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Ecce Terra

Directional ocean wave spectrum properties from the SWIM instrument under tropical cyclone conditions

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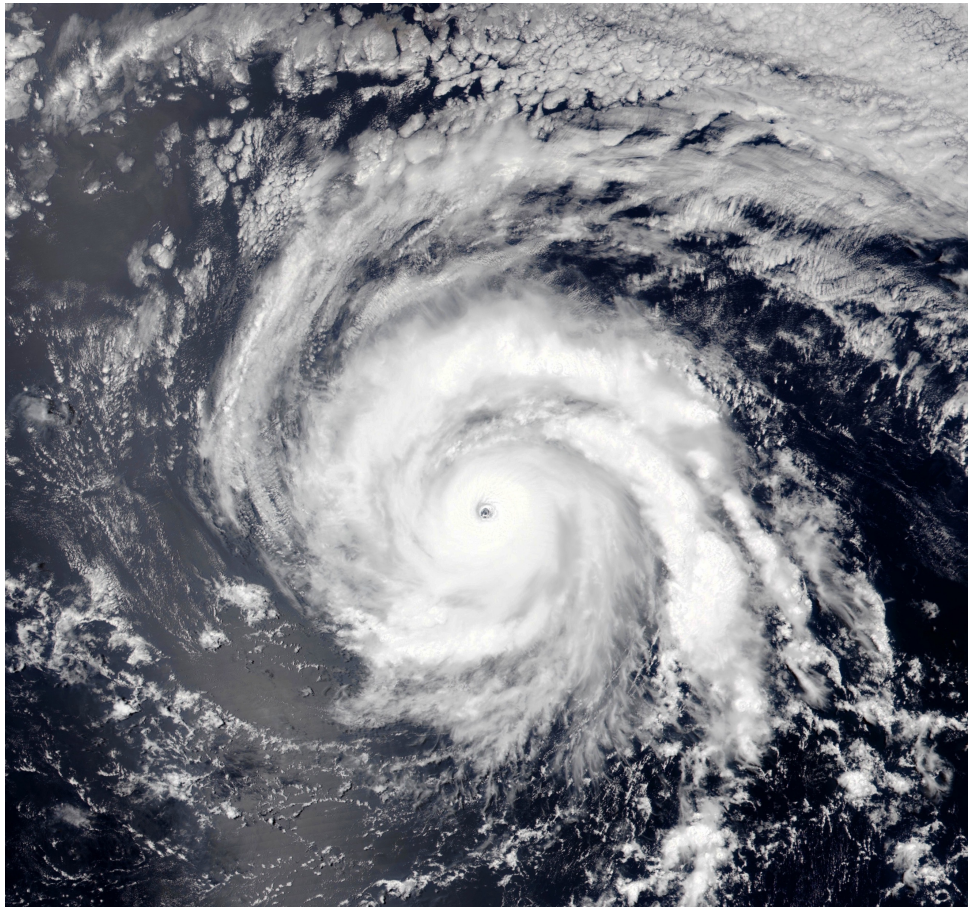
Outline

- Introduction
- Methods
- Case study
- Statistical study
- Conclusions



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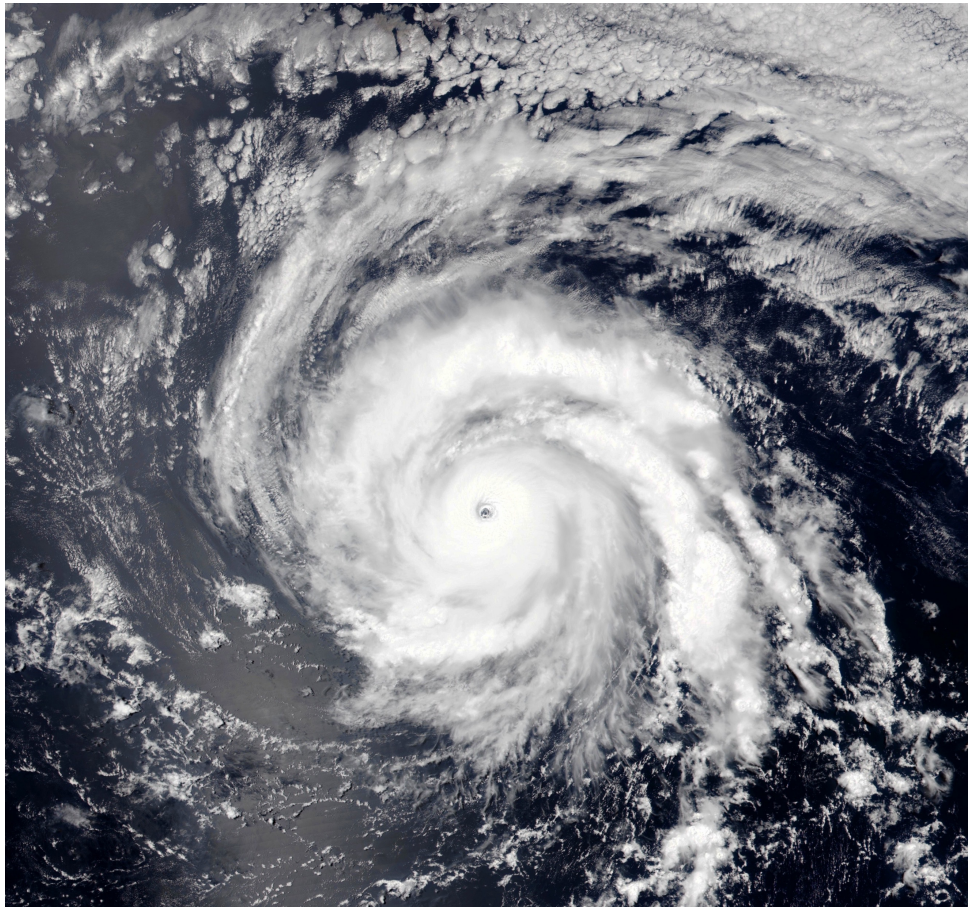

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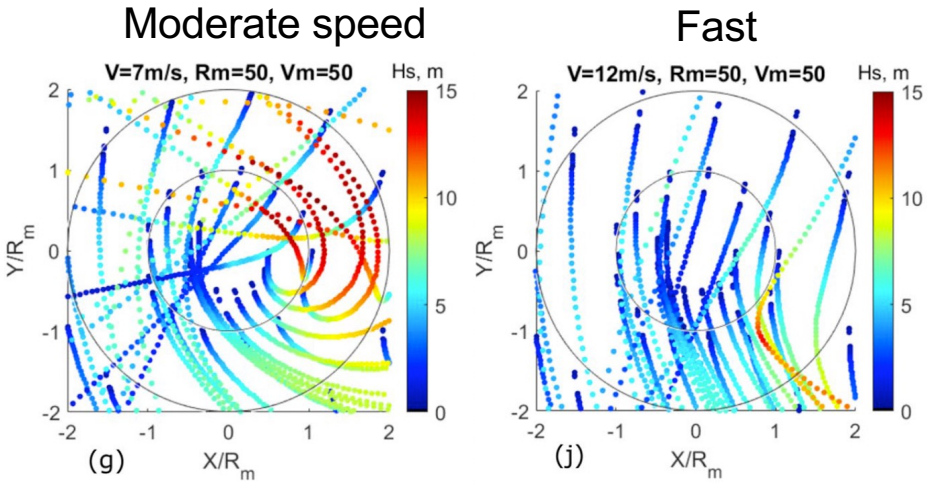
Introduction

- Tropical cyclones (TC) are extreme meteorological events associated with extreme winds, waves and precipitations.
- TC impact the maritime navigation, the risk in coastal areas
- TC modify the ocean–atmosphere interactions
- TC are moving systems with winds in rotation around the TC centre and complex features (asymmetry, radial gradients)
- Importance of improving the behavior of wave field generated by tropical cyclones to better understand and model their evolution in these conditions.

Introduction

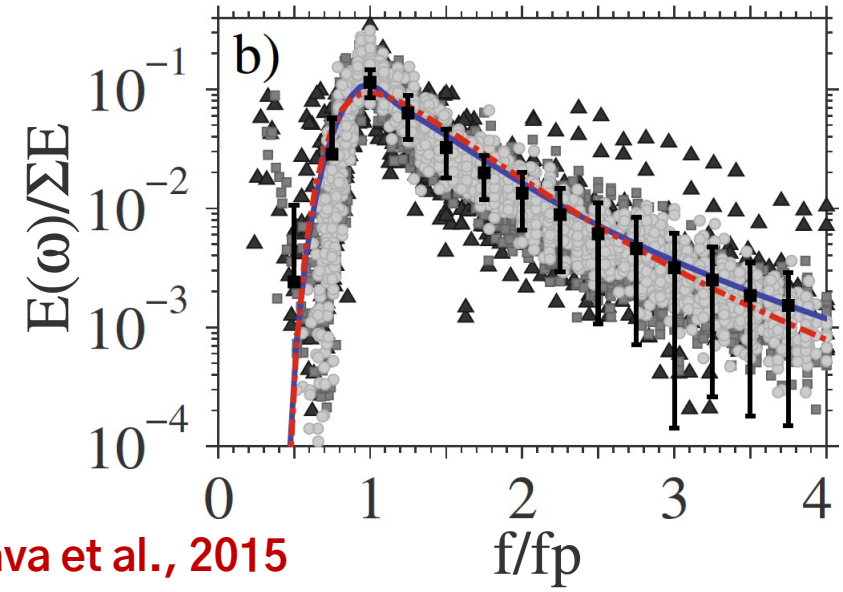
- Hs field is asymmetric in TCs, even when the wind field is symmetric (Young 2006, Kudryavtsev 2015; Shi 2021)
- Explained by “extended fetch” or “trapped waves”, in the forward right quadrant of Northern Hemisphere systems (Young 1998 , Boywer and McAffe,2005),
- Translation speed of TCs impact the wave development (Lagrangian model of Kudryavstev et al, 2021)



