Impacts of Rainfall on Aquarius Sea Surface Salinity Measurements

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***Abstract*— The effect of the rain in the SSS measurement is not a well understood phenomenon. Both instantaneous rain rate (RR) and previous rain accumulation (RA) can cause errors in the AQ SSS measurement. In this paper, we discuss the RR and RA from the CFRSL Rain Accumulation Product (AQ RA) that describes the instantaneous, occurring simultaneously with the AQ L-band IFOV, and accumulated rainfall, based on the 3B42 product. Also, we present examples of the AQ RA data that are compared to the AQ SSS retrievals. Comparison of these results demonstrate the correlation between SSS (1 cm) and the HYCOM oceanographic model, which represents the stead-state 5 m depth salinity. Also plans are presented to use the data to better understand the transient salinity gradient that occurs after a significant rainfall.**

Keywords— Aquarius; salinity retrieval; effects of rainfall; microwave radiometer.

I. Introduction

Aquarius/SAC-D (AQ/SAC-D) is a joint earth science satellite program by NASA and the Argentine Space Agency (CONAE) to provide the scientists with long-term, global-scale salinity measurements. Sea surface salinity (SSS) is an important parameter within the ocean to understand the global water cycle, ocean circulation and climate [1].

The prime instrument, also named Aquarius, is a L-band microwave radiometer. It operates at a 1.4 GHz frequency, to provide weekly maps of global ocean SSS. From these weekly sampling, monthly global maps of SSS measurements are produced, with high spatial (150 Km) resolution and a precision of 0.2 practical salinity units (psu). This corresponds to measuring small changes in the ocean surface microwave brightness temperature (Tb) of about 0.1 Kelvin.

Moreover, the salinity retrieval involves more than simply translating ocean brightness temperature to SSS. For example, it is necessary to remove the Tb influence of many unwanted effects [2], which include Tb correction for: solar and galactic emissions, mixing of polarized ocean Tb's by the ionosphere, ocean roughness warming by winds and waves, and the Tb effects of rain on the ocean surface. To support this ocean Tb measurement accuracy requirement, several ancillary instruments, including the CONAE Microwave Radiometer (MWR) have been deployed on the AQ/SAC-D spacecraft. They provide Aquarius with additional information about geophysical parameters (e.g. ocean surface wind speed and rainfall) that are used to make corrections in the AQ ocean surface Tb measurements, which results in more accurate SSS retrievals. This paper deals solely with the effects of rain on the measured ocean Tb and the corresponding retrieval of SSS.

II. Top of the atmosphere Brightness Temperature

The measured brightness temperature by a satellite is illustrated in Fig. 1. As it is shown the measured temperature is the combination of three different temperatures; upwelling brightness temperature, the reflected downwelling brightness temperature at sea surface, and the temperature due to sea surface emission.

There are several environmental parameters that affect these temperatures. For instance, the reflected down-welling atmospheric Tb and the ocean surface Tb, as they pass through the atmosphere, are attenuated by liquid water, water vapor and oxygen.

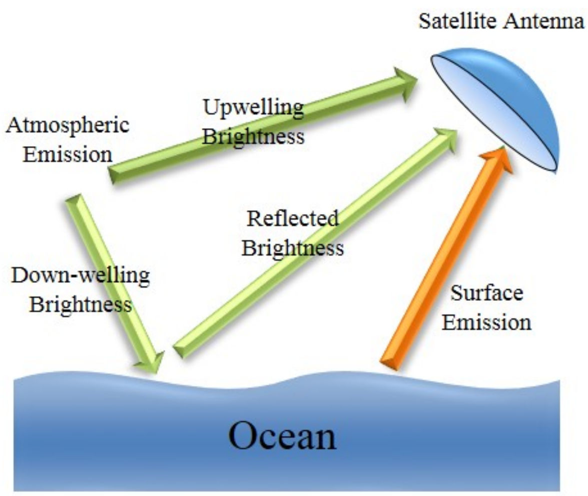

Figure 1. Components of measured brightness temprature

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In AQ L band frequency the surface emission is the dominant element in the measured temperature. Eventually using the measured temperature and the environmental parameters, such as sea surface temperature, wind speed, water vapor and cloud liquid water, the sea surface salinity with high accuracy would be retrieved.

III. The Issue: Rain Impacts on SSS Retrievals

There are several geophysical parameters that affect AQ SSS measurements and rain is one of the most important. Thus, it is necessary to empirically characterize the effect of rainfall on the SSS retrieval algorithm.

