issues. (See page 10 for details on SAC-D instruments.)

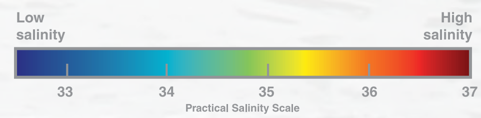




Average annual sea surface salinity in the North Pacific Ocean based on historical data

Image Credit: World Ocean Atlas 2005





Simulated average annual sea surface salinity data showing resolution expected from the Aquarius instrument after launch

Image Credit: Gary Lagerloef

Photo credit: CONAE

Ground control station located in Córdoba, Argentina

NASA-CONAE Partnership

In 1994, CONAE released high-level goals for Argentina's space program that included developing and applying advanced technological knowledge; enhancing economic and human resources; and fostering international cooperation. A major initiative is the SAC satellite series, the fourth of which is Aquarius/SAC-D. For each mission, NASA has provided launch operations and launch vehicles: Space Shuttle (SAC-A), Pegasus (SAC-B), and Delta II (SAC-C and SAC-D). Each satellite was conceived by CONAE and built by the technology company, INVAP, S.E., located in Bariloche. Ground control operations for each mission have been conducted in Córdoba.

SAC-A, launched by Endeavour in 1998, characterized the performance of equipment and technologies for future missions. SAC-B was designed to study solar physics and astrophysics using science instruments from CONAE, NASA, and ASI. Launched in November 2000, SAC-C focuses on Earth observations such as monitoring Argentina's soil conditions and marine ecosystems.

Salinity and the Water Cycle

Data from Aquarius will allow scientists to see how freshwater moves between the ocean and the atmosphere as a result of rainfall, evaporation, ice melt, and river runoff. These data will improve global "water cycle budget" estimates over the ocean, where the majority of global precipitation and evaporation occurs. Accurate data will also be used to improve computer models to better resolve how climate, ocean circulation, and the water cycle are connected, and thereby improve climate prediction.

In Earth's "water cycle," water circulates from the ocean to the atmosphere to the land and back again to the ocean. Water moves as a gas (water vapor), liquid (rain), and solid (snow and ice) through the cycle. Exchanges between the ocean and atmosphere are a major component, with approximately 86 percent of global evaporation and 78 percent of global precipitation occurring over the ocean. Evaporation at the sea surface releases moisture into the atmosphere as water vapor. Atmospheric circulation carries this vapor upwards where it can cool and condense (i.e., change from a gas to a liquid) to form cloud droplets and release latent heat energy to warm the atmosphere.

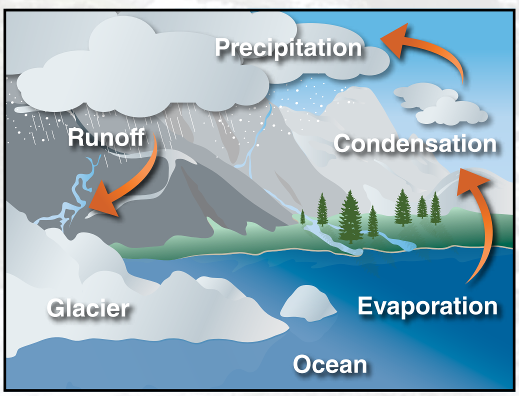


Image credit: Modified from NASA Earth Observatory

Some of the components of the water cycle

These droplets can grow to produce rain or snow that falls on the land or ocean surface. On land, the cycle continues when freshwater returns to the atmosphere as evaporation, seeps into the soil to become groundwater, or flows as runoff from rivers and streams into the ocean.

Over the ocean, variations in the water cycle can manifest themselves as increases or decreases in salinity; these variations include changes in water phase (e.g., from liquid to ice) and also differences in the "path" taken by water molecules during their journey in the water cycle (see sidebar). Precipitation,

