The medicane surface wind structure in spaceborne high-resolution observations

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Context

The medicane, a tropical-like cyclone in the Mediterranean…

Cloudless eye, spiral rainbands, convective cells, and warm-core anomaly;
Importance of surface fluxes and latent heat release;

… with its own specificities:

- Low lifetime maximum intensity, $\lesssim$ 33 m/s, or Saffir-Simpson cat. 1 (*Miglietta et al., 2013*);
- Short mature phase, a few hours to 2 days;
- Small system size, 50 to 200 km (*Picornell et al., 2014*);
- Develop over relatively low sea surface temperature, 15 to 23 °C (*Tous and Romero, 2013*);
- Develop in conditions of vertical wind shear and horizontal temperature gradient (*Flaounas et al., 2015*);
- Impact of coastal areas and land;

⇒ Sometimes, the medicane is not fully sustained by air-sea interaction processes, unlike the tropical cyclone (*Miglietta et Rotunno, 2019, Dafis et al., 2020*).

Context

➢ **Need to better understand the mechanisms involved in the medicane development and mature phase.**

In particular, the contribution of the upper-level flow to the medicane life cycle has been well documented, but the low-level processes have received fewer attention.

What can we learn from surface wind observations, *e.g* with Synthetic Aperture Radar (SAR) data, about the medicane dynamics?

Challenges:

- 0 to 3 event(s) per year;
- Dataset creation and medicane selection;
- No best-track data;

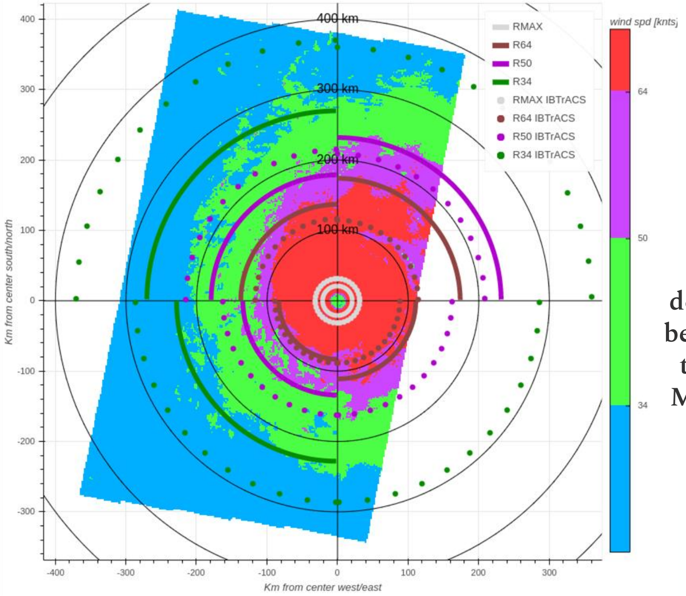
Context

For the **tropical cyclone**, reference data for the surface wind structure is available: the **best-tracks**.
⇒ Subjectively-smoothed representation of the cyclone location, intensity and structure over its lifetime, at 6-hourly intervals.

LON, LAT *Location of perturbation center*	**VMAX** *Maximum wind speed*	**RMAX** *Radius of maximum wind speed*	**R64** *Radius of 64-kts (~33 m/s) winds*	**R50** *Radius of 50-kts (~26 m/s) winds*	**R34** *Radius of 34-kts (~17 m/s) winds*
Location	**Intensity**	**Inner-size**	**Outer-size**		

⇒ Allow to investigate the wind structure life cycle.

However, large spatio-temporal heterogeneities and large uncertainties, especially regarding **Rmax** (*Landsea et Franklin, 2013*, *Combot et al., 2020*, *Avenas et al., 2023*).



Comparison between SAR-derived vitals and best-track data for tropical cyclone Mangkhut (2018).

Context

The contribution of the near-core wind structure (including R_{max}) to the tropical cyclone dynamics was recently emphasized.

Benefited from significant advances in ocean surface wind speed estimates from satellite in the last decade, in particular new acquisition modes and algorithmic progress **with SAR data**.

Context

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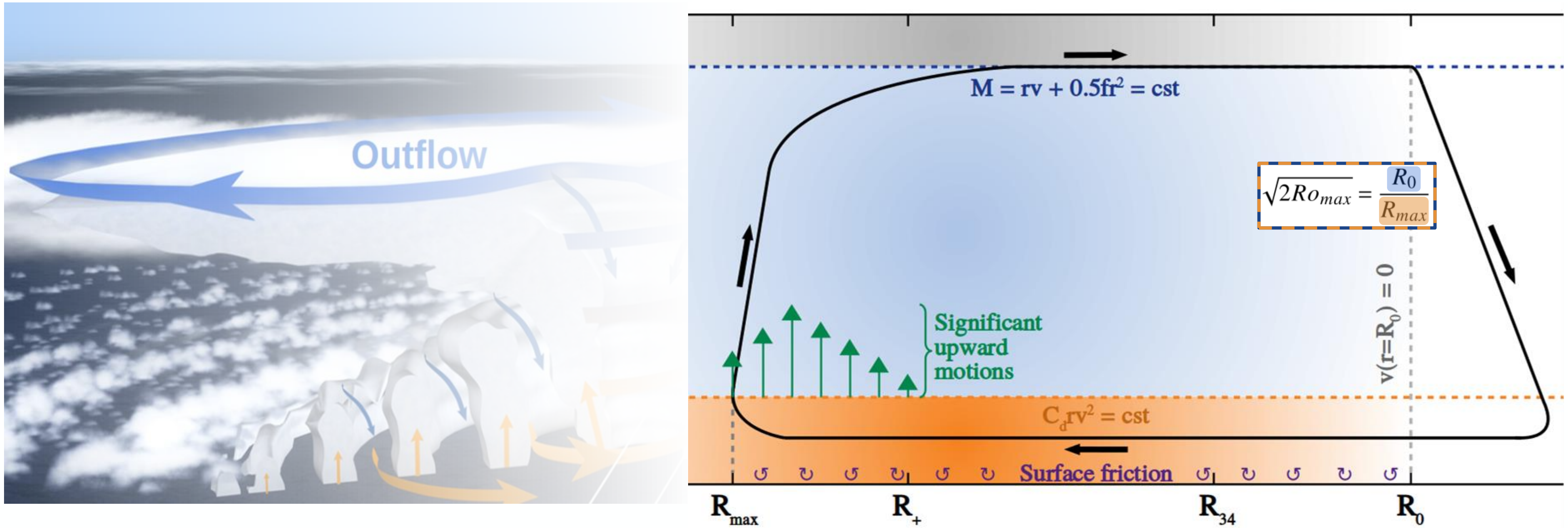
It was first evidenced that the radial distribution of the wind speed was constrained by the simple law:

$$C_d r V^2 = \text{constant}$$

where Cd is the exchange coefficient of momentum, and r, V, the distance from center and the tangential wind speed, respectively (*Avenas et al., 2023*).

Context

The system may then be conceptually thought of as a simple two-layer vortex.



Two-layer conceptual model of the TC system.

Coriolis parameter

$$f = 2\Omega \sin(\phi)$$

Maximal Rossby number

$$Ro_{max} := \frac{V_{max}}{f R_{max}} \sim 50$$

Notations

- r, v: radius, tangential wind speed;
- Ω, φ: Earth's angular velocity (7.292x10^{-5} s^{-1}) and latitude of the TC center;
- V_{max}, R_{max}: Amplitude and location of the maximum velocity.

Context

Two characteristic radii emerge from this view:

- R_0, the **radius of vanishing wind in the outflow**;
- R_+, the **radius of significant upward motions in the inflow**, defined as:

$$\omega_z(R_+) = 5f$$

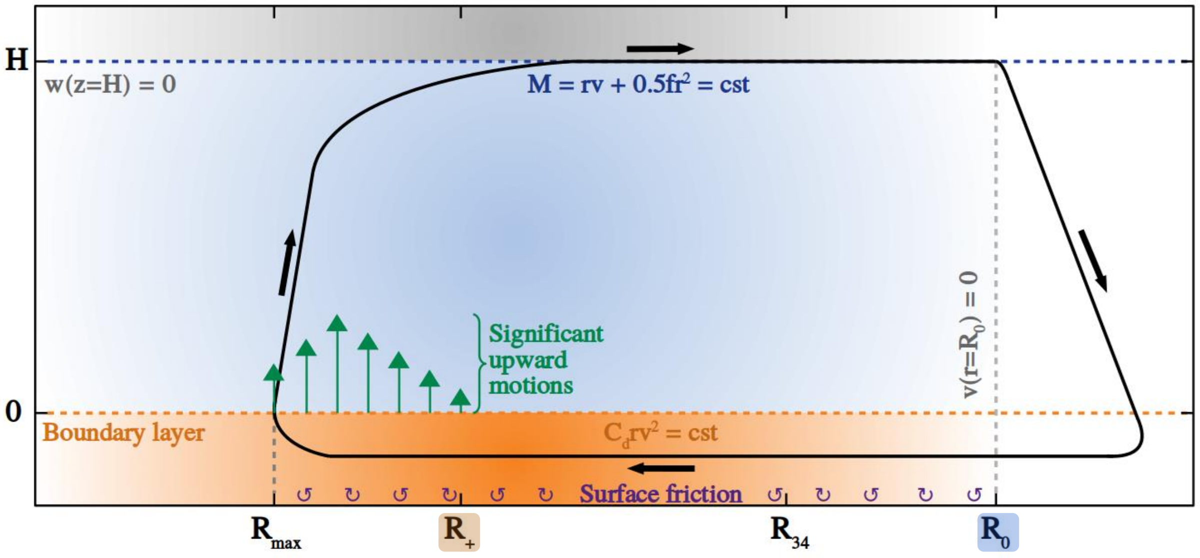
This latter definition is suggested by the expression for the vertical velocity at the top of the boundary layer:

$$w_E(r) = \frac{1}{r}\frac{\partial}{\partial r}\left(\frac{C_d r v^2}{\omega_z + f}\right)$$

Assuming that heating is proportional to vertical velocities, the equation for the energetical steady-state balance is:

$$\int_0^{R_0} \left[C_d r v^3\right]_{z=0} dr = U_c^2 \left[\frac{C_d r v^2}{\omega_z + f}\right]_{z=0,\ r=R_+}$$

Friction — Heating



Schematic illustration of the TC system. The meridional circulation (black lines) is represented in a (r, z)-plane. The radii used in this study are placed in the order given by their average value in the SAR database: R_{max}~32 km, R_+~57 km, R_{34}~139 km, and R_0~216 km.

