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

Larsén, Xiaoli Guo; Du, Jianting; Bolanos, Rodolfo; Badger, Merete; Larsen, Søren Ejling; Kelly, Mark C.

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

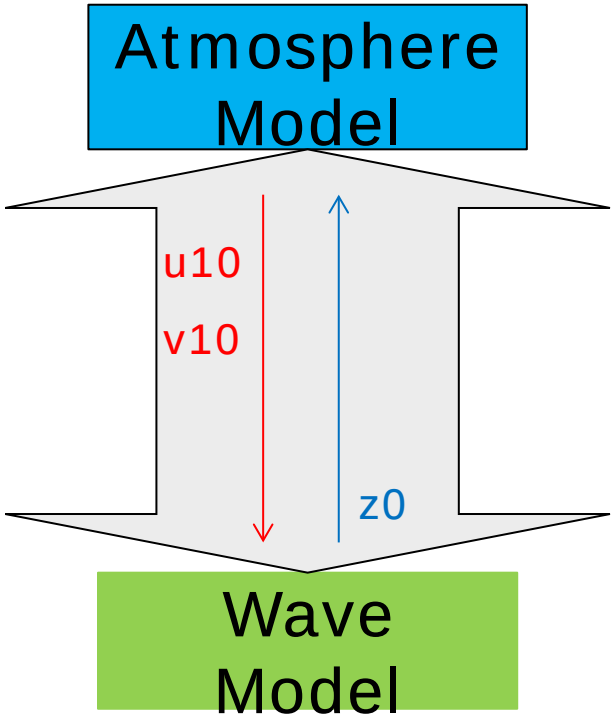
Impact of interfaces for wind and wave modeling

