Redistribution of air-sea momentum flux by surface gravity waves and its influence on cyclone simulations

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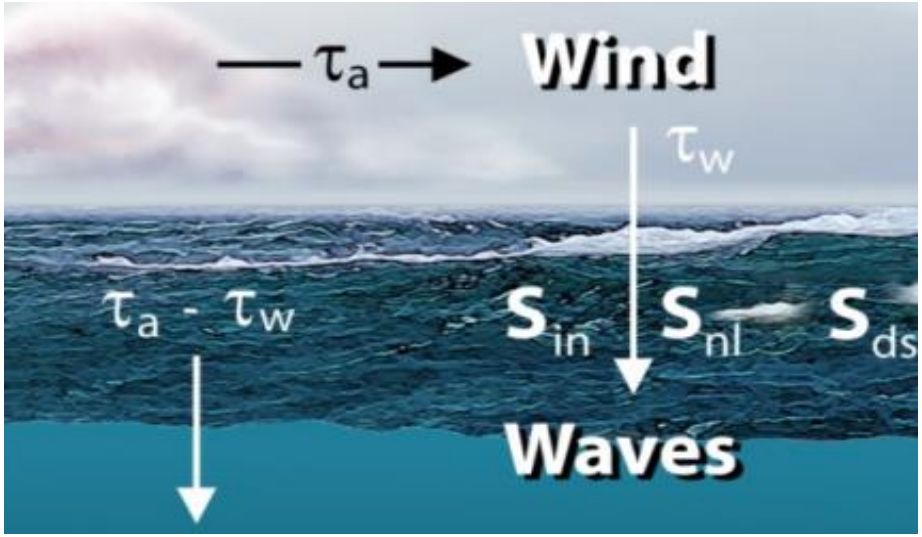
Background



In traditional models, the ocean-side stress is assumed to identical to the air-side stress, in terms of magnitude and direction.

$$\boldsymbol{\tau}_{\mathrm{a}} = \boldsymbol{\tau}_{\mathrm{oc}}$$

In reality:

air-side stress — Wave supported stress

$$\boldsymbol{\tau}_{\mathrm{a}} = \boldsymbol{\tau}_{\mathrm{oc}} + \boldsymbol{\tau}_{\mathrm{w}} + \boldsymbol{\tau}_{\mathrm{ds}}$$

Ocean-side stress — Stress from waves to current through breaking

- In which areas do the differences between air-side and ocean-side stresses become significant?
- Do the air-side stress directions always align with the mean wind direction, as in the bulk formula? Do the misalignment between wind and stress affect TCs?

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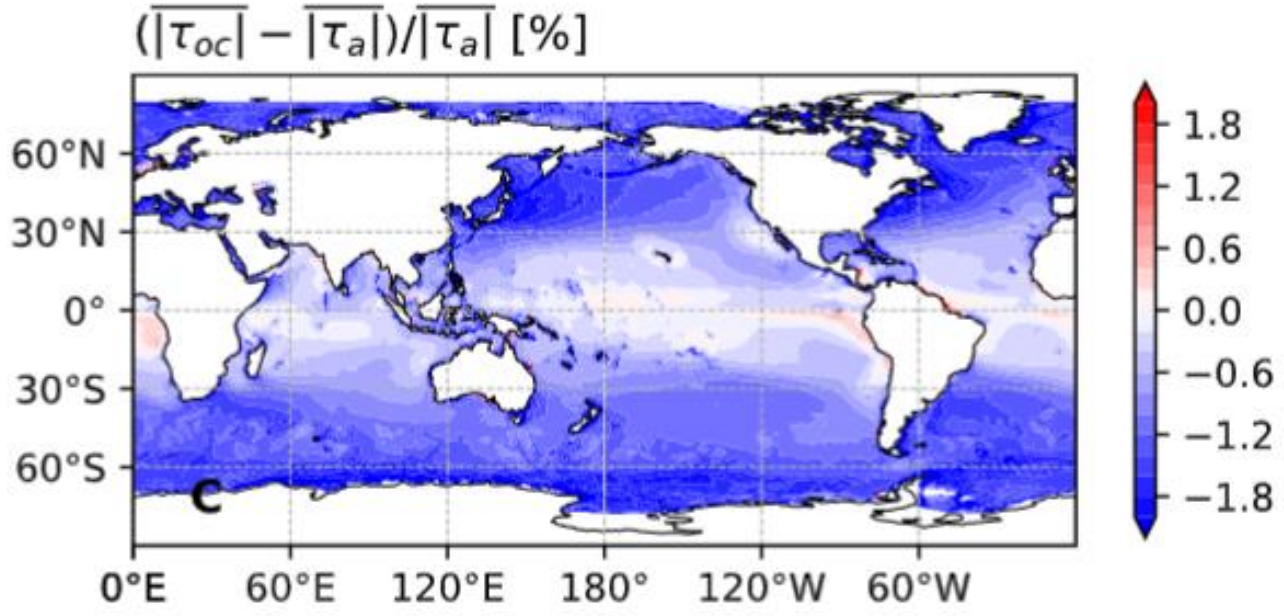
Difference between water and air-side stress

Based on 20 yr IOWAGA wave hindcast data



The buffer role of waves on the wind stress distribution is smaller when checking the time mean.

