Tropical cyclone induced waves

A STATISTICAL CHARACTERIZATION

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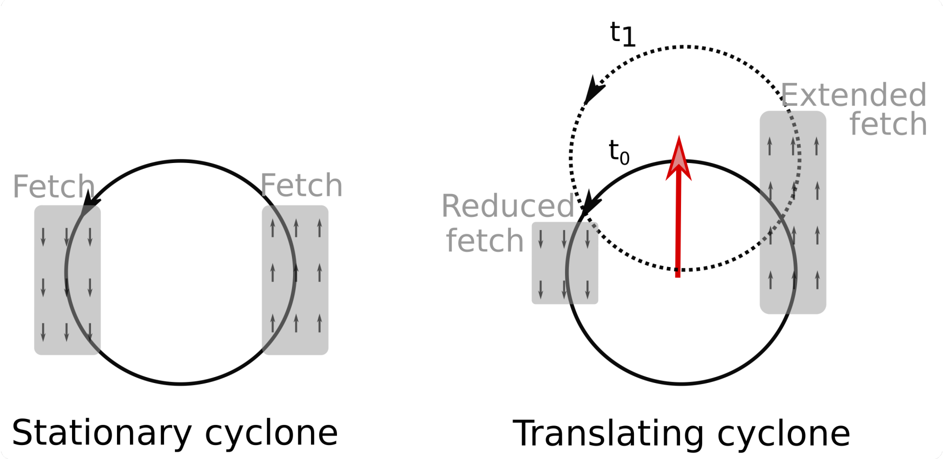
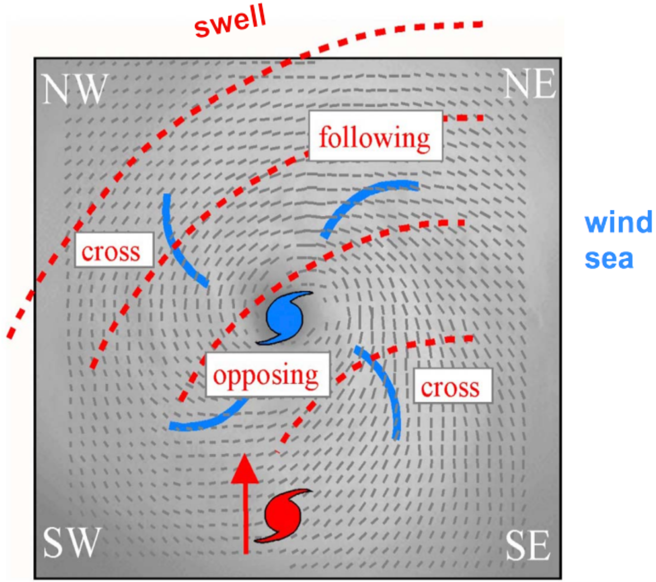
Introduction

WAVE FIELD UNDER TCs: A COMPLEX PICTURE





From Holthuijsen et al. 2012

➢ **How does the TC-induced wave field evolve with TC intensity and translation velocity?**

Introduction

TC-INDUCED WAVES

Observations

- Buoys (Young 2006, Esquivel-Trava et al. 2015…)
- Altimeters (Wright et al. 2001, Young and Vinoth 2013, Hwang 2015, Hwang and Fan 2016, Hwang and Walsh 2016…)
- SAR (King and Shemdin 1978, Moon et al. 2003…)

Modeling (Doyle 2002, Liu et al. 2007, Fan et al. 2009…)

→ description of the wave characteristics under TCs

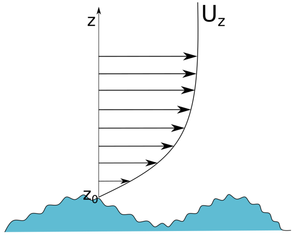
→ Often based on case studies or on one cyclonic basin
And/or used to build parametric description of the H_s^{max}

> ➢ **Need of a statistical characterization of TC-induced wave field**

Introduction

IMPACT ON AIR-SEA EXCHANGES

$$\tau = \rho_a \overline{u'w'} \longrightarrow \tau = \rho_a C_d U_{10}^2 = \rho_a u_*^2$$



$$C_d = \frac{k^2}{\left[\ln\left(\frac{z}{z_0}\right)\right]^2}$$

$$z_0 = \alpha \frac{u_*^2}{g} + 0.11 \frac{1.5 \times 10^{-5}}{u_*}$$

- ➢ Roughness parameterization

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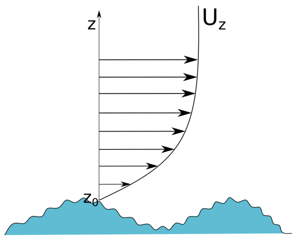

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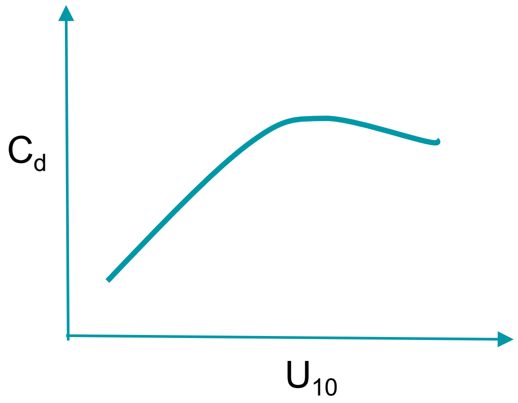

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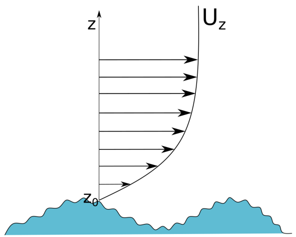

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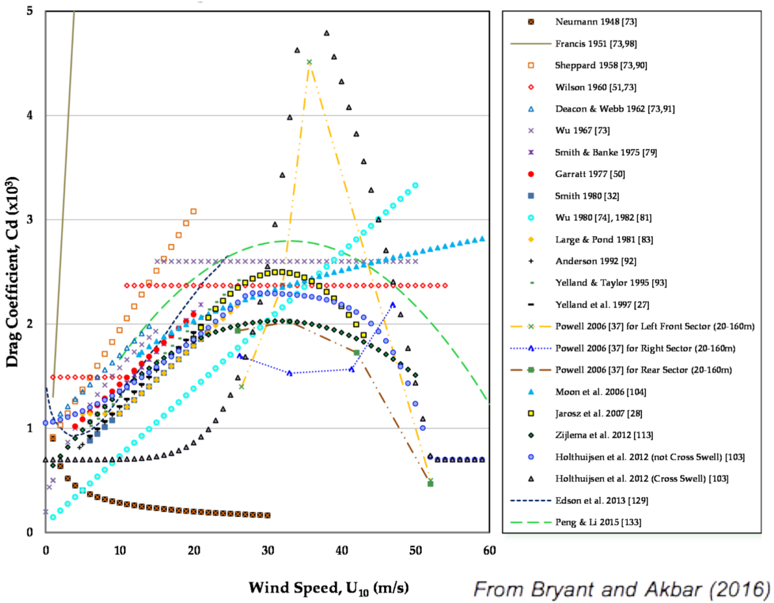

From Bryant and Akbar (2016)

- Roughness parameterization

Introduction

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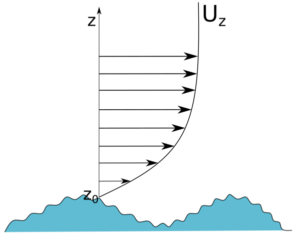

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$$z_0 = \alpha \frac{u_*^2}{g} + 0.11 \frac{1.5 \times 10^{-5}}{u_*}$$

