TC observations from Synthetic Aperture Radar: short term perspectives

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Content

- TC Spaceborne observations
- CYMS presentation
- Currently available SAR-based observations over TC and limitations
- Short terms perspectives for improving these observations

IPCC:

Modeling studies project a likely **increase** in peak wind intensity and near-storm precipitation in **future tropical cyclones** [...] and an **increase** in the frequency of the **most intense storms.**

20%

Tropical Cyclones represent around 20% of the damage and casualties caused by natural hazards, all phenomena included.

Sentinel-1

is the only mission able to provide near real-time and high-resolution observations of tropical cyclones

Available spaceborne wind observations over TC

	Product pixel size	Acquisition scenario	Swath	Data latency	Wind validity	Variables
Radiometers: e.g. SMOS / SMAP / AMSR-2	~30-40 km	Systematic acquisitions	1000 - 1500 km	~4H	No high wind saturation	- Wind speed - Wind radii - MSW
Scatterometers: e.g. ASCAT, HY-2B, CFOSAT, SCATSAT	~12-25km	Systematic acquisitions	~ 1000 km	~4H	<20-25m/s	Wind speed & direction
GNSS-R: CYGNSS	~20-40 km	Systematic acquisitions	NA	no NRT	No high wind saturation	- Wind speed - Wind radii
SAR (C-band dual-pol): e.g. Sentinel-1, RadarSat-2,	1 km	- No **TC obs. with default S1 acquisition strategy** - On-demand acquisitions based on TC forecast track successfully **tested**, => 200 TC eyes caught by S1 in 4 years => Can it be made operational?	250 – 400 km	NRT 10 min, NRT 1-3H, or 24H	No high wind saturation	- Wind speed & direction - Wind radii - Maximum Sustained Wind speed (MSW) - Inner core: TC eye + eye wall

Connected talks in this session:

D2489 | EGU2020-19174 - An In-situ Reference for High and Extreme Winds - Ad Stoffelen et al.

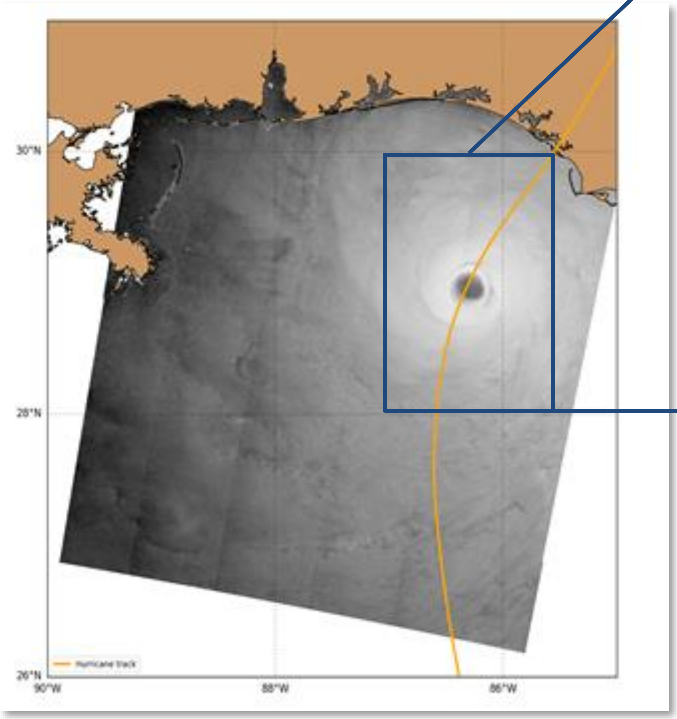
D2515 | EGU2020-9628 - On the use of cross-polarized SAR and GPS-sonde measurements for wind speed retrieval in tropical cyclones - Poplavsky et al.

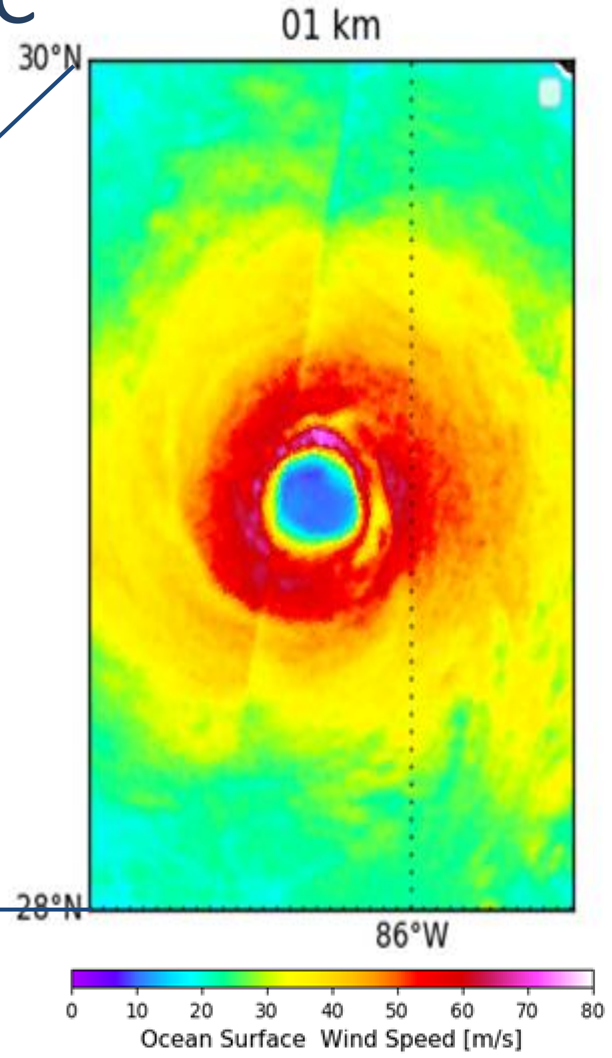
SAR-based ocean surface wind speed over TC

The combination of VV and VH channels as measured by SAR at very high resolution allows to provide Ocean Surface Wind measurements from space

- at high resolution

S1A – 2018/10/10
Michael

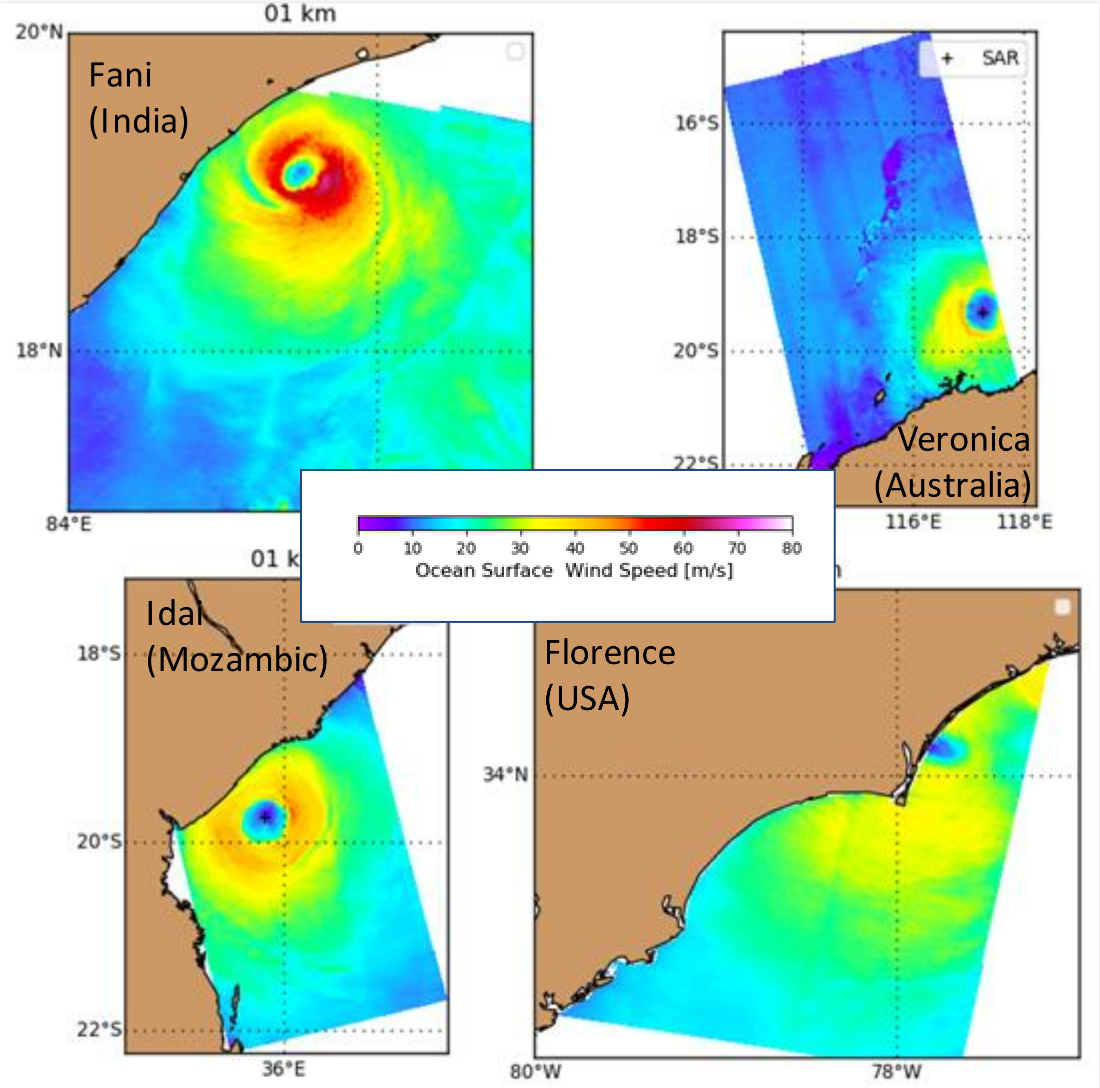




SAR-based ocean surface wind speed over TC

The combination of VV and VH channels as measured by SAR at very high resolution allows to provide Ocean Surface Wind measurements from space

- at high resolution
- in coastal areas (unique capability vs. other spaceborne sensors)



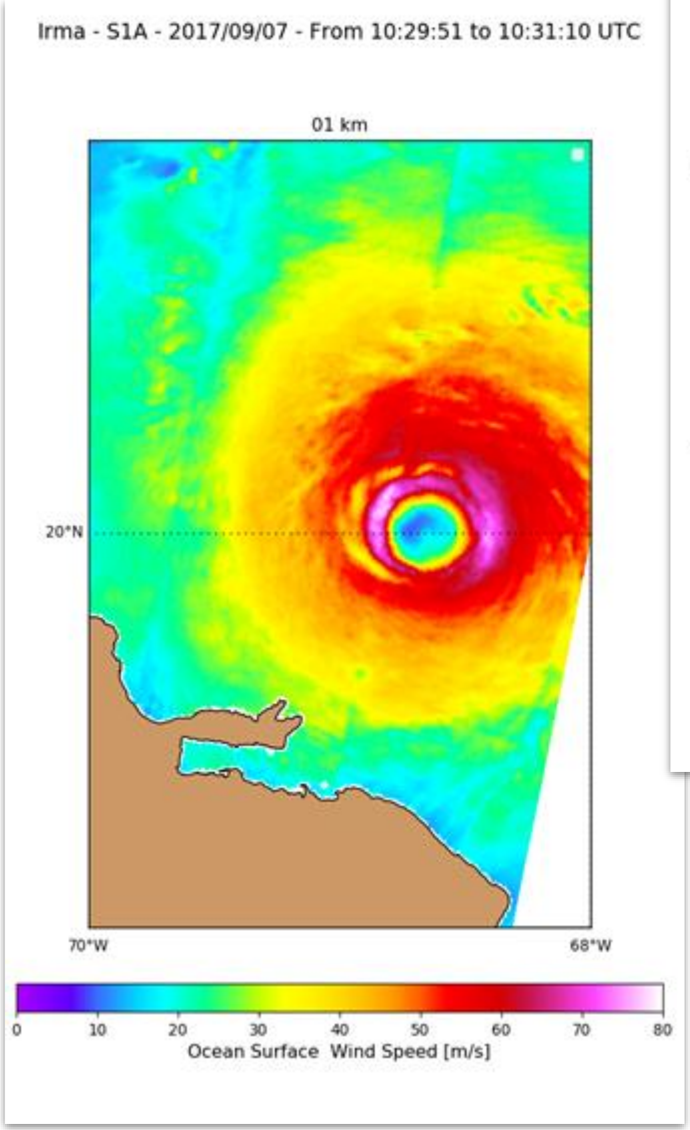
SAR-based ocean surface wind speed over TC