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Difference between water and air-side stress

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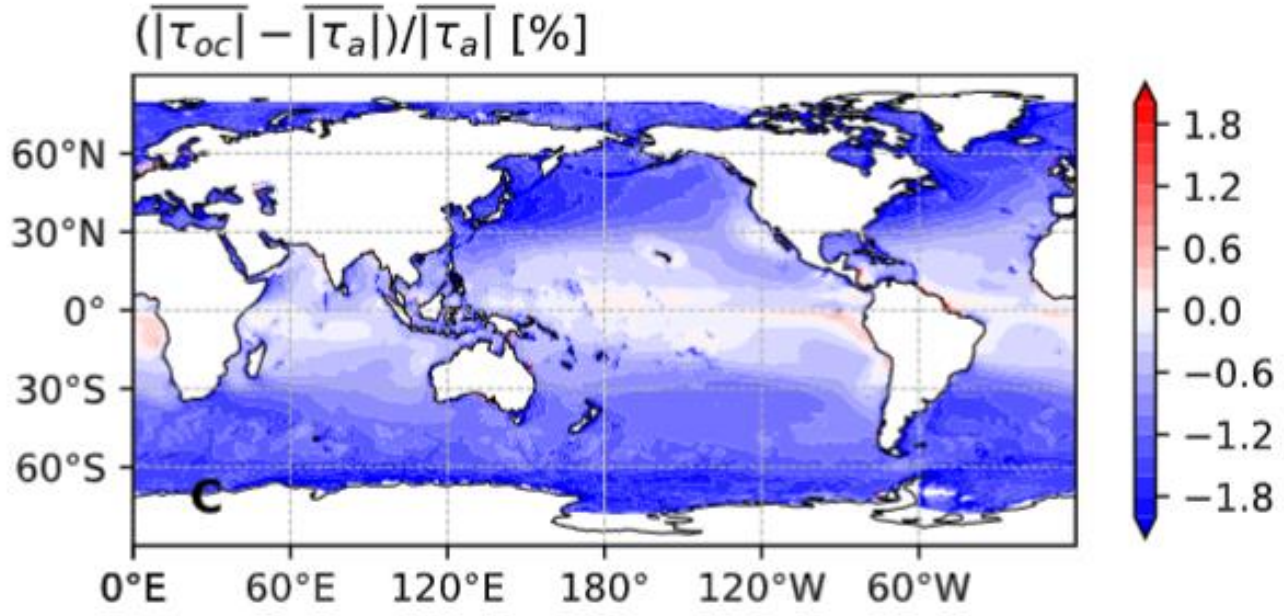
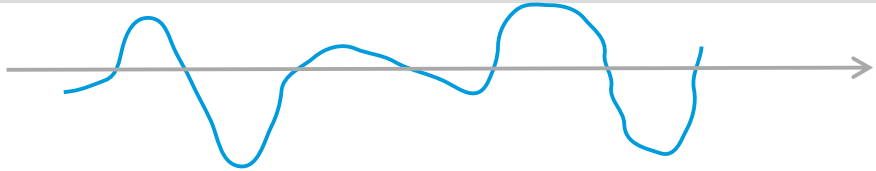


The buffer role of waves on the wind stress distribution is smaller when checking the time mean.

