High resolution wind fields of Tropical Cyclones from combined satellite sensors

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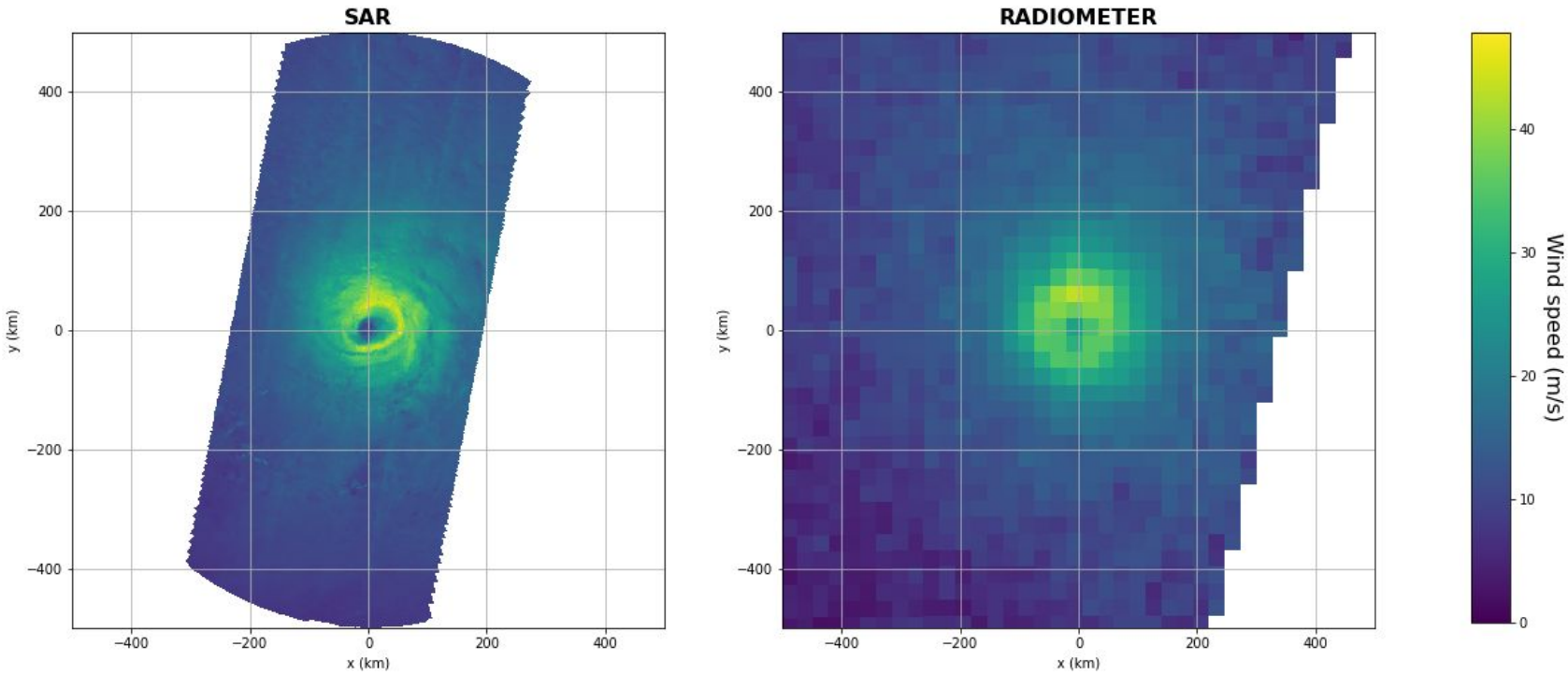
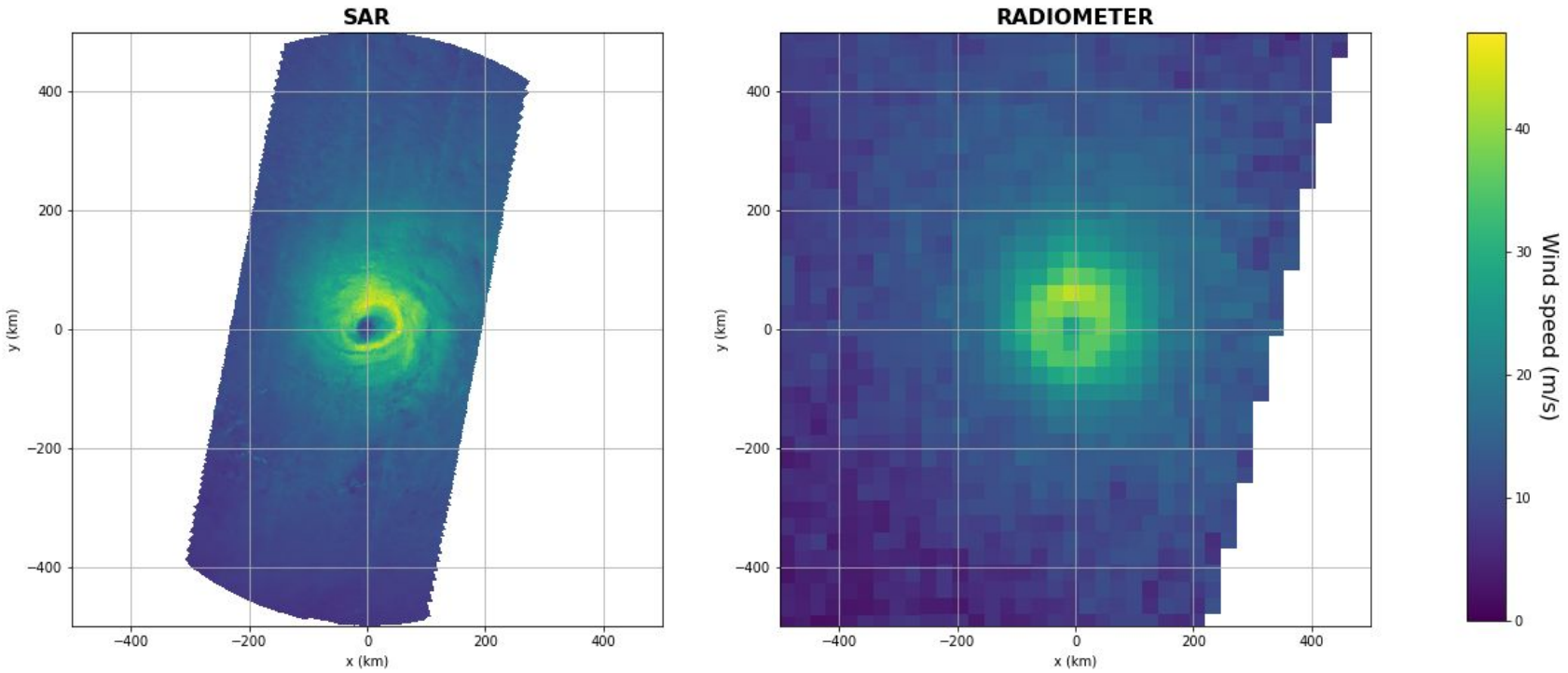


TC Larry (Category 3, 2021, North Atlantic) on 4th September 2021, observed by Sentinel-1B C-SAR (8:51 UTC, left) and by SMAP L-Radiometer** (09:10 UTC, right). Wind fields were rearranged at 1km and 25km resolution respectively.*

* Mouche, A., Chapron, B., Knaff, J., Zhao, Y., Zhang, B., & Combot, C. (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.
** Meissner, T., Ricciardulli, L., & Wentz, F. J. (2017). Capability of the SMAP mission to measure ocean surface winds in storms. *Bulletin of the American Meteorological Society*, 98(8), 1660-1677.



