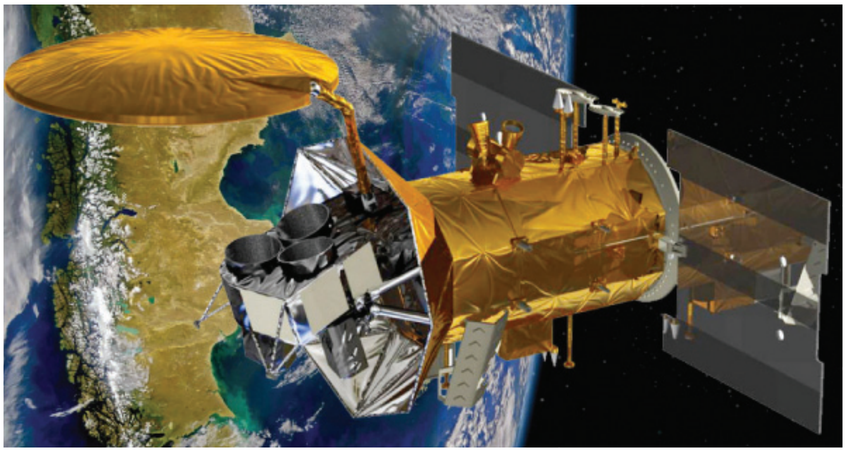
Detecting Ocean Salinity from Space



Ilustration of Aquarius/SAC-D above Earth. Credit: NASA Aquarius Mission.

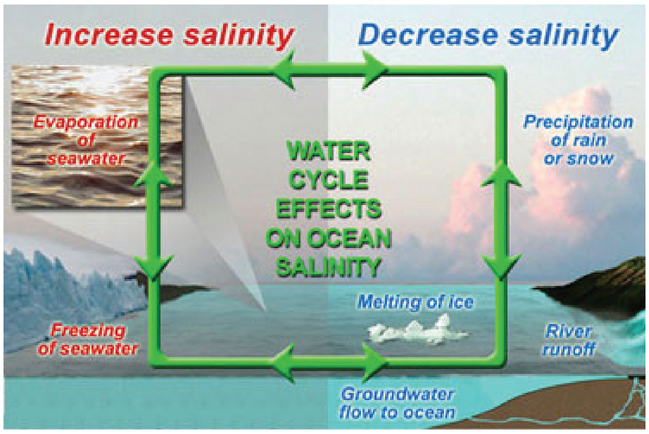
Ocean salinity reflects key processes in ocean circulation, the hydrological cycle, and climate. By defining its density, salinity combined with temperature determine ocean circulation including the large-scale overturning referred to as the thermohaline circulation. Past climate shifts have been accompanied by significant changes in salinity and the thermohaline circulation. Recent studies suggest that abnormal surface salinity in the far North Atlantic and unusual weather in Europe may be linked.

Evaporation and precipitation over the vast oceans, river runoff in coastal regions, and ice melt at high latitudes affect the time and geographical variations in ocean salinity as illustrated in the water cycle schematic. Scientists have seen indications that with global warming the water cycle has been speeding up over the past 50 years, and as a result the ocean's surface is getting saltier in salty regions and fresher in fresh regions. If this trend continues, the ocean circulation could be significantly affected.

Up until the last decade, measurements of sea surface salinity (SSS) have been relatively sparse despite their relevance, because they had to be collected from ships and buoys and therefore they lacked adequate resolution to study important oceanic features. This situation has improved over the past decade with the implementation of the Argo network of profiling floats and is changing dramatically with the launches of European Space Agency's SMOS Mission and the recent NASA Aquarius instrument on the Argentine Space Agency's SAC-D satellite. The Aquarius instrument can detect changes in SSS as tiny as one-eighth of a teaspoon per gallon of water. It now provides weekly, nearly global SSS information with a space and time resolution never achieved before.

Because Aquarius derives ocean salinity from measurements of the brightness and temperature of the ocean surface, numerous corrections for geophysical effects must be made—effects such as solar and galactic radiation, atmospheric gases, water vapor, rain, cloud liquid water, Faraday rotation, the ionosphere temperature, ocean surface temperature and the roughness of the ocean surface. The two years of data collected have allowed the calibration and validation team, including IPRC scientist, to begin to refine these measurements.

The IPRC team of researchers **Oleg Melnichenko**, **Peter Hacker**, **Nikolai Maximenko** (principal investigator), and **Jim Potemra** creates salinity maps by synthesizing Aquarius swath data with information from the array of Argo floats, which until now has been providing the largest volume of salinity data. While over 3600 Argo floats distributed throughout the world ocean provide information about the water column at a cycle of about 10-day and 3-5 degree



Credit: NASA Aquarius Mission.

