Tropical Cyclones Using Satellite Synergy

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2020 November 24

Background

Introduction

- **Motivations**
  - TC lifecycle forecasting (e.g sudden change in intensity)
  - Role of the ocean-atmosphere interactions
  - TC evolution in the context of climate change

- **Tropical Cyclones :**

  - Interactions between ocean and atmosphere
  - Several different processes occur simultaneously
  - These are multi-scale phenomena in both space and time
  - These are rare and extreme events

- **Observations :**

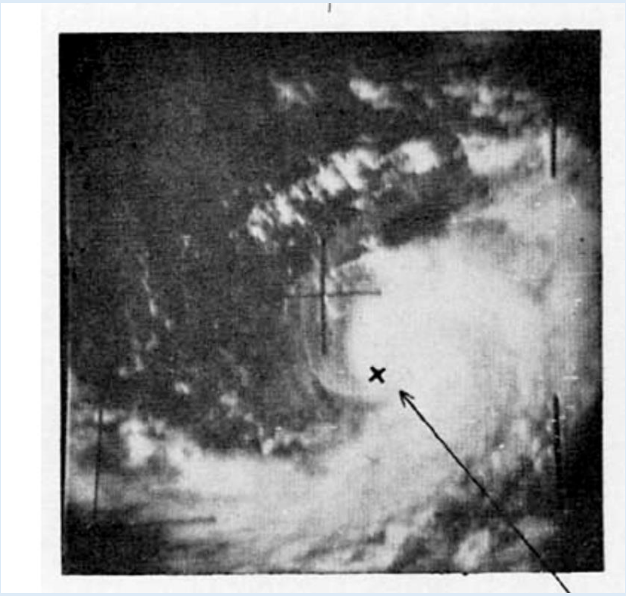
  There is no one single satellite missions with one single sensor able to

  - measure a wide range of different parameters (to describe both ocean and atmosphere),
  - provide both large coverage and high resolution (space)
  - sample at high resolution (time)

When available in-stu observations and when necessary models shall be considered to fully exploit the satellite observations and/or complete the satellite point of view.

Context and History

Tropical Cyclones is monitored with satellite date since the launch of the first meteorological satellites TIROS in the 60’s (Sadler 1962).



Typhoon Ruth (1962)

Satellite/Sensors available

Context and History

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Many countries now have a Earth Observation program to launch satellites or satellite constellations.

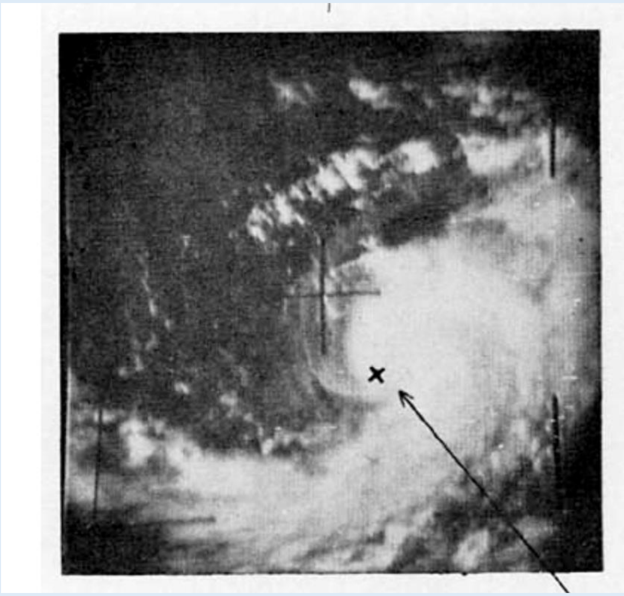
The number of EO observations increases together with spatial and temporal sampling.

The data policy is moving toward public access.

Computation facilities also evolve to become remote (data center)

Using observations in synergy should become more and more easier.

These facts imply to properly define the approach before using data in order to not be overwhelmed by the data volume, data variety and data quality



Typhoon Ruth August 14, 1962

Satellite/Sensors available

Few rules

- Do not focus on data from one single sensor, mission or space agency.

  ⟹ Have a global view of available missions. Take the most of them

- A sensor provides a filtered and distorted view of reality.

  ⟹ Understand the basic principles of the measurement

- Geophysical measurements are only estimates through a inverse problem. Solving such a problem usually requires assumptions and validation exercices.

  ⟹ Know the limitations of the derived geophysical parameters you use.

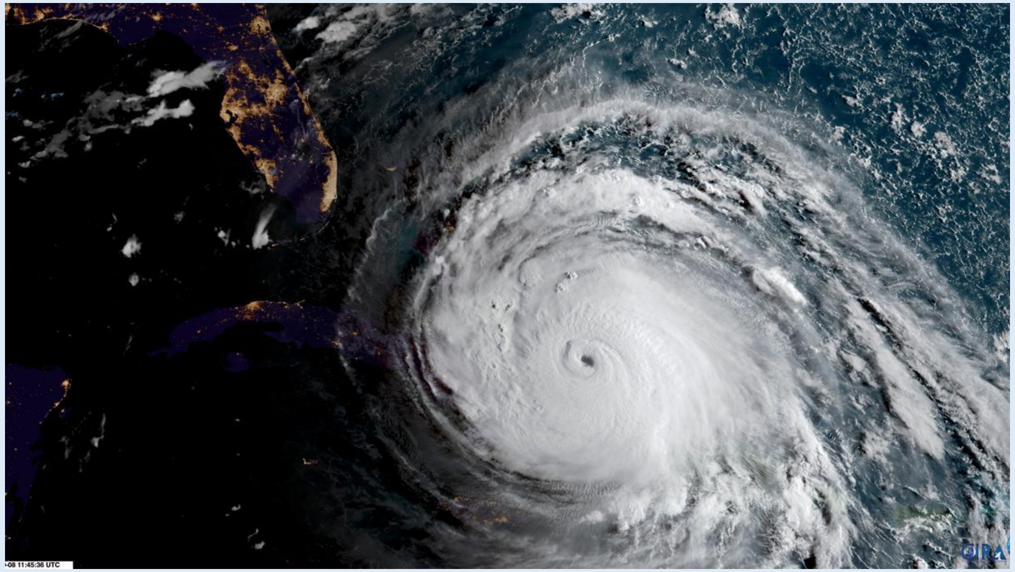
- Instruments parameters contains more than what is provided in the so-called Level-2 products (geophysical information)

  ⟹ Go for Level-1 (Level-0), if you can.

Satellite/Sensors available

High-level Earth Observation missions

- They are called geostationnary satellites. First was launched in 1963.
- Their position is fixed relative to the Earth and their altitude is 36 000 km
- They are widely used in meteorology since the 70's.
- Temporal and spatial resolutions are high
  - Temporal : <1h
  - Spatial : O(km)
- Sensors are radiometers operating in visible and IR. Several channels are available for each band.
- They are commoly used to provide information on clouds (speed, calssification, height) and surface (sea surface temperature)
- They do not see the surface when there are clouds

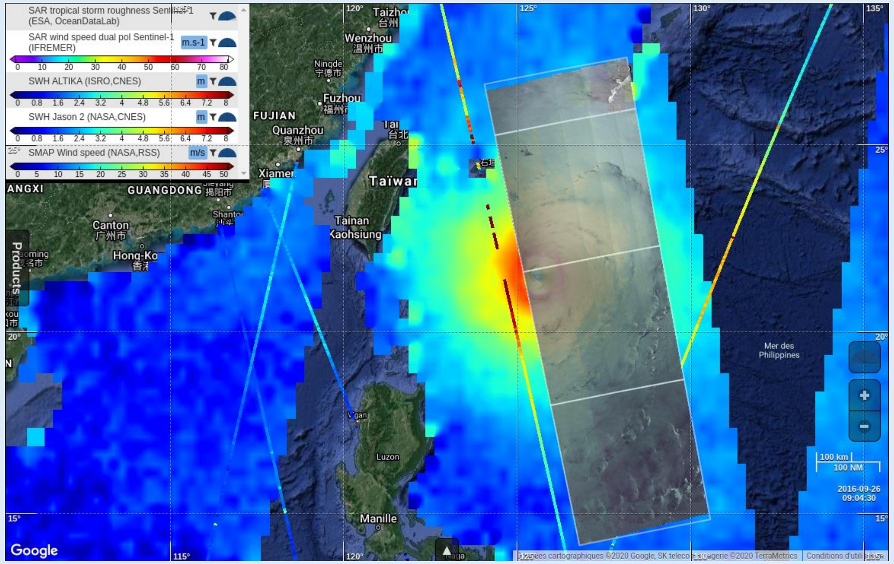


Irma September 8, 2017 (GOES-16)

Satellite/Sensors available

Low-level Earth Observation missions

- They are rotating around the Earth. They do not observe the same point constantly. The satellite cycle defines the duration to come back at the exact same position (typically about tens of days).
- They are used for Earth Observation in geoscience since the 1978 (SEASAT).
- The temporal resolution depends on the orbit parameters and sensor parameters (swath size)
- Spatial resolution is different for each sensors. Microwave sensors are scatterometers, altimeters, radiometers, Synthetic Aperture Radar.
- Over the ocean, they aims at providing information on ocean surface waves, wind, temperature, rain, currents



Geophysical parameters

Geophysical parameters	Sensors
Significant Wave height	Altimeter
Swell Directional spectrum	Synthetic Aperture Radar (SAR)
Sea Surface Height (SSH)	Altimeter
Sea Surface Salinity (SSS)	Radiometer
Sea Surface Temperature	Radiometer (HEO & LEO)
Rain Rate	Radiometer, radar (GPM)
Cloud (motion, height)	Radiometer (HEO)
Ocean surface wind	Radiometer, Altimeter, SAR, scatterometers
Sea surface roughness (Normalized Radar Cross Section)	SAR, scatterometer, altimeter
Radial velocity (Doppler)	SAR

Challenges for Tropical Cyclone monitoring with satellite

- **Orbits & Swath :** Excepted from CYGNSS orbit, there is no satellite mission specifically designed for observing Tropical Cyclone and especially the ocean surface within a Tropical Cyclone.

  Most of the orbits are chosen to be polar with a cycle of several days.

  This precludes continuous observations of the Tropical Cyclone.

  However, thanks to swath width that can be very large (~1000km for SMOS radiometer for instance), the revisit time is generally better than the orbit cycle.

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- **Sensors & Algorithms :** Sensors and associated algorithms are not specifically designed to observe such extreme situations.

  In addition to possibly have significant contributions from a variety of geophyiscal phenomena occuring at the same time,

  - Observations of Tropical Cyclone are rare (w.r.t other situations)
  - Collecting reference data to develop and validate the algorithm is more difficult than for regular met-ocean conditions

Local & Non-local Approaches

- **Local :**

This approach is the most natural : For a given on Tropical Cyclone, it consists in collecting information based on satellite acquisitions that are **collocated in time and space** with the TC vortex.

This requires to have

- Collocated data with the Tropical Cyclone of interest
- Algorithms able to perform in extreme conditions.

Local approach is typically adopted to provide estimates of the wind field, rain, waves in the TC vortex.

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- **Non-local :**

  This approach has been firstly adopted to characterize the impact of the TC vortex on the upper ocean mixed layer. It consists in collecting information on the ocean state ***after*** the Tropical Cyclone has moved away.

  This does not require algorithms able to perform in extreme conditions but data collocated with the TC wake. The time difference between TC and observation is important for the analysis.

  Non-local approach is typically used for analysing the change in sea surface temperature, sea surface height, sea surface salinity or chlorophyll blooms after TC pass. It can also be used for swell analysis

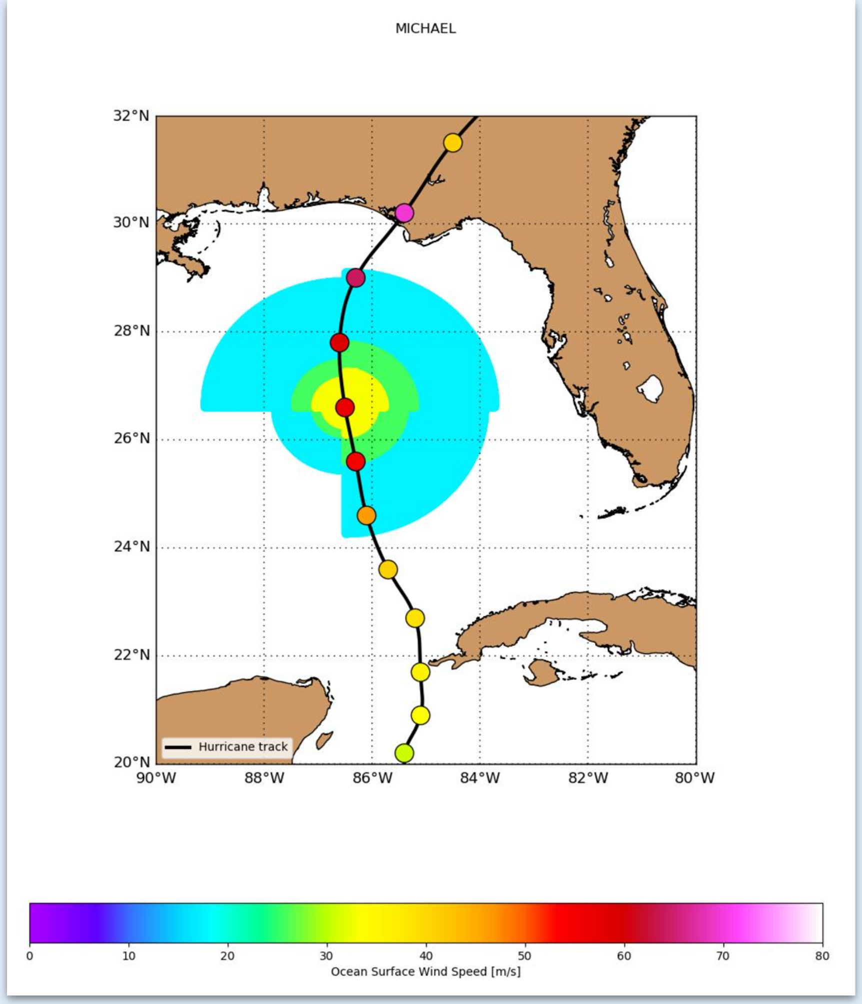
Synergy Examples :
Tropical Cyclone Intensity & Structure

Example 1: TC Track at Operational Centres

Regional Specialized Meteorological Centres from WMO document the TC intensity every 6-hours.

In particular, they provide TC

- Center location
- Eye diameter
- Radius of maximum wind
- Maximum sustained wind speed (defined over 1-min)
- Wind radii at 34, 50 and 64 kts in the four geographical quadrants.
- Surface Pressure



Example of 34-kt, 50-kt and 64-kt wind radii indicated in the strom track of Michael (2018) for each of the four geographical quadrants (SE,SW,NE,NW) at a given date.

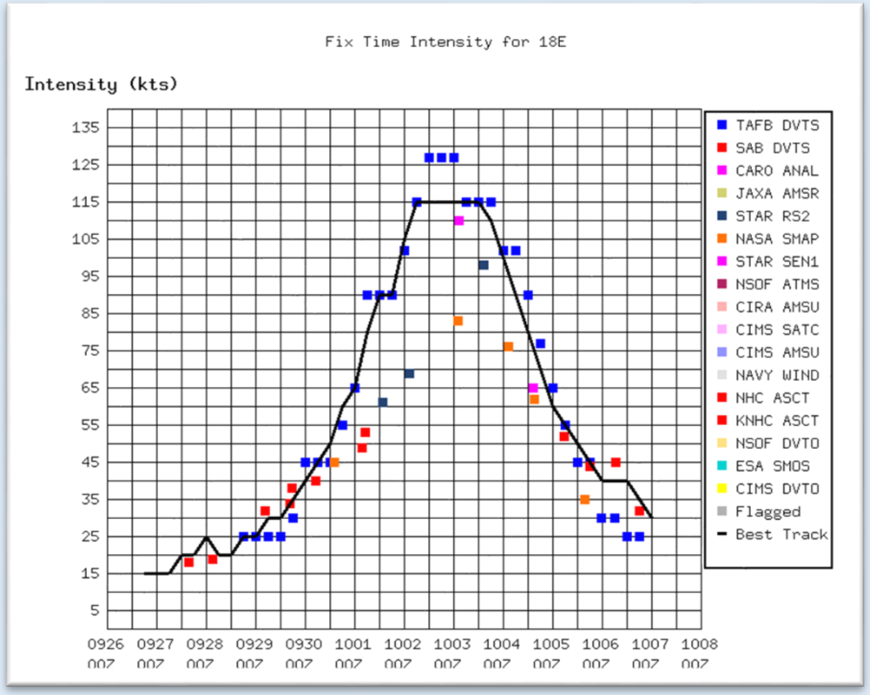
Example 1: TC Track at Operational Centres

All data available are considered to provide a subjective analysis in near-real-time: The so-called « storm track » .

A post-processing is perfomed after the TC event to refine this NRT analysis with additional data. This re-analysis is termed « storm best-track ».

The best-track dataset is widely used in the scientific community for case studies but also to evaluate the TC charactersitics evolution trend on a long term. Best-tracks ranges from 1850 up to now.

This is a first example of synergy to characterize the TC vortex. The approach can be considered as local, although data analysis is performed to provide a information every 6 hours.

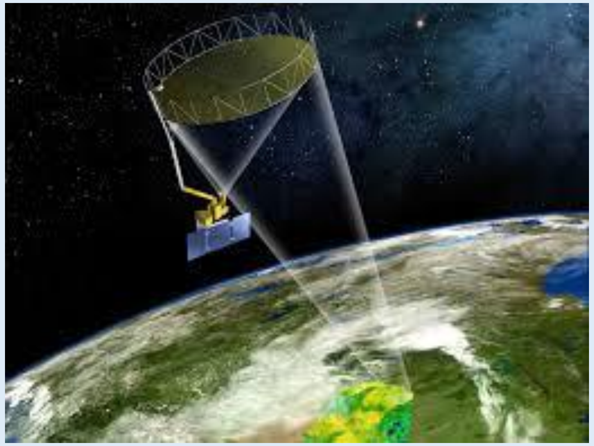


Intensity (kt) vs Time (month and day) plot of Dvorak (light blue), ASCAT (red), SMAP (orange), RadarSat2 (dark blue), Sentinel1 SAR (purple) estimates, along with National Hurricane Center real-time best track for Marie (18th tropical cyclone of the eastern North Pacific season).

Example 2: New generation of radiometers for wind radii estimate

Date used

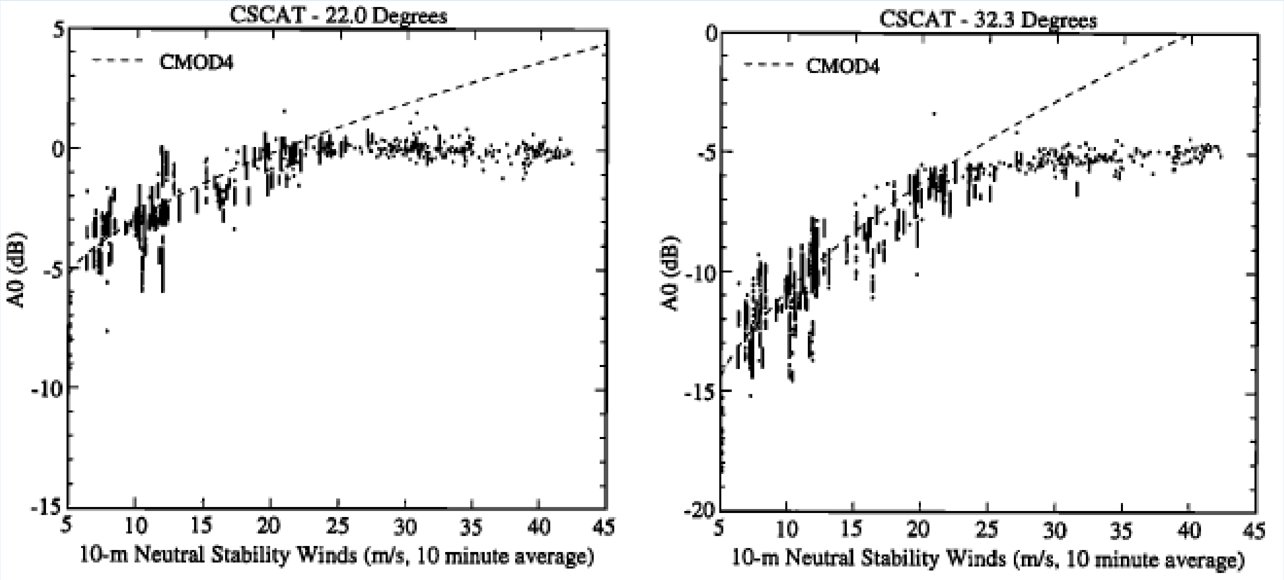
- L-band SMOS (ESA) - Reul et al., 2012; 2016
- L-band SMAP(NASA) - Yueh IEEE TGRS 2016; Meissner, BAMS 2017
- Multi-frequency AMSR-2 (JAXA) - Zabolotskikh et al., GRL 2013 .



Example 2: New generation of radiometers for wind radii estimate

Operational ocean surface wind field from space are usually provided by scatterometers, operating at C- or Ku- Band.

However, Ku-band is rapidly contaminated by rain in TC and C-band backscattered signal in co-polarization sensitivity is decreasing at high wind speeds. This prevents from accurate wind speed estimates in tropical cyclone.