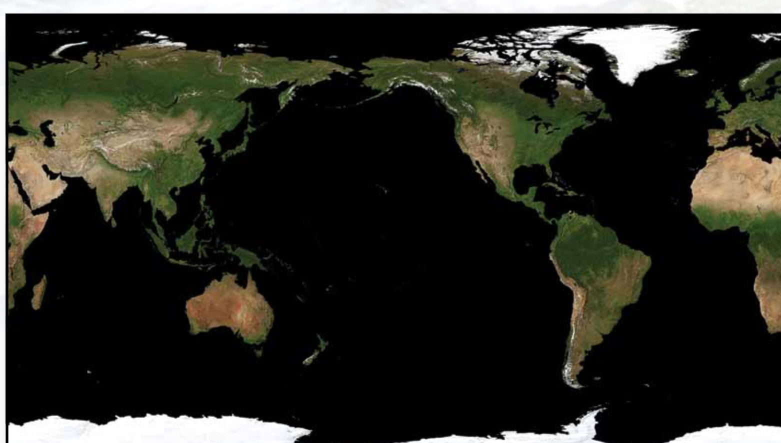


Image credit: NASA's Earth Observatory

Over land, evaporation and precipitation are correlated with vegetation patterns. Moderate Resolution Imaging Spectroradiometer (MODIS) data show regions of dense forest in green and deserts in beige during July 2004.

groundwater flow, the melting of ice, and river runoff all introduce freshwater into the ocean. Conversely, processes such as evaporation and the formation of sea ice remove liquid water from the ocean, leaving saltier water behind.

On land, water cycle processes are tied to vegetation patterns: deserts occur in regions where evaporation is high and rain forests occur in areas of high precipitation. Similarly, over the ocean, the regional differences between evaporation and precipitation are correlated with patterns of sea surface salinity.

To see the connection between salinity and the water cycle, it is helpful to compare salinity patterns with data showing the imbalance between evaporation and precipitation. The map at upper right shows the range in global ocean salinity at the surface based on all historical observations: red areas have high salinity (i.e., 36 PSS or higher) and blue areas have low salinity (i.e., 34 PSS or lower).

At lower right is a map of average evaporation minus precipitation. Areas that are colored red are dominated by evaporation. The areas that are colored blue are dominated by precipitation. There is a correspondence between the red colors on the evaporation minus precipitation map and the red colors on the average salinity map (upper right). This correlation shows the tie between high evaporation in the water cycle and high salinity in the ocean. Likewise, the blue areas on both maps highlight the ties between high precipitation and areas of relatively low sea surface salinity.

Also notable on the map of average salinity is the disparity between the Atlantic Ocean and the other ocean basins: the Atlantic is saltier than the other oceans. The reason is, on average, there is more evaporation than combined rainfall and river runoff into the Atlantic Ocean, maintaining higher salinity than in the other basins. This is very important for the mechanisms of ocean circulation and how ocean circulation helps to regulate climate.

Historical ocean archives show that North Atlantic sub-tropical surface waters have become saltier in the last 40 years, while sub-polar North Atlantic deeper waters have become less salty. These changes in salinity appear to be related to changes in evaporation, precipitation, and ocean circulation.

Over time, such changes in salinity patterns can impact the environment. For example, an increase in salinity reduces seawater's ability to absorb carbon dioxide, a greenhouse gas associated with climate change.

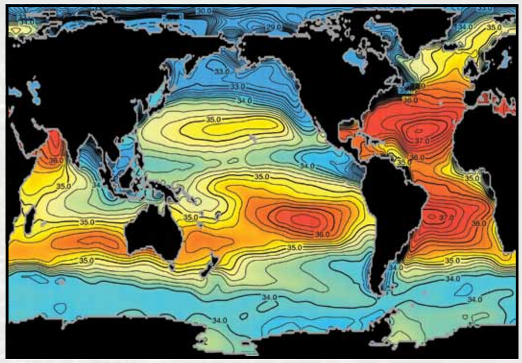


Image credit: World Ocean Atlas, 2009

Average salinity from historical ship and buoy data

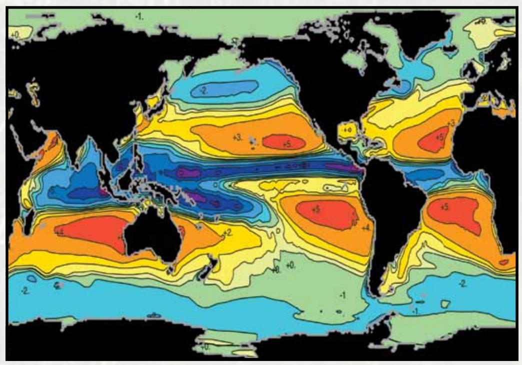


Image credit: Committee on Earth Observation Satellites

Annual average evaporation minus precipitation

Salinity and the Water Cycle - Key Facts

Salinity variations are driven by precipitation, evaporation, runoff, and ice freezing & melting.

