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Implementation of the wave boundary layer model in the OpenIFS model: Preliminary Results

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Motivation

It is well known that exchanges of momentum and heat between the air-sea interface in the atmosphere can significantly impact wind and waves. As a result, the parameterisation of the momentum fluxes (drag coefficient Cd, roughness length z0) in the coupled atmosphere-wave models affect the predictions of ocean waves. ECMWF's coupled model (OpenIFS) uses Janssen's theoretical approach[1] for calculating the momentum fluxes, based on the conservation of momentum in the Wave Boundary Layer (WBL). Even tought this approach has significantly improved the wind and wave predictions, it has some weaknesses; for example, the scheme highly depends on the logarithmic profile, while it does not consider sheltering effects. In this study, the WBL model, which has been recently used for calculating the wind input and dissipation source terms[2,3] is implemented in the OpenIFS model, in an attempt to improve the predictions in coupled mode.

Methodology

Implementation of WBLM source and dissipation functions in OpenIFS

Janssen (1991)

$$S_{in} = \beta_g N$$

$$\beta_g = \frac{\rho_\alpha}{\rho_w} C_\beta \omega \left(\frac{u_*}{c} \max(\cos(\theta-\varphi), 0)\right)^2$$

$$C_g = \frac{\beta max}{\kappa^2} \tan(kh)\, \mu ln^4(\mu)$$

$$\mu = \frac{g z_0}{c^2} \tanh(kh) e^x$$

$$x = \frac{\kappa}{\left(\frac{u_*}{c} + a\right)\cos(\theta - \varphi)}$$

$$z_0 = \frac{\widehat{a\tau}}{g} \frac{1}{\sqrt{1 - \tau_w/\tau}}$$

VS

WBLM (2017,2019)

$$S_{in} = \beta_g N$$

$$\beta_g = \frac{\rho_\alpha}{\rho_w} C_\beta \omega \left(\frac{u_*^l}{c} \max(\cos(\theta-\varphi), 0)\right)^2$$

$$C_g = \frac{\beta max}{\kappa^2} \mu ln^4(\mu)$$

$$\mu = \frac{g z}{c^2} \tanh(kh) e^x$$

$$x = \frac{\kappa}{\left(\frac{u_*^l}{c} + a\right)\cos(\theta - \varphi)} - \frac{\kappa u(z)}{u_*^l}$$

$$z_0 = \frac{z_{10}}{\exp(\kappa \frac{u_{10}}{u_*})}$$

Model Set up

❖ Resolution:
Atmospheric Part: TL255 (78km)
Wave model: 1 degree (111km)
Vertical Levels : 91

❖ Wave model configuration:
12 directions and 25 frequencies
$f_{min} = 0.041$ Hz and $f_{max} = 0.41$ Hz

Case Studies

❖ Storm Desmond 5-6/12/2015:
Strongest gust was 81mph[4]

Case study data

❖ Buoy 62095 – M6 West Coast (lat: 53.30, lon: -15.90)[5]
❖ Buoy 62081 – K2 Buoy (lat: 49.0 lon: -16.5)[5]

Location of buoys

1. Janssen, P. A. E. M. (1991). Quasi-linear Theory of Wind-Wave Generation Applied to Wave Forecasting. *Journal of Physical Oceanography*, *21*(11), 1631–1642
2. Du, J., Bolaños, R., & Guo Larsén, X. (2017). The use of a wave boundary layer model in SWAN. Journal of Geophysical Research: Oceans, 122(1), 42–62
3. Du, J., Bolaños, R., Guo Larsén, X., & Kelly, M. (2019). Wave boundary layer model in SWAN revisited. Ocean Sci, 15, 361–377
4. Storm Desmond, MetOffice official webpage, https://www.metoffice.gov.uk/weather/warnings-and-advice/uk-storm-centre/storm-desmond
5. Personally maintained database by Dr Jean Bidlot
Acknowledgments: The runs have been made on Supercomputing Wales https://www.supercomputing.wales/
SUPERCOMPUTING WALES UWCHGYFRIFIADURA CYMRU

