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中国科技部-欧洲空间局“龙计划”合作

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

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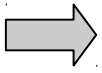
Introduction – Active Radar

Context

- 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.

Introduction – Active Radar

Background

- 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 weakly incidence angle dependent.
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- VH dependence with respect to wind direction is still unclear.
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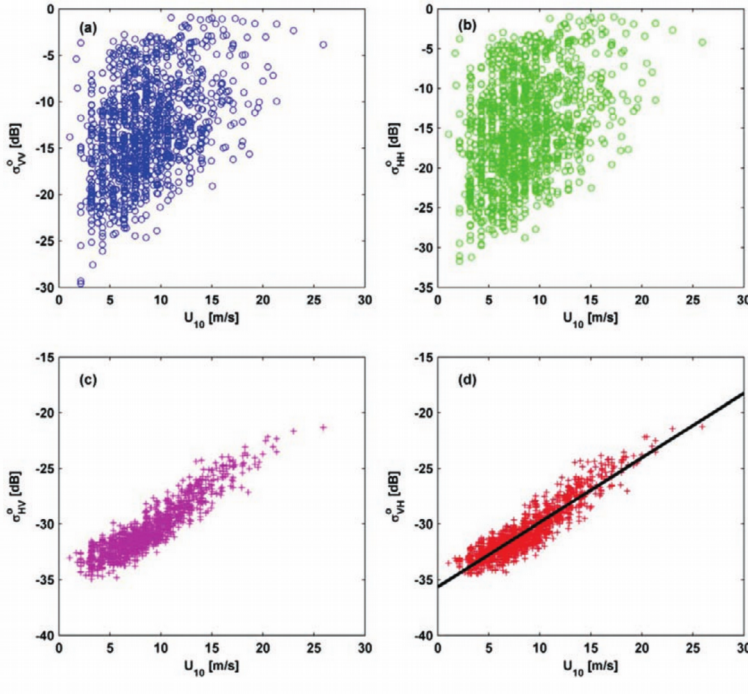
The better sensitivity of VH with respect to VV offers perspectives for extreme winds measurements

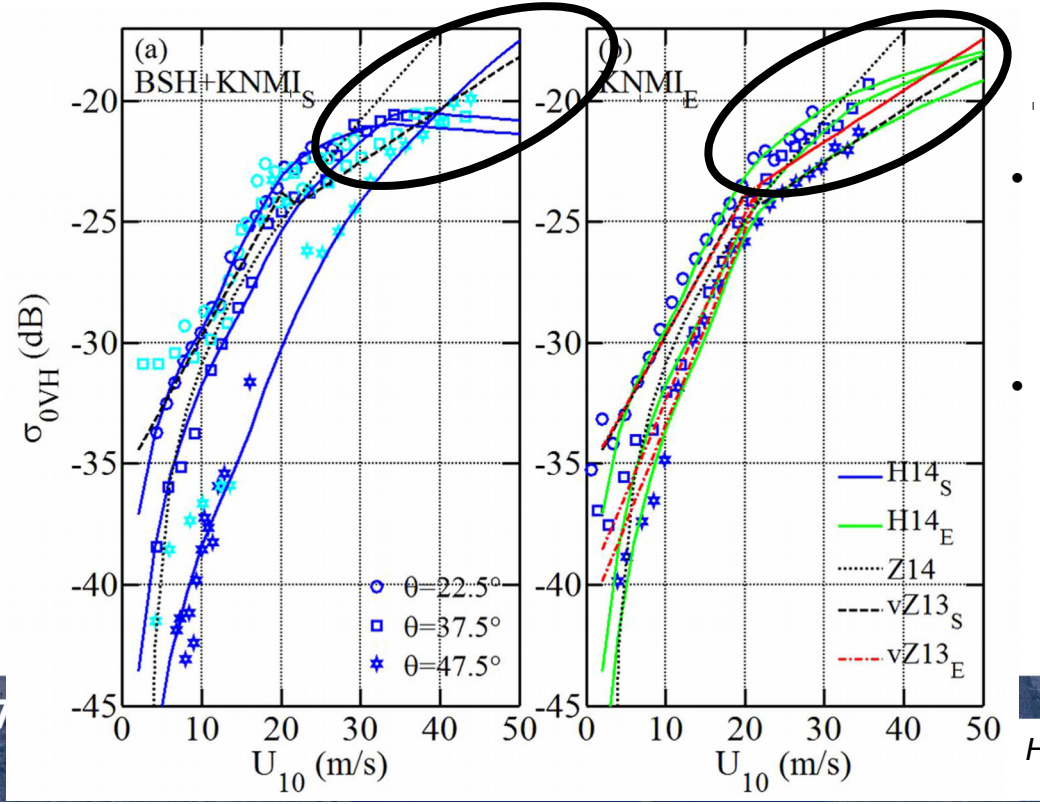


NRCS vs in situ buoy-measured U 10 : (a) VV polarization, (b) HH polarization, (c) HV polarization, (d) VH polarization.

Zhang and Perrie, BAMS 2012

Background

- Based on RS2 data, several relationships (GMF) have been proposed to relate NRCS and ocean surface wind speeds.



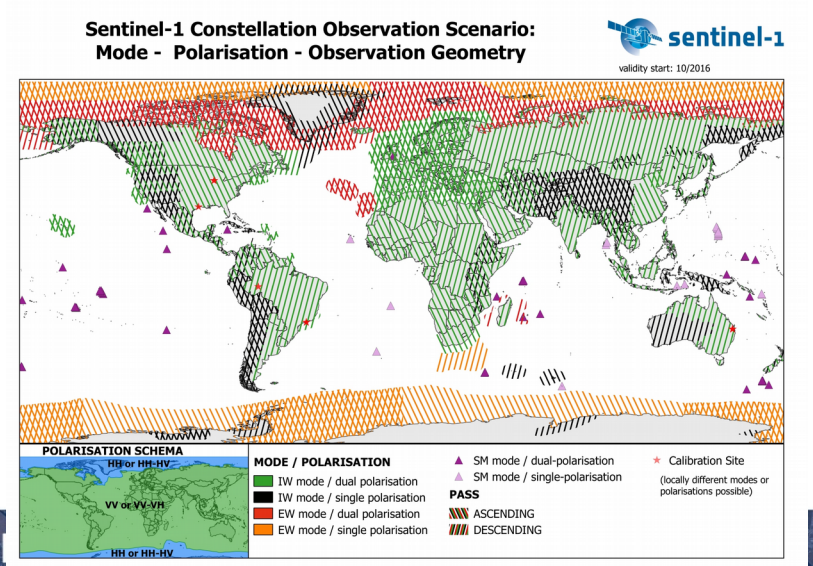
- The small dataset available prevents to validate SAR wind speeds for extremes events with wind speed larger than 40 m/s (77.5 kt). Cat-1 is 64-82 kt !
- To date, rain impact is always neglected.

