THE AQUARIUS/SAC-D MISSION

DESIGNED TO MEET THE SALINITY REMOTE-SENSING CHALLENGE

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In an *Oceanography* article published 13 years ago, three of us identified salinity measurement from satellites as the next ocean remote-sensing challenge. We argued that this represented the next "zeroth order" contribution to oceanography (Lagerloef et al., 1995) because salinity variations form part of the interaction between ocean circulation and the global water cycle, which in turn affects the ocean's capacity to store and transport heat and regulate Earth's climate. Now, we are pleased to report that a new satellite program scheduled for launch in the near future will provide data to reveal how the ocean responds to the combined effects of evaporation, precipitation, ice melt, and river runoff on seasonal and interannual time scales. These measurements can be used, for example, to close the marine hydrologic budget, constrain coupled climate models, monitor mode water formation, investigate the upper-ocean response to precipitation variability in the tropical convergence zones, and provide early detection of low-salinity intrusions in the subpolar Atlantic and Southern oceans. Sea-surface salinity (SSS) and sea-surface temperature (SST) determine sea-surface density, which controls the formation of water masses and regulates three-dimensional ocean circulation.

The 1995 *Oceanography* paper evidently marked a turning point for salinity remote sensing. Until that time, there was no organized program for developing a satellite capability to measure this important yet sparsely observed ocean variable, in contrast to the established satellite programs to observe surface temperatures, winds, sea level, and ocean color. The paper demonstrated that newly evolving technology could provide global salinity measurements at a similar, scientifically useful accuracy and spatio-temporal resolution, and it came at a time of growing scientific awareness of the need for the data. Vigorous efforts begun in the late 1990s by the community of scientists interested in salinity measurements have led to the development of the Aquarius/SAC-D mission (Figure 1), now targeted for launch in mid 2010. This mission's principal scientific objective is to provide monthly global measurements of SSS. Here, we describe the Aquarius/SAC-D mission and how its capabilities are designed to meet the salinity remote-sensing challenge, providing the ocean research community with a preview of the measurement characteristics and scientific applications of this pioneering mission.
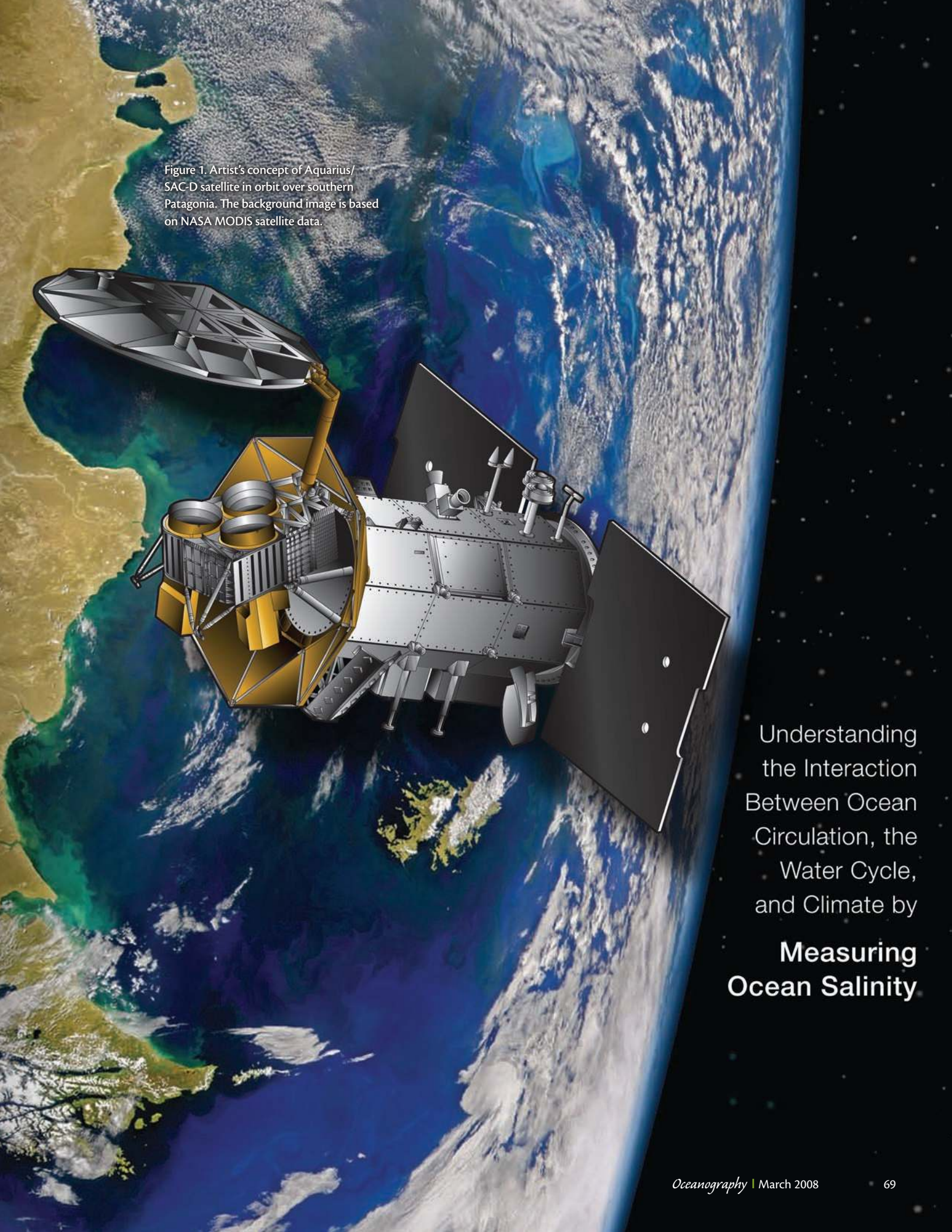
Figure 1. Artist's concept of Aquarius/SAC-D satellite in orbit over southern Patagonia. The background image is based on NASA MODIS satellite data.

Understanding
the Interaction
Between Ocean
Circulation, the
Water Cycle,
and Climate by

**Measuring
Ocean Salinity**

A BRIEF HISTORY FROM 1995 TO THE PRESENT

In early 1998, the Salinity Sea Ice Working Group (SSIWG) was established with a charter to (1) assess the scientific importance and applications of global surface salinity remote-sensing measurements, (2) evaluate the potential accuracy and spatio-temporal resolution of satellite data given present and near-future technologies, (3) recommend measurement requirements and identify technology issues and trade-offs, and (4) provide guidance for ongoing field measurements and algorithm studies. The SSIWG, an international, voluntary, and open forum, held workshops in 1998, 1999, and 2000 focusing on a range of scientific and technical issues covered by the charter (see http://www.esr.org/ssiwg/mainssiwg.html). The SSIWG provided the basic scientific framework and objectives for salinity remote sensing and outlined basic measurement requirements (Table 1).