Kudryavtsev et al., 2021

Introduction

- Shape of 1D/2D spectra analyzed by e.g.Young (2006), Hwang and Walsh (2018) , Tamizi and Young (2020) , Esquivel-Trava et al., (2015) (buoy measurements, airborne measurements)
- 1D frequency spectra have similarities with fetch-limited spectra.
- 2D spectra tend to become multi-modal on the left side of the TCs



Esquivel-Trava et al., 2015

— Spectral shape in fetch-limited conditions

Introduction

- In this study, thanks to CFOSAT:
  - further investigation of the distribution of ocean wave spectra and of their main parameters under TC conditions.
  - Two years of observations between May 2019 and August 2021 :
  - One originality : analysis of the ocean wave spectra properties according to different classes of relative displacement speed of the cyclones and at different distances within the TC

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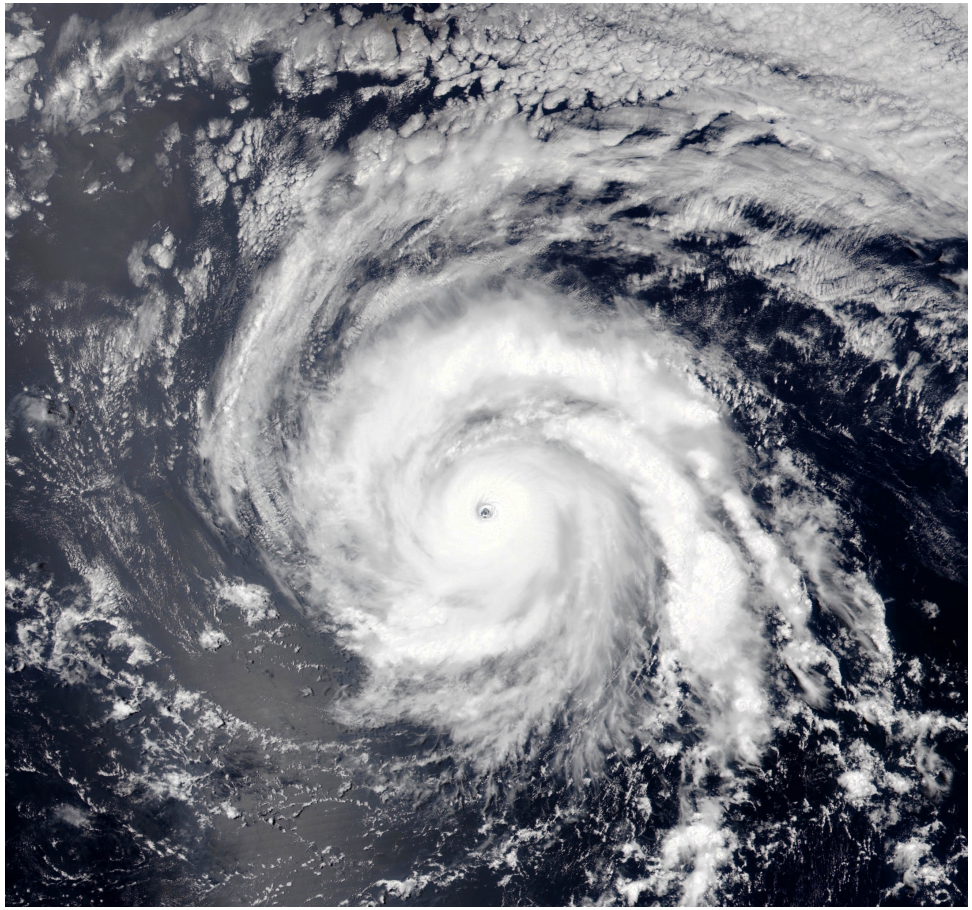

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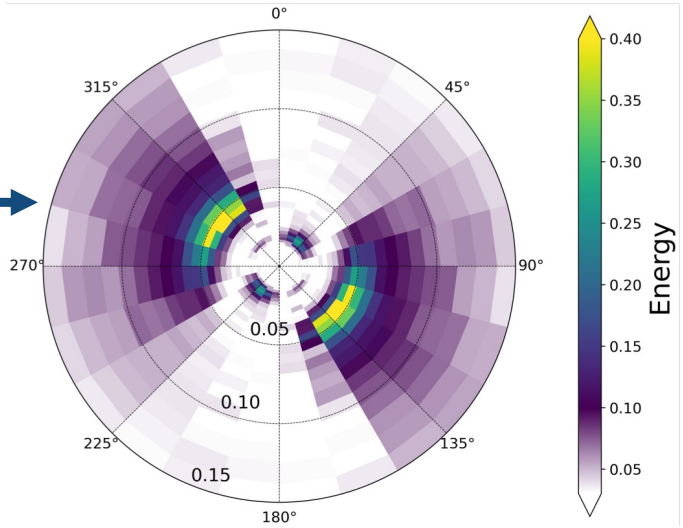
Methods

Observations

- Wave spectra from SWIM



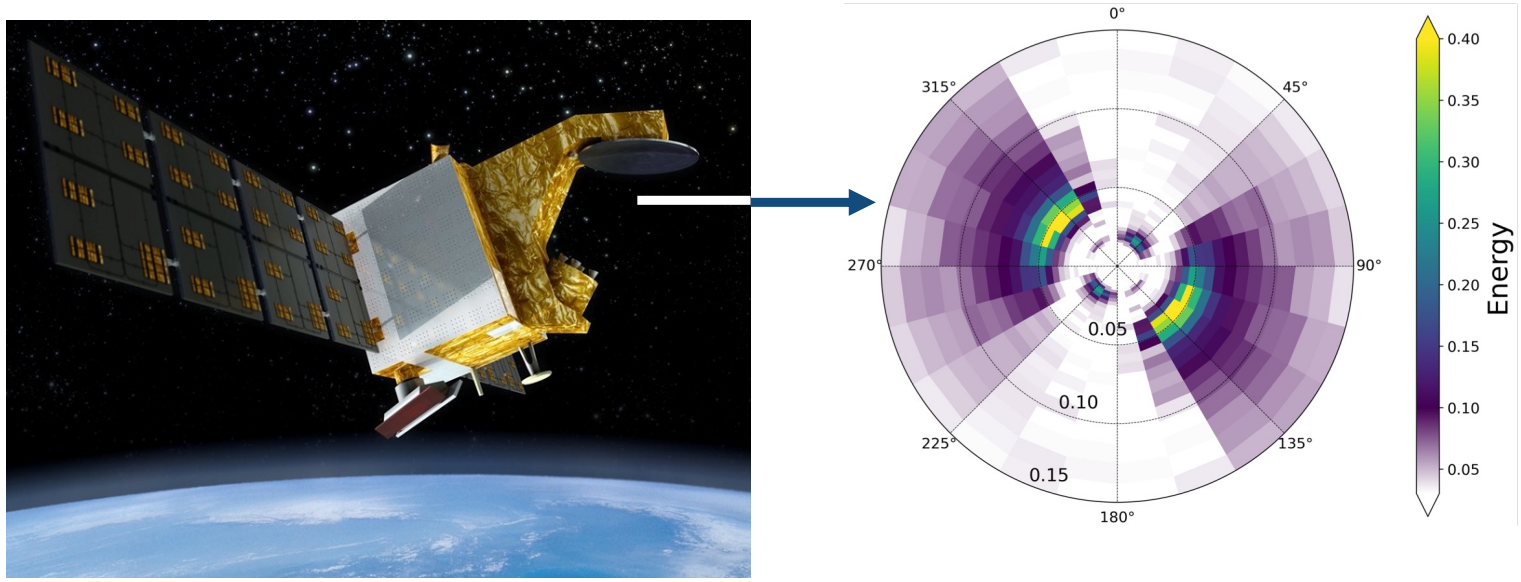
- At global scale, every 70 km along-track.
- Information on waves between ~ 30 and 500 m.
  - Wave spectra
  - Wave parameters

- Wind taken from the ECMWF model analysis

Methods

Observations

- Wave spectra from SWIM



- 2-year analysis (May 2019 – August 2021).
- 46 TCs (Cat 1–5) in the Northern Hemisphere.
- 1869 directional wave spectra (rejecting samples with SWH < 2 m)

Methods

Tropical cyclone classification

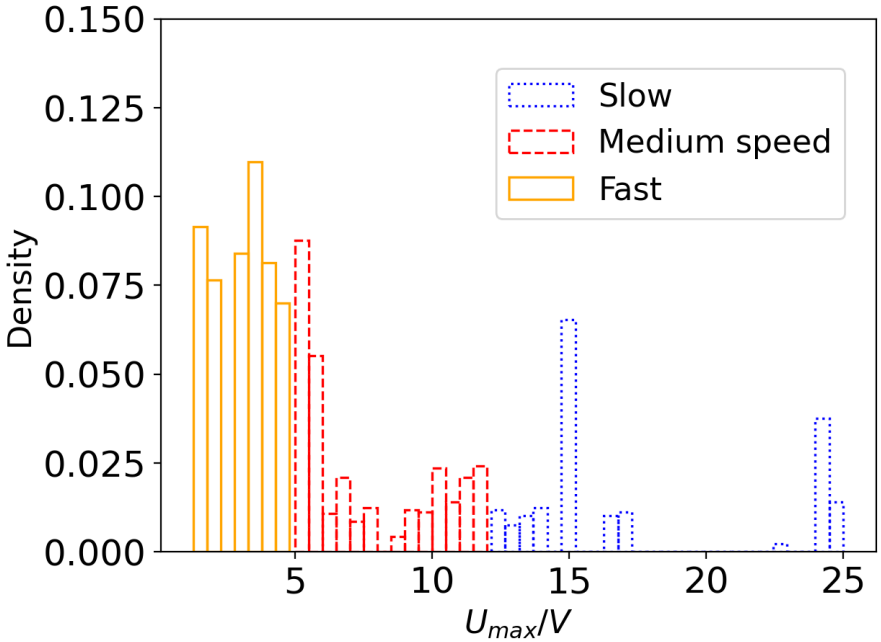
Analyze the wave field within taking into account the TC parameters:

- radius of maximum wind (R_{max}),
- maximum sustained wind (U_{max}),
- translation speed (V_t).

