Response of water temperature to surface wave effects in the Baltic Sea: simulations with the coupled NEMO-WAM model

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Outline

- **Motivation and objective**
- **Model setup for the North Sea-Baltic Sea**
- **Physical processes forming wave-circulation interaction**
- **Wave impact to temperature**
- **Conclusions**

Motivation and objective

- Traditionally ocean models and wind wave models have been applied **separately.**

- Separating wave and ocean models is pragmatic, but leads to **violation** of energy and momentum conservation.

- During EU-FP7 project MyWave a **coupled global scale wave-circulation model** was developed (Breivik *et al*, 2015).

- Applying the coupled model to World Ocean, a **reduction of bias** between modelled and measured SST was noted.

- **Here we demonstrate the importance of coupling on regional scales and focus on the Baltic Sea.**

Model setup (1): geographical view

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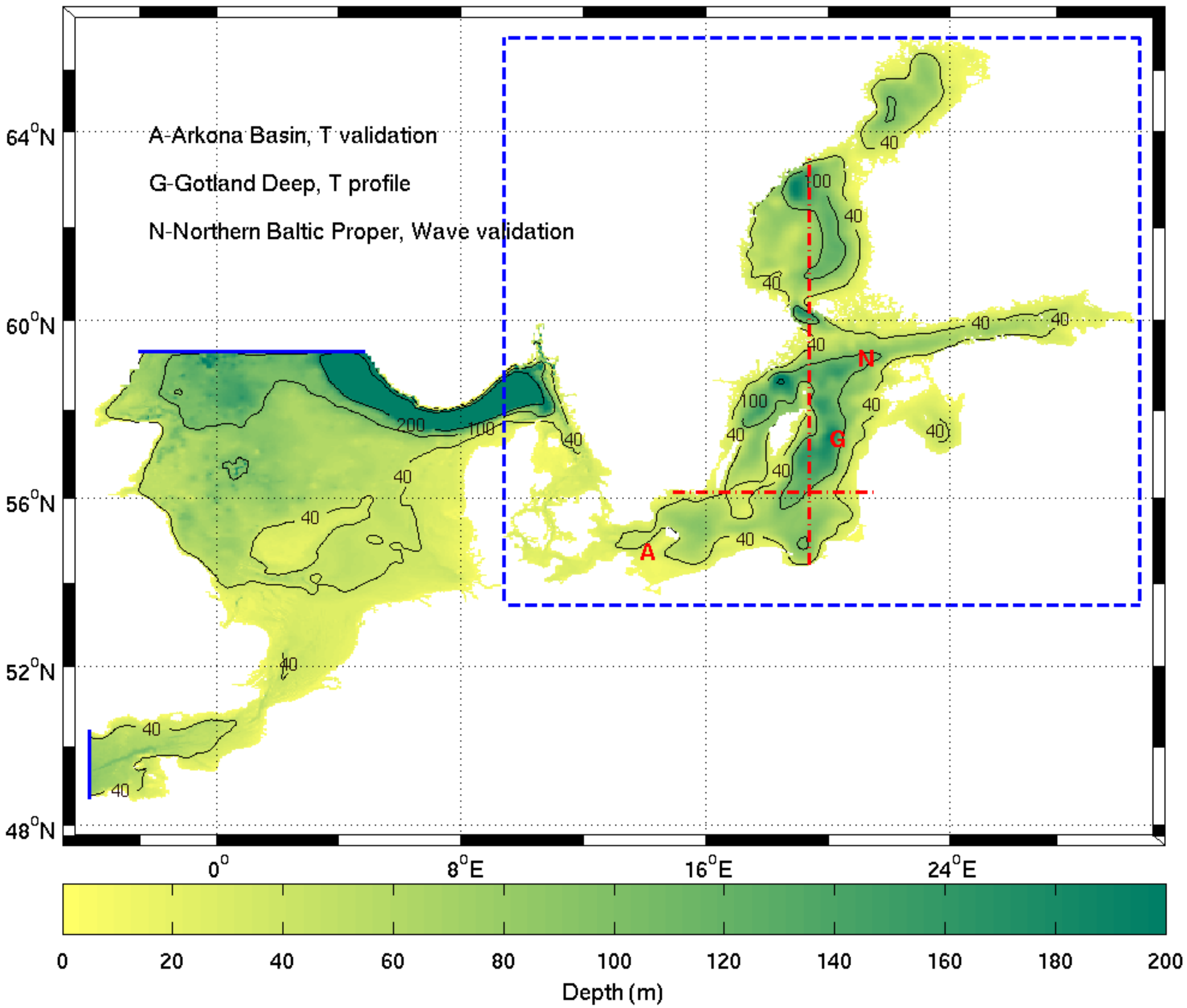

