Institute of Coastal Research

Research Unit 1: System Analysis and Modelling

PACES II / Topic 4

RU 1

Helmholtz-Zentrum Geesthacht

Centre for Materials and Coastal Research

Impact of surface waves on the North Sea and Baltic Sea circulation

Joanna Staneva

Topic 4

Outline

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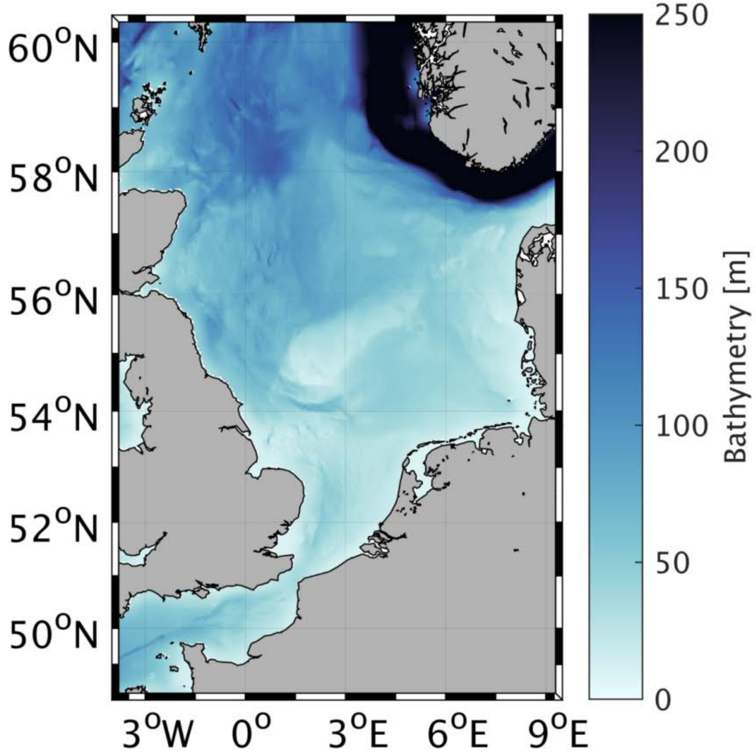
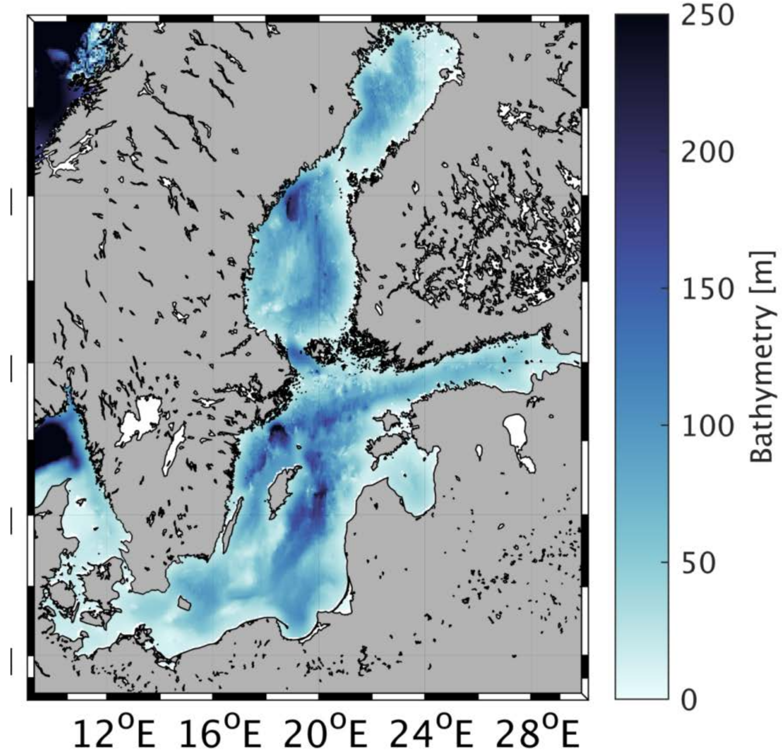
Study areas: North Sea Baltic Sea





- Further **development** and implementation of **both** wave and ocean models
- Study the effects of coupling on **the upper ocean dynamics**
- Process-oriented studies
- **Impact/Knowledge transfer**

Models

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Circulation model :

- **NEMO** (Nucleus for European Modelling of the Ocean, v3.6 r6232) (Madec, 2008).

Wave model:

- **WAM** - third-generation wave model

HZG maintains: http://mywave.github.io/WAM/

- used by most CMEMS Marine Forecasting Centers.

