Tropical cyclone induced waves

A STATISTICAL CHARACTERIZATION

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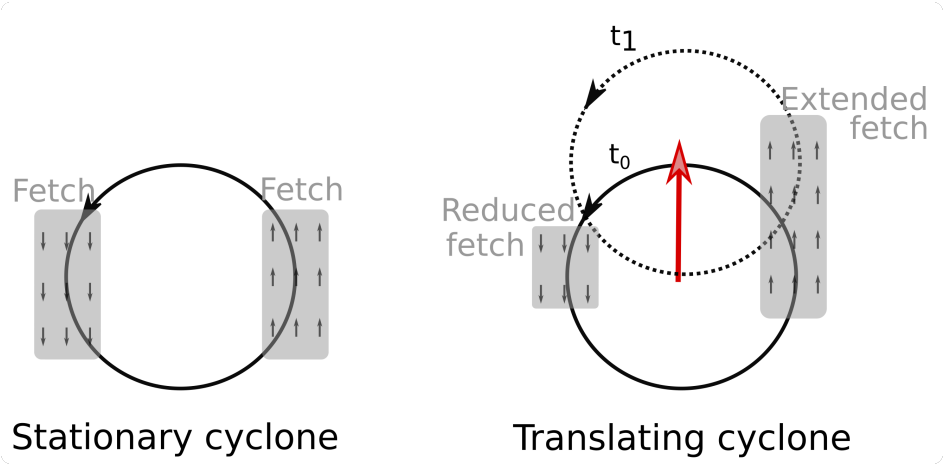
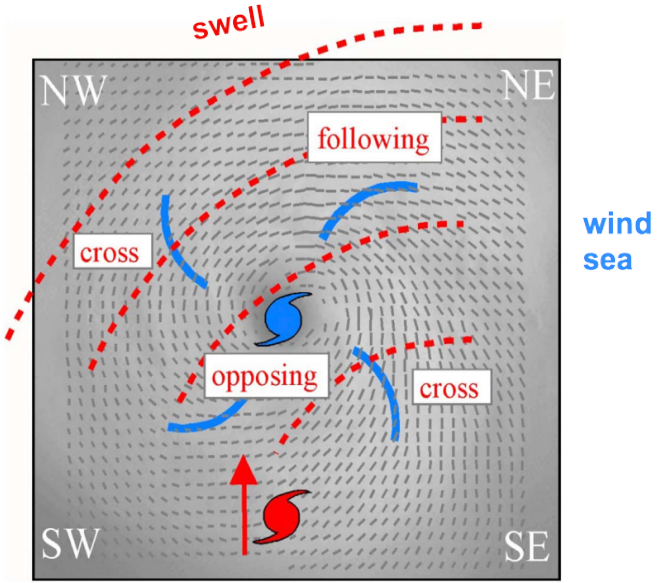
Introduction

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

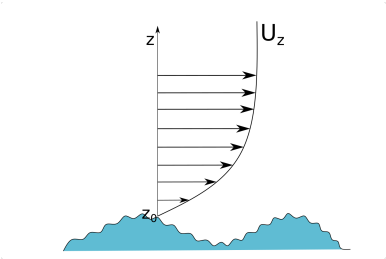
↳ Often based on case studies or on one cyclonic basin
And/or used to build parametric description of the H_s^{max}

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

Introduction

IMPACT ON AIR-SEA EXCHANGES

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



$$C_d = \frac{k^2}{\left[\ln\left(\frac{z}{z_0}\right)\right]^2} \qquad z_0 = \alpha \frac{u_*^2}{g} + 0.11 \frac{1.5 \times 10^{-5}}{u_*}$$

- Roughness parameterization

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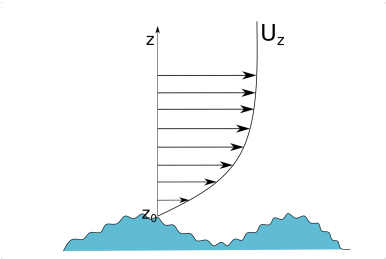

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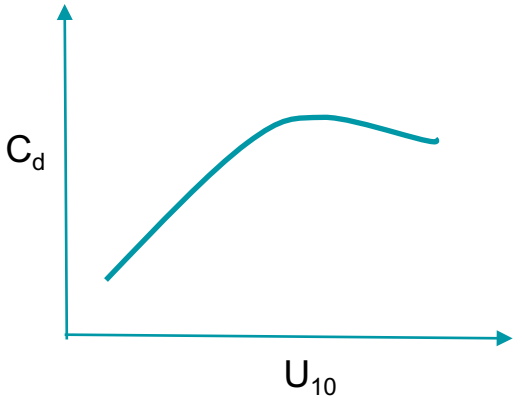

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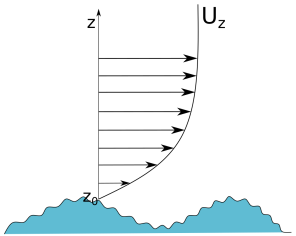

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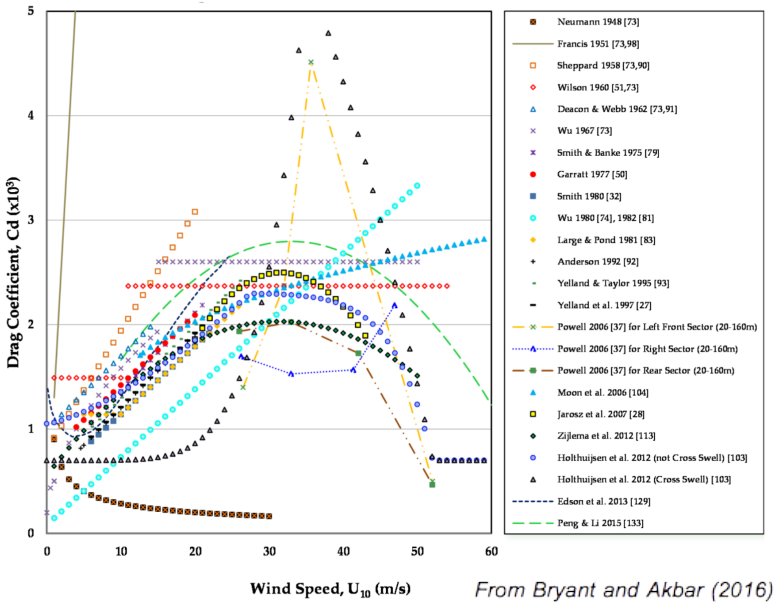

From Bryant and Akbar (2016)

- Roughness parameterization

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IMPACT ON AIR-SEA EXCHANGES

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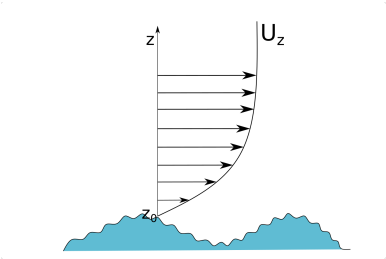

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$\alpha = 0.0185$ Charnock 1955

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

$$\alpha = \begin{cases} (0.085\beta_*^{3/2})^{1-1/\omega}[0.03\beta_* \exp(-0.14\beta_*)]^{1/\omega}, & \beta_* < 35 \\ (17.6)^{1-1/\omega}(0.008)^{1/\omega}, & \beta_* \geq 35 \end{cases}$$ used in Li et al. 2016

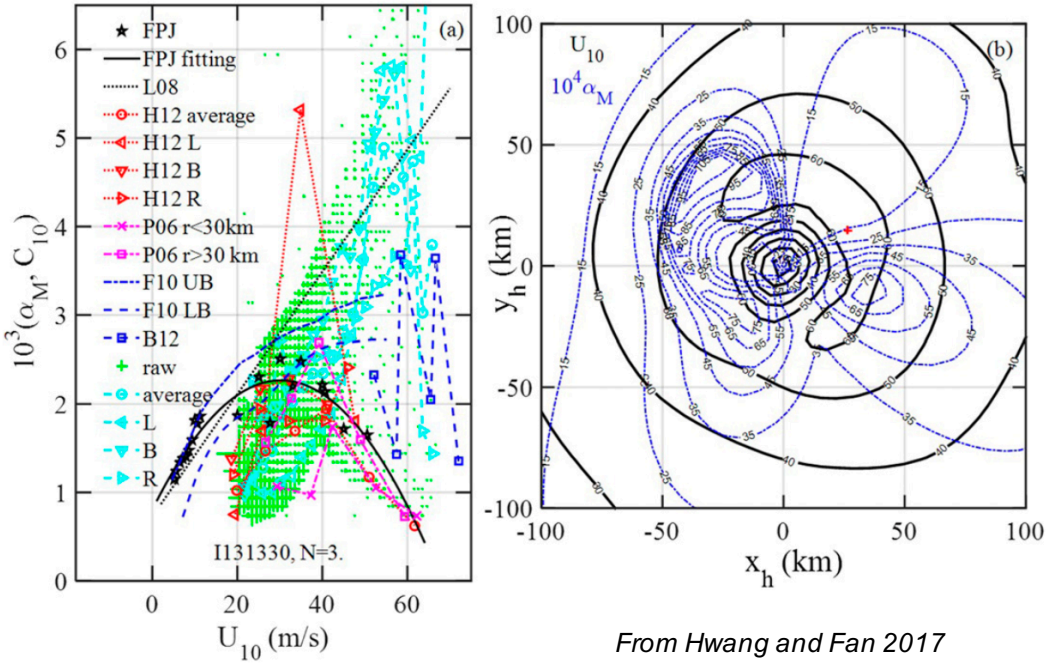
$\boldsymbol{\beta_*} = c_p/u_*$

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

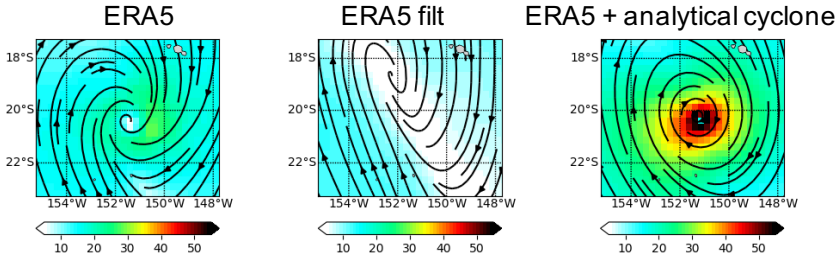
- All cyclonic basins
- 20-year wave simulation (~2000Tcs) → Robust statistical results

