Update on the Aquarius/SAC-D Mission

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Background on Salinity Measurements and Aquarius / SAC-D

One of the most fundamental properties of seawater is its saltiness or *salinity*. Salinity has been measured directly for centuries, perhaps most notably by Benjamin Franklin as part of his efforts to map the Gulf Stream. Thus far, however, remote sensing of salinity of the ocean has been only through limited airborne measurements. But that is about to change…Three decades of scientific and technical development have now made it possible to accurately measure sea-surface salinity (SSS) from a sun-synchronous orbit 408 mi (657 km) above Earth's surface, and in May 2010, a U.S.-Argentine satellite mission will be the first to measure SSS from space.

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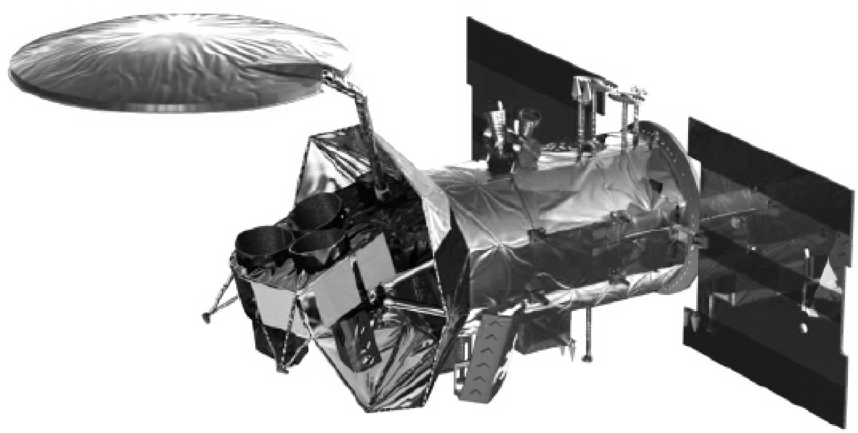
The Aquarius/Satellite de Aplicaciones Cientificas (SAC-D) satellite mission is designed with SSS as its primary measurement—*aquarius.nasa.gov.* Over its three-year baseline mission, data from this pioneering mission will reveal changing SSS patterns over the ice-free global oceans. Two months after launch, the Aquarius instrument will collect more SSS data than has been amassed in the previous 100 years. The SAC-D satellite, built by the Argentinian Space Agency—Comisión Nacional de Actividades Espaciales (CONAE)—will accommodate the primary Aquarius SSS instrument plus several Argentinian SAC-D instruments and instruments from the French Space Agency—Centre National d'Etudes Spatiales—and Italian Space Agency—Agenzia Spaziale Italiana.

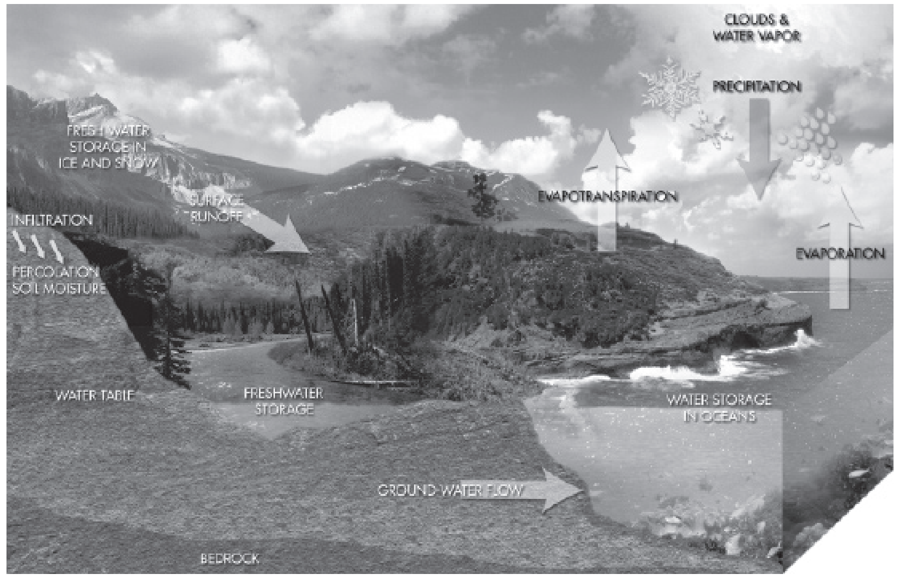


Artist rendering of the Satellite de Aplicaciones Cientificas.