NEW Version WAM 4.6.2 made available

Wave-induced forcing

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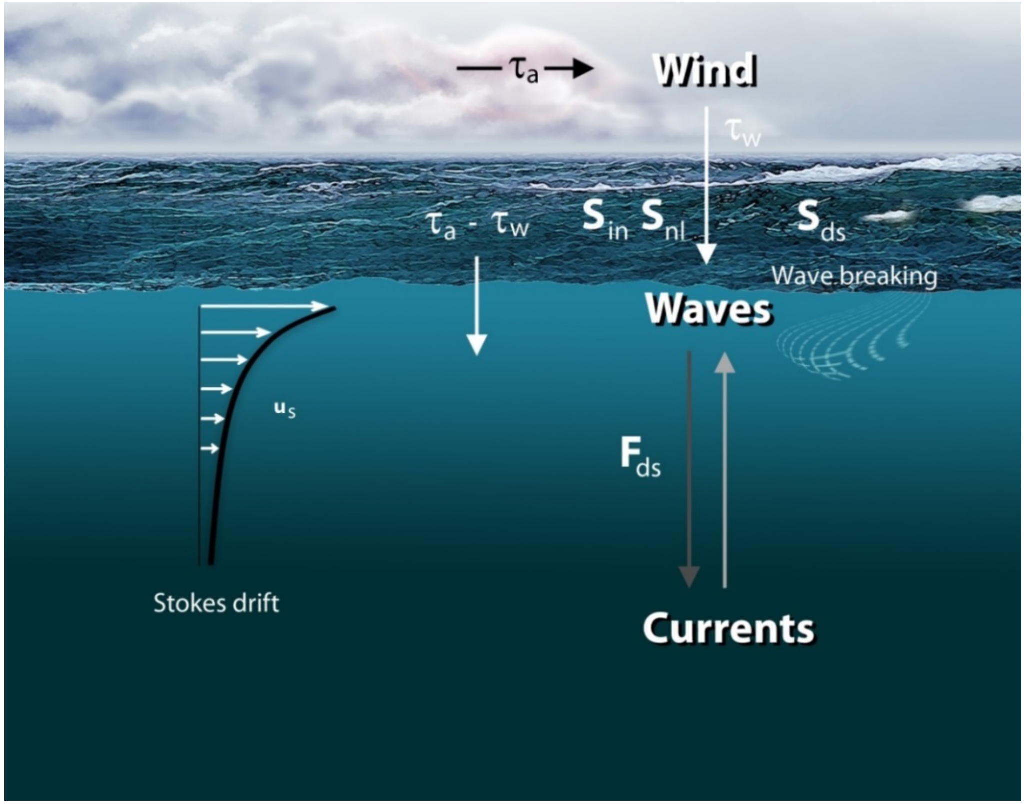
(1) The Stokes-Coriolis forcing (Hasselmann, 1970; Breyvik et al., 2016, Staneva et al., 2017)
(2) Sea state dependent momentum flux (Janssen, 2012, Staneva et al., 2017, 2018)
(3) Surface wave breaking parameterization (Craig and Banner, 1994, Janssen 2013, Breyvik et al., 2015, Staneva et al., 2017)



	NEMO	Stokes-Coriolis Force	Ocean Side Momentum Stress	Wave Breaking
CTRL	√			
STCOR	√	√		
TAUOC	√		√	
TKE	√			√
TAUST	√	√	√	
ALLWAVE	√	√	√	√

Staneva et al., 2017

Stokes-Coriolis forcing

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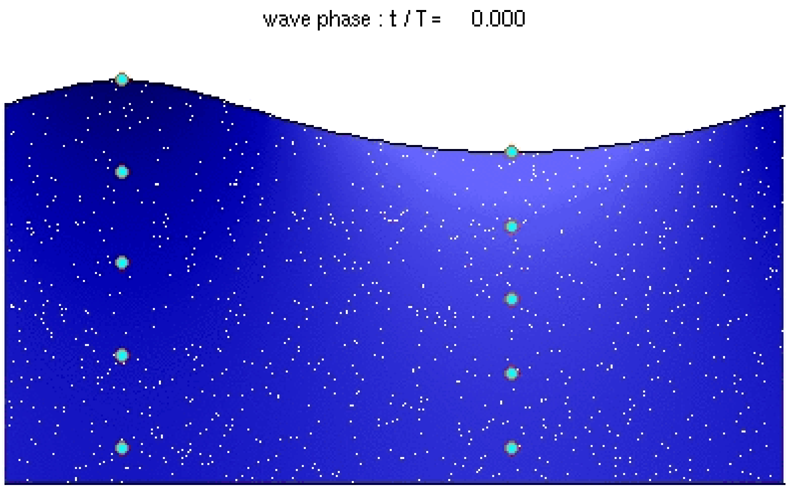
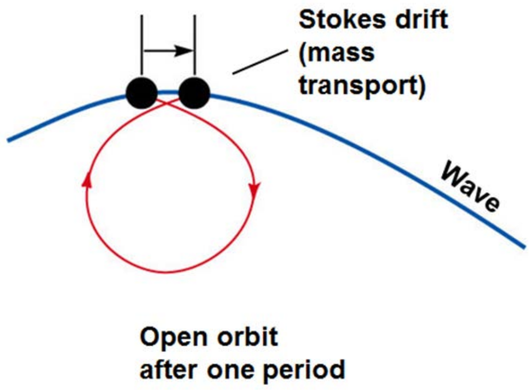
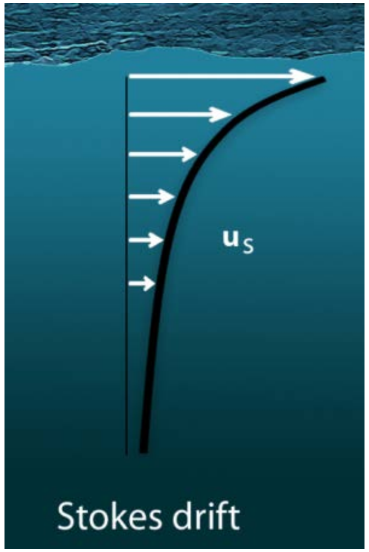


