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SMAP-based Training of All-Weather Wind Speed Retrievals from WindSat and AMSR

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Motivation

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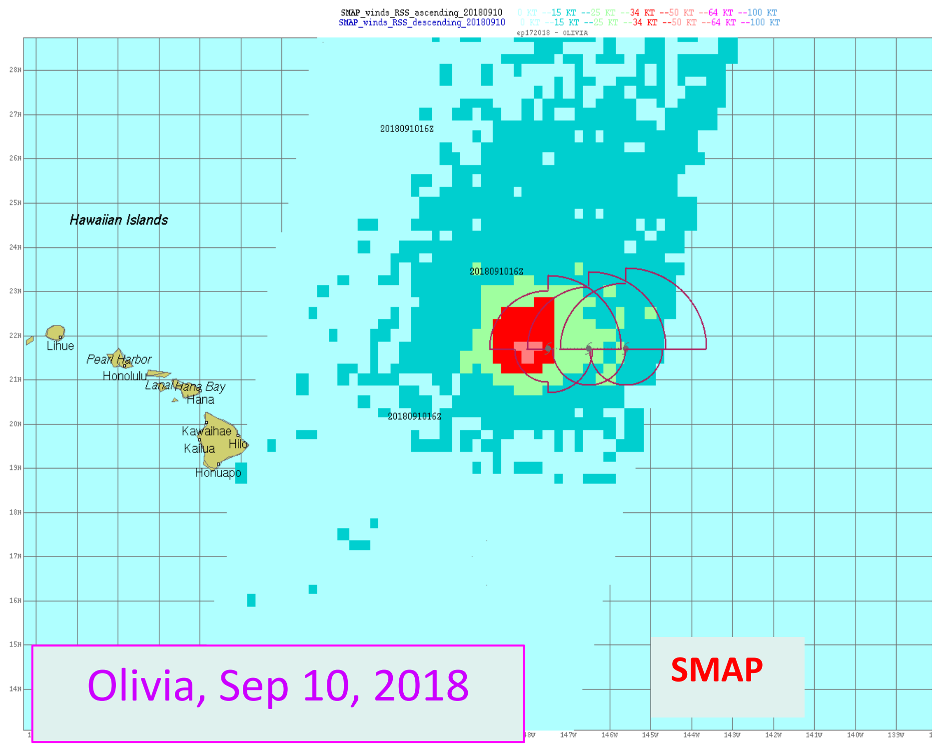
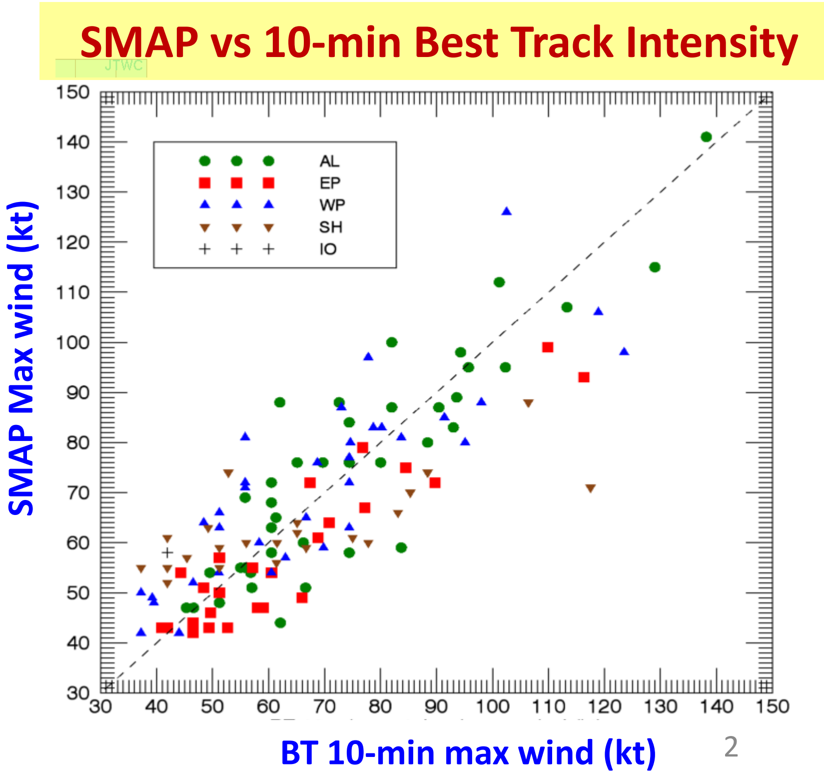
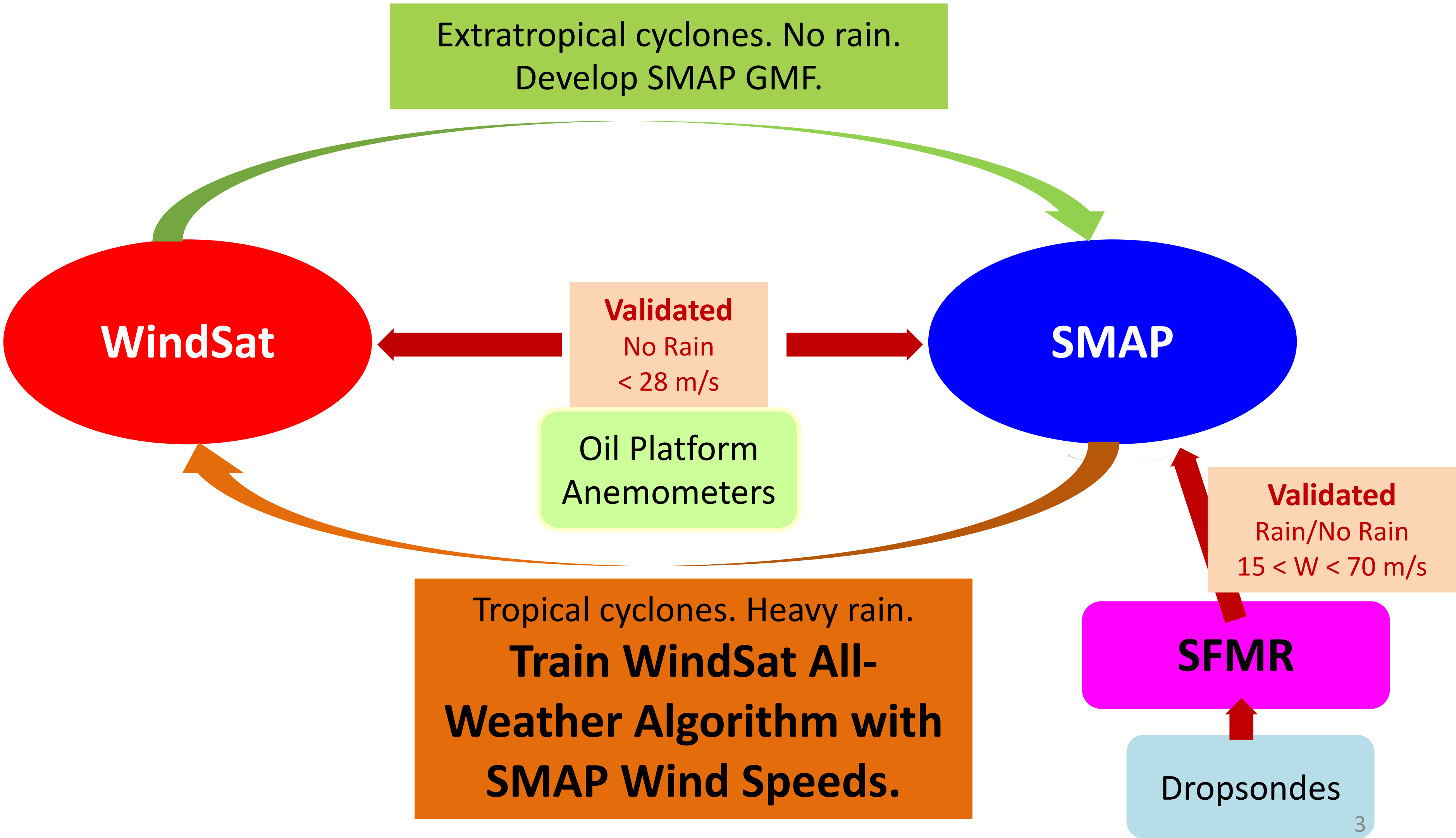
- **Reliable winds from SMAP** (L-band radiometer) in Tropical Cyclones.
- SMAP allows Near-Real Time TC Radii (size) and Intensity estimates.
- Ingested into Automated Tropical Cyclone Forecast (ATCF) system (NRL/Navy) and JTWC.
- **Extend to C/X band radiometers** (WindSat, AMSR) to improve coverage.
- Major obstacle: **rain degradation** at higher frequencies.