Methodology

ATMOSPHERIC FORCING

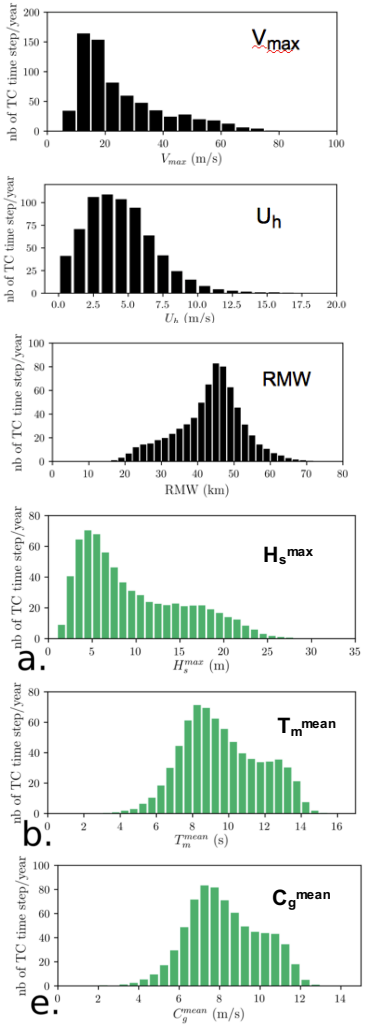
Atmospheric reanalysis ERA5 (1/4°)
+ parametric vortex *(Willoughby, 2006)* on Best Tracks

↳ improved representation of TCs



WAVE MODEL

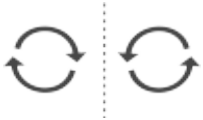
WaveWatch III global configuration (1/2°)