Notations
- ω_z: Relative vorticity;
- g: Standard gravity;
- q_b: Specific BL humidity;
- L: Latent heat of condensation;
- C_p: Heat capacity;
- T: Air temperature;
- β: Heat profile normalized on the interval $[0, H]$, where H is the height of the TC system.

Where U_c is a velocity characterizing thermodynamic atmospheric properties:

$$U_c^2 := \frac{g q_b L}{C_p} \int_0^H \int_0^z \frac{\beta(z)}{\bar{T}(z)}\, dz\, dz$$

Context

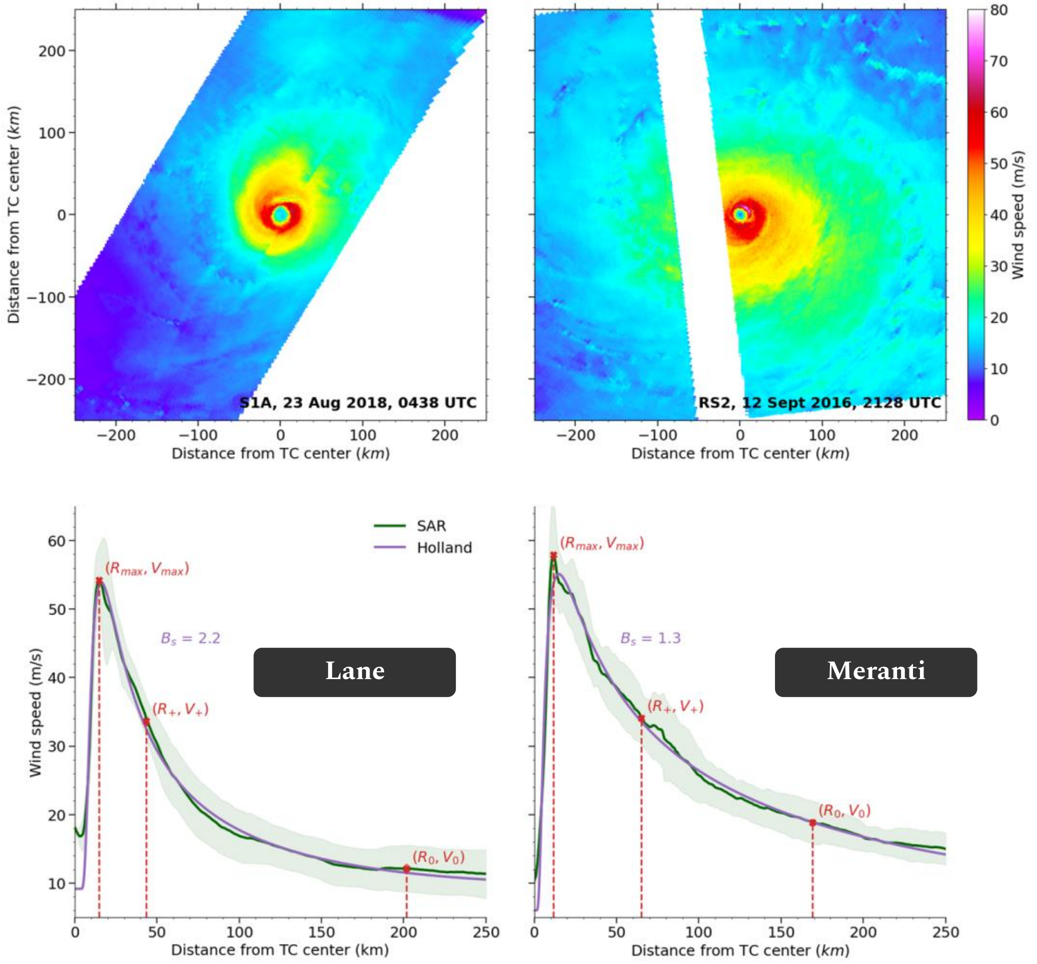
This equation was further reduced to an expression involving 2 surface wind structure parameters (B_s and Ro_{max}):

$$V_{max}^2 = \frac{U_c^2}{3\sqrt{2}}\sqrt{B_s Ro_{max}} \qquad (B_s, Ro_{max}) \Leftrightarrow (R_+, R_0)$$

which was shown to be satisfied by most tropical cyclones, assuming a universal **U_c ~ 30 m/s** (*Avenas et al., 2024a*). In addition, both R_+ and R_{max} were shown to modulate the short-term evolution of the surface wind profile (*Avenas et al., 2024b*).

⇒ Reliable estimates of the near-core wind structure should be more systematically included in tropical cyclone best-tracks.

What about medicanes?



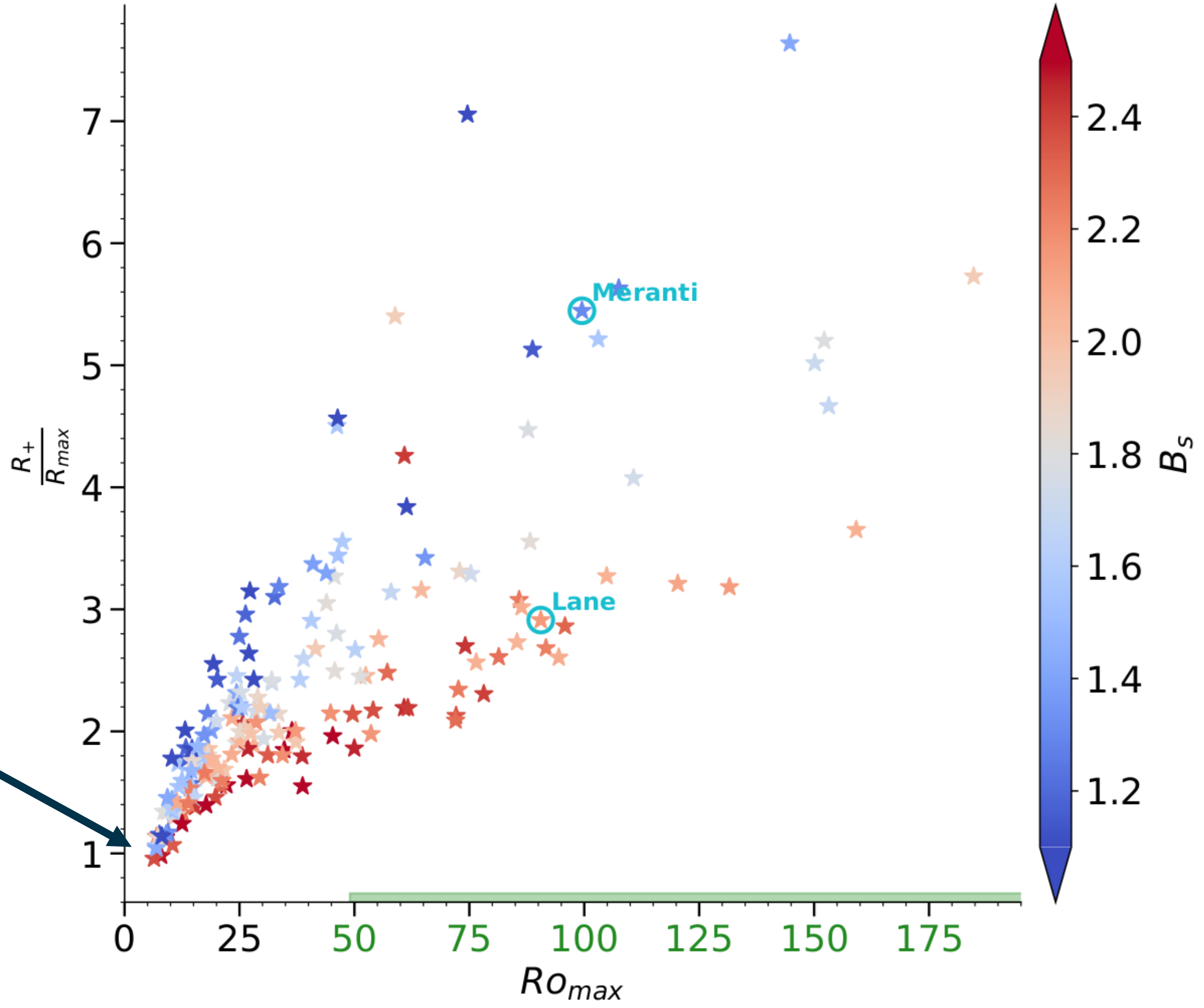
SAR wind speed estimates (Top) and corresponding wind profiles estimates (Bottom) for TC Lane (Middle) and Meranti (Right).

Questions

- A possible extrapolation for R+ values?
- Relevant for the medicane dynamics?

Medicanes = lower Rossby numbers e.g $Ro_{max} \sim 5$

We expect $R_+ \sim R_{max}$

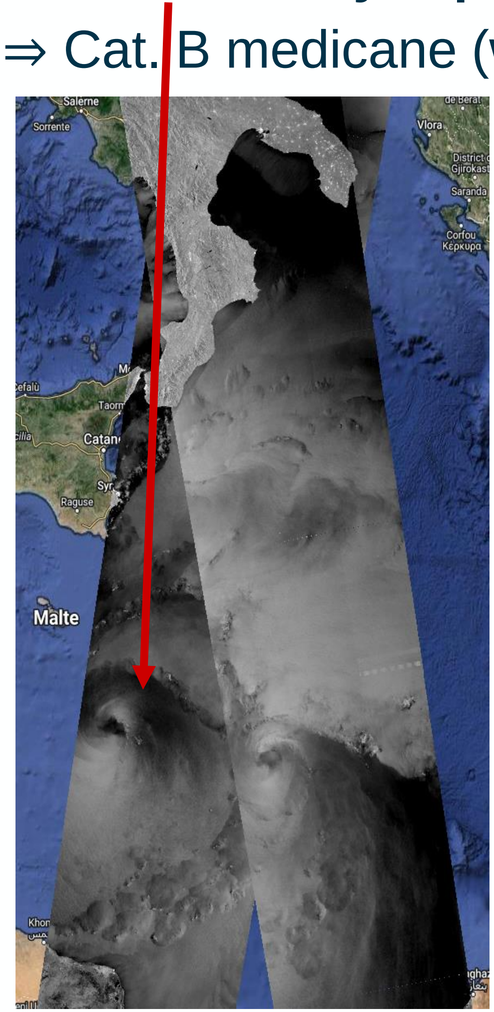


Observed dependency of R +/Rmax on Ro_{max} and B_s . Each star represents a SAR observation. The x-axis is shaded in green for Ro_{max} > 50.