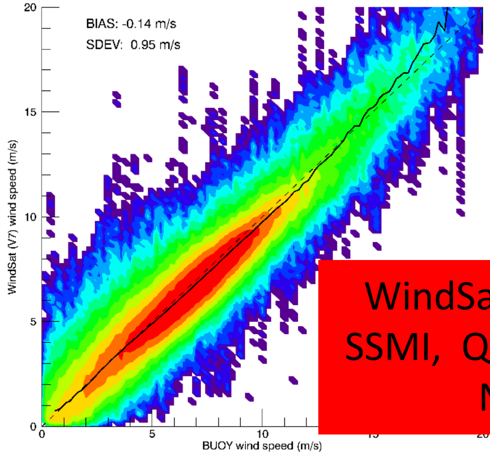
SMAP – WindSat: The Ideal Couple

Same ascending node time. Mutual benefit.



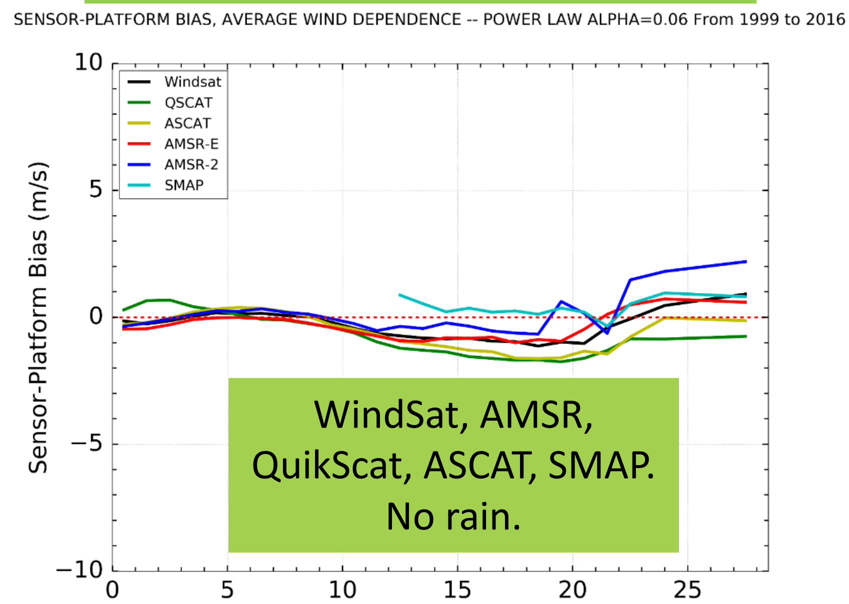
Wind Speed Validation

BUOYS: < 15 m/s

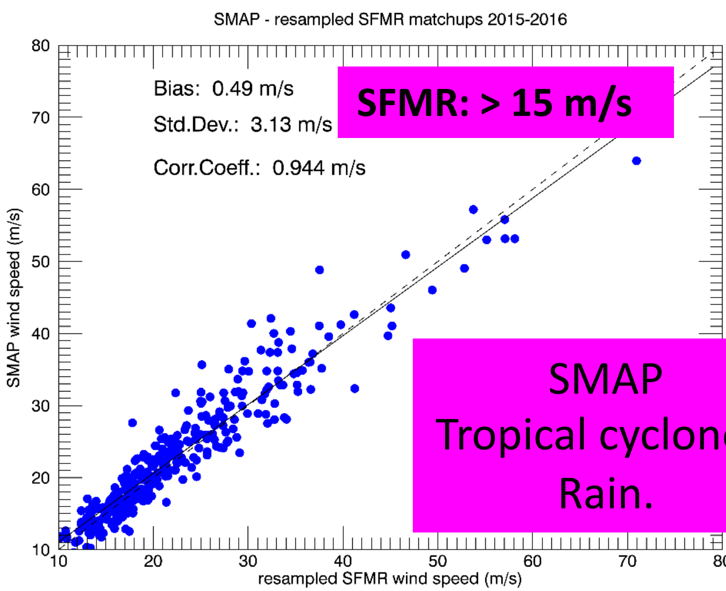


WindSat, AMSR,GMI, SSMI, QuikScat, ASCAT. No rain.

Platform Anemometers: < 28 m/s

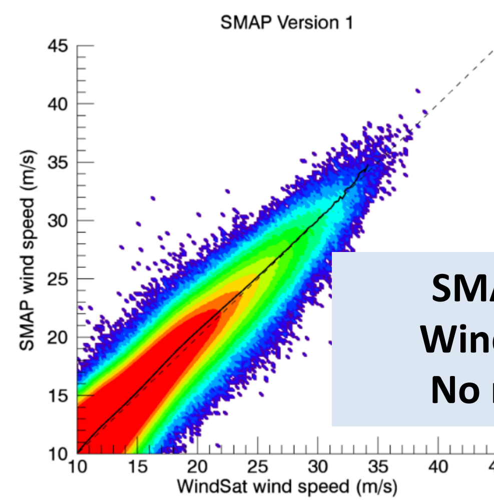


WindSat, AMSR, QuikScat, ASCAT, SMAP. No rain.



SFMR: > 15 m/s

SMAP Tropical cyclones. Rain.



SMAP – WindSat. No rain.

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Objective

- WindSat standard wind algorithm (10.7 – 37 GHz):
  - Rain free.
  - Validated up to 28 m/s (Buoys, Platform anemometers).
- SMAP: (L-band radiometer, 1.4 GHz)
  - Validated for wind speeds above 15 m/s.
  - Rain and no rain.
  - Consistent with WindSat in no rain.
- **Goal: Use SMAP winds in tropical cyclones (high winds, rain) to train WindSat in these conditions.**
  - Based on WindSat TB / SMAP wind speed match-ups.
  - Very good overlap between both sensors at all wind speeds.
- Current (Version 7) RSS WindSat All-Weather algorithm was trained from HRD/H-winds (Powell et al.).
  - Limited number of match-ups at very high winds (> 40 m/s).

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Basic Principle

- Basic principle taken from SFMR, which combines various radiometer C-band channels to take out rain effect.
- Combine **WindSat C-band** (6.8 GHz) and **X-band** (10.7 GHz) channels so that the combination is insensitive to rain (Meissner + Wentz, IEEE TGRS, 2009).

r ocean surface reflectivity

τ atmospheric transmittance

$$T_B \approx \left[1 - r \cdot \tau(R, \ldots)^2\right] \cdot T_{eff}$$

R rain rate

T_{eff} ocean-atmosphere temperature

- The combination $\Delta T_B(\lambda) = T_{B,C} - \lambda T_{B,X}$ is insensitive to rain if $\partial/_{\partial R}\, \Delta T_B(\lambda) = 0$.

$$\lambda \approx 1/3 \ldots 2/5$$

General Method

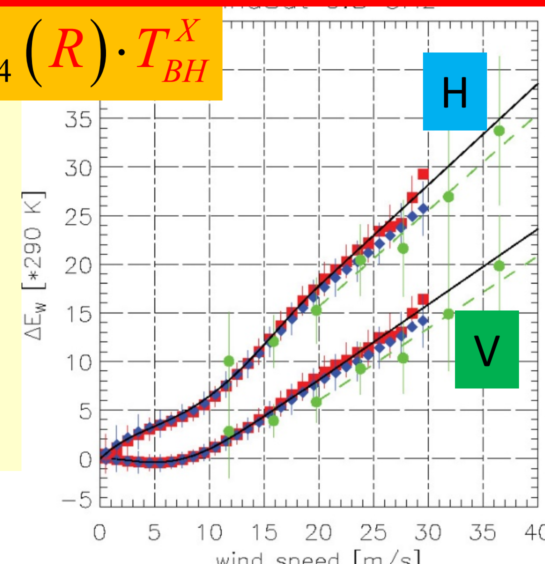
- Create SMAP – WindSat match-up data set in TC
  - 1 hour.
  - SMAP wind speed W_{SMAP} (> 13 m/s)
  - WindSat *TB*
  - WindSat rain rate *R*
- Train **statistical linear regression**:

GMF: WindSat surface TB as function of wind speed. Approx. linear > 12 m/s.

$$W_{reg} = c_0(R) + c_1(R)\cdot T_{BV}^{C} + c_2(R)\cdot T_{BV}^{X} + c_3(R)\cdot T_{BH}^{C} + c_4(R)\cdot T_{BH}^{X}$$

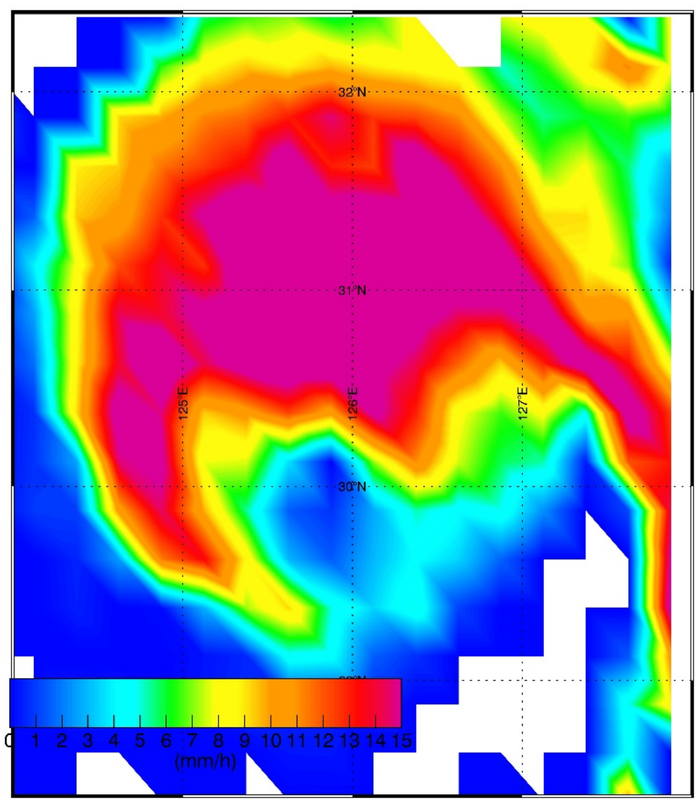
  - In different rain regimes. R from WindSat.