A. Splash Effect:

Instantaneously, rain drops striking the ocean increases the surface roughness. This is known as "splash effect", and it causes a corresponding increase in the ocean surface Tb, which results in a reduction in retrieved SSS (if not properly accounted for). Since rain is heterogeneous (transient) in space and time, simultaneous rain measurements during the collection of AQ L-band Tb are highly desirable, and this will be provided by the CONAE microwave radiometer, MWR. Using MWR rain retrieval, with collocated AQ SSS measurements, it should be possible to develop a statistical correction to remove the roughness effect.

B. Multilayer Effect:

Rain contains pure water, and the volume density of fresh water is less than sea water, that contains salt and minerals. Hence, during intense rainfall, a layer of fresh water (with different intrinsic impedance between air and sea surface) floats on top of the sea surface. This effect changes the measured brightness temperature. Based on the thickness of this layer the retrieved SSS can increase or decrease [4].

C. Accumulated Rain Rate and SSS Ocean Profile:

Ultimately, over time periods of minutes to a few hours, rain accumulated fresh water layer mixes with ocean water freshening the first few centimeters of the ocean surface. Example of this effect has been observed in the high resolution in situ measurements in the near-surface layer of the ocean, during the TOGA Coupled Ocean-Atmosphere Experiment (COARE). This study, reported by Soloviev, A. and R. Lukas [3] revealed cases of quite pronounced spatial variability of near-surface temperature and salinity. Under certain conditions, the shallow diurnal thermocline and rain-formed halocline are subject to perturbations that look like large amplitude internal waves. Under those conditions, AQ SSS measurements would not be representative of the desired steady-state value (i.e., weekly mean) in the ocean layer between 5 – 10 m depth. Thus, rainfall produces a transient condition, whereby the salt diffuses into the fresh water and there is mechanical mixing by ocean waves. Therefore, after several hours, the ocean becomes slightly lower in salinity (assimilation of fresh water) and the SSS vertical profile in the upper 5 m depth is restored to a more predictable value. Since the AQ instrument samples each ocean pixel only once in 7-days, it is important to prevent the transient effects of rain from affecting the desired steady state SSS value.

D. An Empirical Solution:

The correction to the rainfall influence on SSS, will involve both oceanographic modeling and empirical satellite remotely sensed SSS measurements to understand this large-scale transient salinity profile phenomena. A preliminary related work [5] was reported at the recent SMOS/AQ workshop in Brest, FR (http://www.salinityremotesensing.ifremer.fr). This empirical study was conducted using 3-day average of satellite oceanic precipitation measurements (from microwave radiometers), collocated with in situ (buoy and ship-borne) salinity profiles, between 1 m and 5 m depths. Results showed that a robust statistical relationship existed between vertical salinity gradient and rainfall. Their conclusion was that even larger gradients would exist between the 1 cm SSS measured by SMOS and the 1 m depth Salinity. They also proposed a model to relate the profile, based solely on satellite 3-day average rain averages and the SMOS SSS measurements.

IV. Aquarius Rain Accumulation

In order to provide the AQ rain accumulation (RA) product, two data sets have been used; the AQ L-2 data, that contains AQ microwave measurements for each orbit, and the rainfall history for each AQ IFOV, derived from the Tropical Rainfall Measuring Mission (TRMM) 3B42 rain rate product. The last dataset is a near-global rain rate data set on a 0.25° grid, which spatial coverage extends from ±50° latitude and ±180° longitude. TRMM 3B42 files provide the rain rate information in 3 hours windows, so for each day it has 8 files of data.

Fig. 2 shows the spatial model that has been used to calculate rain accumulation over an AQ footprint. Each AQ IFOV is approximately a circle with a diameter of 100 Km (dashed red circle in Fig. 2). For the calculation of rain accumulation over an IFOV, the information of the average rain rate on the 13 corresponding 3B42 pixels is needed.

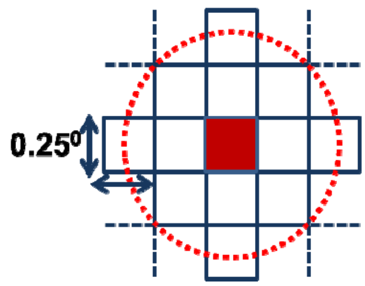

Figure 2. Spatial model to calculate rain accumulation over AQ IFOV

The algorithm to develop the rain accumulation product has been described in the diagram in Fig. 3. First, the AQ IFOVs and the corresponding 3B42 data for each footprint are indicated. Next, a time interpolation of 3B42 over the Aquarius observation time is performed. Following this step, the instantaneous rain rate is calculated. Finally, the procedure is repeated to obtain the rain accumulation for 0-3hr, 3-6hr, 6-9hr, 9-12hr, 12-15hr, 15-18hr, 18-21hr, 21-24hr prior to Aquarius observation time.