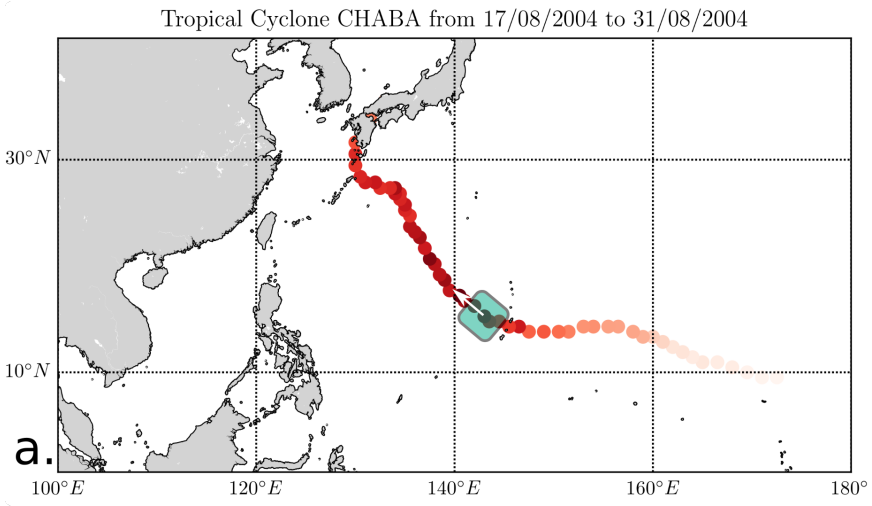


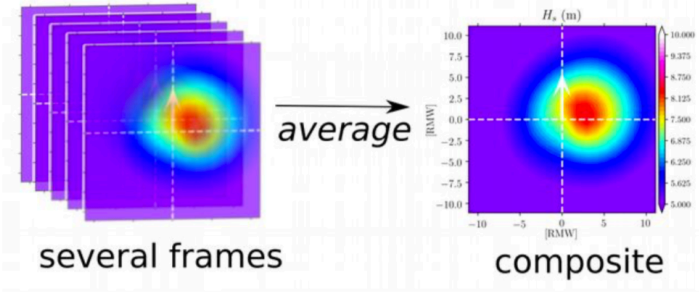
Methodology

COMPOSITE METHODOLOGY

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



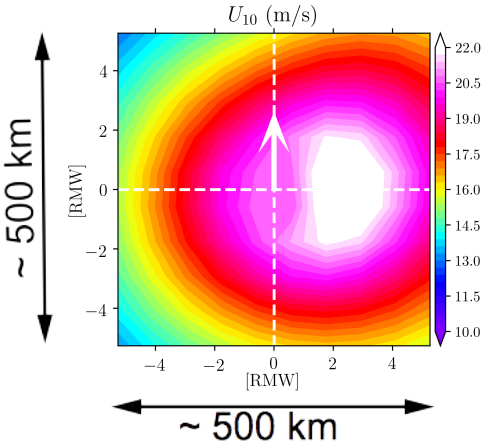


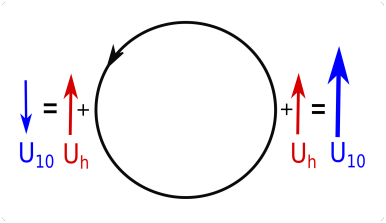


TC-induced waves characteristics

MEAN WIND FIELD U_{10}

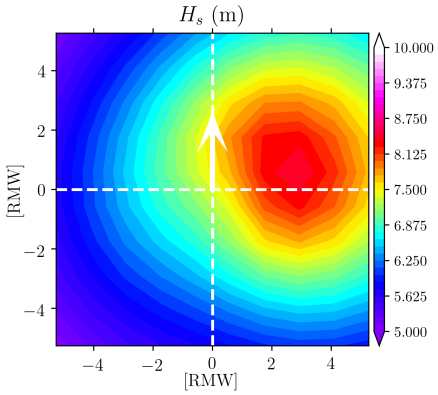
Stronger winds on the right

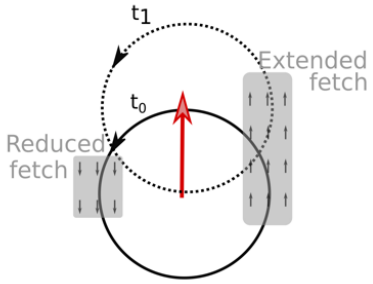




MEAN H_s

Higher waves on the front right

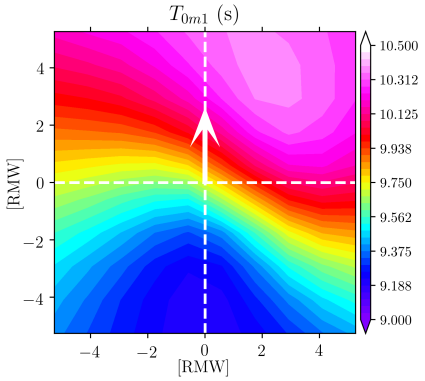




Translating cyclone

MEAN WAVE PERIOD T_{Om1}

Longest periods on the front



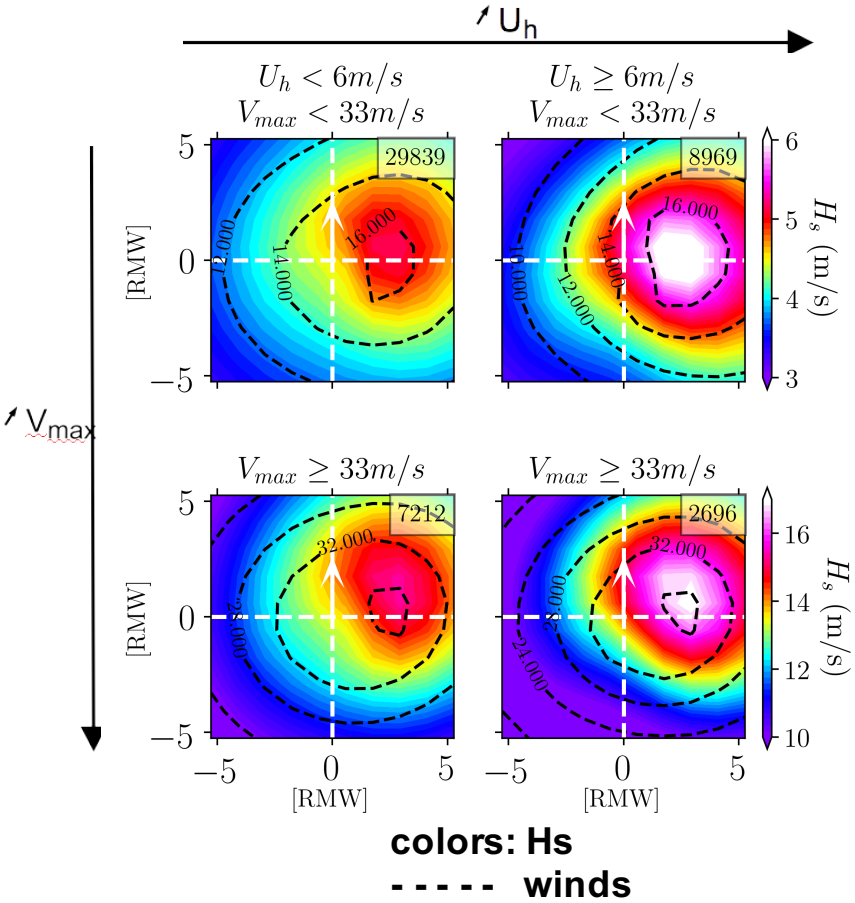
Large standard deviations: variability between TCs

influence of V_{max} and U_h?

TC-induced waves characteristics

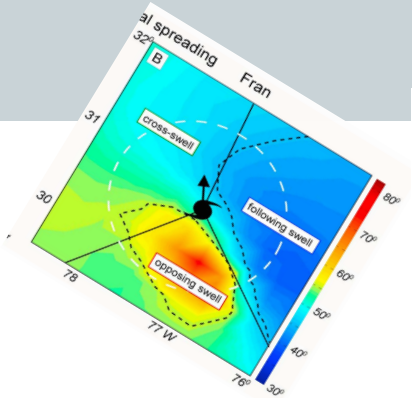
INFLUENCE OF Vmax AND Uh

- 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

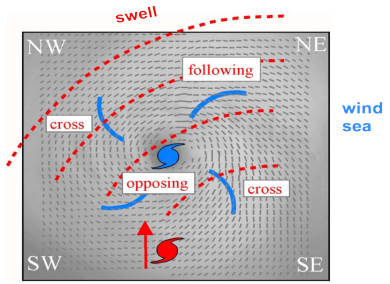


TC-induced directional spreading

WAVE DIRECTIONAL SPREADING PATTERN



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



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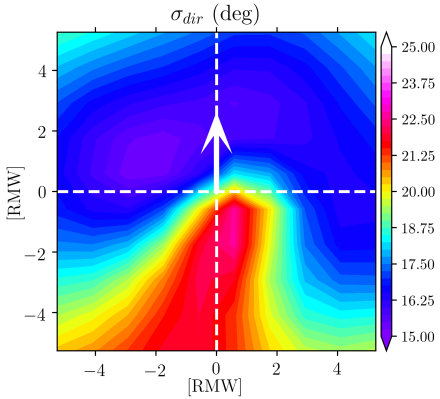

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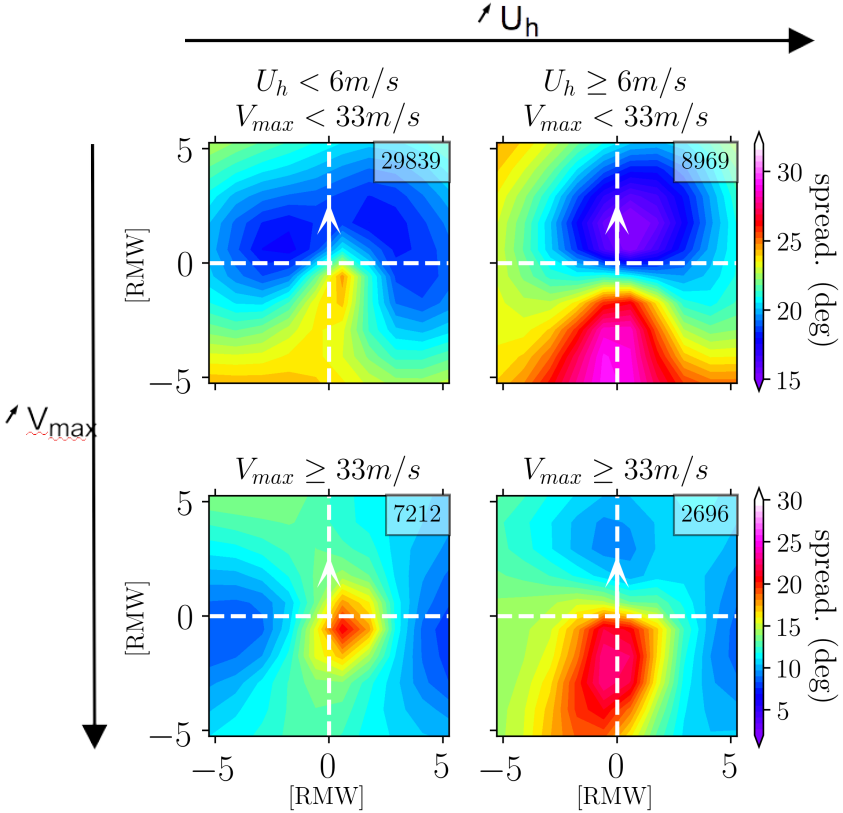

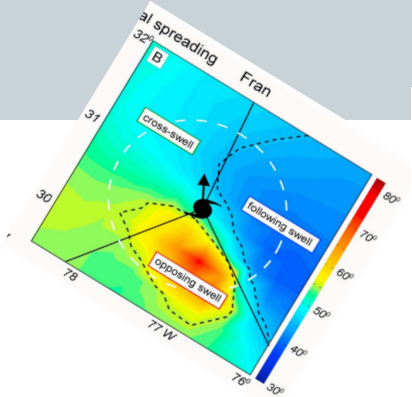

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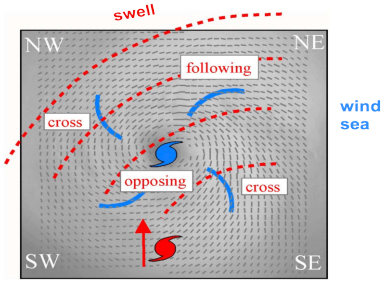

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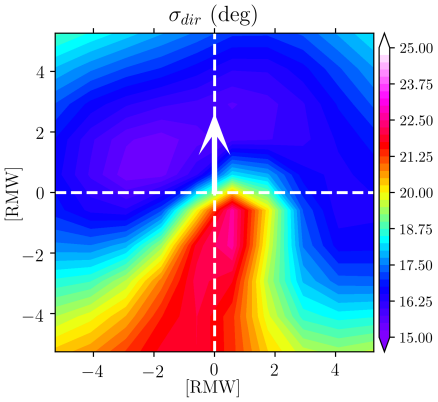

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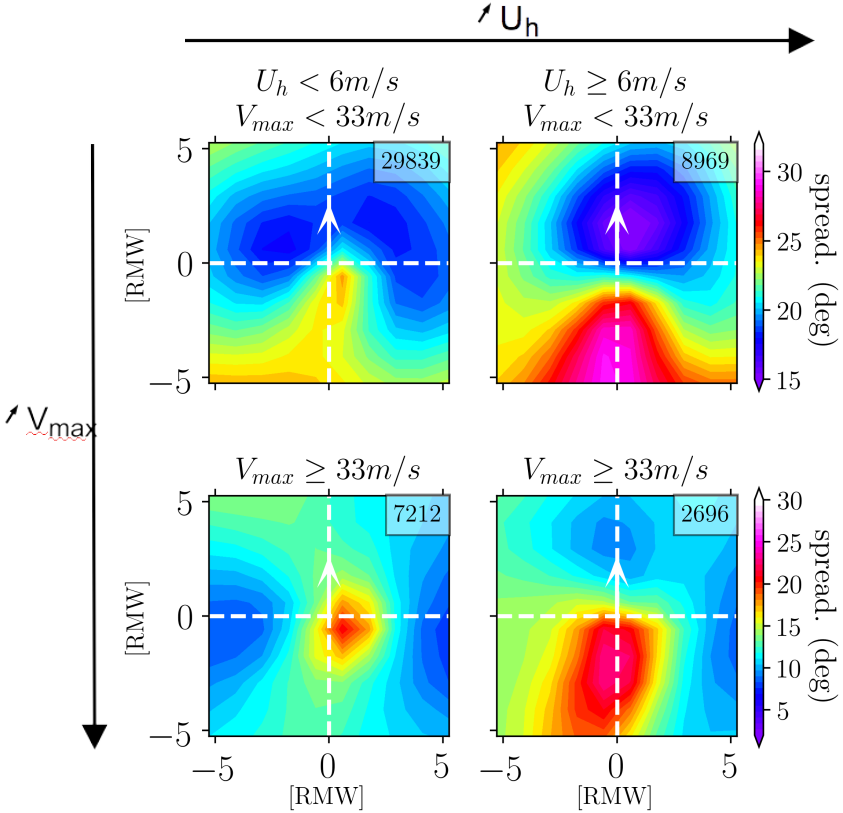

