Aquarius: An Instrument to Monitor Sea Surface Salinity From Space

David M. Le Vine, *Fellow, IEEE*, Gary S. E. Lagerloef, Fernando Raúl Colomb,
Simon H. Yueh, *Senior Member, IEEE*, and Fernando A. Pellerano, *Senior Member, IEEE*

***Abstract*—Aquarius is a combined passive/active L-band microwave instrument that is being developed to map the salinity field at the surface of the ocean from space. The data will support studies of the coupling between ocean circulation, global water cycle, and climate. Aquarius is part of the Aquarius/Satelite de Aplicaciones Cientificas-D mission, which is a partnership between the U.S. (National Aeronautics and Space Administration) and Argentina (Comisión Nacional de Actividades Espaciales). The primary science objective of this mission is to monitor the seasonal and interannual variation of the large-scale features of the surface salinity field in the open ocean with a spatial resolution of 150 km and a retrieval accuracy of 0.2 psu globally on a monthly basis.**

***Index Terms*—Microwave radiometry, microwave remote sensing, ocean salinity, scatterometer.**

I. Introduction

AQUARIUS is a combined active/passive L-band microwave instrument that is designed to map the surface salinity field of the oceans from space. It will be flown on the Aquarius/Satelite de Aplicaciones Cientificas (SAC)-D mission, which is a partnership between the U.S. Space Agency [National Aeronautics and Space Administration (NASA)] and the Argentine Space Agency [Comisión Nacional de Actividades Espaciales (CONAE)]. The mission is composed of two parts: 1) Aquarius, a radiometer/scatterometer instrument combination for measuring sea surface salinity (SSS), which is being developed by NASA as part of the Earth System Science Pathfinder program, and 2) SAC-D, which is the fourth spacecraft service platform in the CONAE SAC program and includes several additional instruments. The primary focus of the mission is to monitor the seasonal and interannual variations of the salinity field in the open ocean. The mission also meets the needs of the Argentine space program for monitoring the environment and for hazard detection. The objective of this paper is to give an overview of the mission and a description of the Aquarius instrument package. For information on a related L-band passive microwave satellite instrument, the reader is referred to the Soil Moisture and Ocean Salinity (SMOS) mission that is being developed by the European Space Agency [1], [2].

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D. M. Le Vine and F. A. Pellerano are with the NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA (e-mail: david.m.levine@nasa.gov).

G. S. E. Lagerloef is with Earth and Space Research, Seattle, WA 98102 USA.

F. R. Colomb is with the Comisión Nacional de Actividades Espaciales, 1063 Buenos Aires, Argentina.

S. H. Yueh is with the Jet Propulsion Laboratory, Pasadena, CA 91109 USA.

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II. Salinity Science Objectives

A. Aquarius Science Objectives

The primary objective of the Aquarius instrument development is to provide information on the interactions between the water cycle (marine rainfall and evaporation, melting and freezing of ice, and river runoff), the ocean circulation, and the climate. This requires monitoring the seasonal and interannual variation of the large-scale features of the SSS field in the open ocean with an accuracy of 0.2 psu (practical salinity scale [3]) or less. For example, salinity modulates the large-scale thermohaline circulation, driven by buoyancy, which moves large masses of water and heat around the globe and maintains the present climate. Of the two variables that determine buoyancy (salinity and temperature), temperature is already being monitored (e.g., [4]). The salinity field is the missing variable needed to understand this circulation.

Salinity also plays an important role in energy exchange between the ocean and atmosphere. In addition to the thermohaline circulation, in areas of strong precipitation, fresh water "lenses" can form on the surface [5]. These are buoyant layers of water that form stable layers and insulate the water in the mixed layer below from the atmosphere [6]. This alters the air–sea coupling (energy exchange) and can affect the evolution of tropical intraseasonal oscillations, monsoons, and the El Nino-Southern Oscillation (ENSO). Ocean–atmosphere water fluxes dominate the global hydrologic cycle, accounting for 86% of global evaporation and 78% of global precipitation [7]. Changes in surface salinity reflect changes in surface freshwater forcing. Systematic mapping of the global salinity field will help to reduce the wide uncertainties in the marine freshwater budget [8] and better understand the global water cycle and how it is changing.