http://en.wikipedia.org/wiki/Stokes_drift

orbits are not exactly closed -waves **contribute** to the transport





Breyvik et al., 2016

The Stokes drift –> WAM

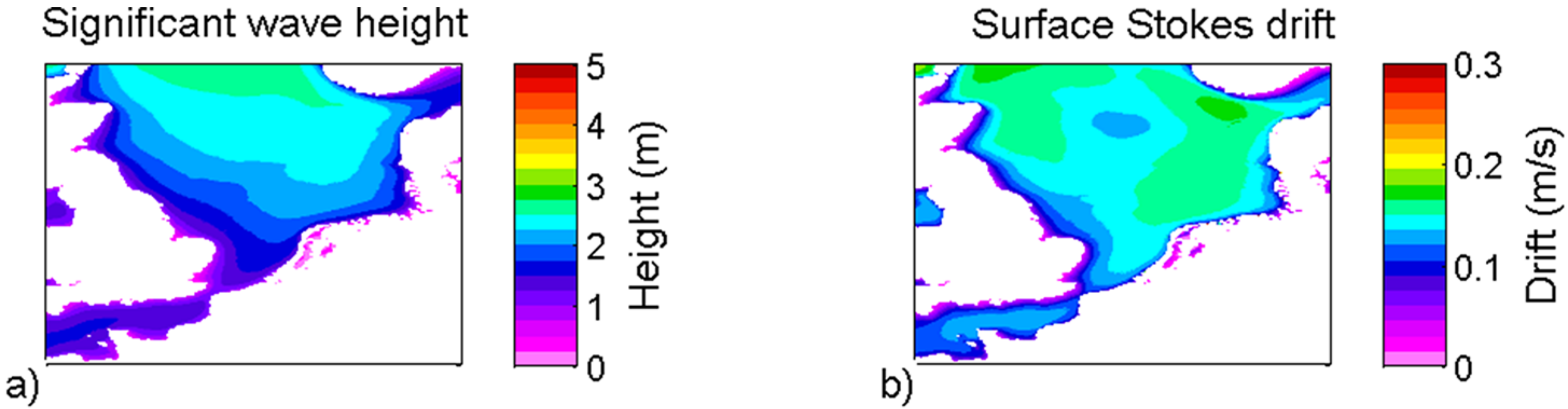
Momentum equations in NEMO:

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

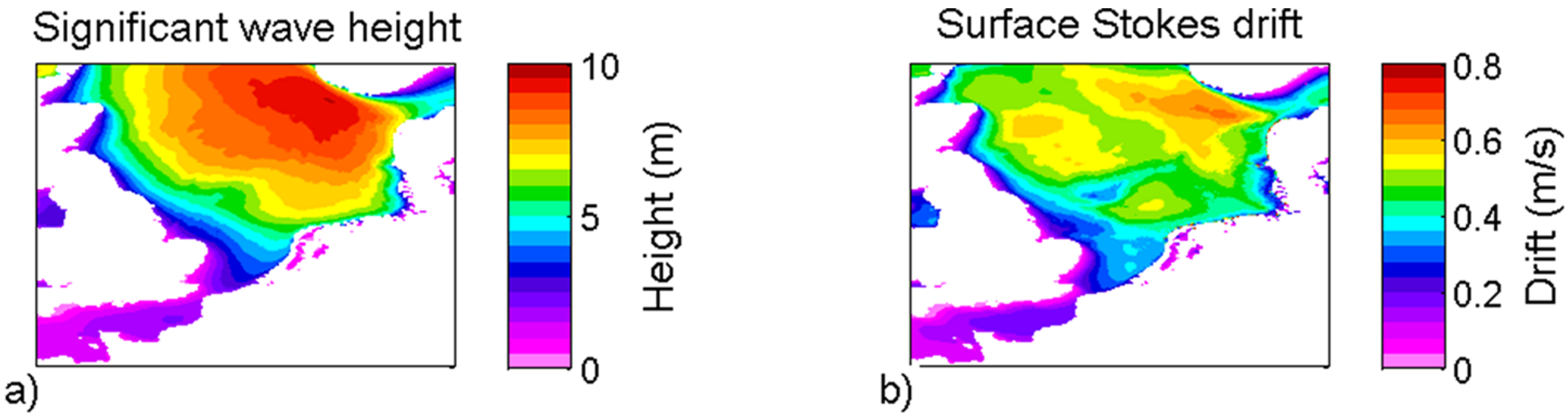
New Phillips approximations

Surface Stokes drift

October-December, 2013



Storm Xaver, 5-6 December, 2013



(Staneva et al., 2016)

