North Sea-Baltic Sea regional models: coupling of ocean and atmosphere through a dynamic wave interface

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MedCORDEX-Baltic Earth-COST Workshop
12-23 February, Hamburg

Relevance of atmosphere-ocean-wave coupling

- Increased interest in reducing prediction errors of state estimates at coastal scales, which in many cases are due to unresolved nonlinear feedback between wind-waves, circulation and atmosphere

- Assessment of the degree of regional coupling

- Study the impact of interaction processes between wind waves, atmosphere and ocean on the quality of coastal ocean simulations

- Substantial effects also on mean fields - energy and momentum transfer

- Extreme weather events in the marine realm

GCOAST
Geestacht COAstal model SysTem

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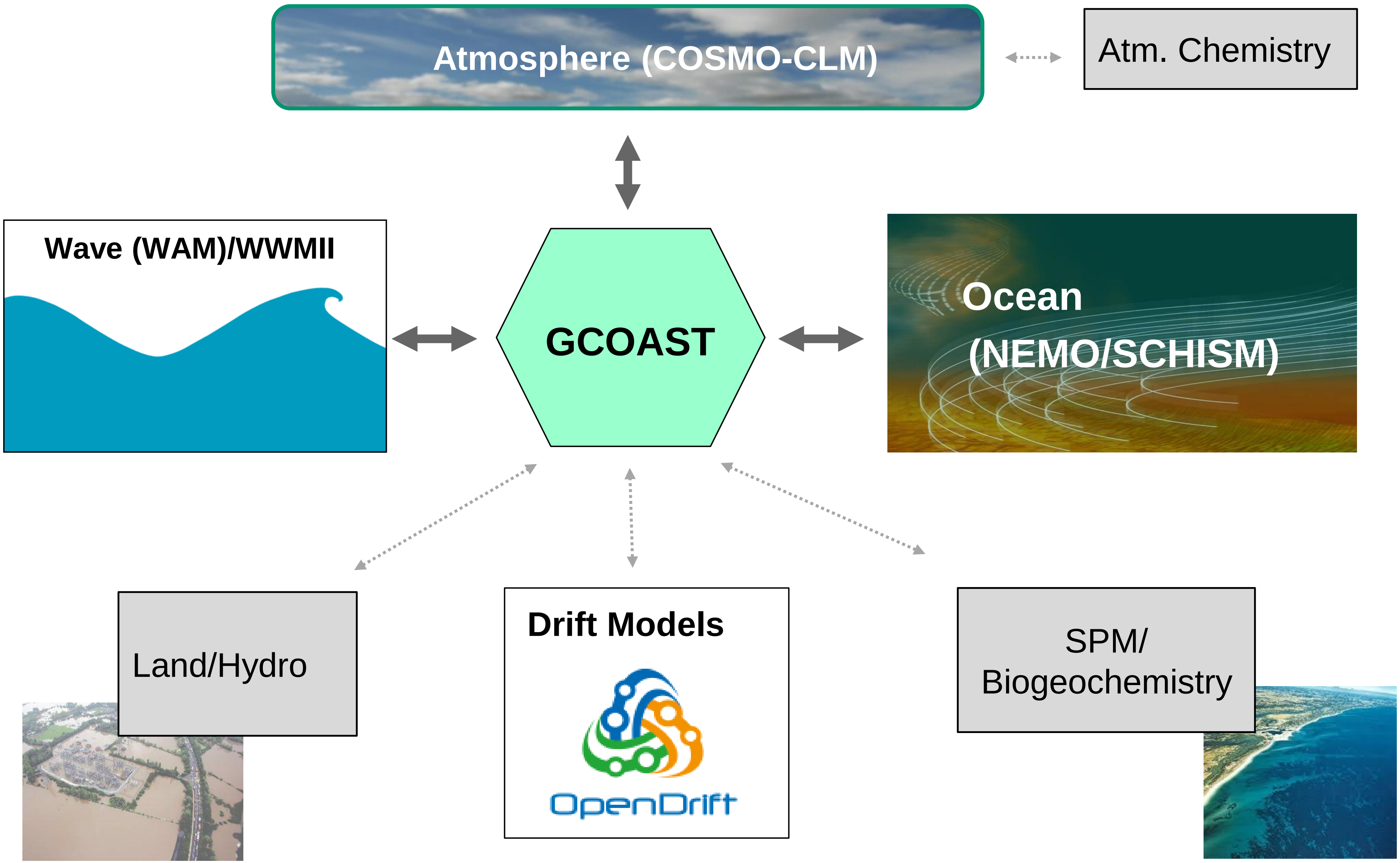

Coupled Model Setup

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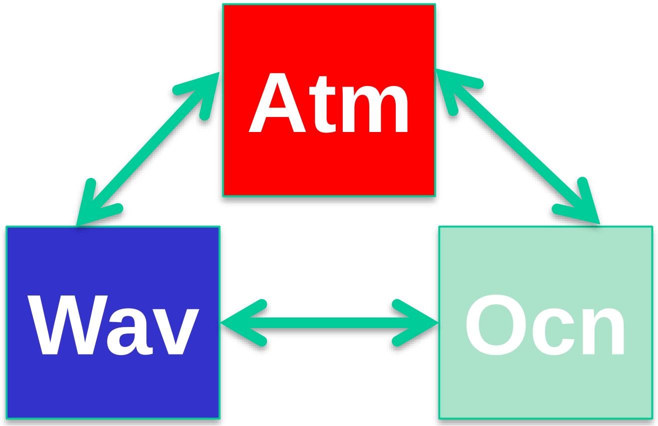
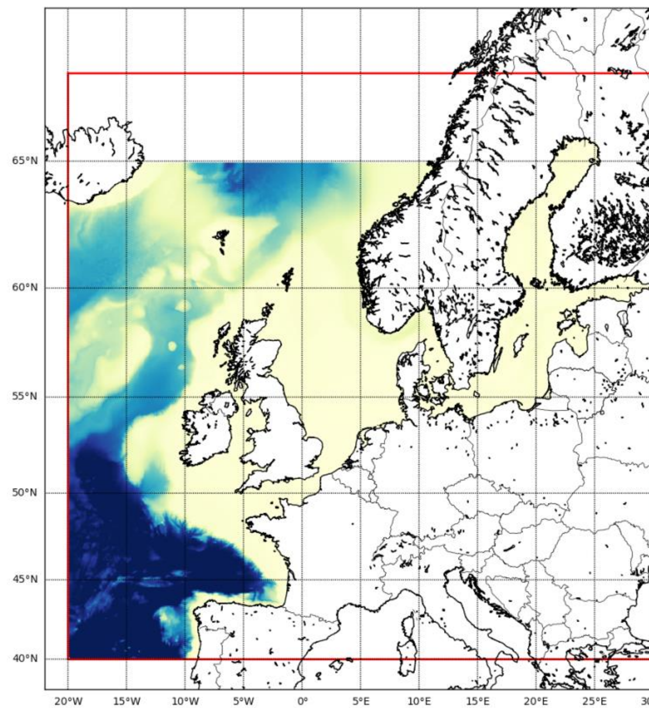
	NEMO 3.6	WAM 4.6.2	COSMO
Horizontal grid	3.5 km covering North Sea and Baltic Sea, 900 m German bight	Same	7 km covering NW European seas
Vertical grid	56 s layers, emphasis on surface	N/A	55 levels
Initial field	CMEMS UKMO Data	EWAM wave data	COSMO-EU Model
Boundary condition	OSU tides, CMEMS UKMO Data for T,S, u,v, SLH	EWAM wave data	NCEP data
Forcing	DWD, ERA-I, ERA-5, COSMO	Same	ERA Boundary data
Vertical diffusion scheme	GLS (*k-eps*)	N/A	
Ice	LIM-3	WAM ice parameterization	NA





External Forcing

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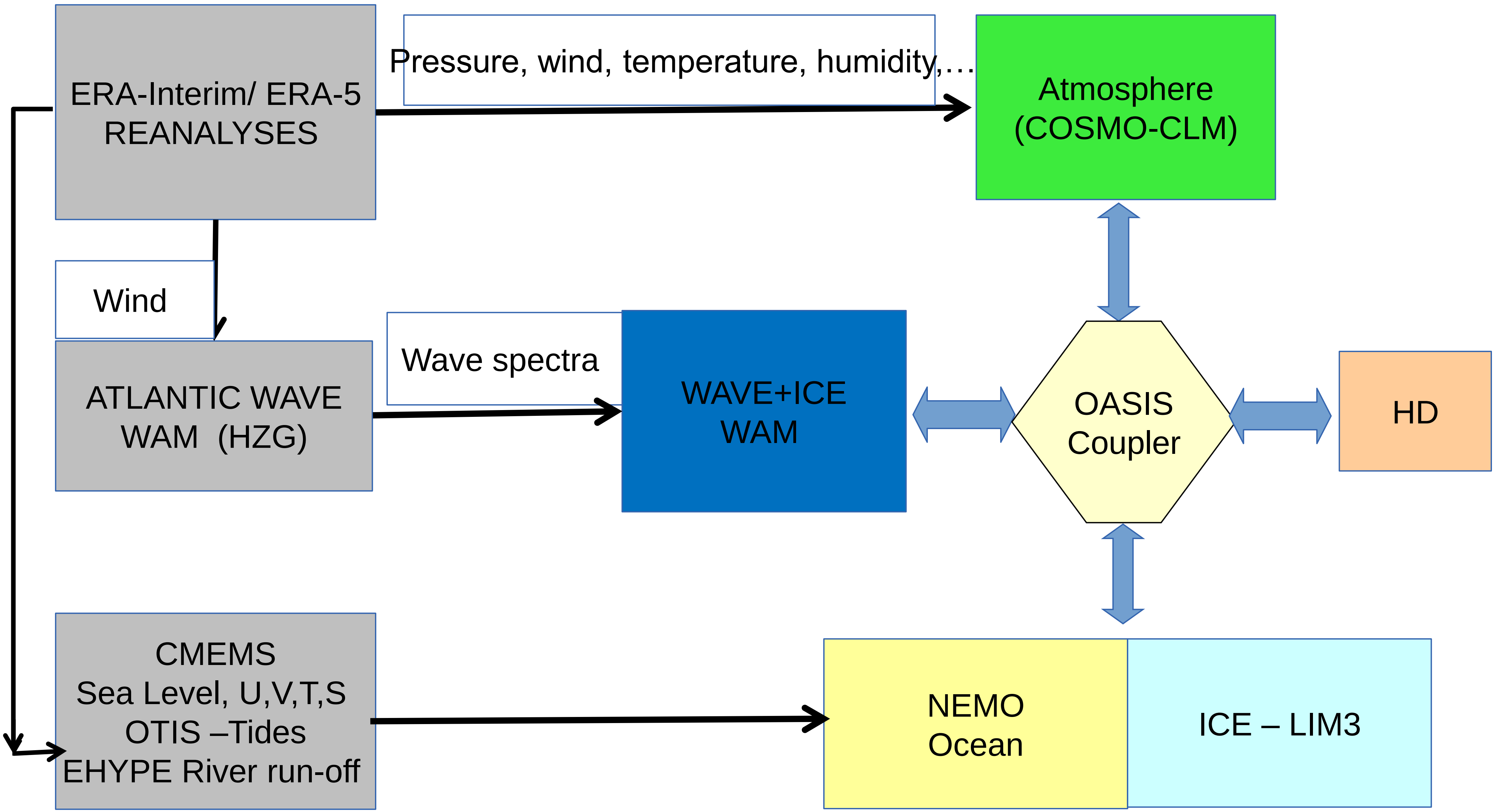

