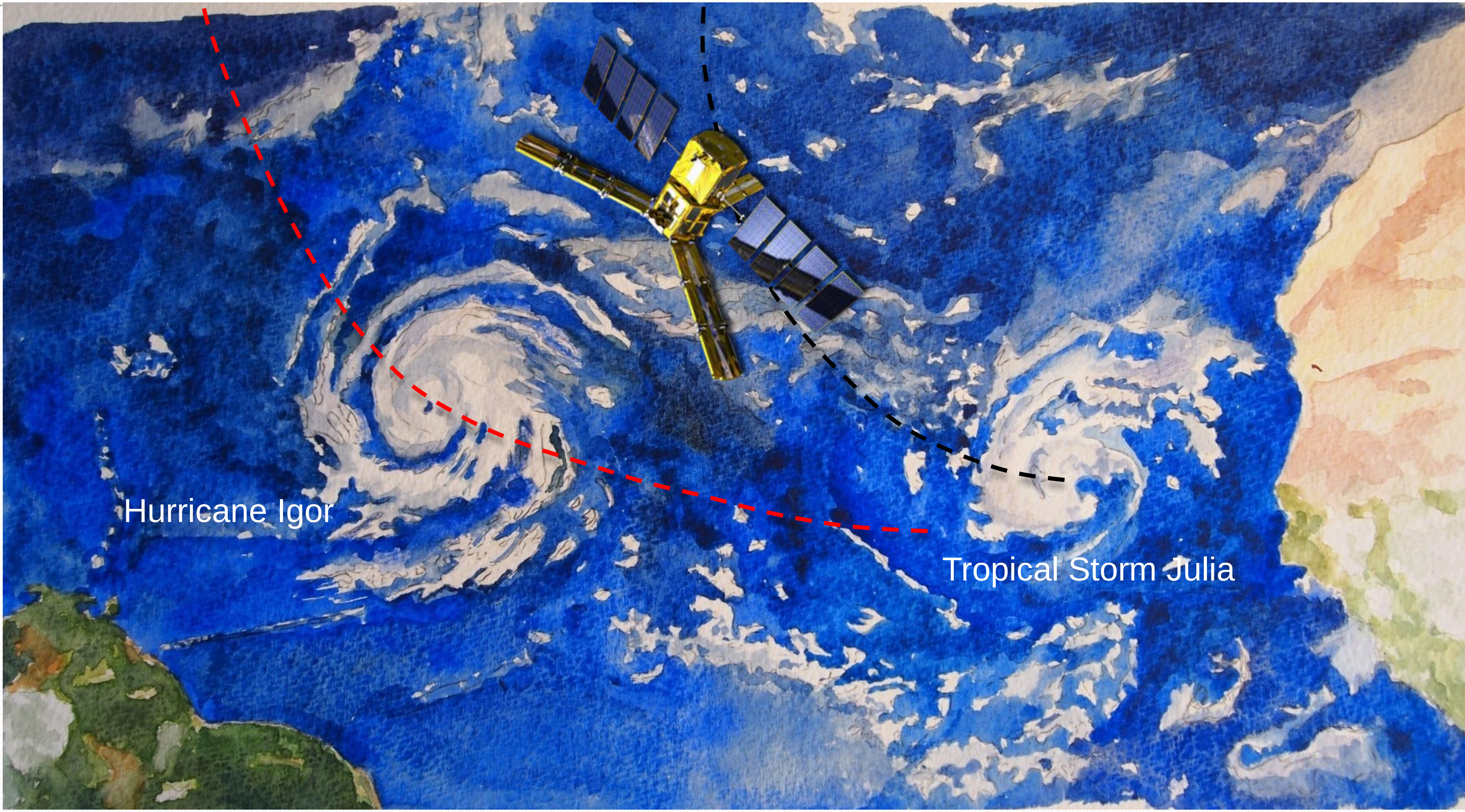
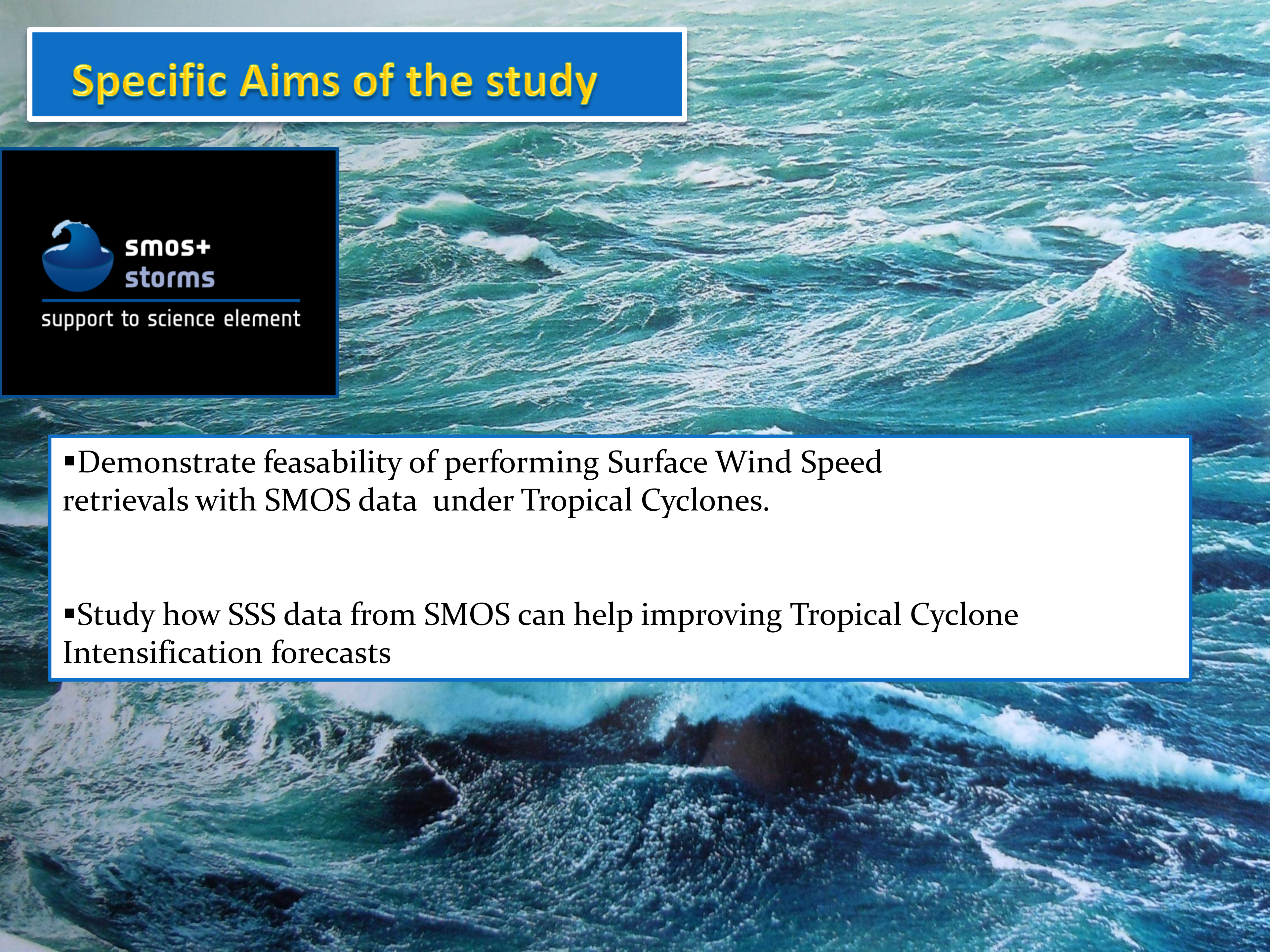
A perspective of the High wind remote sensing With SMOS sensor



Nicolas Reul[1], J. Tenerelli[2], B.Chapron[1], Y. Quilfen[1], D. Vandemark and Y. Kerr[3]

Specific Aims of the study



smos+
storms
support to science element

- Demonstrate feasability of performing Surface Wind Speed retrievals with SMOS data under Tropical Cyclones.

- Study how SSS data from SMOS can help improving Tropical Cyclone Intensification forecasts

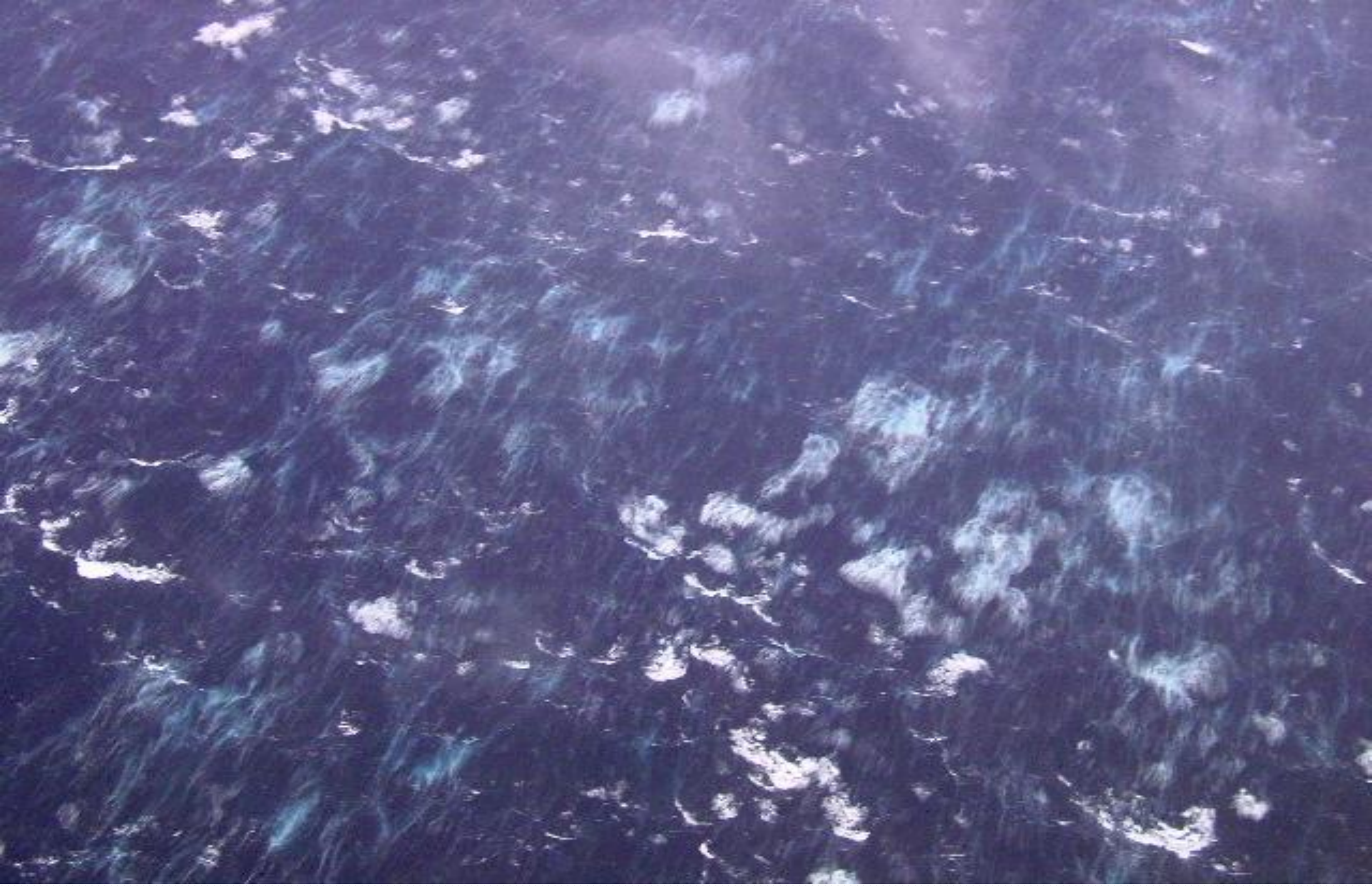


Figure 1: Photograph of the sea surface during a hurricane (Beaufort Force 12) taken from a NOAA ‘‘Hurricane Hunter’’ aircraft (Black *et al.*, 1986).