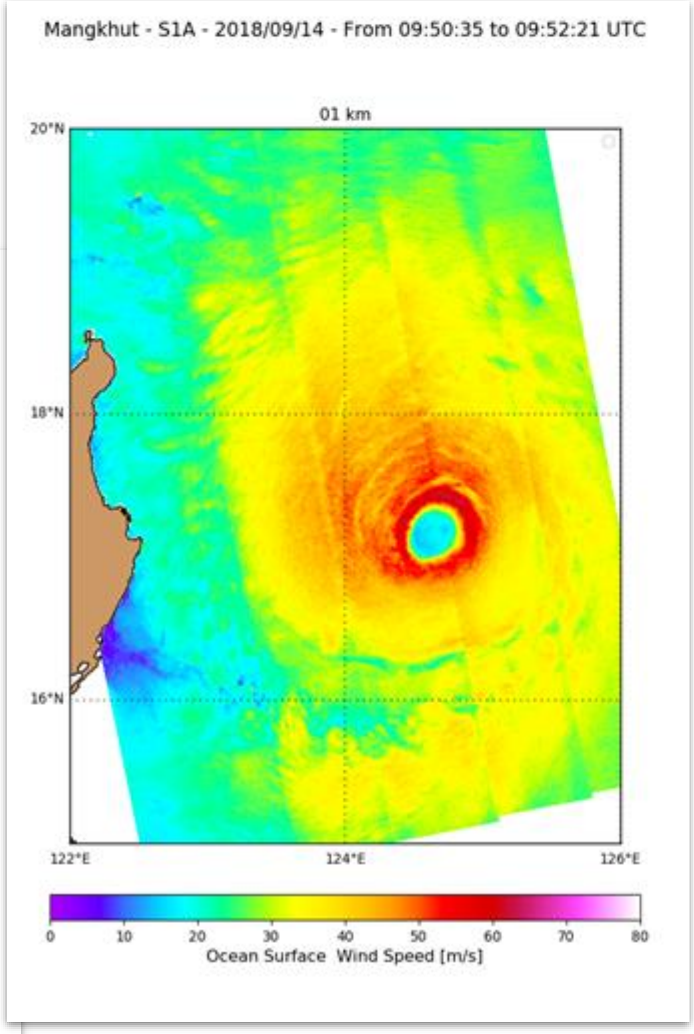
The combination of VV and VH channels as measured by SAR at very high resolution allows to provide Ocean Surface Wind measurements from space

- at high resolution
- in coastal areas (unique capability vs. other spaceborne sensors)
- over extreme Hurricane

Examples of category-5 on the Saffir-Simpson scale:

- **Irma** TC, Sept. 7 2017.
- **Mangkhut** TC, Sept. 14 2018.



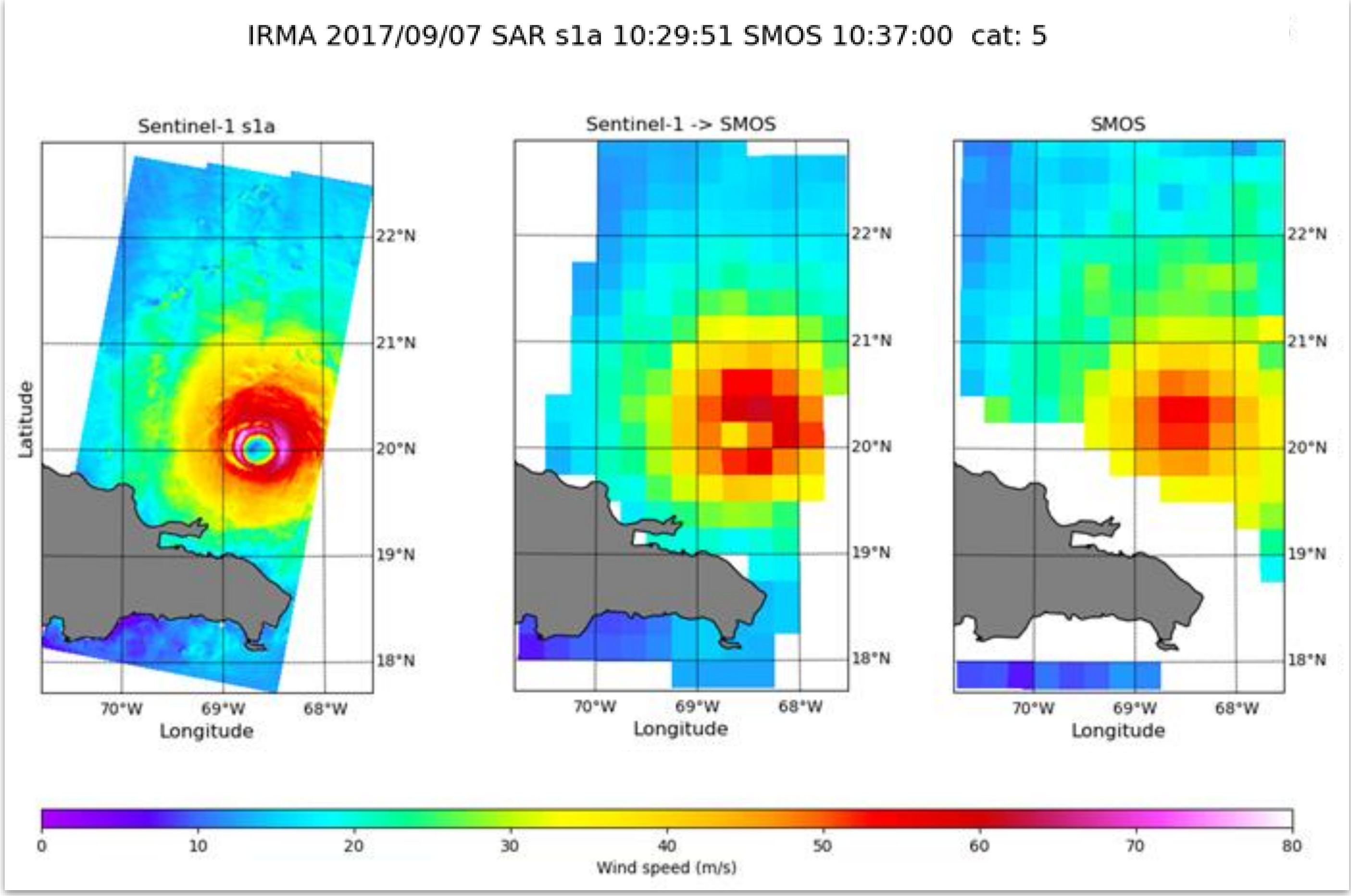


SAR-based ocean surface wind speed over TC

The combination of VV and VH channels as measured by SAR at very high resolution allows to provide Ocean Surface Wind measurements from space

- at high resolution
- in coastal areas (unique capability vs. other spaceborne sensors)
- over extreme Hurricane
- bringing synergies with other sensors (airborne and spaceborne)

When degraded at medium resolution, SMOS and SAR are in good agreement but TC eye cannot be described anymore.



CYMS in a nutshell

Sentinel-1: A Copernicus mission could now offer operational TC monitoring services

- Demonstration of the “Satellite on demand” : A unique acquisition strategy developed for TC observations successfully tested with ESA

- A potential new Copernicus service: This innovative TC acquisition strategy could be developed and operated on a daily basis within the Copernicus Program

    - well-identified applications (emergency response, TC forecast, …),

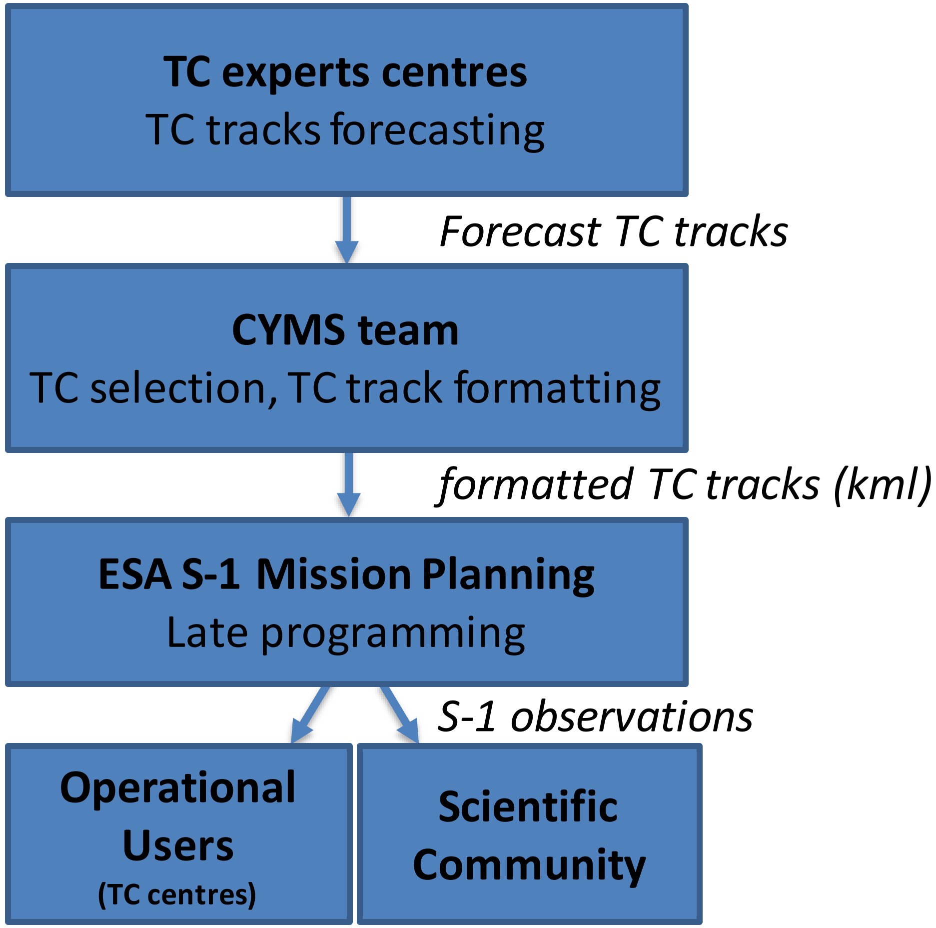
    - well-identified users, although demonstrated over a limited dataset (coverage, sampling),

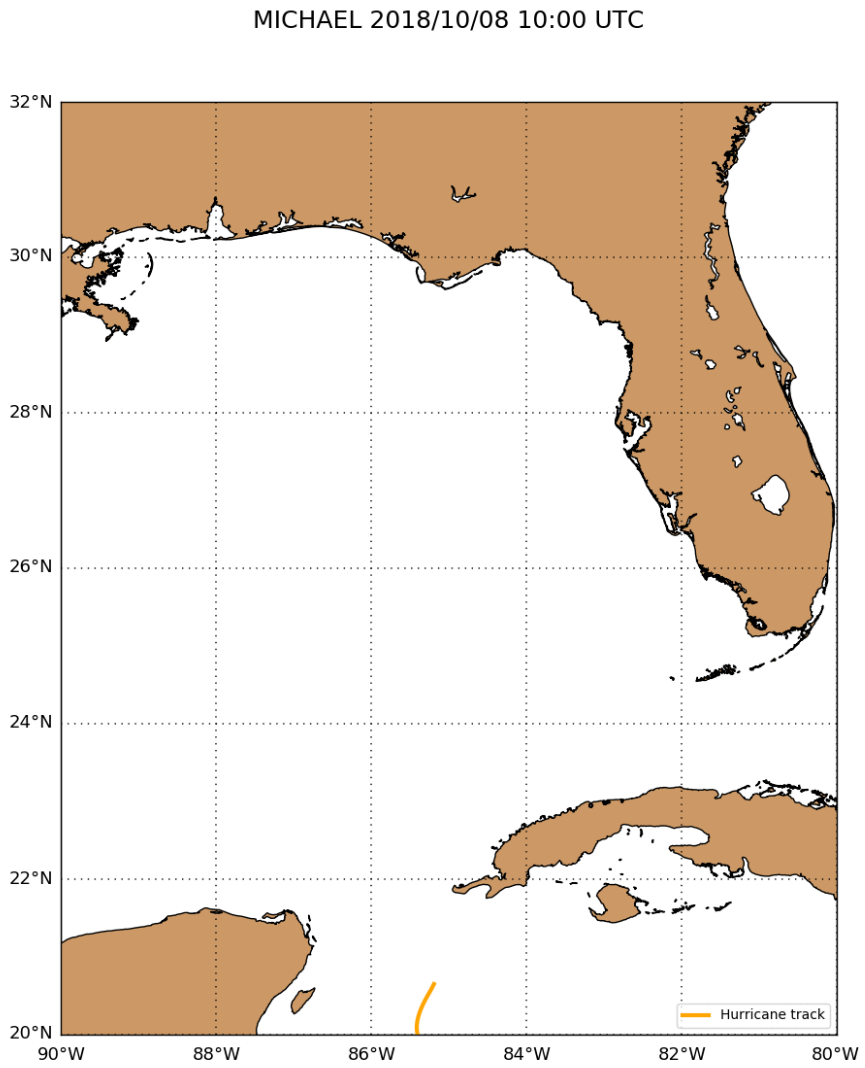
    - long-term operations of the S-1 constellation.

- A service in line with European goals: This new service concurs to Sentinel-1 mission to “help manage our environment, understand and tackle the effects of climate change, and safeguard everyday lives.”