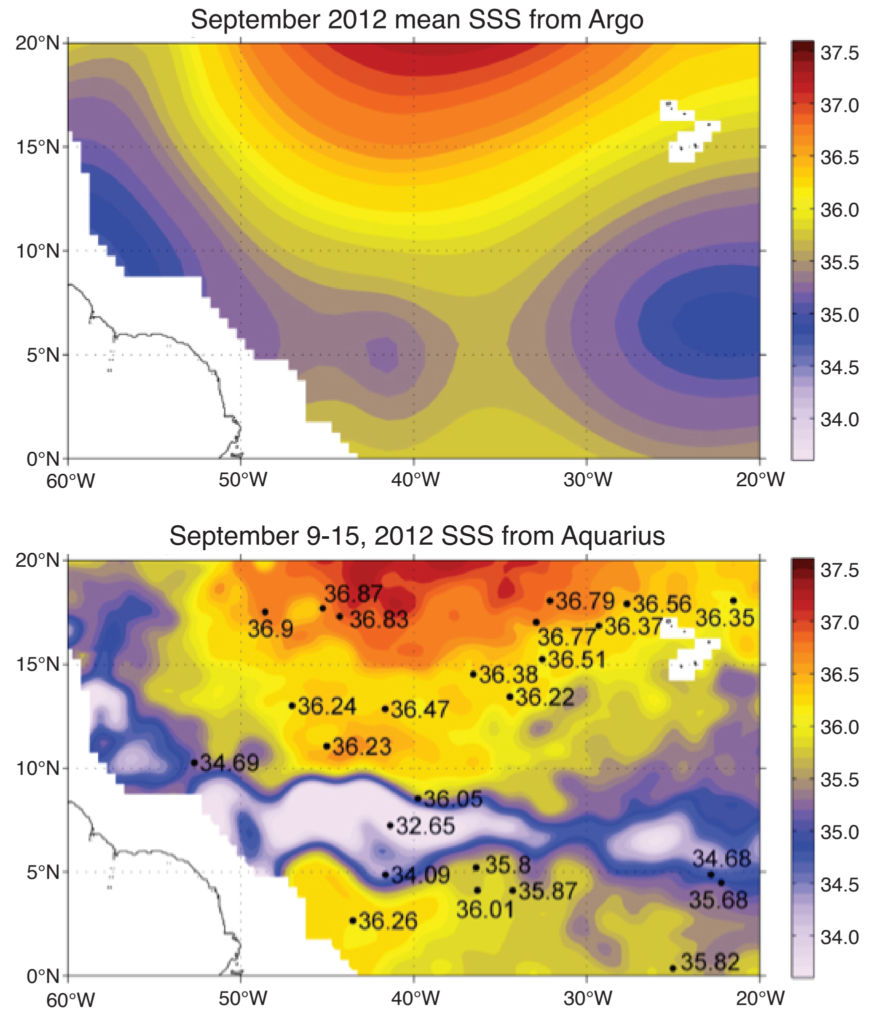


Figure 1. Comparison between the September mean tropical North Atlantic SSS field obtained from in-situ Argo float data (top) and the SSS field for September 9–15, 2013 as reconstructed by IPRC scientists from the Aquarius swath data (bottom). The Aquarius map clearly shows more fine-grained salinity structures than the Argo map; especially noteworthy is the plume of low-salinity water flowing our of the Amazon River and extending far into the Atlantic. (Bold numbers in panel 2 represent points of Argo observations.)

resolution, Aquarius adds great detail at the surface, resolving major oceanic fronts and other mesoscale features.

Because patterns of the Aquarius SSS errors can be expected to occur over large areas, the IPRC team developed a method to detect such error patterns using the data from the Argo array. By synthesizing the large-scale signals sampled at float locations with the mesoscale signal from the along-track satellite measurements, the team is successfully producing meaningful SSS maps based on Aquarius. The maps have reduced the biases present in the original Aquarius data and allow space/time estimates of the signal and noise.

The value of these new Aquarius maps became evident when Melnichenko sent weekly salinity maps from such syntheses to **Raymond Schmitt** who coordinates a project of the Salinity Processes in the Upper Ocean Regional Study (SPURS) on board of R/V *Knorr*. The Aquarius maps showed a region in the North Atlantic where sea surface salinity was so high that some SPURS scientists thought the maps were wrong. The R/V *Knorr* working in the North Atlantic at the time collected on-site samples, which confirmed the extremely high salinity region.

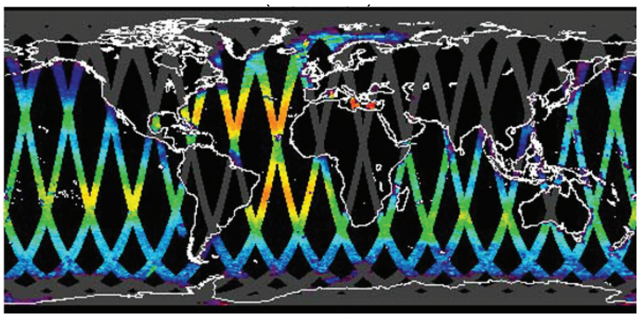
An example of the wide-ranging use of Aquarius data in regional climate studies is seen in Figure 1, which compares the tropical North Atlantic SSS field as reconstructed from IPRC's Argo-calibrated Aquarius data with the mean SSS field obtained from in-situ Argo float data. Among the many features in the Aquarius SSS map is a plume of low-salinity water that extends from the Amazon River outflow far into the tropical Atlantic. The plume, which is visible during summer and fall, but weakens or disappears in other months, is characterized by very low salinity with sharp boundaries setting it off from surrounding salty waters.