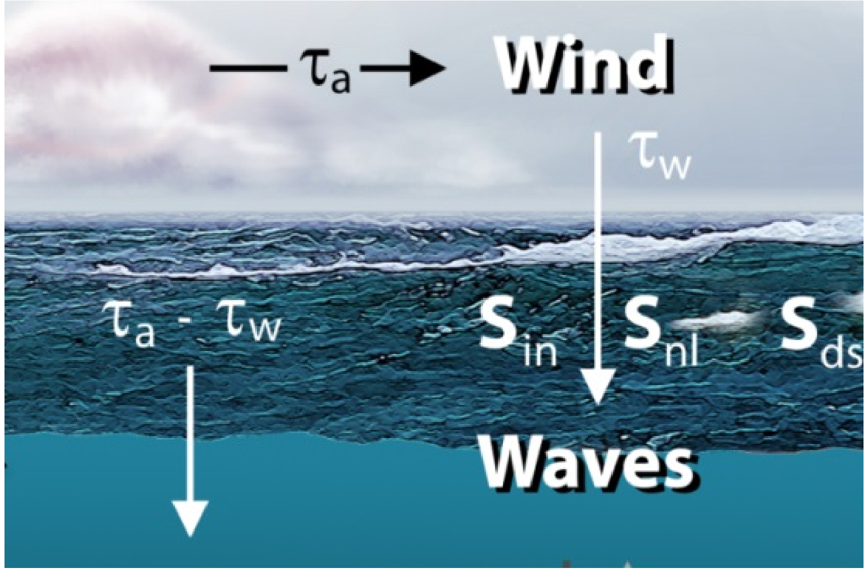
Sea state dependent momentum flux

In ocean models - surface stress - bulk formulas:

$$\tau_s = \rho_a C_d U_{10}^2,$$

In NEMO: Large and Yeager (2008)

$$C_d = 10^{-3}\left(\frac{2.7}{U_{10}} + 0.142 + \frac{U_{10}}{13.09}\right)$$

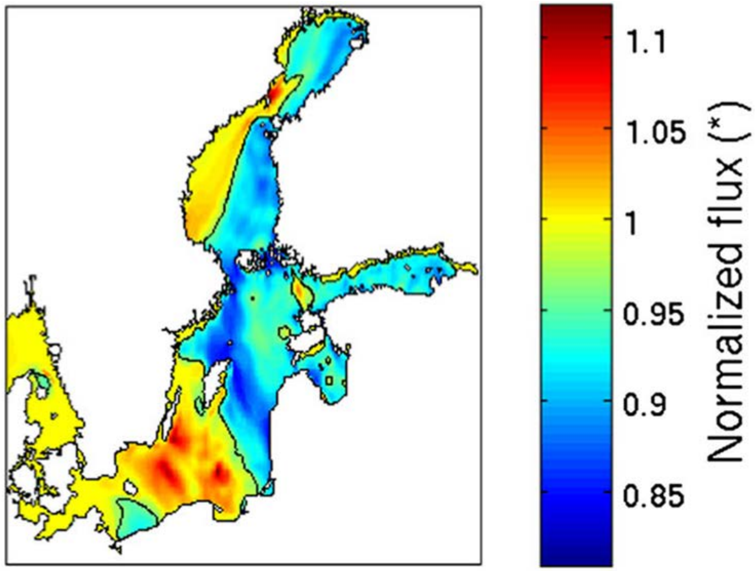


TWO wave dependent mechanisms are considered:

1. **wave-modified drag coefficient**, changes the air-side stress

2. **Newly introduced ocean side stress** - depends on the balance between wave growth and dissipation

$$\overrightarrow{\tau_{oc}} = \overrightarrow{\tau_a} - \rho_w g \int_0^{2\pi} \int_0^{\omega_c} d\omega d\theta \frac{\vec{k}}{\omega} (S_{in} + S_{diss} + S_{NL})$$



Normalized momentum flux to ocean
(Staneva et al., 2017, Alari et al., 2016)

Surface wave breaking parameterization

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In NEMO:

- Craig and Banner (1994):