It does not mean its influence is small on ocean simulations



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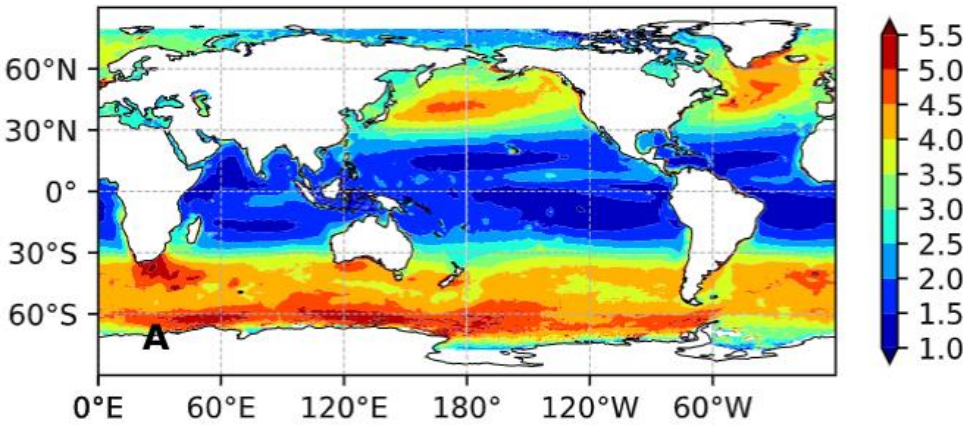
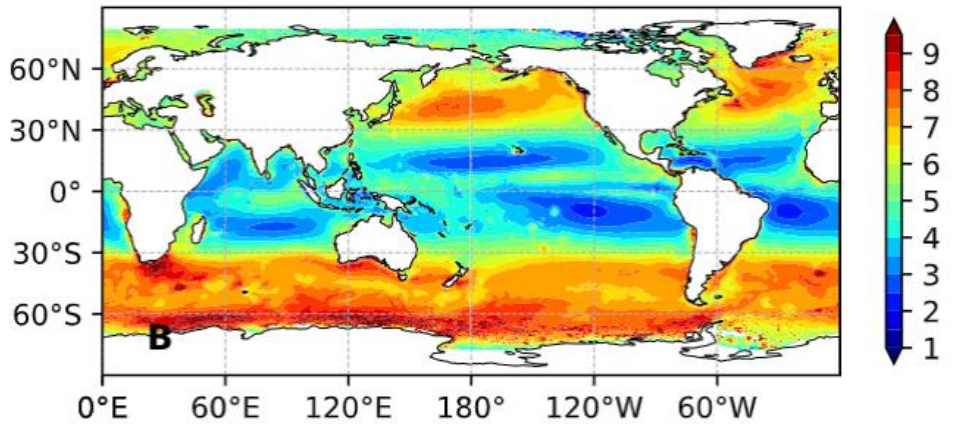
Difference between water and air-side stress

$|(|\boldsymbol{\tau}_{oc}|/|\boldsymbol{\tau}_a|) - 1| \times 100\%$



mean of 90th percentile $|(|\boldsymbol{\tau}_{oc}|/|\boldsymbol{\tau}_a|) - 1| \times 100\%$



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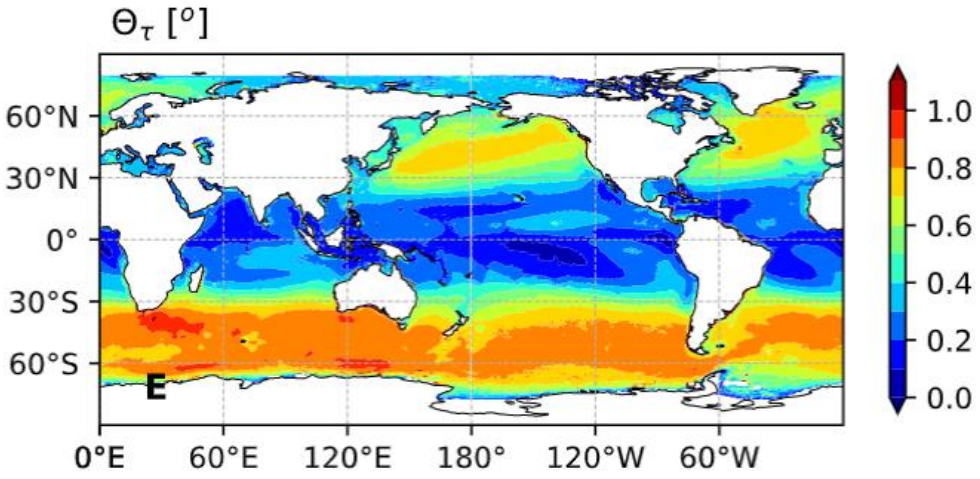
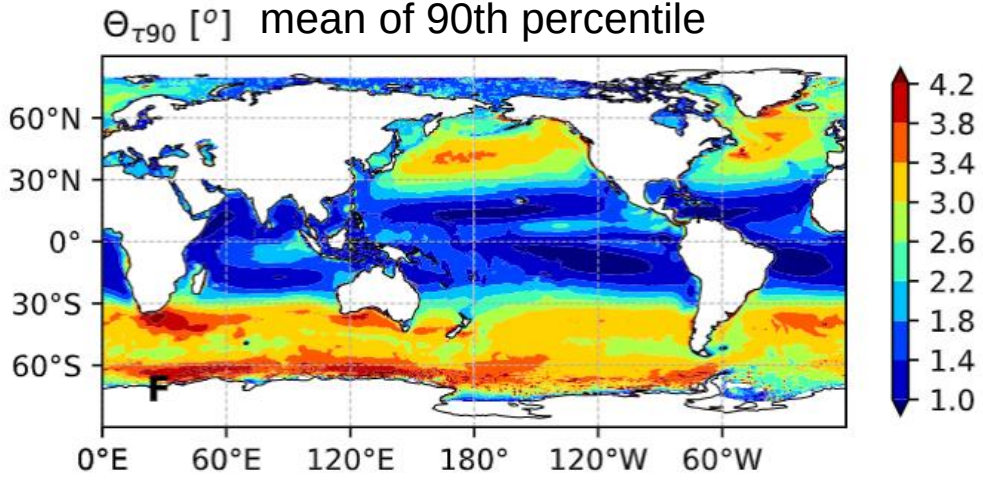
Difference between water and air-side stress