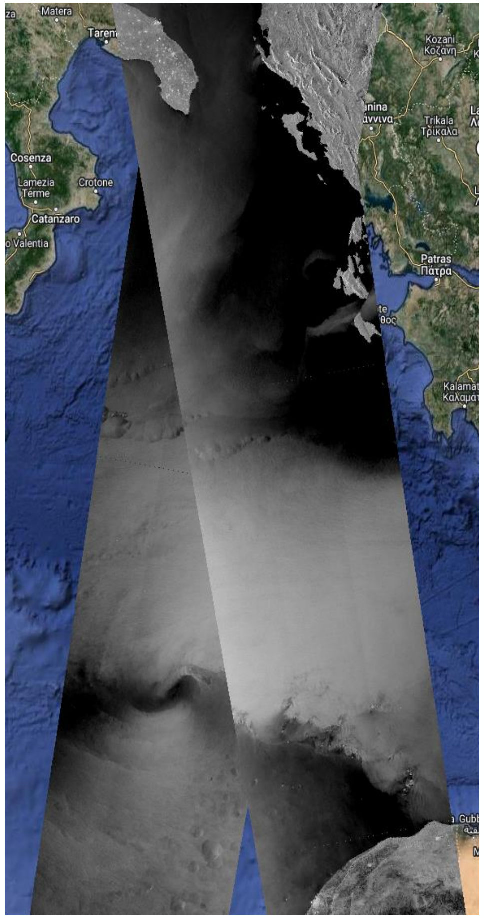
Results

➢ Case study: Apollo, 26 October AM

⇒ Cat. B medicane (warm-air seclusion, strong baroclinic environment)