wave breaking - > affects the mixing

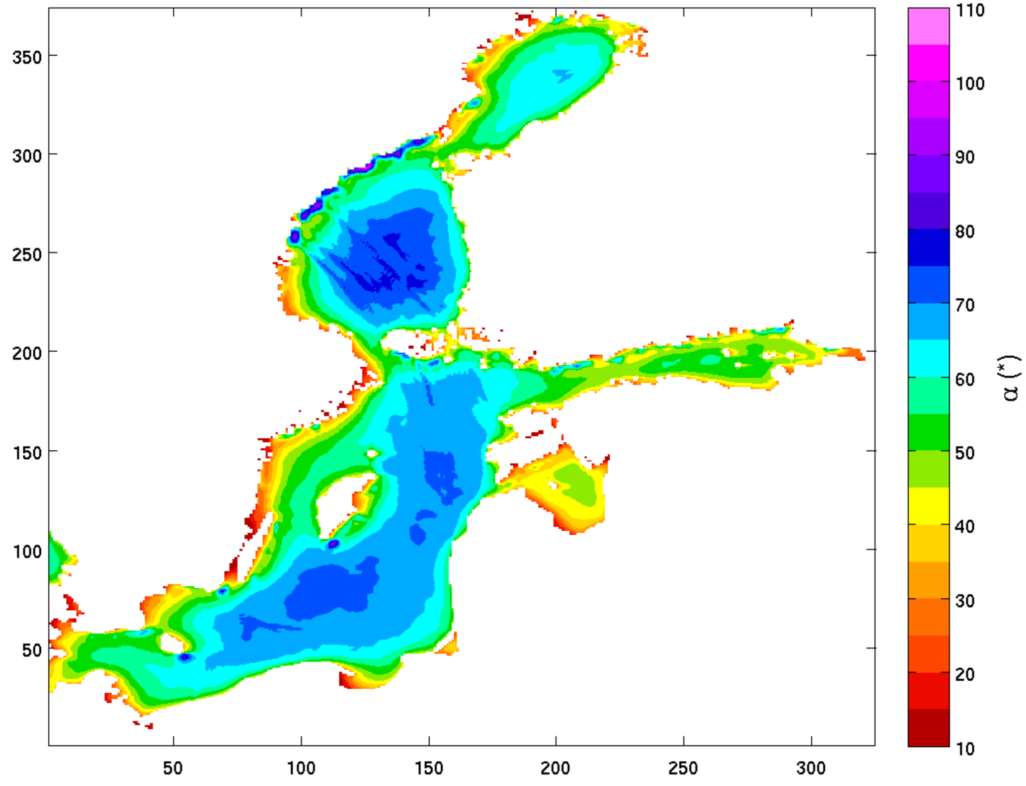
$F \sim \alpha\, u^3_{w*}$

in NEMO only : α =100

- According to different studies, e.g.

Mellor and Blumberg (2004):
α ~57-146

Wave energy factor α - JJASON



(Alari et al., 2016)

Baltic Sea: Impact of waves to Sea Surface Temperature

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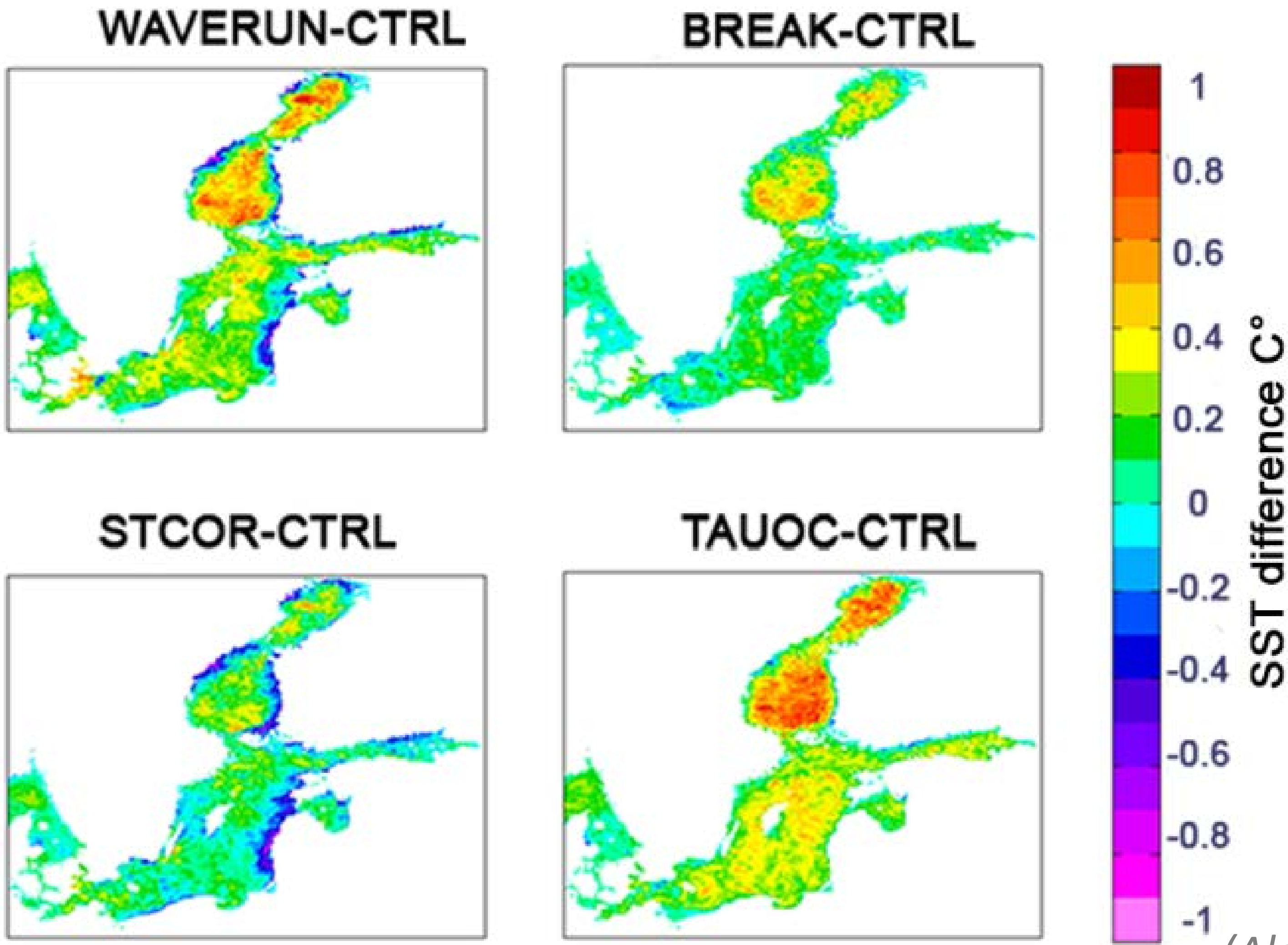
Summer SST Differences