Strategy to acquire SAR images over TC

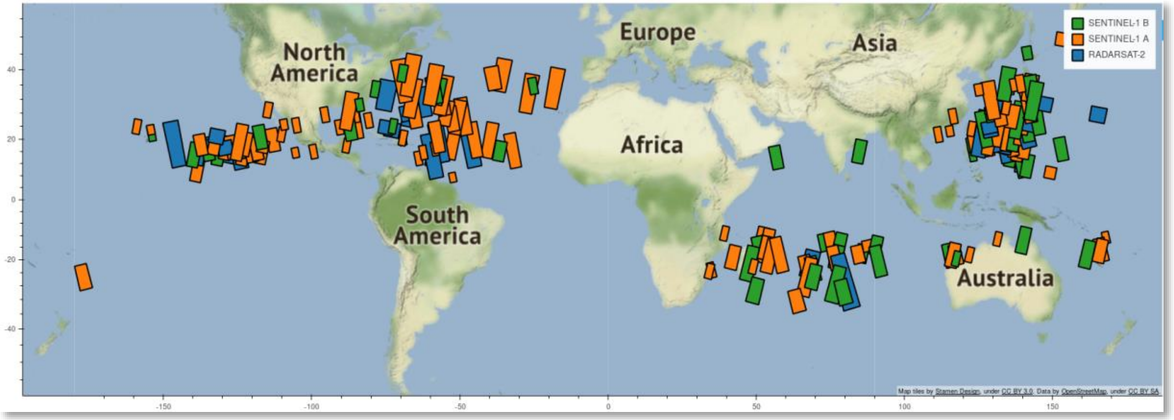
- CYMS manage the first operational campaign maximizing ocean surface observations at very high resolution over extreme events
  - Sentinel-1 Hurricane Observation Campaign (SHOC)
- Methodology inspired by the Canadian Hurricane Watch programme.





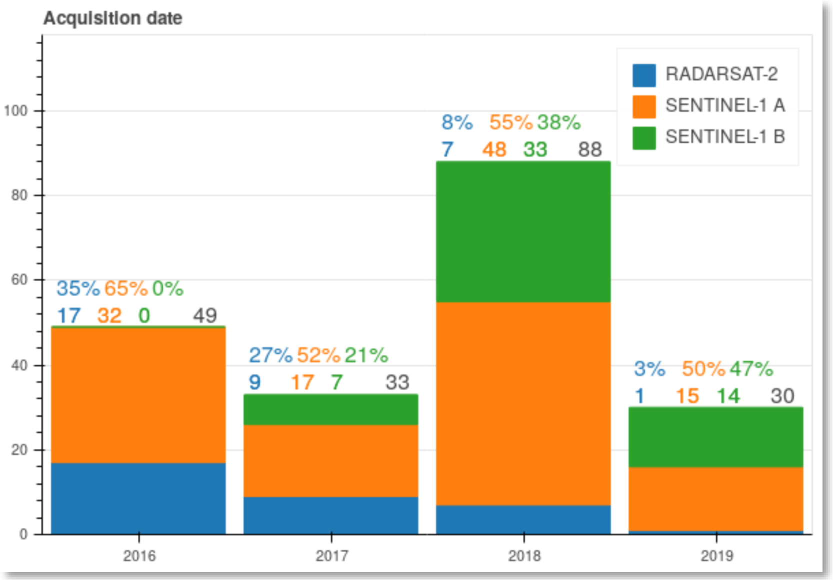
SHOC campaigns (2016-2019)

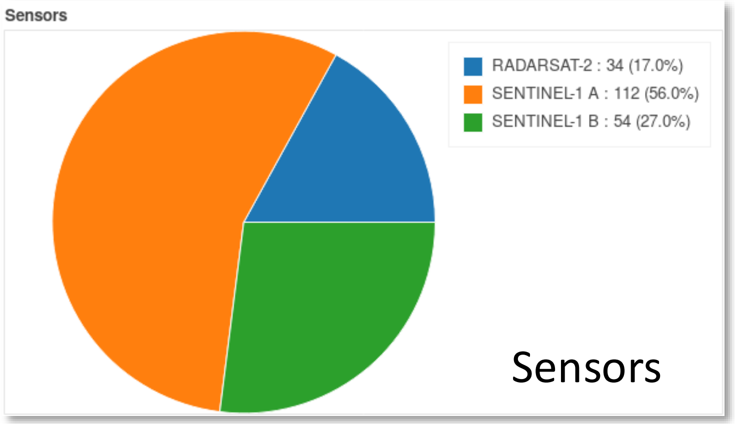
- SHOC does already include more than 200 acquisitions over TC eyes.

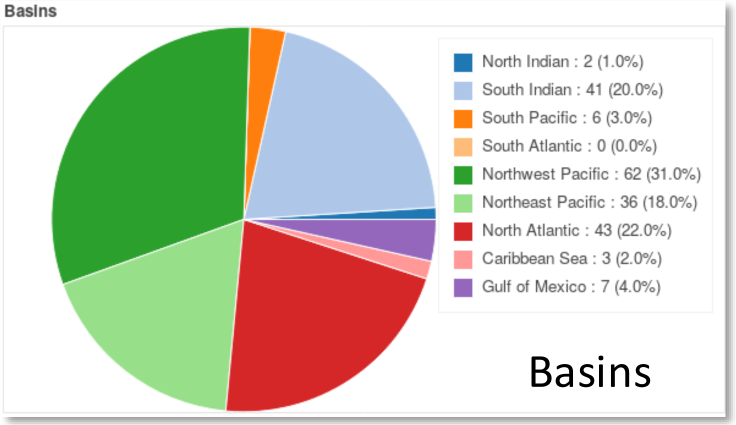


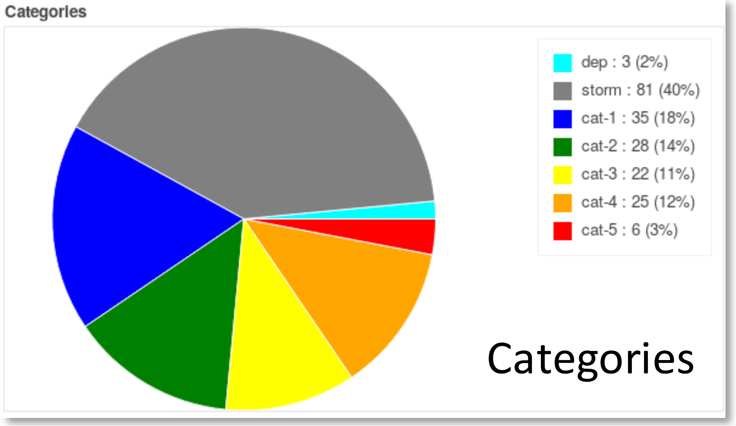
- Up to 50 % of Sentinel-1 planned acquisitions catch TC eyes.

- 80 TC monitored by Sentinel-1









CYMS in a nutshell

ESA-CYMS - a 1-year ESA funded project – started in 02/2020

Objectives:

1. Scale up an operational solution based on SAR images recorded through Sentinel-1, with a SHOC 2020 campaign
2. Prepare its integration into a Copernicus Service.
3. Build and process using state-of-the-art wind algorithms a unique database of TC SAR observations

OCEAN SURFACE WIND FIELD PRODUCTS

Sentinel-1-derived ocean surface wind field products acquired along hurricane forecast tracks:

Near real-time delivery for demonstrating operational use for the upcoming hurricane season

Reprocessing archive center delivering a complete, state-of-the-art and homogeneous dataset since the Sentinel-1 launch.

Foster developments for future Tropical Cyclone seasons and answer fundamental questions on Tropical Cyclone physical processes.

END-USER UPTAKE

Customized, validated and fully acknowledged Tropical Cyclone products

Standardized, interoperable and harmonized service

A SINGLE INTEGRATED PORTAL

WebGIS platform and archive center

High-level service presentation for the general public & decision-makers

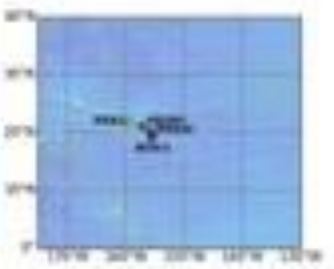
Near real-time information

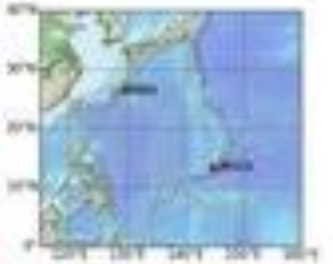
Documentation & selected publications

Rain impact

- Currently, no pre-processing of S-1 data in order to mask phenomena that are not related to the sea surface and/or neutral wind:
  - atmospheric (fronts, rain cells)
  - oceanic (internal waves, slicks, front)

  => Both appear as inhomogeneous regions
- An heterogeneity mask implemented from [Koch 2004] is used to identify those unusable pixels.
- Based on this method, an enhanced version is proposed with internal parameters optimized for EW and IW products using both HR/MR (High and Medium Resolution) and WV products.

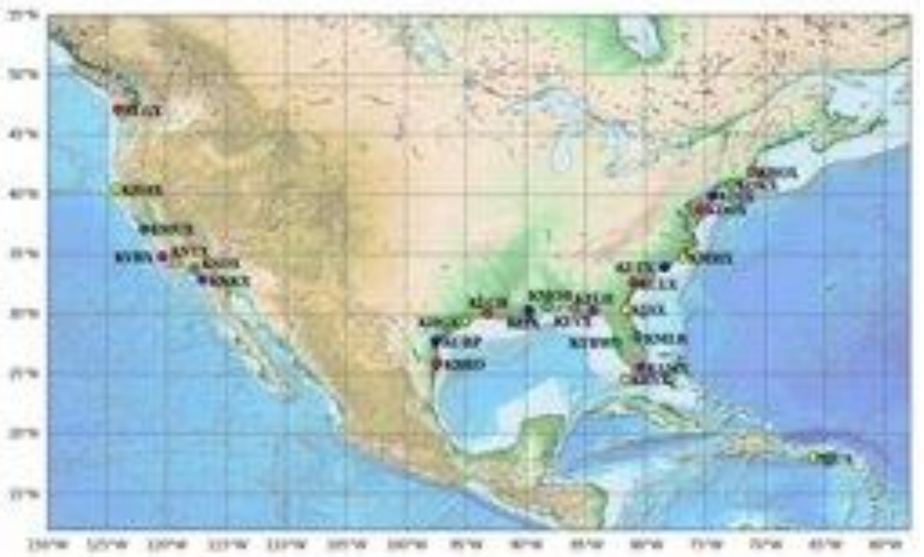




Reference dataset:

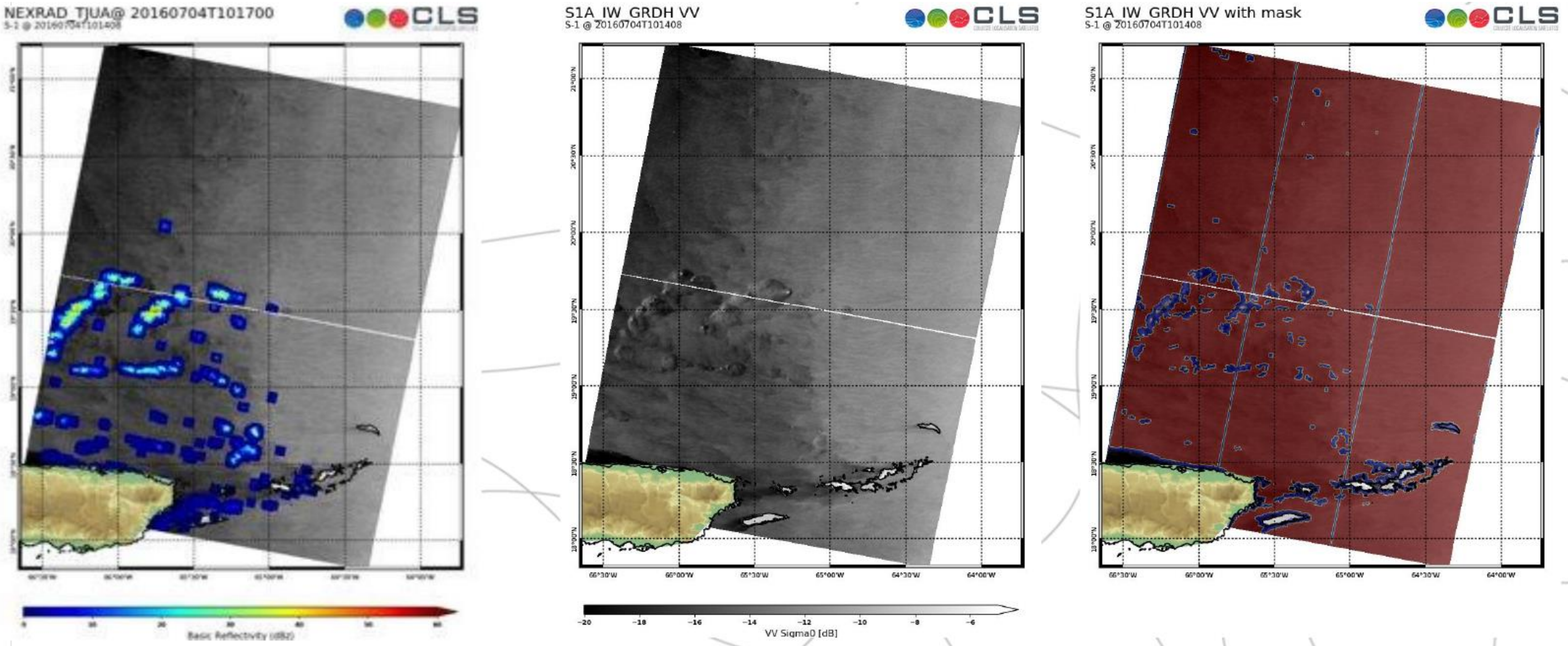
Next Generation Weather Radar (NEXRAD): 159 S-band high-resolution weather radars in USA and overseas (34 coastal) with:

- Base reflectivity (1 km/ ~ 5 min), base velocity (1 km/ ~ 5 min), one-hour precipitation (0.25 km/1 hour) and hydrometeor classification (0.25 km / ~ 5 min).
- Base reflectivity is radar centered product with a radius of 460 km, obtained at the lowest elevation angle of 0.5°
- Note: Altitude of radar beam increase with increasing distance from radar center (up to 5 km near the largest radar coverage) -> effect not consider so far



=> Database of 1055 IW GRDH products collocated with range/az NexRAD base reflectivity

Rain impact – an example



Rain impact

- In [Koch 2004], 4 filters with thresholds computed at 3 different resolutions:
  - 200 m, 400 m, 800 m (IW GRDH)
  - 320, 640, 1280 m for (EW GRDM)

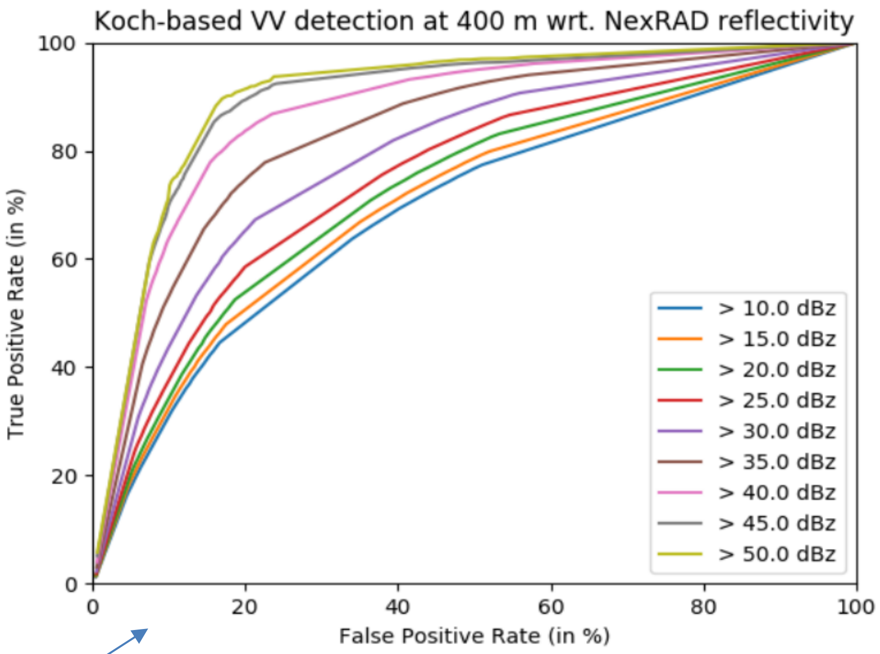
  + Post processing with morphological filter (e.g. avoid areas < 1 km2)

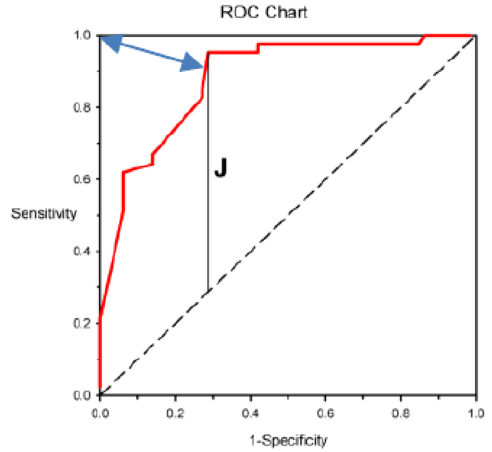
- 1. Are the thresholds on filters proposed by [Koch 2004] optimal ?
- 2. Which resolution gives the best filtering performance ?
- 3. How to consider dual-pol data ?

- Assuming rain mask given by NexRAD base reflectivity value (with various minimum thresholds)
- Depending on Koch-based threhold, different False alarms and good detection rates can be found

=> ROC curves (Receiver Operating Characteristic): to find the best trade-off between good detection and false alarms?

=> Criteria from either Youden J index maximization or top-left distance minimization: consistent thresholds found





- If one single filter: best if VV-pol @ 400 meters
- Little benefit if combined with VH-pol information @ 800 meters

Rain impact

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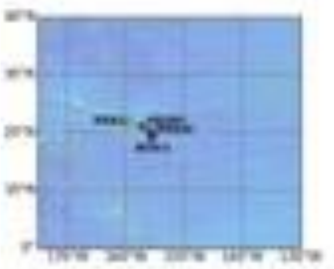

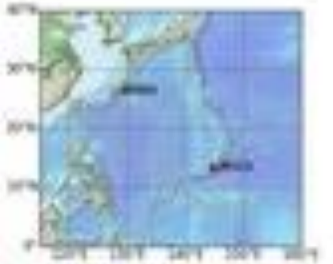

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GMF and Sensor calibration impact

- The consistency of existing C-band HV-pol GMF is investigated wrt **wind speed**

- The RMSE is important for the Bayesian scheme used in the dual-pol inversion.

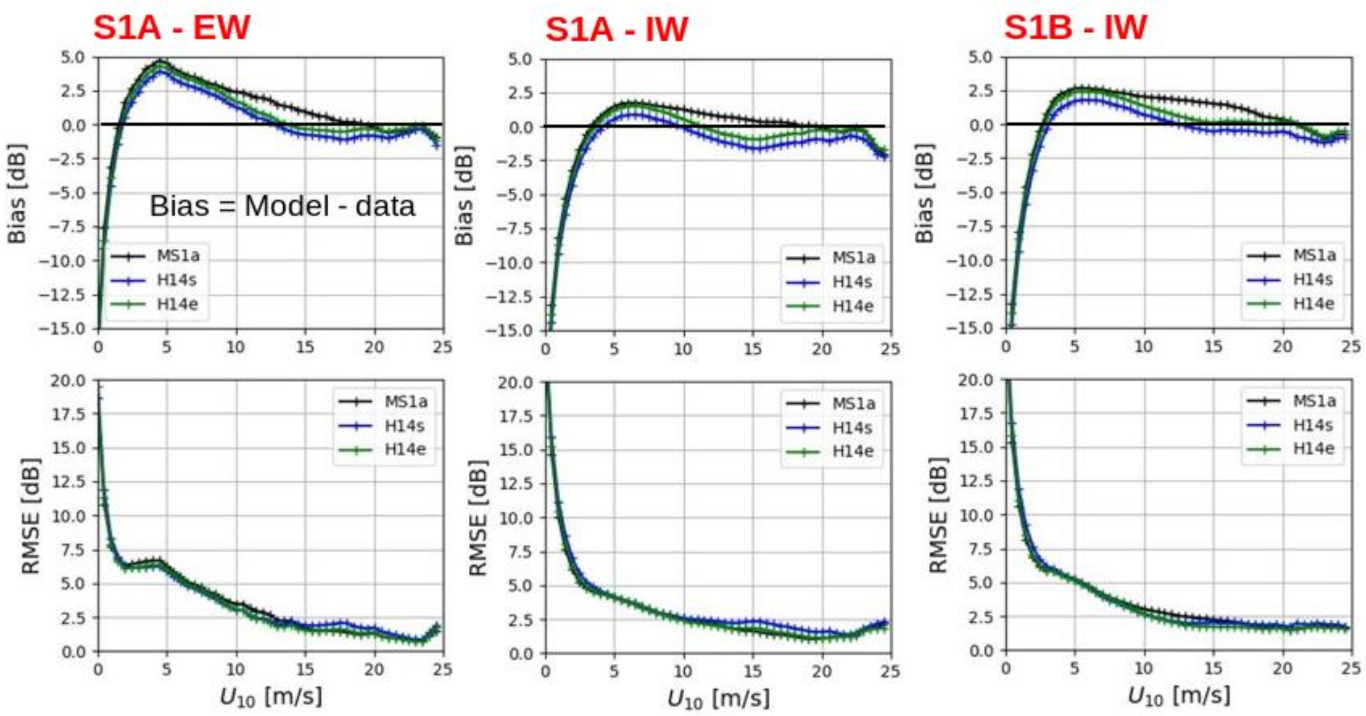
--> Precise assessment of RMSE is useful as input

- Bias varies depending on sensors (S1A vs S1B) and mode (IW vs EW)

--> need for sensor calibration

- General bias trends indicate potential issues with available GMFs (MS1a differs from H14e/s)

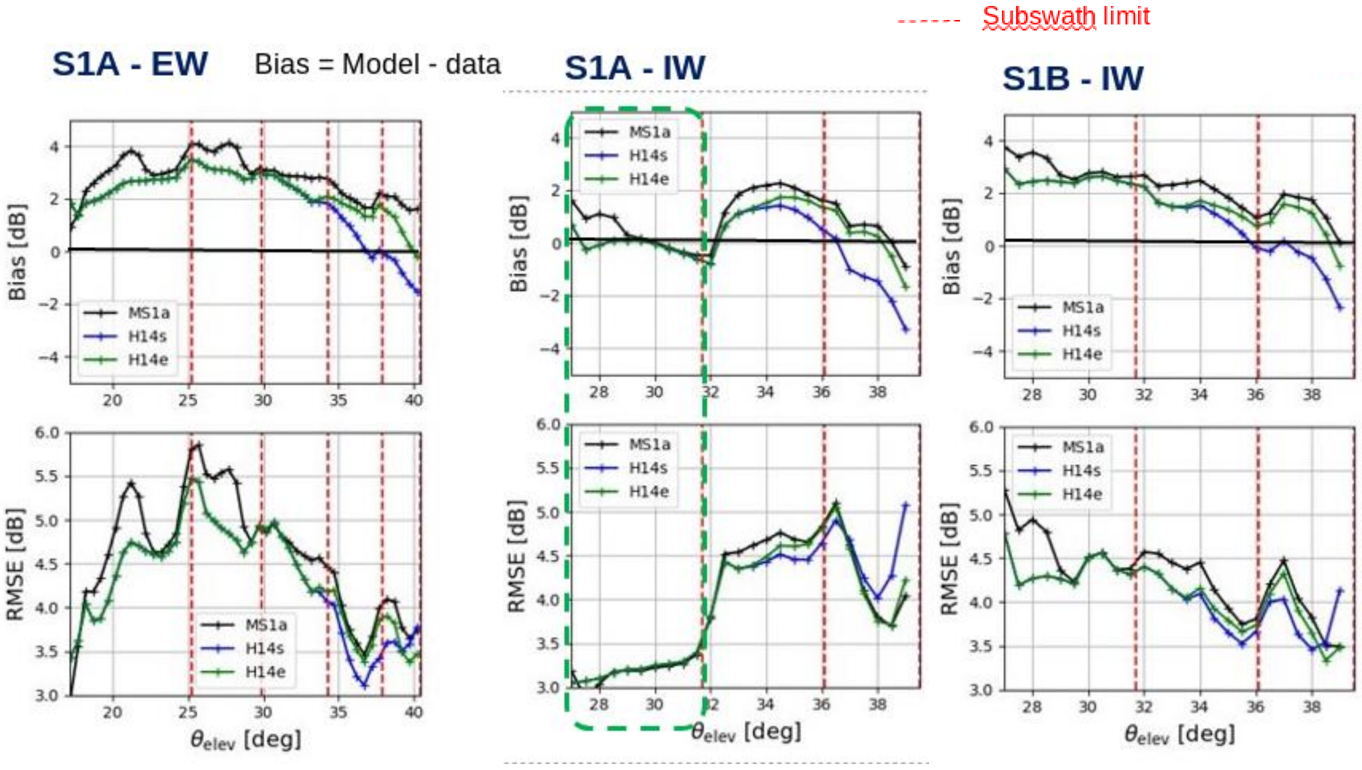
Data	Model
L2 S1A/B VH+HV sigma0 over ocean from Dec. 2019 EW and IW Winds < 20-25 m/s (for the moment)	ECMWF U_{10} interp. at 1 km + GMFs(incidence, U_{10}) -> MS1a by default (Mouche et al. 2017) -> H14s & H14e (Hwang et al. 2015)



GMF and Sensor calibration impact

- The consistency of existing C-band HV-pol GMF is investigated wrt **incidence/elevation angle**

- Subswath limits exhibit error increases, due to lower SNR
- Present diagnostic can be helpful for calibration correction
- Need for both sub-swath calibration and GMF tuning



CCP information

Odd signature of co-cross coherence

- Simulated by (Tsai et al. 2000) for SeaWind/QuickSCAT and first observed in C-band quad-pol Radarsat-2 by Zhang et al. 2012
- Even symmetry for Co and cross-pol NRCS with respect to wind direction
- Odd signature can be used for ambiguity removal and wind vector retrieval

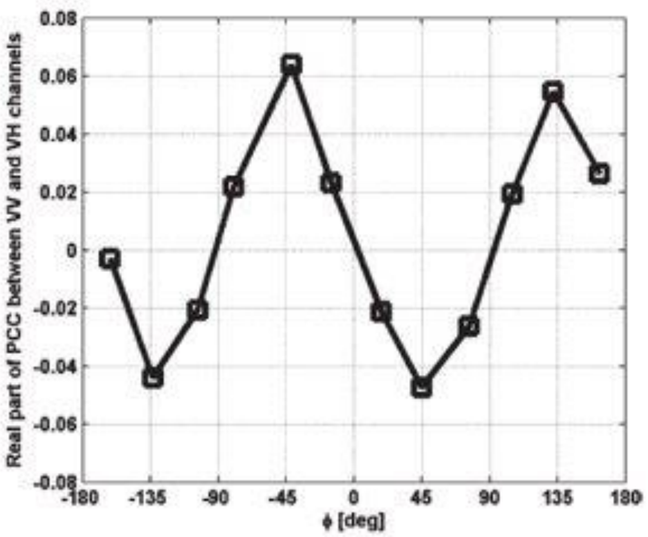


Fig. 5. RADARSAT-2 measured real part of the PCC between VV and VH channels versus relative wind direction. The average wind speed and incidence angle are 10 m/s and 35°, respectively.