The time and spatial scales of observations needed to improve understanding of these processes are relatively long but the salinity changes are relatively small (tenths of a psu) compared, for example, to processes in the coastal ocean. The goal for the Aquarius instrument is to provide global maps of the SSS field in the open ocean on a monthly basis with an average accuracy of 0.2 psu and at a spatial resolution of 150 km. In

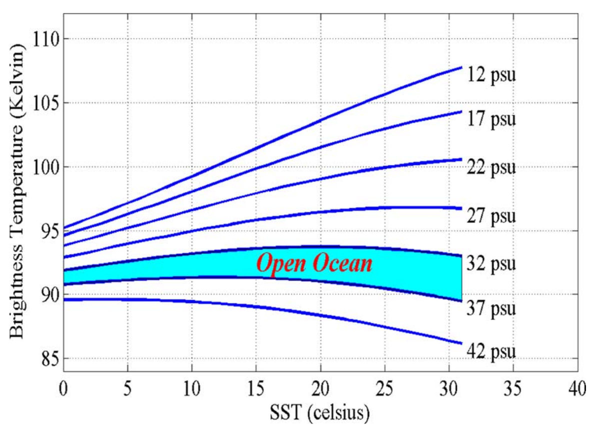

Fig. 1. Level curves of constant salinity as function of (abscissa) SST and (ordinate) microwave brightness temperature for L-band (1.4 GHz) and normal incidence.

comparison, the existing database is too sparse in both time and space to resolve key processes. For example, dividing the ice-free ocean into one-degree squares in latitude and longitude, one finds that about 25% has never been sampled and more than 73% has fewer than ten samples [9], [10]. The sparse data are primarily a reflection of the limitations of *in situ* sampling. Aquarius will record more SSS observations in two months than have been measured since such observations began about 125 years ago.

B. *Remote Sensing Heritage*

Research in the 1970s at the NASA's Langley Research Center [11] and later at the Goddard Space Flight Center (GSFC) [12] demonstrated that SSS can be measured remotely with a passive microwave sensor. Salinity modulates the thermal emission from seawater at a level that is measurable when observed at the long wavelength end of the microwave spectrum. This is illustrated in Fig. 1, which shows the observable parameter (brightness temperature T_B) as a function of water temperature for constant values of salinity. These curves are for an ideal surface (no waves) when looking perpendicular to the surface (nadir) and were computed using the model developed by Klein and Swift [13] for the dielectric constant of seawater at L-band. In the remote sensing approach adopted for Aquarius, the sensor measures T_B (vertical axis) and sea surface temperature (SST) is obtained from an ancillary source (e.g., maps derived from satellite sensors).

The range of salinity and temperature to be encountered in the open ocean is indicated by the shaded area in Fig. 1. The associated change in brightness temperature is small but measurable with modern radiometers. The window at 1.413 GHz (L-band) set aside for passive use only, where Aquarius will operate, is an optimum choice for remote sensing of salinity and is very near the peak in sensitivity of brightness temperature T_B to changes in salinity. On the other hand, when actually making the remote sensing measurement from space, there are a number of complicating issues that must be taken into account. For example, surface roughness (e.g., waves) can also cause changes in the observed brightness temperature with an order of magnitude comparable to the salinity signature [14]. Aquarius includes a scatterometer to help correct for this effect. The scatterometer (backscatter) responds directly to surface roughness, and in the design of Aquarius, the radiometer and scatterometer operate at nearly the same frequency and will share the same antenna feed and look at the same pixel with approximately the same footprint. The approach is based on experiments at the Jet Propulsion Laboratory (JPL) with the passive/active L-band instrument PALS [15], [16]. Another issue to be taken into account is Faraday rotation (rotation of the polarization vectors as the radiation propagates from the surface through the ionosphere) which can be significant at L-band [17]. The inversion from brightness temperature to salinity depends (except at nadir) on polarization. To help correct for this potential source of error, the radiometer in Aquarius will include a polarimetric channel and will use the measured third Stokes parameter and an algorithm suggested by Yueh [18] to retrieve the angle of polarization rotation. Finally, the sun is a significant source of radiation at L-band [19] and to avoid reflection from the ocean surface into the main beam of the antenna, the mission will be in a sun-synchronous orbit near the day–night terminator (i.e., 6 A.M./6 P.M. equatorial crossing) with the antenna beams pointing toward the nighttime side of the orbit. A review of the issues associated with remote sensing of SSS from space has been given in [20].

V. Summary

Aquarius is a combined passive/active L-band microwave instrument that will be flown as part of the Aquarius/SAC-D mission to map the surface salinity field of the oceans from space. The goal is to monitor the seasonal and interannual variation of the large-scale features of the surface salinity field in the open ocean with a spatial resolution of 150 km and a retrieval accuracy of 0.2 psu globally on a monthly basis. Salinity is the missing variable needed to understand the thermohaline circulation of the oceans, and the data provided by Aquarius will permit expanded understanding of the coupling between ocean circulation, the global water cycle, and climate. The impact of Aquarius will be dramatic: Aquarius will record more SSS observations in two months than have been measured since such observations began about 125 years ago.