2021/10/26 morning/afternoon

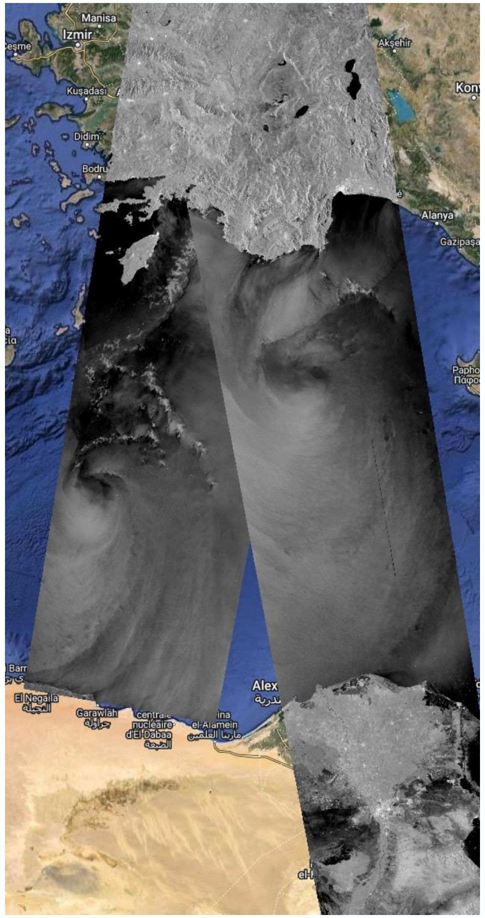


2021/10/27 morning

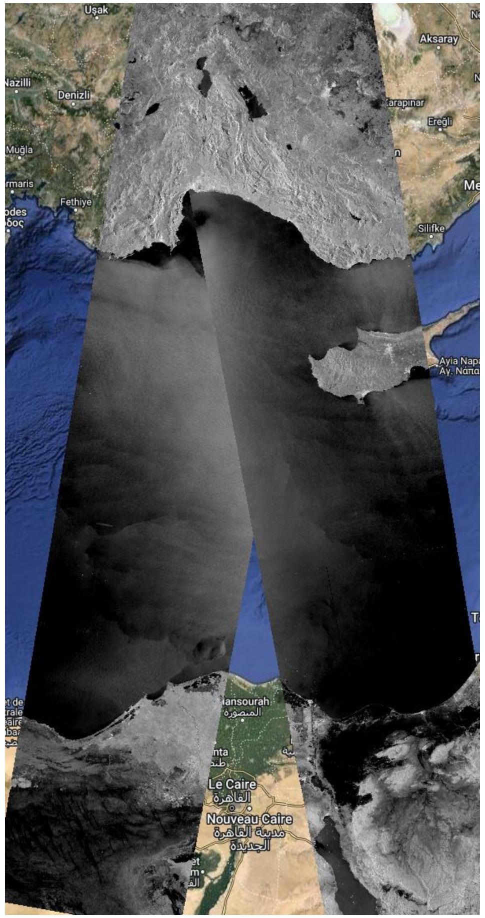
Max. intensity

28-30 October

No SAR data

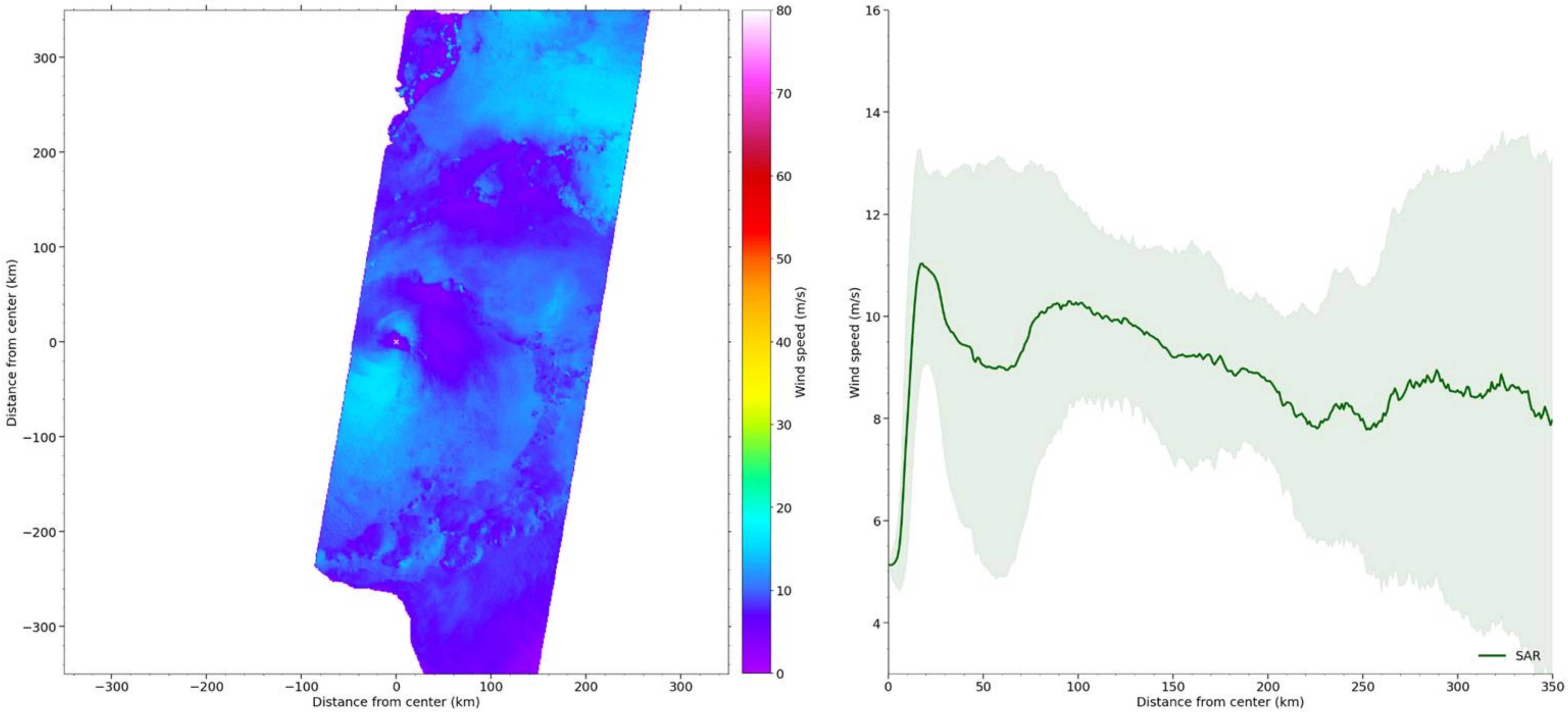


2021/11/01 morning/afternoon



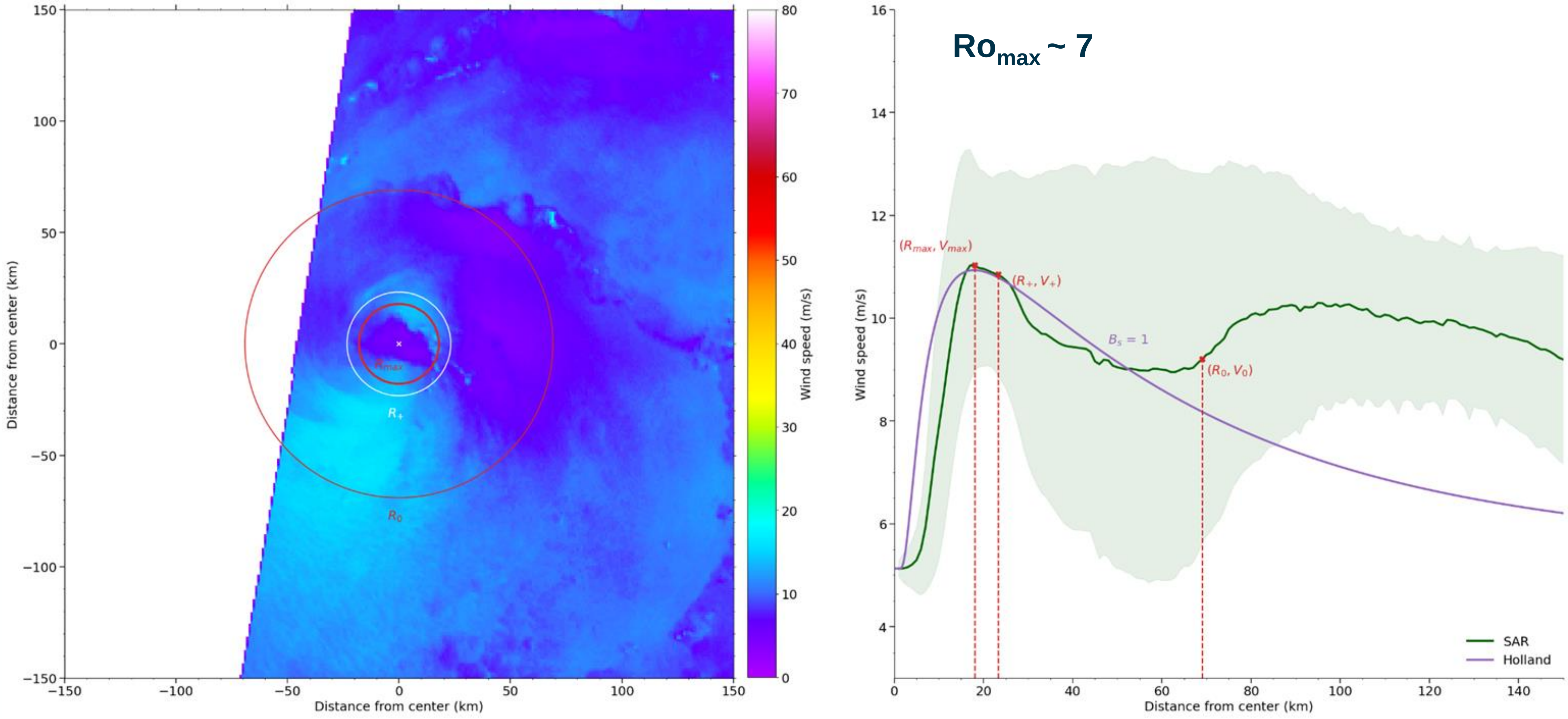
2021/11/02 morning/afternoon

Results



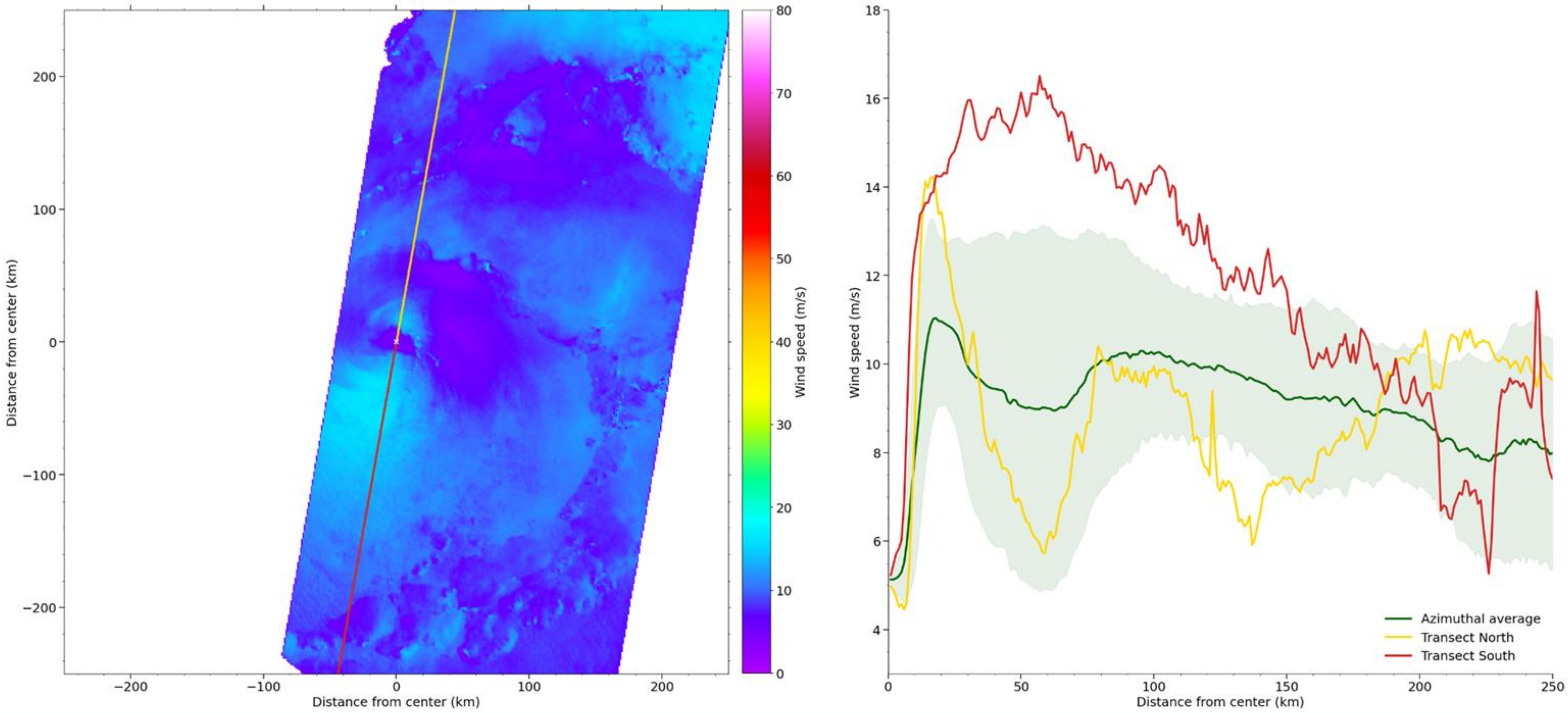
SAR wind speed estimates (Left) and corresponding wind profiles estimates (Right) for medicane Apollo on 26 October at 0457 UTC.

Results



SAR wind speed estimates (Left) and corresponding wind profiles estimates (Right) for medicane Apollo on 26 October at 0457 UTC.

Results



SAR wind speed estimates (Left) and corresponding wind profiles estimates (Right) for medicane Apollo on 26 October at 0457 UTC, for the North and South transects.