Methods

Tropical cyclone classification

- Based on the numerical studies of Kudryavstev et al (2021) => 3 TC categories, according to their relative speed of displacement V_t / U_{max}
  - Slow $12 < U_{max}/V_t$
  - Moderate speed $5 \leq U_{max}/V_t \leq 12$
  - Fast $U_{max}/V_t < 5$



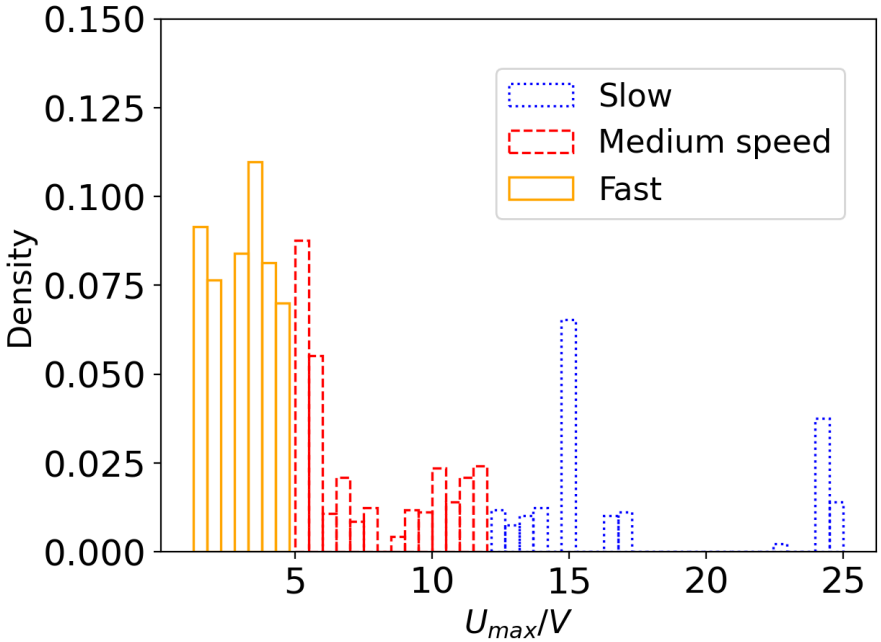
=> half of the SWIM observations correspond to fast moving TCs

Methods

Tropical cyclone classification

- Based on the numerical studies of Kudryavstev et al (2021) => 3 TC categories, according to their relative speed of displacement V_t / U_{max}
  - Slow $12 < U_{max}/V_t$
  - Moderate speed $5 \leq U_{max}/V_t \leq 12$
  - Fast $U_{max}/V_t < 5$

- 3 distance ranges relative to R_{max} :
  - $0 \leq d/R_{max} < 3$
  - $3 \leq d/R_{max} < 6$
  - $6 \leq d/R_{max} < 9$



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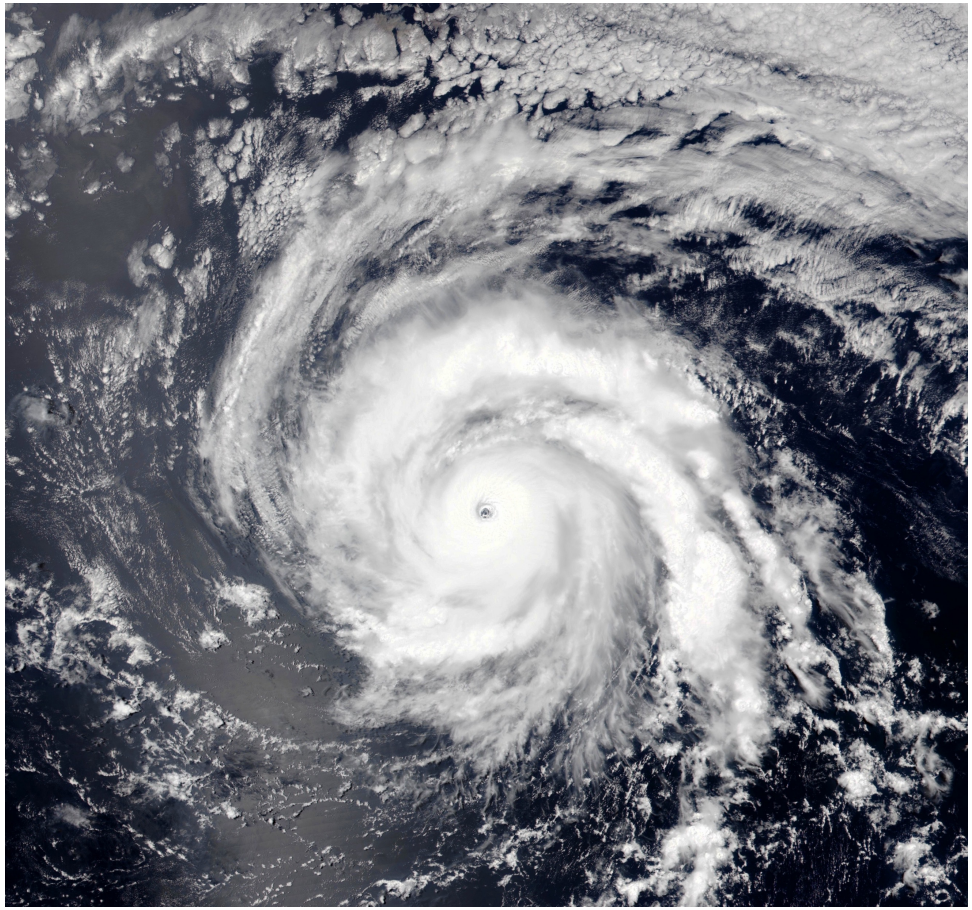

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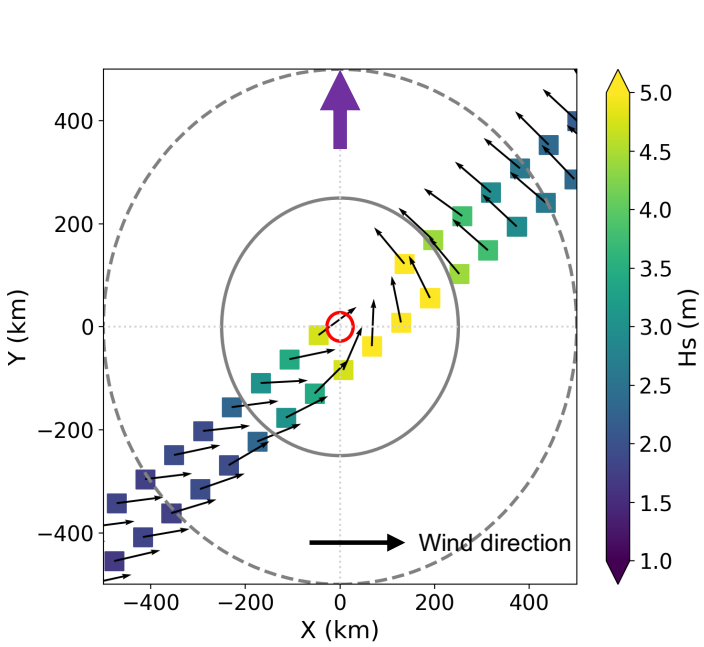
Case study: Hurricane Douglas

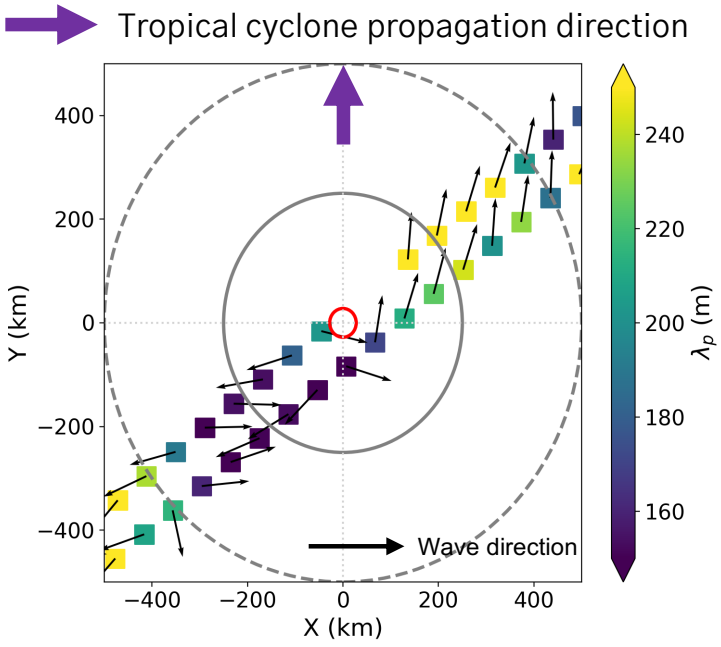
- Eastern Pacific
- 20th –30th July 2020
- Observed by CFOSAT on the 24th of July:
  - R_{max} = 27 km
  - U_{max} = 59 m/s
  - V_t = 8 m/s
  - → Moderate speed TC

Wind information from the ECMWF model forecast



✓ High values of Hs on the right side of the TC.

