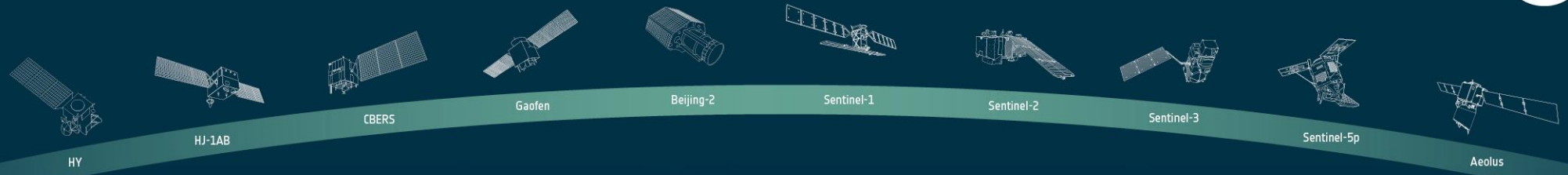
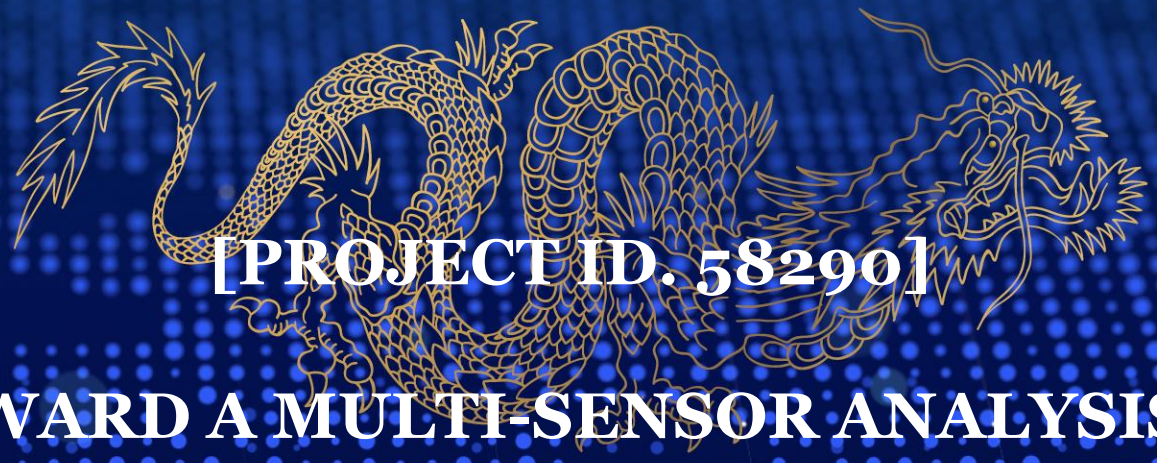


First Quasi-Synchronous Hurricane Quad-Polarization Observations by C-band Radar Constellation Mission and Radarsat-2



[PROJECT ID. 58290]

[TOWARD A MULTI-SENSOR ANALYSIS OF TROPICAL CYCLONE]

Dragon 5 Mid-term Results Project

<18 OCTOBER & 9:30 AM ~ 10:00 AM CEST (3:30 PM ~ 4:30 PM CST)>

ID. 58290

PROJECT TITLE: TOWARD A MULTI-SENSOR ANALYSIS OF TROPICAL CYCLONE

PRINCIPAL INVESTIGATORS: [DR. BIAO ZHANG DR. ALEXIS MOUCHE]

NUIST (CHINA) IFREMER (FRANCE)

CO-AUTHORS: [DR. WILLIAM PERRIE]

BIO (CANADA)

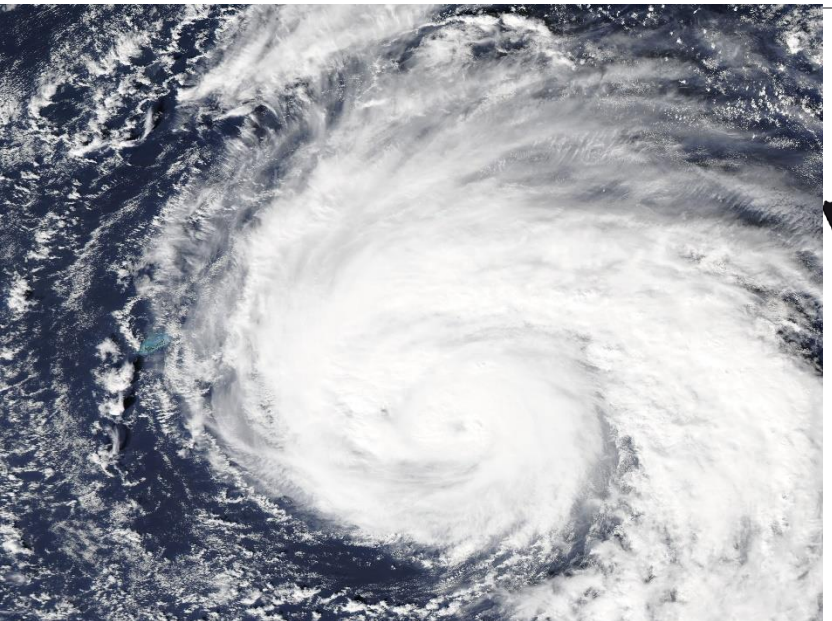
PRESENTED BY: [DR. BIAO ZHANG]

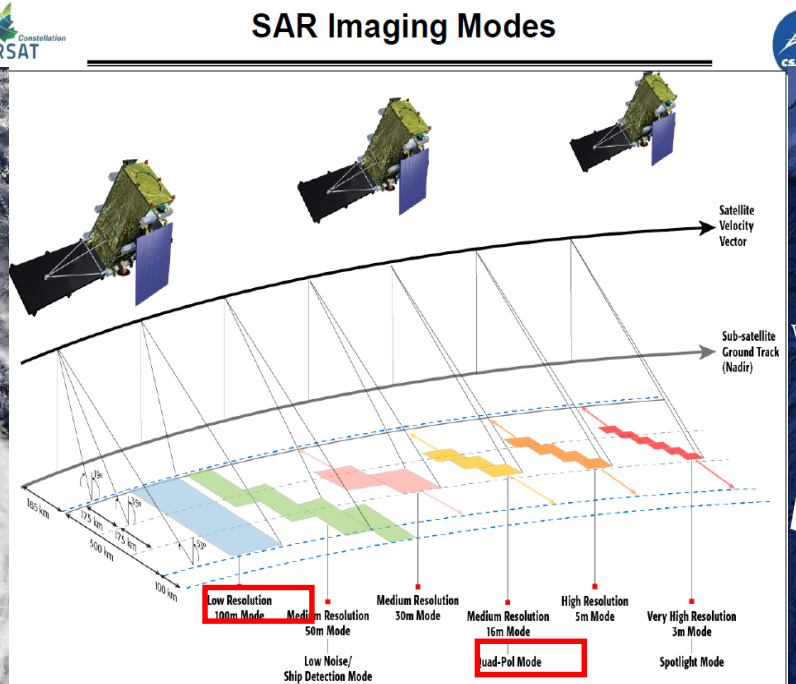
Hurricane SAR Monitoring (Requirements)

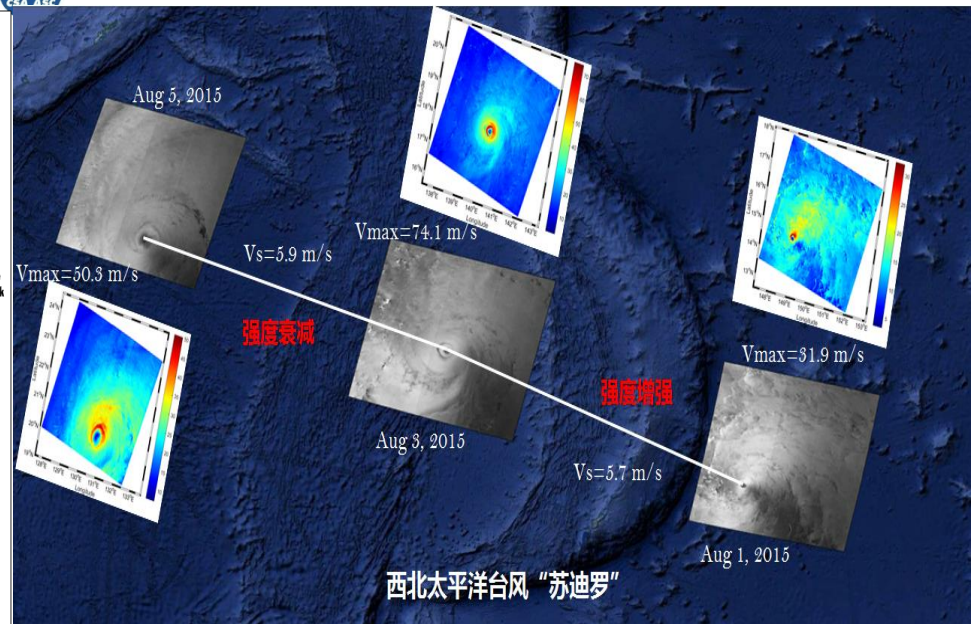
- From the perspective of hurricane monitoring from space, it is necessary to design more advanced SAR satellites with higher resolution, wide swath, and quad-polarization capability.

- High resolution will allow better exhibition of the spatial variations in the hurricane wind fields, especially in the TC inner core, where no other satellite measurements are able to probe the ocean surface at high resolution.

- Large spatial coverage enables SAR to capture the complete structure of the hurricane, and therefore to estimate the structural wind parameters (e.g., 34-, 50-, and 64- wind radii).



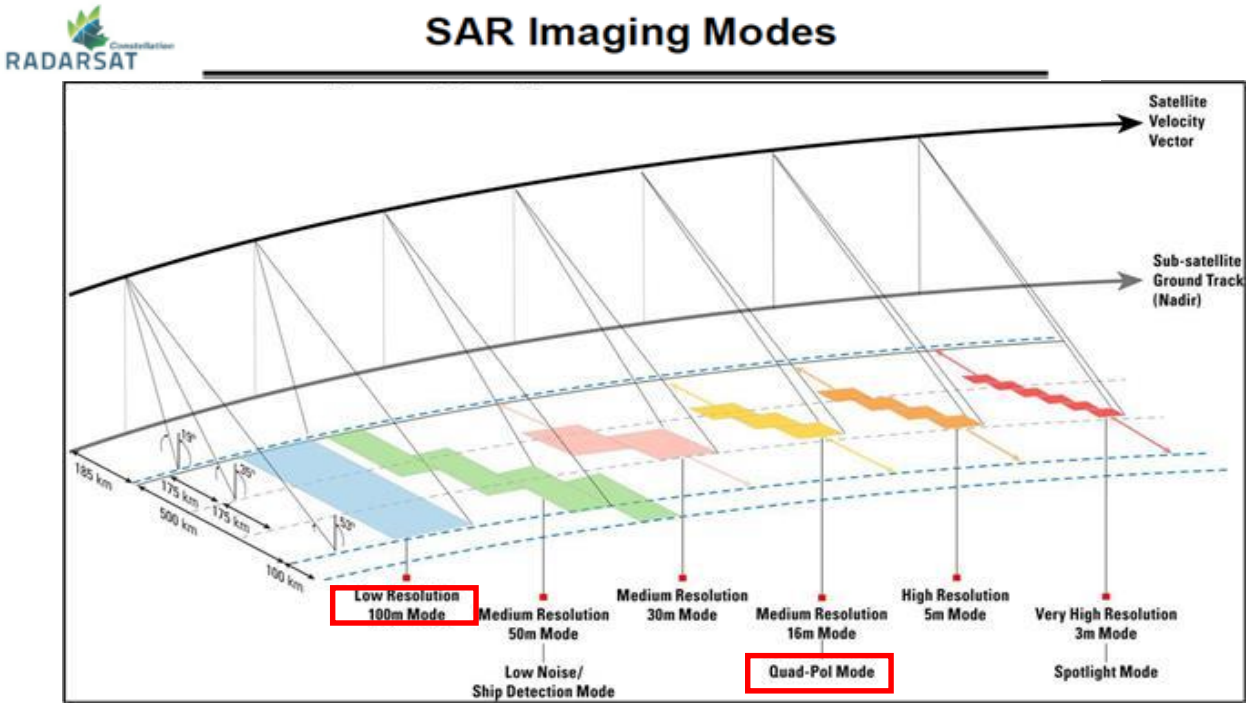


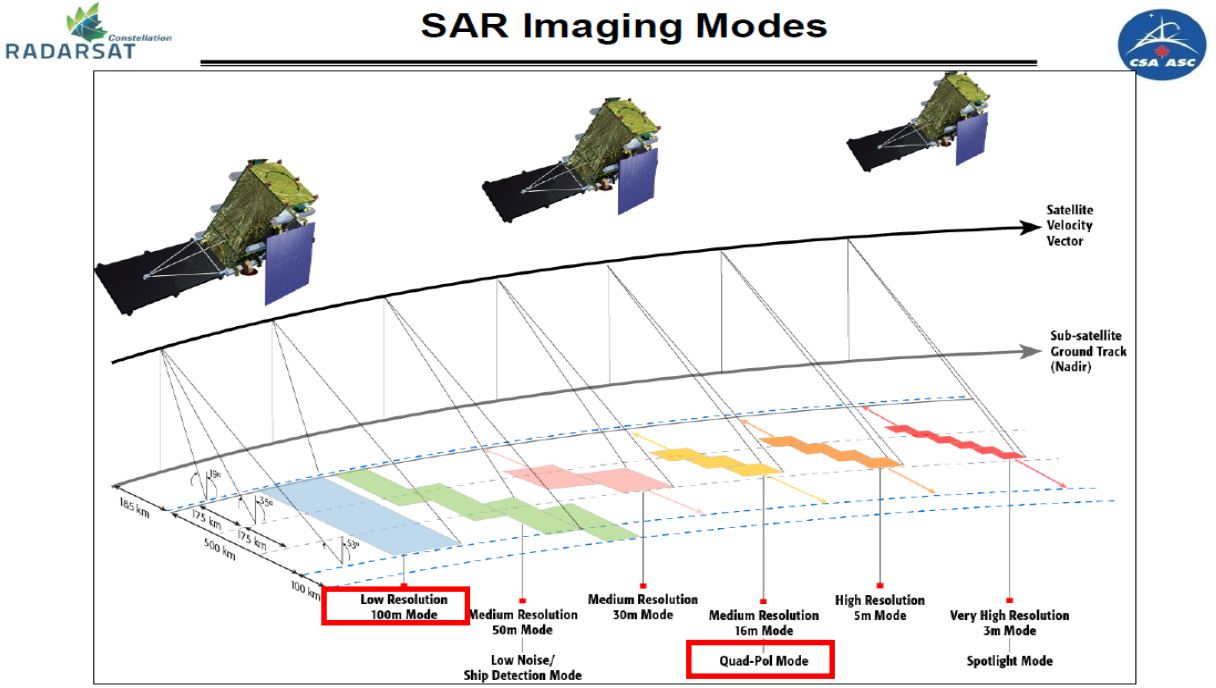


Hurricane SAR Monitoring (Wide Swath & Quad-Polarization)

- For spaceborne SAR hurricane monitoring, **dual-polarization (VV, VH) is routine option**: large coverage (350~500 km) and medium resolution (50~100 m)
- **quad-polarization** (HH, HV, VH, VV) is favorable because of high resolution (~5 m) and abundant polarimetric information content, while **swath (25~50 km) is much smaller** compared to that of dual-polarization .