In conjunction with the SSIWG, parallel efforts in both Europe and United States continued to study satellite sensor concepts and mission designs that could measure salinity either as a secondary or primary objective. Further analyses provided more rigorous assessment of the technical issues and feasibility (e.g., Yueh et al., 2001). A number of field campaigns were launched to obtain new data and test retrieval models (Le Vine et al., 1998; Wilson et al., 2001; Camps et al., 2004). Two explorer-class missions, one on each side of the Atlantic Ocean, were proposed and approved as a result. The European Space Agency (ESA) Soil Moisture Ocean Salinity (SMOS) mission is now scheduled for launch in late 2008 (http://www.esa.int). SMOS targets both land and ocean measurements, and uses a phased-array sensor that will provide ~ 45 km average spatial resolution with primary requirements to measure soil moisture. Studies indicate that the best-case salinity retrieval accuracy has the potential to meet the measurement requirements (Table 1) when the uncorrelated sensor noise alone and spatio-temporal averaging are taken into account (e.g., Font et al., 2004; Sabia et al., 2006). The impacts of SMOS instrument biases and many geophysical error sources on the final measurement accuracy continue to be investigated.

On the western side of the Atlantic Ocean, the Aquarius/SAC-D mission (http://aquarius.gsfc.nasa.gov) is being developed with the primary scientific objective to accurately measure ocean salinity from space. This program, a partnership between the United States National Aeronautics and Space Administration (NASA) and the Argentina Comisión Nacional de Actividades Espaciales (CONAE), is now planned to launch in mid 2010.[1] Although Aquarius/SAC-D is primarily designed to measure salinity, it will include several other remote-sensing measurements. These measurements include a number of CONAE and other European payloads (see below). The baseline mission is designed to operate for up to three years, with potential extended durations of two years or longer. The principal scientific objective is to make global SSS measurements over the ice-free oceans with 150-km spatial resolution, and to achieve a measurement error less than 0.2 (PSS-78 [practical salinity scale of 1978]) on a 30-day time scale, taking into account all sensor and geophysical random errors and biases. For comparison, the Global

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[1] NASA uses the term "Aquarius" for the mission within its ESSP (Earth System Science Pathfinder) program, where Aquarius is the prime instrument of the mission. At CONAE, the mission is referred to as "SAC-D" (Satélite Aplicaciones Científicas-D), in reference to its previous missions. The respective agency contributions are described in a later section of this article. Both agencies have committed the necessary resources to meet the recently revised launch date of May 2010, and construction phases for the instruments and satellite are on schedule.

Ocean Data Assimilation Experiment (GODAE) requirement is one sample every 10 days per 200 km² and SSS error of 0.1. Presently, the Global Ocean Observing System (GOOS) provides about 25–30% of this global coverage with in situ observations. Aquarius/SAC-D will provide one complete global survey every seven days with root mean square (RMS) errors that will be reduced to less than 0.2 on monthly averages (see section below on Aquarius/SAC-D mission design).

EVOLVING SCIENTIFIC IMPERATIVES

As an indicator of the growing scientific interest, a special section of papers on ocean salinity appeared in *Journal of Geophysical Research* in 2002 (Lagerloef, 2002). The importance of ocean salinity to understanding and predicting climate variability is further documented in the recent report of the US CLIVAR Salinity Working Group (US CLIVAR Office, 2007). The working group's activities included organizing a special session at the 2006 Ocean Sciences meeting, which was followed by an international workshop at Woods Hole, Massachusetts, in May 2006, held jointly with an Aquarius/SAC-D science workshop (Lagerloef and Schmitt, 2006). The resulting report identifies salinity as an important indicator of the strength of the hydrologic cycle because it tracks the differences created by varying evaporation and precipitation, runoff, and ice processes. These variables lead to important dynamical consequences for oceanic currents and mixing that influence the ocean's capacity to absorb, transport, and store heat, freshwater, and carbon dioxide. There is clear observational evidence in recent decades of large-scale, integrated changes in the cycling and distribution of freshwater, for example, in the form of decreasing salinity in the subpolar North Atlantic as well as in the Southern Ocean, while over the same time the near-surface salinity in the subtropics has been increasing. Many of the processes governing the role of salinity in the modulation of upper-ocean mixing in both tropical and high-latitude regions are neither well understood nor adequately represented in climate models. Model studies suggest that expanded monitoring of salinity (satellite and in situ) will improve climate forecasts on interannual to decadal time scales.

The working group also recognized the limitations of historical observations and recommended the maintenance and expansion of the current in situ observing system, including the global Argo array and volunteer observing ships. In particular, they supported specific enhancements to the global observing system to improve SSS estimation by (a) expanding the Argo instrument suite to include salinity profiling within the

Table 1. Salinity Sea Ice Working Group (SSIWG) Principal Scientific Objectives for Sea Surface Salinity (SSS) Remote Sensing

1. Improving seasonal to interannual [ENSO] climate predictions: This effort involves the effective use of SSS data to initialize and improve the coupled climate forecast models, and to study and model the role of freshwater flux in the formation and maintenance of barrier layers and mixed layer heat budget in the tropics.

2. Improving ocean rainfall estimates and global hydrologic budgets: Precipitation over the ocean is still poorly known and relates to both the hydrologic budget and to latent heating of the overlying atmosphere. The "ocean rain gauge" concept shows considerable promise in reducing uncertainties in the surface freshwater flux on climate time scales, given SSS observations, surface velocities, and adequate mixed-layer modeling.

3. Monitoring large-scale salinity events: This effort may include ice melt, major river runoff events, or monsoons. In particular, tracking interannual SSS variations in the Nordic seas is vital to long-time-scale climate prediction and modeling. High-latitude SSS variations influence the rate of oceanic convection and poleward heat transport. These measurements will also be the most technically challenging because of the SSS accuracy needed, and the relatively weaker radiometric signature at low sea temperature.

Basic Measurement Requirements		
Accuracy (PSS-78*)	Spatial Resolution (km)	Temporal Resolution (days)
0.1–0.2	100–300	7–30

* practical salinity scale of 1978

upper 5 m to allow more precise calibration of satellite data (with optical depth of ~ 2 cm) and quantify "skin-bulk" SSS differences, and (b) developing and testing of SSS sensors for deployment on the surface drifters of the Global Drifter Program. In addition to these and other conclusions, the report emphasizes that: "The launch of Aquarius/SAC-D, as well as improvements in meteorological observing systems and models, offers the scientific community a unique opportunity to step beyond monitoring and to attempt to constrain the complete surface atmosphere/ocean hydrologic cycle based on observations." The report goes on to propose a coordinated field program in conjunction with the mission to attempt such a water budget closure experiment (see CLIVAR Salinity Working Group, this issue). Such closure studies are essential. A major unresolved problem for climate modeling and analyses is the large surface water flux adjustment required to bring stand-alone ocean general circulation model (OGCM) salt budgets in balance with the net air-sea flux derived from atmospheric analyses or spaceborne precipitation measurements (Lagerloef, 2002; Stammer et al., 2002); this indicates the present level of uncertainty of the air-sea hydrological budgets.