Hwang et al, JGR 2015

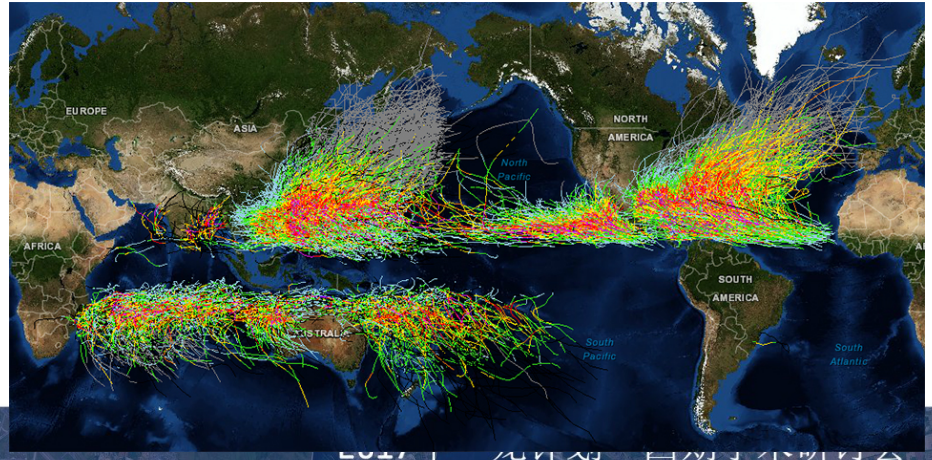
Introduction – SAR Acquisitions

Background

- Sentinel-1 SAR do not continuously acquire data.
- Very few Dual-Polarizaton SAR data are available over ocean for hurricane.
- Reference data for hurricanes combined with the low amount of SAR data makes the probability to have SFMR or dropsondes very unlikely

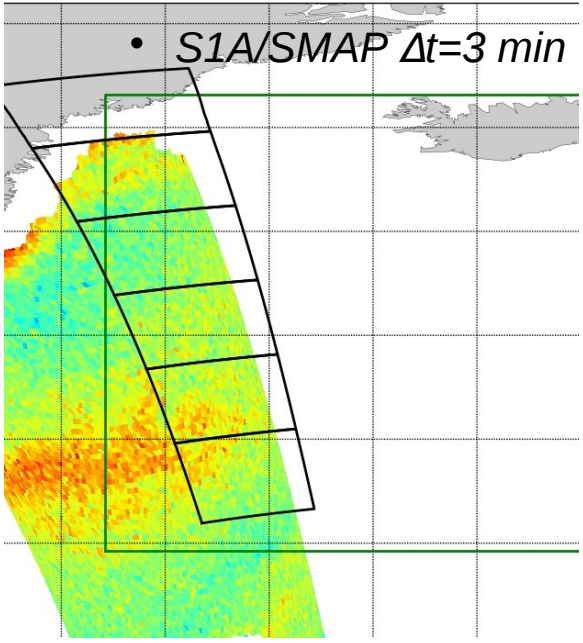


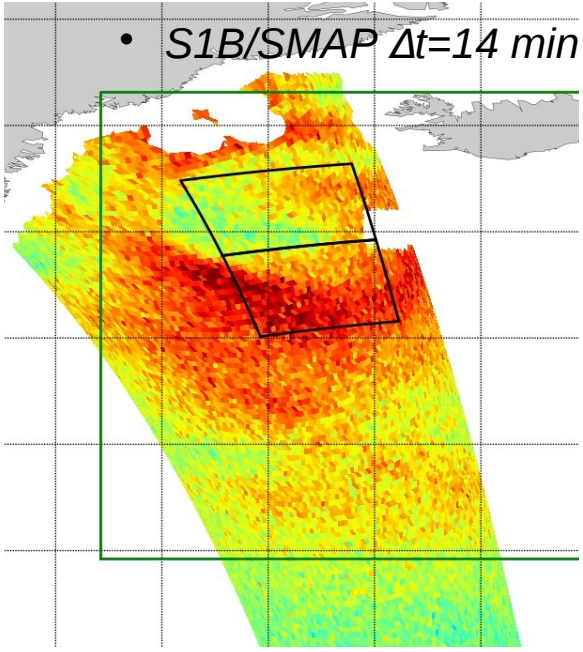
Historical tracks, NOAA



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

Background

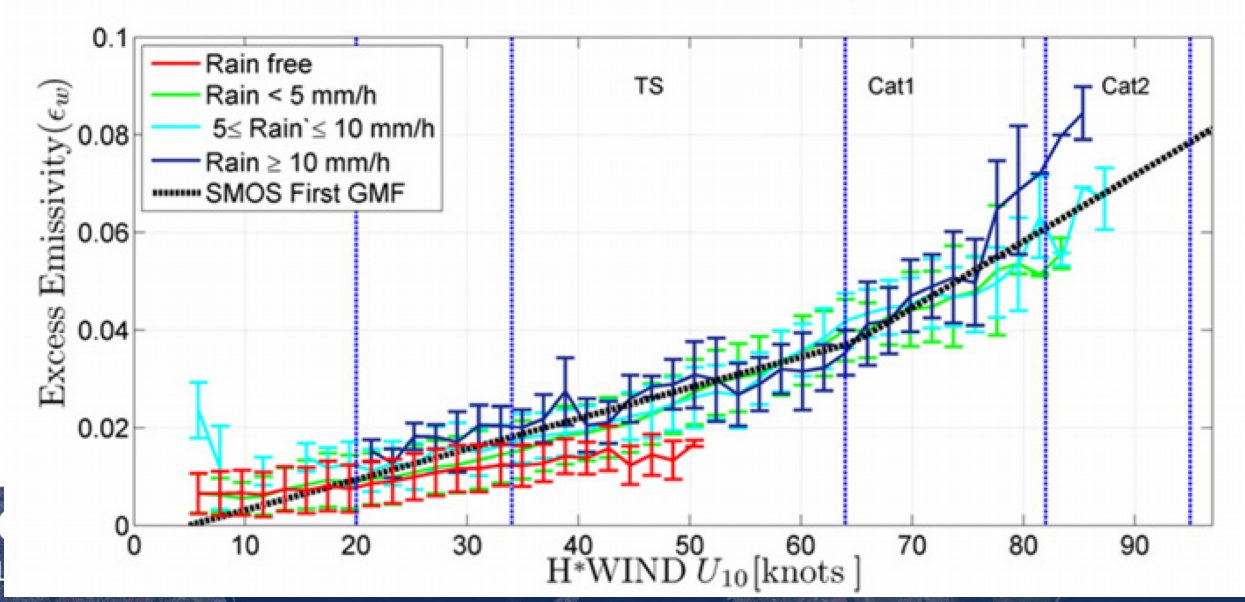




Introduction – L-Band Radiometer

Background

- L-Band radiometers are weakly sensitive to rainfall and water content in the atmosphere.
- Tb is less sensitive to ocean surface wind speeds that C-Band radiometer but but does not saturate at high winds (in the contrary of active C-band radar).
- High rain rate and sea state impacts on Tb remain uncertain.



