Hurricane observations by C-Band SAR and L-Band Radiometer

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R. Husson and R. Vadaine; CLS
J. Tenerrelli; ODL

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Outline of talk

- Motivations
- SHOC campaign
- NRCS & ocean surface wind speed
- NRCS & $T_{B,rough}$
- Conclusions & Perspectives

Ifremer

Motivations

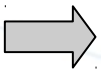
- Sentinel-1A & Sentinal-1B C-Band SARs have the capabilities of measuring NRCS in VV and VH or HH and HV.
- Sentinel-1C and Sentinel-1D C-Band SARs will have the same capabilities than Sentinel-1 A & B.

  Launch date:

  - Sentinel-1C: 2021
  - Sentinel-1D: 202?
- Next Metop-SG scatterometers will have the capability of measuring NRCS in VH, VV and HH.

  Launch date :

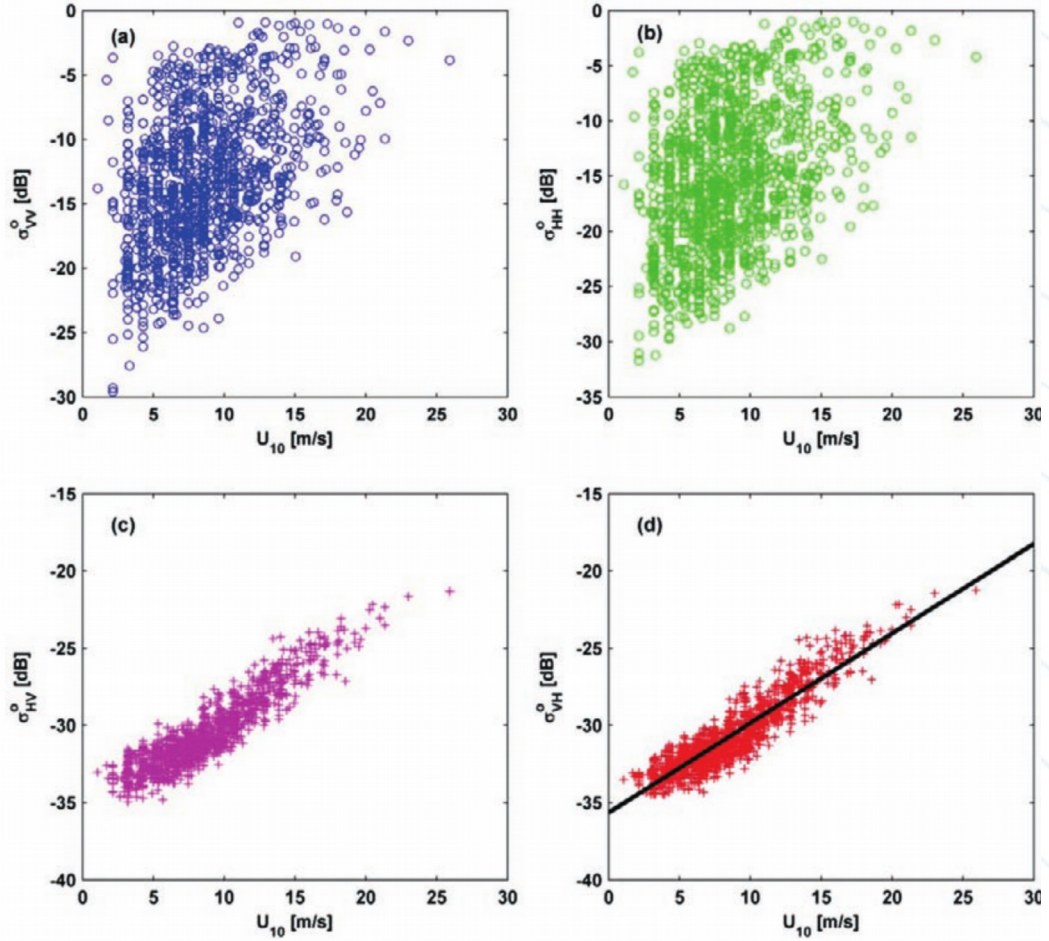
  - Metop-SG-A: 2022
  - Metop-SG-B: 2023



- Metop-SG scatterometers will start a new area of active radar in Europe.
- Sentinel-1 SARs already operate at C-Band in co- and cross- polarization.

Motivations

- Since 2007, RadarSat2 provides NRCS measurements in co- and cross- polarizations.
- RS2-based studies enabled to show
  - VV signal is saturating but RS2 VH is not.
  - VH is much lower than VV.
  - VH is not incidence angle dependent.
- VH dependence with respect to wind direction is still unclear.



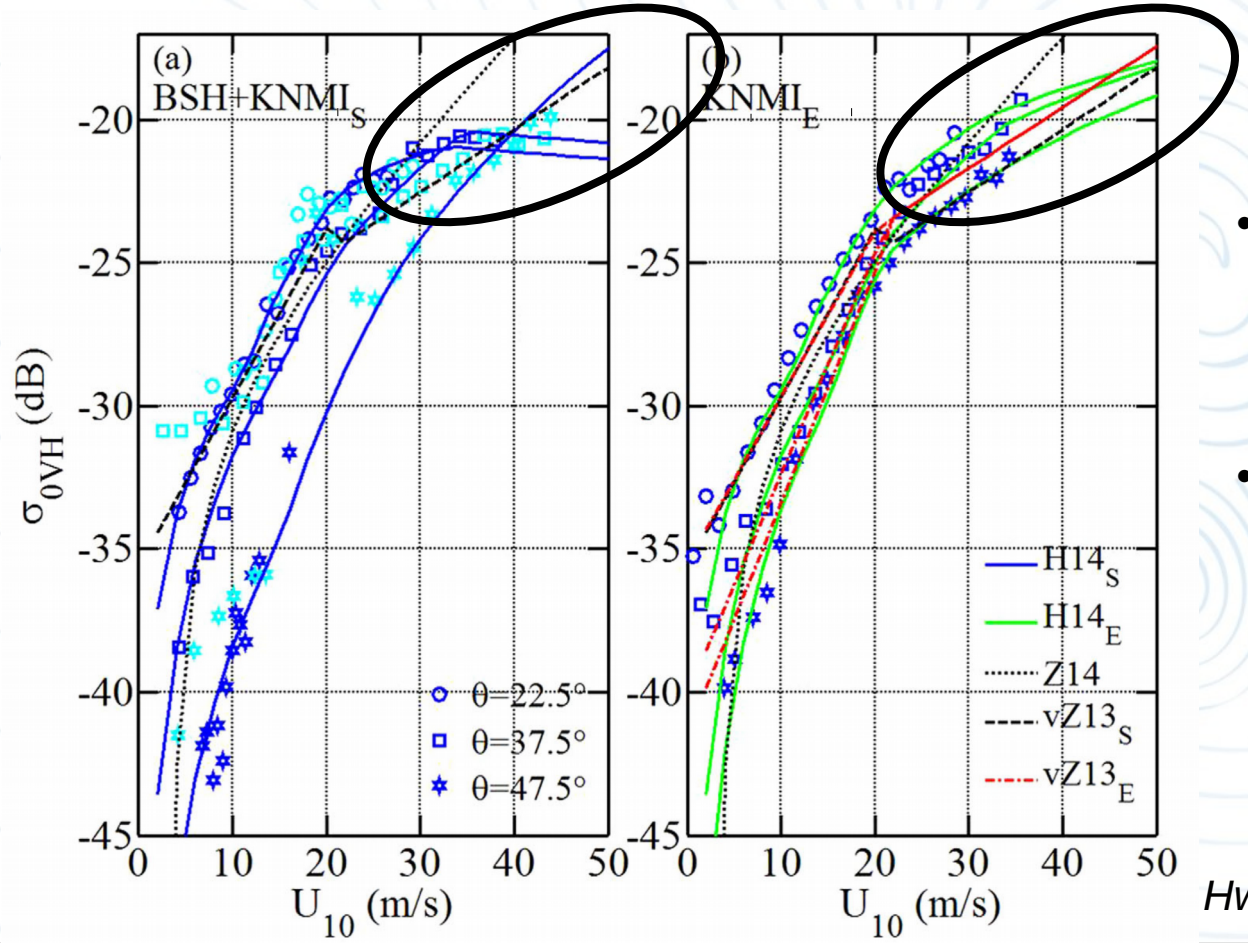
NRCS vs in situ buoy-measured U 10 : (a) VV polarization, (b) HH polarization, (c) HV polarization, (d) VH polarization.

Zhang and Perrie, BAMS 2012

⇨ The better sensitivity of VH with respect to VV offers perspectives for extreme winds measurements

Motivations

- Based on RS2 data, several relationships (GMF) have been proposed to relate NRCS and ocean surface wind speeds.
- The small dataset available prevents to establish a robust GMF for wind larger than 35 m/s. In the most recent study, Hwang et al. proposed 2 different GMFs obtained with 2 different reference datasets and with and without considering noise in RS2 products.



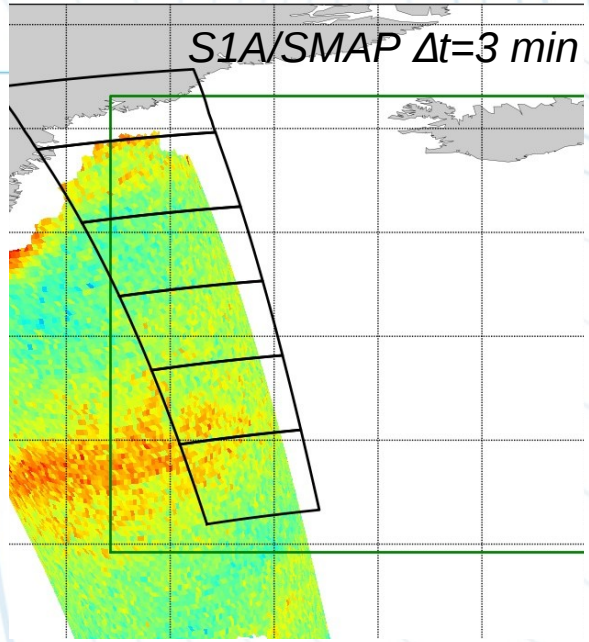
- The small dataset available also prevents to validate SAR wind speeds for extremes events with wind speed larger than 40 m/s
- To date, rain impact is always neglected.

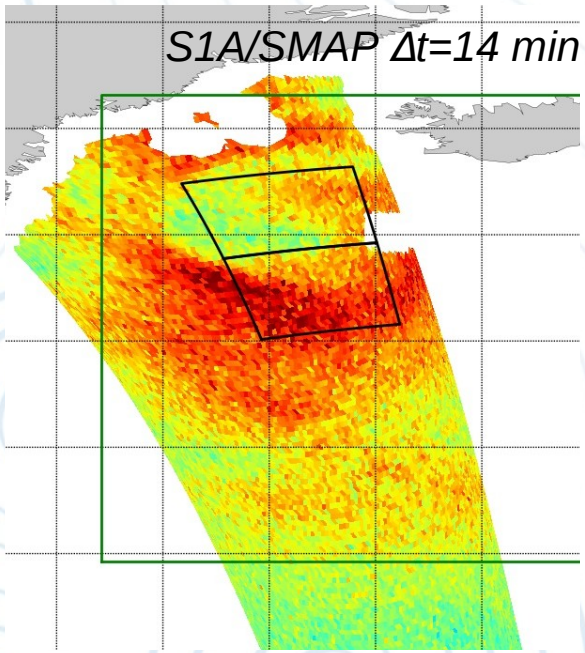
Hwang et al, JGR 2015

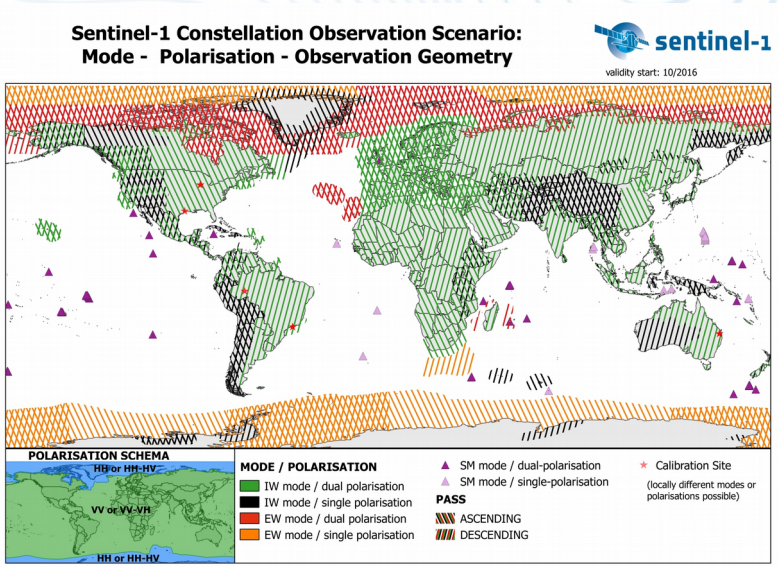
Ifremer

Motivations

- SAR does not continuously acquire data.
- Very few Dual-Polarizaton SAR data are available over ocean hurricane.
- Reference data for hurricanes combined with the low amount of SAR data makes the probability to have SFMR or dropsondes very unlikely
- When SAR images are acquired, there is potential for co-locations in time and space with less than 30 minutes time difference.