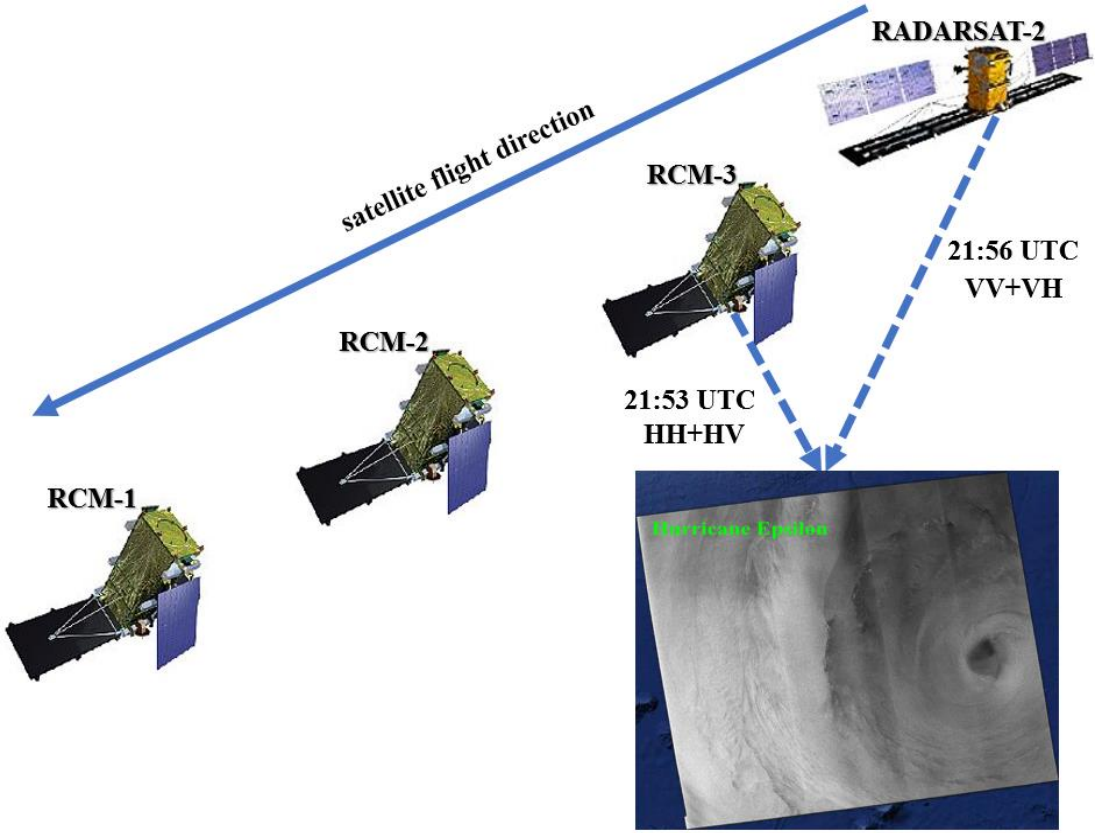
Bottleneck issue: Due to the tradeoff between high resolution and wide coverage, it is not possible to obtain **wide swath fully polarimetric synthetic aperture radar hurricane observations**.

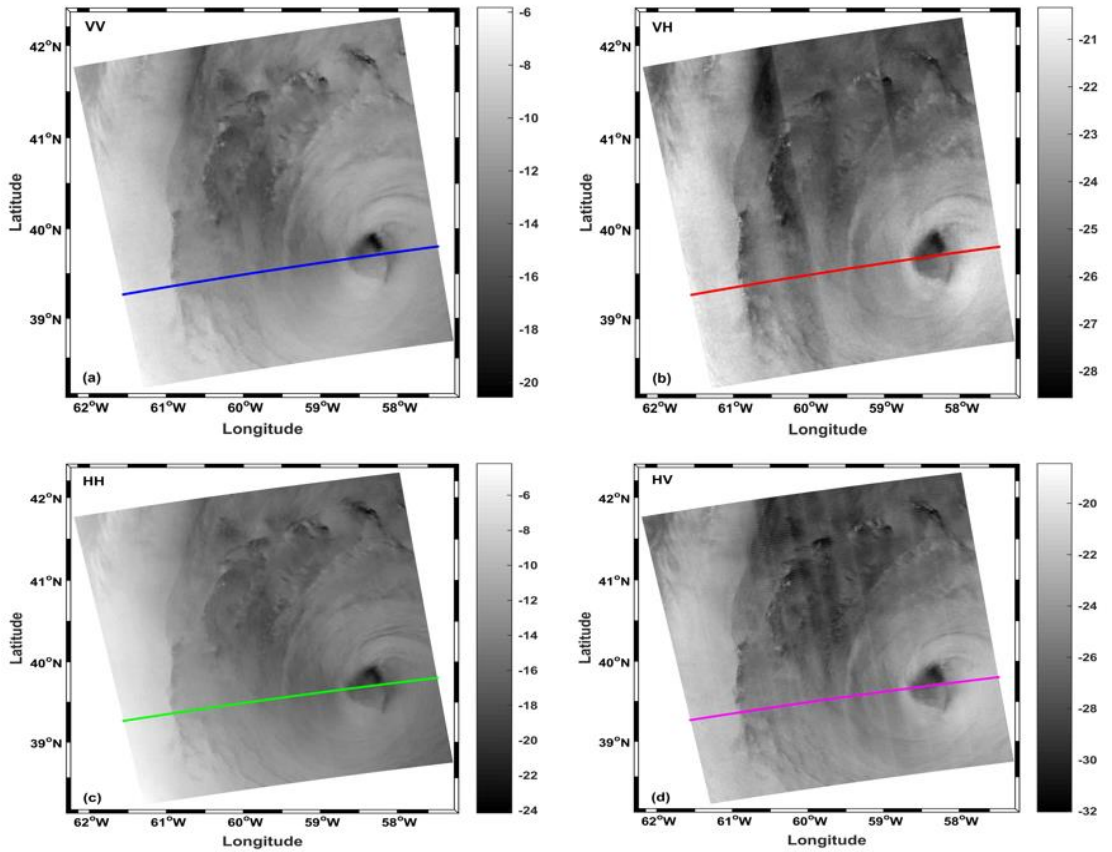




Hurricane SAR Monitoring (Wide Swath & Quad-Polarization)

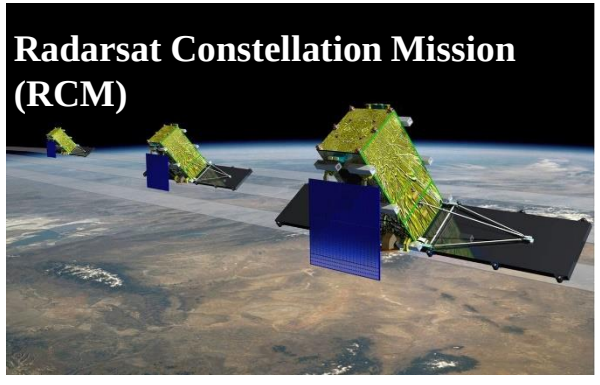
- For the first time, quasi-synchronous hurricane quad-polarization wide swath observations are achieved by using synergistic observations of C-band Radarsat Constellation Mission (RCM) and RADARSAT-2.
- C-band RCM and RADARSAT-2 observe the Hurricane Epsilon within a very short time interval (3 minutes), which provide a very good opportunity to yield fully polarimetric SAR hurricane observations over a large area.

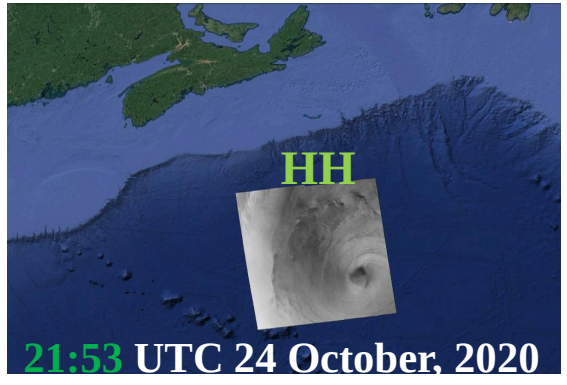


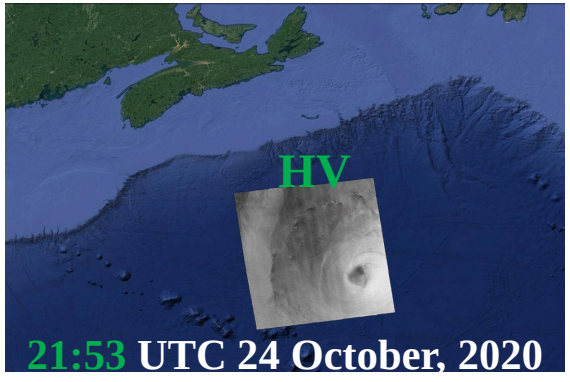


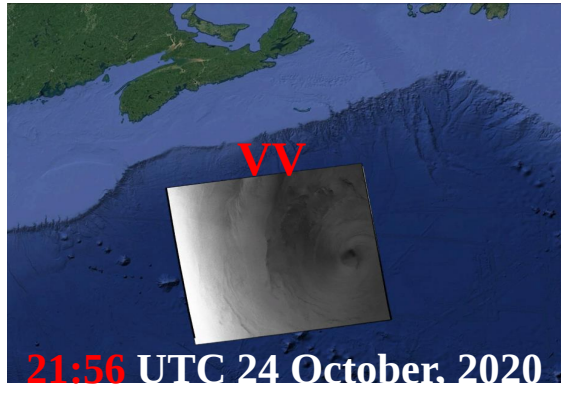
Motivations

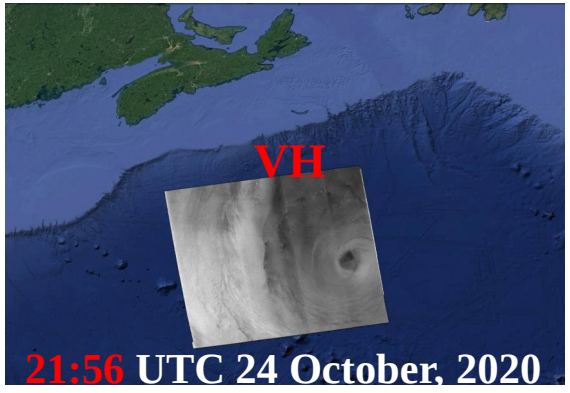
- document the microwave scattering characteristics of quad-polarization radar backscatters under hurricane wind conditions from the same active microwave sensor.
- investigate the short time-scale variations in high-resolution backscattering and thus reveal the most dynamical areas within the hurricane vortex.
- determine the rain impacts of heavy rainfall on fully polarimetric radar signals in a strong wind environment.