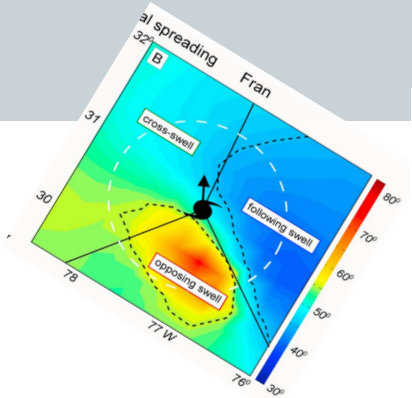

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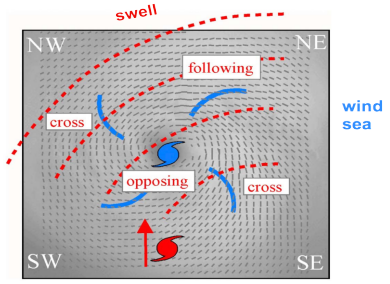

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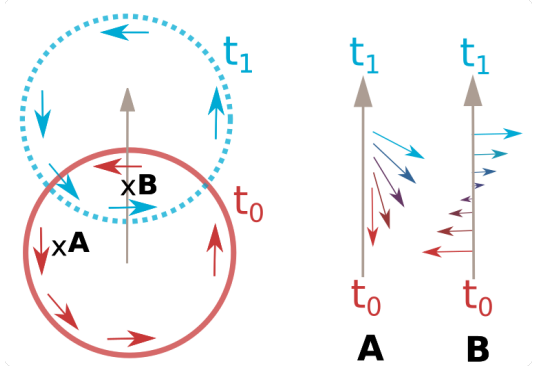
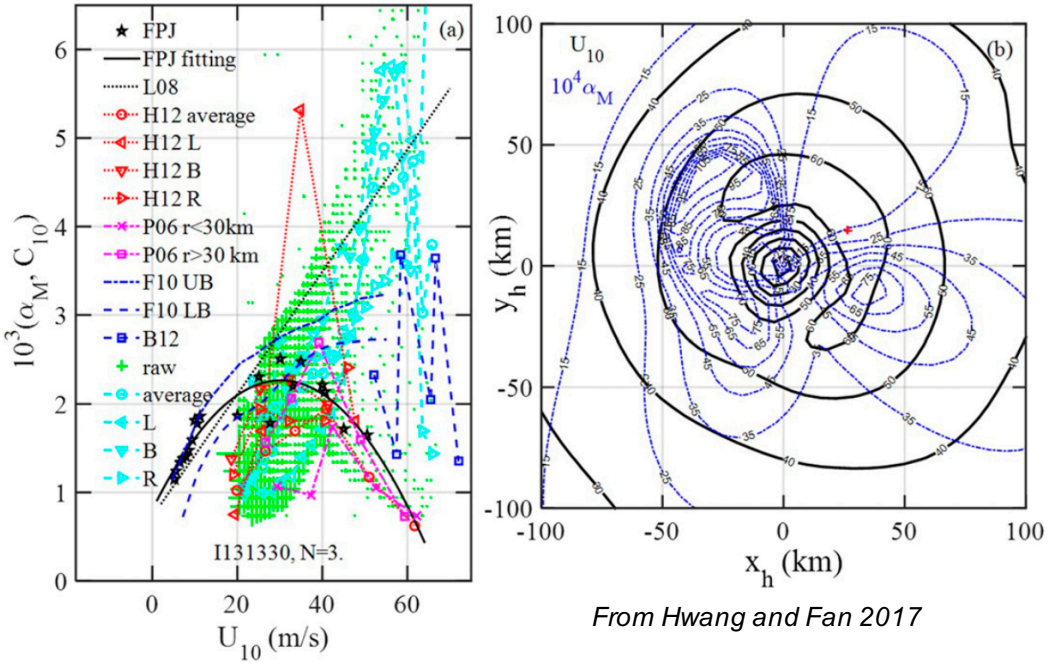


Impact on the air-sea exchanges



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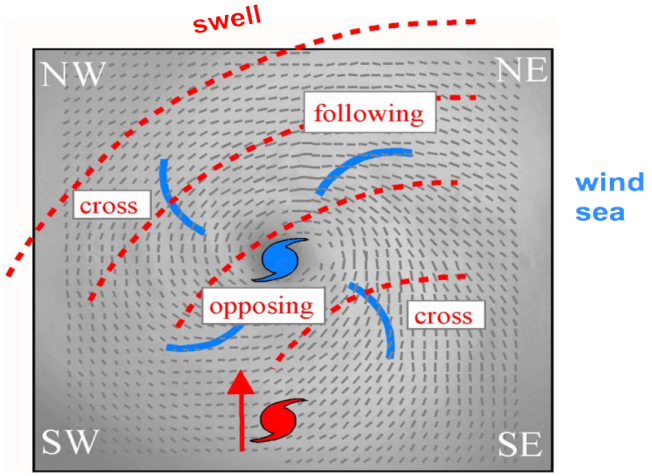

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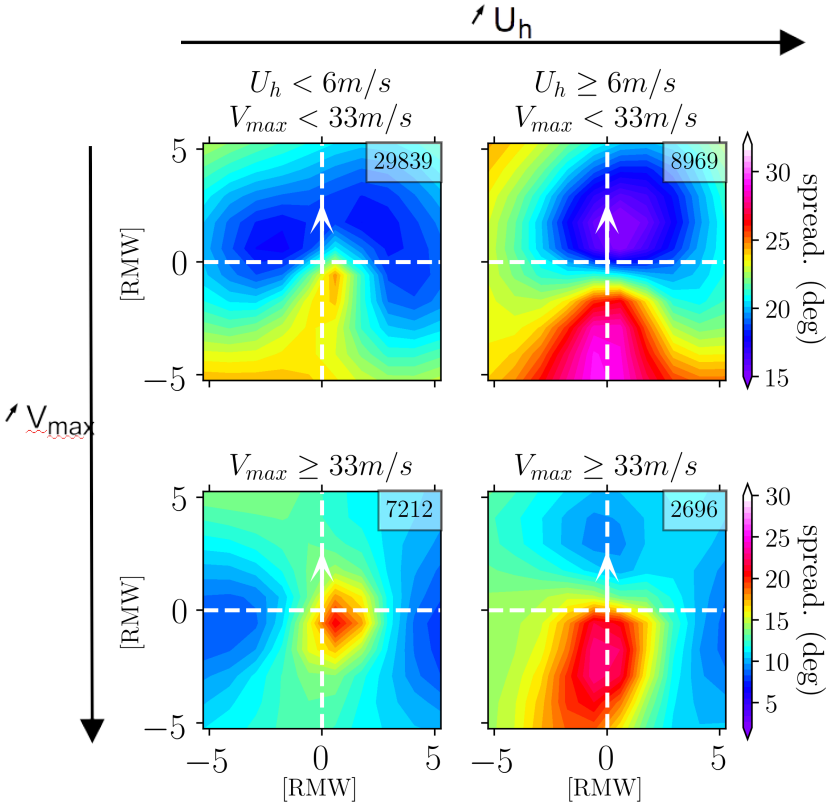
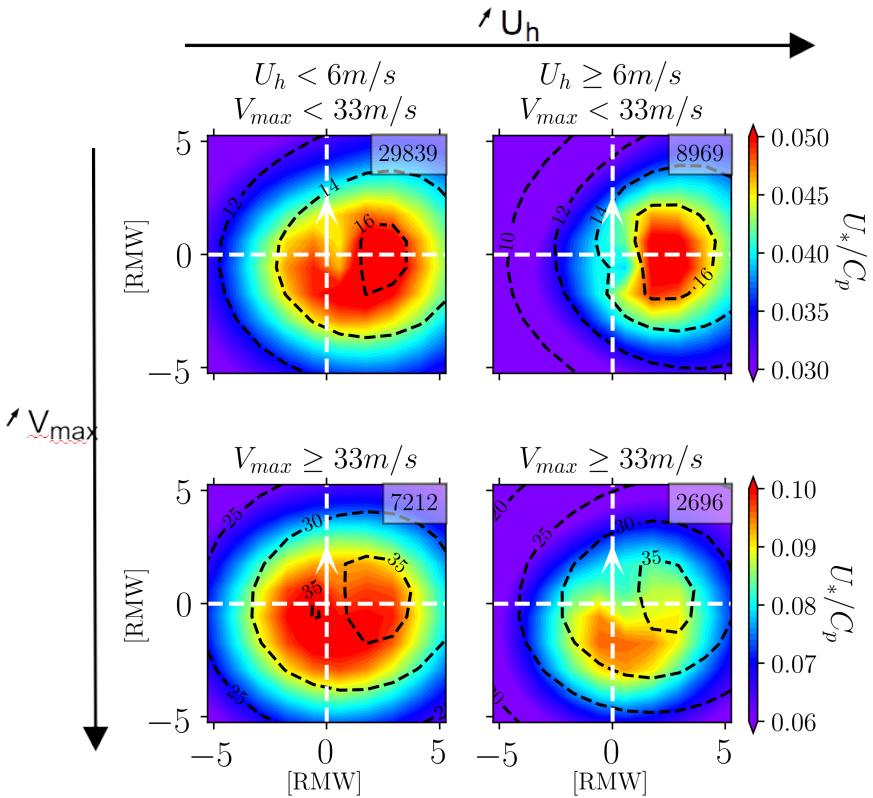