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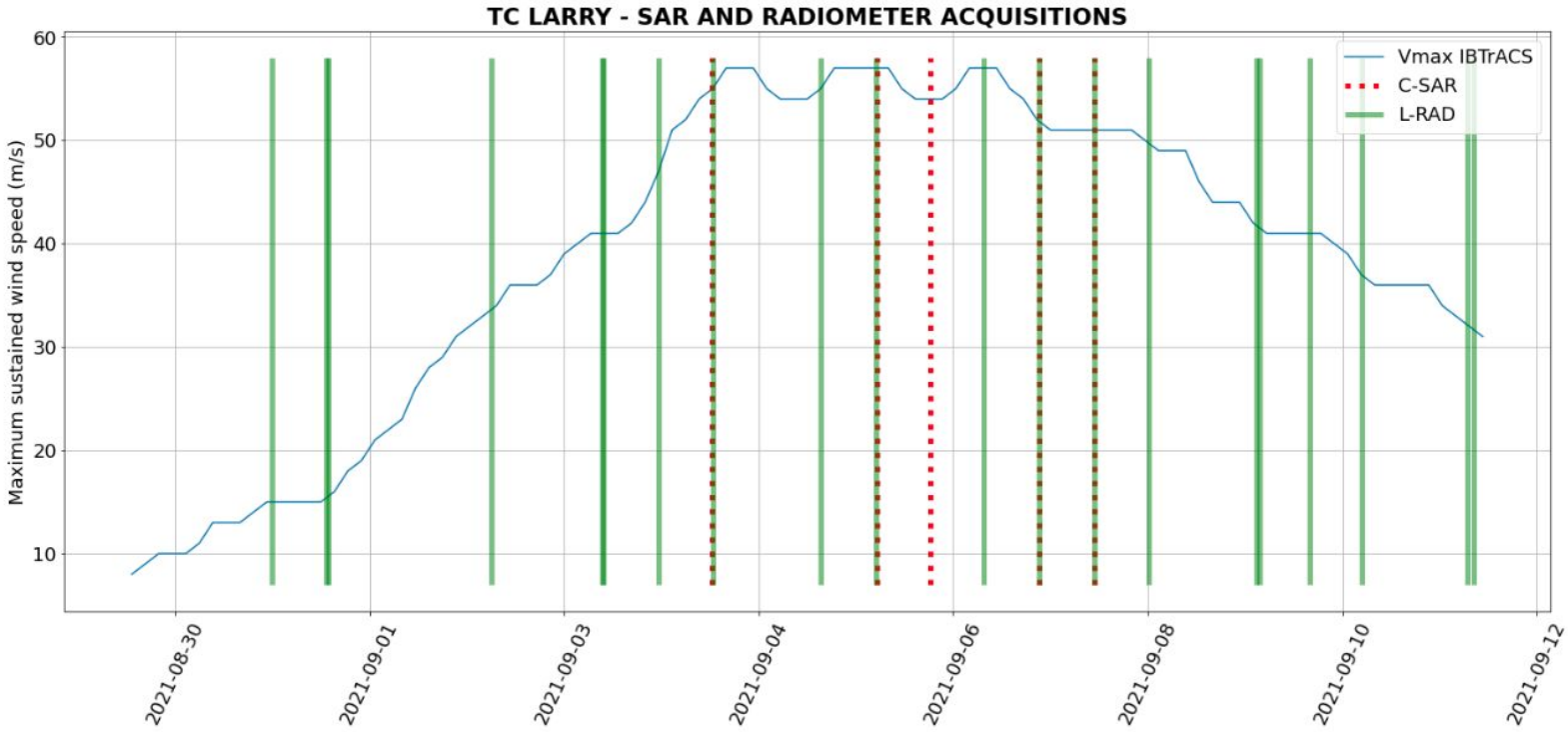
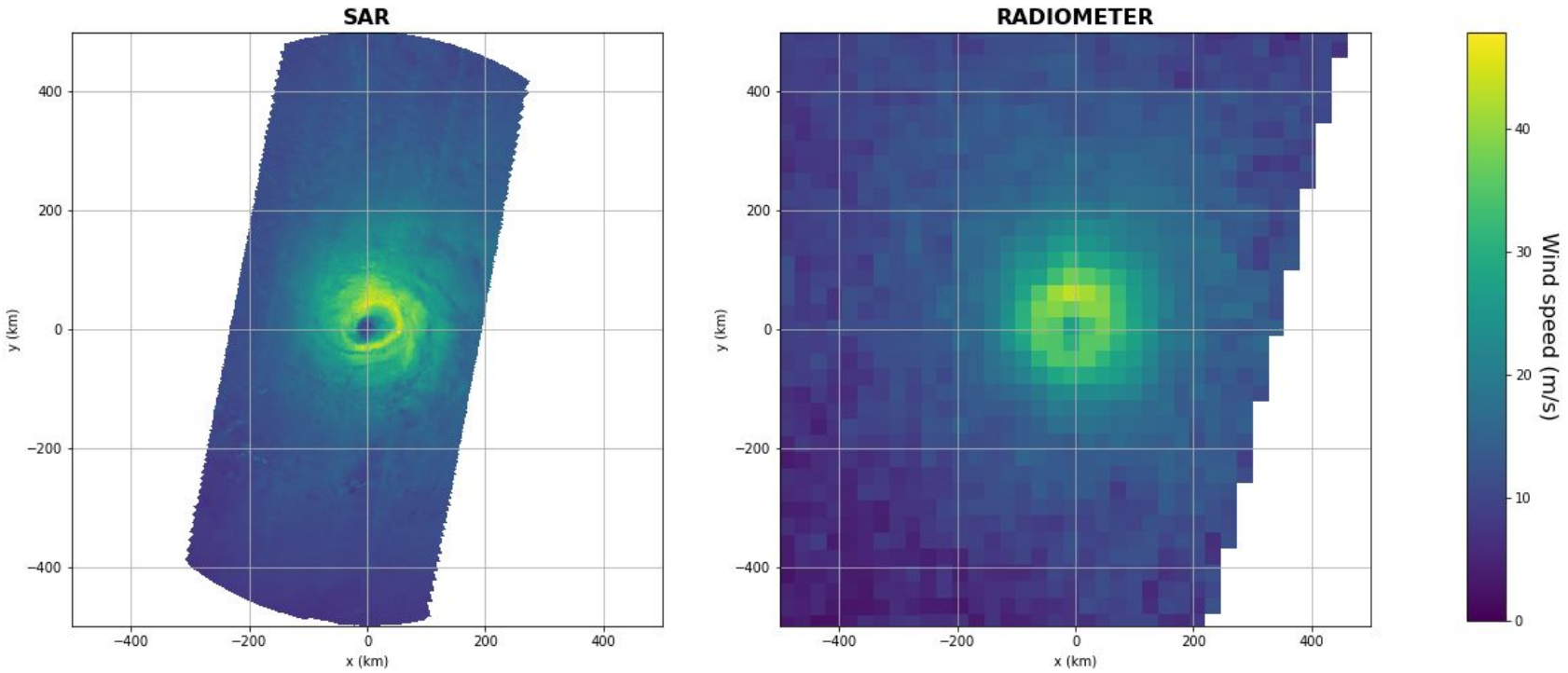
➔ **SAR (Synthetic Aperture Radar) reveals a lot of surface small-scale features compared to radiometer**

➔ **Radiometer ⇒ estimates of TC intensity and outer-core wind speed gradients**



Maximum sustained winds (m/s) of TC Larry (2021, North Atlantic) in the IBTrACS database. Vertical lines represent C-SAR (Sentinel-1A&B, Radarsat-2) and L-radiometer (SMAP, SMOS) acquisitions.

➔ **Many more radiometer data than SAR data in general**



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- **High spatial resolution;**
- **Low temporal resolution.**

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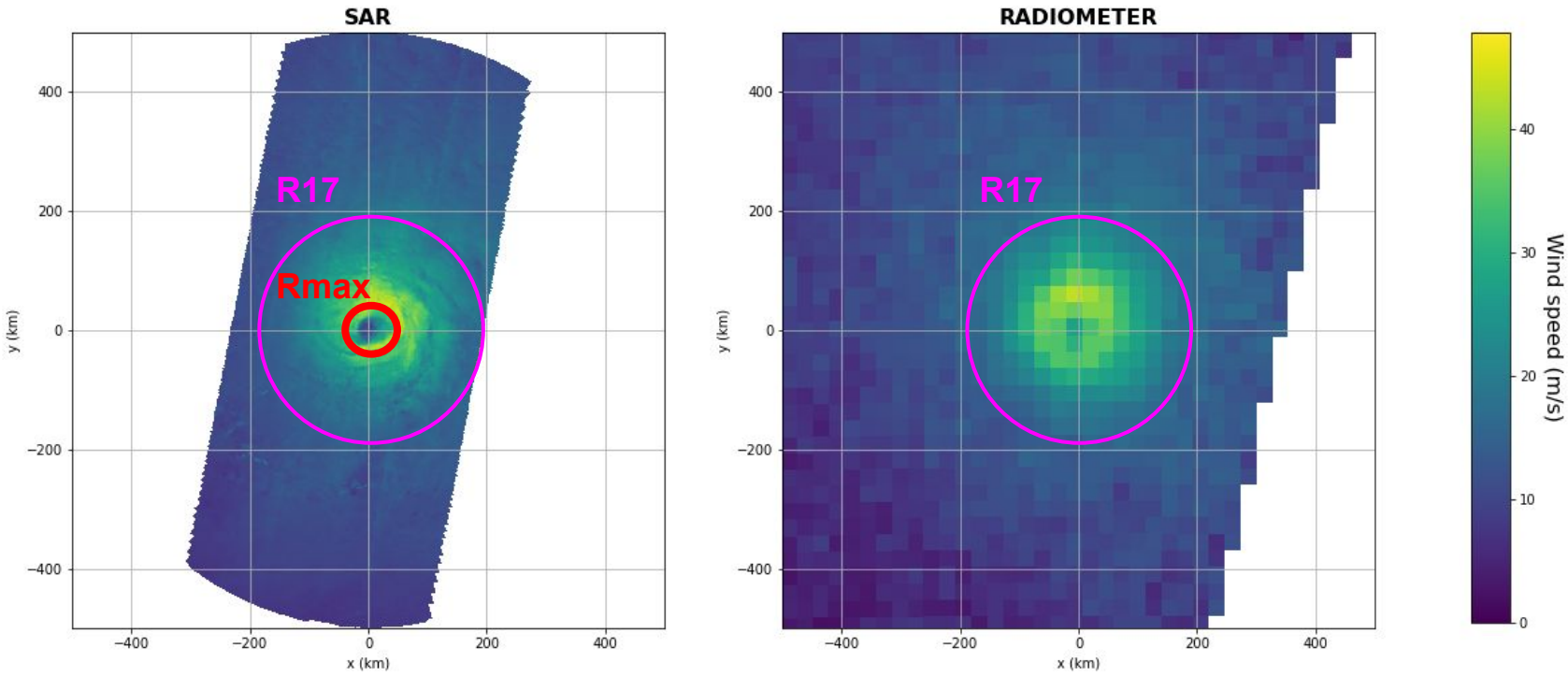
- **High temporal resolution.**