Importance of Salinity Measurements

SSS data from Aquarius will complement existing satellite programs that monitor sea surface temperature. Together, salinity and temperature control density at the ocean surface. Sea-surface density is extremely important since it drives the formation of ocean water masses and thus influences the three-dimensional ocean circulation. Better understanding of SSS patterns will improve scientists' understanding of the ocean's capacity to store heat, transport heat, and regulate Earth's climate. In addition, monthly maps of global SSS will improve understanding of the interaction between ocean circulation and the global water cycle.

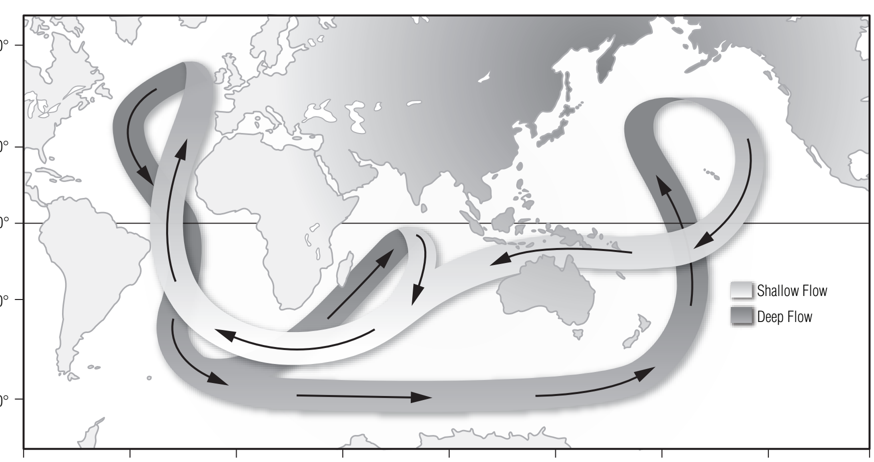
Ancient Greeks, including Homer and Plato, knew that water continually circulates from the ocean to the atmosphere to the land and back again to the ocean. Today's scientists know that Earth's *water cycle* is dominated by exchanges between the ocean and atmosphere. In fact, 86% of global evaporation and 78% of global precipitation occur



This diagram illustrates Earth's water cycle. Aquarius/SAC-D data will help scientists relate sea surface salinity variations to global evaporation minus precipitation, and give them insight into how the ocean responds to changes in the water cycle from season-to-season and year-to-year.

over the ocean—see diagram above. SSS is a key tracer for understanding freshwater *fluxes*—i.e., movement of water into and out of the ocean system. This is because some parts of the water cycle decrease salinity (e.g., precipitation, groundwater flow to the ocean, river runoff), while other parts increase it (e.g., evaporation of seawater, freezing of seawater). To track changes in SSS patterns over time, scientists monitor the relationship between two primary processes in the oceans: *evaporation* and *precipitation*. With Aquarius data, scientists will be able to relate SSS variations to global evaporation minus precipitation, providing insight into how the ocean responds to variability in the water cycle, from season-to-season and year-to-year. Increases in SSS (i.e., evaporation exceeding precipitation) in high latitudes can increase seawater density and speed up the deep overturning circulation in the ocean. Conversely, decreases in SSS (i.e., precipitation exceeding evaporation or melting ice) may result in widespread decreases in seawater density, reducing its ability to sink. Oceanographers believe that maintaining density-controlled ocean circulation is key to keeping ocean heat transport in balance—and ocean heat transport plays a key role in regulating Earth's climate.

Well before widespread recognition of climate change, the scientific community understood the need for global SSS data to help diagnose shifts in the ocean-atmosphere system [*Lagerloef*, 1995]. The principal scientific objective of Aquarius is to make global SSS measurements over the open oceans with 150-km spatial resolution, and to achieve a measurement error less than 0.2 practical salinity scale of 1978 (PSS-78) on a 30-day time scale, taking into account all sensor and geophysical random errors and



This diagram illustrates the so-called global ocean conveyor belt that transports heat from the tropics to the poles and thus plays an important role in regulating global climate. Data from Aquarius should help scientists understand the impact that changes in sea surface salinity have on the efficiency of these ocean currents.

biases [*Lagerloef et al*, 2008]. Although Aquarius measurements will have relatively low spatial resolution, they will provide much greater detail than can be derived from historical data [World Ocean Atlas 2005].

In addition to Aquarius/SAC-D, the European Space Agency is developing an explorer-class mission—Soil Moisture Ocean Salinity (SMOS)—scheduled for launch in mid 2009, whose primary measurement will be soil moisture with about 45 km average spatial resolutions. However, SMOS will also measure SSS, though the final measurement accuracy of these measurements is still being investigated. Between Aquarius/SAC-D and SMOS, satellite-based SSS observations scientists hope to "fill in the blanks" that currently cover 25% of the ocean surface—vast areas where salinity has never been measured.

