International Workshop on
Measuring High Wind Speeds over the Ocean
15 – 17 November 2016
UK Met Office, Exeter

Remote Sensing Systems
www.remss.com

Ocean Vector Winds in Storms from the SMAP L-Band Radiometer

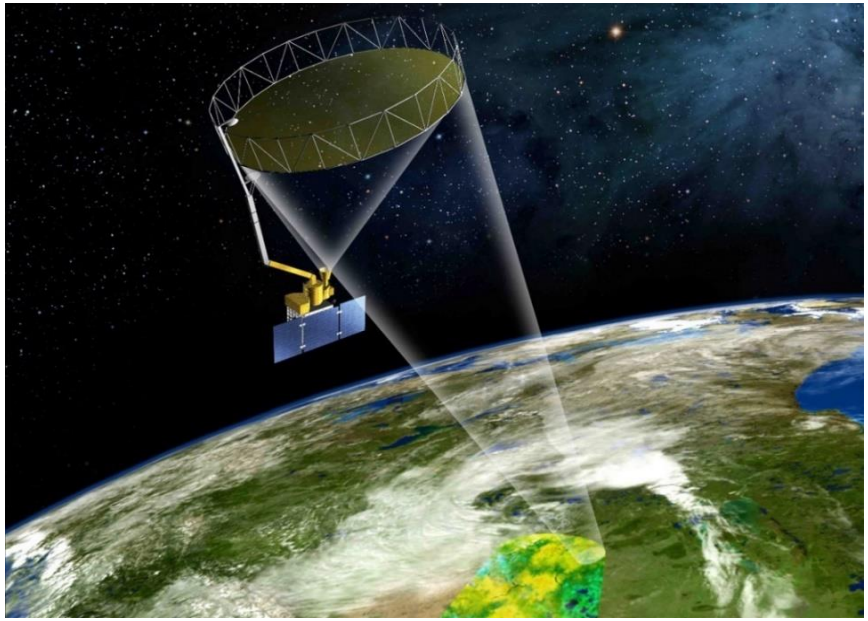
Thomas Meissner, Lucrezia Ricciardulli, Frank Wentz
Remote Sensing Systems, Santa Rosa, CA

submitted to BAMS

Photo courtesy:
www.DaveSandfordphotos.com

SMAP Soil Moisture Active Passive

Ocean Products: Sea Surface Salinity + Wind Speed

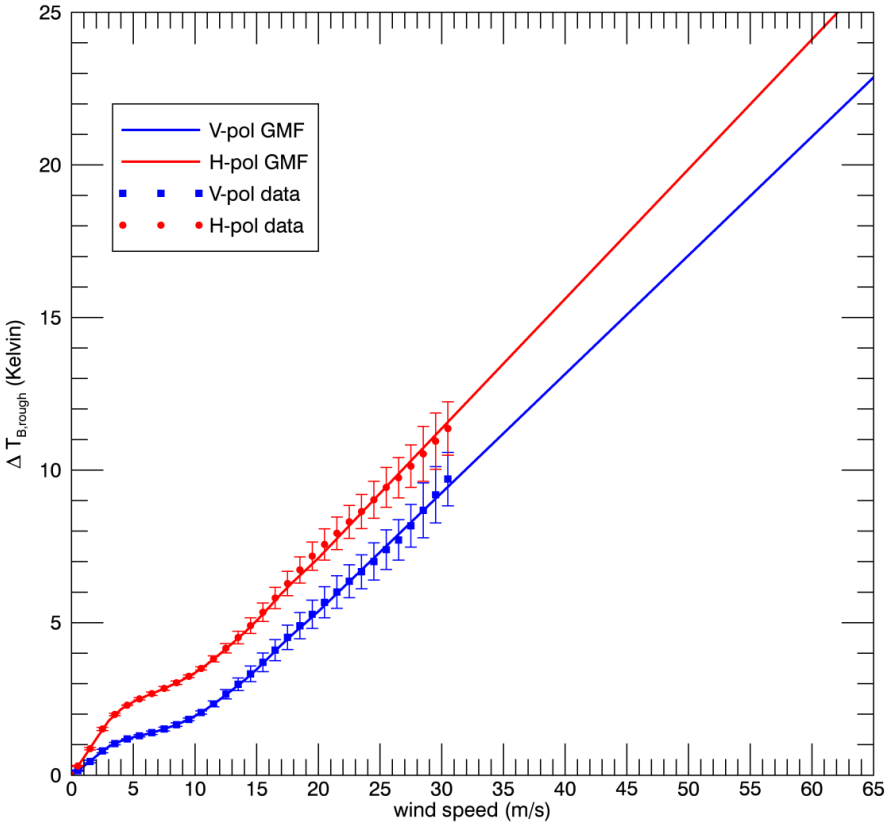


- Orbit Altitude: 685 km.
- Inclination: 98 deg.
- Local ascending/descending time: 6 PM/AM.
- 8-day repeat orbit.

- 6-meter mesh antenna.
- Conical scanning @ 14.6 rpm. Scan time: 4.1 sec.
- Earth Incidence Angle: 40°.
- Radiometer: Center frequency: 1.41 GHz ~~Radar.~~
- Full 360° scan views the Earth. 1000 km wide swath.
- 3-dB (half power) footprint size: 40 km.
- Time for sampling 1 footprint: 17 msec.

Wind Speed Response

Geophysical Model Function (GMF)



- Derived "off-line"
- Wind induced (excess) emissivity:
  $\Delta T_B = T_{B\ rough} - T_{B\ flat}$
- Derived from **SMAP TB – WindSat wind speed match-ups**.
  - Rain free scenes.
- Linear increase above 18 m/s.
  - **Emissivity signal from sea foam**
  - Extrapolate to high wind speeds.
- Consistent with results from Aquarius L-band radiometer.
  - *Meissner, Wentz + Ricciardulli, JGR Oceans, 2014.*
- This L-band wind GMF is used in salinity and wind speed retrievals for Aquarius and SMAP.

Wind Speed Retrieval

Remote Sensing Systems
www.remss.com

Algorithm

SMAP Level 1B swath ordered antenna temperature measurements T_A V-pol and H-pol

↓

optimum interpolated onto fixed 0.25°Earth grid

↓

remove spurious signals at L-band:
emissive SMAP antenna
cold space radiation (spillover)
antenna cross polarization
galactic radiation
solar + lunar radiation
land emission in antenna sidelobes
Faraday rotation (ionosphere)
atmospheric attenuation (O_2, clouds)

↓

gridded brightness temperatures at rough ocean surface $T_{B,surf}$
separate for for/backward looks

→

$T_{B,surf}$ -$T_{B,surf,flat}$
roughness induced part

↑

calculate brightness temperature of flat ocean surface $T_{B,surf,flat}$
Meissner-Wentz dielectric model

↑

ancillary fields
Salinity (HYCOM)
SST (CMC)

no NWP input necessary

↑

MLE
match to **GMF** for wind response
V-pol + H-pol

↑

average for/backward looks
noise reduction

↑

SMAP wind speed W

Wind Speed Retrieval

Uncertainty Sources

Uncertainty Source	Estimated Contribution to Global Error in Wind Speed	
Radiometer Noise	**1.20 m/s**	**dominant uncertainty source**
Ancillary Salinity	0.60 m/s	can be much higher in fresh-water plumes
Ancillary SST	0.45 m/s	
Wind Direction	0 m/s (W < 10 m/s) 1.5 m/s (W > 15 m/s)	only relevant at high winds
RTM	< 0.3 m/s. very accurate. used for retrieving ocean salinity which is the most unforgiving environmental parameter	
Instrument Calibration		
Total Global Wind Speed Uncertainty	**1.5 m/s**	**Validation SMAP - WindSat**

The strength of L-band radiometers is in high winds (> 15 m/s).