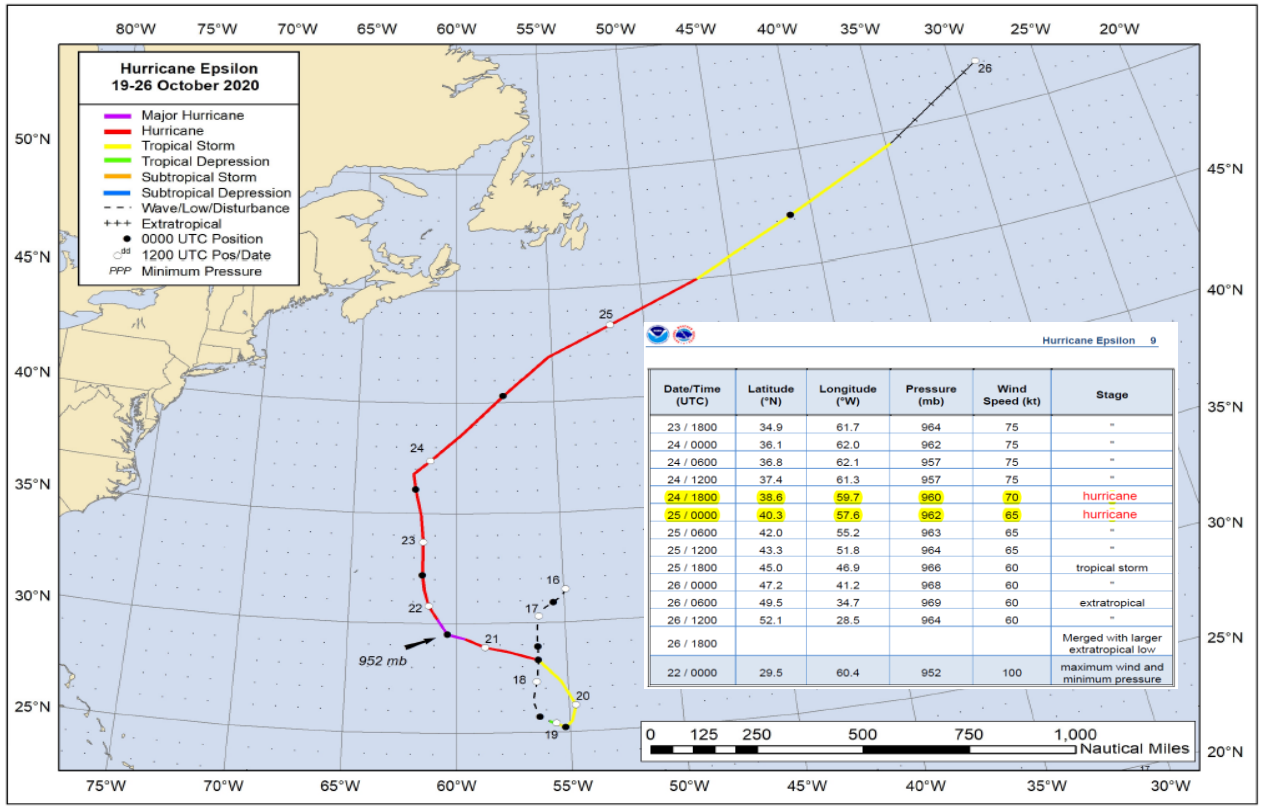


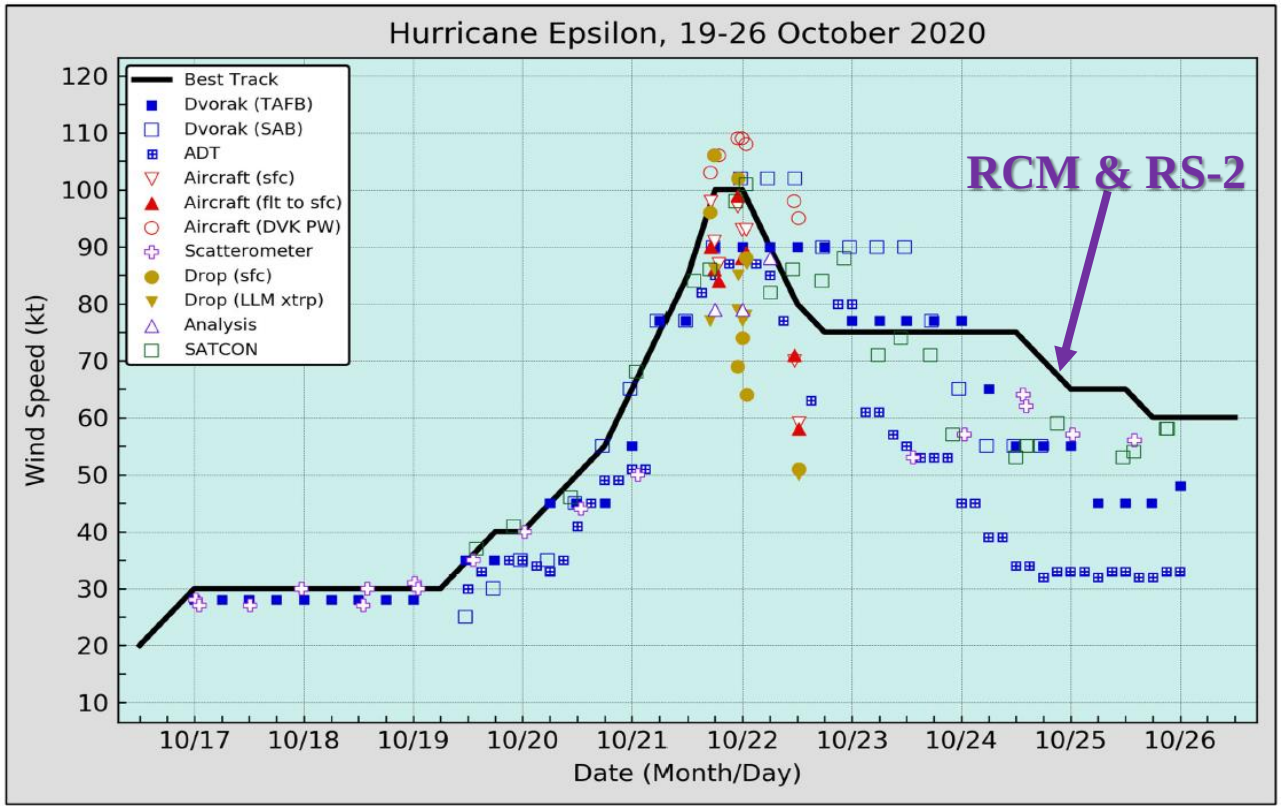




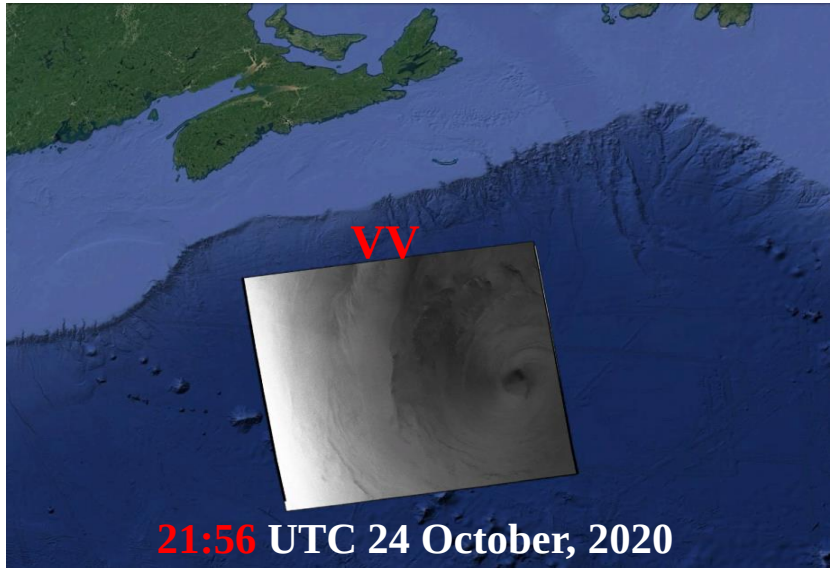
Hurricane Epsilon

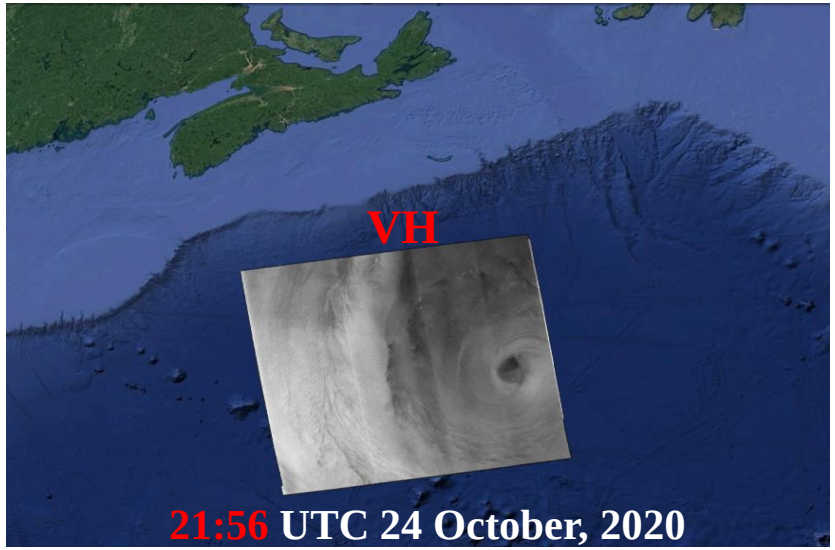
- Hurricane Epsilon was a category 3 storm in the North Atlantic, reaching its peak intensity with maximum wind of 100 kt and a minimum pressure of 952 hPa at 18:00 UTC on 21 October 2020.
- RCM and RADARSAT-2 observed the Hurricane Epsilon at 21:53 and 21:56 UTC on the same day (24 October 2020), with different polarization options. The former is HH and HV, while the latter is VV and VH.

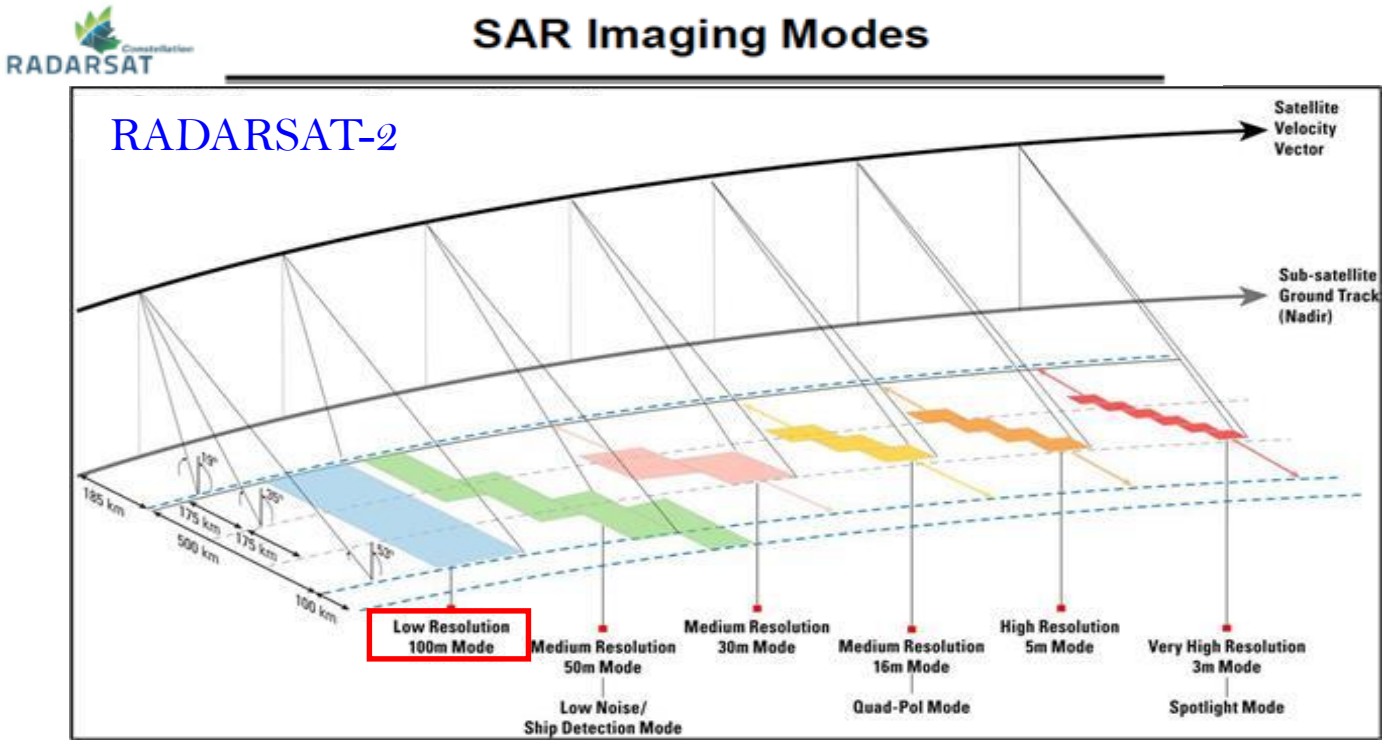




Hurricane Epsilon (RADARSAT-2)

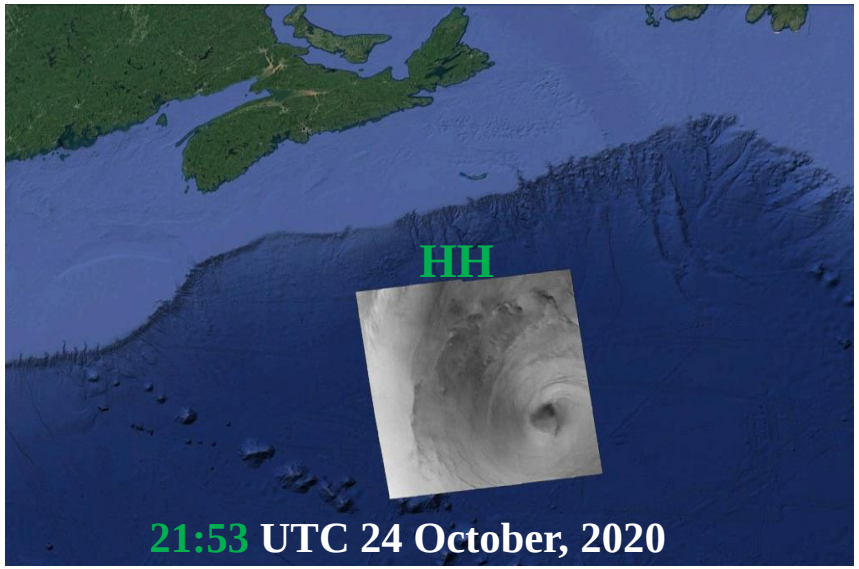


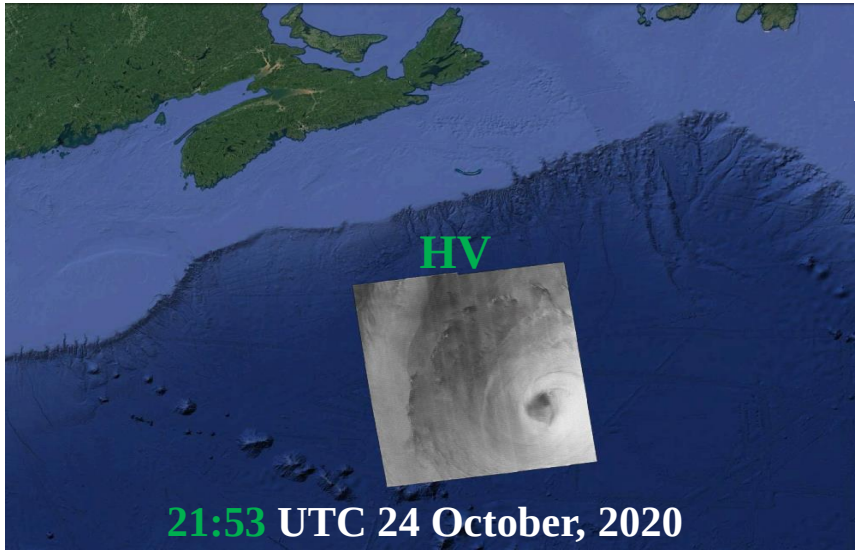


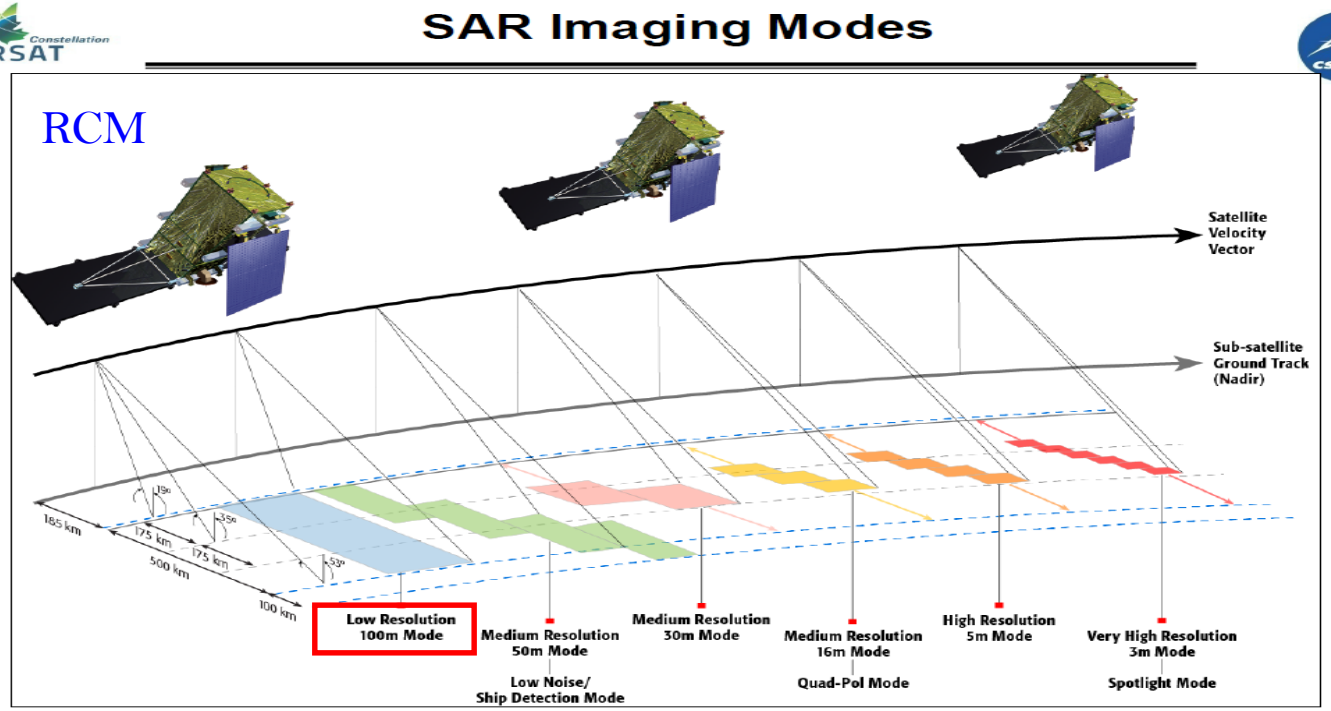


Beam mode: ScanSAR Wide A (W1 W2 W3 S7)
Beam mode type: Medium resolution 100 m
Polarization: **VV+ VH**
Incidence Angle (Low): 20
Incidence Angle (High): 49
Product Type: SCF

Hurricane Epsilon (RCM)