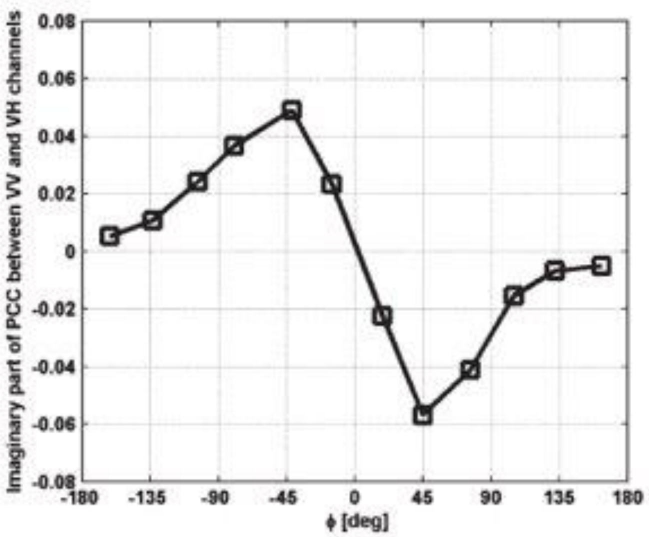


Fig. 6. RADARSAT-2 measured imaginary part of the PCC between VV and VH channels versus relative wind direction. The average wind speed and incidence angle are 10 m/s and 35°, respectively.

CCP information

Can we observe the same basic feature with Sentinel-1 data ?
Some S-1 particularities: Noise level, TOPS imaging, no polarimetric calibration…

Can we fully characterize the C-band co-cross coherence for a wide range of condition ?
Dependency on sea state? Incidence angle?

Can we define a Polarimetric Geophysical Model Function (PGMF) ?
No current C-band PGMF (see Zhang, Jiang et al. Acta Oceanol Sin. 2014 with mixed Ku- and C-band derived parameterization)

Can we assess its complementarities with CMOD and/or Doppler information ?

Can we use it in the wind field inversion scheme ?
Any benefit ?

Submitted in TGRS 2020
"Co-Cross Polarization Coherence over Sea Surface from Sentinel-1 SAR Data: Perspectives for Mission Calibration and Wind Field Retrieval" - Longepe et al.

CCP information

- A unique new calibration method has been prototyped based on:
  - Massive collocation process between SLC IW and ECMWF (about 40TB SLC processed)
  - a priori null co-cross coherence only when reflection symmetry applied (upwind/downwind)

=> Unique estimation of 3 cross-talk parameters based on wide range of observations conditions (incidence angle, wind speed)

=> Calibrated co-cross coherence (amplitude, phase, real, imaginary parts) now in agreement with previous study (e.g. RS2)

- A first version of PGMF analytical functions (real and imaginary parts) is proposed

- Complementarities between Doppler-based information (Radial velocities) and PGMF (cross wind)
  - Inversion without any a priori model seems feasible pending the joint use of CMOD + CDOP + PGMF

- First trial of wind field inversion based on PGMF
  - In the absence of calibrated Doppler from S-1, with a priori information from meteorological model (but with high uncertainties)

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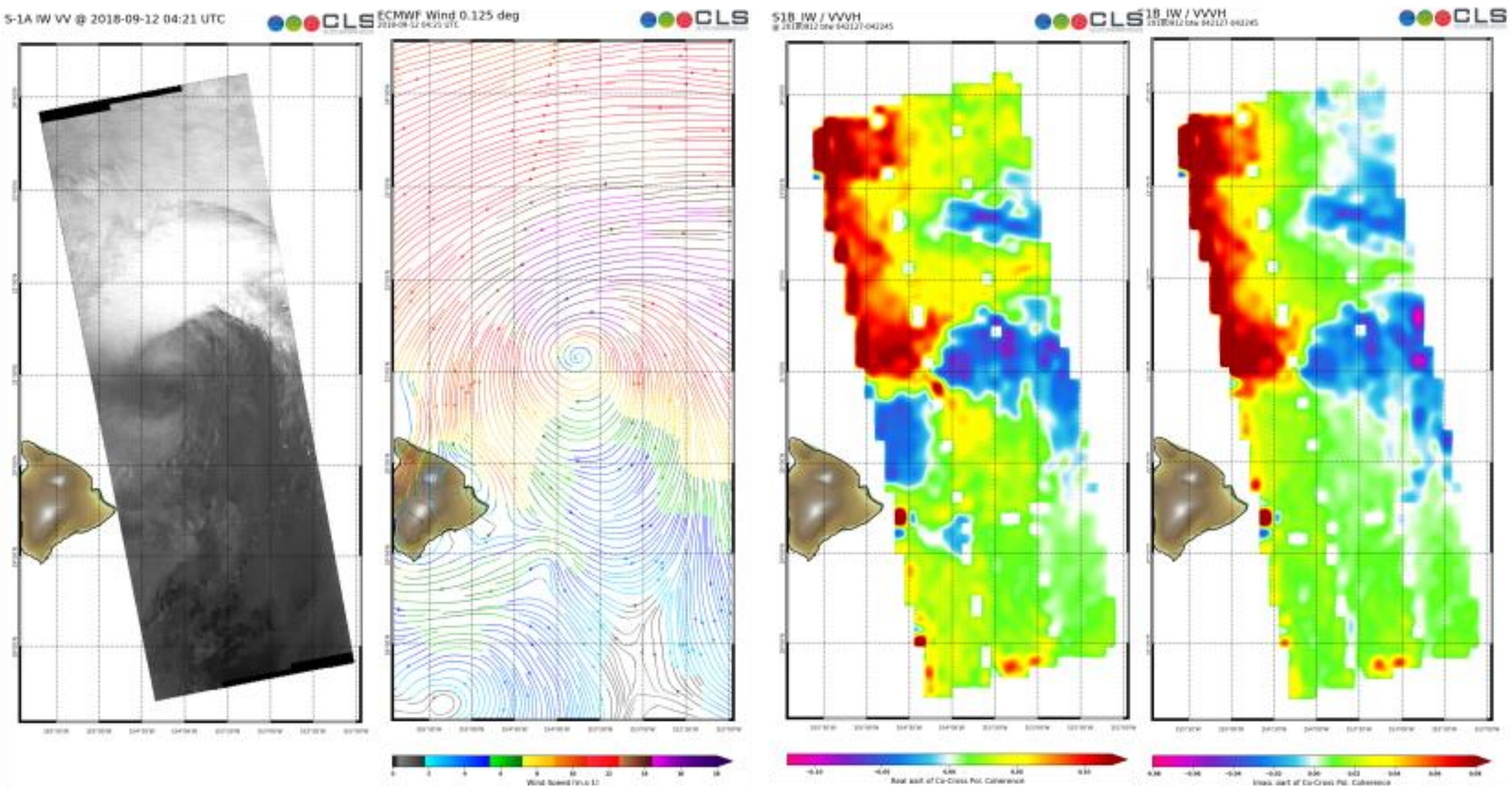
CCP information

Study case : Olivia hurricanes 2018/09/12

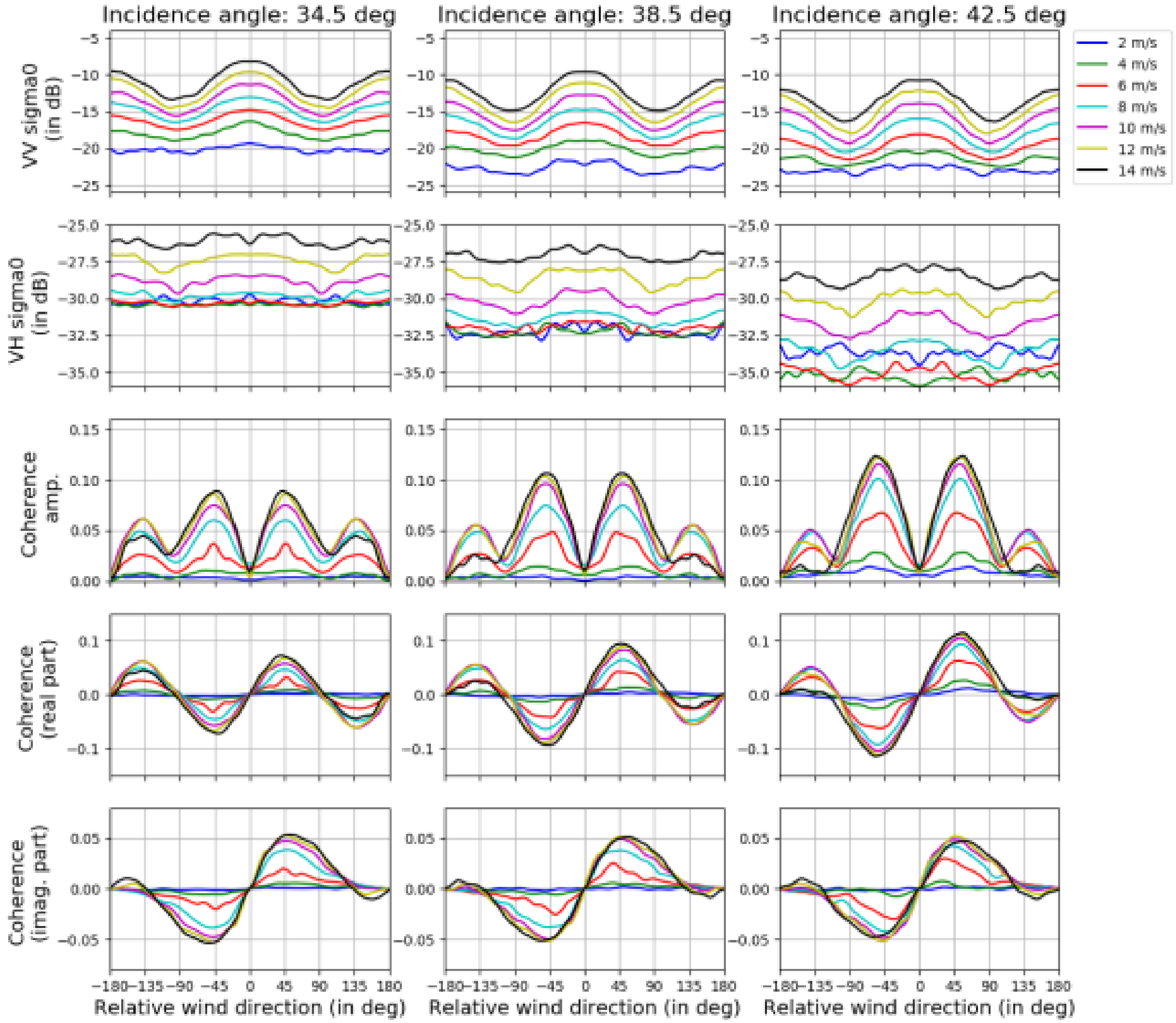


VV SAR image | ECMWF model wind field | Real co-cross coherence | Imag. co-cross coherence