$\alpha = 0.0185$ Charnock 1955

$\alpha = 0.01\left(\frac{c_P}{U}\right)^{-1}$ Smith et al. 1992

Liu et al. 2012

Li et al. 2016

$$\alpha = \begin{cases} (0.085\beta_*^{3/2})^{1-1/\omega}[0.03\beta_* \exp(-0.14\beta_*)]^{1/\omega}, & \beta_* < 35 \\ (17.6)^{1-1/\omega}(0.008)^{1/\omega}, & \beta_* \geq 35 \end{cases}$$

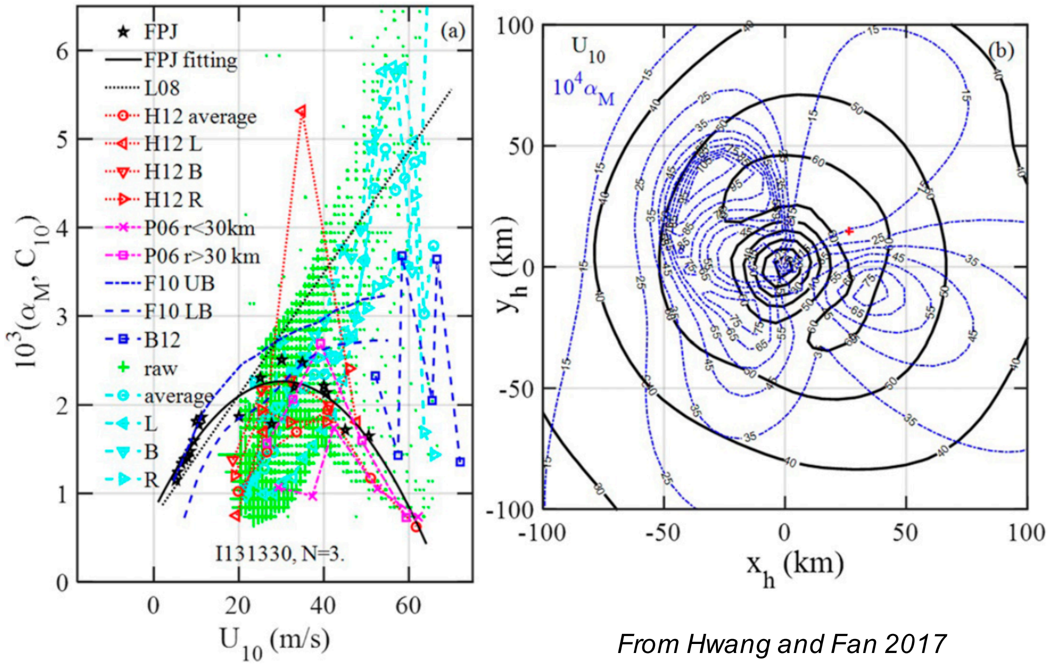
$\beta_* = c_p/u_*$

α_{ww3}

- Roughness parameterization
- Dependence on wave age

Introduction

IMPACT ON AIR-SEA EXCHANGES



From Hwang and Fan 2017

Few observations under extreme winds

Various relations found in the literature, no consensus

Dependency to the cyclone quadrant

- **How does the TC-induced wave field pattern impact air-sea exchanges?**

Objectives of the study

OBJECTIVES

To assess statistically

- The spatial distribution of the wave field under TCs
- Its potential impact on air-sea exchanges
- Its dependency on TC parameters (V_{max}, U_h)

SPECIFICITIES

- All cyclonic basins
- 20-year wave simulation (~2000Tcs) → Robust statistical results

Methodology

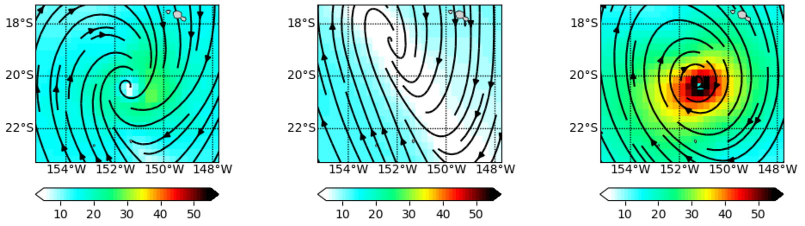
ATMOSPHERIC FORCING

Atmospheric reanalysis ERA5 (1/4°)

+ parametric vortex *(Willoughby, 2006)* on Best Tracks

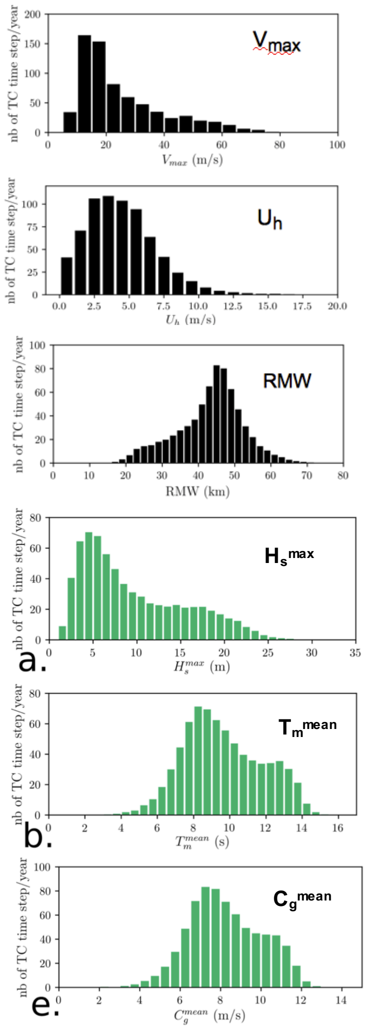
→ improved representation of TCs

ERA5 | ERA5 filt | ERA5 + analytical cyclone



WAVE MODEL

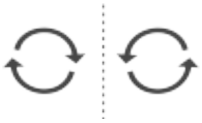
WaveWatch III global configuration (1/2°)

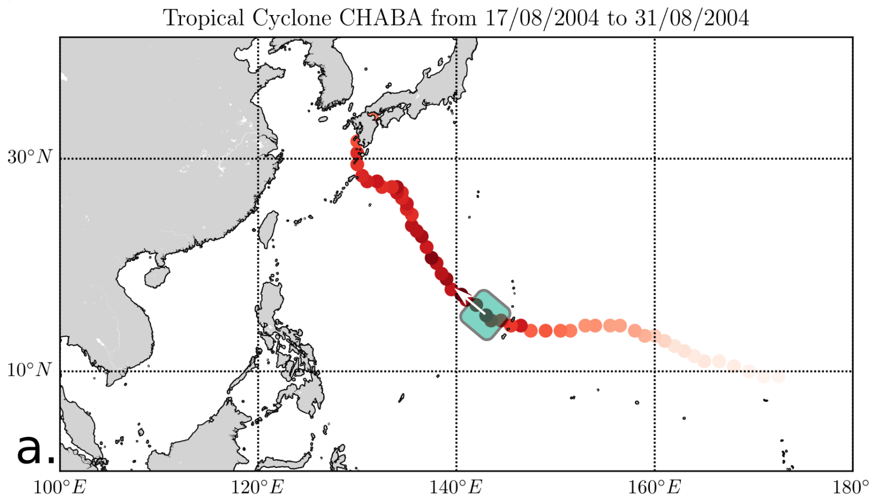


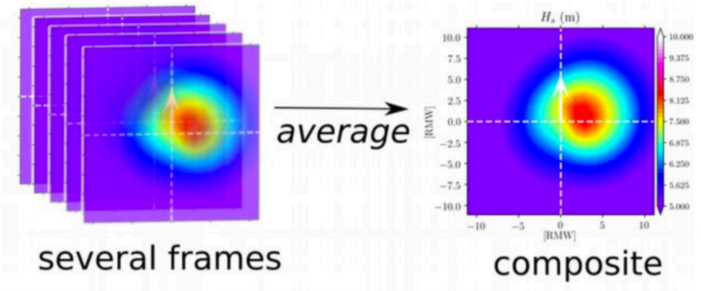
Methodology

COMPOSITE METHODOLOGY

- Rotating the direction of motion
- Mirroring of Southern Hemisphere frames
- Rescaling on RMW





