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SEA SURFACE SALINITY: RESEARCH CHALLENGES AND OPPORTUNITIES

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Abstract

Sea surface salinity (SSS) can be important in regulating sea surface temperature (SST). Two technological breakthrough satellite SSS missions, Aquarius and Soil Moisture and Ocean Salinity (SMOS), are currently producing high-quality SSS data. This paper provides an overview of the importance of SSS for weather and climate applications and describes the Aquarius and SMOS missions. The newness of adequately sampled SSS data prompted a first-time at-sea field campaign devoted to improved understanding of SSS variations.

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1 INTRODUCTION

Salinity throughout the global ocean has a relatively small range from 32 – 38 practical salinity units (psu) or parts per thousand (ppt), except in a relatively few small areas like Shark Bay, Australia, near the mouths of major rivers, Bay of Bengal, and in the eastern Mediterranean Sea. Salinity represents the weight of salt in a kilogram of seawater, and is a dimensionless unit. Salinity has a large impact on ocean circulation and can be a driver of SST variability, which influences atmospheric circulation.

Salinity influences ocean circulation through vertical motion caused by unstable density stratification and through geostrophic motion caused by horizontal gradients of density. In some regions, SSS can be important in regulating SST. Shallow salinity stratified layers can form under heavy rainfall conditions, and these thin surface layers can warm and cool more rapidly from surface heat fluxes. Both SSS and SST are adjusted by wind-generated mixing of the upper ocean depending on upper-ocean salinity stratification.

The north-south distributions of SSS and SST are vastly different through the central Atlantic and Pacific and South Indian oceans. Throughout these areas, SST decreases monotonically from the equatorial zone to high latitudes but the SSS has maximum values around 30-degrees latitude (Figure 1). Over the global ocean, solar forcing produces the SST distribution and atmospheric processes of evaporation (E) and precipitation (P) cause the SSS distribution, excluding some relatively small regions where riverine water has a substantial impact.

The E – P difference over the global ocean modifies SSS. Thus, SSS is a strong proxy for the global water cycle. Over the past 50 years, SSS increased in regions with high SSS and decreased in regions with low SSS (Durack et al., 2012) and the pattern was qualitatively consistent with E – P if ocean mixing and circulation are neglected. Satellite SSS data will reduce the error produced by the under sampling in the in-situ SSS dataset, reduce uncertainties in the marine freshwater cycle and contribute to improving global climate models (Lagerloef et al., 2010).

2 SSS MEASUREMENTS

Salinity measurements are recorded from ships, which are located along a small number of shipping lanes; moored buoys, whose number is less than 1% of ships; and about 3,500 Argo subsurface floats located throughout the global ocean, in which each float rises to the surface at non-simultaneous 10-day intervals. Aquarius and SMOS provided the breakthrough measurement of SSS over the global ocean; in 1 week each satellite maps the entire open ocean at much higher spatial resolution than can be obtained from the in situ array.

Two proof-of-concept satellite missions are currently recording SSS – both missions represent first-time technological achievements (Lagerloef and Font, 2010). The missions have different engineering approaches. The European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) uses a synthetic thinned array radiometer. The United States (US) National Aeronautics and Space Administration (NASA) Aquarius mission uses a large-size 3-beam push-broom real aperture antenna. SMOS uses the European Centre for Medium-range Weather Forecasts (ECMWF) operational numerical weather prediction surface wind data product and Aquarius has a companion scatterometer sensor that measures radar backscatter data to correct the effects of surface roughness. Both missions successfully captured SSS features of the global ocean (Figure 1), such as lower values in the Intertropical Convergence Zone and near the mouths of major rivers like the Mississippi and Amazon and higher values in the central regions of mid-latitude oceans that coincide with the descending limb of the Hadley circulation.

The SMOS mission was launched on 2 November 2009 and measured open ocean SSS with an average accuracy of 0.3-0.5 psu over 10 days and 100 km by 100 km (Boutin et al. 2012). Work continues to reach the goal of 0.1-0.2 psu averaged for 10-30 days over a 100- to 200-km grid (Font et al., 2010).

The Aquarius instrument was launched on 10 June 2011 on the fourth (or “D”) Argentine Satelite de Aplicicaciones Cientificas (SAC-D) mission. The Aquarius/SAC-D mission is working towards a 0.2 psu average root-mean-square accuracy for a 30-day average over an open ocean area of 150 km by 150 km (Lagerloef et al., 2012).

