Wave model simulation of the near-surface Stokes drift under shifting winds

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Operational tracking of oil spill and pollutants

For our operational users we provide an interactive tool (‘SeaTrackWeb’) for estimating the mean drift of small particles near the surface. The drift is a sum of the Stokes drift and the current. The Stokes drift is derived from a wave model (WAVEWATCH-III) and the surface layer current is simulated by means of a 3D hydrodynamic model. Forecasts are provided to the public at https://fcoo.dk/.

Stokes drift

For a harmonic wave of amplitude a, wavenumber k, and angular frequency ω on water at depth D, the Stokes drift depends on the depth z below the surface as

$$U_S = c(ak)^2 \frac{\cosh(2k(D-z))}{2\sinh^2(kD)} + O((ak)^6) \quad (1)$$

where c = ω/k is the phase speed. In the high-frequency range we will assume the waves are free harmonics represented by wave components in a 2D wave spectrum (Peureux et al. [2018]). We further assume that the mean Stokes drift can be derived as an integral over a spectral version of Eq. 1 (Kenyon [1969]) because of only ‘weak’ non-linear interactions between spectral components.

The output of a (2D) frequency spectrum of Stokes drift at the surface (z = 0) has been implemented in WAVEWATCH-III (’WW3’) since its version 4.18, and instructions on how to derive a vertical profile for z > 0 is given in the WW3 User manual (Tolman et al. [2014-2023]).

Implementation in the wave model

Output from WW3 is provided to netcdf data format at a number of levels with progressively increasing intervals below the surface. The number of depths and interval progression is controlled in a Fortran namelist ‘STVP’. The figure to the right shows an example of such output, here for NDP = 22 depths. The user may find a number of NDP = 7 or NDP = 11 sufficient.

Under an oil slick a resonance-type Marangoni damping is likely to occur (Benetazzo et al. [2019]). We infer from their presented observations that this may be represented roughly as a truncation of the spectrum at frequencies above 2.0 Hz.

We apply the ‘ST4-Romero’ forcing terms in WW3 (Romero [2019]).

Optional parametric spectral tail above e.g. 1 Hz

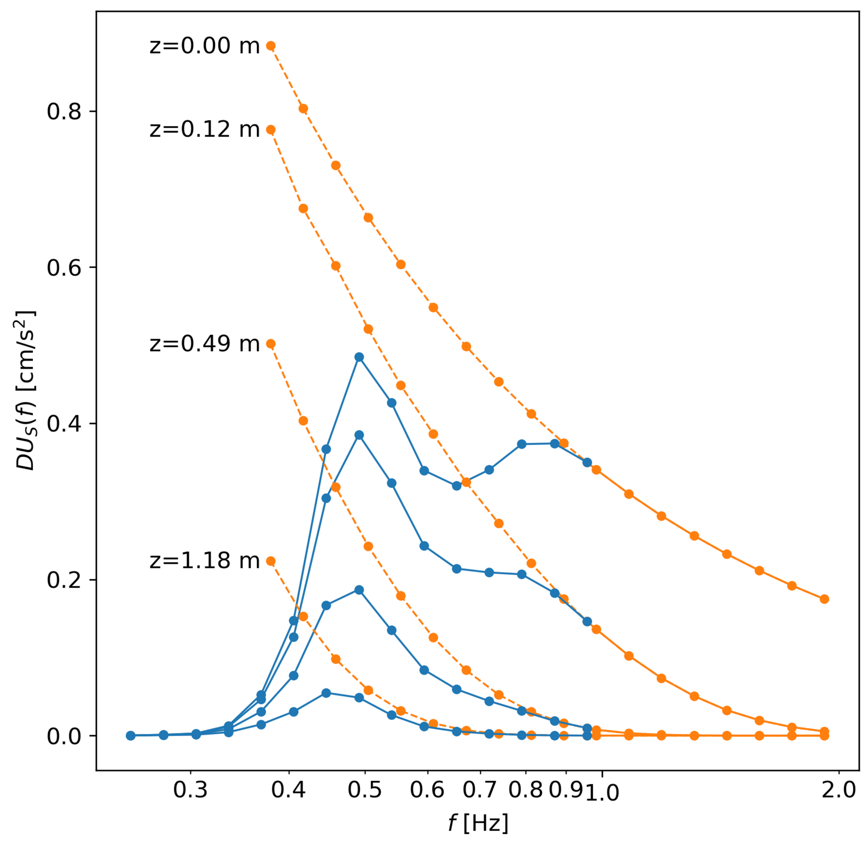
To reduce the computation time we have applied a parametric spectral tail at the high frequencies with a shape of $S(\omega) \sim \omega^{-5}$.