A complex distribution of two-phase oceanic phenomena

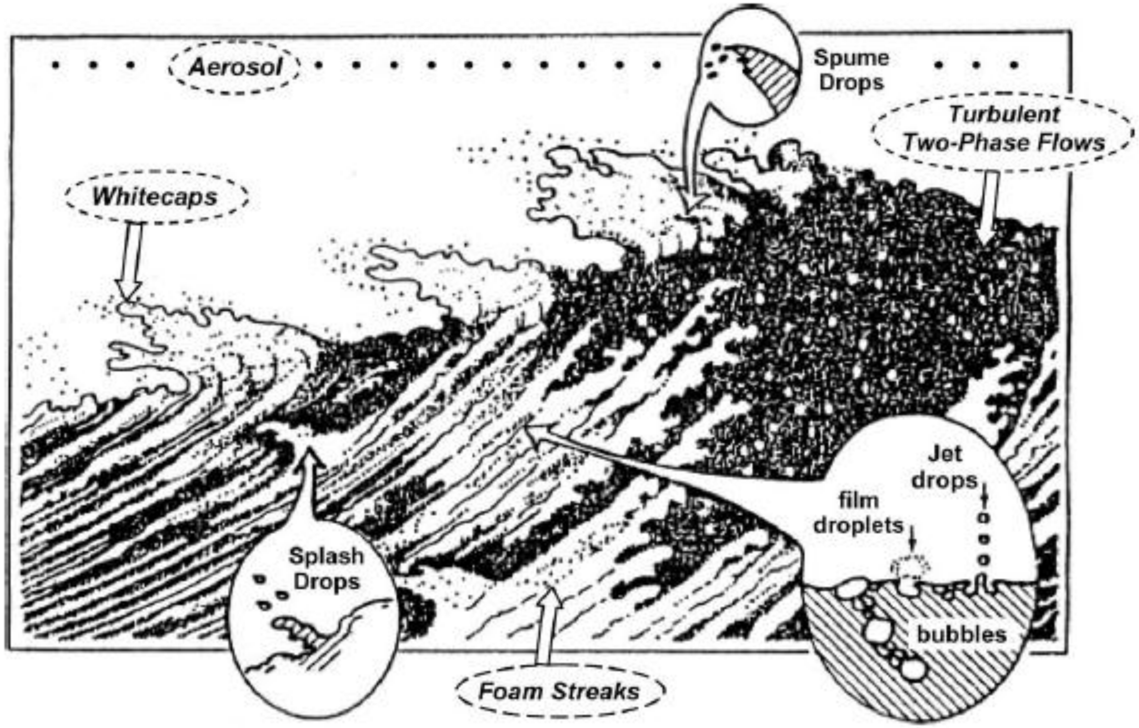
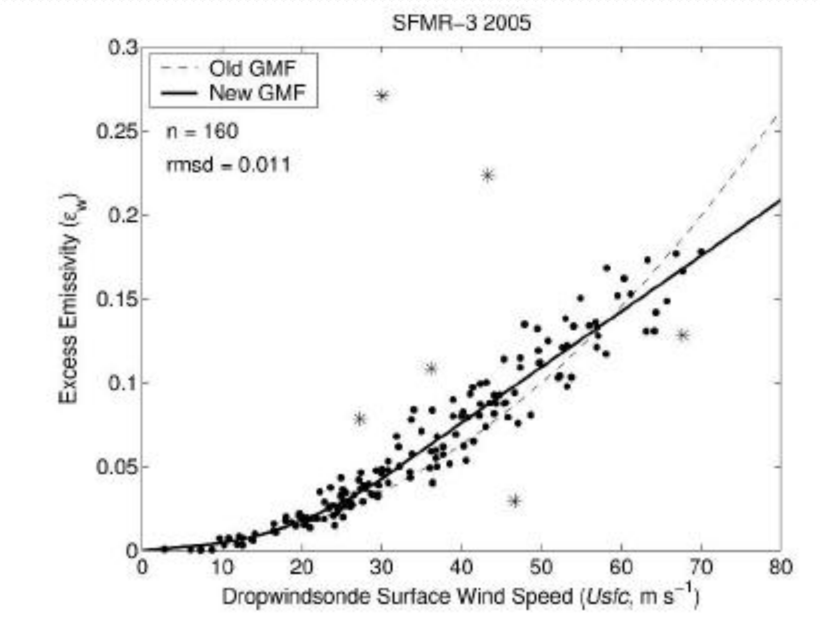


Fig. 1. Classifications of oceanic dispersed media for remote sensing.

Increase of the microwave ocean emissivity with wind speed ⬄ foam change induce effect



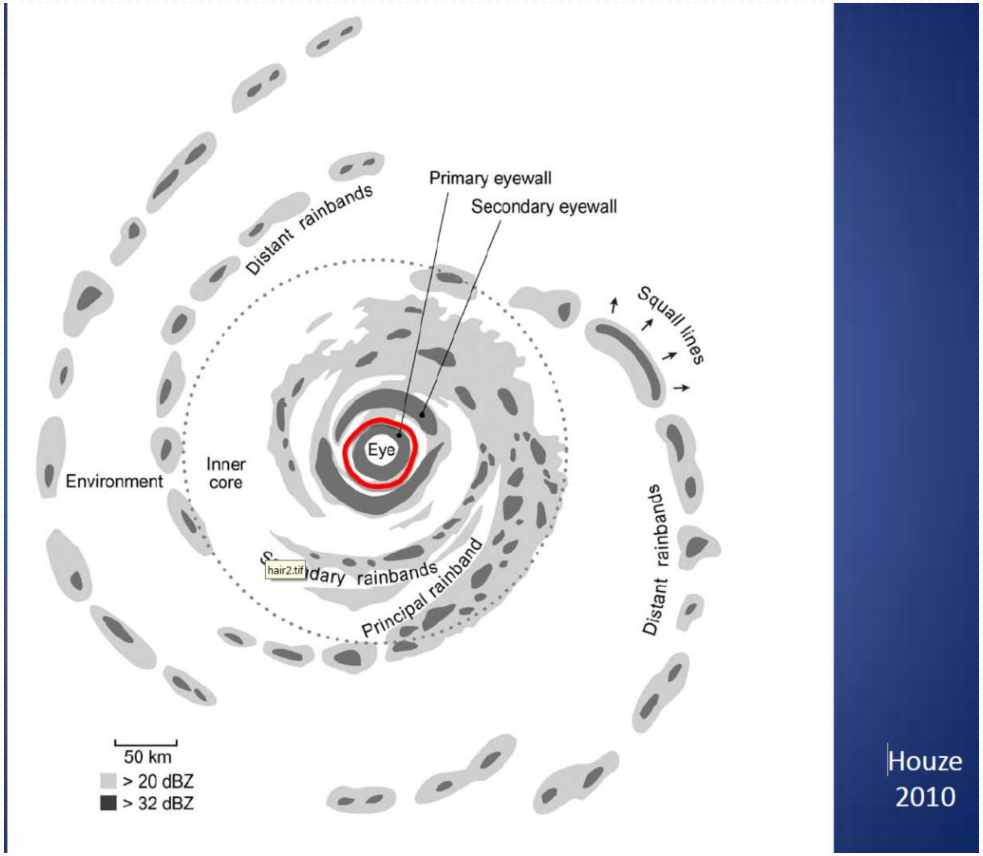
This information can be used to retrieve the surface wind speed in Hurricanes:

Principle of the Step Frequency Microwave Radiometer (SFMR) C-band:

NOAA's primary airborn sensor for measuring Tropical Cyclone surface wind speeds since 30 year (Ulhorn et al., 2003, 2007).

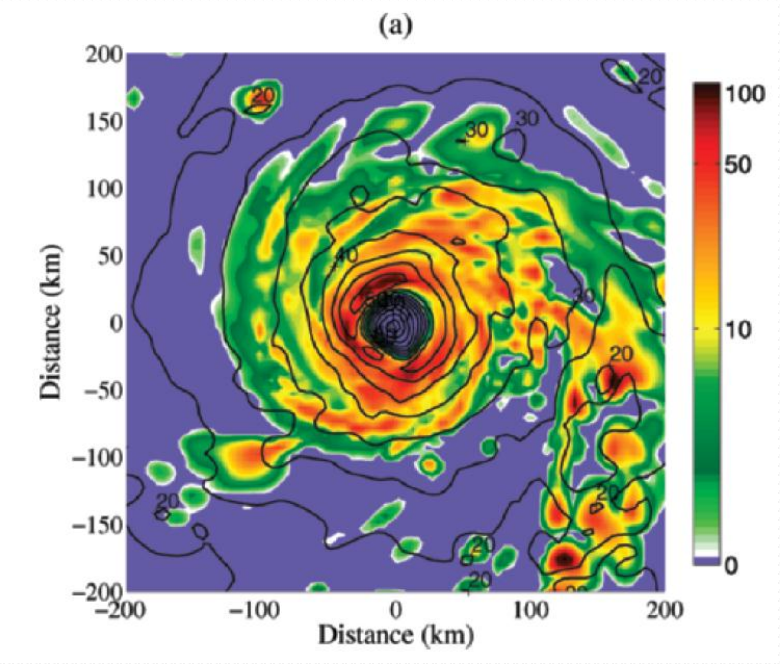
High winds in Hurricanes are very often associated with High rain rates

Rain Anatomy in a hurricane



Houze
2010

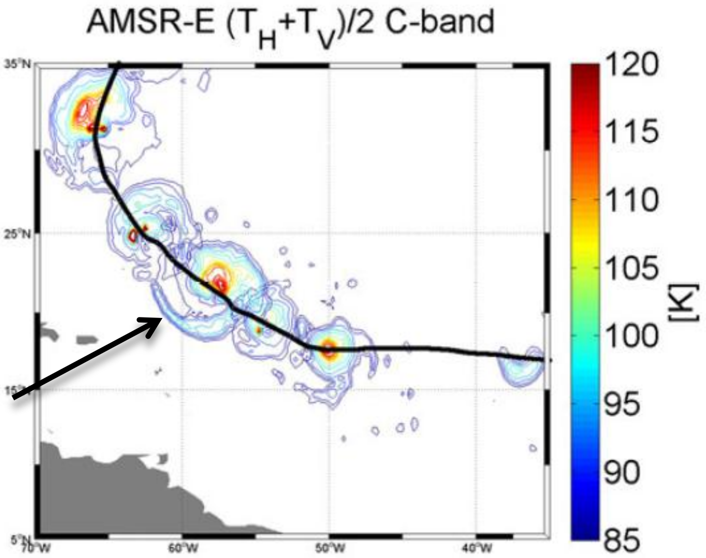
Rain rate [mm/h]



S.Shen and J. Tenerelli 2007

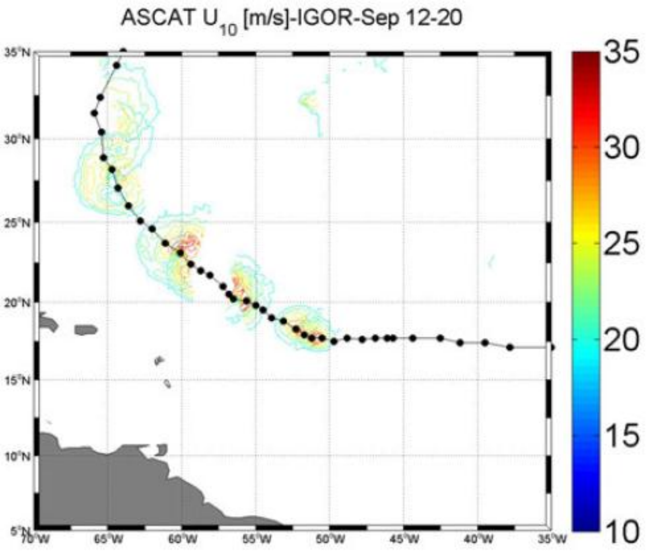
Limitations of current satellite MW observing systems
Operating at frequencies ≥ C-band

AMSR-E $(T_H+T_V)/2$ C-band



Rain
Bands
Signatures
At
C-band

ASCAT U_{10} [m/s]-IGOR-Sep 12-20



- Passive/active data are strongly affected by rain for f ≥ C-band

•Radar data saturates at high winds

=>very difficult to retrieve surface winds
(for passive multiple frequency is required (SFMR))

As L-band is much less affected=>opportunity!

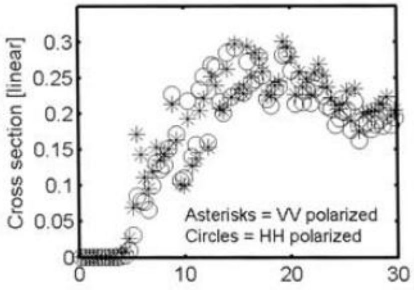
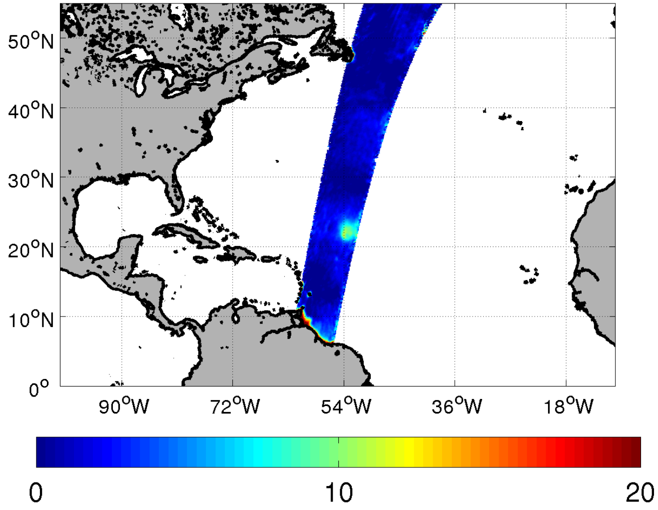


Figure 5. Normalized radar cross section (NRCS) versus centerline (0.3 m height) wind speed in the tank. Note that U_{10} is approximately $1.5U_{0.3}$.