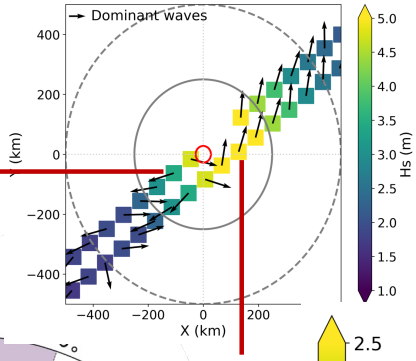
Tropical cyclone propagation direction

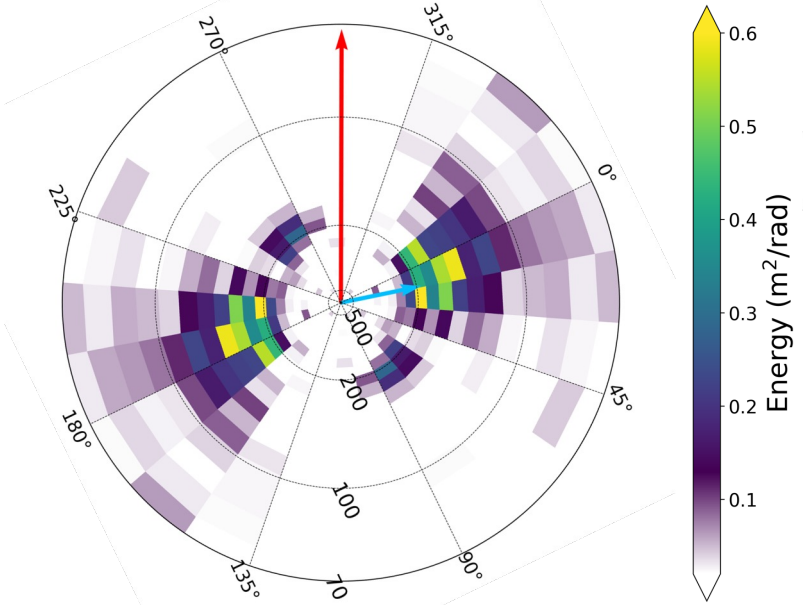


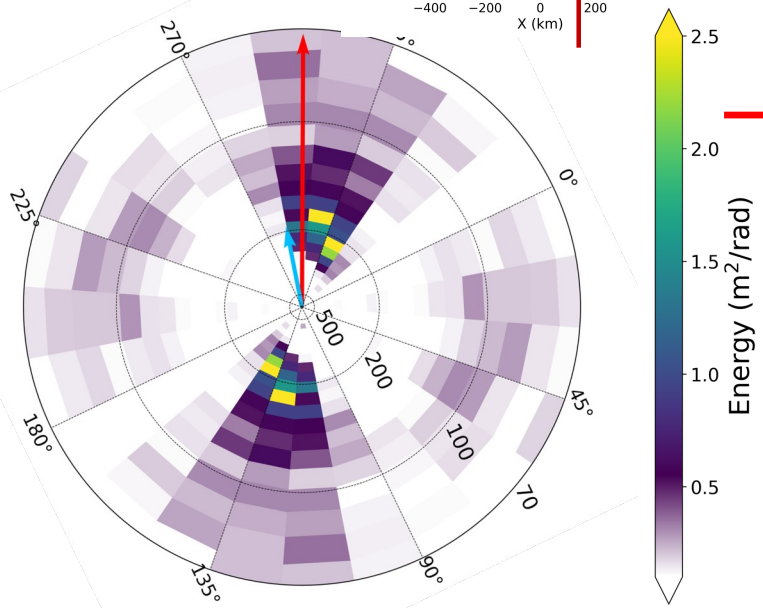
✓ Asymmetry of λ_p and ϕ_p

✓ Waves aligned with the TC propagation direction on the right side

Case study: Hurricane Douglas







Wind direction

Hurricane direction

0° = North direction

Left side wave spectrum

- ✓ Hs = 3.44 m
- ✓ λ_p = 181 m
- ✓ bi-modal with similar wavelength

Right side wave spectrum

- ✓ Hs = 6.87 m
- ✓ λ_p = 212 m
- ✓ mono-modal
- ✓ wind, hurricane and wave direction aligned

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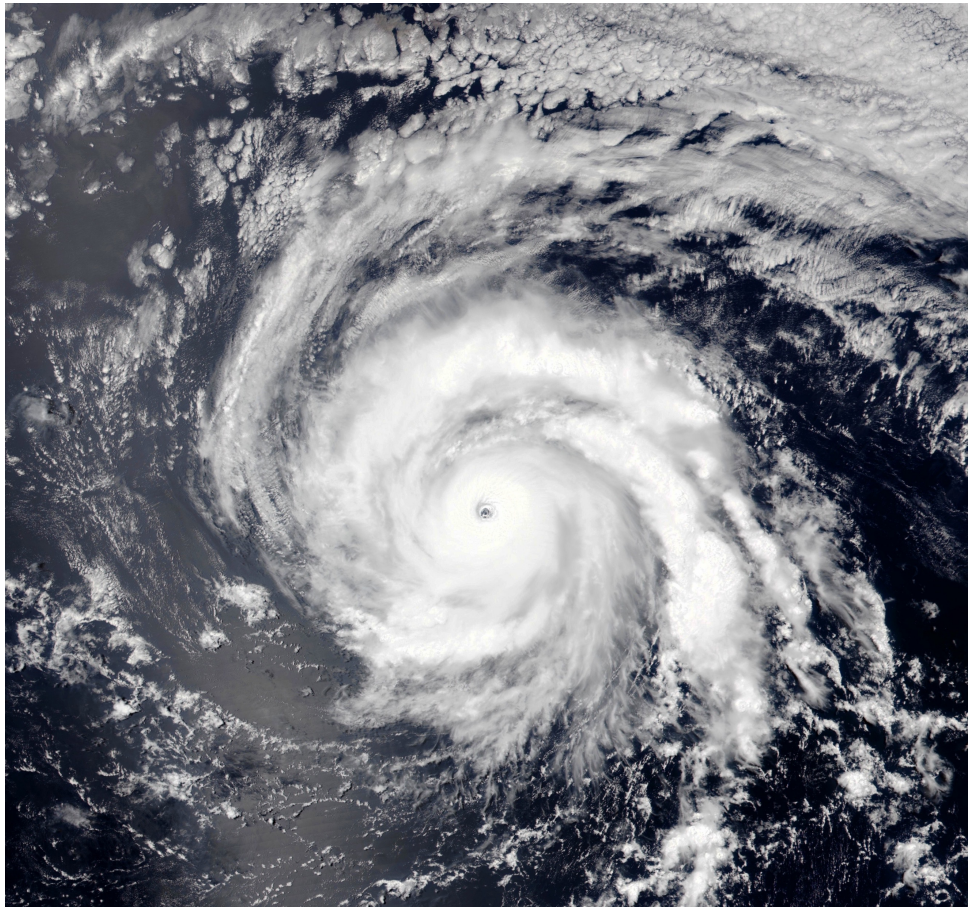

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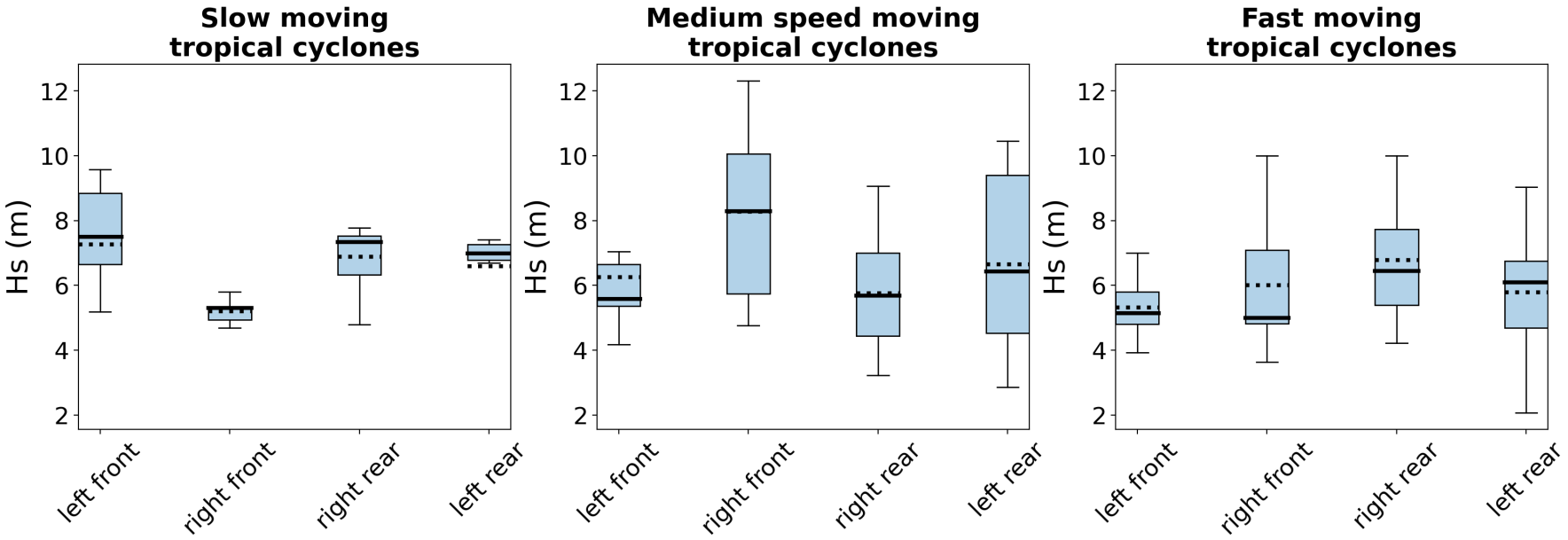
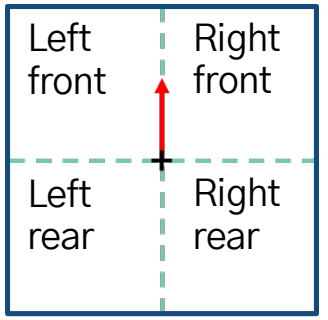
Statistical study