Blue solid lines – model open boundaries

Blue dashed box – our analysis area

Red dashed lines – vertical transects

Model setup (2) : key information

Parameter/Model	NEMO (version 3.4)	WAM (version CY40R3)
Modelling period	01.10.2012-30.09.2013	Switched on at 01.05.2013
Horizontal grid	2 nautical miles covering North Sea and Baltic Sea	Same horizontal grid. Spectral resolution: 24 directions and 25 frequencies
Vertical grid	56 z layers	N/A
Integration timestep(s)	10 s for barotropic part; 180 s for baroclinic part	30 s
Initial field	Janssen et al. (1999) climatology for T & S	Coldstart
Boundary condition	OSU tides, Janssen et al. (1999) climatological periodic boundary	No
Atmospheric forcing	German Weather Service (DWD), 1 h. Meridional and zonal wind speed; shortwave and longwave radiation; air temperature; humidity; air pressure	Same source, but only wind components
Vertical diffusion scheme	Generic Length Scale (k-ε), Umlauf and Burchard (2003)	N/A
Ice	LIM2	No ice, as wave model input was used starting from May

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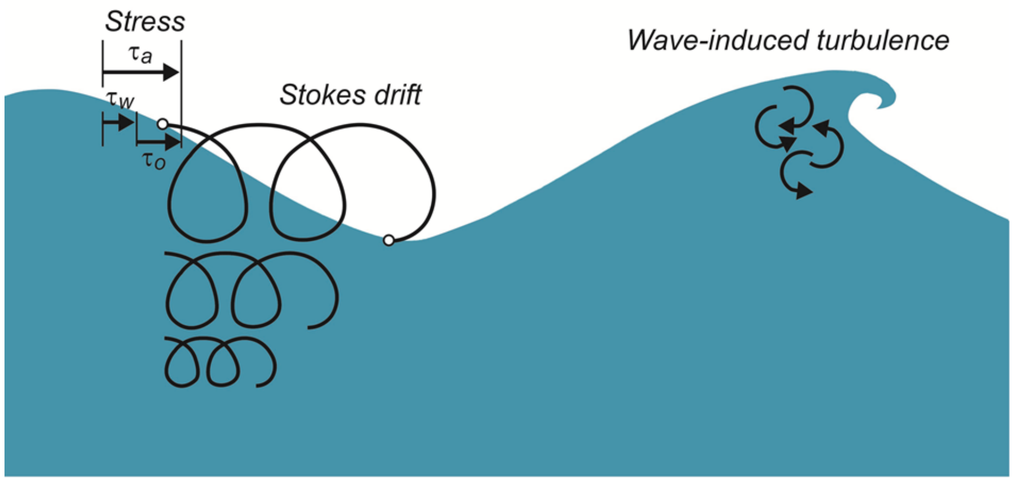
Physical processes forming wave-circulation interaction (1)

1) **Sea-state dependent momentum flux**
2) **Sea-state dependent energy flux**
3) **Stokes-Coriolis forcing**

NEMO

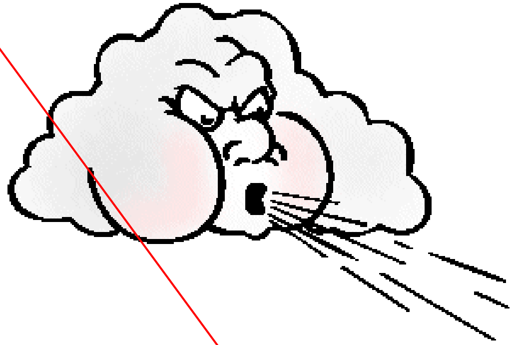
WAM



Currents

Breivik, O., Mogensen, K., Bidlot, J.-R., Balmaseda, M.A., Janssen, P.A.E.M. Surface wave effects in the NEMO ocean model: Forced and coupled experiments (2015) Journal of Geophysical Research C: Oceans, 120 (4), pp. 2973-2992.

Physical processes forming wave-circulation interaction (2): **ocean side stress**

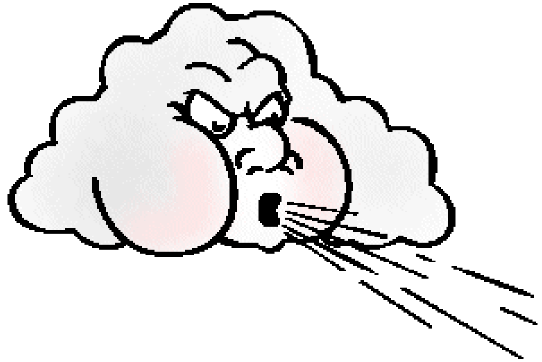


$$\vec{\tau} = c_{aw}^{d}\ \rho_a \left|\vec{U}_{10}\right| \vec{U}_{10}$$

$$c_{aw}^{d} \times 10^3 = \begin{cases} 1.2 & : 0 < \left|\vec{U}_{10}\right| \le 11\, m/s \\ 0.49 + 0.065\left|\vec{U}_{10}\right| & : 11 < \left|\vec{U}_{10}\right| \le 22\, m/s \end{cases}$$

$$\frac{\partial U}{\partial t} - fV = -gH\frac{\partial \xi}{\partial x} + \tau_x - \tau_{xb}$$

$$\frac{\partial V}{\partial t} + fU = -gH\frac{\partial \xi}{\partial y} + \tau_y - \tau_{yb}$$



$$\tau_{oc} = \tau_a - \rho_w g \int_0^{2\pi}\int_0^{\infty} \frac{\mathbf{k}}{\omega}\left(S_{in} + S_{ds}\right) d\omega\, d\theta$$

$$\frac{\partial U}{\partial t} - fV = -gH\frac{\partial \xi}{\partial x} + \tau_{ocx} - \tau_{xb}$$

$$\frac{\partial V}{\partial t} + fU = -gH\frac{\partial \xi}{\partial y} + \tau_{ocy} - \tau_{yb}$$