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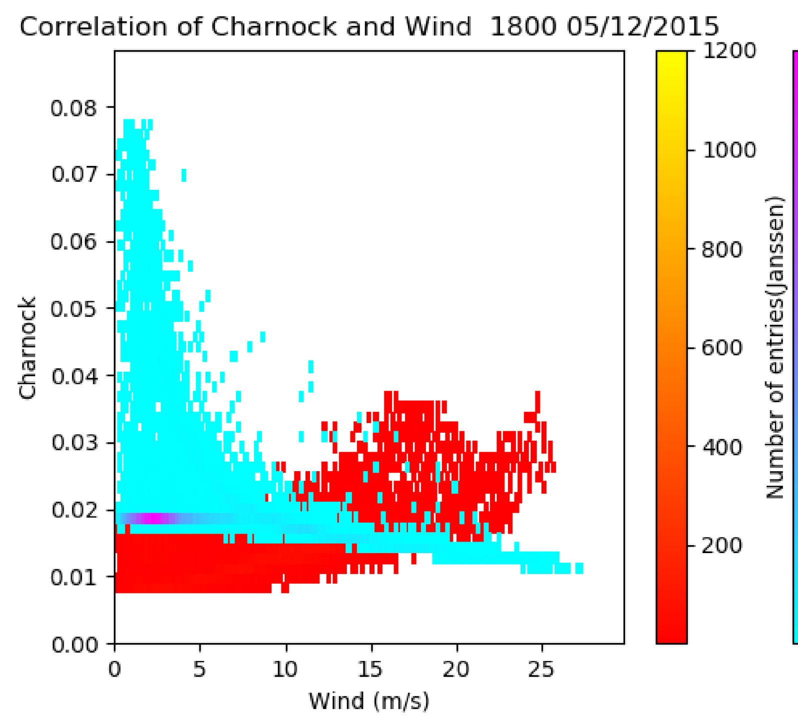
