Retrieving Sea Surface Roughness and Salinity from Microwave Radiometry and Reflectometry Measurements Obtained During the Maine Offshore (Maineo) Experiment.

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Acknowledgements: This work was supported by NASA under Grant NNX15AU18G, and by the Office of Naval Research for NRL Project “Combined Use of L-band Reflectometry and Radiometry to Retrieve Surface Winds, Waves, and Wakes in Tropical Cyclones (TCW3)” under Program Element 0601153N7.

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Outline

• Maine Offshore (Maineo) Equipment and Flights (March, 2016).
• Radiometry and Reflectometry Retrieval Concepts.
• Prevailing Conditions, Wind Speed and Salinity Retrievals (Wind-driven Roughness Model Corrections)
• Simulations using the Finite Difference Time Domain Method (Effect of Mount on Antenna Patterns)
• The Carolina Offshore (Caro) Experiment (May, 2017)
• Findings and Future Work
NRL/Purdue Maine Offshore (Maineo)
Reflectometry and Radiometry Experiment
(Dates: 2-13 March, 2016)

Goal: Use GNSS-R+ surface roughness observations
to correct L-band radiometer SSS retrievals

Twin Otter Aircraft

Operations Area over Gulf of Maine

NRL/Purdue 6 Ch., Dual-pol GPS/XM SDR Reflectometer
NRL's STARRS radiometer system, with Infra-Red (IR) and L- and C-band Microwave radiometer pods, shown installed on a Piper Navajo aircraft.

The 6-beam sampling pattern for the L-band instrument is shown with pixel size 1 km and scan width of 6 km, at nominal 2600 m flight altitude. The IR and C-band instruments are nadir viewing, dual and 6-channel, single-beam systems, respectively, with footprint similar to L-band instrument.

<table>
<thead>
<tr>
<th>Flight Direction</th>
<th>Ocean (Ts, Tb, Oc)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STARRS Antenna Footprints</td>
</tr>
<tr>
<td></td>
<td>NEDT(1s)= 0.50 K</td>
</tr>
<tr>
<td></td>
<td>dS=1 psu</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Incidence Angles:</th>
<th>L-Band</th>
<th>C, IR &amp; Vis-Bands (SeaWiFS Chs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+/- 7,22,37 (deg)</td>
<td>Scan</td>
<td>Pixel</td>
</tr>
<tr>
<td>6.0</td>
<td>6.0</td>
<td>~1</td>
</tr>
<tr>
<td>0.6</td>
<td>0.6</td>
<td>~0.1</td>
</tr>
</tbody>
</table>
NRL Salinity Temperature and Roughness Remote Scanner (STARRS)
L-, C- and IR- Radiometer system.

Reflectometer Antenna Mounting
GPS: L-band RHCP (Direct, Topside)
RHCP and LHCP Reflected (Right side)
XM: S-band LHCP (Direct, Topside)
LHCP and RCHP Reflected, (Left side)