Like vegetation patterns on land, global salinity patterns are linked to rainfall and evaporation.

SALINITY INCREASES WITH:

Evaporation of seawater

Freezing of seawater

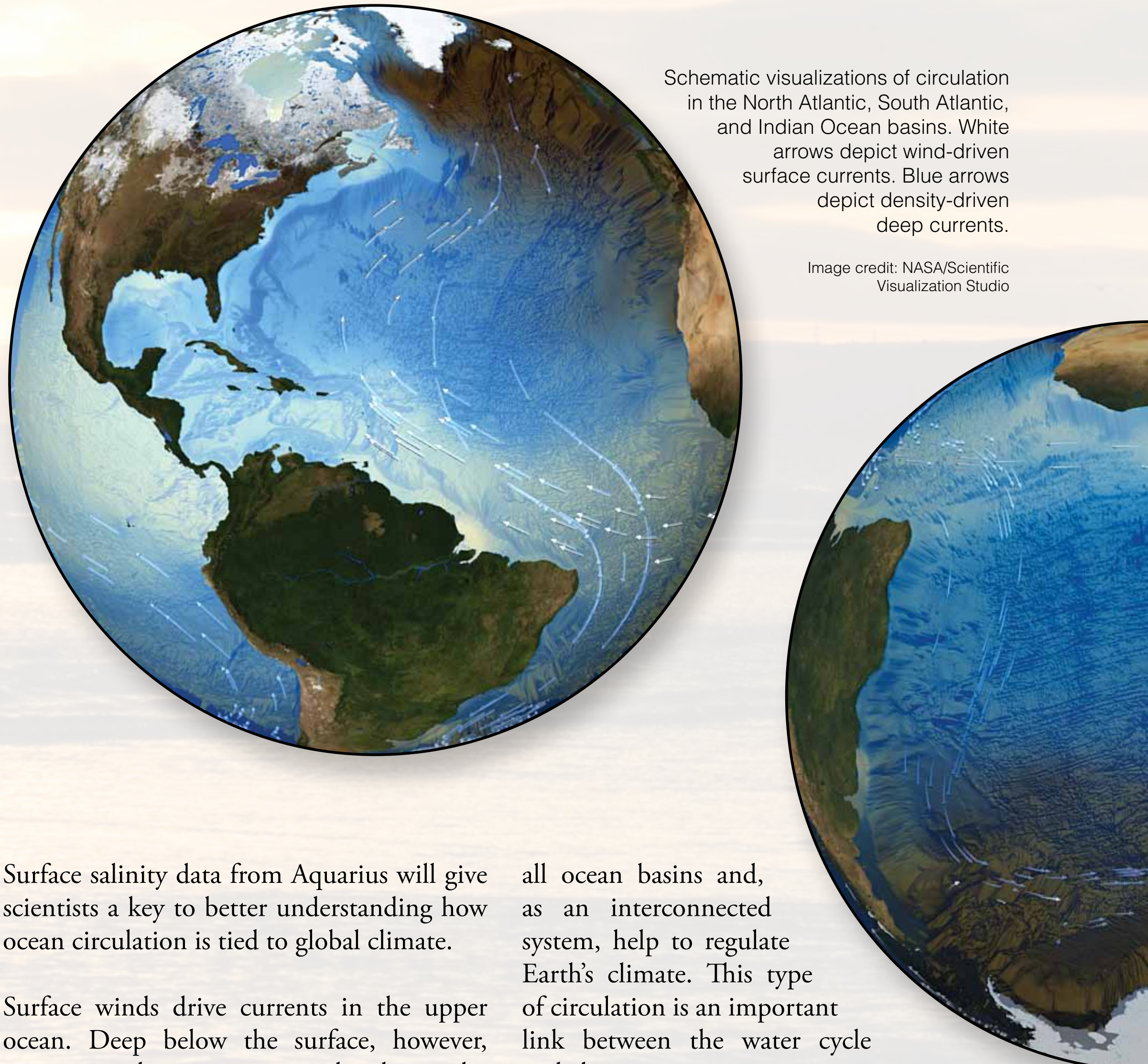
SALINITY DECREASES WITH:

Precipitation over the ocean

Melting of glaciers, icebergs

Freshwater input by rivers and groundwater

Salinity and Ocean Circulation



Schematic visualizations of circulation in the North Atlantic, South Atlantic, and Indian Ocean basins. White arrows depict wind-driven surface currents. Blue arrows depict density-driven deep currents.