Regional Downscaling via OASIS

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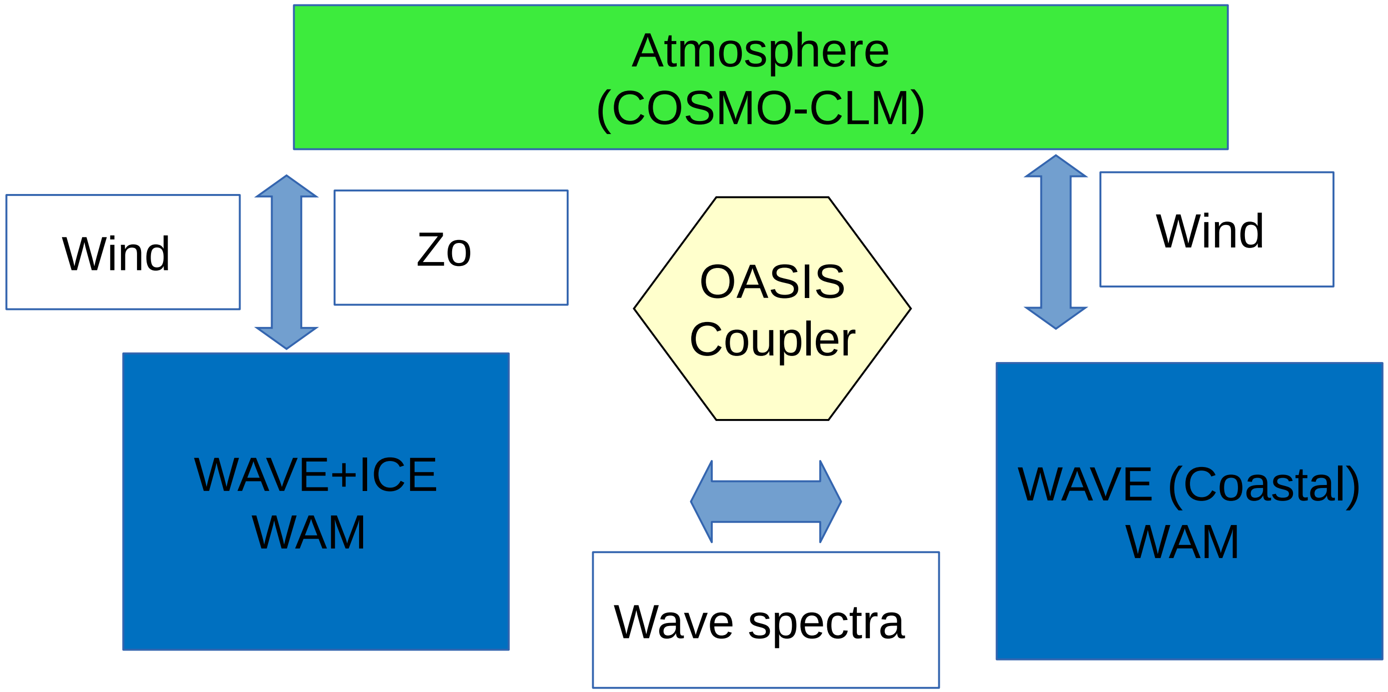
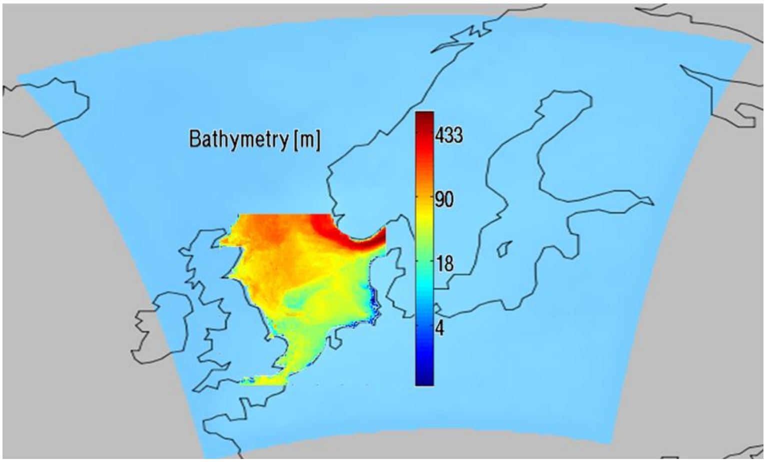
→Waves extract energy and momentum from the atmosphere.
→The effect is largest for young sea states and high wind speeds.

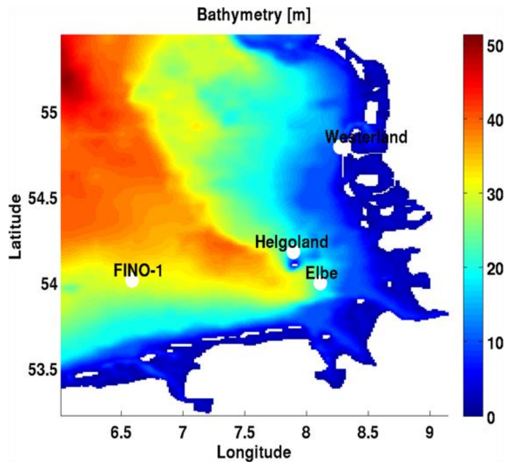


$$U(z) = \sqrt{\frac{\tau}{C_D(z)}}$$

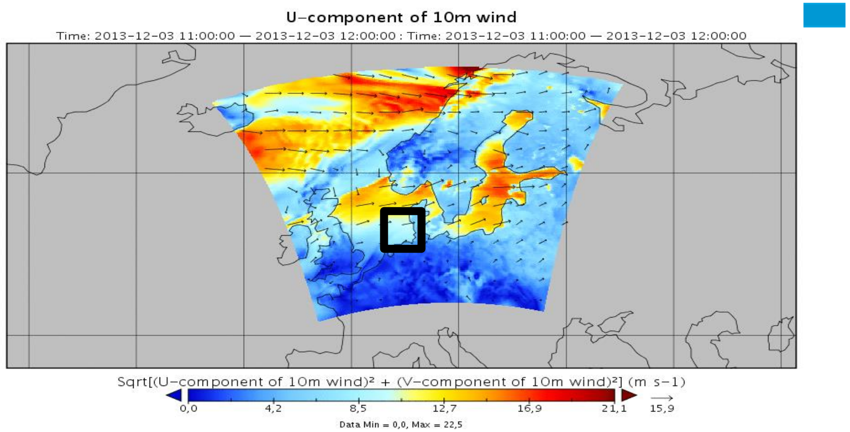
$$C_D(z) = \frac{\kappa^2}{ln^2(z/z_0)}$$

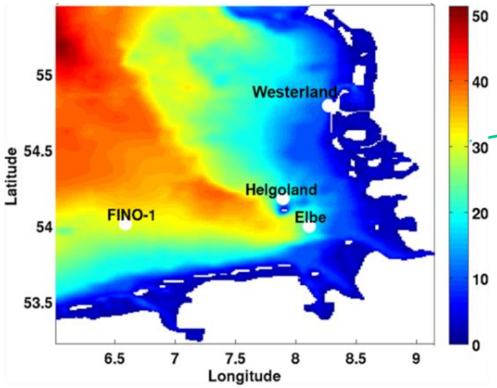
$$z_0 = \frac{\alpha\tau}{g} = \frac{1}{\sqrt{1-\tau_w/\tau}}$$