<number>

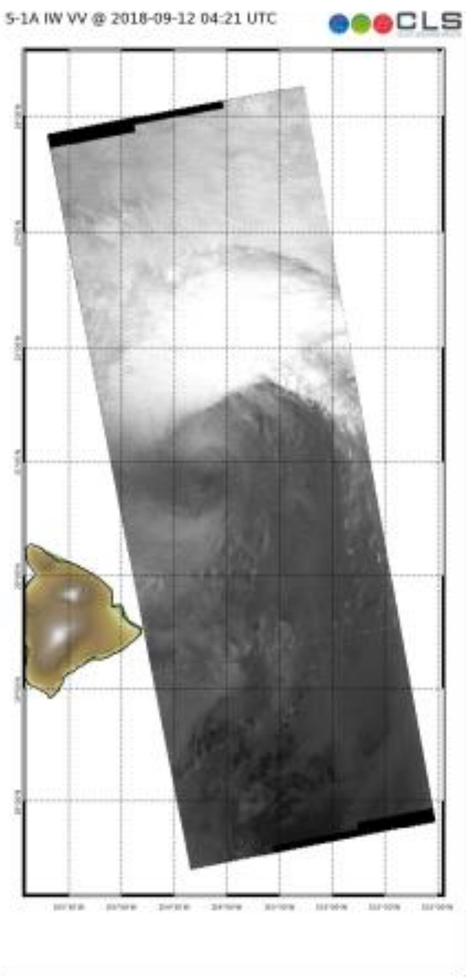
CCP information

Analysis of calibrated S-1 Co-Cross Coherence

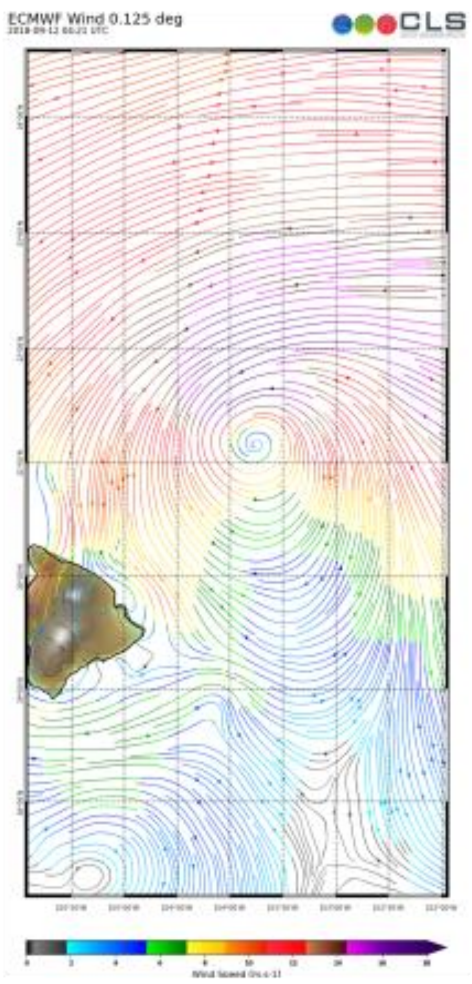


Polarimetric GMF can now be investigated !

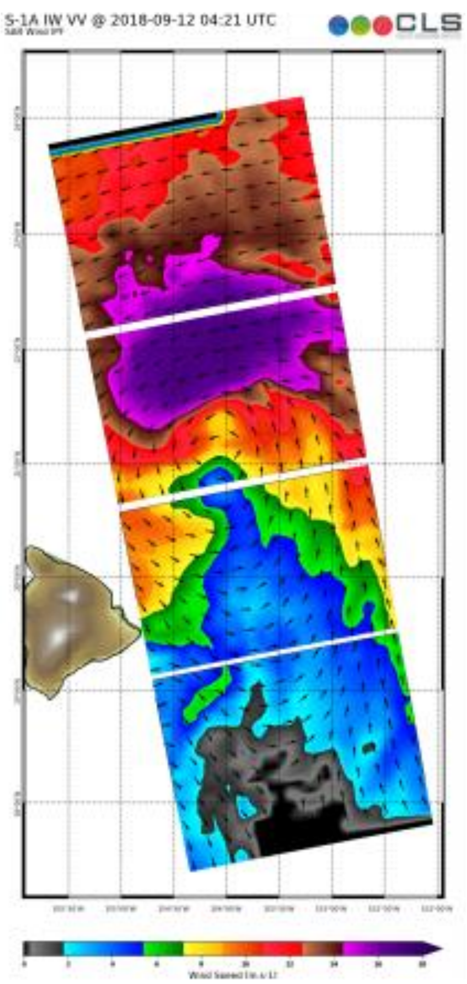
CCP information



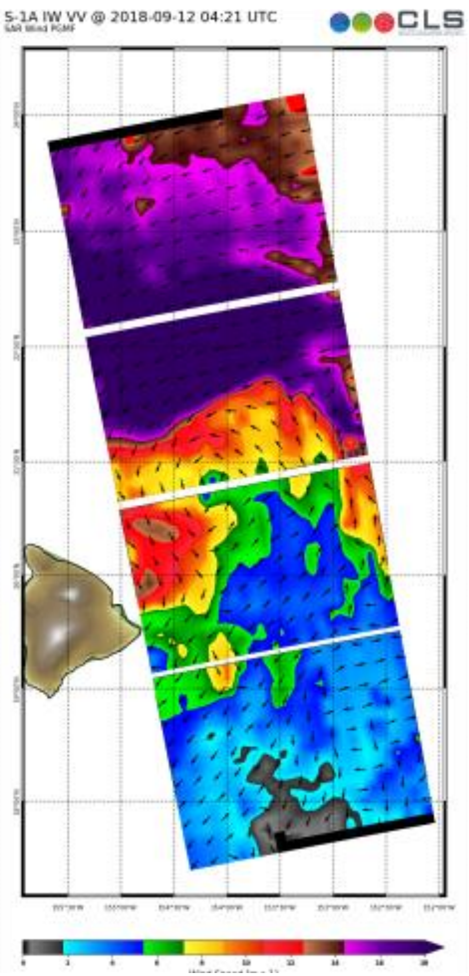
VV SAR image



ECMWF model wind field



$$\Delta\sigma = 0{,}5\ dB$$
$$\Delta_{model} = \{\sqrt{3}, \sqrt{3})$$



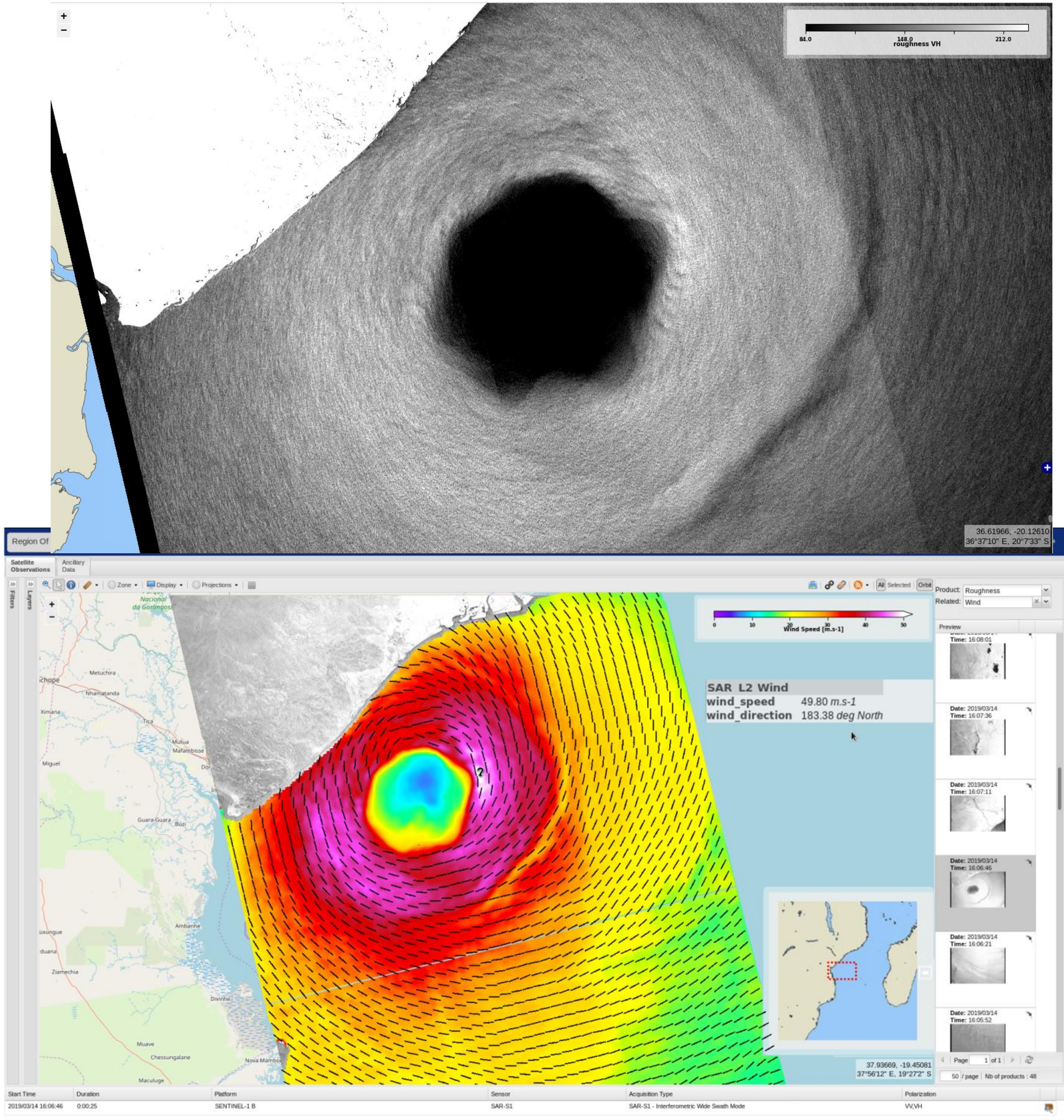
$$\Delta\sigma = 0{,}5\ dB$$
$$\Delta_{model} = \{10, 10\}$$
$$\Delta\rho = (0.01, 0.006)$$

Wind streaks information

- In TC, observations of wind streaks on SAR images resulting from dynamical instabilities are frequently reported. They are approximatley aligned with wind direction.

- Several methods have been developped to estimate wind streaks direction (e.g. Estimation of Wind Direction in Tropical Cyclones Using C-Band Dual-Polarization Synthetic Aperture Radar, Fan et al. 2019)

- Yet, the confidence in the estimated wind streaks is expected to vary with many parameters (eg. Wind speed, SNR...)
- --> Possibilty to estimate wind directions based on wind-streaks together with a confidence index for the two polarization channels, VV and VH?



S1 over Idai

Some references & data access

Mouche Alexis, Chapron Bertrand, Knaff John, Zhao Yuan, Zhang Biao, Combot Clement (2019). Copolarized and Cross-Polarized SAR Measurements for High-Resolution Description of Major Hurricane Wind Structures: Application to Irma Category 5 Hurricane . Journal Of Geophysical Research-oceans , 124(6), 3905-3922.

Mouche Alexis, Chapron Bertrand, Zhang Biao, Husson Romain (2017). Combined Co- and Cross-Polarized SAR Measurements Under Extreme Wind Conditions . IEEE Transactions On Geoscience And Remote Sensing , 55(12), 6746-6755, https://doi.org/10.1109/TGRS.2017.2732508

General website: http://esa-cyms.org [under construction]

WebGIS visualisation platform: http://eoda.cls.fr/cyms

Data archive center [under construction]

Thank you !

Backup slides

SAR and TC: background

Spaceborne SAR systems are able to probe the ocean surface at very high spatial resolution (~10m).

SAR potential to observe Hurricanes is well known:

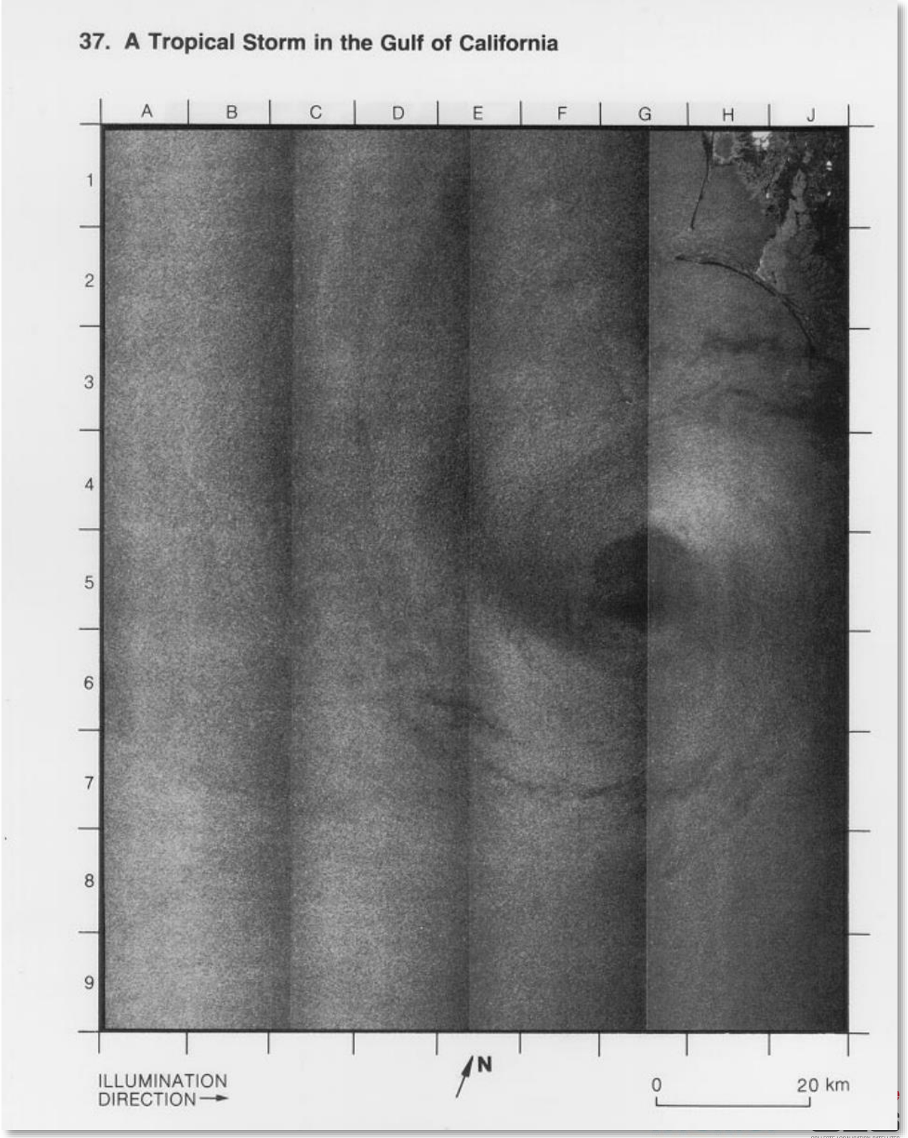
- Since the 80's with SEASAT, the first L-Band SAR,
- In 2007 with Radarsat-2 (co- and cross-polarized channels).