In other related activities, the World Climate Research Programme (WCRP) climate modeling community is considering priorities for the next series of climate modeling studies after the Fourth Assessment of the Intergovernmental Panel on Climate Change (Hibbard et al., 2007). Part of the agenda calls for an ensemble of near-term (25-year) numerical experiments to provide improved guidance and likelihoods of extreme climate changes on regional scales. How best to initialize these near-term coupled simulations with the present-day climate state is identified as an ongoing research problem. One key issue is the need to accurately represent ocean salinity and soil moisture, which is presently problematic because observations are too sparse—a condition that will be remedied with the upcoming new satellite measurements. (It should be noted that Aquarius/SAC-D will also be capable of measuring soil moisture at somewhat less spatio-temporal resolution than SMOS, and so can help address the initialization problem for both parameters.) The initialization problem also calls for improved initialization of sea ice. One present difficulty with satellite sea-ice measurements is that, during summer, melt ponds in floating sea ice cannot be distinguished from open water with the higher-frequency microwave (> 18 GHz) data historically available. An important research application for Aquarius/SAC-D and SMOS data is to evaluate how well the lower-frequency microwave information they provide could allow discrimination of relatively fresh melt-pond water from ambient seawater and significantly improve summer ice-concentration estimates.

Fourth Assessment reports released by the Intergovernmental Panel on Climate Change (IPCC) in early 2007 verified that the Arctic is experiencing the most rapid and widespread climate change of any large region around the globe. A more recent study (Overland and Wang, 2007) predicts that the summer sea ice will disappear by mid century, some decades earlier than recently forecast by the IPCC. The late summer ice cover in September 2007 was dramatically reduced by another ~ 25% relative to the previous low record in 2005 (http://nsidc.org). These astonishing changes indicate that there will be considerably more open water in the Arctic Ocean than was ever envisioned when Aquarius/SAC-D and SMOS were conceived. The dwindling ice cover suggests that the ice-albedo positive feedback is rapidly taking hold (as ice covered areas with high albedo shrink, open water area with low albedo expands, absorbing more solar radiation, melting more ice cover). In the Arctic Ocean, sea ice melting and continental runoff maintain a shallow cold fresh layer, which sustains a halocline that separates the surface layer from warmer and saltier water below. The recent trends raise several timely scientific questions to which Aquarius/SAC-D data can be applied, such as: Will the halocline break down where the ice cover recedes? Will there be measurable open-water salinity and temperature changes at the surface? How will these influence the summer melting rate and the re-forming of seasonal winter ice? What is the fate of the summer melt water? The Aquarius/SAC-D data coverage will extend to about 88°N latitude.

It is increasingly evident that the Aquarius/SAC-D mission comes at a time when we are continuing to observe and identify significant changes in the climate system related to ocean salinity. The potential scientific applications are already beginning to reach beyond the still-important oceanographic science objectives first put forth by the SSIWG. Aquarius/SAC-D's overarching scientific goal is to quantify and understand the linkages among ocean circulation, the global water cycle, and climate by accurately measuring surface salinity.

THE AQUARIUS/SAC-D MISSION DESIGN

As noted above, the Aquarius/SAC-D mission is being developed as a partnership between the United States (NASA) and Argentina (CONAE). The principal NASA contributions are the Aquarius salinity instrument, the Aquarius salinity data processing system, and the launch into orbit. CONAE is building the spacecraft and a number other science payloads, and will provide mission operations and the data downlink. Overall mission design has been developed in concert to best meet the goals of each agency, while giving priority to salinity measurements. CONAE is building complementary sensors to detect rain, sea ice, and wind speed, plus limited SST sampling.

To meet the overarching salinity science requirements to survey the global ice-free ocean at least monthly and with minimum measurement error, the design strategy called for the following functional elements: (a) a ~ 390-km-wide measurement swath consisting of three elliptical beam footprints with dimensions of 76 x 94 km, 84 x 120 km, and 96 x 156 km (Figure 2); (b) positioning of the satellite in a sun-synchronous polar orbit crossing the equator northward (ascending) at 6 p.m., with the

MISSION DESIGN AND SAMPLING STRATEGY

- Sun-synchronous exact repeat orbit
- 6 pm ascending node
- Altitude 657 km

- Beams point toward the nightside to avoid sun glint
- Global coverage in 7 days
- 4 repeat cycles per month