➔ **We seek to combine SAR with radiometer/scatterometer to get a high spatial resolution at a high temporal resolution**



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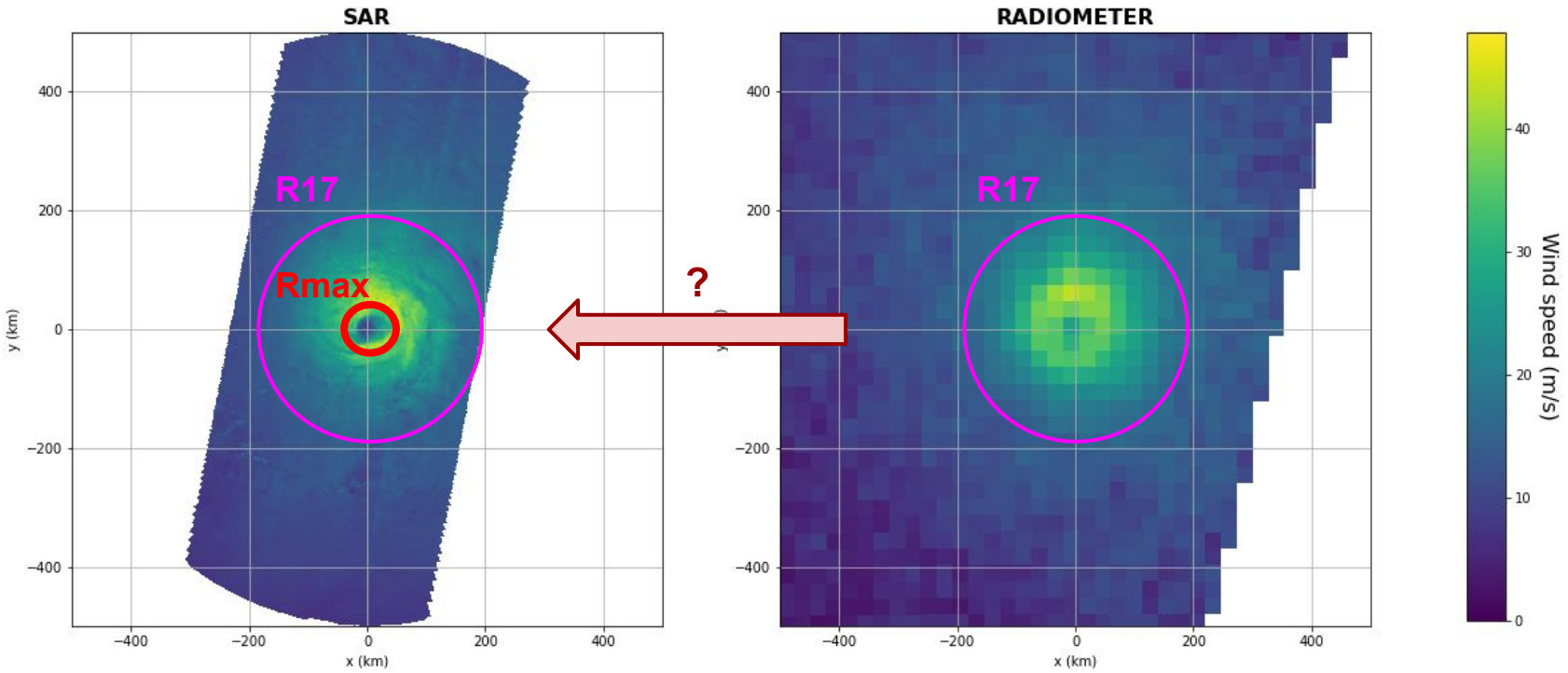
➔ **Best-Tracks = Post-season reanalyses: Vmax is well known**

➔ **SAR ⇒ Rmax*, R17** **Radiometer ⇒ R17****

* Combot, C., Mouche, A., Knaff, J., Zhao, Y., Zhao, Y., Vinour, L., ... & Chapron, B. (2020). Extensive high-resolution synthetic aperture radar (SAR) data analysis of tropical cyclones: Comparisons with SFMR flights and best track. *Monthly Weather Review*, 148(11), 4545-4563.

** Reul, N., Chapron, B., Zabolotskikh, E., Donlon, C., Mouche, A., Tenerelli, J., ... & Kudryavtsev, V. (2017). A new generation of tropical cyclone size measurements from space. *Bulletin of the American Meteorological Society*, 98(11), 2367-2385.



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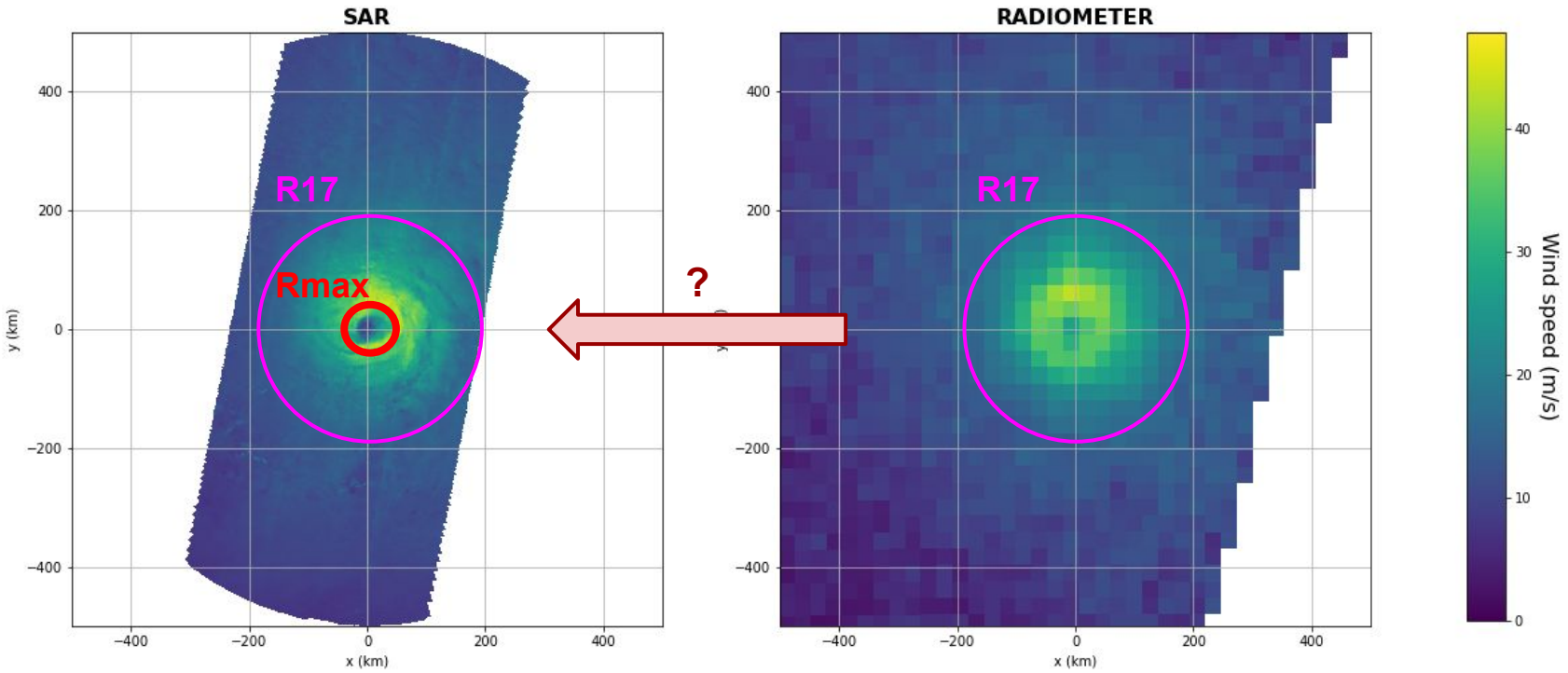
➔ **Can we find a relationship between radiometer and SAR?**

Rmax ⇐ (Vmax, R17)?



