SEA SURFACE SALINITY AND WIND RETRIEVAL ALGORITHM USING COMBINED PASSIVE-ACTIVE L-BAND MICROWAVE DATA

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1. INTRODUCTION

Aquarius is a combined passive/active L-band microwave instrument 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, the global water cycle, and climate. 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 [1]. The measurement principle is based on the response of the L-band (1.413 GHz) sea surface brightness temperatures (T_B) to sea surface salinity. To achieve the required 0.2 psu accuracy, the impact of sea surface roughness (e.g. wind-generated ripples and waves) along with several factors on the observed brightness temperature has to be corrected to better than a few tenths of a degree Kelvin. To this end, Aquarius includes a scatterometer to help correct for this surface roughness effect [2, 3].

To quantify the benefits of combining passive and active microwave sensors for ocean salinity remote sensing, the Jet Propulsion Laboratory (JPL) Passive/Active L-band Sensor (PALS) was used to acquire data over a wide range of ocean surface wind conditions during the High Ocean Wind (HOW) Campaign in 2009 [3]. The PALS brightness temperatures and the radar σ_0 from the campaign show response to ocean surface wind speed as well as direction. The brightness temperature changes are about 0.2 to 0.3 K for every one m/s change in wind speed. In addition, there is significant wind direction dependence for high winds (>10 m/s), about 0.5 K peak to peak at 9 m/s wind speed and 1.5 K at 24 m/s wind speed. The PALS data suggest that the L-band radar and radiometer signals for ocean surfaces can be represented by the sea surface salinity (SSS), sea surface temperature (SST), wind speed (w) and wind direction (ϕ) using the cosine series expansion:

$$T_{BV}(SSS,SST,w,\phi) = T_{BV0}(SSS,SST) + b_V W + T_{BV1}(w)\cos\phi + T_{BV2}(w)\cos 2\phi$$
$$T_{BH}(SSS,SST,w,\phi) = T_{BH0}(SSS,SST) + b_H W + T_{BH1}(w)\cos\phi + T_{BH2}(w)\cos 2\phi$$
$$\sigma_{VV}(w,\phi) = A_{0VV}(w) + A_{1VV}(w)\cos\phi + A_{2VV}(w)\cos 2\phi$$
$$\sigma_{HH}(w,\phi) = A_{0HH}(w) + A_{1HH}(w)\cos\phi + A_{2HH}(w)\cos 2\phi$$

We have developed a geophysical model function (GMF) at 45 degree incidence angle with the modeling coefficients for the cosine series reduced from the PALS/HOW 2009 campaign data. Figure 1 illustrates the directional variations of T_{BV}, T_{BH}, σ_{VV} and σ_{HH} calculated from the GMF at 5, 15 and 25 m/s wind speeds.

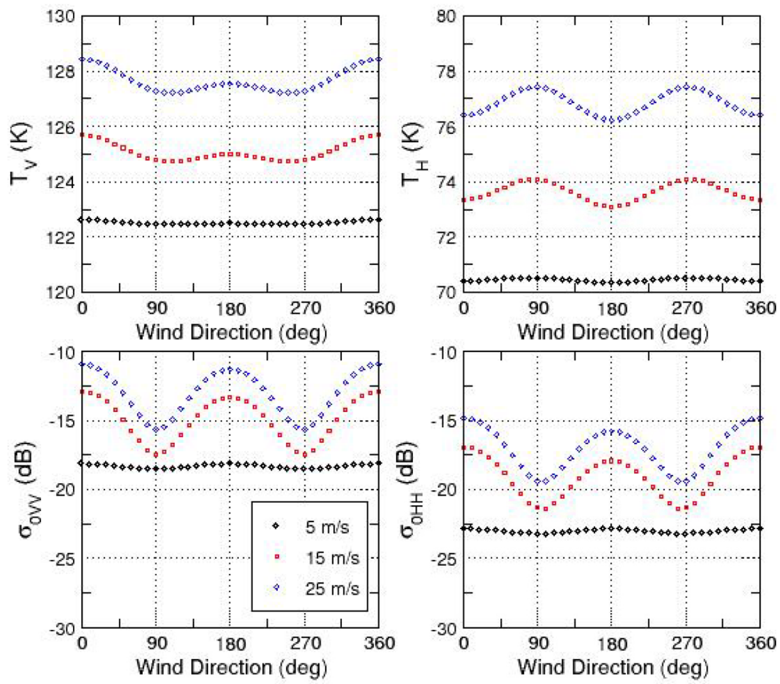

Figure 1. The directional variations of T_{BV}, T_{BH}, σ_{VV} and σ_{HH} of the GMF are plotted at three wind speeds at an incidence angle of 45 degrees. T_{BV0} and T_{BH0} are modeled using Klein and Swift's dielectric model [4] for sea water.

2. SALINITY-WIND RETRIEVAL ALGORITHM

The wind direction effects may introduce significant errors. For example, a directional variation of 0.7 Kelvin will result in a salinity retrieval error of about 1 practical salinity unit (psu) for warm waters at 25 degrees C and greater than 2 psu error for cold waters at 5 degrees C. The current approach for Aquarius salinity retrieval algorithm requires the use of ancillary ocean wind direction from the National Centers for Environmental Prediction (NCEP) to enable the correction. Because the NCEP wind analyses have been improving over the years, the current approach has the potential to produce reasonable accuracy. However, any errors in the NCEP analyses, particularly for high winds or near the front, as well as temporal mismatch with the Aquarius sampling may not allow the directional effects to be accurately removed using ancillary wind data. It is highly desirable to have an algorithm using the Aquarius data itself to correct the effects of both wind speed and direction.