Surface Validation

In Orbit Check Out

Launch 2010

3 Beams (390 km wide swath)

Antenna Footprints (3 dB, one-way/two-way). Look angle (deg) 33

Altitude (km) = 657
Radiometer outer, one-way
Scatterometer inner, two way

76 x 94 km   96 x 156 km

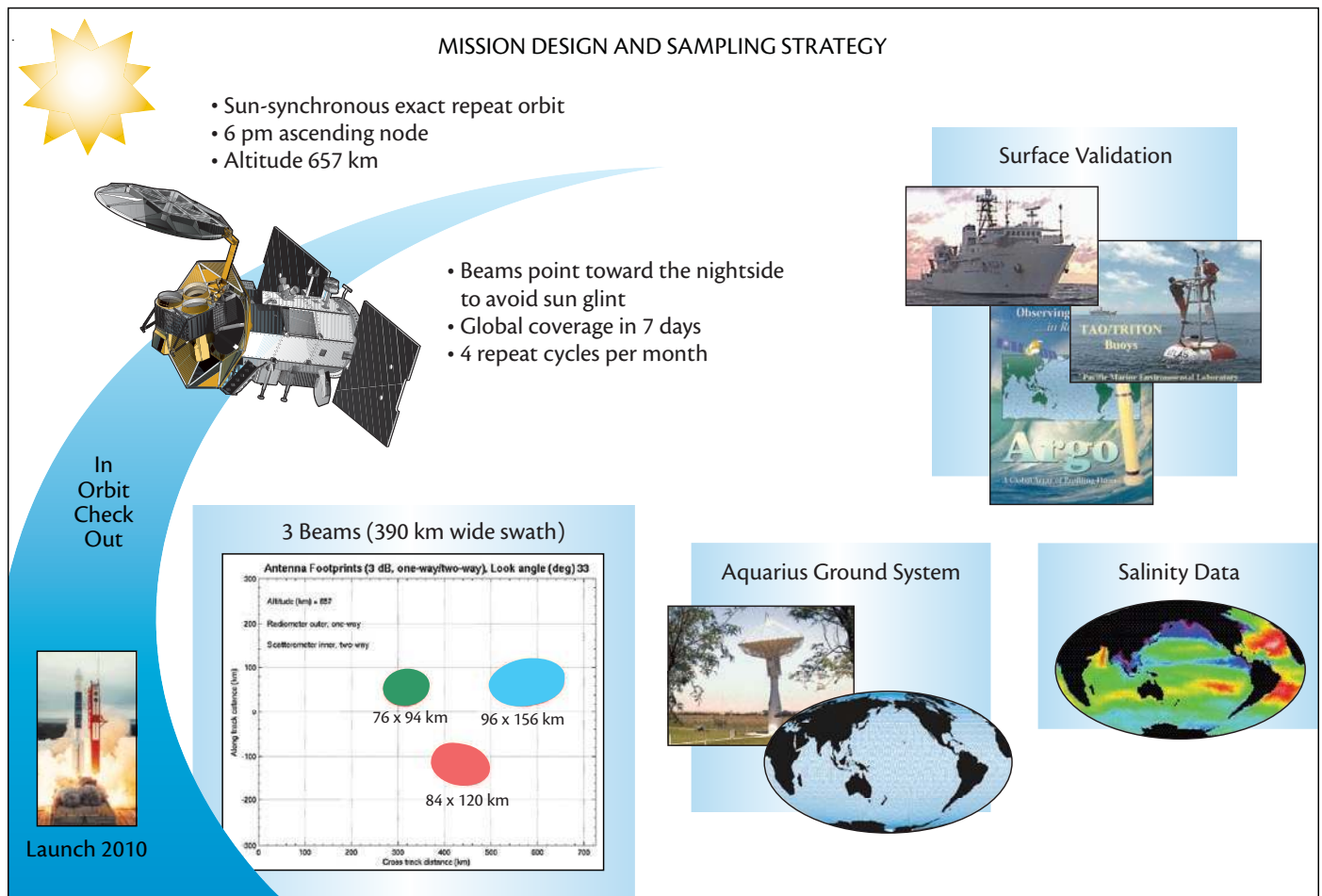84 x 120 km

Aquarius Ground System

Salinity Data

Figure 2. The Aquarius/SAC-D mission concept. The satellite will be in a polar sun-synchronous orbit crossing the equator at 6 p.m. (ascending) and 6 a.m. (descending) local time. The Aquarius sensor views continually away from the sun to avoid signal contamination from solar L-band energy flux. The three beams vary in width and incidence angle to form a 390-km-wide ground swath. The orbit has an exact repeat ground track every seven days, with 390-km track spacing at the equator, ensuring complete global coverage of the swath. Salinity data calibration and validation will be based on available in situ surface measurements by ships, buoys, and Argo floats.
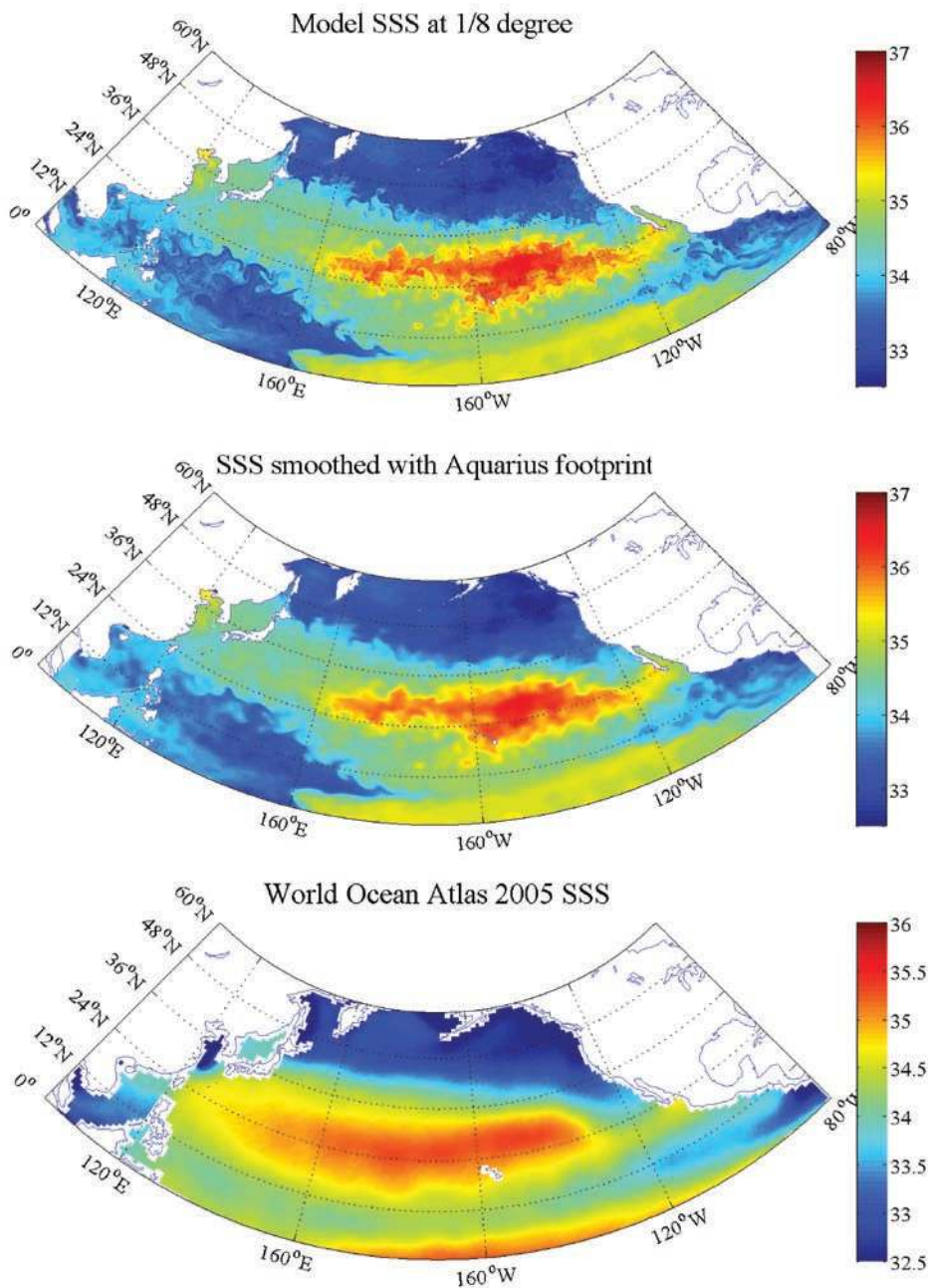
Figure 3. Illustration of the basin-scale spatial resolution provided by the Aquarius footprint dimensions. Top: Snapshot of a 1/8-degree Ocean General Circulation Model sea surface salinity (SSS) field. Middle: The same field with a 150-km Gaussian filter applied to simulate the Aquarius spatial resolution, removing much of the eddy-scale structure while preserving good spatial resolution of basin- and gyre-scale structures. Bottom: Mean annual SSS from World Ocean Atlas 2005.

sensor always viewing away from the sun to avoid solar contamination of the science measurement; (c) an exact seven-day repeat orbit with track spacing equal to the swath width to provide total area coverage and sufficient repeat observations that will to allow errors to be reduced by monthly averages; and (d) combination of a microwave radiometer of unprecedented accuracy and an integrated radar in the primary Aquarius microwave sensor to provide measurement correction for surface roughness caused by wind and waves.