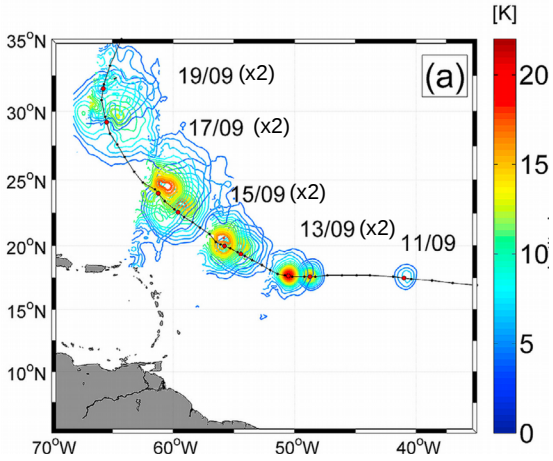
Reul et al, JGR 2012

Introduction – L-Band Radiometer

Large coverage and continuous acquisition enable

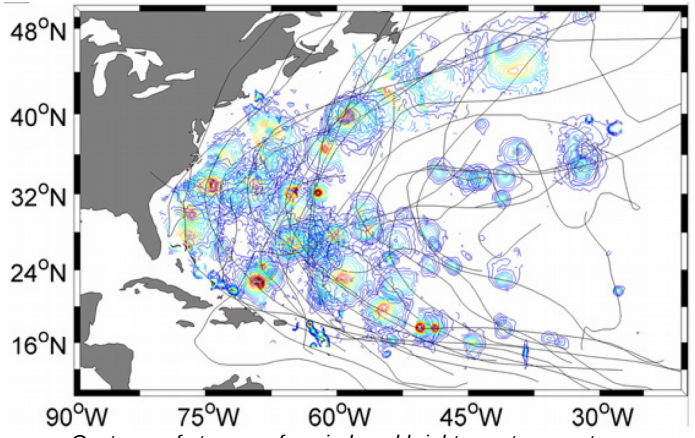
- short revisit time to describe Hurricanes during their lifetime.
- many observations over hurricanes
- Opportunities for co-locations with SFMR winds for GMF and wind inversion scheme validation.

Background



Contours of storm-surface induced brightness temperature contrasts ΔI [K] estimated from SMOS L-band data for Igor Hurricane in 2010.

Reul et al., JGR 2012



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

Proposed strategy

- 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”

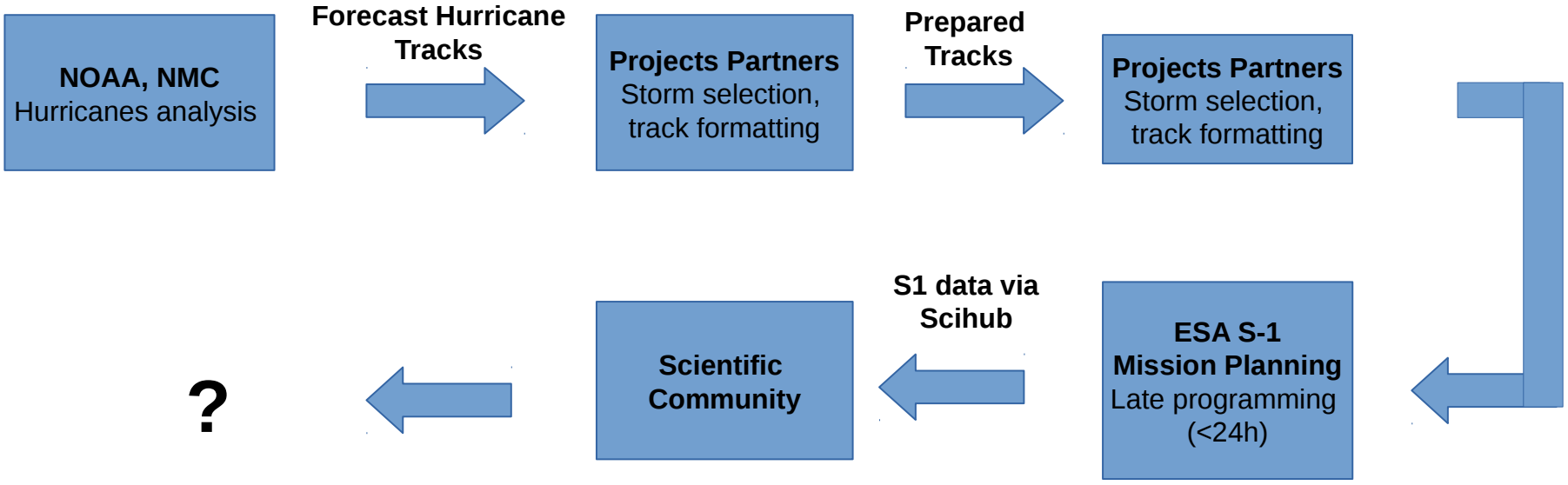
  - Analyze NRCS from SAR with SMAP winds

  => Discuss/Extend existing GMFs

  - Analyze NRCS from SAR with Tb from SMAP

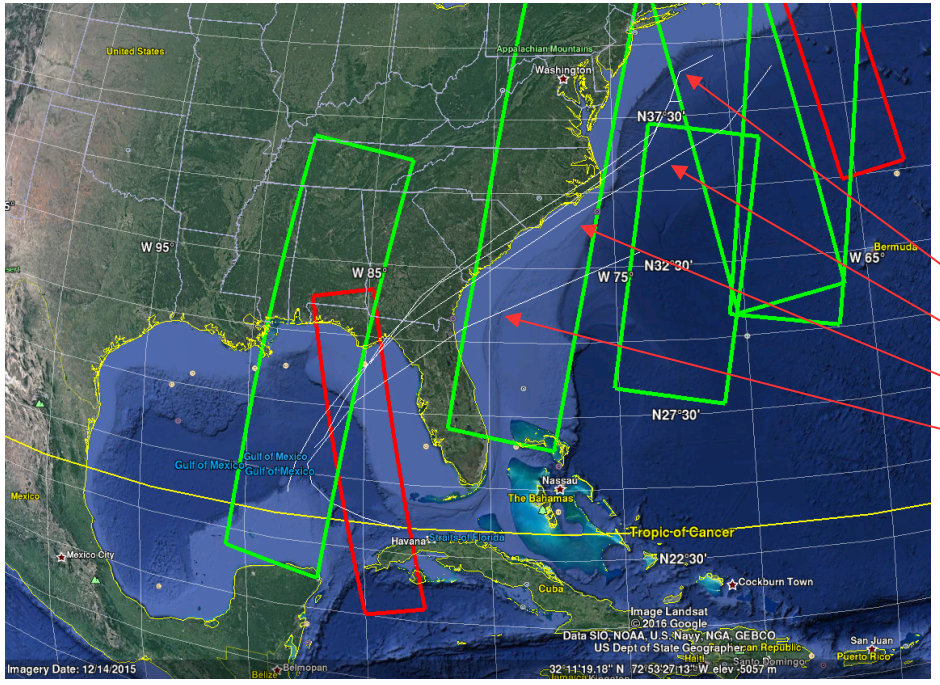
- Ultimately this should allow to evaluate the ability of Sentinel-1 SARs for extreme winds measurements.

