# Aquarius Third Stokes Parameter Measurements: Initial Results

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*Abstract*—**The Aquarius/SAC-D observatory was launched on June 10, 2011 and the Aquarius instrument has been collecting data continuously since late August. One of the unique features of the L-band radiometers comprising Aquarius is the presence of a polarimetric channel to measure the third Stokes parameter. The purpose is to provide a measure of Faraday rotation, which can be important for remote sensing at L-band, especially in the case of remote sensing of salinity which requires high precision. Initial results are presented here showing a reasonable agreement between retrieved and modeled Faraday rotation and also the "noisy" behavior at land-water boundaries and other mixed scenes predicted by theory.**

***Keywords - Faradayrotation; Microwave remote sensing; radiometry***

## I. INTRODUCTION

The goal of Aquarius is to map the surface salinity field of the global oceans with spatial resolution of 150 km and a monthly RMS accuracy of 0.2 psu. This is a challenging remote sensing measurement and Aquarius has a number of features focused on addressing the difficulties of obtaining this level of accuracy. One of these is the inclusion of a polarimetric channel on the radiometers to measure the third Stokes parameter to provide an in situ correction for Faraday rotation

Faraday rotation is the change in polarization of the signal emitted from the surface as it propagates through the ionosphere. The change in polarization is given to a reasonable approximation at L-band by [1]:

$$\Psi_F \approx \mathrm{VTEC} \times B_o \sec\theta \cos\Theta \qquad (1)$$

where $\Psi_F$ is the rotation angle of the polarization vectors (see Fig. 1); VTEC and B are the vertical total electron content and magnetic field measured evaluated at the ionospheric pierce point (IPP), the point where the ray from the spacecraft to the surface crosses 400 km; $\theta$ is the angle the ray makes with the vertical and $\Theta$ is the angle between the magnetic field vector and the ray from spacecraft to the surface at the pierce point.

At L-band the angle of rotation of the polarization vector can be several degrees [1] and a correction is needed to recover salinity with sufficient accuracy to meet the goals of Aquarius. The purpose of including a measurement of the third Stokes parameter on Aquarius is to provide a local (i.e. in situ) measurement of the rotation angle,$\Psi_F$. This can be obtained by noting that [2]:

2nd Stokes parameter: $$Q_A = Q\cos(2\Psi_F) \qquad (2)$$

3rd Stokes parameter: $$U_A = Q\sin(2\Psi_F) \qquad (3)$$

where the subscripts "A" denote the measured (observed) values and the symbols without a subscript denote values before propagation through the ionosphere. It follows that [2]:

$$\Psi_F = -\frac{1}{2}\tan^{-1}\left(\frac{U_A}{Q_A}\right) \qquad (4)$$

Equations (2)-(4) apply to the ideal case. When the antenna is not ideal (e.g. finite beam and non-zero cross-polarization coupling) the results are similar but the expressions are more complicated [2, 3]. In addition, spurious results are possible. These occur over inhomogeneous scenes such as at land-water boundaries or scenes of mixed water and ice [3].

## II. INITIAL RESULTS

Fig. 2 shows a global map of the Faraday rotation, for PM passes, retrieved by the Aquarius outer beam. The map represents 7 days of measurements (days 275-281 in 2011), which is the time it takes Aquarius to map the complete globe. Notice the change of sign near the equator (white line near 0 degrees) which occurs where the magnetic dip angle changes sign. Also notice the region below 75 degrees south latitude which is not covered by the radiometer at this time of year. The data is in reasonable agreement with predictions using the International GNSS Service (IGS) TEC product [4]. This has to be corrected to obtain the TEC at the altitude of Aquarius (657 km) which is done using the NeQuick profiles [5]. After this correction, the Faraday rotation angle, $\Psi_F$, is computed using (1). Differences are on the order of several tenths of a degree. The map in Fig. 2 is not a snap shot (i.e. it took 7 days to complete the map). Also, adjacent orbits are not adjacent in

