Technical University of Denmark



Impact of the interfaces for wind and wave modeling - interpretation using COAWST, SAR and point measurements

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Impact of interfaces for wind and wave modeling

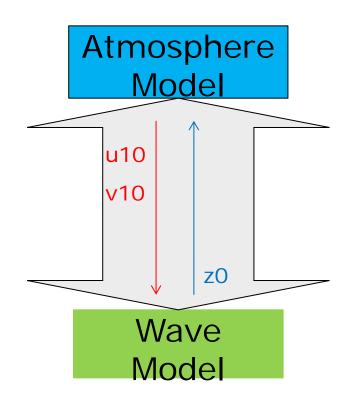
via coupled atmospheric & ocean wave models, with SAR and mast measurements

Presenter: Xiaoli Guo Larsén xgal@dtu.dk

With contributions from Jianting Du (first author) Rodolfo Bolaños Merete Badger Søren Larsen Mark Kelly



Focal point



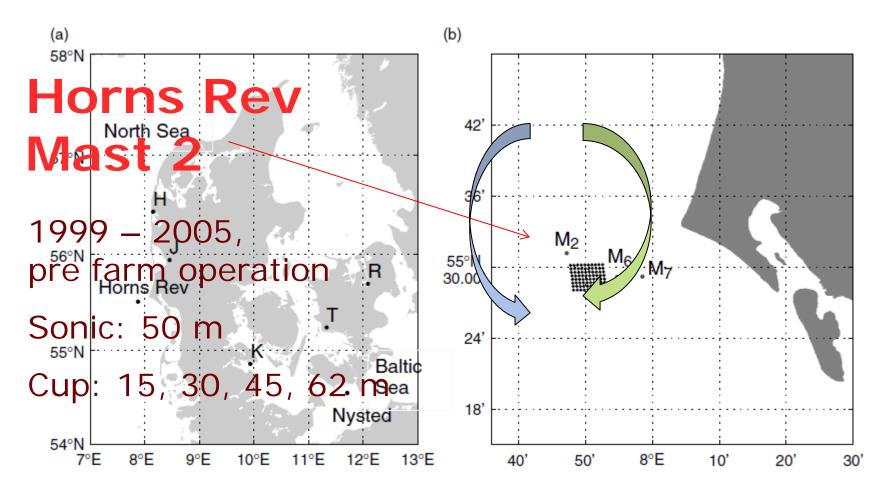


Method

- 1. Measurements
- 2. Development of the Wave Boundary Layer Model (WBLM)
- 3. Results of application of WBLM

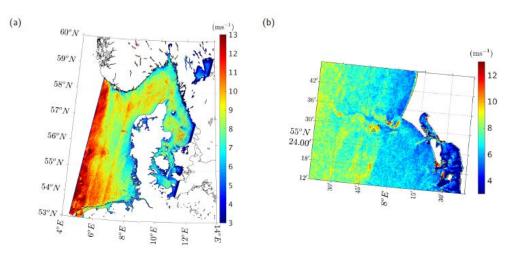


Measurements: from mast & buoy

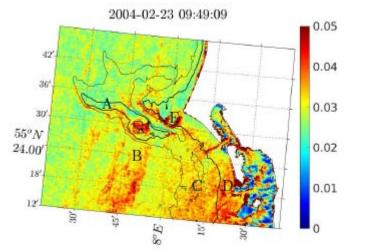




Measurements: ENVISAT Synthetic Aperture Radar



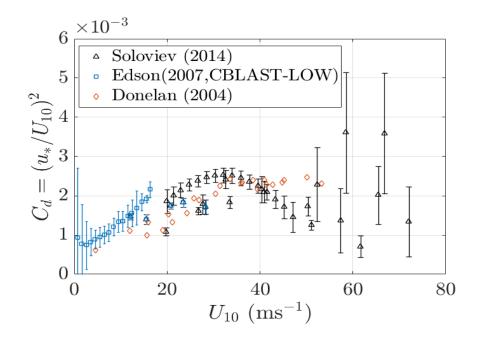
SAR 10 m "wind speed"



Radar backscatter measured by ASAR



Measurements: from literature



Soloviev (2014): A collection of measurements from Powell (2003), Black (2007, CBLAST-Hurricane), Bell (2012), Jarosz (2007), Holthuijsen (2012)

Edson (2007): CBLAST-LOW

Donelan (2004): Laboratory measurements in a wave tank (15m long x 1m wide x 1m high)