- 50% of the match-up set is used for training, the rest is used for testing.

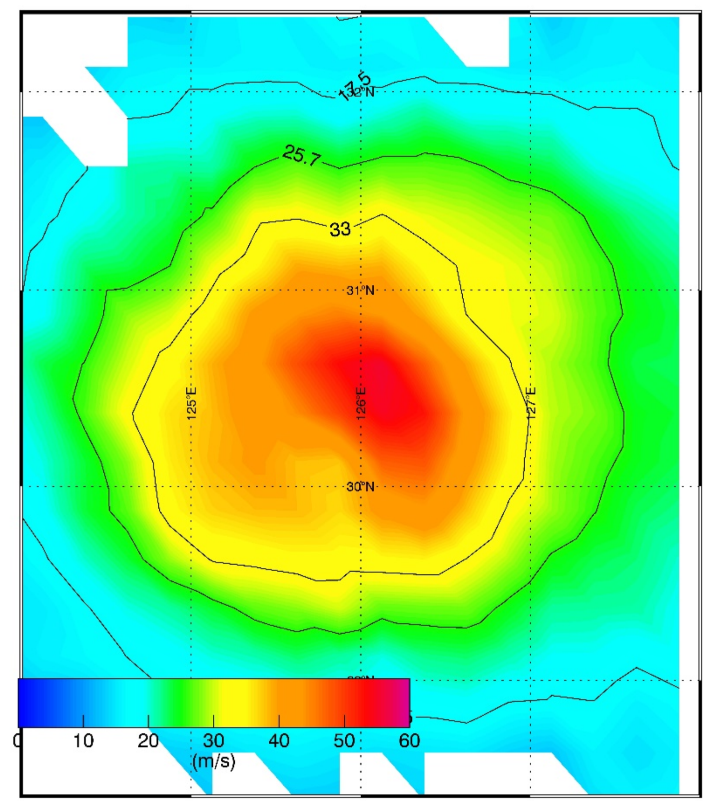


Chaba 10/04/2016

WindSat V7.0.1 rain rate L2B 71168



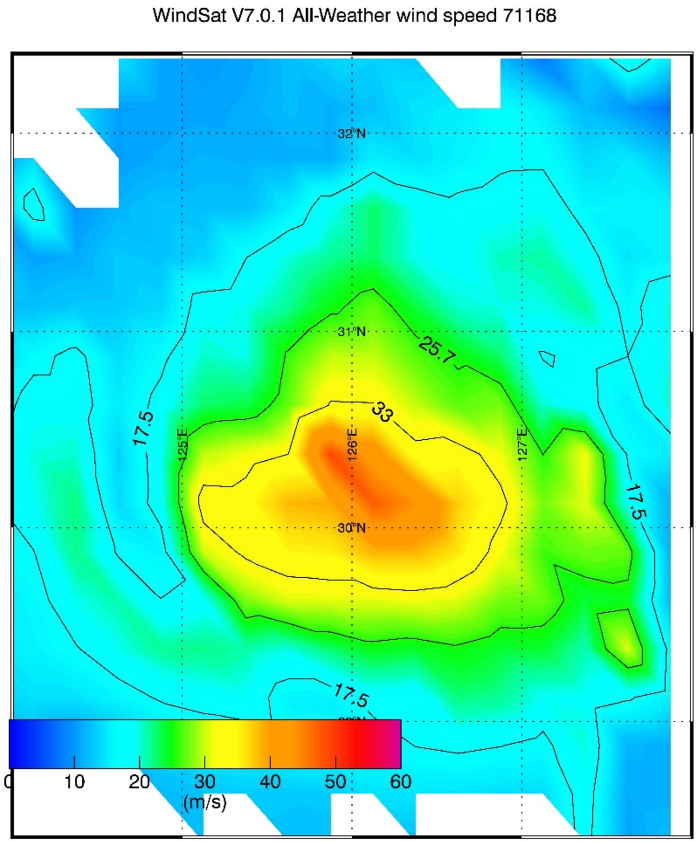
SMAP V1.0 wind speed 04 Oct 2016 09:30UTC

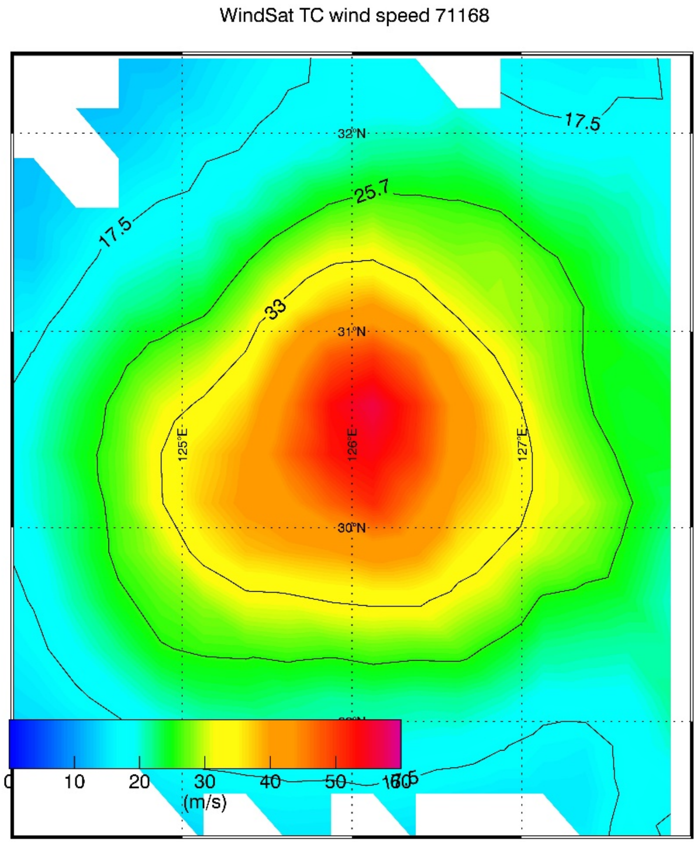


Rain Rate (WindSat)

Wind speed (SMAP)