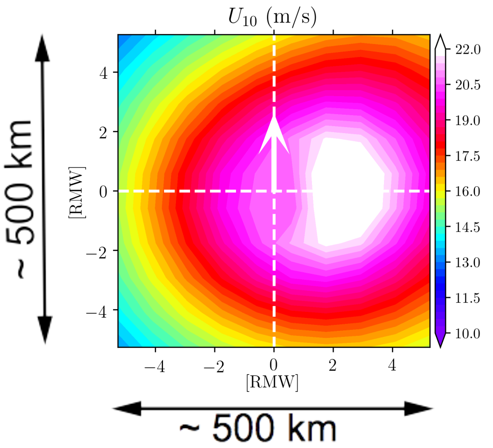


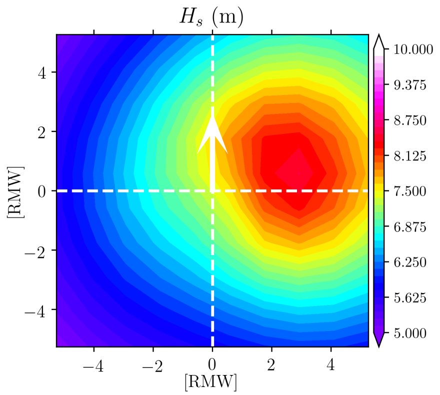
TC-induced waves characteristics

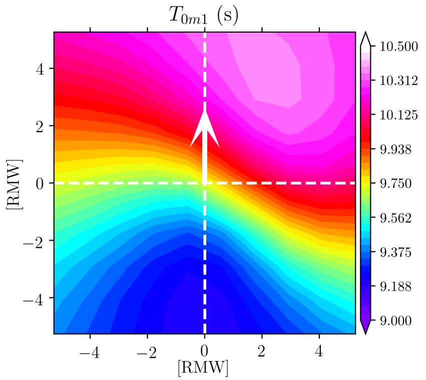
MEAN WIND FIELD U_{10}
Stronger winds on the right

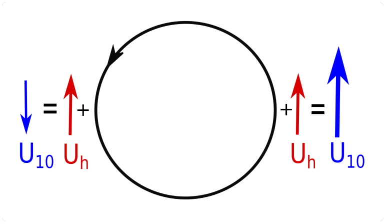
MEAN H_s
Higher waves on the front right

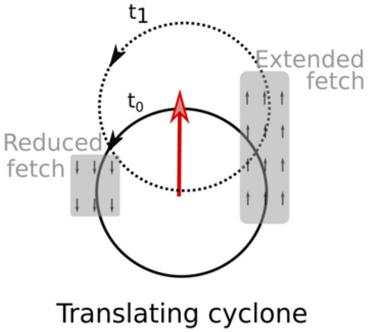
MEAN WAVE PERIOD T_{Om1}
Longest periods on the front











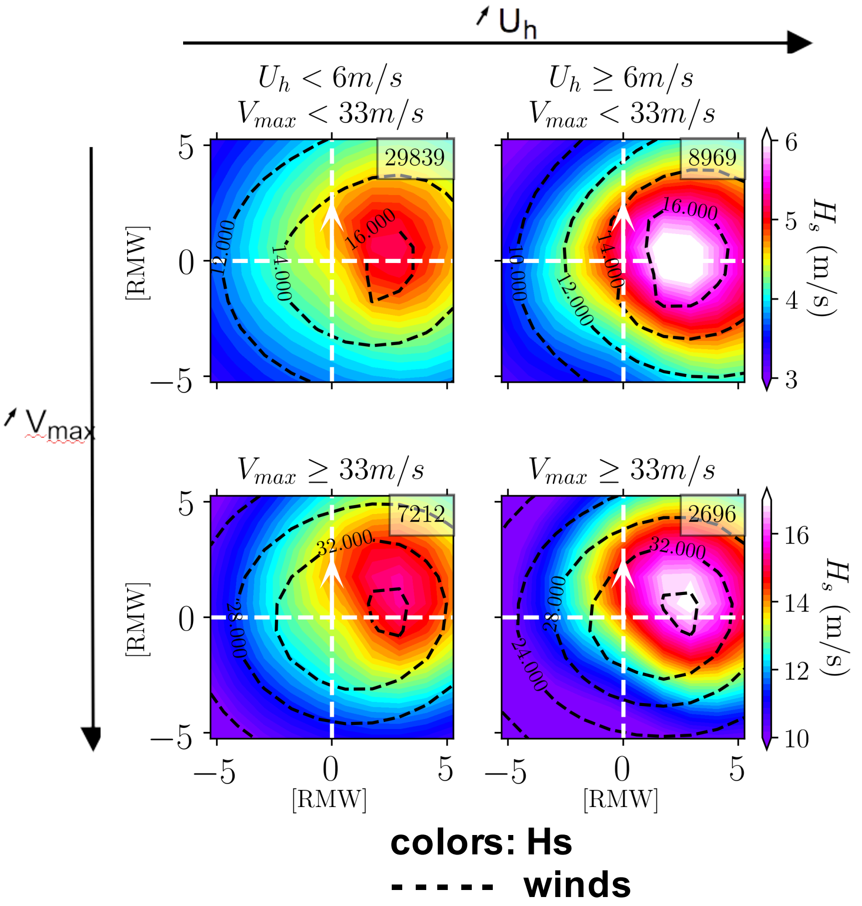
Large standard deviations: variability between TCs

influence of V_{max} and U_h?

TC-induced waves characteristics

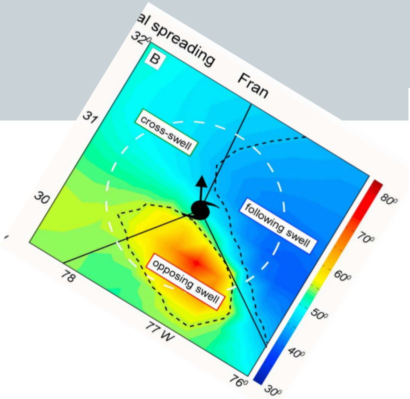
INFLUENCE OF Vmax AND Uh

- Increasing asymmetry with U_h
- Max winds and waves less co-located for intense TCs
  - Swell goes faster at high intensities
  - Waves submitted to the larger fetch are further from the eyewall

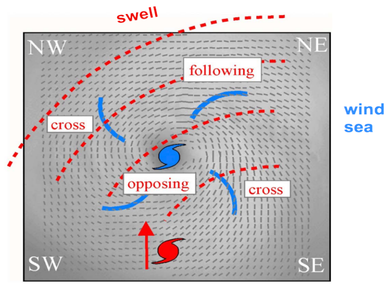


TC-induced directional spreading

WAVE DIRECTIONAL SPREADING PATTERN



σ_{dir}, *hurricane Fran (Sept. 5, 1996, 15:00 UTC)*
From Holthuijsen et al. (2012)



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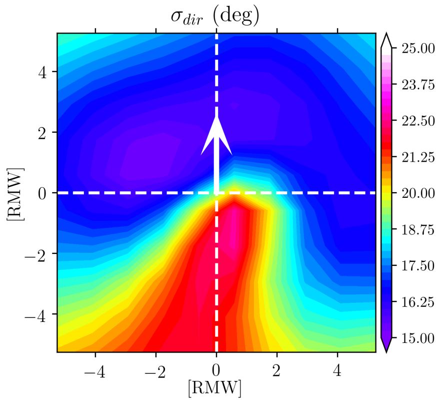