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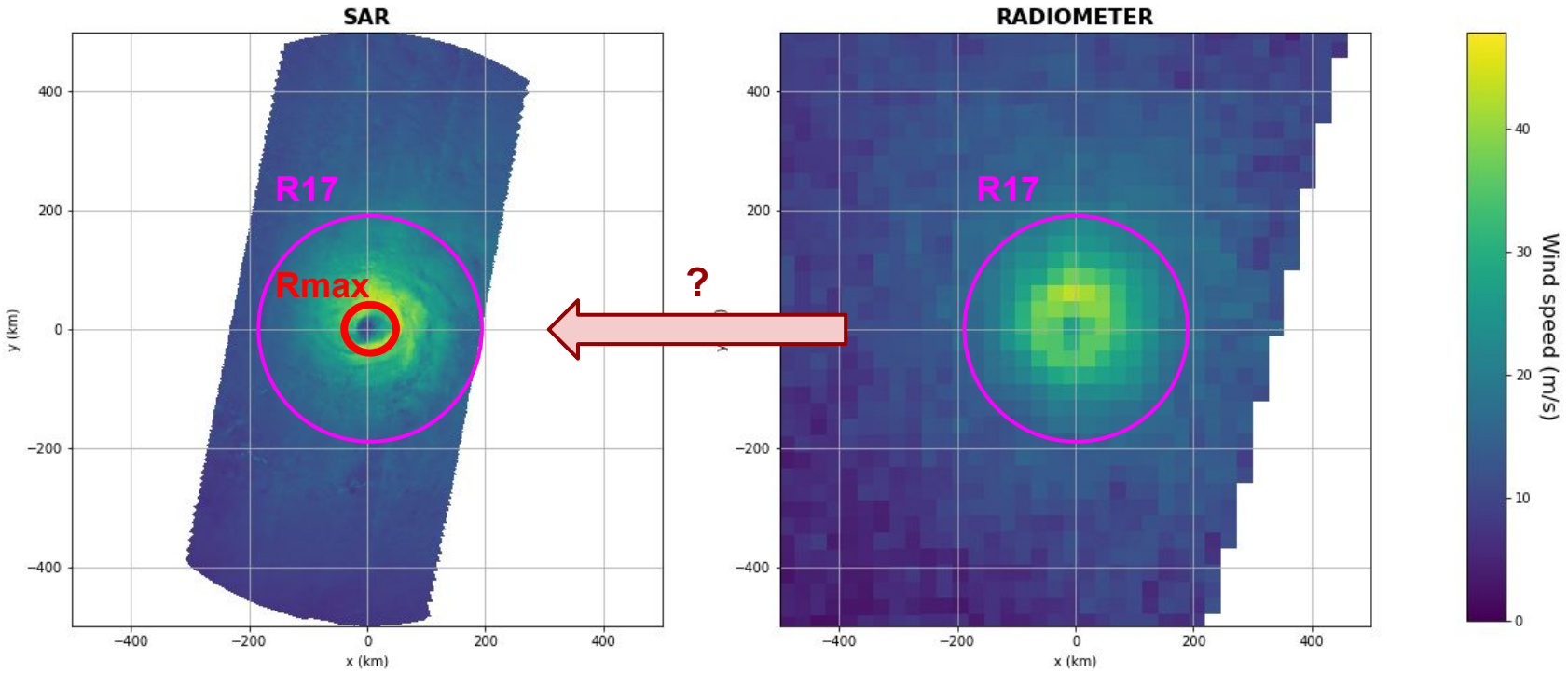
➔ **State of the art: Chavas and Knaff (2022) model***

Rmax ⇐ (Vmax, R17, f)

* Chavas, D. R., & Knaff, J. A. (2022). A simple model for predicting the tropical cyclone radius of maximum wind from outer size. *Weather and Forecasting*.



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➔ **State of the art: Chavas and Knaff (2022) model**

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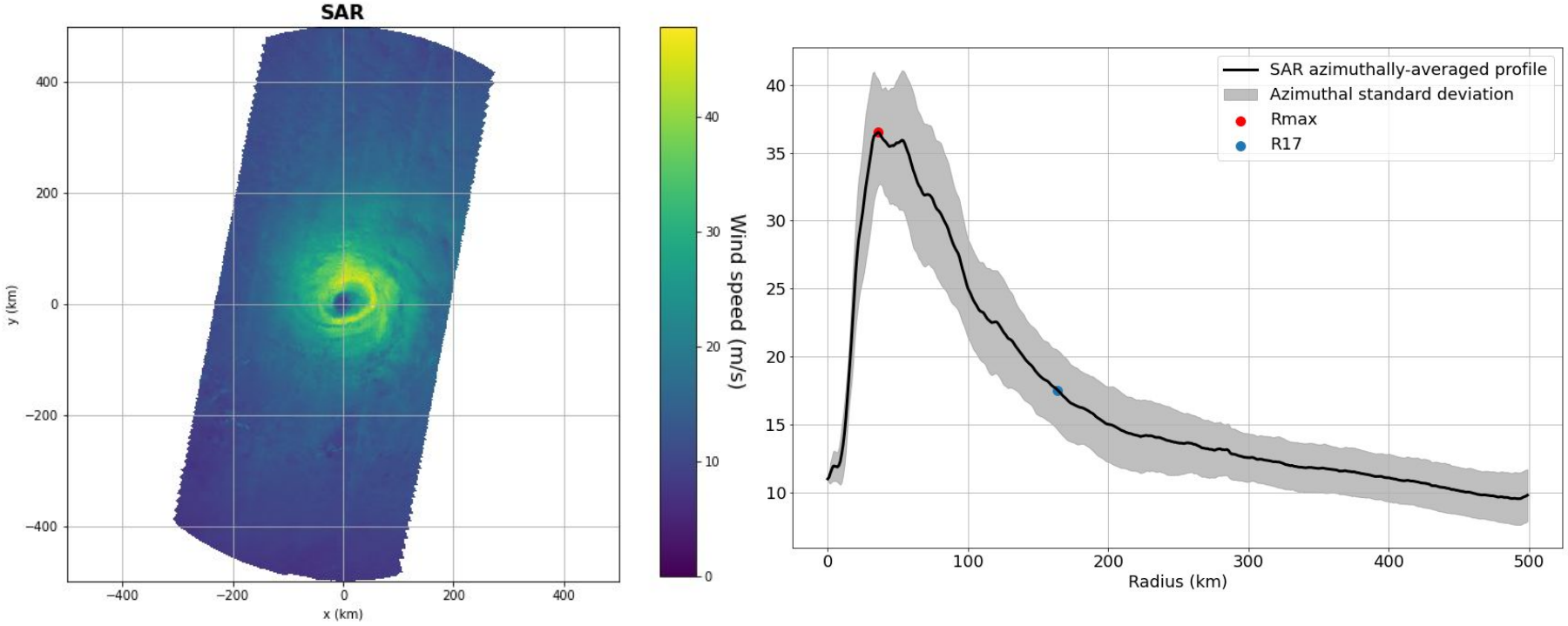
➔ **Consistent with SAR data?**

➔ **If not, can we adjust the relation?**



TC Larry SAR-derived wind field (left) and azimuthally-averaged profile (right), with associated Rmax and R17.

➔ **From observational to parametric space**

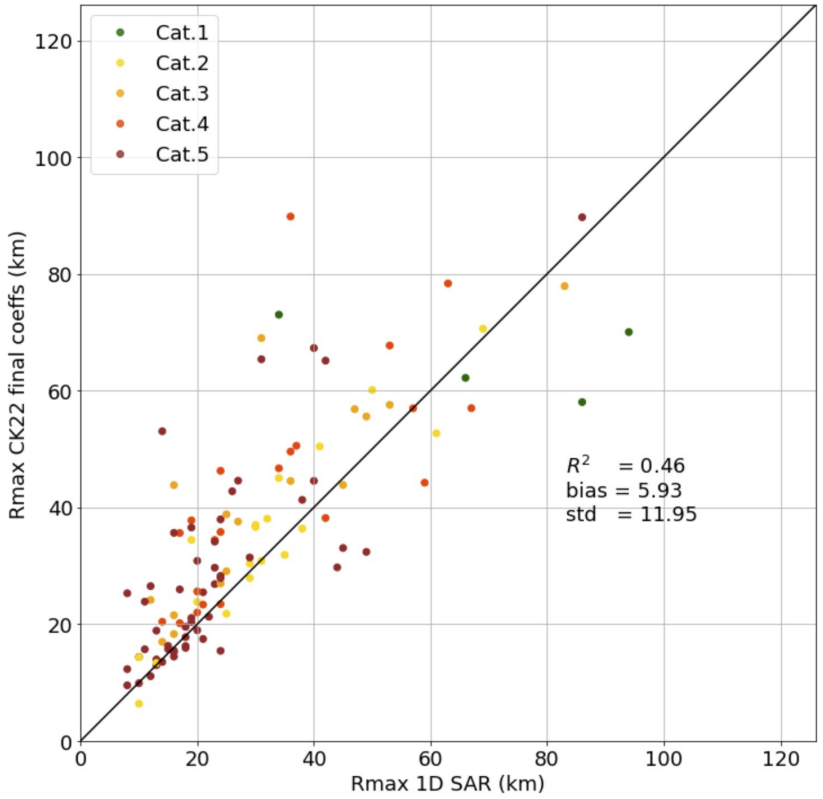
➔ **Vmax, Rmax and R17 are computed using the SAR 1D profile***

** Vmax, Rmax, and R17 estimates on SAR have been checked against best track data (not shown), and have also been assessed by a previous study (though with a 2D definition):* Combot, C., Mouche, A., Knaff, J., Zhao, Y., Zhao, Y., Vinour, L., ... & Chapron, B. (2020). Extensive high-resolution synthetic aperture radar (SAR) data analysis of tropical cyclones: Comparisons with SFMR flights and best track. *Monthly Weather Review*, 148(11), 4545-4563.