Chaba 10/04/2016

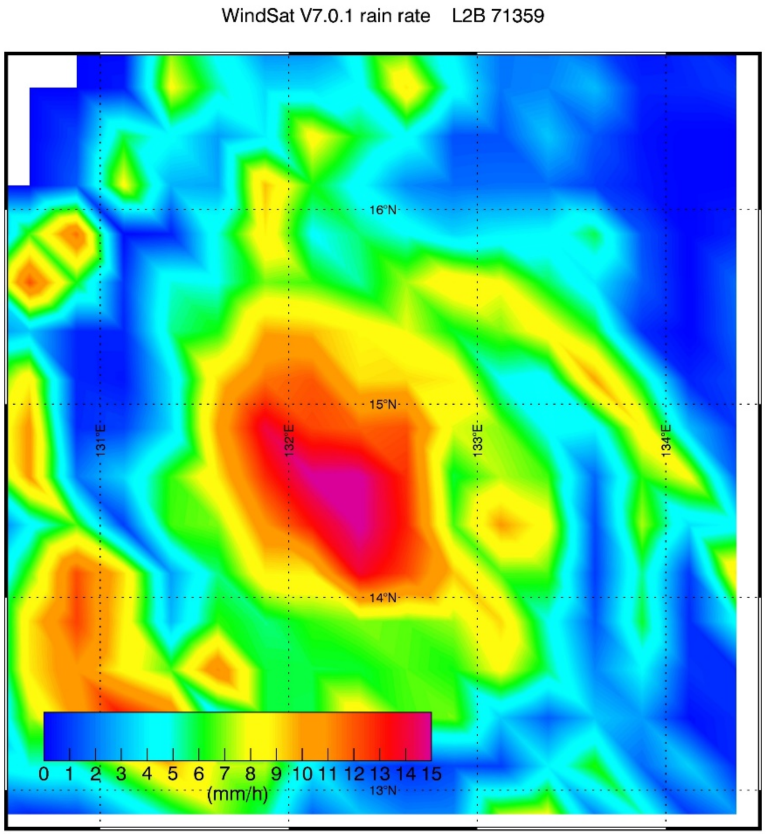




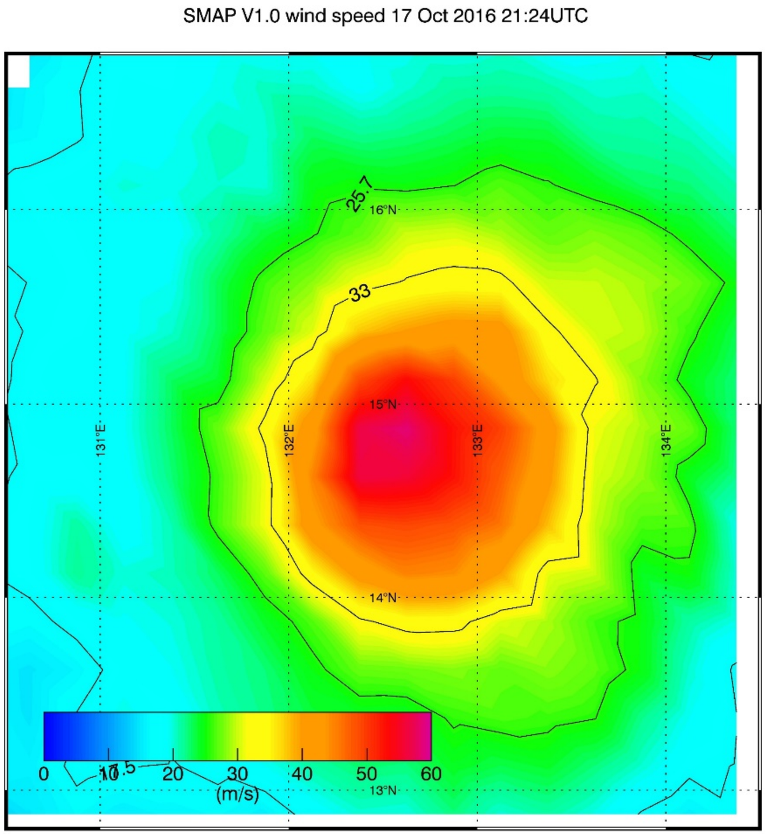
WindSat V7 All-Weather wind speed **trained with H-wind**

WindSat V7.1 TC wind speed **trained with SMAP wind**

Haima 10/17/2016

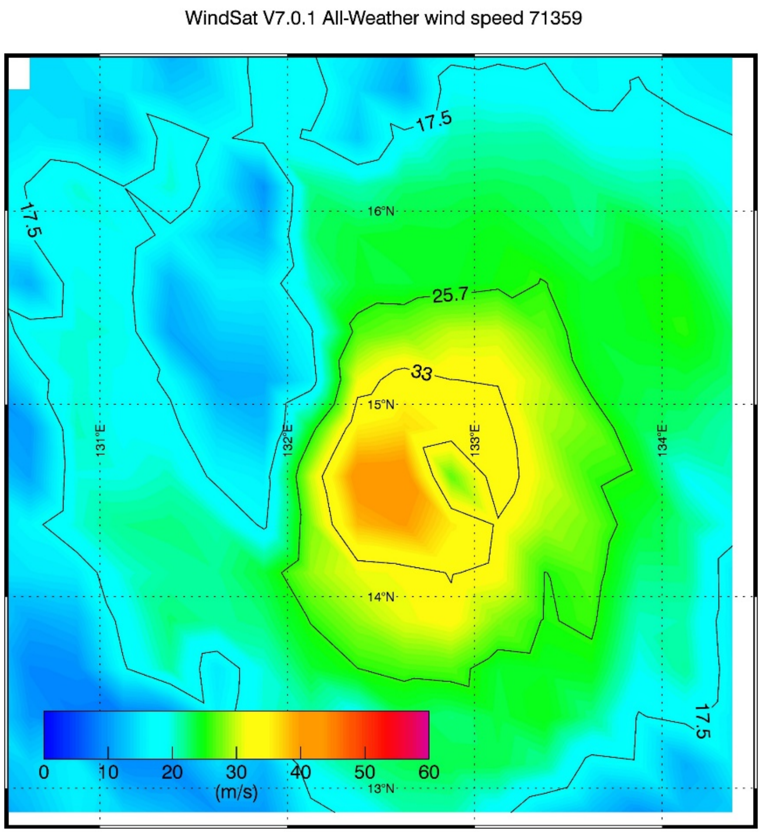


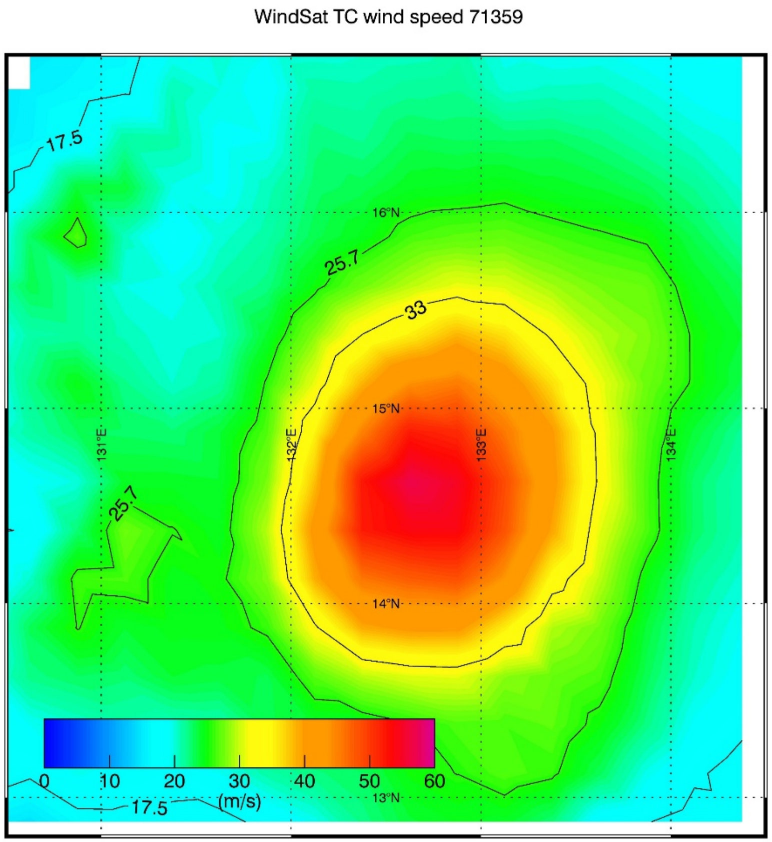
Rain Rate (WindSat)



Wind speed (SMAP)

Haima 10/17/2016





WindSat V7 All-Weather wind speed **trained with H-wind**

WindSat V7.1 TC wind speed **trained with SMAP wind**

NORU, 7-31-2017

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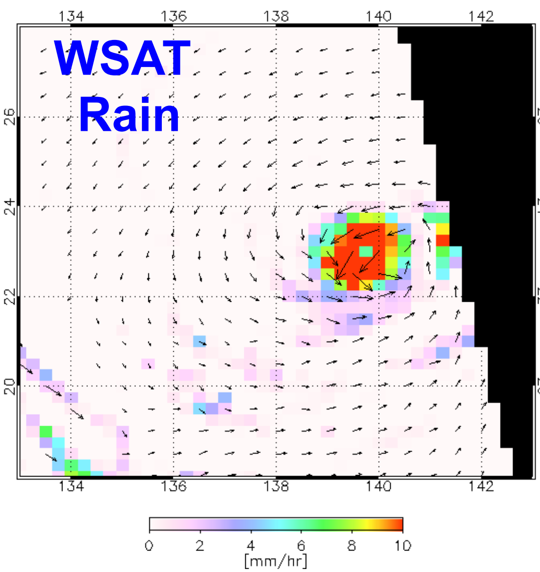
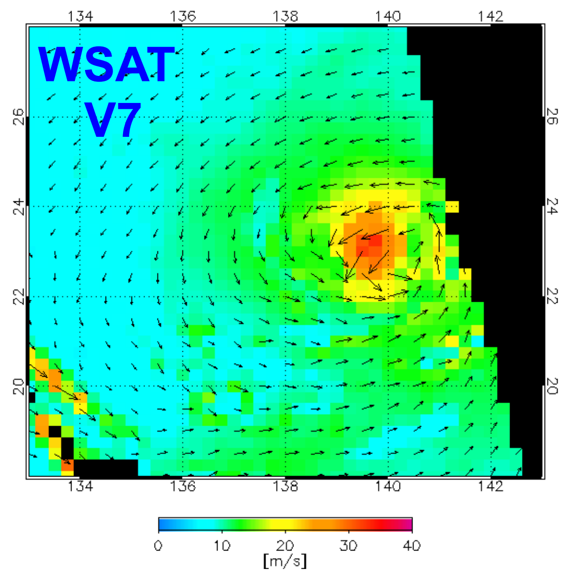
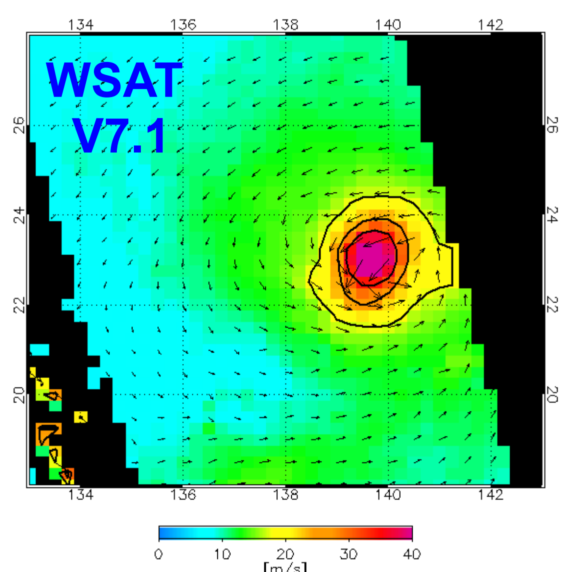
WindSat Rain Rate, 07–31–2017 8:50 UTC