Physical processes forming wave-circulation interaction (3): **storm on 22 July 2013**

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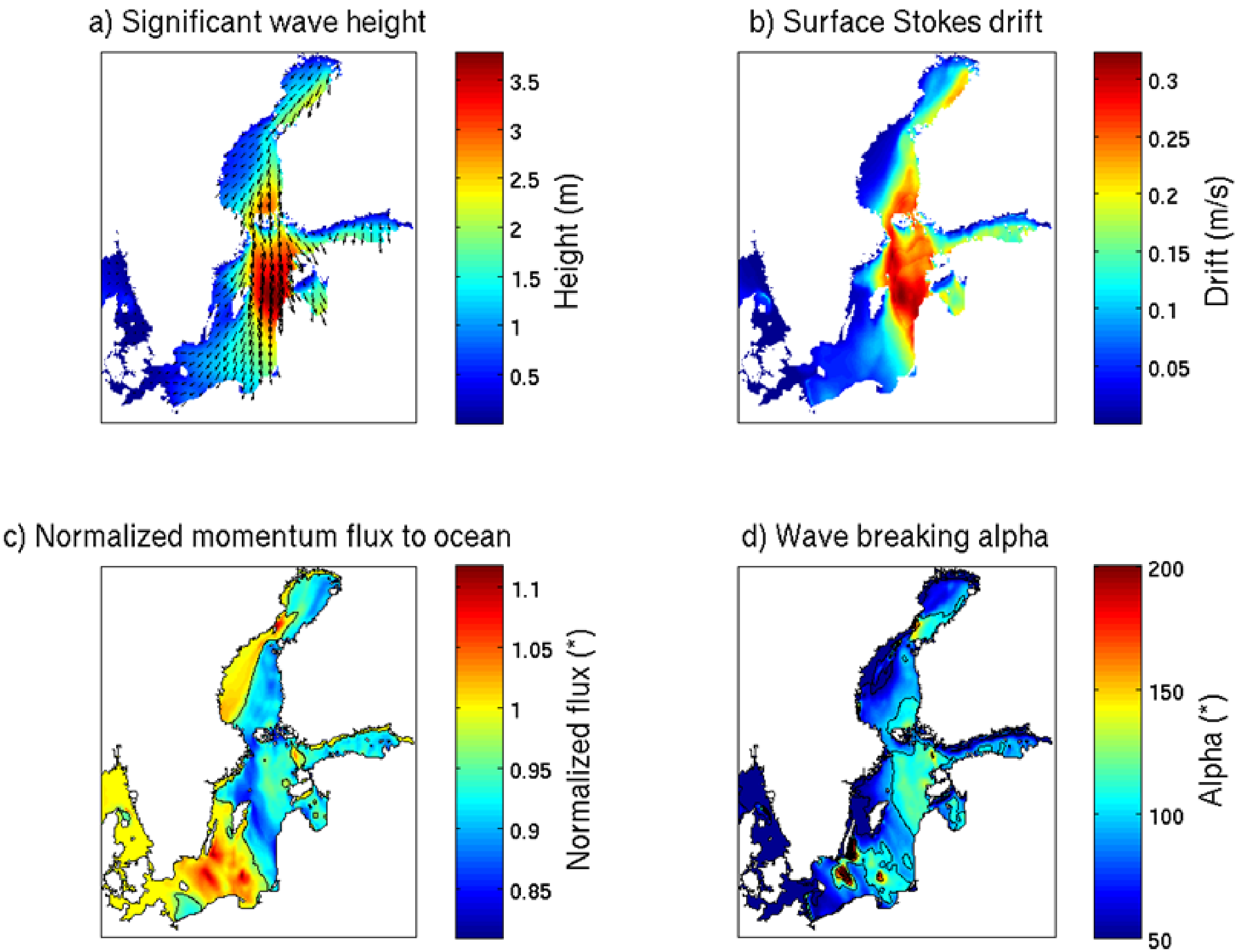

$$\frac{D\mathbf{u}}{Dt} = -\frac{1}{\rho}\nabla p + (\mathbf{u}+\mathbf{v}_s)\times f\hat{\mathbf{z}} + \frac{1}{\rho}\frac{\partial \tau}{\partial z}.$$

