Ocean Surface Salinity from Space: Early Results from the Aquarius/SAC-D Mission

Eric Lindstrom
Program Scientist, NASA Headquarters

With thanks to: Gary Lagerloef & Thomas Meissner

Oceanology International
15 March 2012
United States – Argentina and other agencies

- Aquarius Salinity Microwave Instrument (Instrument Ops + Science Data Processing)
- Launch Vehicle
- Service Platform and SAC-D Science Instruments
- Mission Operations & Ground System

International Partnership

United States – Argentina and other agencies
OUTLINE

• Origins of Aquarius and where we are today (with qualifications)
• Why measure surface salinity?
• Mission design
• How do you measure salinity from space?
• A detailed (initial) look at salinity in a couple of locations
• A salinity process study in the North Atlantic in 2012-13
• Access to the Aquarius data
Aquarius will map the salinity—with an accuracy of 0.2 practical salinity unit (psu) from 657-km above the ocean surface.

0.2 psu: add a pinch of salt to a Gallon of water.
New technology enables NASA’s first salinity mission - Path to Aquarius Mission
Aquarius Salinity Data

Composite Mean of the Initial 5.5 months

Aquarius/SAC-D Launch: 10 June 2011
Aquarius data record start: 25 August 2011
Island and coastal halos

Streaks: Ascending-descending biases and other issues

Noisy Southern Ocean data due to high wind and low SST

Version 1.2 data
Aquarius Mission Science

Understanding the Interactions Between the Ocean Circulation, Global Water Cycle and Climate by Measuring Sea Surface Salinity

Equation of State for Sea Water

\[ r_{sw}(S,T) = r_{fw}(T) + b(T)S + c(T)S^{3/2} + dS^2 \]

Global salinity patterns are linked to rainfall and evaporation.

Salinity affects seawater density, which in turn governs ocean circulation and climate.

The higher salinity of the Atlantic sustains the oceanic deep overturning circulation.

Salinity variations are driven by precipitation, evaporation, runoff and ice freezing and melting.
Early Results from Aquarius/SAC-D:

SSS

Change in SSS

Evaporation - Precipitation

Lindstrom - Early Results frc
Mission Design and Measurement Approach

- Global Coverage in 7 Days
- 4 Repeat Cycles per Month

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

Beams point toward the night side to avoid sun glint

Science Data Validation

More than 300 surface validation observations per day

Salinity Data
150km, Monthly, 0.2 (psu)
Microwave radiometers measure the emitted power of a surface in terms of a parameter called the radiometric brightness temperature \( T_B \), which is proportional to the ideal black body radiation.

\[ T_B = eT, \text{ where } e \sim 0.3 \text{ for seawater} \]

\( T_B \) is the product of emissivity \( (e) \) and absolute surface temperature \( (T) \) in Kelvins.

\[ e \text{ is a function of, incidence angle } \theta, \text{ polarization H or V, sea state and the dielectric coefficient } \varepsilon. \]

\( \varepsilon \) depends on \( S, T, \) and radio frequency \( (f) \):

\[ \varepsilon = \varepsilon_\infty + \frac{\varepsilon_s(S,T) - \varepsilon_\infty}{1 + i2\pi f \tau(S,T)} \cdot \frac{iC(S,T)}{2\pi f \varepsilon_0} \]

Klein & Swift (1977) – The Basics

**Salinity is Derived by Measuring Brightness Temperature at L-Band (1.413 GHz)**

1.41 GHz Brightness Temperature vs T, S at 0° incidence angle

- Klein & Swift (1977) dielectric model at microwave frequencies
- Sensitivity increases with SST

Open Ocean

G.Lagerloef, ESR
Challenge:
Many Other Signals Must be Removed

Aquarius

Sun

Ionosphere
Atmosphere
Land

Solar Reflection
Solar Backscatter
Quasi Specular

Galaxy & Cosmic
Moon

Ocean Surface
L2 Salinity Retrieval Algorithm

Aquarius Radiometer Counts
   Earth + Calibration View

Radiometer Calibration Algorithm

Total Antenna Temperature

Remove Space Contributions: Galaxy, Sun, Moon, CS

Earth Antenna Temperature

Remove the Antenna Pattern Effect

Earth Brightness Temperature

Correct for Faraday Rotation

Top of the Atmosphere Brightness Temperature

Remove Atmospheric Contribution

Sea-Surface Brightness Temperature

Remove Surface Roughness Effects

Specular Brightness Temperature

Find Salinity for which emissivity of Meissner-Wentz dielectric model matches specular TB (v-pol only for now)