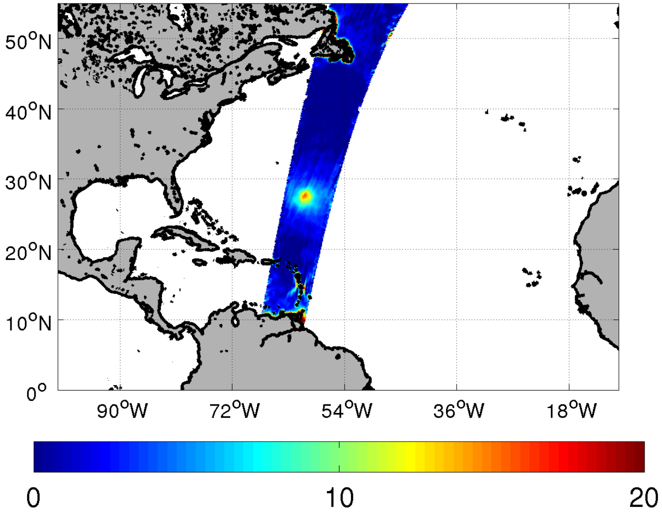
Signatures of Tropical Cyclones in SMOS data

HURRICANE DANIELLE

SMOS Residual (Tx+Ty)/2 for Aug 25 21:33 [K] (AF)

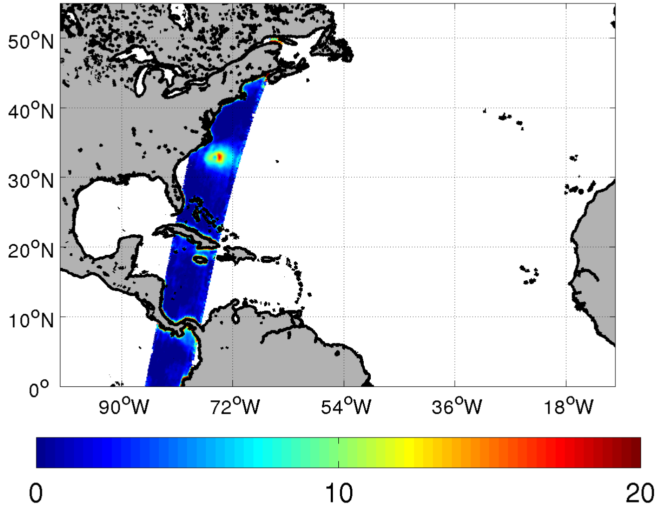


SMOS Residual (Tx+Ty)/2 for Aug 27 21:55 [K] (AF)

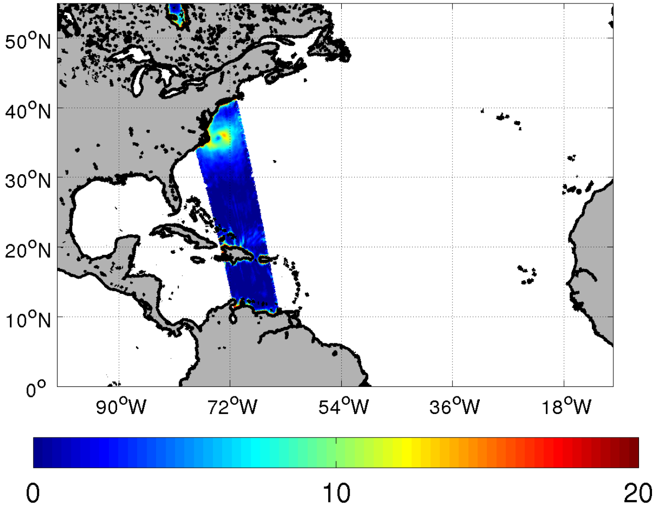


HURRICANE EARL

SMOS Residual (Tx+Ty)/2 for Sep 02 23:01 [K] (AF)

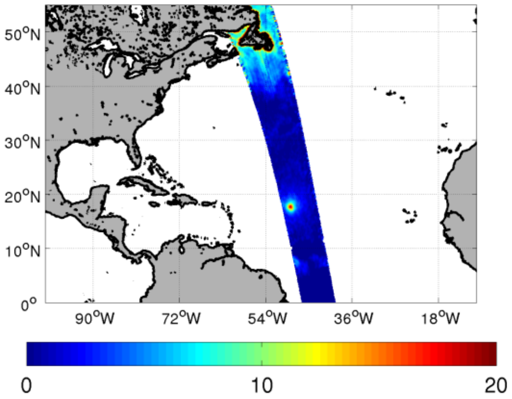


SMOS Residual (Tx+Ty)/2 for Sep 03 09:52 [K] (AF)

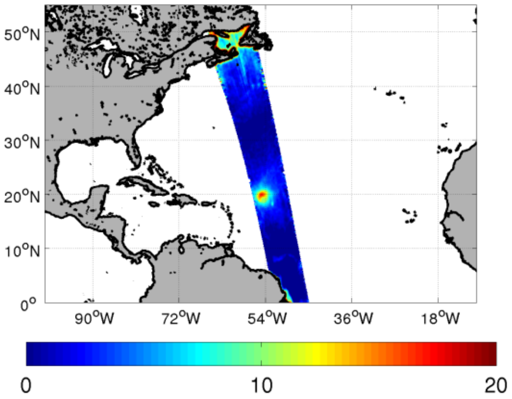


Signatures of Tropical Cyclones in 2010 SMOS data

SMOS Residual (Tx+Ty)/2 for Sep 13 08:22 [K] (AF)

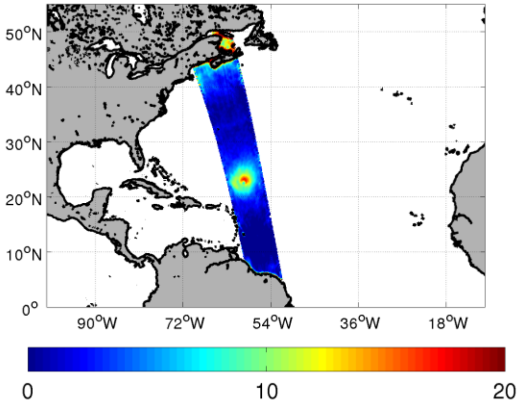


SMOS Residual (Tx+Ty)/2 for Sep 15 08:45 [K] (AF)

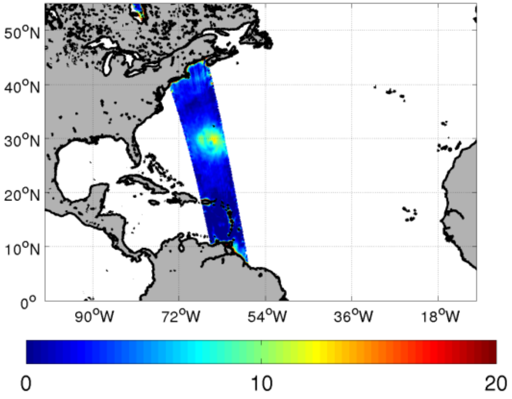


HURRICANE IGOR

SMOS Residual (Tx+Ty)/2 for Sep 17 09:07 [K] (AF)

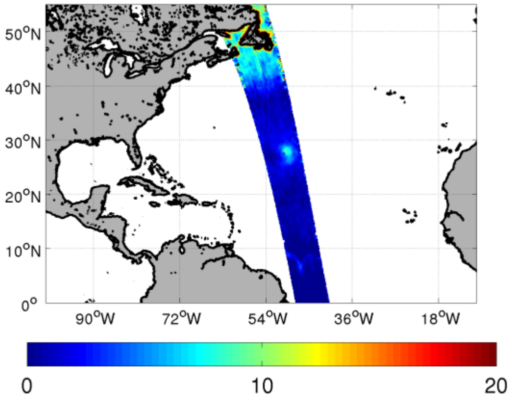


SMOS Residual (Tx+Ty)/2 for Sep 19 09:29 [K] (AF)



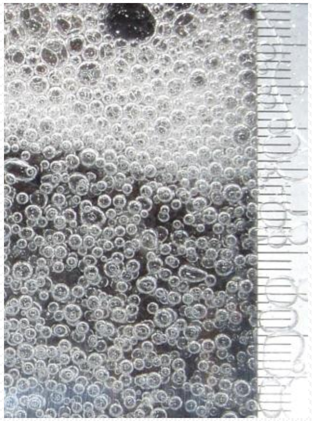
TROPICAL STORM JULIA

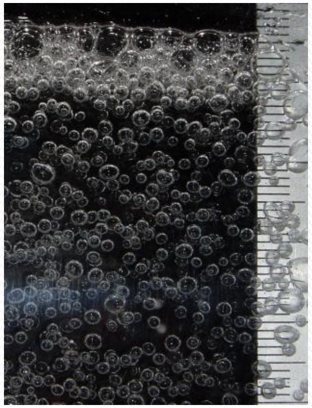
SMOS Residual (Tx+Ty)/2 for Sep 18 08:28 [K] (AF)



Understanding of
L-band radiometry in High winds:
A review:

Sensitivity of L-band emissivity to foam: FROG Campaign





Empirical measurements pre-launch of the impact of foam at L-band

+

Developement of a theoretical foam emissivity model

- N.Reul and B. Chapron, "*A model of sea-foam thickness distribution for passive microwave remote sensing applications*", *J. Geophys. Res.,* 108 (C10), Oct, 2003.

A.Camps, et al, "*The Emissivity Of Foam-Covered Water Surface at L-Band: Theoretical Modeling And Experimental Results From The Frog 2003 Field Experiment", IEEE TGRS*, vol 43, No 5, pp 925-937, 2005.

Airborn Campaign with PALS during a storm in 2010

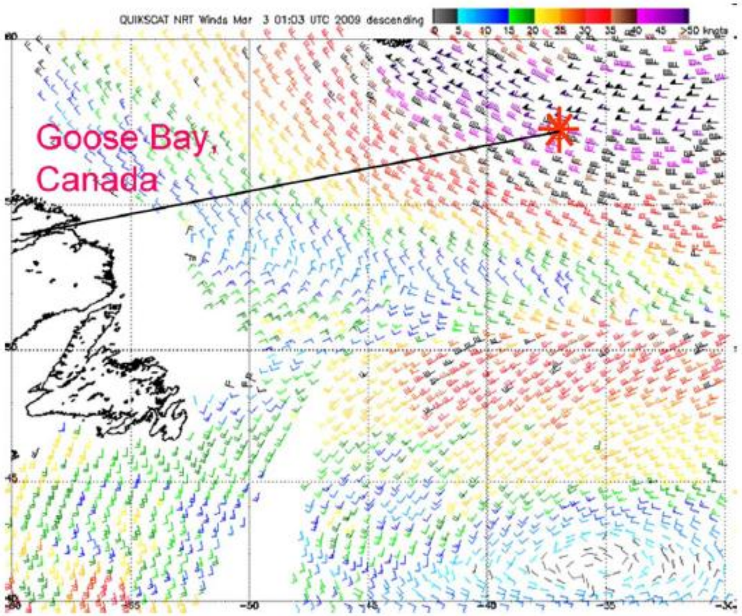


Fig. 1. NASA P-3 flight track from Goose Bay, Canada, to the selected way point in the North Atlantic. Near the way point, we performed the star-pattern, wing wag, and circle flights.