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



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

Example of Forecast track for Hermine Hurricane: 7 SAR acquisitions were obtained



4 Forecast trajectories

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

- 23 acquisitions with eye captured in SAR images (~30 %)

- Very few co-locations with SFMR airborne radiometer (3). And **None of them** during most intense regimes of the TC

- S1 acq over most extreme winds:

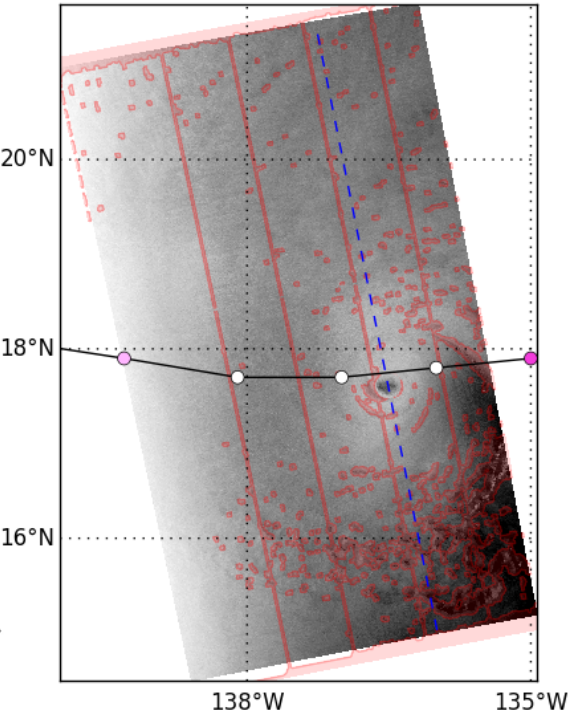
- Typhoon Lyonrock: 2 acq. in Cat 3, both at 105 knots max sustained winds

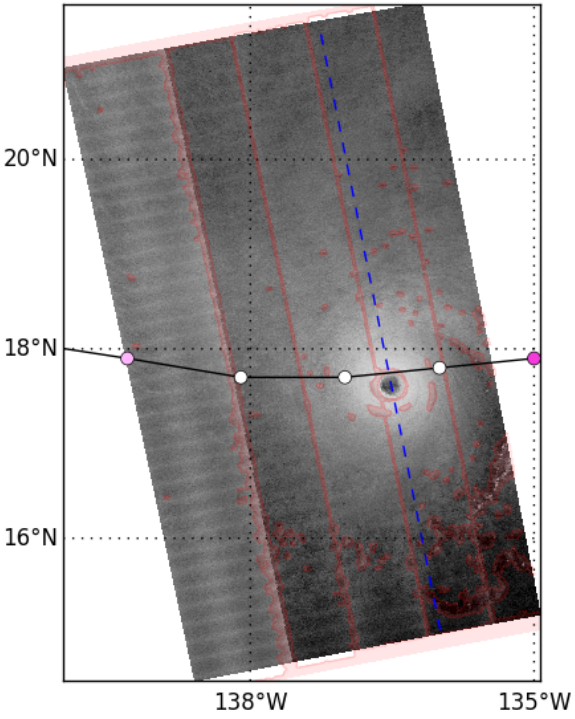
- Typhoon Megi: 1 acq. in Cat 3, 100 knots max sustained winds

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

In-situ China, Summer 2016

SAR NRCS & Ocean Surface

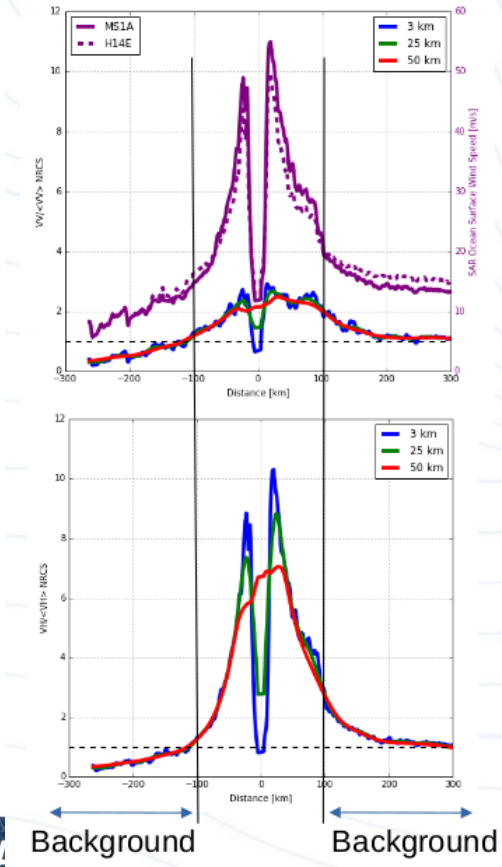




- Both VV and VV captures hurricane features (eye, rain impact, wind acceleration)
- VV-NRCS is much higher than VH-NRCS
- VH is significantly affected by noise.
  - In Near range, SNR is very low
  - Far from the eye the SNR is very low.