In uncoupled NEMO, *alpha* is constant=100

$$K_q \frac{\partial q^2}{\partial z} = 2\alpha_{\mathrm{CB}} u_{\tau}^3, \qquad z = 0.$$

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Simulations

Simulation name	Description of simulation
CTRL	Control simulation, without wave model
ALLWAVE	All three wave processes included
TAUOC	Sea state dependent momentum flux included only
BREAK	Sea state dependent energy flux included only
STCOR	Stokes-Coriolis forcing included only

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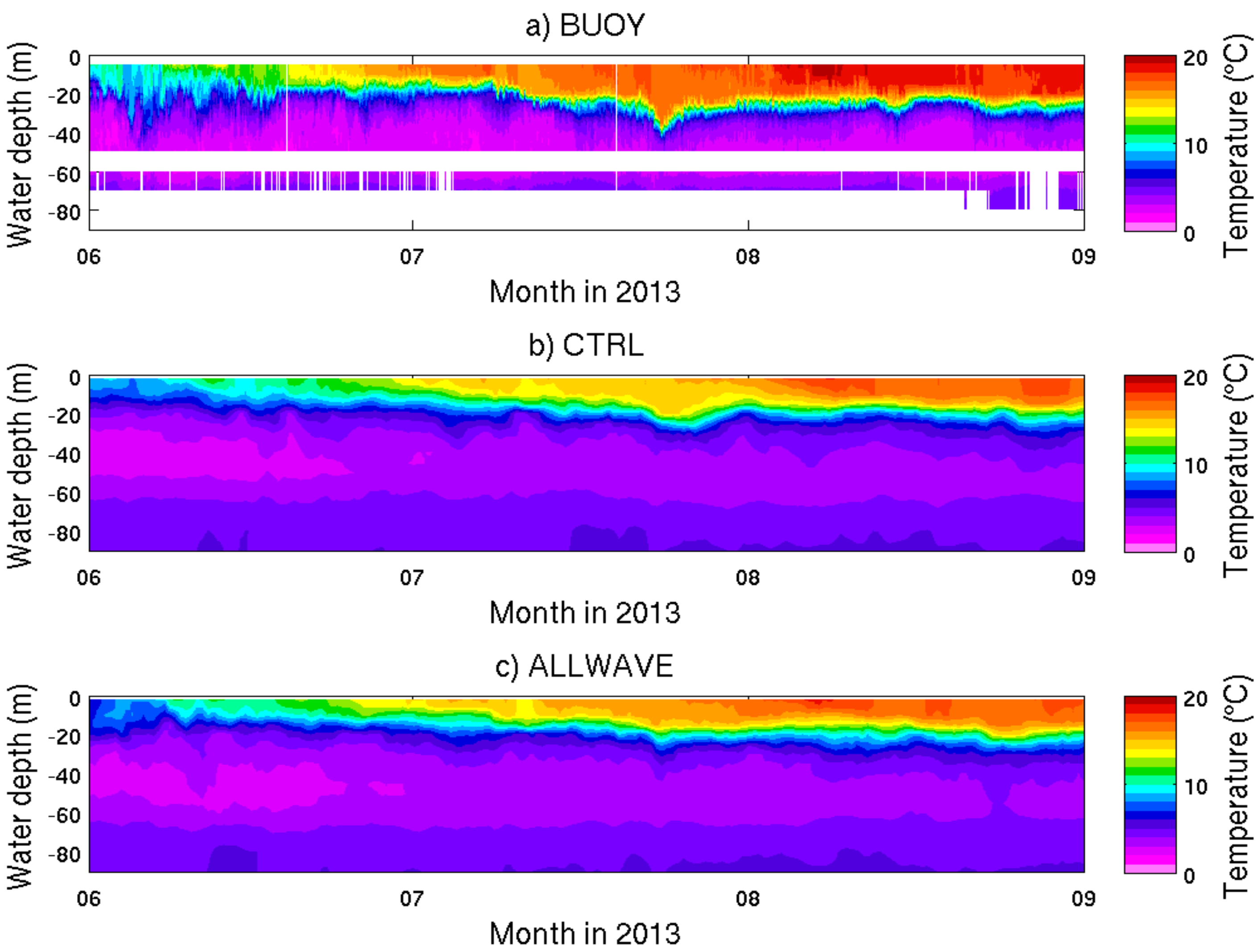
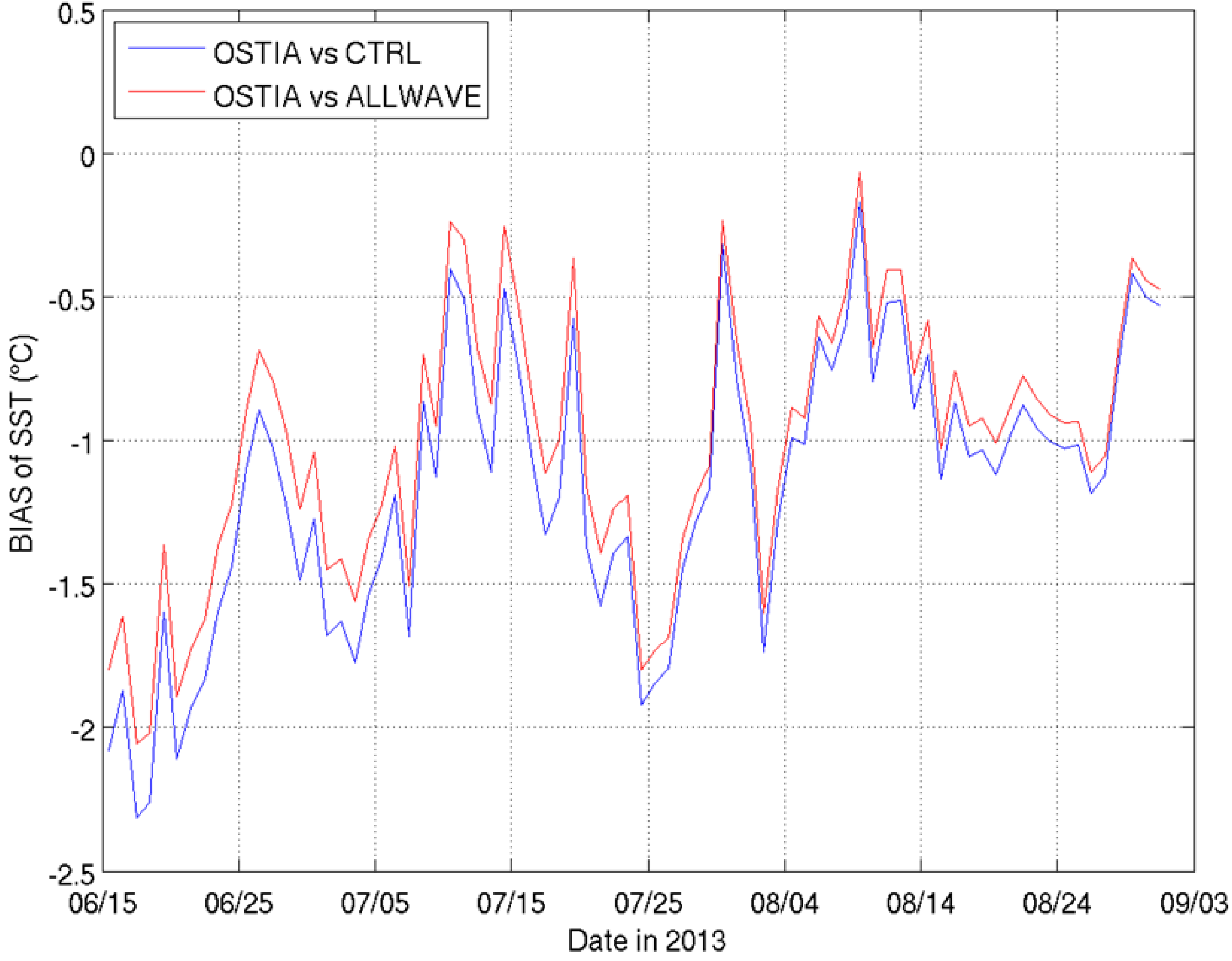
Results (1): Baltic Proper, water temperature