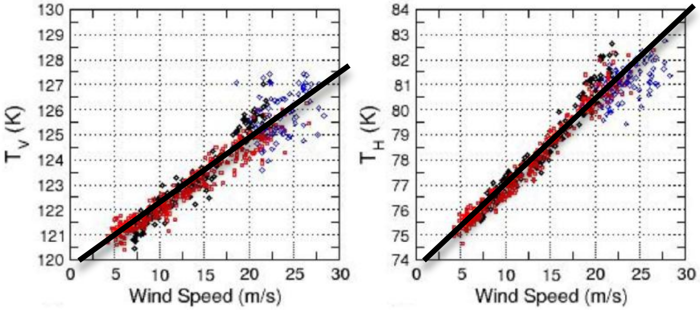


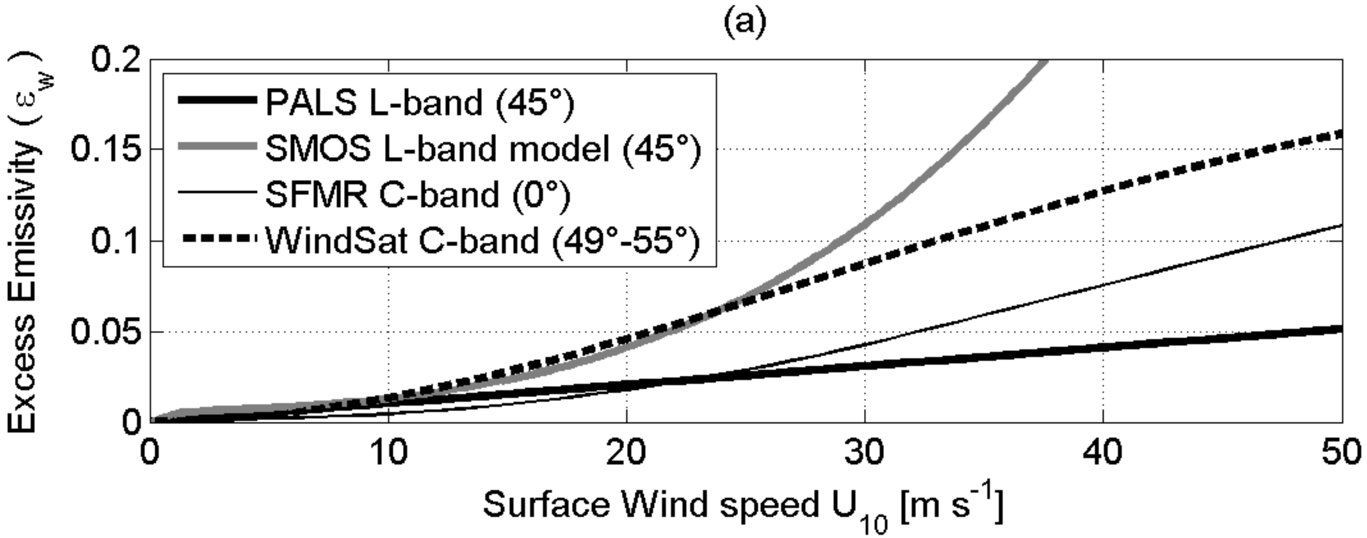
Fig. 13. V and H brightness temperatures taken at a 45° incidence angle from the star pattern (blue), inbound (red), and outbound (black) tracks on March 2, 2009, are plotted versus the wind speed derived from the POLSCAT measurements. All brightness temperature measurements have been translated to a 45° incidence angle and corrected for galactic radiation.

Linear increase of Tb with wind
Up to 28 m/s

Weak incidence angle dependence
At high winds

Yueh S.H., S.J. Dinardo, A.G. Fore, F.K. Li (2010), "Passive and Active L-band Microwave Observations and Modeling of Ocean Surface Winds", IEEE Trans. Geosci. Remote Sens., vol. 48, no. 8, pp. 3087-3100.

Wind Excess Emissivity at High winds



According to PALS sensitivity ~0.35K/m/s for the First Stokes parameter/2

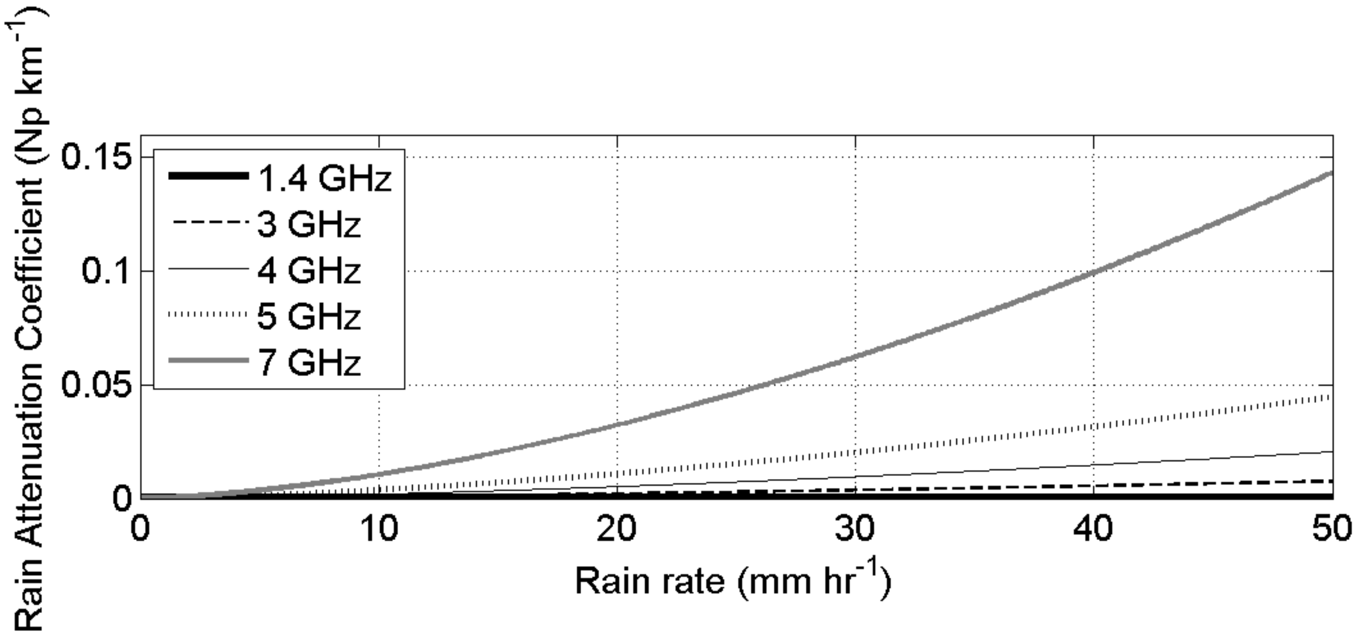
C-band TB~3 times more sensitive to wind speed than L-band

SMOS L-band model overestimates the Tb increase with wind for U>12 m/s

Rain attenuation at L-band

Because of the small ratio of raindrop size to the SMOS electromagnetic wavelength (~21 cm), scattering by rain is almost negligible at L-band, even at the high rain rates experienced in hurricanes.

Rain impact at 1.4 GHz can be approximated entirely by absorption and emission (Rayleigh scattering approximation valid)



Generally two order of magnitude smaller at L-band (1.4 GHz) than at C-band (5-7 GHz)

Analysis of SMOS signature over Category 4 Hurricane IGOR in 2010

Reul Nicolas, Tenerelli Joseph, Chapron Bertrand, Vandemark Doug, Quilfen Yves, Kerr Yann (2012). **SMOS satellite L-band radiometer: A new capability for ocean surface remote sensing in hurricanes**. *Journal Of Geophysical Research-oceans*, 117, -. http://dx.doi.org/10.1029/2011JC007474

Collection of Data for analysis

Collection of Hurricane Igor data:

- SMOS L1B data corrected for all contibutions except roughness (sss=clim)

- National Hurricane Center Best Track data:

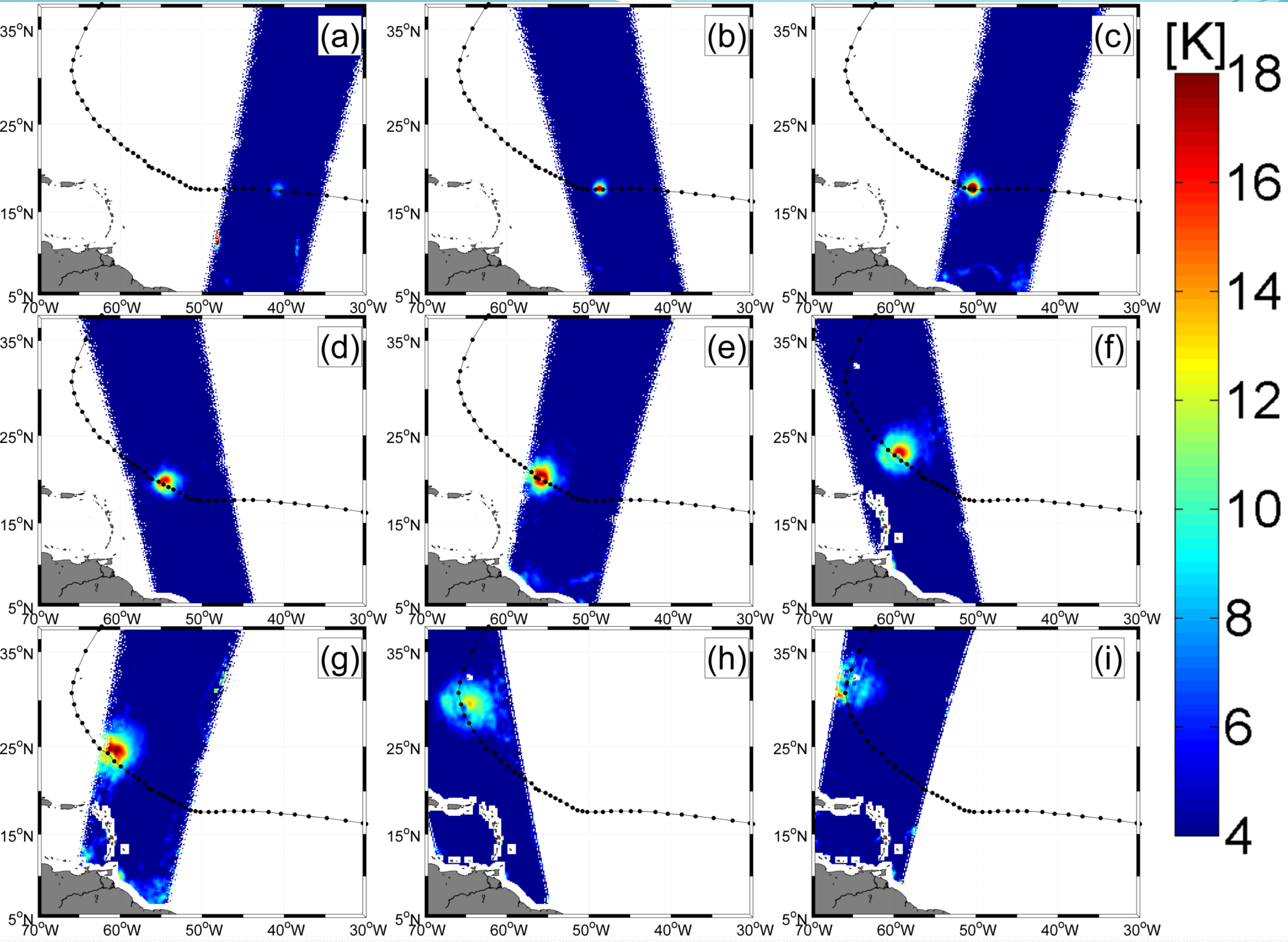
=>track; max winds, radius at 34, 50 and 64 knots