Image credit: NASA/Scientific Visualization Studio

Surface salinity data from Aquarius will give scientists a key to better understanding how ocean circulation is tied to global climate.

Surface winds drive currents in the upper ocean. Deep below the surface, however, ocean circulation is primarily driven by changes in seawater density, which is determined by salinity and temperature. In some regions—such as the North Atlantic near Greenland—cooled high-salinity surface waters can become dense enough to sink to great depths. This circulation moves southward to the South Atlantic and joins the Southern Ocean circulation around the African continent and into the Indian Ocean. These deep overturning currents occur in all ocean basins and, as an interconnected system, help to regulate Earth's climate. This type of circulation is an important link between the water cycle and climate.

Salinity and Circulation - Key Facts

Seawater density is governed by temperature and salinity.

Below the wind-driven surface – tens to hundreds of meters – ocean circulation is driven by changes in seawater density.

Density-controlled circulation is key to transporting heat in the ocean and maintaining Earth's climate. In the geologic past there have been influxes of freshwater from melting glaciers that have disrupted overturning circulation and caused extreme climate variability. In some instances, salinity changes have disrupted ocean circulation and coincided with cooling episodes, such as the one triggered about 700 years ago, called The Little Ice Age. In recent decades, studies indicate that abnormal surface salinity around the far North Atlantic, called Great Salinity Anomalies, brought unusual weather to Europe.

Our planet's climate is changing and geographic coverage from in-water observing systems (e.g., ships, buoys) is not enough to fully understand how changes in global salinity affect climate, and vice versa. Excess heat associated with the increase in global temperature during the last century is being absorbed and moved by the ocean. Surface ocean and atmospheric temperature changes may cause evaporation to intensify and, as a result, significantly alter sea surface salinity and ocean circulation patterns.

Is the global water cycle accelerating in response to climate change? Studies suggest that seawater is becoming fresher in high latitudes and tropical areas dominated by rain, while in sub-tropical high evaporation regions, waters are getting saltier (see sidebar). Such changes could significantly impact not only ocean circulation but also the climate in which we live.

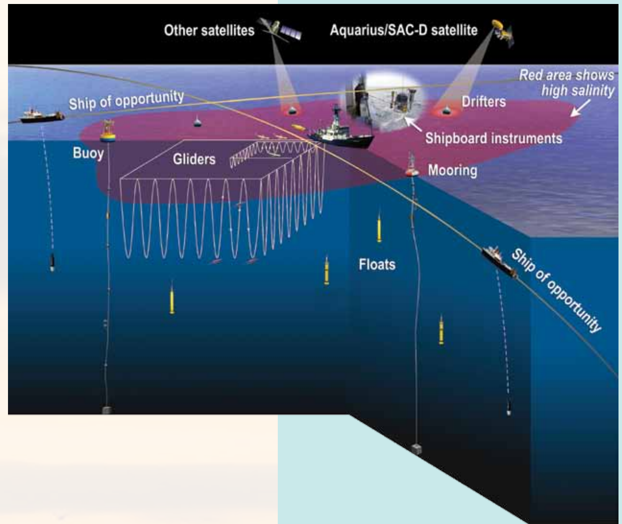


Image credit: NASA/JPL

Schematic overview of SPURS Field Experiment

SPURS Field Experiment

The Salinity Processes in the Upper Ocean Regional Study (SPURS) is a field experiment that will investigate how changes in the water cycle and ocean circulation impact sea surface salinity. SPURS will use a variety of tools—floats, gliders, drifters, moorings, ships, satellites, (e.g., Aquarius/SAC-D) and computer models—to help scientists understand the processes controlling upper-ocean salinity.