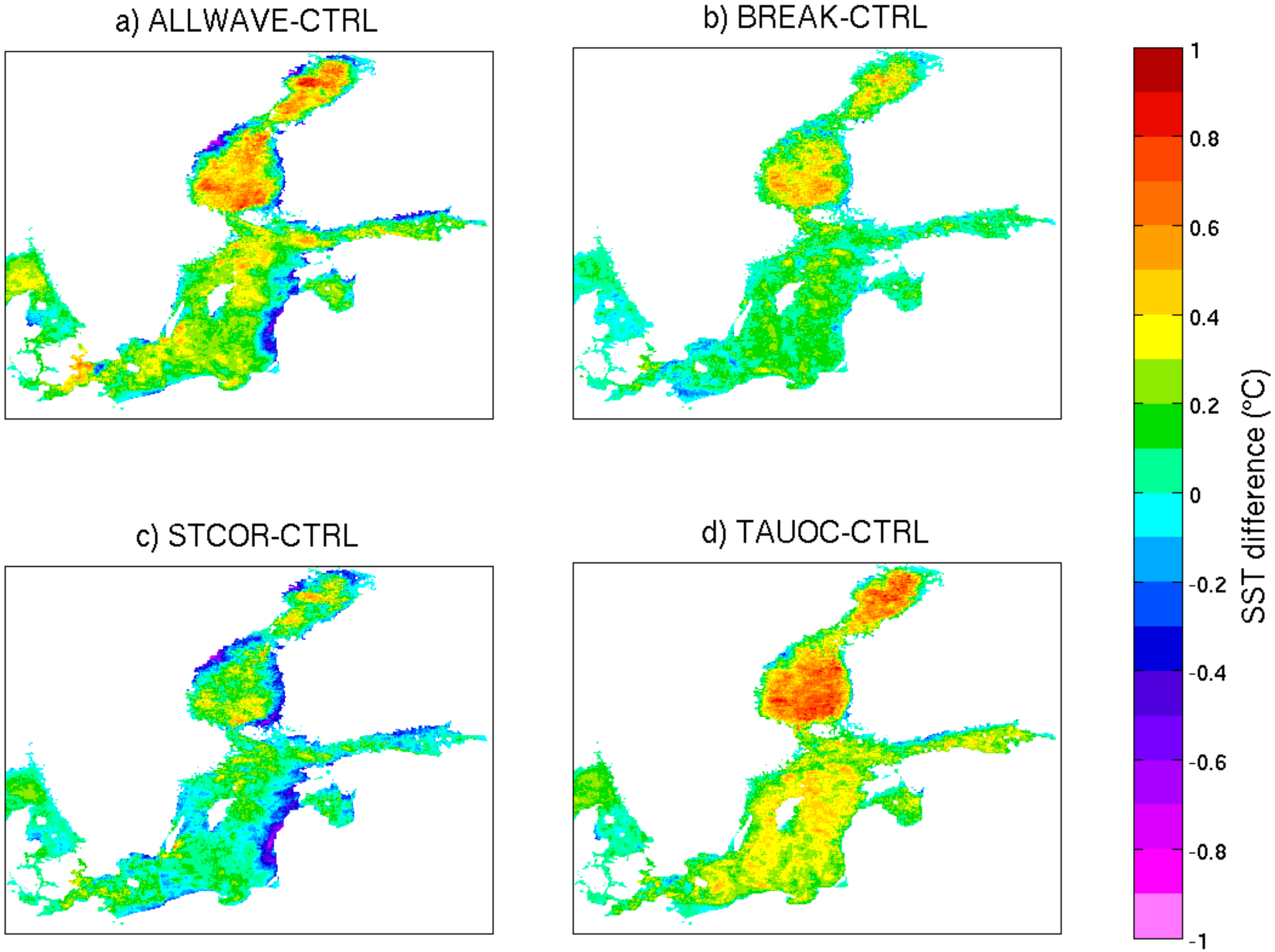
Time-depth profiles of measured temperature, control run (CTRL) and the all-wave processes (ALLWAVE) run at a buoy station in Baltic Proper