(Alari et al., 2016)

North Sea: Impact of wave-induced processed on sea level

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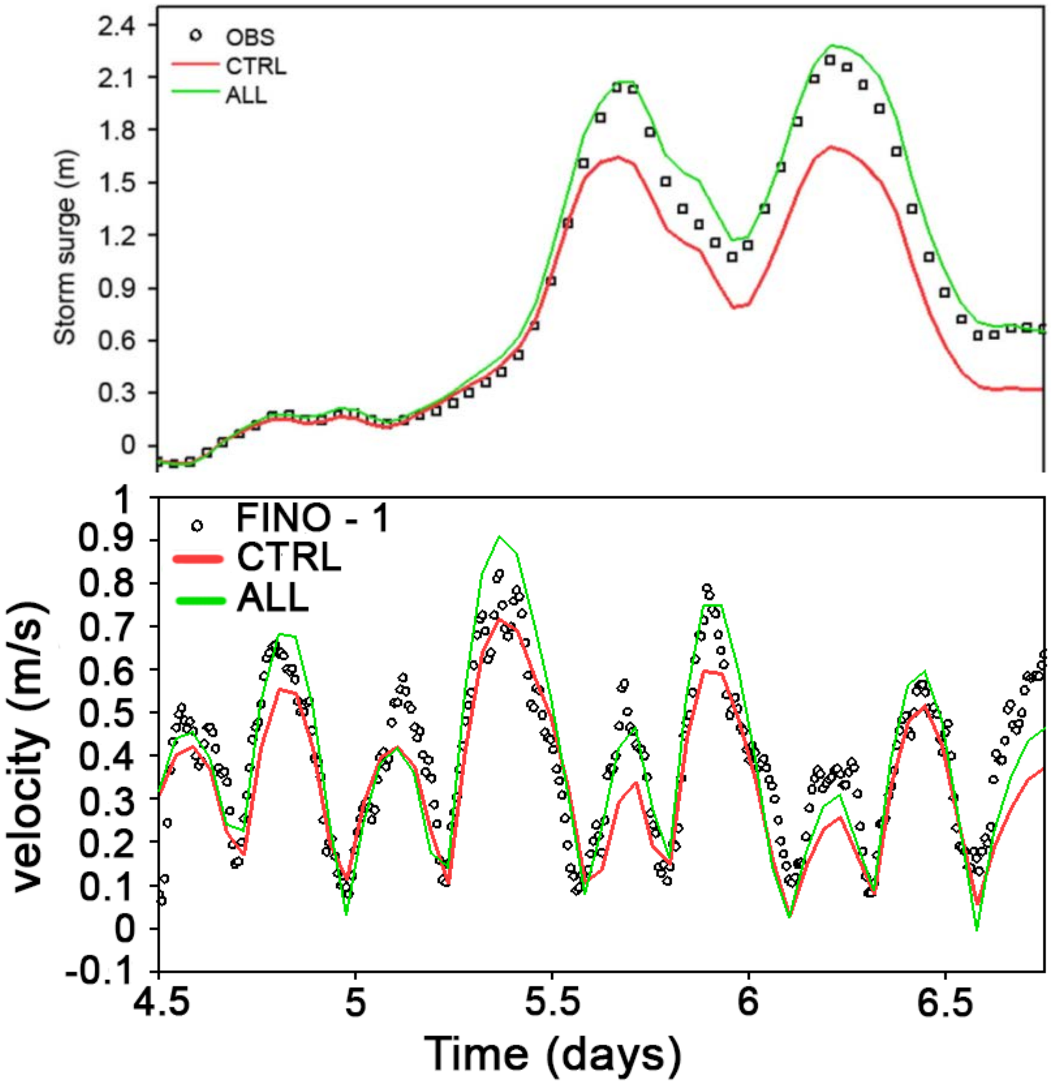
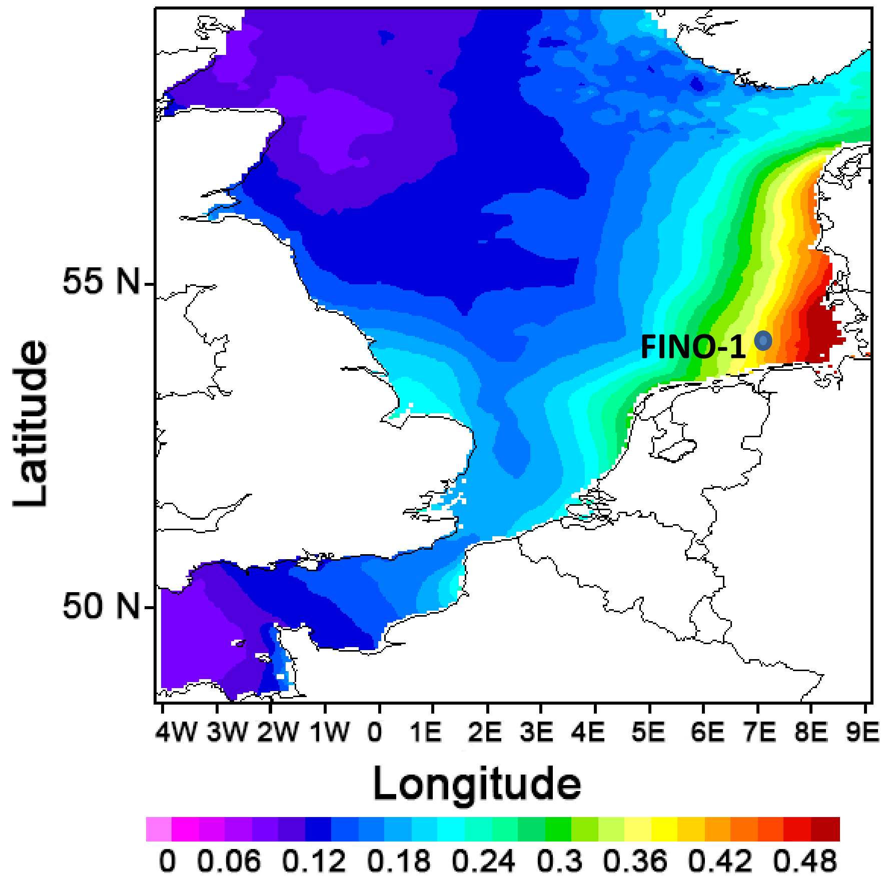