SPURS will initially focus on high-salinity regions, such as a region of the North Atlantic where salinity is at a maximum, and evidence shows it has been increasing in recent decades. Science objectives include determining what processes maintain the salinity maximum and influence salinity variations over time, finding where the excess salt goes, and examining the effects of salinity change on ocean circulation.

Making the Measurements

Photo credit: NASA

Aquarius radiometer in clean room at GSFC

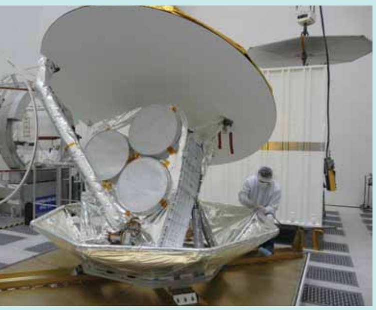


Photo credit: NASA

Aquarius instrument in clean room at JPL

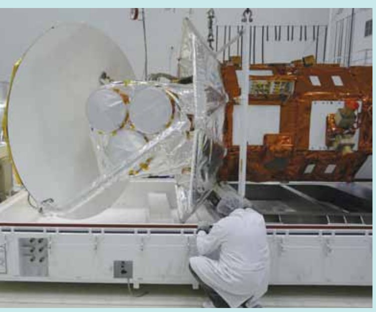


Photo credit: CONAE

Aquarius instrument integrated with SAC-D platform

Aquarius will measure sea surface salinity by observing the natural thermal emission from the ocean surface with an instrument called a radiometer. At frequencies near those used in microwave ovens, the level of emitted signal depends on the salinity of the ocean water, in addition to temperature. This energy, which is measured as an equivalent "brightness" temperature in Kelvin, has a direct correlation to surface salinity. Other things being equal, salty water appears cooler than freshwater.

Over the open ocean, salinity ranges only from about 32 to 37 PSS. An accuracy of about 0.2 PSS is needed to achieve the mission's science goals. This corresponds to a change in brightness temperature of about 0.1 Kelvin which is a challenging measurement for an Earth remote sensing instrument.

In addition, Aquarius must correct for interference with the salinity signal from other sources. Ocean waves are a particular problem because they modify the emission and can confuse the signal from salinity. Thus Aquarius has an additional instrument onboard, a radar scatterometer, to measure and correct for the effects caused by ocean waves.

Complementing data from Aquarius, the SAC-D payload has CONAE-sponsored instruments, including sensors from the French Space Agency (Centre National d'Etudes Spatiales) and the Italian Space Agency (Agenzia Spaziale Italiana) (see table below).

Once the satellite is on orbit, mission operations will be conducted at the CONAE ground station in Córdoba, Argentina. CONAE will transmit raw Aquarius data to the ground system at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Md., where the data will be processed and instrument operations managed. The Aquarius data processing system will generate timely salinity products to be disseminated by and archived at NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the Jet Propulsion Laboratory (JPL) in Pasadena, Calif.

Aquarius/SAC-D Science Instruments

Instrument	Objective	Description	Resolution	Source
Aquarius	Sea surface salinity	• Integrated 1.413 GHZ polarimetric radiometer • 1.26 GHz radar • 390 km swath	3 beams • 76 x 94 km • 84 x 120 km • 96 x 156 km	NASA
MWR Microwave Radometer	Precipitation, wind speed, sea ice concentration, water vapor	• 23.8 GHz and 36.5 GHz • Dual polarized • 390 km swath	• 40 km	CONAE
NIRST New Infrared Sensor Technology	Hot spots (fires), sea surface temperature	• Bands: 3.8, 10.7, and 11.7 µm • Swath: 180 km	• 350 m	CONAE
HSC High Sensitivity Camera	Urban lights, fires, aurora	• Bands: 450 - 900 µm • Swath: 700 km	• 200 - 300 m	CONAE
DCS Data Collection System	Environmental data collection	• Band: 401.55 MHz uplink	• 2 contacts per day with 200 platforms	CONAE
ROSA Radio Occultation Sounder for Atmosphere	Atmosphere temperature and humidity profiles	• GPS occulation	• Horizontal: 300 km • Vertical: 300 km	ASI (Italy)
CARMEN 1 ICARE and SODAD	ICARE: Effect of cosmic radiation on electronics SODAD: Distribution of microparticles and space debris	• ICARE: Three depleted Si and Si/Li detectors • SODAD: Four SMOS sensors	• ICARE: 256 channels • SODAD: 0.5 µ at 20 km/s sensitivity	CNES (France)

Use of Aquarius Data

Aquarius observations will contribute significantly to improving computer models that are used to forecast future climate conditions. With this new data stream, scientists can begin to understand the correlation of changes in salinity with changes in the water cycle, ocean circulation and climate.

