Near-Real-Time Ocean Surface Vector Wind Retrievals from Passive Microwave Measurements: Status and Future Plans

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Basis for Passive Ocean Wind Retrievals

\[ T_b = T_U + \tau [eT_S + (1 - e)T_D] \]

approximates measured \( T_b \)
where:
- \( T_b \) = brightness temp.
- \( T_S \) = sea surface temp.
- \( e \) = ocean surface emissivity
- \( \tau \) = atmospheric transmissivity
- \( T_U \) = atmospheric upwelling temp.
- \( T_D \) = atmospheric downwelling temp.

▶ Ocean surface emission and scattering vary with wind vector
  ▶ Wind stress drives ocean surface wave spectrum
  ▶ Emission is also enhanced by sea foam
▶ Wind direction retrieval requires polarimetric radiometer
  ▶ Need 3rd/4th Stokes components to reduce direction ambiguity
Passive Ocean Vector Wind Timeline

- Early 1990’s: identification of wind direction signal in SSM/I data
- Mid-1990’s and later: aircraft campaigns to measure the wind direction signal for polarimetric radiometers
- 1990’s and later: rough surface modeling of wind direction signal in ocean surface emissivity and reflectivity
- 2003: WindSat launched
- 2004 and later: WindSat ocean vector wind retrievals demonstrated
- 2006: operational assimilation of WindSat wind vector retrievals in Navy NOGAPS model begins
- 2006: NPOESS CMIS canceled; replaced with MIS
- 2010: NPOESS split into JPSS and DWSS; DWSS microwave configuration TBD
WindSat Description

- Fully polarimetric at 10.7, 18.7 and 37 GHz
- Swath limited to allow for forward and aft looks
- Three rows of feed horns so for forward look
  - 18.7 GHz scan leads 37 GHz scan
  - 10.7 GHz scan lags 37 GHz scan

<table>
<thead>
<tr>
<th>Freq. (GHz)</th>
<th>Channels</th>
<th>BW (MHz)</th>
<th>EIA (deg)</th>
<th>IFOV (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.8</td>
<td>v, h</td>
<td>125</td>
<td>54.0</td>
<td>39 x 71</td>
</tr>
<tr>
<td>10.7</td>
<td>v, h, +/- 45, lc, rc</td>
<td>300</td>
<td>50.3</td>
<td>25 x 38</td>
</tr>
<tr>
<td>18.7</td>
<td>v, h, +/- 45, lc, rc</td>
<td>750</td>
<td>55.9</td>
<td>16 x 27</td>
</tr>
<tr>
<td>23.8</td>
<td>v, h</td>
<td>500</td>
<td>53.5</td>
<td>20 x 30</td>
</tr>
<tr>
<td>37.0</td>
<td>v, h, +/- 45, lc, rc</td>
<td>2000</td>
<td>53.5</td>
<td>8 x 13</td>
</tr>
</tbody>
</table>
WindSat Reflector and Feeds

Overview:
• WindSat/Coriolis Successfully Demonstrated Capability of Polarimetric Microwave Radiometry to Measure Ocean Surface Vector – Algorithms continue to improve
• Jointly Sponsored by US Navy and the NPOESS Integrated Program Ofﬁce
• Launched 06 Jan 2003 on STP' s Coriolis Satellite Bus Into a Sun-Synchronous Orbit
• Current Plan Calls for Continued Operation Throughout Useful Life of Coriolis/WindSat
• More than 46 months of data collected

Feedbench view from the main reﬂector.
Interpolation and Footprint Matching

- All frequencies and polarizations are interpolated to a common field of view
- Reduces side lobe contributions
- Mitigates shadowing effects seen in 3rd and 4th Stokes near coastlines and cloud or precipitation boundaries
- Varies with scan angle and position in the orbit

WindSat field-of-views for a subset of 4 spins.
Sensor Data Records (SDRs)

- Swath width is about 900 km
  - 6.8 GHz available over about 3/4 of the swath
- Three chosen resolutions (not optimized):
  - Low: 50 km x 71 km (All channels)
  - Medium: 35 km x 53 km (No 6.8 GHz channels)
  - High: 25 km x 35 km (No 6.8 GHz channels)
- Sampling is the same for all resolutions
  - about 12.5 km along track and along scan
- Retrieval distance to land depends on orientation of elliptical footprint to coastline
  - Low: 80 km to 115 km
  - Medium: 55 km to 80 km
  - High: 35 km to 60 km
Quality Control Flagging

