Simulating a Tropical Cyclone in Opposing Swell

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John M. Edwards[1]

Motivation

Numerical weather prediction systems are increasingly coupled, making more information on the sea state available to the atmospheric model. Current drag parametrizations are largely based on data for aligned waves in wind-sea conditions, but process models and observations suggest higher drag in opposing swell. Parametrizations that increase the aerodynamic roughness length in misaligned swell have been suggested (Patton *et al.,* 2019; Porchetta *et al.,* 2019; Sauvage *et al.,* 2023). In a coupled system, can information from a wave model be used to represent opposed swell more directly?

Parametrization

We divide the surface stress into an interfacial stress largely due to short waves and form drag due to longer faster waves around the spectral peak. Borrowing ideas from orographic drag parametrization, form drag is represented as an explicit momentum source in the surface layer. (N.B. In this initial test surface layer similarity theory has not yet been modified.) We expect that

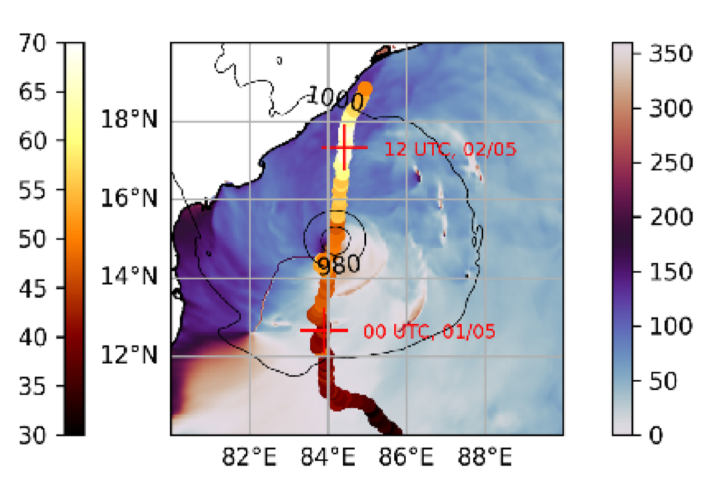
$$\boldsymbol{\tau}_F = -\rho_a C_{Di} A_F f(\nu)(H_s/L_p)^2 |\mathbf{U}-\mathbf{c_p}|(\mathbf{U}-\mathbf{c_p})$$

for some constant $A_F = O(100)$ taken from orographic modelling and a function, f, of the spectral width, ν; in this test, $A_F f(\nu)$ is set to 178, partly based on the comparisons below. Note the quadratic dependence on wave steepness. Wave direction, peak steepness and peak phase speed are passed from the wave model to the atmospheric model.

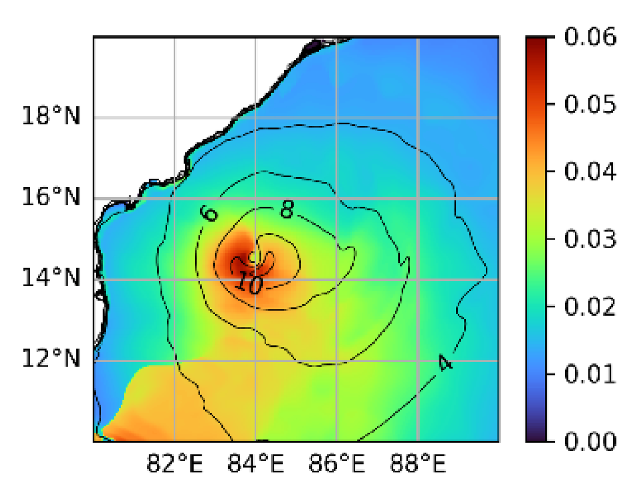
Tropical Cyclone Fani

Tropical cyclone Fani was an extremely severe cyclonic storm in the Bay of Bengal at the beginning of May 2019. We simulate it in a regional coupled atmosphere-wave modelling system (Castillo et al., 2022).

Plots show Fani 29 hours before landfall. To the right of the storm, waves are aligned with the wind. Opposing swell and the steepest waves occur to the left of the storm