It is realistic to assume that at values of ω/ω_P in the range 2 to 4 there exist a transition to a spectrum of saturated form of Phillips [1958], going asymptotically as $S(\omega) \sim \omega^{-5}$ (Lenain and Pizzo [2020]). An asymptotic behaviour like this may be reproduced by ST4-Romero or the ‘ST6’ source terms as well after proper configuration (Liu et al., 2019). It may be realistic to assume that this transition occurs at frequencies below 1 Hz (except for a light breeze or a very short fetch).

The three figures to the right show the difference between a simulation with the prognostic range extending to 2 Hz, and a simulation with a tail added beyond a highest model bin at 1 Hz.

A pre-calculated look-up table in 2d (frequency and depths) is applied after linear scaling and interpolation.

The figure here shows an example of the match to the highest prognostic bin centered at 0.97 Hz. Each orange dot represents a value in the look-up table.



Technical details

This work is implemented as an extension to WW3 in a local feature branch fb_stvp under https://github.com/CarstenHansen/WW3

It is activated in each grid of the model by a WW3 ‘switch’ ‘STVP’, and Fortran namelists fcoo/inp/BAL3/setup/namelists.nml. The namelist to construct output at e.g. 11 depth levels is:

&STVP NDP = 11, DSC = 2.0, BP = 2.0 /

The extended tail shape and its high-frequency cut-off are set with:

&XSTP USXTT = "Pf-5", USXFM = 2.0 /

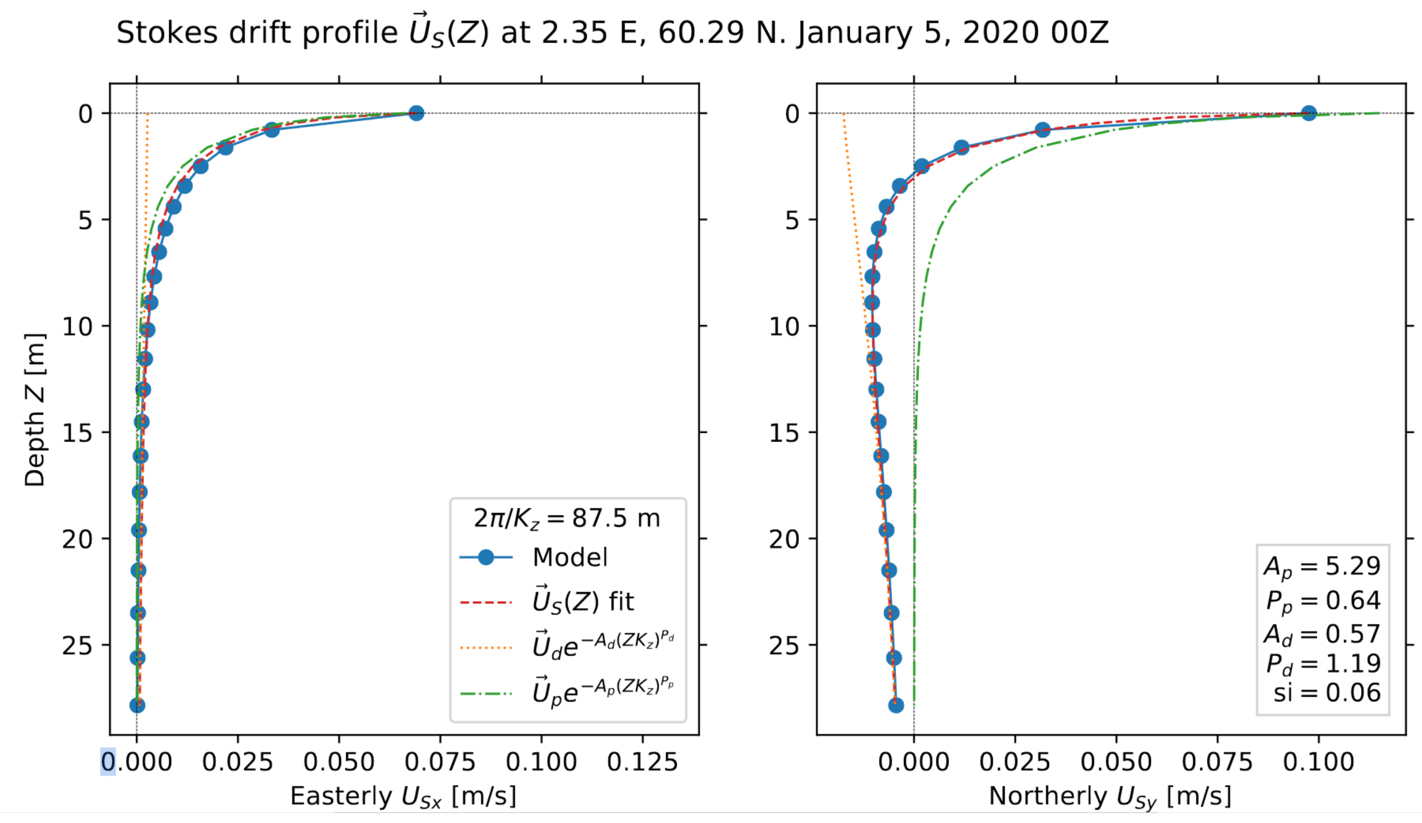
The highest prognostic bin (e.g. 1 Hz or 2 Hz) is set in ww3_grid.nml.

