SALINITY RAIN IMPACT MODEL (RIM) OPTIMIZATION: PRELIMINARY RESULTS

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ABSTRACT

Based upon research with the Aquarius (AQ) satellite remote sensor, a rain impact model (RIM) has been developed which estimates the occurrence of sea surface salinity (SSS) stratification. RIM uses global salinity (HYCOM) and rainfall (CMORPH) products to estimate the transient change in SSS due to rainfall. Previously SSS predicted by RIM have exhibited good correlations with AQ, but the choice for the duration window (24 h) was arbitrary. In this paper, we examine the effect on RIM of different time duration windows.

Index Terms— Sea surface salinity, rain rate, stratification

1. INTRODUCTION

Oceanic rain is a major contributor to the global salinity, creating fresh-water lenses that can have thicknesses of meters and generating vertical density gradients. This results in differences between sea surface salinity (SSS) satellite-measured (~ 1 cm depth) and traditional in-situ platforms (e.g., Argo floats, drifters, and moorings), which typically sample at a 1-5 m depth. Therefore, accurate comparisons between satellite and in-situ salinities during rain requires knowledge of how the upper ocean behaves with precipitation.

This ocean-surface freshening due to rain can be observed in global maps of SSS, with areas of high precipitation broadly coincident with areas of low salinity and regions of high salinity occurring in regions with low precipitation and high evaporation. Thus, accurate global SSS measurements are important to improve ocean circulation numerical models that are used for climate prediction.

The Central Florida Remote Sensing Lab (CFRSL) determined, upon research conducted with the NASA/CONAE Aquarius/SAC-D mission [1] that the primary impact of precipitation is to dilute the SSS, which was captured by the Aquarius (AQ) instrument observations. When precipitation occurs, Asher et al. [2] observed that a rain event produces a quasi-uniform mixed layer of few cm of diluted water, which rapidly mixes downward, and after several hours, the salinity gradient becomes very small.

In order to estimate this fresh bias, a rain impact model (RIM) was developed [1], which estimates the rain-induced freshening in SSS at the time of the satellite observation. RIM is based upon one-dimensional vertical diffusion in the upper ocean, which is driven by the ocean salinity model HYCOM (does not include the short-term rain effects) and the NOAA global rainfall product CMORPH. The RIM output is SSS in 0.5 hour increments for 24 h prior to the AQ observation time; thereby predicting transient changes in the near-surface salinity profile caused by rain fresh-water influx.

Drushka et al. [3] finds that the persistence of rain-induced salinity gradients also depends on wind speed, with rain freshening during weak winds (2 m/s) persisting for 8 hours or more. Although salinities predicted by RIM have good correlations with AQ SSS, the duration window of 24 h was chosen arbitrarily. Therefore, to optimize the present RIM model, comparison of RIM integrated over different time duration windows will be presented that will yield to a new version of RIM (RIM-2).

2. DATASETS

AQUARIUS: The Aquarius (AQ) instrument was an L-band push-broom radiometer/scatterometer with three contiguous antenna beams of instantaneous fields of view (IFOV) of ~ 100 km. Given this 390-km swath, global salinity maps were produced every 7 days [4]. This papers uses L2 AQ V4.0 product, which is processed into a global grid of a0.25° resolution.

CMORPH: The NOAA CMORPH (CPC-Climate Prediction Center-Morphing technique) global rainfall V1.0 product is used to estimate the change in sea surface salinity (SSS) due to rain at the time of the satellite observation. The CMORPH morphing technique is applied with inter-calibrated precipitation measurements from available satellite microwave radiometers, where the precipitation

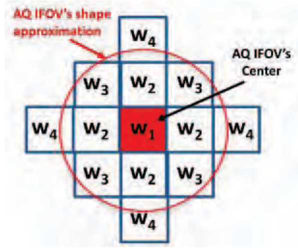

Fig. 1 Spatial model used to calculate average IRR and RA over an AQ IFOV. Boxes are 0.25° lat/lon grid cells.

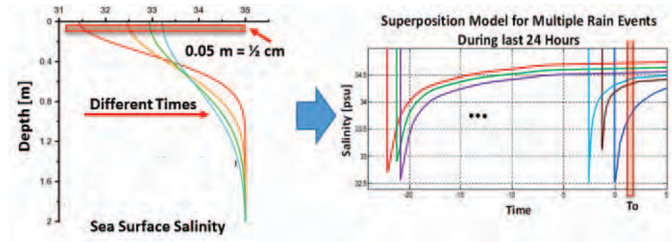

Fig. 2 Rain Impact Model for a single rain event: based on superposition of one dimensional stratification model.

features are propagated using cloud tracking information from geostationary IR (infrared) satellites thereby yielding to a global precipitation image every 30 minutes [5].