colors: wave directional spreading



colors: Inverse wave age

- - - - - winds

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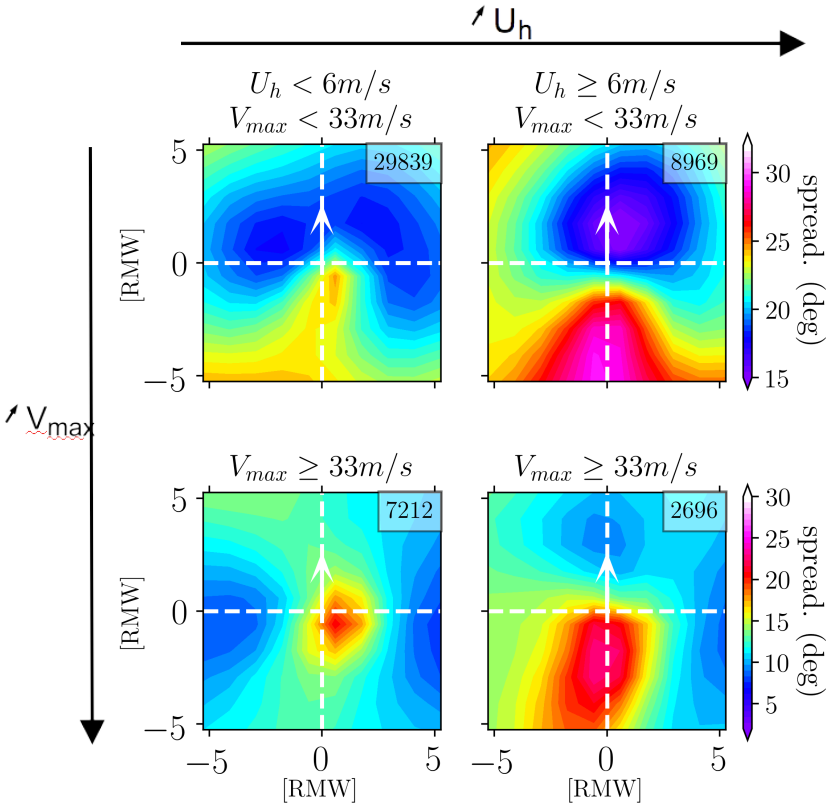

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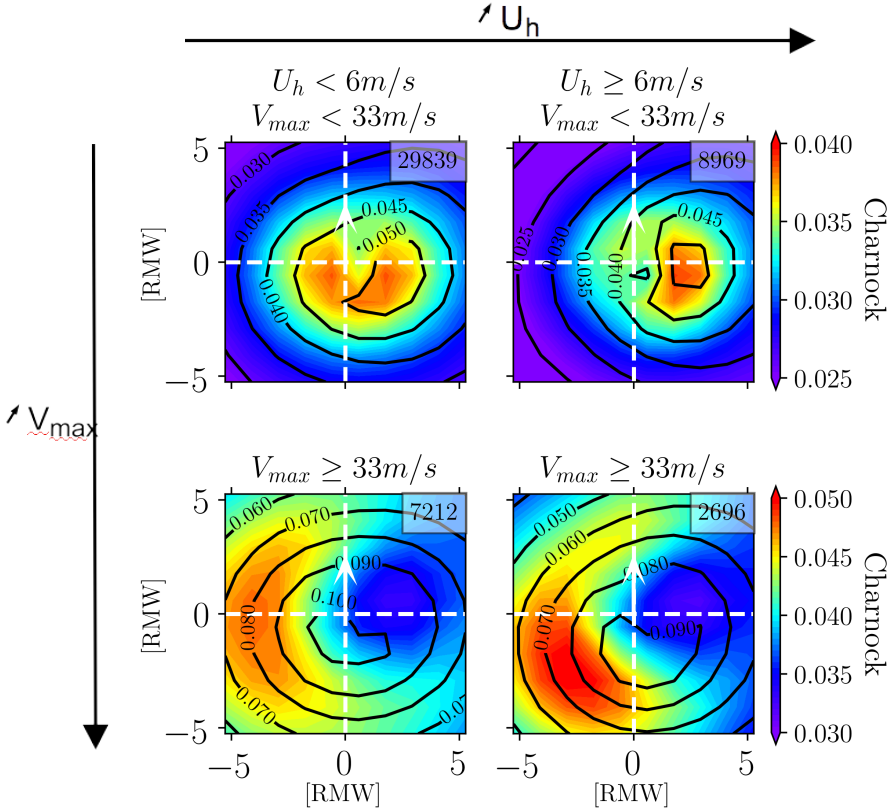

colors: Charnock coef.
------ inverse wave age

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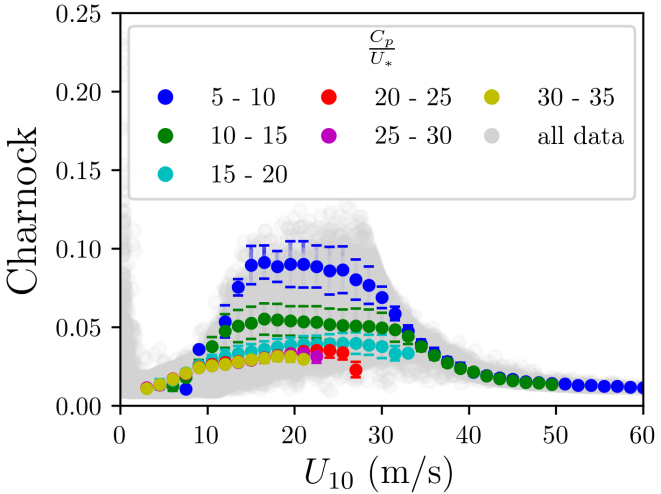