The Romero [2019] dissipation is configured with switch ‘ST4’. In the namelist &SDS4, the high frequency cut-off values of FXFM3, FXPM3 are enhanced:

&SDS4 SDSBCHOICE=3, SDSC2 = -3.8, SDSBR = 0.005, SDSSTRAIN =0., SDSSTRAIN2 = 0., FXFM3 = 40., FXPM3 = 20., SDSFACMTF = 400., SDSCUM=0., SDSC5 =0. /

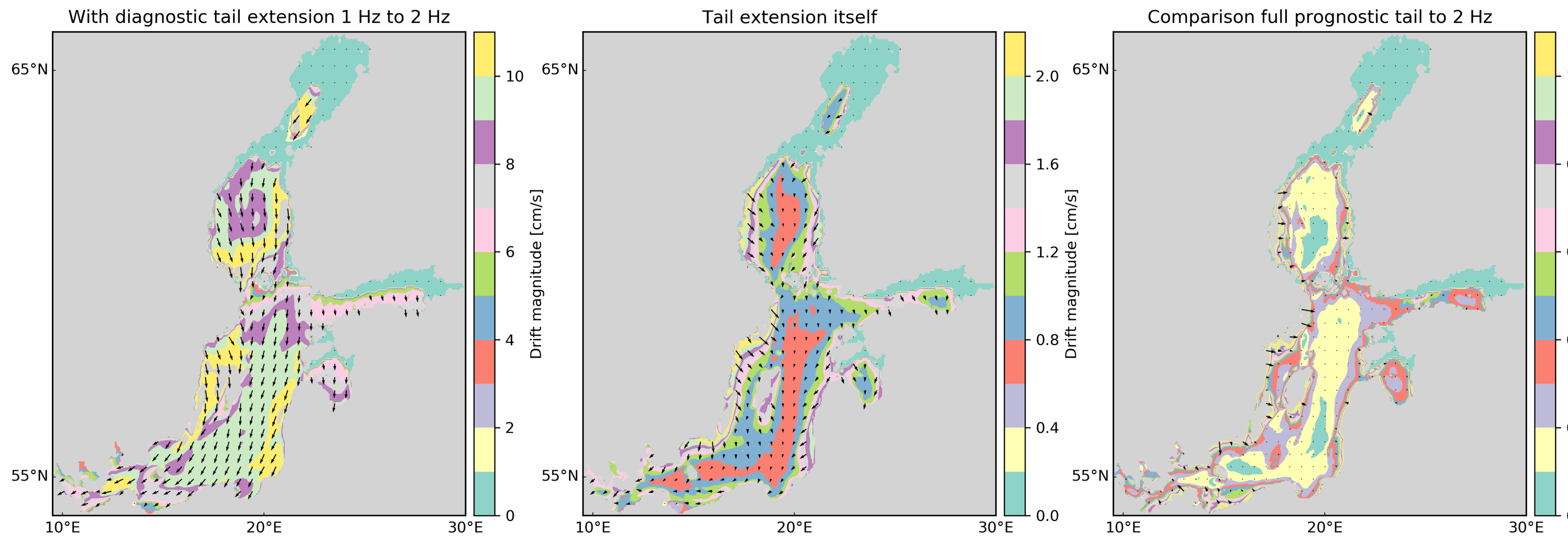
Example model output

The figure shows a modeled-derived Stokes drift profile for a characteristic situation in the northern North Sea with a transverse swell from the Atlantic. The fitted lines are a parametric representation for subsequent application in a particle tracking tool (‘SeaTrackWeb’, J. Mattsson, pers.comm.)



Example comparison with and without a parametric tail

A model run with full prognostic range to 2 Hz is compared to a model run with a diagnostic tail added beyond 1 Hz. The simulation for the Baltic Sea is run on 2021 -02-04 with light ice cover in the northern parts.



References

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Parts of this work has been presented in Carsten Hansen (2021): https://presentations.copernicus.org/EGU21/EGU21-9520_presentation.pdf