Recent drastic changes in Arctic sea ice cover—e.g., as documented in 2007 by the National Science and Ice Data Center (*nsidc.org*)—have made the collection of SSS data more important than ever. A decrease in Arctic sea ice and associated increase in albedo are projected to result in a feedback loop that will exacerbate climate warming. In a very simple model, decreasing SSS in the North Atlantic (i.e., increasing "freshening") would reduce the formation of deep-water masses and, in turn, the efficiency of the ocean *global conveyer belt,* which helps to regulate global climate by moving heat from the tropics to higher latitudes—see diagram at bottom of page 18.

The Aquarius Salinity Measurement Mission and Design

To measure salinity from space, scientists must measure microwave emission from the sea surface, and they do this by observing a parameter called *brightness temperature*, in Kelvins (K), and correcting for other natural emission sources and sinks. Ocean brightness temperatures are related to the dielectric properties of seawater, and at lower microwave frequencies, these are dependent on salinity. Aquarius science instruments will include a set of three L-band (1.413 GHz) radiometers and a scatterometer that corrects for the ocean's surface roughness. Legally protected for scientific purposes (i.e., radio astronomy and Earth remote sensing) from radio interference, L-band is sufficiently sensitive to make viable measurements of salinity [*Klein and Swift*, 1977; *Swift and McIntosh*, 1983]. Two SAC-D instruments will complement Aquarius science measurements: the CONAE Microwave Radiometer for wind, rain, cloud water, sea-ice detection; and the CONAE New Infrared Scanner Technology for supplementary sea surface temperature.

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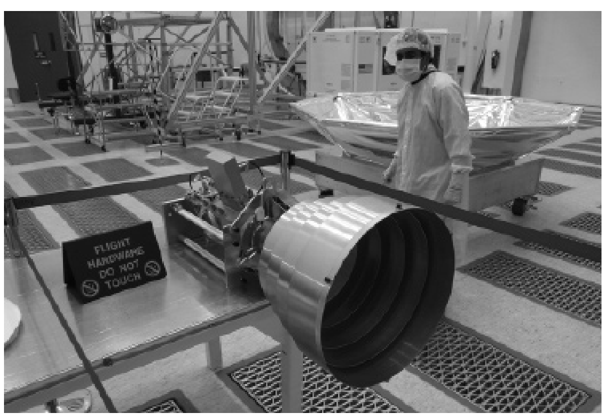


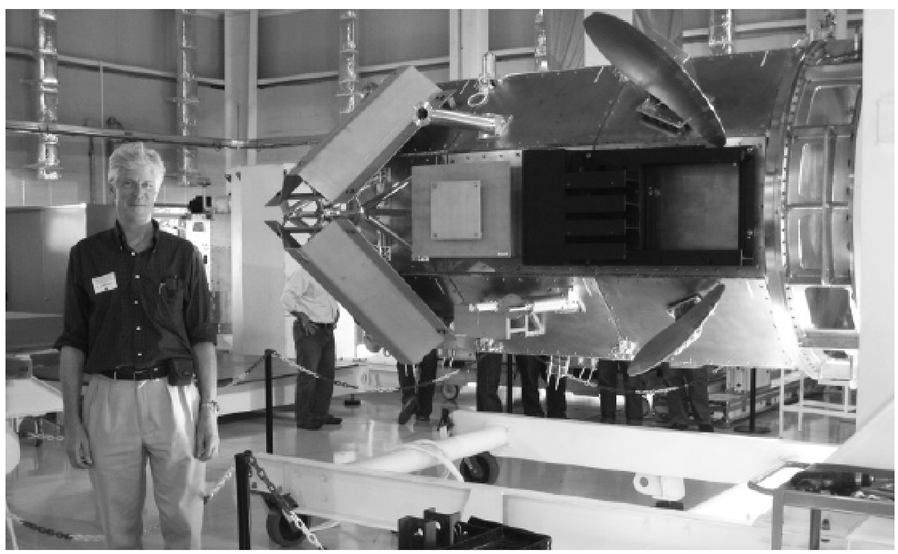
The Aquarius Ortho-Mode Transducer (OMT), around which the radiometer front-end components are mounted to achieve thermal stability. The Aquarius sunshade is also shown in the background. Photo was taken at JPL.

The Aquarius Radiometer in a Goddard Space Flight Center clean room.