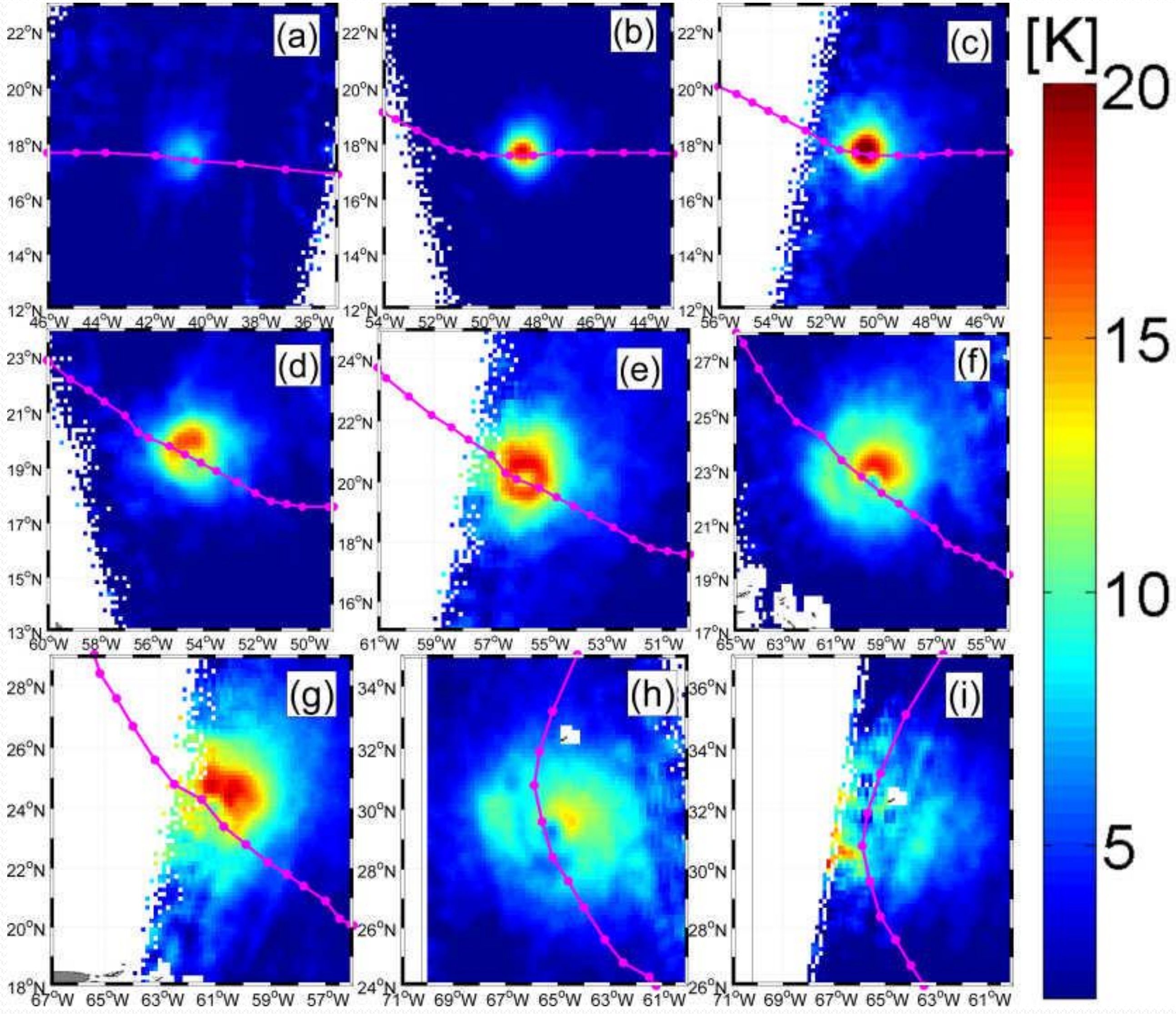
- AOML Hurricane research division

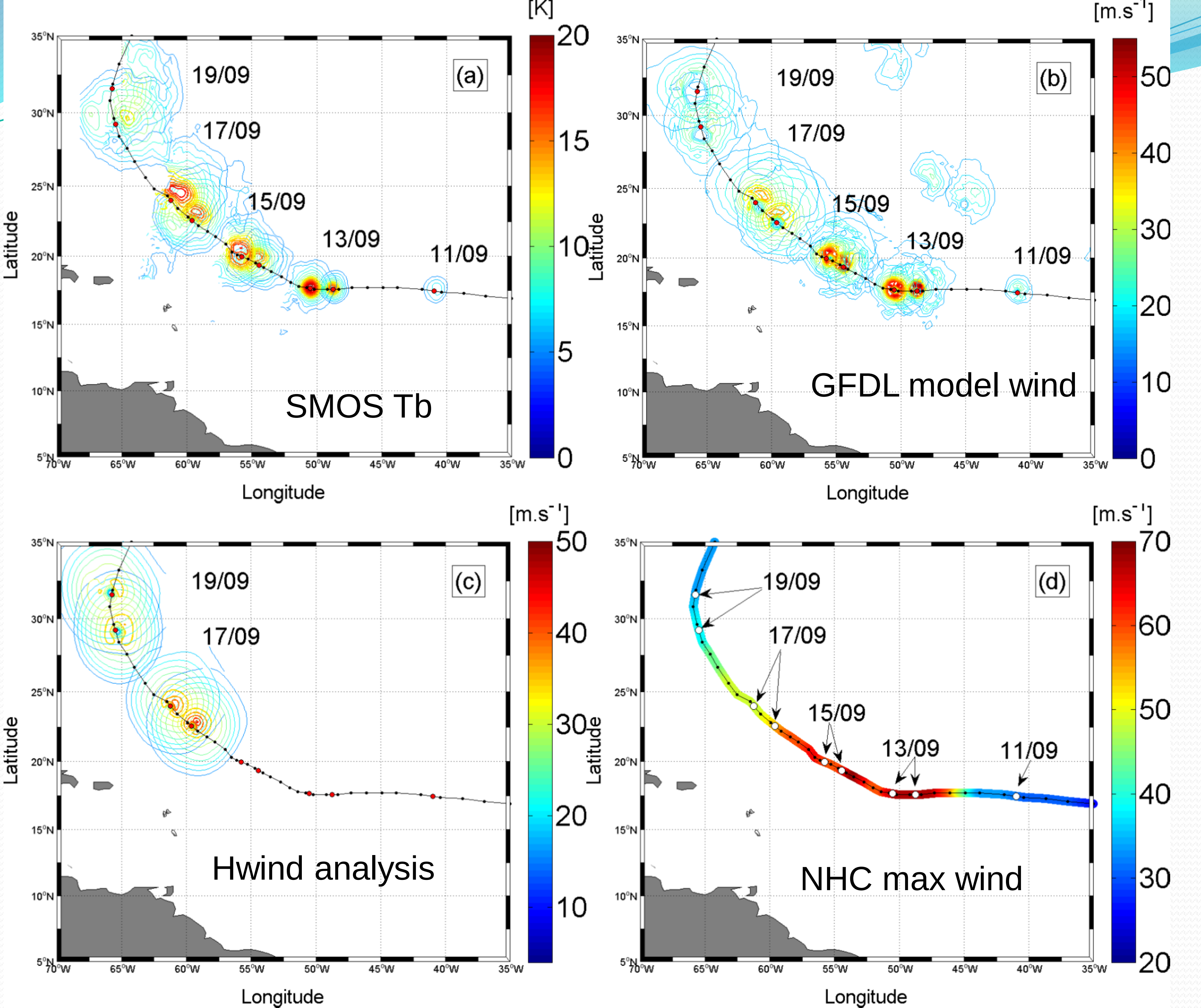
=>H*WIND observation analysis winds
=>SFMR data
- NOAA/NWS/NCEP North Atlantic Hurricane Wind Wave forecasting system (NAH):

=>Wave parameters

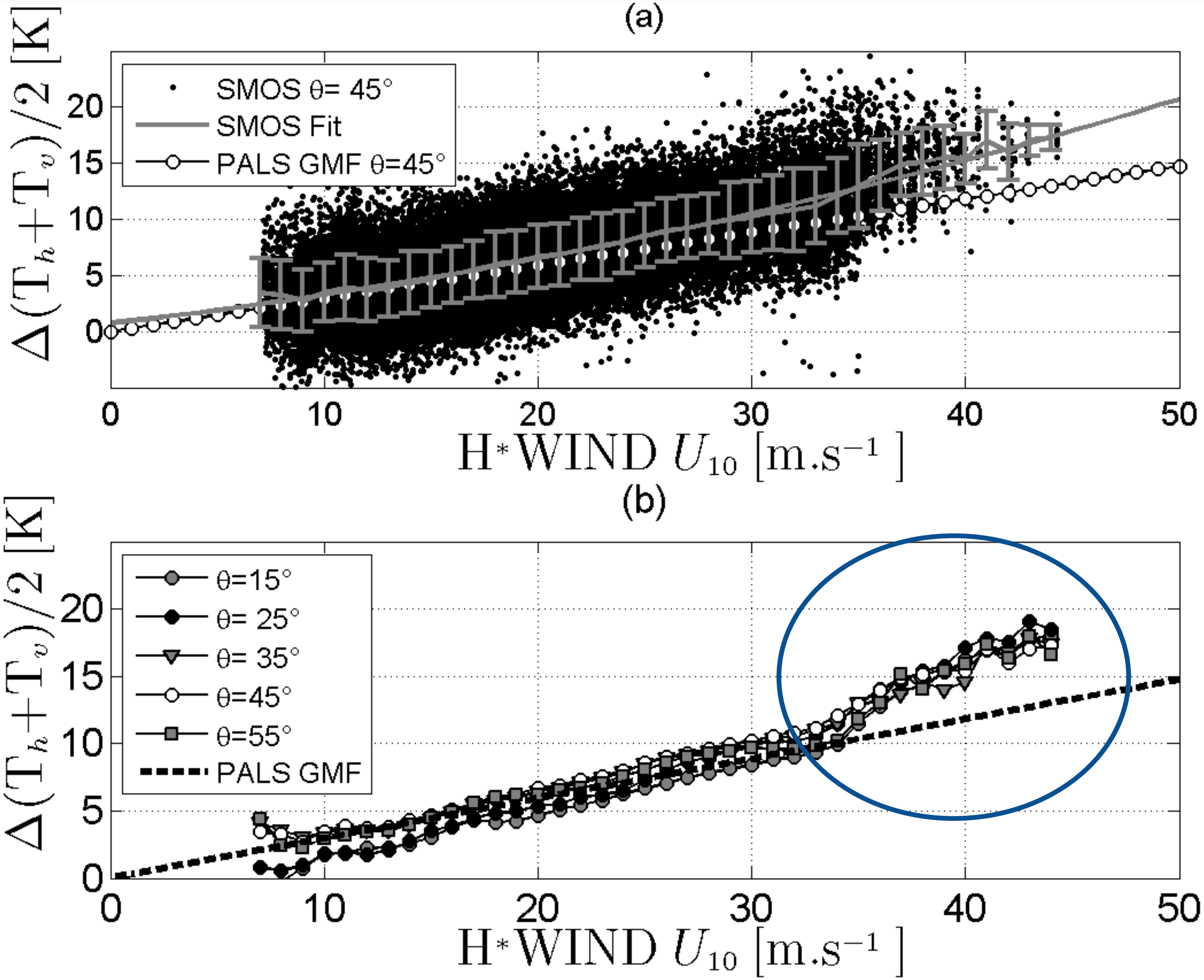
- NOAA/Geophysical Fluid Dynamic Laboratory (GFDL) hurricane model winds
- ECMWF
- ASCAT
- SSM/I, WindSAt


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
35°N
25°N
15°N
5°N
70°W
60°W
50°W
40°W
30°W
[K]
18
16
14
12
10
8
6
4


(a)
22°N
20°N
18°N
16°N
14°N
12°N
46°W
44°W
42°W
40°W
38°W
36°W
(b)
22°N
20°N
18°N
16°N
14°N
12°N
54°W
52°W
50°W
48°W
46°W
44°W
(c)
22°N
20°N
18°N
16°N
14°N
12°N
56°W
54°W
52°W
50°W
48°W
46°W
(d)
23°N
21°N
19°N
17°N
15°N
13°N
60°W
58°W
56°W
54°W
52°W
50°W
(e)
24°N
22°N
20°N
18°N
16°N
61°W
59°W
57°W
55°W
53°W
51°W
(f)
27°N
25°N
23°N
21°N
19°N
17°N
65°W
63°W
61°W
59°W
57°W
55°W
(g)
28°N
26°N
24°N
22°N
20°N
18°N
67°W
65°W
63°W
61°W
59°W
57°W
(h)
34°N
32°N
30°N
28°N
26°N
24°N
71°W
69°W
67°W
65°W
63°W
61°W
(i)
36°N
34°N
32°N
30°N
28°N
26°N
71°W
69°W
67°W
65°W
63°W
61°W
[K]
20
15
10
5


(a)
19/09
17/09
15/09
13/09
11/09
SMOS Tb
[K]
20
15
10
5
0
(b)
GFDL model wind
[m.s^{-1}]
50
40
30
20
10
0
(c)
Hwind analysis
[m.s^{-1}]
50
40
30
20
10
(d)
NHC max wind
[m.s^{-1}]
70
60
50
40
30
20
35°N
30°N
25°N
20°N
15°N
10°N
5°N
70°W
65°W
60°W
55°W
50°W
45°W
40°W
35°W
Latitude
Longitude

Geophysical Model function: Tb=f(wind speed)

