Bringing Consistency into High Wind Measurements with Spaceborne Microwave Radiometers and Scatterometers

Thomas Meissner, Lucrezia Ricciardulli, Frank Wentz, Andrew Manaster
Remote Sensing Systems, Santa Rosa, CA

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Photo courtesy: Seychelles Islands Development Company
Goals + Outline

- **Challenges of High Wind Measurements:**
  - Sparse ground truth.
  - Rain: Error source for most radiometers + scatterometers.
  - Sensitivity (signal) at high wind speeds.

- **Goal:** Develop concept for *inter-calibrating and validating* high wind speed measurements for various spaceborne sensors.
  - *WindSat* (radiometer 7 - 37 GHz, V + H-pol).
  - *QuikScat* (Ku-band scatterometer, VV-pol + HH-pol).
  - *ASCAT* (C-band scatterometer, VV-pol).
  - *SMAP* (L-band radiometer, V + H-pol).

- **Major validation source:** *SFMR* (NOAA HRD).

- **Key technique:** *Utilize strengths of each instrument* where appropriate:
  - Sensitivity to wind speed ranges.
  - (Non-) degradation in rain.
Low - Moderate Wind Speeds
Buoys Ground Truth Below 15 m/s

QuikScat (Ku 2011) – BUOYS
bias: -0.03 m/s
sdev: 0.87 m/s

RSS WindSat (V7) – BUOYS
bias: -0.14 m/s
sdev: 0.95 m/s

RSS ASCAT (V2.1) – BUOYS
bias: -0.01 m/s
sdev: 1.11 m/s

- Excellent correlation between satellite (QuikScat, WindSat, RSS ASCAT) and buoy wind speeds below 15 m/s.
- Buoys observations are sparse and unreliable above 15 m/s (high waves, tipping over, ...).
- NWP (ECMWF, NCEP) are not reliable in very high winds (> 20 m/s).
L-Band Radiometers

**SMAP (Soil Moisture Active Passive) + SMOS**

- First results were presented at IOVWST 2016 + Exeter workshop.
- L-band radiometer wind response does not saturate even at very high winds.
- L-band radiometer is *unaffected by precipitation* (< 25 mm h⁻¹).
- Extended to study of intense TC in 2015 + 2016 including intensity and wind radii.
- We started to create *microwave database of SMAP* maximum sustained winds and wind radii for NOAA and NRL.

Wind response =

Wind induced (excess) emissivity

\[
\Delta T_B = T_{B \text{ rough}} - T_{B \text{ flat}}
\]

<table>
<thead>
<tr>
<th>V-pol GMF</th>
<th>H-pol GMF</th>
<th>V-pol data</th>
<th>H-pol data</th>
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Wind response vs. Wind speed (m/s)
Main Validation Source for High Winds

Stepped Frequency Microwave Radiometer SFMR

SFMR has **not** been used in deriving GMF. Provides independent source for validation for satellites that can see through rain (SMAP, ASCAT).


Data provided by NOAA AOML HRD. Reprocessed release.

**Satellite – SFMR Match-Ups**

*requires careful editing of each storm*

- SFMR observations (3 km resolution) need to be resampled along-track to satellite resolution (25 – 40 km).
- **Need to limit intensity changes.**
  - Time match < 5 hours.
  - Use Best Track data to limit intensity change.
- **Shift in location.**
- Avoid eye/eyewall (discussion at Exeter High Winds Workshop)
- Need sufficient number of match-ups, not only one or two flights.
- Assessment possible within **uncertainty limits** (about 3 m/s).

SFMR correlate well with dropsonde wind speeds.

![Graph showing correlation between W dropsonde [m/s] and W SFMR [m/s]](chart)

- $n = 2713$
- $y = 0.98x + 0.73$
- $r^2 = 0.92$
- rmse = 3.9 m s$^{-1}$
SMAP/ASCAT vs resampled SFMR Match-Ups for 2015 + 2016

- Very good correlation + agreement between SMAP and resampled SFMR over whole wind speed range up to 70 m/s.
- No degradation in rain.
- L-band radiometer signal does not saturate at high winds.

Very good correlation + agreement between RSS ASCAT and resampled SFMR below 30 m/s.