State of the art: Chavas and Knaff (2022)*.
Statistical method to determine Rmax:

(Vmax, R17, f) ⟶ Rmax

NB: The SAR dataset consists of N = 112 samples.



Comparison between Rmax computed on SAR 1D profile (x-axis) and Rmax computed with Chavas and Knaff 2022 model using Vmax and R17 from SAR 1D profile (y-axis). The SAR dataset contains 112 samples, filtered by category (>= 1), latitude (<= 30°), basin (North Atlantic) and distance to coast (>= R17).

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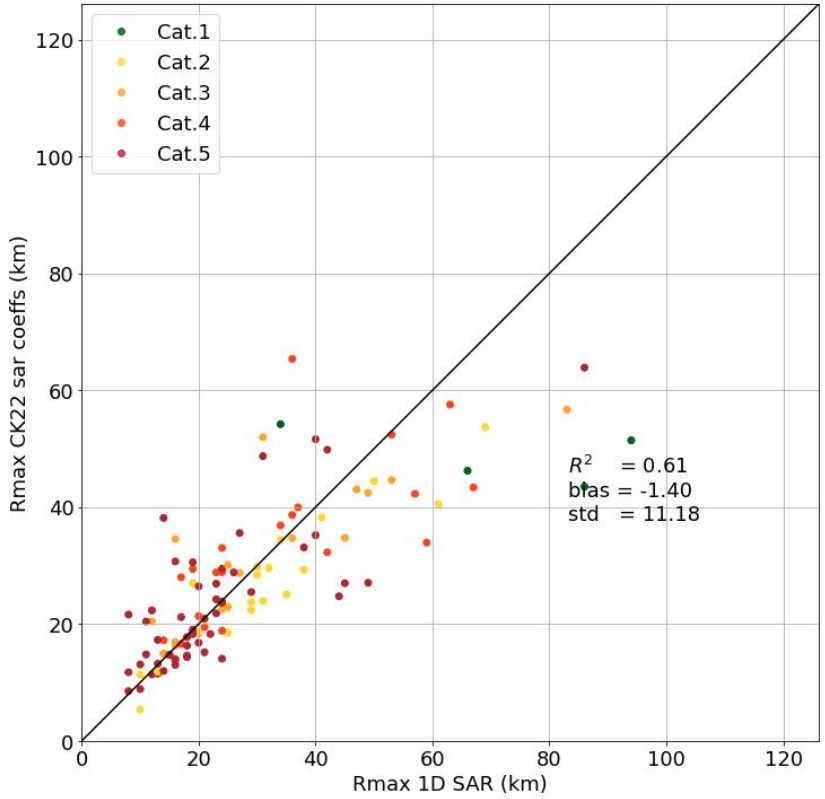
State of the art: Chavas and Knaff (2022)*.
Statistical method to determine Rmax:

(Vmax, R17, f) ⟶ **Rmax**

Coefficients of the Chavas and Knaff 2022 model have been **fitted using the SAR dataset** (N = 112 samples).

➔ **Improvement of the model using the SAR dataset**



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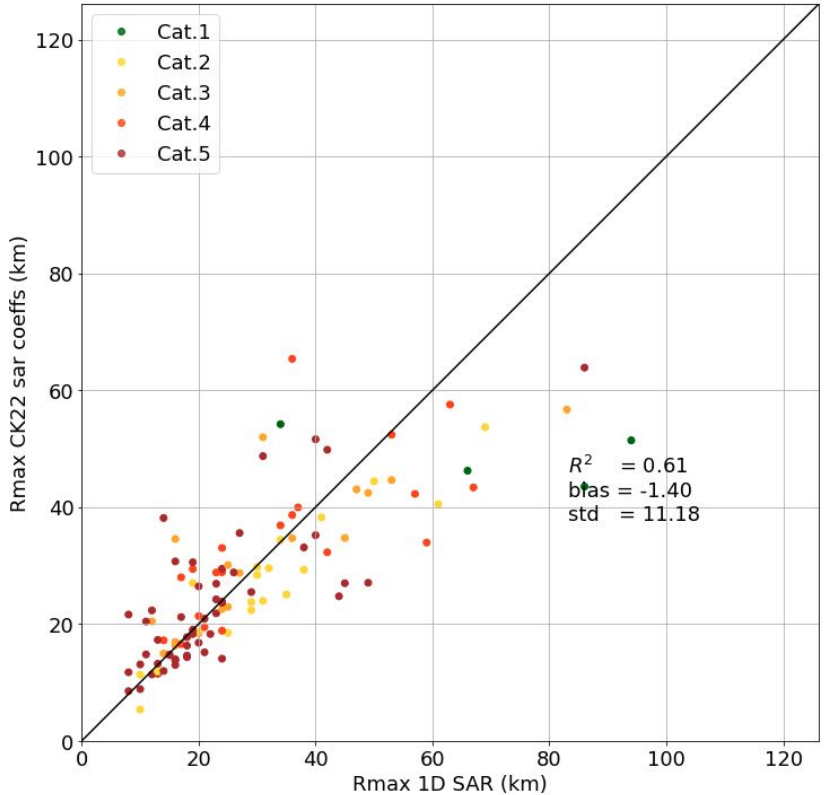
State of the art: Chavas and Knaff (2022)*.
Statistical method to determine Rmax:

(Vmax, R17, f) ⟶ **Rmax**

Can we find an additional parameter that controls the spread? After many tests (size, intensification rate, R17 asymmetry, storm age, many adimensional parameters…) ⇒ **shape of radial profile** seems to play an important role!

➔ **We investigated** $\frac{Ck}{Cd}$

- Ck: Exchange coefficient of enthalpy
- Cd: Exchange coefficient of momentum



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Fitting $\frac{Ck}{Cd}$ on SAR data:

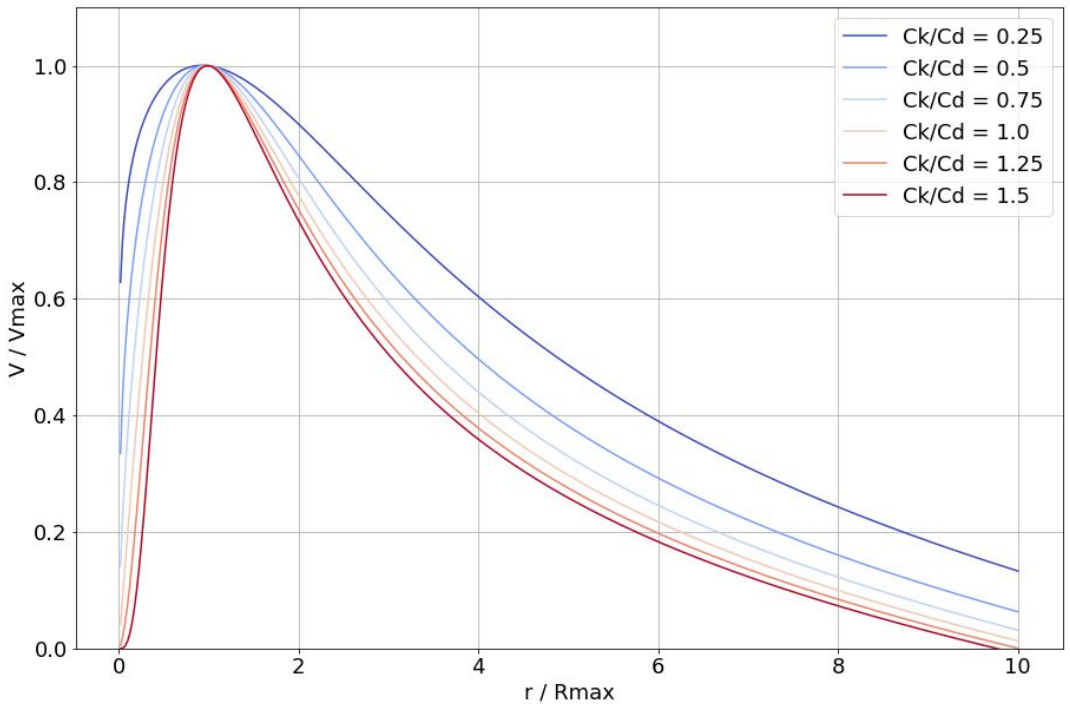
based on Emmanuel and Rotunno (2011)*:

$$\frac{RmaxVmax}{17.5\,R_{17.5} + \frac{1}{2} f R_{17.5}^2} = \phi\left(\frac{Ck}{Cd}\right)$$

where $$\phi(x) = \left(\frac{1}{2}x\right)^{\frac{1}{2-x}}$$

and if $Vmax \gg fRmax$ and $R_{17.5} \gg Rmax$

➔ **For each SAR image, we can fit one value of $\frac{Ck}{Cd}$**



Parametric wind speed profile as defined in Emmanuel and Rotunno (2011) and its sensitivity to the Ck/Cd parameter. Radius and wind speed are normalized.

* Emanuel, K., & Rotunno, R. (2011). Self-stratification of tropical cyclone outflow. Part I: Implications for storm structure. *Journal of the Atmospheric Sciences*, 68(10), 2236-2249.