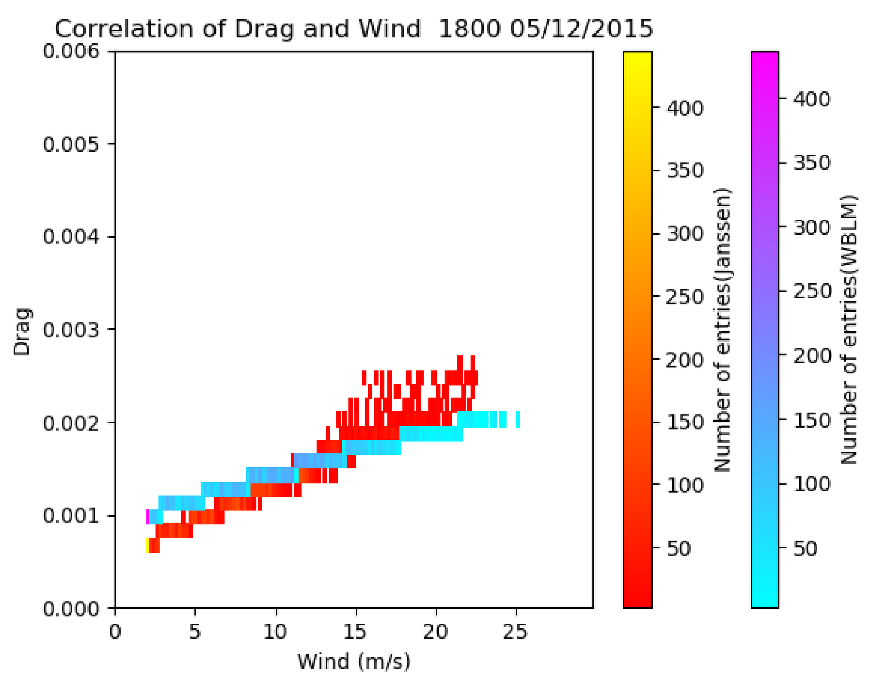
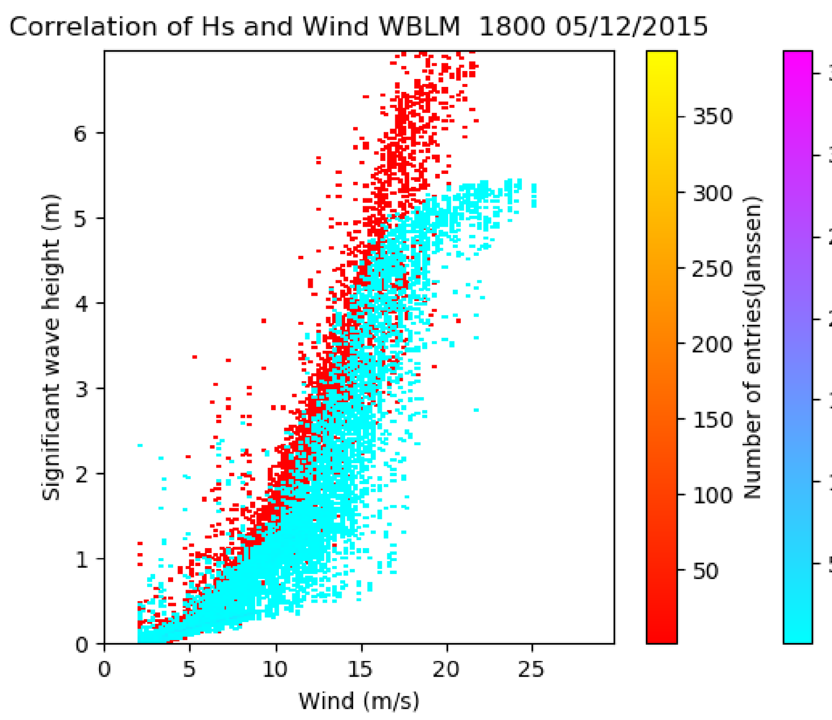
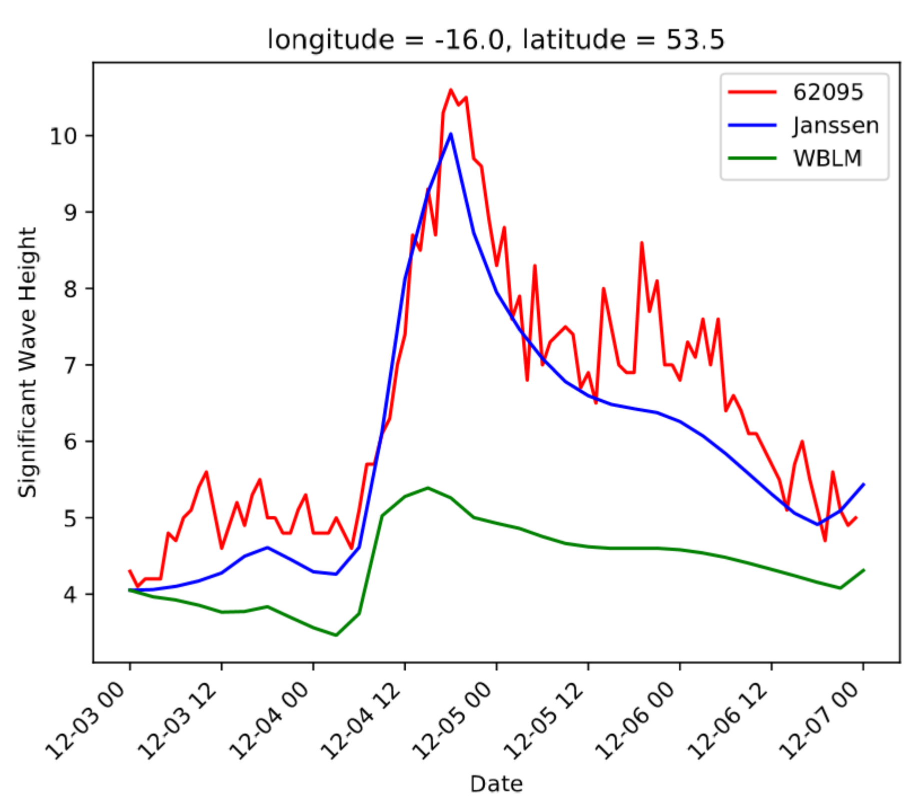
Results