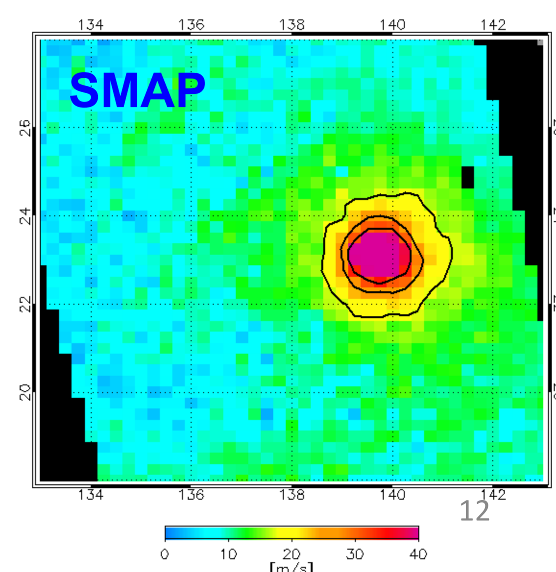
WindSat All–weather Wind, 07–31–2017 8:50 UTC



WindSat V7.1 All–weather Wind, 07–31–2017 8:50 UTC



SMAP WIND, 07–31–2017 8:37 UTC



- V7.1: Consistent wind field, and 34, 50 and 64 kt radii vs SMAP
- WSAT wind direction is mostly fine, except some noise in intense rain

IRMA, 9-5-2017

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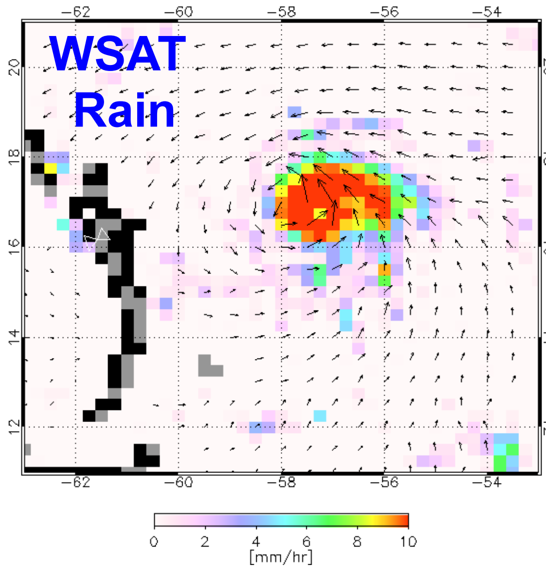
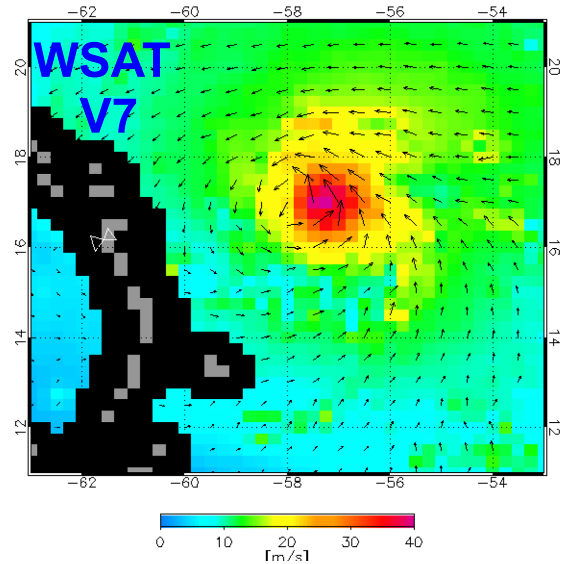
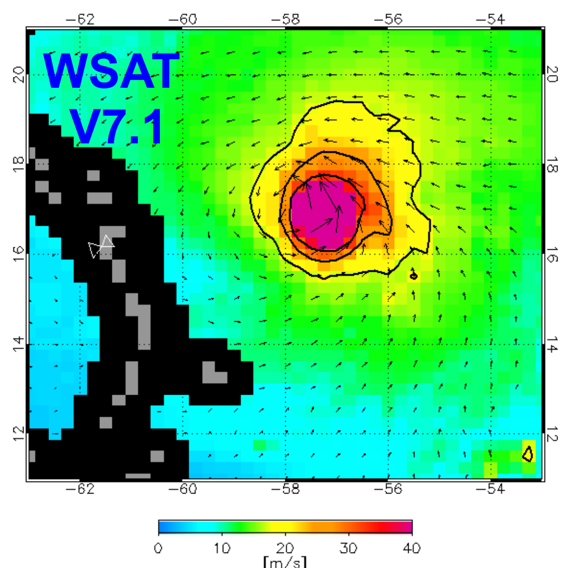
WindSat Rain Rate, 09−05−2017 10:17 UTC



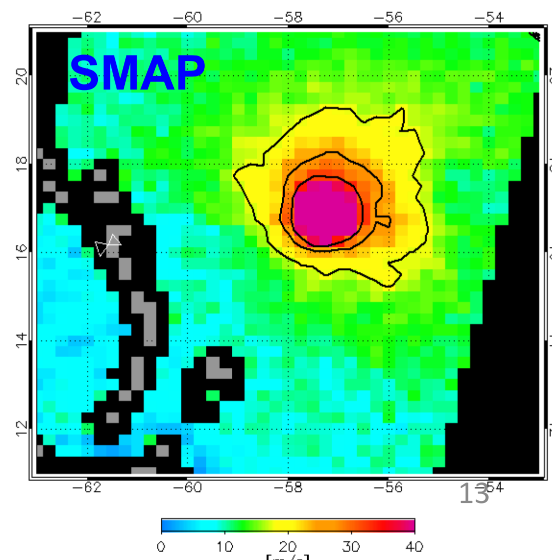
WindSat All−weather Wind, 09−05−2017 10:17 UTC



WindSat V7.1 All−weather Wind, 09−05−2017 10:17 UTC



SMAP WIND, 09−05−2017 10:06 UTC



YUTU, 10-25-2018

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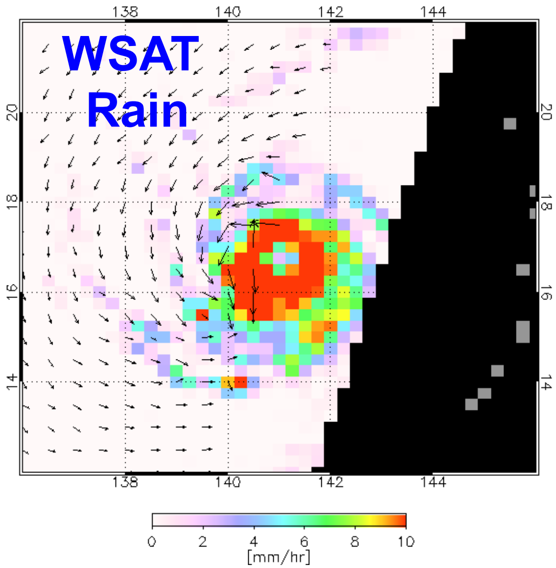
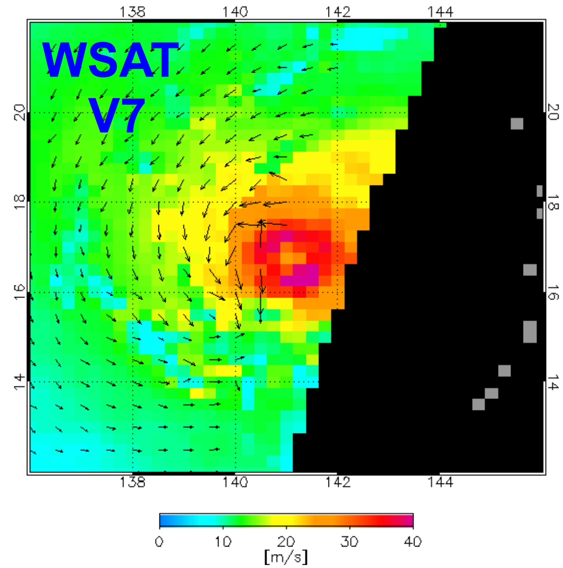
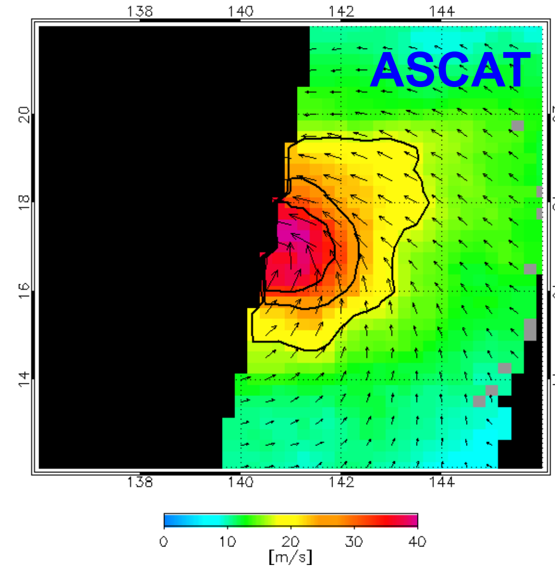
WindSat Rain Rate, 10–25–2018 21:24 UTC