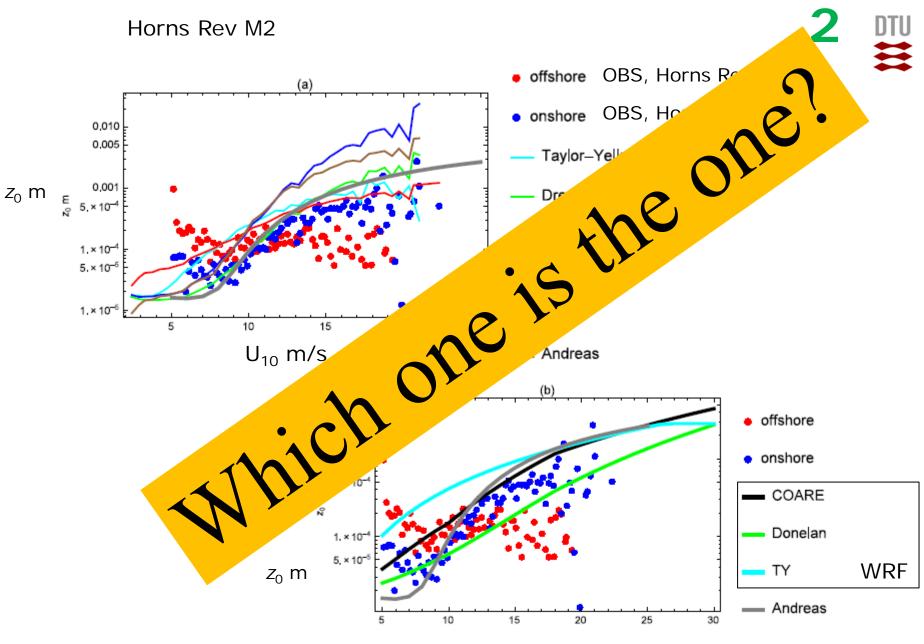
Motivation (1)





Motivation (2)

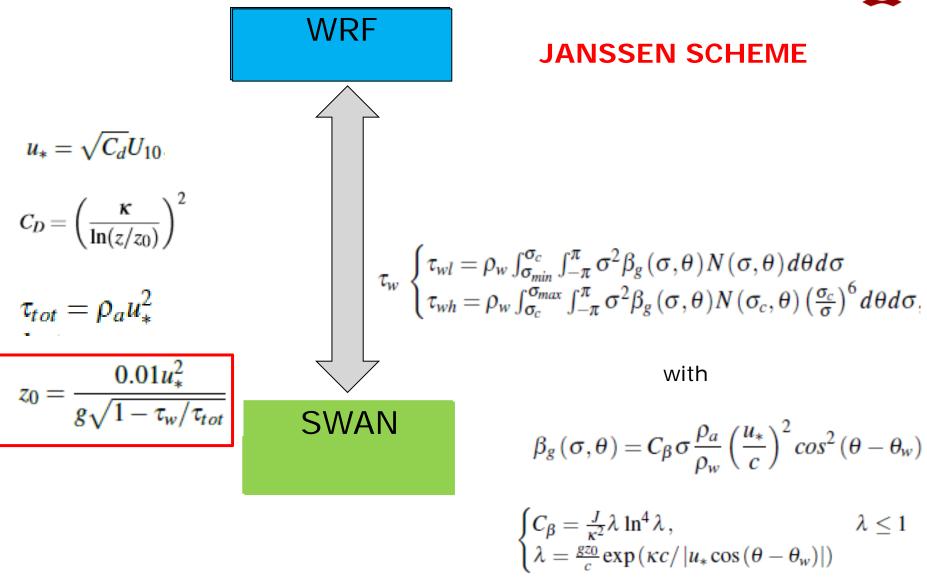
Schemes	
Charnock	$z_0 = \alpha u_*^2/g$
Drennan et al	$z_0 = 3.35 H_s (u_*/c$
Fan et al.	$z_0 = \alpha u_*^2 / g + 0.11 \nu \qquad \qquad$
Liu et al.	for $0.35 < c$ $*)^{3/2})^{1-1/\omega}(0.03c_p/u_* \exp(-0.14c_p/u_*))^{1/\omega}$ $\alpha = 17.61^{1-1/\omega}0.008^{1/\omega}$ where $\omega = \min(1, a_{cr}/(\kappa u_*))$, with $a_{cr} = 0.64$ ms ⁻
Oost et a'	$z_0 = \frac{50}{2\pi} L_v (\frac{u_*}{c_p})^{4.5} + 0.11\nu/u_*$
SWA	$z_0 = z \exp\left(-u_*/U_{10}\right)$ $u_* = 0.239 + 0.0433 \left((U_{10} - 8.271) + \sqrt{0.12(U_{10} - 8.271)^2 + 0.181} \right)$
Taylor-Yelland	$z_0 = 1200 H_s (H_s/L_p)^{4.5}$