Given the global availability and high time resolution in the CMORPH rain dataset, it is possible to build the rainfall history associated with each satellite SSS retrieval. In the case of AQ, the average instantaneous rain rate (IRR) and rain accumulation (RA) are calculated using a structure of 13 pixels around the center of the IFOV (see Fig. 1). Therefore, given CMORPH's time resolution, the input to RIM is 49 samples of rain history for each satellite SSS measurement.

HYCOM: The Hybrid Coordinate Ocean Model (HYCOM) salinity (at ~10 m depth) was used as a reference to which the satellite SSS is compared. HYCOM provides a horizontal resolution of 0.080° (9 Km), and it is configured to produce a better model of the upper ocean characteristics.

Further, the following input parameters are from HYCOM: surface wind stress, air temperature, and specific humidity from dew-point temperature, sea level pressure, and shortwave and long-wave radiances. Vertical salinity and temperature profiles from XBTs, CTDs, and profiling floats like Argo, which provide information about the vertical stratification, are also used as inputs. Through data assimilation into an ocean model, it is possible to produce a dynamically consistent depiction of the ocean [6].

3. NEAR-SURFACE SALINITY STRATIFICATION

Typically, oceanic in-situ salinity measurements occur at depths greater than 5 meters, while satellite L-band radiometer measurements are representative of 1 cm (penetration depth of L-band microwaves). Recent studies [1] suggested that the main geophysical source of variability between satellite and in-situ salinity, particularly after rainfall, are vertical salinity gradients (stratification) that occur between 1 cm and a few meters.

The combination of the salinity gradient magnitude and the fresh lens lifetime determines the effect on satellite salinity measurements. The rate of salinity changes is determined by the influx of fresh-water and by ocean wave mixing (correlated with the surface wind speed). Both the magnitude and lifetime are functions of rain rate, total amount of rainfall, and vertical mixing at the ocean surface. For example, rain events with high peak rain rates that occur when wind speeds are low generate fresh lenses with strong near-surface salinity gradients that can have lifetimes on the order of hours. In contrast, rain events at high wind speeds have smaller gradients and shorter lifetimes because vertical mixing is larger. Similarly, rain events with long duration and low peak rain rates generate fresh lenses with smaller vertical gradients.

From both cases, the important feature is that if the bulk salinity is measured in a layer below the rain induced fresh-water surface layer, there will be a bias in the remotely sensed salinity, although it will be considerably reduced with the increasing of time. Therefore, precipitation introduces a transient condition; and after several hours, when the fresh-water is assimilated, the ocean becomes slightly less salty, restoring the SSS vertical profile in the upper 5 m depth.

4. RAIN IMPACT MODEL

As was mentioned previously, an empirical forward Rain Impact Model (RIM) has been developed to estimate the macro-scale salinity effects of rainfall on AQ SSS retrievals. RIM was developed using an empirically derived rainfall history averaged over the AQ SSS observations for the previous 24 hrs and a micro-scale model for the in-situ near-surface salinity profiles.

The time series of near-surface salinity profiles from Asher et al. [2] is illustrated in the left panel of Fig 2. Raindrops hitting the ocean surface are assumed to instantaneously mix uniformly to form a low-salinity layer of ~10 mm depth. Over a period of a few hours, diffusion causes downward mixing and the vertical salinity gradient weakens. The right panel of Fig. 2 illustrates the RIM models successive rain events as a series of impulse functions that act as successive dilutions, where multiple rain events (weighted by the rain rate) are superimposed. Each event contributes a separate dilution of salinity, and the resulting net effect is calculated as the product of each of the individual dilutions [1] starting with the initial HYCOM salinity. In RIM, there are up to 49 rain events (every 0.5 h for 24 h) per day.

The model is represented by the following expression [1]:

$$RIM_{SSS}(z) = S_0\left[\prod_{i=1}^{48}\left(1+\frac{R_{1i}}{\sqrt{K_z{*}t_i}}e^{-z^2/4K_z t_i}\right)*\left(1+\frac{R_2}{\sqrt{K_z{*}t_0}}e^{-z^2/4K_z t_0}\right)\right]^{-1} \quad (1)$$