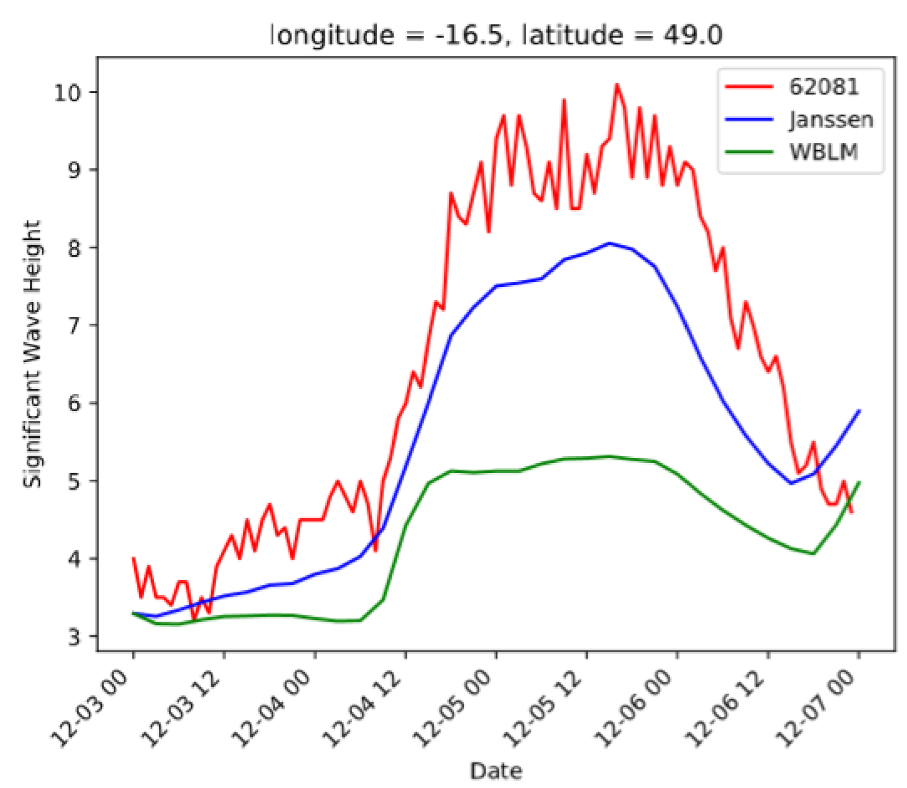






Figures show the comparisons between Charnock (left), Drag coefficient (middle) and significant wave height (Hs) (right) with wind speed at 10m, from WBLM and Janssen model. Whilst the Charnock for WBLM follows its bulk parameterisation, for high wind speeds, there are obvious inconsistencies; WBLM keeps the Charnock values lower than expected. With the same happening for drag coefficient, it leads to the significant wave height at high winds being significantly under-predicted as shown.





Preliminary results of Hs from WBLM at two stations in the open sea: Buoy 62095 (left) and Buoy 62081 (right) in comparison with those from Janssen Model. At both locations, the WBLM with its default parameters shows significant under-prediction, although trends of the time variations are reasonably similar to the observations, indicating that the modifications are required for WBLM.

Future work

1. Utilise higher resolution model and initial conditions for more severe storms, with 16km- atmospheric simulations and 28km - wave predictions on recent storms (e.g. Ciara 2020).
2. Identify parameters for adjustments and optimisations to examine underlying processes
3. Apply the WBLM to areas with extremely high winds and waves (i.e. typhoon affected areas)