Traditionally, researchers have used salinity measurements taken from ships, buoys, and floats (see sidebar). These data are from isolated sampling areas, over inconsistent periods of time, and based on a wide range of methods. Thus researchers have not been able to fine-tune computer models to obtain a true global picture of how sea surface salinity is influencing the ocean. Aquarius will enable a new era of ocean-climate models by consistently mapping the entire ice-free ocean every seven days.

Aquarius will also provide a missing link in satellite observations of Earth. Satellites already measure sea surface temperature, rainfall, water vapor, sea level, surface wind, and ocean color. Some of these data can also be used to derive surface currents and surface evaporation. Aquarius will provide a key variable that links ocean circulation, the global water cycle, and climate. Its data will also improve the accuracy of computer models that forecast climate changes and patterns.

With Earth's changing climate, small perturbations in ocean salinity have the potential to be of great impact. Hurricanes can dump hundreds of trillions of gallons of freshwater on the ocean surface, potentially altering ocean circulation if the frequency and intensity of these storms increases. Polar ice melt from climate warming can cause large-scale seawater freshening, potentially changing ocean circulation and associated weather patterns. Tracking high-latitude sea surface salinity over time will help to predict these fluctuations. Changes to ocean temperature and salinity can also lead to amplified El Niño and La Niña events. These and other studies made possible with information from Aquarius have direct relevance to our society and its future.

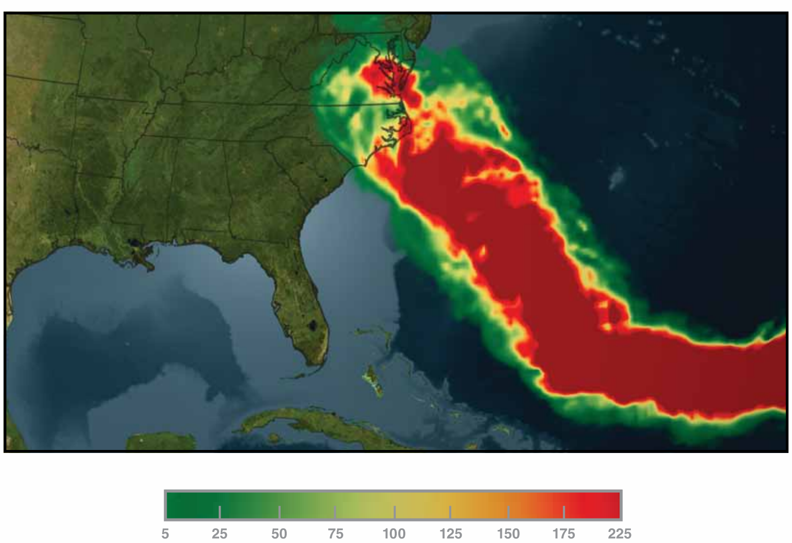


Image credit: NASA Scientific Visualization Studio

Aquarius measurements will complement other satellite data sets such as the Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis. This image shows rain accumulation from Hurricane Isabel for September 6-20, 2003.