LG gradient method can be applied to filter out heterogeneities in the images

SAR NRCS & Ocean Surface



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

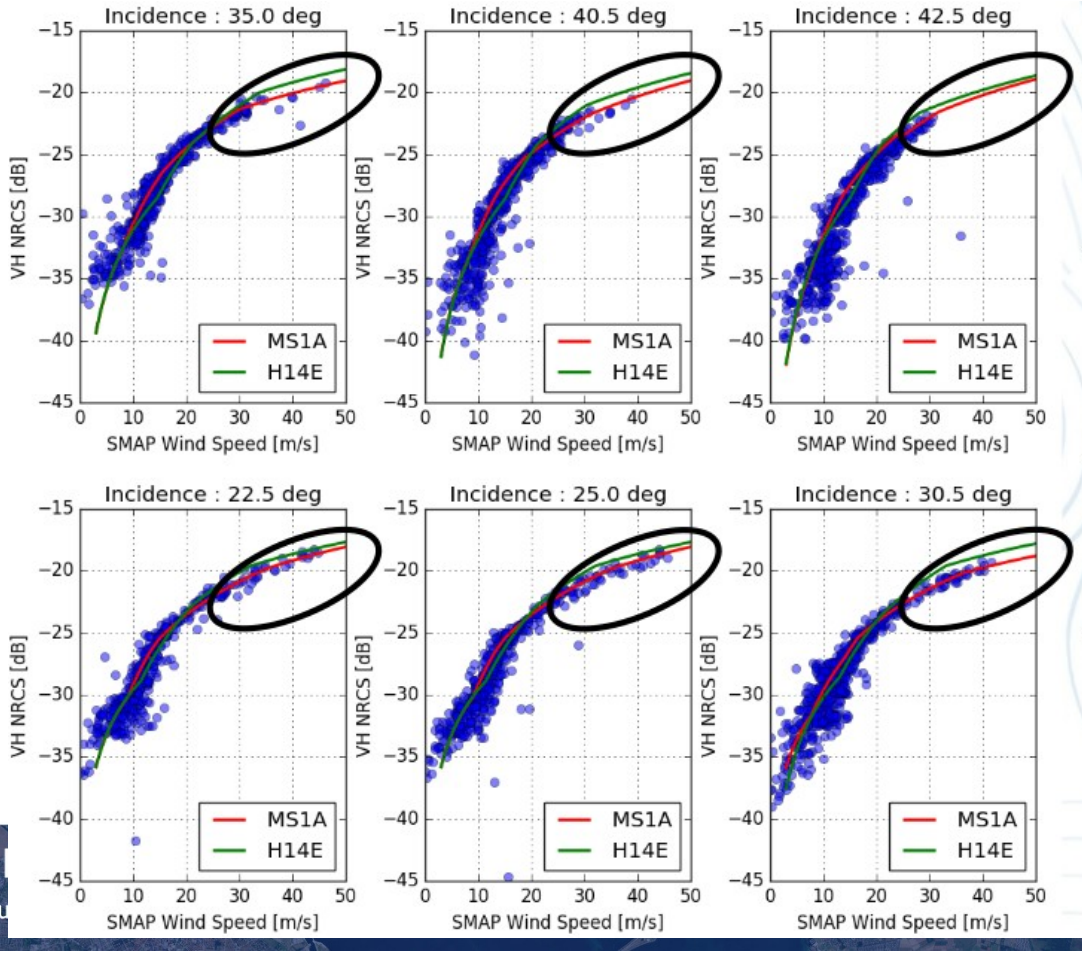
C_pp = NRCS_pp/<NRCS_pp>

- 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.

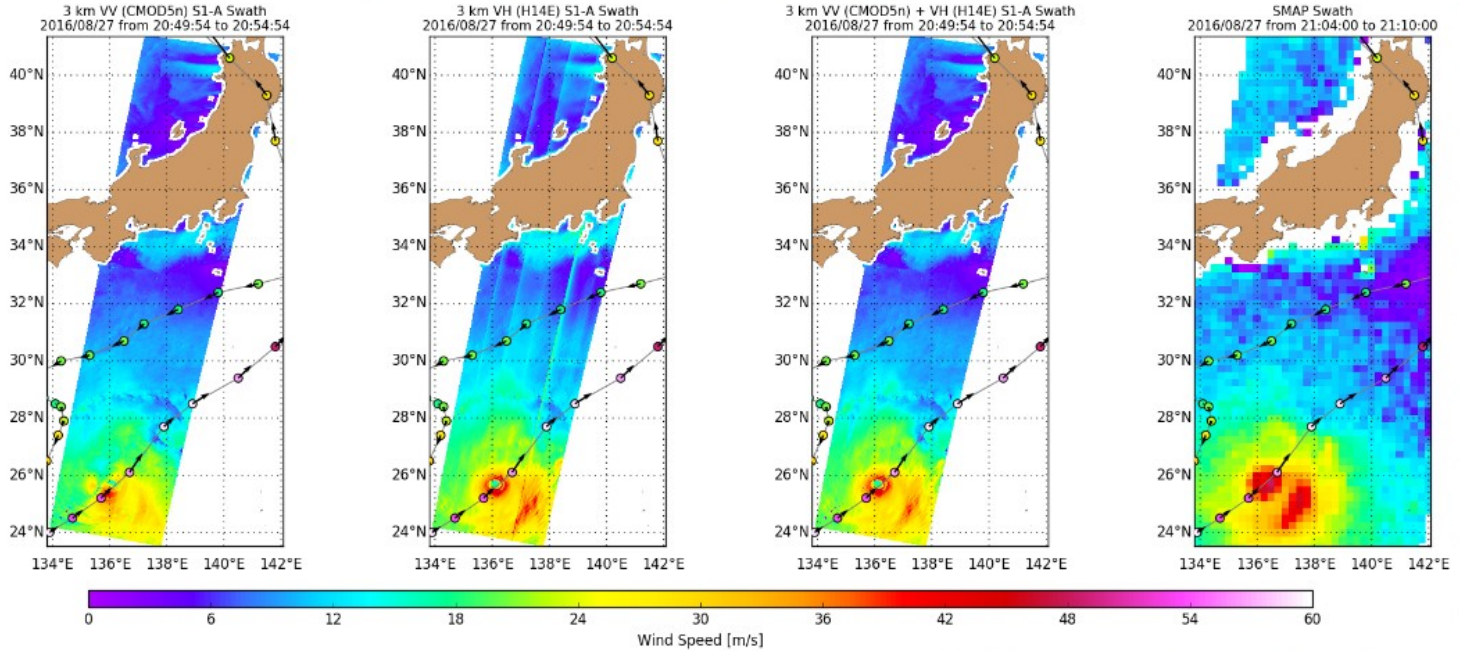
- Resolution changes impacts more VH than VV.

SAR NRCS & SMAP Wind



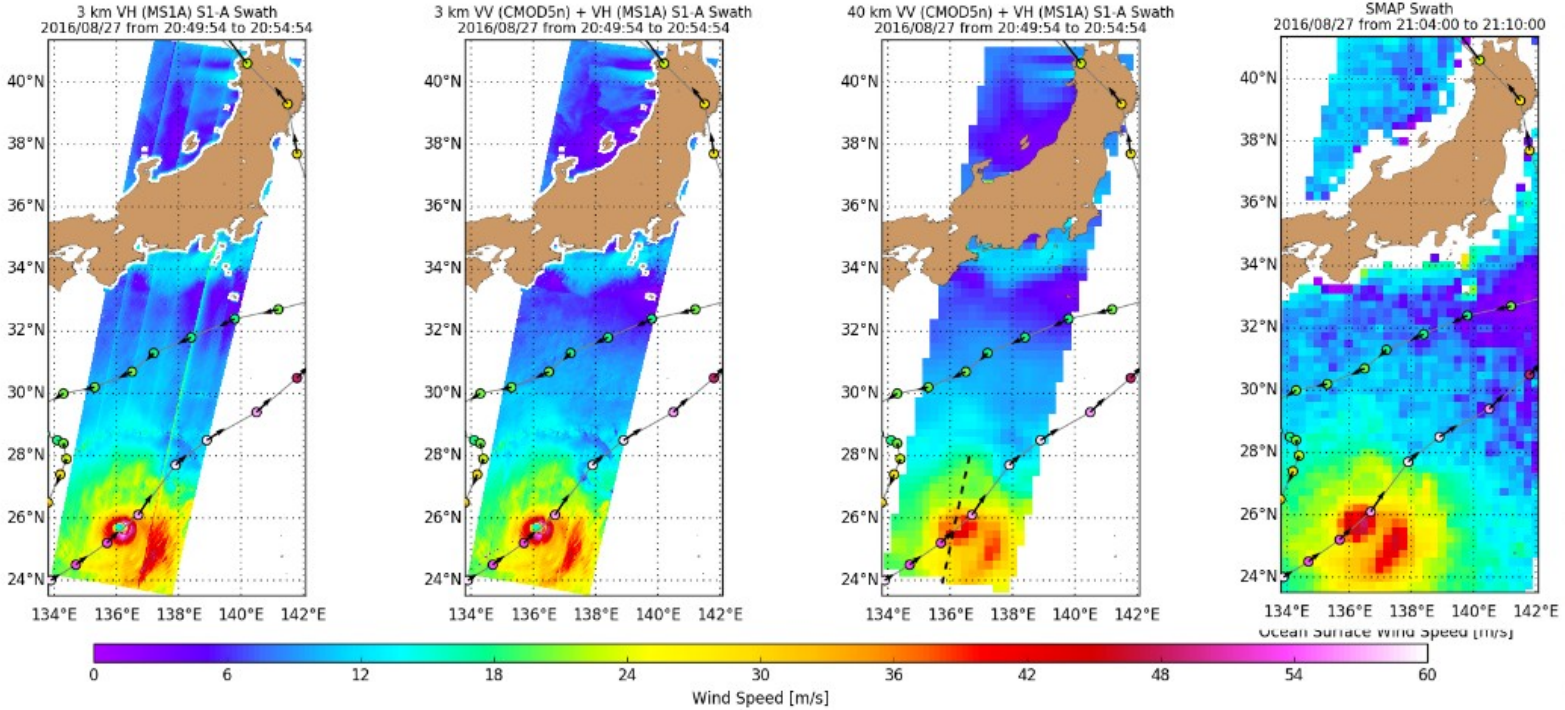
- More than 8500 co-locations at SMAP resolution
- Analysis confirm higher sensitivity to ocean surface wind speed in VH than in VV
- Confirm small incidence angle dependency
- Allow to extend the GMF for winds higher than 25 m/s