U₁₀ m/s

Motivation (3)







 \rightarrow

The Wave Boundary Layer Model

Conservation of momentum :

$$\vec{\tau}_{tot}(z) = \begin{bmatrix} \vec{\tau}_t(z) \end{bmatrix} + \vec{\tau}_w(z) = constant \qquad \vec{\tau}_w(z) = \rho_w \int_{\sigma_{min}}^{\sigma_z} \int_{-\pi}^{\pi} \beta_g(\sigma, \theta) \, \sigma^2 N(\sigma, \theta) \, \frac{k}{k} d\theta d\sigma$$

$$\beta_g(\sigma, \theta) = C_\beta \sigma \frac{\rho_a}{\rho_w} \begin{pmatrix} u_*^l \\ c \end{pmatrix}^2 \cos^2(\theta - \theta_w) \qquad \text{--Wave growth is proportional to the local turbulent stress}$$

Conservation of kinetic energy:

$$\frac{d}{dz}\left(\vec{u}\cdot\vec{\tau}_{tot}\right) + \frac{d\Pi}{dz} + \frac{d\Pi'}{dz} - \rho_a\varepsilon = 0$$

Wave-induced energy flux

$$\Pi(z) = \int_{\sigma_{min}}^{\sigma} \tilde{F}_w(\sigma) \, d\sigma \qquad \tilde{F}_w(\sigma) = \rho_w \int_{-\pi}^{\pi} \beta_g(\sigma, \theta) \, g\sigma N(\sigma, \theta) \, d\theta$$
$$\frac{d\vec{u}}{dz} = \left[\frac{\delta}{z^2} \tilde{F}_w\left(\sigma = \sqrt{g\delta/z}\right) + \frac{\rho_a}{\kappa z} \left|\frac{\vec{\tau}_t(z)}{\rho_a}\right|^{\frac{3}{2}}\right] \times \frac{\vec{\tau}_t(z)}{\vec{\tau}_t(z) \cdot \vec{\tau}_{tot}} \qquad \text{-Wind profile in the wave boundary layer}$$



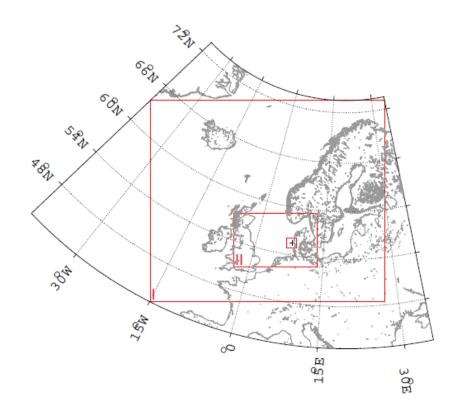
WRF Momentum conservation Kinetic Energy conservation 10m 10 τ_t Atmosphere 100 10⁰ $\tau_{tot} = \tau_t + \tau_w$ WBL $u_{10} = 10 ms^{-1}$ height $u_{10} = 10 \ ms^{-1}$ 10 ⁻¹ 10 -1 $Height\left(m\right)$ Height(m)10 ⁻² 10 ⁻² Equivalent z₀ ~ ~ / 10 ⁻³ 10 -3 Wind profile Logarithm profile VBL 10 -4 10 -4 WBL height $(2.1 \times 10^{-1}m)$ O **Ocean Wave** VBL height $(5.8 \times 10^{-5}m)$ height Equivalent z_0 (1.8 × 10⁻⁴m) 10 ⁻⁵ 10 0 0.05 0.1 0.15 0.2 0 10 5 b) a) $Stress(Nm^{-2})$ $u \ (ms^{-1})$

Du, J., Bolaños, R., and Larsén, X. (2017a). The use of a wave boundary layer model in SWAN. Journal of Geophysical Research: Oceans, pages 1063–1084.