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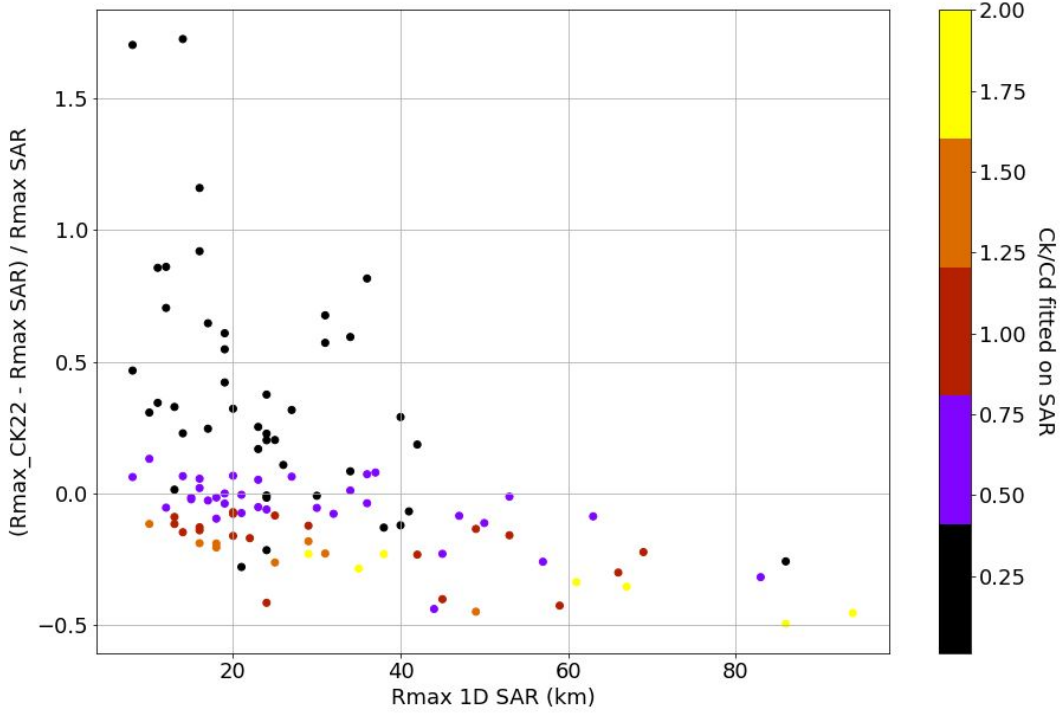
➔ **Errors are stratified by $\frac{Ck}{Cd}$**

➔ **Small errors for $\frac{Ck}{Cd}$ ~ 0.5-0.75**

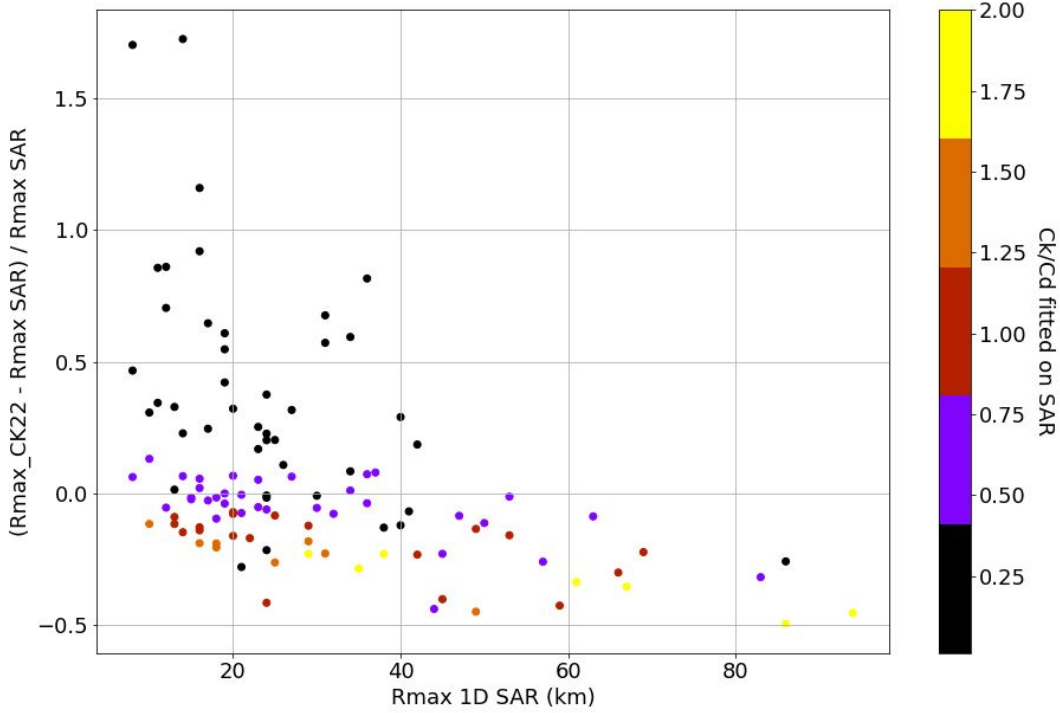


Error of Chavas and Knaff 2022 Rmax model normalized by SAR Rmax, as a function of SAR Rmax. Each point represents one of the 112 SAR samples.

* Emanuel, K., & Rotunno, R. (2011). Self-stratification of tropical cyclone outflow. Part I: Implications for storm structure. *Journal of the Atmospheric Sciences*, 68(10), 2236-2249.

- ➔ $\frac{Ck}{Cd}$ **acts as a hidden parameter that constrains how Rmax is linked to (Vmax, R17, f).**

- ➔ **Can we use this prior knowledge to more accurately reconstruct Rmax time series?**



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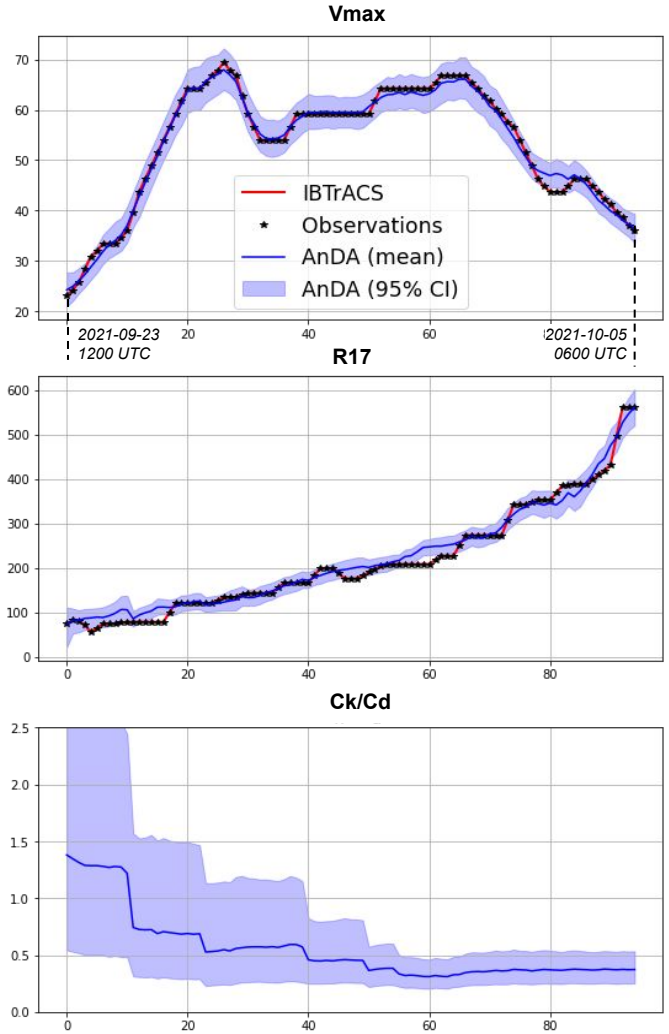
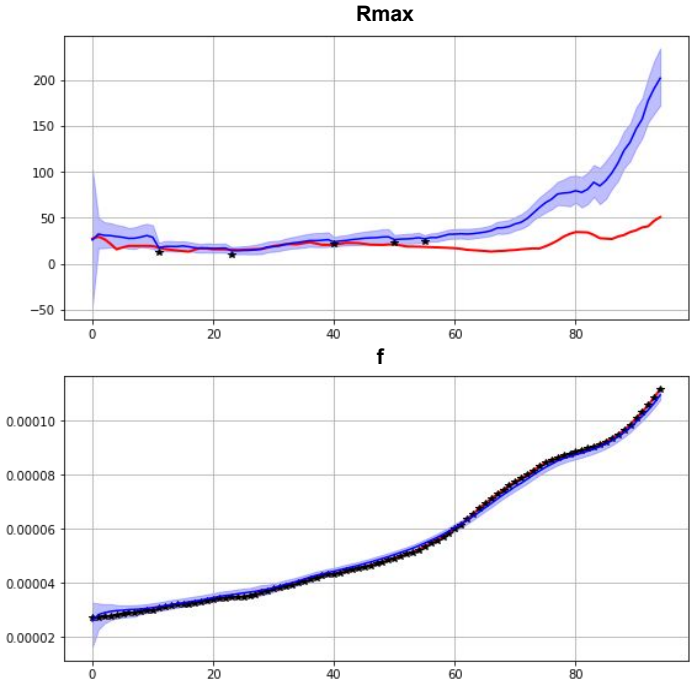
<u>SAM (2021, North Atlantic)</u>:
Reconstruction of “realistic” Rmax time series

- ➔ $\frac{Ck}{Cd}$ **is used in an augmented state to constrain Rmax reconstruction**
- ➔ **Kalman-like framework allows to estimate parameters uncertainties**





Time series of SAM (2021, North Atlantic) issued from the IBTrACS database (red), from September 23rd 12:00 UTC to October 5th 06:00 UTC (= starting time of extratropical phase). Reconstruction of these time series using an Analog Data Assimilation method (AnDA, blue) with a catalog of 110 TCs. Black stars represent assimilated observations. Rmax time series correspond to Chavas and Knaff 2022 model applied to IBTrACS (red) and observations (black stars) correspond to SAR-derived Rmax, which have been assimilated. Ck/Cd is modeled by a random walk and used to constrain Rmax reconstruction.