The misaligment between τ_a and τ_{oc}





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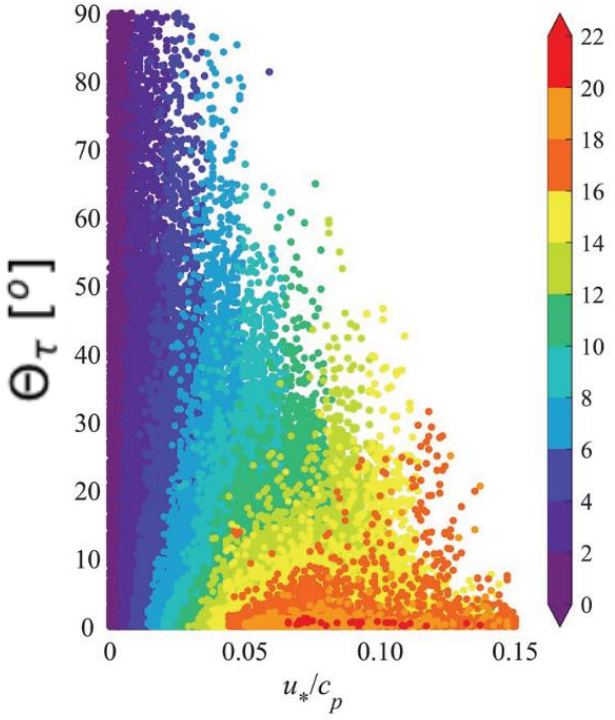
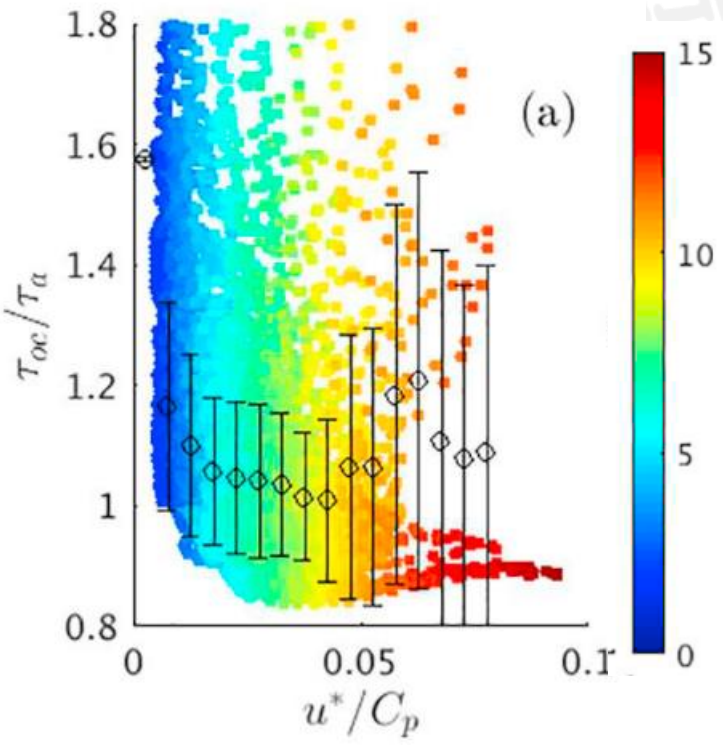
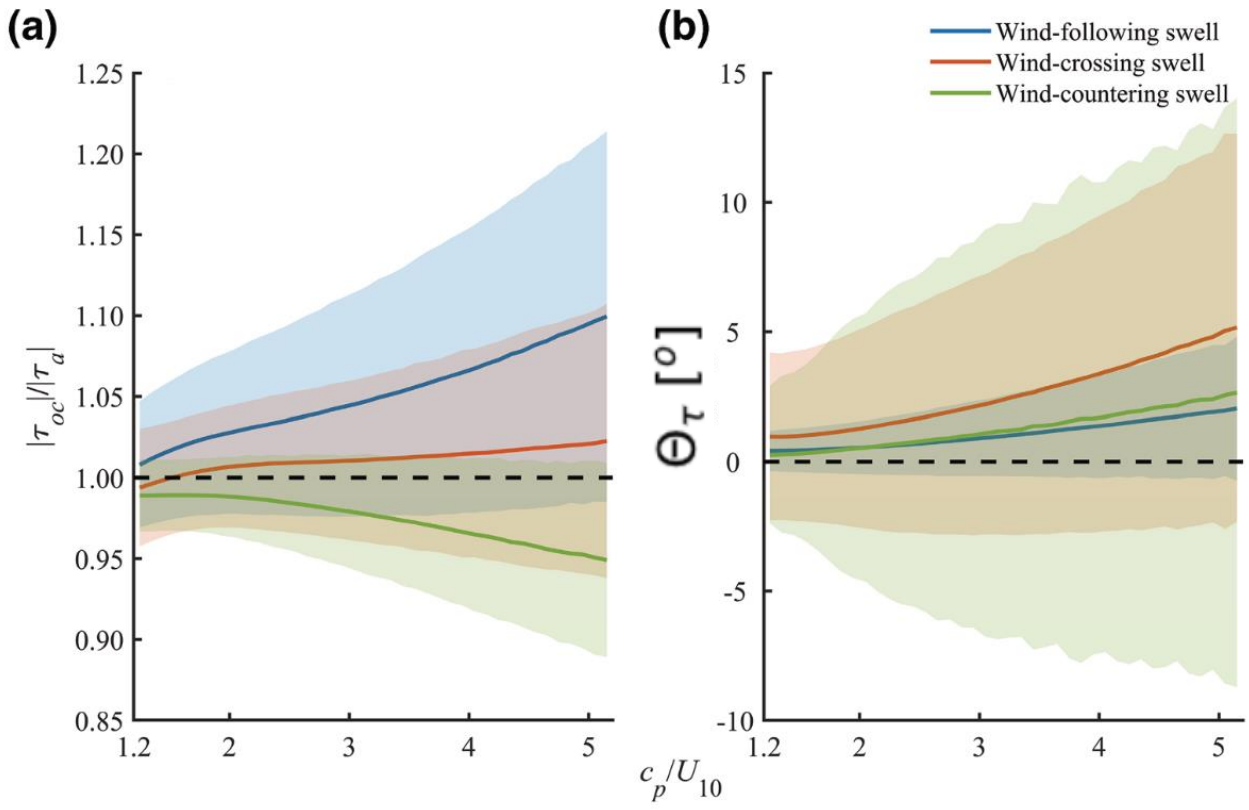
Difference between water and air-side stress





