Roughness Corrections for Aquarius SSS Retrieval

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10/11/12
SMOS-MODE
L-Band Combined Active/Passive Aquarius

Aquarius (Sea Surface Salinity)
L-band radiometer and scatterometer
Push-broom (single look) with three feeds
<0.1 K for radiometer
<0.1 dB for scatterometer
Approach

• Test different roughness correction methods
  – Matchup Aquarius TB and sigma0 with NCEP wind and NOAA WW3 SWH, develop the roughness GMF for TB and sigma0, and use CAP algorithm
  – NCEP vs. Radar for wind correction
  – Correction for SWH

• Assess the galactic reflection correction
  – Derive effective wave slope
  – Use CAP retrieval algorithm
L-band Passive Microwave TB vs. Wind

- (a) 5 m/s
- (b) 8 m/s
- (c) 10 m/s
- (d) 12 m/s
- (e) 15 m/s
- (f) 20 m/s
Aquarius Radiometer Model

- TBH is more sensitive to wind speed
- TBV has a larger upwind-downwind asymmetry.

$$\Delta e(w, \phi) = e_0(w) + e_1(w)\cos \phi + e_2(w)\cos 2\phi$$

- $e_2$ changes phase at about 3 and 8 m/s
- Similar to active Non-Bragg?
Aquarius Radiometer Model with Wave Effects

- $e_1$ and $e_2$ have no obvious dependence on SWH
Radiometer Model with Wave Effects

- TH at low winds is more sensitive to the effects of SWH.
Aquarius Scatterometer Model

- Sigma0 model

$$\sigma_0(w, \phi) = A_0(w)[1 + A_1(w)\cos\phi + A_2(w)\cos2\phi]$$

Negative A2 from 3 to 8 m/s
Non-Bragg?

- Aquarius GMF for HH agrees well with the Japanese PALSAR GMF (Osamu Isoguchi and Masanobu Shimada, IEEE TGRS, 2009.)
Aquarius Scatterometer Model with Wave Effects

- HH is more sensitive to the effects of SWH.
Aquarius Scatterometer Model with Wave Effects

• Beam 1 is more sensitive to the effects of SWH.
Active-Passive Algorithms for Aquarius SSS and Wind Retrievals

• Combined Active-Passive (CAP) Algorithm
  • Retrieve SSS, Wind Speed and Direction Using Combined Passive and Active Data
  • Do not use NCEP winds for TB correction

\[
F_{pol}(SSS, W, \phi) = \frac{(I - I_m)^2}{2\Delta T^2} + \frac{(\sqrt{Q^2 + U^2} - \sqrt{Q_m^2 + U_m^2})^2}{2\Delta T^2} + \frac{(\sigma_{0VV} - \sigma_{0VV_m})^2}{(k_p \sigma_{0VV})^2} + \frac{(\sigma_{0HH} - \sigma_{0HH_m})^2}{(k_p \sigma_{0HH})^2}
\]

\[
I = T_{BV} + T_{BH}
\]

\[
Q = T_{BV} - T_{BH}
\]

Yueh and Chaubell, IEEE TGRS, April 2012

• \(TB_m = TB_m(W, \phi, SST)\)
• \(\sigma_m = \sigma_m(W, \phi)\)
• Ancillary input: Reynolds SST
Aquarius CAP Wind and SSS Composites

Aquarius CAP SSS and Wind from Aug 25, 2011 to July 12, 2012
CAP Wind Speed comparison with SSM/I

- Aquarius CAP winds agree well with SSM/I
  - standard deviation of speed difference $< 1.5$ m/s for 0-15 m/s
Wind Direction Difference with Respect to NCEP

- RMS wind direction difference smaller than 20 degrees for mid to high winds

Day 240 2011 to Day 91 in 2012
### Results of Triple Collocation Analysis

- Apply triple collocation method (Stoffelen, 1998)
- Aquarius RMS wind speed error about 0.76 m/s