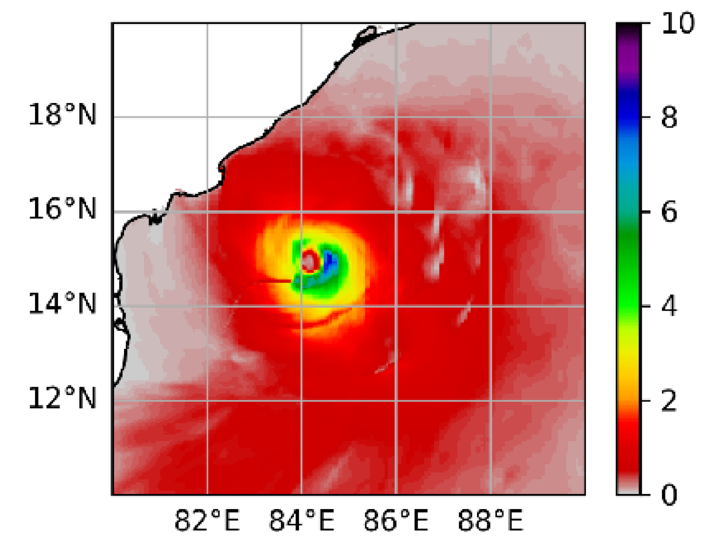


Misalignment (degrees, colour, right bar); PMSL (hPa, contours); track with maximum wind speed (ms^{-1}, left bar)

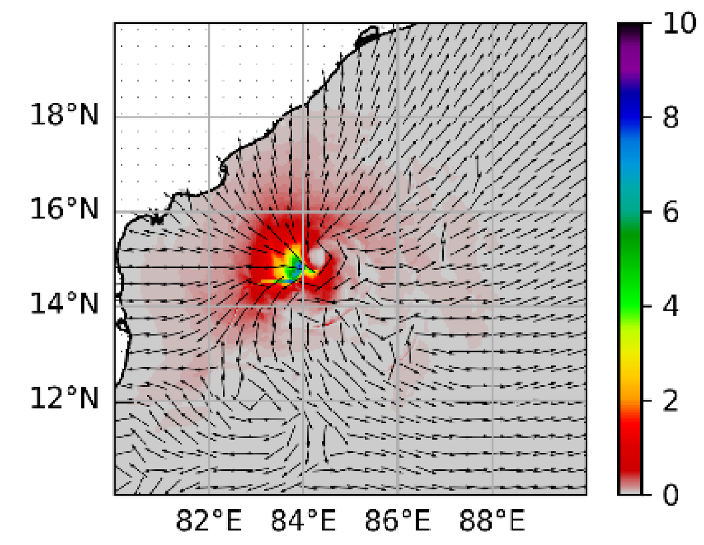


Steepness (colour) Sig. Wave Height (m, contours)

Form drag is largest in the region of steep opposing swell to the left and rear of the storm, where it is locally comparable to the interfacial drag.