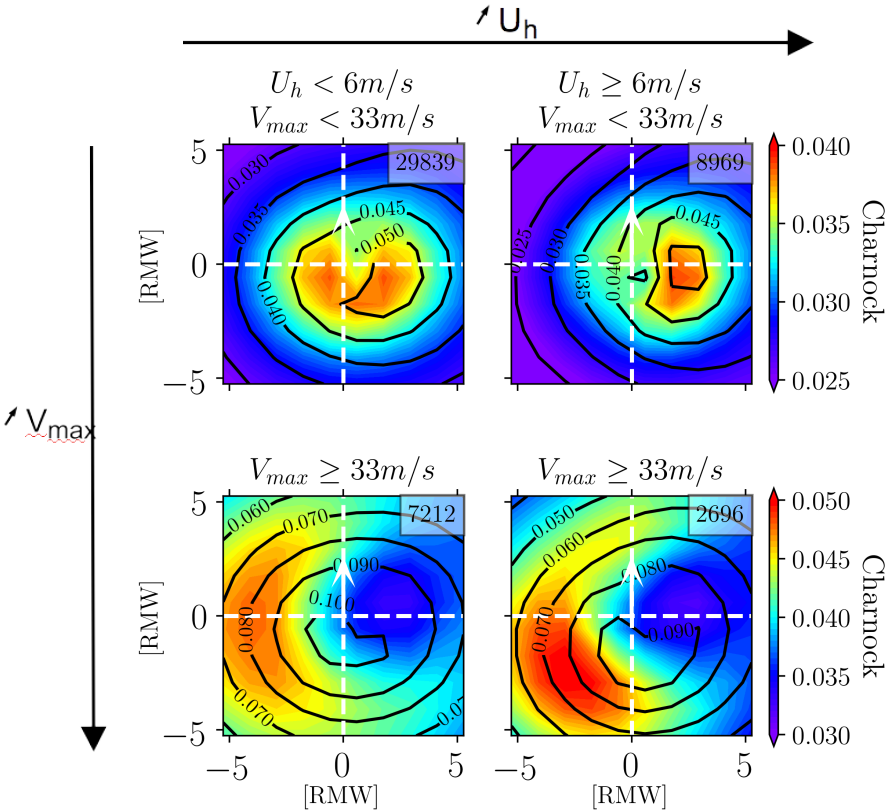

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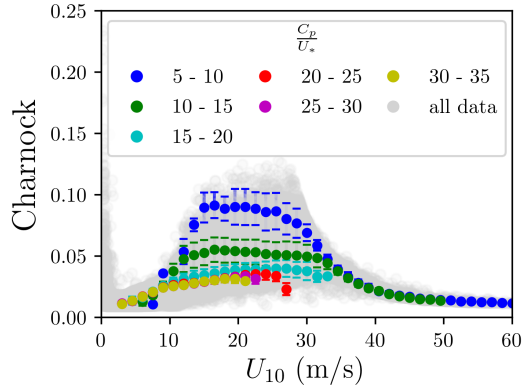
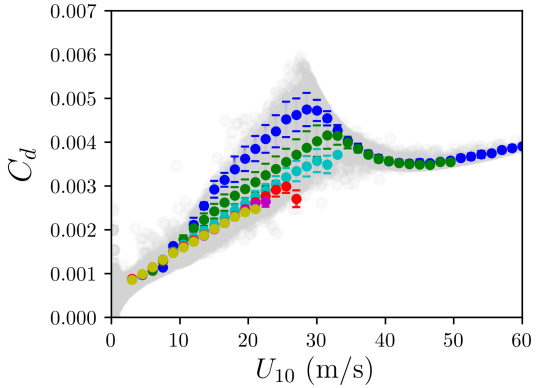
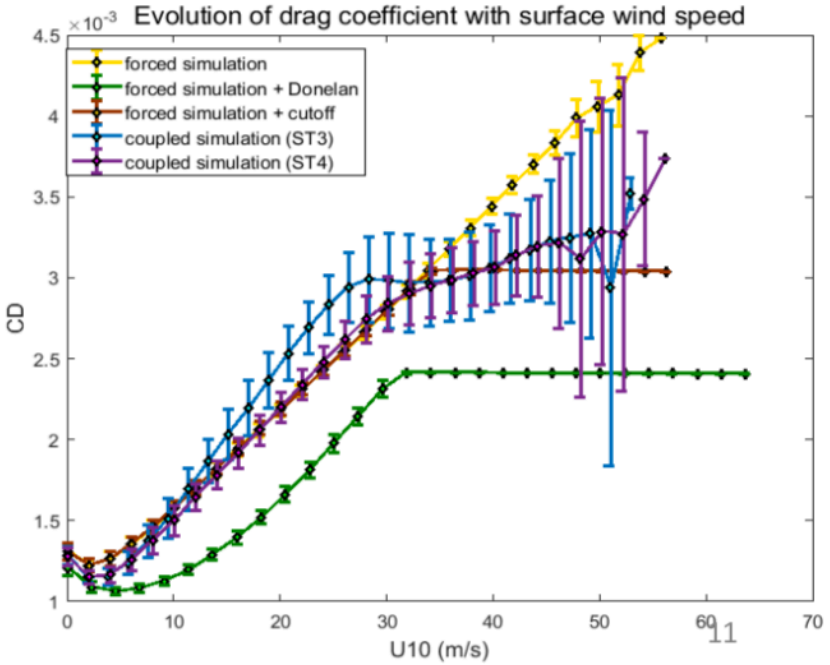






Summary

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

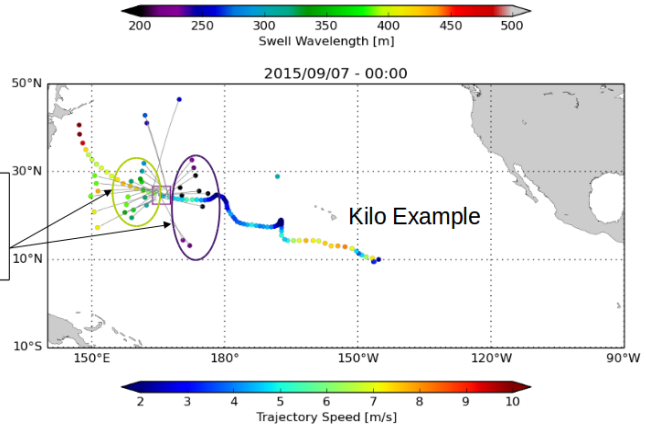
Low resolution (1/2°)
TCs might be oversized
No coupling

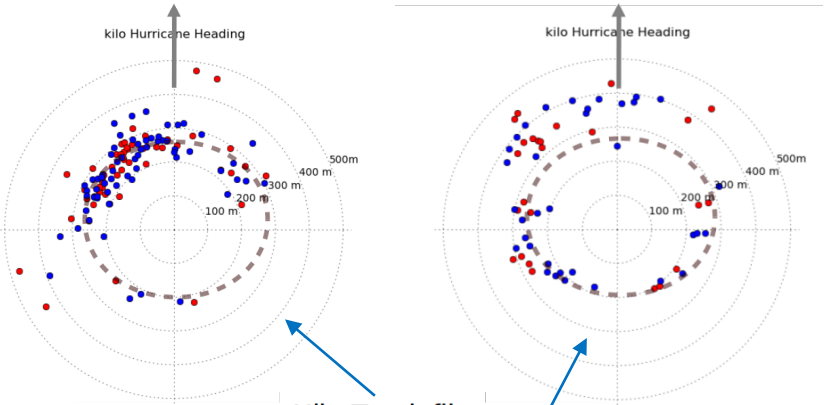
Air-sea interactions: let's remember that we are in the limit of both observations and model parameterizations

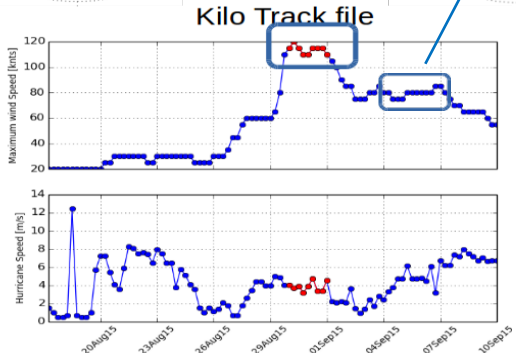
On-going work: use of spectral observations

→ retro-propagation of wave systems to the generation area

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







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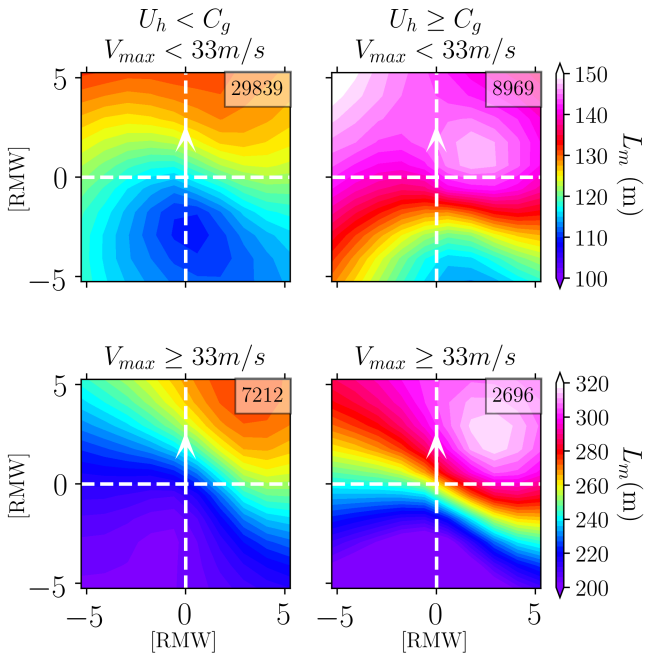
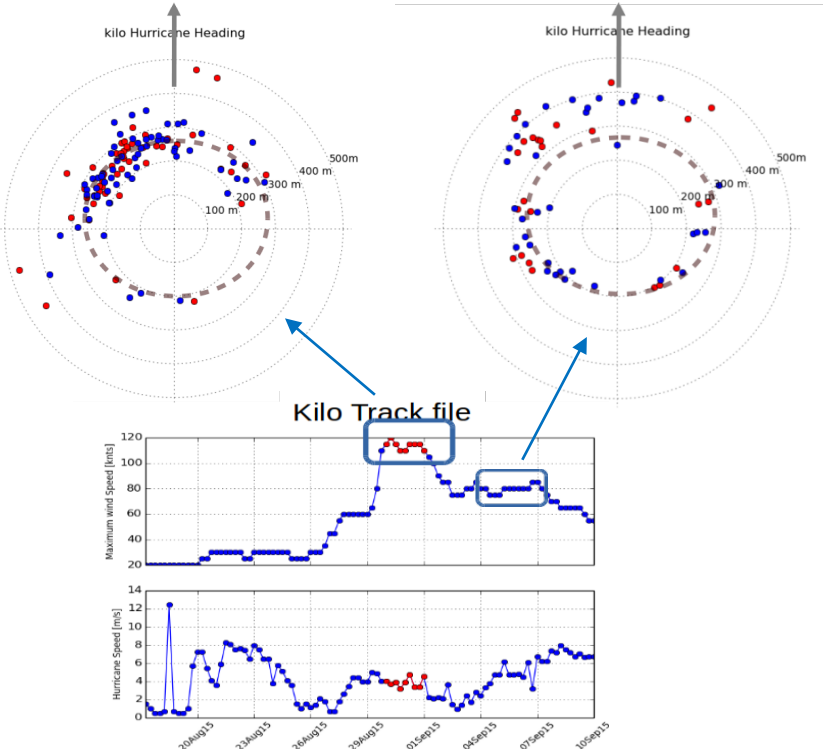
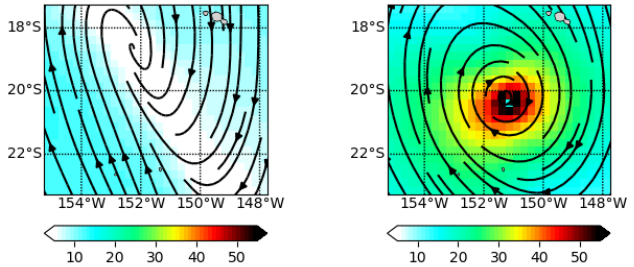