1) Hs, illustrated here only for distances less than 3 R_{max}





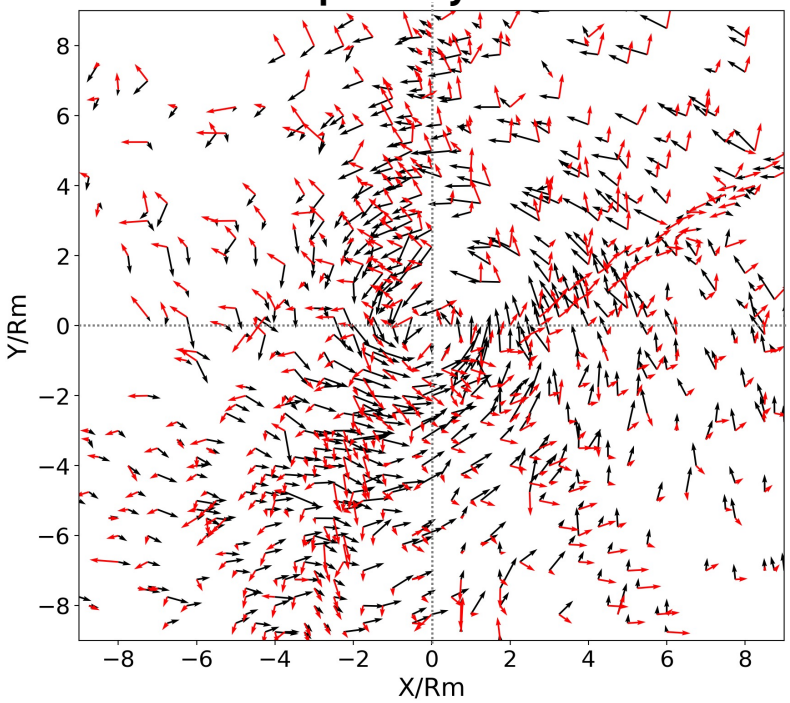
- ✓ Asymmetry of Hs varies with the TC category.
- ✓ Largest Hs in the right front quadrant of moderate speed TCs:

  → conditions for trapped waves more favorable under this kind of TCs.

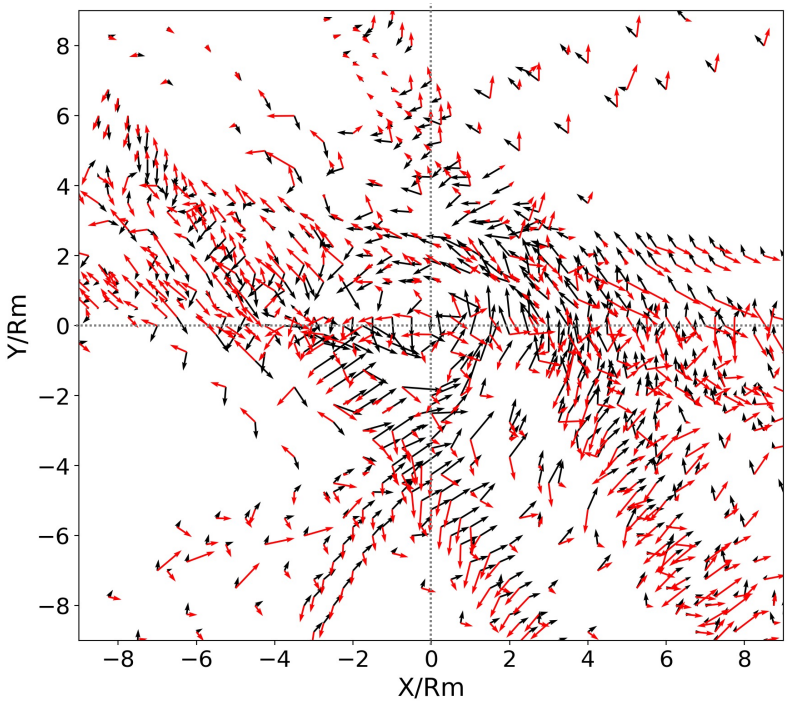
Statistical study

2) wind and wave directions

Slow and moderate speed tropical cyclones



Fast tropical cyclones



Wind direction
Wave direction

Waves from SWIM.

Wind from the ECMWF model.

In slow and moderate speed TCs:

- ✓ large angle between wind and waves in the left quadrants.

In fast moving TCs:

- ✓ More variabiliy in wave directions :

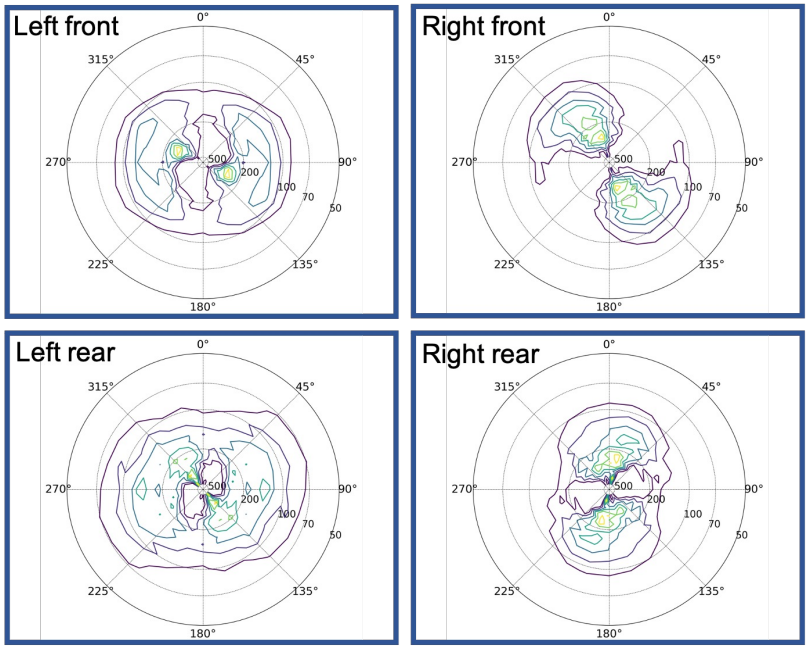
→ presence of mixed-sea.

Statistical study

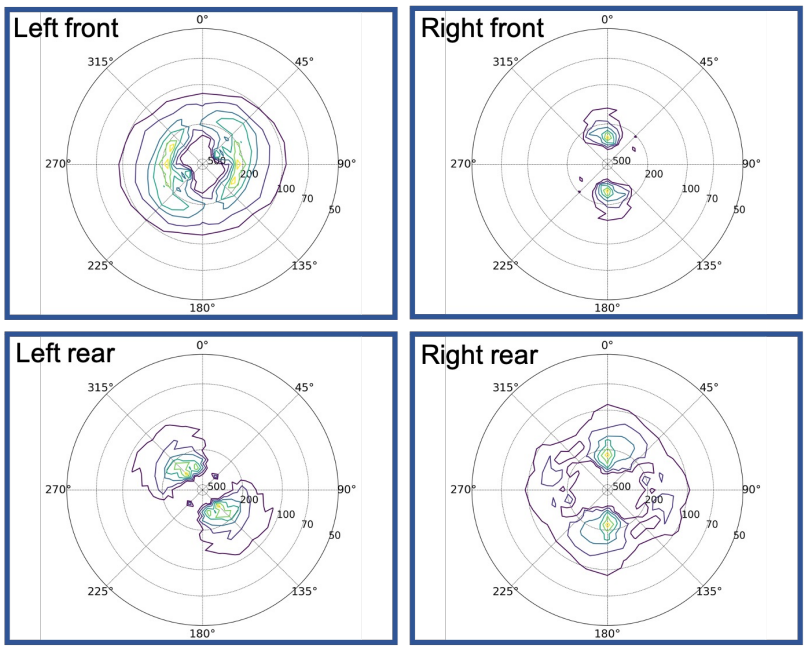
0°: propagation direction of the TC

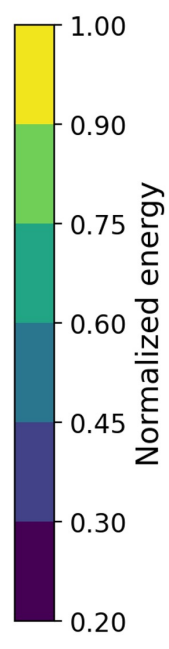
Mean 2D spectra, for distances less than 3 R_{max}

Fast speed cases



Moderate speed cases



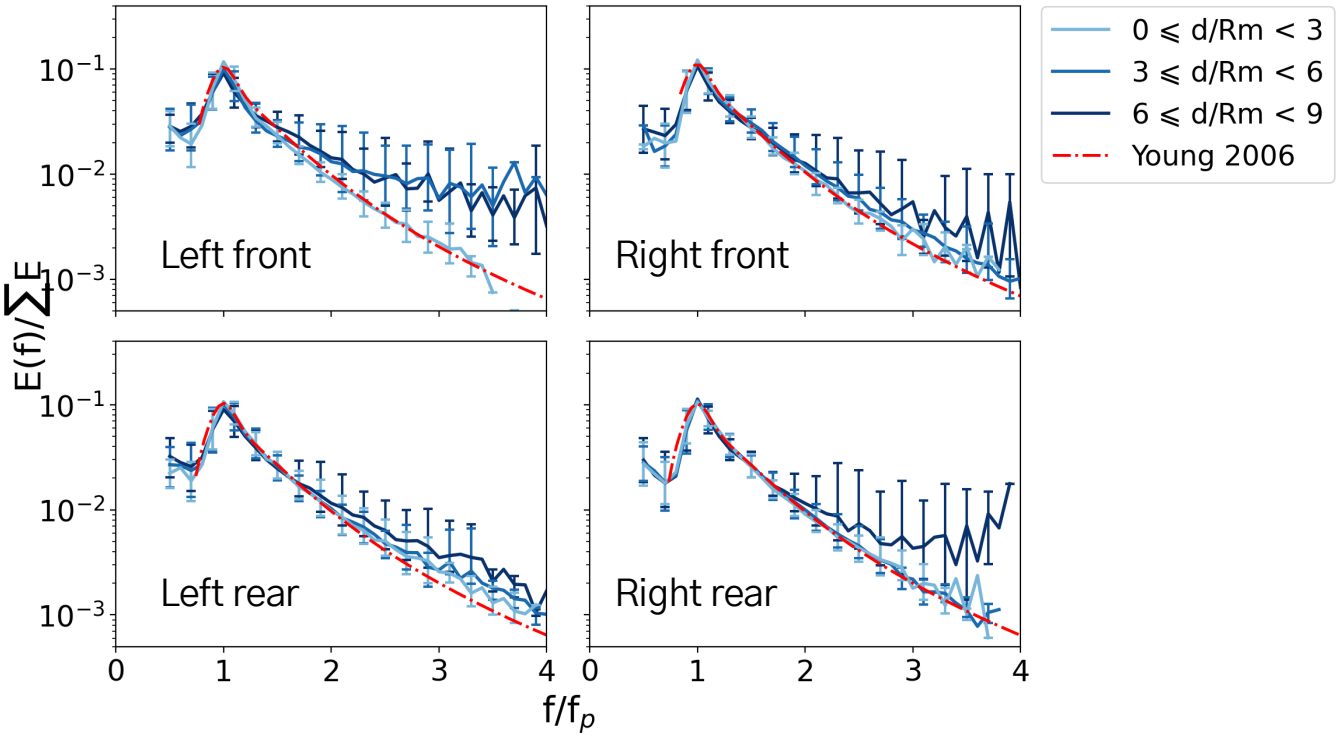


- ✓ In moderate speed TC: Monomodal in the right front quadrant with wave propagation aligned with TC displacement (similar at all distances– not shown here) and monomodal in the left rear quadrant (waves leave the TC with a mean 135° angle)