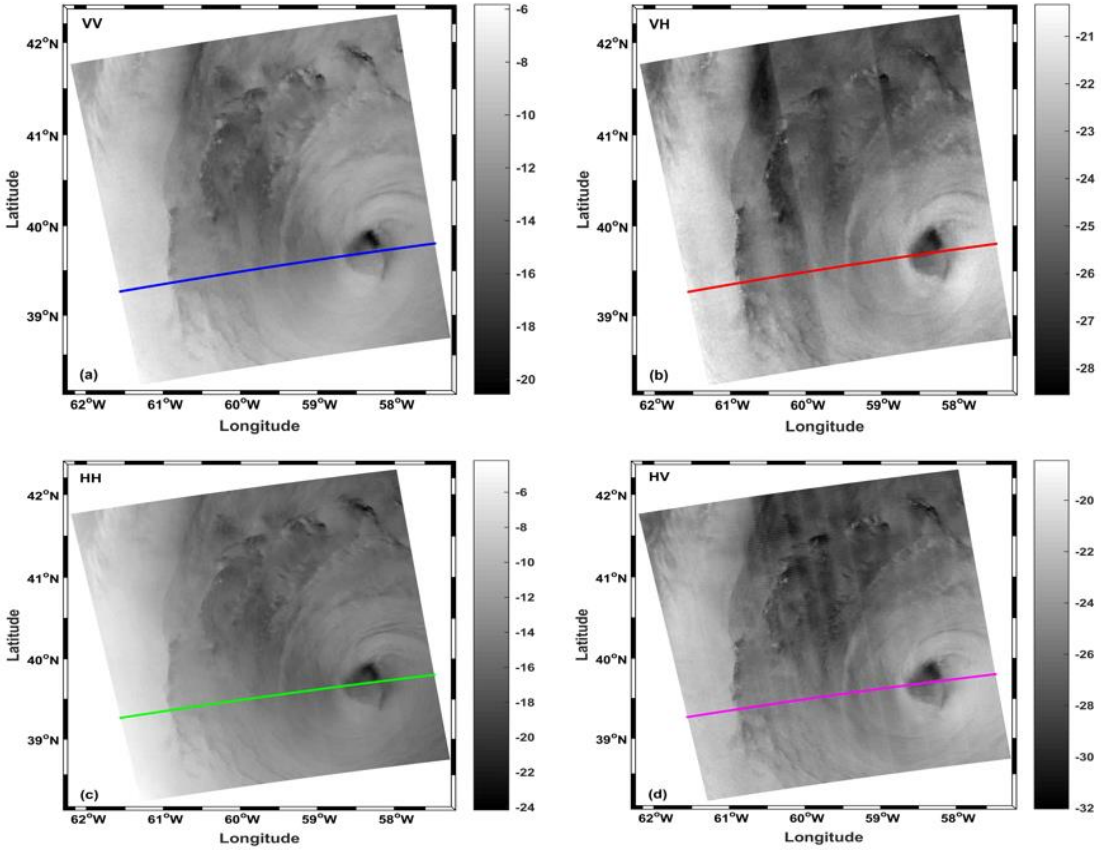


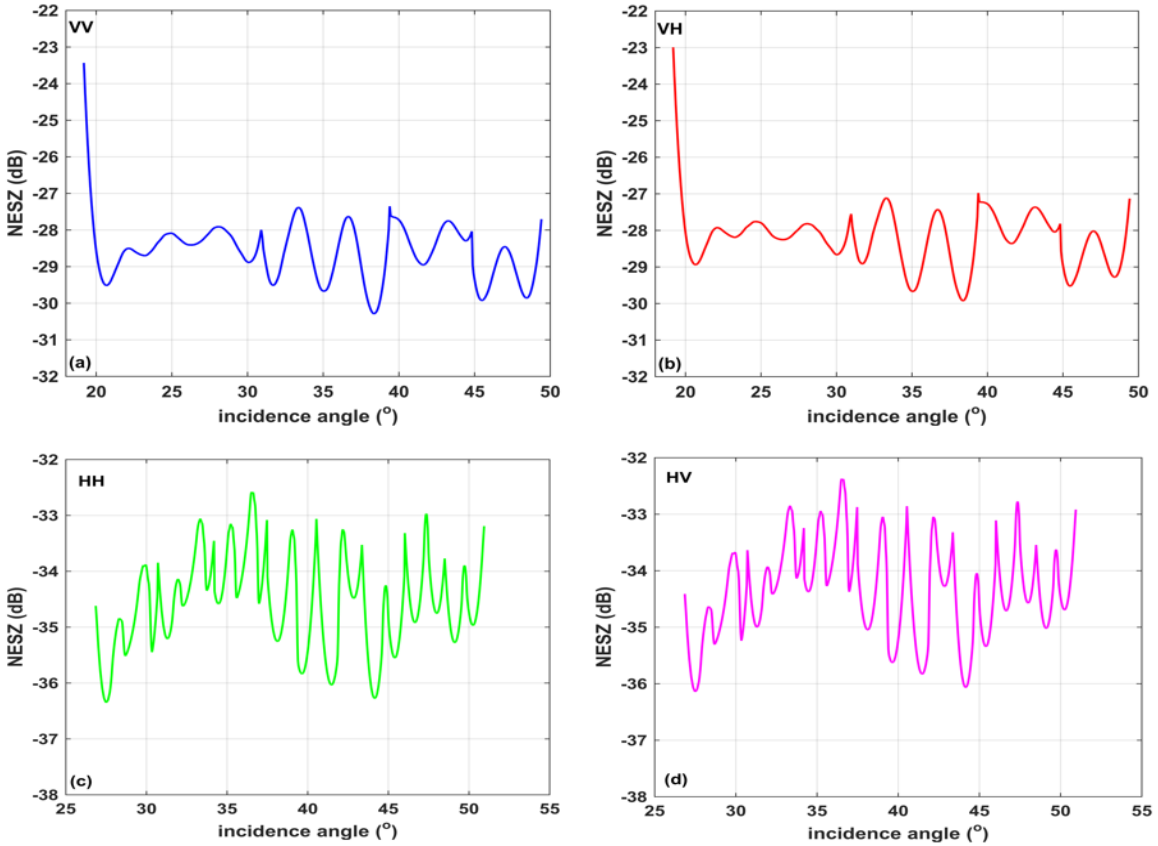
Beam mode: ScanSAR 50 m Resolution 350 km Swath B
Beam mode type: Medium resolution 50 m
Polarization: **HH + HV**
Incidence Angle (Low): 17
Incidence Angle (High): 52
Satellite ID: RCM-3

Quad-Pol NRCS vs Incidence Angle

- To analyze the dependence of NRCS on radar incidence angle, transects are designated from the near range to far range in HH-, VV-, HV-, and VH-polarized SAR images.

- Compared with RADARSAT-2 measurements at VV- and VH-polarizations, the noise equivalent sigma zero (NESZ) values of RCM at HH- and HV-polarizations are much lower, ranging between -32 and -36 dB.

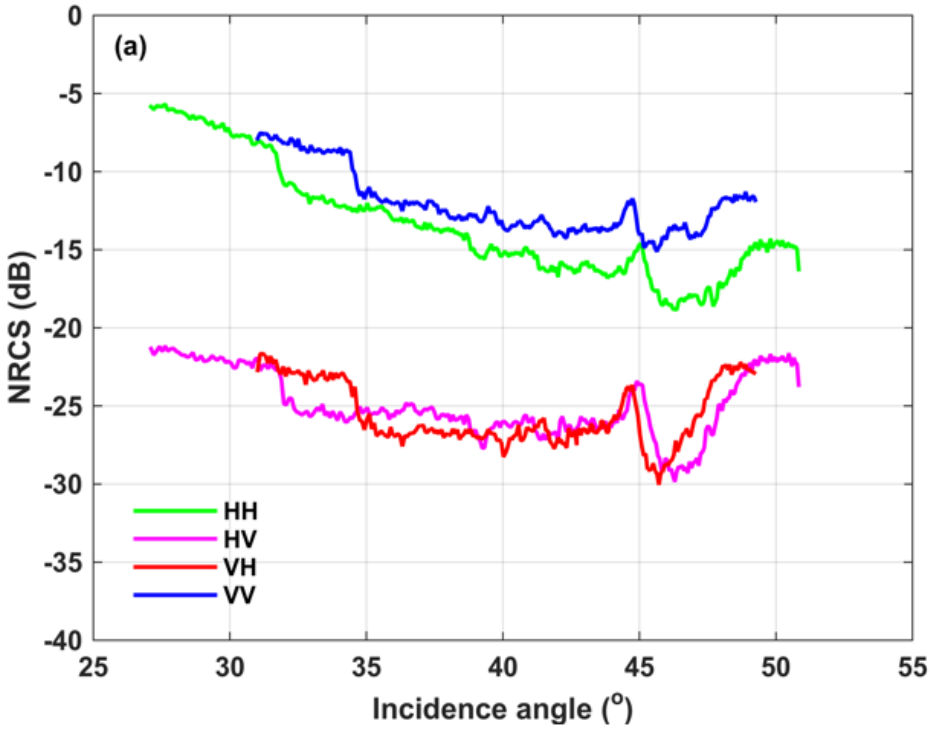


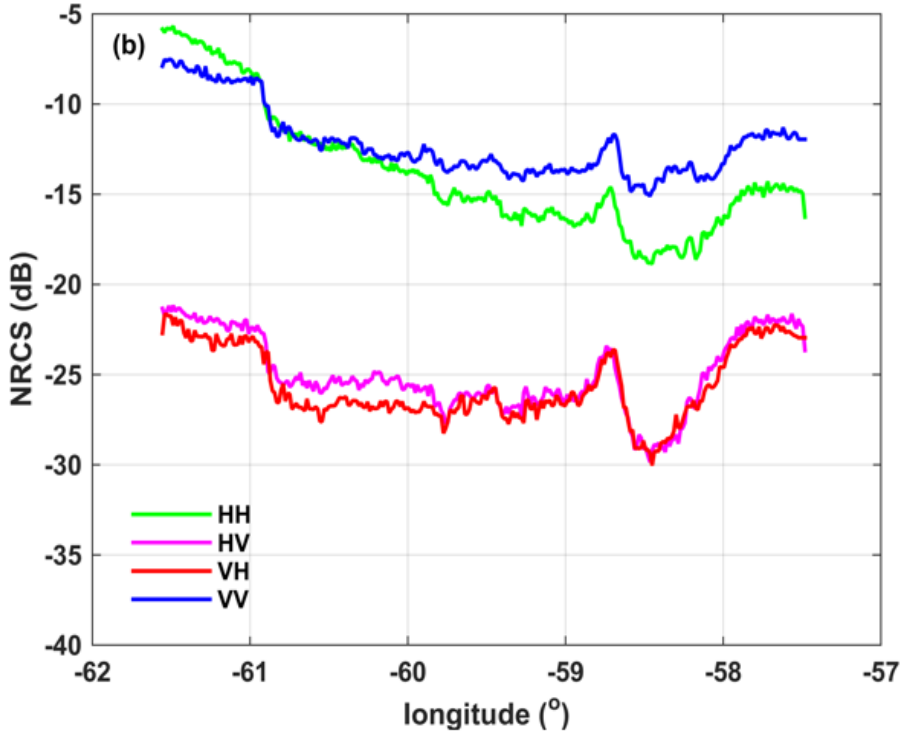


Quad-Pol NRCS vs Incidence Angle

- HV- and VH-pol NRCS show great consistency and do not significantly vary with incidence angles.

- HV- and VH-pol NRCS dramatically increase or decrease in the hurricane inner core (eyewall and eye regions), possibly due to notable changes in wind speeds.

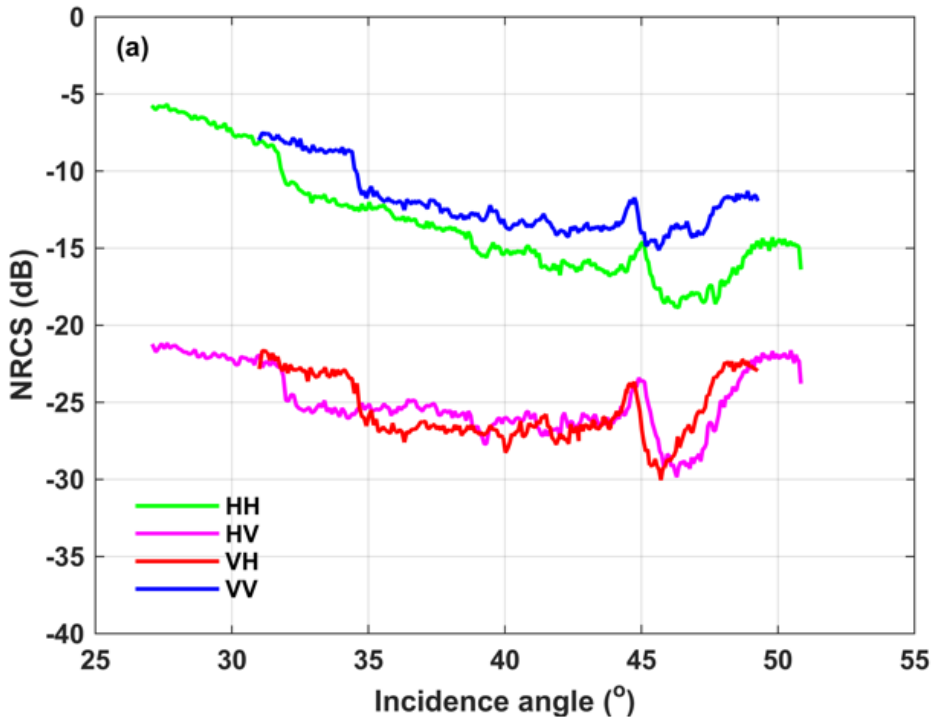


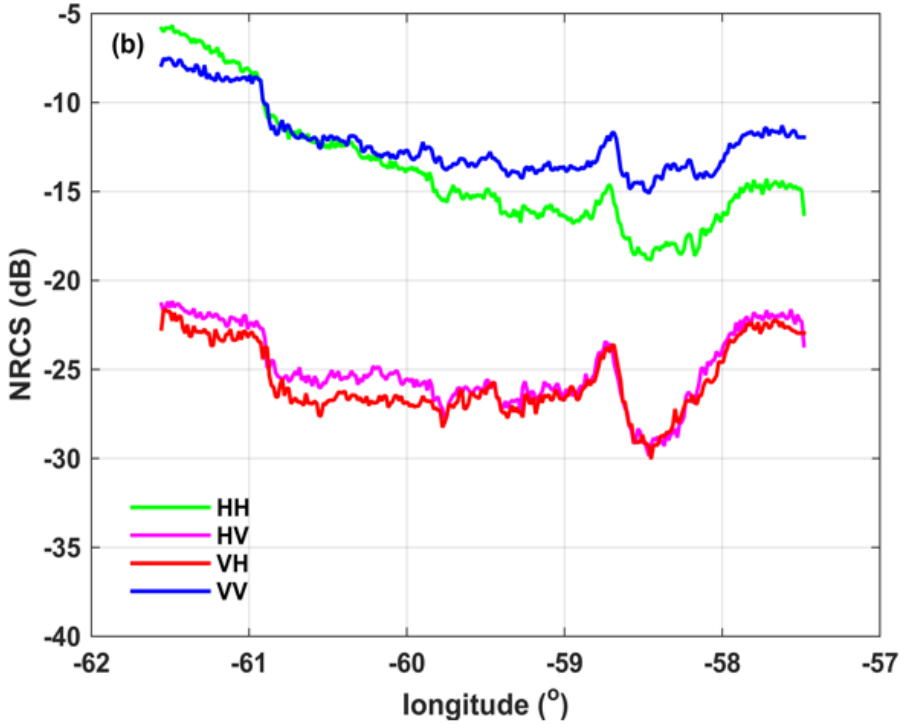


Quad-Pol NRCS vs Incidence Angle

- From near range to far range (adjacent to the hurricane eye), HH- and VV-pol NRCS values decrease with increasing incidence angle. In this area, a magnitude of about 12.5 dB is for both VV and HH, whereas only 5 dB is found for VH and HV.

- Compared with HH and VV, NRCS values at HV and VH-pol are much less dependent on incidence angle.