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



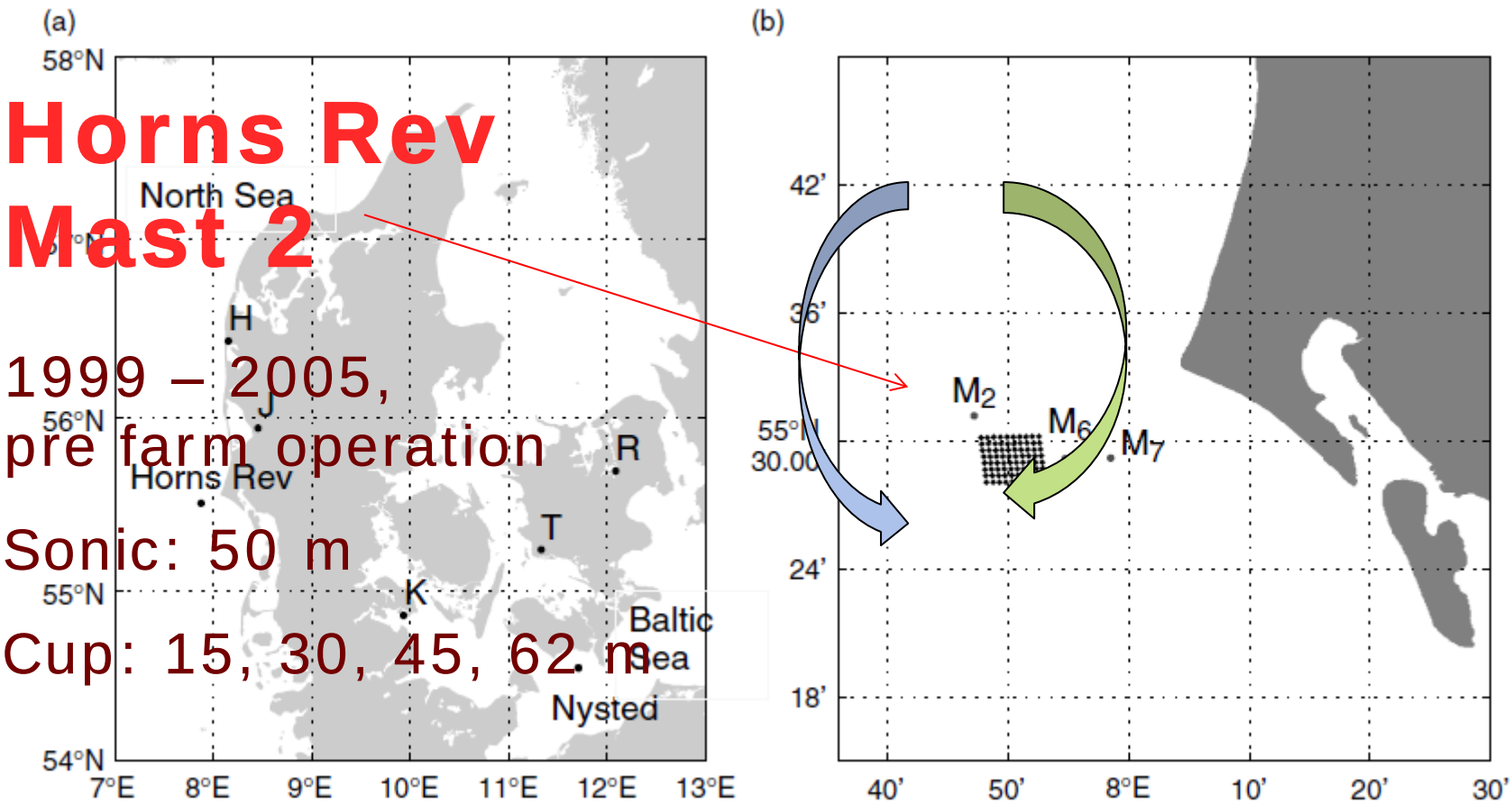
Method

1. Measurements

2. Development of the Wave Boundary Layer Model (WBLM)

3. Results of application of WBLM

Measurements: from mast & buoy



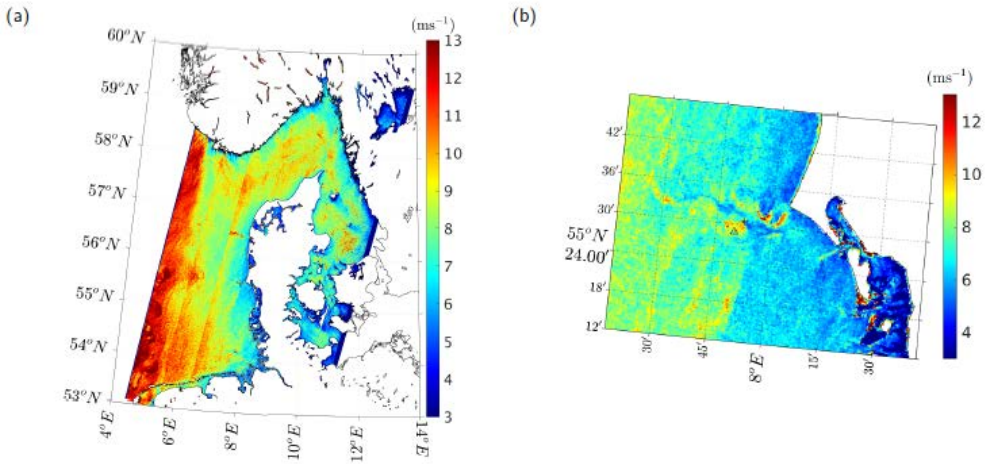
Horns Rev
Mast 2

1999 – 2005,
pre farm operation

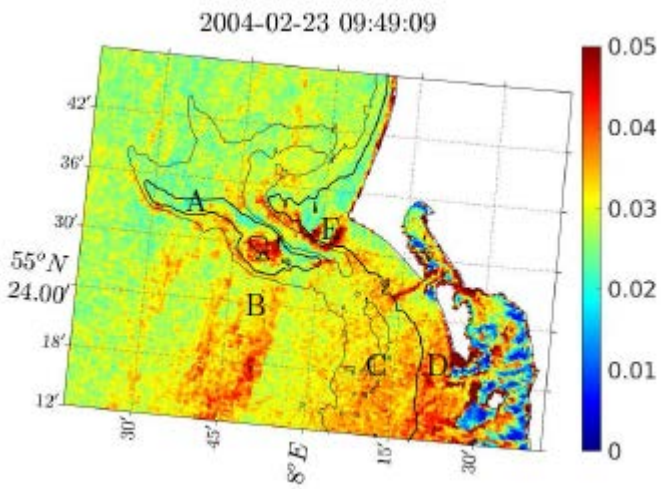
Sonic: 50 m

Cup: 15, 30, 45, 62 m

Measurements: ENVISAT Synthetic Aperture Radar

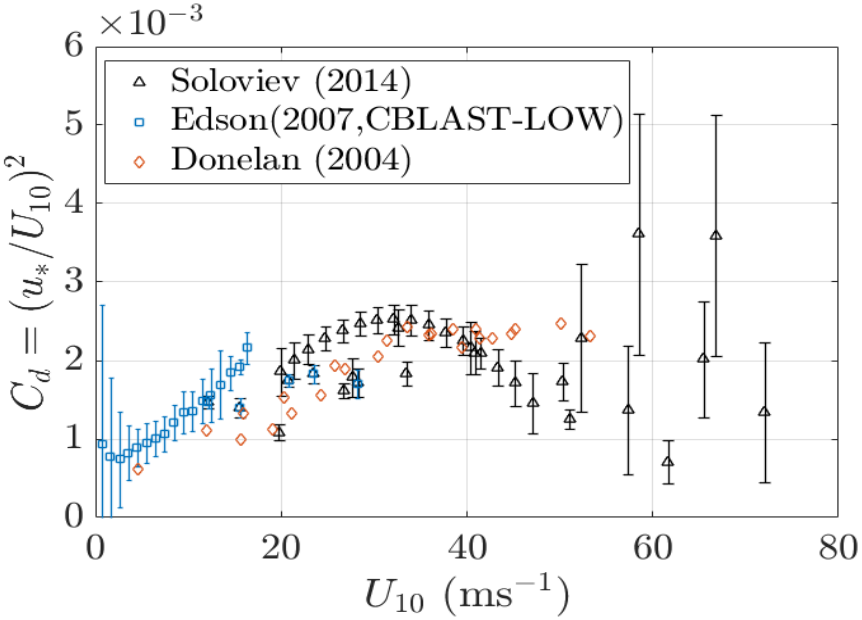


SAR 10 m “wind speed”



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)