Validation

Remote Sensing Systems
www.remss.com

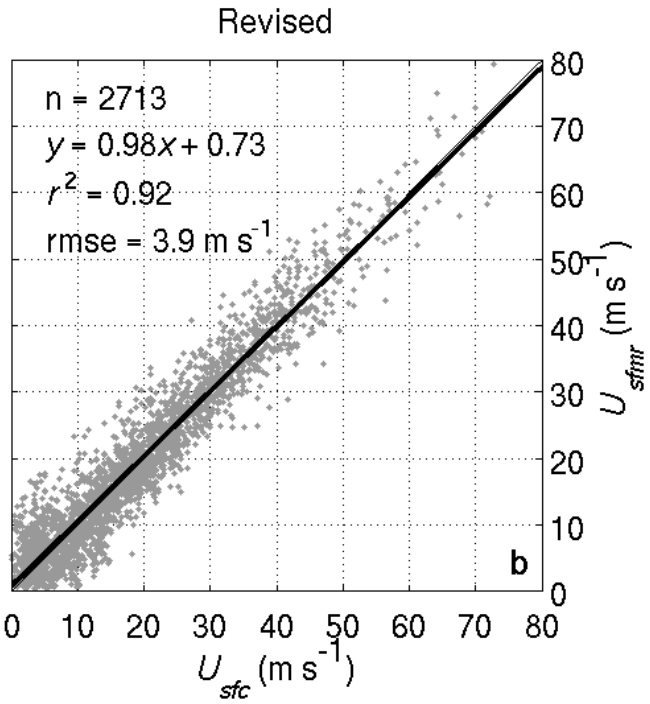
Stepped Frequency Microwave Radiometer **SFMR**

SFMR correlate well with GPS dropsonde wind speeds
No systematic biases. Estimated **accuracy** about **3 m/s**.

SFMR has **not** been used in deriving GMF.
Provides independent source for validation.

Uncertainties:

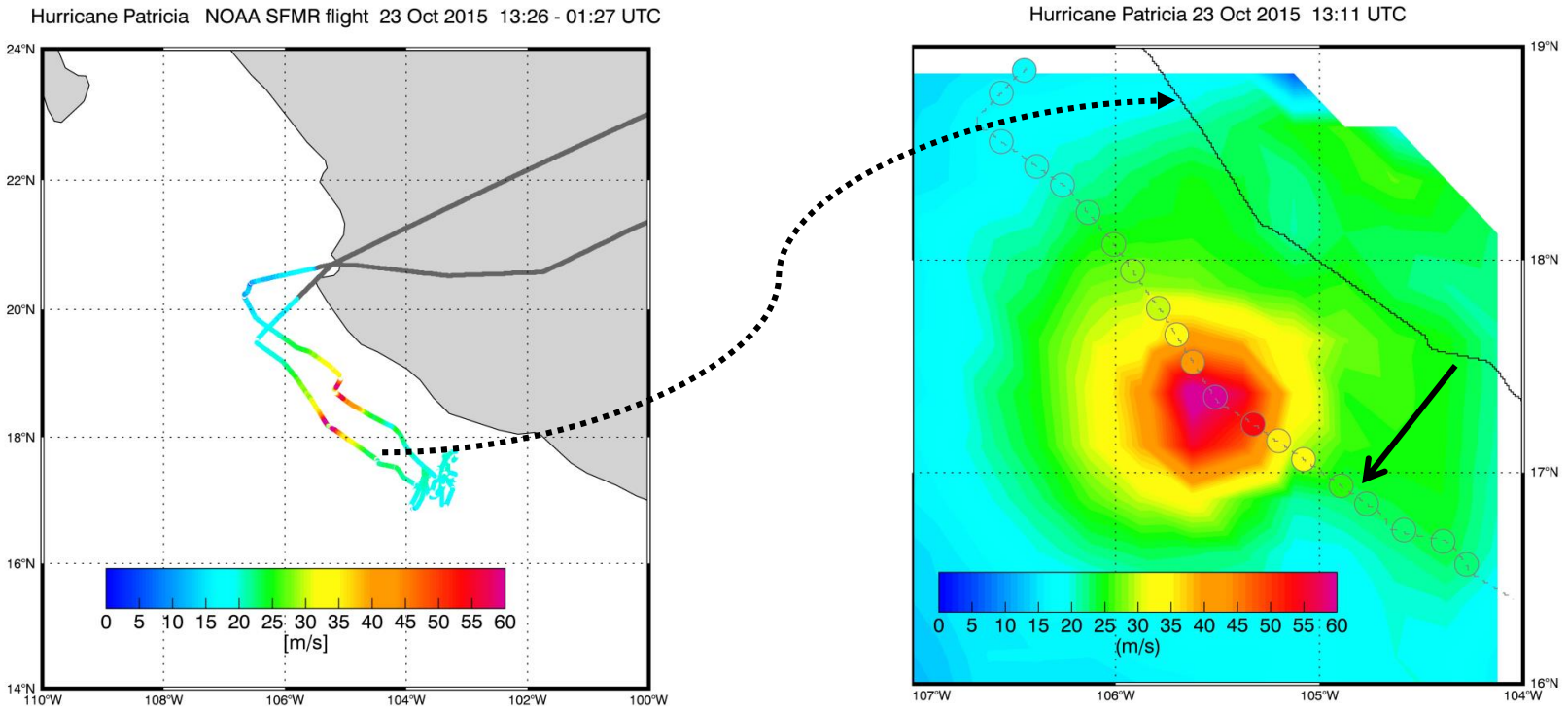
- Horizontal displacement
- Vertical interpolation to surface.
- SFMR calibration



from: **B. Klotz and E. Uhlhorn, *J. of Atmosph. Ocean. Tech.*, 2014, 41, 2392 – 2408.**
observations between 1999 - 2012
Data available from NOAA AOML HRD http://www.aoml.noaa.gov/hrd/data_sub/

SMAP – SFMR Match-Ups

Method

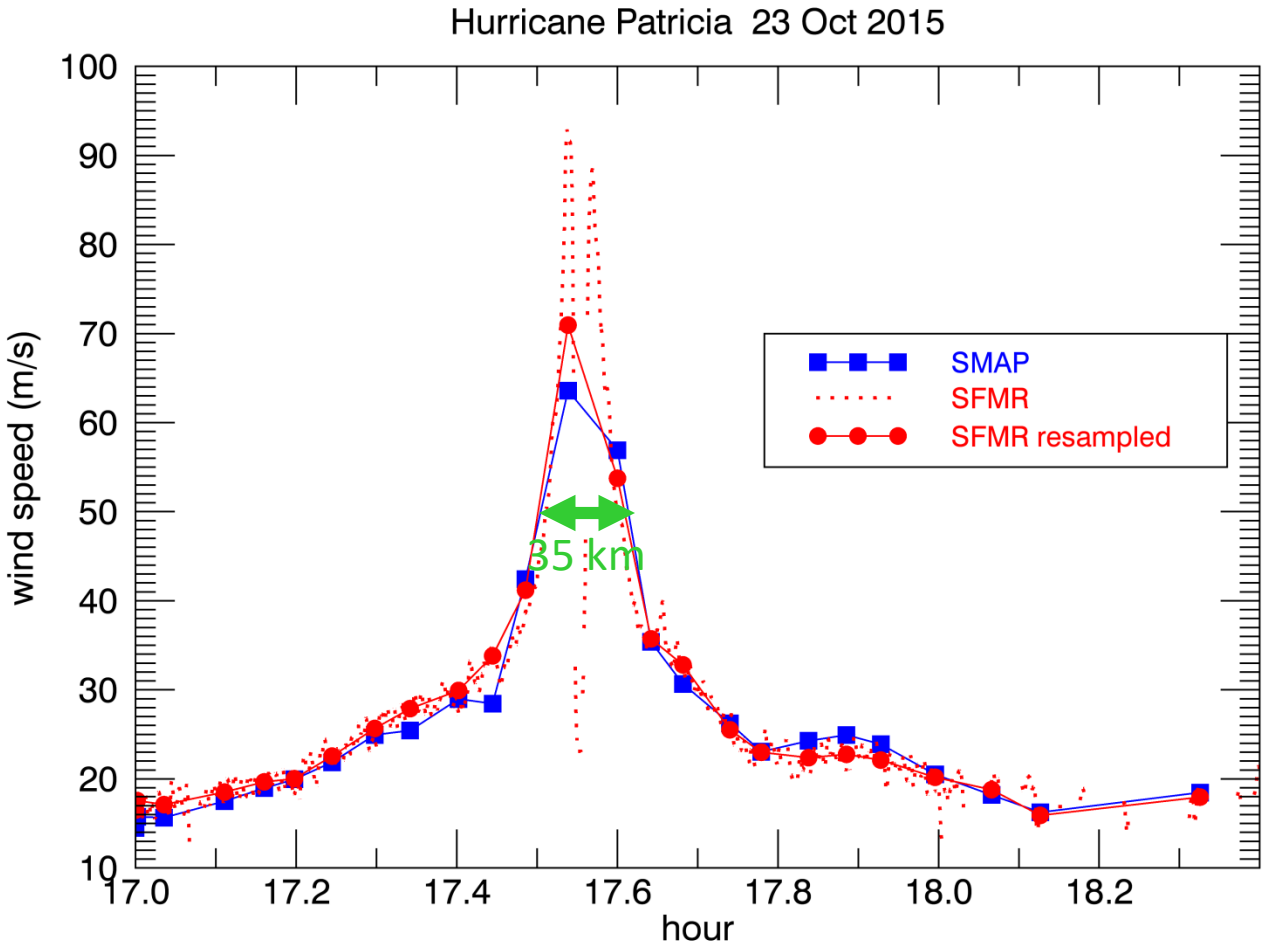


- Lower SFMR segment (17:30 h) closest in time to SMAP overpass (13:10 h).
- **Shift** SMAP segment so that SMAP and SFMR storm centers align.
- **Average SFMR observations** (≈1 sec, 0.1 km) into 0.25° cells to **represent** approximate **resolution of SMAP** (and other spaceborne sensors).