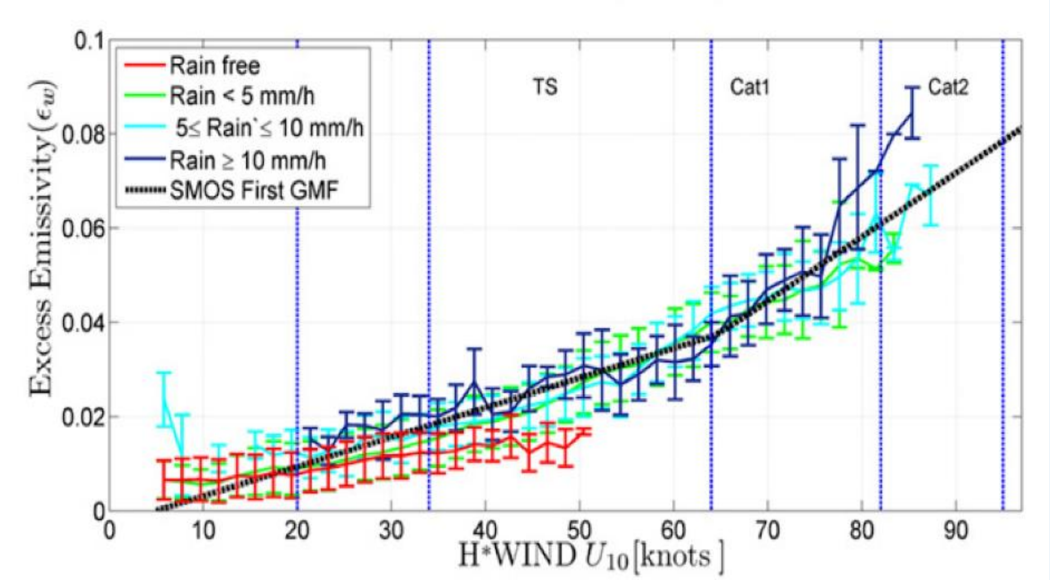
Donelly et al., JGR 1999

Example 2: New generation of radiometers for wind radii estimate

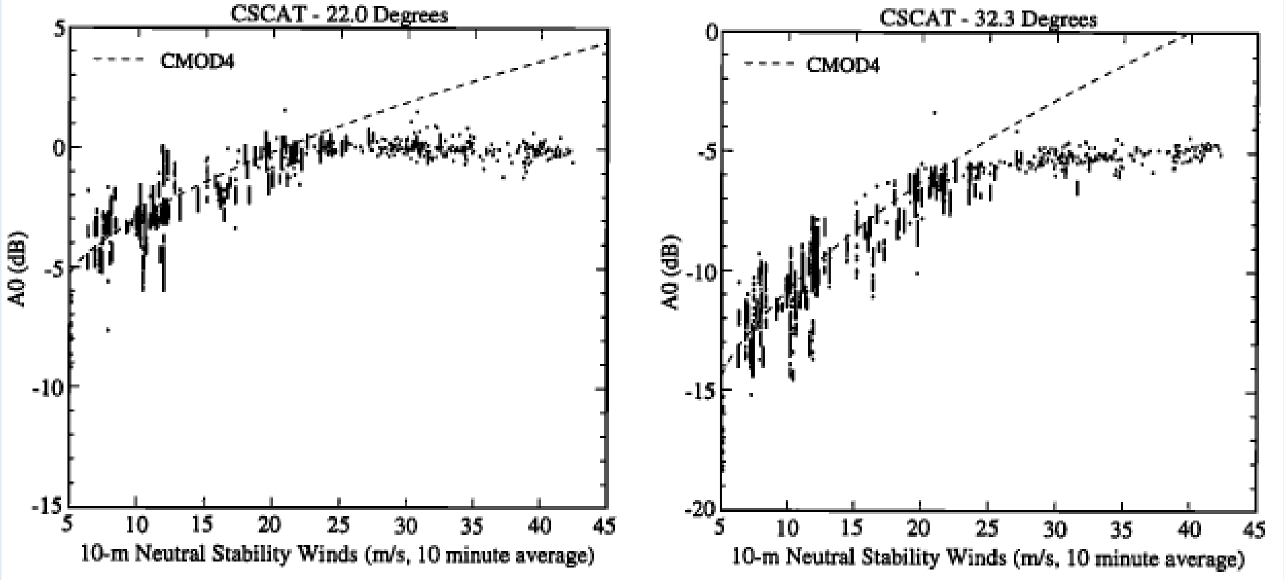
In particular,

- the use of L-band and the combination of different frequencies for AMSR-2 allows to be less sensitive to the hydrometeors in the atmosphere.

- at theses frequencies the brightness temperature measured by radiometer is more correlated to the ocean surface wind speed than the normalized radar cross section as measured by scatterometers in co-polarization



Reul et al., JGR 2012



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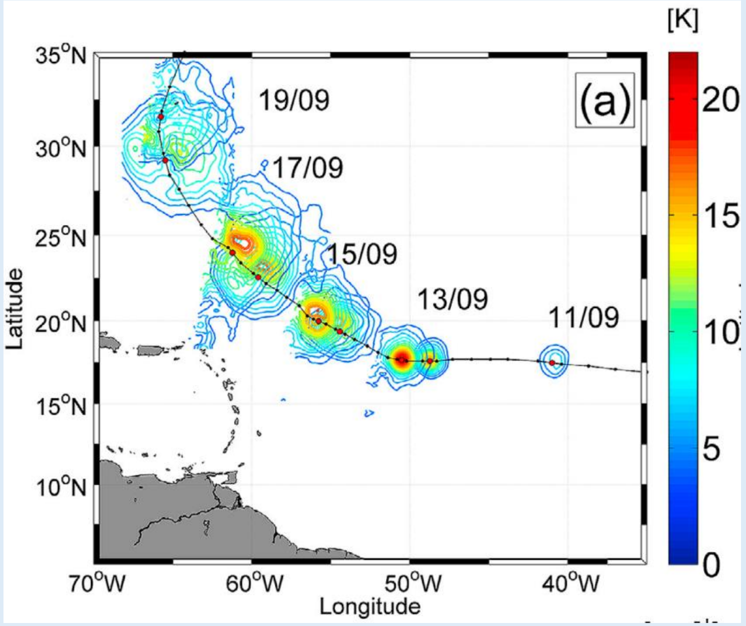
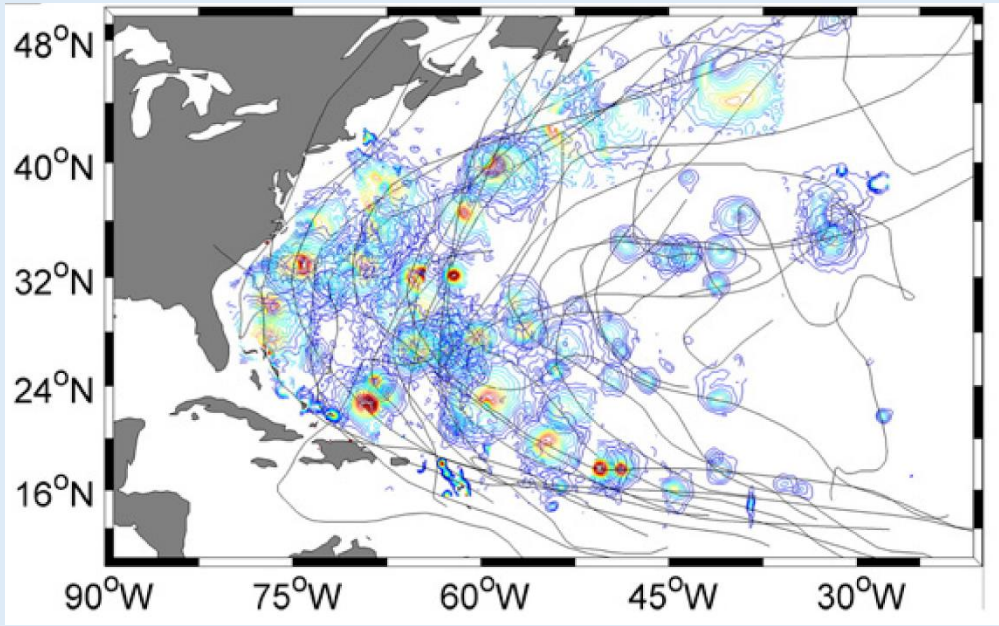
Example 2: New generation of radiometers for wind radii estimate

These 3 Radiometers have large swath and continuous acquisitions that allows providing TC observations regularly. This favors simultaneous acquisitions over TC when airborne data are available. This point is particulary important for algorithm development and validation.



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



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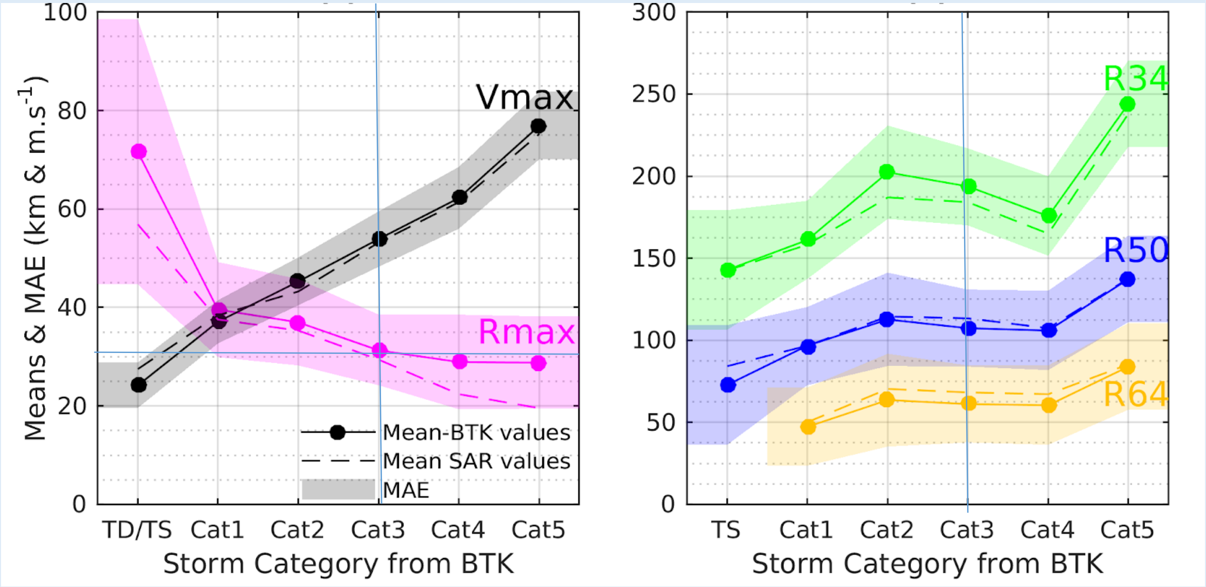
Their spatial resolution is about same, around 50 km. To note a radius of maximum wind speed of a major hurricane (cat-3 to -5) is about 40 km. These sensors are thus limited to be describe the inner core of a Tropical Cyclone, but are rather adapted for wind radii estimate.



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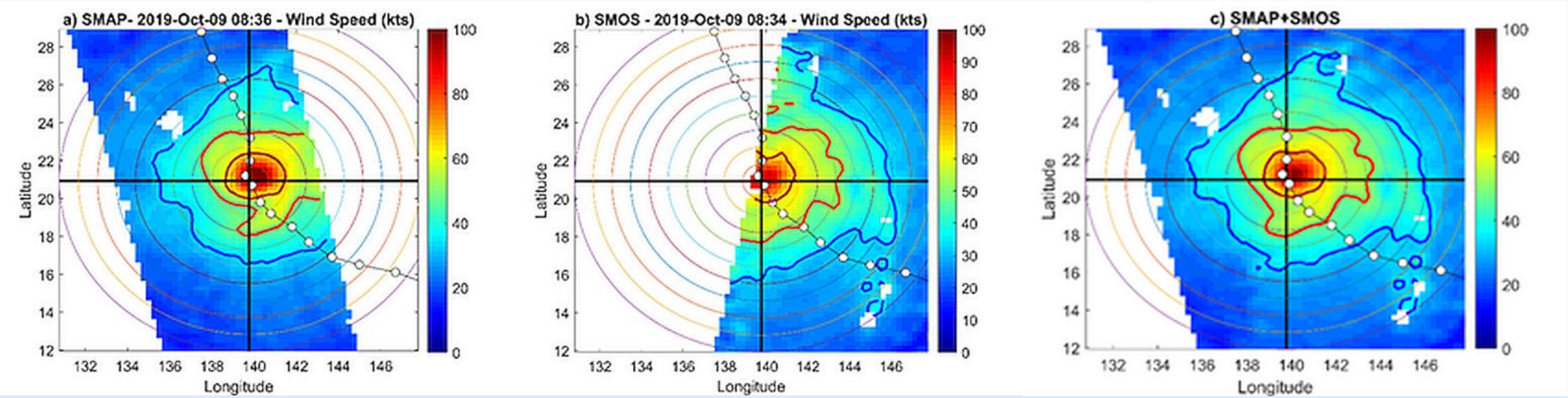
If properly intercalibrated they can be used together to describe the TC structure



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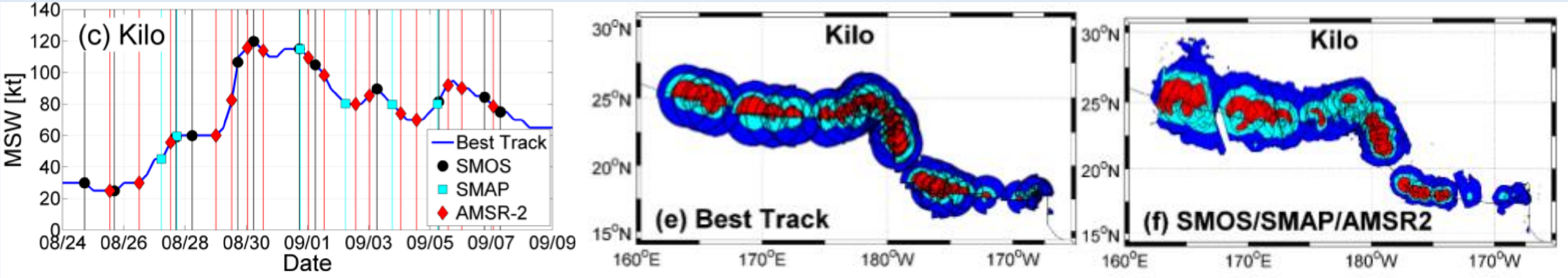
When combined together, it has been shown that they could be used to monitor the TC outer structure evolution along the whole TC lifecycle with an increased time sampling.



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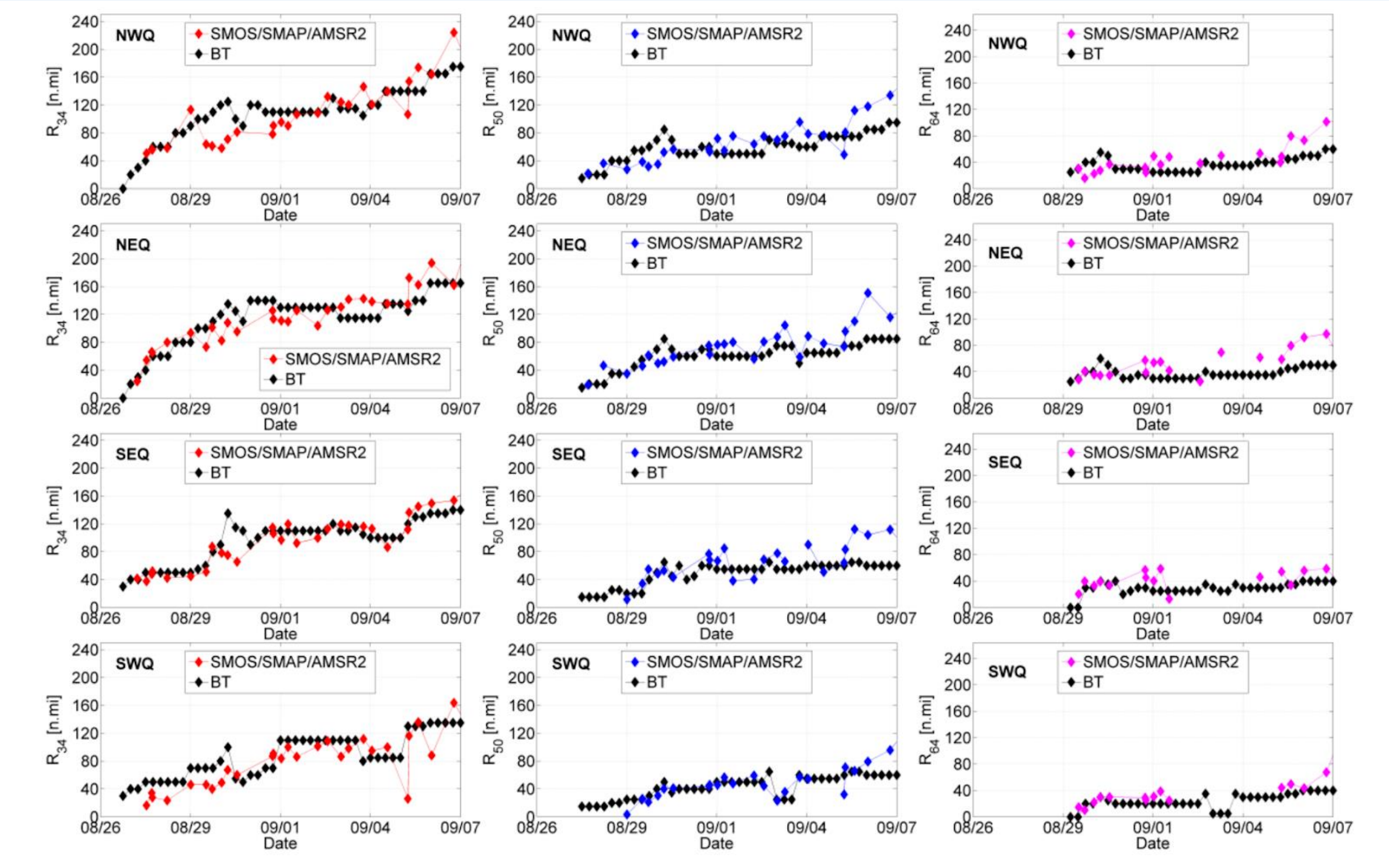

Reul et al., BAMS 2017

Example 3: Synergy between Sensors C-Band SAR & L-Band Radiometers

Data Used:

C-band SAR from Sentinel-1 A, Sentinel-1 B (ESA) and Radarsat-2 (MDA/CSA)

L-band Radiometer from SMAP (NASA)

Example 3: Synergy between Sensors C-Band SAR & L-Band Radiometers

Recent measurements with active radar (SAR) have shown a different sensitivity between the bakscattered signal from the surface at C-Band depending on the polarization.

In particular, the sensitivity of the measured signal across the hurricane eye is much higher in cross-polarization than in co-polarization. This is new compared to scatterometers operating in co-polarization (see slide before).

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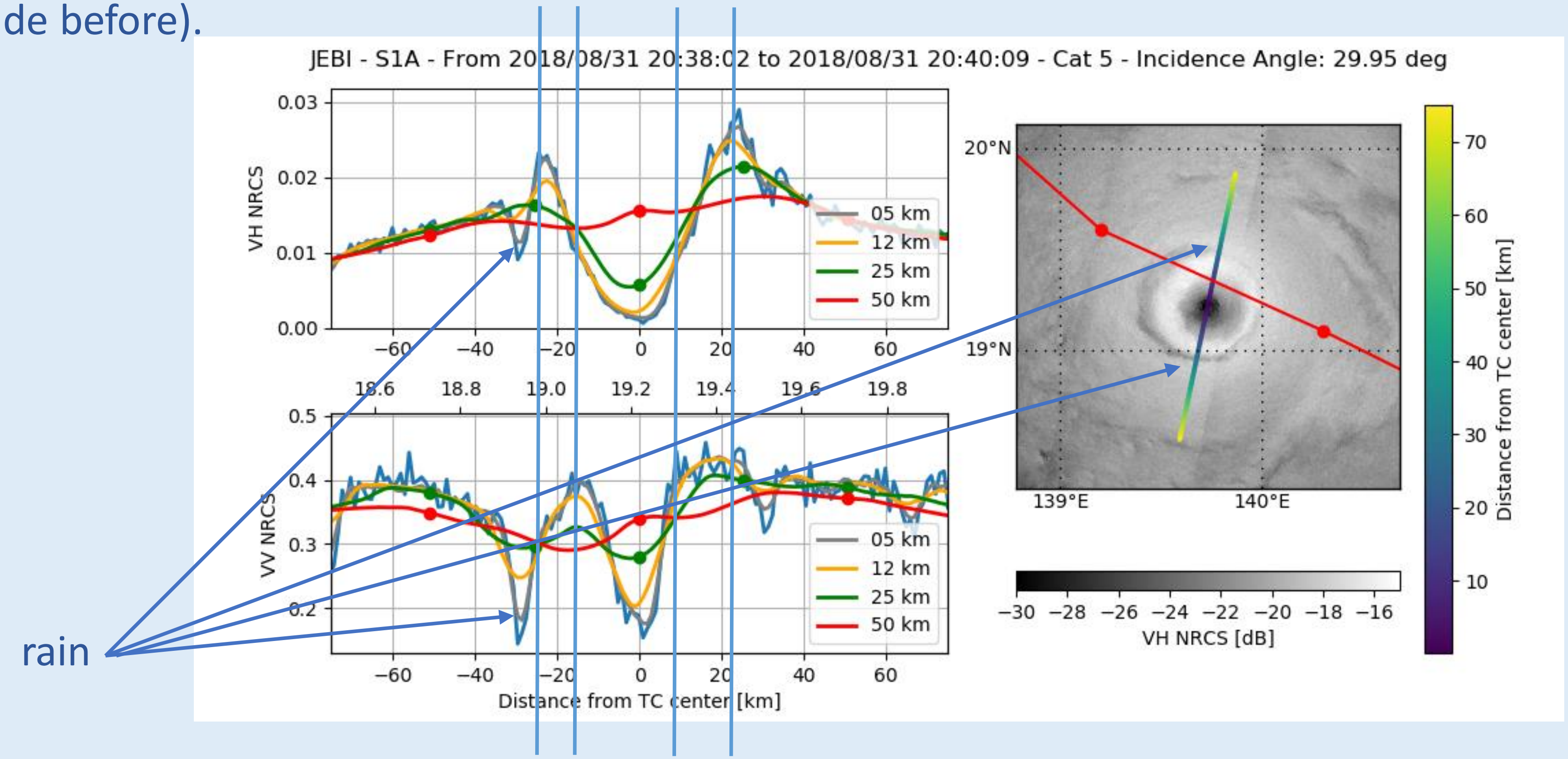
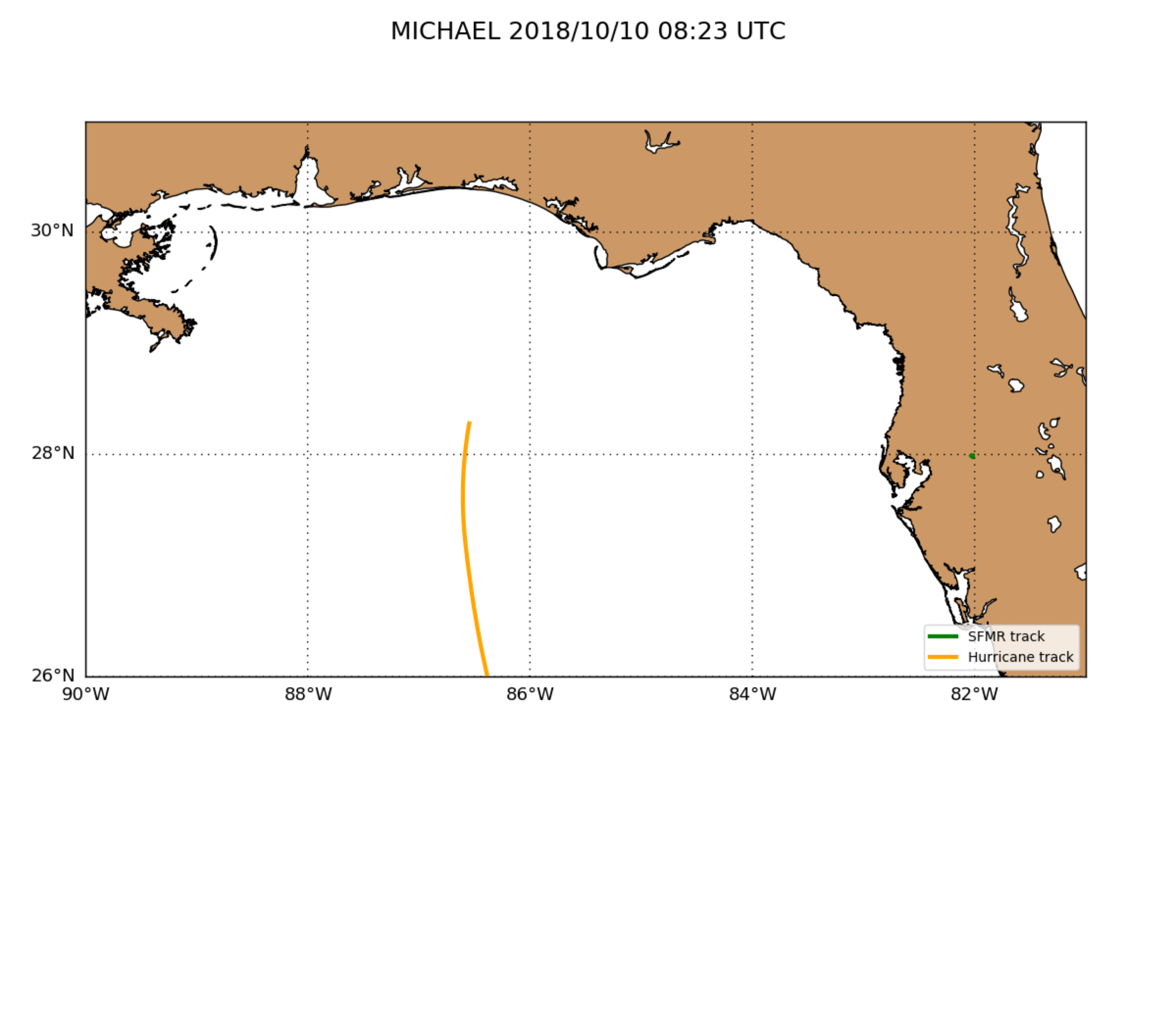


Example 3: Synergy between Sensors C-Band SAR & L-Band Radiometers

In the case of ocean surface wind speed, algorithms have been developed to infer ocean surface wind speed from the radar backscattered in co- and cross-polarization.