Based on high resolution simulation with domain covering the Baltic Sea

Difference between water and air-side stress



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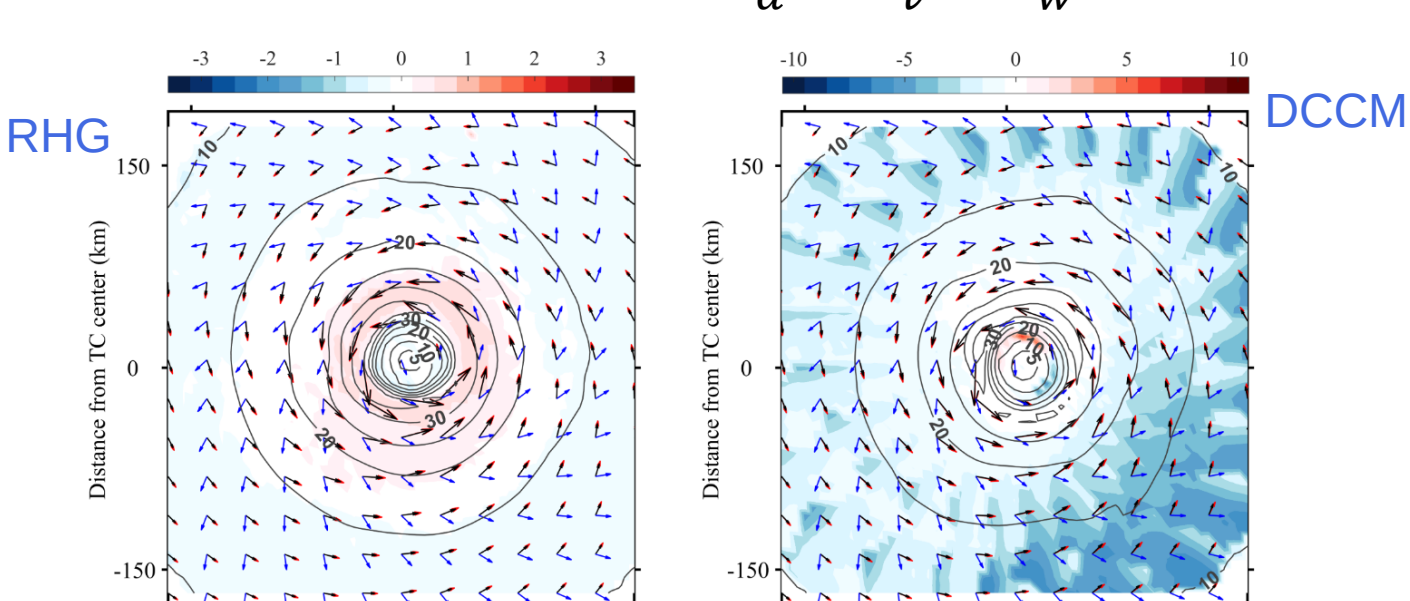
Based on high resolution simulation with domain covering the Baltic Sea