Sentinel-1 operational since 2014 (S1-A) and 2016 (S1-B), offering polarization diversity.

No specific strategy today within the Copernicus programme to observe and provide analysis related to TC before landfall.
But related activities could in the future become part of a Copernicus operational service.

→ We report here on activities performed since 2016 (SEOM program).

Tropical Storm observed by SEASAT (L-Band SAR)



Fu & Holt, 1982

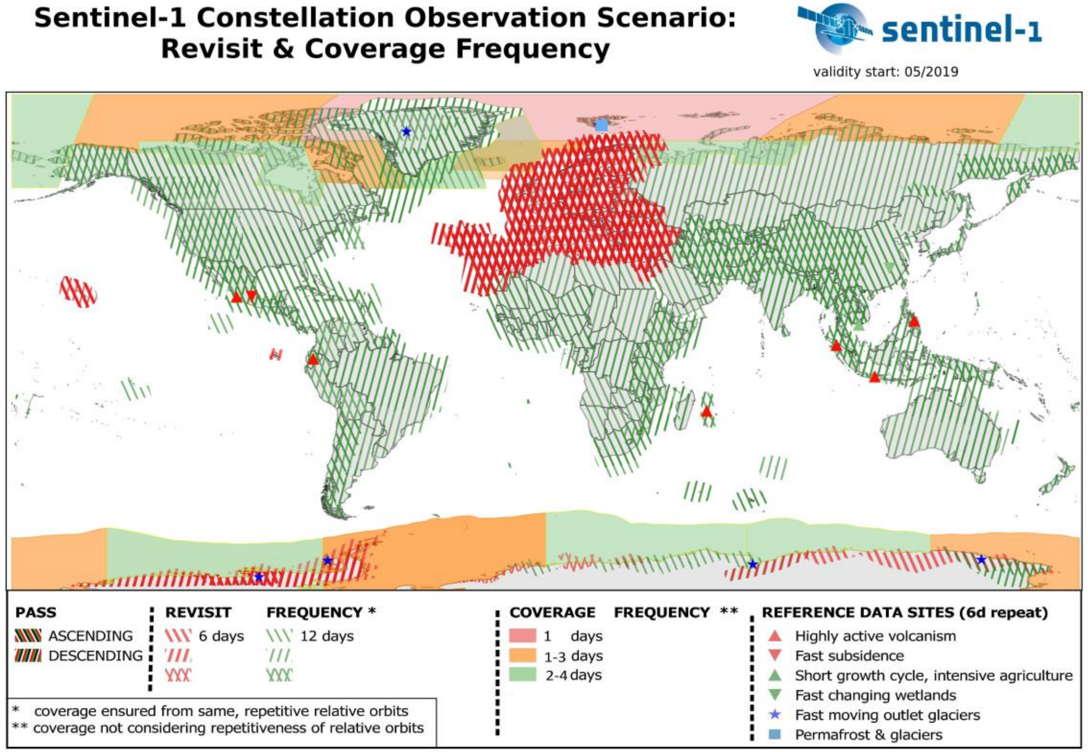
Toward a strategy to acquire SAR images over TC

- No routine large swath acquisitions (EW, IW) over the ocean basins in the Tropical belt where TC occur.
  - ✓ S1 A&B are operated according to a standard and repetitive acquisition plan as defined in the Sentinel HLOP (High Level Operation Plan), regularly updated.
  - ✓ Exceptions made for specific observation tasking in response to activations mainly from the Copernicus Emergency Management Service and from the International Charter Space and Major Disasters.

- In **2016**, a dedicated stategy has been set up in cooperation with ESA to maximize S-1 acquisitions:
  - ✓ large swath (EW or IW)
  - ✓ in both co- and cross- polarization (VV & VH)
  - ✓ over the TC in open ocean - before landfall

- Tropical Cyclones tracks:
  - ✓ 5-day forecasts routinely produced by TC centres,
  - ✓ updated every 6 hours,

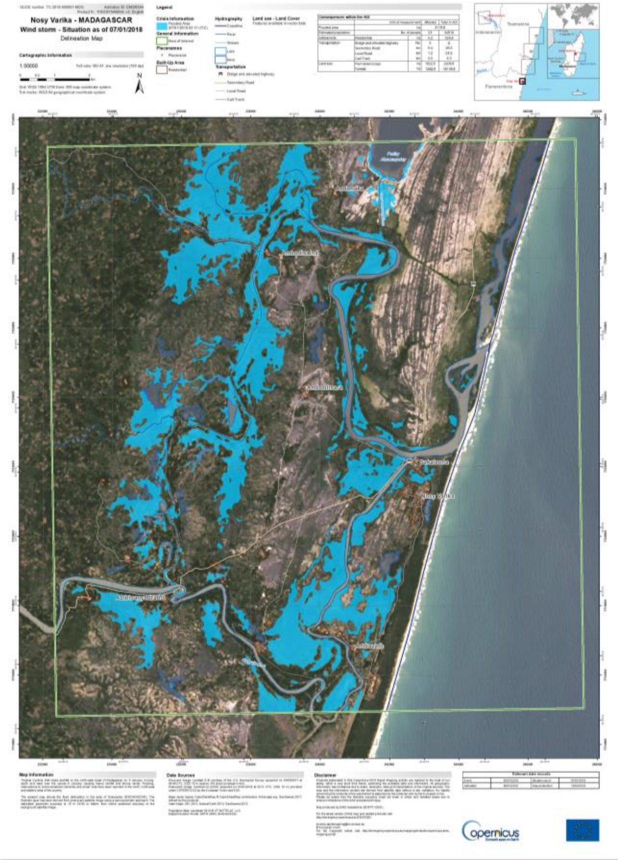
  → **Used to request specific acquisitions to ESA and get a change in S-1 acquisition plan on short notice.**



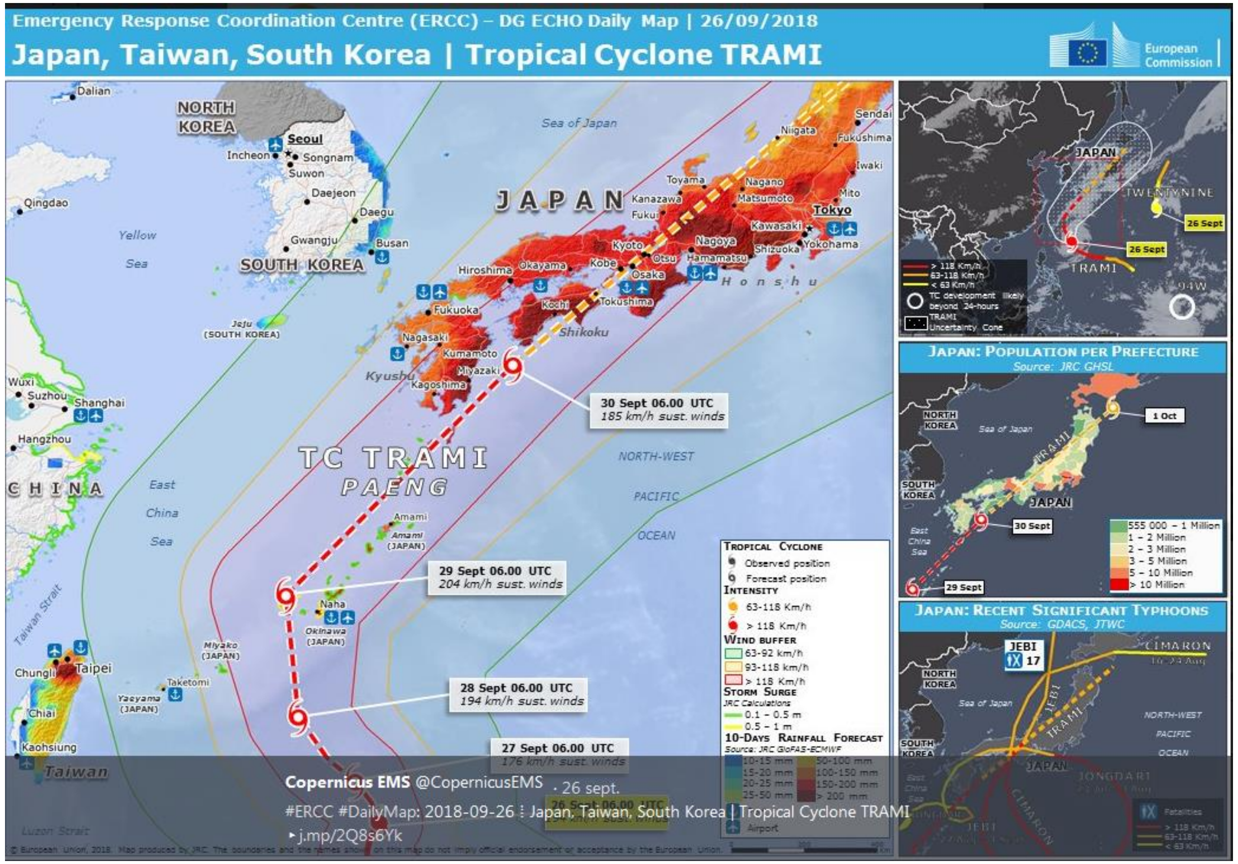
Cyclones and emergency services

- Mainly activated at landfall
  - Over land: report on coastal damages and environmental changes
  - Over ocean: existing framework

CEMS Bulletin, flood map
Tropical Cyclone AVA



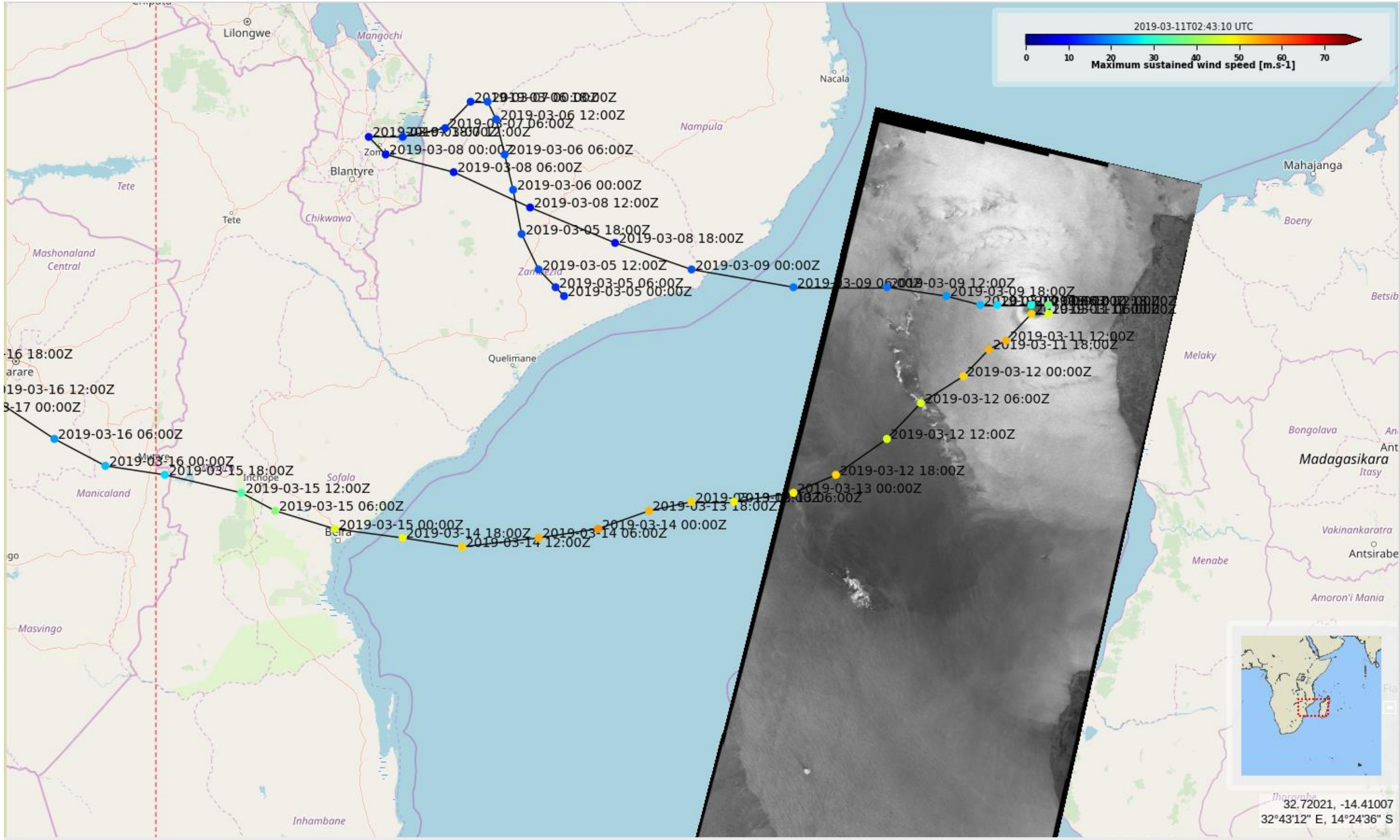
CEMS/ERCC Bulletin
Tropical Cyclone Trami