SMAP-SFMR Match-Ups

Time Series

Remote Sensing Systems
www.remss.com



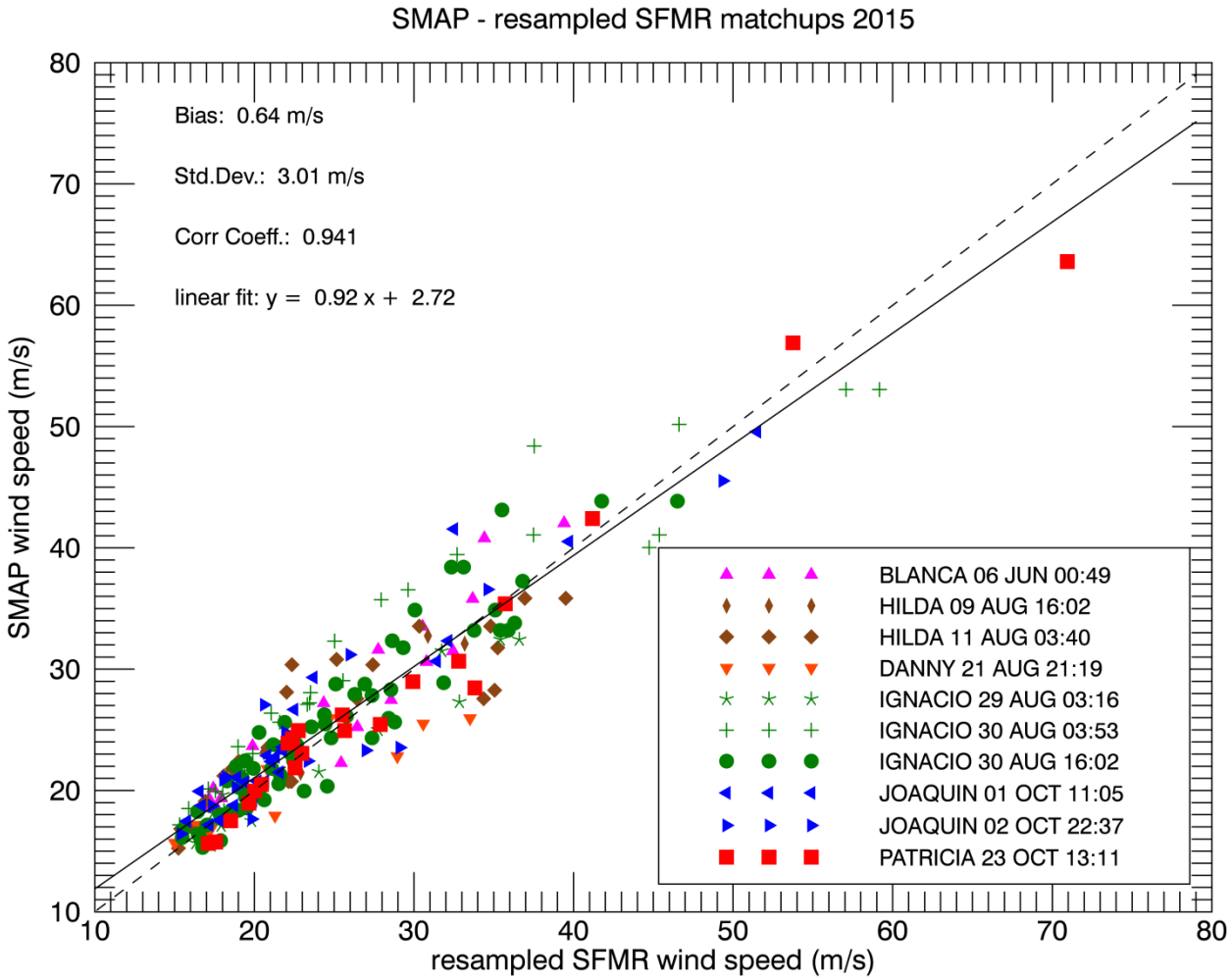
Resampled SFMR wind speeds reach 70 m/s.

They should be observable by spaceborne sensors (SMAP, ASCAT, RapidScat, WindSat).

SMAP-SFMR Match-Ups

Statistics

Remote Sensing Systems
www.remss.com



227 match-ups in 2015

SMAP-SFMR Match-Ups

Statistics for different wind speed ranges

SMAP - SFMR		
Wind speed (m/s)	Bias (m/s)	Std.Dev (m/s)
15 – 25	0.76	1.86
25 – 35	0.21	3.83
35 – 45	2.40	4.50
> 45	-2.40	3.96

Small biases above 35 m/s: potential fine tune of GMF.

1. Estimated uncertainty for SMAP wind speeds above 15 m/s: 10% or better.

2. RMS does NOT grow in very high winds.

Rain Impact

SMAP – SFMR as function of SFMR Rain Rate

SMAP – SFMR The SFMR rain rates were averaged to 0.25° to represent the rain rate that is approximately seen by SMAP		
Rain Rate (mm/h)	Bias (m/s)	Std.Dev (m/s)
0 – 5	0.68	2.55
5 - 10	1.57	3.37
10 - 15	0.46	2.85
> 15	-1.86	3.69

No systematic degradation in rain.