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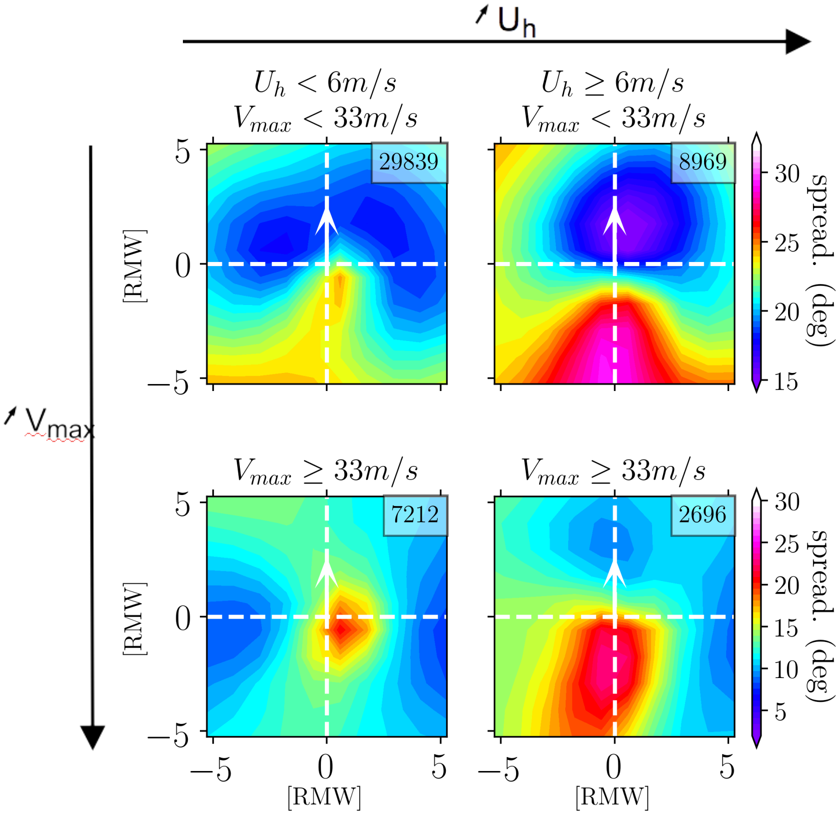

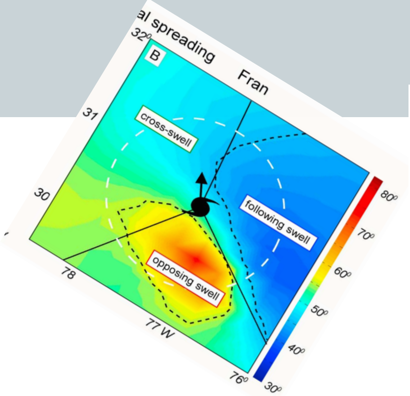

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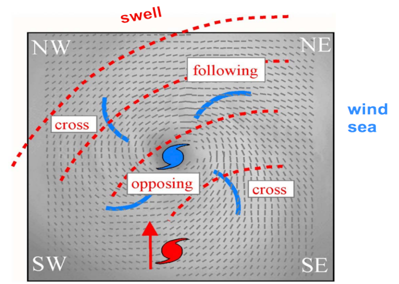

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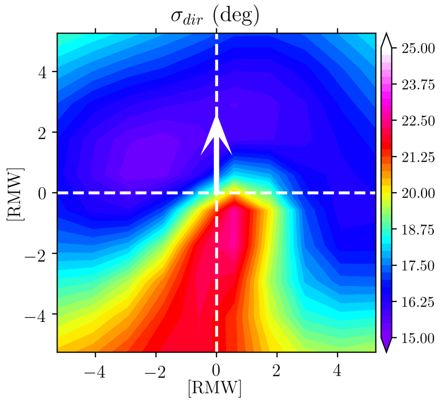

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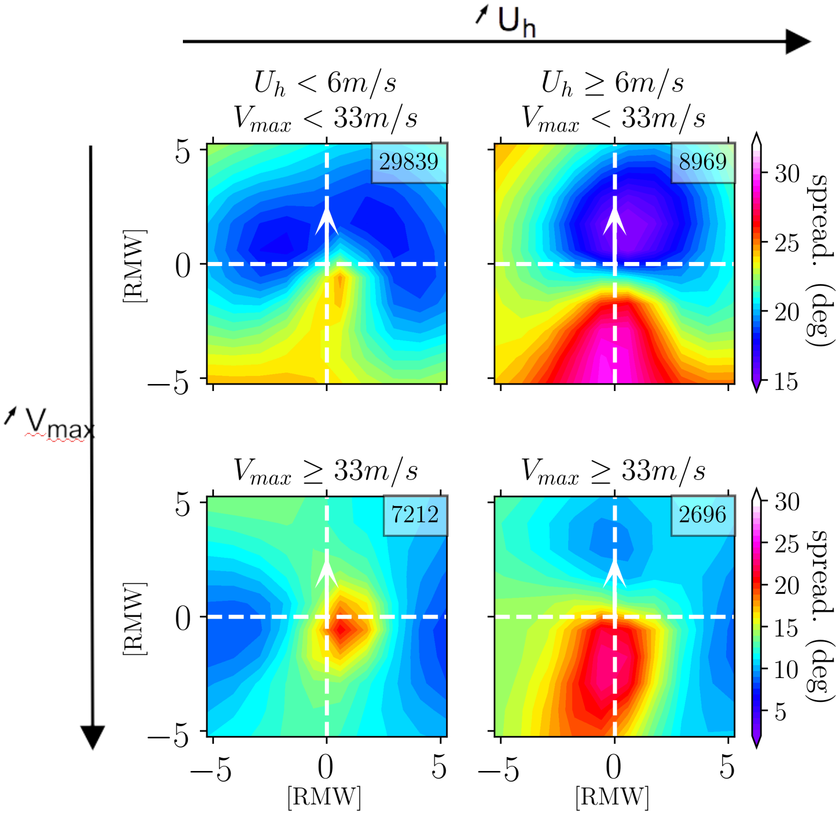

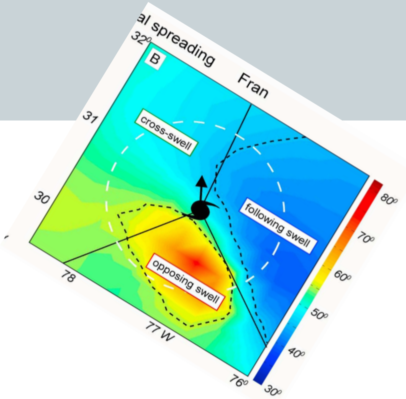

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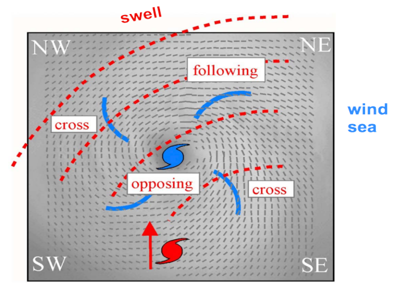