Collocations with US airplane measurements have been used.



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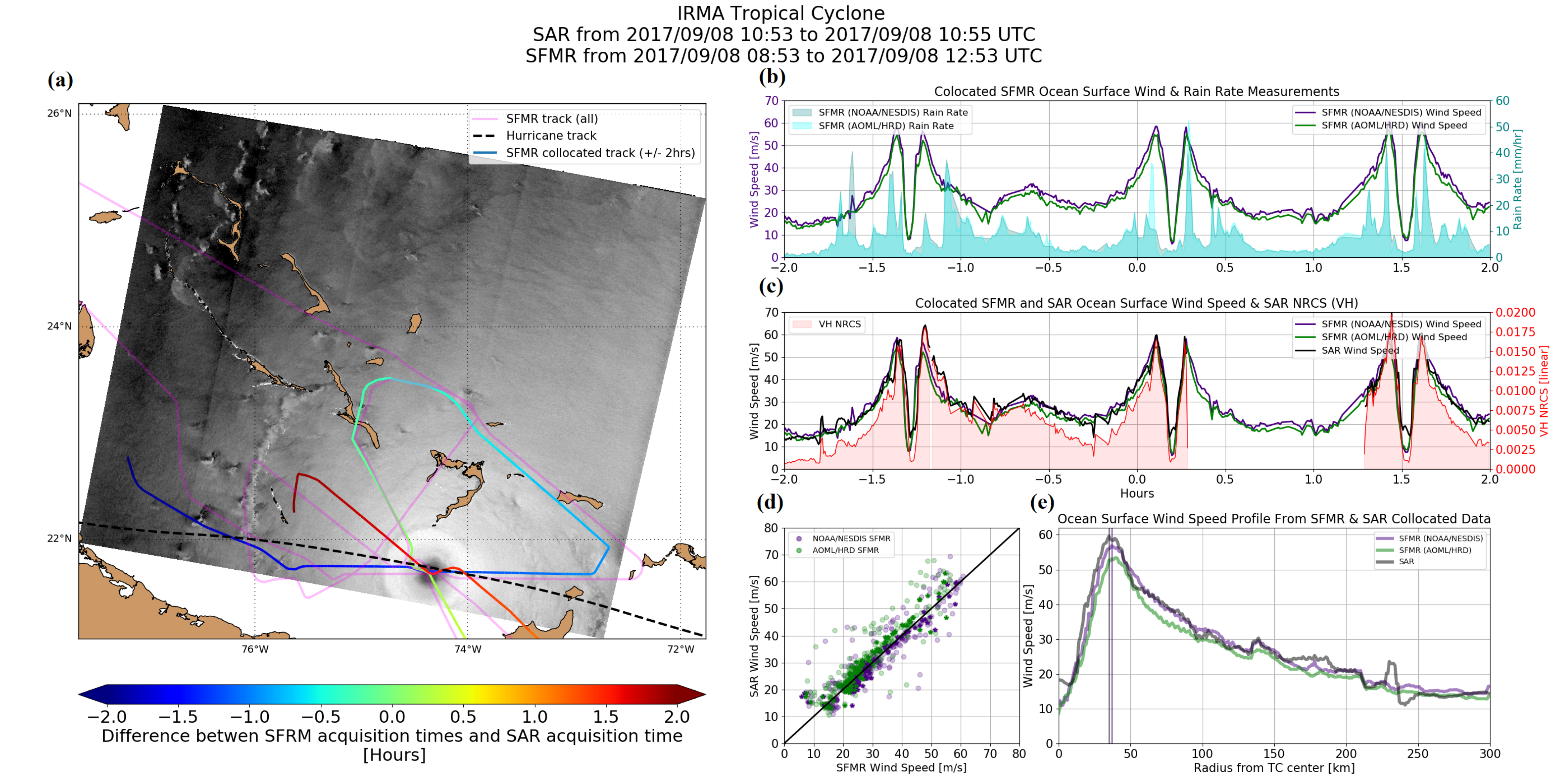

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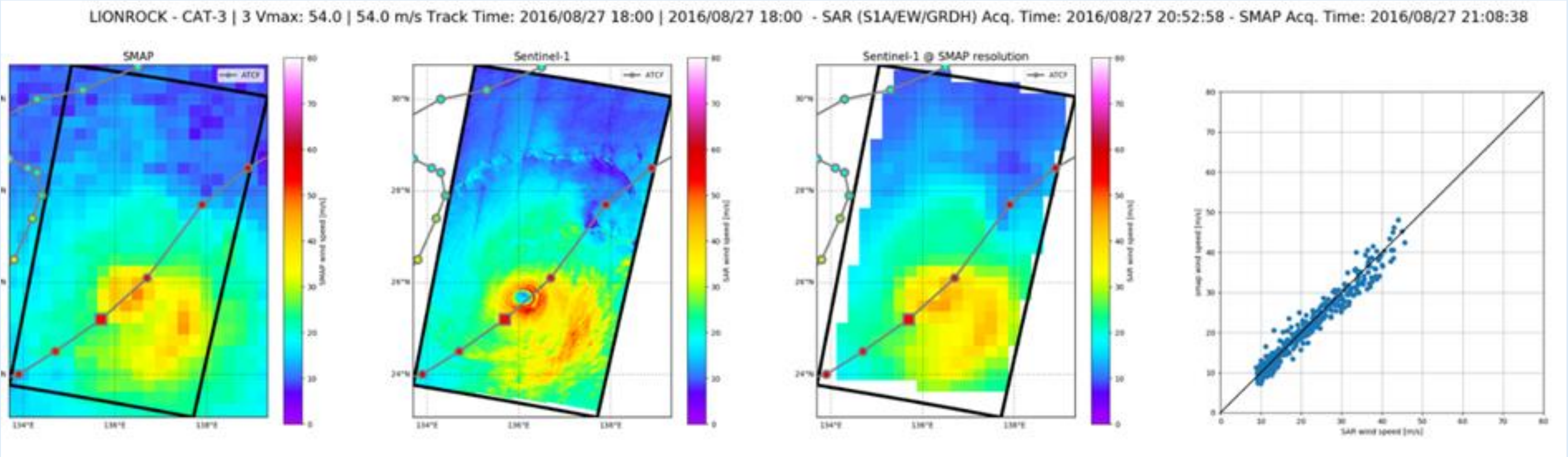
In spite of the different technology used between a L-band radiometer and C-band SAR, a remarkable agreement has been found between the two sensors when comparing at low resolution



To be done

Example 3: Synergy between Sensors C-Band SAR & L-Band Radiometers

SAR swath are smaller than radiometer and due to the high resolution of the volume data to store onboard and to downlink SAR cannot perform acquisitions continuously. HR SAR TC observations are sparse

Thus, in practice, we have

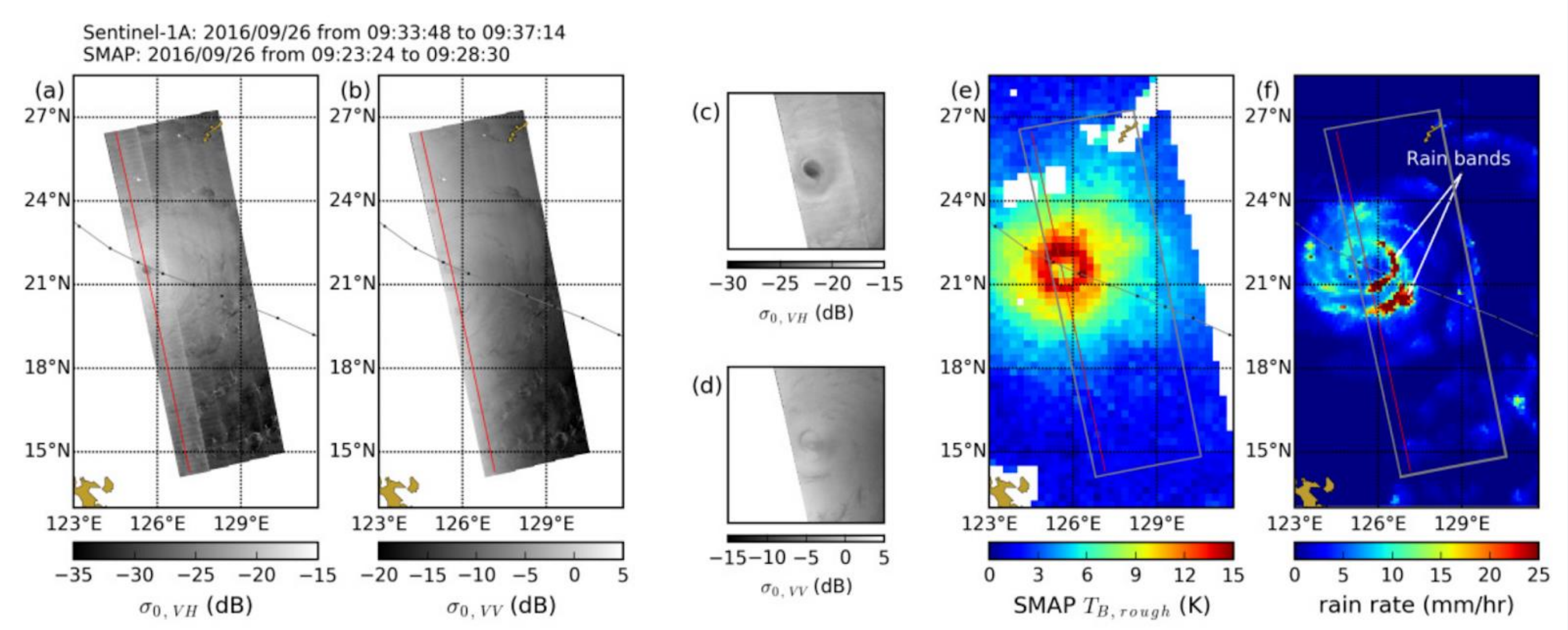
- a large number of observations at low resolution that can be used to document the TC outer core
- a much smaller number at very high resolution that can be used to document the TC inner core, inlcuding the eyewall.

This represents a unique data set to

- Assess the impact of the resolution on the TC vortex as observed by a radiometer
- Learn this resolution effect to possibly emulate high resolution observations from any radiometer data and derive relationship between outercore, innercore and TC evolution.

Example 3: Synergy between Sensors C-Band SAR & L-Band Radiometers

Taking benefit of collocations between C-band SAR and L-band SMAP radiometer, direct comparisons between C-band radar cross-section and L-band brightness temperature have been performed at L-band resolution.



Zhao et al., IEEE TGRS 2018

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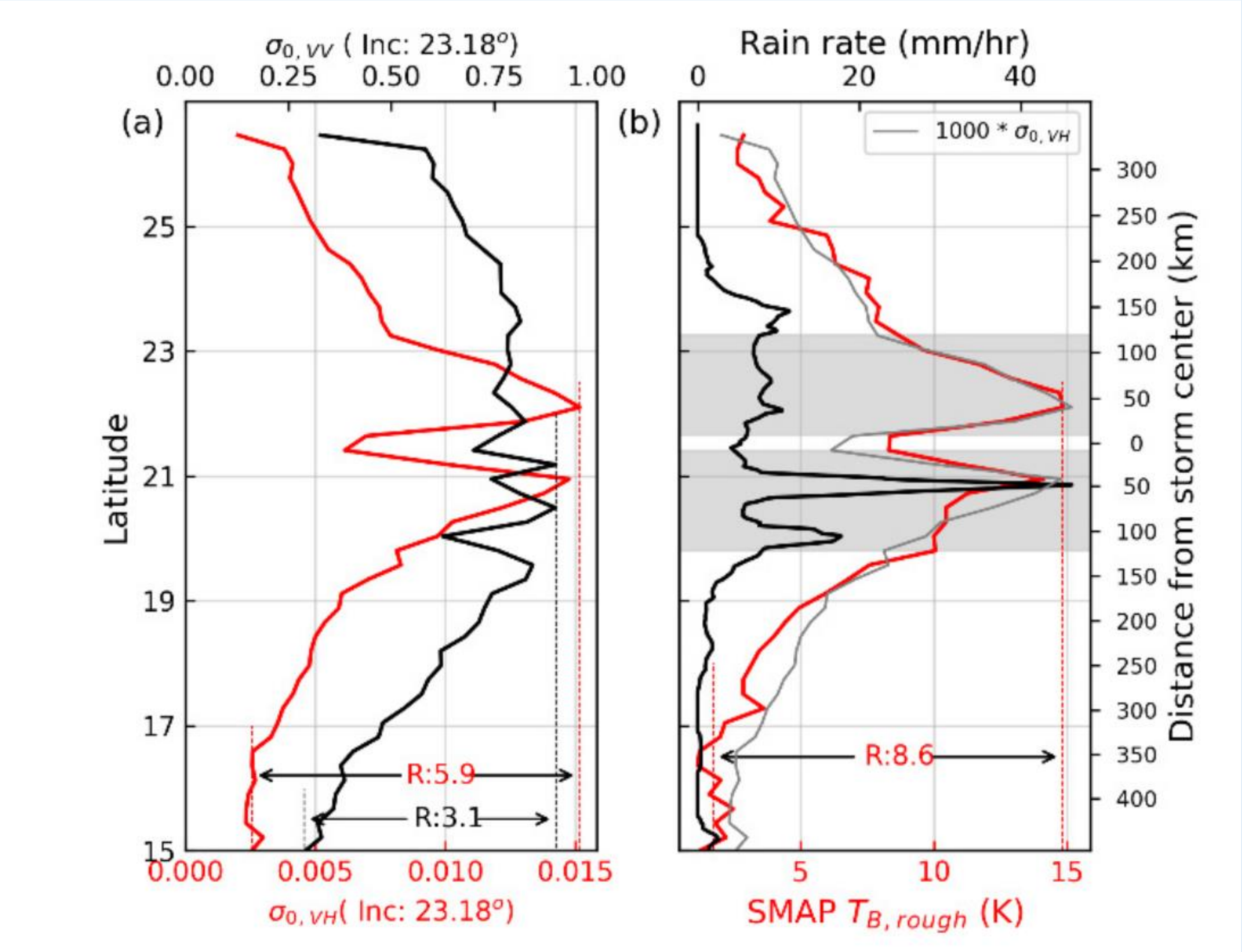

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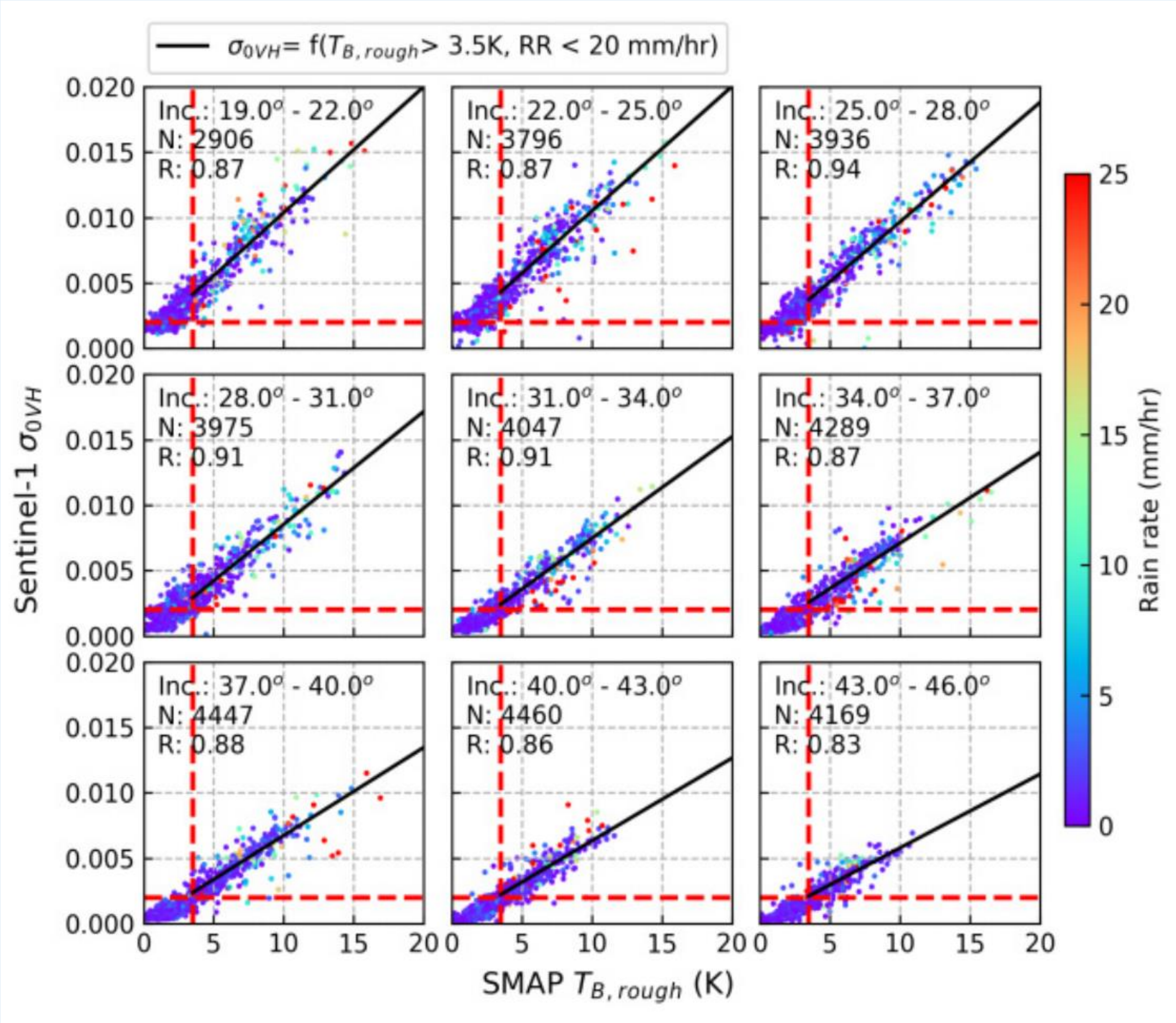

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The very strong similarity between the two signals confirms the same sensitivity to the ocean surface over extreme.

As the sensitivity of L-band radiometer to the foam has already been demonstrated [Nordberg, 1971], we could conclude from this joint analysis that C-band radar in cross-polarizations is

- more sensitive to foam than in co-polarization

or

- Sensitivie to different breaking waves than in cross-polarizaiton, those breaking waves being less directional and directly linked to the foam contributing to L-Band

The reason for this similarity is still to be fully explained. This may be answered with electromagnetic model coupled with ocean surface model to simulate both passive and active signals

To be done

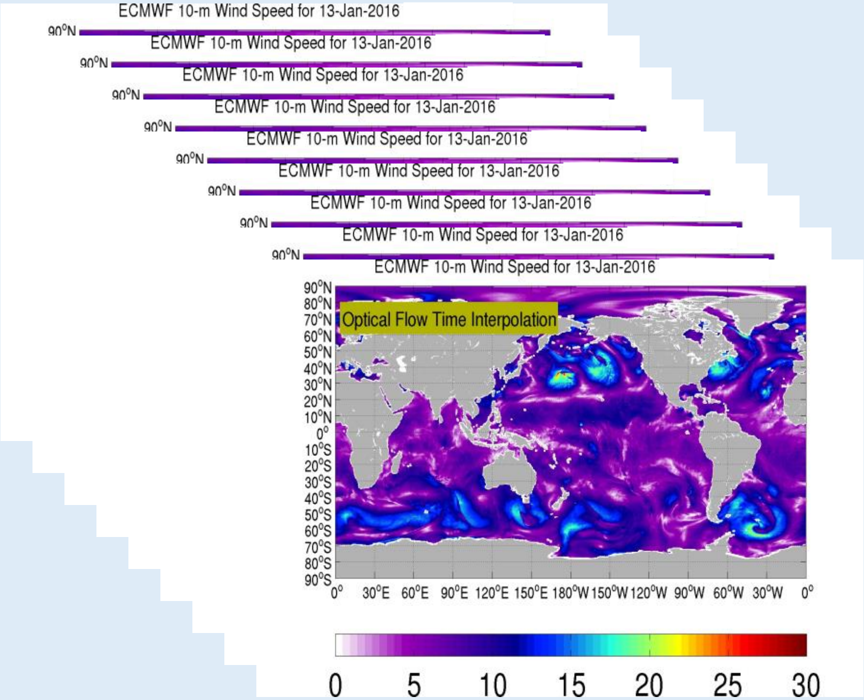
Example 4: Combining the wind estimates with model

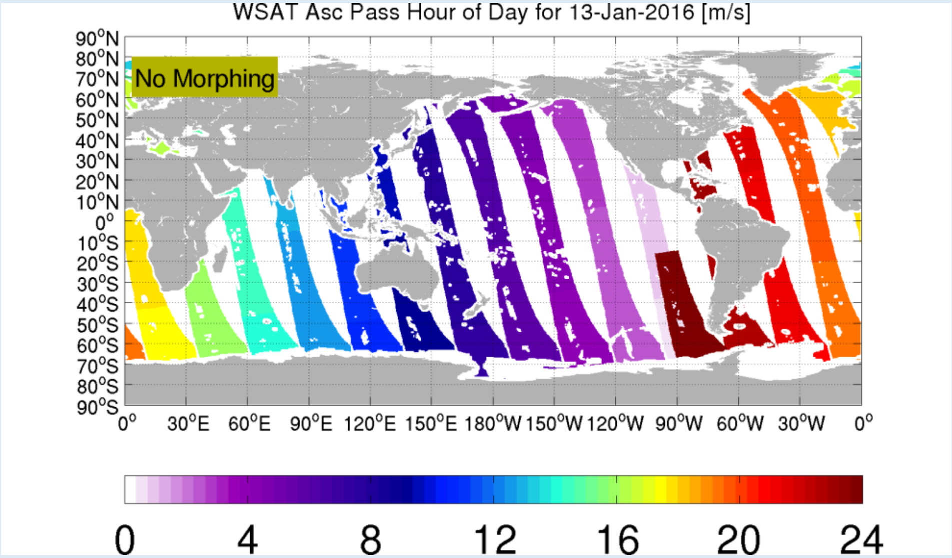
Although the combination of low resolution measurements allows a higher resolution sampling of the storms, the sampling is not on a regular grid in time and space.