TC of interest: IDAI

TC eye captured by S1 twice

- **S1 image of the sea surface roughness**
- S1-derived wind field



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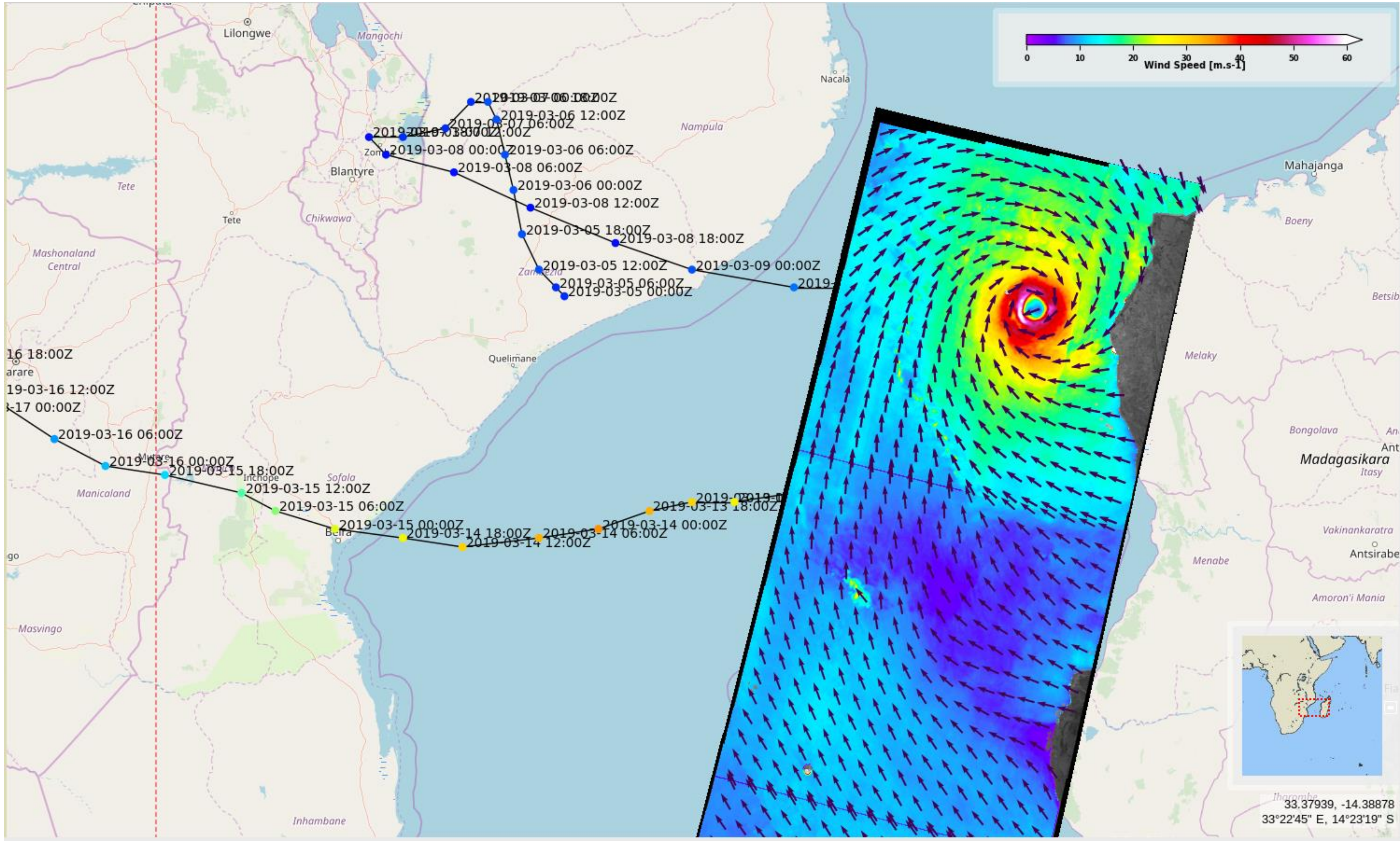

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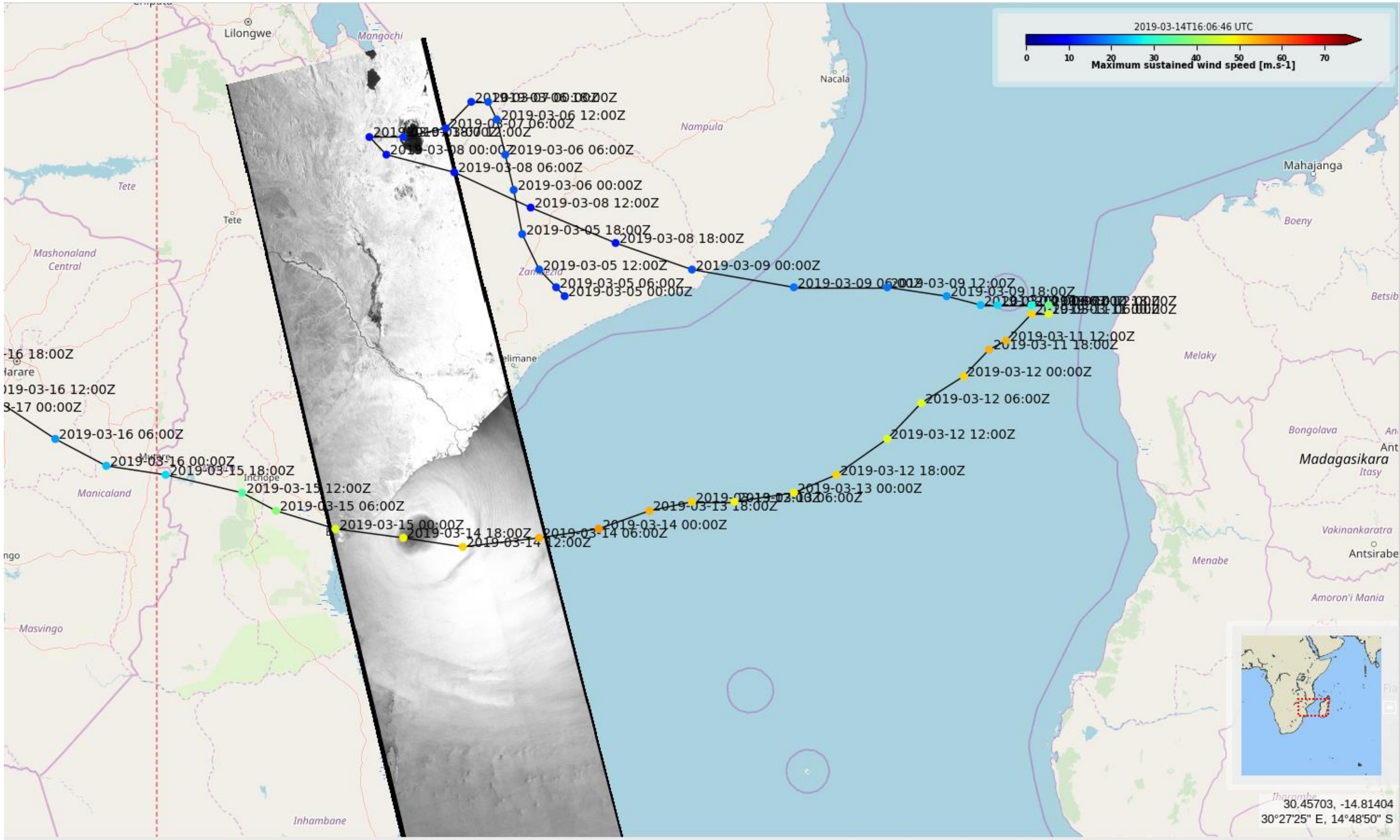

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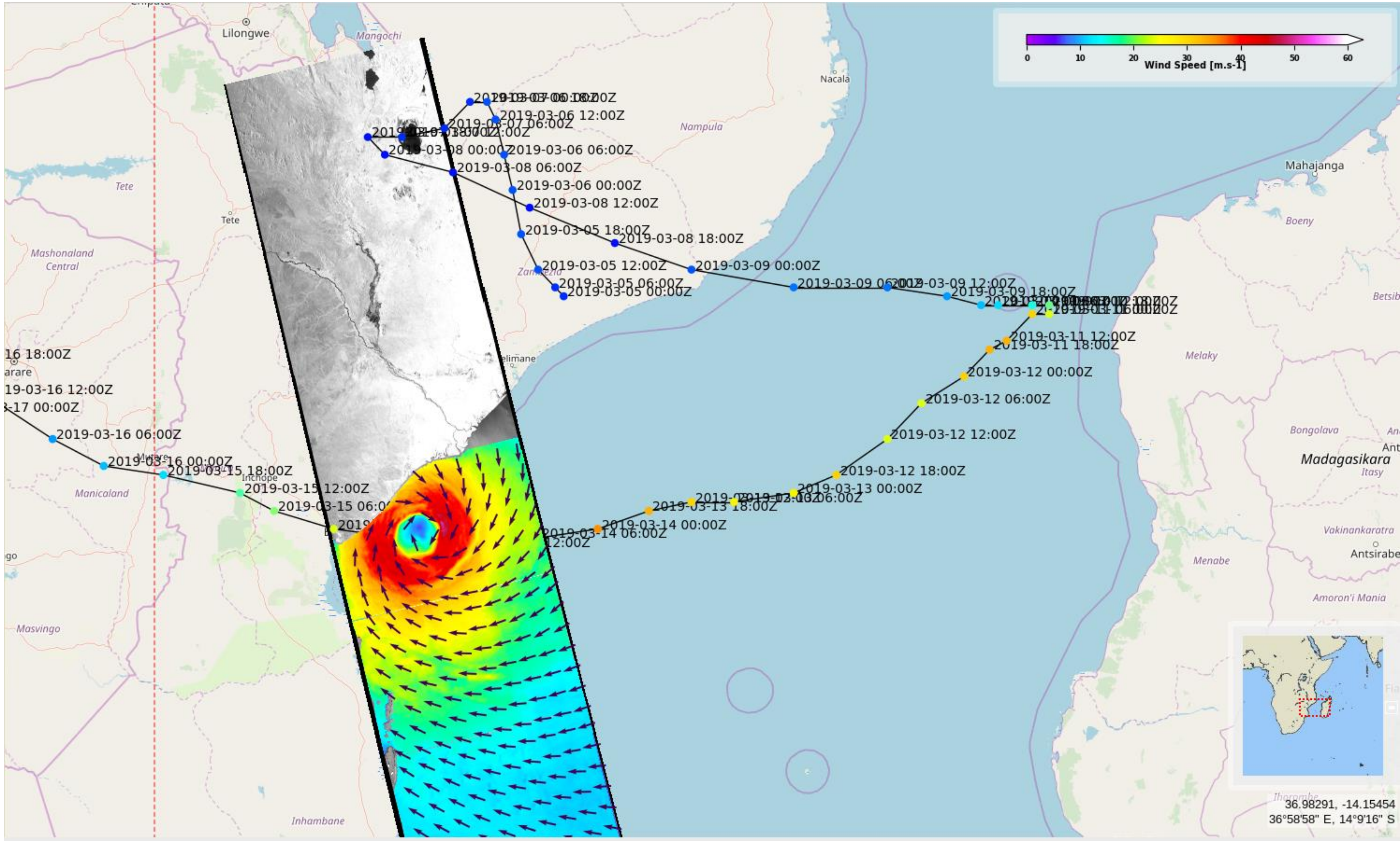

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