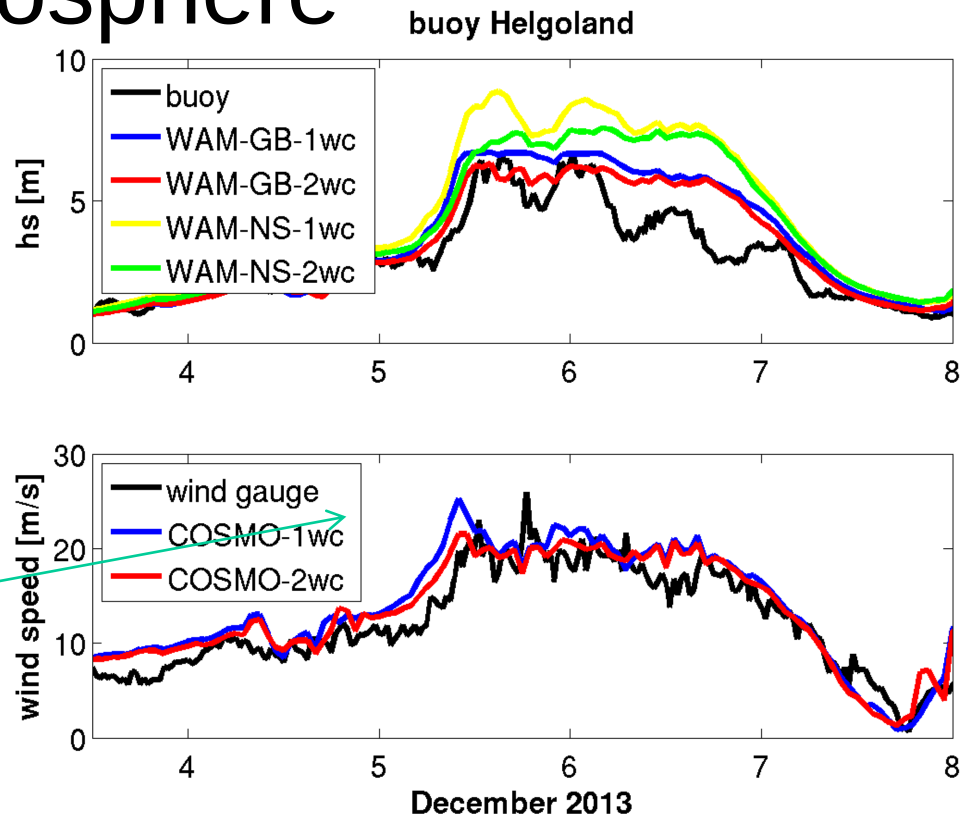




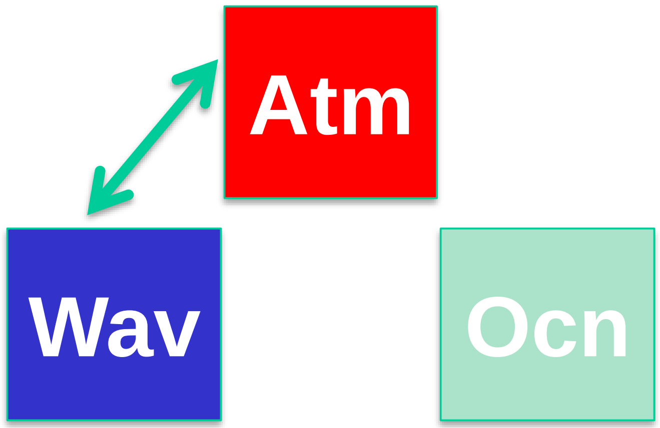
Impact of two-way coupling between waves and atmosphere







mean hs	Hel:1.95		Fino-1:1.42		Wes: 1.63	
	1-way	2-way	1-way	2-way	1-way	2-way
bias hs [m]	-0.14	-0.03	-0.07	-0.01	-0.13	-0.03



Wahle et al. (2017),

The role of wave-atmosphere coupling

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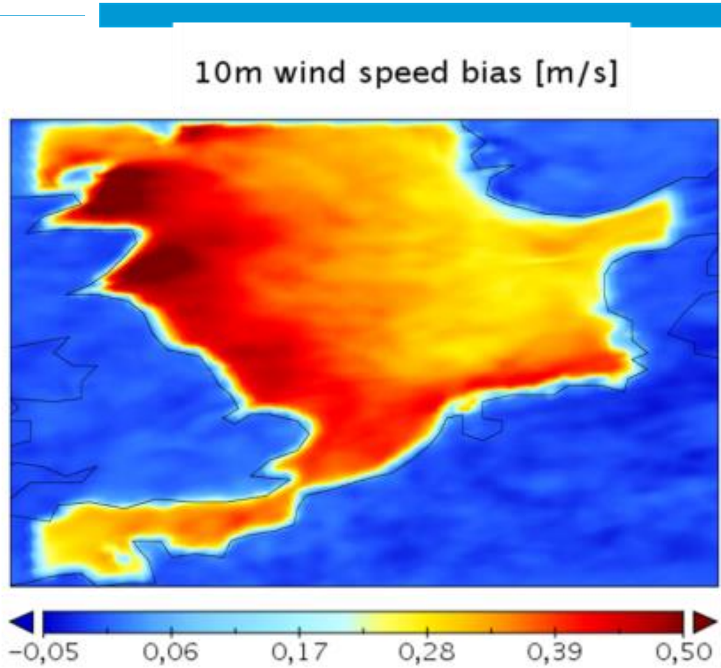
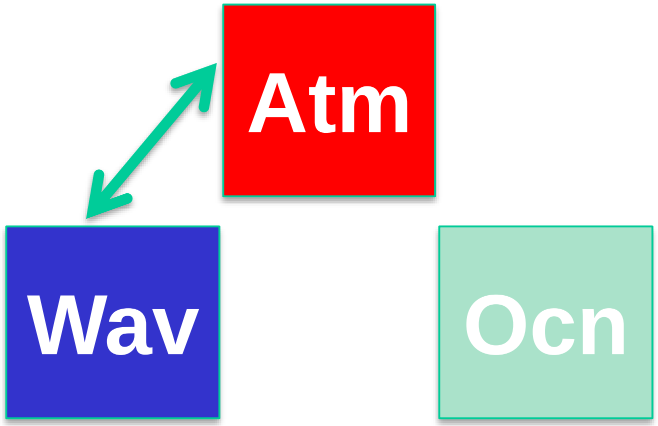
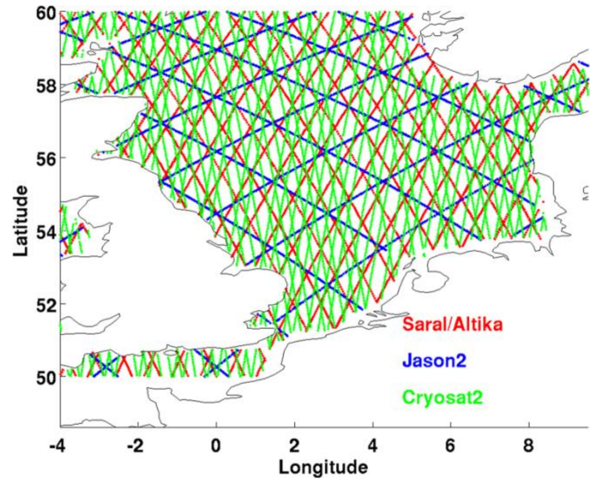
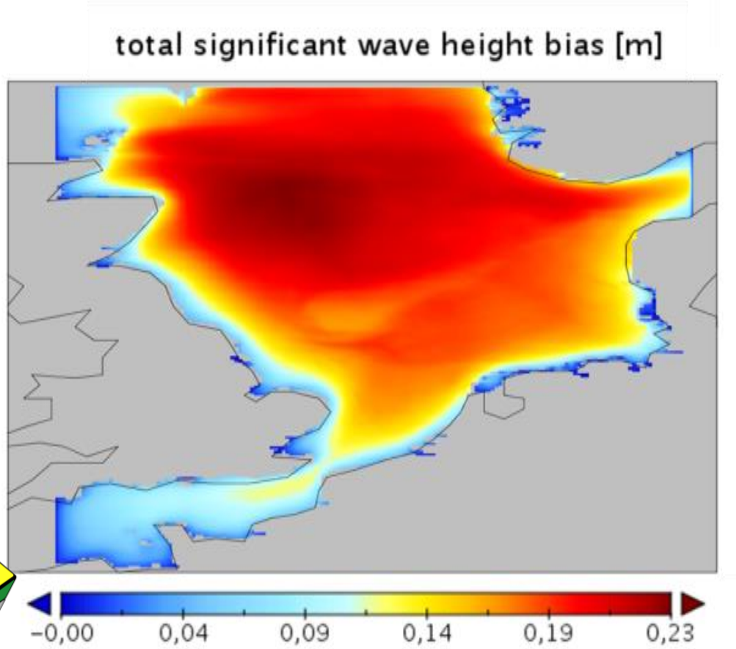








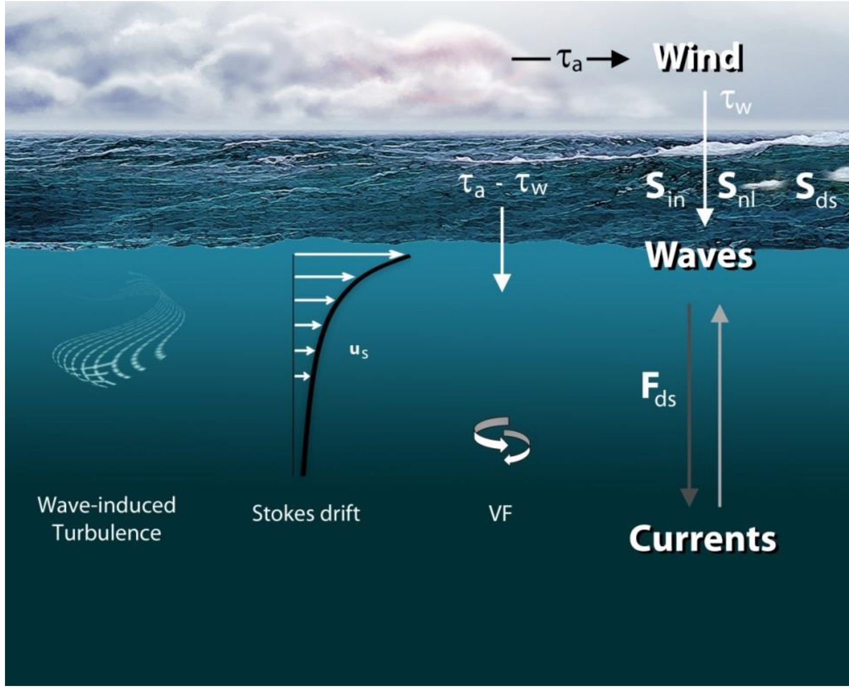
	Significant wave height		Windspeed [m/s]	
	one-way	two-way	one-way	two-way
Saral/AltiKa # 6886				
bias	-0.27	-0.12	-0.64	-0.33
std. dev.	0.93	0.86	3.33	3.16
Jason2 # 6710				
bias	-0.29	-0.15	-0.73	-0.40
std. dev.	1.07	1.01	3.85	3.75