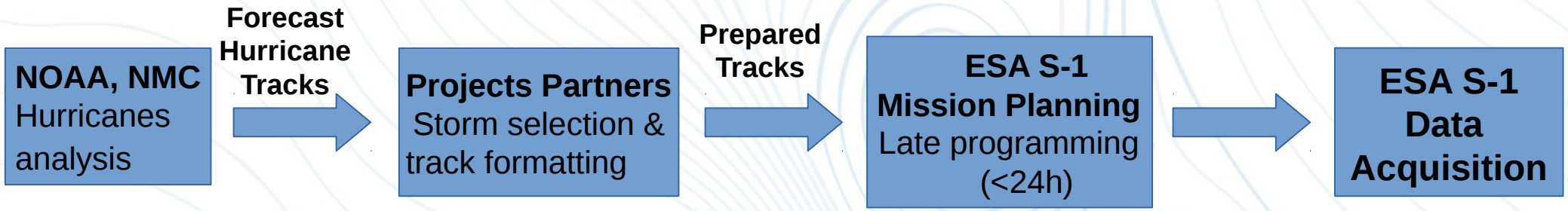
Satellite **H**urricane **O**bservations **C**ampaign

- Based on these facts, a strategy is proposed to take benefit of S-1/SMAP co-locations potential. It consists in using
  - Sentinel-1 A acquisitions over hurricanes
    - ⇨ Optimize the acquisition plans with ESA mission planning
  - SMAP ability to measure ocean surface wind
    - ⇨ Get significant amount of “reference data”
  - Analyze NRCS from SAR with SMAP winds
    - ⇨ Discuss/Extend existing GMFs

- This should allow to
  - Assess the quality of VH-NRCS from Sentinel-1 SARs
  - Investigate the relationship between VH-NRCS and geophysical parameters in the case of Hurricanes
  - Suggets a new acquisition strategy and a new wind product to ESA for Sentinel-1 SARs

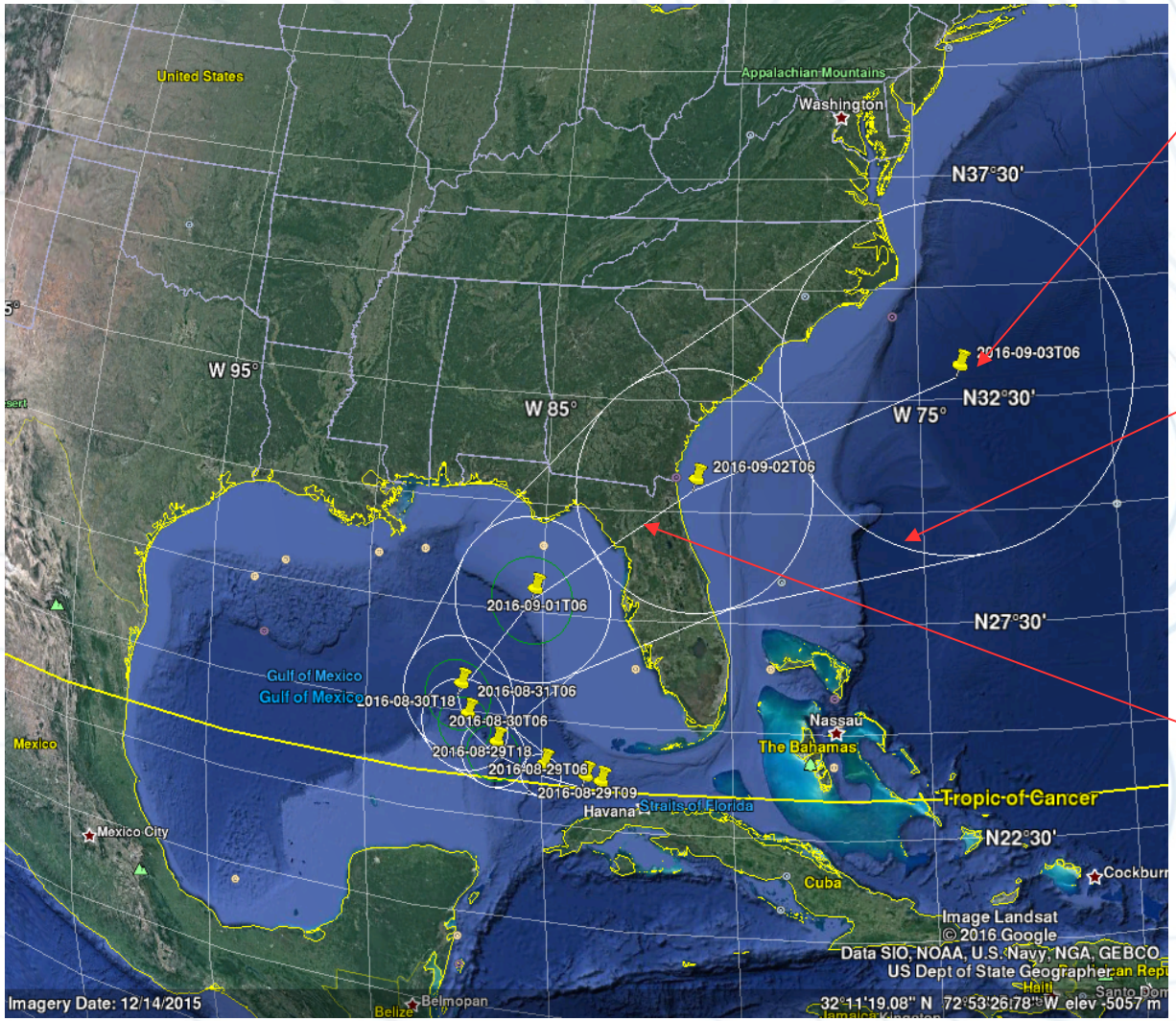
Satellite **H**urricane **O**bservations **C**ampaign

- **S**atellite **H**urricane **O**bservations **C**ampaign was organized by IFREMER, CLS with a strong support from ESA and in collaboration with NOAA



Satellite **H**urricane **O**bservations **C**ampaign

- Example of Forecast track for Hermine Hurricane



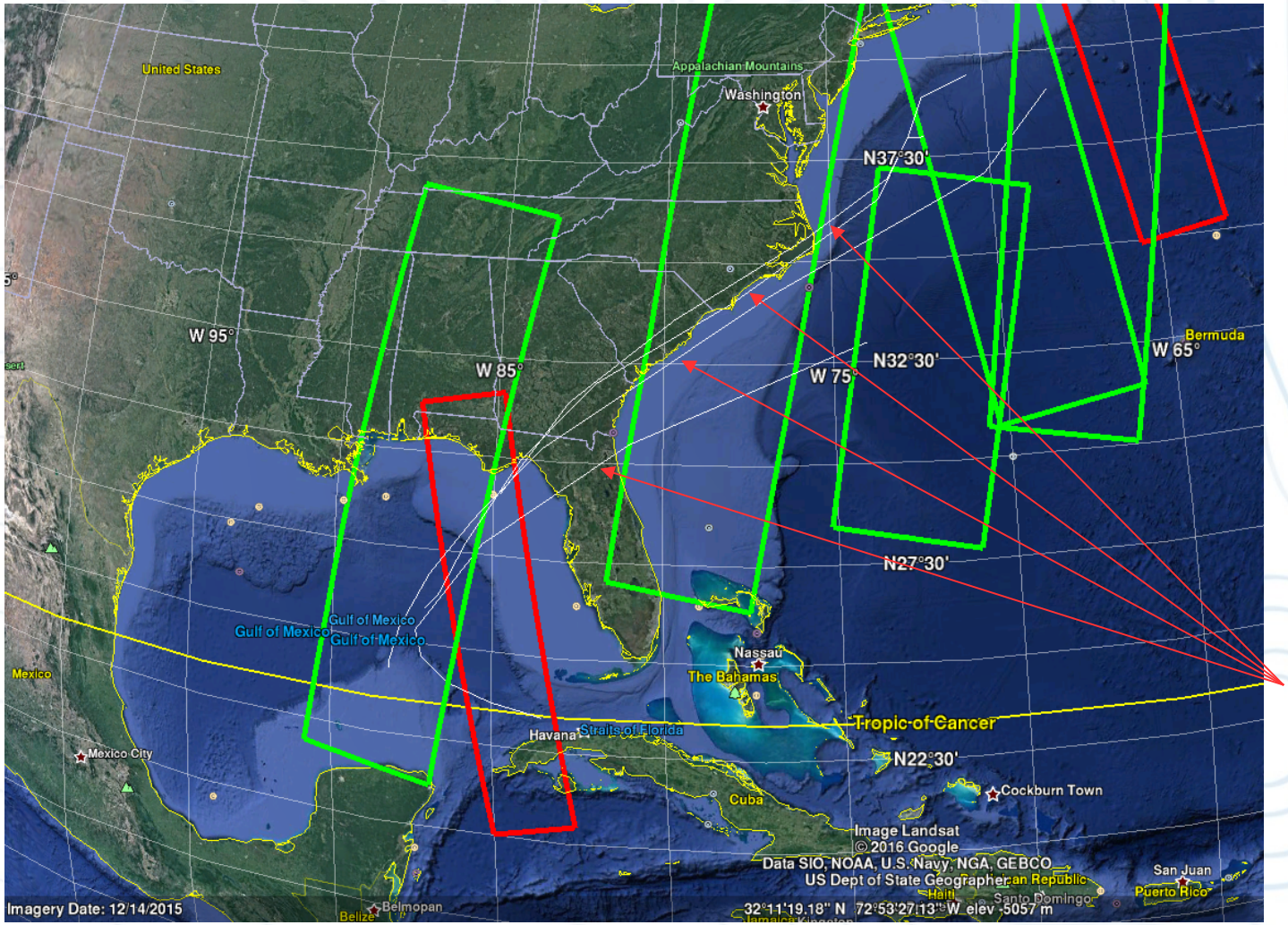
Forecast Eye location for 2016/09/03 at 6H

Uncertainty of the forecast location. It increases with forecast time.

Forecast trajectory

Satellite **H**urricane **O**bservations **C**ampaign

- Example of Forecast tracks for Hermine Hurricane and associated Sentinel -1 acquisitions : 5 Extended Wide swaths (EW) and 2 Interferometric Wide swaths (IW).



4 Forecast trajectories

#	Name	Nbr of Acq	SM FR	Eye
1	Kay	1		
2	Lyonrock	4		3
3	Gaston	10		6
4	Lester	10		4
5	TS8	3		
6	Hermine	6	1	2
7	Madeline	4		
8	Namtheum	2		1
9	Orlene	2		
10	Meranti	1		
11	Malakas	4		
12	Karl	5	3	2
13	Lisa	10		
14	Megi	3		2
15	Hulika	6		

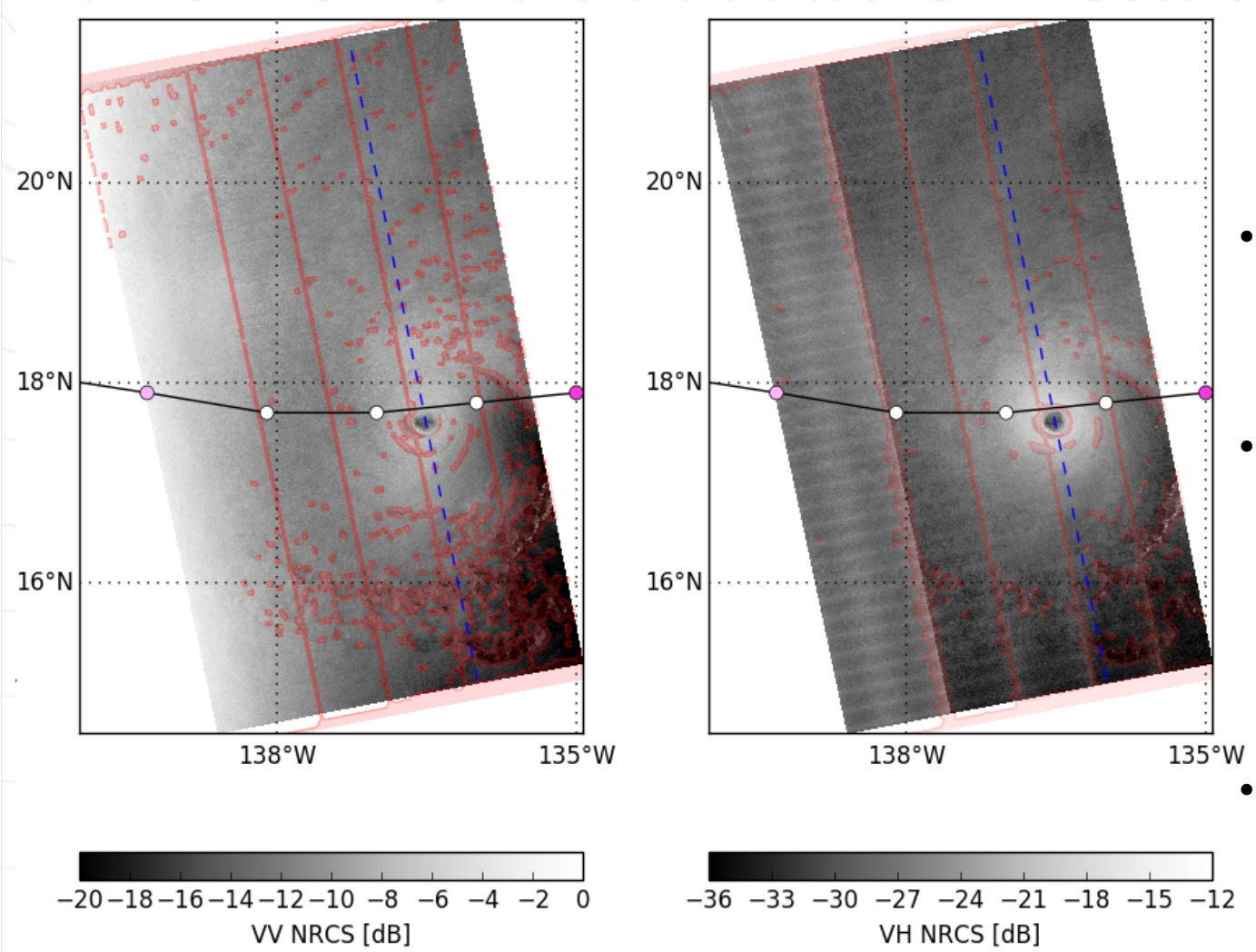
- 20 acquisitions with eye captured in SAR images (~30 %)
- Very few co-locations with SFMR airborne radiometer (3). And **None of them** during most intense phases of the TC
- S1 acq over most extreme winds:

- Typhoon Lyonrock: 2 acq. in Cat 3, both at 105 knots max sustained winds

- Typhoon Megi: 1 acq. in Cat 3, 100 knots max sustained winds

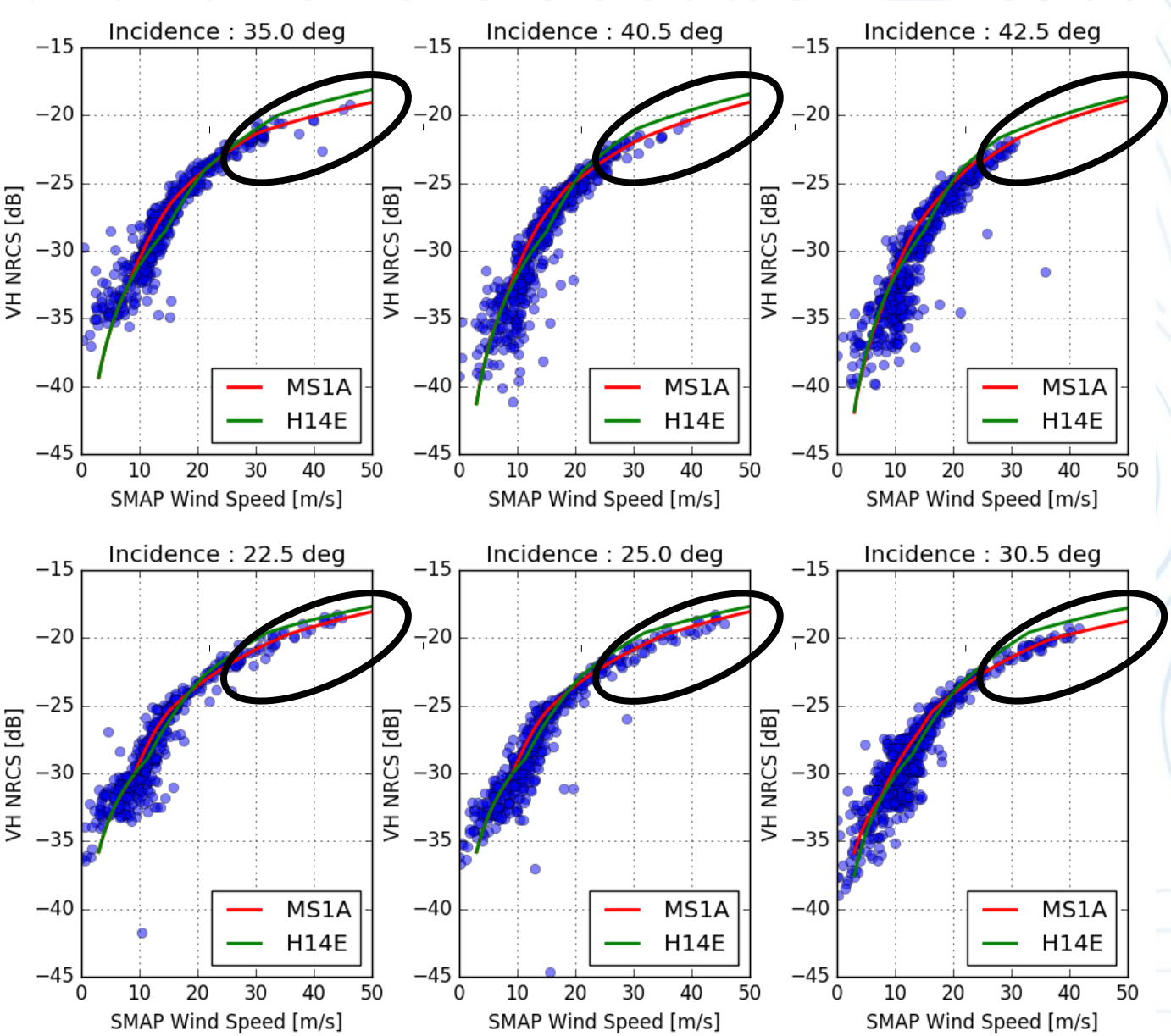
- Hurricane Lester: 2 acq. in Cat 3 and 4, 105 and 120 knots max sustained winds

- NRCS & Wind



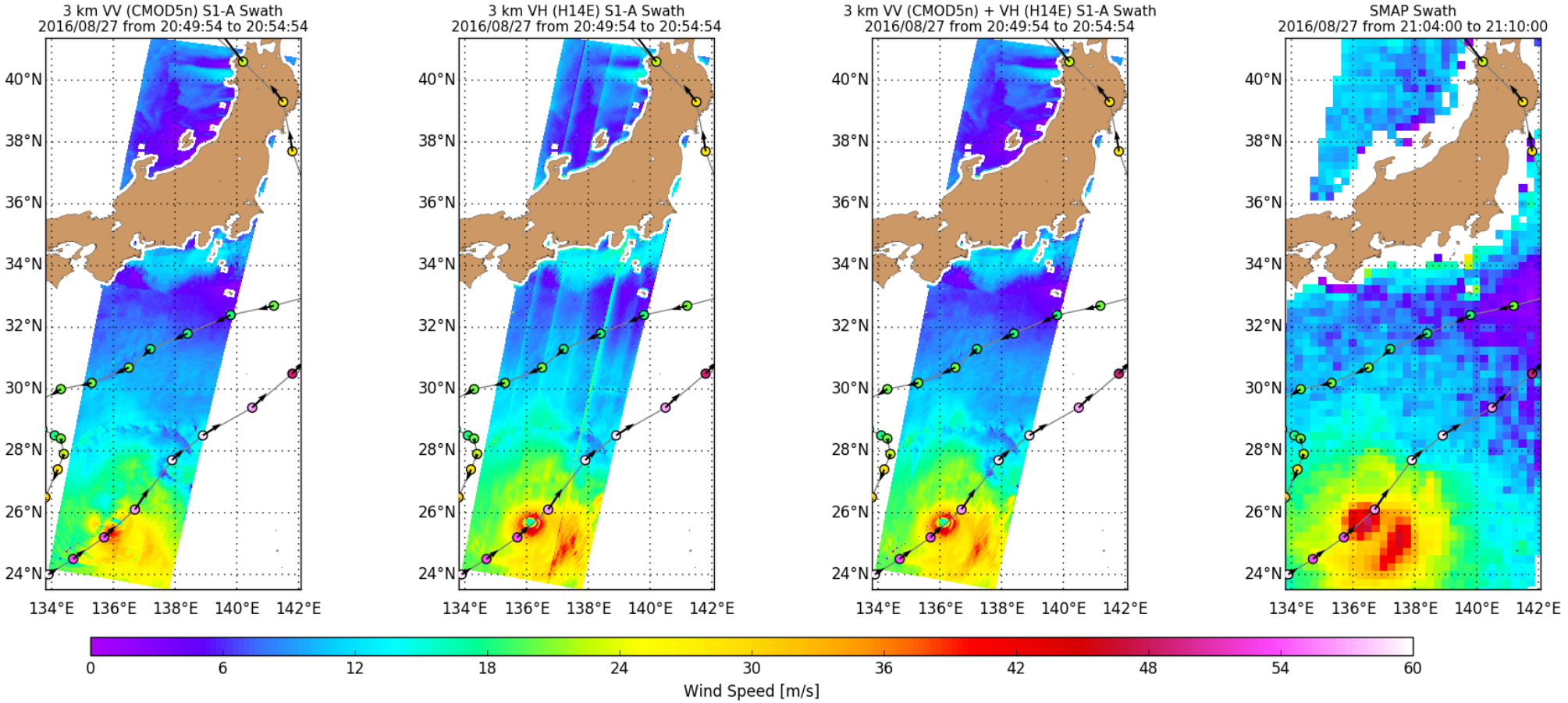
- Both VV and VV captures hurricane features (eye, rain impact, wind acceleration)
- VV-NRCS is much higher than VH-NRCS
- VH is significantly affected by noise.
  - In Near range, SNR is very low
  - Far from the eye the SNR is very low.
- LG gradient method can be applied to filter out heterogeneities in the images

- NRCS & Wind



- More than 8500 co-locations at SMAP resolution
- Analysis confirm higher sensitivity to ocean surface wind speed in VH than in VV
- Analysis confirm small incidence angle dependency
- Analysis allow to extend the GMF for winds higher than 25 m/s

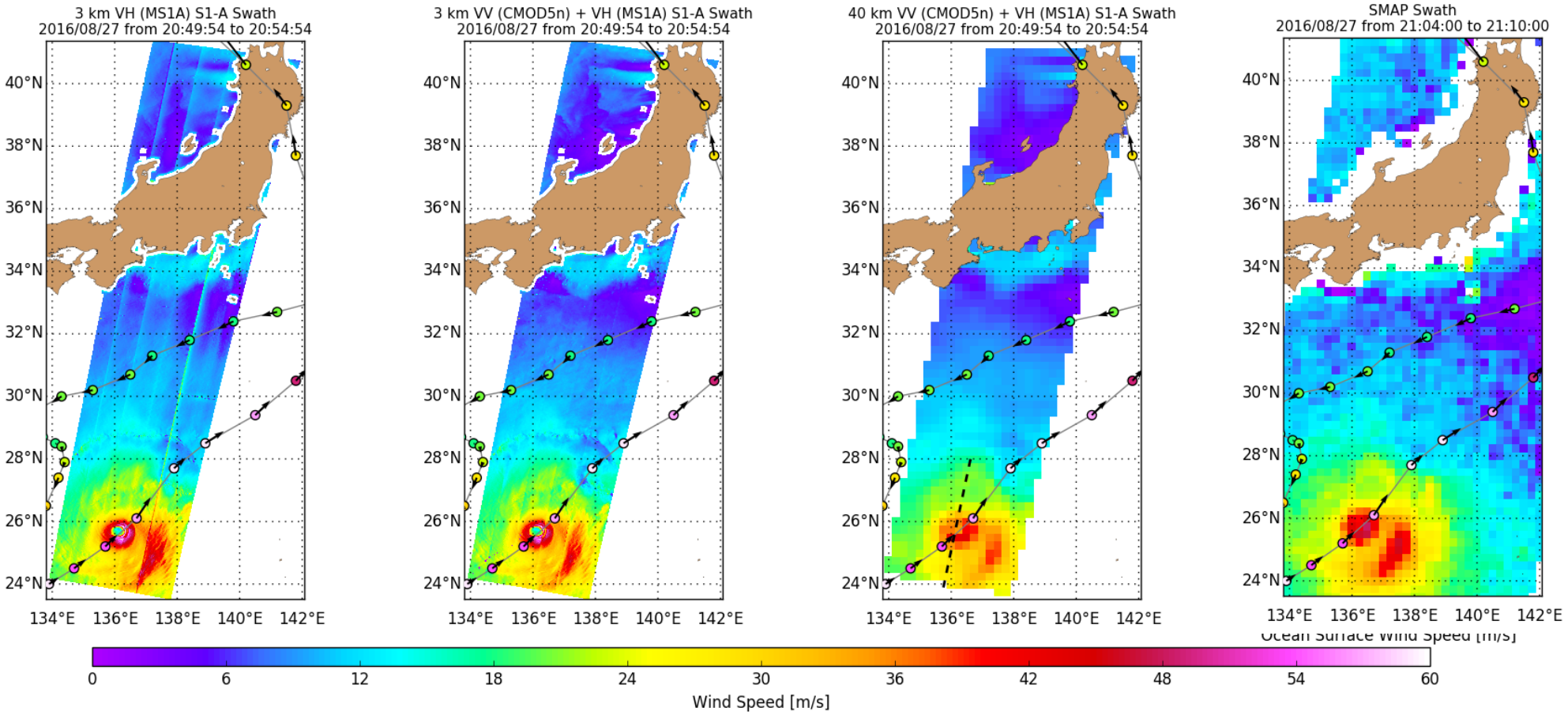
- NRCS & wind (H14E GMF)



- VV seems to predict unrealistic hurricane wind structure and lower winds speeds values compared to SMAP (at lower resolution)
- VH enables higher values of wind speeds but NESZ issues affect the retrieved wind speed in VH.
- The combination of both channels mitigate the NESZ issues. S-1 Wind speeds seems to remain lower than SMAP winds

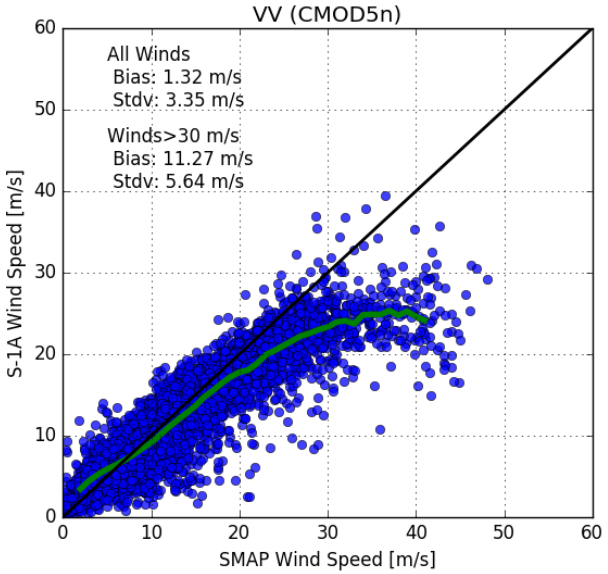
Satellite Hurricane Observations Campaign

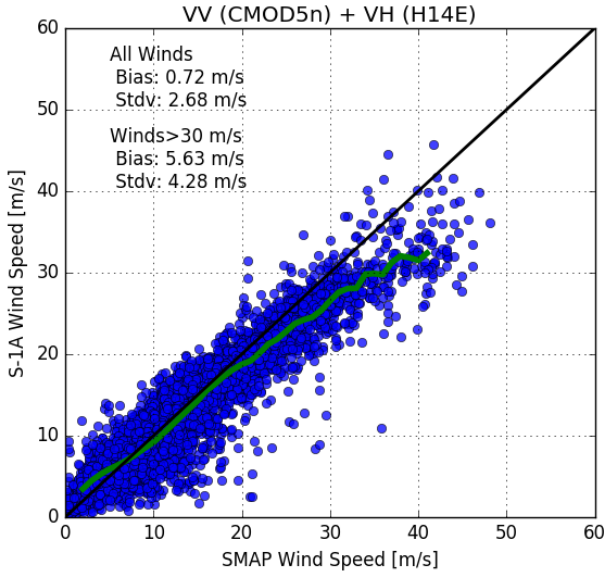
- NRCS & wind (S1A GMF)

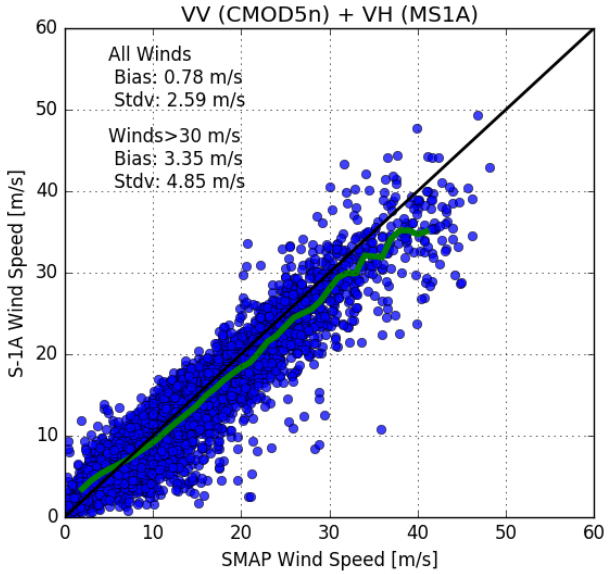


- With the new GMF, VH and VH+VV combination give wind speed values more consistent with SMAP winds
- When doing 40-km SAR wind instead of high resolution wind, both sensors can be directly compared. 40-km SAR winds and SMAP winds are found to be very consistent.