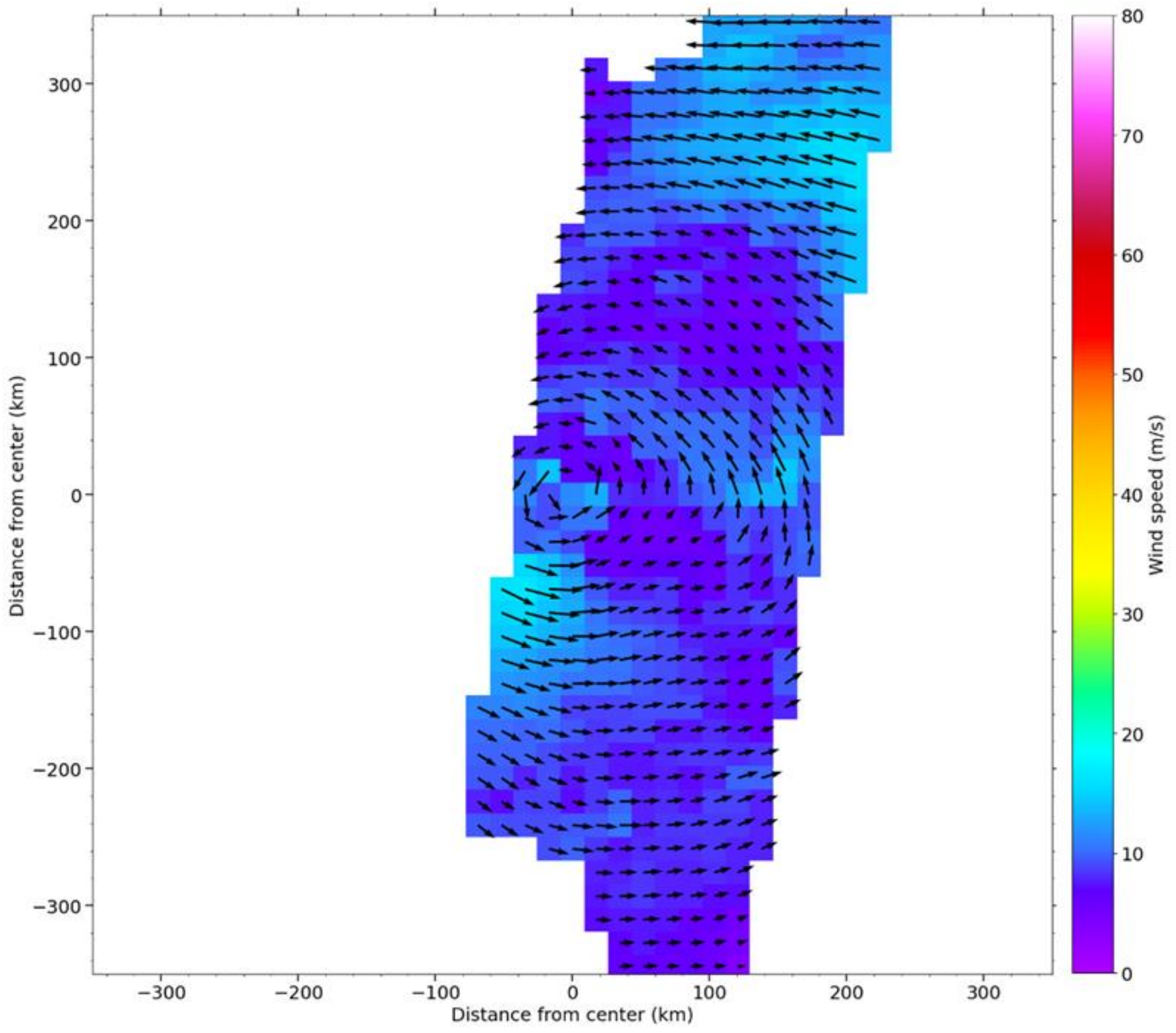
Results

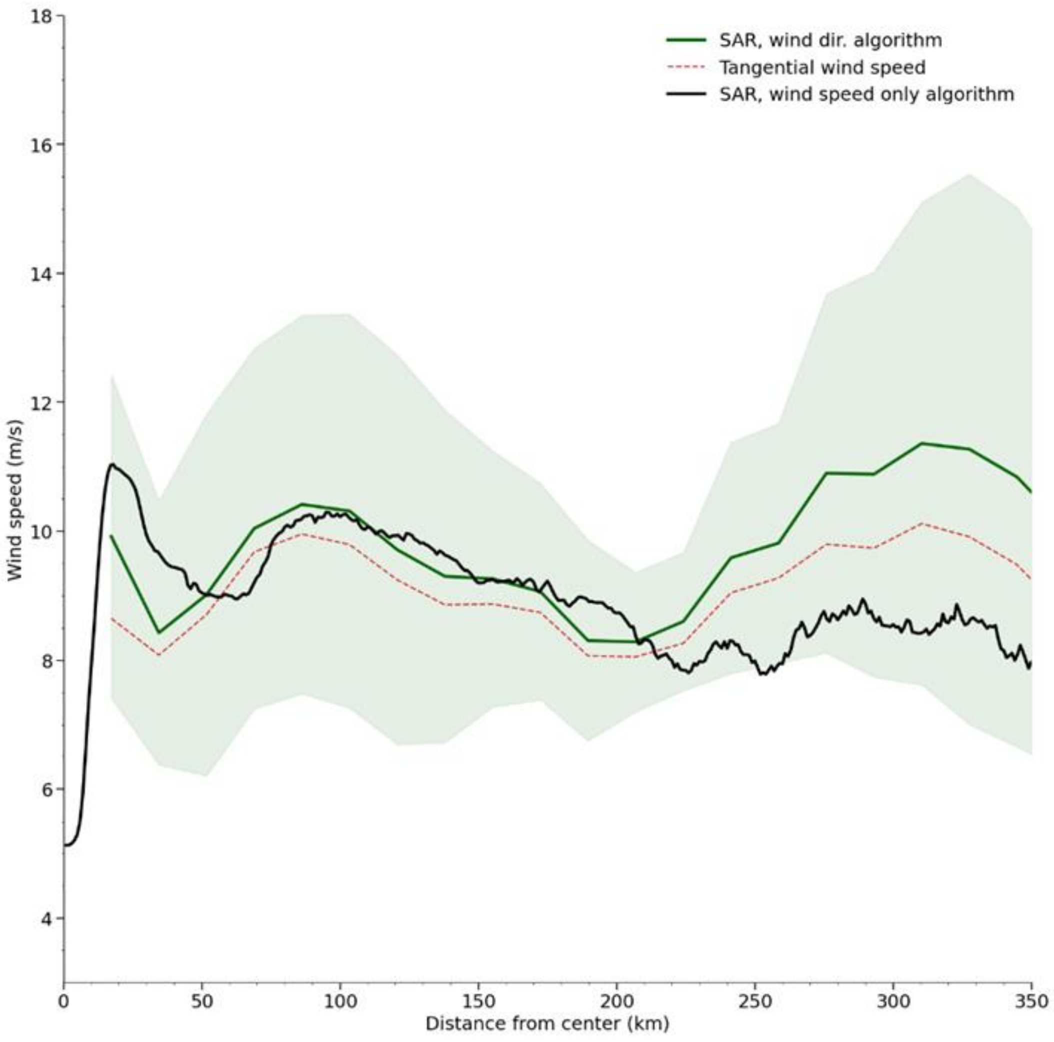
➢ **Apollo, 26 October AM**

- Low-level asymmetries;
- Contribution from background flow;

⇒ Small inflow angle assumption?

Results





SAR wind vector estimates (Left) and corresponding wind profiles estimates (Right) for medicane Apollo on 26 October at 0457 UTC.

Conclusion & Perspectives

Conclusion

Thanks to SAR data on medicane Apollo, we showed that:

- System size in the range
  - R_{max} ~ 20-25 km;
  - R_0 ~ 70-100 km;

    ⇒ Values close to that of tropical cyclones of similar intensities (not shown);

    ⇒ High-resolution is crucial to correctly estimate the radial distribution of the wind speed near the medicane core;
- $R_+ \sim R_{max}$ and $B_s \sim 1$ also seem to take reasonable values (/!\ axisymmetric assumption);

    ⇒ Potential to apply the energetical equilibrium theory during mature phase;

Perspectives

- More SAR cases, especially during mature phase, to apply theory and check whether near-core parameters also matter to the medicane dynamics;
- Contribution from the background flow, upper-level winds, and sea surface temperature to the medicane surface wind structure (including near-core)?
- Can scatterometer data support the analysis?

Thanks for listening

Contact

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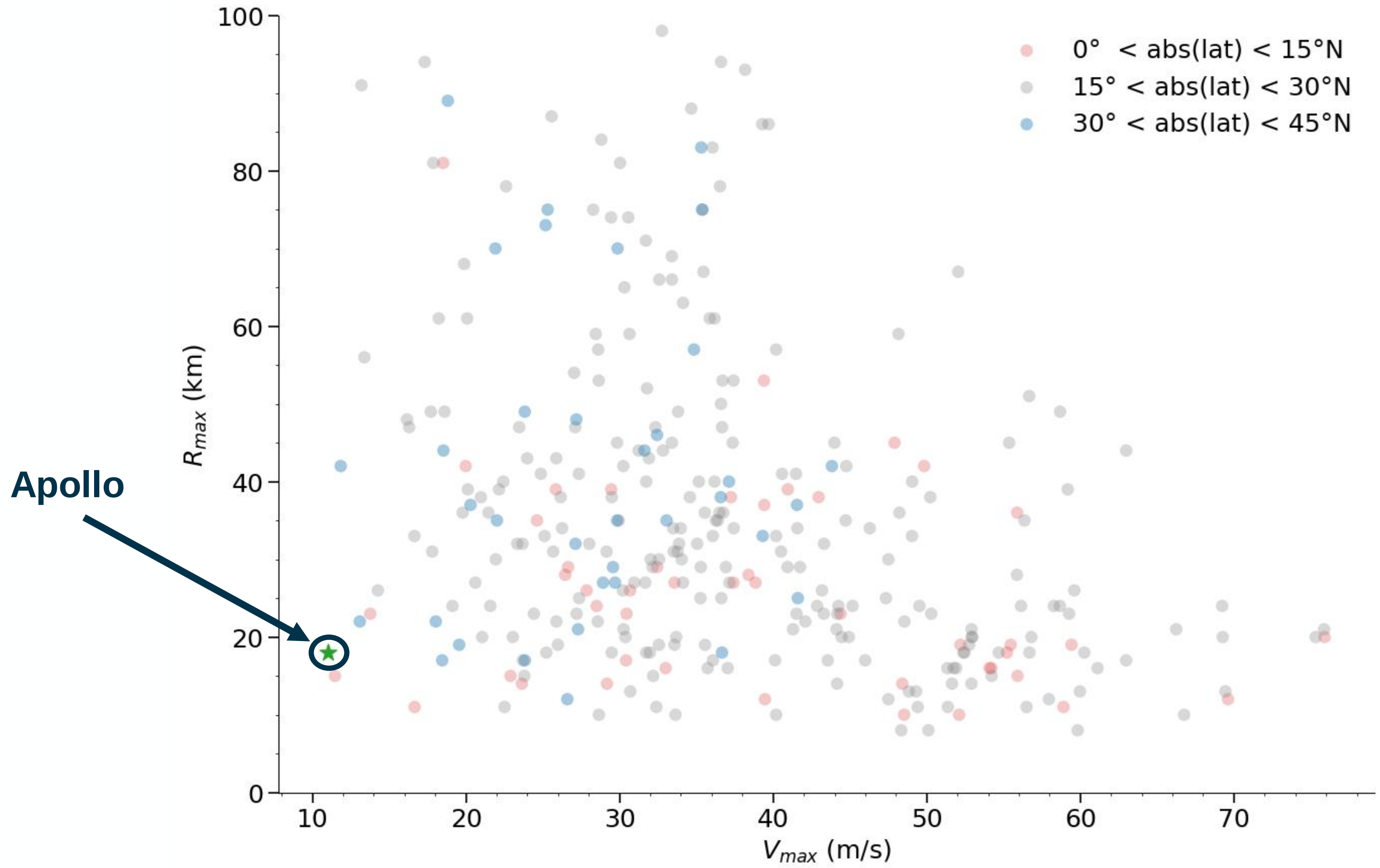
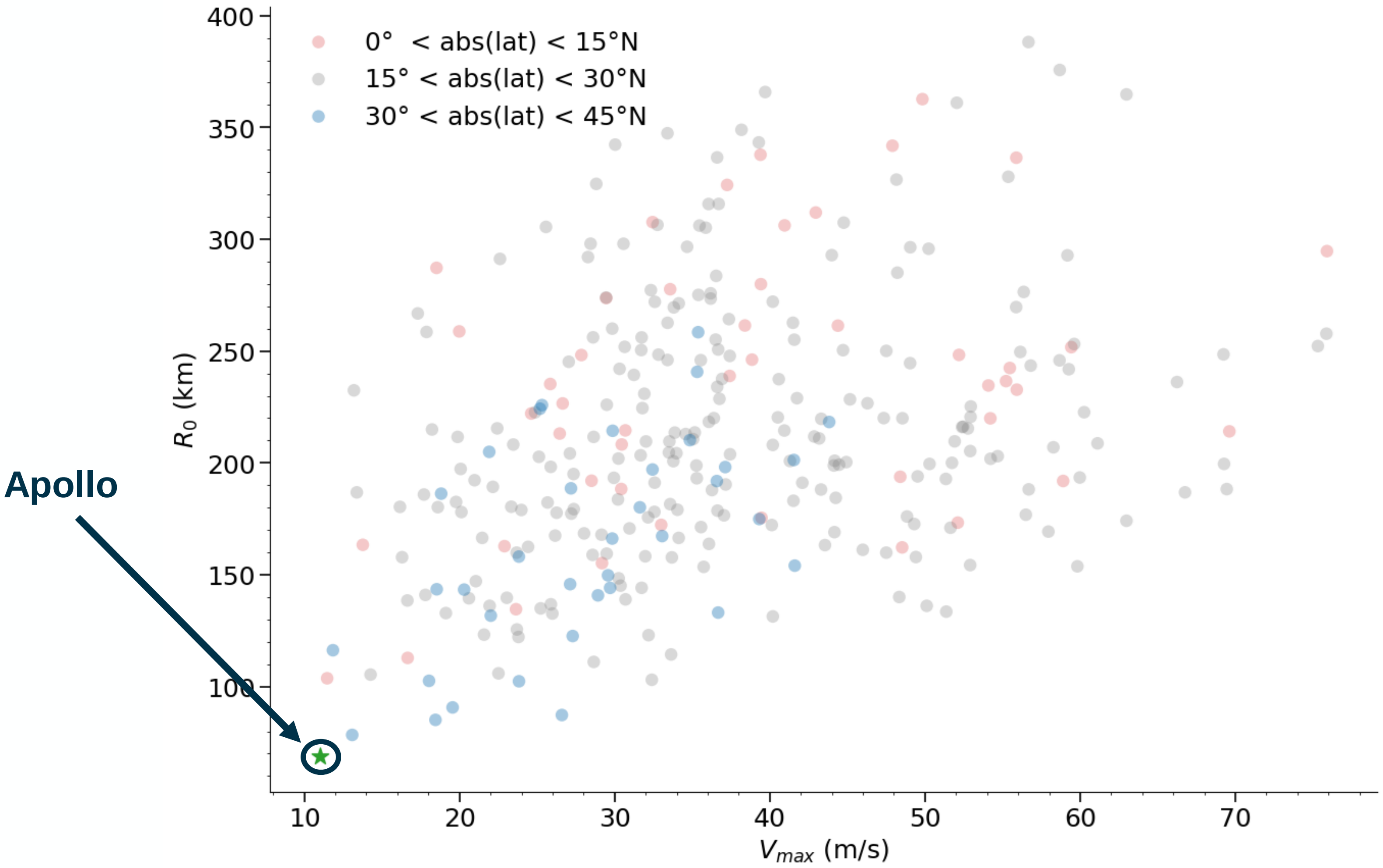
Appendix A1