Results (2): BIAS of SST



Bias (model mean minus mean of measurements) of simulated SST with respect to OSTIA data in the Baltic Proper.

Results (3): Impact of waves to SST



Sea surface temperature differences between ALLWAVE and CTRL averaged over a 3-month period, from 01 June 2013 to 31 August 2013.

Results (4): Impact of waves to bottom temperature

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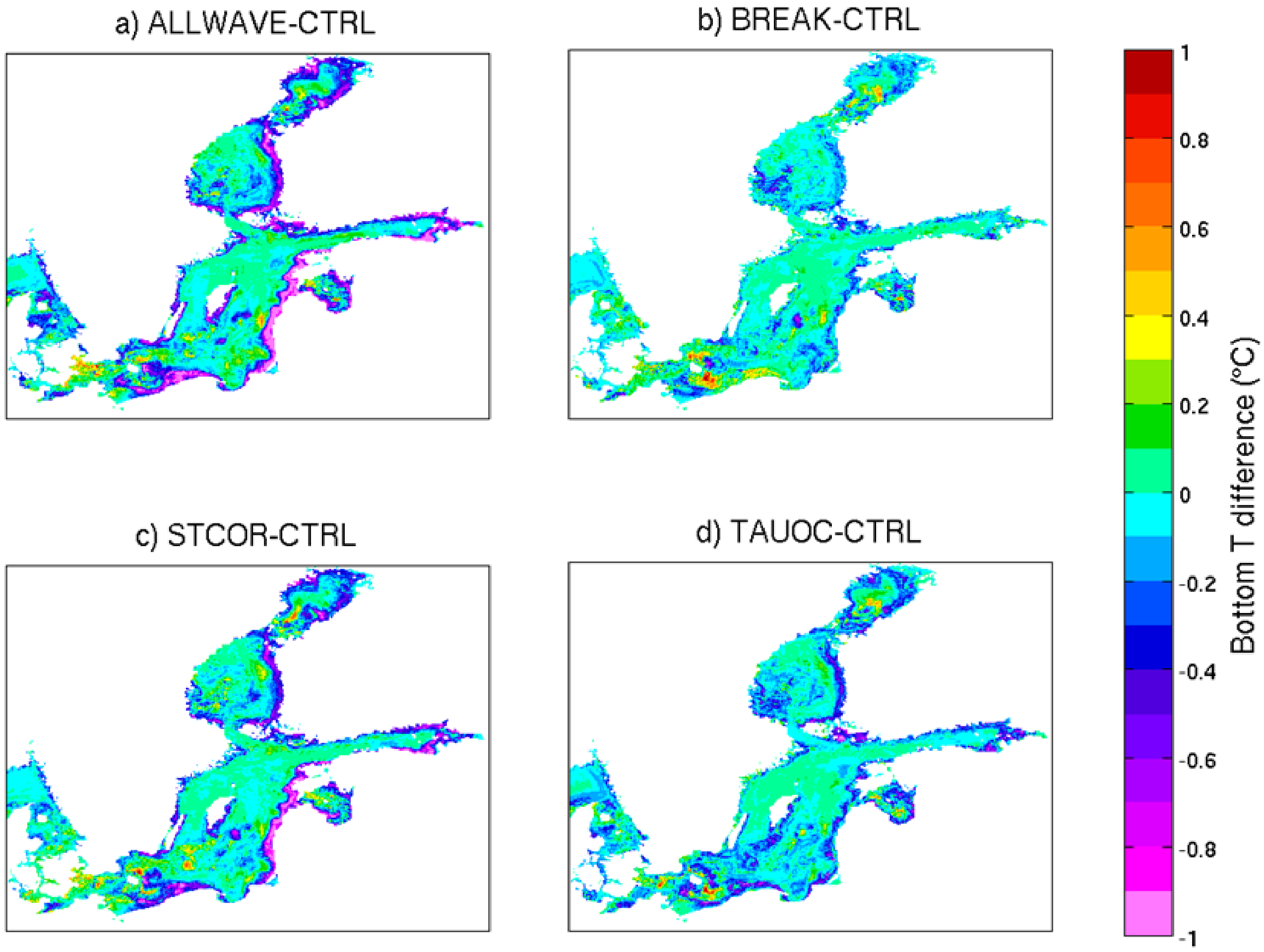
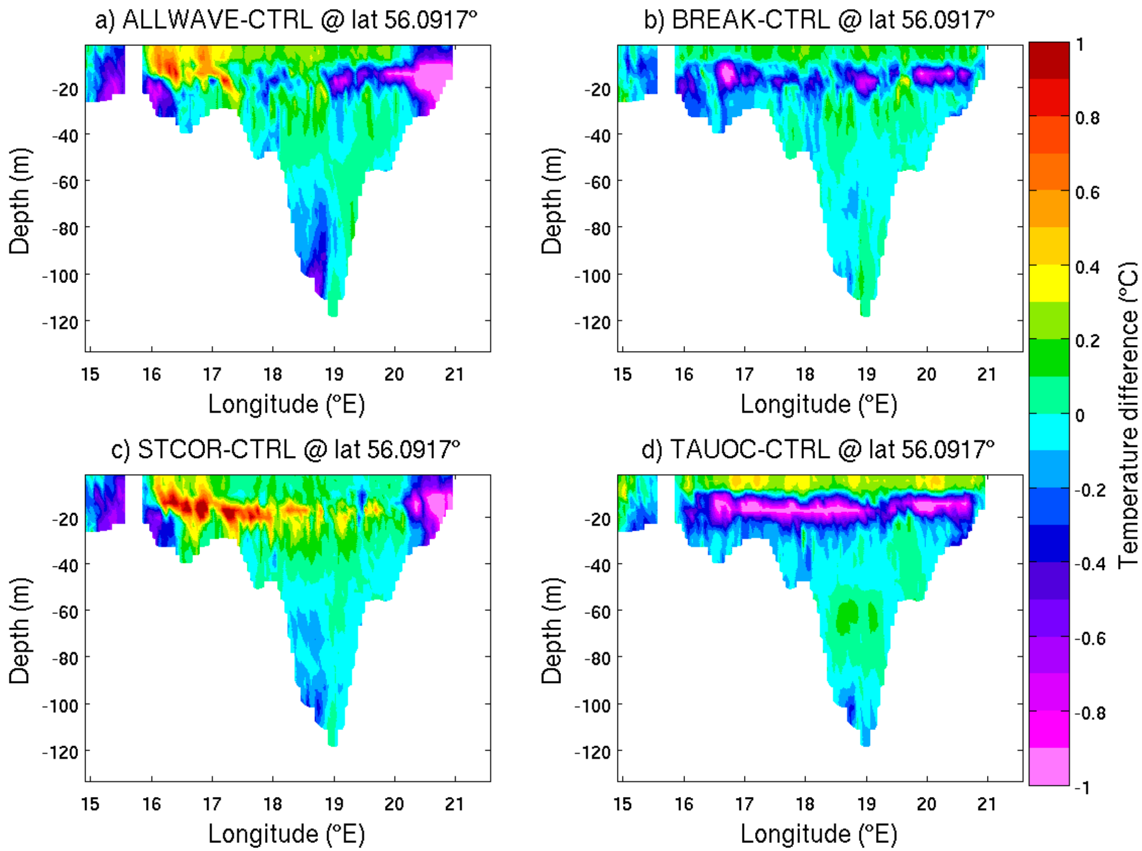
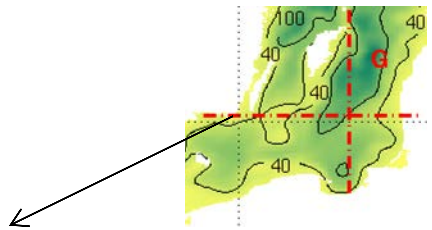


Sea bottom temperature differences between ALLWAVE and CTRL averaged over a 3-month period, from 01 June 2013 to 31 August 2013.