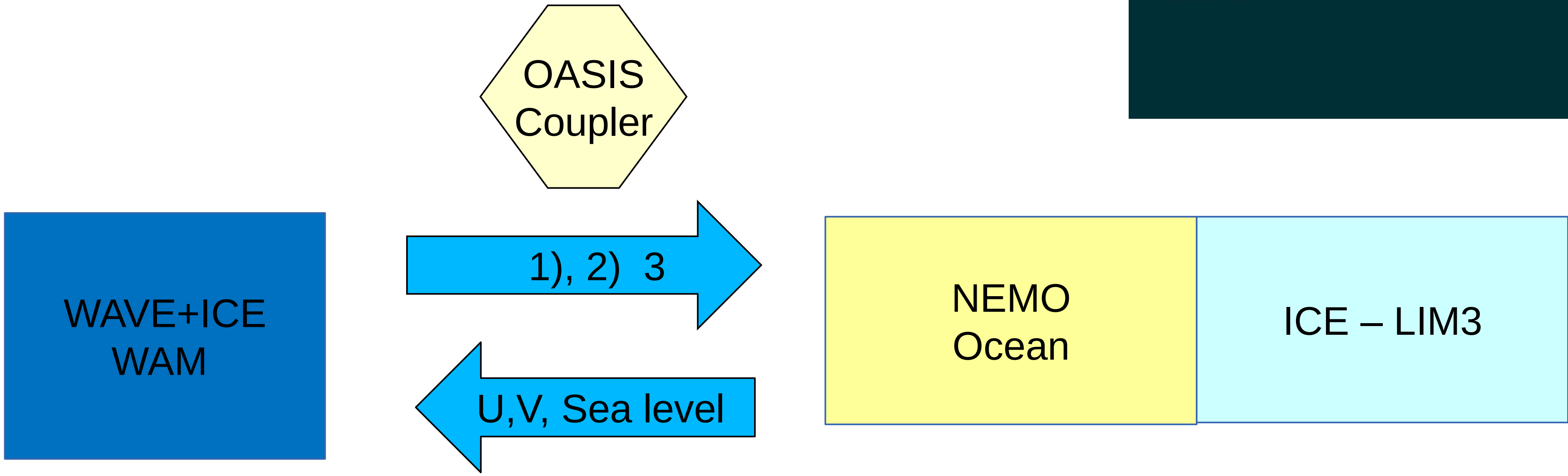
Wave-current interaction:

(1) The Stokes-Coriolis forcing (Hasselmann, 1970; Breyvik, 2015, 2016)

(2) Sea state dependent momentum flux (Janssen, 1989; Janssen, 2012, Staneva et al., 2016, 17);

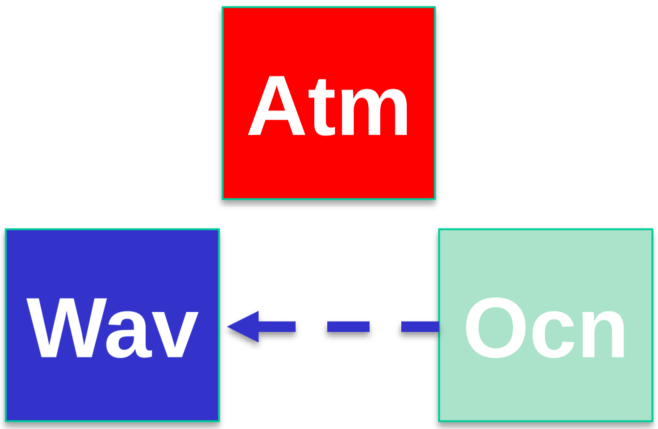
(3) Sea state dependent energy flux (Craig and Banner, 1994)

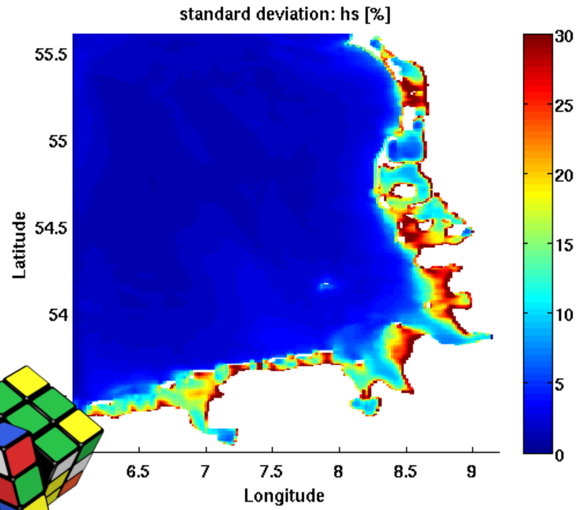


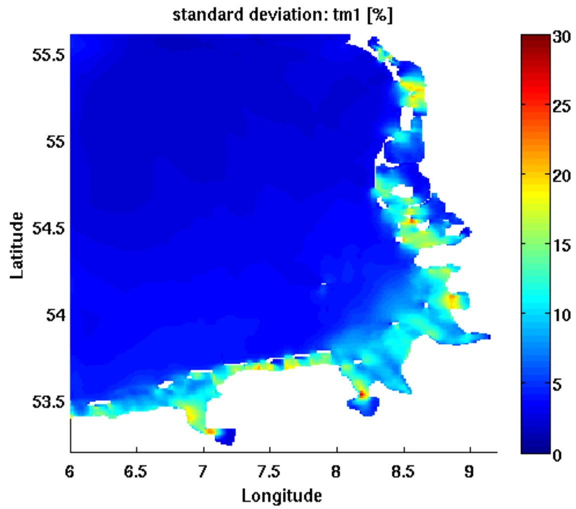


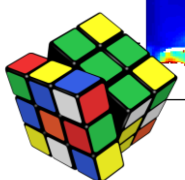
Impact of coupling of hydrodynamics on waves

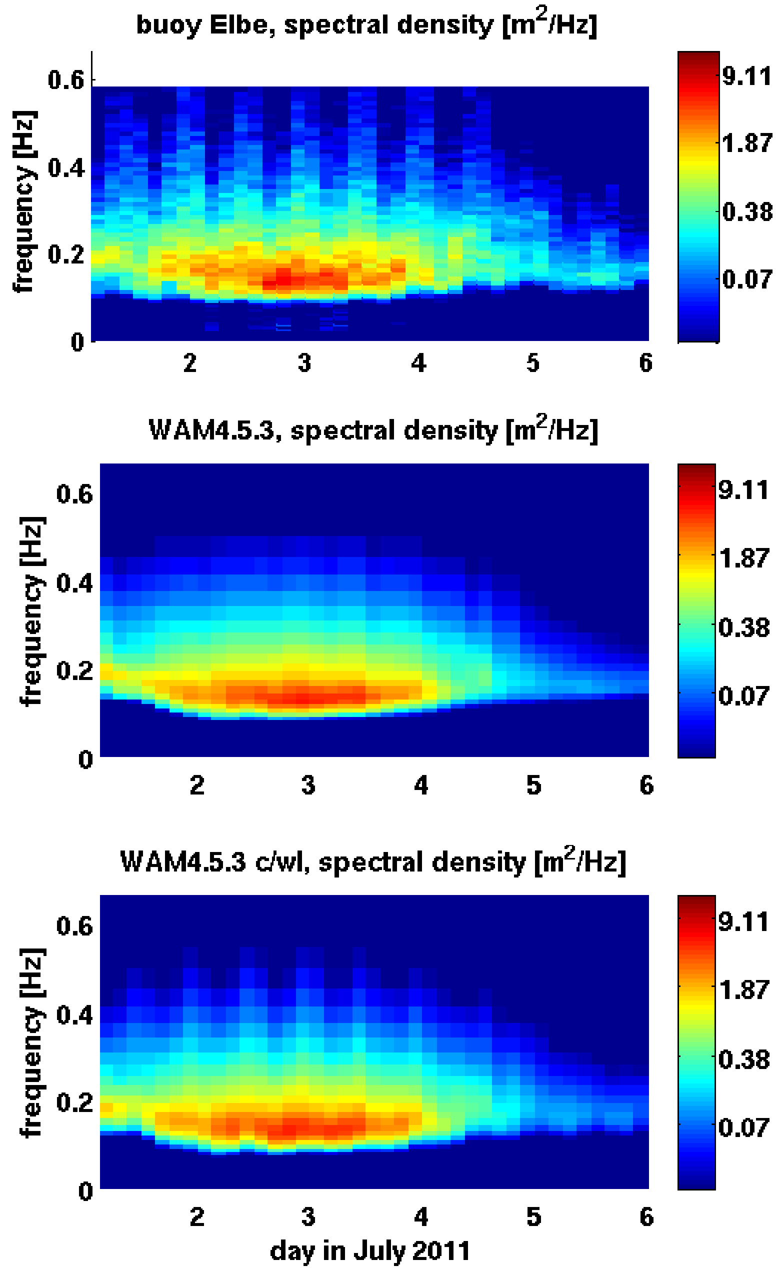
- in the open North Sea nearly no difference is found
- significant differences (30% hs, 10-15% tm1) near the coast and in the Wadden Sea
  (mainly due to water depth changes)
- small areas where STD of tm1 up to 30% (Doppler Shift)



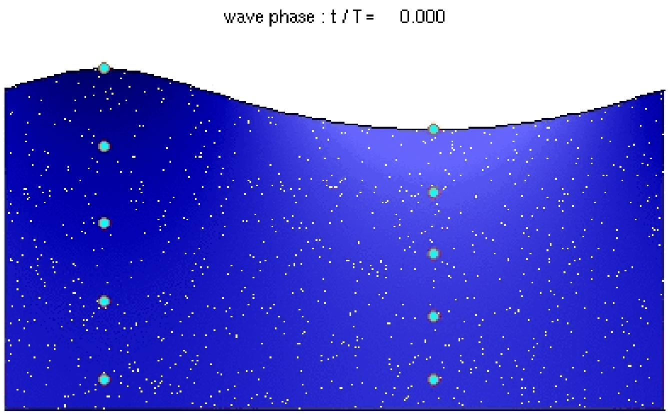




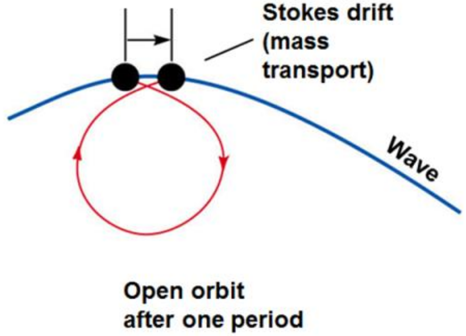




Stokes-Coriolis forcing



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



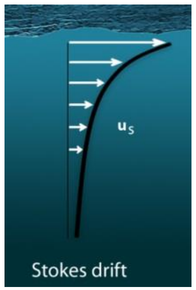
The Stokes drift –> WAM

Momentum equations
in NEMO:

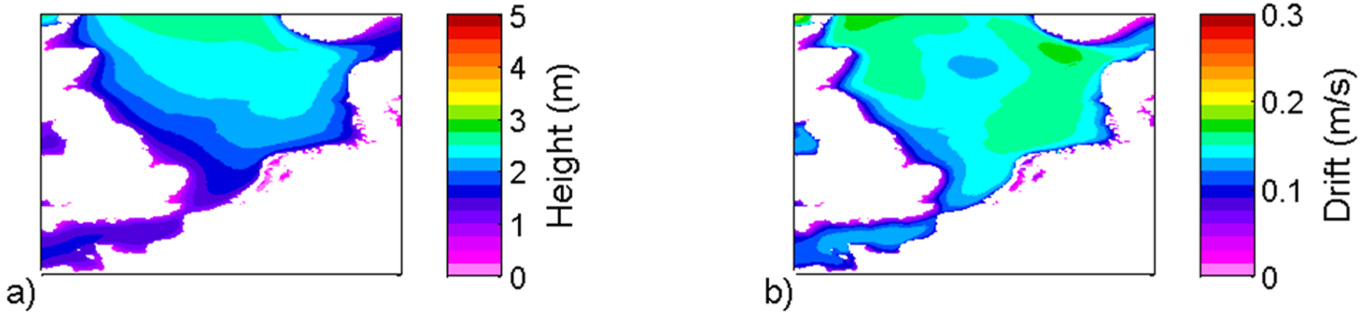
$$\frac{D\mathbf{u}}{Dt} = -\frac{1}{\rho}\nabla p + (\mathbf{u} + \mathbf{v}_S) \times f\hat{\mathbf{z}} + \frac{1}{\rho}\frac{\partial \tau}{\partial z}$$

New Phillips approximations

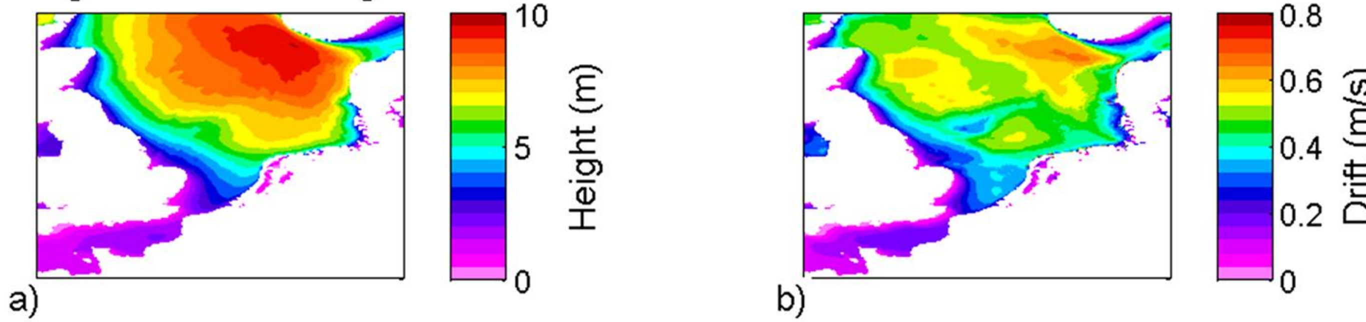
Breyvik et al., 2016



October-December, 2013



Storm Xaver, 5-6 December, 2013



Staneva et al. (2017)

Sea state dependent momentum flux

In ocean models - surface stress - bulk formulas:

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

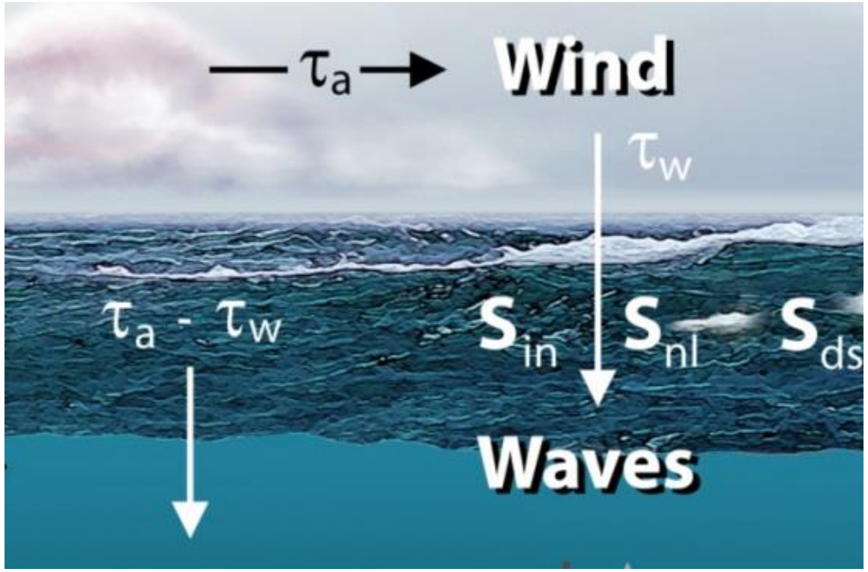
In NEMO: Large and Yeager (2008)

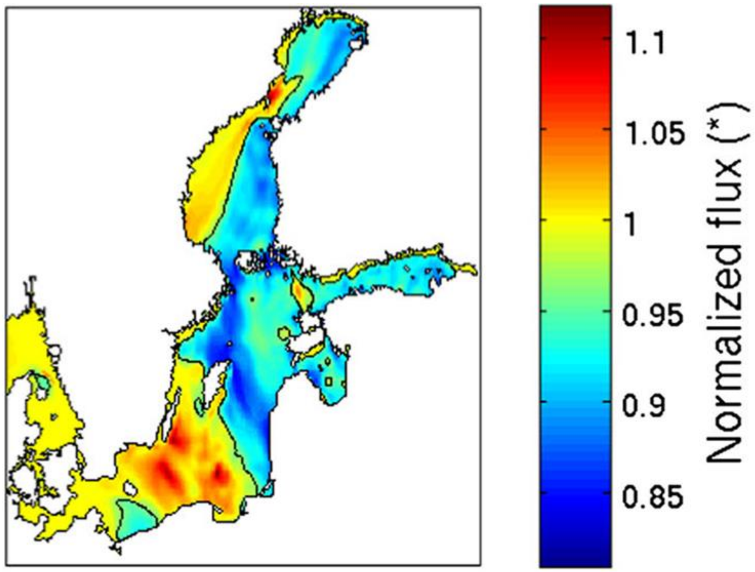
$$C_d = 10^{-3}\left(\frac{2.7}{U_{10}} + 0.142 + \frac{U_{10}}{13.09}\right)$$

TWO wave dependent mechanisms are considered:

1. **wave-modified drag coefficient**, changes the air-side stress
2. **Ocean side stress** - depends on the balance between wave

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





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

Physical processes forming wave-circulation interaction: **breaking waves**

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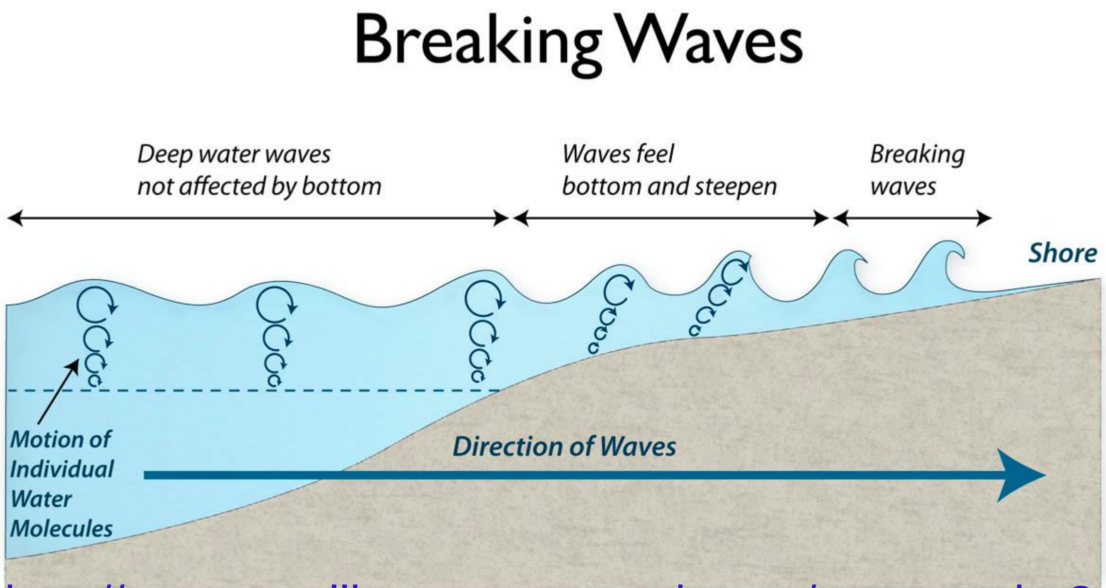
- Craig and Banner (1994):