Salinity
Correction for Reflected Galactic Radiation

Rough surface: 4-dimensional integration over tilted facets and antenna pattern

Green arrows from Galaxy to Ocean: Red arrows from Ocean to Aquarius
Detail in the E. Pacific ITCZ Region

To Appear in Brief Reports, EOS 2012
Aquarius SSS 7-day smoothed map

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
Aquarius SSS 7-day smoothed map EP ITCZ

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
Aquarius SSS 7-day smoothed map **EP ITCZ**

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
Aquarius SSS 7-day smoothed map EP ITCZ

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
Aquarius SSS 7-day smoothed map **EP ITCZ**

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
Aquarius SSS 7-day smoothed map

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree

09 / 26
Aquarius SSS 7-day smoothed map **EP ITCZ**

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
Aquarius SSS 7-day smoothed map **EP ITCZ**

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree

10 / 06

![Aquarius SSS 7-day smoothed map](image-url)
Aquarius SSS 7-day smoothed map EP ITCZ

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
Aquarius SSS 7-day smoothed map EP ITCZ

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
Aquarius SSS 7-day smoothed map EP ITCZ

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
Aquarius SSS 7-day smoothed map EP ITCZ

- Land contamination (0.05)
- Salinity Resolution 1/3 degree * 1/3 degree
- Currents Resolution 2/3 degree * 2/3 degree
East Equatorial Pacific Freshening
Late Dec 2011 – Early Feb 2012

Lindstrom - Early Results from Aquarius/SAC-D

27 Dec 2011

04 Jan 2012

11 Jan 2012

18 Jan 2012

25 Jan 2012

01 Feb 2012
Aquarius SSS 7-day smoothed map Amazon Plume

- Land contamination (0.05)
- Resolution 1/3 degree * 1/3 degree
What is controlling the upper ocean salinity?

\[
\frac{\partial \langle S \rangle}{\partial t} = -h \langle \vec{u} \rangle \cdot \nabla \langle S \rangle - \nabla \cdot \int_{-h}^{0} \hat{u} \hat{S} \, dz - \left( \langle S \rangle - S_{-h} \right) \left( \frac{\partial h}{\partial t} + \vec{u}_{-h} \cdot \nabla h + w_{-h} \right) + (E - P) S_0 + SSM
\]

(a) The salt storage
(b) The advection by the vertically averaged flow
(c) The advection by the vertically sheared flow
(d) Entrainment/detraiment & subduction/obduction at the base of the layer
(e) Surface forcing from evaporation (E) and precipitation (P)
(f) Mixing by small scale turbulence (internal gravity waves, microstructure, etc) at the base of the layer
SPURS 2012 Field Campaign

Science Question: What is controlling the upper ocean salinity?
This question is addressed with measurements from satellites, ships, drifting surface buoys & profiling floats, gliders, AUVs and theoretical & numerical model simulations.

Motivation
The launch of the Aquarius/SAC-D satellite motivates plans for a field campaign in the salinity maximum region of the North Atlantic.

Planning
- Community workshop in December 2009
- Interagency/international collaborations established
- Investigations funded
- Field program set for Aug 2012-Oct 2013
Cruise Planning: ports and destinations
Salinity Processes in the Upper Ocean Regional Study (SPURS)
Sea Surface Salinity as simulated by ocean models