SAR NRCS & SMAP Wind



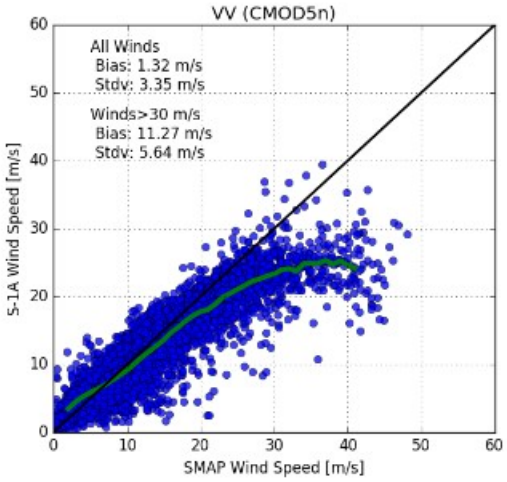
- VV seems to predict unrealistic hurricane wind structure and lower winds speeds values compared to SMAP (at lower resolution)
- VH enables higher values of wind speeds but NESZ issues affect the retrieved wind in VH.
- Combination of both channel mitigate the NESZ issues. S-1 Wind speeds remains lower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

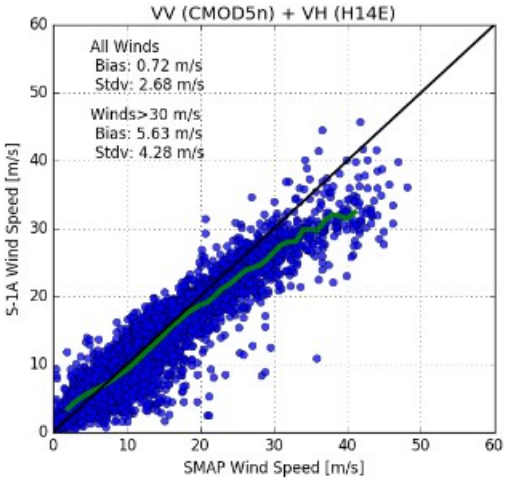
SAR NRCS & SMAP Wind

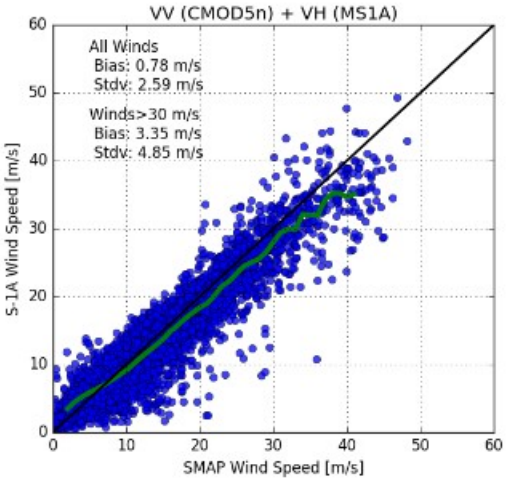


- With new GMF, VH and VH;VV combination give wind speed values more consistent with SMAP winds
- When doing 40-km SAR wind instead of High resolution wind we can be directly compared. 40-km SAR winds and SMAP winds are found to be very consistent.