Sea surface view of sun glint on moderate sea
## Maine Offshore (Maineo) Flights

<table>
<thead>
<tr>
<th>No.</th>
<th>Date(Z)</th>
<th>Start (hh:mm)</th>
<th>Finish (hh:mm)</th>
<th>Dur (hrs)</th>
<th>Flight Plan</th>
<th>Event, Destination or NDBC Buoy#</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3/1</td>
<td>20:21</td>
<td>21:27</td>
<td>1.1</td>
<td>Grand Jn. CO Install/Test Small Lake, const. bank turn</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3/2</td>
<td>13:15</td>
<td>17:43</td>
<td>4.5</td>
<td>Transit over Rockies</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3/2</td>
<td>19:15</td>
<td>21:40</td>
<td>2.4</td>
<td>Lake Michigan</td>
<td>Chicago, Lake Transit, Jackson a/p</td>
</tr>
<tr>
<td>5</td>
<td>3/3</td>
<td>16:32</td>
<td>18:39</td>
<td>2.1</td>
<td>Transit to ME</td>
<td>Small Lake 18:23, Brunswick a/p</td>
</tr>
<tr>
<td>6</td>
<td>3/5</td>
<td>18:53</td>
<td>22:12</td>
<td>3.3</td>
<td>Buoy Cross 1</td>
<td>44005</td>
</tr>
<tr>
<td>7</td>
<td>3/6</td>
<td>18:39</td>
<td>22:33</td>
<td>3.9</td>
<td>Outer BuoyTrans1S</td>
<td>44005, 44011</td>
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<tr>
<td>8</td>
<td>3/8</td>
<td>19:08</td>
<td>22:48</td>
<td>3.7</td>
<td>Outer BuoyTrans2N</td>
<td>44024, 44034 (S), 44037(S)</td>
</tr>
<tr>
<td>9</td>
<td>3/9</td>
<td>#22:34</td>
<td>02:49</td>
<td>4.3</td>
<td>Buoy Cross 2</td>
<td>44037(S)</td>
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<tr>
<td>10</td>
<td>3/10</td>
<td>#12:30</td>
<td>16:34</td>
<td>4.1</td>
<td>Offshore Trans1</td>
<td>4005, 44011, 44024(S), 44037(S)</td>
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<tr>
<td>11</td>
<td>3/11</td>
<td>22:11</td>
<td>02:47</td>
<td>4.6</td>
<td>Coastal S Map 1</td>
<td>44037, 44037, 44032(S), 44034(S)</td>
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<tr>
<td>12</td>
<td>3/12</td>
<td>18:18</td>
<td>22:38</td>
<td>4.3</td>
<td>Offshore Trans2</td>
<td>4005, 44011, 44024(S), 44037(S)</td>
</tr>
<tr>
<td>13</td>
<td>3/13</td>
<td>11:49</td>
<td>15:54</td>
<td>4.1</td>
<td>Coastal S Map 2</td>
<td>40037, 44037, 44032(S), 44034(S)</td>
</tr>
<tr>
<td>14</td>
<td>3/14</td>
<td>12:15</td>
<td>13:46</td>
<td>1.5</td>
<td>Transit</td>
<td>Rutland, VT a/p, Lebanon, NH a/p</td>
</tr>
<tr>
<td>15</td>
<td>3/15</td>
<td>14:40</td>
<td>18:10</td>
<td>3.5</td>
<td>Transit</td>
<td>Eddie Rickebacker, OH a/p</td>
</tr>
</tbody>
</table>

S ⇔ NDBC buoy also observing in situ near-surface Salinity
# ⇔ Near-coincident overpasses of TechDemosat (TD-1) satellite reflectometry mission
Maine Flight Ground Tracks and NDBC Weather Buoy Stations
L-Band “Flat Sea” Salinity Retrieval Algorithm

SSS Dependence on Flat Sea L-Band Brightness and Surface Temperature

Source: Klein and Swift (1977)
Sea Surface Roughness and Salinity Retrieval

Reflectometry

Scattered Power

E-M Model

MSS

Reflectivity

Wave Model

Wind Speed & Direction

Radiometry

Wind Speed & Direction

Wave Model

MSS

Roughness

E-M Model

E-M Model

Salinity

Brightness & Physical Temps.

Flat Sea

(Klein & Swift, 1977)

\[ R = 1 - E \]

Kirchoff’s Law

Geometric Optics
Small Slope Approx./
Small Parameter Method
Radiative Transfer Model
Empirical Methods
(Variational, EKF etc.)

Wave

Emissivity

Elfouhailly
Hwang
Kudryavtsev
Donelan
Maineo 1-15 Mar, 2016 NOAA Buoy Wind Speed and Surface Salinity Time Series

Note: Red Bars Span Overflight Times

Source: NOAA National Data Buoy Center Weather Buoys
STARRS L-Band Coastal Salinity Retrieval

11 March 16

- Beams: 3L-3R
- L-Tb [K]

11 March 16

- Nadir View x 6
- IR-SST [deg C]

11 March 16

- 4.5 m/s, 1.1 m
- Beam Equalization (11 mar)
- SSS (32.1 psu)

13 March 16

- 10.2 m/s, 1.8 m
- Sun Glint (3R,3L)
- Beam Adjustment (11 mar)
- SSS (psu)

SSS Retrieval with Various Tb Roughness Models

No Roughness Correction

13 March 16
10.2 m/s
1.8 m

SSS

25.1 psu

Ssa/spm with Elfouhaily Spectrum

SSS

30.0 psu

Ssa/spm with
Elfouhaily
Spectrum

SSS

32.5 psu

Avg. Buoys
44034, 44037
32.0 psu

wise (Camps)
Emp. Wave
Model

WISe (CamPs)
Emp. Wave
Model

30.9 psu
Wind Speed derived from NRL/Purdue Reflectometry System – XM (LL and LR)

Departures between Cross and Co-pol retrievals associated with changes in flight direction

Zhang, H et al.: Sea Roughness Retrievals Using Dual-pol Reflectometry in S and L-Band
Simulating Antennas and Surface Scattering using FDTD Method

Maxwell’s Curl Equations:

\[
\frac{\partial E}{\partial t} = \left( \frac{1}{\varepsilon} \right) \left( \nabla \times H - \sigma E \right)
\]

\[
\frac{\partial H}{\partial t} = \left( \frac{1}{\mu} \right) \left( \nabla \times E \right)
\]

Faraday’s Law
Ampere’s Law

\( E \) = Electric Field, \( H \) = Magnetic Field, \( t \) = Time
\( \sigma \) = Conductivity, \( \varepsilon \) = Permittivity, \( \mu \) = Permeability

Numerical Procedure (Yee Algorithm):

Yee computational cell solves Maxwell’s equations efficiently, using explicit second-order differencing, interleaving E and H fields in space and time.