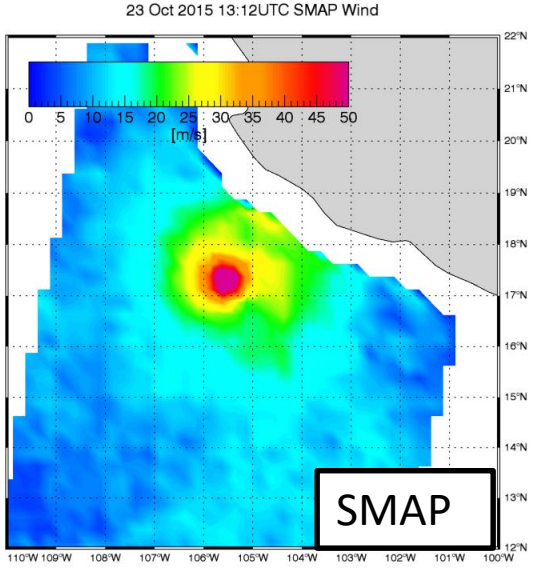
Some Very Intense TC

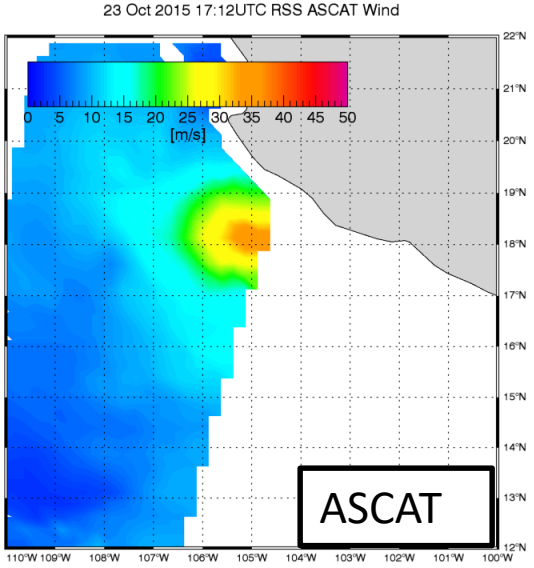
Comparison Data Sets

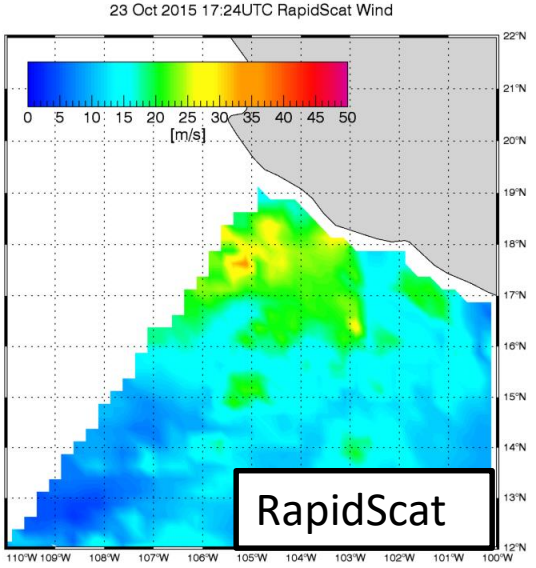
Instrument / Data Source	Description/Algorithm/Resolution
SMAP	L-band Radiometer RSS algorithm. 40 km
ASCAT-A	EUMETSAT C-band Scatterometer RSS algorithm. 25 km
RapidScat	NASA Ku-band Scatterometer JPL Science 12.5 km (uncorrected)
WindSat	US Navy Polarimetric Radiometer RSS All-Weather (AW) Winds (statistical algorithm C/X band to mitigate rain) Rain Rates
NCEP GDAS	0.25°
JTWC best track	scaled to maximum 10 min sustained winds
	minimum sea level pressure (MSLP) characterizes intensity of storm