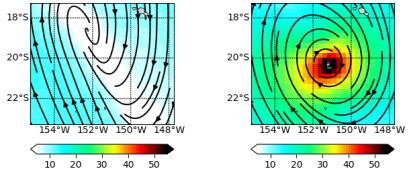


Impact on wave extremes in the Bay of Bengale

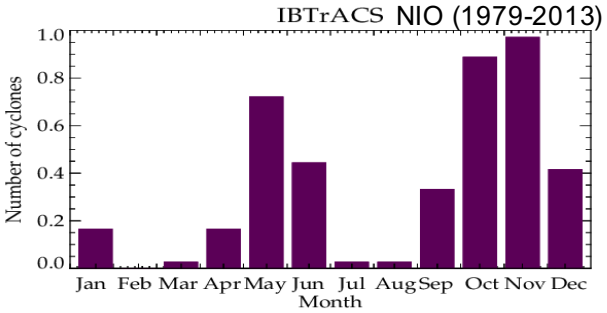
- Contribution of TCs on the wave climate in the BoB:



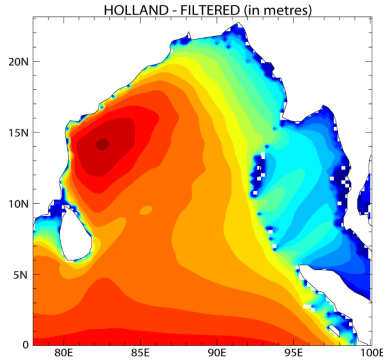
Impact on wave extremes in the Bay of Bengale

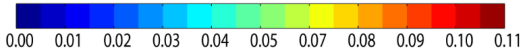


- Contribution of TCs on the wave climate in the BoB:
  - 9% in average
  - **42 to 76 %** of extreme waves in pre- and post-monsoon seasons
  - 7% of extreme waves during the monsoon season

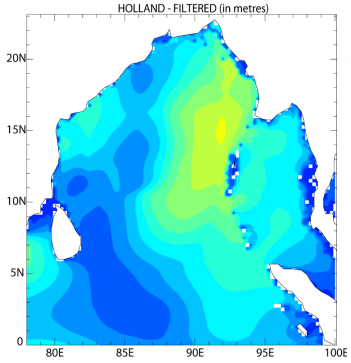


AVERAGE
TC contribution: => 9%

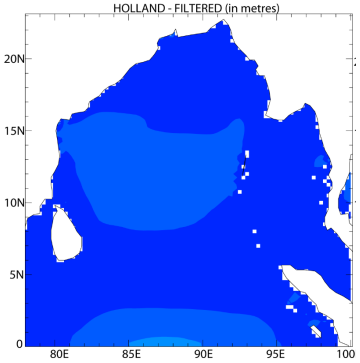




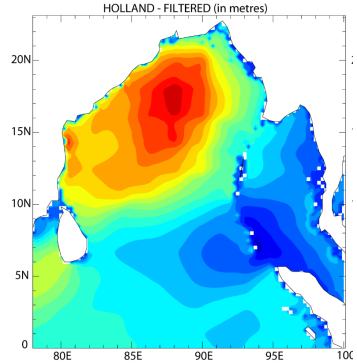
MAY(Pre-monsoon) => 42%



AUGUST (Monsoon) => 7%



DECEMBER (Post-monsoon) => 76%



Thank you!


LOPS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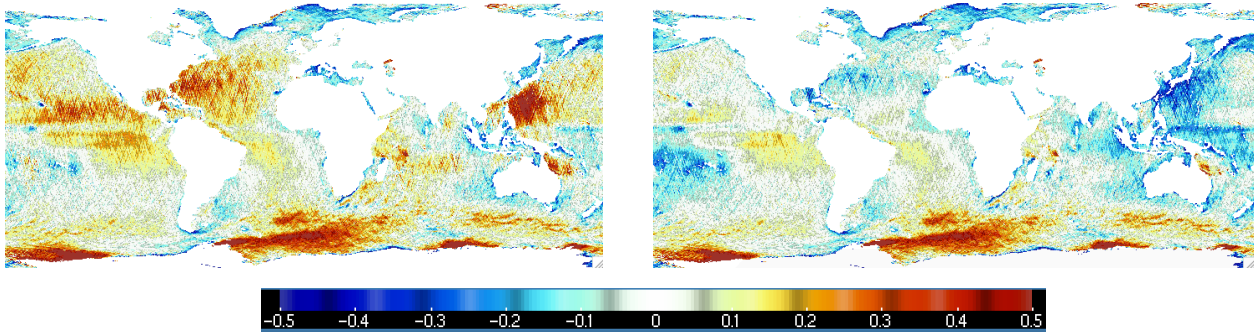
cnes

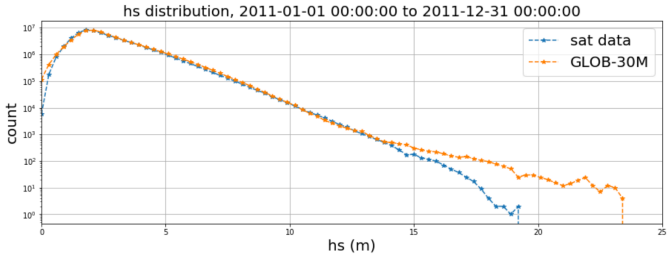
Methodology

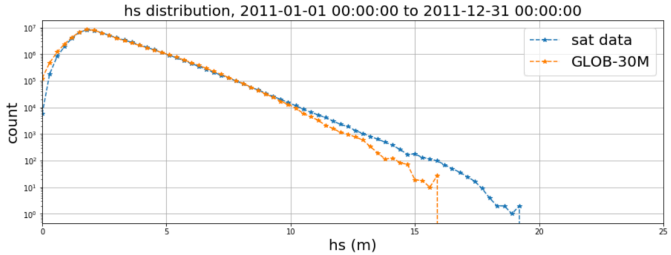
ST4	
BETAMAX	1.6
SWELLF	0.69
SWELLF4	150 000
SWELLF7	468 000