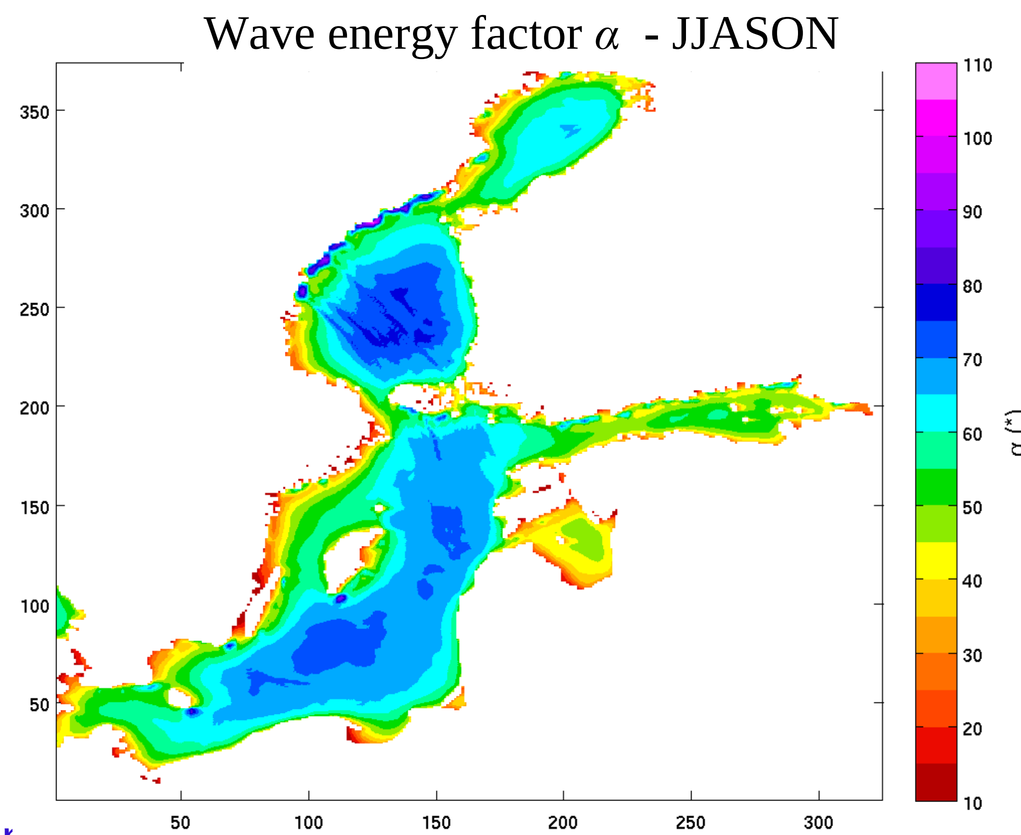
wave breaking - > affects the mixing

in NEMO only : α =100

- According to different studies, e.g.