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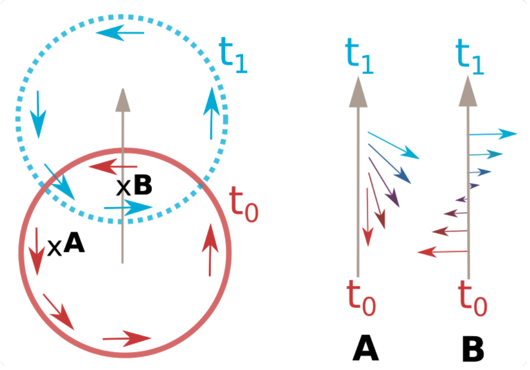
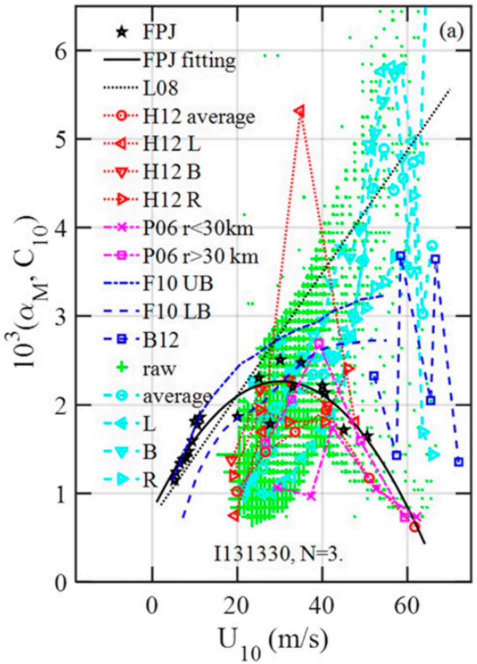
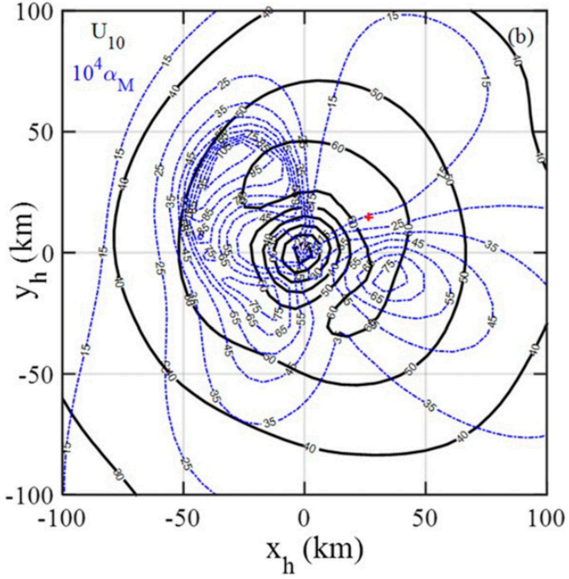


Impact on the air-sea exchanges





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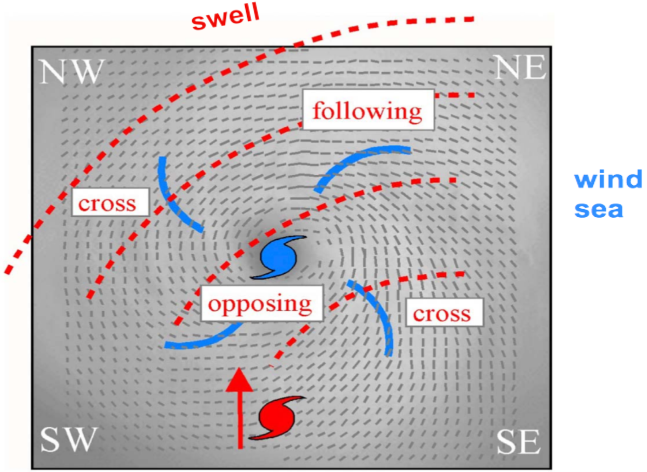

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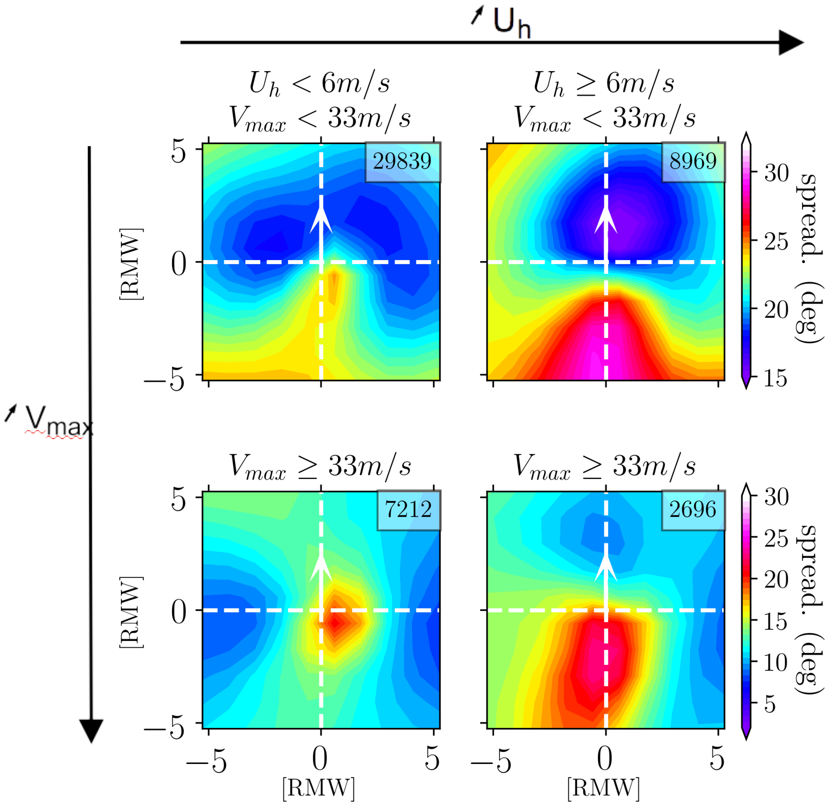
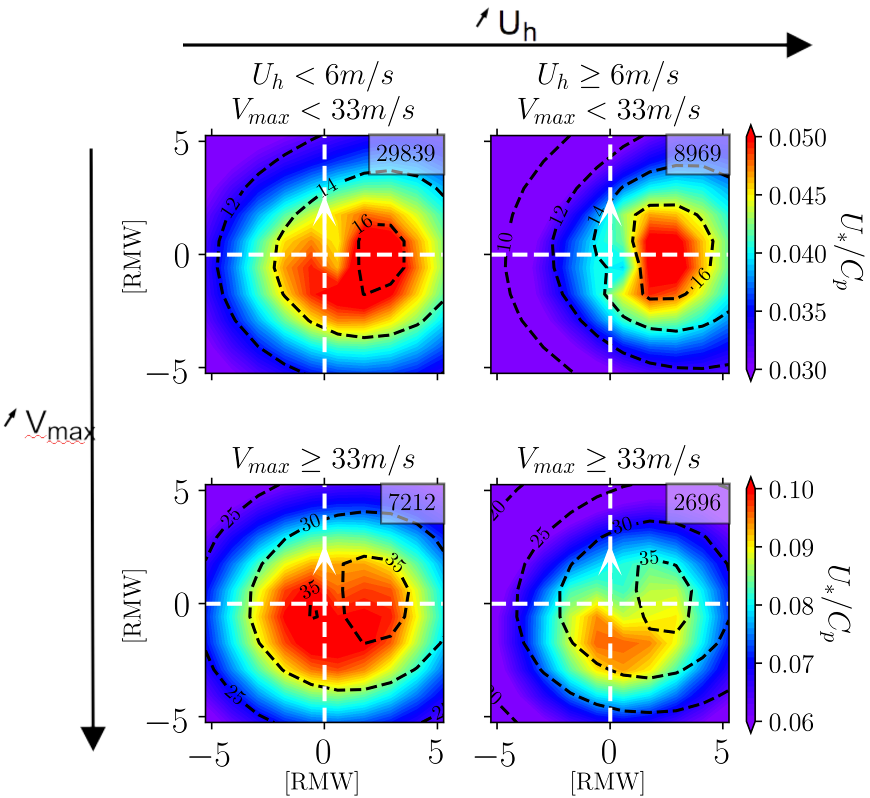