It is important to recognize that the measurements will have relatively low spatial resolution, as emphasized in Lagerloef et al. (1995), and will be most suited for resolving the basin-scale SSS field. Figure 3 shows that this resolution will filter much of the eddy and frontal scales, yet provide much greater detail than can be derived from historical data (World Ocean Atlas 2005, available at http://www.nodc.noaa.gov/OC5/WOA05/pr_woa05.html). Figure 4 illustrates the scale of the footprint and the sampling geometry over the Labrador Sea. The central Labrador basin, which is the key region for deep convection, will be well covered. The SSS retrieval accuracy will degrade significantly as the footprint nears the ocean boundaries due to the much different surface emmisivities of the land and ice surfaces.

The Aquarius Salinity Measurement

Salinity remote sensing is accomplished by measuring microwave emission from the sea surface in terms of 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 modulated by salinity. The frequency 1.413 GHz (L-band) is sufficiently sensitive to salinity to make viable measurements (Klein and Swift, 1977; Swift and McIntosh, 1983) and is legally protected for scientific purposes (radio astronomy and Earth remote sensing) from radio interference. The dielectric model function, commonly known as the "Klein and Swift" was derived more than 30 years ago from rather antiquated seawater dielectric measurements, yet has proven to be quite accurate relative to recent experiments (Wilson et al., 2004). A comprehensive new set of seawater dielectric measurements at 1.413 GHz are now being done to update the model (Lang et al., 2007).

The three Aquarius microwave radiometers will measure microwave brightness temperature in vertical and horizontal polarizations (T_H and T_V, respectively). The radiometers will also measure polarimetric channels to correct for the Faraday rotation of the signal as it passes through the ionosphere (Yueh, 2000). These sensors will be aligned with an offset 2.5-m-aperture antenna reflector to generate the three fixed beams at incidence angles of 28.7°, 37.8°, and 45.6° relative to the ocean surface to form the three distinct footprints aligned across the ~ 390-km swath width (Figure 2). A detailed technical description of the instrument is given by Le Vine et al. (2007). The Aquarius microwave radiometers have 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.
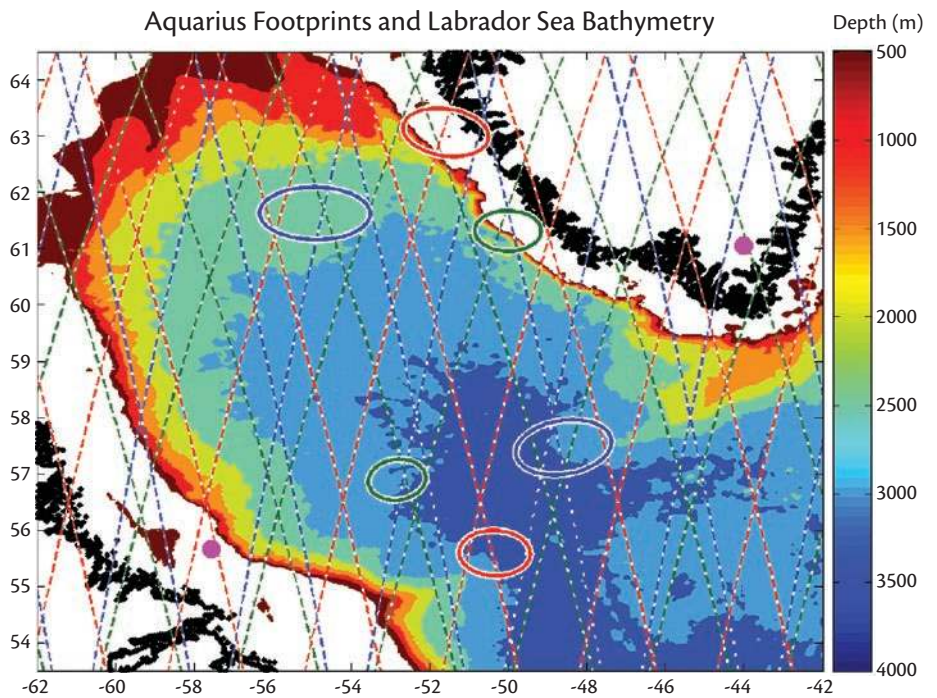

Figure 4. The Aquarius beam pattern superimposed on a bathymetry map of the Labrador Sea. Colors indicate the three Aquarius beams: inner (green), middle (red), and outer (blue). Ascending tracks are oriented southeast to northwest.

Figure 5 illustrates the basic model function showing T_V as a function of SST for constant values of open ocean salinity (32 to 37) and a flat surface (no waves) at the middle incidence angle. The variation is nonlinear with temperature, but the gradient with SSS is quite linear at any given SST. Note that SSS is determined unambiguously from T_V as long as SST is independently known. Aquarius data processing will use the highest quality available SST fields obtained by other satellites (Donlon et al., 2007). The spread between the salinity isolines indicates the measurement sensitivity ($\Delta T_V / \Delta S$). The salient feature is the decline in sensitivity with decreasing SST, reducing the ratio of ocean signal to the measurement noise in the higher latitude seas. This is partly offset

by the increased sample density toward the poles as the ground tracks converge, allowing more samples to be averaged. The net result is an error budget that varies with latitude (Table 2, lower half). The analysis of monthly RMS salinity error by latitude band for all Aquarius samples averaged within 150-km bins yields a global monthly RMS salinity error of 0.2 when the total T_V root sum square (RSS) measurement error for each individual observation is 0.38 K.