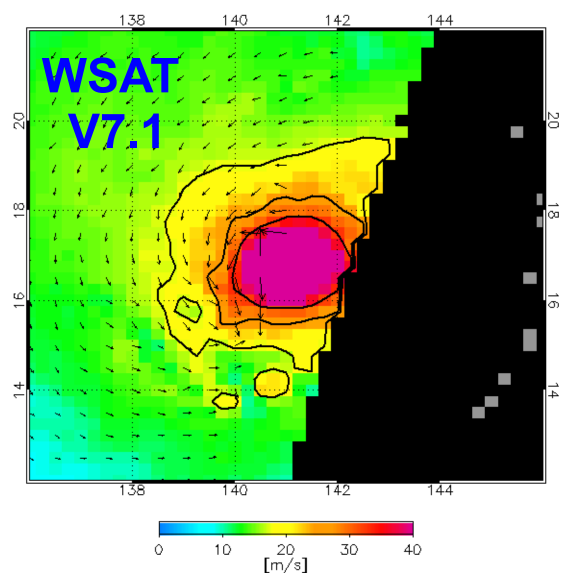
WindSat All–weather Wind, 10–25–2018 21:24 UTC



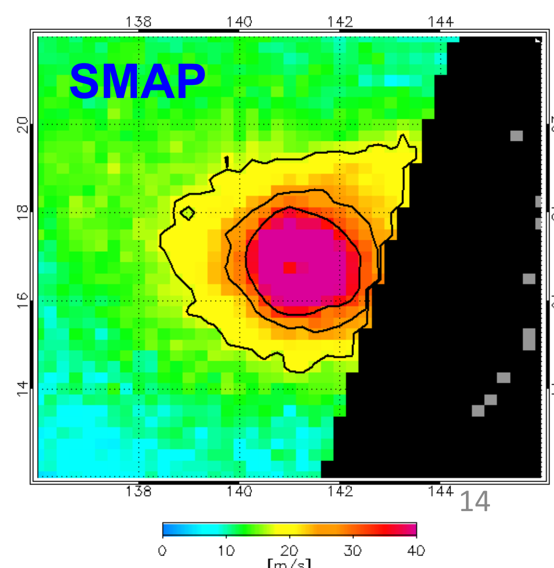
RSS ASCAT WIND, 10–25–2018 23:30 UTC



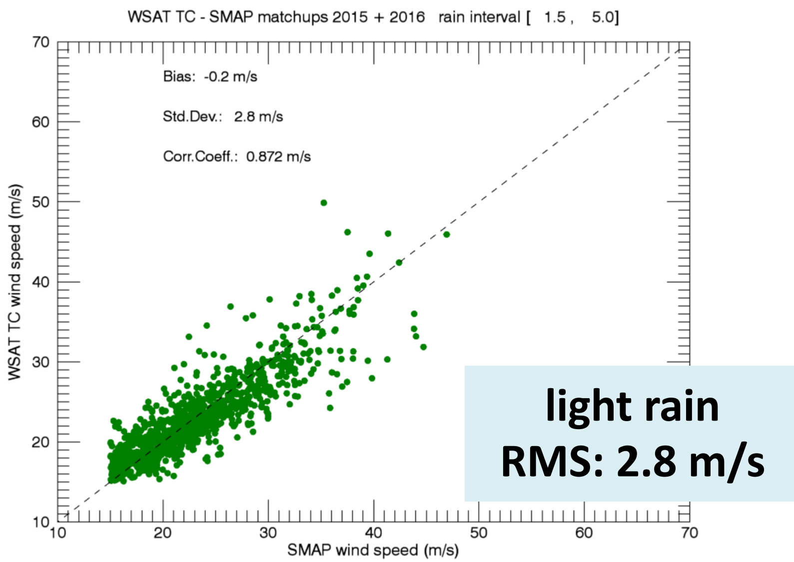
WindSat V7.1 All–weather Wind, 10–25–2018 21:24 UTC

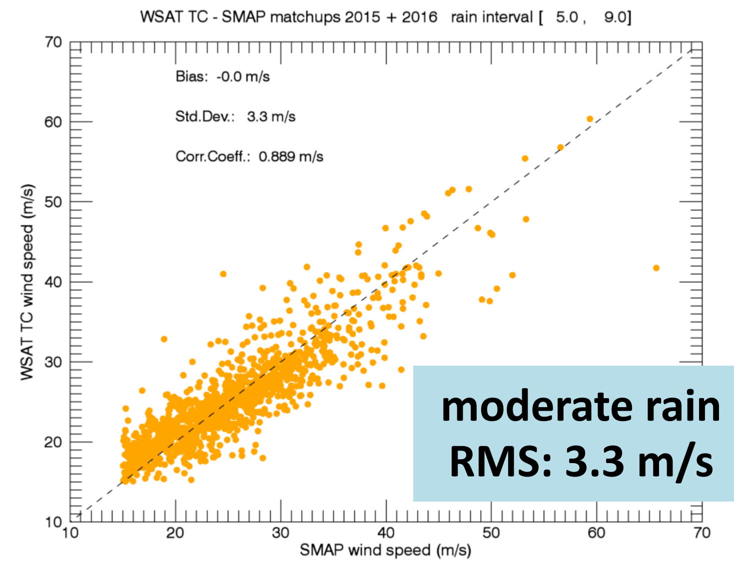


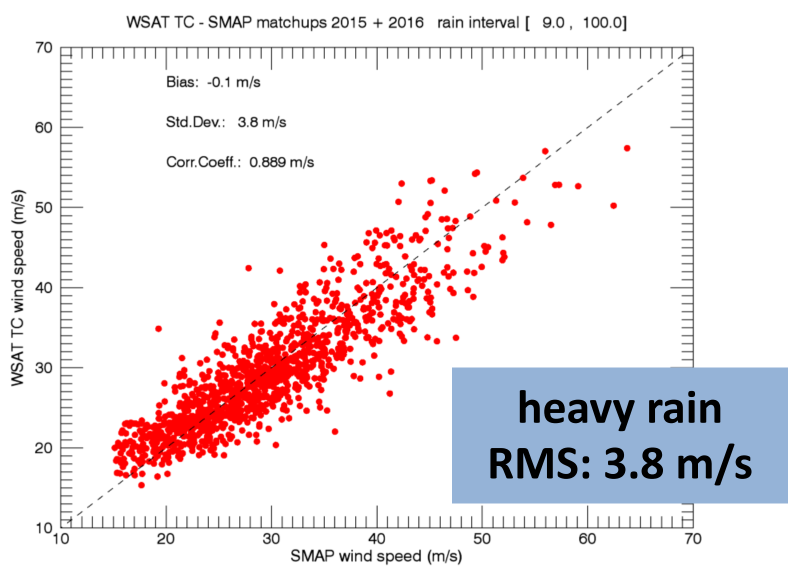
SMAP WIND, 10–25–2018 20:57 UTC



WindSat – SMAP Match-Up Statistics







Summary

- **SMAP** wind speeds in TC
  - Validated with **SFMR**.
  - Good agreement with Best Track data.
  - Range: 15 m/s to at least 70 m/s.
  - Not affected in precipitation, even in heavy rain.
- Used for training **WindSat** winds in TC conditions
  - High winds (> 13 m/s) and rain.
  - Good match-ups (same time).
  - Much better for training than H-winds (RSS V7.0 All-Weather winds).
  - Basis for RSS WindSat V7.1 All-Weather winds.
  - WindSat also provides good wind directions in TC.