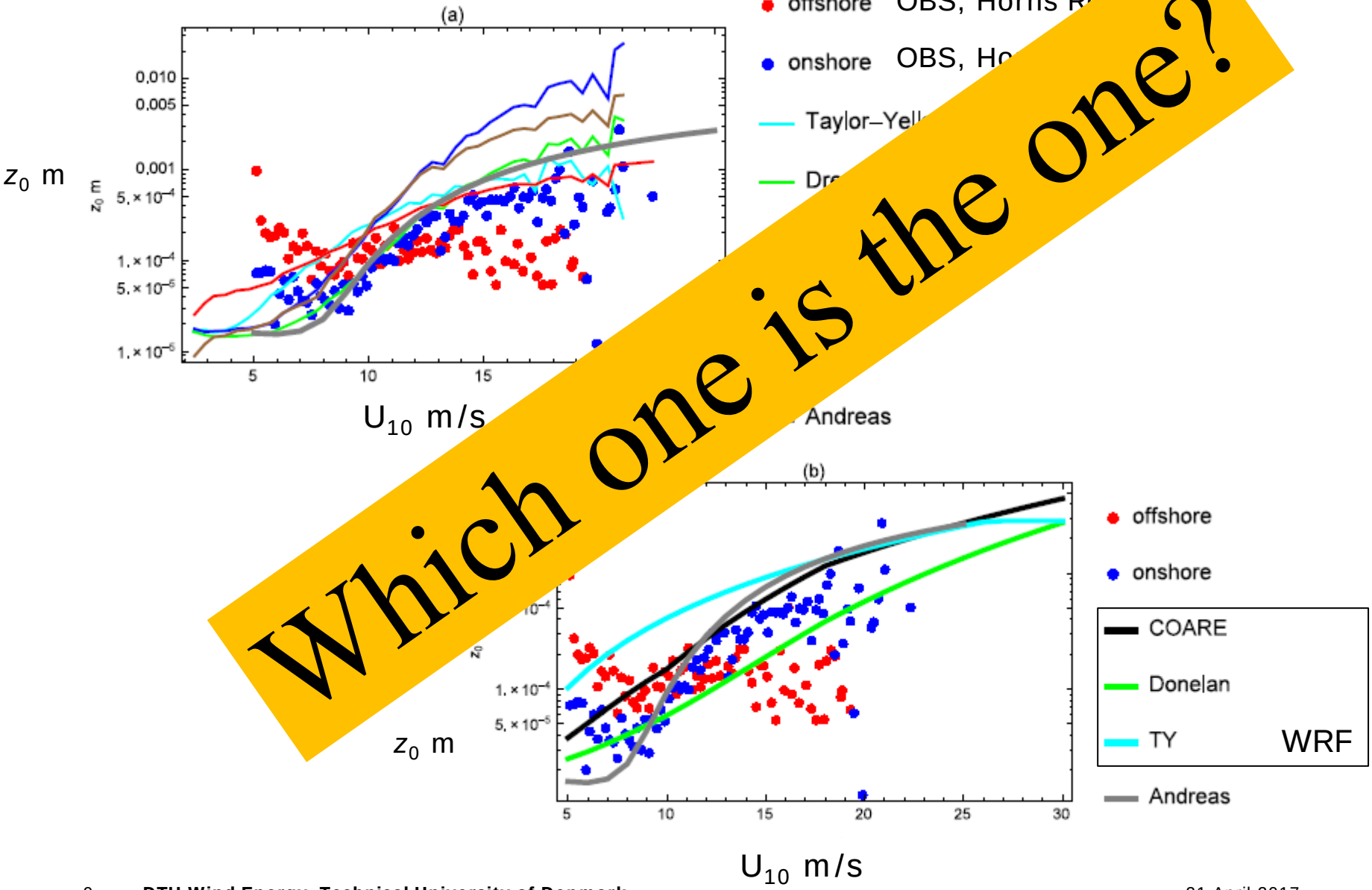
DTU

Schemes	z_0
Charnock	$z_0 = \alpha u_*^2/g$
Drennan et al	$z_0 = 3.35H_s(u_*/c$
Fan et al.	$z_0 = \alpha u_*^2/g + 0.11\nu$ $)^{-b}$ $a = \frac{0.023}{1.0568^{U_{10}}}$ $b = 0.012U_{10}$
Liu et al.	for $0.35 <$ $)^{3/2})^{1-1/\omega}(0.03c_p/u_* \exp(-0.14c_p/u_*))^{1/\omega}$ $\alpha = 17.61^{1-1/\omega}0.008^{1/\omega}$ where $\omega = \min(1, a_{cr}/(\kappa u_*))$, with a_{cr} =0.64 ms^{-1}
Oost et al	$z_0 = \frac{50}{2\pi}L_v(\frac{u_*}{c_p})^{4.5} + 0.11\nu/u_*$
SWA	$z_0 = z\exp(-u_*/U_{10})$ $u_* = 0.239+0.0433\left((U_{10}-8.271)+\sqrt{0.12(U_{10}-8.271)^2+0.181}\right)$
Taylor-Yelland	$z_0 = 1200H_s(H_s/L_p)^{4.5}$

TOO MANY OPTIONS!

Horns Rev M2

2



Which one is the one?

Motivation (3)

2

WRF

JANSSEN SCHEME

$$u_* = \sqrt{C_d} U_{10}$$

$$C_D = \left(\frac{\kappa}{\ln(z/z_0)}\right)^2$$

$$\tau_{tot} = \rho_a u_*^2$$

$$z_0 = \frac{0.01 u_*^2}{g\sqrt{1 - \tau_w/\tau_{tot}}}$$

SWAN

$$\tau_w \begin{cases} \tau_{wl} = \rho_w \int_{\sigma_{min}}^{\sigma_c} \int_{-\pi}^{\pi} \sigma^2 \beta_g(\sigma,\theta) N(\sigma,\theta) d\theta d\sigma \\ \tau_{wh} = \rho_w \int_{\sigma_c}^{\sigma_{max}} \int_{-\pi}^{\pi} \sigma^2 \beta_g(\sigma,\theta) N(\sigma_c,\theta) \left(\frac{\sigma_c}{\sigma}\right)^6 d\theta d\sigma \end{cases}$$

with

$$\beta_g(\sigma,\theta) = C_\beta \sigma \frac{\rho_a}{\rho_w} \left(\frac{u_*}{c}\right)^2 cos^2(\theta - \theta_w)$$

$$\begin{cases} C_\beta = \frac{J}{\kappa^2} \lambda \ln^4 \lambda, & \lambda \leq 1 \\ \lambda = \frac{g z_0}{c} \exp(\kappa c / |u_* \cos(\theta - \theta_w)|) \end{cases}$$