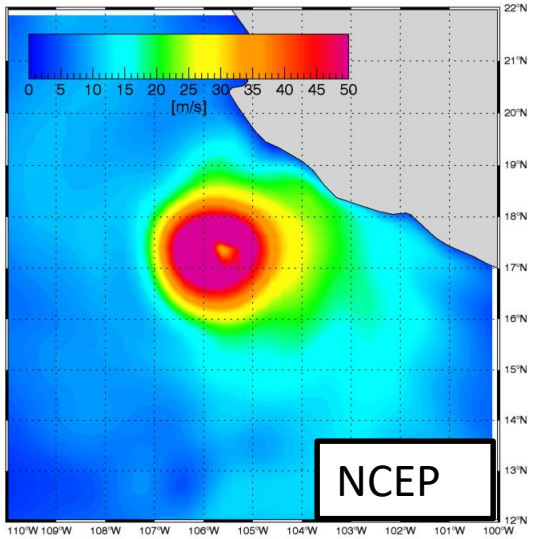
Remote Sensing Systems
www.remss.com

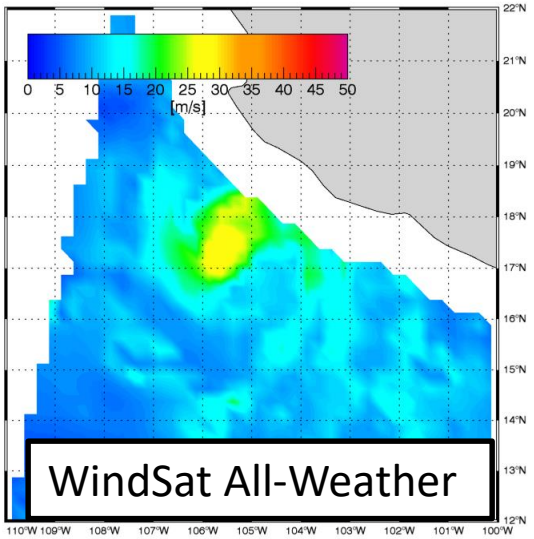
Hurricane Patricia

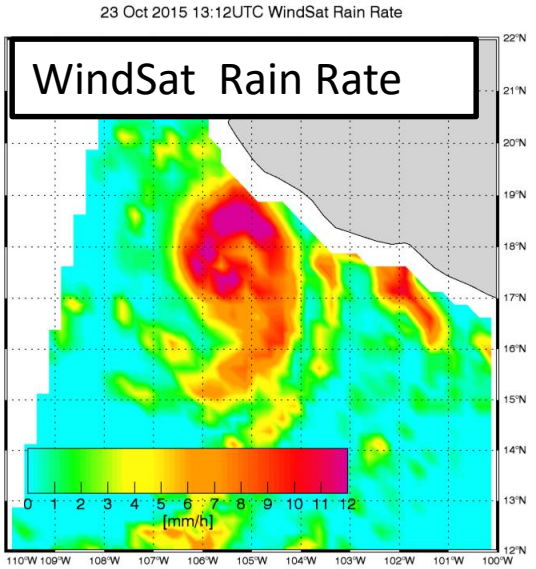








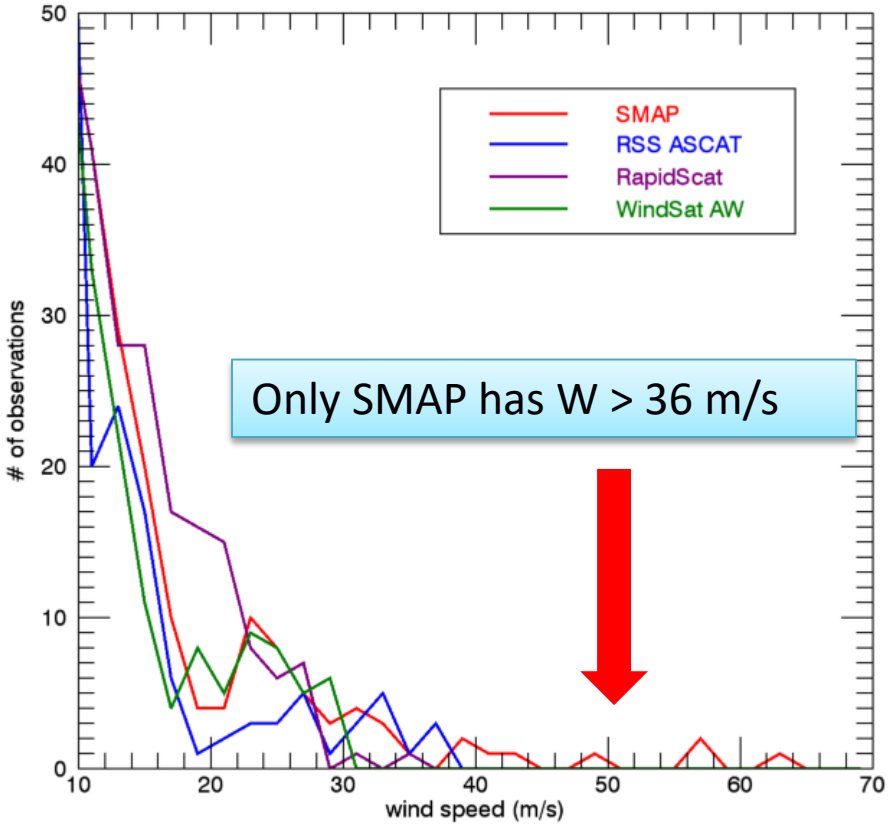




Hurricane Patricia

Collocated Wind Speed Distribution

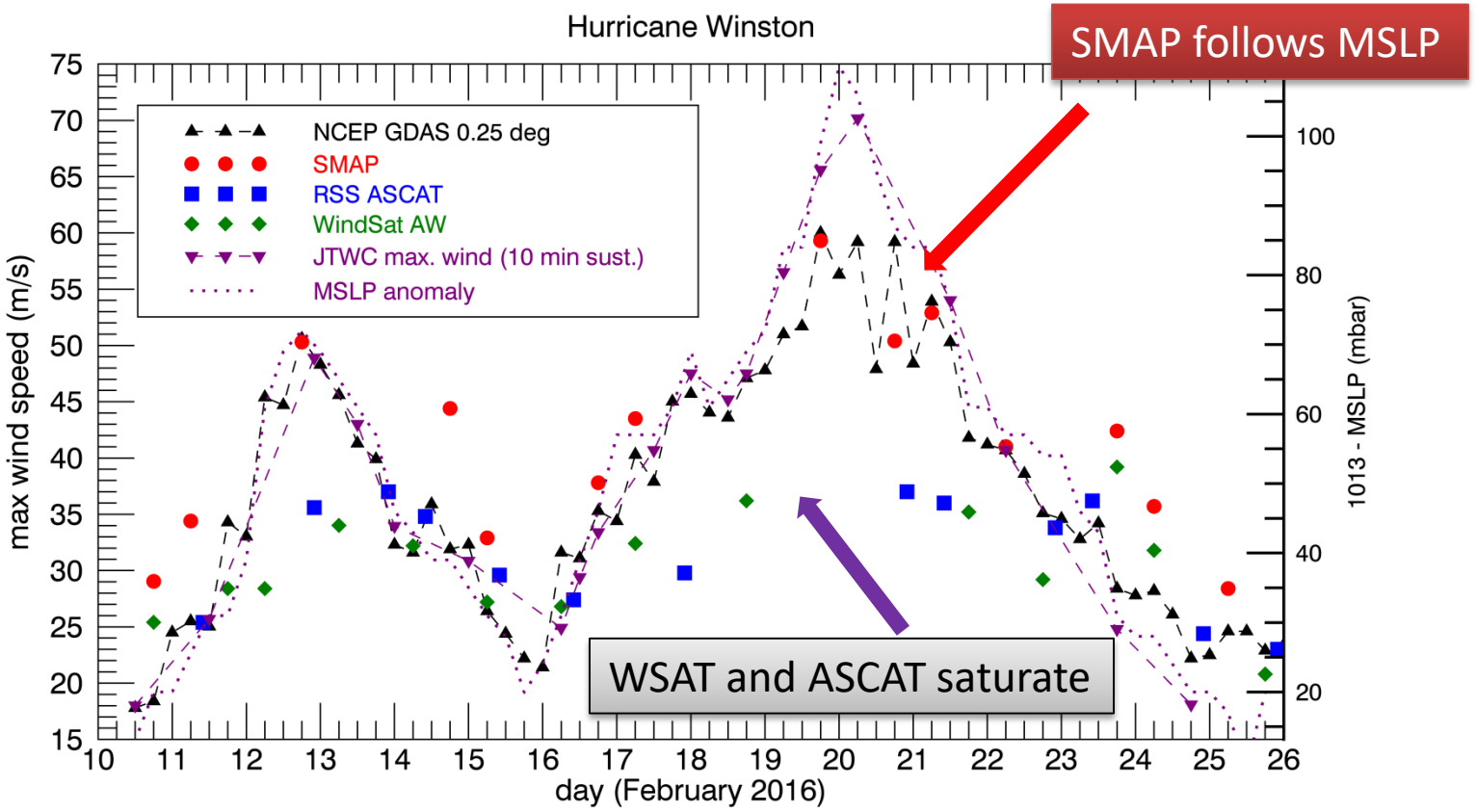
SMAP – ASCAT – RapidScat – WindSat



	Max wind in storm	collocated area (km^2) W > 30 m/s
SMAP	64 m/s	10105
ASCAT	36 m/s	7130
WindSat	29 m/s	0
RapidScat	28 m/s	0
Best Track 10-min sustained	79 m/s MSLP: 880 mbar	
SFMR resampled	71 m/s	

Hurricane Winston

2-Week Time Evolution



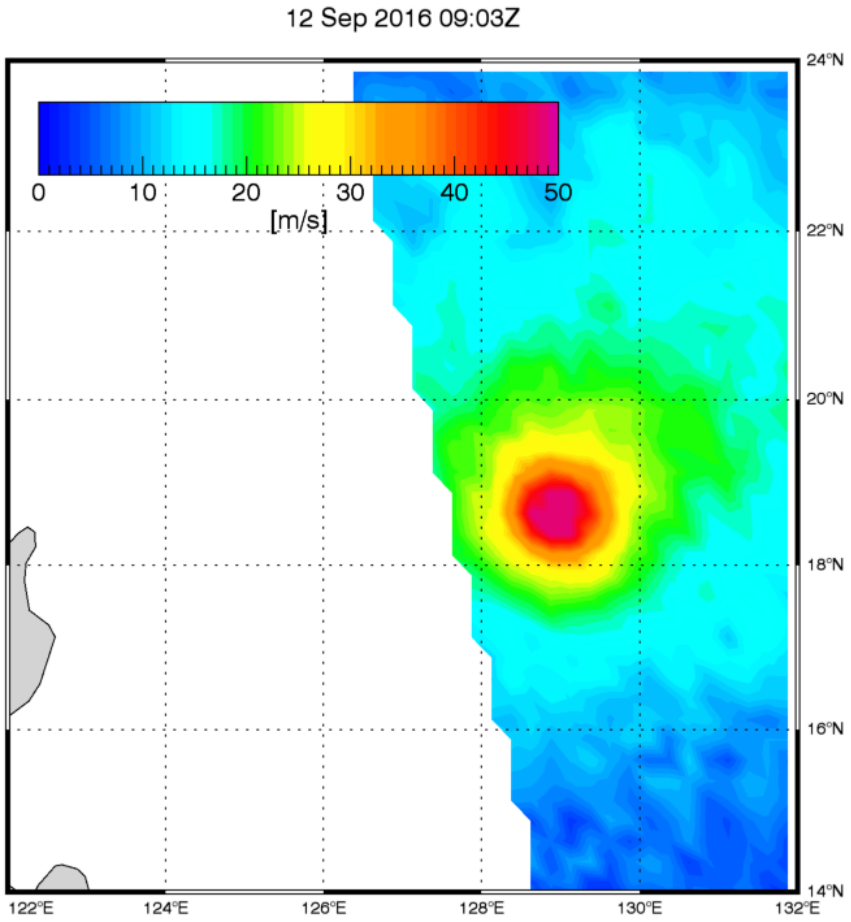
Minimum Sea Level Pressure (MSLP) anomaly is metric for intensity of the storm.

Hurricane Matthew: See presentation by Lucrezia Ricciardulli

2016 Typhoons

Meranti + Malakas

Remote Sensing Systems
www.remss.com



Meranti	
Date	9/12
SMAP W_{max}	**74 m/s**
Best Track W_{max}	**70 m/s**
MSLP	907 mbar
WindSat W_{max}	39 m/s

Malakas		
Date	9/16	9/18
SMAP W_{max}	**61 m/s**	**43 m/s**
Best Track W_{max}	**52 m/s**	**41 m/s**
MSLP	937 mbar	961 mbar
ASCAT W_{max}	35 m/s	32 m/s