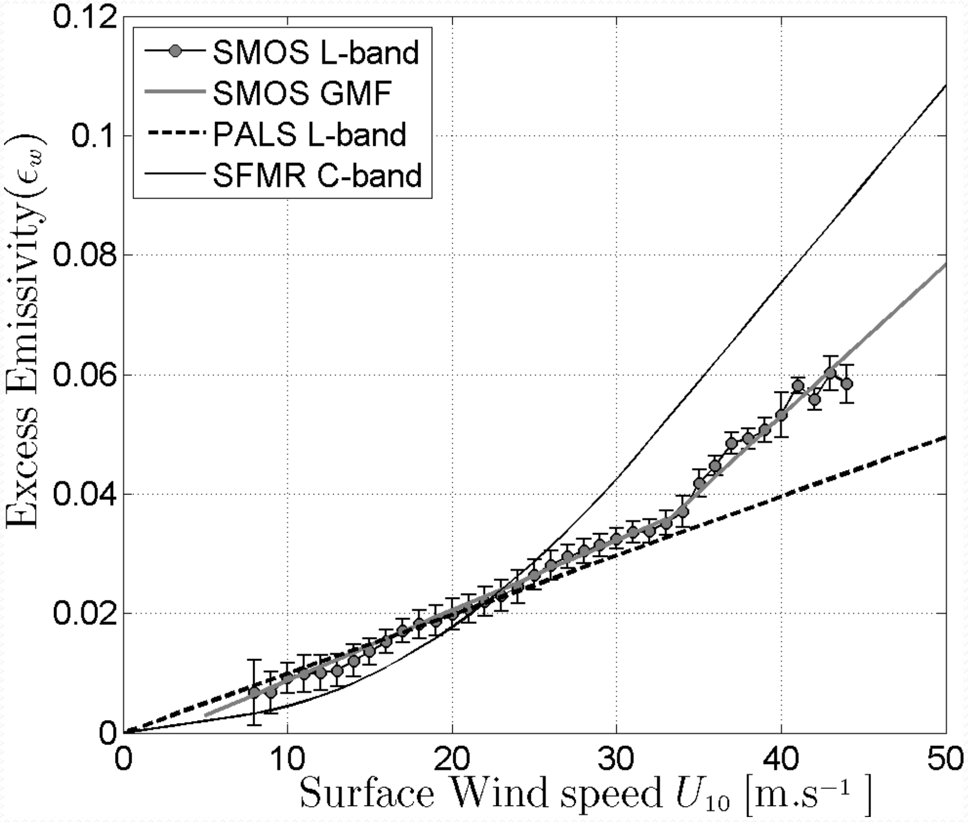


Change
of sensitivity
at
Hurricane
wind
Force (>33 m/s)

Weak Incidence
Angle dependence

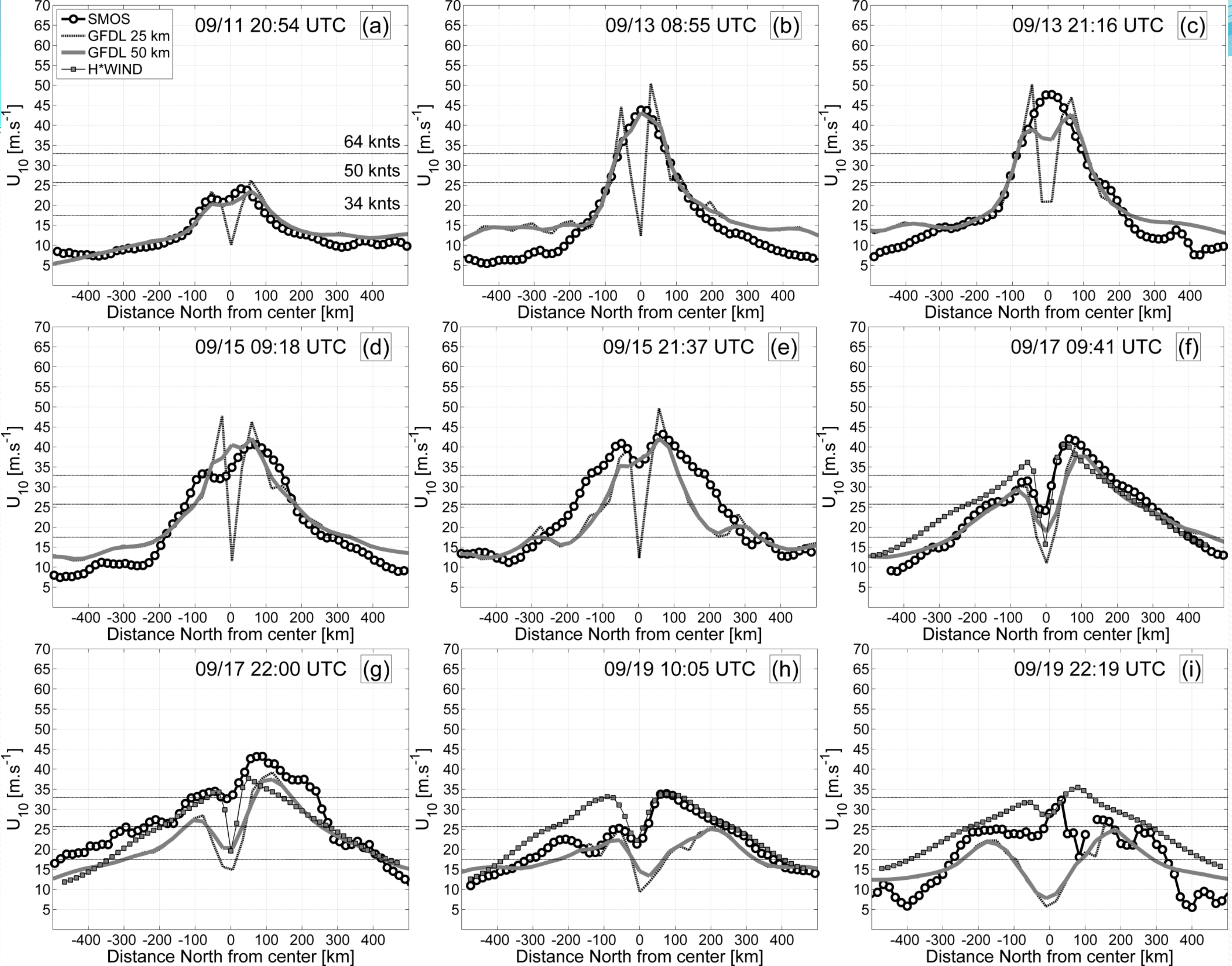
Very consistent
With PALS

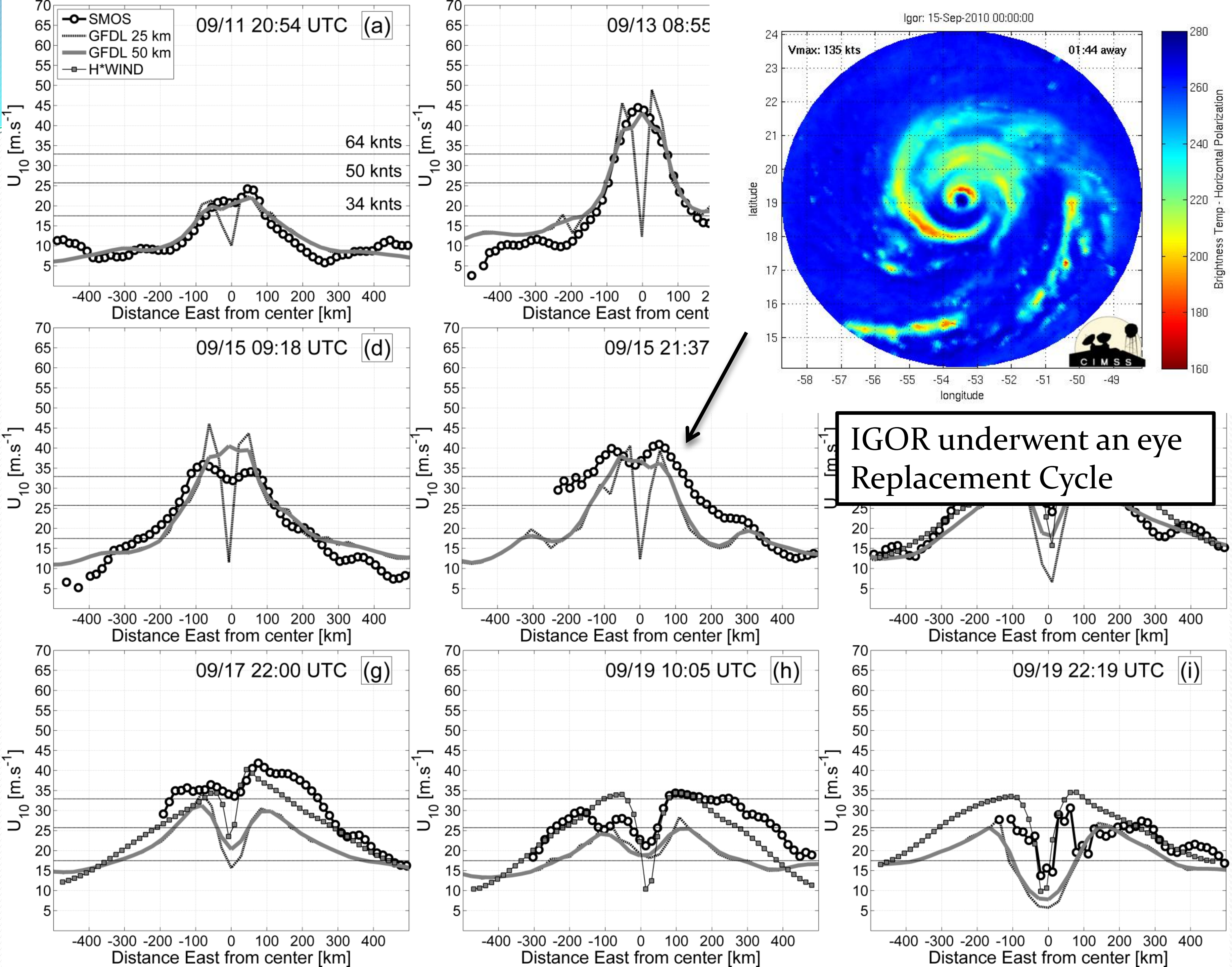
Geophysical Model function: Tb=f(wind speed)



$$\Delta I = \frac{\Delta(T_H + T_V)}{2} = 0.35\ U_{10}\text{-}1.3 \qquad U_{10} \leq 33\ \text{m.s}^{-1}$$

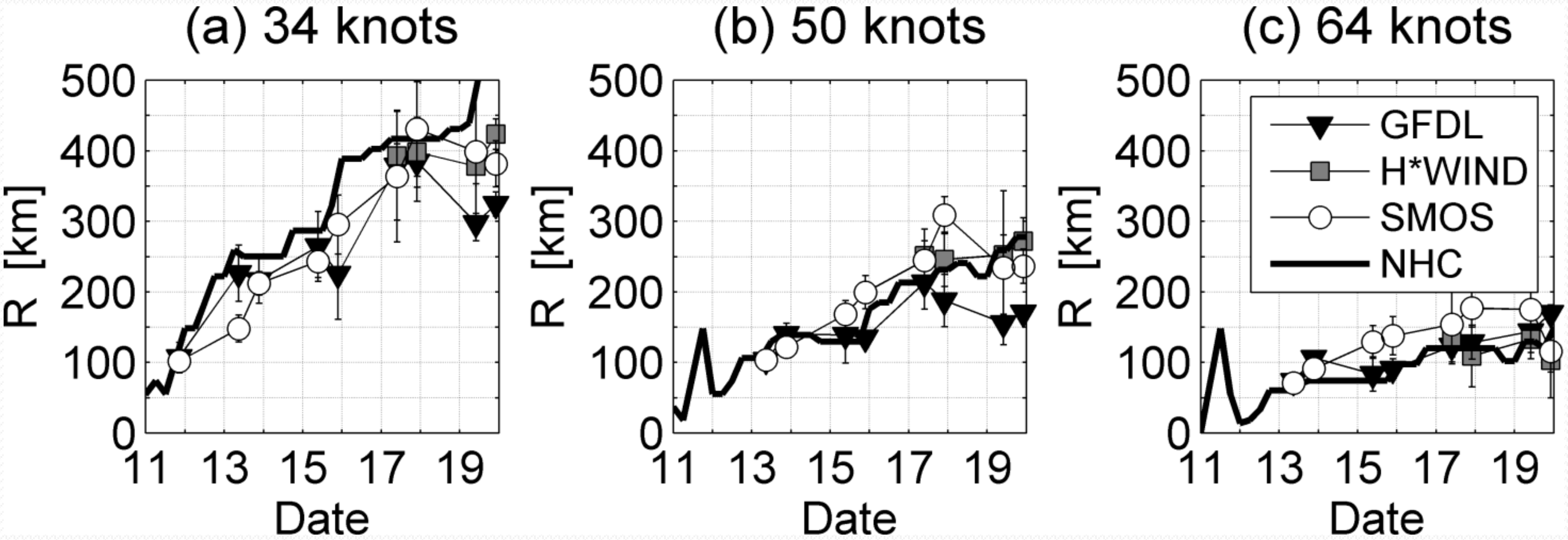
$$= 0.75\ U_{10}\text{-}14.5 \qquad U_{10} \geq 33\ \text{m.s}^{-1}$$