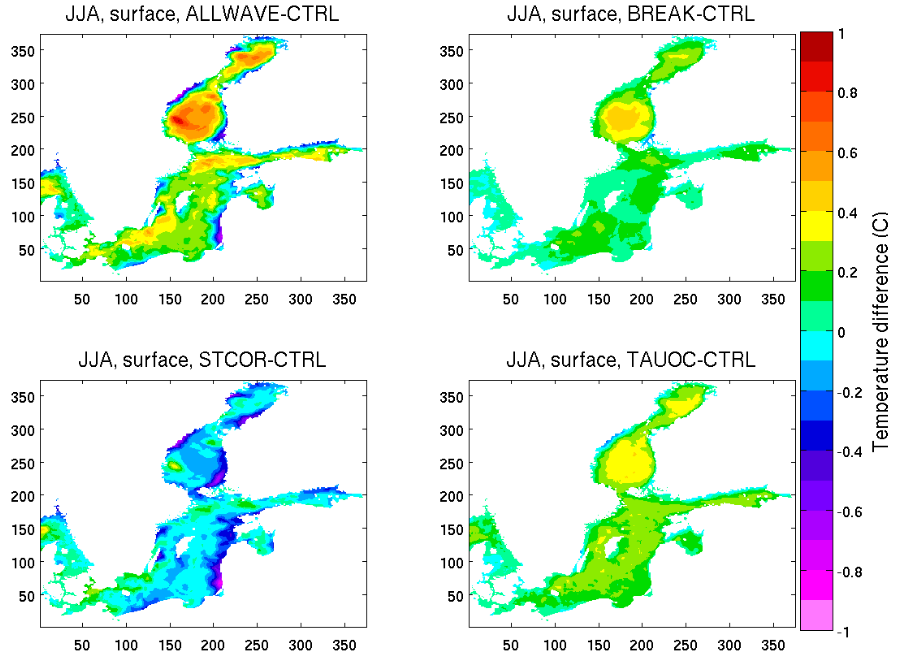
Mellor and Blumberg (2004): α ~57-146

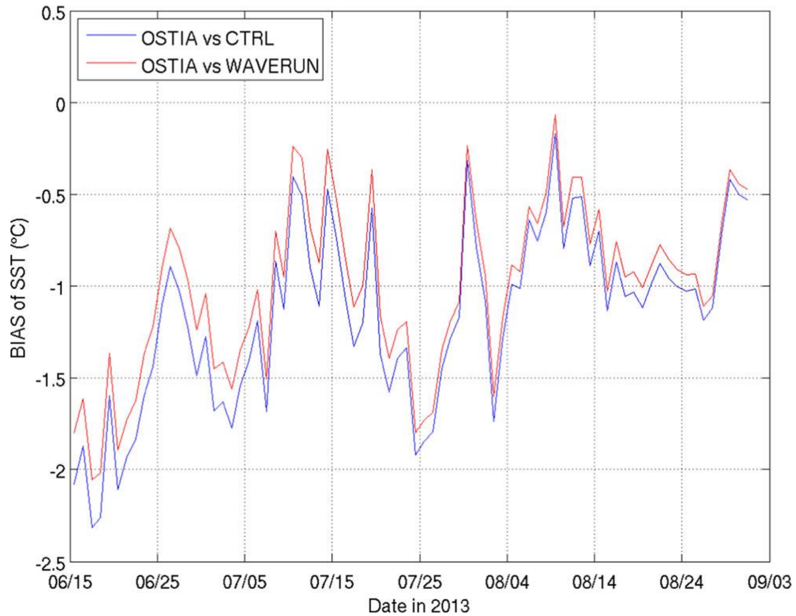


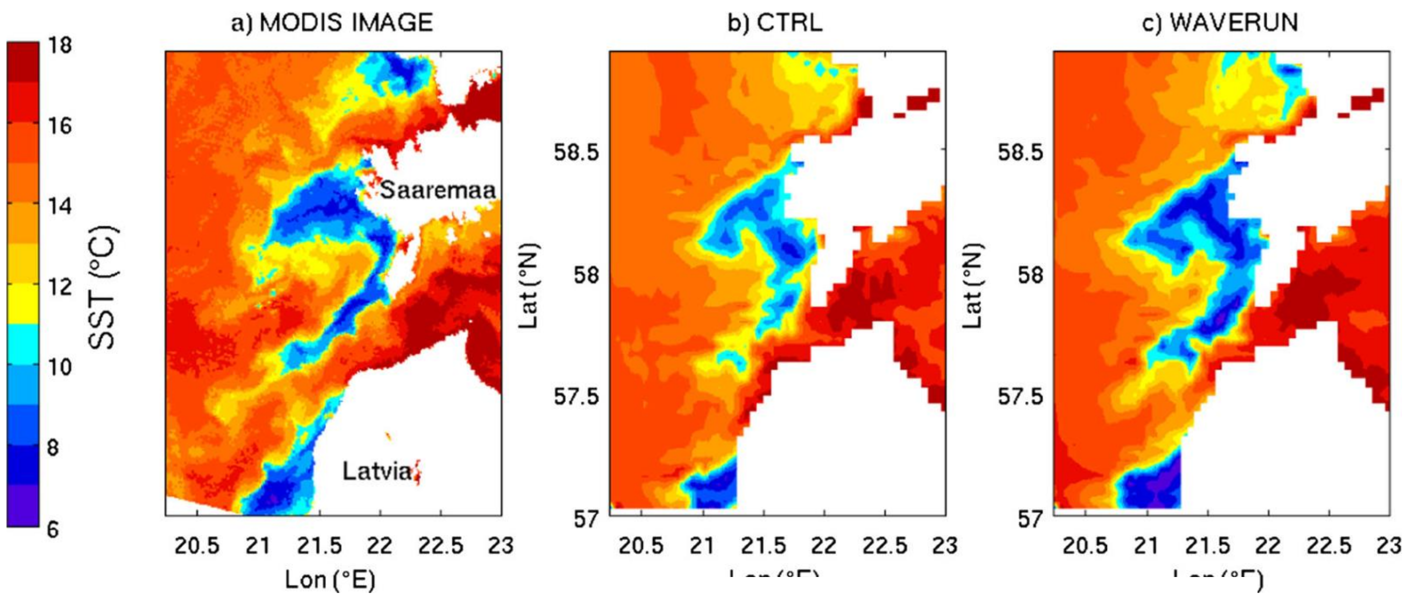


http://www.satellitesportsnetwork.com/content.php?contentID=2934

Baltic Sea: Impact of waves on SST

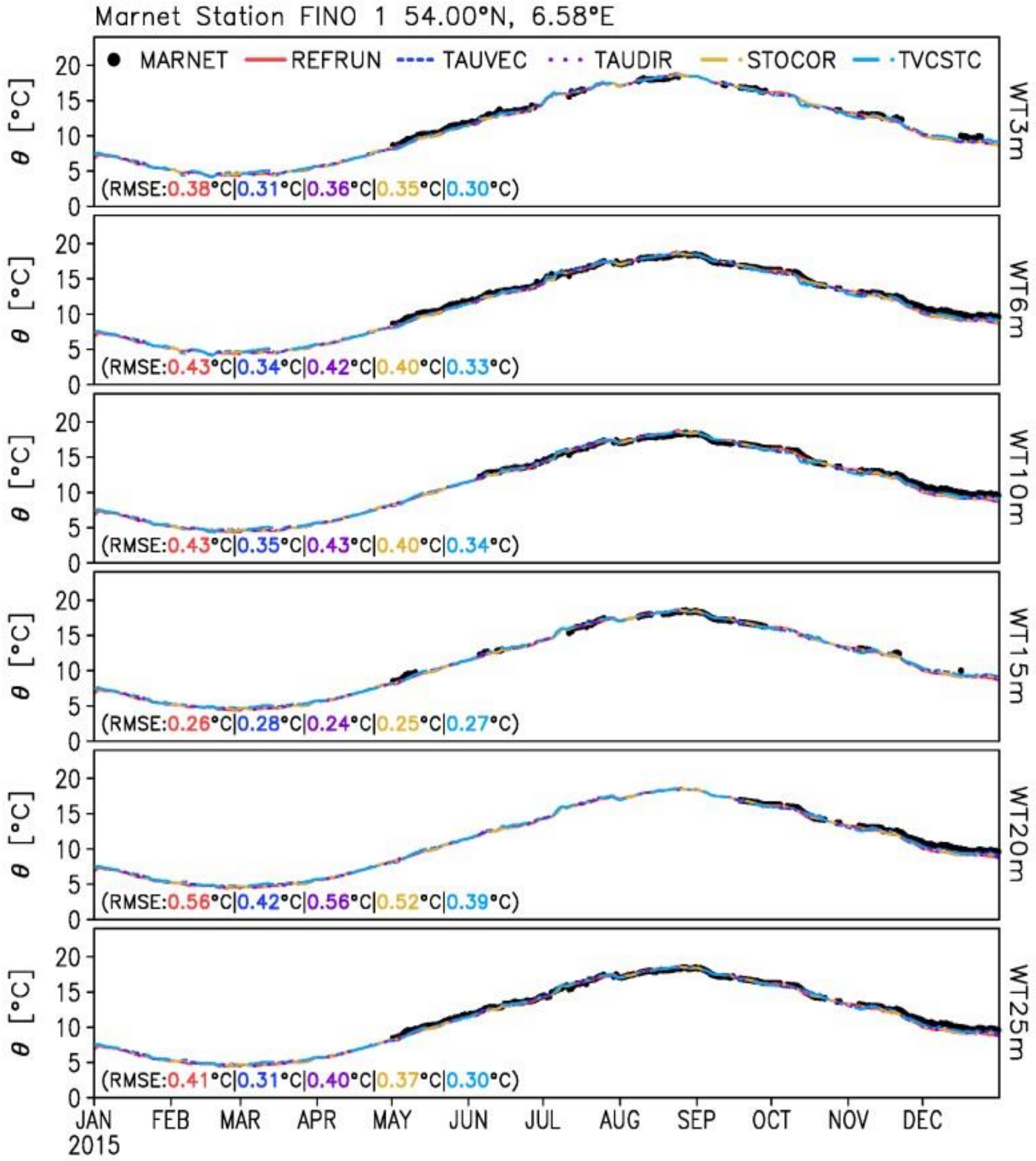


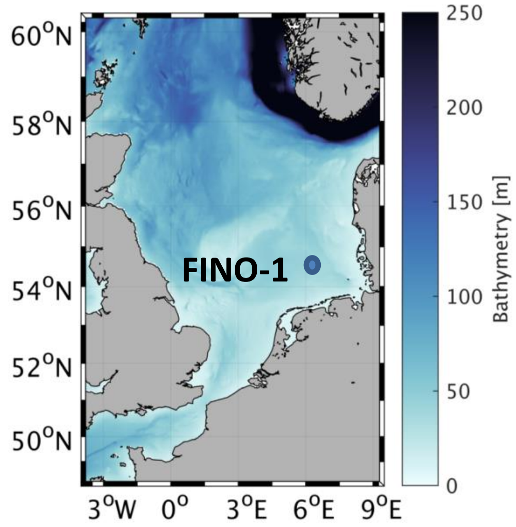


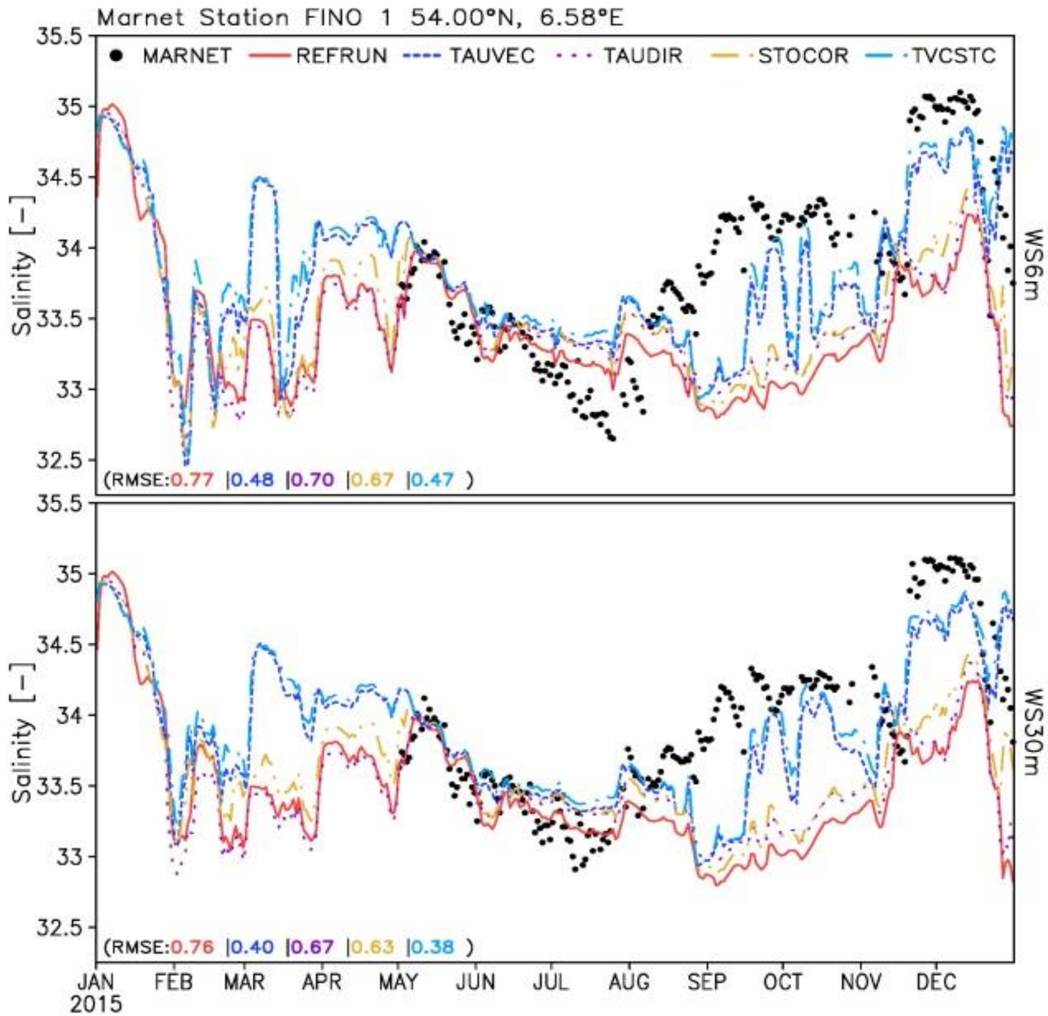


Alari et al (2016)

Impact of waves on T&S
FINO-1 MARNET Station







Impact of wave-induced forcing on sea level during storm Xaver (5-6 12.2013)

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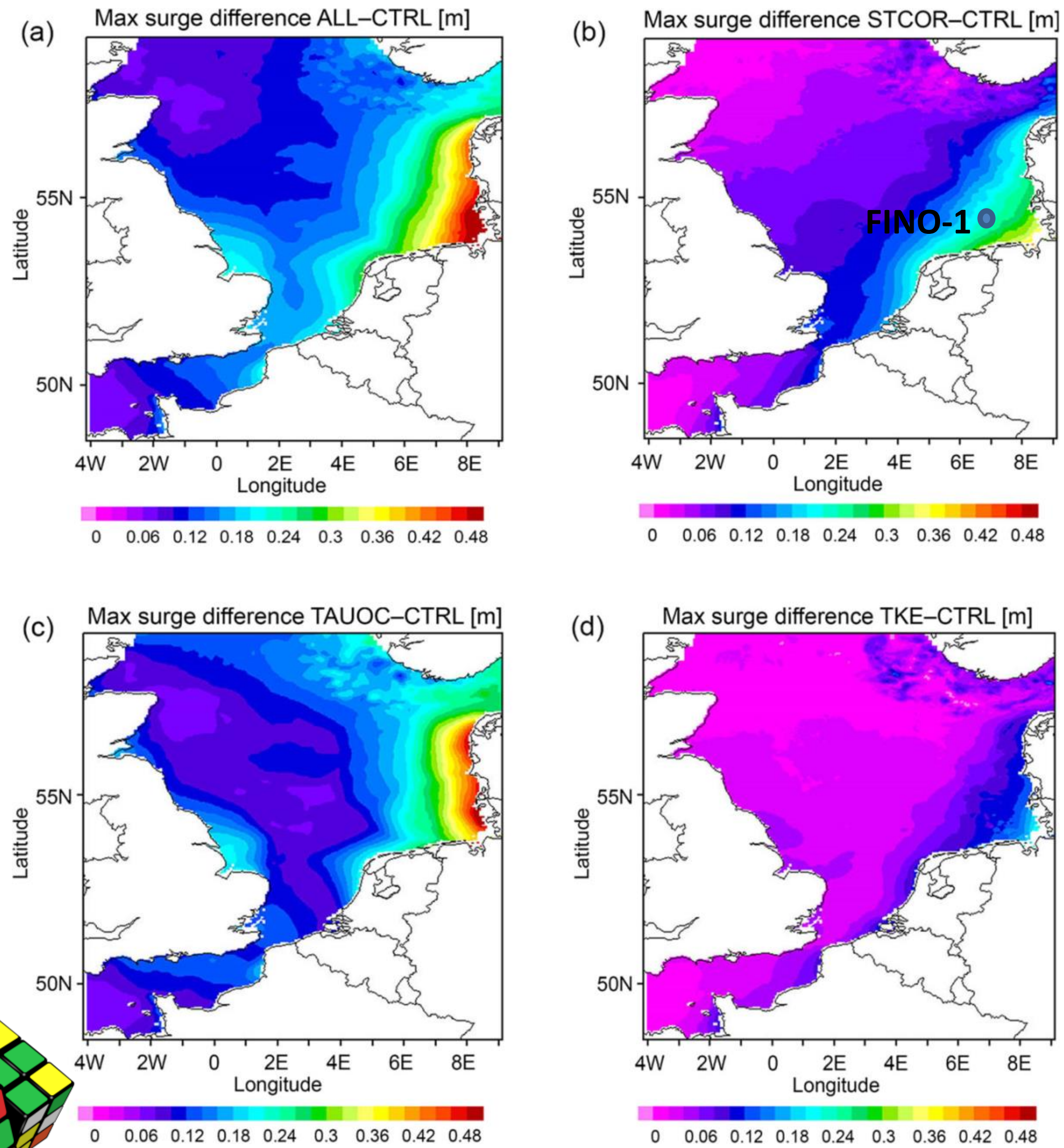
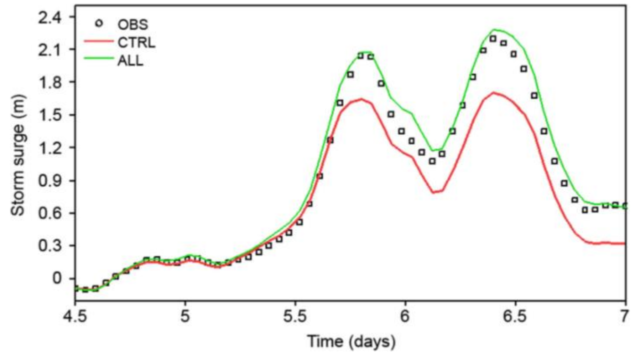
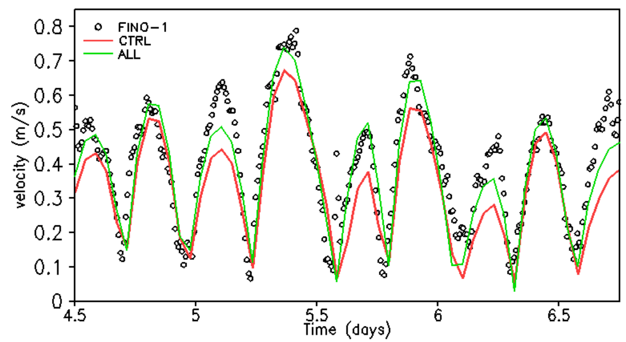
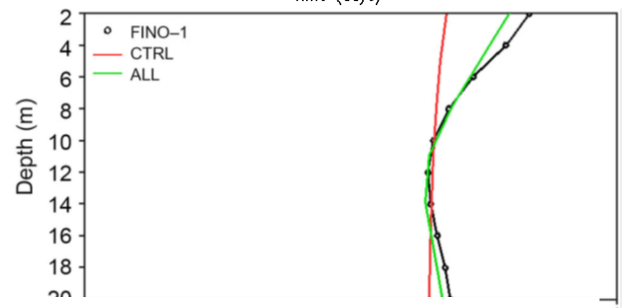
Maximum surge difference (m)