- Two rain flags
  1. Retrieved cloud liquid water path $> 0.2$ mm
  2. First flag expanded by one “pixel”
- Radio-Frequency Interference (RFI) (more on this later)
- Land contamination
  - Footprints at each resolution are convolved with high resolution land mask
  - Orientation of elliptical footprint is accounted for
- Sea ice
- Satellite attitude anomalies
  - IFM is inaccurate if attitude changes significantly over several spins
  - $10.7$ GHz matching to $18.7$ GHz channels is worst case
Retrieval Algorithm

- Uses our parameterized geophysical model function
- Retrieval of 5 EDRs: $SST$, $W$, $PWV$, $CLW$ and wind direction $\phi_R$
- Inversion technique is two-stage optimal estimation (OE)

First Stage OE
Retrieval for $W$, $PWV$ and $CLW$

Second Stage OE
Retrieval for SST, $W$, $PWV$ and $CLW$
Ambiguity Selection

- 13 x 13 box size

- Cost function weighting
  - by wind speed
  - by first rank $\chi^2$ probability

- Nudging: Initialize using spatially interpolated wind from NWP
  - Ambiguities reported both with and without nudging
Radio Frequency Interference

- Persistent terrestrial and space-based RFI sources at 6.8, 10.7 and 18.7 GHz
  - Space-based RFI: signals from satellites broadcasting from geosynchronous orbit reflect off earth surface
- Detection of RFI over ocean uses chi-squared test from wind retrieval algorithm
- RFI has changed throughout WindSat Mission
RFI Mitigation

- Frequency bands flagged using:
  - Lon. / Lat. mask
  - Line-of-sight calculation from satellite to WindSat
  - Pixel-by-pixel flagging varies along scan
- Northern Hemi. for descending pass
- Southern Hemi. for ascending pass
- Channels flagged for RFI are excluded from retrieval
  - Pixel-by-pixel
Statistical Evaluations of WindSat OSVW Retrievals

- Compare to nearest QuikSCAT wind retrieval within 25 km and within one hour of the WindSat measurement
- Seven-month data set: 2008-09 through 2009-03
- Exclude rain (cloud liquid water (CLW) retrieval $> 0.2$ mm), land, sea ice contamination and RFI

The QuikSCAT L2B OVW 25 km data were obtained from the Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the NASA Jet Propulsion Laboratory, Pasadena, CA. http://podaac.jpl.nasa.gov.
Wind Speed Comparisons

- Good agreement below 20 m/s
- Above 20 m/s collocation errors become more important
  - Fewer collocations
  - Higher temporal and spatial variability
Wind Direction Comparisons

- **Performance**
  - improves with increasing wind speed
  - is comparable to QuikSCAT above about 6 or 7 m/s
  - weak dependence on ambiguity selection above 10 m/s wind speed
Graphics Display of WindSat Winds

- Winds are displayed as colored barbs
- Retrieved columnar cloud liquid water is plotted in gray-scale in the background
  - Helps to interpret winds because current algorithm is sensitive to rain
  - Provides additional information on the structure of storms and fronts
- All examples shown here use Hi. Res. WindSat retrievals.

Thanks to Tom Lee (NRL-Monterey) for choosing several of the examples shown in this talk.
Hurricane Earl

3 September 2010

CLW (mm) WS (knots)
0.50 60
0.45 55
0.40 50
0.35 45
0.30 40
0.25 35
0.20 30
0.15 25
0.10 20
0.05 15
0.00 10
0.00 5
0.00 0
Eastern Pacific Cold Front - PWV

29 Dec 2003
Eastern Pacific Cold Front - Winds

29 Dec 2003
Cyclone South of Aluetian Islands
Future Plans

- Examples show rain effects are the primary limitation of current algorithm
- Work to improve retrievals in rain
  - Basic physics investigations
  - Parameterizations for use in the forward model
  - Modified retrieval algorithm when rain is present
- Calibration
  - Reanalysis of pre-launch sensor test data
  - Documentation of sensor test data and analysis
  - High wind speeds and high water vapor
- Faraday rotation
  - Three-shell algorithm for accurate near-real-time corrections
  - Singh and Bettenhausen, Radio Science, in press