SMOS
GFDL 25 km
GFDL 50 km
H*WIND
09/11 20:54 UTC (a)
09/13 08:55 UTC (b)
09/13 21:16 UTC (c)
09/15 09:18 UTC (d)
09/15 21:37 UTC (e)
09/17 09:41 UTC (f)
09/17 22:00 UTC (g)
09/19 10:05 UTC (h)
09/19 22:19 UTC (i)
64 knts
50 knts
34 knts
U_{10} [m.s^{-1}]
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-400
-300
-200
-100
0
100
200
300
400
Distance North from center [km]



IGOR underwent an eye Replacement Cycle

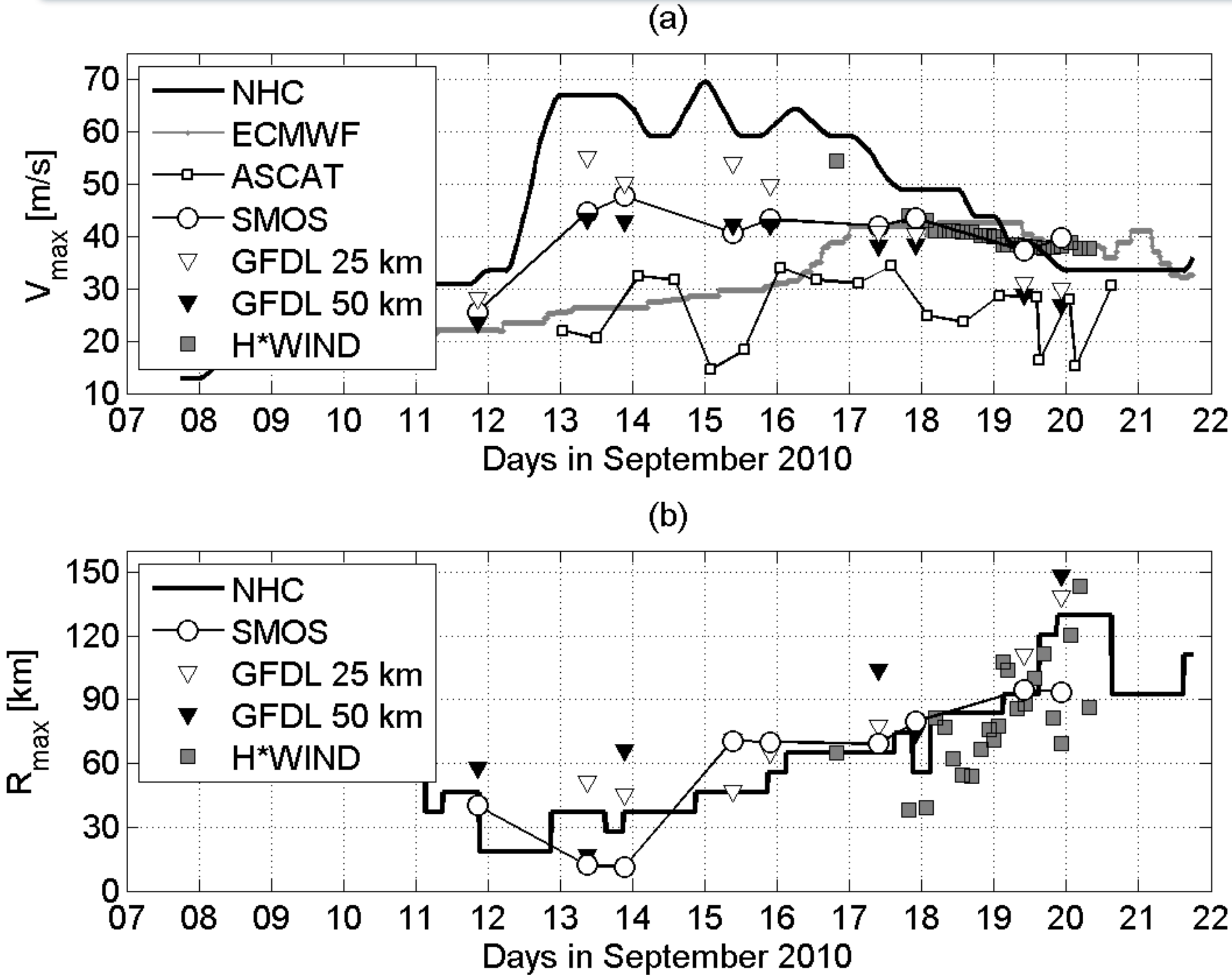
Wind field Structure from SMOS



Radius of wind speed larger than 34, 50 and 64 knots

Key parameters to monitor tropical cyclone intensification
Ascat can provide R34 but not R50 & R64=>SMOS does

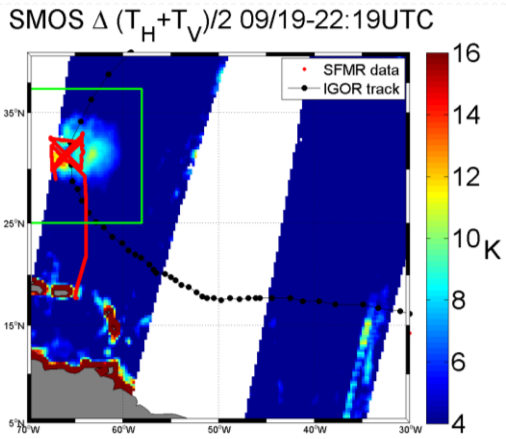
Maximum Wind estimates from SMOS

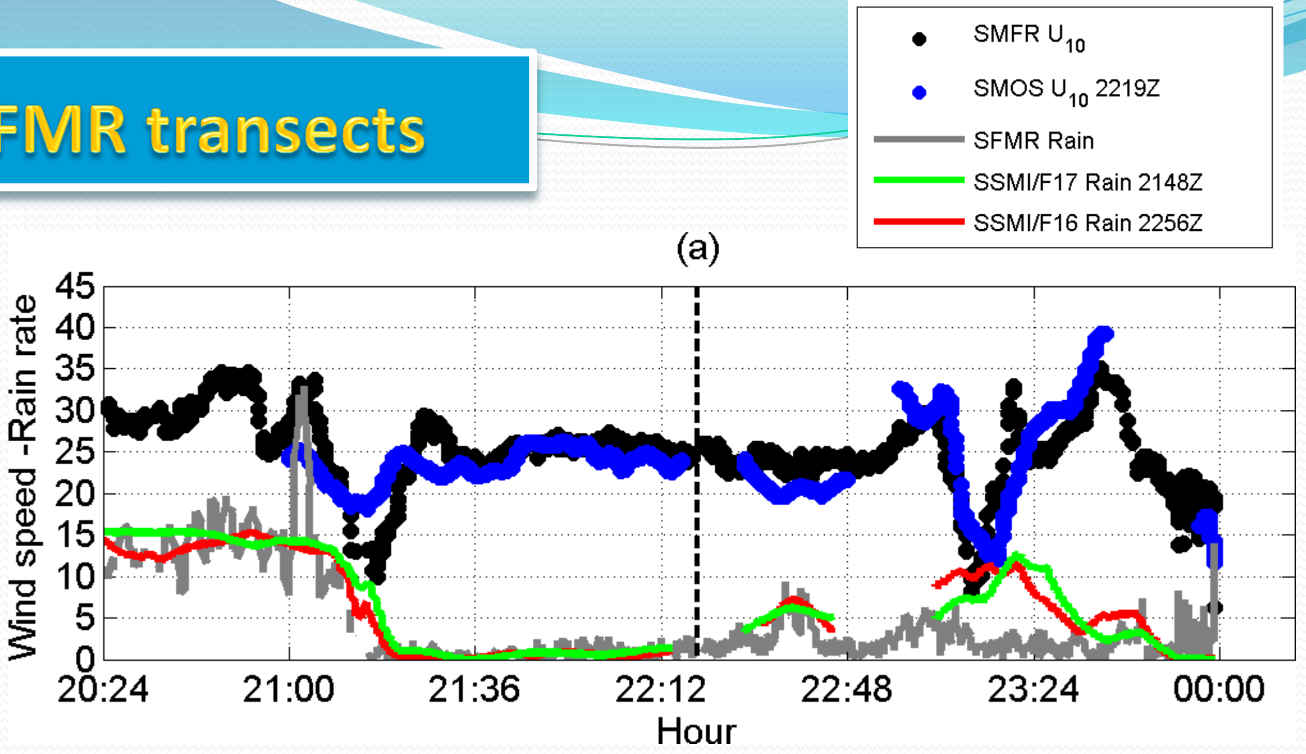


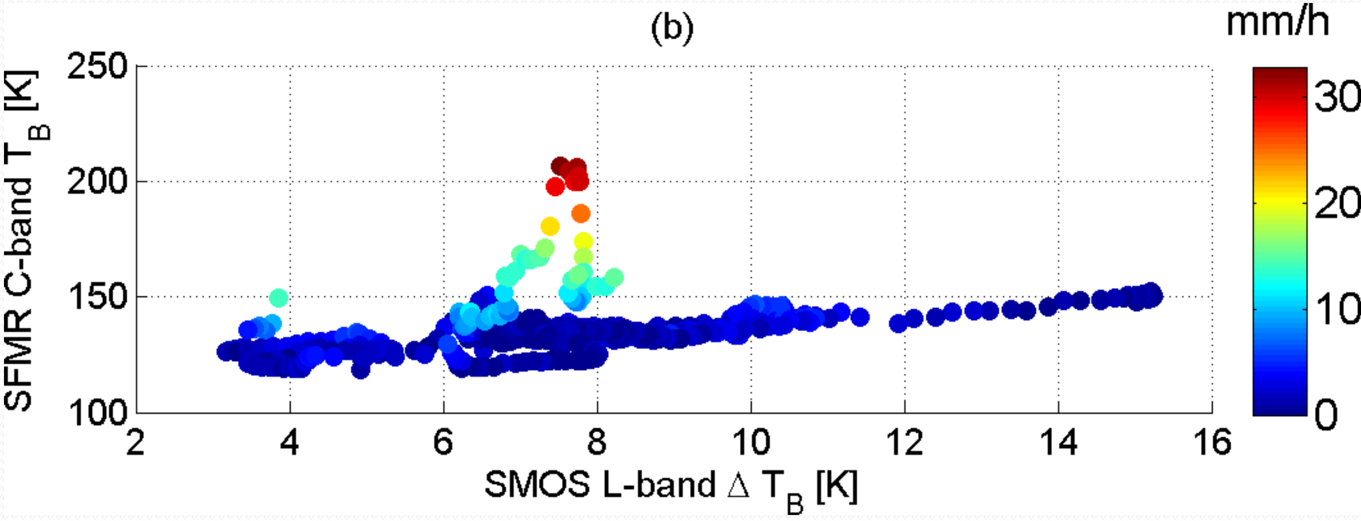
SMOS clearly outperform ASCAT in that case