- NRCS & wind

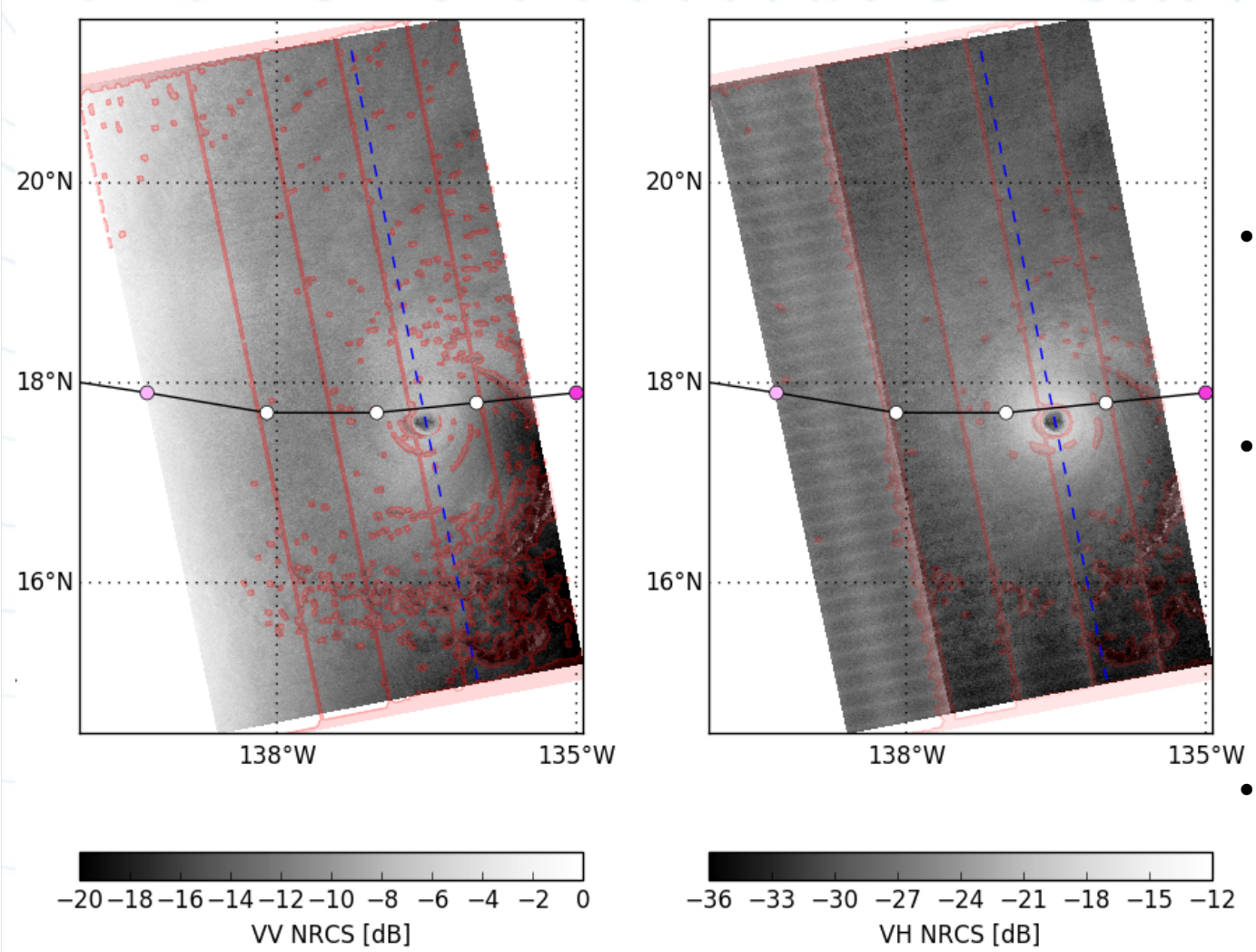






- Statistical comparison of VV-Winds, VV+VH wind with existing GMF and VV+VH wind obtained with new GMF confirm that Sentinel-1 winds and SMAP winds can be very consistent.
- In particular, the use of the new GMF improves statistics (bias is reduced) for wind speeds larger than 30 m/s.

- SAR NRCS & $T_{B,rough}$



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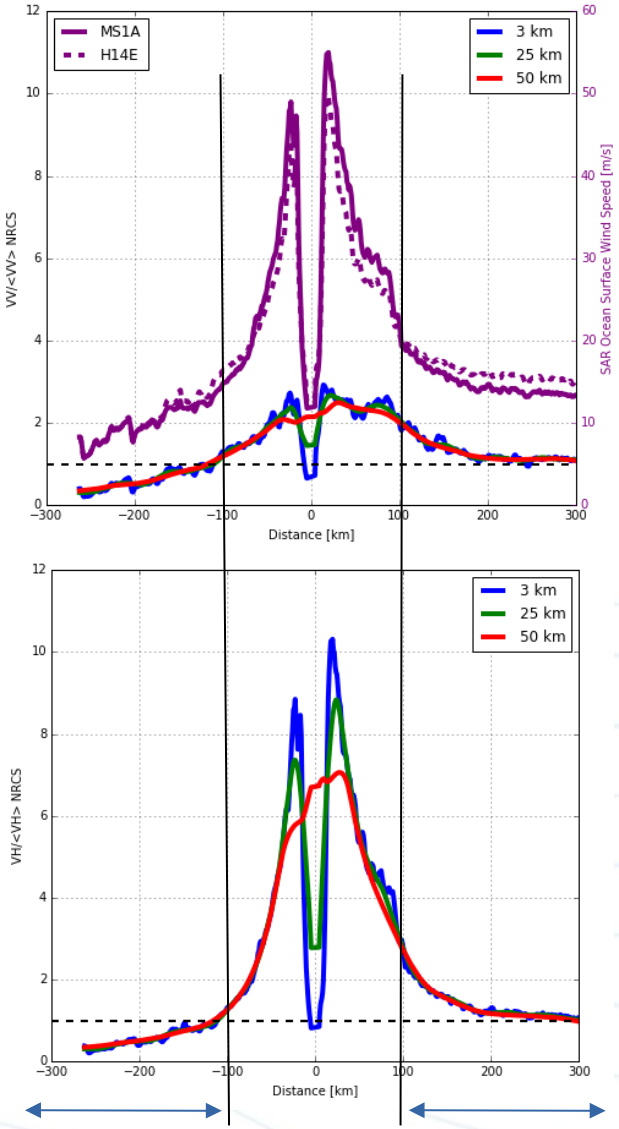


- Difference of NRCS sensitivity is analyzed with respect to the background signal :

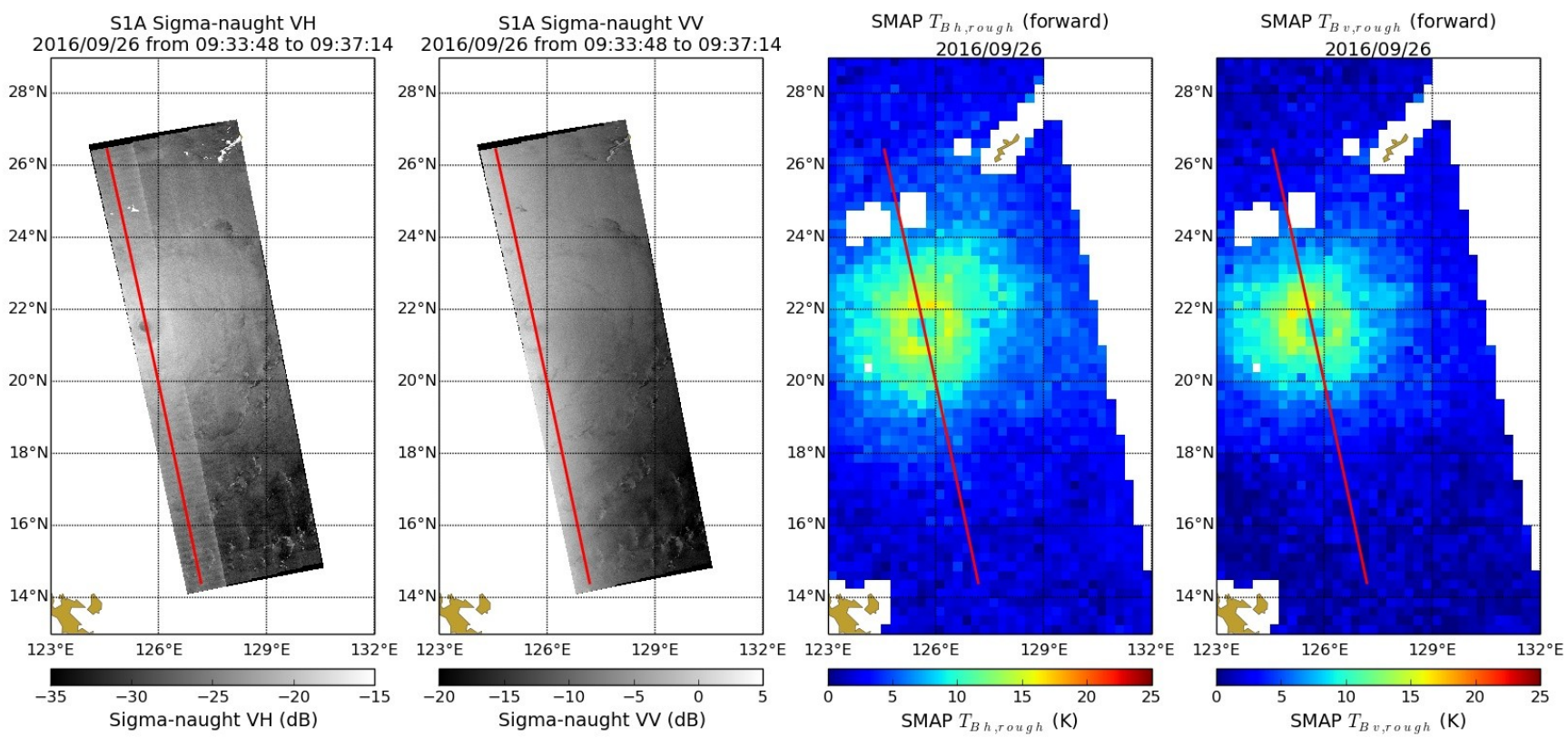
C_pp = NRCS_pp/<NRCS_pp>

- Sensitivity of VV-NRCS is found to be much lower (up to 3 times) than in VH-NRCS

- Sensitivity of NRCS decreases when resolution increases ; but remains much higher in VH.

- Resolution changes impacts more VH than VV.