SWAN

DTU

Model setup



Two-way online Nested 9-3-0.6km 30 hours for each run

WRF:

CFSR+OISST 77 vertical sigma levels MYNN 3.0 PBL scheme RRTM long and short wave radiation Kain-Fritsch cumulus scheme (domain I) Corine land use

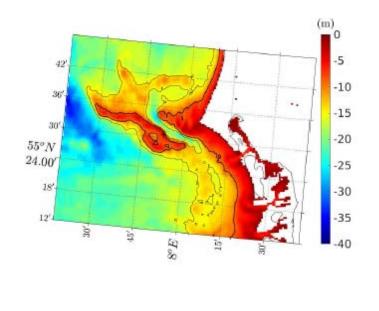
SWAN:

1/8 arc-minute bathymetry data
Initiated 24h before the simulation
Close boundary for open sea
36 directional bins.
0.03 Hz < f < 10.05 Hz (KOM and WBLM)
0.03 Hz < f < 0.57 Hz (JANS)

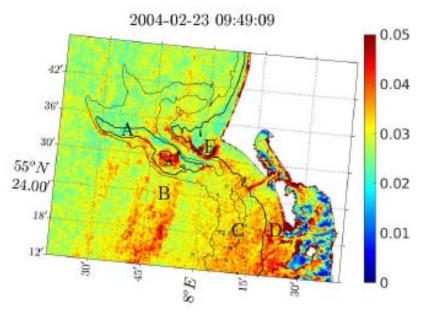


Cases are chosen to emphasize the conditions: storm and/or coastal

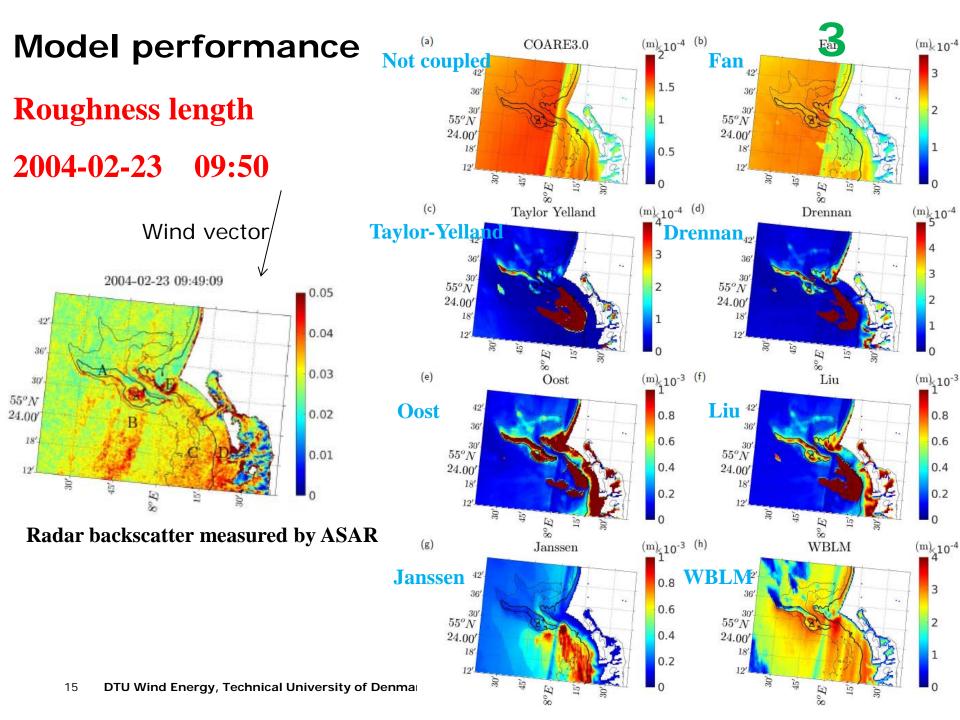
Example case 1: 2004-02-22 – 2004-02-24 (coastal, moderate to strong wind)