Maximum storm surge difference [m]

COUPLED-NEMO (Xaver, 5-6.12.2013)



- Uncoupled run
- in-situ data
- Wave-circulation coupled run

(Staneva et al, 2017)

The role of wave-induced forcing on particle drift modelling

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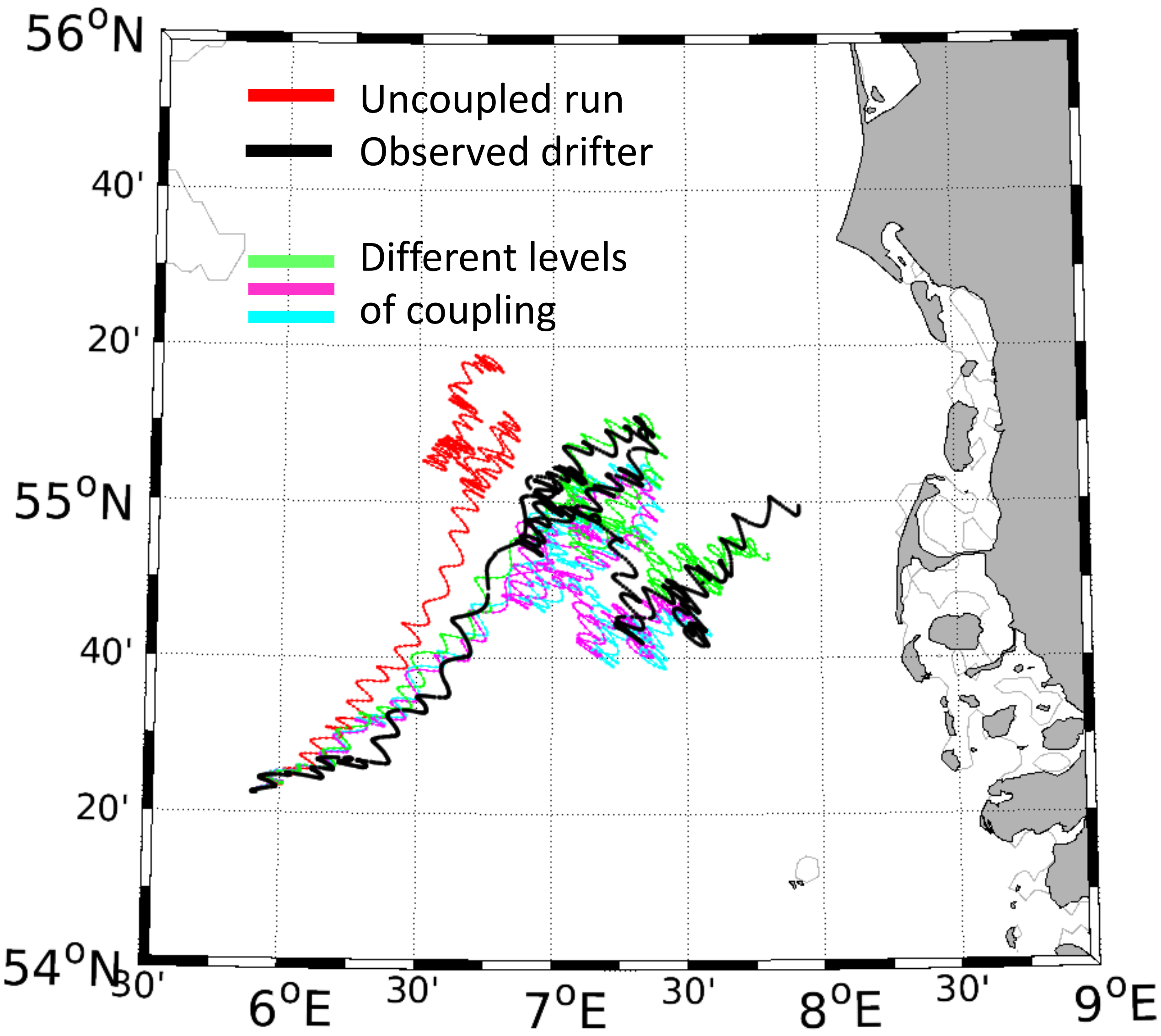
Coupling of waves and circulation models improves drifter simulations