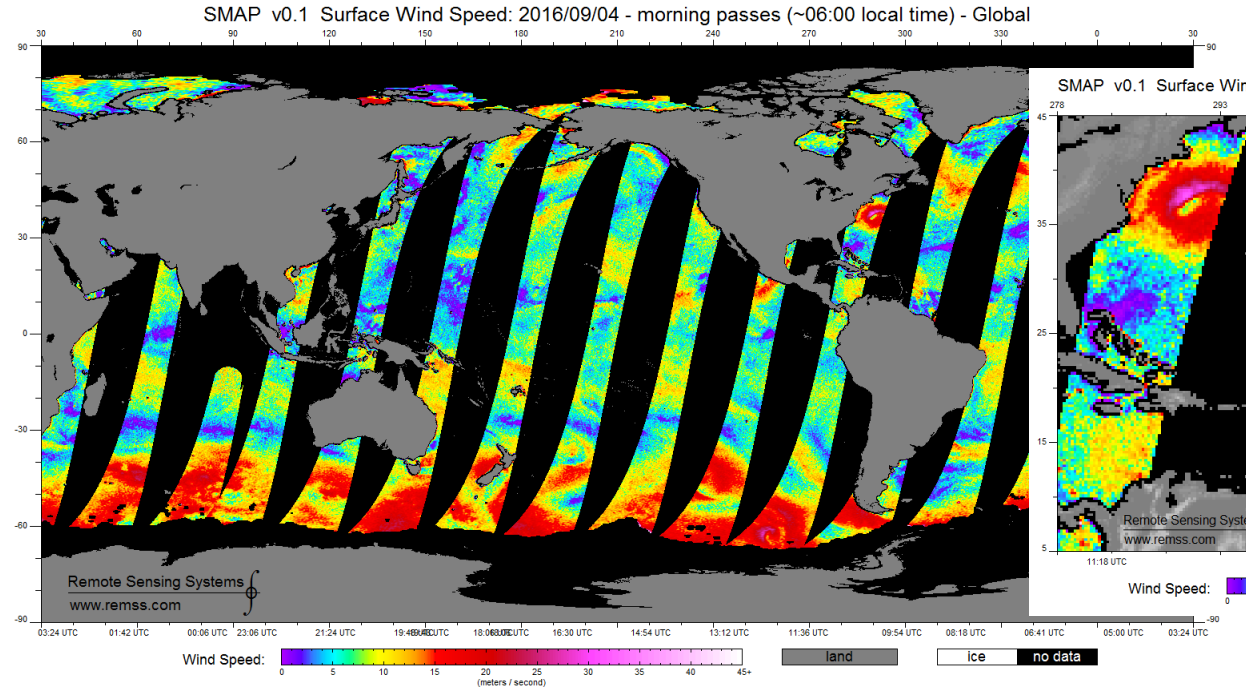
Near Real Time Processing

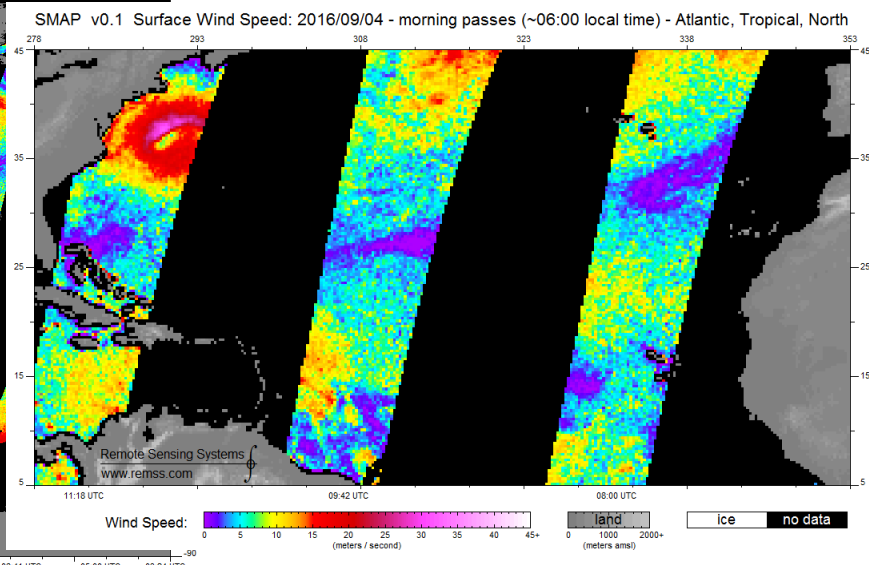
Remote Sensing Systems
www.remss.com

Daily 0.25° maps @RSS Website

netCDF4

ftp://ftp.remss.com/smap/wind/

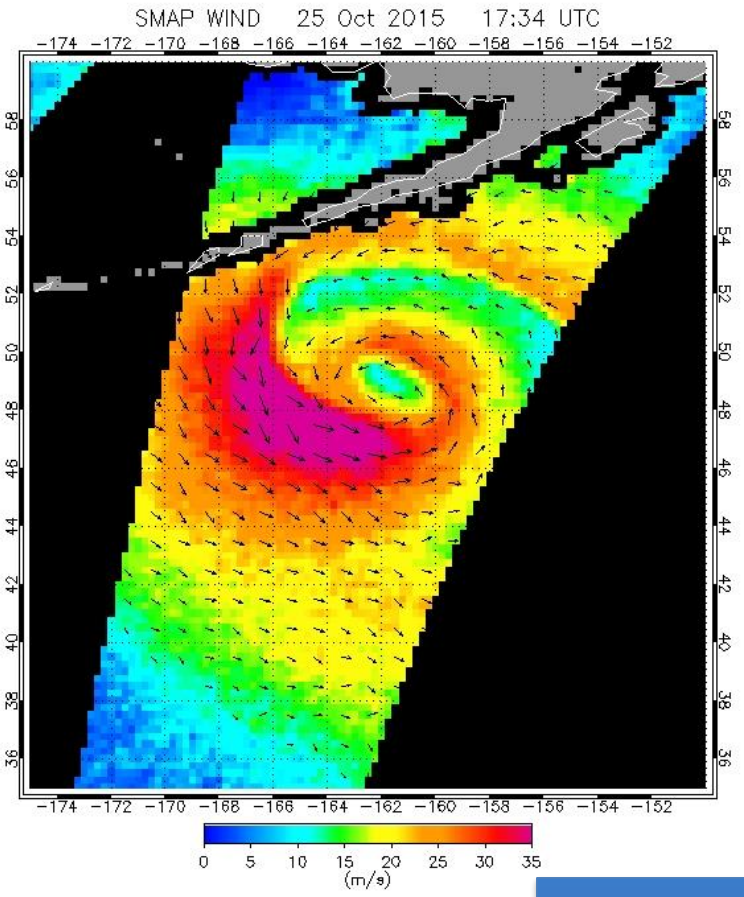


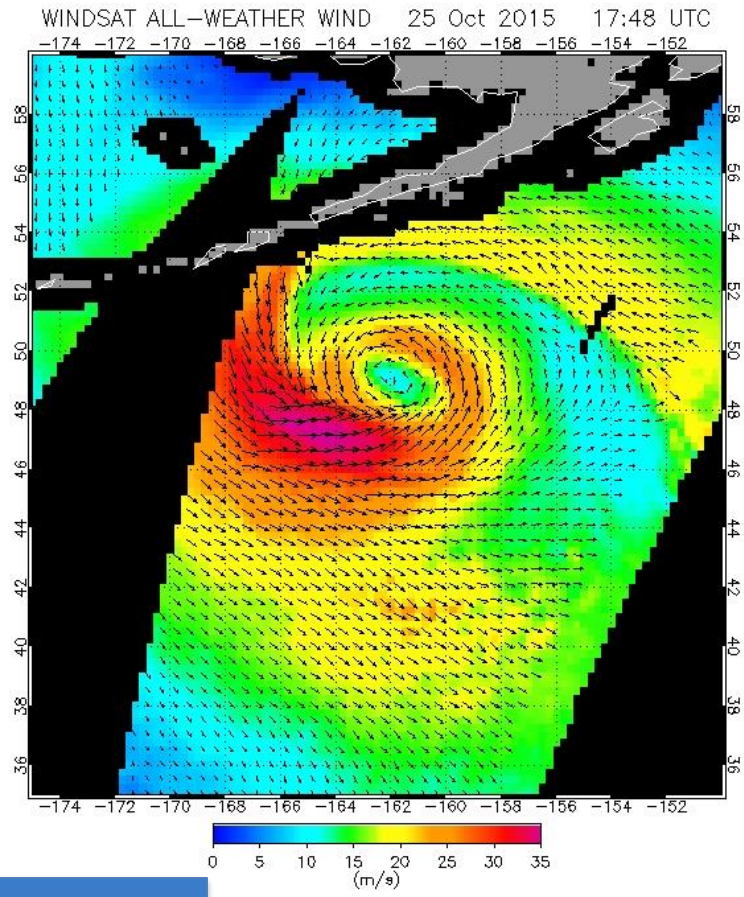


TC *Hermine*
Sep-04, 2016

Limited Wind Vector Capabilities

Weak polarimetric directional signal > 12 m/s





extra-tropical cyclone

SMAP wind direction retrieval done @ 100 km resolution. Noise reduction.

Summary

Remote Sensing Systems
www.remss.com

- The SMAP L-band radiometer has excellent capabilities to measure very strong wind speeds in intense TC
  - Range: 15 m/s to at least 75 m/s
  - 40 km resolution
  - SFMR validation: about 10% accuracy
  - **Valuable tool for assessing intensity and size of TC**
  - limited capability to measure wind direction
- Key:
  - Keeps good sensitivity at very high wind speeds
  - No significant degradation in rain
- At high winds it outperforms other spaceborne missions, such as scatterometers (ASCAT, RapidScat) or other spaceborne radiometers (WindSat), whose signals saturate above ~ 35 m/s and which are affected by rain
- **Data and images available near-real time from RSS**
  - ftp://ftp.remss.com/smap/wind/

Future Work

- Potential refinement of high wind L-band GMF
  - Adjust slope of $\Delta T_B/\Delta W$
  - We expect this adjustment to be small
  - Try to reach consistency with SMOS and V/H-pol radars (Sentinel-1 SAR)
- **Linear slope of $\Delta T_B/\Delta W$ becomes metric to measure satellite high winds**.
- L-band radiometer satellite high winds (SMAP, SMOS) can **become reference for high wind measurements** wih other spaceborne instruments:
  - WindSat "all-weather" wind algorithm
  - AMSR-2: Two C-band channels (SFMR-like capability to separate out rain)
  - CYGNSS ?