bathymetry

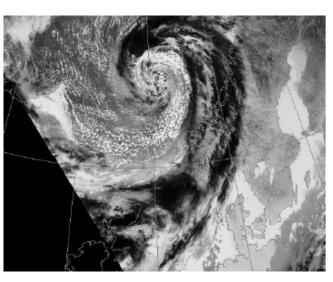


Radar backscatter measured by ASAR

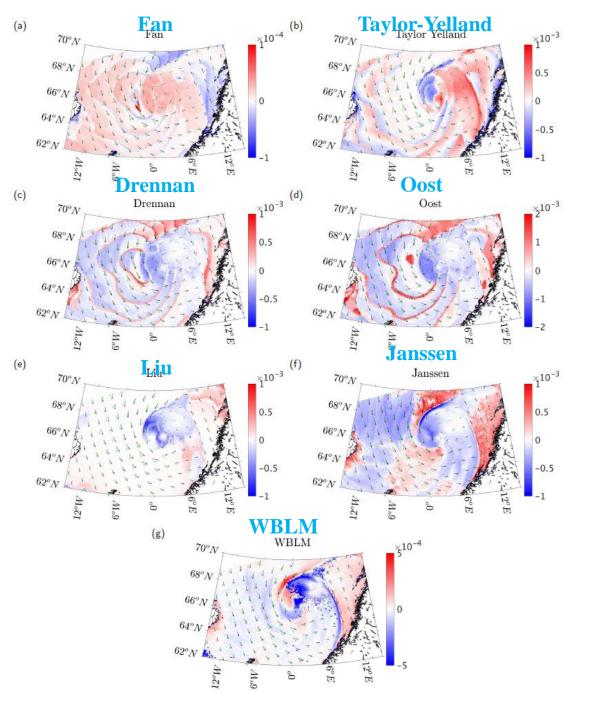


Drag coefficient difference:

coupled - uncoupled

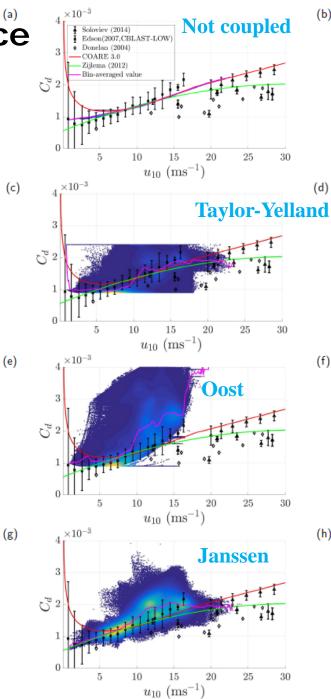


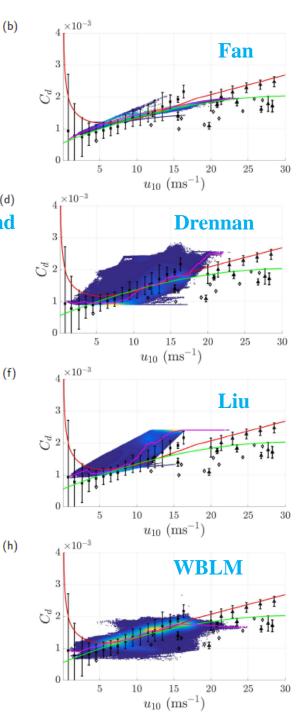
20:45, 2004-02-23



Drag coefficient vs. U₁₀

Whole domain III, entire period





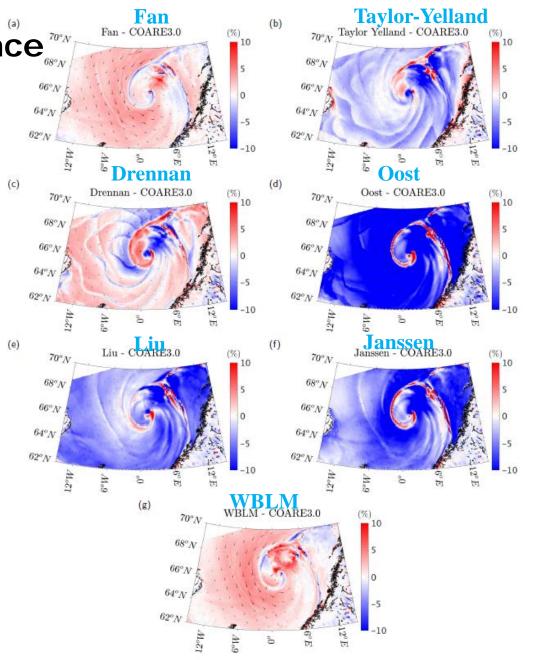
(d)

(f)

 $\Delta U_{10}/U_{10}$ (%)

Between coupled and not-coupled

20:45, 2004-02-23



18 DTU Wind Energy, Technical Univ, Figure 8.13: Percentage of deviation in U₁₀ between the coupled and non-coupled modeling at the same 2017 time as Figure 8.12.)

Discussion and summary

- Coastal wind-wave relations are more complicated than for open sea conditions
- Existing modeling approaches are of limited use during storm conditions
- Tests of z0 -parameterizations to couple atmospheric models and wave models are inconclusive
- A Wave Boundary Layer Model (WBLM) is implemented in SWAN, using conservations of momentum and turbulence kinetic energy to be coupled to WRF
- WBLM outperforms the other schemes in coastal and stormy conditions



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- Project: Danish PSO 12020 X-WiWa
- Project: EU CEASELESS

- Horns Rev data from DONG Energy
- SAR data from European Space Agency
- Open source WRF, SWAN, COAWST