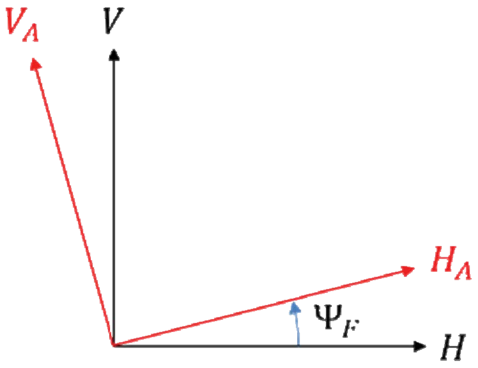

Fig. 1: Faraday rotation angle, $\Psi_F$

time. Since Aquarius is sun-synchronous, adjacent orbits are shifted about 15 degrees in longitude and the missing 15 degrees is gradually filled during the 103 orbits each week. Also notice dark spots (e.g. in an arc from central Europe to Asia and at spots in South America). These are anomalously high values of rotation angle, and correspond to the distribution of RFI as seen by Aquarius and SMOS at L-band.

In addition to the check using the IGS TEC product, an attempt has been made to compare with simultaneous observations using TEC measurements obtained in connection with the altimeter (Poseidon) on the Jason-II ocean surface topography mission. This was done by searching for the closest encounters between Aquarius and Jason and selecting orbital crossings that occur within temporal and spatial windows of 0.6 hours and 0.5 degrees respectively. All Jason observations within this time-space window (centered at Aquarius IPP) are averaged and compared with the Aquarius TEC. Fig. 3 is an example, showing the comparison over the ocean during the period October 10-29, 2011 for AM passes. The curve shows the Aquarius rotation angle retrieved from the middle beam and the Faraday rotation obtained from the TEC measured by the altimeter and also the DORIS receivers aboard Jason-II. Faraday rotation for comparison with Aquarius is obtained by correcting the TEC for the Aquarius altitude using the NeQuick profiles and then applying (1) assuming the slant path of the Aquarius radiometers. Similar results are obtained with the other two Aquarius radiometers with a difference between the Jason and Aquarius estimates largely in the range of +/- 0.5 degrees.

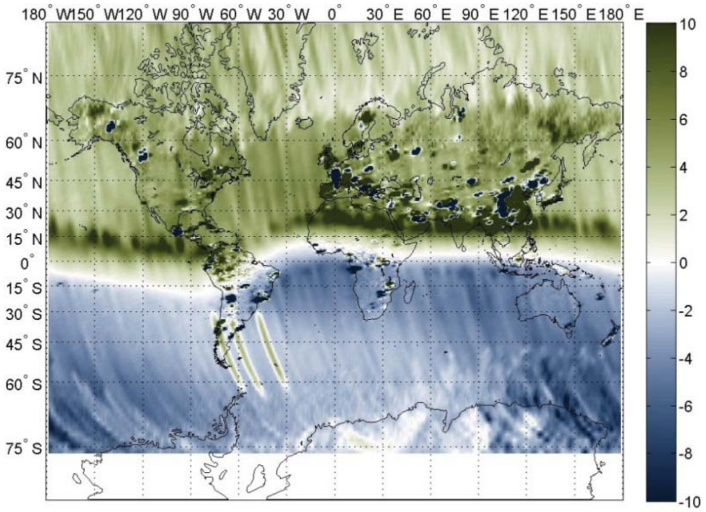

Fig. 2: Global map of retrieve Faraday rotation: Outer beam, PM passes, for one week: days 275-281, 2011

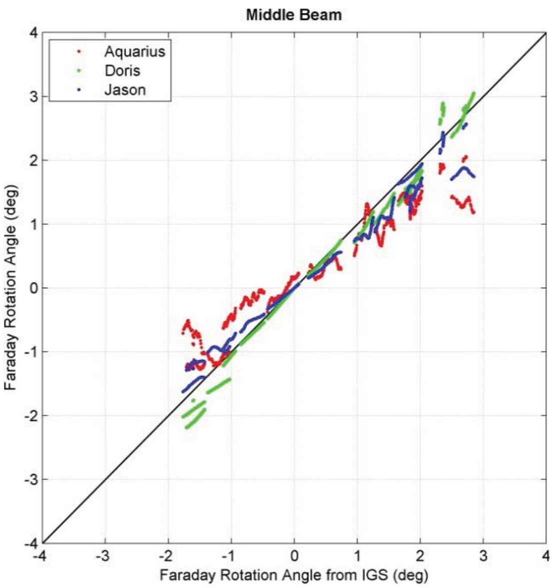

Fig. 3: Comparison of Faraday rotation retrieved from the middle beam of Aquarius (red) and Faraday rotation obtained using the TEC from the Jason altimeter (blue) and DORIS (green).