This measurement error is based on an individual observation consisting of a ~ 6-second data integration along track, and the allocation includes the various error sources (Table 2) that combine as an RSS. Both the allocation and the current best estimate (CBE) are shown, and the margin is defined as
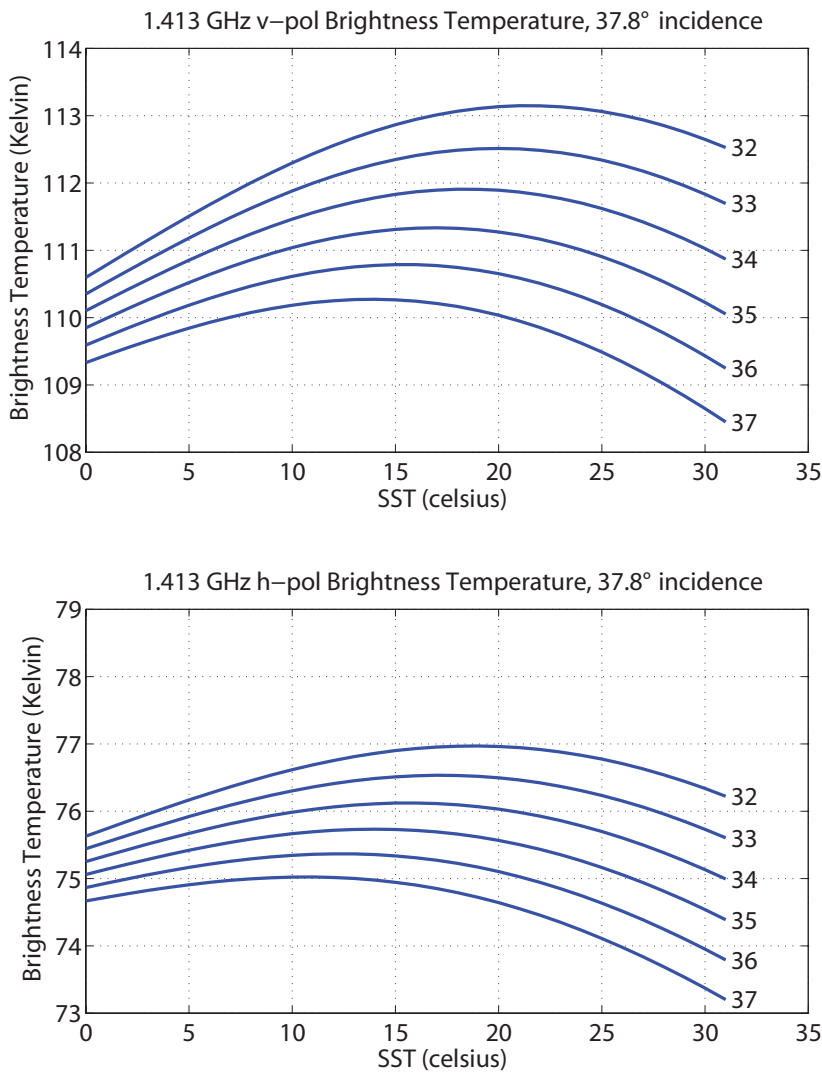
1.413 GHz v–pol Brightness Temperature, 37.8° incidence

1.413 GHz h–pol Brightness Temperature, 37.8° incidence

Figure 5. 1.413 GHz v-polarized brightness temperature (T_v) as a function of sea surface temperature (SST) for constant values of open ocean salinity (32 to 37) and a flat surface (no waves), when viewed at the 37.8° incidence angle (Aquarius middle beam), based on the Klein and Swift (1977) model. The family of curves is very similar for the other incidence angles and polarization, but the ordinate scales are offset.

the additional RSS error that could be added to the CBE without exceeding the allocation. The largest single error source is roughness effects due to wind and waves; therefore, the Aquarius instrument includes an integrated L-band (1.26 GHz) radar scatterometer to measure simultaneous oceanic backscatter in the footprint.[2] The Aquarius roughness error allocation is presently based on limited airborne radiometer and radar combined measurements (Wilson et al., 2001) and is expected to improve with additional airborne data to be collected in late 2008, and once the satellite is on orbit. The remaining geophysical error sources are the estimated uncertainty residuals after the best-known correction models have been applied. The degree of understanding has been the result of a number of rigorous studies of the ionosphere, galactic reflections, the sun, and so forth (Le Vine and Abraham, 2002, 2004; Le Vine et al., 2005).

These tables and RMS estimates are based on the assumption that all the errors are uncorrelated. In nature, however, errors are likely to exhibit long correlation scales, especially among the various geophysical effects, and when there are slow variations in the sensor calibration. The assumptions are tested with an Aquarius science simulator that produces a forward computation of top-of-the-atmosphere brightness temperatures based on ocean model SSS and SST fields; including all the geophysical sources, it also convolves the antenna gain patterns and derives the input to the radiometers. Sensor and

[2] This sensor differs fundamentally from other orbiting scatterometers designed to measure ocean winds in that it does not provide multiple directional views to resolve wind direction.

geophysical error sources are added, and then the inverse calculation is performed to compare with the input SSS field. The difference field shown in Figure 6 simulates one complete seven-day cycle. As expected, based on the model function and Table 2, the smallest errors appear in the tropical and mid latitudes, and the largest in the subpolar regions. The global RMS is about 0.4. However, these simulated statistics apply to individual measurements (every 6 sec) along the swath and will be less than 0.2 when averaged monthly on 150-km scales. One further check is made by analyzing the impact of a long baseline instrument calibration error on a monthly gridded analysis. We also factored in a significantly reduced number of independent samples for the geophysical errors to account for their longer correlation scales. In this analytical calculation, the resultant global RMS error for a monthly gridded salinity analysis is ~ 0.18. Based on all these assessments, we are confident that the Aquarius/SAC-D observatory will do better than the required 0.2 global monthly RMS salinity error.

The error tables and many of the foregoing assessments assume vertical polarization because the radiometric sensitivity to salinity is somewhat greater than for horizontal polarization at off-nadir incidence angles. Nevertheless, horizontally polarized data contain useful information, and the Aquarius baseline algorithm and science simulator utilize both channels in the basic retrieval model (1).

$$S = a_0 + a_1 T_V + a_2 T_H + a_3 W + \dots \quad (1)$$

The coefficients a_0, a_1, a_2, and a_3 are independent functions of SST and the individual beam incidence angle θ. These

Table 2. Aquarius Salinity Retrieval Error Table

Error Sources	3 Beam RMS	
	Allocation	CBE
Radiometer	0.15	0.09
Antenna	0.08	0.01
System Pointing	0.05	0.02
Roughness	0.28	0.20
Solar	0.05	0.02
Galactic	0.05	0.004
Rain (Total Liquid Water)	0.02	0.01
Ionosphere	0.06	0.043
Atmosphere (Other)	0.05	0.02
SST	0.10	0.07
Antenna Gain Near Land & Ice	0.10	0.10
Model Function	0.08	0.07

Brightness Temperature Error Per Observation	Baseline Mission	
	Allocation	CBE
Total RSS (K)	0.38	0.27
Margin RSS (K)	0.27	0.27