The Wave Boundary Layer Model

Conservation of momentum :

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

$$\beta_g(\sigma,\theta) = C_\beta \sigma \frac{\rho_a}{\rho_w}\left(\frac{\boxed{u_*^l}}{c}\right)^2 cos^2(\theta-\theta_w)$$

--Wave growth is proportional to the local turbulent stress

Conservation of kinetic energy:

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

Wave-induced energy flux

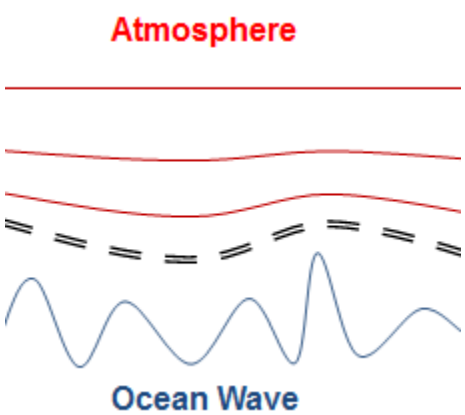
$$\Pi(z) = \int_{\sigma_{min}}^{\sigma} \tilde{F}_w(\sigma)\,d\sigma \qquad \tilde{F}_w(\sigma) = \rho_w \int_{-\pi}^{\pi} \beta_g(\sigma,\theta)\,g\sigma N(\sigma,\theta)\,d\theta$$

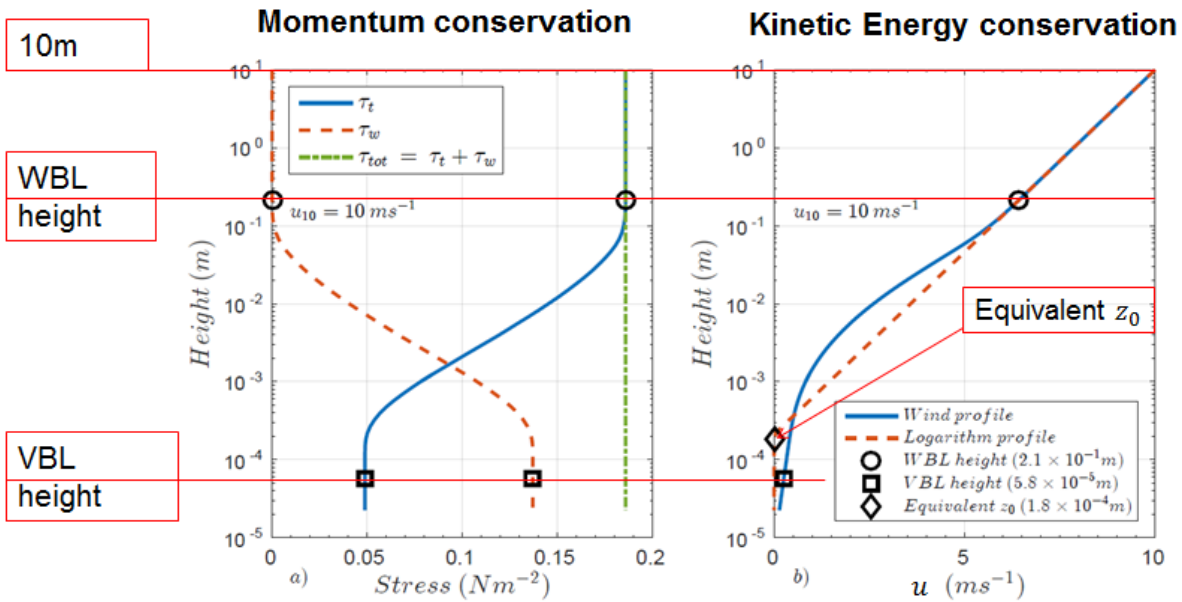
$$\frac{d\vec{u}}{dz} = \left[\frac{\delta}{z^2}\tilde{F}_w\left(\sigma = \sqrt{g\delta/z}\right) + \frac{\rho_a}{\kappa z}\left|\frac{\boxed{\vec{\tau}_t(z)}}{\rho_a}\right|^{\frac{3}{2}}\right] \times \frac{\vec{\tau}_t(z)}{\vec{\tau}_t(z)\cdot\vec{\tau}_{tot}}$$