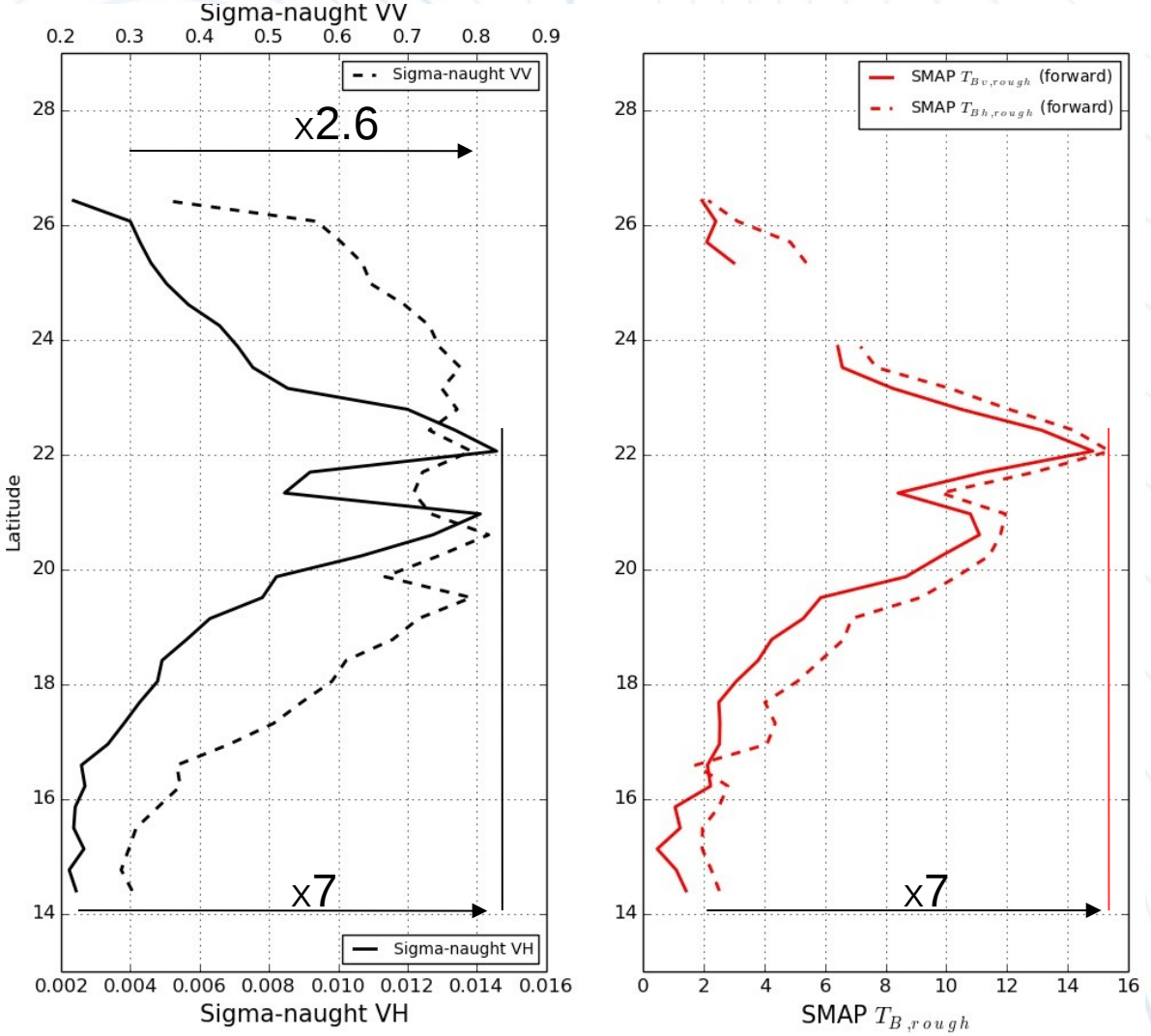
- SAR NRCS & $T_{B,rough}$



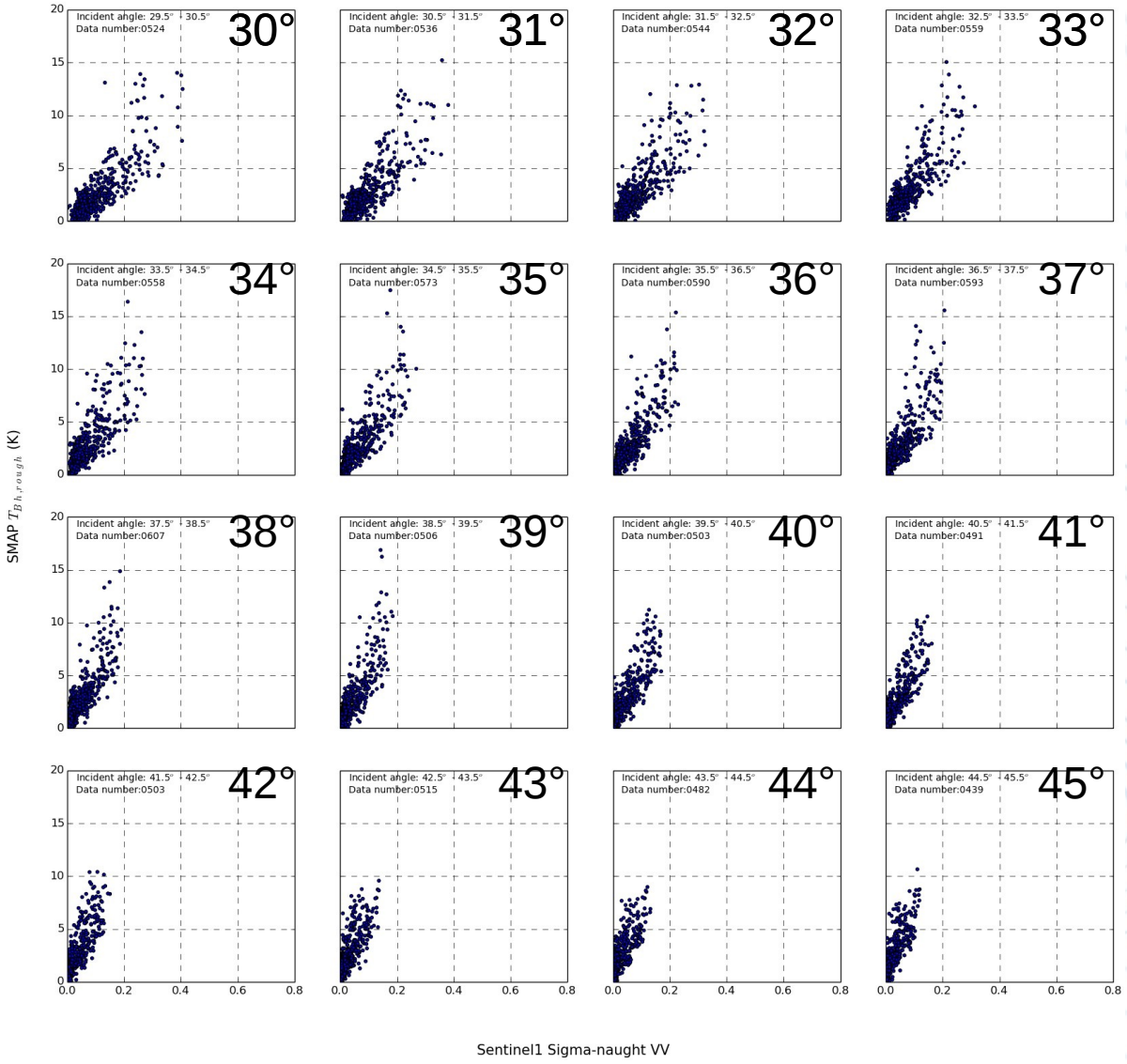
- Sentinel-1 and SMAP co-locations can allow a joint analysis of Tb and NRCS without any geophysical proxy.

- SAR NRCS & $T_{B,surf}$

- Co-incident analysis of both C-Band VH-NRCS and L-Band Tb across hurricane eye shows:
  - VV-NRCS saturates and does not capture the variability observed in the backscattered signal in VH.
  - VH-NRCS variations are close to $T_{B,surf}$

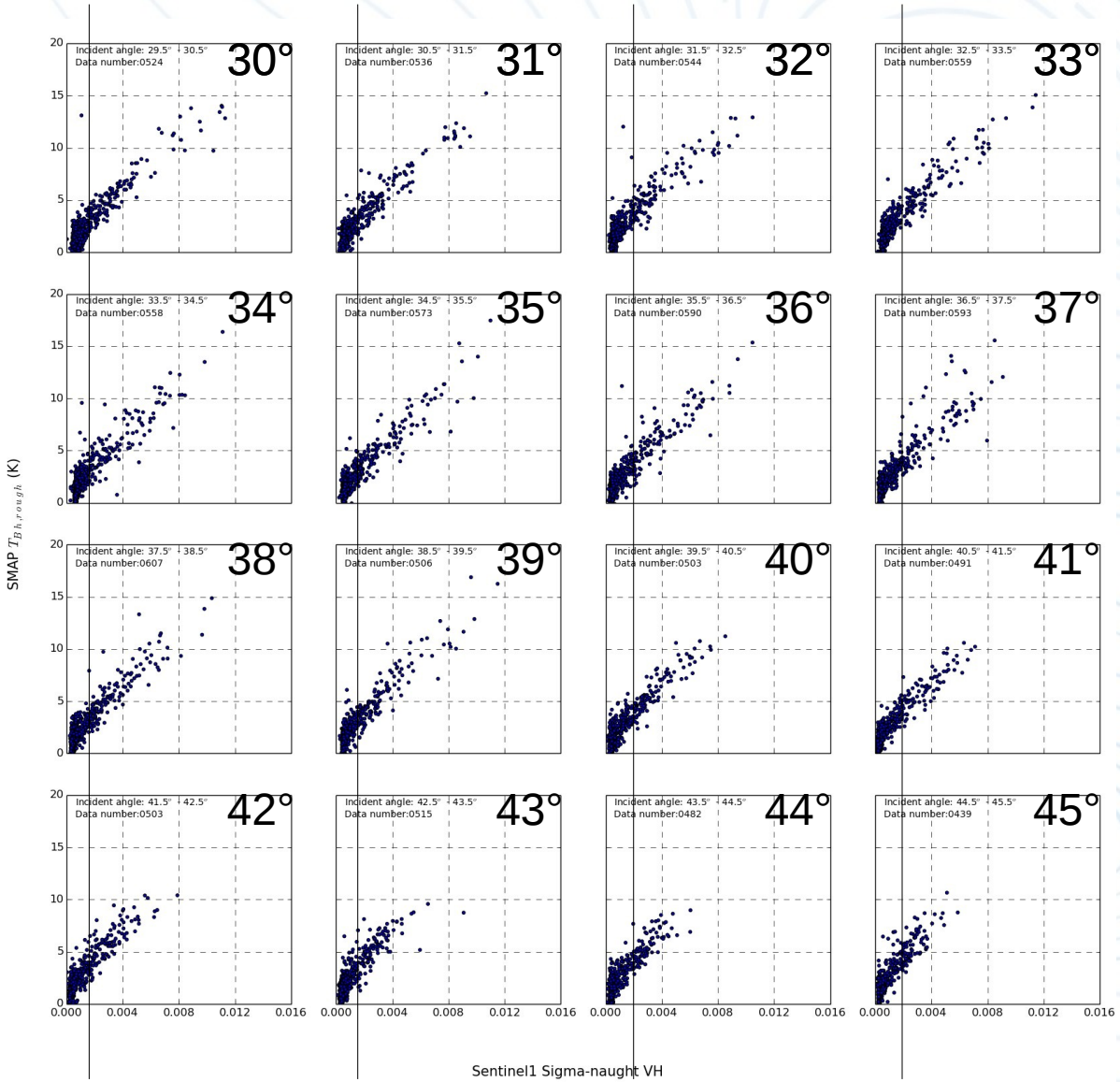


- SAR NRCS & $T_{B,rough}$



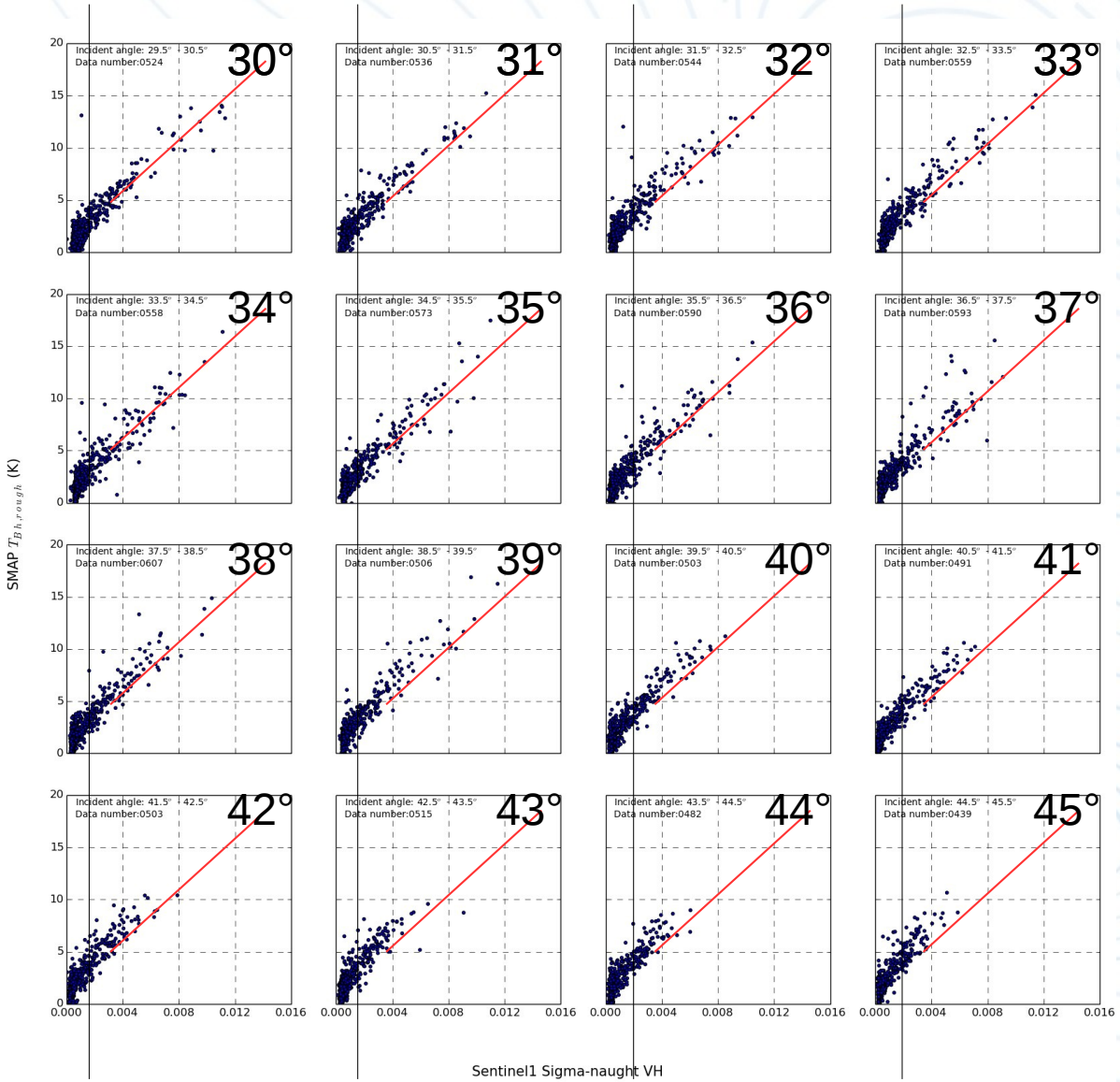
- The sensitivity of VV-NRCS to the ocean surface is much less than for $T_{B,surf}$ (rough) HH or VV (not shown)
- Worse at high incidence angles

- SAR NRCS & $T_{B,rough}$



- Two regimes in VH-NRCS variations seem to be present.
- Sensitivity of VH-NRCS may be significantly impacted by noise.
- Below 0.002 (~27 dB; ~15 m/s), NRCS seems less sensitive than above
- Below 0.002 (~27 dB; ~15 m/s), NRCS seems less sensitive than Tb (rough) HH and VV.

- SAR NRCS & $T_{B,rough}$



- Two regimes in VH-NRCS variations seem to be present.
- Above 0.002 (~27 dB; ~15 m/s), NRCS to have the **same sensitivity** than $T_{B,surf}$ (rough) HH and VV.