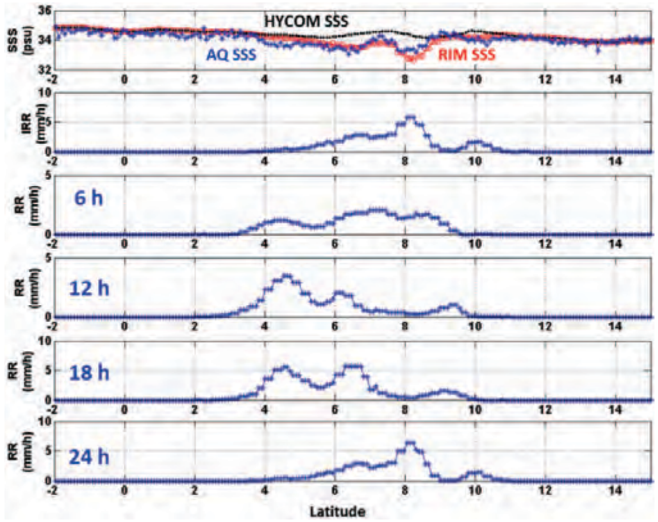

Fig. 3 Latitude series over the ITCZ. Jan 23, 2012—AQ Orbit #2—Beam 2.

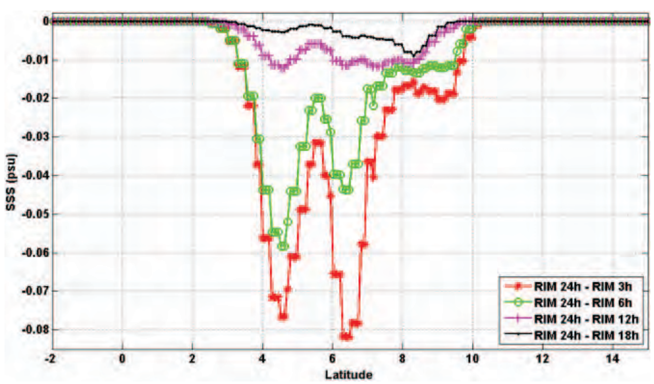

Fig. 4 RIM SSS integrated over different time windows: 3 h in red, 6 h in green, 12 h in magenta, 18h in black and 24 h in cyan.

where z is depth in meters, t_0 is the AQ observation time, t_i is the 0.5h time step of precipitation records during the previous 24 hours, S_0 (psu) is the initial bulk salinity taken from HYCOM, and K_z (m^2/s) is the vertical eddy diffusivity coefficient.

Equation (1) has two terms; the first accounts for the dilution of surface salinity due to rain for the previous 24 hours, and the second accounts for the effect of the instantaneous rain rate. The calculation of R_{1i} and R_2 rain impulse functions involves the use of empirical coefficients that were derived by tuning RIM to match AQ SSS [1].

5. RESULTS

A typical example of the salinity stratification is presented in Fig. 3 for AQ measurements that occurred on Jan 23, 2012 during orbit 2 for beam 1. In this figure, there is a six-plot presentation, whereby all the spatially sampled data are plotted against the corresponding IFOV latitude. The top plot #1 has multiple curves for the comparison of salinity, namely: (1) the latitude series of RIM SSS (red circles), (2) AQ SSS (blue asterisk) and, (3) HYCOM values from the current orbit (black dots). The next 5 plots are respectively: (plot #2)— IRR for t_0 (AQ observation time) in mm/h, (plot #3)—IRR in mm/h 6 h prior t_0, (plot #4)—IRR 12 h prior to t_0, (plot #5)—IRR 18 h prior to t_0 and, (plot #6)—IRR 24 h prior to t_0. While there is precipitation over the previous 24 h, the large reduction in the surface salinity is most affected by the IRR (plot #2). The effects of the rainfall in plots #3–6 are significantly reduced because over time the stratification is removed by ocean wave mixing and diffusion mechanisms, although there is some effect of previous rain in latitudes between 4° to 5°.

As mentioned previously, although the comparisons between RIM SSS and AQ SSS are very good, with correlations greater than 90%, the time duration window of 24 h in the model was chosen arbitrarily. An example of a typical case of retrieving RIM SSS for different time duration windows is presented in Fig. 4 for the same case as

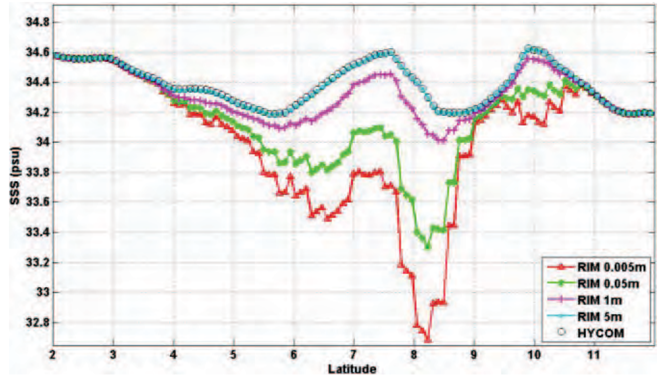

Fig. 5 RIM SSS for different depths: 0.005 m (surface) in red, 0.05 m in green, 1m in magenta, and 5m in cyan. HYCOM SSS is represented by black circles.