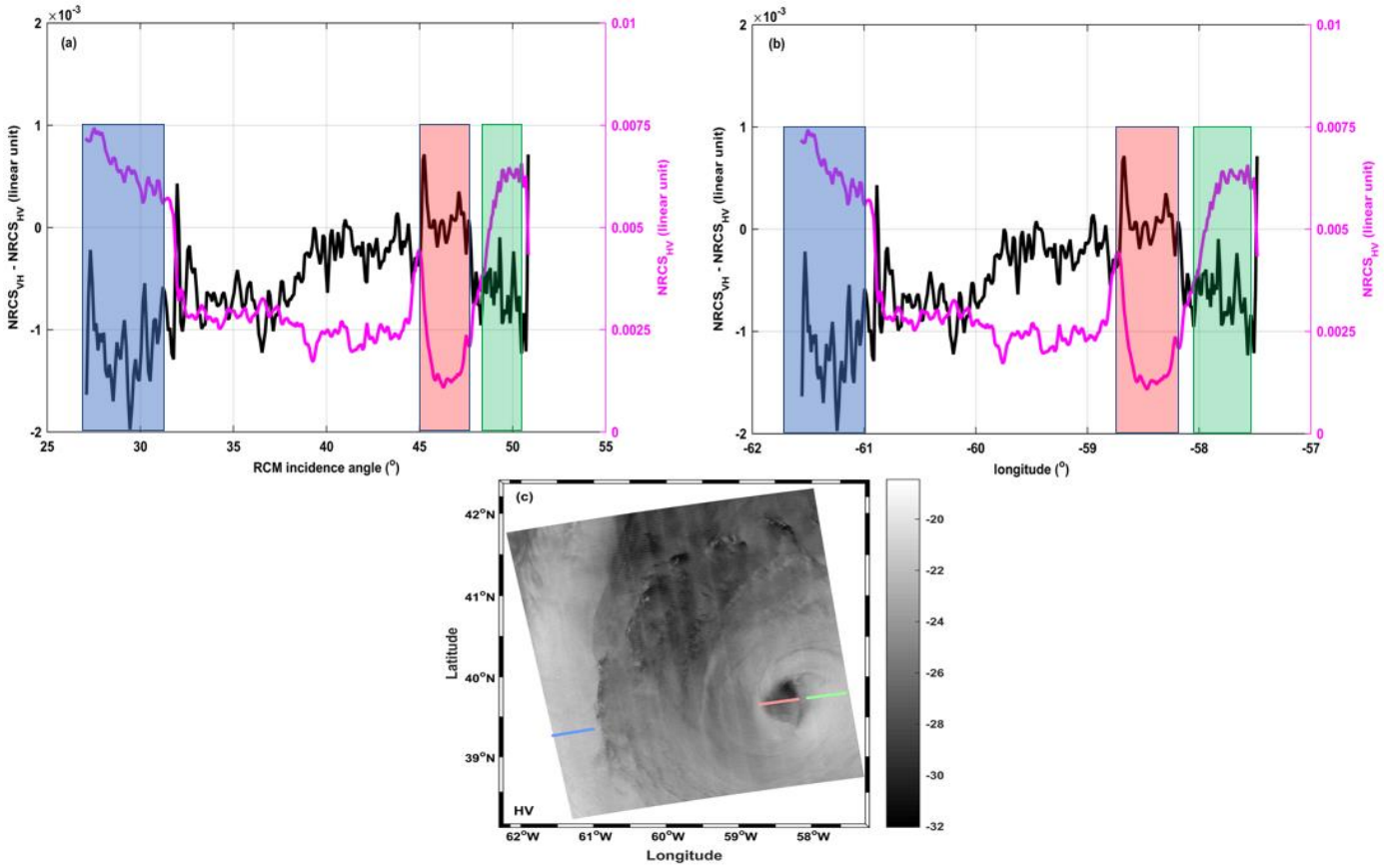




Hurricane Inner Core Dynamic

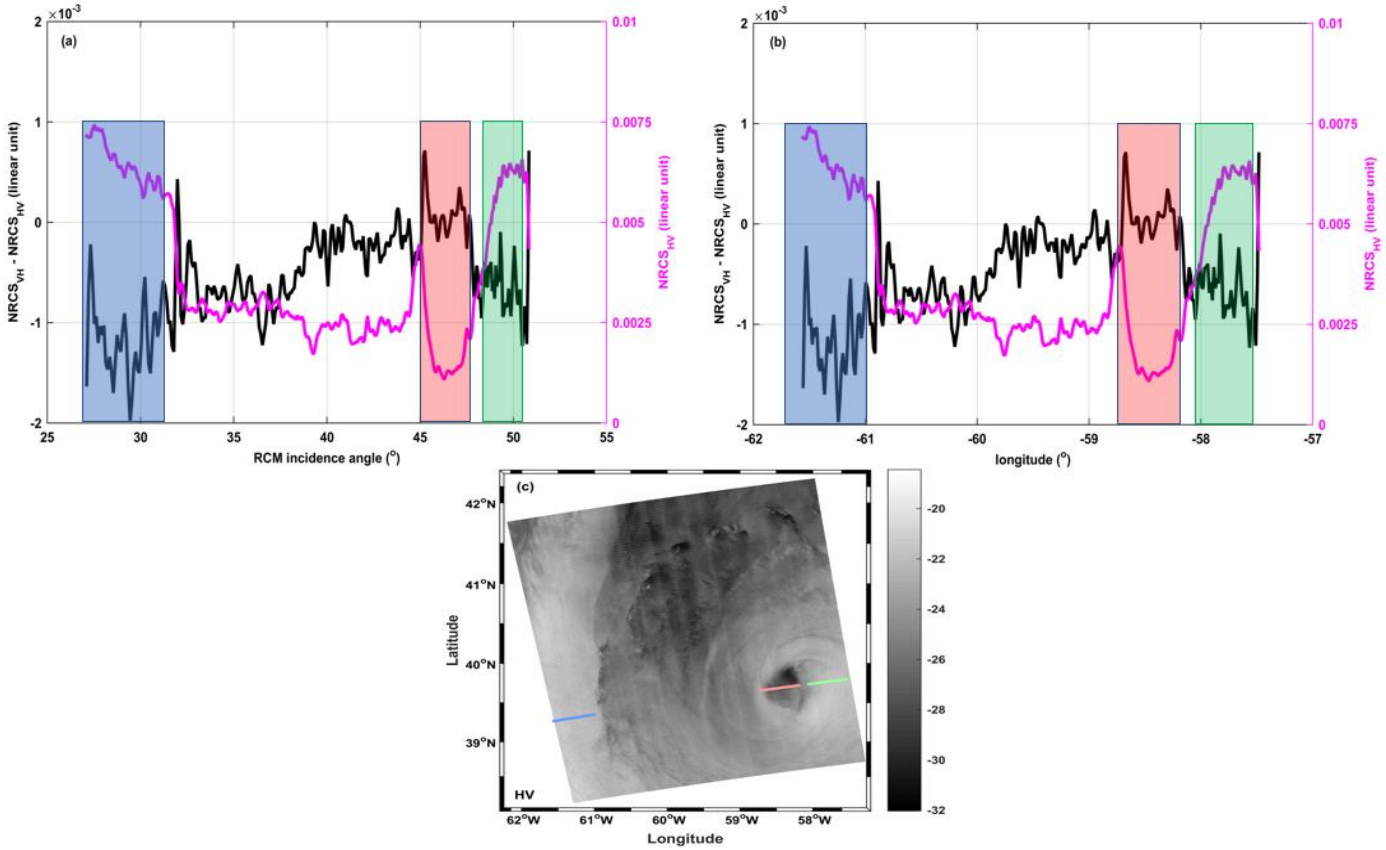
- The maximum difference is found in the western part of the scene, about 330 km from the eye (light blue shading), where the highest values of VH-pol NRCS are measured, ~-21.3 dB.

- In this area, the signal to noise ratio is high and the noise correction impact is negligible. Therefore, the differences between VH and HV can be attributed to the changes in the ocean scenes between the two acquisition times.



Hurricane Inner Core Dynamic

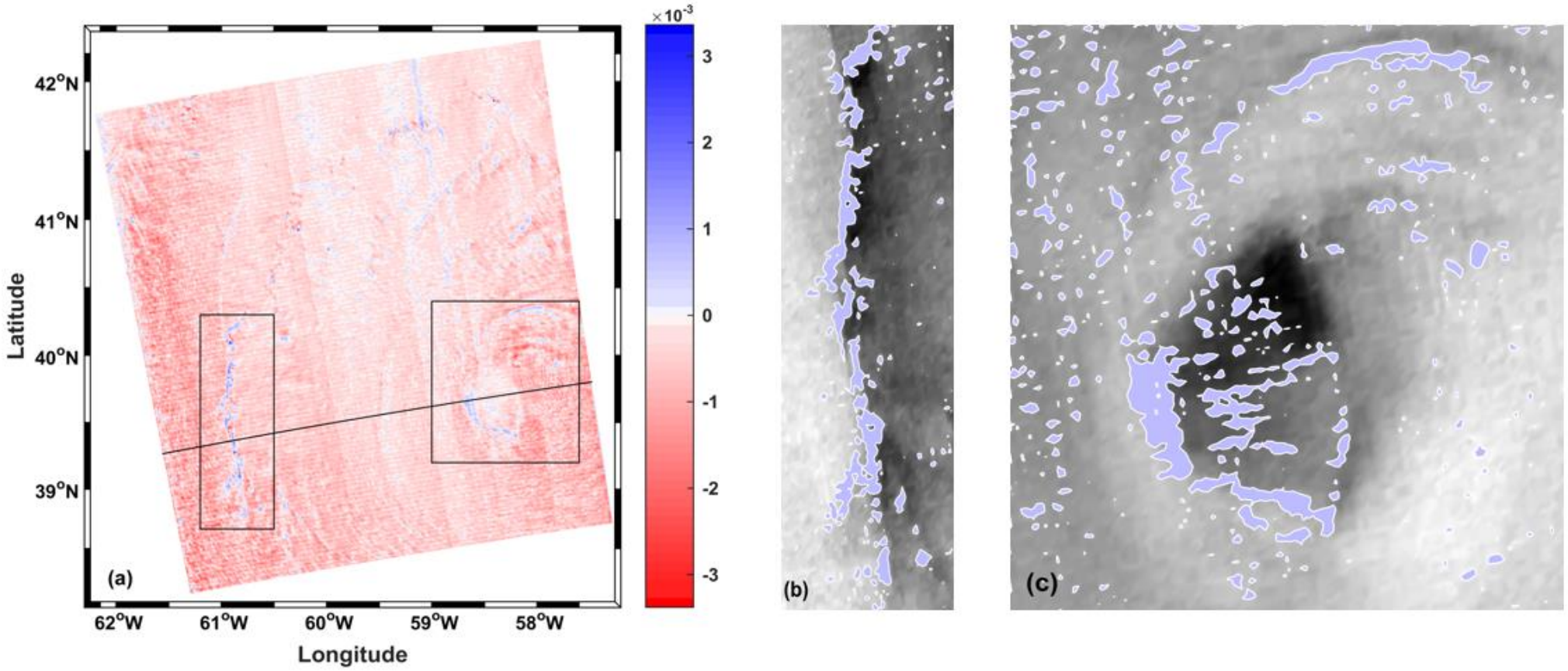
- We also can observe positive values for the HV-VH differences in the western part of the hurricane eye and negative differences in the eastern part (red and green shadings).
- These results could indicate asymmetry in the dynamic process taking place in the hurricane eyewall. These changes are found to be less intense than those occurring in the outer core, far from the eye center (light blue shading).



Zhang et al., 2022 IEEE TGRS

Hurricane Inner Core Dynamic

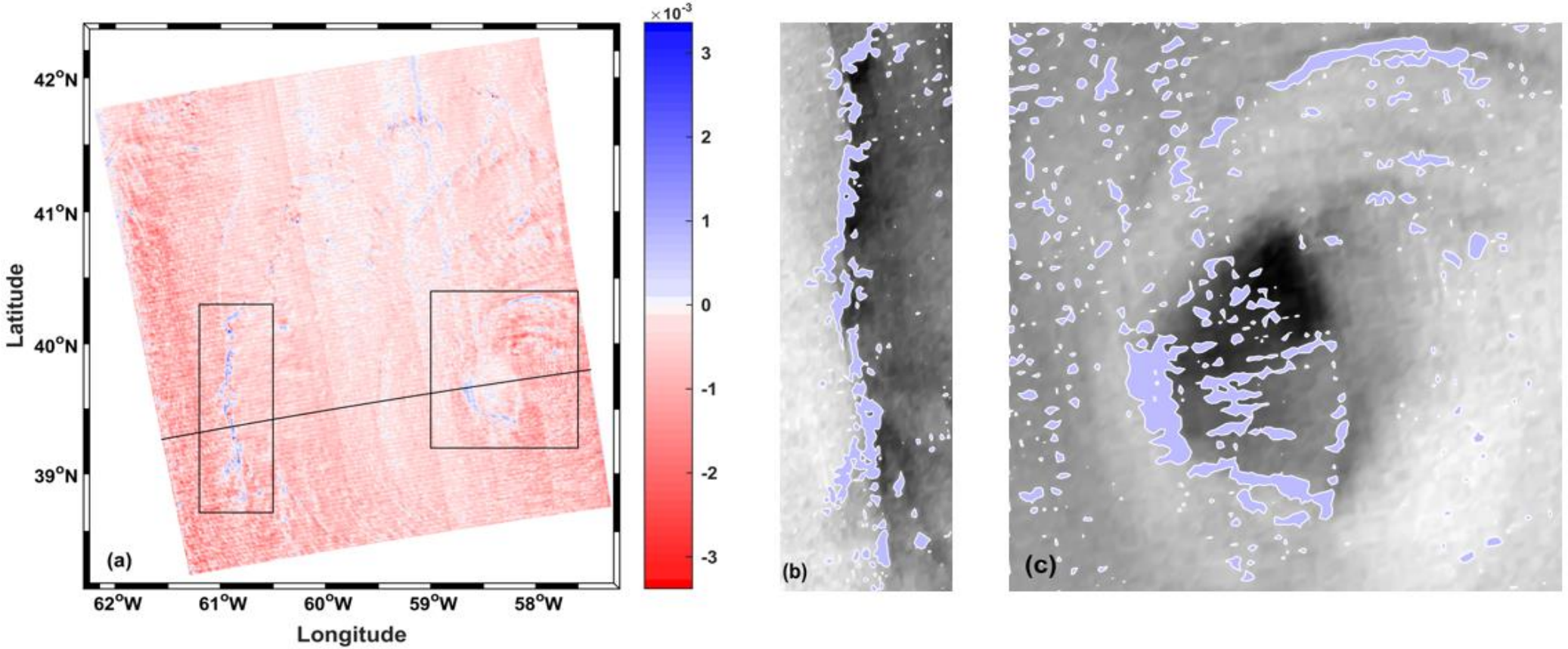
- Going beyond the transect analysis, we can directly map the VH and HV-pol differences.
- The negative HV-VH values suggest that the wind speeds in these areas are decreasing.



Hurricane Inner Core Dynamic

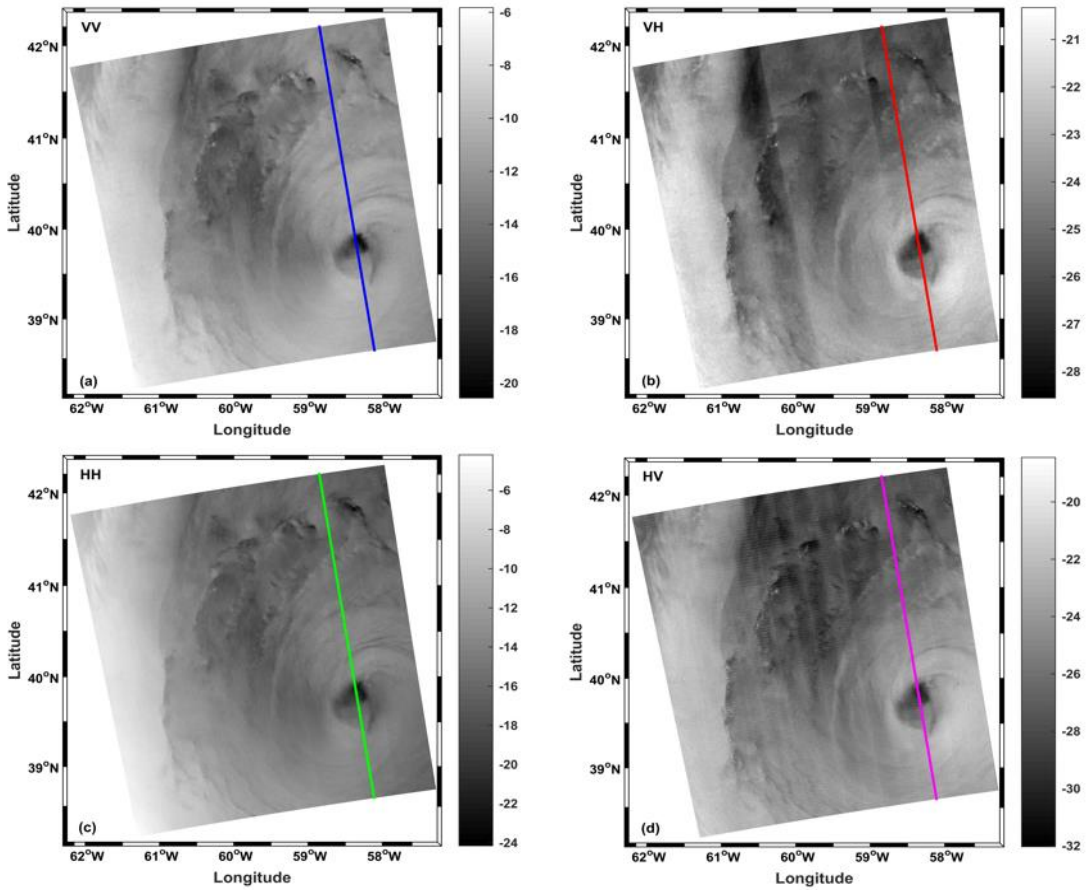
- The positive differences (narrow bands) within the hurricane vortex are associated with rain bands. They are most likely due to the local intense rain rates.

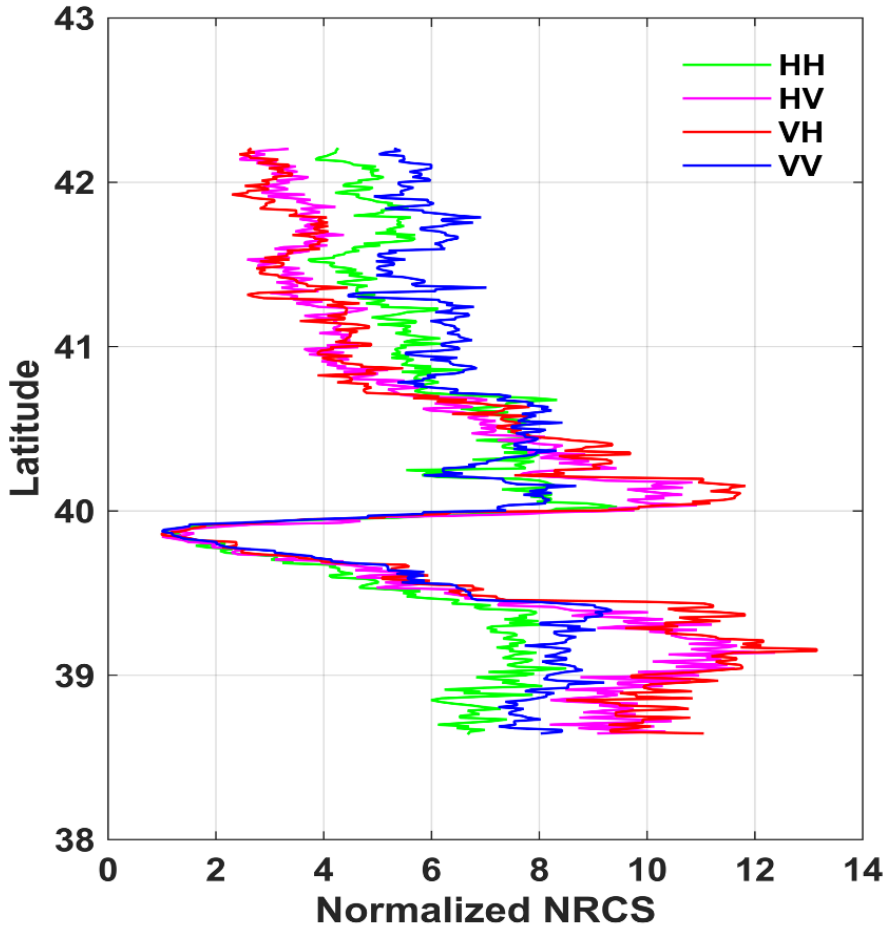
- The difference map also confirms a significant area, with positive VH-HV differences in the hurricane eye region, mostly located in its western part. This suggests asymmetrical dynamics around the hurricane eye.