Assimilation schemes used to include wind measurements in the numerical models usually assimilate zonal and meridional components of the wind field, reject the stongest values of wind speed as measured by radiometers and decimate the data before assimilation.

Another approach is to use the model as a guide to interpolate the observations on a regular grid in space and time and provide a product that combines the data without the limitation of the assimilation.

Example 4: Combining the wind estimates with model





The model outputs are used at each time step available during a window of 24 hours to compute the flow field

All observations available during this windows are considered

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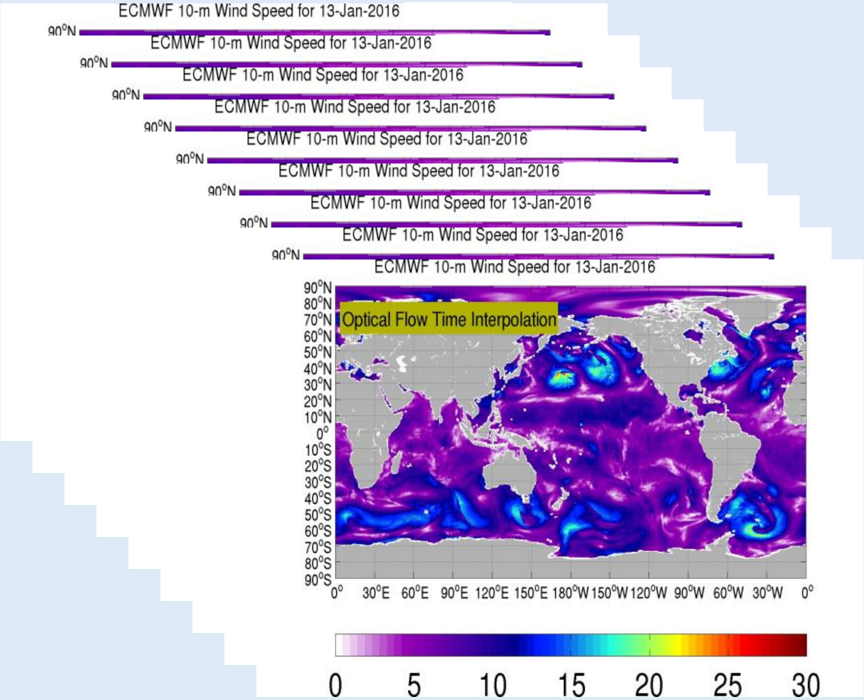

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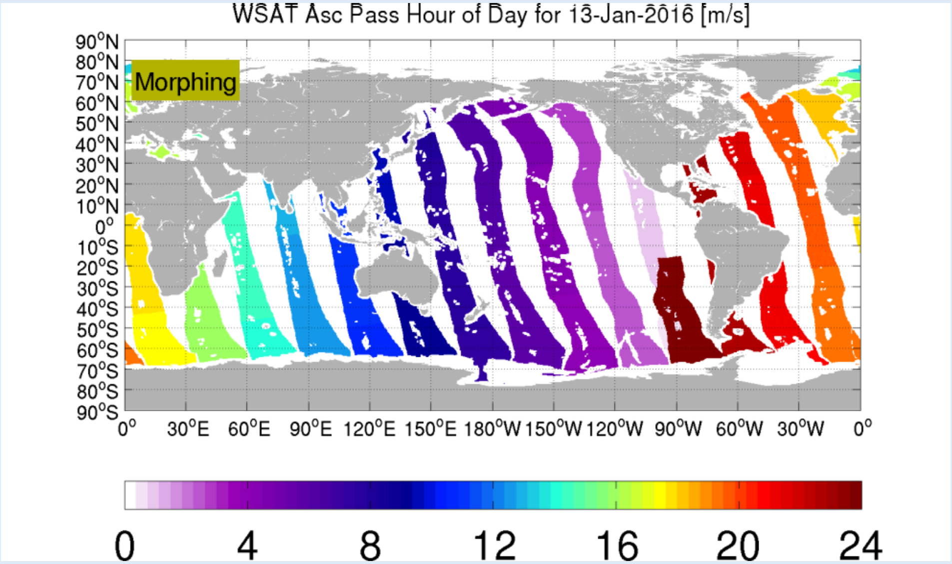

All observations available during this windows are considered and morphed with respect to the flow field estimated from the model

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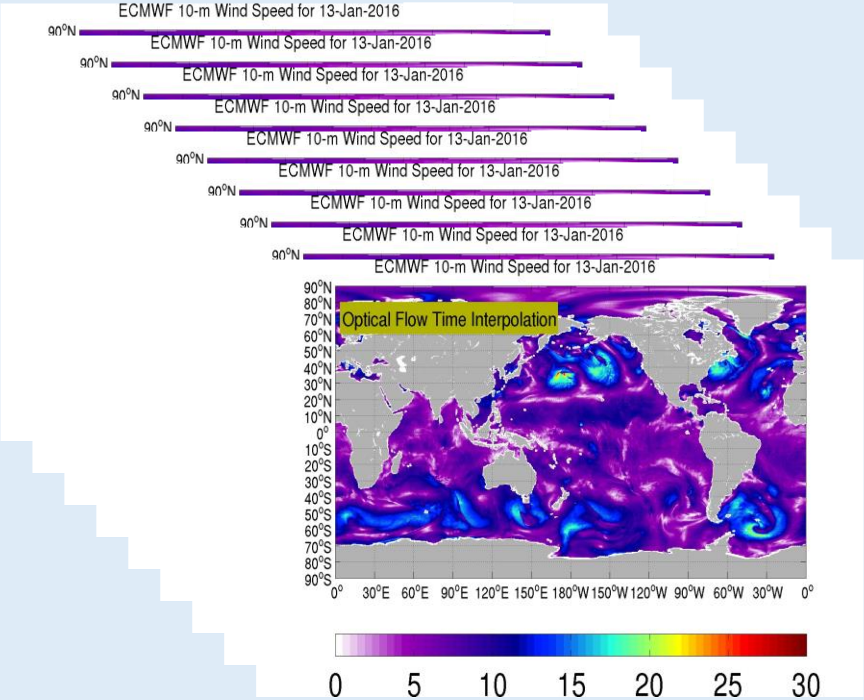

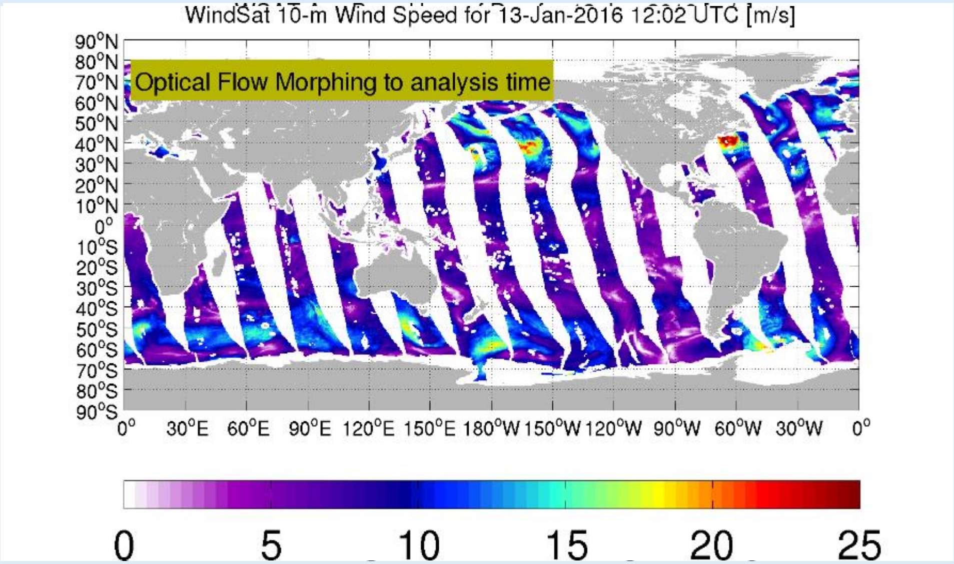

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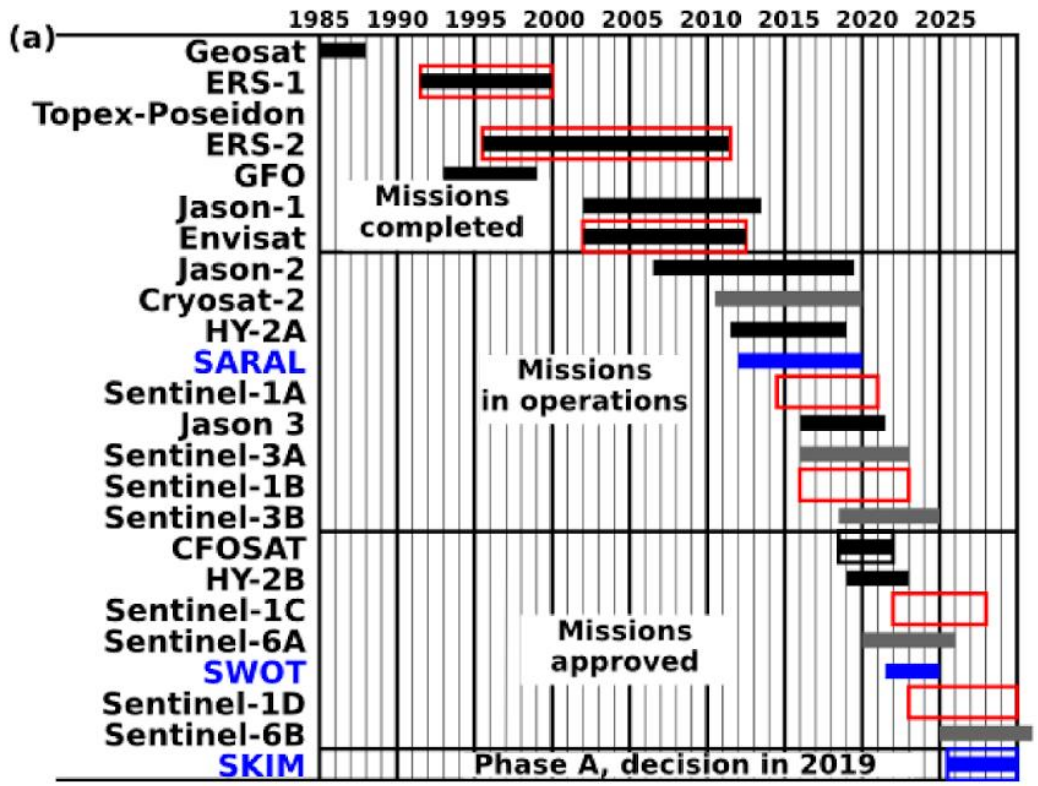
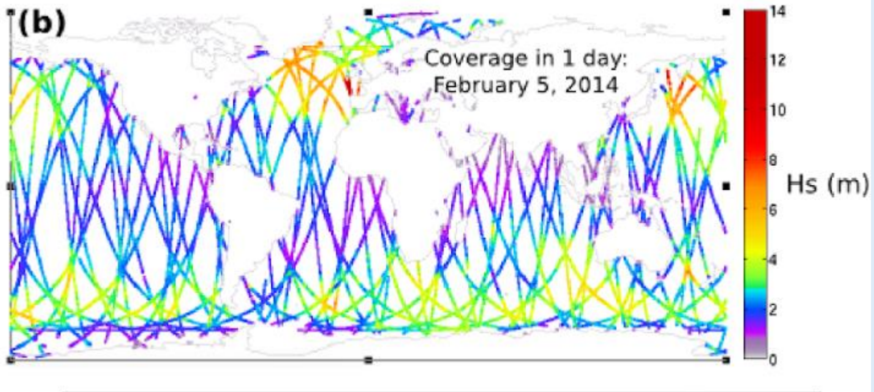
All observations available during this windows are considered and advected with respect to the flow field estimated from the model to produce wind estimates at any given time

Example 4: Combining the wind estimates with model

Synergy Example :
Tropical Cyclone Intensity & Tropical Cyclone Waves

- Two types of sensor can provide information on waves through the clouds
    - Altimeters provide a significant wave height measurement along the satellite track



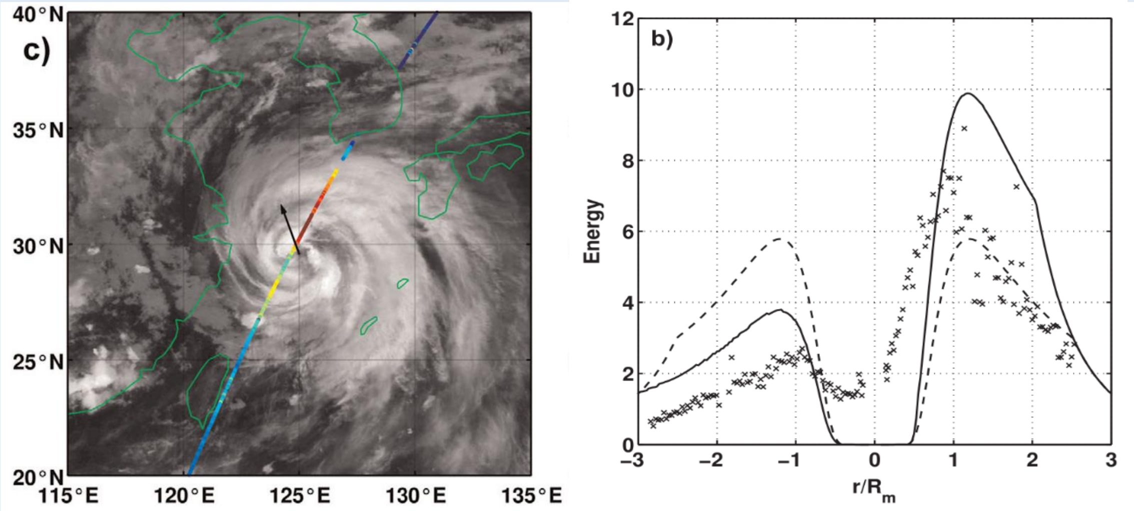


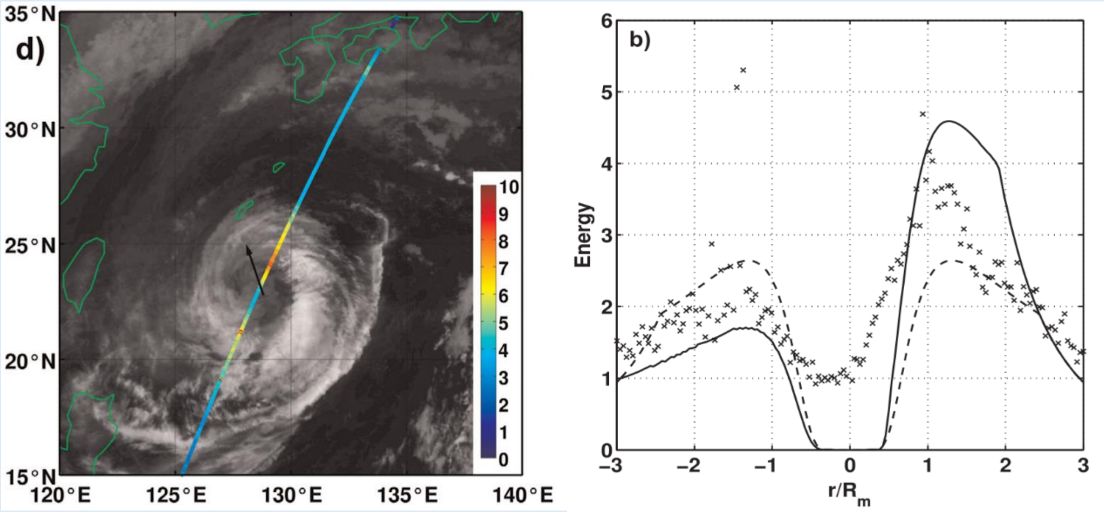
Altimeters have no swath. This is a strong limitation for coverage.

2016-2020 is the golden age of altimetry with 6 different satellite missions.

- Two types of sensor can provide information on waves through the clouds
    - Altimeters provide a significant wave height measurement along the satellite track

The exploitation of altimeters measurements allowed to provide empirical and semi-empirical models to estimate integrated waves parameters with respect to storm parameters such as translation speed, maximum sustained wind speed and radius of maximum wind speed





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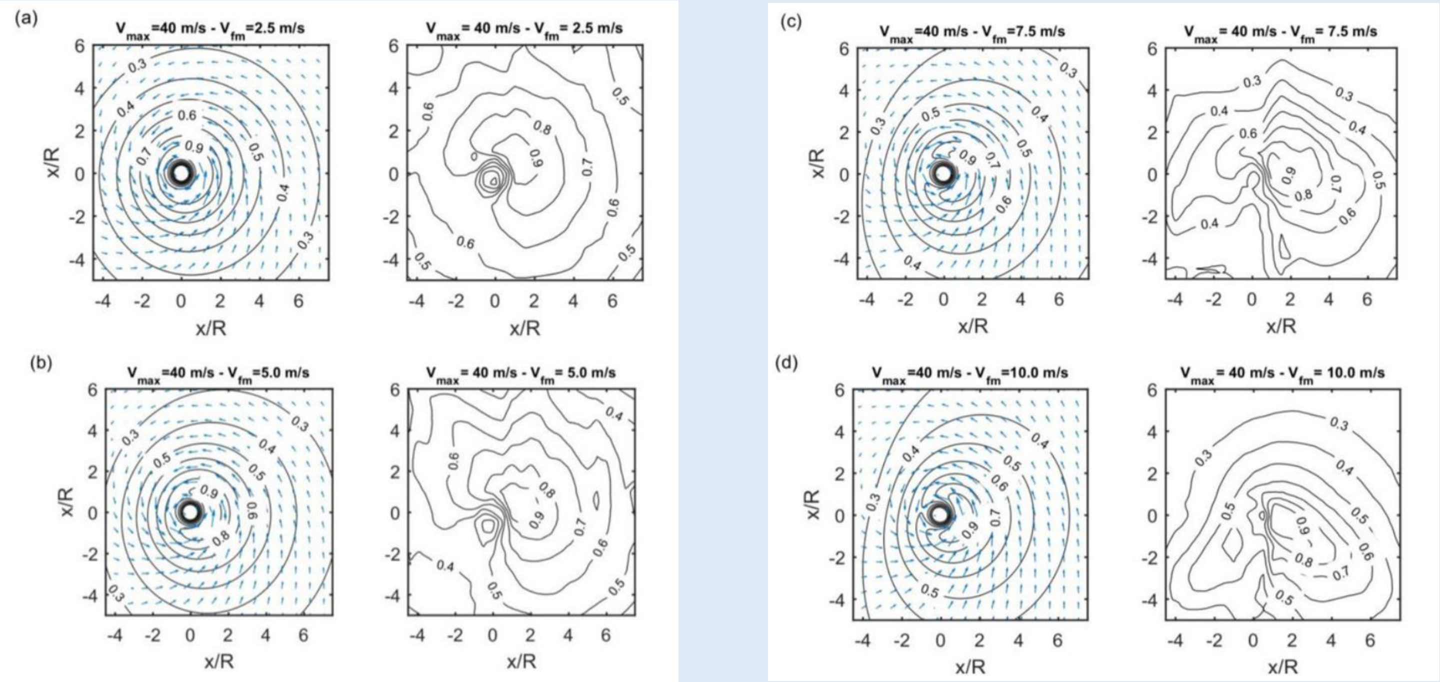


Tropical cyclone wind fields and associated wave fields. The wind is calculated from the Holland vortex and the waves from the results of Young. The contours show normalized wind speed U_{10}/V_{max} (left) and normalized wave height $H_s/H_{max\,s}$ (right). Each of the panels (a–d) are for a different combination of V_{fm} and V_{max}, as marked

- Two types of sensor can provide information on waves through the clouds
  - Altimeters provide a significant wave height measurement along the satellite track
  - SAR provide an estimate of the ocean swell

    SAR has been used for a while to provide ocean swell measurements and then to combined all swell mesurements available from SAR at different times but corresponding to the same storm.