Latitude Range	Mean Sensitivity (dT_v/dS)	Mean # Samples in 28 Days	Baseline Mission Monthly Salinity Error (psu)	
			Allocation	CBE
0–10	0.756	10.9	0.15	0.11
11–20	0.731	11.3	0.16	0.11
21–30	0.671	12.1	0.16	0.12
31–40	0.567	13.5	0.18	0.13
41–50	0.455	15.9	0.21	0.15
51–60	0.357	20.3	0.24	0.17
61–70	0.271	30.2	0.26	0.18
Global RMS (psu)			0.20	0.14
Marin RSS (psu)			0.14	0.14

The top portion shows the allocated sensor and geophysical errors (left column) in terms of v-polarized brightness temperature (T_v) in Kelvins (K), and the current best estimate (CBE, right column). The margin is the additional root sum square (RSS) error that could be included before exceeding the allocation. The bottom portion shows the monthly root mean square (RMS) salinity error by latitude band based on the total error allocation of 0.38 K for each data point. These figures include the measurement sensitivity as it varies with sea surface temperature (SST) and the number of samples averaged per latitude band. The global RMS error allocation over the latitude bands is 0.2 (PSS-78) and CBE 0.14 (PSS-78).

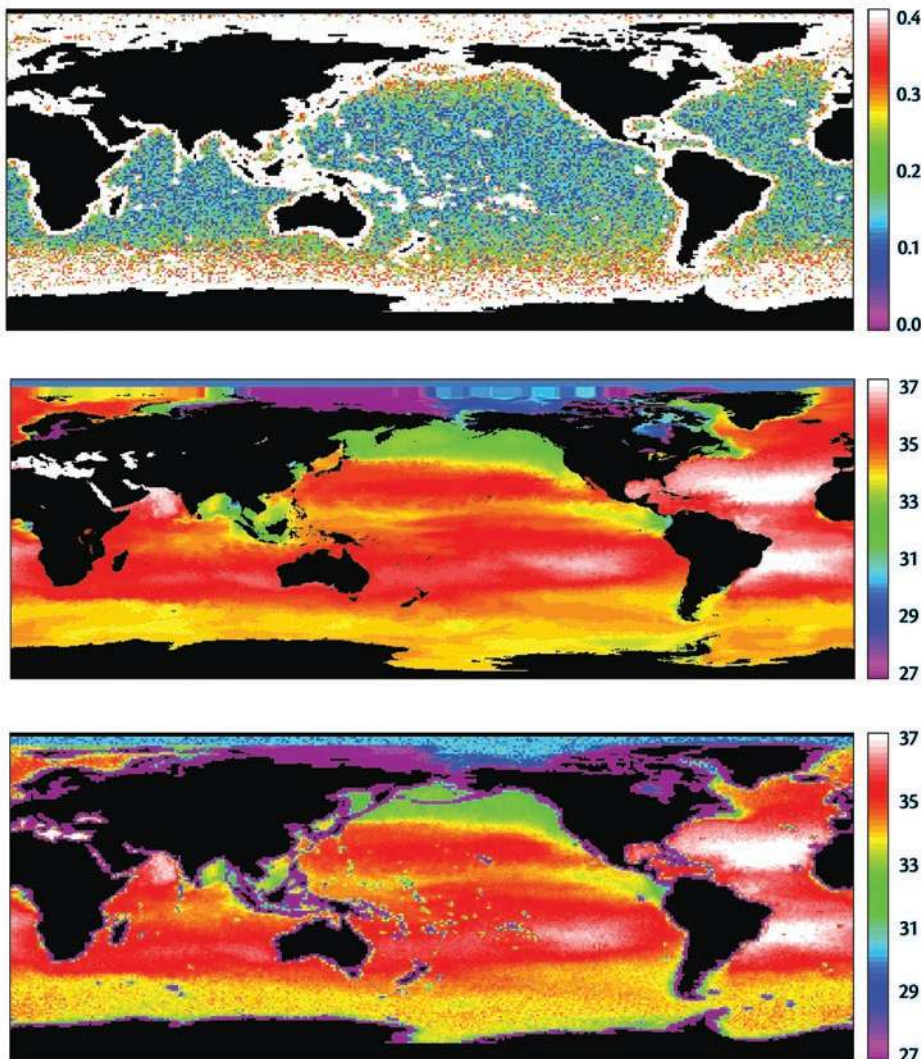## Aquarius Science Algorithm Simulation

Figure 6. Preliminary results of the Aquarius science algorithm simulator over a seven-day orbit cycle, showing root mean square retrieval errors (top) between the reference (middle) and simulated retrieval (bottom). Key assumptions and inputs: solar max conditions, worst-case Faraday rotation, radiometer six-second average sensor noise of 0.08 K, SST input error 0.3°C, wind speed error 1.0 m/s.

coefficients are presently derived by regression analysis with the simulated data and will be tuned with surface calibration during the mission. The sensitivity to wind roughness is less for T_V than for T_H (Camps et al., 2004). This condition allows the possible tuning of coefficients a_1 and a_2 to offset the roughness effect to some degree. W represents an independent wind parameterization that can be input based on the radar scatterometer data or data from an ancillary source such as a numerical analysis. The present simulator uses ancillary wind fields, and the "at launch" processor will do likewise until both the radiometer and radar sensors have been calibrated on-orbit and the correction algorithms tuned accordingly. The model can also be expanded to include nonlinearities and additional ancillary terms such as wave height, rain rate, or wind direction. We intend to publish a comprehensive simulated data set on the Aquarius Web site (http://aquarius.gsfc.nasa.gov) before the end of 2008.

The SAC-D Science Payloads

The Aquarius/SAC-D mission also serves many of Argentina's national goals for satellite Earth observations, and it provides a flight of opportunity for two additional European instruments. The mission is the fourth Satélite Aplicaciones Científicas (SAC) developed by Argentina in partnership with the United States. The SAC-D scientific objectives are to conduct local measurements over Argentina and contribute to global investigations of the atmosphere, the oceans, and the effects of human and natural processes on the environment as defined in the Strategic Plan of the Argentine National Space Program.