Aquarius and SMOS instruments have a similar goal of measuring SSS with an accuracy of 0.2 psu. A SSS increase of 0.2 psu and a decrease of 1 °C in SST would each increase seawater density by roughly the same amount. Aquarius and SMOS instruments represent the start of a new age of SSS observations, which, similar to the satellite SST observing system with its extensive network of drifters measuring SST, should include an in-situ network for validation and integration of SSS data products. A new research challenge is integration of in-situ and satellite SSS data and the penetration of this information into the subsurface using models and other methods.

Both Aquarius and SMOS instruments are challenged to yield reliable data within about 200 km of the coast and sea ice. Also, both datasets are not yet dependable for wind speeds greater than 15 m s^{-1} (Boutin et al., 2012; Lagerloef et al., 2012) and for SST less than 5 °C (Lagerloef et al., 2012). The generation of improved SSS data is an on-going activity.

3 SPURS

Developing a quality-controlled SSS dataset is a daunting challenge because of very limited in-situ SSS measurements and relatively poor knowledge of ocean-atmosphere processes that influence the dynamics of SSS. Both features are considerably better for SST. A worldwide network of free-drifting surface buoys regularly transmits SST on the Global Telecommunications System for open and transparent acquisition. The ocean and atmosphere processes causing SST variability have been studied over a long period, beginning with the Barbados Oceanographic and Meteorological Experiment (BOMEX) in 1969 and through many follow-on projects (Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE) in 1974, First Global GARP Experiment (FGGE) in 1979, Tropical Ocean Global Atmosphere (TOGA) TOGA – Coupled Ocean Atmosphere Response Experiment (COARE) in 1992-93, etc.). No such sequence of field campaigns occurred for understanding the dynamics of SSS, primarily because of immature technology, until 2012.

NASA Headquarters and the Aquarius mission, in partnership with US agencies and international institutions (including the SMOS mission), organized the Salinity Processes in the Upper Ocean Regional Study (SPURS) field campaign in the central North Atlantic Ocean to acquire measurements to improve the calibration of SMOS and Aquarius SSS data. SPURS occurs in a high SSS region where SSS is above 37.5 psu at 25°N, 38°W, the SPURS centre of action. This open ocean region has larger SSS values than in the oceanographically similar region in the North Pacific (Figure 1). High SSS values in the North Atlantic Ocean are produced by excessive evaporation and little rainfall; also, upward diffusion from intermediate depths of high-saline Mediterranean outflow water adds to the SSS. Another equally important objective is to quantify the relative importance of different processes that produce the observed SSS variations, e.g., E – P, upper-ocean horizontal and vertical advections, and turbulent mixing caused by wind generation and horizontal shear produced by transient eddies. In the SPURS first intensive observing phase, the French Research Vessel (RV) *Thalassa* (15 August – 14 September 2012) and the US RV *Knorr* (6 September – 9 October 2012) recorded a variety of measurements and deployed moorings, gliders and other equipment (http://podaac.jpl.nasa.gov/OceanEvents/SPURS_SalinityProcessesWaterCycle_Sept2012); some equipment will remain on site until their recovery in 1 year.

4 CONCLUSION

The Aquarius and SMOS SSS datasets are a work in progress, and early results suggest that the ambitious measurement goals will be achieved.

Every new oceanographic dataset presents research challenges to make the data as accurate as possible and, in the case of a measurement at the sea surface, research opportunities exist to utilize the new data to improve understanding of ocean-atmosphere interactions.

The 2012 SPURS experiment in a high SSS area is a unique effort to gain knowledge about processes that control SSS. Three SPURS cruises are scheduled in 2013. A possible follow-on field campaign in a salinity minimum region of the open ocean is envisaged as a potential future activity for the SPURS project.

Salinity has long been known to be a wonderful tracer of oceanic motions, such as in the western and central equatorial Pacific where in-situ SSS measurements are regularly recorded (Singh et al., 2011). Aquarius data have already been critical to fill a knowledge gap in the sparse SSS sampling in the eastern equatorial Pacific (Lee et al., 2012). Aquarius and SMOS data have the potential to improve El Nino/La Nina forecasts (Ballabrera-Poy et al., 2002). A plethora of innovative science results based on Aquarius and SMOS datasets are in preparation.