Quad-Pol NRCS vs Wind Speed

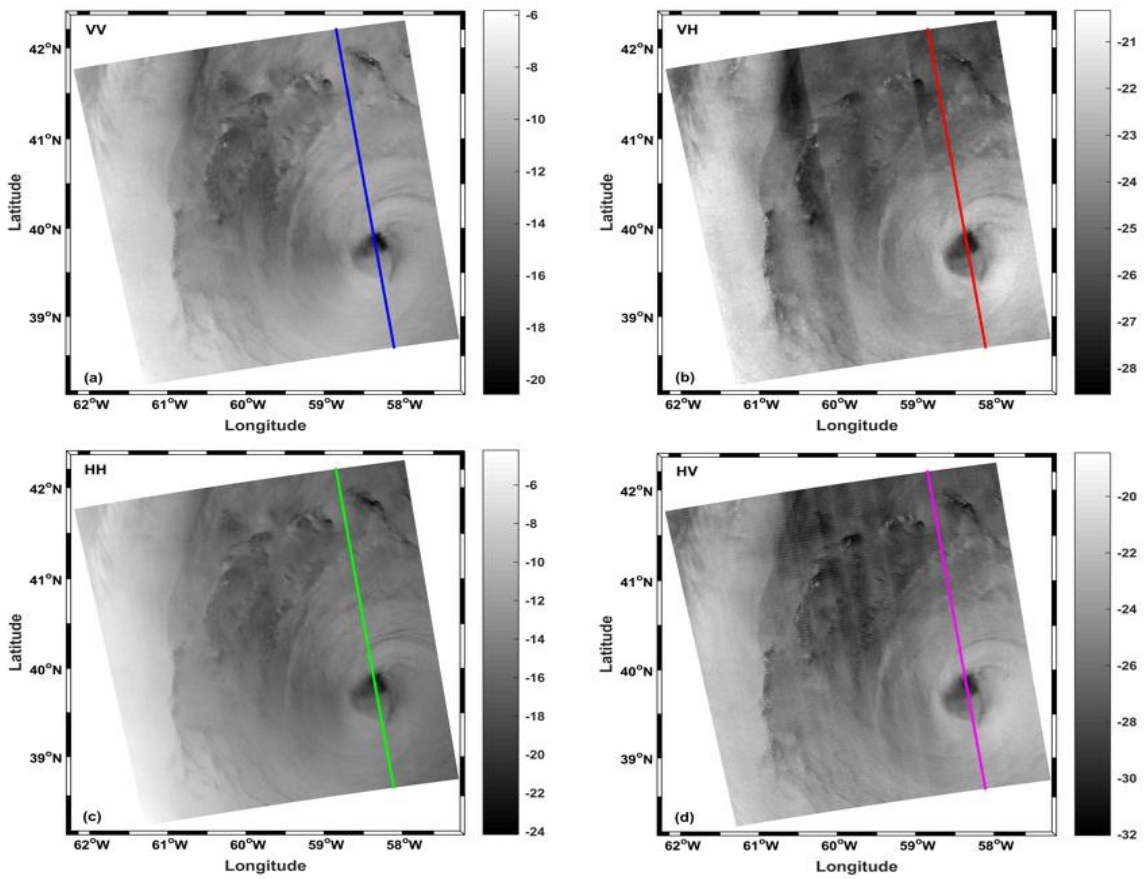
- The relative variation in HV- or VH-pol NRCS values are much larger than those of HH- and VV-pol in hurricane eyewall region, suggesting that the normalized HV and VH observations are more sensitive to wind speed variation (in the range of high wind speeds) than those of HH and VV.

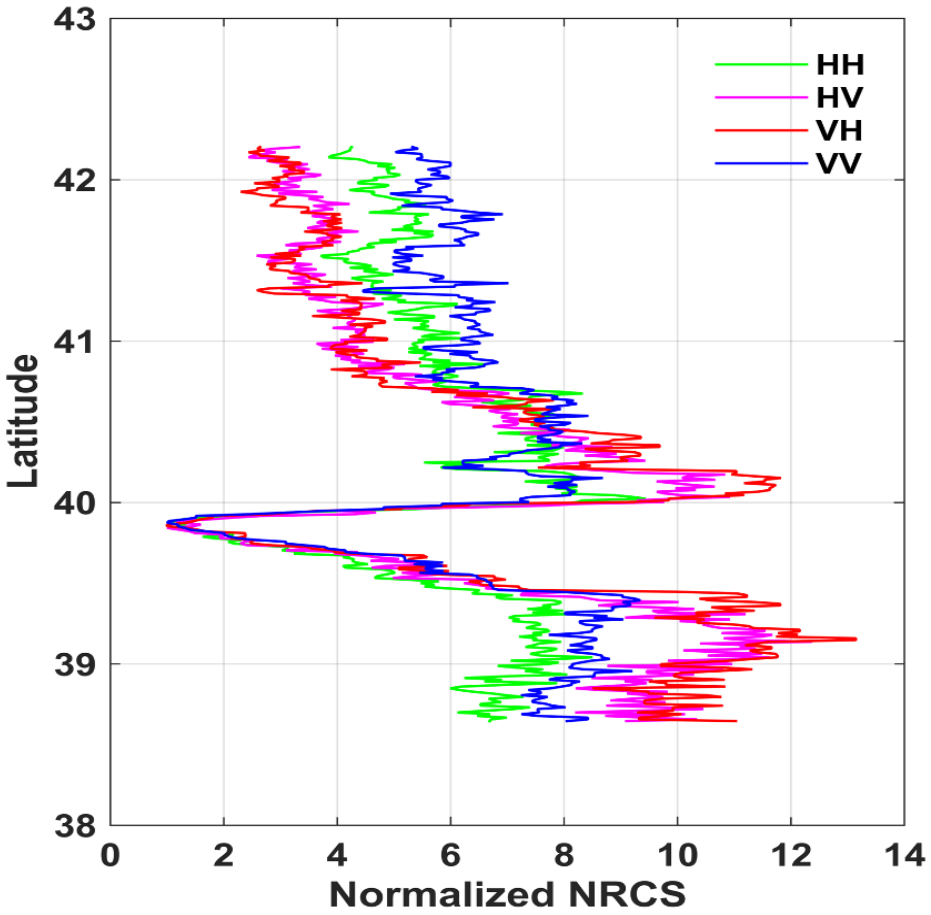




Quad-Pol NRCS vs Wind Speed

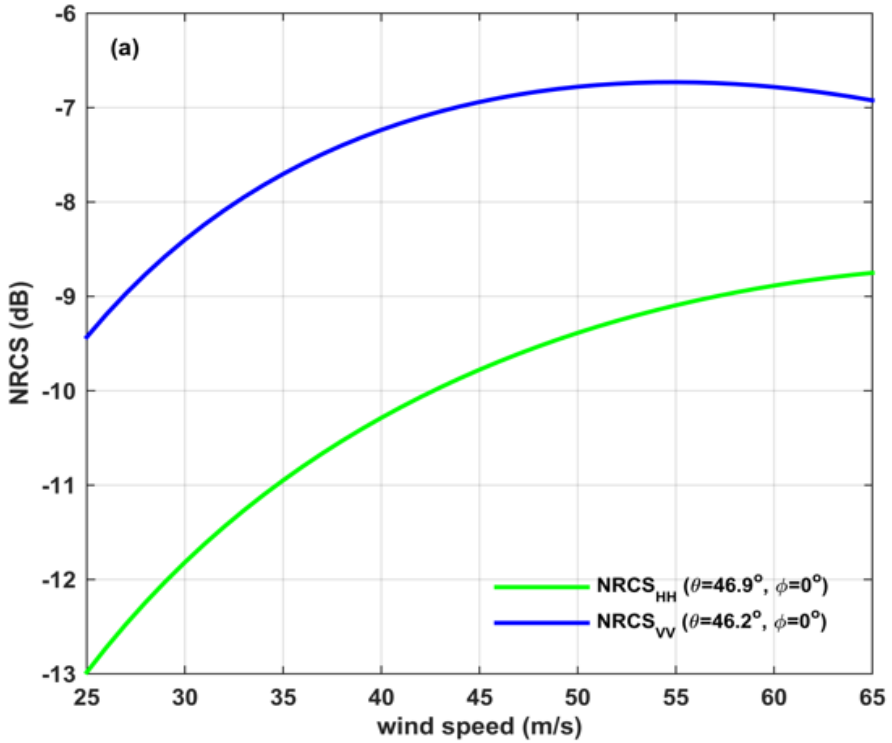
- The relative variation in HV- or VH-pol NRCS values are much lower than those of HH and VV in hurricane periphery regions. This is due to the fact that VV and HH measurements have higher signal-to-noise ratios than HV and VH in these areas (low wind speed).

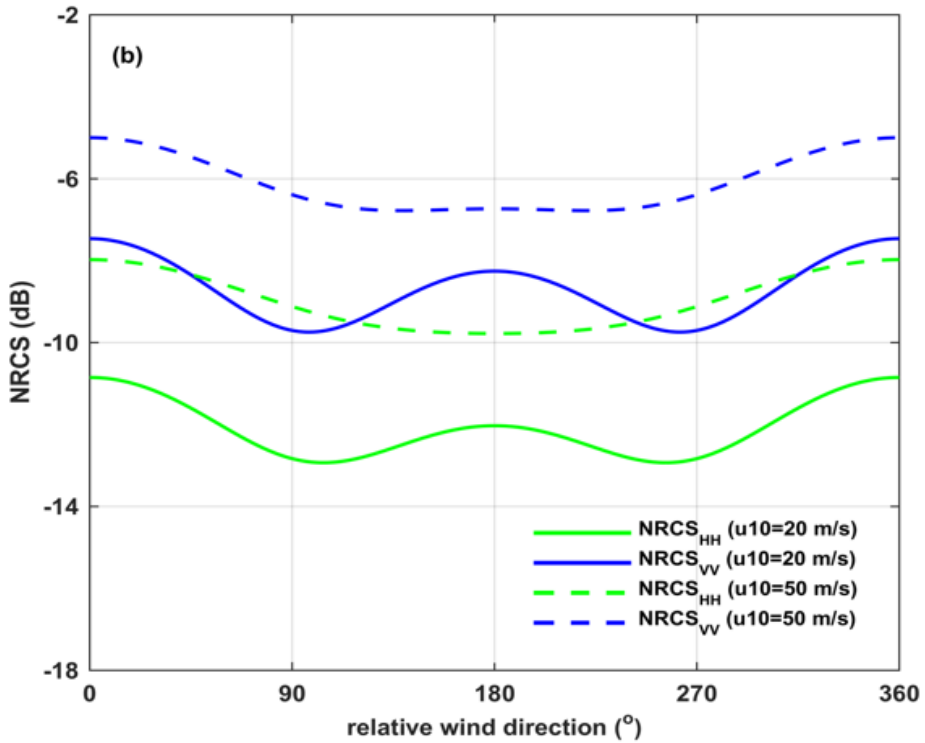




Quad-Pol NRCS vs Wind Speed

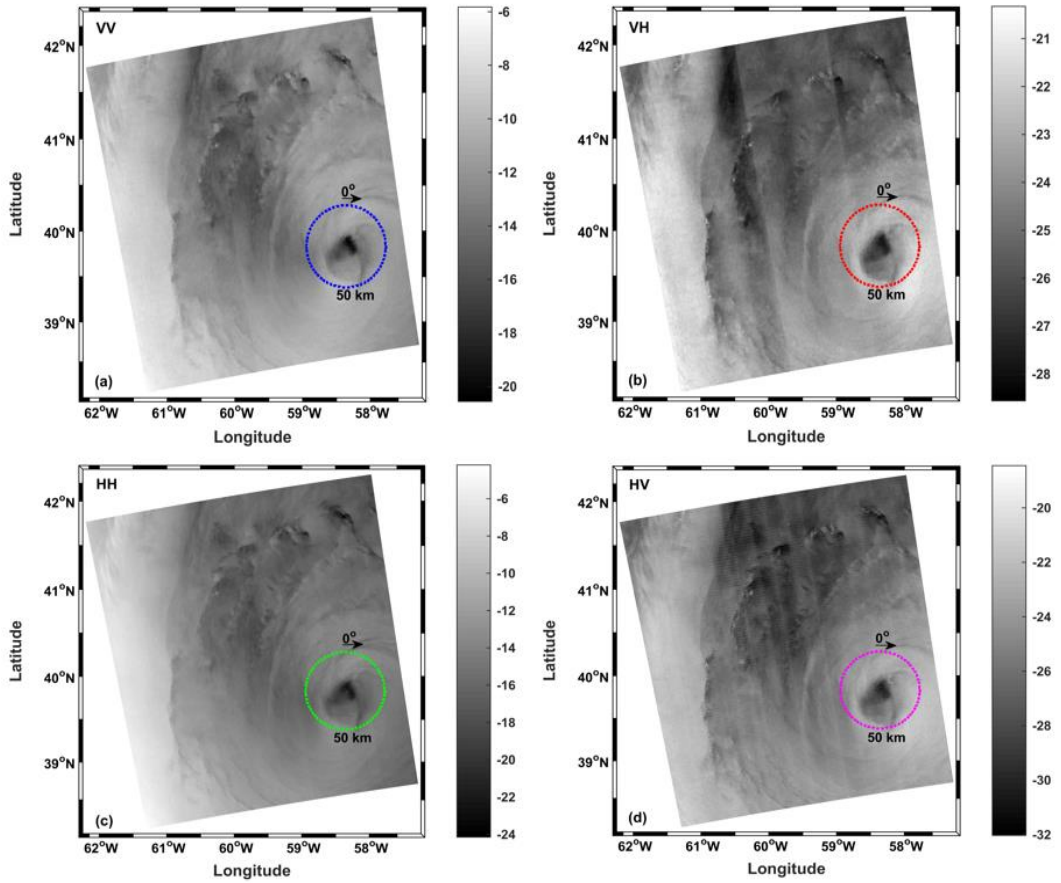
- HH- and VV-pol NRCS for wind speeds ranging from 25 to 65 m/s are estimated, using the C-band high wind speed geophysical model function (GMF) as derived from airborne observations in hurricanes.
- HH-pol NRCS values continue to increase with increasing wind speeds, whereas NRCS at VV-pol tends to flatten.
- The slope of the HH-pol NRCS is larger than that of the VV-pol NRCS, suggesting that HH is more sensitive to high wind speed than VV.

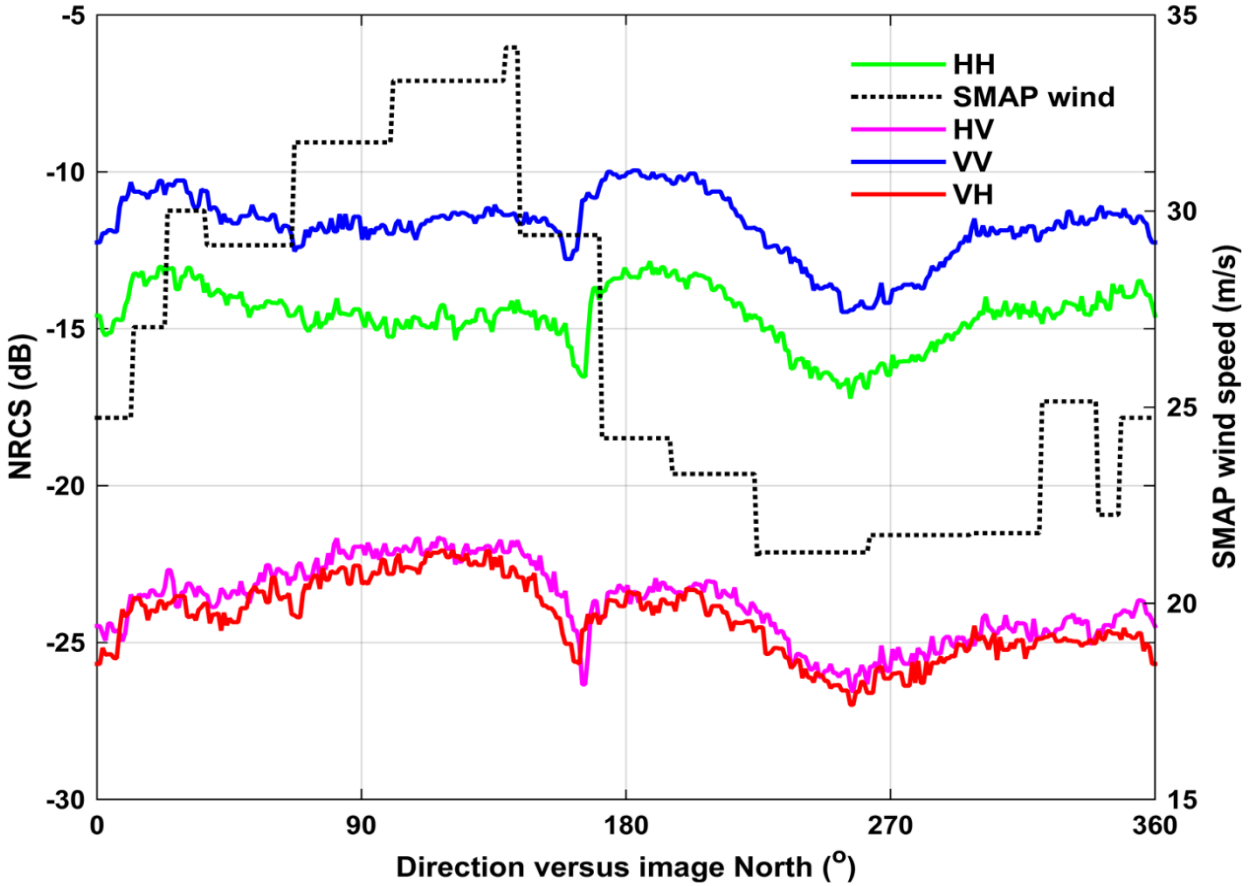




Quad-Pol NRCS vs Azimuth

- Quad-polarized NRCS exhibit wind direction dependence (harmonic behavior) for azimuth angles ranging between 180 deg and 360 deg and wind speed between 22 and 25 m/s. Compared with HV or VH, the amplitudes of the azimuth modulation of HH and VV are larger.