Zoom-in from 9-km resolution to 3-km and 1-km

- **Before field phase**, to perform simulations to optimize deployment design
- **During field phase**, to issue routine forecast to enable decision making
- **After field phase**, to diagnose dynamical processes (b-f) influencing salinity (a) as in equation:

\[
h \frac{\partial \langle S \rangle}{\partial t} = h \langle \vec{u} \rangle \cdot \nabla \langle S \rangle - \nabla \cdot \int_{-h}^{0} \hat{u} \hat{S} dz - \left( \langle S \rangle - S_{-h} \right) \left( \frac{\partial h}{\partial t} + \hat{u}_{-h} \cdot \nabla h + w_{-h} \right) + \left( E - P \right) S_0 + SSM
\]
How to Exploit the Temporal and Spatial Sampling of Sea Surface Salinity From Aquarius
William Large and Frank Bryan (NCAR)

Objectives

• Develop alternative strategies for estimating upper ocean salinity budgets.
• Utilize simulated salinity distributions from high resolution models to test the accuracy requirements and relative merits of these alternative approaches.
• Test the compatibility of precipitation data sets with observed salinity variability within the context of these budgets.
**Motivation and significance:**
Variations in ocean salinity are caused by ocean currents and evaporation and precipitation at the sea surface, but a lack of data hinders scientific understanding of the detailed physical processes. Aquarius, SPURS, and this project will improve our understanding.

**Project Objectives:**
1. Collect accurate and detailed measurements of sea-surface evaporation and precipitation over a full year.
2. Collect measurements of the vertical profiles of ocean salinity and currents.
3. Use the data from SPURS and Aquarius to understand the detailed physical processes that control the distribution and change of ocean salinity.
Approximately 50 UW profiling floats will be deployed in the greater SPURS region of the N. Atlantic. All will measure wind speed, rainfall, and near-surface $T$ and $S$, with the goal of augmentation the Aquarius satellite observations and comparing to model results. Surfacing times will be optimized in space-time to be colocated with Aquarius orbit passes.
Objective: To directly measure the detailed structure of upper-ocean salinity, its temporal evolution, and its relationship to larger-scale atmospheric and oceanic forcing.

Methods: Multiscale nested surveys using a family of autonomous vehicles emphasizing the historically undersampled horizontal salinity scales of a few meters to a few kilometers.

(a) Propeller-driven AUVs (minimal endurance, very high resolution)  
(b) Underwater gliders (moderate endurance)  
(c) Environmentally-propelled Wave Gliders (extreme endurance)

Significance: This project will define the character of the upper-ocean salinity field at the limits of our present in-situ observational capabilities and provide direct measurement of time-dependent horizontal gradient terms to aid closure of local and regional hydrological budgets.
High-resolution near-surface turbulence measurements using Lagrangian floats

Synchronous high resolution salinity profiles with Aquarius satellite
Measure boundary layer structure, turbulence and fluxes
Estimate daily, monthly and annual salt budgets
Model boundary layer physics

2 floats, 1 year
Spatial and Temporal Characteristics of Sea Surface Salinity fluctuations and links to the Marine Hydrological Cycle.

PI: Arnold L. Gordon  Co-PI: Claudia F. Giulivi
Lamont-Doherty Earth Observatory of Columbia University, Palisades NY

“I think we are in for surprises as Aquarius reveals the spatial and temporal aspects of SSS on a near global scale that we have never seen before.”

SSS (color field), Sea height (white contours), Ekman transport (arrows)

SSS and SST, April-May 2004 (RAPIDMOC cruises)

Right: Note sudden drops in SSS and SST, where do these come from? Aquarius (red dots) will detect these in the SSS as satellite presently do in the SST field and provide information on their role to the larger scale hydrological cycle and ocean dynamics.

SSS = Sea Surface Salinity along Rapid line
SST = Sea Surface Temperature along Rapid line, ship and satellite SST data

SSS, >50 year composite

SST, 20-22 May 2011
Level 2 Data Access

http://aquarius.nasa.gov/

Aquarius is a focused effort to measure Sea Surface Salinity and will provide the global view of salinity variability needed for climate studies. The mission is a collaboration between NASA and the Space Agency of Argentina (Comisión Nacional de Actividades Espaciales). More >>
Version 1.x data policy

- Level 2 data are available for community evaluation
- Data are not fully validated.
- Frequent algorithm updates and reprocessing will occur
- Comments and feedback are welcome

Thank you!

Version 1.2 data

Aug. 28 – Nov. 10, 2011