Tropical Cyclone Intensity & Tropical Cyclone Waves

November 2020

Tropical Cyclone Intensity & Tropical Cyclone Waves

- Two types of sensor can provide information on waves through the clouds
  - Altimeters provide a significant wave height measurement along the satellite track
  - SAR provide an estimate of the ocean swell

Same exercice is applied to the case of Tropical Cyclones

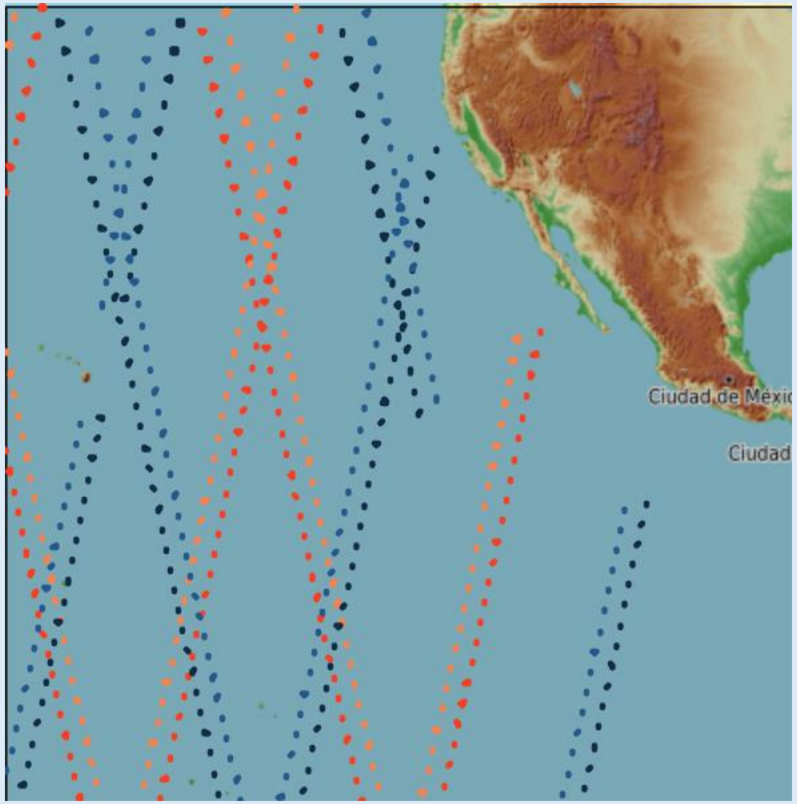
Data used

- Sentinel-1 A and Sentinel-1 B operating in Wave Mode

  SAR is used to estimate the swell wavelength and direction with the x-spectra computed from wave mode acquisitions
- Tropical Cyclone tracks

  Tracks are used to know the location of the TC w.r.t to time and help finding the waves source.
- L-band radiometer

  SMOS-derived wind define the TC vortex structure



Tropical Cyclone Intensity & Tropical Cyclone Waves

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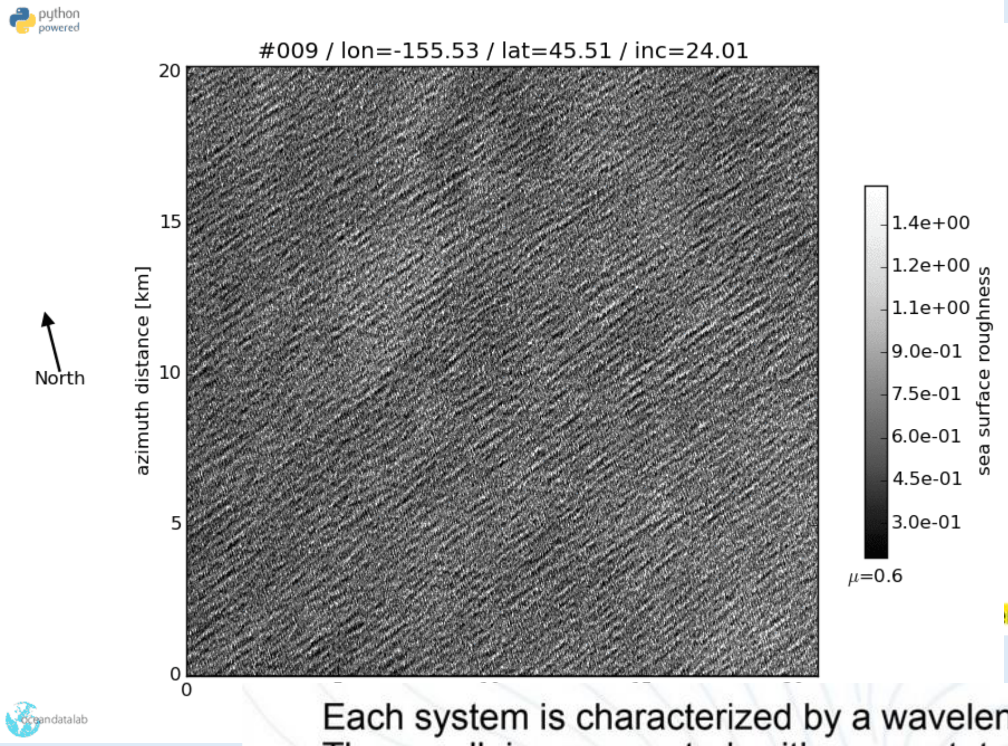
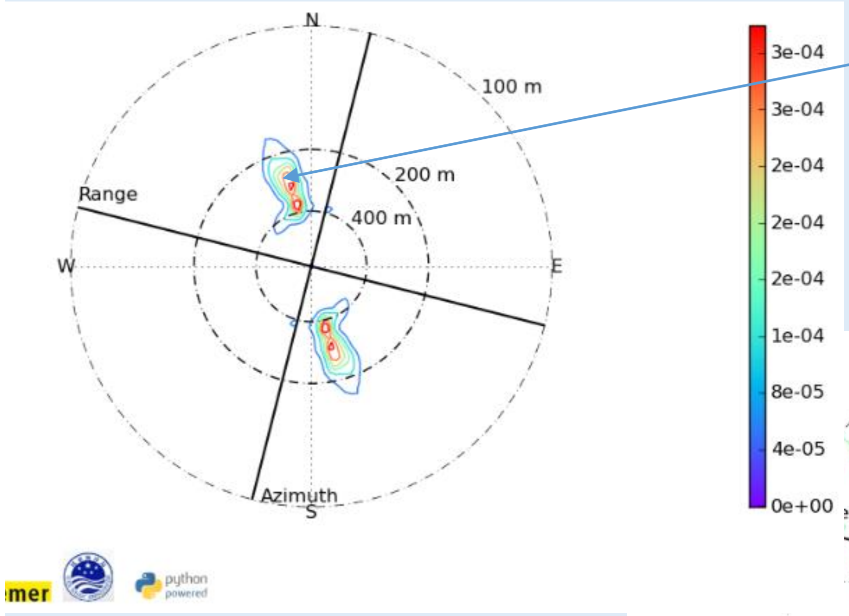
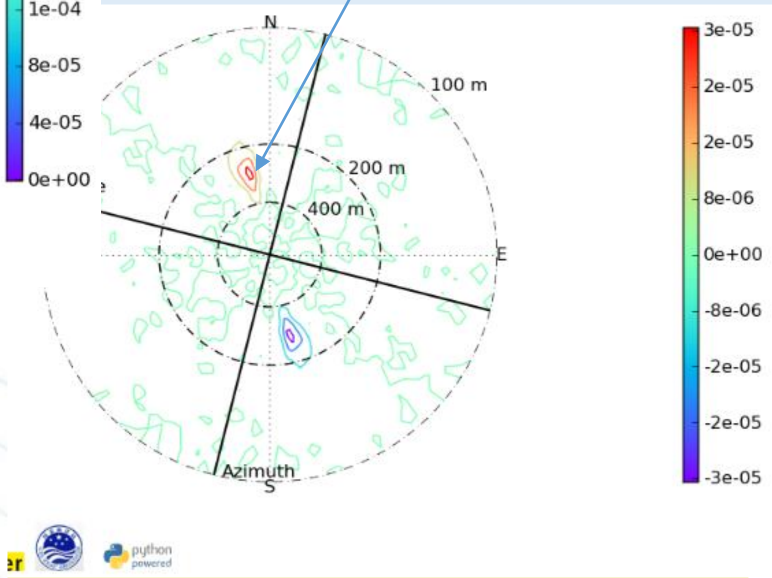




Swell Peak signature. Wavelength, direction

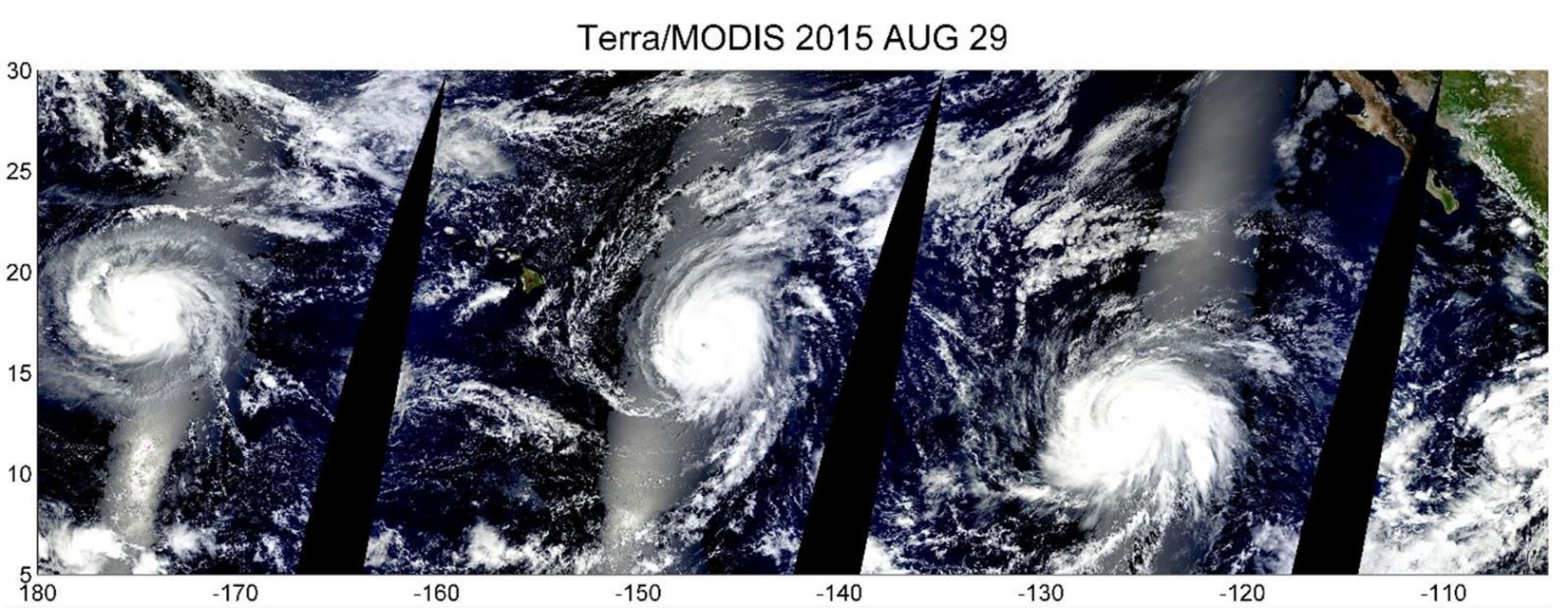


Each system is characterized by a wavelength, direction and a significant wave height. The swell is propagated with respect to its direction and group velocity assuming propagation in open ocean without swell-current interactions.

$c_g = \frac{1}{2}\sqrt{\frac{g\lambda}{2\pi}}$, where λ is the wavelength of the wave partition to propagate and g the acceleration of gravity constant.

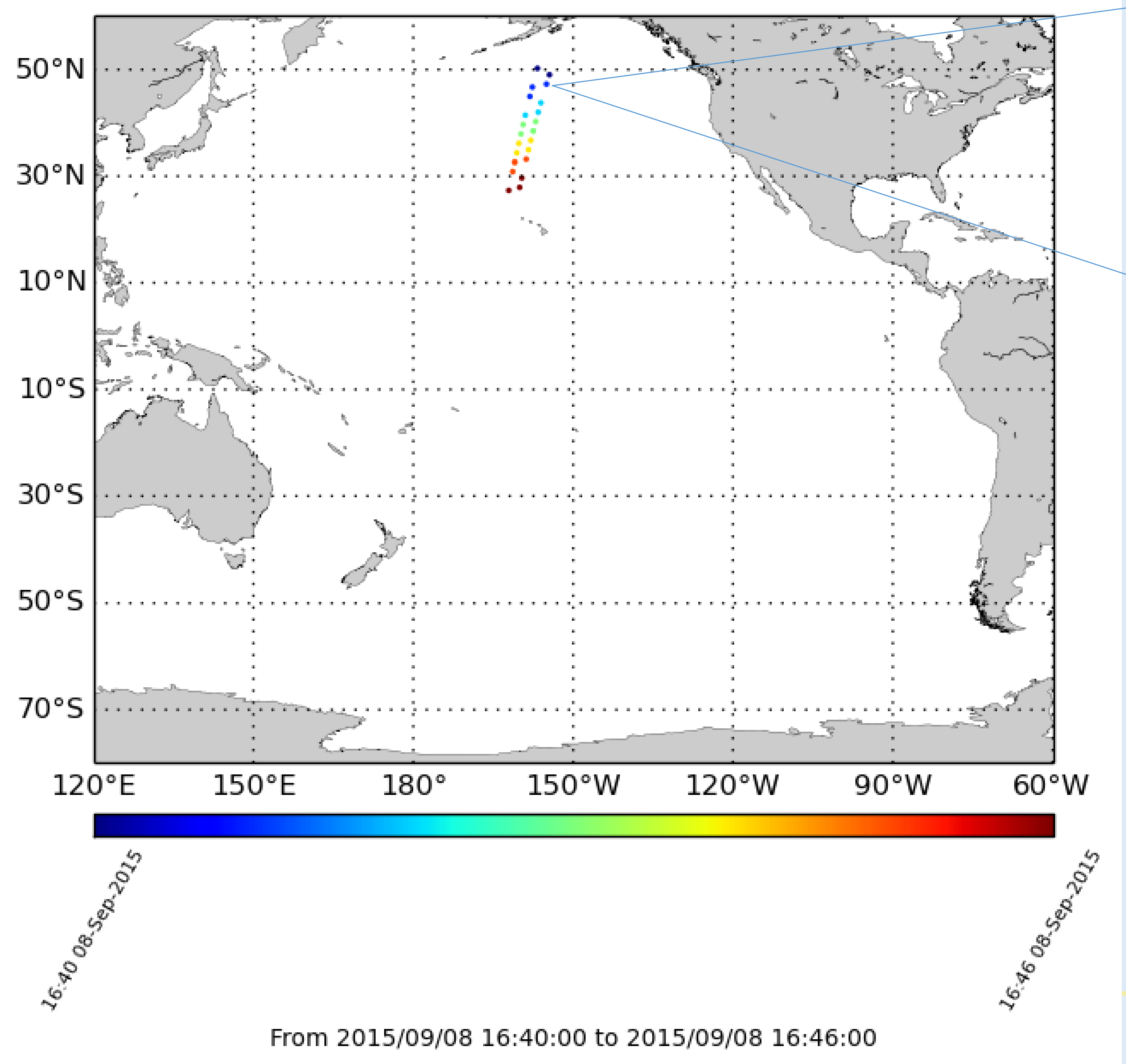
Tropical Cyclone Intensity & Tropical Cyclone Waves

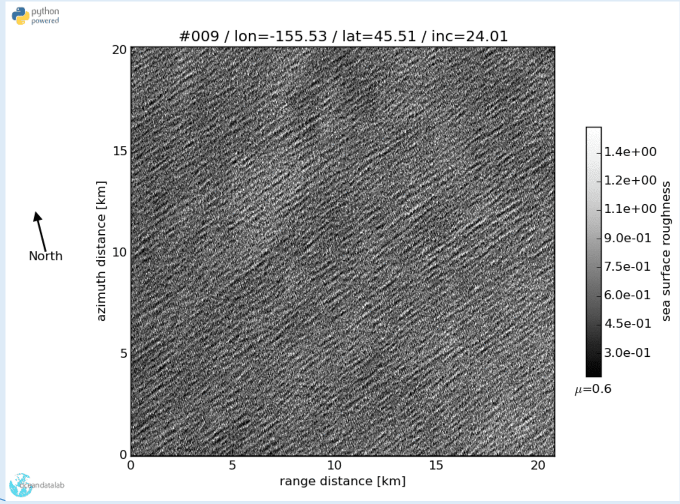
- Two types of sensor can provide information on waves through the clouds
  - Altimeters provide a significant wave height measurement along the satellite track
  - SAR provide an estimate of the ocean swell