Downscaling the wind structure

1. The reconstruction of a TC HR wind structure requires a **high quality estimate of Rmax**, as well as other features: asymmetry, wind directions, spiral rainbands…

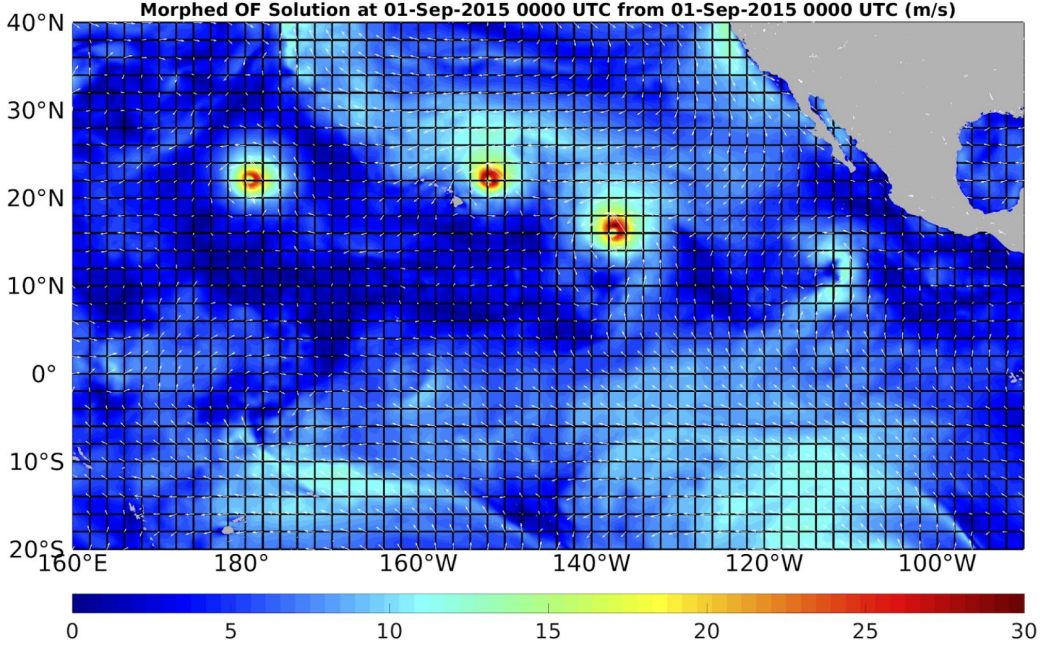
2. To what extent do such features **constrain Rmax values**?

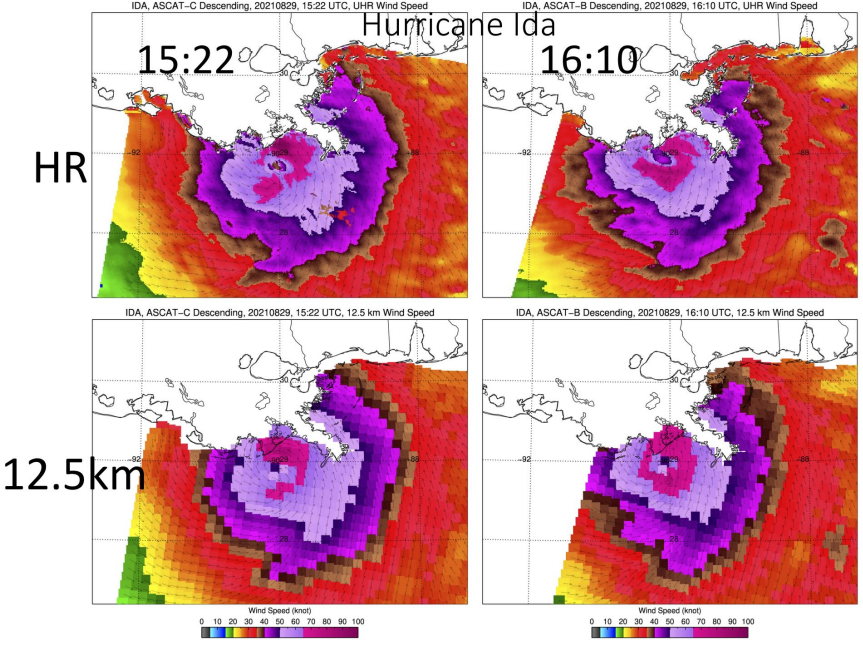
Contact: arthur.avenas@ifremer.fr

Related studies

3 **Multi-mission blended wind fields** (ESA MAXSS project) ⇒ global and gridded product merging radiometer/scatterometer data, but at low spatial resolution (left, courtesy of Joe Tenerelli).

4 **High spatial resolution wind fields from scatterometer data** ⇒ detailed representation of the inner-core (right, courtesy of Seubson Soisuvarn).





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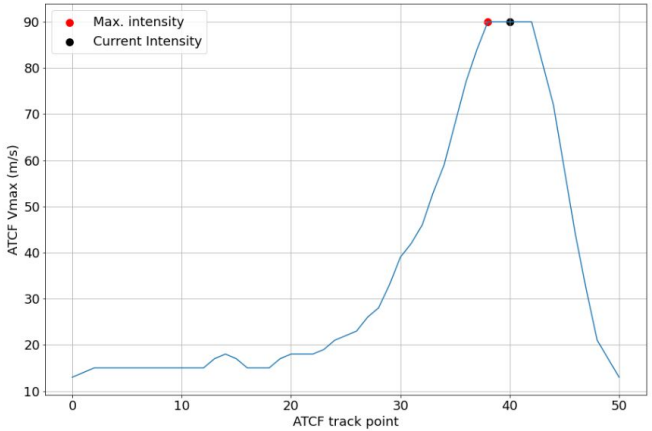
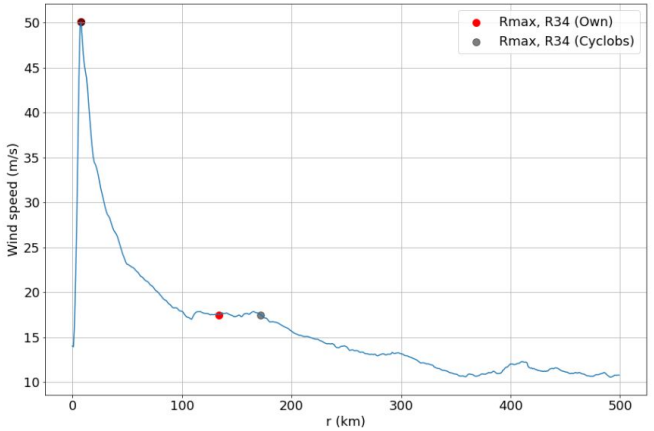
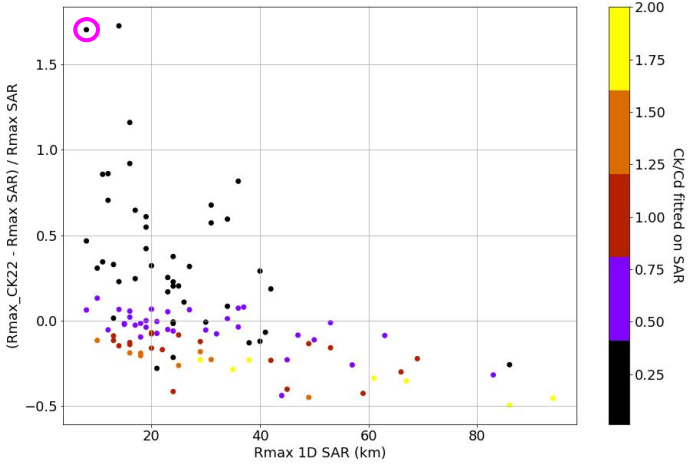
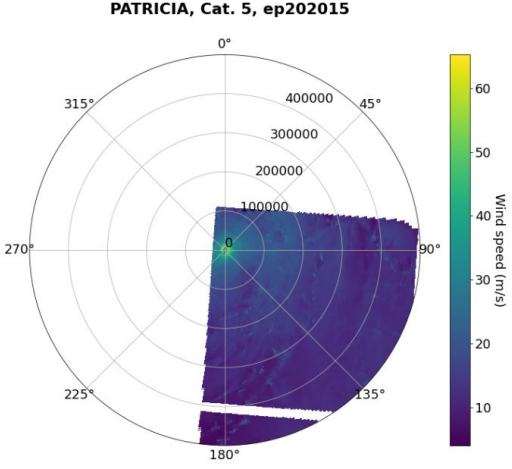