GLOBAL WAVE SIMULATION

- WaveWatch III (WW3) spectral wave model at ½°

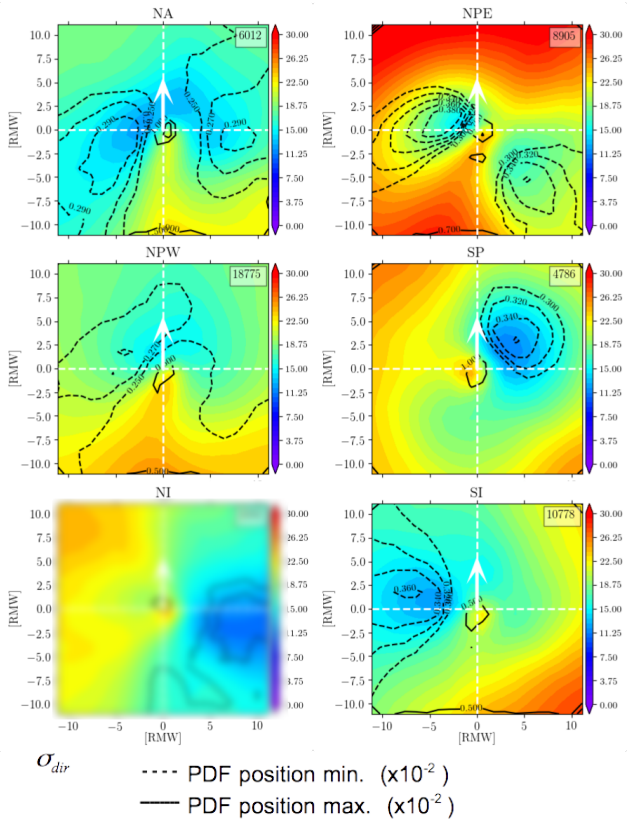




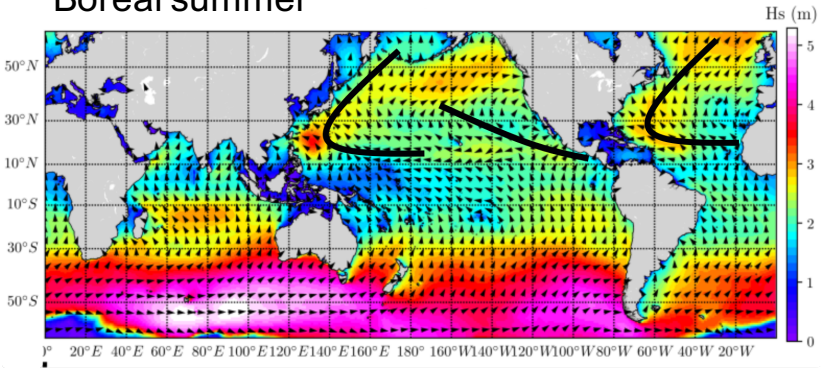


Wave directional spreading

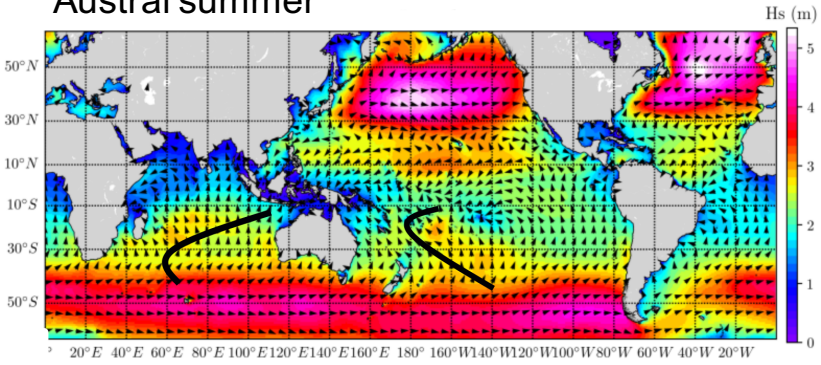
INFLUENCE OF THE BACKGROUND SWELL



Climatology of Hs and wave direction
Boreal summer



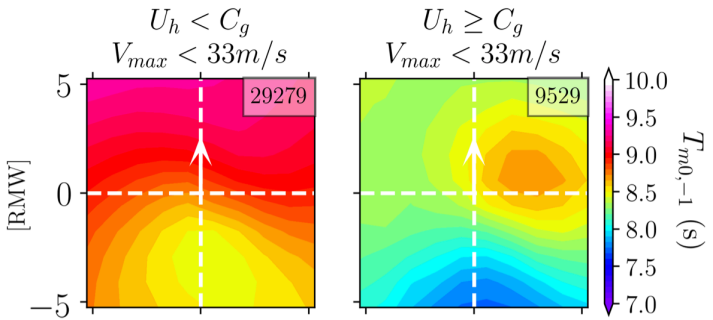
Austral summer

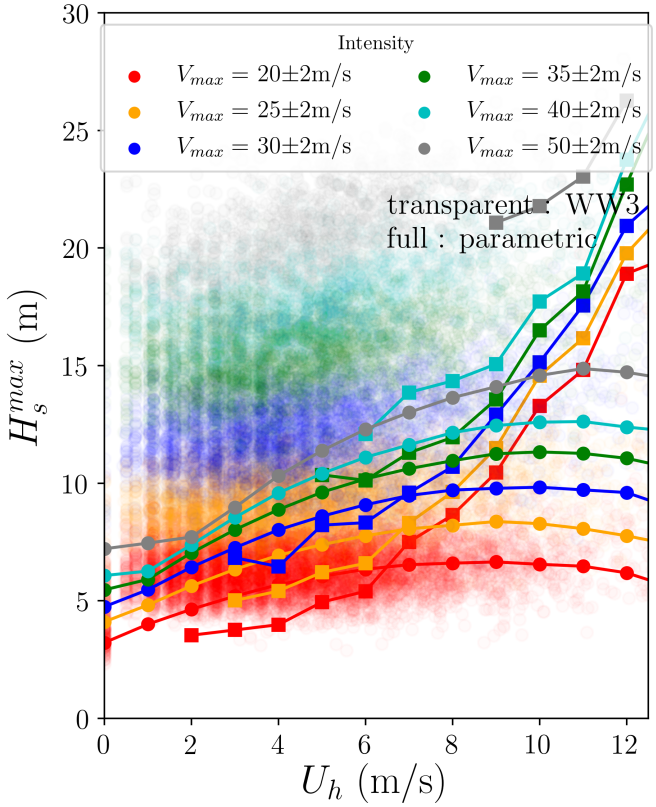


TC-induced waves characteristics

COMPARISON TO ANALYTICAL MODELS

- H_s^{max} suggest that **trapped waves** are generated
- Overestimation of H_s^{max} at slow translation velocity (probably due to the ½° horizontal resolution)





Analytical models

YOUNG AND VINOTH 2013

$$H_s^{max} = 0.0016\sqrt{\frac{FV_{max}^2}{g}}$$

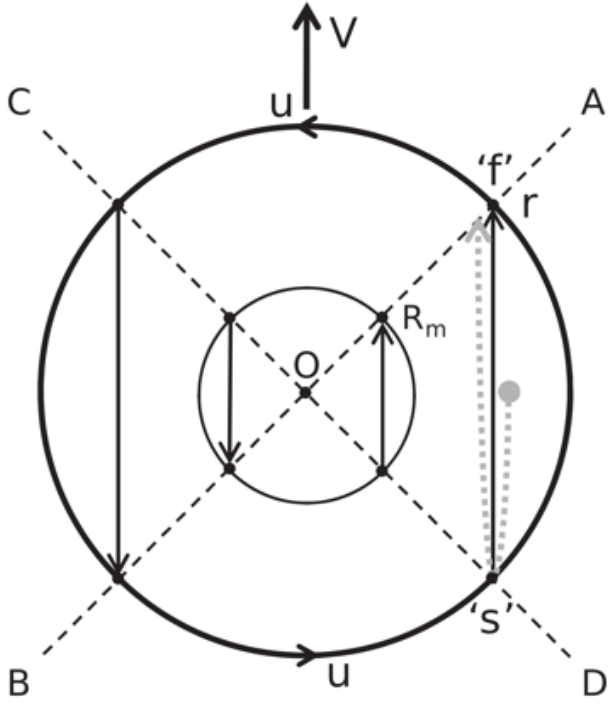
$$F = R'\psi\left[aV_{max}^2 + bV_{max}U_h + cU_h^2 + dV_{max} + eU_h + f\right]$$

$$\psi = -0.015\,V_{max} + 0.0431\,U_h + 1.3$$

$$R' = 22.5\times10^{-3}\log(RMW) - 70.8\times10^{3}$$

KUDRYAVTSEV ET AL. 2015

$$H_s^{max} = 4\sqrt{7.8e^{-2}}\,V_{max}^{0.38}\,U_h^{1.6}\,g^{-1}$$

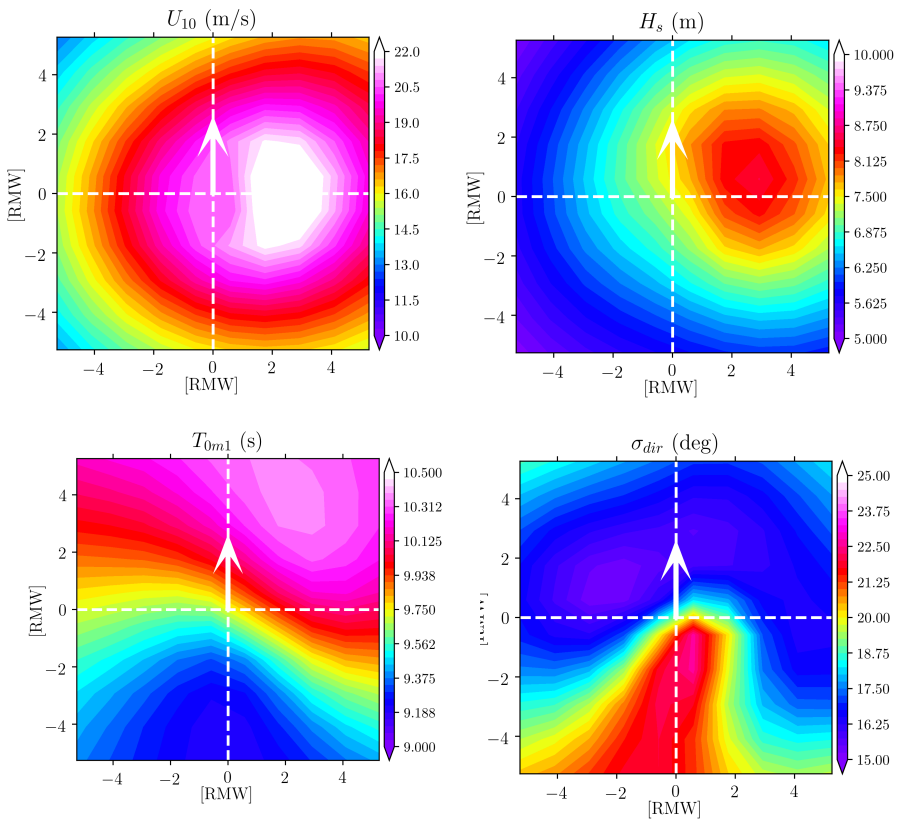


WW3: Charnock coefficient

$$z_0 = \alpha_0 \frac{\tau}{\sqrt{1 - \tau_w/\tau}}$$

$$\tau_w = | \int_0^{kmax} \int_0^{2\pi} \frac{S_{in}(k', \theta)}{C_1} (cos\theta, sin\theta) dk' d\theta + \tau_{hf}(cos\theta_u, sin\theta_u) |$$

TC-induced waves characteristics



	Mean	10-90 percentiles
V_{max}	28 m/s	14-48 m/s
RMW	66 km	51-106 km
U_h	4.5 m/s	0-8 m/s
H_s^{max}	8.2 m	3-16.5 m
T_m^{mean}	9.3 s	7-12.5 s
c_g^{mean}	8 m/s	6-10.5 m/s

Stronger H_s and larger period on the front right quadrant

- **Stronger the TC, more to the front H_s^{max}**
- **Faster the TC, more asymetric the wave field**