It is noteworthy that the plume stretches into an area where many of the tropical cyclones in the North Atlantic form during the peak hurricane season. The hypothesized connection is as follows: due to its lower density, the low SSS plume is kept from mixing downward into the cold subsurface waters, creating a so-called barrier layer and a region of high sea surface temperature and deep atmospheric convection, conditions favorable for hurricanes.

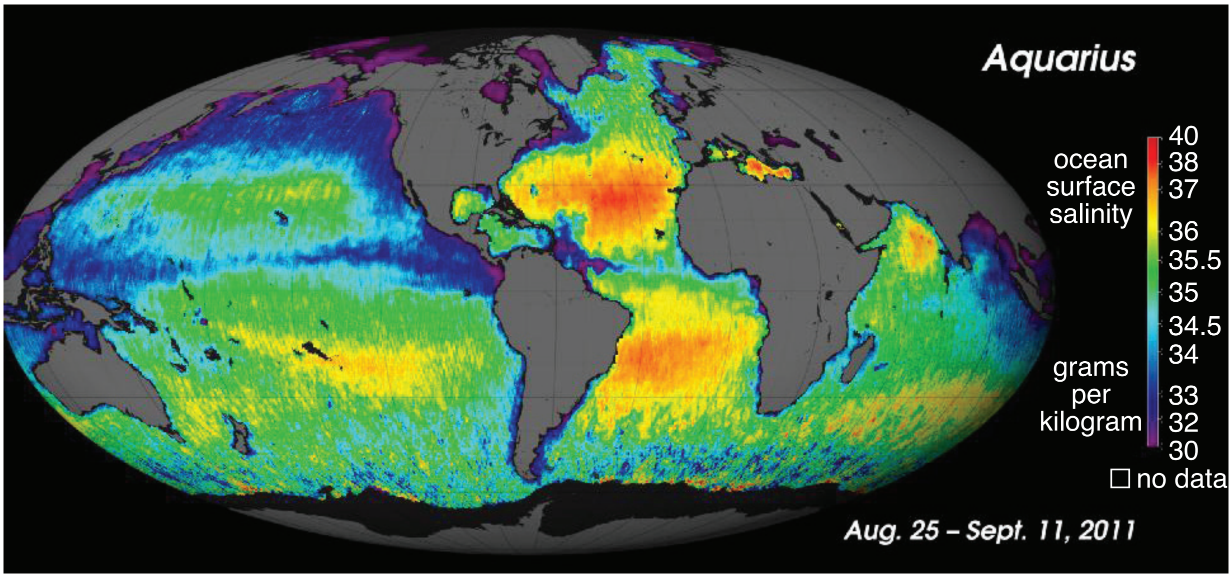
IPRC scientists are using these new high-resolution SSS maps to study the formation of subtropical salinity maxima and their connection with the equatorial oceans. As already known, each subtropical ocean has a region where the surface is the saltiest. These regions, seen below on the global salinity map from Aquarius, are part of the subtropical overturning circulation. The salty, dense water in these regions subducts into the thermocline, contributing to the subtropical overturning circulation and transporting excess salt out of the subtropics toward the equator. Hydrographic observations show that these SSS maxima vary from year to year in location and magnitude and are greatly influenced by natural and anthropogenic processes. Through the ocean's shallow overturning circulation, such variations affect the atmosphere and thereby longer climate fluctuations.

As part of the Aquarius Science Team, **Tangdong Qu** is leading a project with **Niklas Schneider** at the IPRC and **Ichiro Fukumori** at the Jet Propulsion Laboratory that aims to understand the formation and variation of these salinity maxima. The project's objectives include: (1) identifying the ocean processes governing the subtropical salinity maxima, (2) examining the transport of subtropical salinity maximum waters and their impact on the global thermohaline circulation, and (3) determining the variability and time scales of subtropical salinity maxima and the large-scale forces that shape them.

Aquarius salinity maps will also be used to constrain the "next-generation" long-term integration of JAMSTEC's Ocean Model for the Earth Simulator (OFES). Schneider plans to use the results of this integration to study the role of long-term salinity variations and their relation to the formation of mode water in the North Pacific. A recent analysis of decadal variations in water properties in coupled models run by IPRC and JAMSTEC scientists suggests that wind-driven meridional shifts in the sharp temperature and salinity gradients at the fronts between subtropical and subpolar water impact North Pacific mode-water formation. These results however are at odds with observational estimates that show the decadal variations in eddy-fields modulate mode-water formation. Aquarius salinity data together with OFES simulation results should help to untangle the dynamics of the region's mode-water formation.



Aquarius sea surface salinity swaths on January 4, 2011. Credit: NASA/GSFC/JPL-Caltech.



The first Aquarius global map of ocean saltiness, a composite of the first two and a half weeks of data since the instrument became operational on August 25, 2011. Credit: NASA/GSFC/JPL-Caltech.