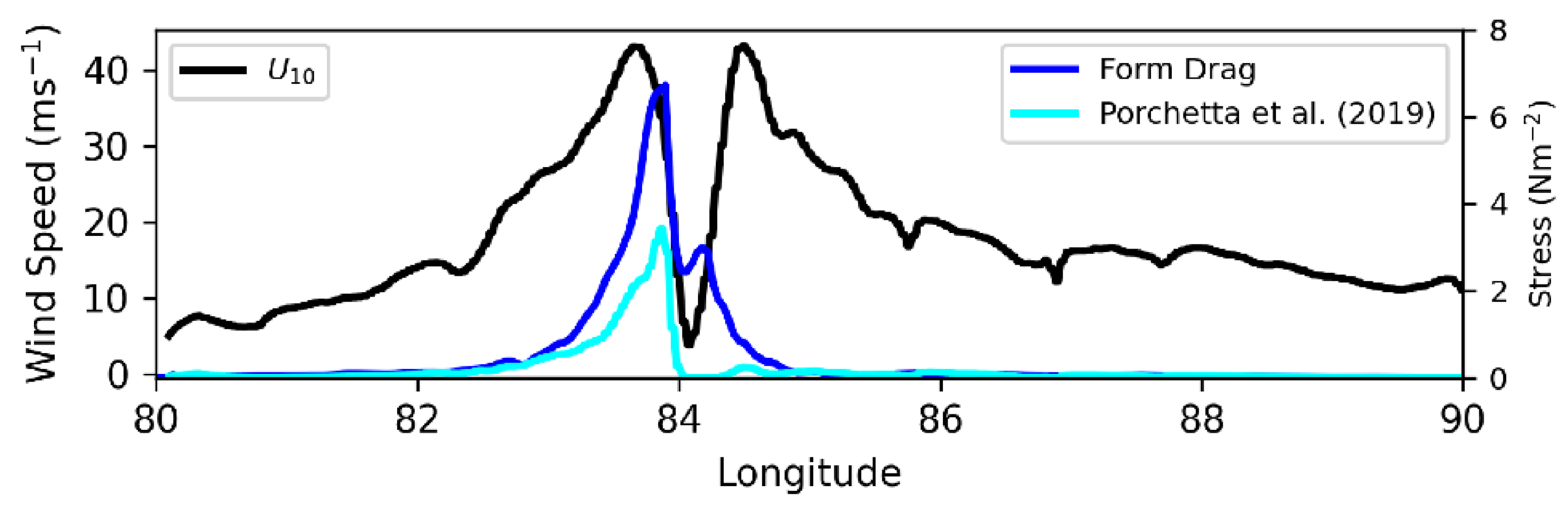
Interfacial Drag



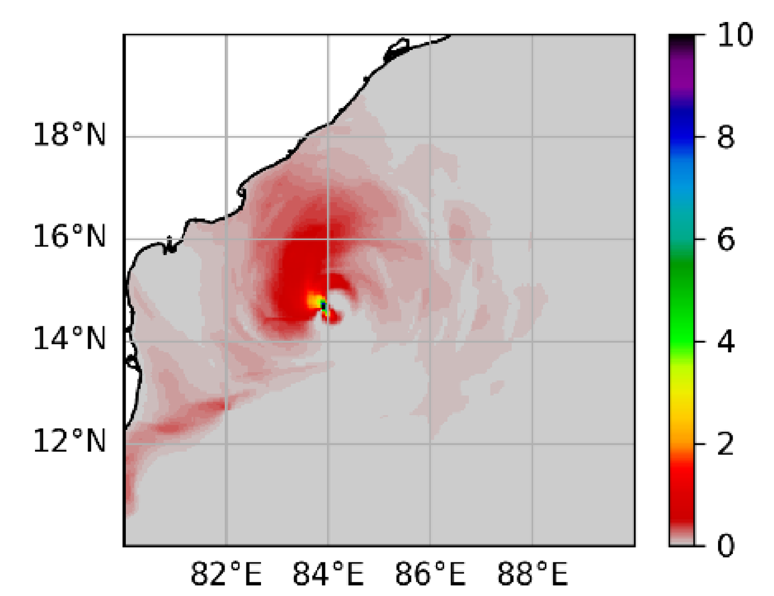
Wave Form Drag

Comparison with other schemes

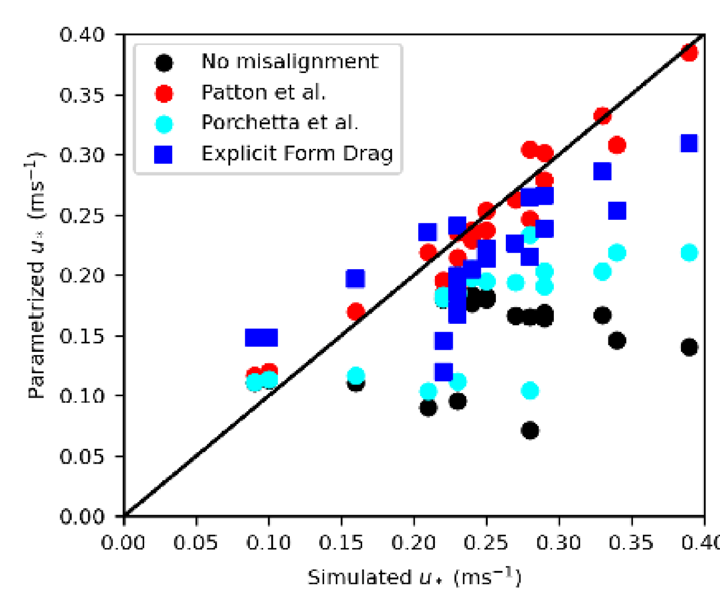
We compare the magnitude of the from drag with the enhancement of the drag predicted by Porchetta *et al.*'s scheme applied to these wind and wave fields, shown as an E-W cross-section just to the south of its centre and as a 2D image. A comparison can also be made with the large-eddy simulations of Patton *et al.*, where the lower boundary condition is a statistically generated wave field.



Cross section of misaligned stress form stress



Excess stress due to misalignment following Porchetta *et al.*



Comparison with LES results of Patton *et al.*

References

Castillo, J. M. *et al.* (2022), "The Regional Coupled Suite (RCS-IND1): application of a flexible regional coupled modelling framework to the Indian region at kilometre scale", Geosci. Model Dev., doi:10.5194/gmd-15-4193-2022

Patton, E. G. *et al.* (2019), "On the Influence of Swell Propagation Angle on Surface Drag", J. Appl. Meteorol. Climatol., doi:10.1175/JAMC-D-18-0211.1

Porchetta, S. *et al.* (2019), "A new roughness length parameterization accounting for wind–wave (mis)alignment", Atmos. Chem. Phys., doi:10.5194/acp-19-6681-2019

Sauvage, C. *et al.* (2023), "Improving Wave-Based Air-Sea Momentum Flux Parameterization in Mixed Seas", J. Geophys. Res., doi:10.1029/2022JC019277

[1]**Met Office** FitzRoy Road, Exeter, Devon, EX1 3PB United Kingdom
Tel: +44 (0)330 135 1264 Fax: +44 (0)330 135 0050
Email: john.m.edwards@metoffice.gov.uk