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Acronyms

BOMEX	Barbados Oceanographic and Meteorological Experiment
COARE	Coupled Ocean Atmosphere Response Experiment
E	Evaporation
ECMWF	European Centre for Medium-range Weather Forecasts
ESA	European Space Agency
FGGE	First GARP Global Experiment
GATE	GARP Atlantic Tropical Experiment
NASA	National Aeronautics and Space Administration
P	Precipitation
SAC-D	Satelite de Aplicicaciones Cientificas
SMOS	Soil Moisture and Ocean Salinity
SPURS	Salinity Processes in the Upper Ocean Regional Study
SSS	Sea surface salinity
SST	Sea surface temperature
TOGA	Tropical Ocean Global Atmosphere
United States	US

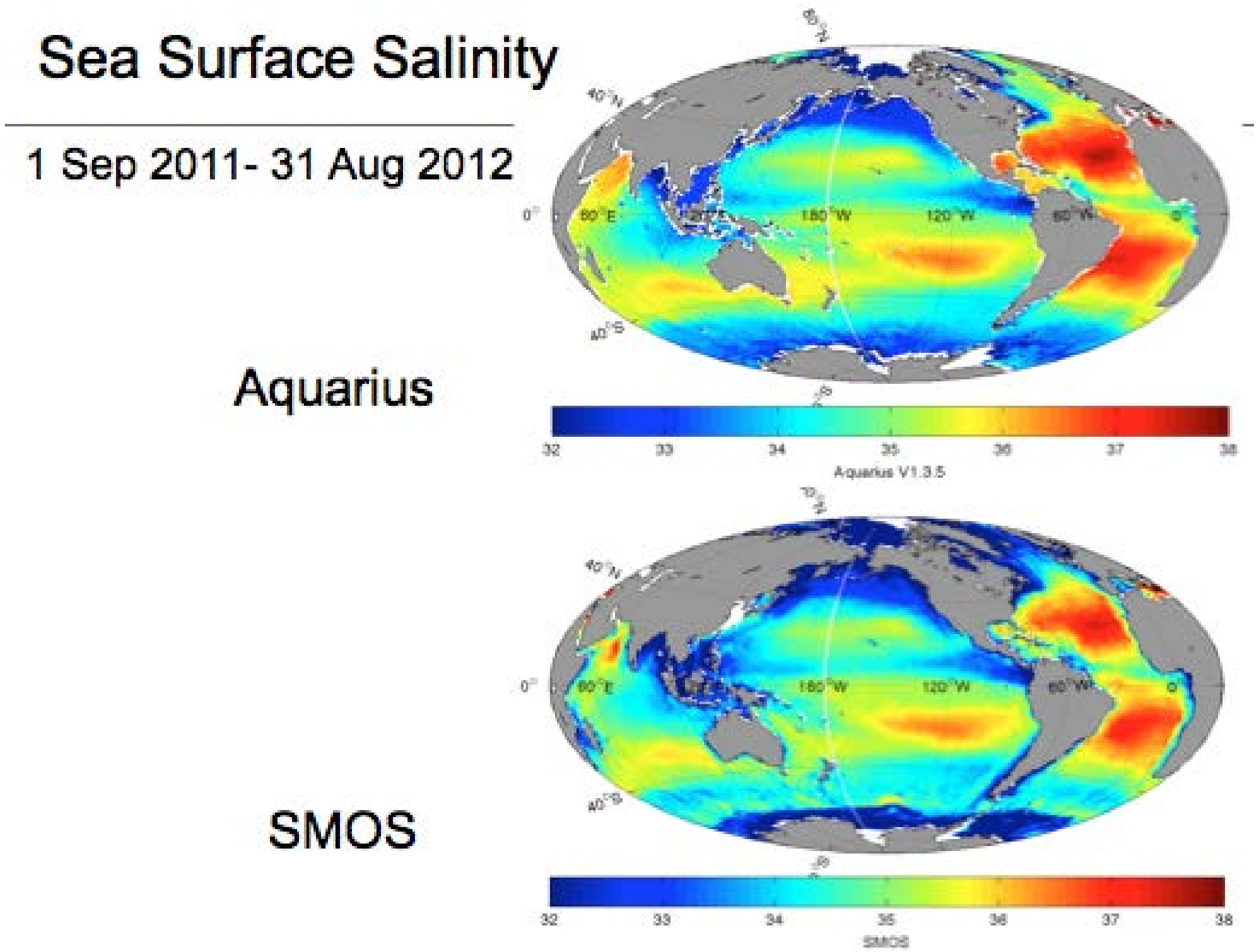

Figure 1. Mean distributions of SSS recorded during 1 September 2010 to 31 August 2011 from the Aquarius (upper) and SMOS (lower) missions. SSS values in latitudes higher than about 50° are not likely dependable until additional knowledge is acquired on how an L-band radiometer signal is influenced by SST less than 5 °C.