colors: wave directional spreading



colors: Inverse wave age

- - - - - winds

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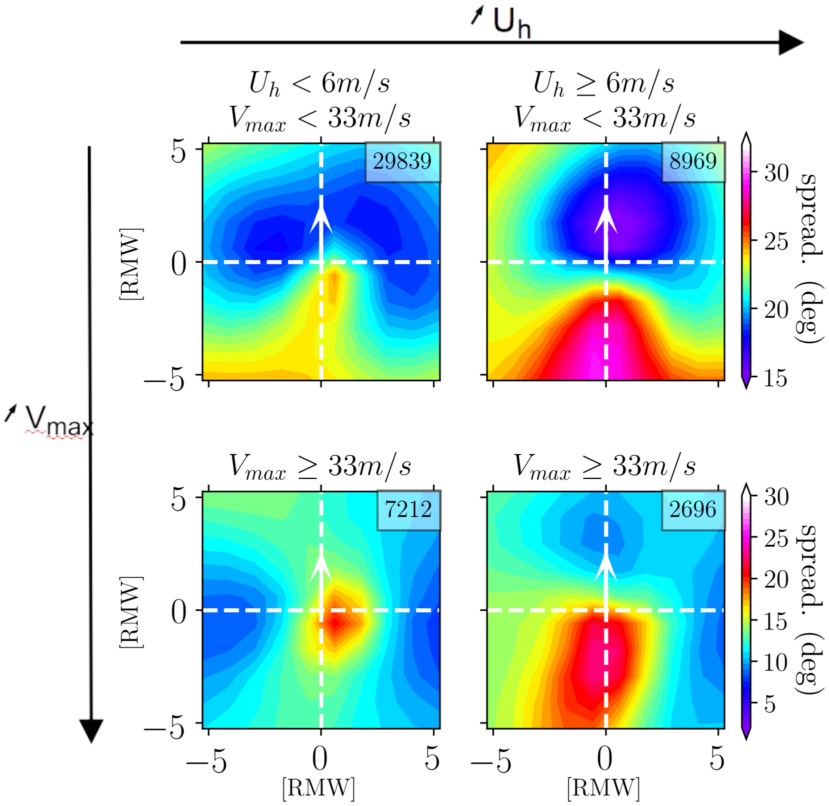

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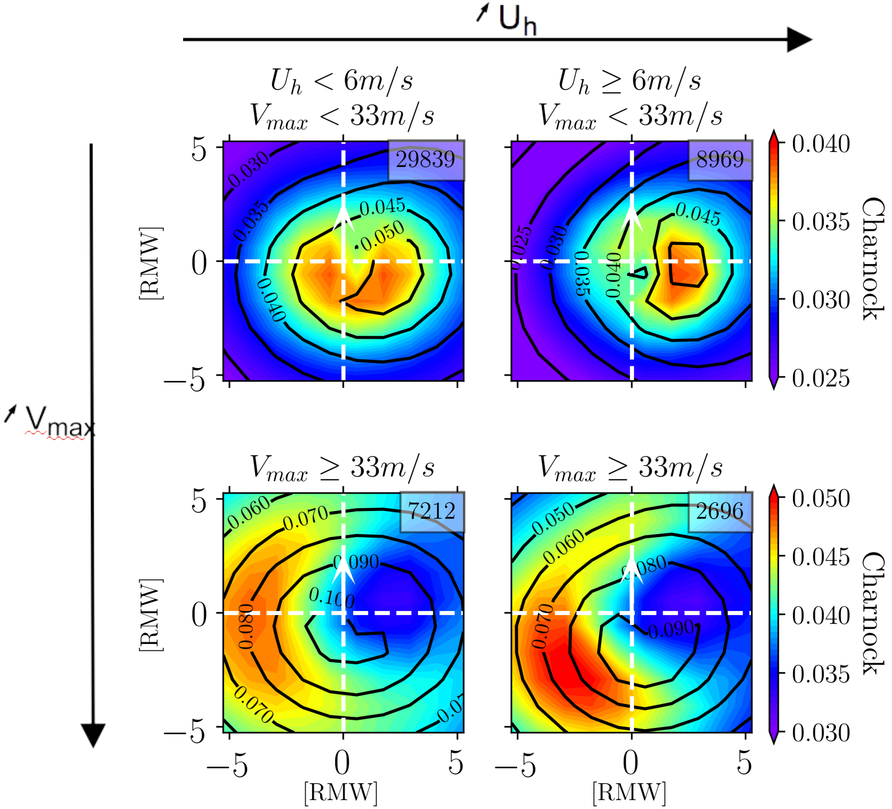

colors: Charnock coef.

------ inverse wave age

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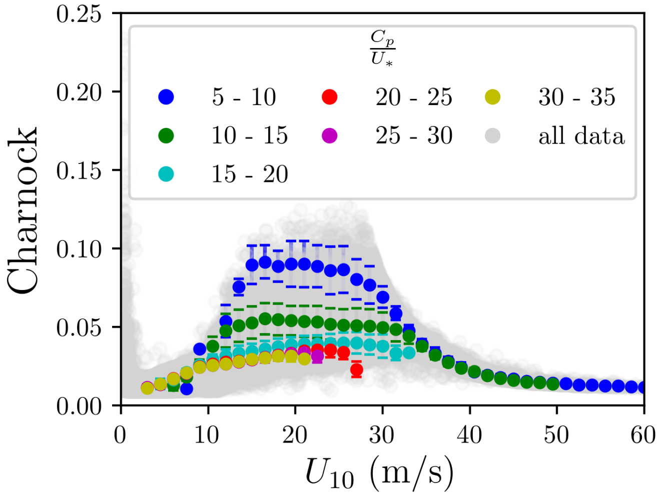