<table>
<thead>
<tr>
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<th>SSM/I</th>
<th>NCEP</th>
<th>AQ-CAP</th>
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<tbody>
<tr>
<td>Beam 1 Random Error (m/s)</td>
<td>0.77</td>
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<td>Beam 2 Random Error (m/s)</td>
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<td>Beam 3 Random Error (m/s)</td>
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<table>
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<td>-0.33</td>
</tr>
<tr>
<td>Beam 3 bias B (m•s⁻¹)</td>
<td>0</td>
<td>-0.27</td>
<td>-0.43</td>
</tr>
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</table>
Influence of Rain on AQ CAP Wind Speed Retrieval

- AQ CAP Wind Speed retrieval appear reasonable over areas with precipitation – where there were no SSM/I speed retrievals.
- Windsat AW speed retrievals could be problematic above 4-5 mm/h
Comparison of AQ and NCEP Wind Speed under Rainy Conditions

- Aquarius CAP wind speed appears unbiased with respect to NCEP when SSM/I rain rate > 0.
NCEP vs Radar for Roughness Correction

Aquarius SSS Comparison with Hycom for Each Satellite Pass

• Radar is far superior to NCEP for roughness correction: 0.9 psu (s.d.) vs. 0.7 psu

• Land and ice fractions < 0.0005
• All wind speed and SST
Active-Passive Algorithms for Aquarius SSS and Wind Retrievals with SWH Correction

- Combined Active-Passive (CAP) Algorithm
  - Retrieve SSS, Wind Speed and Direction Using Combined Passive and Active Data
  - Do not use NCEP winds for TB correction

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\]

Yueh and Chaubell, IEEE TGRS, April 2012

- \(TB_m = TB_m(W,\phi,SST,SWH)\)

- \(\sigma_m = \sigma_m(W,\phi,SWH)\)

- Ancillary input: Reynolds SST and NOAA WW3 SWH
Effects of SWH Roughness Correction:

Aquarius SSS Comparison with Hycom for Each Satellite Pass

- SWH correction improves the s.d. accuracy by about a few percent

- Land and ice fractions < 0.0005
- All wind speed and SST
Wave correction reduces the systematic bias and standard deviation

V1.3.5 Difference with HYCOM
8/25/11-9/22/11

- CAP retrievals w/o and with SWH correction
Wave correction reduces the systematic bias and standard deviation

V1.3.5 Difference with HYCOM
4/5/12-5/3/12

• CAP retrievals w/o and with SWH correction
Wave correction reduces the systematic bias and standard deviation

V1.3.5 Difference with HYCOM

7/26/12-8/3/12

- CAP retrievals w/o and with SWH correction
Comparison with the Hybrid Algorithm for Aquarius V1.3.5

- Current V1.3 5 product uses the hybrid algorithm, which estimates an empirical TB correction for v-pol brightness from the NCEP wind speed, direction and radar VV sigma0
- The corrected V-pol TB is then used to retrieved SSS
CAP with SWH correction has smaller bias and standard deviation than the Hybrid Algorithm used for v1.3.5.

V1.3.5 Difference with HYCOM
8/25/11-9/22/11

V1.3.5 (Hybrid)
CAP with SWH correction has smaller bias and standard deviation than the Hybrid Algorithm.

V1.3.5 Difference with HYCOM
4/5/12-5/3/12

V1.3.5 (Hybrid)  V1.3.5 CAP Wave Correction
CAP with SWH correction has smaller bias and standard deviation than the Hybrid Algorithm

V1.3.5 Difference with HYCOM

7/26/12-8/23/12

V1.3.5 (Hybrid)

V1.3.5 CAP Wave Correction
CAP with SWH correction has smaller bias and standard deviation than the Hybrid Algorithm

V1.3.5 Difference with HYCOM
8/23/12-9/20/12

V1.3.5 (Hybrid)  V1.3.5 CAP Wave Correction
Error Assessment of 28-day Average for v1.3.5cap