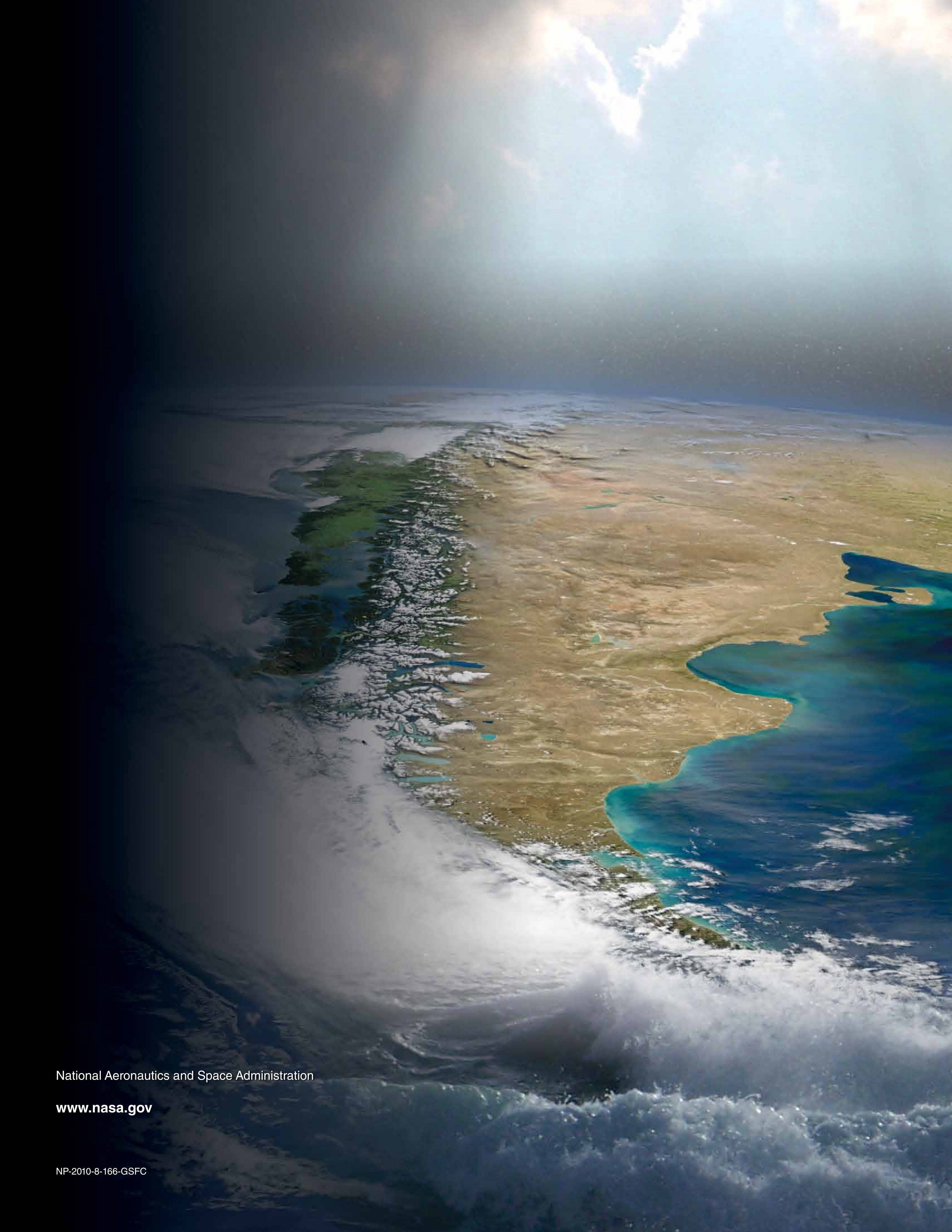
Photo credit: Kara Lavender

Pacific Marine Environmental Laboratory Argo float being deployed in the Pacific Ocean from the Sailing School Vessel *Robert C. Seamans*

The Argo Array

Argo is a global array of free-drifting, battery-operated profiling floats that measures the temperature and salinity of the upper 2,000 meters (6,500 feet) of the ocean. Aquarius will use surface Argo data for calibration and validation. The combination of Aquarius and Argo data will enable oceanographers to gain a full three-dimensional understanding of ocean salinity variations in the coming years.

Argo deployments began in 2000 and reached the goal of 3,000 floats in November 2007. To maintain this fleet, about 800 new floats are added each year. Argo floats produce 100,000 temperature/salinity profiles per year and the data are publicly available within 24 hours of collection. Improved forecasts of El Niño events, monsoons, and other climate patterns are possible using Argo data. The coverage of Argo floats has expanded into the polar regions and, in the future, floats will be capable of sampling to depths of more than 5,000 meters (16,400 feet).



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