Influence on cyclone simulation

The air-side stress is estimated by: $\tau_a = \tau_v + \tau_w$

viscous stress

wave-induced stress



Warm (cold) colors correspond to the stress vector oriented to the right (left) of the wind direction

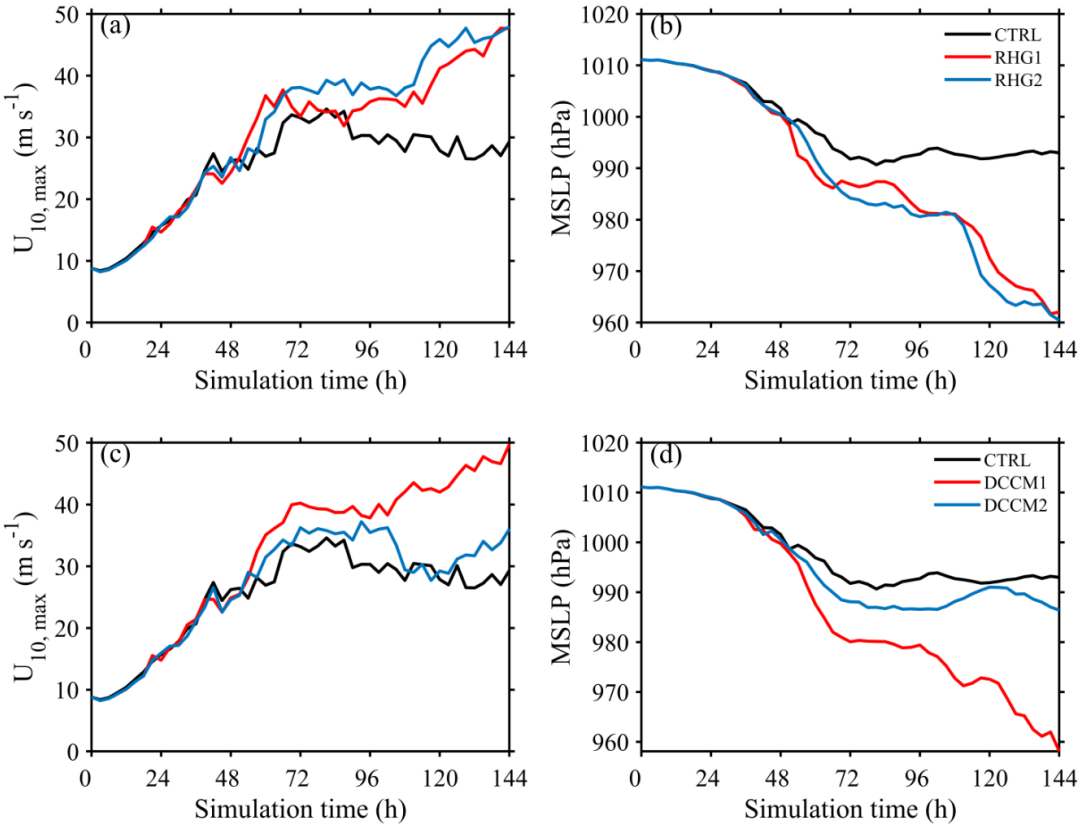
RHG: Reichl, B. G., Hara, T., & Ginis, I. (2014). Sea state dependence of the wind stress over the ocean under hurricane winds. Journal of Geophysica

DCCM: Donelan, M., Curcic, M., Chen, S. S., & Magnusson, A. (2012). Modeling waves and wind stress. Journal of Geophysical Research: Oceans, 1

Influence on cyclone simulation

RHG

DCCM



default WRF model

wave influence on wind stress magnitude

wave influence on stress magnitude and direction

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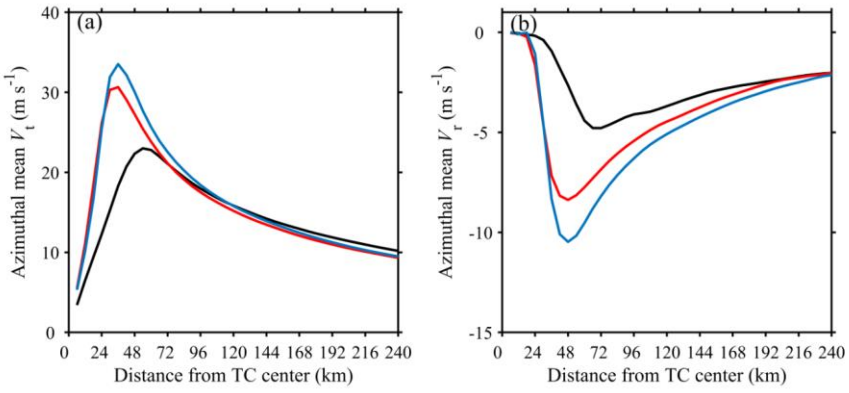
Influence on cyclone simulation