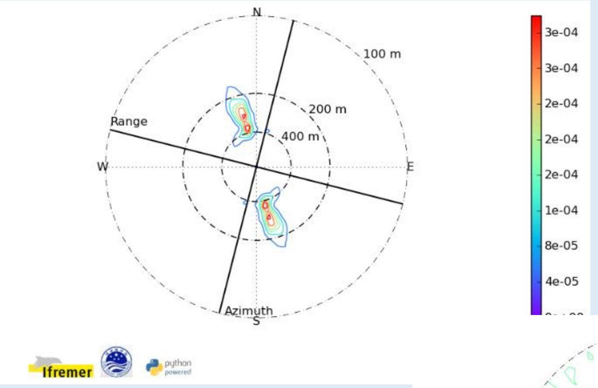


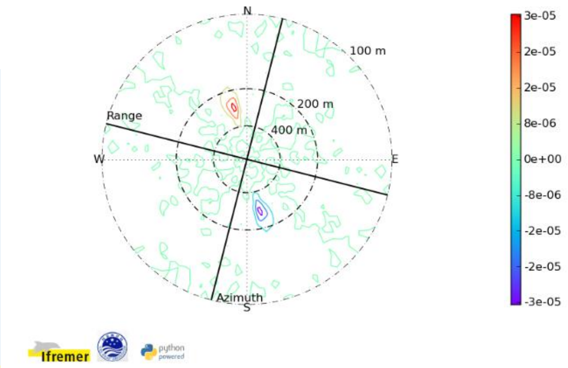
Kilo Ignacio Jimena

Tropical Cyclone Intensity & Tropical Cyclone Waves

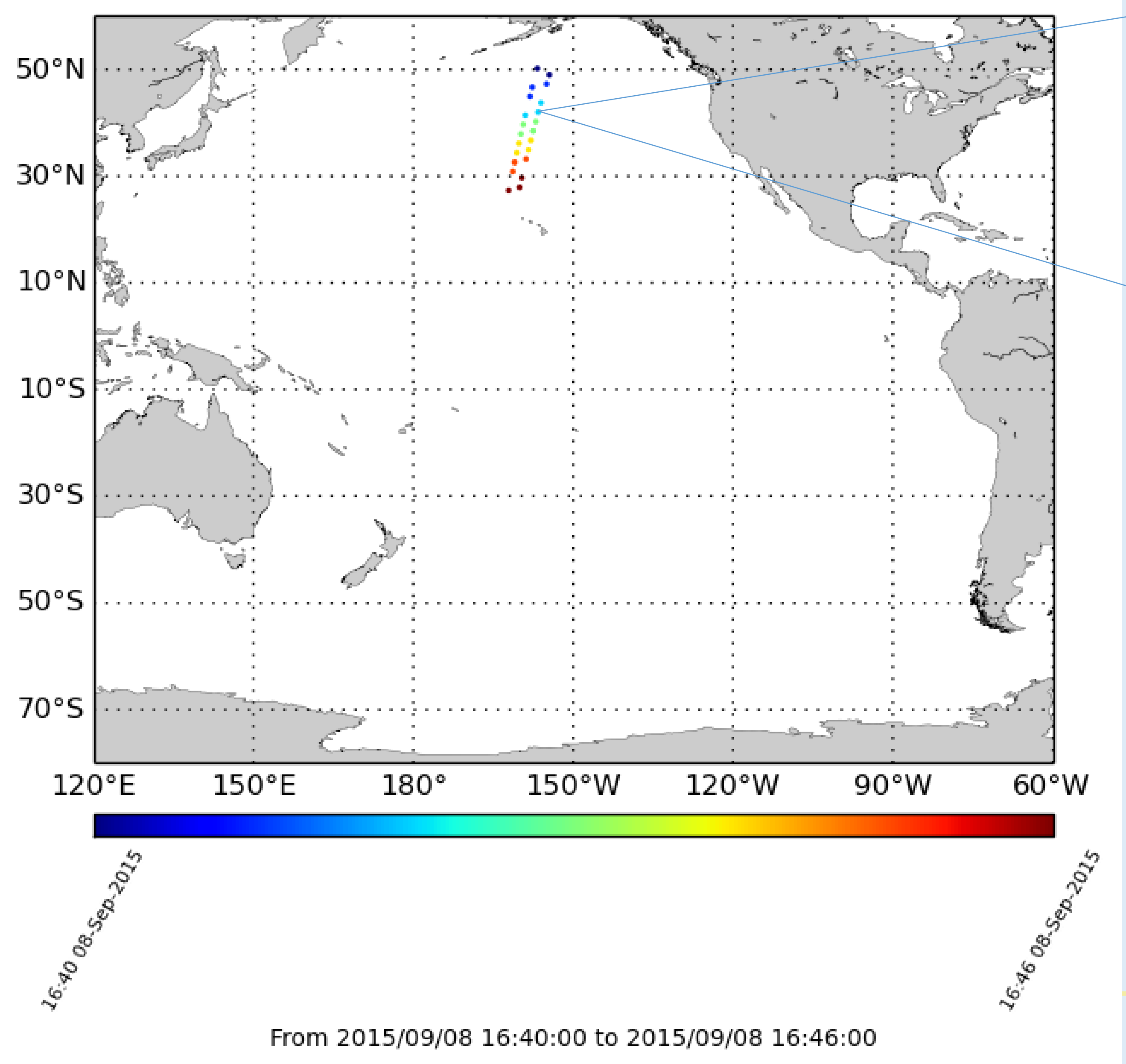


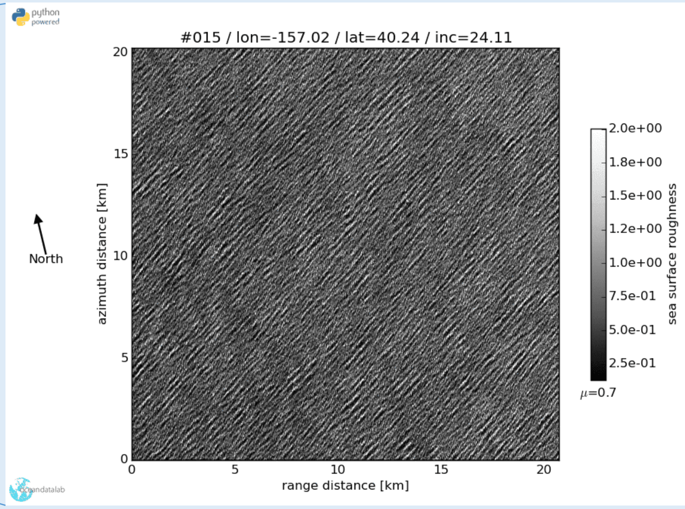


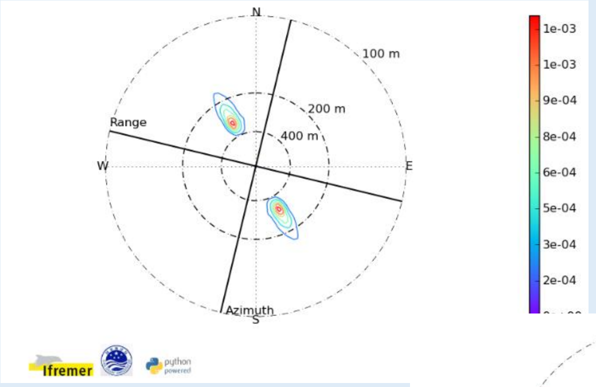


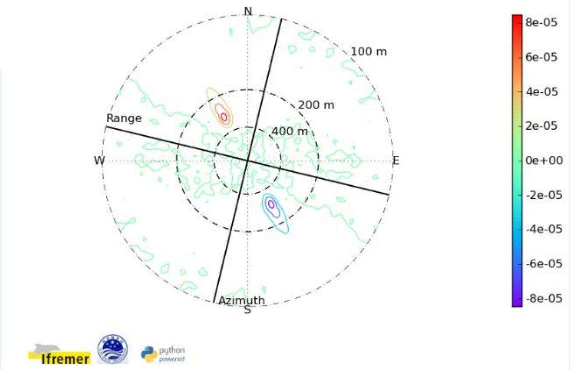


Tropical Cyclone Intensity & Tropical Cyclone Waves

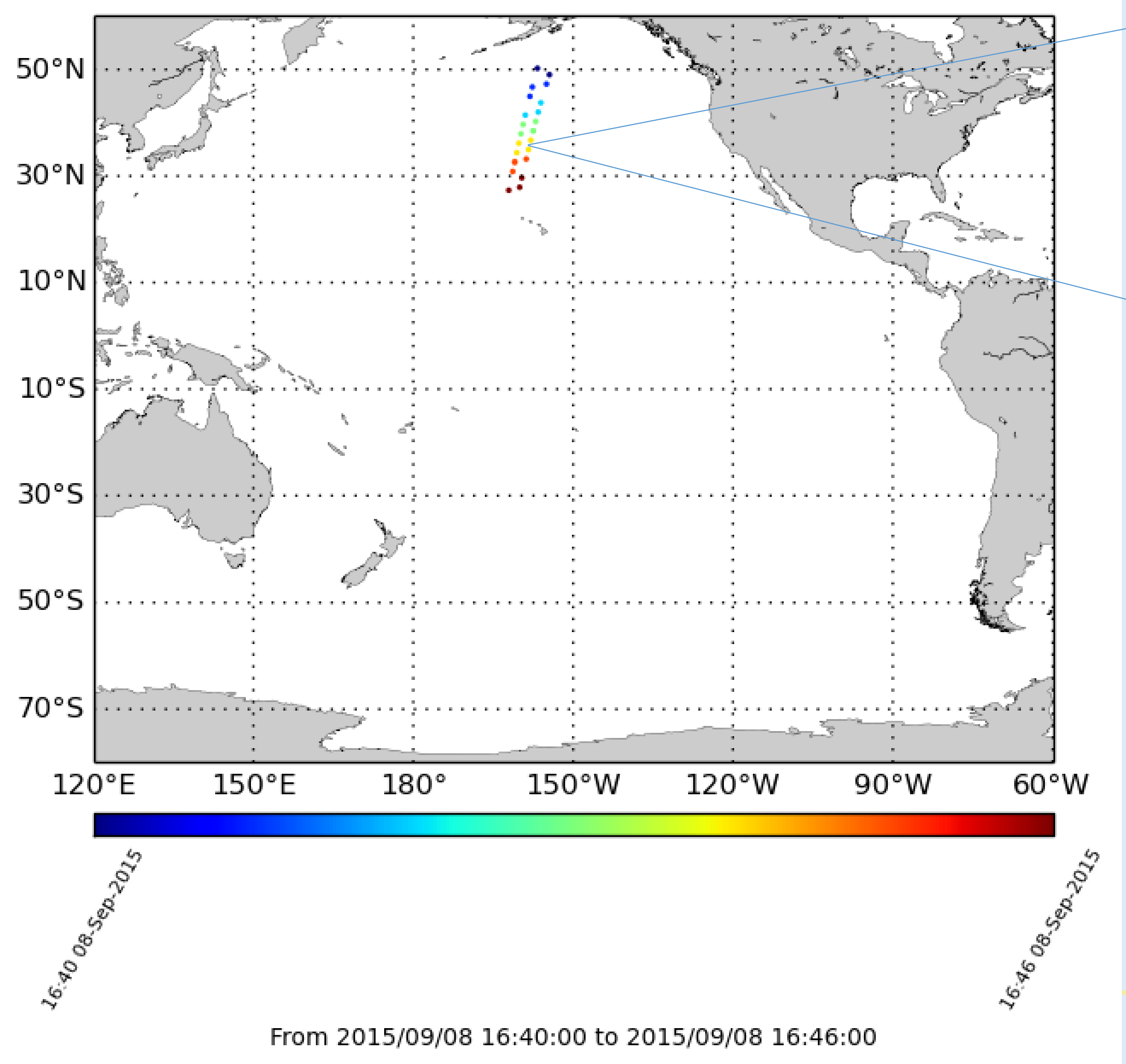


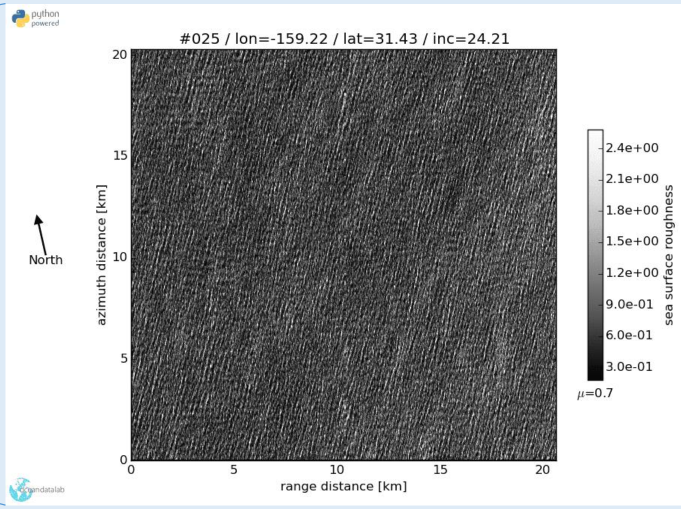


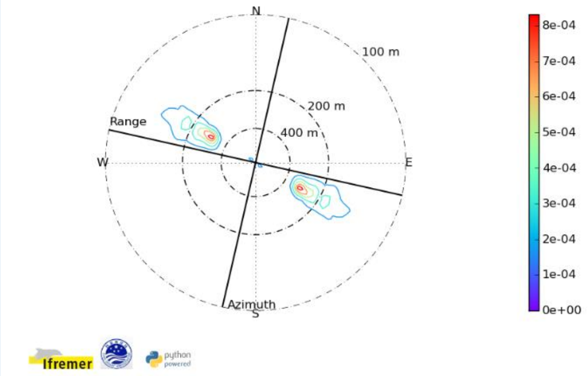


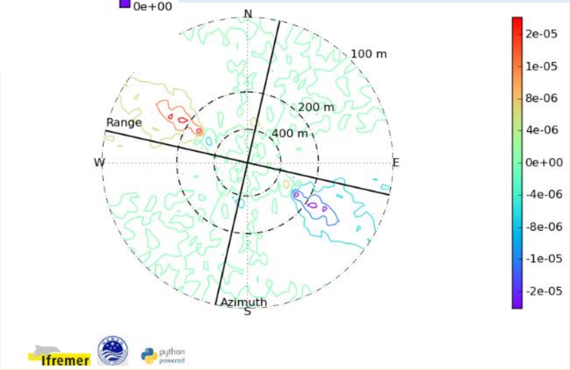


Tropical Cyclone Intensity & Tropical Cyclone Waves

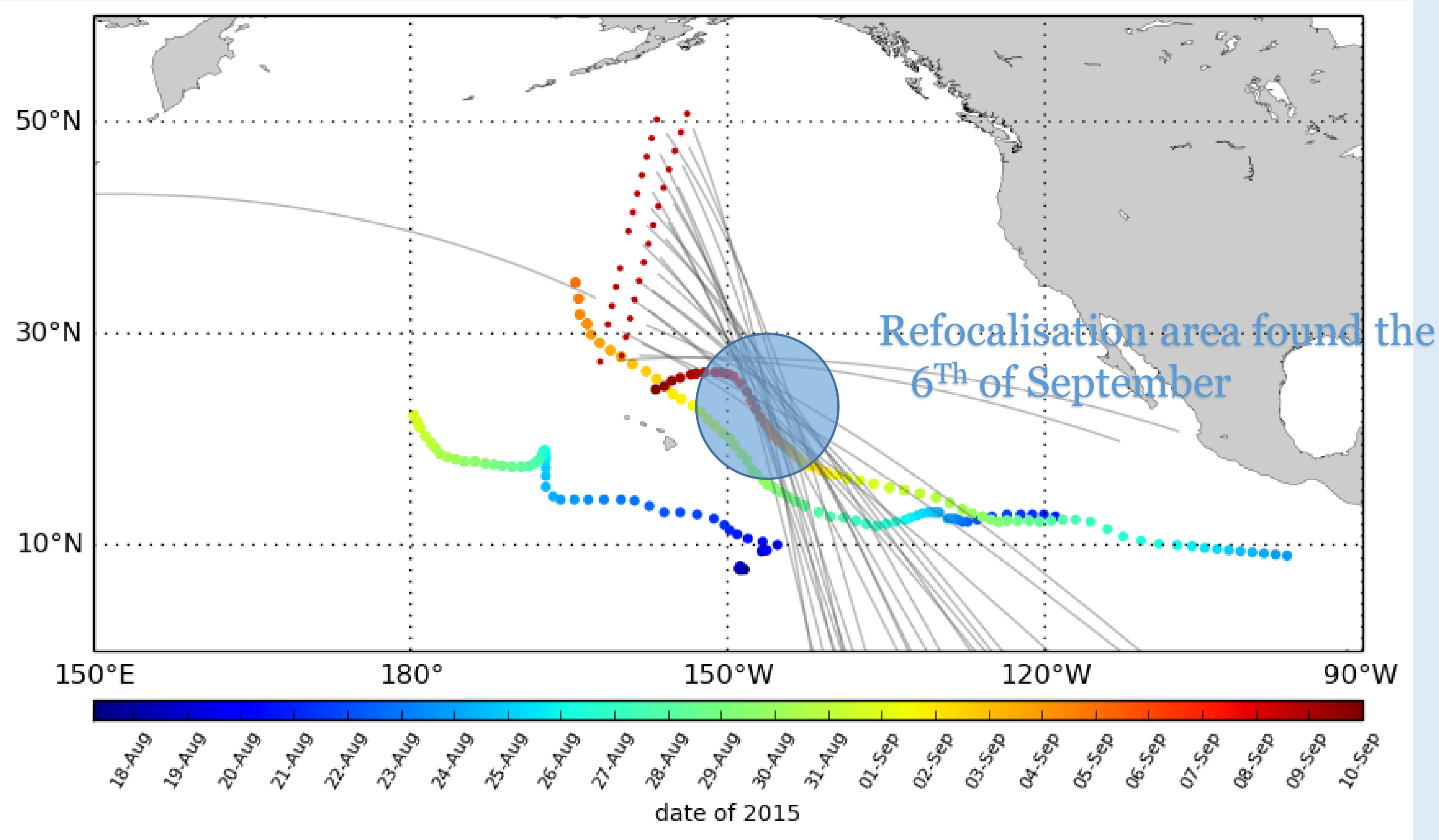








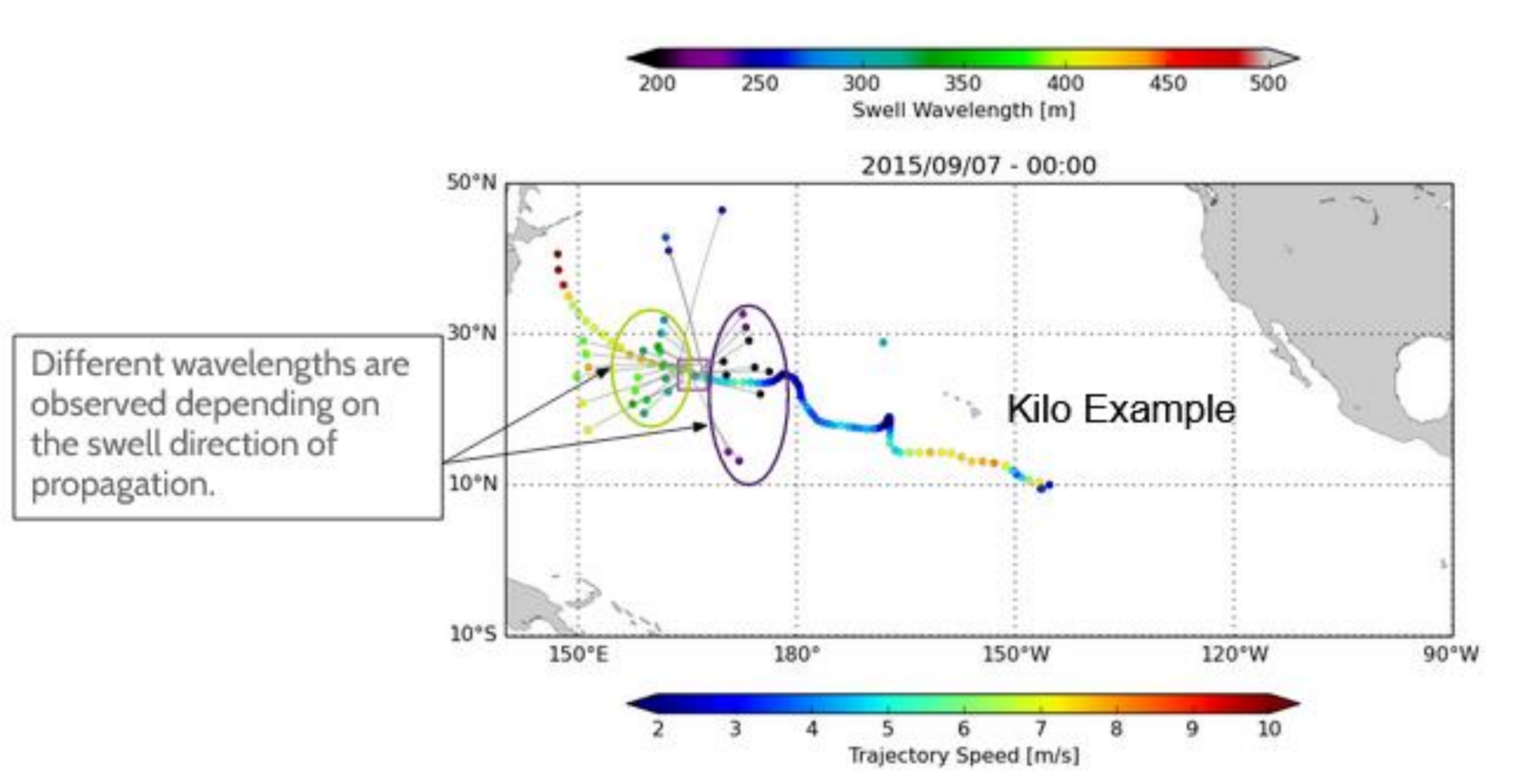
Tropical Cyclone Intensity & Tropical Cyclone Waves

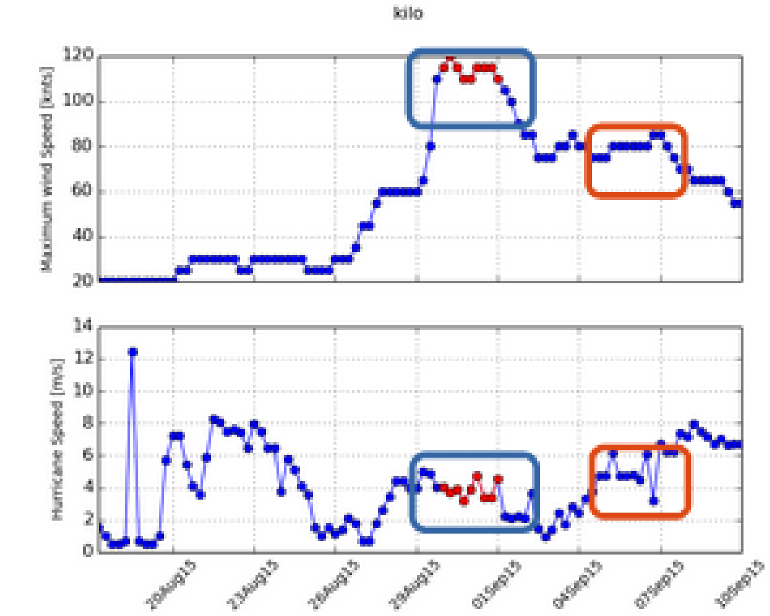


Example of retro-propagated Sentinel-1 A Swell Measurements. Data acquired the 2015 Sept 8 16:40 to 16:46 UTC.

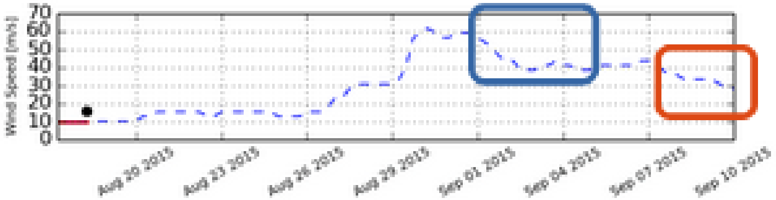
Refocalisation area is found along the Jimena track the 6th of September. On the right hand side of the track.

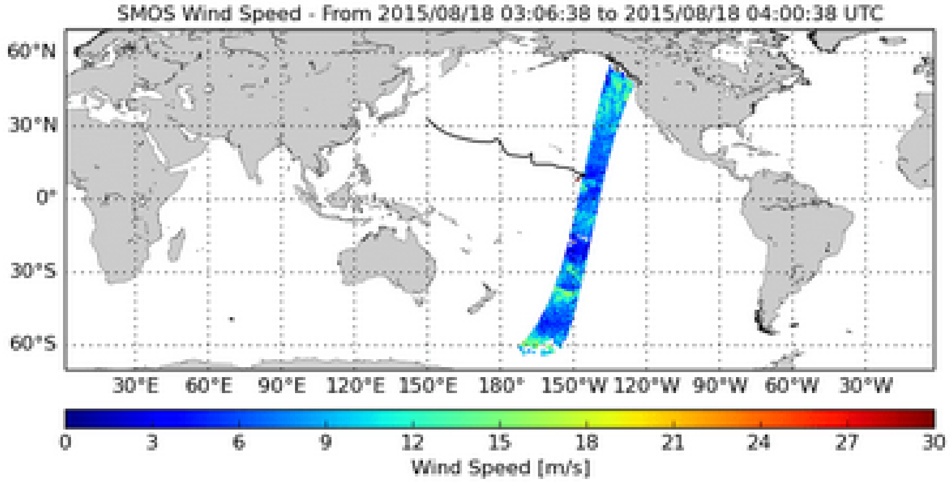
Tropical Cyclone Intensity & Tropical Cyclone Waves



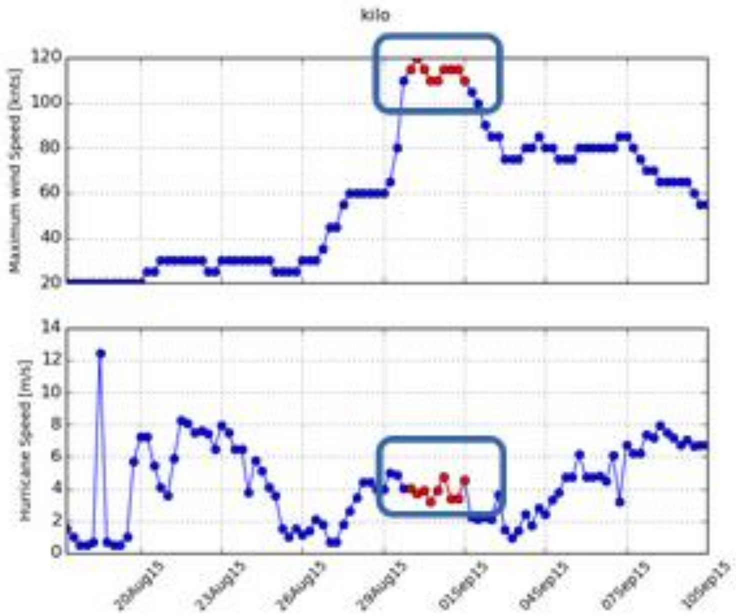


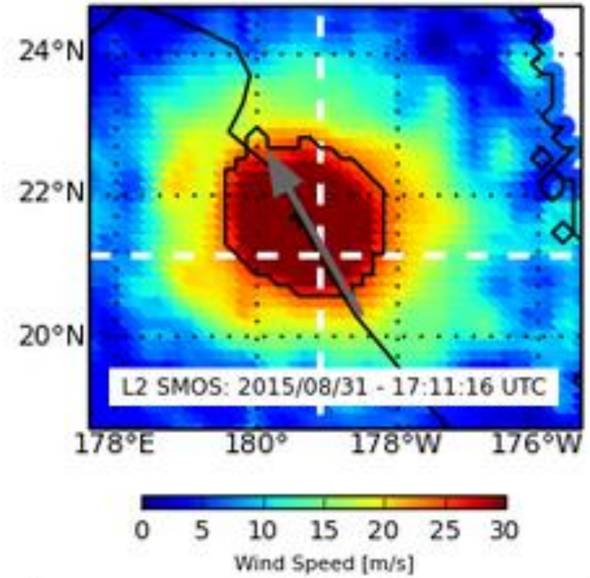
- Kilo is interesting case because it has several phases of development
  - Extreme wind speed/narrow radius of maximum wind speed/slow motion
  - Moderate wind speeds/large radius of maximum wind speed/slow motion





Tropical Cyclone Intensity & Tropical Cyclone Waves



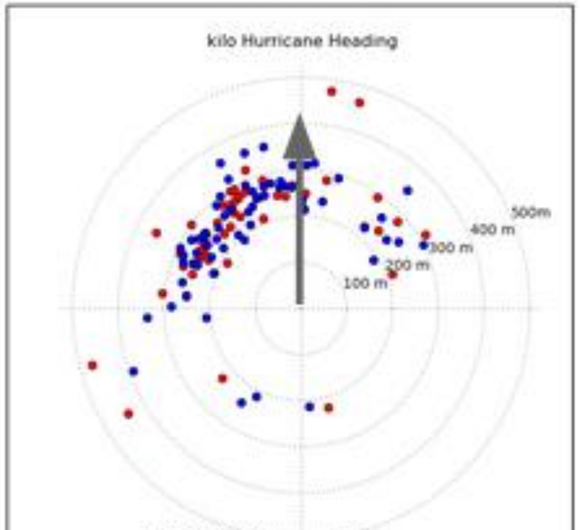


In this case where,

- Wind speed is very intense (110-120 kts),
- Hurricane translation speed is 4 m/s,
- Radius of maximum wind speed is about 100 km

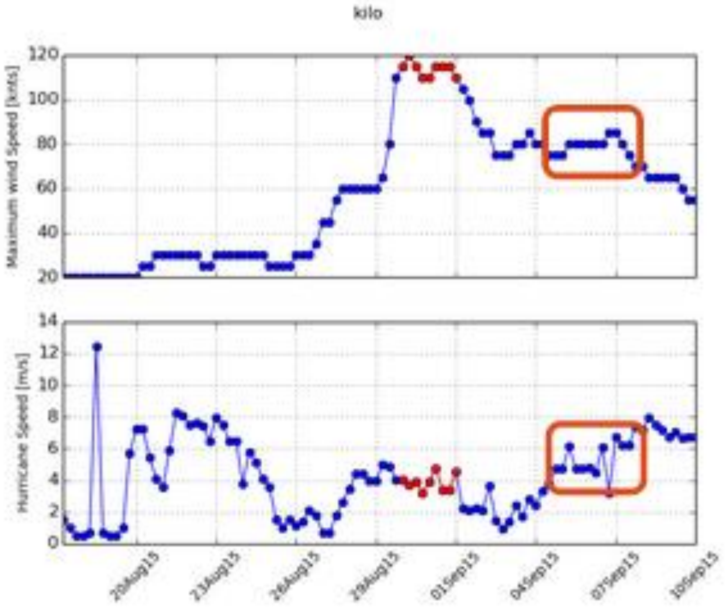
The extended fetch is small. Front/Rear asymmetry between wind generated waves wavelengths is not pronounced (300/200m).