Next Steps

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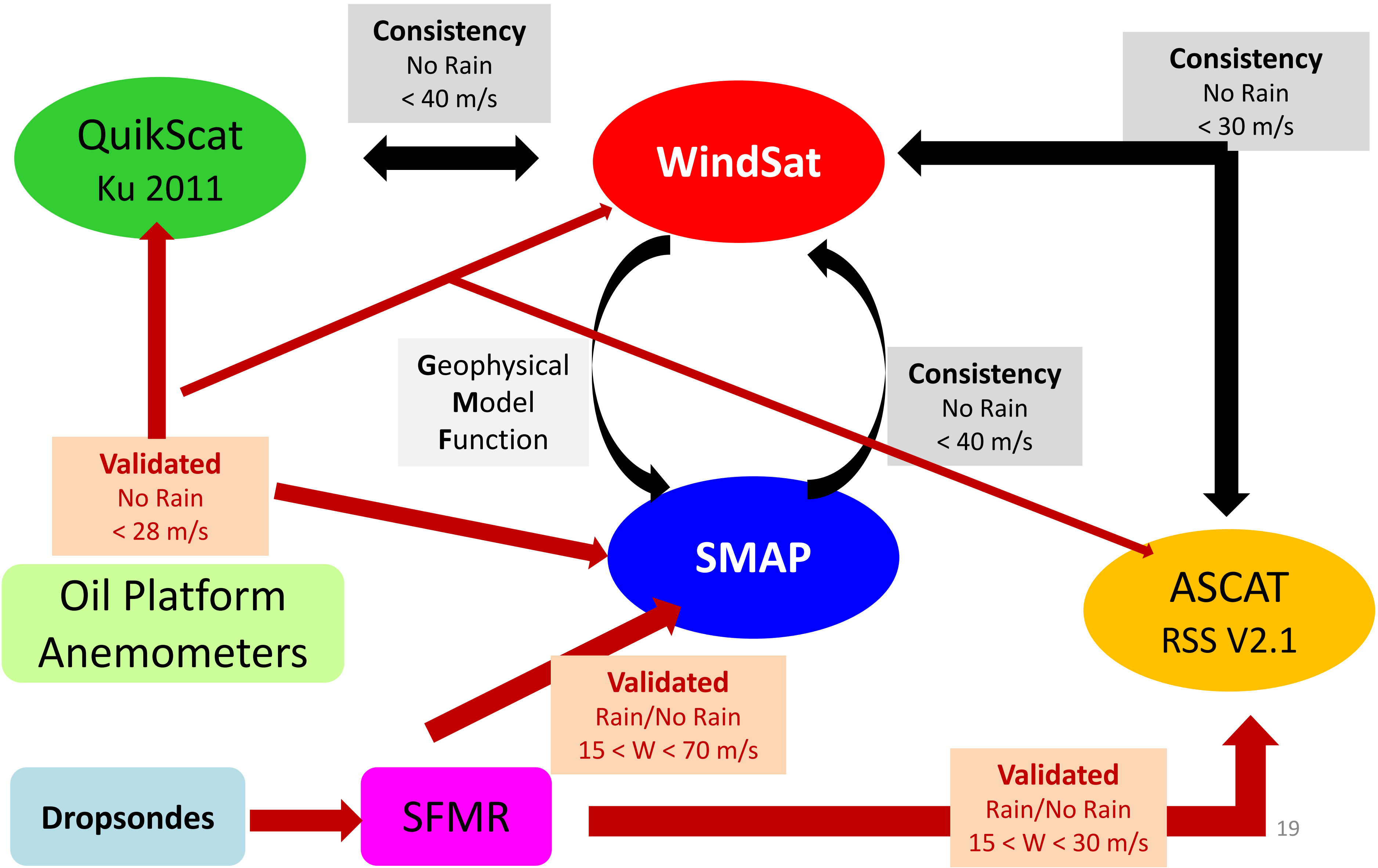
- Can and will be **extended to other MW radiometers with C/X band channels**.
  - **AMSR-E and AMSR2** (2 C-band + 1 X-band).
  - Frequencies and Earth Incidence angles slightly different from WindSat.
  - 1 AM/PM crossing time. No direct match-ups with SMAP.
  - Use RTM to adjust:
    $TB_{meas}(AMSR) - TB_{meas}(WSAT) = TB_{RTM}(AMSR) - TB_{RTM}(WSAT)$.
  - **Three MW radiometers to determine intensity and size (radii) of TC**.
- Extend to **extratropical cyclones**.
  - Straightforward in high winds (> 13 m/s).
  - Less precipitation.
  - Different SST.
  - All- weather blend together with TC and regular (no-rain) winds.
- More problematic in low winds.
  - SMAP winds degrade below 12 m/s.
  - TB – wind speed relation becomes non-linear at lower winds.

Backup Slides

Intra-Satellite Consistency

High Wind Speed Calibration + Validation



The WindSat wind direction retrieval in rain uses polarimetric channels (3rd and 4th Stokes) only at 10.7, 18.7, 37 GHz. They attenuate in very high rain giving noisy retrievals, but otherwise are OK.

Most likely, the wind direction signal stays constant or changes very little above a certain wind speed. That means, even if your wind speed is too low (V7.0 all-weather) the wind direction would still be OK.

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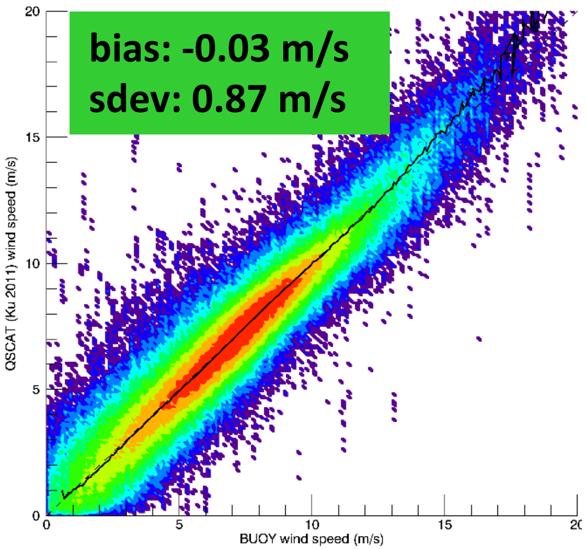
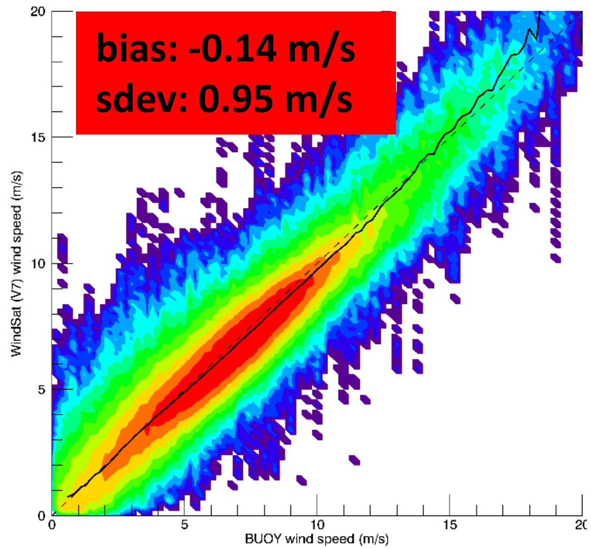
Low - Moderate Wind Speeds

Buoys Ground Truth Below 15 m/s

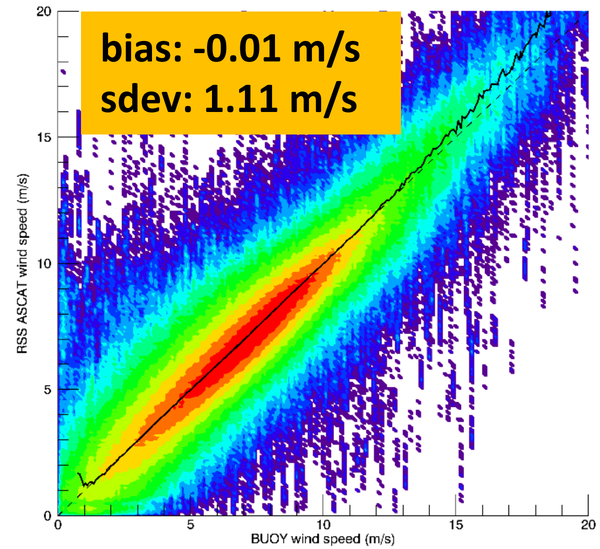
QuikScat (Ku 2011) – BUOYS



RSS WindSat (V7) – BUOYS



RSS ASCAT (V2.1) – BUOYS



- 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).