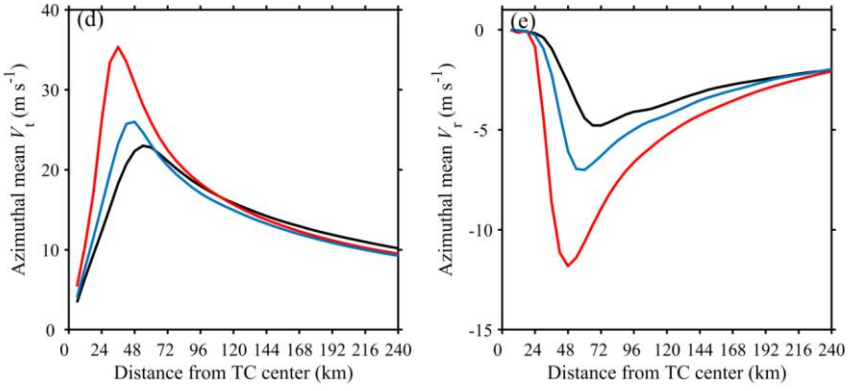
azimuthal tangential wind

Radial wind

RHG



DCCM



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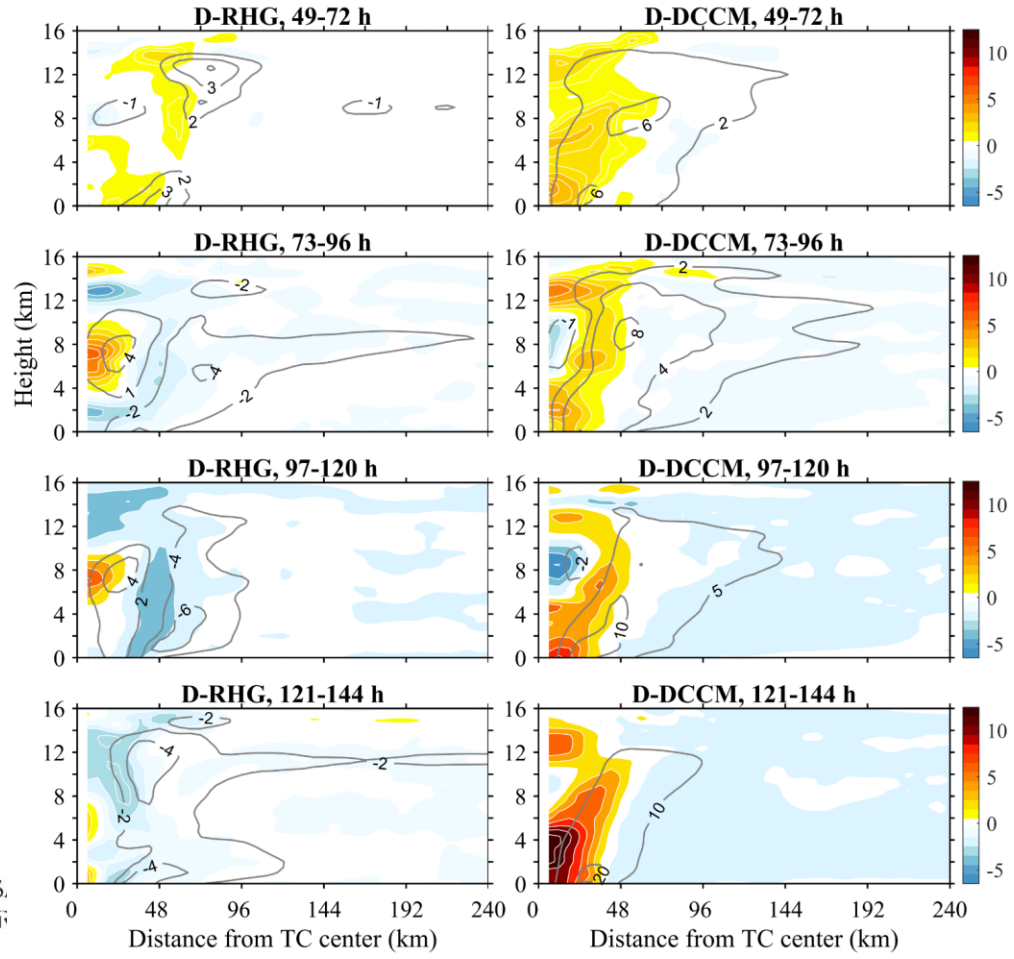
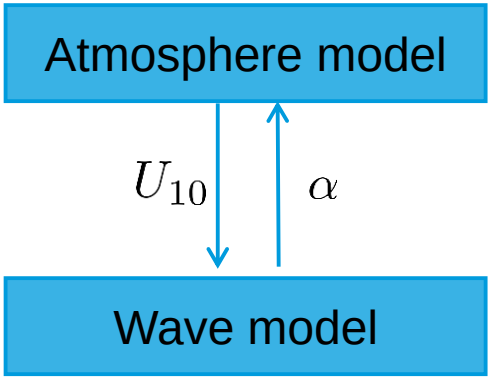