"Salinity remote sensing signatures are quite small and present a difficult measurement challenge. Accordingly, the Aquarius microwave radiometer has very exacting requirements for low noise and calibration stability, and will be the most accurate (by about an order of magnitude) ever developed for Earth remote sensing," says Gary Lagerloef [Earth & Space Research—Aquarius Principal Investigator].

measurement challenge. Accordingly, the Aquarius microwave radiometer has very exacting requirements for low noise and calibration stability, and will be the most accurate (by about an order of magnitude) ever developed for Earth remote sensing," says **Gary Lagerloef** [Earth & Space Research—*Aquarius Principal Investigator*]. To achieve the Aquarius goal for an accuracy of 0.2 practical salinity units (psu) on a monthly basis, the design requirement is that the radiometers be stable to within 0.13 K over seven days. A primary element in maintaining stability is adequate internal calibration and good thermal control. The design adopted for the Aquarius radiometers is based on research conducted under NASA's Instrument Incubator Program.

Initially approved as a NASA Earth System Science Pathfinder mission in 2001, Aquarius passed Mission Confirmation Review (MCR) in September 2005. At that point, the project had completed formulation activities during which the mission requirements, design, and costs were developed and reviewed. Since MCR, Aquarius/SAC-D has been in the implementation phase, during which the flight hardware is being built, tested, and readied for launch. In January 2008, the NASA Goddard Space Flight Center (GSFC) delivered the Aquarius radiometer to the Jet Propulsion Laboratory (JPL) in Pasadena, CA. Leading up to the Mission Critical Design Review (MCDR) in July 2008, the radiometer was integrated with the Aquarius instrument at JPL, including the JPL-built and tested scatterometer and antenna. Aquarius instrument integration and testing will continue through Spring 2009, followed by Aquarius/SAC-D observatory integration. The Aquarius/SAC-D Operations Readiness Review is scheduled for late Fall 2009, six months before the scheduled May 2010 launch.



Aquarius PI Gary Lagerloef poses with the SAC-D satellite at CONAE.

Data Distribution

SSS data are crucial for improving computer models of ocean circulation; data calibration, validation, and dissemination are key goals for the Aquarius/SAC-D mission. NASA and CONAE will share the data processing and distribution activity. CONAE will manage satellite telemetry and transmit raw Aquarius data to GSFC. The Aquarius data processing system will generate timely salinity products for ready access by the science community. Aquarius data will eventually be archived in NASA's Physical Oceanography Distributed Active Archive Center (PO-DAAC), located at JPL.

Like many other ocean-observing satellite missions, Aquarius will rely on *sea-truth* data from a variety of platforms including the global array of 3,000 free-drifting profiling Argo floats that measure the temperature and salinity of the upper 2000 meters of the ocean (*www.argo.ucsd.edu/*). They will also rely on volunteer observing ships, research ships, and moored and drifting buoys. The system being developed will not only calibrate and validate Aquarius measurements; it will also accumulate and format *in situ* SSS and SST data, thus providing a valuable independent resource to the science community.

Education and Public Outreach

From the outset, education and public outreach (EPO) have been important, highly integrated and complementary components of the Aquarius/SAC-D mission. The Aquarius EPO objective is to demonstrate how better understanding of salinity-driven ocean circulation—and its influence on climate and the water cycle—can benefit student learning and society as a whole. A key strategy is offering "hands on" activities and online data access tools that can be directly integrated into classroom settings. Reviewed and approved by the NASA Science Mission Directorate Education Product Review, Aquarius offers nine "hands on" activities for elementary through high school audiences (*aquarius.nasa.gov/education.php*). Content focuses on essential concepts that are aligned with National Science Education Standards [National Research Council, 1996] and include: properties of water, the hydrologic cycle, phases of water, and heat capacity.

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In addition, the Aquarius education technology team has developed a set of interactive tools using historical salinity, temperature, and density data sets [World Ocean Atlas, 2005]. These data are available as three distinct, yet complementary, tools that highlight: (1) spatial patterns of long-term mean data; (2) annual cycle of monthly mean data; and (3) change over time of yearly mean data. In addition, Aquarius data tools are augmented by interactive tutorials and guiding questions and answers (*aquarius.jpl.nasa.gov/AQUARIUS/*)—for example: *Is salinity the same everywhere in the oceans? Were the oceans as salty a hundred years ago?*

Another important component of Aquarius EPO is its "thematic partners" whose common vision is to better understand the ocean-atmosphere system and its potential impacts on society. Aquarius efforts are well-coordinated with the SAC-D Mission, whose specific EPO goal is to improve understanding of the water cycle and its impact on human life. Another key partner is the Centers for Ocean Sciences Education Excellence (COSEE), a nationwide network funded primarily by the National Science Foundation to promote ocean literacy through effective partnerships between research scientists and educators (*cosee.net*).

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