- ✓ In fast TCs: multi–modal or significantly spread in direction (similar at all distances).

Statistical study

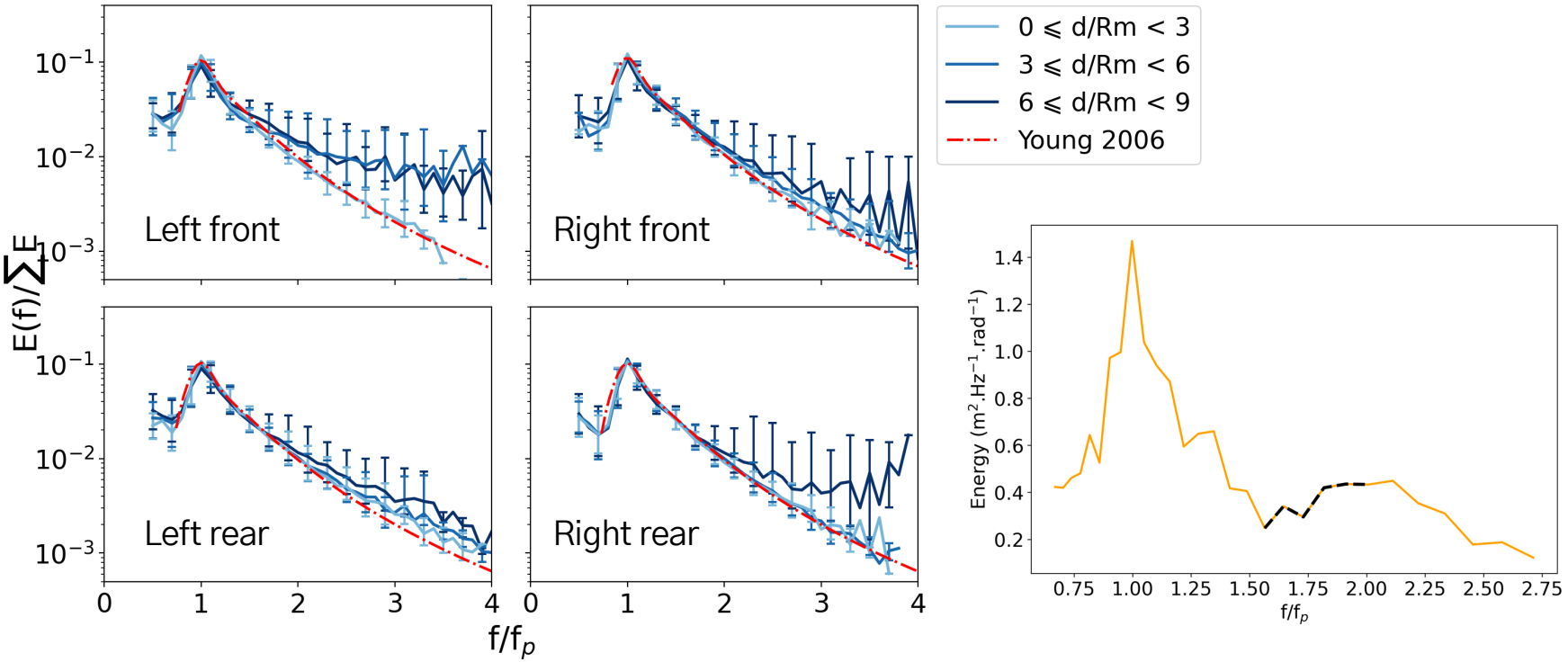
Mean 1D spectra in moderate speed TCs



- ✓ Slope with normalized frequency close to the results of Young, 2006, but only at the smallest distances (less than 3 Rmax)
- ✓ large scatter at larger distances and smaller slope (except in the right front quadrant), mostly explained by the presence of mixed-sea conditions

Statistical study

Mean 1D spectra in moderate speed TCs



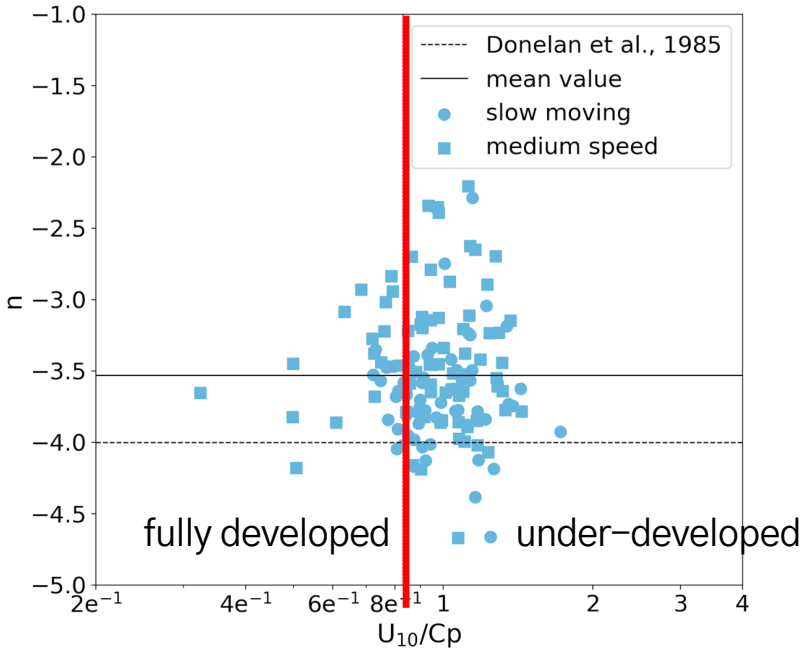
- ✓ Slope with normalized frequency close to the results of Young, 2006, but only at the smallest distances (less than 3 Rmax)
- ✓ large scatter at larger distances and smaller slope (except in the right front quadrant), mostly explained by the presence of mixed-sea conditions

Statistical study

Frequency decay exponent

- Exponent n such as: $E(f) \sim A f^{-n}$
- Calculated between 1.5 and 3.5 f_p

Here results illustrated for slow and medium speed TC only, and d < 3 R_{max},



- No obvious relationship between the frequency exponent and the inverse wave age (same as in Tamizi and Young (2020)
- Absolute mean value of n from SWIM data (3.58) is smaller than the value from Donelan et al (4) and smaller than that from Tamizy and Young (4.68)

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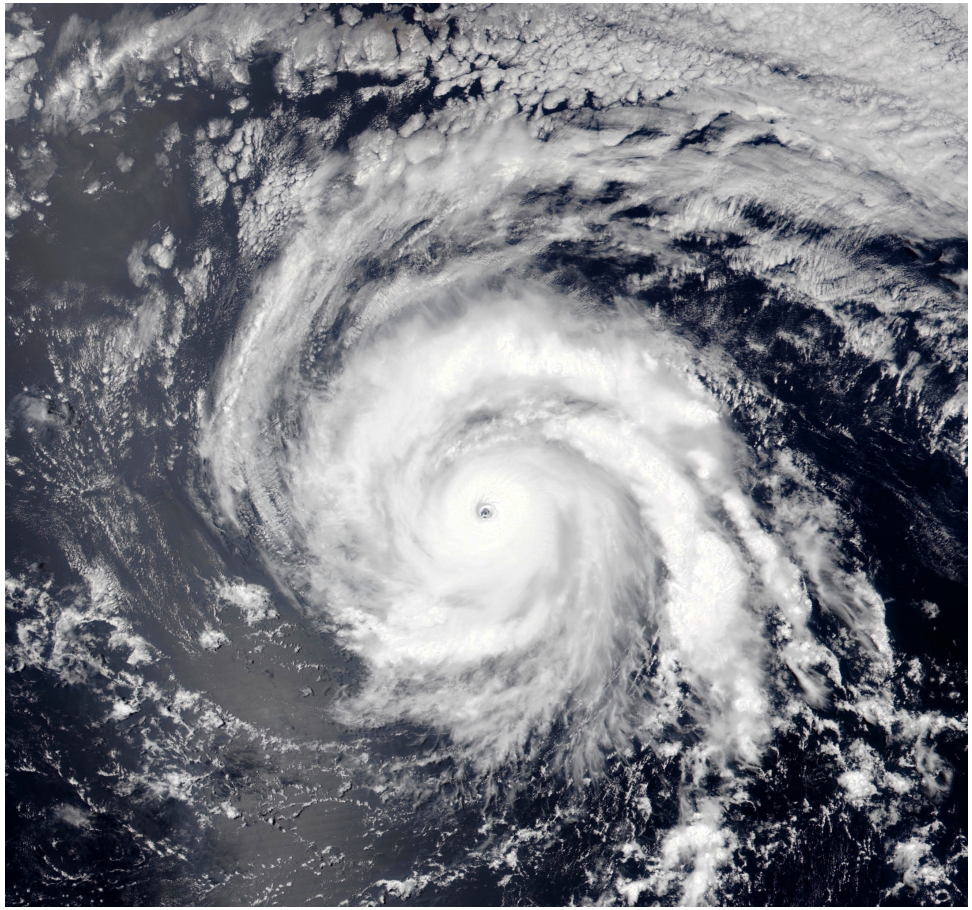

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Conclusions (1/2)

- **SWIM provides unprecedent detailed and repeated observations to study wave characteristics in tropical cyclones:**

- **SWIM brings new insights:**
  - Asymmetry of wave parameters (SWH and wavelength) confirmed, but only in TC of slow and moderate speed:
  - → conditions for trapped waves are more favorable in this kind of event (confirmation of the model of Kudryavstev et al, 2021, generalization of the results of Yurovskaya et al , 2022)

Conclusions (2/2)

- multi-modal spectra are observed on the left side of slow and moderate speed TCs and in all quadrants in fast TCs,

- the frequency decay exponent is significant only for conditions where monomodal spectra are observed (slow, moderate speed, close to the centre) and seems to be smaller in average than the Jonswap exponent (less steep 1D frequency spectra) .