--Wind profile in the wave boundary layer

The Wave Boundary Layer Model

WRF

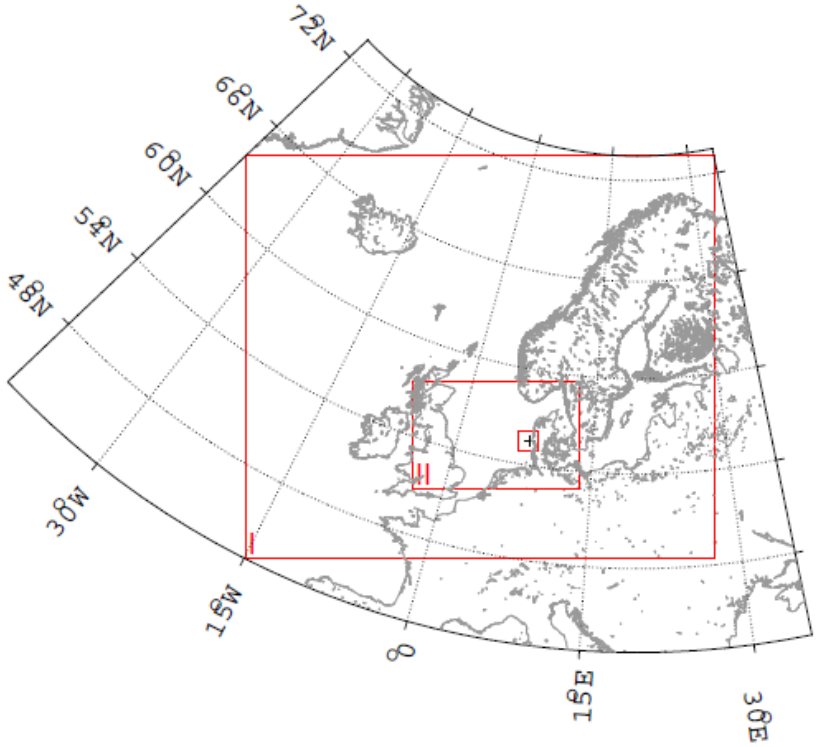




Du, J., Bolaños, R., and Larsén, X. (2017a). The use of a wave boundary layer model in SWAN. *Journal of Geophysical Research: Oceans*, pages 1063–1084.

SWAN

Model setup



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

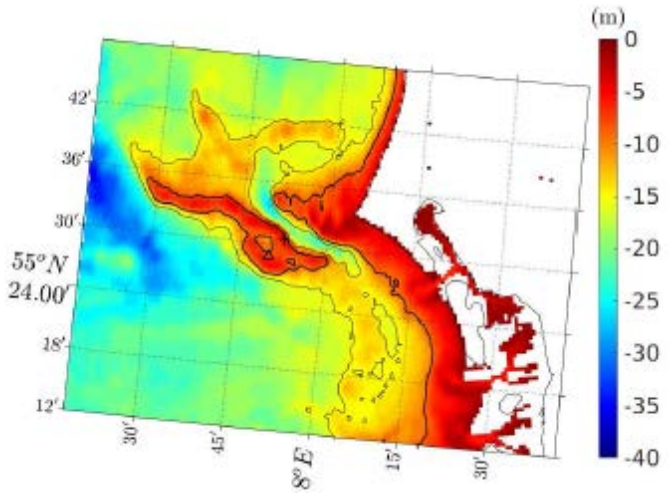
WRF:
CFSR+OISST
77 vertical sigma levels
MYNN 3.0 PBL scheme
RRTM long and short wave radiation
Kain-Fritsch cumulus scheme (domain I)
Corine land use

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)