SAR NRCS & SMAP Wind

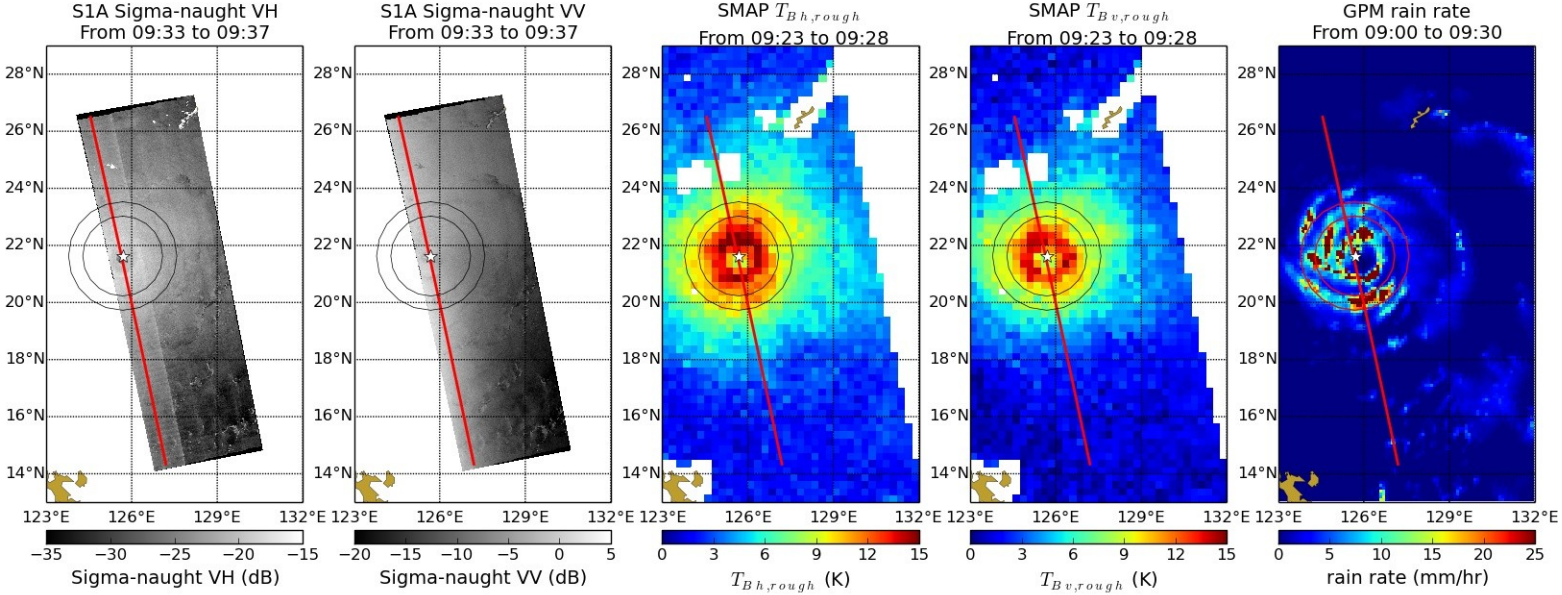




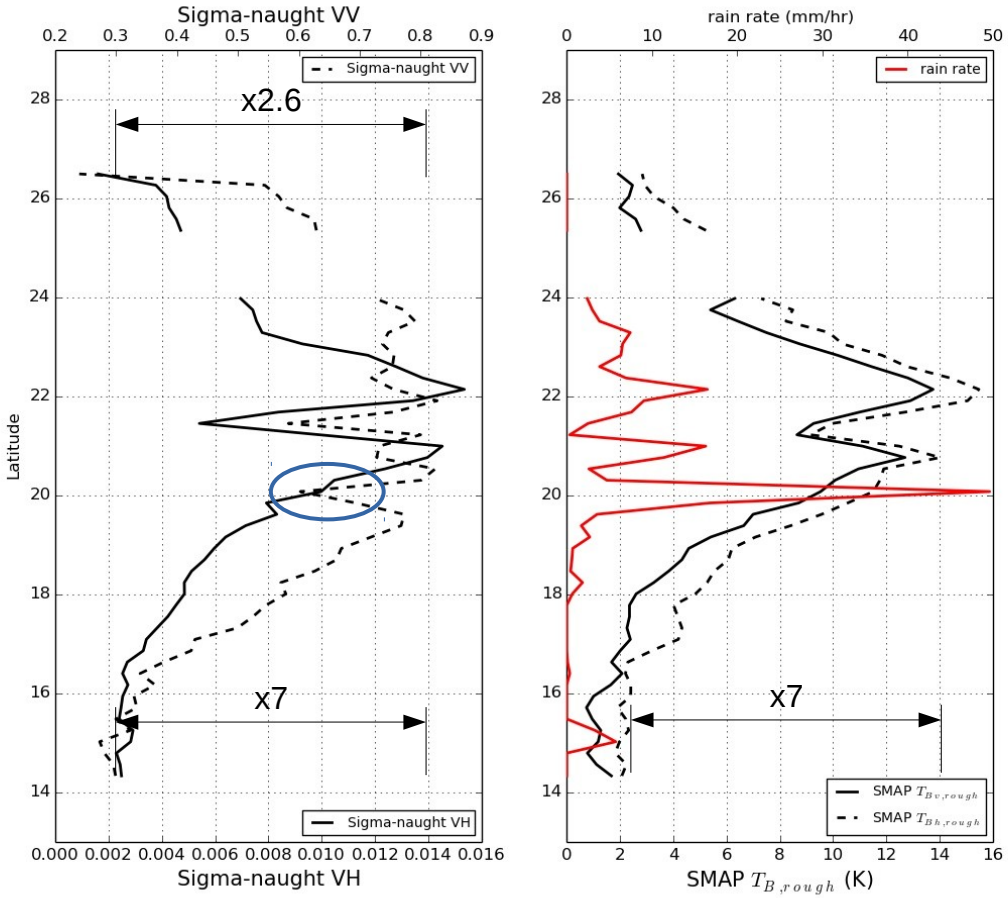


- Statistical comparison of VV-Winds, VV+VH wind with existing GMF and VV+VH wind obtained with new GMF confirm that Sentinel-1 winds and SMAP winds can be very consistent.
- In particular, the use of the new GMF improves statistics (bias is reduced) for wind speeds larger than 30 m/s.