- *Results presented in the manuscript by Le Merle et al (2022), currently under review at JGR*

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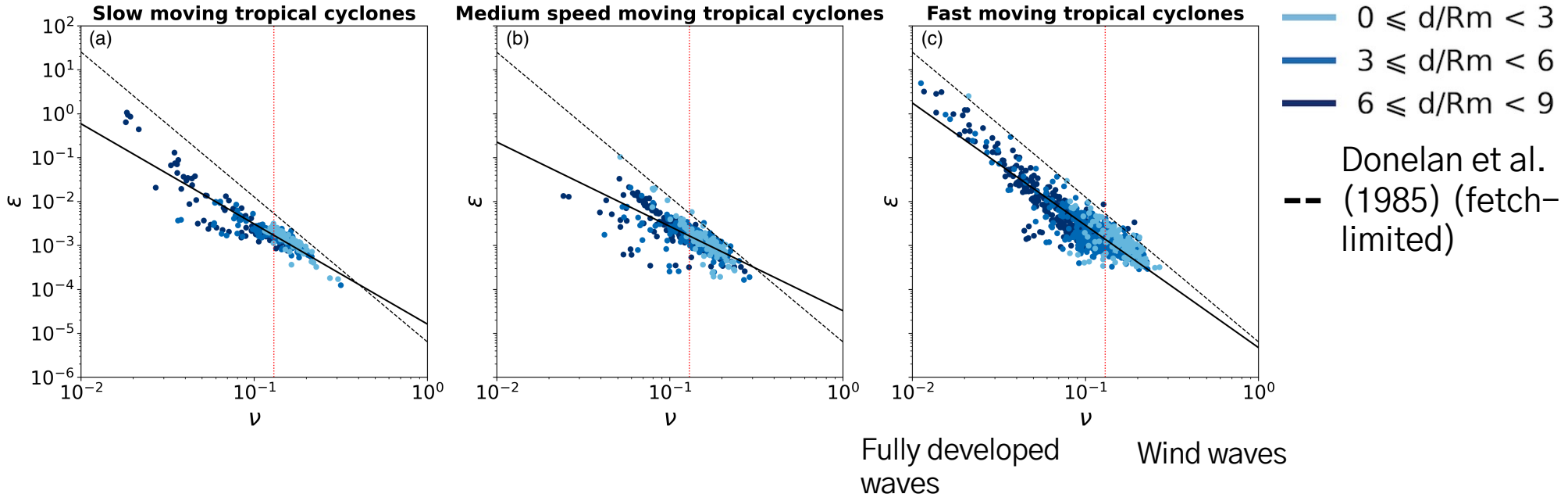
Statistical study

Nondimensional frequency and energy

- $\varepsilon = g^2 \frac{E_{tot}}{\mu^4}$ nondimensional energy



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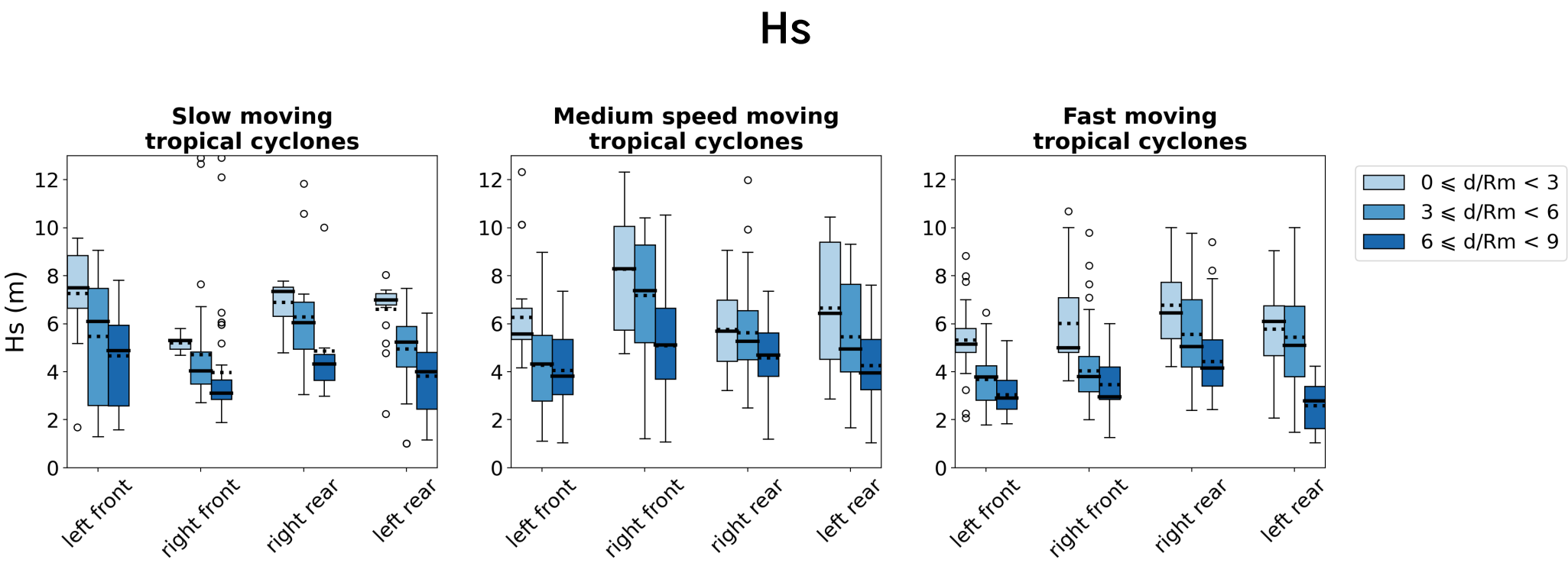

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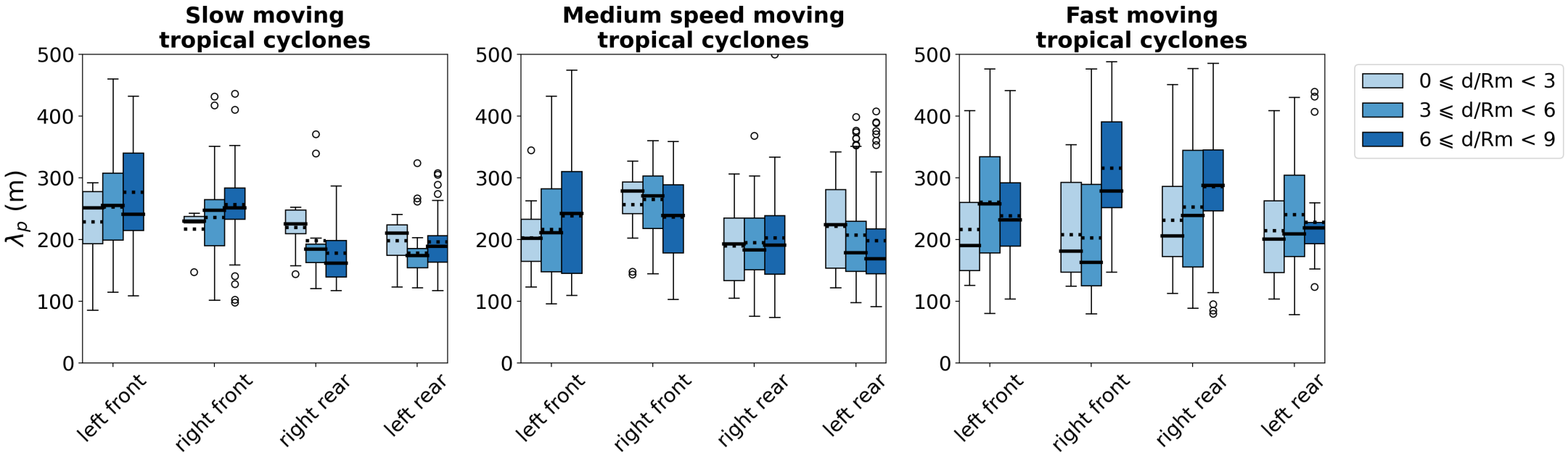
Dominant wavelength



- ✓ Asymmetry of λ_p different according to the TC category
- ✓ Higher dispersion of the λ_p distributions in fast moving TCs:

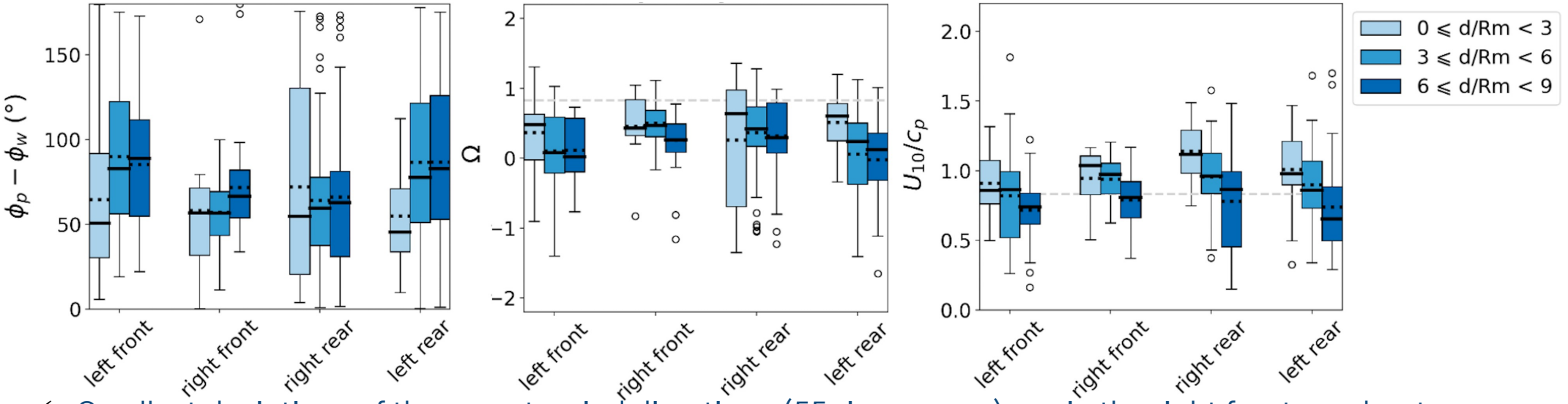
  → Presence of mixed-sea conditions

Cases of moderate translation speed

Angle between waves and wind

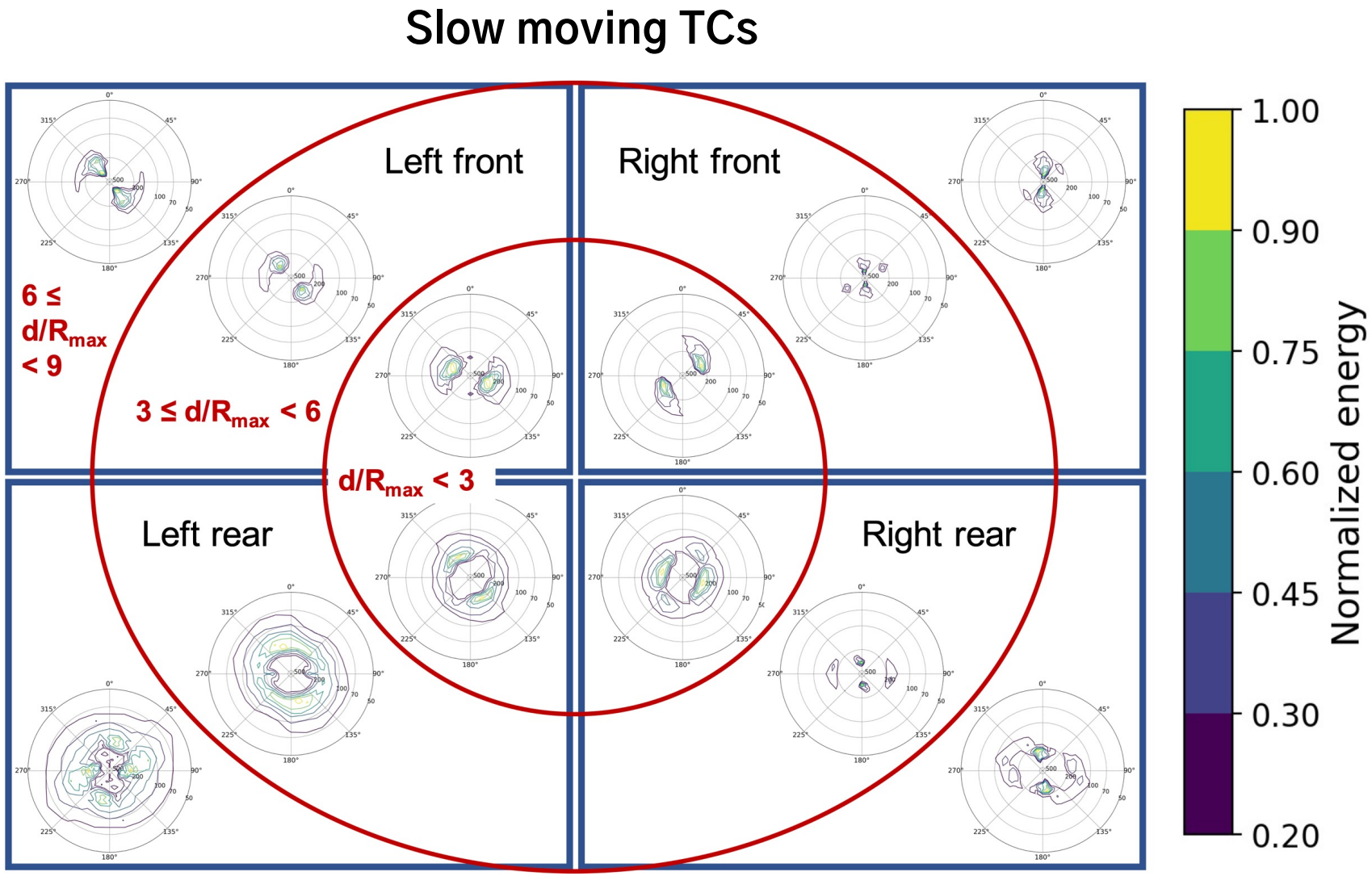
Inverse wave age accounting for wind–wave angle

Inverse wave age as U/C_p



- ✓ Smallest deviations of the wave to wind directions (55◦ in average) are in the right front quadrant.
- ✓ Significant fraction of samples with waves propagating opposite to the wind (angles larger than 90◦), except in the right front quadrant.
- ✓ Although large number of cases with under–developed conditions according to U/Cp, only small fraction with effective inverse wave age > 0.83 (due to angle between wind and waves)

Back up slides



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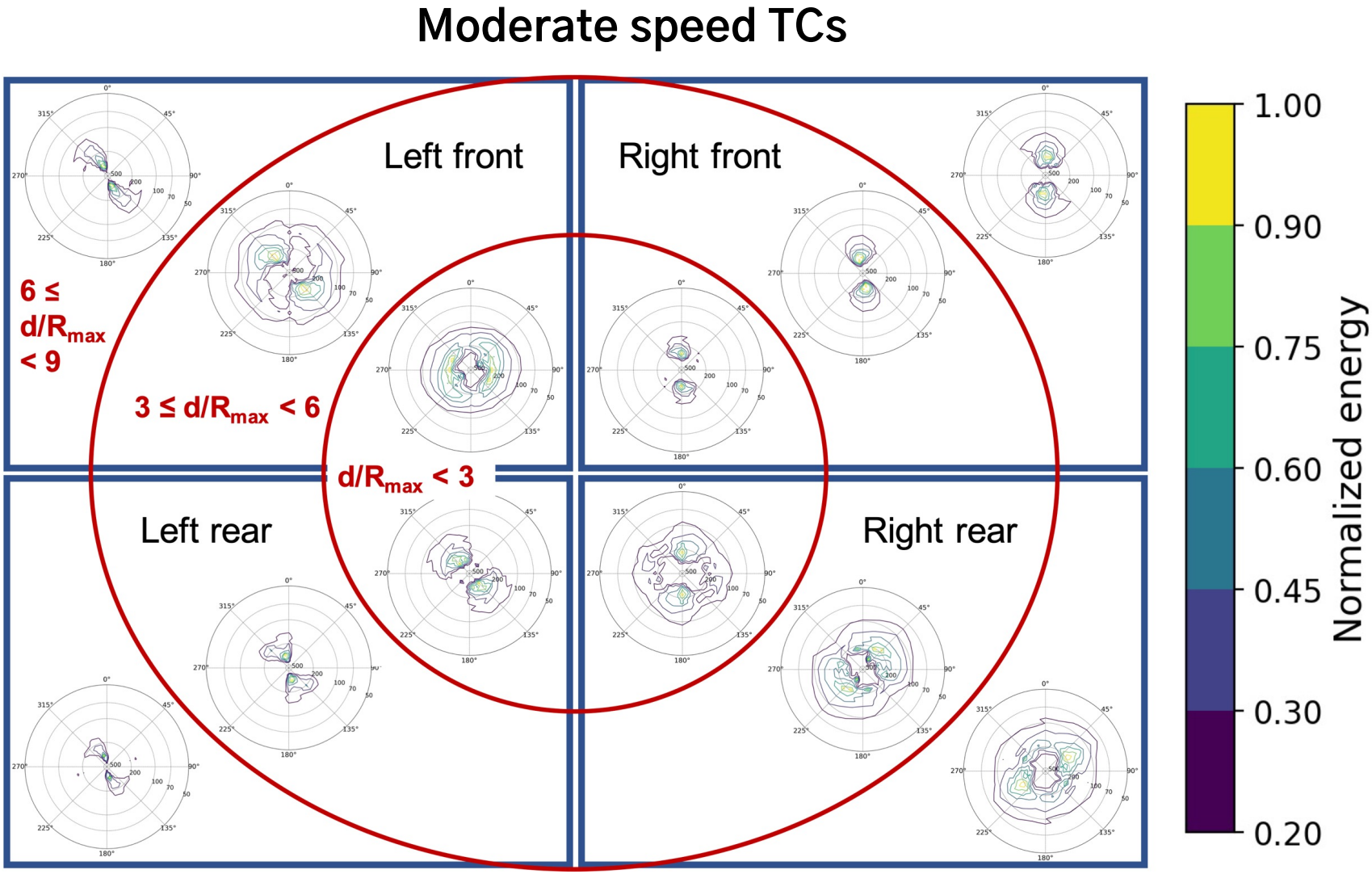

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