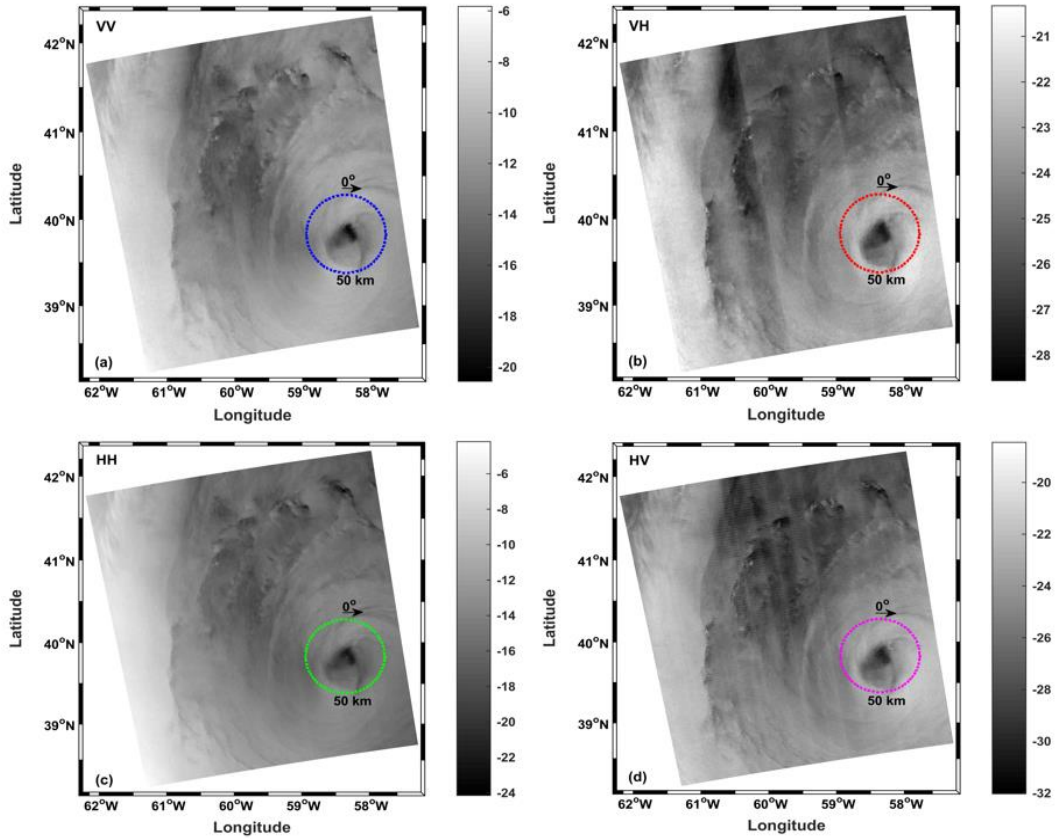


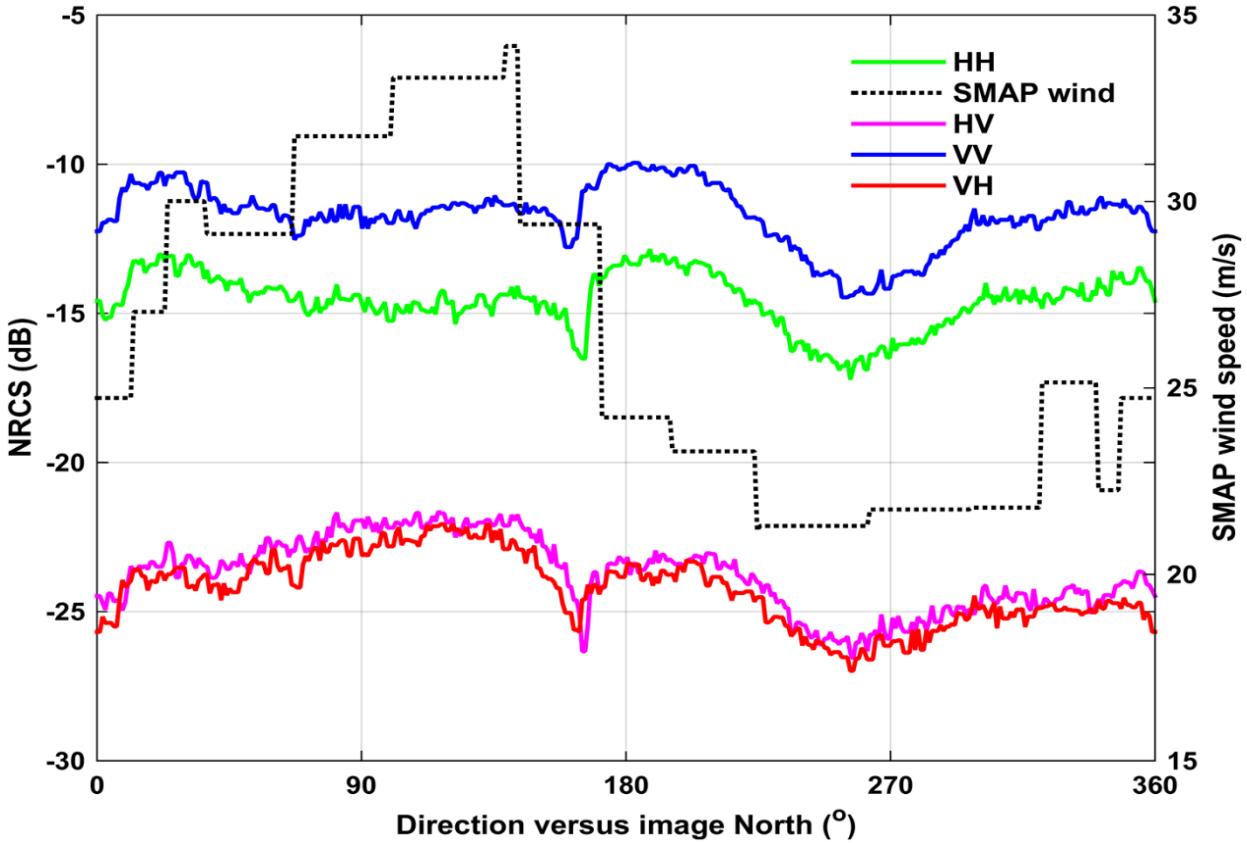


Quad-Pol NRCS vs Azimuth

- Quad-polarized NRCS decrease as azimuth angles vary between 180 and 225 deg which could result from the combination of wind speeds reductions, and wind direction changes from downwind to crosswind.

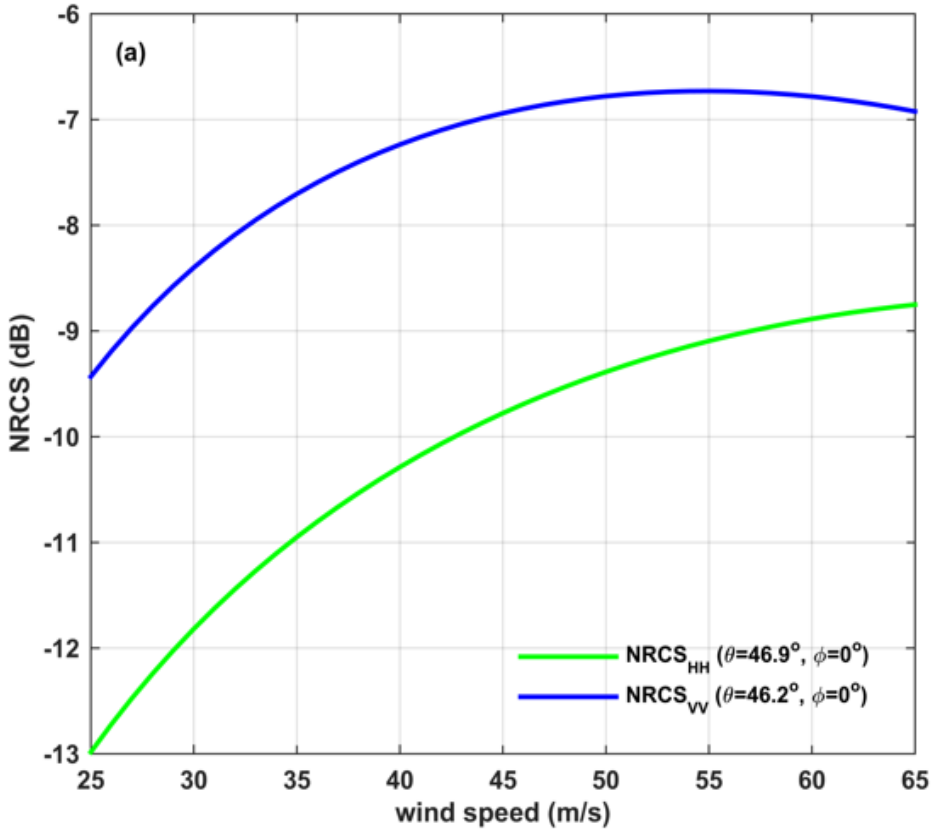
- The wind direction dependences of co- and cross-pol NRCS become weak with increasing wind speeds.

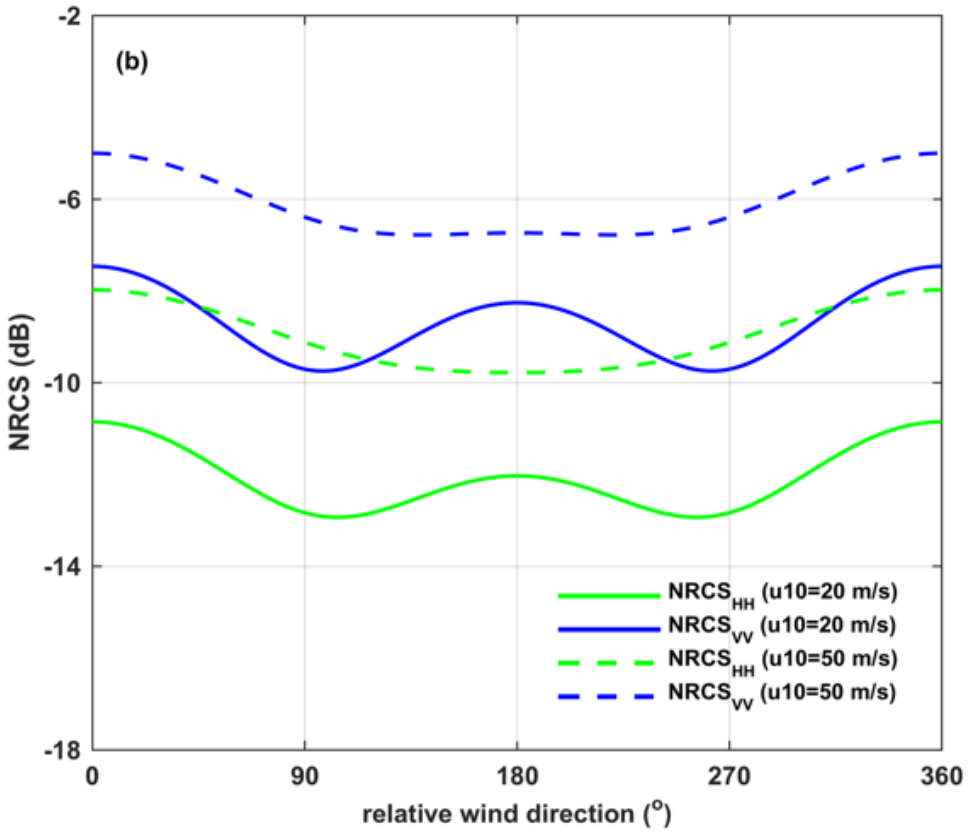




Quad-Pol NRCS vs Azimuth

- We also estimate HH- and VV-pol NRCS values with the C-band high wind speed GMF.
- NRCS at HH- and VV-pol appears to be independent of wind direction when wind speeds increase from 20 to 50 m/s. These estimates are consistent with the observations from RCM and RADARSAT-2.