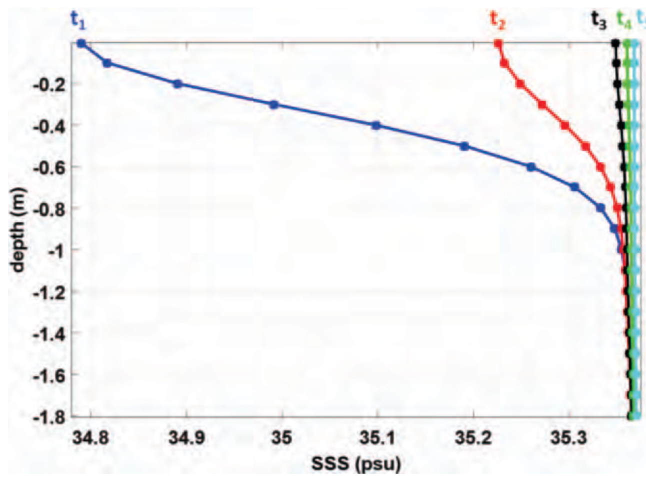

Fig. 6 Near-surface salinity profile for hourly time steps, where t_1 is the time of the rain event and $t_1 < t_2 < t_3 < t_4 < t_5$.

Fig. 3. The image shows the time series of the difference of RIM SSS for 4 different time windows: 3 h in red asterisks, 6 h in green circles, 12 h in magenta cruces, and 18 h in black dots, each with respect to RIM SSS 24 h. It shows that the SSS retrievals between 12 h and 24 h are indistinguishable. Although there are some differences between 3 h and 6 h window, these differences are small, with a maximum difference of 0.082 psu. And as expected, when there is no rain, all different RIM applications produce the same result.

Figure 5 presents an example of RIM SSS for different depths, for a chosen time duration window of 12h for the same case as Fig. 3. In the figure, RIM SSS: for the surface (0.005m) is represented by red triangles, for 5cm by green asterisks, for 1m by magenta cruces, for 5m by cyan points; and in black circles is represented HYCOM SSS. As expected, RIM SSS at 5m depths is almost identical to HYCOM SSS (HYCOM model does not take rain into account).

Finally, Fig. 6 presents the near-surface salinity profile in 1h time step, for AQ measurements at a fixed latitude (3.8°) on Jan 10, 2012, orbit 5, beam 1. In this case, only instantaneous rain rate (at the AQ observation time t_1 is present) and salinity are calculated using RIM. As it is shown, the largest stratification occurs at the time of the rain event; and for later times, the salinity gradient decreases until finally reaches steady state profile at a slightly lower salinity than that before the rain event. According to this, the salinity change is indistinguishable for depths greater than ~3 m.

6. CONCLUSIONS

The most important effect of rainfall is the creation of a stratified layer of lower-salinity near the surface. This layer of fresher water mixes laterally and vertically over timescales of a few hours, depending on wind speed, to produce a layer of water a few meters deep with slightly lower salinity and a nearly uniform salinity as a function of depth. Because AQ samples once every 7 days, if rain has occurred a few hours prior to the AQ measurement time, then the SSS measured by AQ at a depth of 1 cm would be fresh compared to the SSS measured at a depth of a few meters, as observed in Fig. 5.

Furthermore, from Figs. 5 and 6, the important feature is that if the bulk salinity is measured in the layer below the fresh surface layer, there will be a fresh-bias in SSS, although with increasing time this salinity anomaly is considerably reduced. Thus, if AQ measures SSS, when salinity stratification is present, the retrieval of SSS would not be representative of the desired steady state value (i.e., weekly average) that would be measured by an in-situ sensor in the ocean layer between 5 and 10 m depth. Moreover, RIM SSS at 5 m depths seems to have an excellent correlation with HYCOM SSS.

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 predictable value. However, since AQ samples each ocean pixel only once every 7 days, it is important to characterize the effect of rain for the SSS to be representative of the bulk salinity.

Choosing a 12 h instead of 24 h window will not introduce any significant change in the model prediction of SSS but will reduce the processing time greatly.

Further analysis needs to be done, not only on the impact of changing the time duration window but also the time step (0.5 h). This could yield an optimization of the RIM model to dramatically reduce processing time as well as storage.

7. REFERENCES

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