Model Features:

High resolution 2D and 3D computational grids.
Absorbing boundaries (Perfectly Matched Layer – Berenger; CPML – Gedney).
Plane-wave generator (Gedney, Ch. 7 in Taflove and Hagness (2005)).
Near to far-field transformation and Radar Cross Section – Taflove et al.

Simulating GNSS XM S-band Patch Antenna and Mounts with 2D FDTD E-M Model

Source Mode Structure Used for 2D FDTD Simulation

\[ E_z(x,y) = A_{mn} \cos\left(\frac{m\pi x}{W_{\text{eff}}}\right) \cos\left(\frac{n\pi y}{L_{\text{eff}}}\right) \]

HP Antenna Pattern

FDTD Simulation of Antenna Driven by a Patch Mode 0 Source with various PEC and/or Dielectric (at f=3.0E9 Hz)

PEC ↔ Perfect Electric Conductor
H-Pol Radiation Patterns for Patch Antenna Driven by Mode 0 source with Various Mounting Plate Configurations

Large PEC Mount

Small PEC Mount

Small Dielectric Mount

PEC/Dielectric Mount
A GNSS antenna was simulated at S-band, as a simple patch antenna (dielectric substrate separating conductive patch and ground plane)

Simulations were performed in 2D TMz mode (Ez, Hx, Hy) with Mode 0 source function feed on the active patch (at top).

Antenna Simulation Findings

1) Small PEC mounting plate produces a wide pattern at near grazing angles.
2) Larger PEC plate narrows the pattern (reduced power at grazing angles).
3) Pattern for a large lossless dielectric mount is narrow (like that for a small PEC mount).
4) Pattern for large lossy dielectric mount is wider (more like large PEC case).
5) Long mount of half dielectric and half PEC produces pattern asymmetry.
6) PEC plate under the half dielectric of 5, further increases asymmetry.
NRL/Purdue Carolinas Offshore (Caro) Reflectometry and Radiometry Experiment (Dates: 6-11 May, 2017)

**Goal:** Underfly CYGNSS and over-fly NDBC buoys using Dual Pol L- and S-band Reflectometer

**Experimental Domain**

**South Atlantic Bight**

Source: http://cordc.ucsd.edu/projects/mapping/maps/

Source: CYGNSS Specular point ground tracks were provided by Charles Bussy-Virat, Univ. of Michigan
Summary of Results

- Observations were made during Maineo using GPS and XM Reflectometers, and the STARRS Radiometer system.

- SST was low, so TBs were relatively insensitive to SSS variations. This means roughness effects dominate the retrievals.

- Consequently, it is challenging to estimate SSS precisely, but the effect of SSS variations on roughness emission increments is reduced.

- Estimates are proceeding by contrasting pairs of flights performed over similar tracks under differing wind conditions.

- A variety of semi-analytical and empirical roughness models are being tested using NDBC Data buoy and Reflectometry-derived wind speeds (or retrieved Mean Square Slope).

- For the modest satellite elevations at the latitude of Maine, antenna mount geometry apparently influenced the GNSS antenna patterns, and impacted the XM S-band retrievals (Higher elevation GPS retrievals where unaffected).
Future Work

Surface Salinity and Roughness

- Complete Salinity Retrieval and Roughness Corrections for Maineo.
- Process radiometry and reflectometry CYGNSS under-flight data from the latest (Caro) experiment.
- Apply CYGNSS Wind speeds with selected roughness models and observed MSS to correct SMOS and SMAP L-band SSS retrievals for roughness influence.

GNSS Antenna Patterns

- Measure the Antenna Patterns experimentally
- Implement a 3D version of the FDTD GPS patch antenna model to represent circular polarization.
- Correct the retrievals for antenna pattern effects.
Simulating White Cap Reflectivity using FDTD

YeeGrid_2D_CPML_TFSF_ADE_Loose_8c6i
wcrd=0.20-0.50 m, nwc=5, Fmth=0.05 m

Randomly distributed WC’s of 0.40-1.00 m diam.

High Emissivity (~0.6) over foam (WC’s)
Uniformly lower values (~ 0.3) over sea water.
FDTD Studies of Rough Seas and Foam Based on Anguelova’s RTM Foam Dielectric Profiles