- Monthly average errors have reduced to about 0.36 psu for >5 deg C and < 15 m/s

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<th>Period</th>
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<td>0.39</td>
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</table>
Principle for Effective Ocean Wave Slope Estimate

\[ \Delta T_{B_g} = R \int GP(\theta_x, \theta_y) T_{sky} d\theta_x d\theta_y \]

- \( \Delta T_{BG} \) varies with angular spread (or wave slope or wind speed) and position of beam in the galaxy
- For each Aquarius footprint, \( \Delta T_{BG} \) is evaluated for Gaussian beam width (B) of 5, 10, 15, 20, 25 and 30 degrees
- Use 3 months of Aquarius Beam 1 data for each wind speed range to find B(w) that minimizes the mean square difference.

Background figure from LeVine and Abraham, 2004
Sensitivity of TBG to B

- $\Delta$TBG has more variations for low B (low wind speed) near galactic plane
Aquarius B vs. Wind Speed

- $B(w)$ estimated from v-pol and H-pol agree with each other
Slope Model Comparison

- Larger than Cox-Munk – could this be caused by swell or long wave?
Improvement on Salinity Retrieval
Case Study 1 (High TBG and low wind)

- Use CAP algorithm to retrieve SSS using existing (red) and modified (black) TBG corrections
- Hycom SSS in green
Effects of Galactic Reflection Correction:

Aquarius SSS Comparison with Hycom for Each Satellite Pass

- Modified galactic reflection correction slightly improves the s.d. accuracy
- Galactic reflection has not been fully corrected.

- Land and ice fractions < 0.0005
- All wind speed and SST
Summary

• Aquarius radar sigma0 is much more effective than NCEP wind speed for roughness correction – about 30 percent better

• Wave correction using NOAA WW3 SWH allows the removal of systematic bias dependent on wind speed and SWH. Wave correction also improves the accuracy over a broader range of wind speed and SWH.

• The effective wave slope derived from the Aquarius data improves SSS retrieval.
  – The improvement did not provide much reduction for global averaged SSS error.

• Current monthly averaged accuracy is
  – About 0.36 psu for > 5 deg C and < 15 m/s
  – About 0.4 psu for all conditions.

• Ascending/descending bias not yet removed.
Delta TB estimate

- Compute the difference between model and observed TBs.
  - An exponential drift of the noise diode TB has been removed from v1.3.5
- Perform daily average of the differences for each channel
- V-pol channels appear quite stable lately, but H-pol channels are going through some steep drop.
Error Analysis - Triple Collocation Method

• 3 wind speed datasets: SSMI, NCEP, Aquarius retrieval.
  - \( w_{ssmi} = w + r_{ssmi} \)
  - \( w_{ncep} = a_{ncep} + b_{ncep}w + r_{ncep} \)
  - \( w_{scat} = a_{scat} + b_{scat}w + r_{scat} \)

• \( a, b \) are bias and scale factors, \( r \) is random error, \( w \) is true wind speed.

• Apply triple collocation method (Stoffelen, 1998) to determine \( a, b, \) and \( r \) for each.

• Assumptions:
  - \( <r_{ssmi}r_{ncep}> = <r_{ssmi}r_{scat}> = <r_{ncep}r_{scat}> = 0 \) (all errors uncorrelated)
  - SSMI has no bias and no scale offset from true winds.
  - \( <r_{ssmi}w> = <r_{ncep}w> = <r_{scat}w> = 0 \) (errors not correlated with true winds).
Improvement on Salinity Retrieval

Case Study 2 (Repeat case 1)

- Use CAP algorithm to retrieve SSS using existing (red) and modified (black) TBG corrections
Improvement on Salinity Retrieval

Case Study 3

- Use CAP algorithm to retrieve SSS using existing (red) and modified (black) TBG corrections