- Conclusions & Perspectives

  - Co-locations between Sentinel-1 SARs & SMAP radiometers with time difference less than 30 min are possible
  - SHOC campaign allowed to capture more hurricanes and Typhoon in 2 months than in 2 years of Sentinel-1 operation
  - SMAP winds allowed to document the relationship between VH-NRCS and wind ocean speed over hurricanes
  - Rain and wind direction impacts are not well documented and understood at C-Band in VH polarization

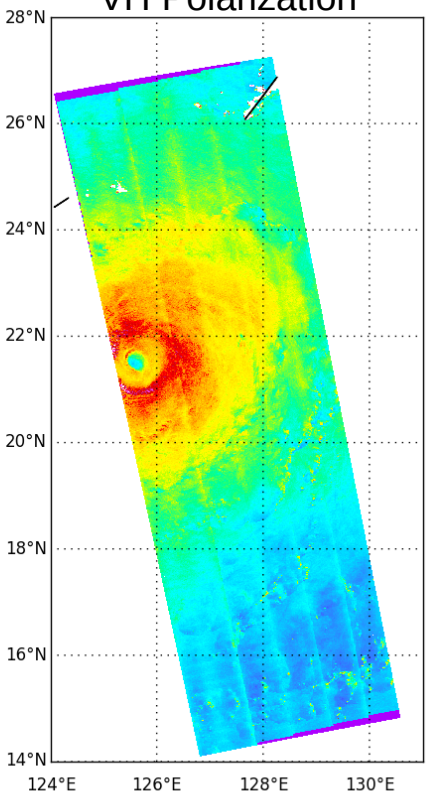
  - VH-NRCS sensitivity to ocean surface response has been found much higher than in VV over extremes (more than 3 times)
  - This sensitivity difference has been studied at different resolutions. It is still valid at typical “scatterometer” resolutions (>25km)
  - Very small sensitivity has been found with respect to incidence angle for extreme wind speeds.

  - Over extremes, sensitivity of C-Band VH-NRCS is found to be the same than for L-Band Tbv and Tbh.
    - Encouraging results obtained from Radiometry community opened perspectives for the next MeTop-SG scatterometer performances. Complementarity between co-polarization for low,medium wind speeds and for wind direction with cross-polarization for very strong wind are promising.
    - The physical explanation of the same sensitivity remains to be explored.

- Conclusions & Perspectives

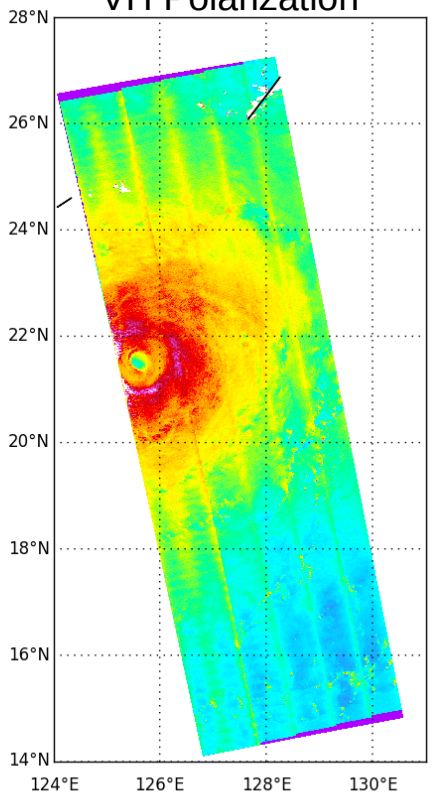
1. Sentinel-1 A & B quality can be improved to get a better correction of the noise

Wind Speed from
VH Polarization

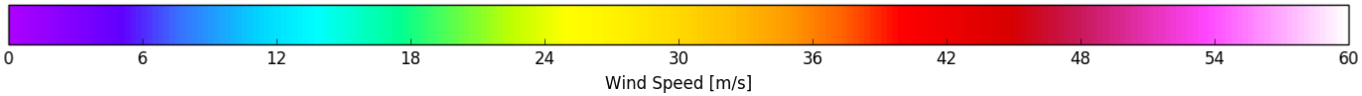


ESRIN Processing
WITH noise correction in L1 processing

Wind Speed from
VH Polarization

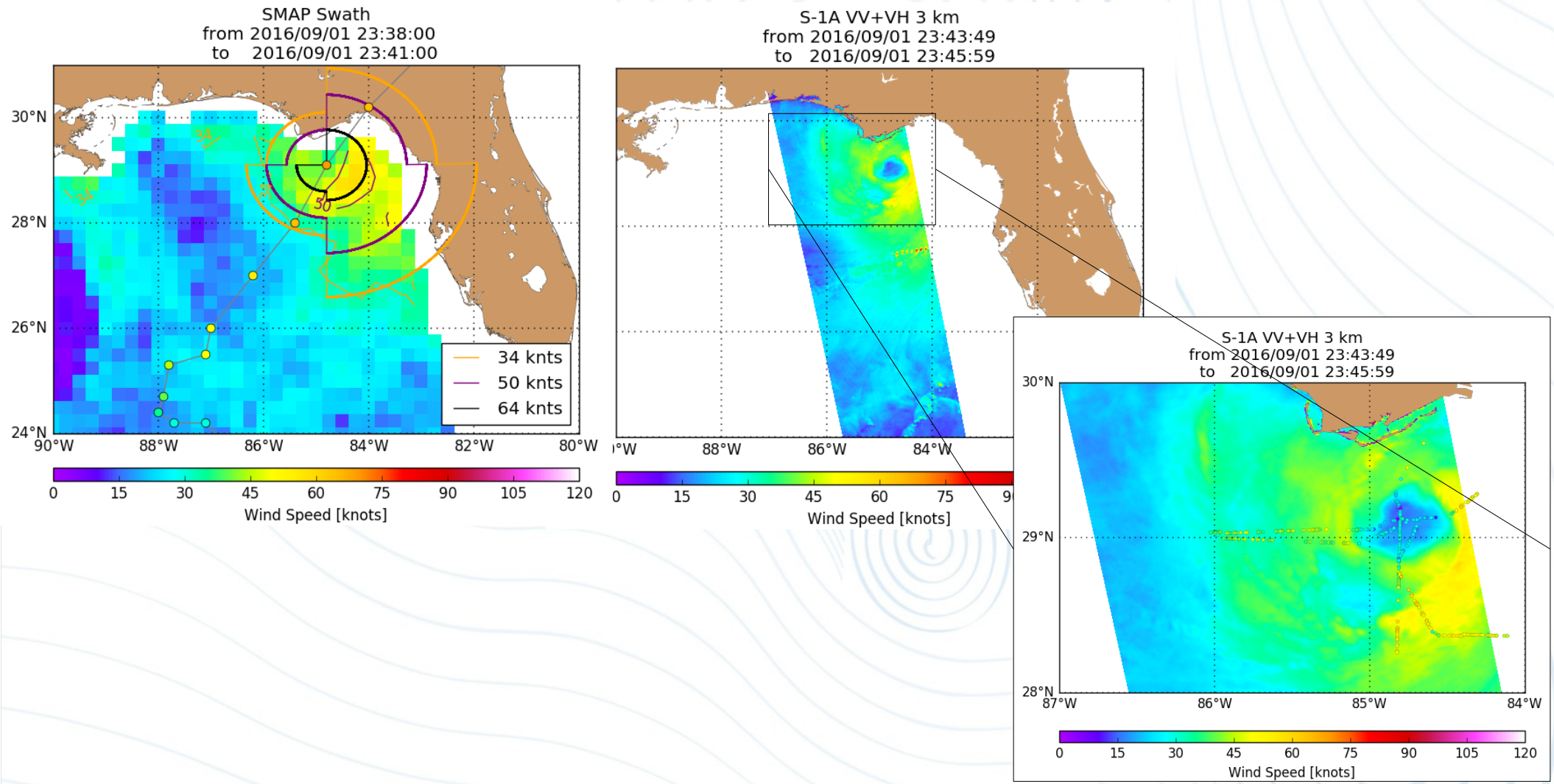


ESRIN Processing
WITHOUT noise correction in L1 processing



- Conclusions & Perspectives

  2. When possible Sentinel-1 data needs to be thoroughly analysed together with rain radar and available SFMR data



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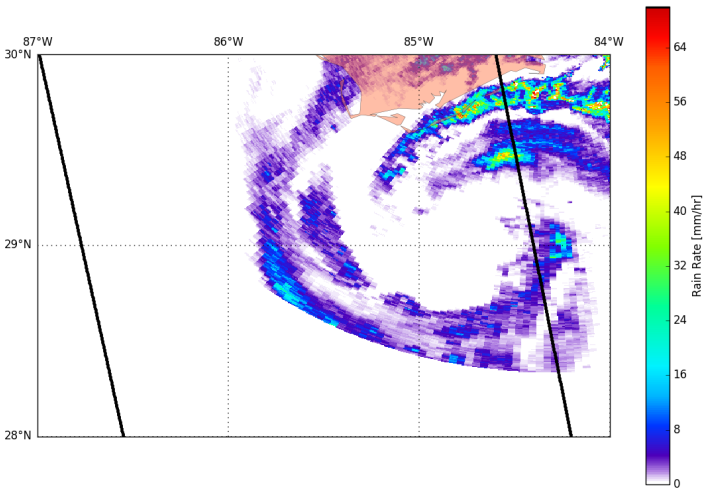
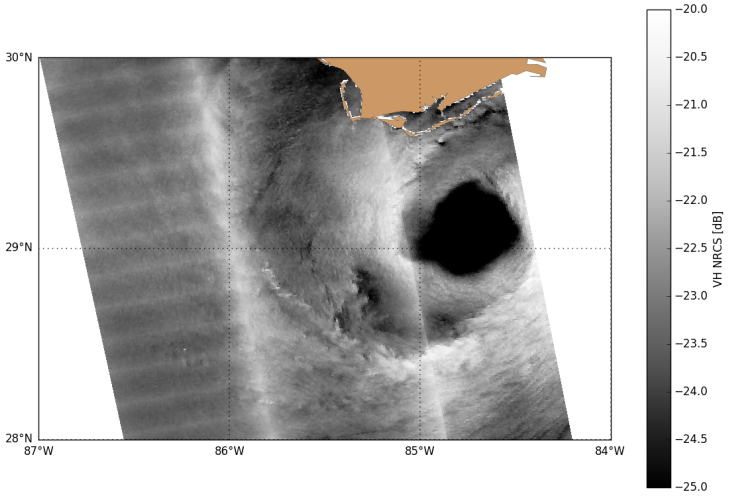
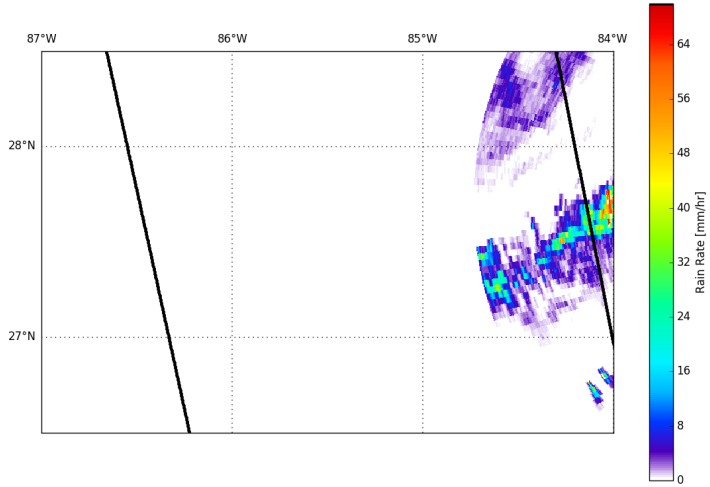
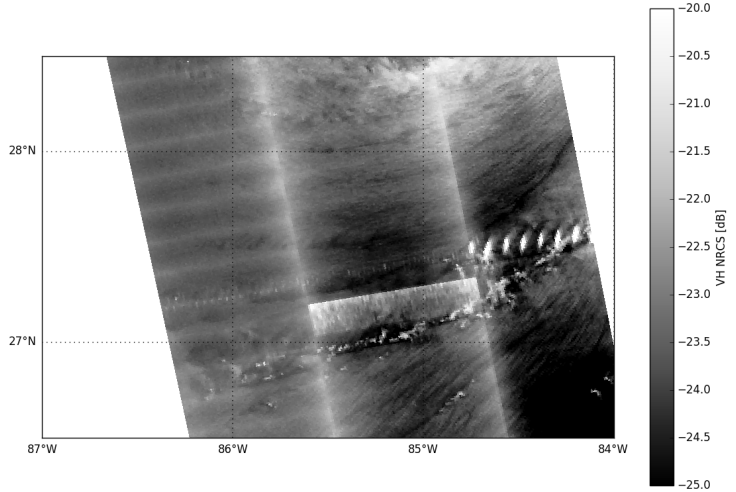