Very poor - no correlation above 35 m/s. C-band VV-pol scatterometer signal saturates. Cannot be cured by scaling/adjusting GMF.
SMAP/ASCAT in TC Fantala
strongest observed cyclone in Indian Ocean (Seychelles)

<table>
<thead>
<tr>
<th></th>
<th>Max wind</th>
<th>33 m/s Rad</th>
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</thead>
<tbody>
<tr>
<td>SMAP</td>
<td>70 m/s</td>
<td>55 km</td>
</tr>
<tr>
<td>ASCAT</td>
<td>35 m/s</td>
<td>10 km</td>
</tr>
<tr>
<td>Best Track</td>
<td>69 m/s</td>
<td>63 km</td>
</tr>
</tbody>
</table>

April 17, 2016.
Estimated max. 10-min sustained winds: 69 m/s.
Almost **perfect line-up** of QuikScat (Ku 2011), SMAP and WindSat up to 40 m/s.
- Expect little changes in updated Ku-band scatterometer GMF at high winds.

- SMAP has a small positive constant bias (+ 1 m/s) compared to WindSat up to 40 m/s.
- RSS ASCAT has small negative (- 1 m/s) bias compared to WindSat. Bias increases at high winds (saturation).

- **Demonstrates consistency** between RSS radiometer and scatterometer winds in extratropical cyclones (rain free).
Intra-Satellite Consistency Calibration + Validation: Overview

- **WindSat**: Consistency - No Rain < 40 m/s
- **SMAP**: Consistency - No Rain < 40 m/s
- **ASCAT RSS V2.1**: Consistency - No Rain < 30 m/s

- **QuikScat Ku 2011**: Validated - Rain/No Rain All wind speeds (< 70 m/s)
- **GMF**: Consistency - No Rain < 40 m/s
- **Drop Sondes**: Validated - Rain/No Rain < 30 m/s
SMAP – WindSat: The Ideal Couple

Same ascending node time. Mutual benefit.

Extratropical cyclones. No rain. Develop SMAP GMF.

Tropical cyclones. Heavy rain. Train WindSat All-Weather Algorithm with SMAP Wind Speeds.

Drop Sondes

Validated Rain/No Rain All wind speeds (< 70 m/s)
WindSat Wind Speeds in Rain

Training: PATRICIA  Testing: JIMENA

- Current RSS WindSat all-weather algorithm had been trained up to 40 m/s.
- Train WindSat in rain retrieval algorithm with SMAP winds.
- Statistical algorithm.
  - Different from standard physical WindSat wind speed retrieval algorithm.
- Combine WindSat C-band and X-band channels to take out rain (SFMR-like).

\[
W_{\text{reg}} = c_0 + c_1 \cdot T_B^{C\text{-band}} + c_2 \cdot T_B^{X\text{-band}} + \ldots
\]

WindSat TB

linear regression

SMAP wind speed
Summary + Outlook

- **SMAP** wind speeds validated with **SFMR**.
  - Range: 15 m/s to at least 70 m/s. No saturation.
  - Not affected in precipitation, even in heavy rain.
  - Very valuable spaceborne sensor for assessing intensity and size of TC.
  - Cal/Val source for CYGNSS at high winds.

- **RSS ASCAT** winds validated with **SFMR**.
  - Agree very well below 30 m/s.
  - Demonstrate sensitivity loss and saturation of ASCAT wind speed response.

- Very good consistency between RSS radiometer (**WindSat, SMAP**) and scatterometer (**QuikScat, ASCAT**) in extratropical cyclones.
  - Particular: **QuikScat / WindSat agreement** to 40 m/s (no rain).
  - Need careful rain filter and go through many storms.

- First results indicate capability to train **WindSat** winds in rain (C/X-band channels) using **SMAP**.
  - Up to TC with intensity 4 – 5.
  - Can be extended to other C/X-band radiometers (**AMSR-E, AMSR2**).
Backup Slides
Greenland Flow Distortion Experiment

Up to 25 m/s

- Aircraft observations during Feb + Mar 2007.
- 150 measurements during 5 missions.
- Wind vectors measured by turbulence probe.
- Adjusted to 10m above surface.
- Contamination from land and sea ice. Makes satellite wind speeds systematically high. Radiometer most affected.
WindSat Wind Speeds in Rain

Use SMAP wind speeds as "truth"

- Current RSS WindSat all-weather algorithm had been trained up to 40 m/s.
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- Combine WindSat C-band and X-band channels to take out rain (SFMR-like).

\[ W_{reg} = c_0 + c_1 \cdot T_B^{C\text{-band}} + c_2 \cdot T_B^{X\text{-band}} + K \]

\[ \frac{c_1}{c_2} \approx -\frac{5}{2} \]

T. Meissner + F. Wentz
IEEE TGRS, 47(9), 3065 – 3083, 2009