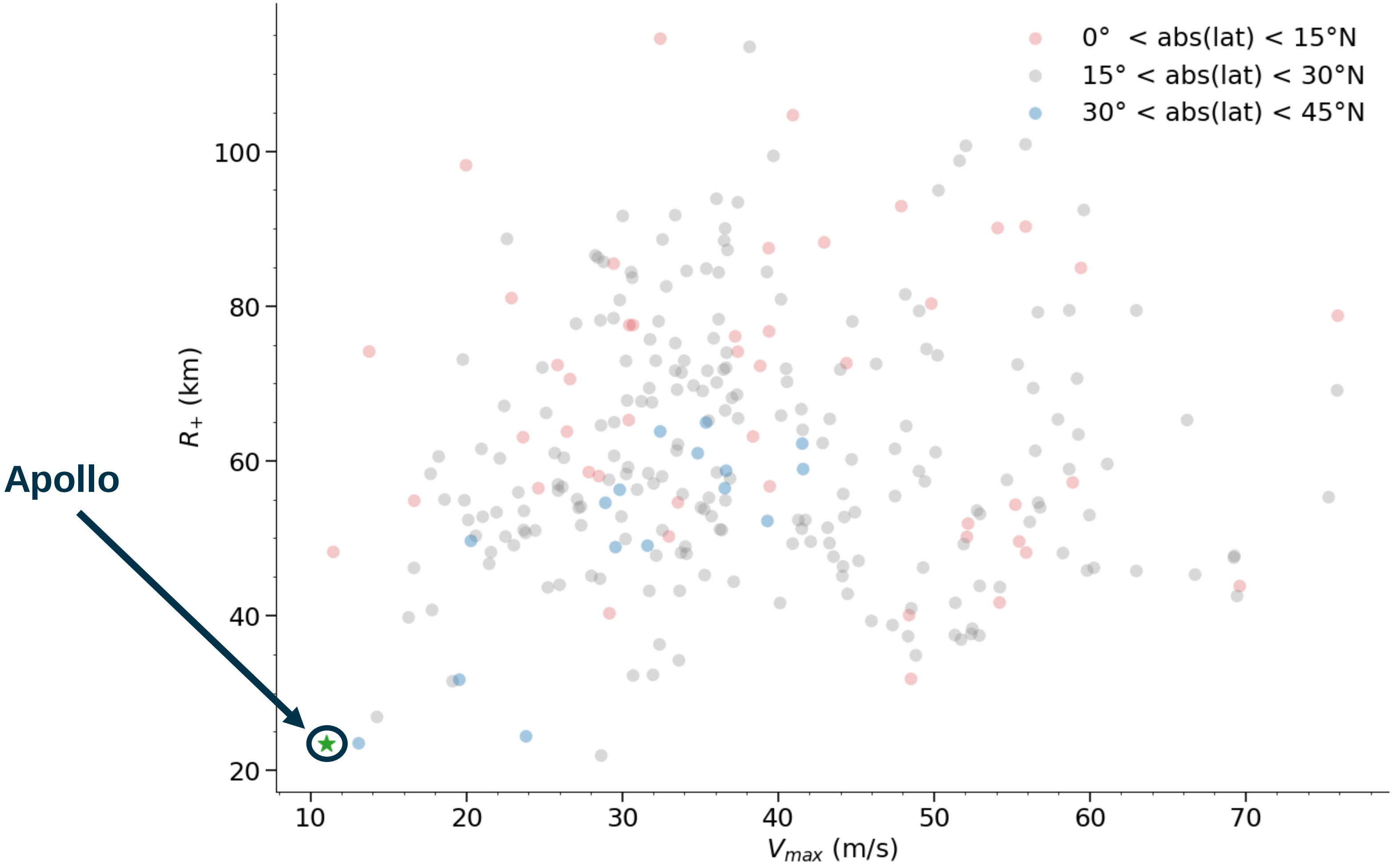


Apollo
100
80
60
40
20
0
10
20
30
40
50
60
70
R_{max} (km)
V_{max} (m/s)
0° < abs(lat) < 15°N
15° < abs(lat) < 30°N
30° < abs(lat) < 45°N