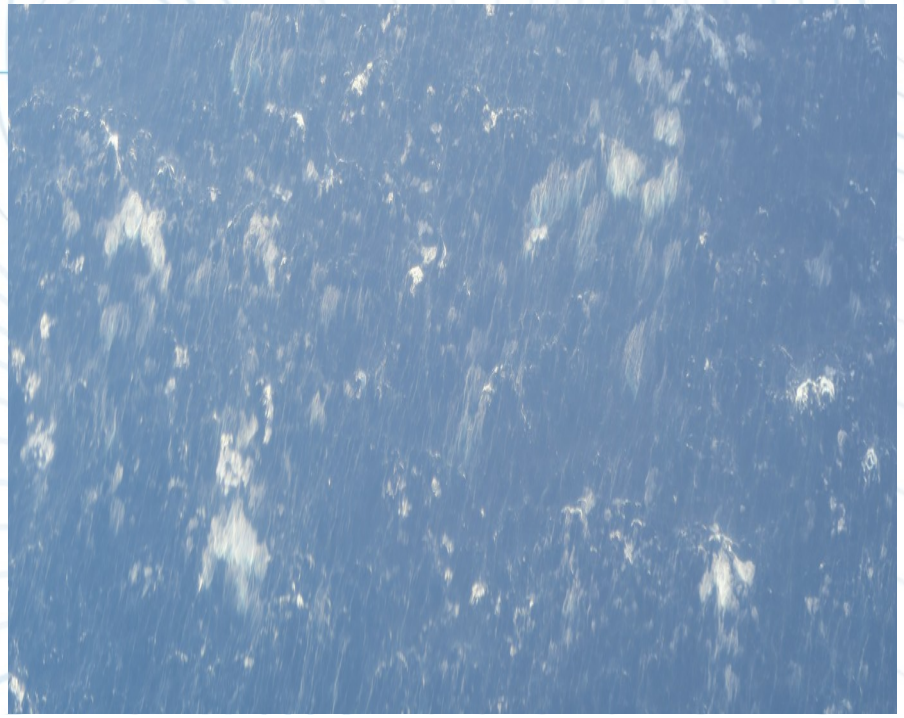




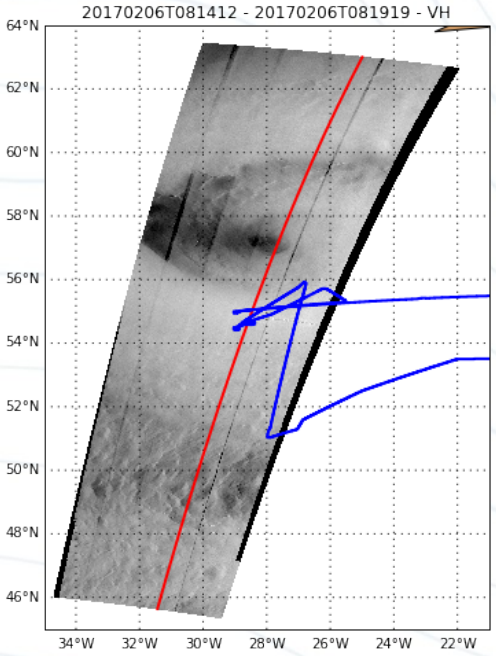


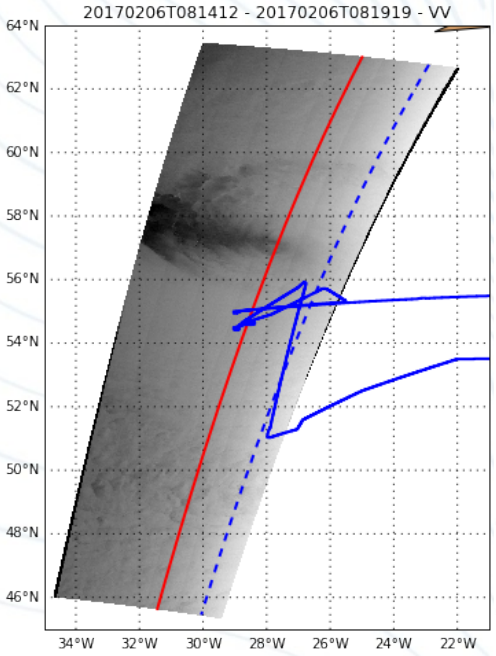
- Conclusions & Perspectives

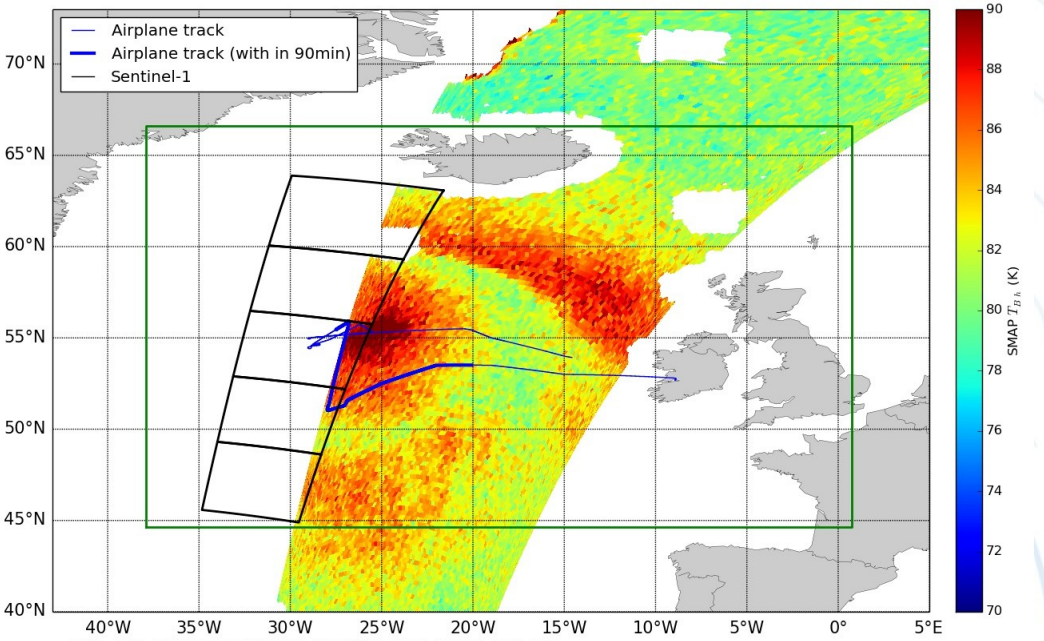
  3. Recent joint project between ESA, IFREMER and NOAA allowed data acquisition over ETC with
     - SMAP, SMOS, Sentinel-1 A & B acquisitions
     - IWRAP VV, HH, VH C-Band radar and SFMR radiometer



Sentinel-1_SMAP_Airplane Collocation







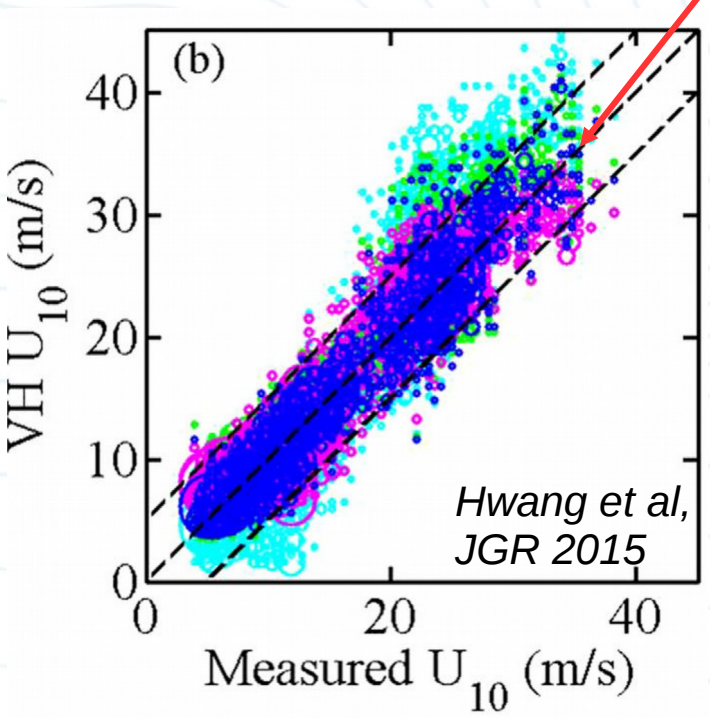
S1B_EW_GRDM_20170206T081412_20170206T081919
SMAP_L1B_TB_10775_D_20170206T075223_R14010_001.desc.formodel.sunglint.mat
Mean time difference (SMAP-S1): -12 min
Airplane_20170206T033350-20170206T133616

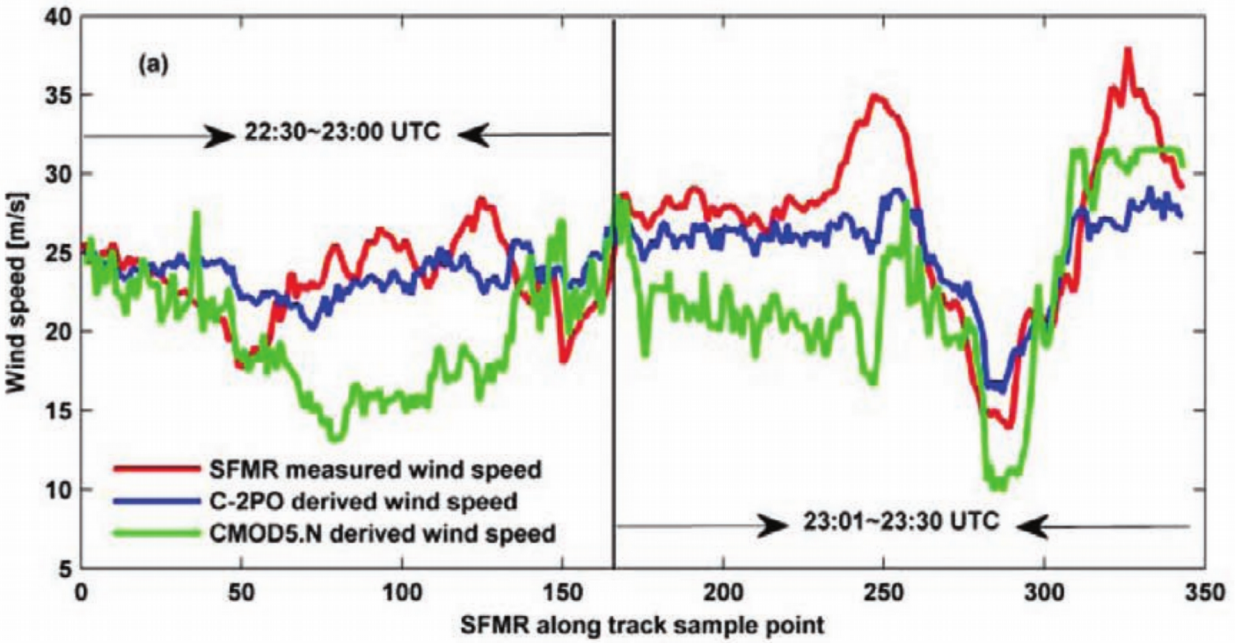
Thank you

C-Band Radar at Cross-Polarization

- The small dataset available also prevents to validate SAR wind speeds for extremes events with wind speed larger than 40 m/s
- To date, rain impact is always neglected.