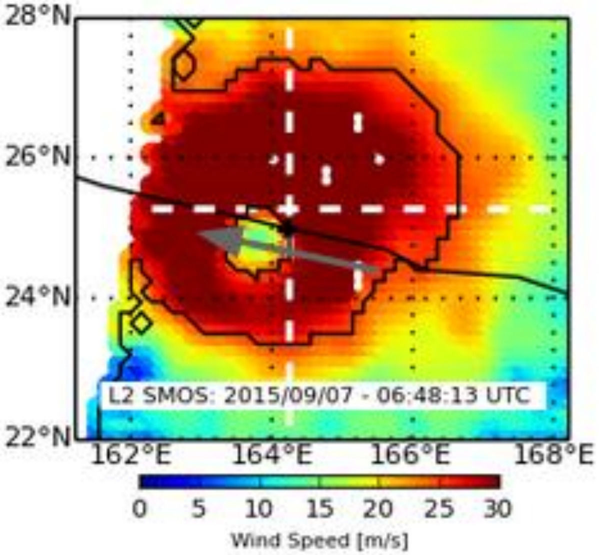
No Left/Right asymmetry can be observed.



TC Waves Rose

Tropical Cyclone Intensity & Tropical Cyclone Waves



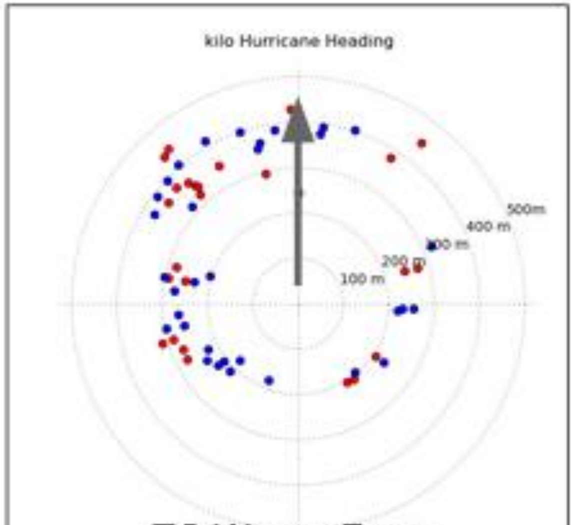


In this case, where

- Wind speed is less intense (~80 kts),
- Hurricane translation speed is the same (~4 m/s),
- Radius with wind speed > 25 m/s is about 200 km

The extended fetch is higher than in the previous case. Front/rear asymmetry in the hurricane generated waves wavelength is very pronounced. No left/right asymmetry.

200 m wavelengths are emitted at the rear whereas wavelengths up to 400 m are generated ahead of the TC

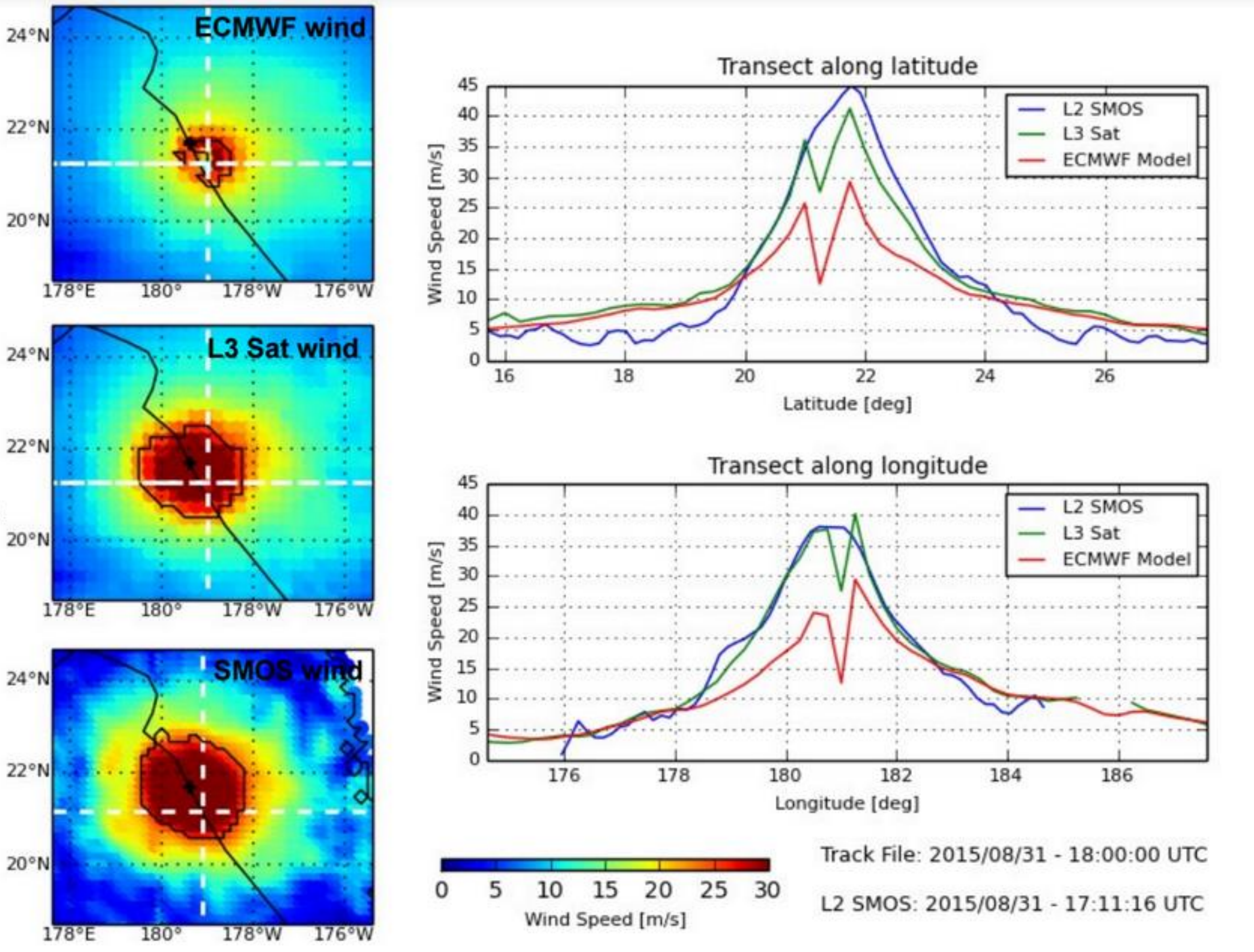


TC Waves Rose

Tropical Cyclone Intensity & Tropical Cyclone Waves

Between L2 SMOS, L3 Winds and ECMWF wind speeds

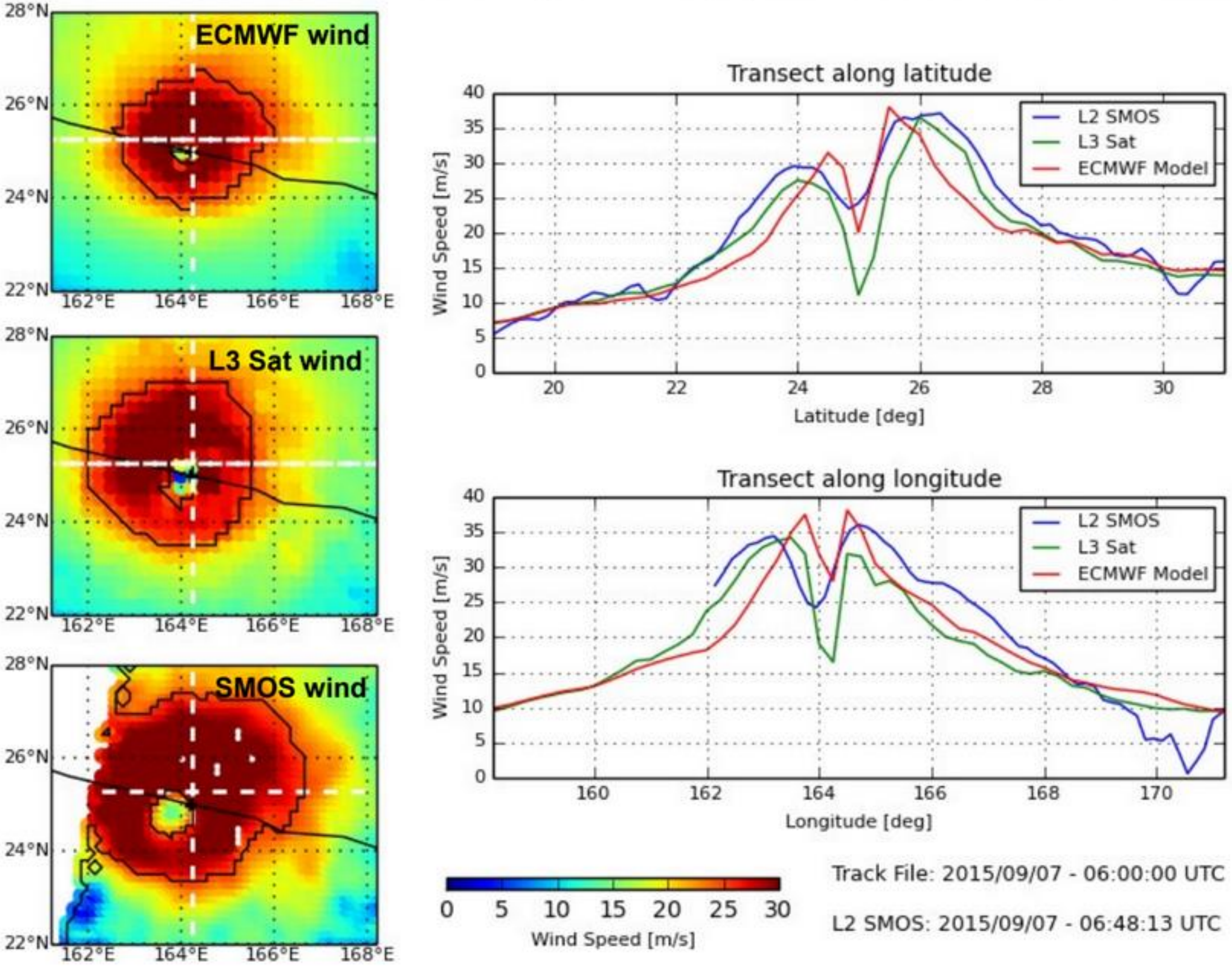
- Radius of the maximum wind speed are comparable
- Maximum wind speeds from measurements are significantly higher



Tropical Cyclone Intensity & Tropical Cyclone Waves

Between L2 SMOS, L3 Winds and ECMWF wind speeds

- Radius of the maximum wind speed are comparable
- Maximum wind speeds are comparable



Tropical Cyclone Intensity & Tropical Cyclone Waves

- Swell generated by hurricanes can be documented using Sentinel-1A coupled with hurricanes tracks and taking advantage of the back-propagation technique.

- Application to Kilo hurricane, show that S-1A enables to describe the wavelength emitted by hurricane:
  - wavelength variation of hurricanes generated waves can be studied with respect to their propagation direction and during the hurricane lifetime
  - wave properties as observed by SAR are consistent with available wind speed from SMOS or/and other radiometers measurements. The extended fetch effect is clearly observed

Synergy Example :
Tropical Cyclone Intensity & Tropical Cyclone Wake

Tropical Cyclone Intensity & Tropical Cyclone Wake

- Here the goal is to study the relationship between the TC wake properties and the TC vortex properties.

- Focus is the cooling of the sea surface temperature and the trench in the sea surface height following work from Kusryavtsev et al. (2019), where it is assumed that the ocean response to a moving TC is largely dominated by baroclinic effects to derive the following relationships between sea surface anomaly (SSTA) or the sea surface height anomaly (SSHA) and TC properties (Vmax, Rmax, Vfm) and the Brunt-Väisälä frequency of the seasonal thermocline (N).

$$\frac{SSTA}{V_{max} \cdot N^{(3/2)} / (g \cdot \alpha \cdot f^{(1/2)})} \propto \left(\frac{V_{fm}}{f \cdot R_{max}}\right)^{-1}$$

$$\frac{g \cdot SSHA}{V_{max}^2} \propto \frac{R_{max} \cdot N}{V_{fm}}$$

- First analysis of SST anomalies due to TC have been performed by Ginis (2002) and for instance more recently by Mei and Pasquero (2013) or Vincent et al. (2012).

- First analysis of SSH anomalies due to TC have been performed by Emanuel (2001) .

Sea Surface Height

- For SSH, 6 different altimeters are used to get the maximum observations available.

Instrument	Jason 1 Poseidon-2	Jason 2 Poseidon-3	Jason 3 Poseidon-3B	HY-2A ALT	SARAL Altika	Cryosat-2 SIRAL	S3A SRAL
Chanel	C/Ku	C/Ku	C/Ku	C/Ku	Ka	Ku	C/Ku
Orbit	66	66	66	SSO	SSO	near polar	SSO
Cycle (days)	10	10	10	14	35	29	27
Center	CNES	CNES	CNES	NSOAS	CNES	ESA	ESA
Version	j1n/j1g	j2/j2n	j3	h2/h2g	al/alg	c2	s3a
Years	2002-2013	2008-now	2016-now	2011-now	2013-now	2011-now	2016-now
Database	2010-2013	2010-2018	2016-2018	2011-2018	2013-2018	2011-2018	2016-2018

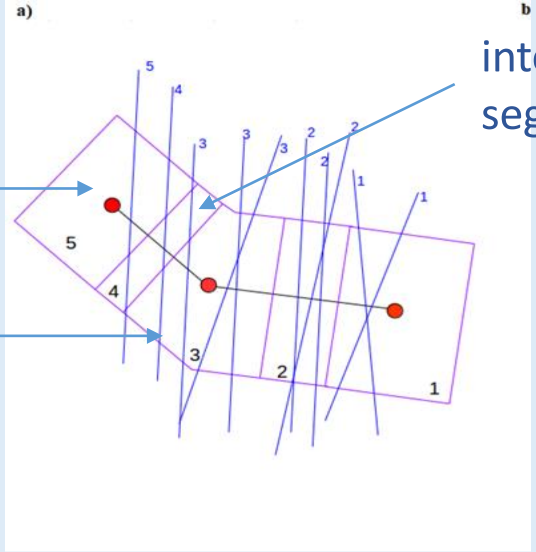
Tropical Cyclone Intensity & Tropical Cyclone Wake

Instead of using a daily product that gathers all the measurements with unadapted averaging, here each track is analyzed individually w.r.t the TC location.

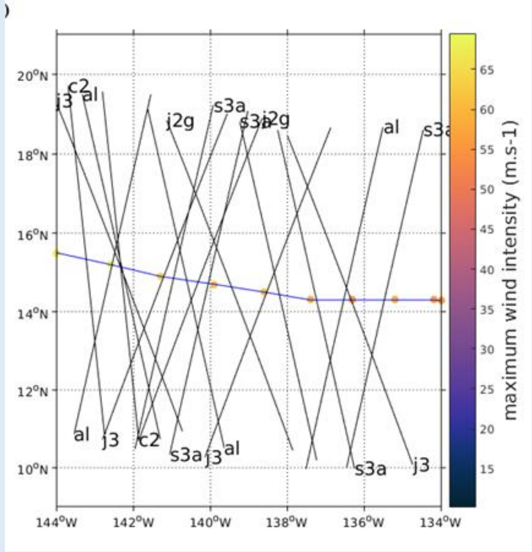
Each segment between the 6 –hourly track information is divided into three equivalent segments (2 collocated. 1 intermediate). In the intermediate segment, the track information are interpolated.

The pre-storm condition associated to sea surface height is computed using the measurements acquired during the 2 weeks before the storm arrival.

Collocated segment



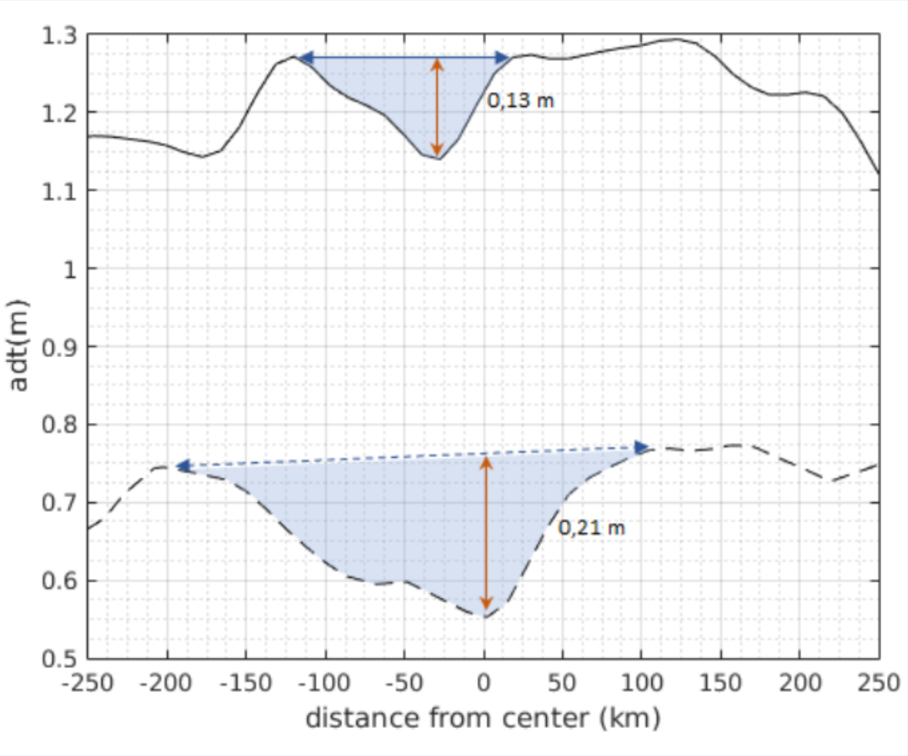
intermediate segment



Tropical Cyclone Intensity & Tropical Cyclone Wake

The sea surface height anomaly is computed for each track.

Within each segment, the altimeter track with highest value of anomaly is kept for the analysis



Example of two sea surface height anomalied as measured by altimeter for Hector (top) and Lane (bottom) TC

Sea Surface Temperature

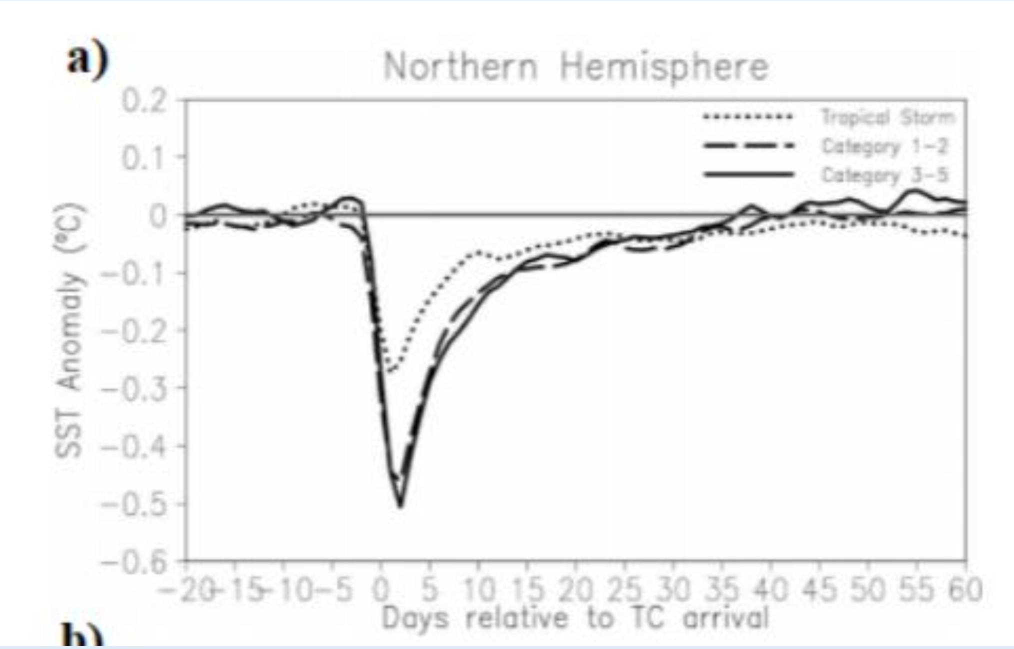
- For SST the analysis has been done from daily products.

	L4-SSH	OSTIA	REMSS	ISAS-15	Argo
Type/Level	L4-daily	L4-daily	L4-daily	Climatology	Individual Profile
Resolution	0.25	0.25	0.25	0.01	fluctuating
Version	Delayed mode	N/A	1)MW 2)MW+IR	N/A	Delayed only
Center	CMEMS	CMEMS	REMSS	IFREMER	CMEMS
Database	2010-2018	2010-2018	2010-2018	N/A	2010-2018
Variables	SSH	SST	SST	N-frequency	N-frequency, MLD/SST/SSS

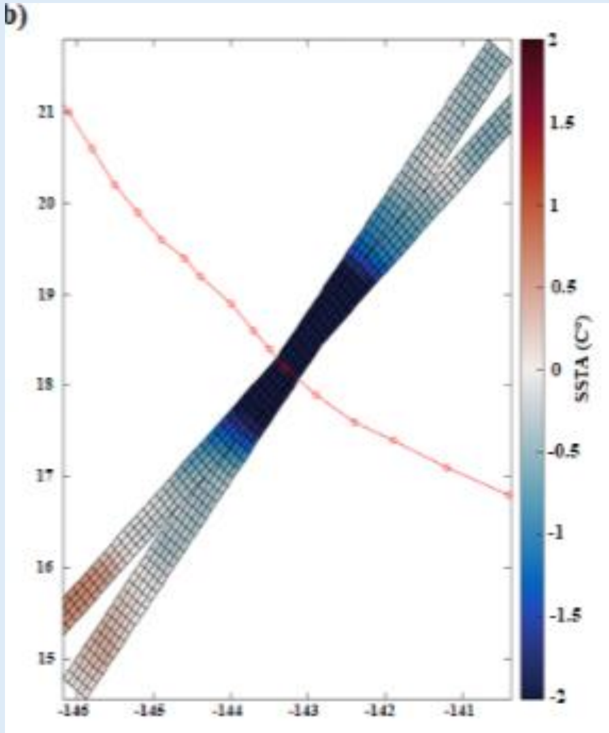
Tropical Cyclone Intensity & Tropical Cyclone Wake

The pre-storm condition associated to sea surface temperature is computed using the measurements acquired during the 2 weeks before the storm arrival.

The post-storm SST anomalies are then computed for the 10 days after the TC (1 per day). The strongest values is selected. It is generally found to be between 1 and 3 days after TC pass.



Hart et al., 2007



Vortex Properties

The vortex properties are given by high resolution available from SAR and TC best-track. SAR data are from Sentinel-1 A, Sentinel-1 B and Radarsat-2.

Because SAR is high resolution with exclusive acquisition modes and data storage/limitations, there is no continuous acquisition in the mode suited for TC monitoring.

An acquisition strategy has been developed. It relies on two assumptions (valid)

- TC track can be forecasted up to 5 days in advance (with associated uncertainty cone)
- Satellite Mission Planning teams operating Sentinel-1 and Radarsat-2 can change the acquisition plan on short notice

SHOC, a campaign for TC monitoring with SAR is now operated since 2016 to maximize the number of TC observations.