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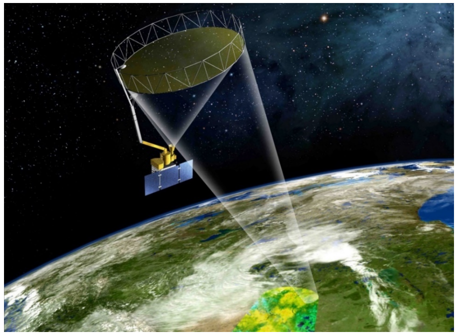
L-Band Radiometers

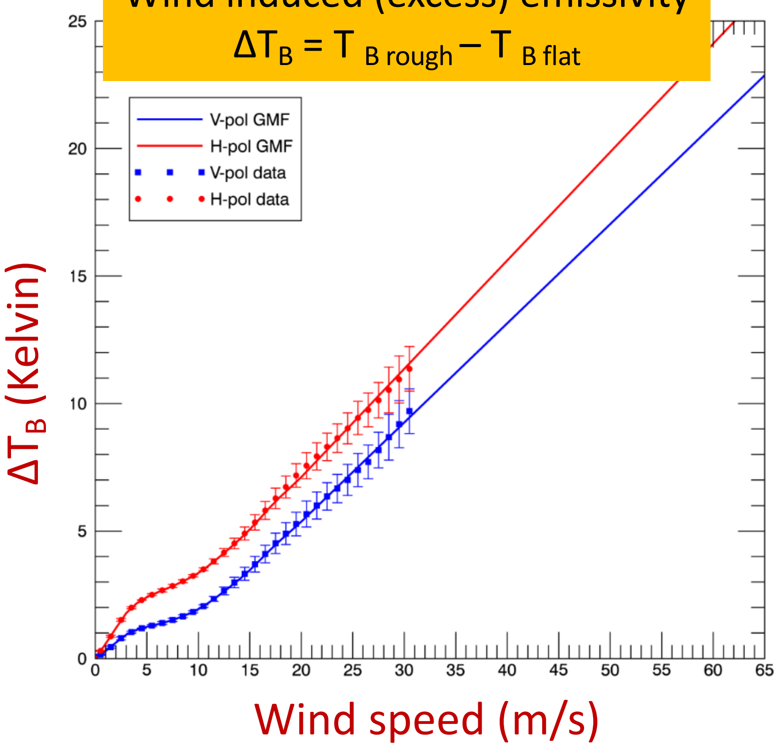
SMAP (**S**oil **M**oisture **A**ctive **P**assive) + SMOS



Wind response =

Wind induced (excess) emissivity

$\Delta T_B = T_{B\ rough} - T_{B\ flat}$



- First results were presented at IOVWST 2016.
- L-band radiometer wind response does not saturate even at very high winds.
- L-band radiometer is **basically unaffected by precipitation** (< 25 mm h^{-1}).
- Extended to study of intense TC in 2015 + 2016 including intensity and wind radii.
- **T. Meissner, L. Ricciardulli + F. Wentz: BAMS 08/2017. http://journals.ametsoc.org/doi/10.1175/BAMS-D-16-0052.1.**
- Data available at www.remss.com/smap.
- We started to create **microwave database of SMAP** maximum sustained winds and wind radii for NOAA and NRL.

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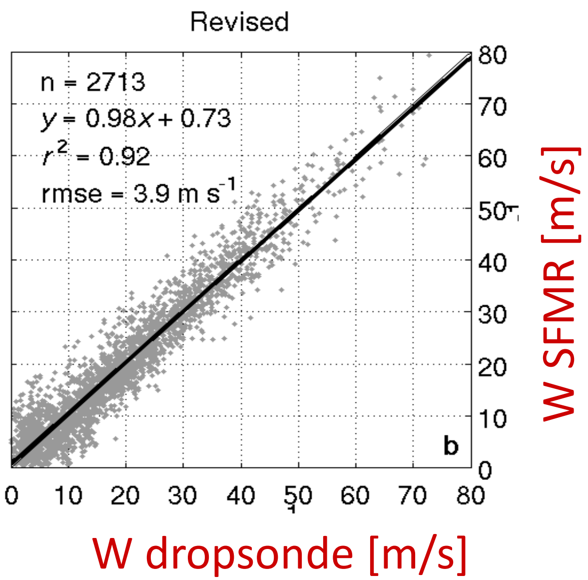
Main Validation Source for High Winds

Stepped **F**requency **M**icrowave **R**adiometer **SFMR**

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

B. Klotz and E. Uhlhorn, *JAOT,* 2014, 41, 2392 – 2408.
Data provided by NOAA AOML HRD.



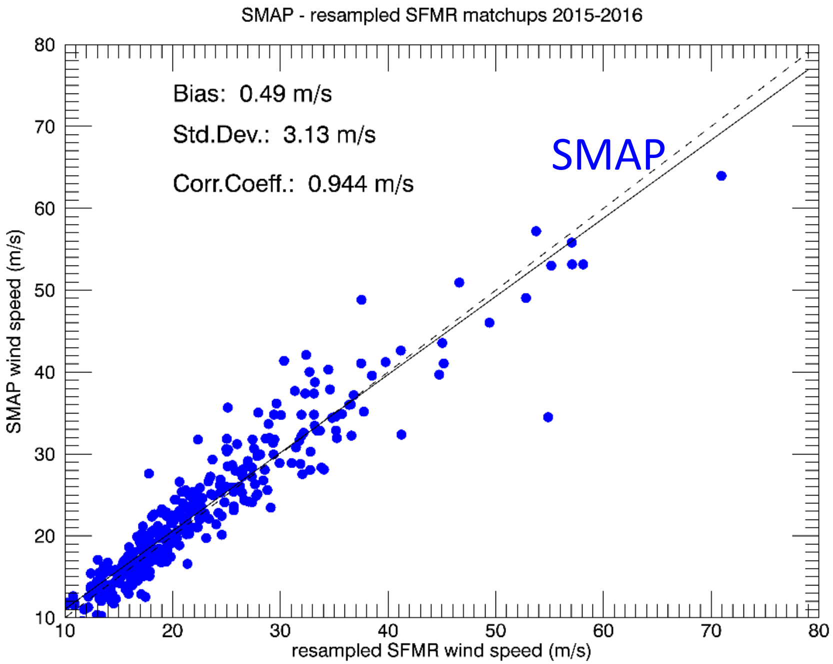
SFMR correlate well with dropsonde wind speeds.

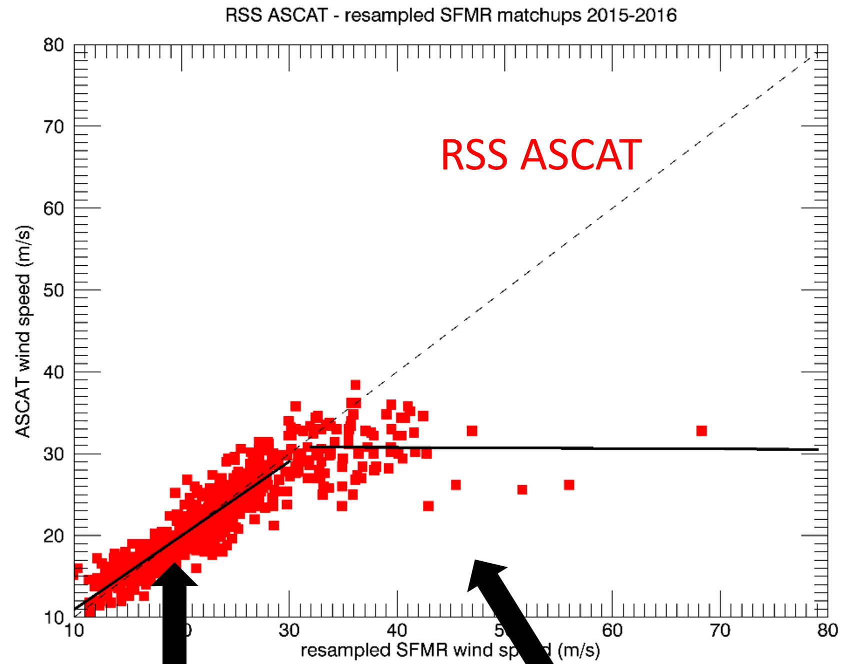
Satellite – SFMR Match-Ups

- SFMR observations (3 km resolution) need to be resampled along-track to satellite resolution (25 – 40 km).
- Time match: 5 hours. Need to limit intensity changes.
- 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).

SMAP/ASCAT vs resampled SFMR

Match-Ups for 2015 + 2016





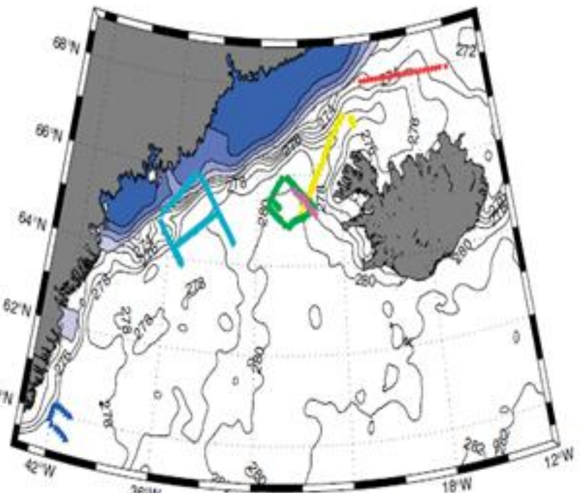
- **Very good correlation + agreement between SMAP and resampled SFMR over whole wind speed range up to 70 m/s.**
- No degradation in rain.
- L-band radiometer signal does not saturate at high winds.

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.

Greenland Flow Distortion Experiment

Up to 25 m/s



Renfrew et al. QJRMS 135, 2009, 2046 – 2066.

- 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.