## III. DISCUSSSION

Equation (3) applies to the case of an ideal antenna. Imperfections in real radiometer antennas such as finite beam width, asymmetry in the main beam pattern and cross-polarization coupling (coupling of signal between the two orthogonal polarization ports) can cause “errors”. These can occur in the form of bias and “spurious” jumps in the third Stokes parameter. The latter are most likely over mixed scenes such as land-water boundaries or ice-water mixtures [3]. This is illustrated in Fig. 4 which shows the Faraday rotation retrieved for the middle beam of Aquarius along one orbit. The vertical axis is $\Psi_F$ and the horizontal axis is time along the orbit (the index labeled “snapshot number” is the number of 1.44 sec data samples which is the basic Aquarius data block). The red line is the Faraday rotation retrieved using (4) and the blue curve is the Faraday rotation obtained using the IGS TEC product [4], adjusted to the altitude of Aquarius (657 km) using the NeQuick profiles [5], and then applying (1). In the mean, the agreement of retrieved and predicted Faraday rotation is reasonable. The two curves agree quite well when the spacecraft is over ocean (index 400 – 700 and 2500 - 3700) and over land the trend is consistent with the expected Faraday rotation but the retrieved values are very “noisy”. This noise is spurious behavior caused by the inhomogeneity of the scene and the characteristics of the antenna pattern. The observations are consistent with theory and computer simulations of the third Stokes parameter expected to be measured by the Aquarius radiometers [3]. Theory predicts that the agreement will be good over homogenous scenes such as the ocean with

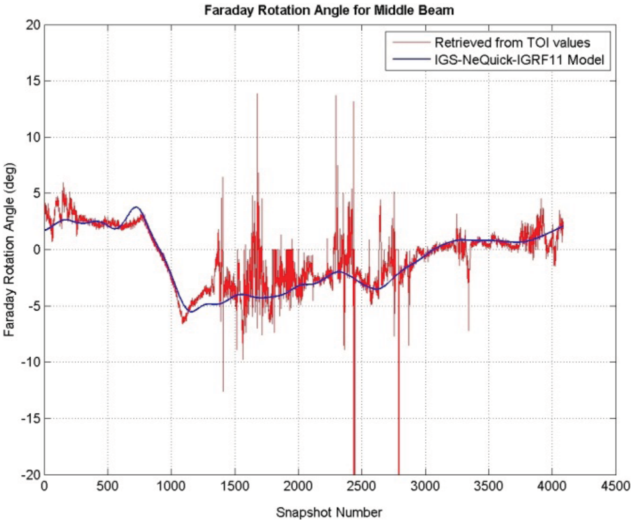

Fig. 4: Faraday rotation retrieved from Aquarius middle beam (red) compared with Faraday rotation obtained using the IGS prediction scaled to the Aquarius altitude in (1).

biases that depends on the details of the antenna (specifically cross polarization coupling). However, over inhomogeneous scenes such as land and at land-water boundaries the third Stokes parameter can change rapidly and can reach large spurious values. This results in the noisy retrieval evident in the figure [3].

## IV. CONCLUSION

Based on the retrieved Faraday rotation, the Aquarius polarimetric channels appear to be performing well. The retrieved rotation angles are consistent with values predicted using TEC values from the IGS and also with measurements obtained from the Jason-II altimeter that are made at closely coincident points. Differences exist and work is still underway to determine if this is an issue with the calibration of the polarimetric channels. It is anticipated that differences in the retrieved Faraday rotation will be reduced as the algorithm is refined and as the calibration is confirmed.

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