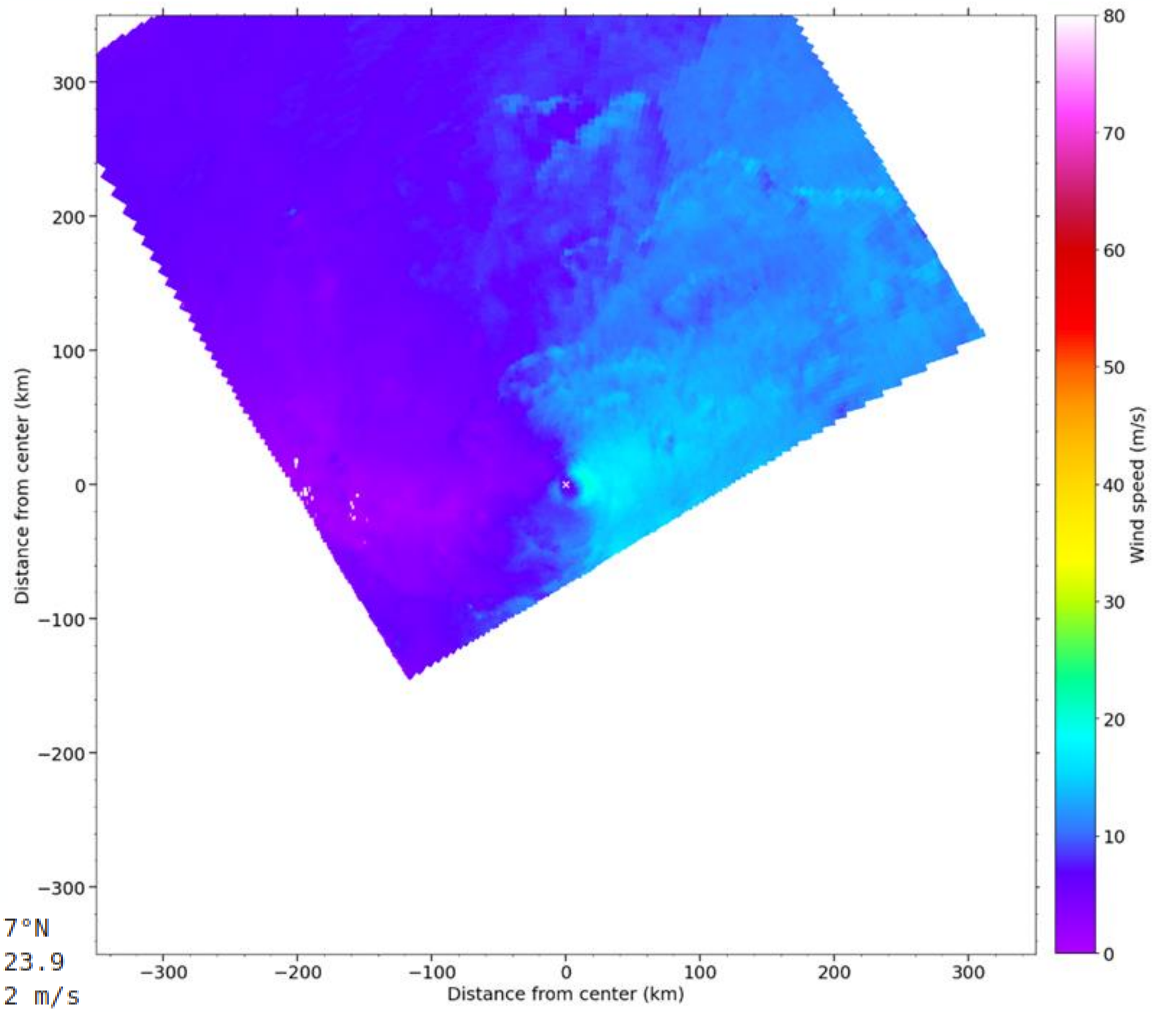
Appendix A2

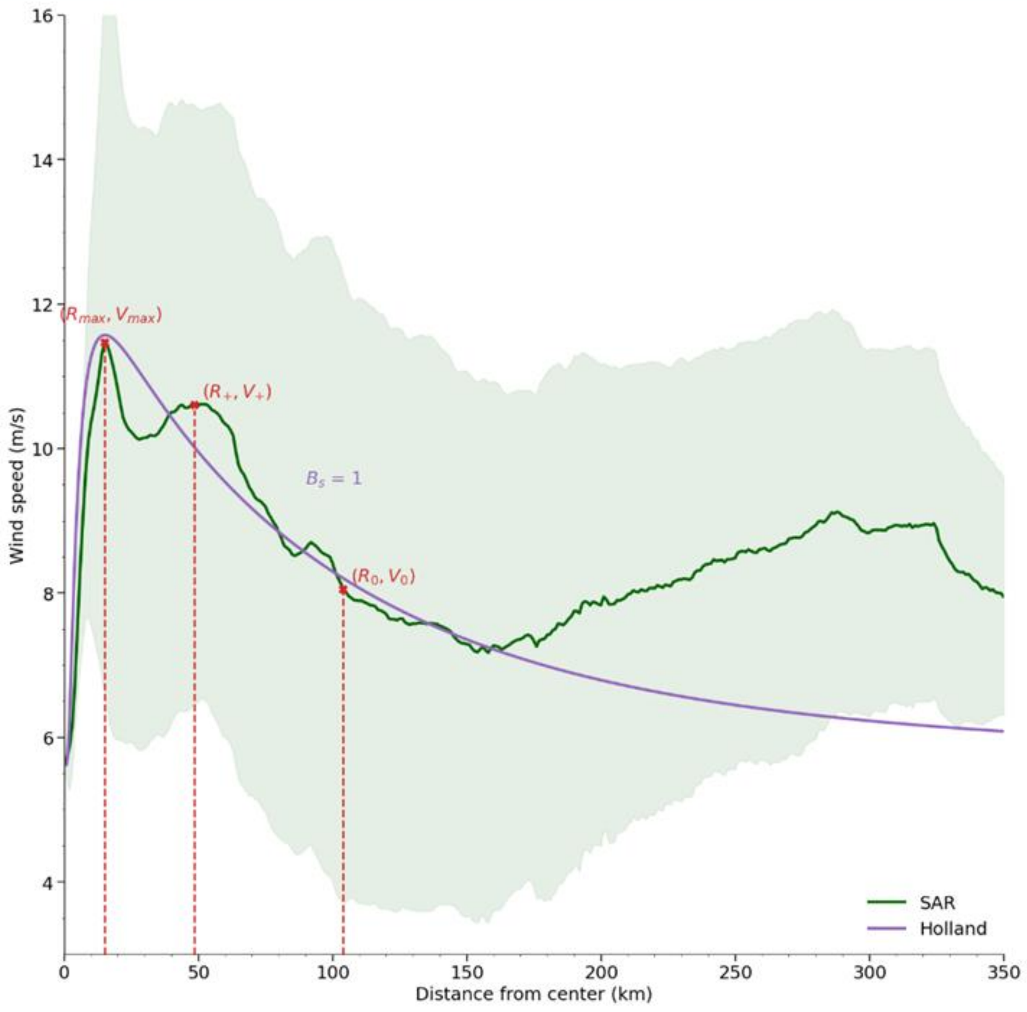


Appendix A3



0° < abs(lat) < 15°N
15° < abs(lat) < 30°N
30° < abs(lat) < 45°N
100
80
60
40
20
R_+ (km)
10
20
30
40
50
60
70
V_{max} (m/s)
Apollo