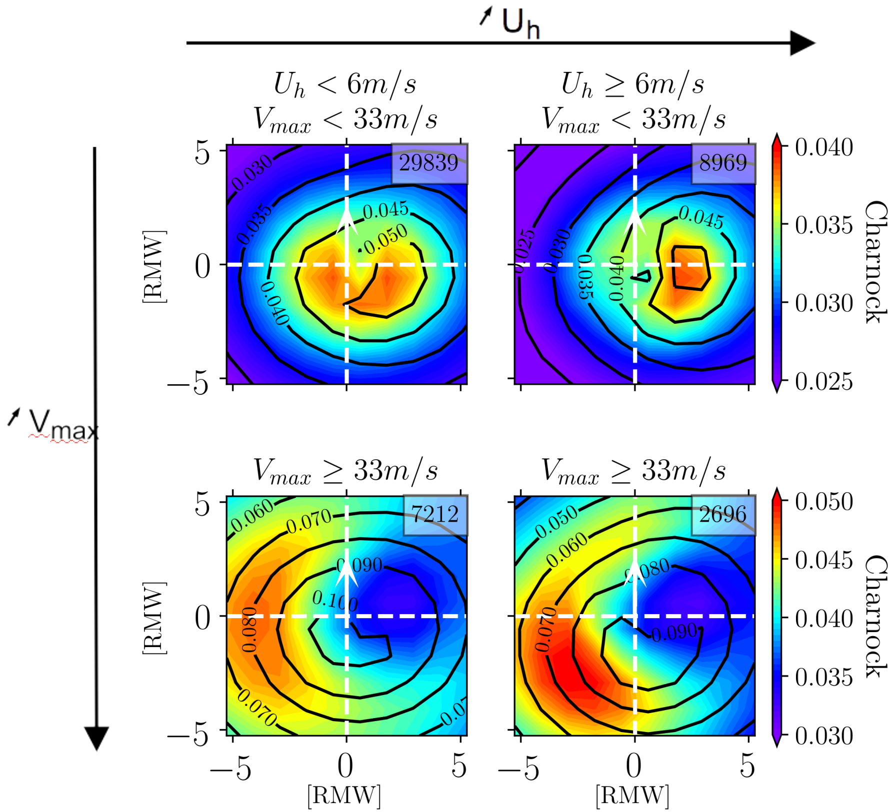

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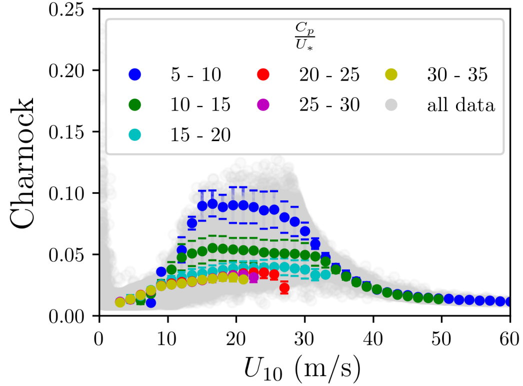
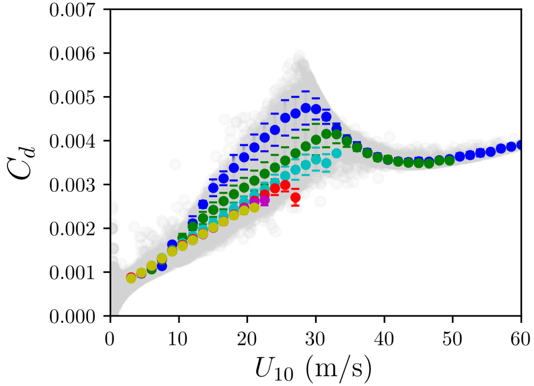
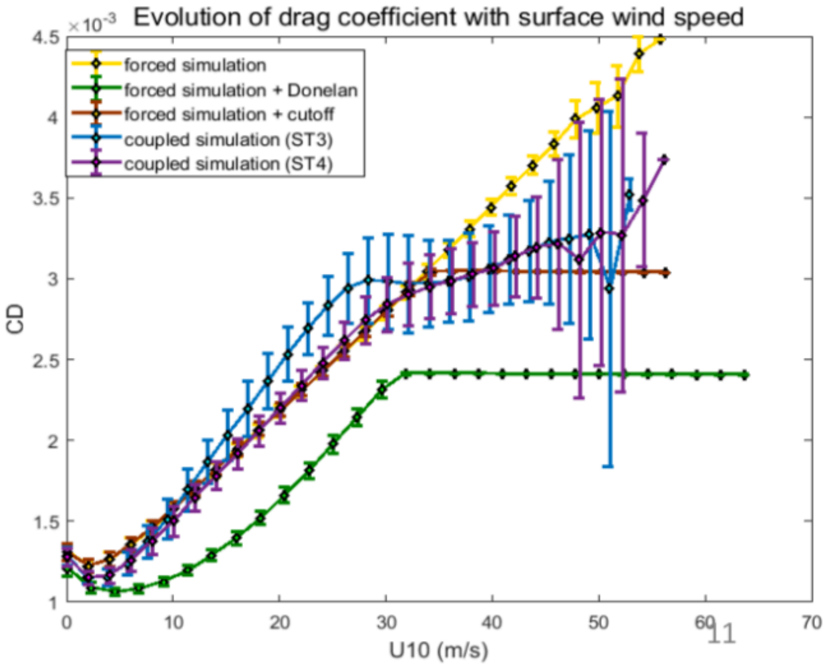






Summary

TC-INDUCED WAVES SPATIAL PATTERN

Influence of U_h and V_{max}

- Stronger asymmetry with both U_h and V_{max}
- Wave spreading strongly modulated by U_h and basin background swell

- Charnock coefficient pattern very different for weak and strong TCs

ASSETS

- All cyclonic basins
- 20-year simulation (~2000Tcs)
- Realistic TC forcing

LIMITATIONS

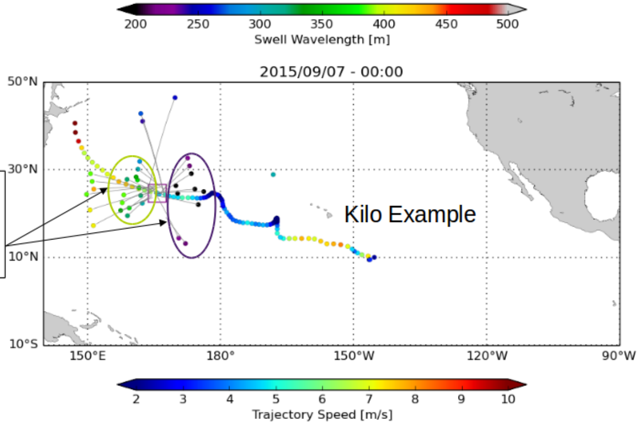
Low resolution (1/2°)
TCs might be oversized
No coupling

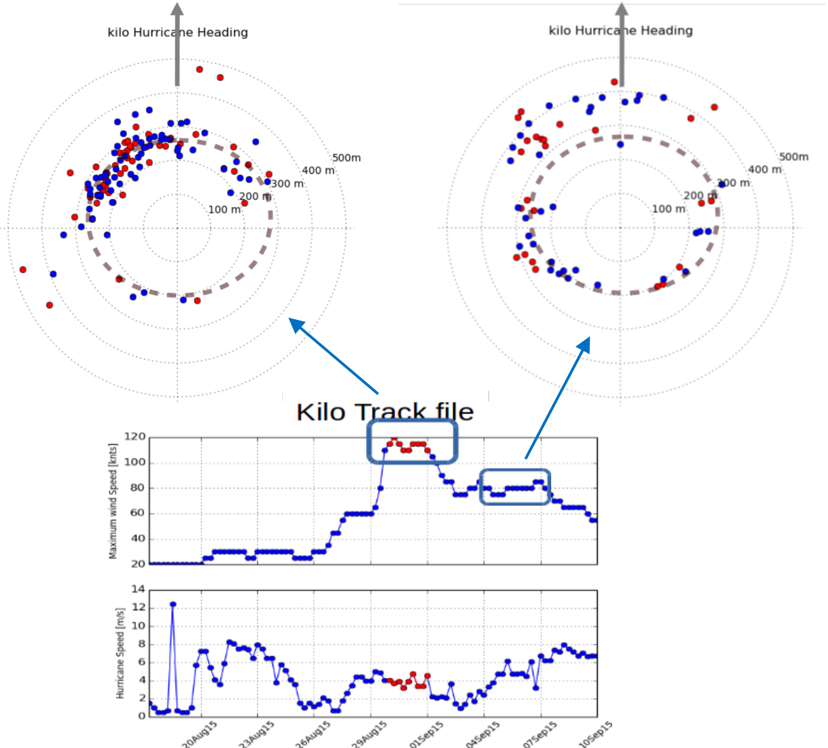
! Air-sea interactions: let's remember that we are in the limit of both observations and model parameterizations

On-going work: use of spectral observations

→ retro-propagation of wave systems to the generation area

Different wavelengths are observed depending on the swell direction of propagation.