Wind stress direction influence on the potential vorticity

Can current fully coupled model capture those influence?



Some things that we need to keep in mind:

1) the wind stress calculated in the atmosphere considering the stability influence

$$C_d = \left[\frac{\kappa}{\ln(z/z_0) - \psi_m(z/L)}\right]^2 \qquad z_0 = \alpha\frac{u^{*2}}{g}$$

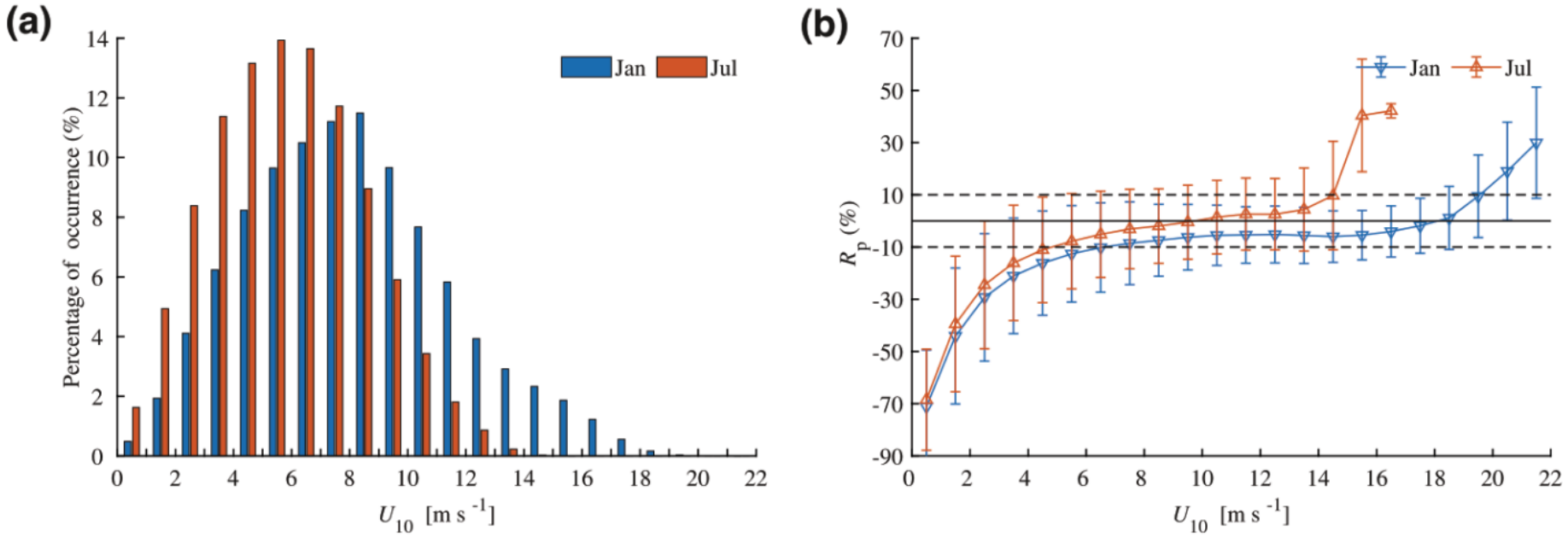
$$\alpha = \frac{\alpha'}{(1-\tau_w/\tau_a)^{1/2}}$$

2) wave model usually does not consider the stability influence on the stress

3) coupling time step is usually larger than 10min

Air-side stress estimated in atmospheric models may differ from that estimated in wave models

Can current fully coupled model capture those influence?



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Conclusions

- Waves play a redistribution role in the air-sea momentum flux, more significantly in the windy oceans in middle and high latitudes than that in the oceans in the tropics.
- The most significant difference between air- and water-side stress is under relative low winds and large wave age.
- Intensity of tropical cyclones is sensitivity to the stress direction.

Thanks for your attentions!

Questions and comments?