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

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Outline of talk

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

- Sentinel-1A & Sentinel-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.

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
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
Motivations

- SAR does not continuously acquire data.
- Very few Dual-Polarization 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 Hurricane Observations Campaign**

- 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 Hurricane Observations Campaign

- Satellite Hurricane Observations Campaign was organized by IFREMER, CLS with a strong support from ESA and in collaboration with NOAA.
**Satellite Hurricane Observations Campaign**

- 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 Hurricane Observations Campaign**

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

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Nbr of Acq</th>
<th>SM</th>
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<td>Kay</td>
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<td>15</td>
<td>Hulika</td>
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</table>
- 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
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.
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.
Both VV and VV captures hurricane features (eye, rain impact, wind acceleration)

VV-NRCS is much higher than VH-NRCS

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

Satellite Hurricane Observations Campaign
• SAR NRCS & $T_{B,\text{rough}}$

- Difference of NRCS sensitivity is analyzed with respect to the background signal:
  \[ C_{pp} = \frac{\text{NRCS}_{pp}}{<\text{NRCS}_{pp}>} \]

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

• SAR NRCS & $T_{B,\text{rough}}$
• SAR NRCS & $T_{B,\text{surf}}$

• 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 $T_{B,\text{surf}}$
- SAR NRCS & $T_{B,\text{rough}}$

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

- Worse at high incidence angles
- 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.
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 \( T_{B,\text{surf}} \) (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.
• Conclusions & Perspectives

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

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

Conclusions & Perspectives
Thank you
The small dataset available also prevents to validate SAR wind speeds for extremes events with wind speed larger than 40 m/s

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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.
• 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

<table>
<thead>
<tr>
<th></th>
<th>S-1 C-SAR</th>
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<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>C-Band, 5.405 GHz, ~5 cm</td>
</tr>
<tr>
<td><strong>Variables</strong></td>
<td>NRCS VV&amp;VH Or HH&amp;HV (Doppler)</td>
</tr>
<tr>
<td><strong>Incidence angle</strong></td>
<td>~17-45 deg</td>
</tr>
<tr>
<td><strong>Swath coverage</strong></td>
<td>250 (IW) or 400 (EW) km</td>
</tr>
<tr>
<td><strong>Acquisition type</strong></td>
<td>Not continuous</td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td>Local/coastal areas EEZ</td>
</tr>
</tbody>
</table>

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
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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.


Reul et al., RSE 2016

Meissner et al., BAMS 2017
On the use of VH polarization

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