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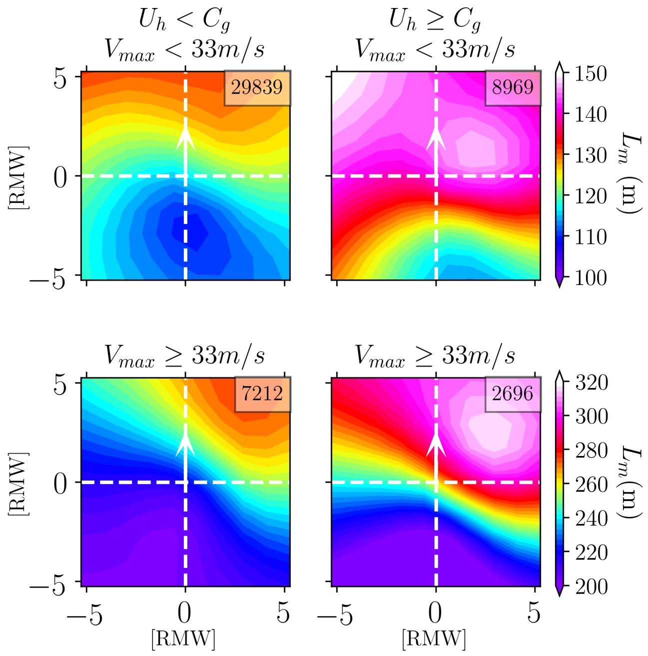
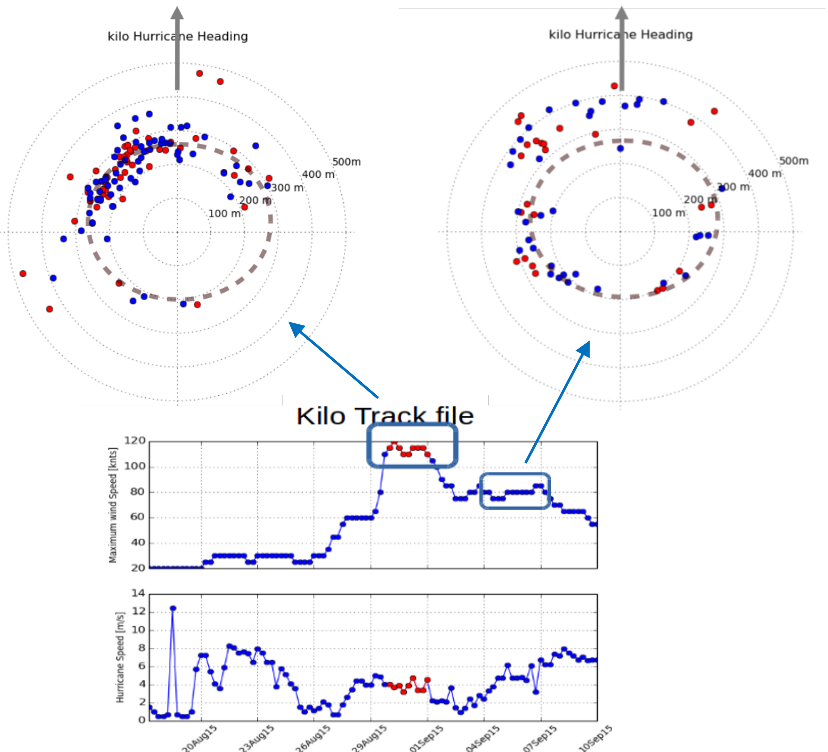
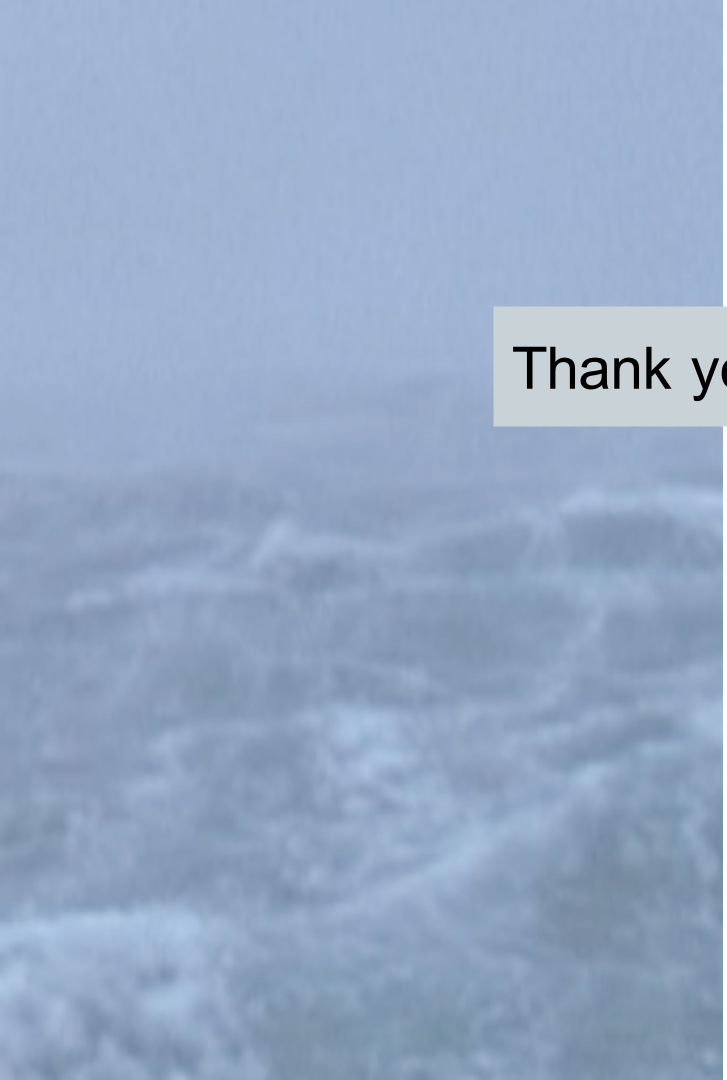


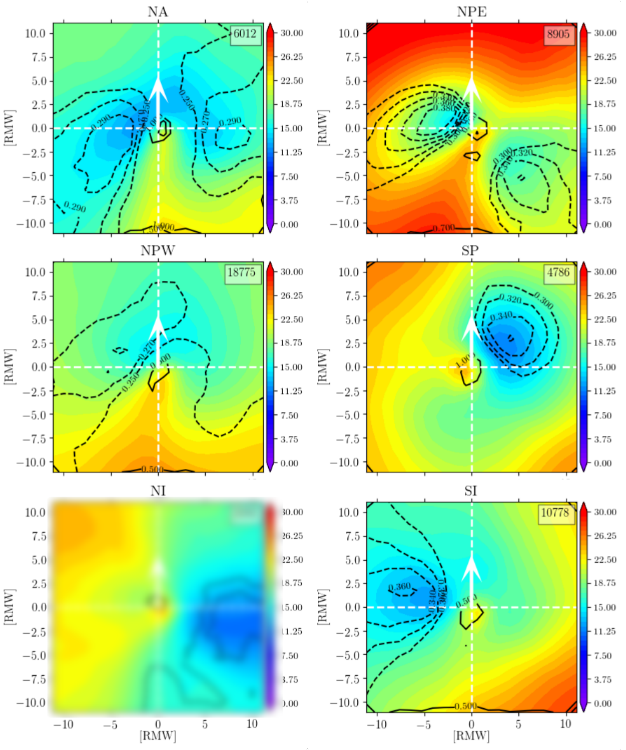




Thank you!

Wave directional spreading

INFLUENCE OF THE BACKGROUND SWELL

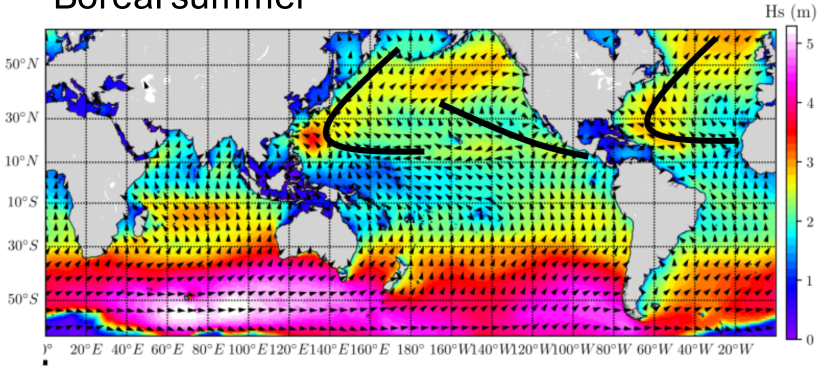


σ_{dir} ---- PDF position min. ($\times10^{-2}$)

—— PDF position max. ($\times10^{-2}$)

Climatology of Hs and wave direction

Boreal summer



Austral summer