Cut off at 35 m/s

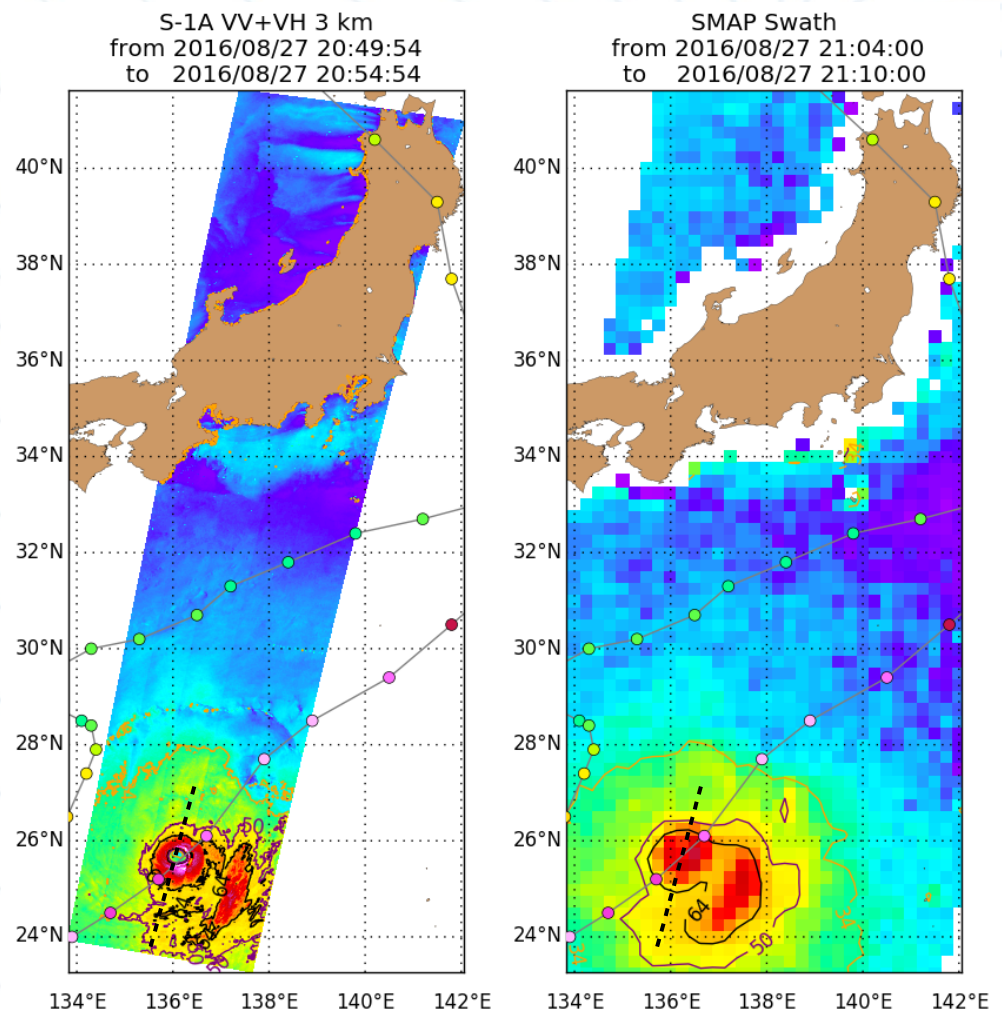


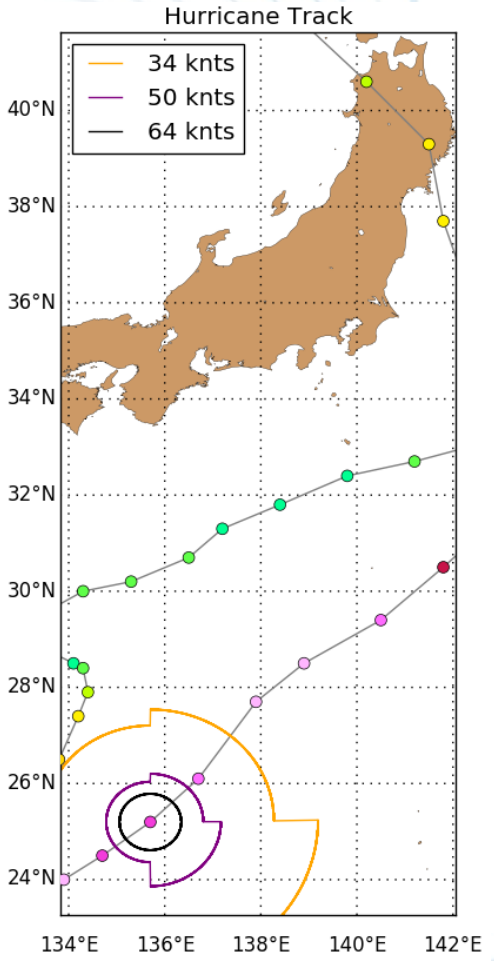


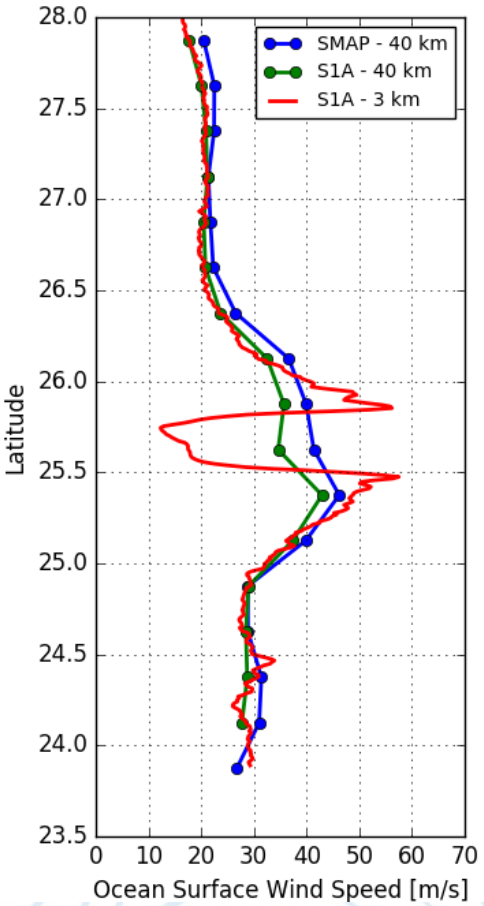
Hwang et al, JGR 2015

Zhang and Perrie, BAMS 2012

- NRCS & wind





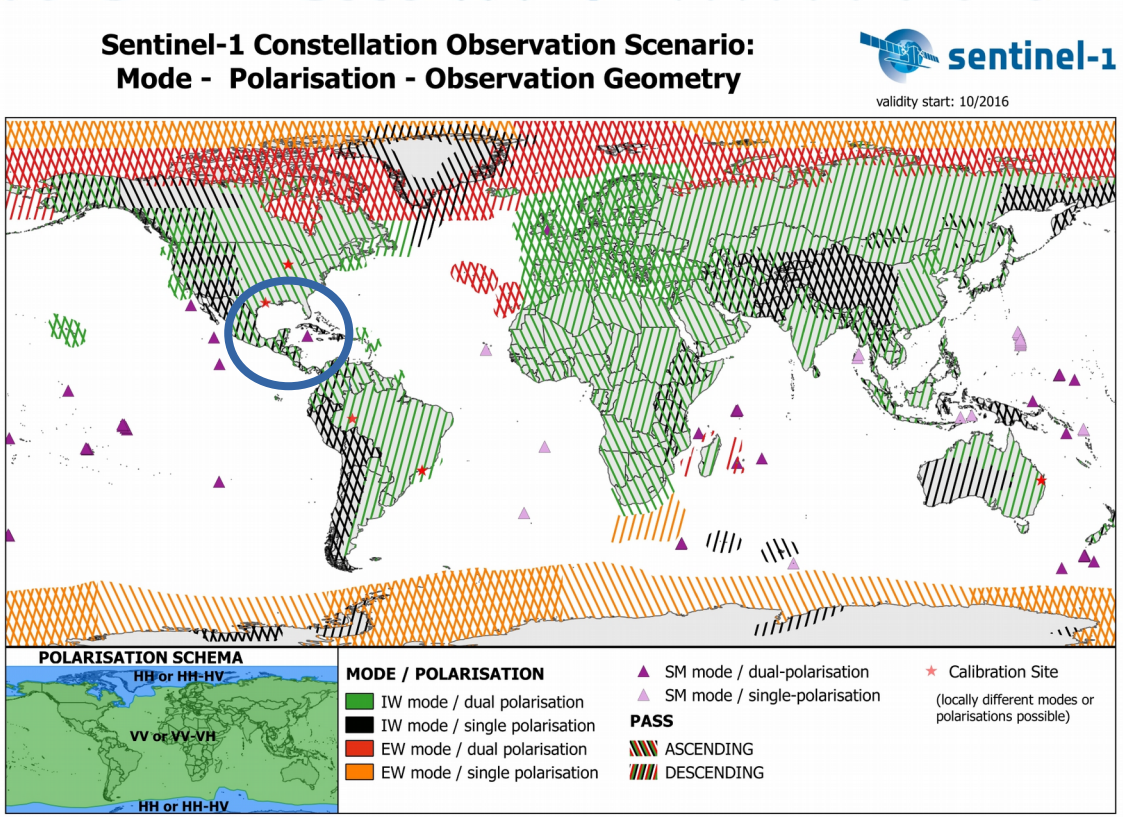


- Sentinel-1 SAR winds can provide a unique HR description of Hurricane wind structure i.e. wind radii.

- When hurricane is very strong with small eyes, 1-km SAR winds or VH-NRCS can allow measuring hurricane parameters such as Rmax, Vmax.

C-Band Radar at Cross-Polarization

	S-1 C-SAR
Frequency	C-Band, 5.405 GHz, ~5 cm
Variables	NRCS VV&VH Or HH&HV *(Doppler)*
Incidence angle	~17-45 deg
Swath coverage	250 (IW) or 400 (EW) km
Acquisition type	Not continuous
Coverage	Local/coastal areas EEZ



Very few acquisitions over oceans with large swath modes

On the use of VH polarization

- Existing SAR can provide
  - NRCs in co- and cross- polarizations
  - Over a large range of incidence angles
- Sentinel-1 SAR mission
  - does not acquired data continuously
  - does not have a dedicate acquisition strategy for hurricanes
- Very few reference data exist for hurricane – SFMR, dropsondes
- Probability to have SAR acquisitions over hurricane with simultaneous SFMR/dropsondes is small

Ifremer

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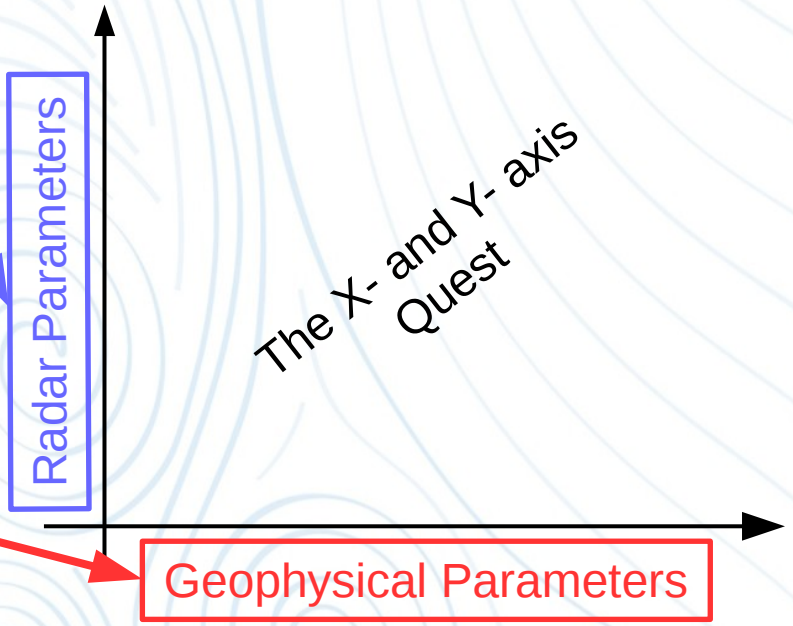
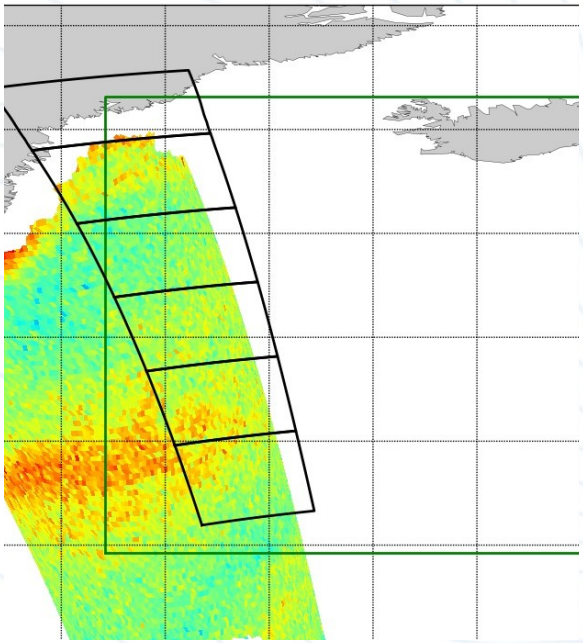
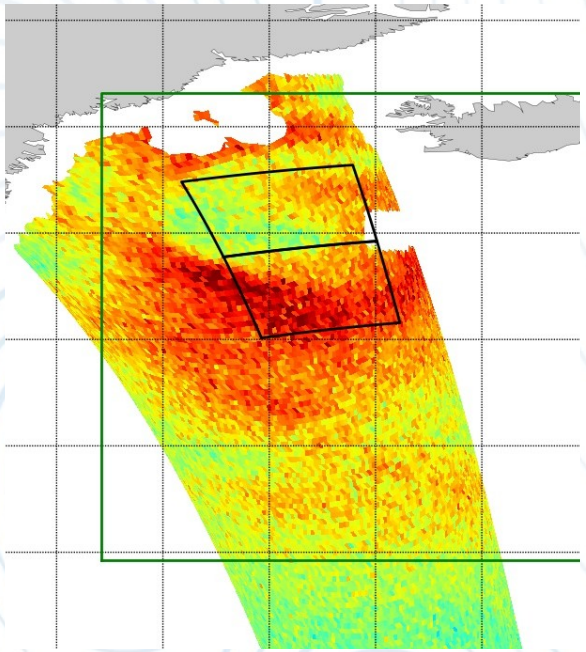


SMAP & Sentinel-1



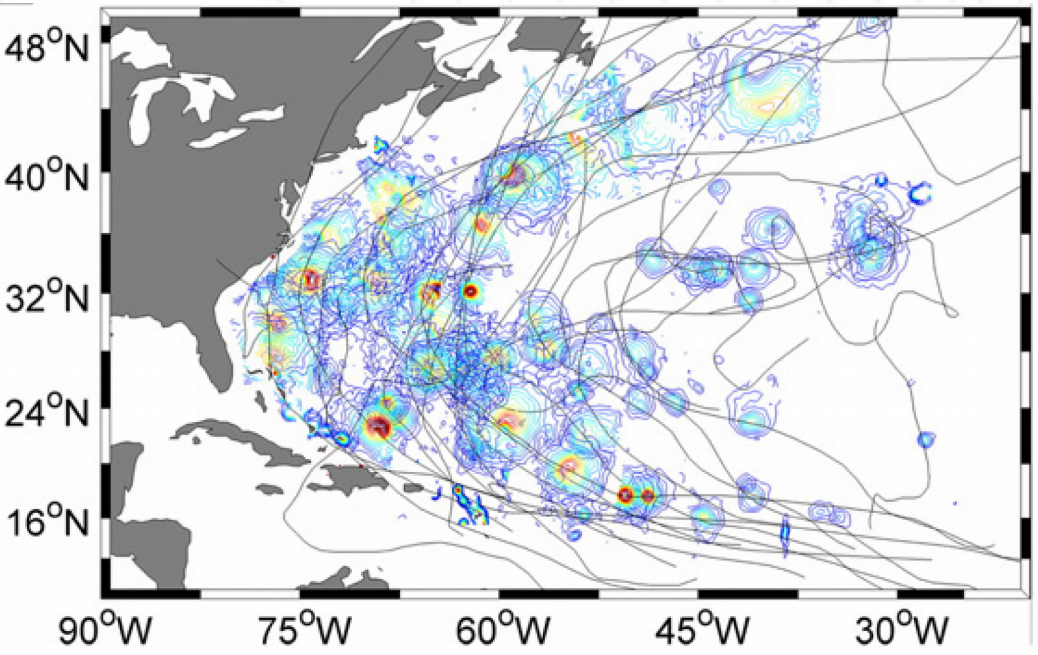
S1A/SMAP Δt=3 min



S1B/SMAP Δt=14 min

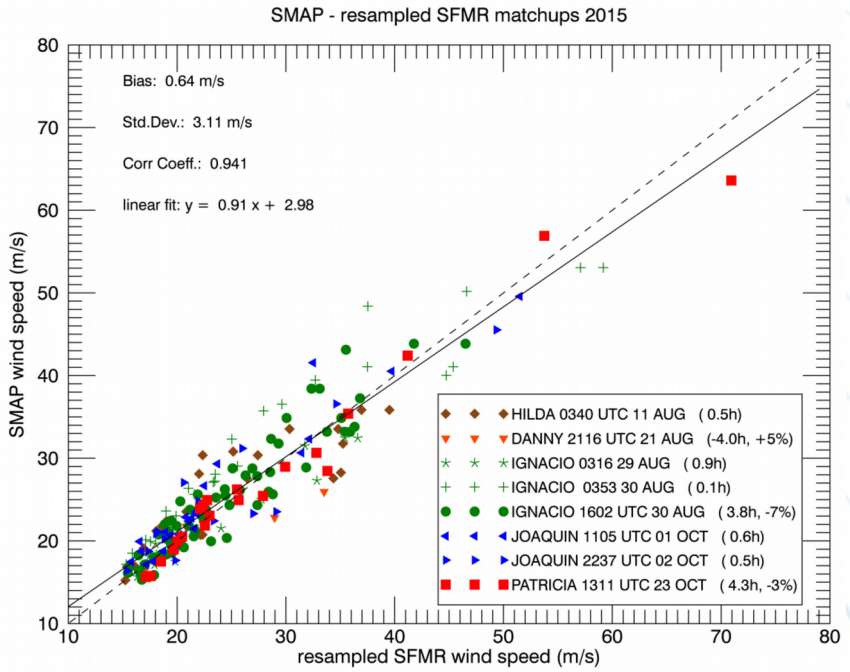
When SAR images are acquired, there is potential for co-locations in time and space with less than 30 minutes time difference.

- Large coverage and continuous acquisition enable
  - short revisit time to describe Hurricanes during their lifetime.
  - many observations over hurricanes.
  - Opportunities for co-locations with SFMR winds for GMF and wind inversion scheme validation.



Contours of storm-surface induced brightness temperature contrasts ΔI [K] estimated from SMOS L-band data in North Atlantic during 2010–2015.

Reul et al., RSE 2016



Meissner et al., BAMS 2017

Ifremer

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- **L-Band SMAP wind can be co-located with SAR NRCS measurement**