Results (5): Impact of waves, vertical/transect





Results (6): Impact of waves, vertical/transect

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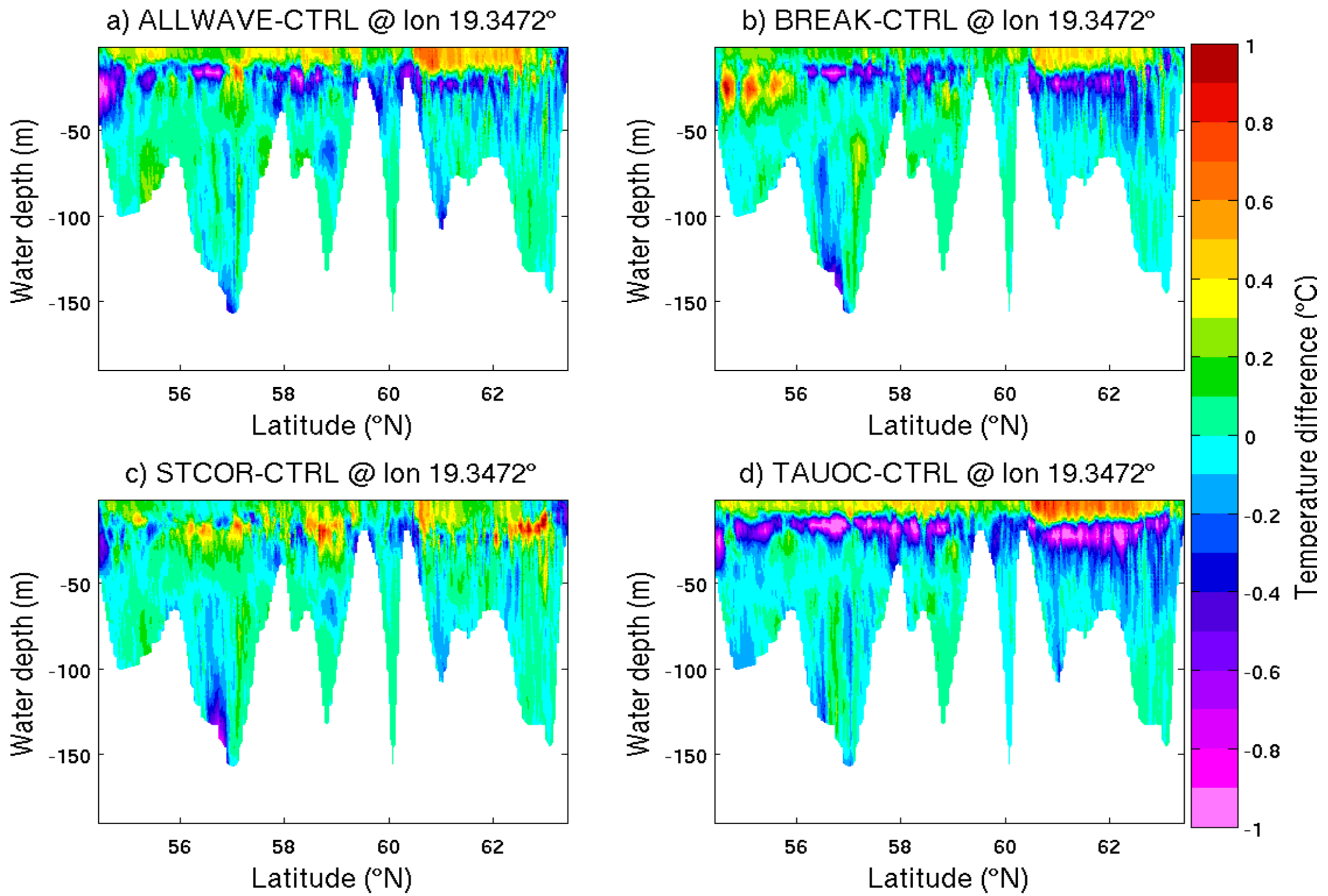

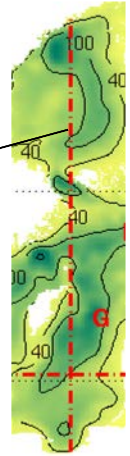

Conclusions

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- The effects of wind waves on the Baltic Sea water temperature has been studied by coupling the hydrodynamical model NEMO with the wave model WAM.

- The results indicate a pronounced effect of waves on surface temperature, on the distribution of vertical temperature and on upwelling´s.

- In northern parts of the Baltic Sea a warming of the surface layer occurs in the wave included simulations. This in turn reduces the cold bias between simulated and measured data. The warming is primarily caused by sea-state dependent energy flux.

- During the summer the wave induced water temperature changes were up to 1 °C.