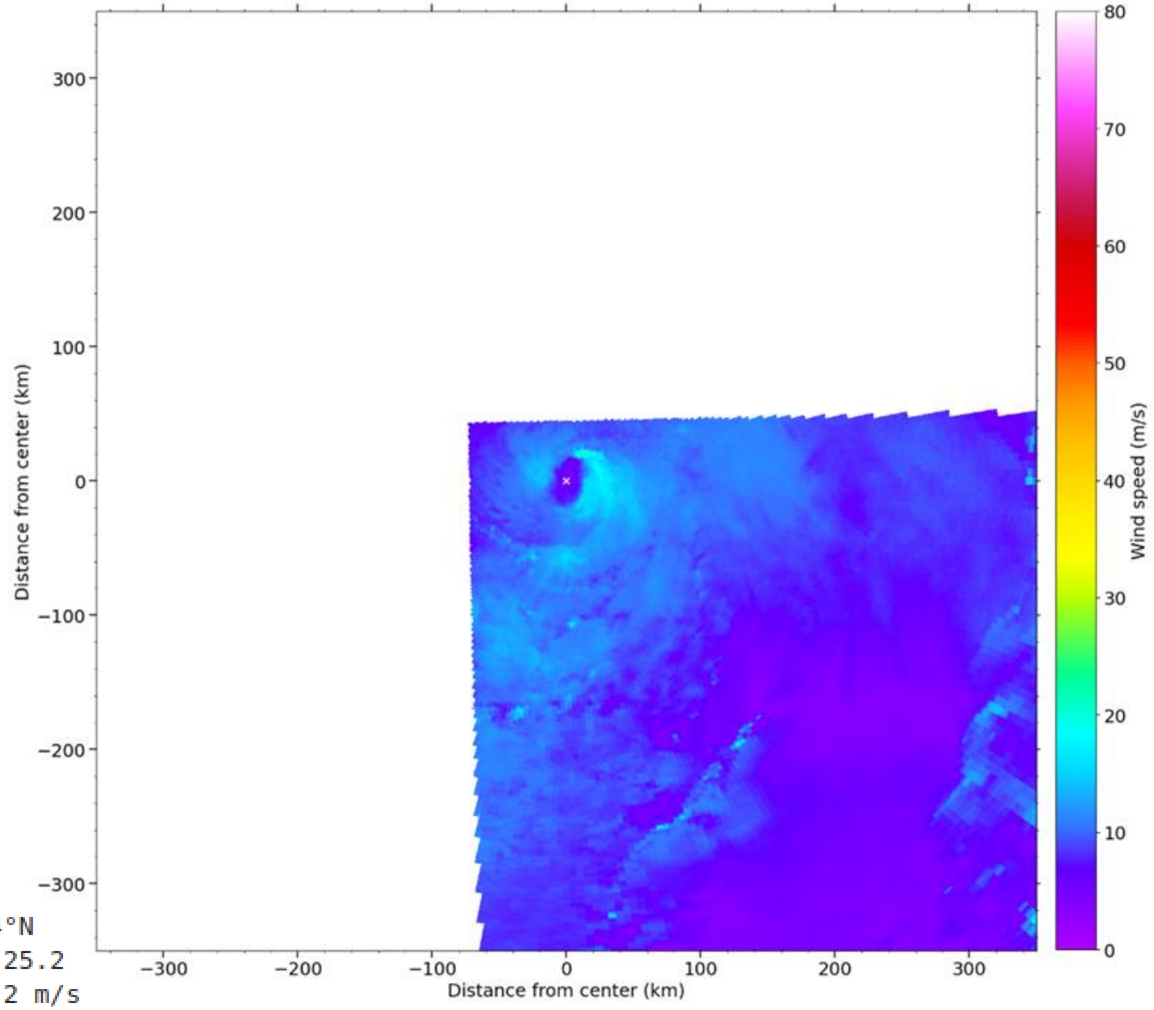


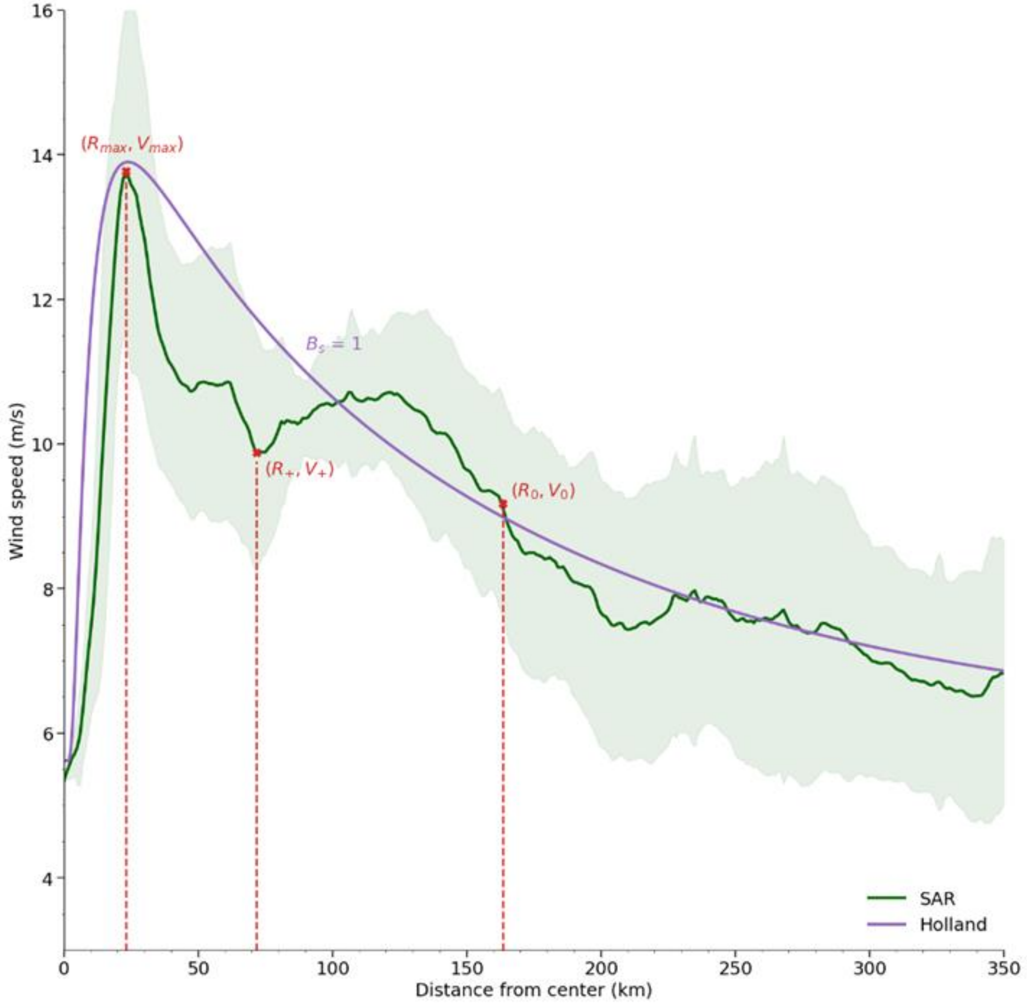


Lat = 12.7°N
Rossby = 23.9
Vmin = 5.2 m/s
R0 = 104 km
R+ = 49 km
Uc = 10.8 m/s

Beryl, 2018

Appendix B2

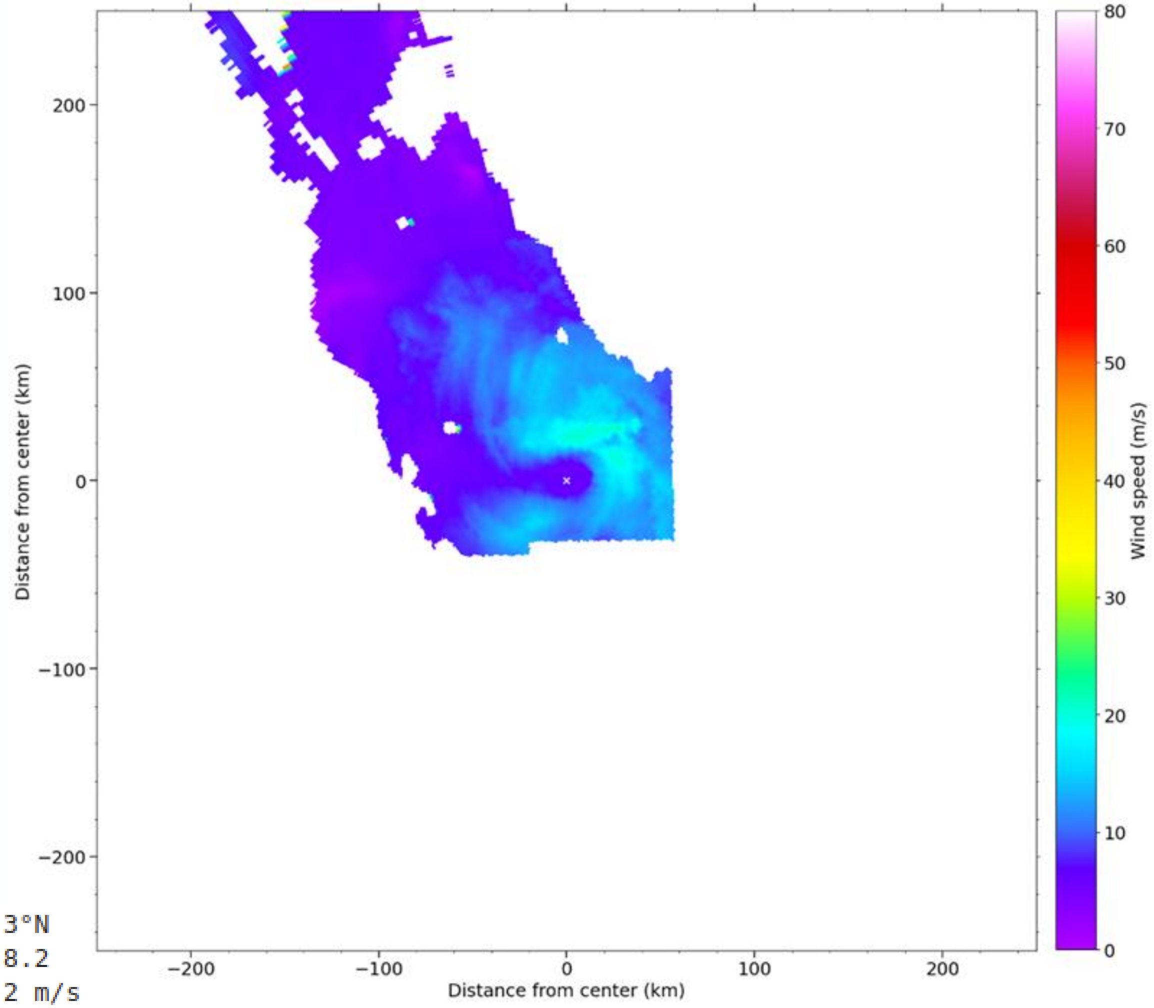


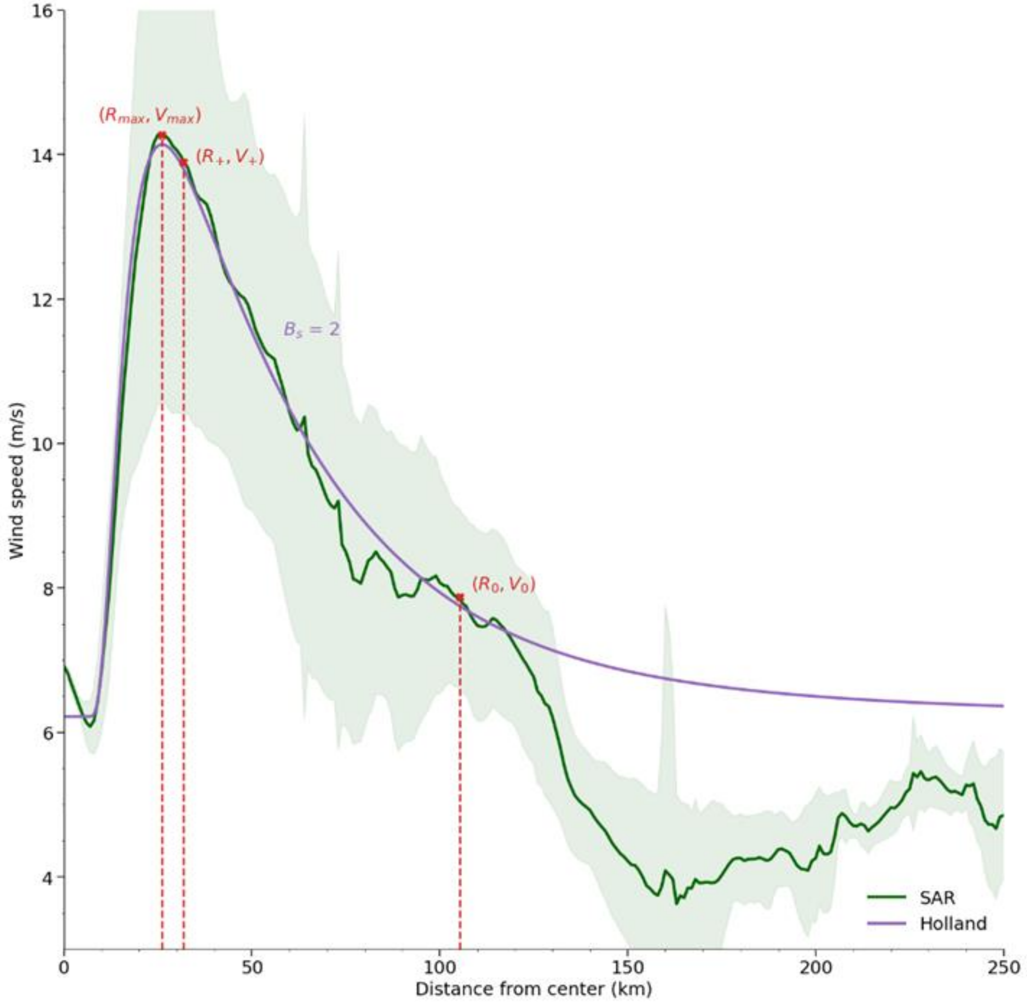


Lat = 9.4°N
Rossby = 25.2
Vmin = 5.2 m/s
R0 = 163 km
R+ = 72 km
Uc = 12.5 m/s

Vance, 2014

Appendix B3

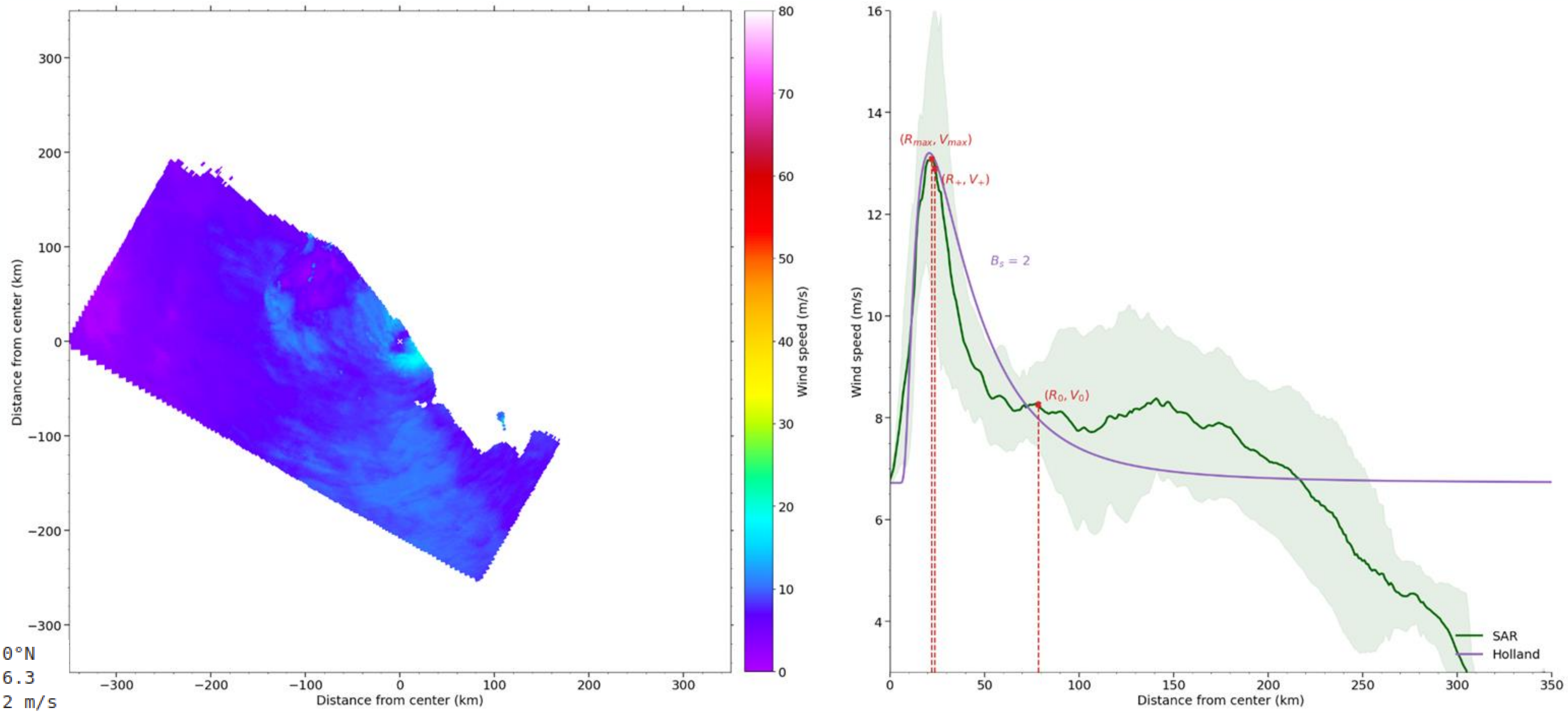




Lat = 27.3°N
Rossby = 8.2
Vmin = 5.2 m/s
R0 = 105 km
R+ = 32 km
Uc = 14.6 m/s

Lorena, 2019

Appendix B4



Lat = 40.0°N
Rossby = 6.3
Vmin = 5.2 m/s
R0 = 78 km
R+ = 24 km
Uc = 14.3 m/s

Alpha, 2020