Comparison at SFMR transects

NOAA hurricane
Hunter flight



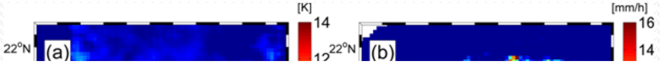


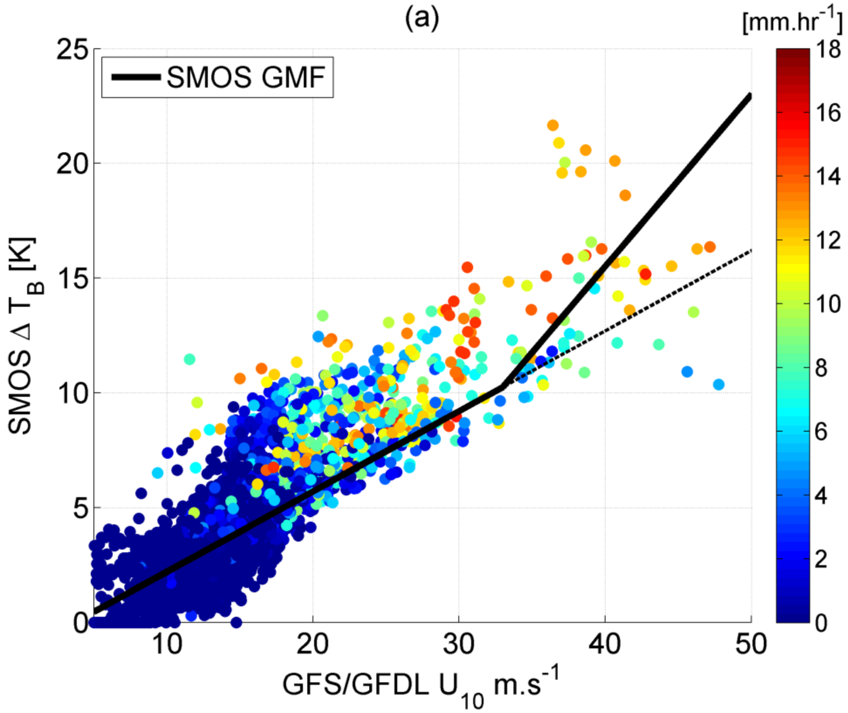


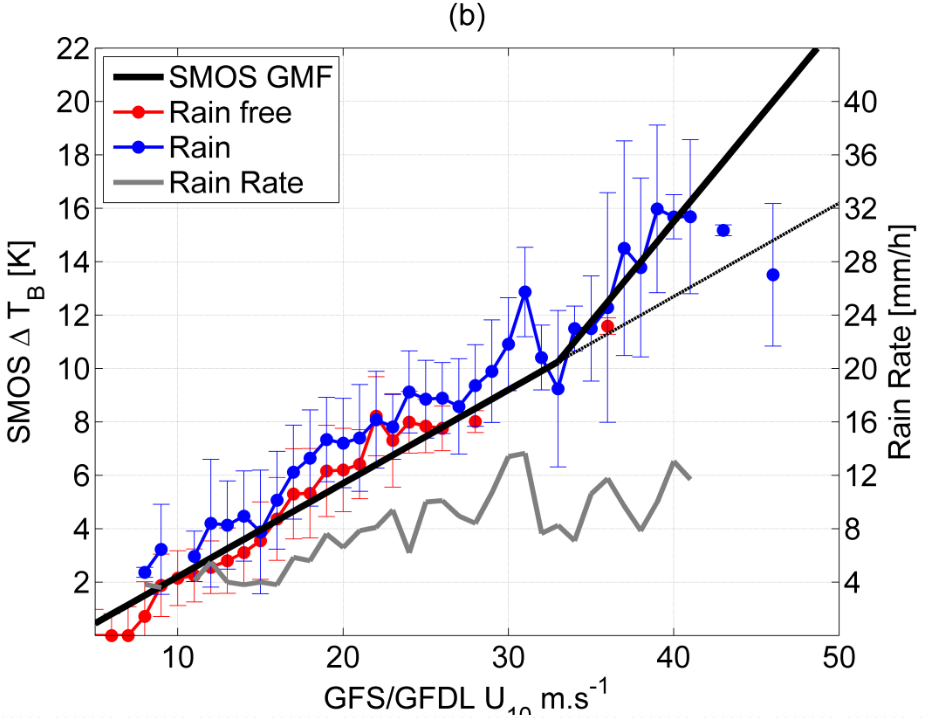
Potential rain Impact at L-band

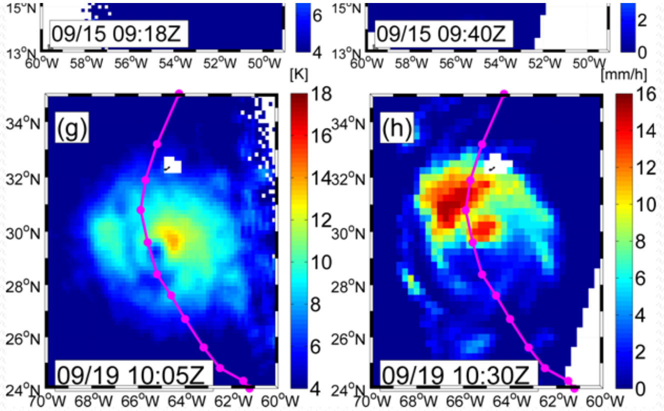
SMOS Tb

Rain rates









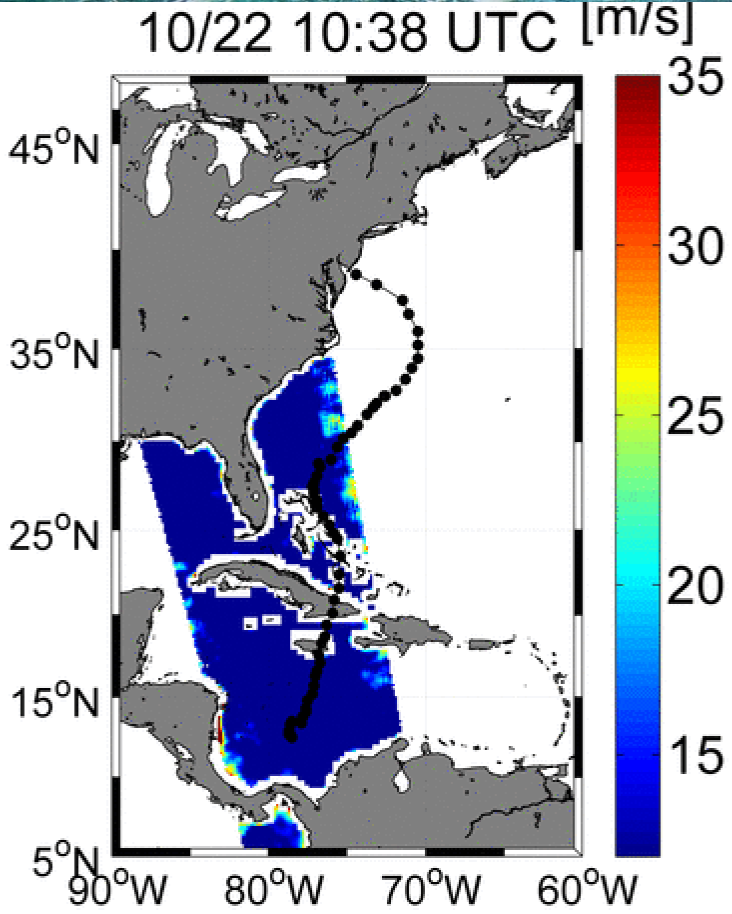
SSM/I F16

Below hurricane force (33 m/s)
=>some Rain impacts but small
(errors on wind speed < 5 m/s)

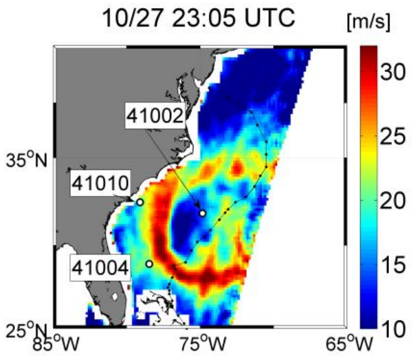
At very high winds, lack of rain-free data
to conclude

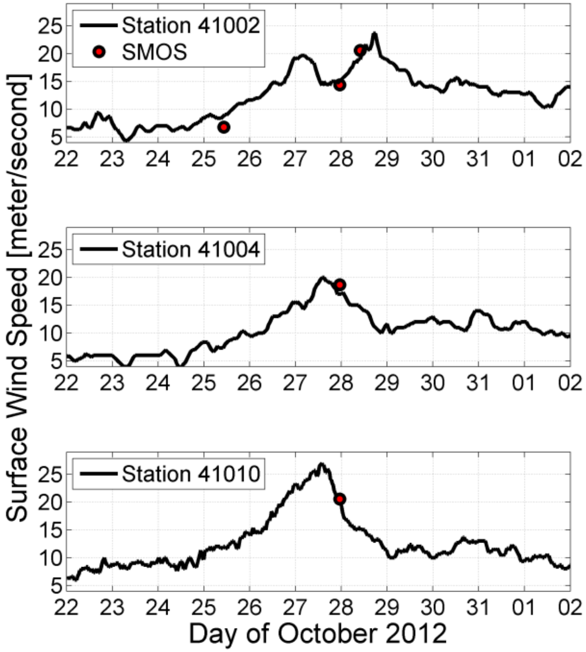
SuperStorm Sandy Viewed by SMOS

Hurricane Sandy Oct 2012



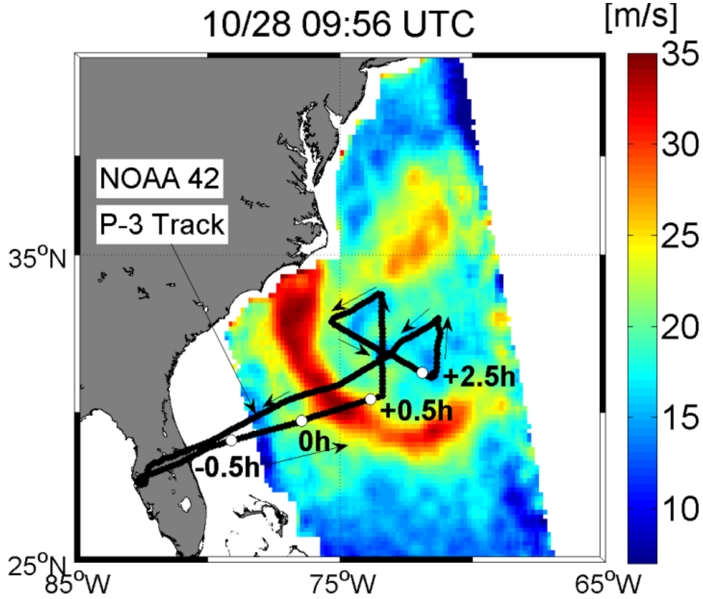
Validation with buoy data



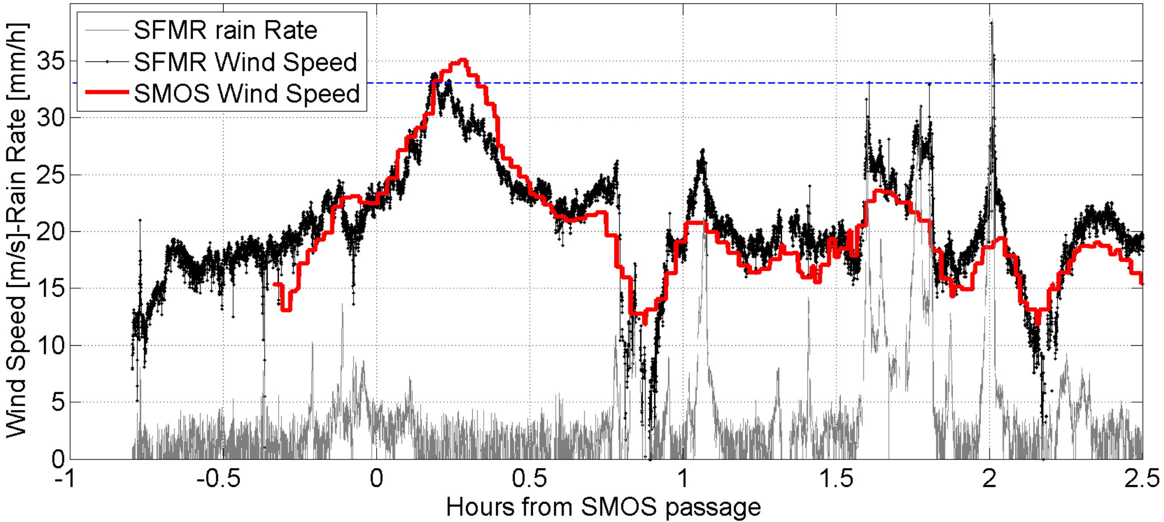


Hurricane Sandy

Validation with NOAA hurricane hunter Aircraft Data (C-band)SFMR


10/28 09:56 UTC

10/28 09:56 UTC



Summary (1)

- We evidenced clear SMOS brightness temperature signal associated with the passage of Hurricanes

- By analysing SMOS intercept with Hurricane Igor in 2010 and collecting an ensemble on auxilliary wind speed informations, we developed a Geophysical Model Function relating the SMOS Tb estimated at the surface (corrected for atmosphere) to the surface wind speed.

- We have shown that SMOS can allow to retrieve important structural surface wind features within hurricanes such as the radius of wind speed larger than 34, 50 and 64 knots. These are Key parameters to monitor tropical cyclone intensification

Ascat can provide R34 but not R50 & R64=>SMOS does

SMOS clearly outperform ASCAT & ECMWF in the Igor case in area far from Aircraft observations

Summary (2)

- **The potential effect on rain at L-band was analyzed:**

Below hurricane force (33 m/s)
=>some Rain impacts on the Tbs were found but small
(errors on wind speed < 5 m/s)

At very high winds, lack of rain-free data to firmly conclude but certainly weaker than at C-band

- An empirical wind speed retrieval algorithm was developed
- The latter was tested against an independant Hurricane: the Cat-1 Hurricane Sandy in 2012. SMOS wind speed retrievals were compared to NODC buoy data and SFMR wind speed:

- Agreement within ± 3 m/s was found

- Main instrumental limitations are spatial resolution, RFI & land contamination