Rmax_1D = 8.0

Rmax_CK22 = 21.47

cyclone_speed = 4.67

lat_center = 17.27

distance_to_coast = 225189.55

forw_inten = -1.5

curr_inten = 0.0

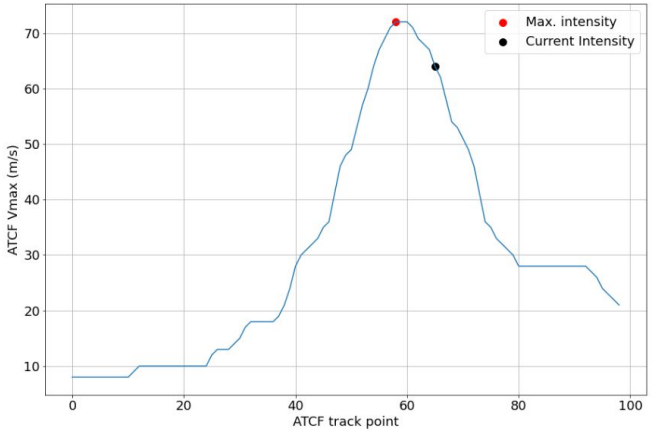
back_inten = 1.08

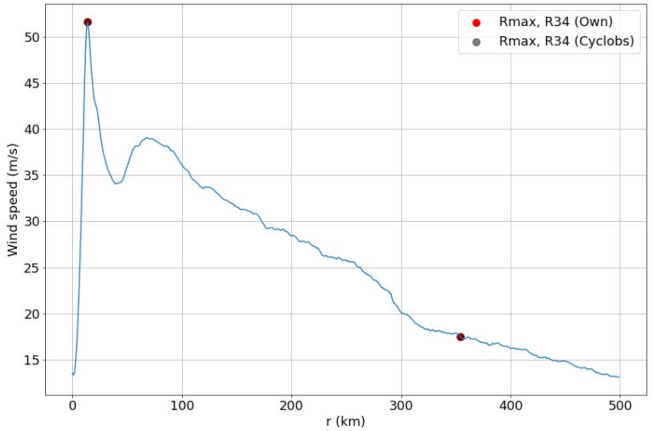
life_cyc_idx = 0.8

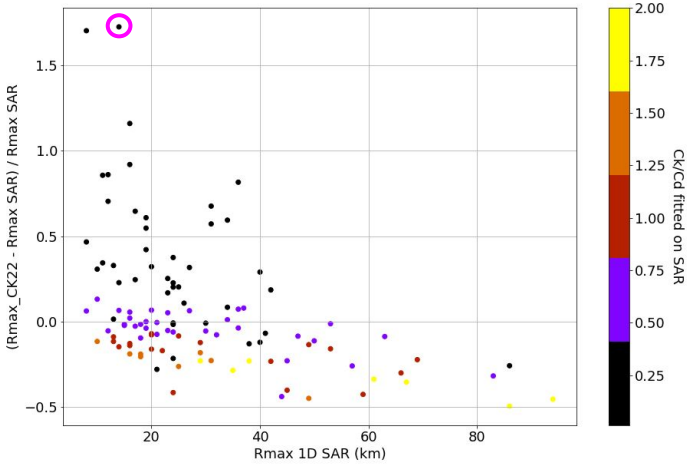
life_vmax_idx = 1.05

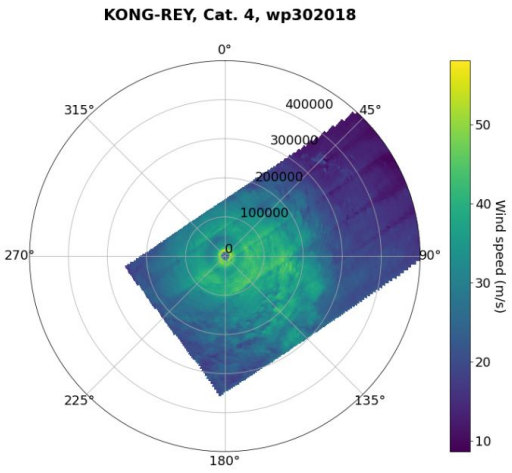
Vmax_STD = 6.96

V17_STD = 2.61









Rmax_1D = 14.0

Rmax_CK22 = 35.6

cyclone_speed = 4.57

lat_center = 19.82

distance_to_coast = 675469.47

forw_inten = -0.92

curr_inten = -0.83

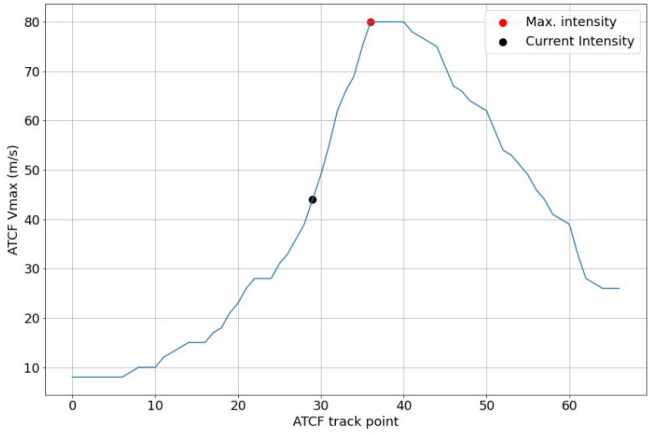
back_inten = -0.58

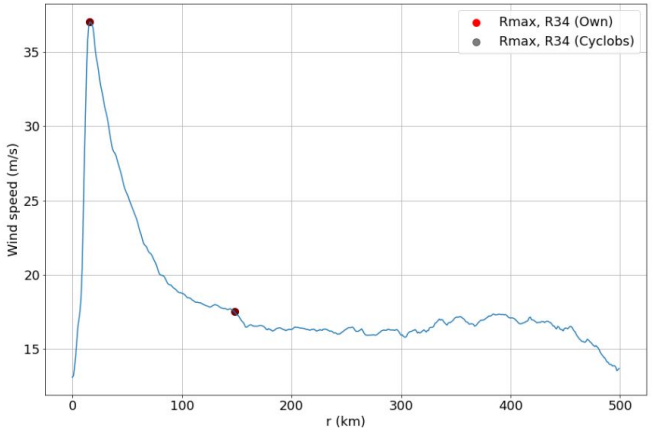
life_cyc_idx = 0.66

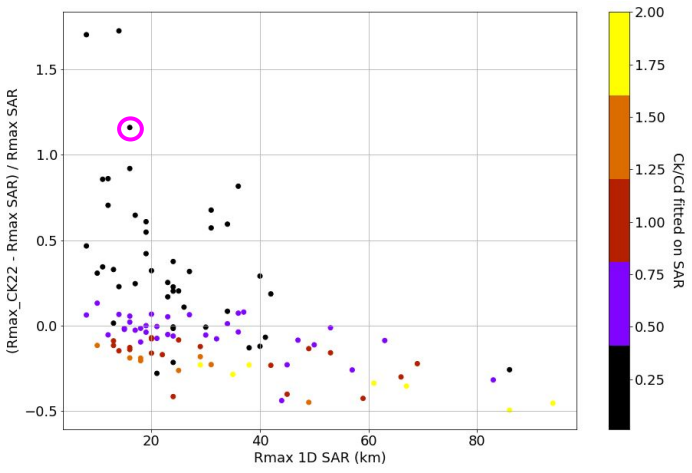
life_vmax_idx = 1.12

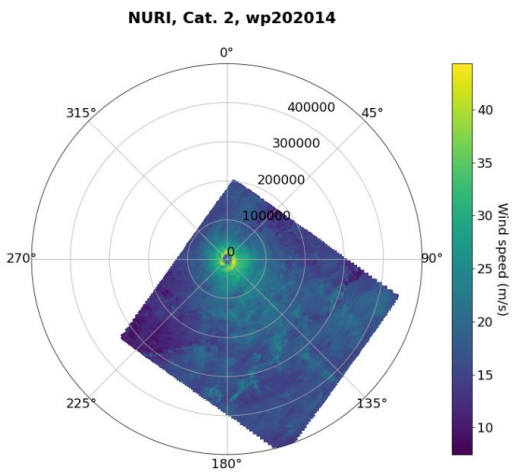
Vmax_STD = 2.79

V17_STD = 2.86









Rmax_1D = 16.0

Rmax_CK22 = 33.77

cyclone_speed = 3.52

lat_center = 15.12

distance_to_coast = 839652.89

forw_inten = 1.83

curr_inten = 1.58

back_inten = 1.08

life_cyc_idx = 0.44

life_vmax_idx = 0.81

Vmax_STD = 3.85

V17_STD = 2.93