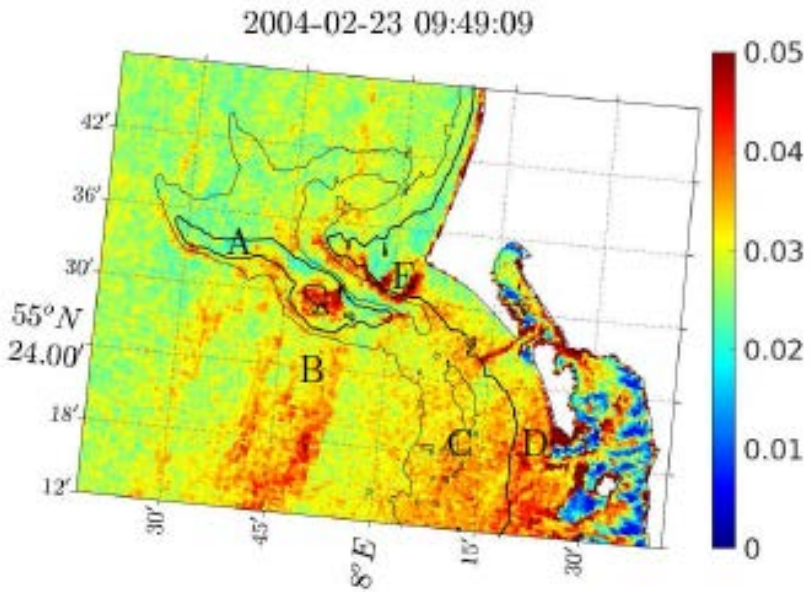
Model performance

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



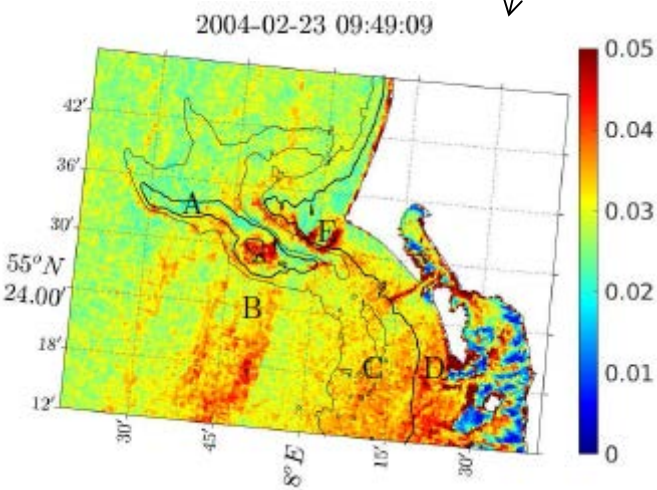
Radar backscatter measured by ASAR

Model performance

Roughness length