Tropical Cyclone Intensity & Tropical Cyclone Wake

SAR data collection

TC experts centres
TC tracks forecasting

↓ *Forecast TC tracks*

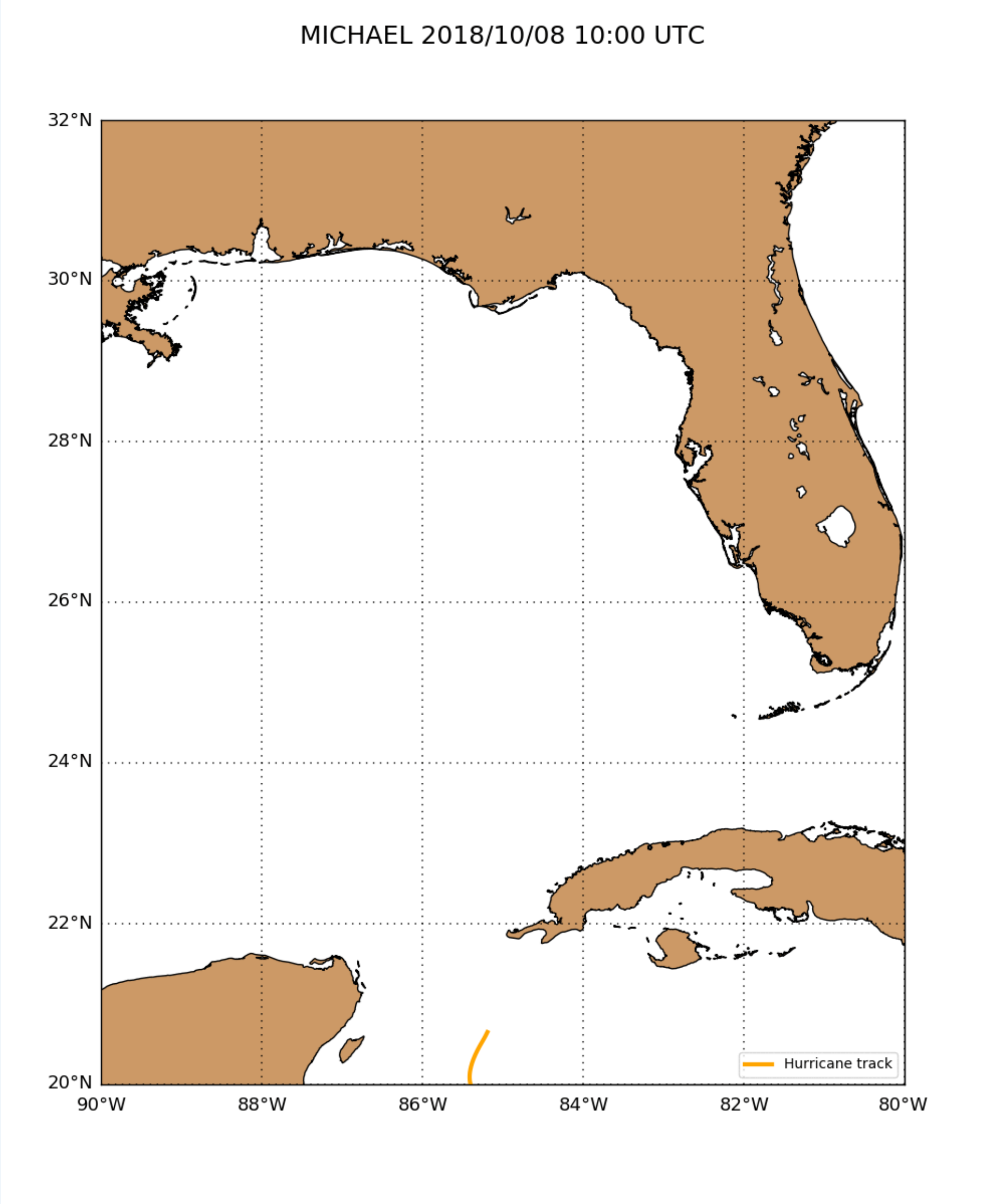
Project partners
TC selection, TC track formatting

↓

SAR Mission Planning
Late programming

↓ *SAR data*

Scientific Community
Data analysis

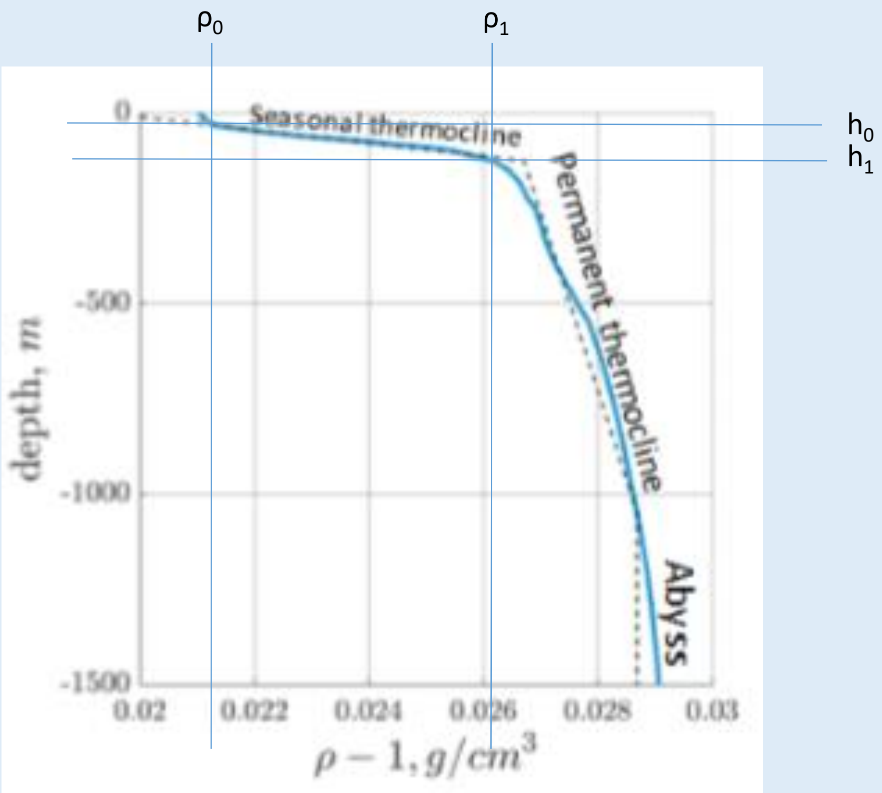


Ocean Properties

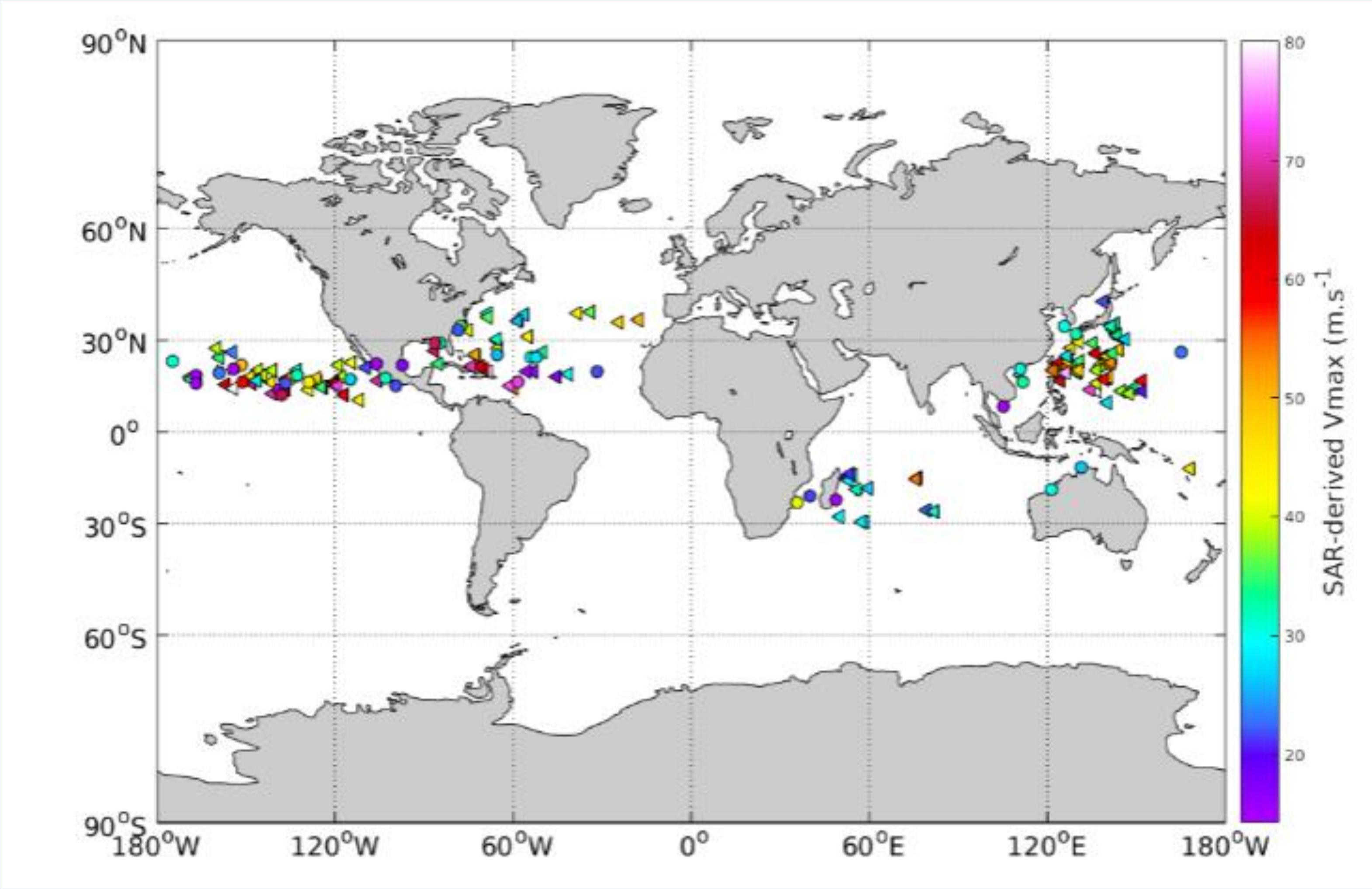
The modulation of the oceanic response to any forcing depends on its stratification described by the Brunt-Väisälä frequency N define by the density gradient of the seasonal thermocline:

$$N_1 = \sqrt{\frac{-g}{\rho}\frac{\rho_1 - \rho 0}{h1 - h0}}$$

N_1 is computed from by in-situ measurements in the vicinity of TC before the TC arrival or from the ISAS-15 climatology of vertical profiles after estimating h_0 and h_1 for each profile

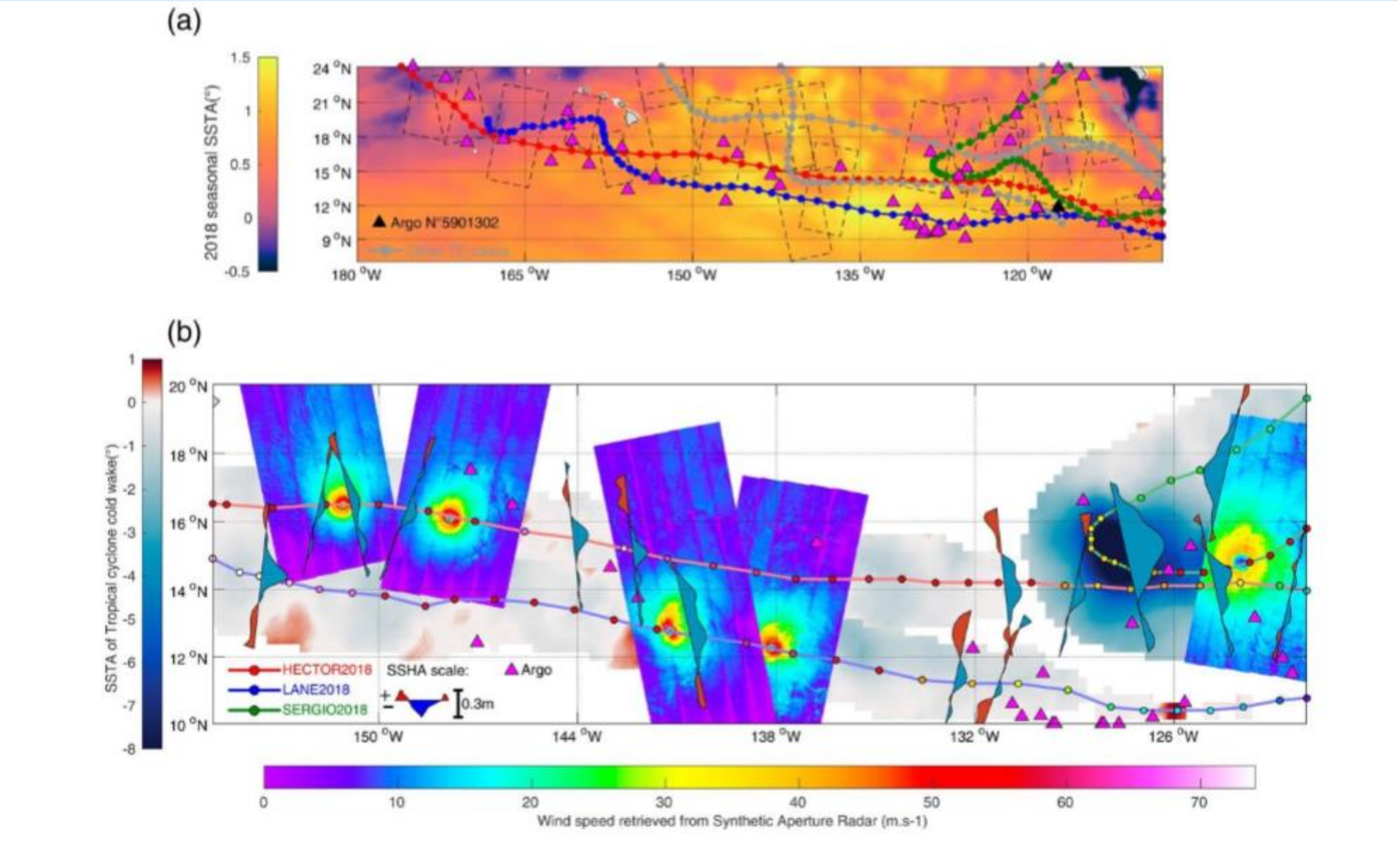


Tropical Cyclone Intensity & Tropical Cyclone Wake



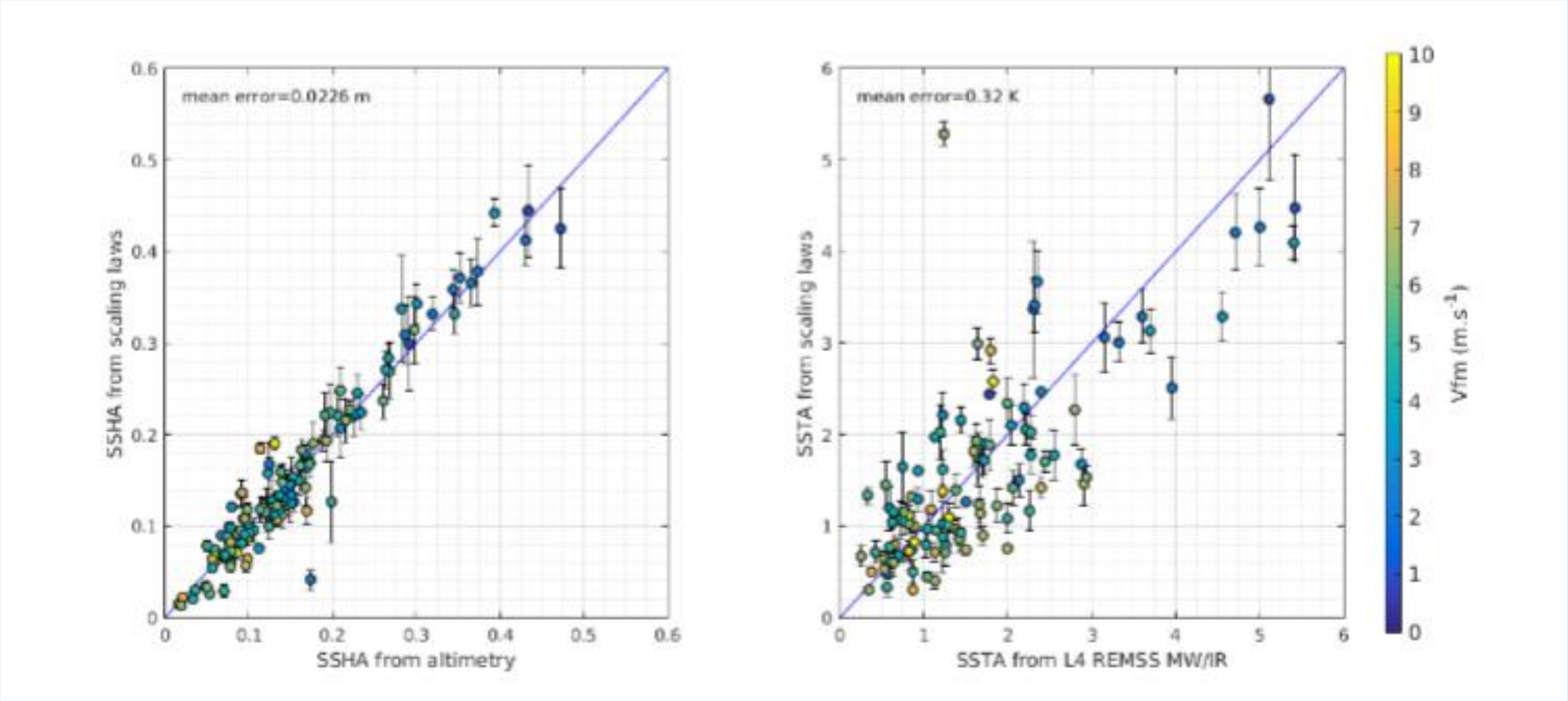
Database of SAR acquisitions available for the study.

Tropical Cyclone Intensity & Tropical Cyclone Wake



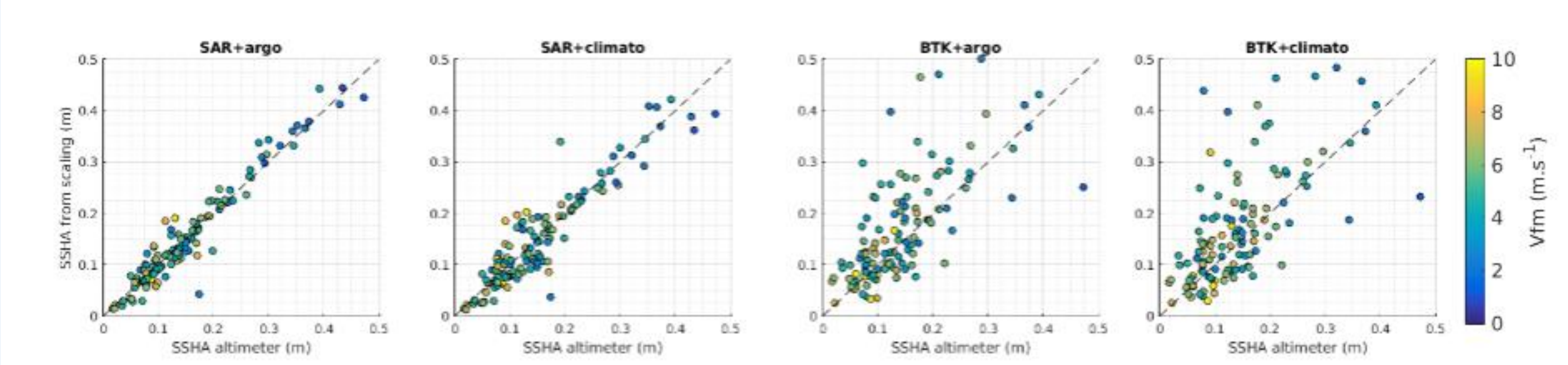
Example of dataset used for three different storm in East Pacific in 2018

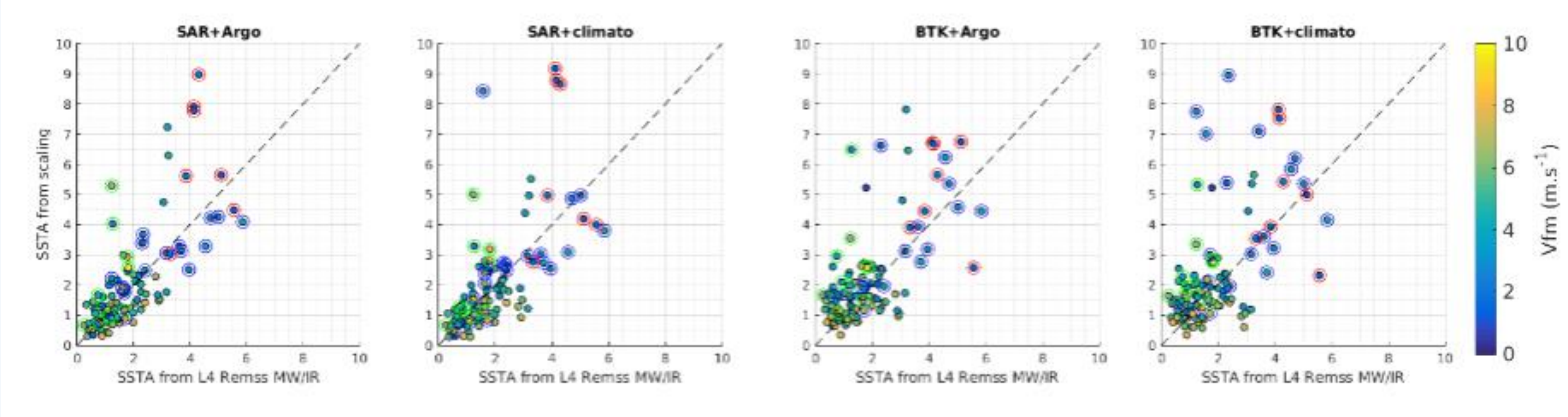
Results


mean error=0.0226 m
SSHA from scaling laws
SSHA from altimetry
0
0.1
0.2
0.3
0.4
0.5
0.6
mean error=0.32 K
SSTA from scaling laws
SSTA from L4 REMSS MW/IR
0
1
2
3
4
5
6
10
9
8
7
6
5
4
3
2
1
0
Vfm (m.s^{-1})

Tropical Cyclone Intensity & Tropical Cyclone Wake

Results





Conclusions

Conclusions

- Do not focus on data from one single sensor, mission or space agency.

  ➡ Have a global view of available missions. Take the most of them

- A sensor provides a filtered and distorted view of reality.

  ➡ Understand the basic principles of the measurement

- Geophysical measurements are only estimates through a inverse problem. Solving such a problem usually requires assumptions and validation exercices.

  ➡ Know the limitations of the derived geophysical parameters you use.

- Instruments parameters contains more than what is provided in the so-called Level-2 products (geophysical information)

  ➡ Go for Level-1 (Level-0), if you can.

- When combining data from different sensors
  - Intercalibration may be required to ensure consistency between 2 missions/instruments/algorithms
  - Semi-physical, statistical models, numerical is often needed to guide/help the synergy