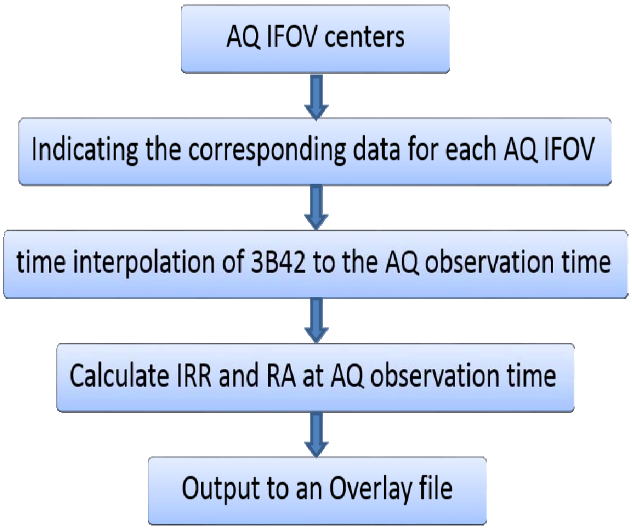

Figure 3. Rain Accumulation algorithm

V. SIMULATION AND RESULTS

With the described algorithm, an analysis to investigate the rain accumulation effect on sea surface salinity measurements was performed, using the AQ L-2 V.2 data and 3B42 data. 3B42 rain rate data was used for creating the rain accumulation product on each AQ footprint, and retrieved SSS for each orbit was driven from AQ data. Fig. 4 shows the result of the analysis for one AQ orbit; in the top it can be seen the instantaneous rain rate (RR00) with black line, and the rain accumulation for 0-3hr (RA03) and for 3-6hr (RA06) with red and blue lines, respectively. The lower plot shows the difference between retrieved SSS using AQ and SSS from hybrid coordinate ocean model (HYCOM). As it can be noted, in the presence of intense rainfall, there is a significant difference between the measured SSS and the HYCOM model.

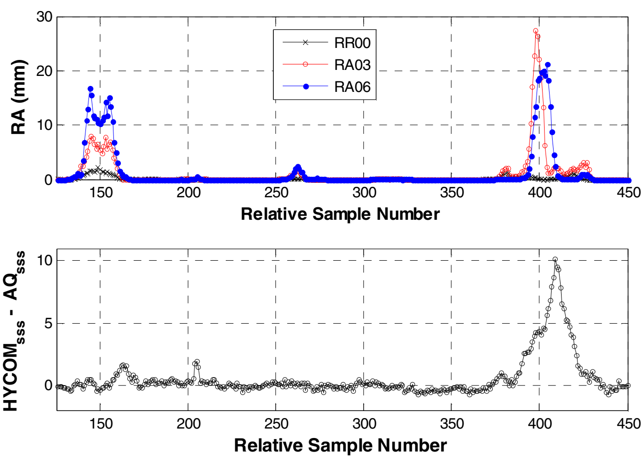

Figure 4. Accumulated rain and SSS measurement mismatch

Fig. 5 shows the values of retrieved SSS of Aquarius and HYCOM and the difference between them for the same day. As it is shown the SSS in HYCOM changes very smoothly over the time, but significant changes on Aquarius SSS (due to rainfall) are observed. So the difference between the SSS from HYCOM model and retrieved SSS from Aquarius data has been used to show the changes on SSS measurement.