Backup Slides

Wind Speed Retrieval

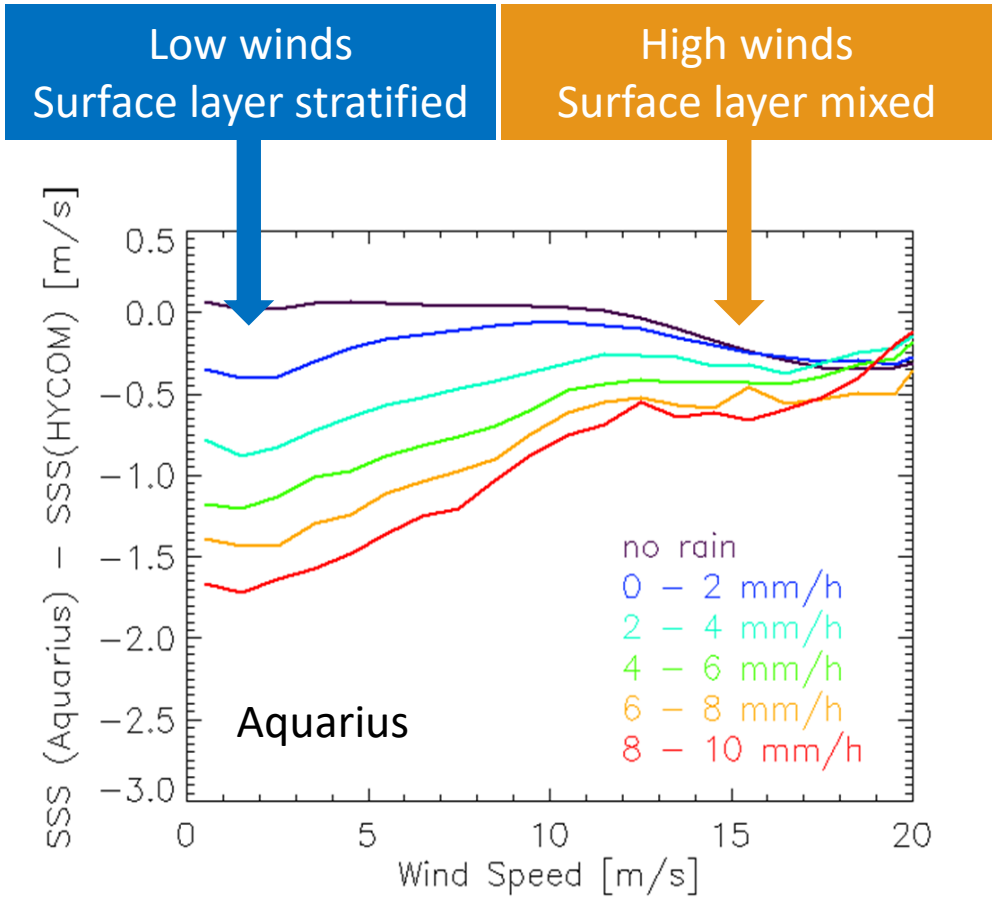
Correction Tables + Ancillary Fields

- Sea Surface Salinity (SSS)
  - strong dependence at L-band (SSS is prime EDR for SMOS + Aquarius).
  - need external field: **HYCOM**, FOAM, WOA, …
  - Generally accurate enough to be used in SMAP wind speeds.
  - Inaccurate in large freshwater plumes (Amazon, Congo, …) resulting in inaccurate SMAP wind speeds in those areas.
- Sea Surface Temperature (SST)
  - weak to moderate dependence
  - need external field: **CMC**, NOAA OI SST, OSTIA, …
- SSS/SST slow varying
  - can use field from previous day(s) in near-real time processing
- Atmospheric profiles
  - NCEP
  - very weak dependence. can use climatology or field from previous day(s).
- Galaxy/Sun: Fixed tables
- **No ancillary NWP wind fields are necessary as input to SMAP wind speed retrievals**

Rain

expect little degradation at high winds

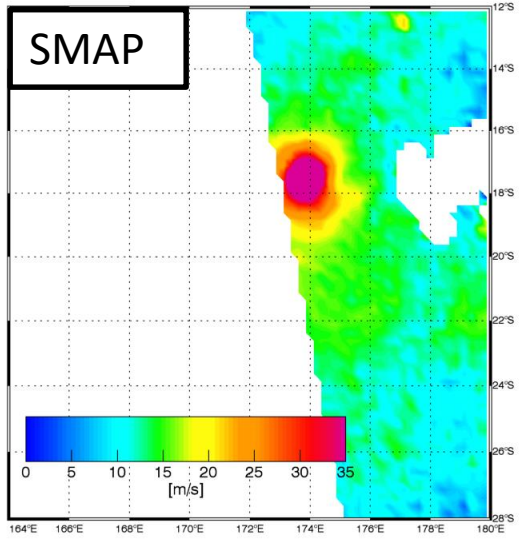
- Atmospheric attenuation: Very small
  - At a rain rate of 15 mm/h within the SMAP footprint (which is large!) the T_B attenuation is less than 0.30 K ≡0.9 m/s.
- Salinity Stratification within upper (5 m) ocean layer
  - SMAP measures within few cm of surface.
  - HYCOM model/ARGO drifters refer to ≈ 5 m depth.
  - **At high winds the upper layer is well mixed.**
- Roughness increase through surface splashing
  - Very small at high winds.



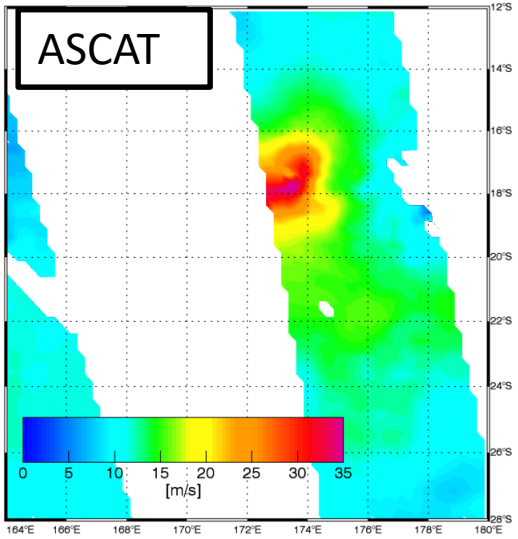
J. Boutin et. al, BAMS (online), December 2015