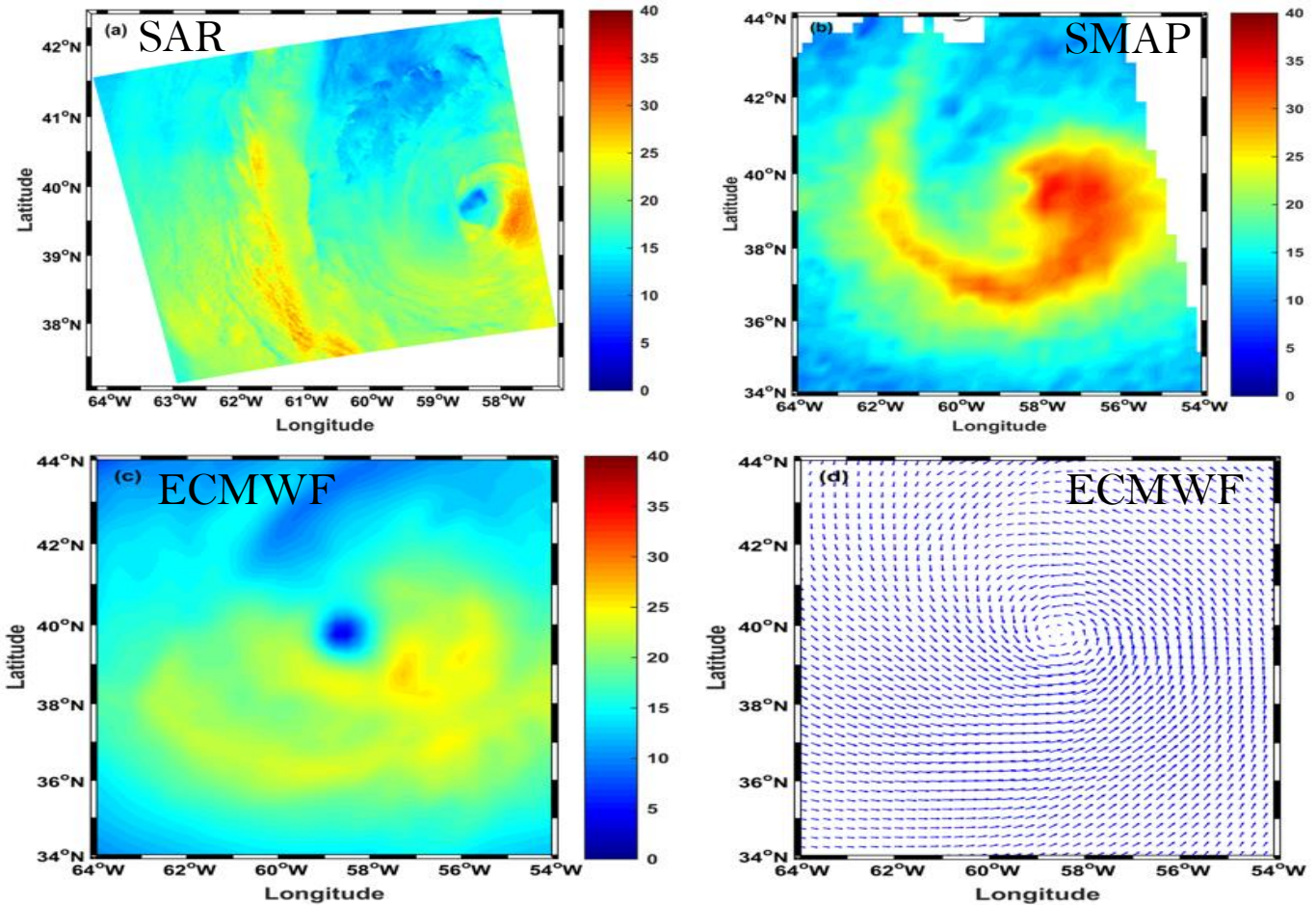




Hurricane Wind Fields & Rain Rates

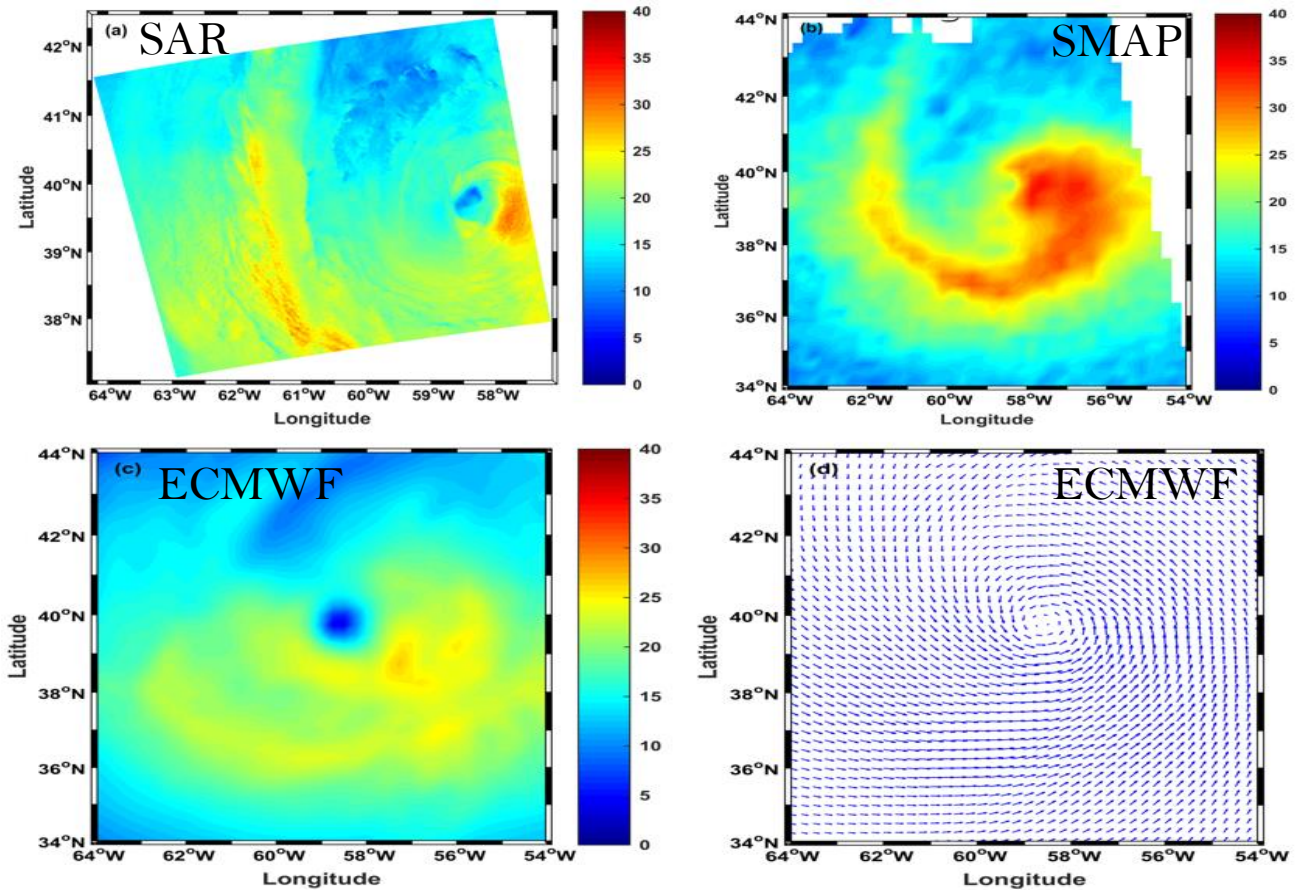
- We use RADARSAT-2 VV- and VH-pol SAR images to retrieve ocean surface wind speeds in Hurricane Epsilon.

- SAR-derived high-solution (3 km) wind speeds clearly resolve the hurricane eye structure and exhibit the wind speed variations between the eye and eyewall.



Hurricane Wind Fields & Rain Rates

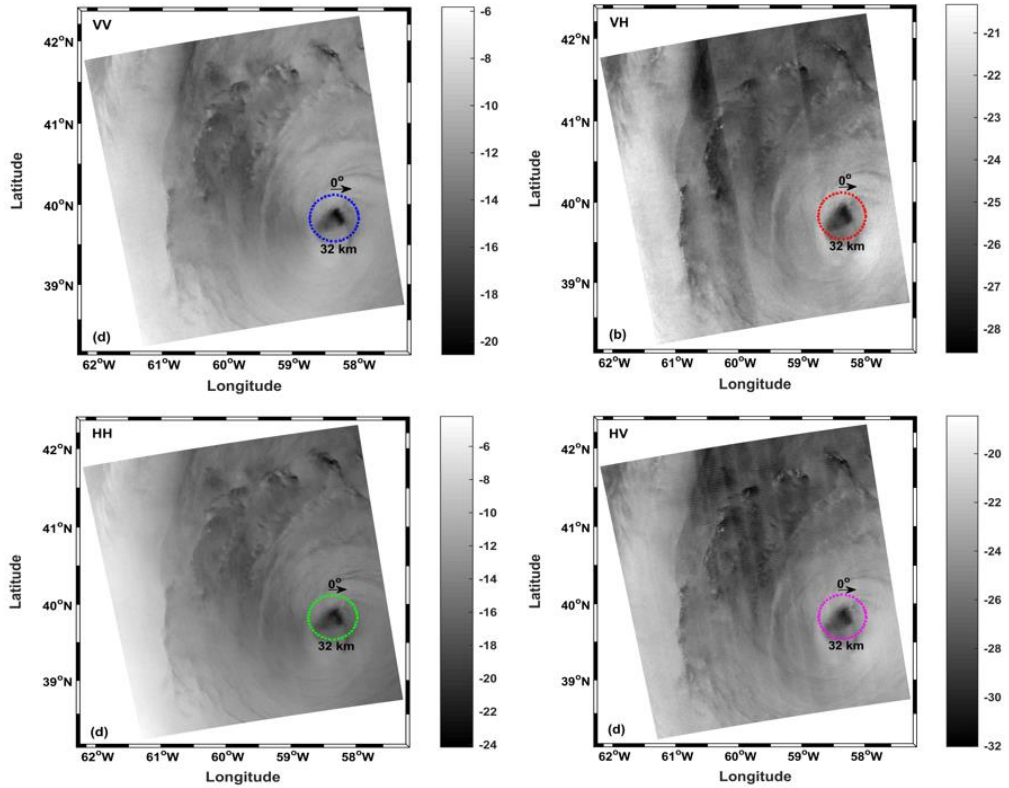
- SAR and SMAP wind fields both exhibit the asymmetric structure of Hurricane Epsilon, and the maximum wind speeds from these two sensors are in good agreement (32.3 m/s & 34.6 m/s).
- The location of the hurricane eye from ECMWF ERA5 wind field is very close to that from SAR, while the maximum wind speed (26.6 m/s) was significantly underestimated compared to best-track report (33.4 m/s).

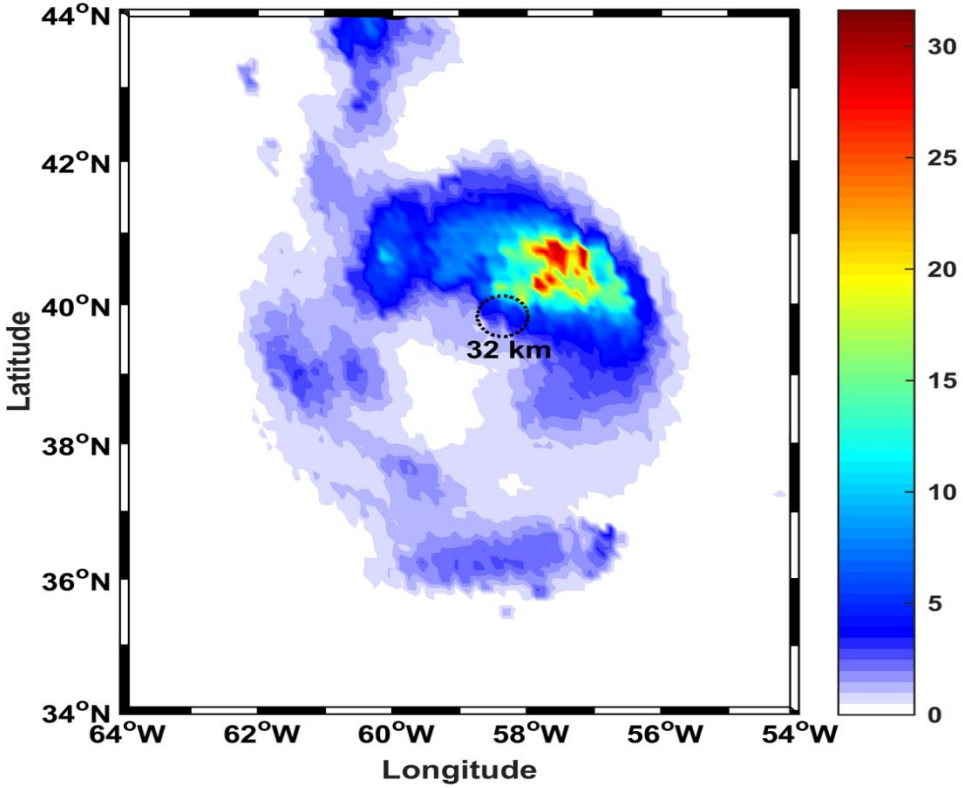


Hurricane Wind Fields & Rain Rates

- To investigate the rain effects on quad-pol NRCS observations, we select "circle transect" with 32-km radius from the hurricane eye. This radial distance is chosen because circles can pass through dark spiral-shaped features associated with the rain bands.

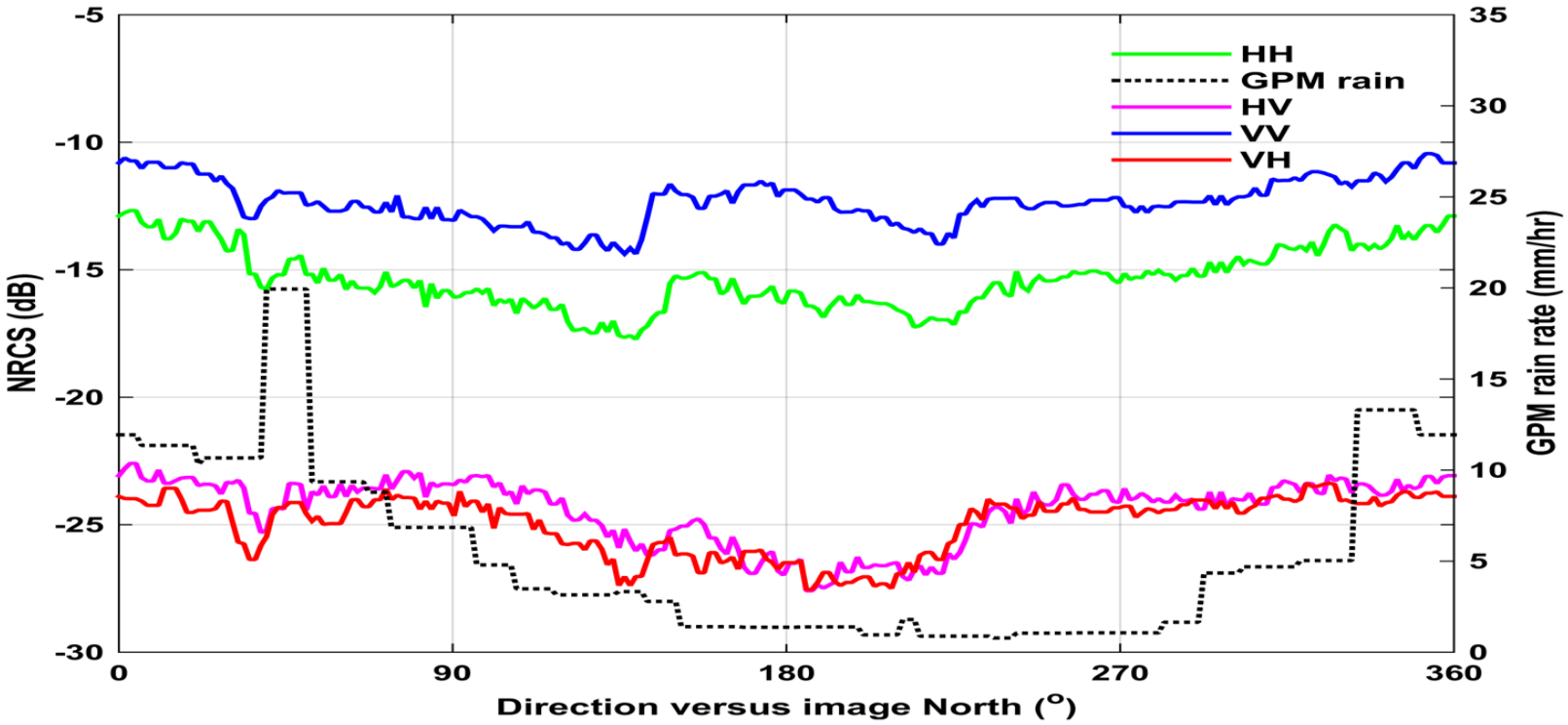
- The time difference between SAR (RS-2 & RCM) observations and GPM rain rates are very short, only 4 and 7 minutes. The spatial and temporal resolutions of GPM rain rates are 0.1 deg and 30 minutes, respectively.





Hurricane Wind Fields & Rain Rates

- Quad-polarized NRCS are significantly attenuated by rain rates of about 20 mm/hr. The rain-induced attenuation is about 1.7 dB for HH and VV and 2.1 dB for HV and VH, respectively.
- This attenuation is likely caused by a combination of effects, rain-induced damping of surface capillary waves and reduction of radar signal in the atmosphere.
- The attenuation of short gravity waves may be caused by enhanced turbulence or by wave dissipation through small-scale breaking, which reduces the surface roughness and hence the momentum transfer to longer waves.



Summary & Conclusions

- The wide swath fully polarimetric SAR observations over a hurricane are first obtained by C-band RCM and RADARSAT-2 virtual constellation within very short time interval.

- The denoised HV and VH-pol NRCS have great consistency. They are more sensitive to wind speeds and less sensitive to incidence angles and wind directions than those at HH and VV for hurricane forced winds.

- A direct comparison of HV and VH-pol images allows to investigate the variations in high-resolution radar backscattering within the hurricane vortex, thereby revealing the most dynamical areas.

- An asymmetric dynamic is observed around the eye of Hurricane Epsilon, based on positive and negative differences (VH-HV) in the western and eastern parts of the eye.

Summary & Conclusions

- The impacts of rain on quad-polarized NRCS are also examined using collocated rain rates from GPM and wind speeds from SMAP.

- Significant rain-induced NRCS attenuations are about 1.7 dB for HH and VV, and 2.2 dB for HV and VH, when the rain rate is 20 mm/hr. These attenuations are associated with rain-induced turbulence and atmospheric absorption.

- RCM and RADARSAT-2 hurricane synergistic observations provide a unique analysis of synoptic and joint C-band measurements of the ocean surface in quad-polarization; this is noteworthy in view of preparations for the next generation of dual-polarization scatterometer (SCA) onboard second-generation meteorological operational satellite program (MetOp-SG).

Reference

Zhang, B*., Mouche, A., Perrie, W. (2022). First quasi-synchronous hurricane quad-polarization observations by C-band Radar Constellation Mission and RADARSAT-2, *IEEE Trans. Geosci. Remote Sens.*, vol. 60, pp.1-10, doi:10.1109/TGRS.2022.3161002.