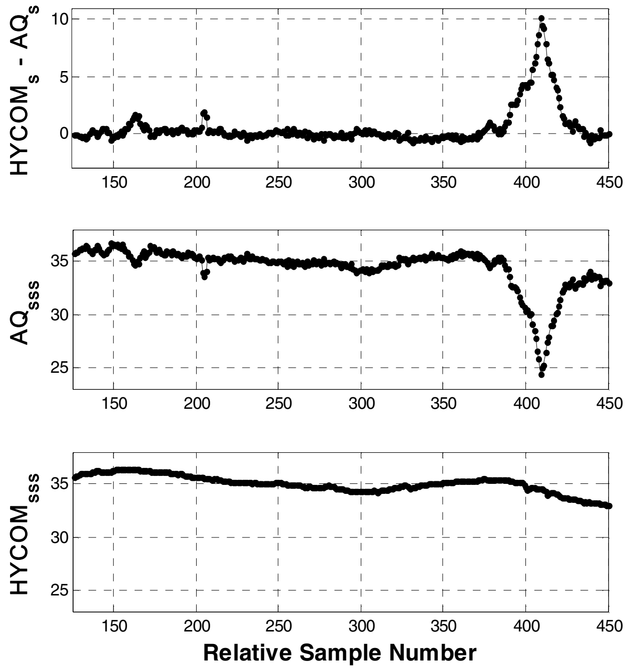

Figure 5. SSS measurement difference with HYCOM model, AQ SSS and HYCOM SSS

Fig. 6 and Fig. 7 represent the rain accumulation for two different days with significant rainfall. The instantaneous rain rate (RR00), the rain accumulation for 0-3hr (RA03), 3-6hr (RA06) and 6-9hr (RA09) are represented by black, red, magenta and blue colors, respectively in top plot, and the lower plot represents the difference of measured SSS and the SSS from HYCOM model for the corresponding samples. For the better resolution the redundant samples with no rain and with the same values for the measured SSS have been removed. It is shown that in presence of intense rainfall, the difference between measured SSS and the oceanic model increase significantly. Moreover, it can be seen from Fig 6 that even when the instantaneous rain rate is zero the RA values are higher than 10 mm. Therefore, this shows that both instantaneous rain rate and rain accumulation affect the retrieved SSS considerably. Fig.7 presents the rain accumulation for another day with higher precipitation. In comparison with Fig 6, it can be seen that with the increase of rain accumulation, the difference between HYCOM SSS and retrieved SSS becomes greater.

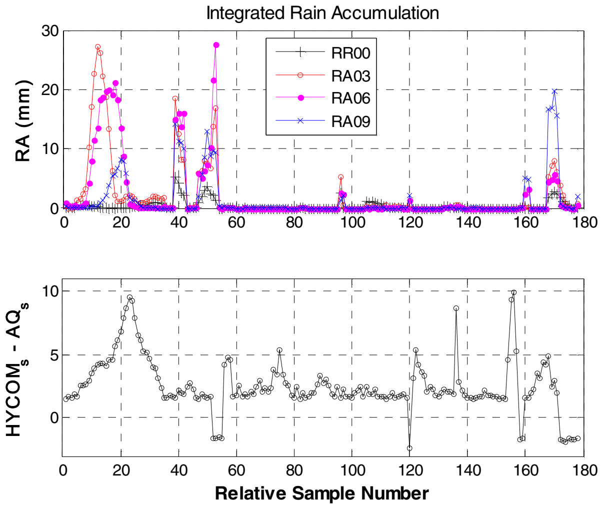

Figure 6. Rain accumulation over one day

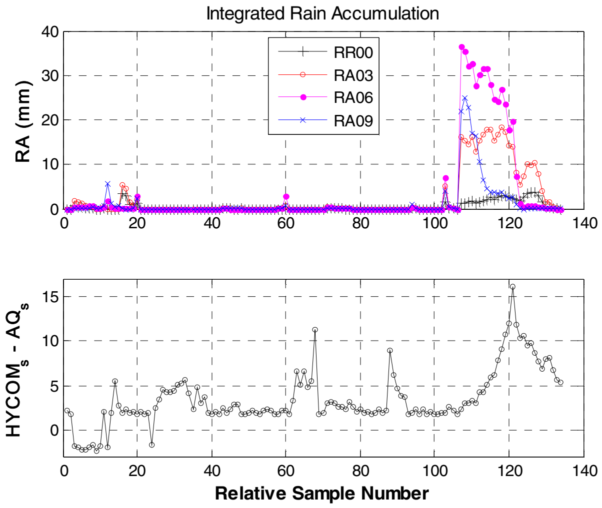

Figure 7. Rain accumulation in an intense rainy case

VI. CONCLUSION

In this paper, the instantaneous rain rate and rain accumulation effect on Aquarius SSS measurements was investigated. It is showed that not only the rainfall at the time of the SSS measurement can have an effect on the retrieved salinity value but also, the previous accumulated rain have a significant impact on SSS measurements. These data will be used in further analysis to determine the effect of rain accumulation on the retrieval of SSS.

ACKNOWLEDGMENT

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