Hurricane Winston

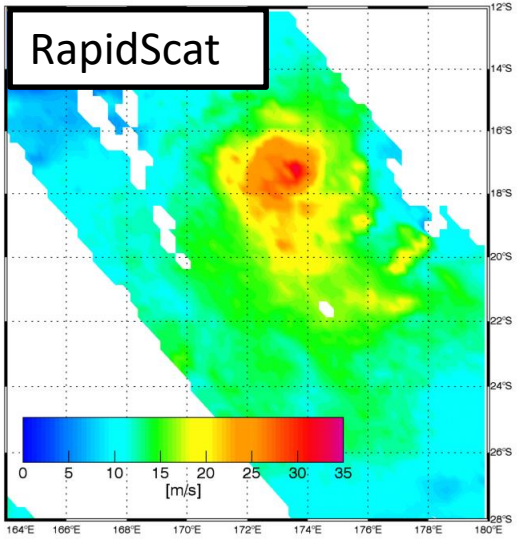
21 Feb 2016 06:25UTC SMAP Wind



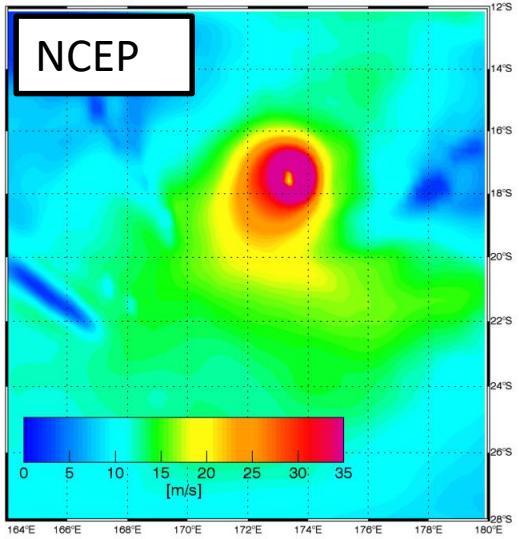
21 Feb 2016 09:36UTC RSS ASCAT Wind



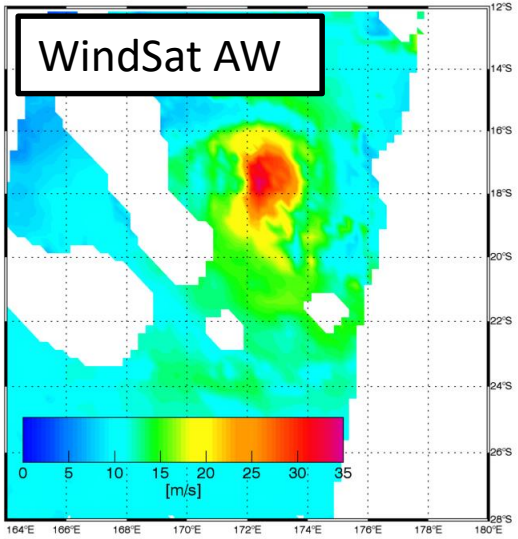
21 Feb 2016 10:30UTC RapidScat Wind



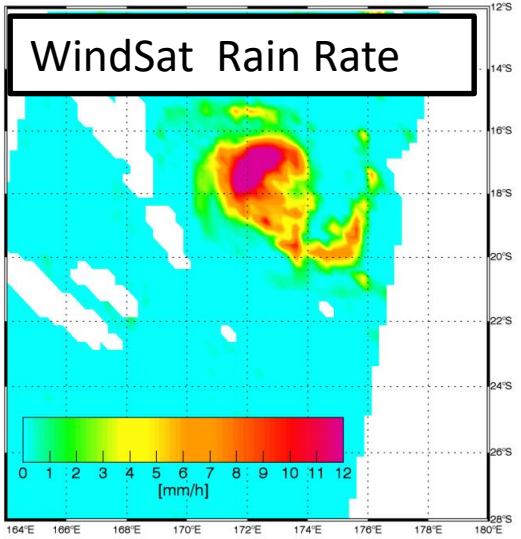
21 Feb 2016 12:00 UTC NCEP 0.25 deg



21 Feb 2016 18:42UTC WindSat AW Wind



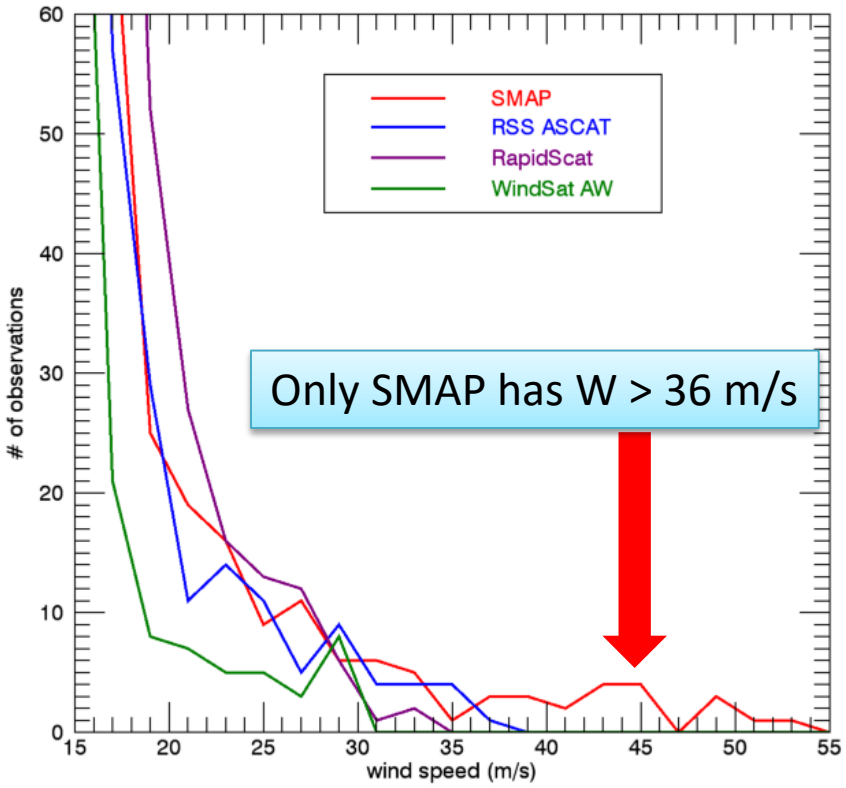
21 Feb 2016 18:42UTC WindSat Rain Rate



Hurricane Winston

Collocated Wind Speed Distribution

SMAP – ASCAT – RapidScat – WindSat

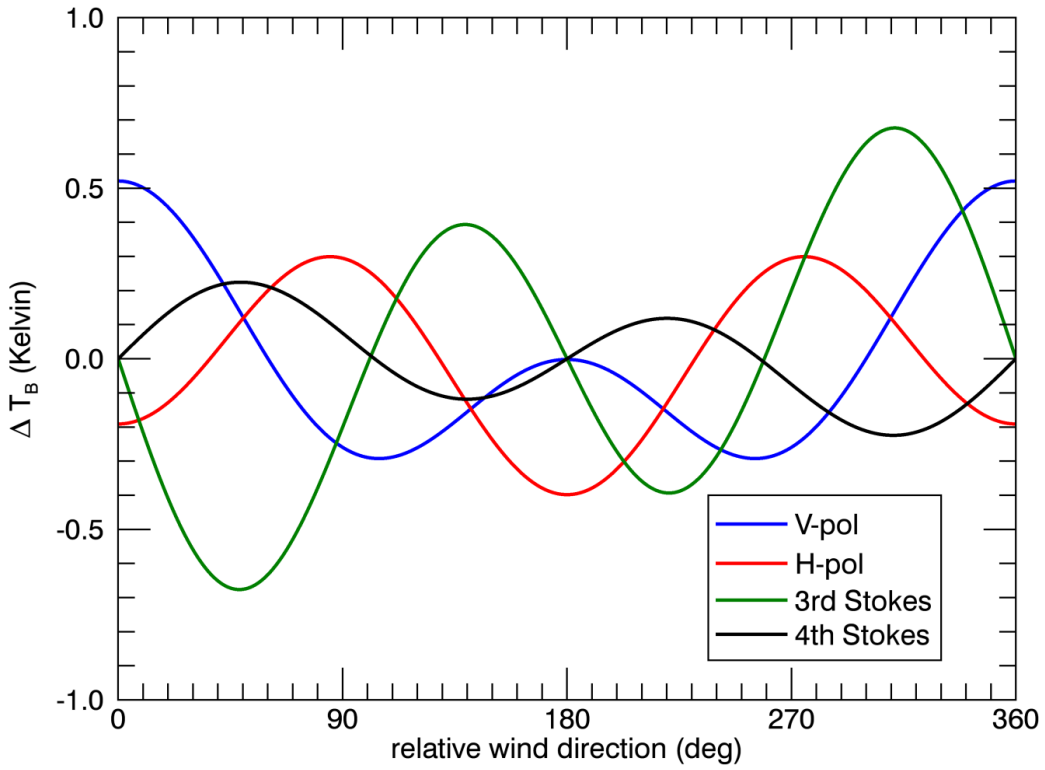


	Max wind in storm	collocated area (km^2) W > 30 m/s
SMAP	53 m/s	19165
ASCAT	36 m/s	7727
RapidScat	34 m/s	2872
Best Track 10-min	54 m/s MSLP: 937 mbar	

- Scatterometer (ASCAT, RapidScat) wind signal starts saturating at high winds.
- Ku-band scatterometer (RapidScat) affected by rain.
- WindSat all-weather algorithm is statistical algorithm. Has not been trained above 40 m/s.

Wind Direction Response

Polarimetric Signal



- SMAP is fully polarimetric.
- Small directional signal.
- Wind direction retrieval possible above 12 m/s
-
- 1º averaging.
- 3rd Stokes signal dominated by Faraday Rotation in Earth's ionosphere.

Use combinations of polarimetric channels that are not affected by Faraday rotation: (V+H), $Q^2+S_3^2$, S_4 Q=V-H