Table 3. Aquarius/SAC-D Science Instruments

Instrument	Objective	Description	Resolution	Source
Aquarius	Sea Surface Salinity (SSS)	• 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 Radiometer	Precipitation, wind speed, sea ice concentration, water vapor	• 23.8 GHz and 37 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 occultation	• Horizontal: 300 km • Vertical: 300 km	ASI (Italy)
CARMEN 1 ICARE and SODAD	ICARE: Effect of cosmic radiation on electronics SODAD: Distribution of micro-particles 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)

In addition to the NASA Aquarius instrument, the observatory will include five other scientific instruments and a data-relay system (Table 3). The CONAE Microwave Radiometer (MWR) will make complementary measurements of rain, wind, and sea ice with 23.8 and 36.5 GHz channels in an overlapping swath pattern (Figure 7). The MWR data will be used by the Aquarius data processor for rain and sea-ice flags, and as supplementary rain and surface wind-speed correction algorithms. The New InfraRed Scanner Technology (NIRST) camera is a narrow swath imager intended to detect forest fires and other thermal events on land. It can be tilted to observe preferred targets, and on occasion will be used to map SST within one Aquarius footprint. A High Sensitivity Camera (HSC) is designed to make nighttime images of urban lighting and fires, as well as aurora events. The data collection system (DCS) relays scientific data from autonomous ground stations (similar to Argos). Also included among the instruments on SAC-D is a GPS atmospheric occultation experiment called ROSA, for measuring atmospheric temperature and humidity profiles, which will be provided by the Italian Space Agency (ASI) and the ICARE/ SODAD instrument, called CARMEN1, provided by the French Centre National d'Études Spatiales (CNES) to measure the radiation and microparticle environment in space.

Data Processing, Distribution, and Science Education

NASA and CONAE will share the data processing and distribution activity. CONAE will manage the telemetry from the satellite and data processing and distribution from the SAC-D instruments. The raw Aquarius data will be transmitted to the NASA Goddard Space Flight Center in Greenbelt, Maryland,
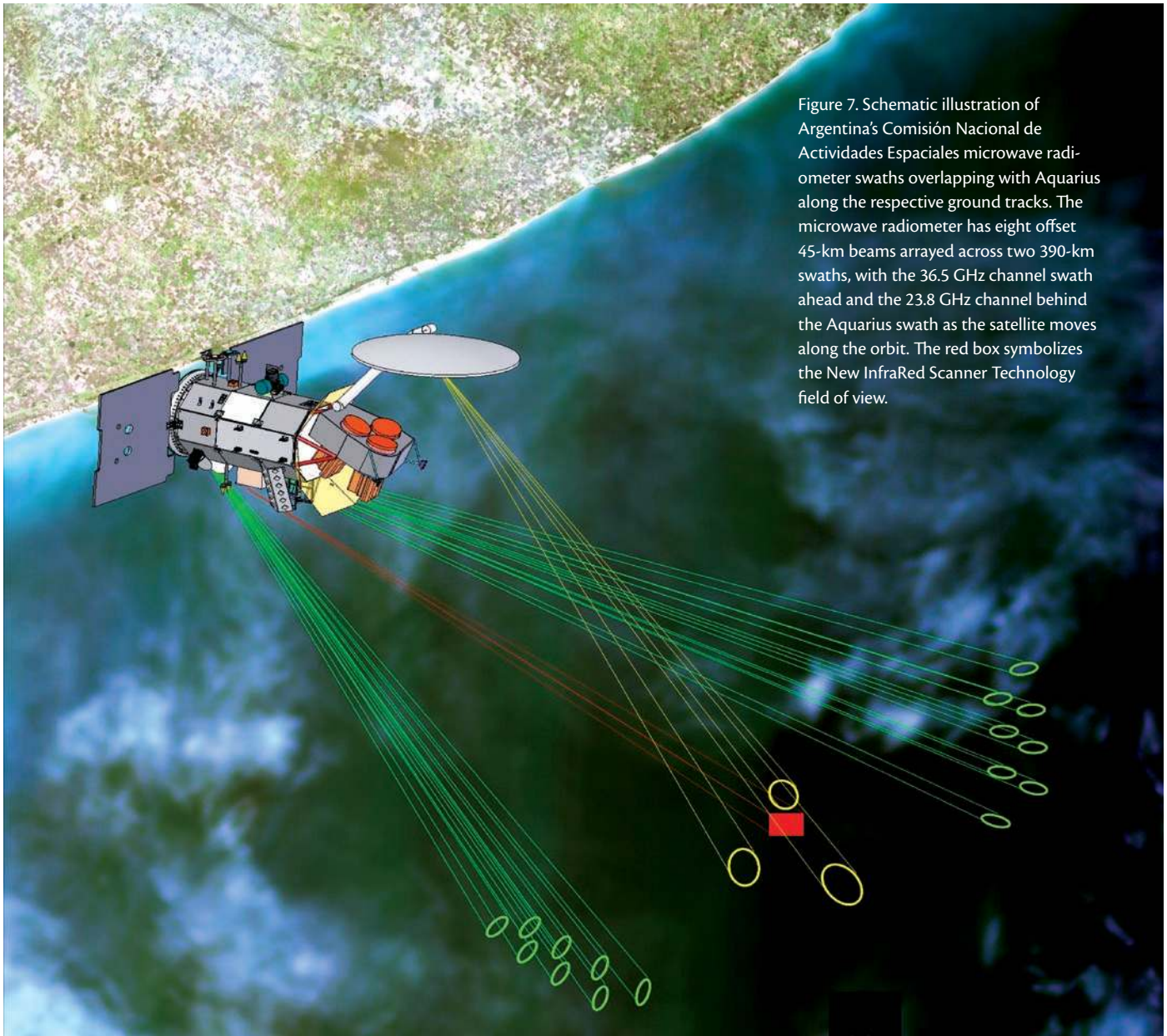
Figure 7. Schematic illustration of Argentina's Comisión Nacional de Actividades Espaciales microwave radiometer swaths overlapping with Aquarius along the respective ground tracks. The microwave radiometer has eight offset 45-km beams arrayed across two 390-km swaths, with the 36.5 GHz channel swath ahead and the 23.8 GHz channel behind the Aquarius swath as the satellite moves along the orbit. The red box symbolizes the New InfraRed Scanner Technology field of view.

where the Aquarius data processing system (ADPS) will generate salinity products and provide access for the science community. The eventual Aquarius data archive will be with NASA's Physical Oceanography Distributed Active Archive Center (PO-DAAC) at the Jet Propulsion Laboratory. The Aquarius validation data system (AVDS) is being developed to accumulate and format in situ SSS and SST data from a variety of platforms such as Argo floats, volunteer observing ships, research ships, moored buoys, and drifting buoys. This consolidated AVDS data set will be tailored to calibrate and validate the Aquarius data, and will also be available to the science community as an independent resource.

Aquarius will collect data continuously over all ocean, land, and ice surfaces in its field of view. The ADPS, and eventually PO-DAAC, will retain all lower-level data for use by researchers in other disciplines. Preliminary plans are also developing for the ADPS to process a land soil moisture data set with algorithms provided by a separate working group.

The Aquarius/SAC-D program maintains an innovative education and public outreach effort. This activity is highly integrated and complementary to the NASA and CONAE scientific goals; its 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 whole. The effort is designed to bridge the gap between what people know and what they can learn about our oceans. A key goal is to develop innovative Web-based tools that can be directly integrated into classroom settings (http://aquarius.gsfc.nasa.gov/education.php). ✉

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