Our algorithm uses the conjugate gradient method to search for the local minima of the weighted Least Square Error (LSE) measure:

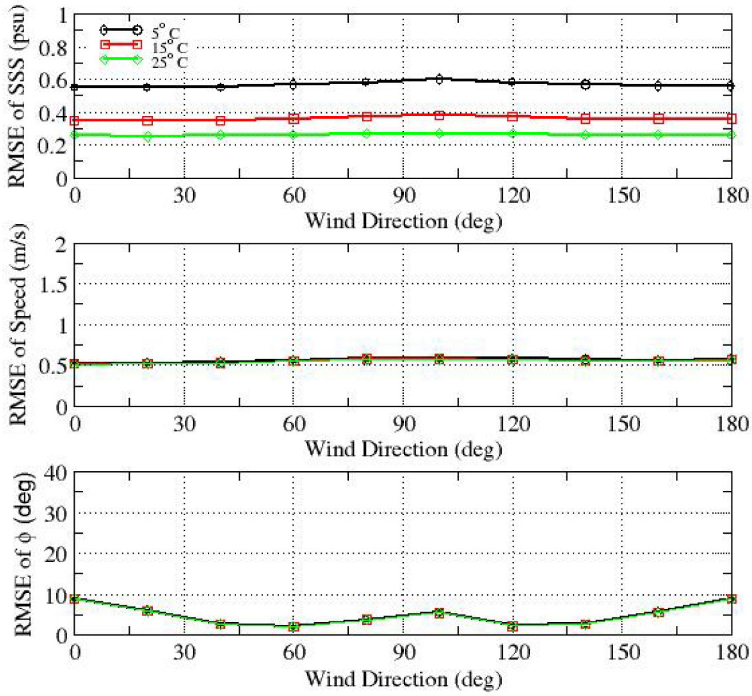

Figure 2. Simulated Root-Mean-Square (RMS) error of the retrieved salinity, wind speed and wind direction for the closest ambiguity. The input wind speed is 15 m/s. Gaussian random noise with ΔT=0.1K or k_{pc}=0.05 is assumed. We use the same SST for forward simulation and retrieval.

$$LSE(SSS,W,\phi)=\frac{(T_{BV}-T_{BVm})^2}{\Delta T^2}+\frac{(T_{BH}-T_{BHm})^2}{\Delta T^2}+\frac{(\sigma_{VV}-\sigma_{VVm})^2}{k_{pc}^2\sigma_{VV}{}^2}+\frac{(\sigma_{HH}-\sigma_{HHm})^2}{k_{pc}^2\sigma_{HH}{}^2}$$

In the LSE cost function, T_{BV}, T_{BH}, σ_{VV} and σ_{HH} correspond to the measurements. The brightness temperatures and radar backscatter, T_{BVm}, T_{BHm}, σ_{VVm} and σ_{HHm}, are computed from the model function for given salinity, wind speed and direction and temperature. The weighting factor ΔT is the noise equivalent delta T for radiometers, and k_{pc} is the expected residual error due to limited time-bandwidth product for radar power detection.

We carried out a set of simulations to test the feasibility and accuracy of the optimization algorithm. We simulated the radiometer and radar measurements. Gaussian random noises were added with standard deviation equal to ΔT or k_{pc}. The Conjugate Gradient search with a range of initial guesses in general provide four local minima (directional ambiguities), corresponding to four wind directions: ϕ, $-\phi$, $\sim\phi+180^o$ and $\sim 180^o-\phi$. The first two differ in sign, just as expected from the solution of cosine dependence of T_B and σ_0, while the last two are the result of inverting $\cos 2\phi$. If the first harmonic coefficients, T_{BV1}, T_{BH1}, A_{1VV}, and A_{1HH}, are zero, the last two will be off from the first and second ambiguities by 180 degrees exactly. However, the small first harmonic coefficients in the GMF will push these two directional ambiguities away from 180 degrees. When the directional ambiguity approaches 0, 90, 180 or 270 degrees, these four ambiguities will degenerate into two. Also expected from the cosine series representation of the GMF is that the retrieved salinity (or wind speed) values for the first two ambiguities will be identical, so are those for the third and fourth ambiguities.

In general, it is not too challenging to use the NCEP analyses to remove the directional ambiguities with about 180 degree offset. Therefore, the accuracy of the salinity and speed of the directional ambiguity closest to the truth will provide good error estimate of the algorithm. Fig. 2 illustrates the root-mean-square (RMS) error of the closest ambiguity for ΔT=0.1K, k_{pc}=0.05 at 15 m/s wind speed.

Our simulations show that we can use the passive and active microwave data together to retrieve sea surface salinity along with wind speed and direction. The RMS errors for the retrieved salinity and wind speed are nearly independent of wind direction (Fig. 2). At 25 deg C, the RMS SSS error is about 0.26 psu, fairly close to the error expected from the net effects of 0.1 K for ΔT and 0.5 m/s error for wind speed. It is also shown that the retrieved wind speed and direction derived from this algorithm can be very accurate, thus allowing Aquarius to provide coincident ocean surface wind products.

3. ACKNOWLEDGMENT

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4. REFERENCES

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