SAR NRCS & SMAP Tb

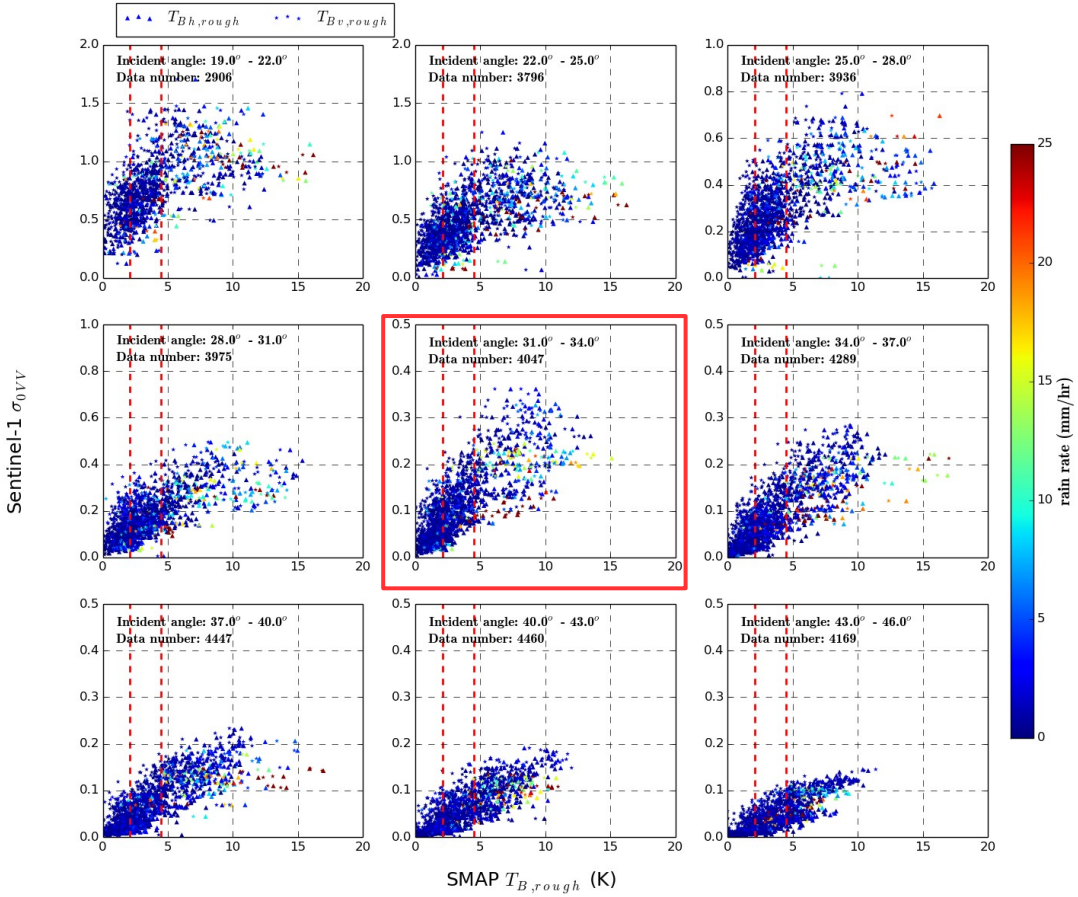


SAR NRCS & SMAP Tb

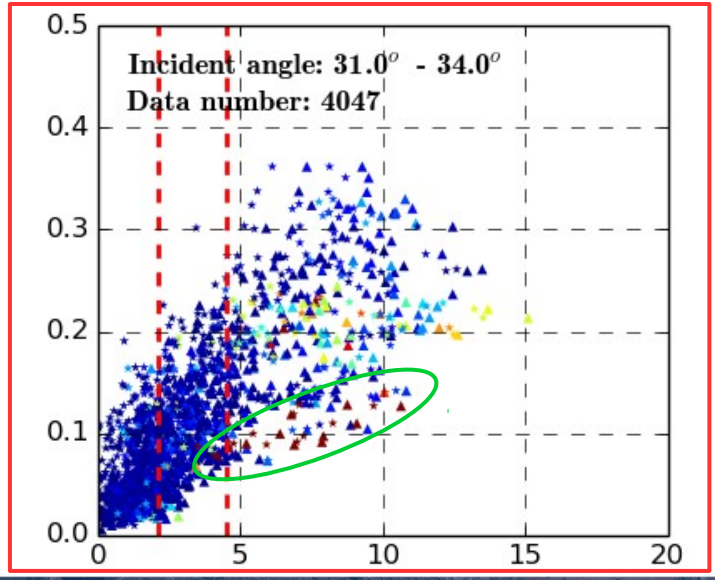


- At first order the dynamic of the wind induced excess surface brightness temperature and VH-NRCS have the same dynamic
- VV-NRCS seems to be more sensitive to atmospheric rain than VH (absorption).

SAR NRCS & SMAP Tb



- Clear saturation of VV-NRCS with respect to Tb is observed for lower incidence angles
- Strongest rain rate tends to decrease the VV-NRCS



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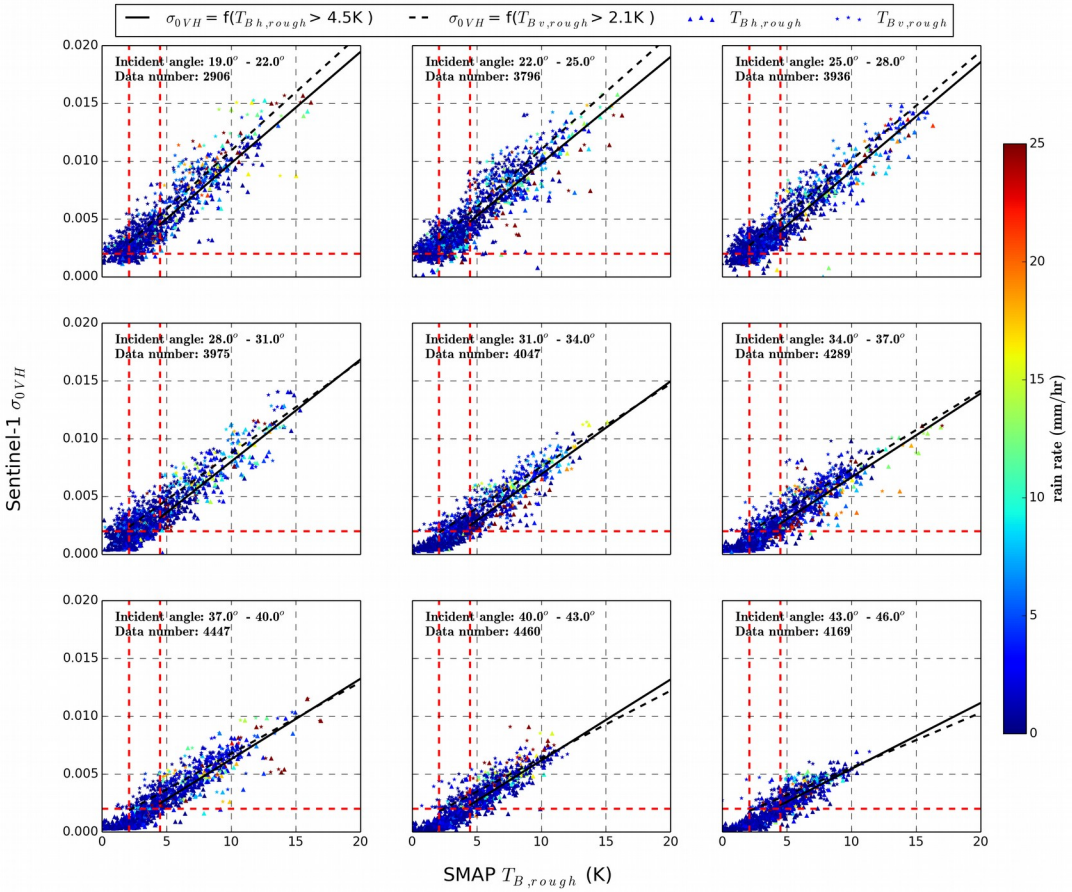

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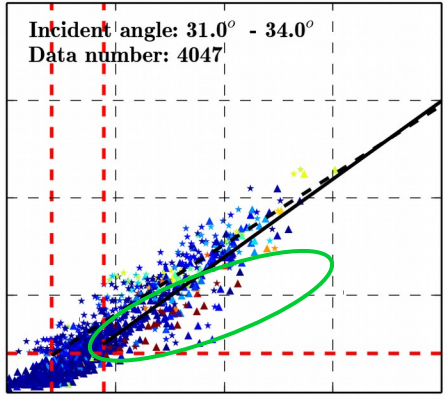

Conclusions

- SMAP and Sentinel-1 A & Sentinel-1 B orbits properties allow co-locations with less than 30 minutes

- The use of the unique capability of SMAP winds has allowed to demonstrate the benefit of having Sentinel-1 acquisitions with co- and cross-polarization to measure winds over extremes. To date:
  - cross-polarization channel is not used in the ESA L2 processor
  - there is no strategy to get Sentinel-1 acquisitions over hurricanes
  - cross-polarization is not yet optimized

- SHOC has demonstrated the ESA S-1 mission planning ability to optimize Sentinel-1 acquisition plan for late programming and successfully observe hurricanes.

- SMAP winds and SAR winds are found to be very consistent at 40 km resolution.

Conclusions

- 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 of VH-NRCS 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 for extreme winds 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.