(Staneva et al., 2018)

Impact: Knowledge transfer and outreach activities

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- Collaborative activities:
  national (BSH, DWD, German Navy, ESM), European (H2020-CEASELESS, Wave2NEMO CMEMS, BS-MFC), International (GODAE COSS-TT)
- NEMO-WAVE working group
- Connections with CMEMS Marine Forecasting Centers
- Software and data sharing with UKMO North-western shelf common set-up: NEMO V3.6 r6232 code
- To be included in the Coupled Earth System Model
- Presented at different forums

Summary

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- For the first time, a coupled NEMO-WAM model has been setup and applied for the North Sea-Baltic Sea.
- The new wave-induced parameterizations used in the coupled model improve the representation in the upper ocean dynamics and model skill.
- Storm surge and circulation of the NEMO-WAM are in better agreement with observations than the stand-alone NEMO, especially during extremes.
- Effects resulting from the improved treatment of wind waves affect also the thermohaline fields.
- Our new developments enable higher-quality simulations in both operational forecasting and climate research.
- Extensive cooperation with operational centers and scientific organizations, along with publication productivity, manifests the international recognition.

Thank you
for your attention!

Arno Behrens, Heinz Günther, Wolfgang Koch, Emil Stanev, Kathrin Wahle, Sebastian Grayek, Oliver Krüger , Corinna. Schrum (HZG, Germany)

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Luigi Cavaleri, Paolo Pezzutto (CNR, Italy)

Huw Lewis, Juan Castillo (UKMO, UK)

Victor Alari (MSI, Estonia)

V. Kourafalou (RSMAS, U. Miami, USA)

Related scientific publications

Helmholtz-Zentrum Geesthacht
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- Cavaleri L. Bidlot, J., Staneva J. et al. (2018). Wave modelling in coastal and inner seas, Progress in Oceanography, under review
- Alari V, Staneva J, Breivik O, Bidlot JR, Mogensen K and Janssen PAEM (2016). Response of water temperature to surface wave effects in the Baltic Sea: simulations with the coupled NEMO-WAM model. Ocean Dynamics, DOI 10.1007/s10236-016-0963-x
- Kourafalou V., P. De Mey, J. Staneva, N. Ayoub, A. Barth, Y. Chao, M. Cirano, J. Fiechter, M. Herzfeld, A. Kurapov, A.M. Moore, P. Oddo, J. Pullen, A. van der Westhuysen, and R.H. Weisberg, Coastal Ocean Forecasting: science foundation and user benefits, Journal of Operational Oceanography Vol. 8 , Iss. sup1,2015, Pages s147-s167, doi:10.1080/1755876X.2015.10223488, 147.
- Le Traon et al. (2017), The Copernicus Marine Environmental Monitoring Service: Main Scientific Achievements and future Prospects. Mercator Ocean Journal #56, CMEMS Special Issue
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- Staneva J, Wahle K, Koch W, Behrens A, Fenoglio-Marc L., and Stanev E., (2016). Coastal flooding: impact of waves on storm surge during extremes – a case study for the German Bight, Nat. Hazards Earth Syst. Sci., 16, 2373-2389, doi:10.5194/nhess-16-2373-2016
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- Wahle, K., Staneva, J., Koch, W., Fenoglio-Marc, L., Ho-Hagemann, H. T. M., and Stanev, E. V., (2017). An atmosphere–wave regional coupled model: improving predictions of wave heights and surface winds in the southern North Sea, Ocean Sci., 13, 289-301, doi:10.5194/os-13-289-2017