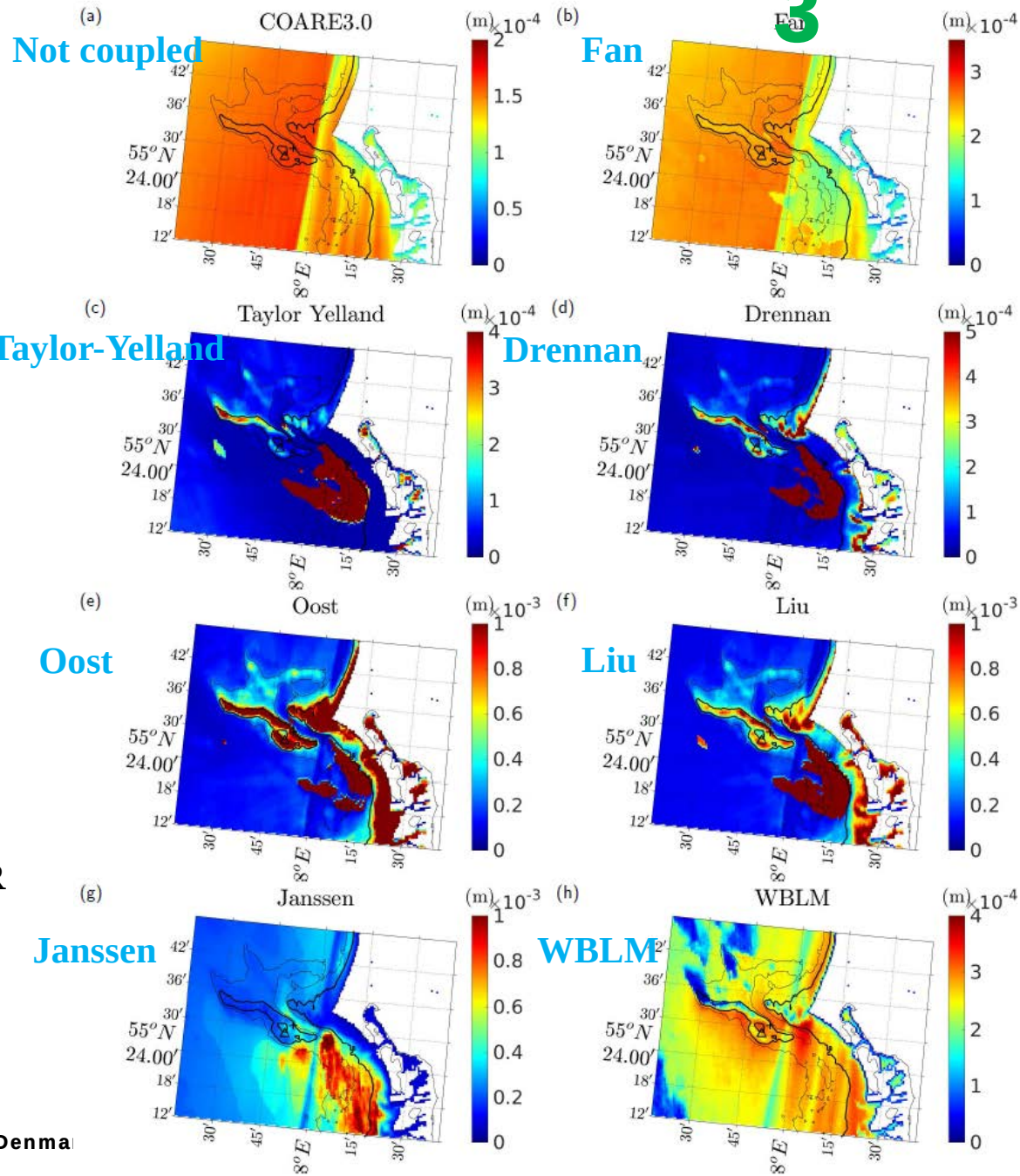
2004-02-23 09:50

Wind vector



Radar backscatter measured by ASAR

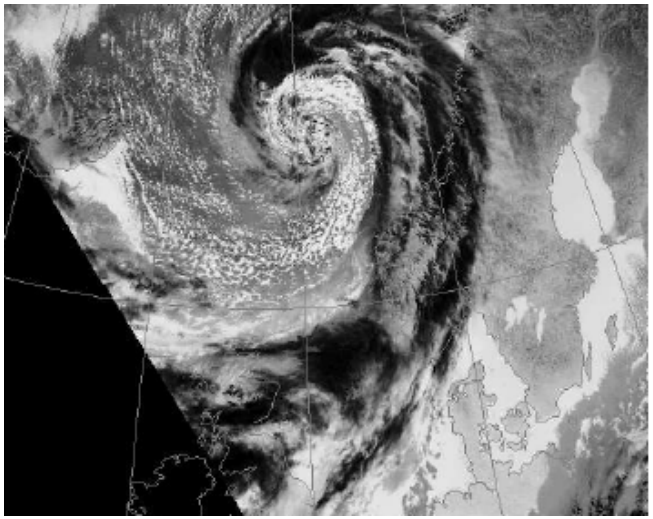
3



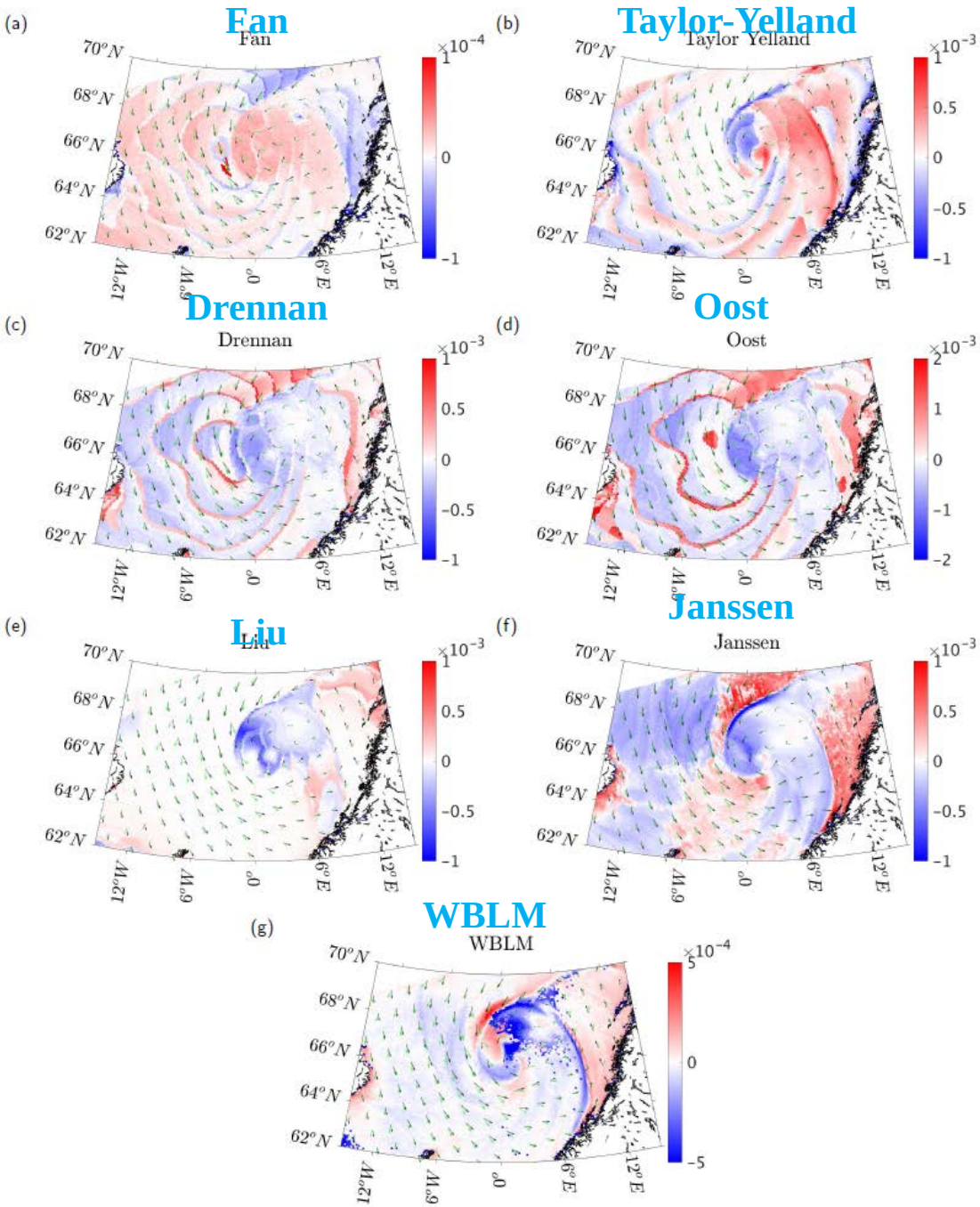
Model performance

Drag coefficient difference:

coupled - uncoupled



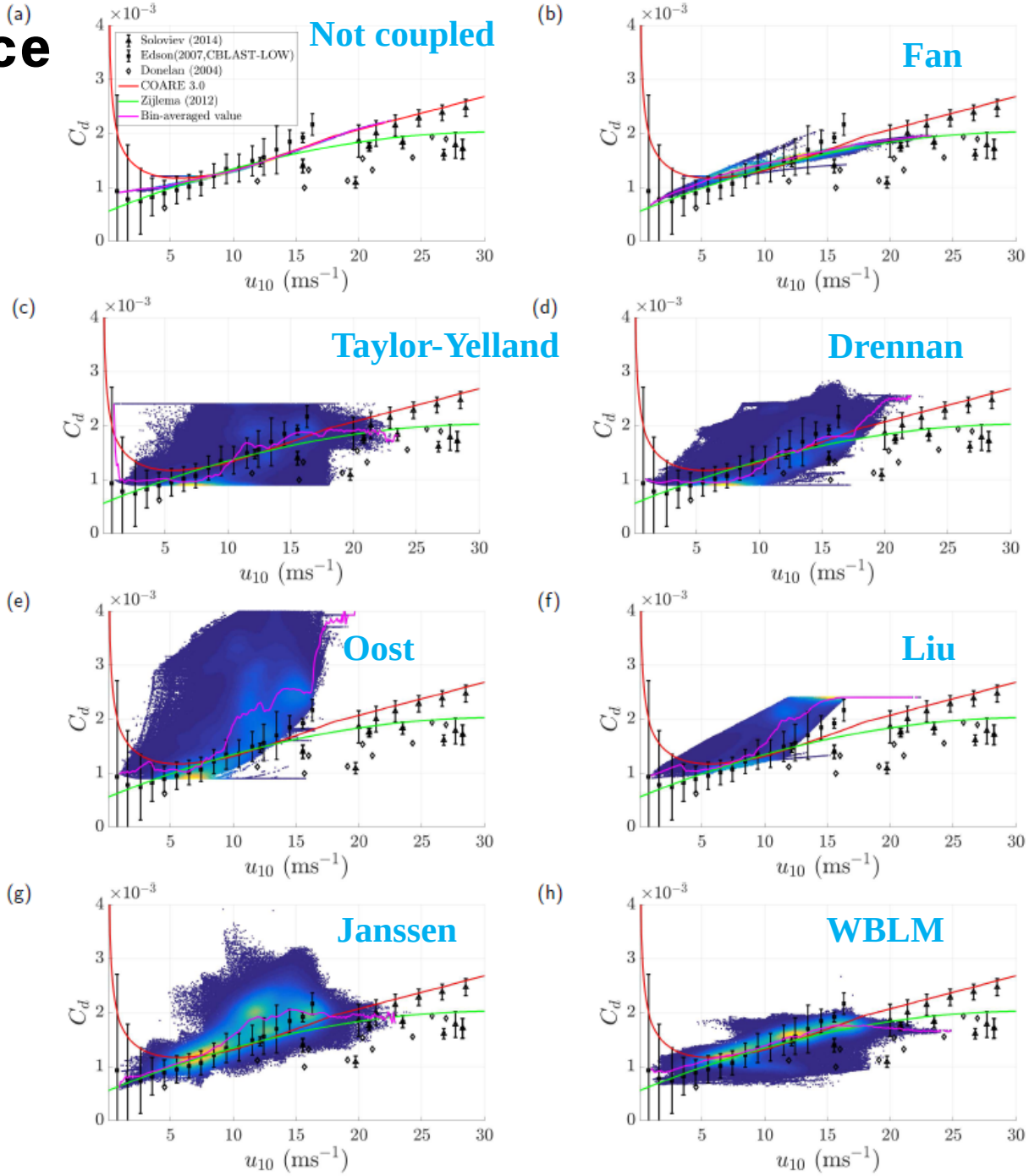
20:45, 2004-02-23



Model performance

Drag coefficient *vs.* U_{10}

Whole domain III, entire period



Model performance

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

Between coupled and not-coupled

20:45, 2004-02-23

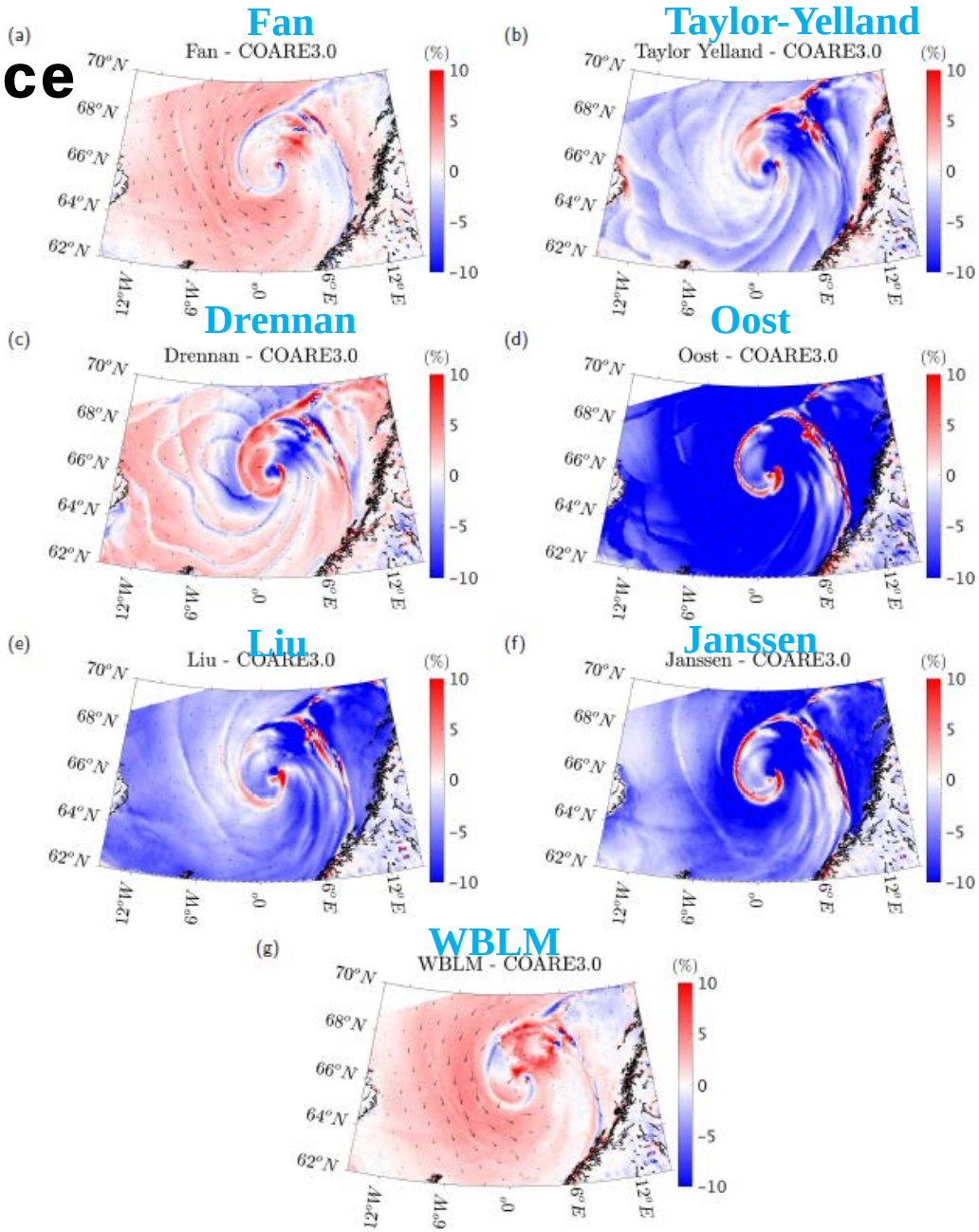


Figure 8.13: Percentage of deviation in U_{10} between the coupled and non-coupled modeling at the same time as Figure 8.12.)

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

Thanks to the support

- 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