Storm surge and velocity at FINO-1 Station: NEMO (red), NEMO_WAM (green) and observations







Staneva et al. (2017)

Impact of wave-induced forcing on Sea Level
Different meteoconditions during 2016

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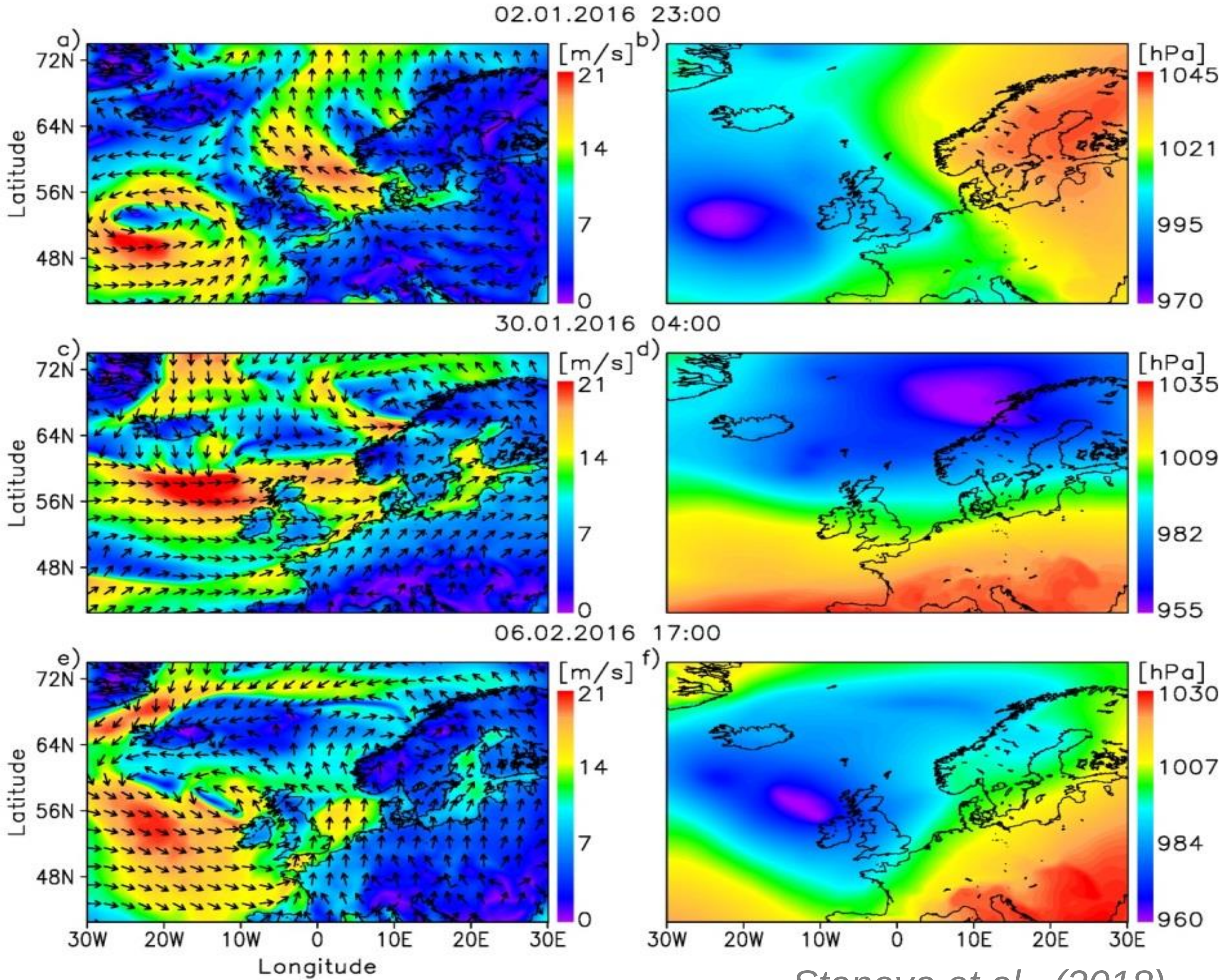

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Staneva et al., (2018)

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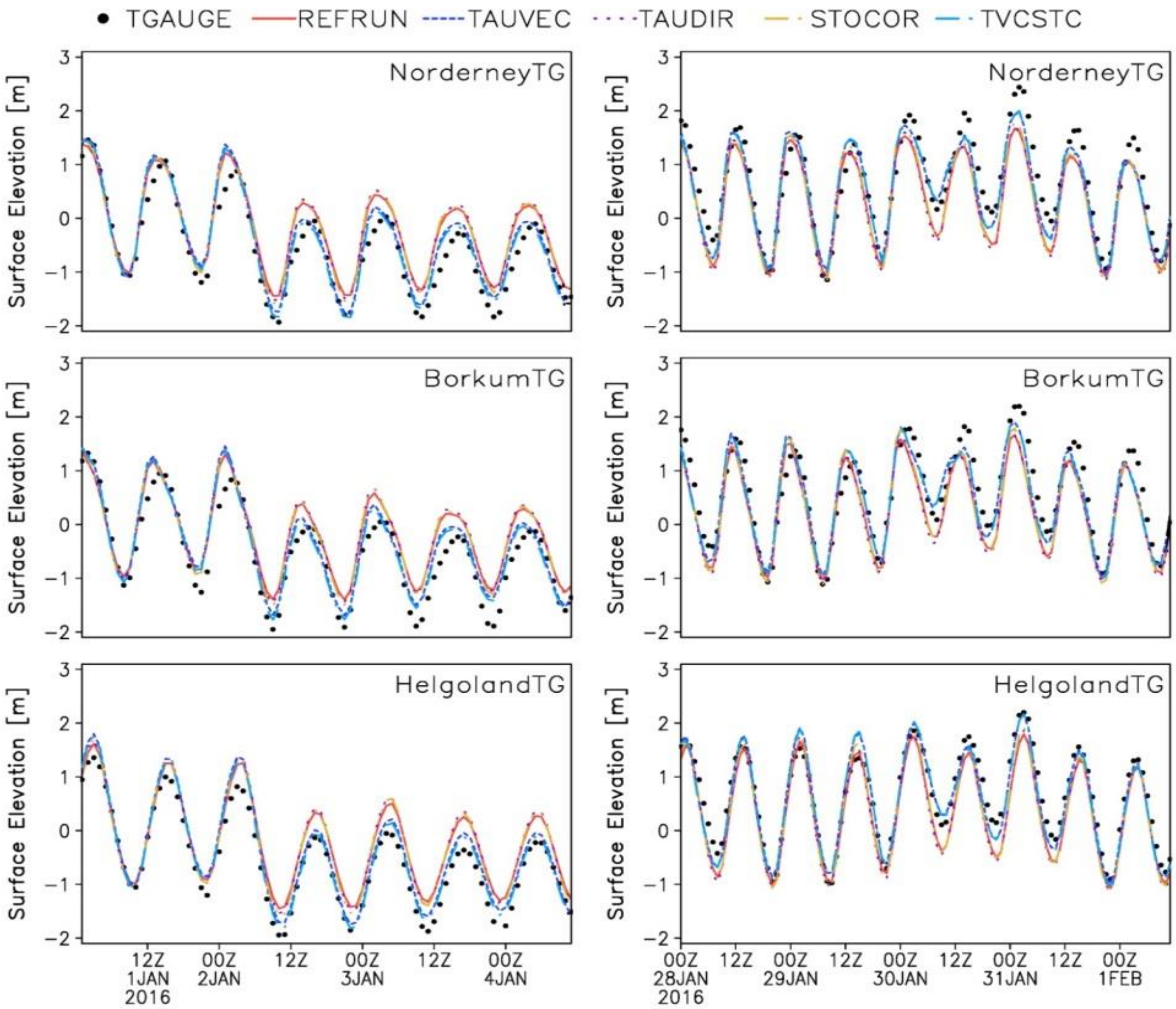

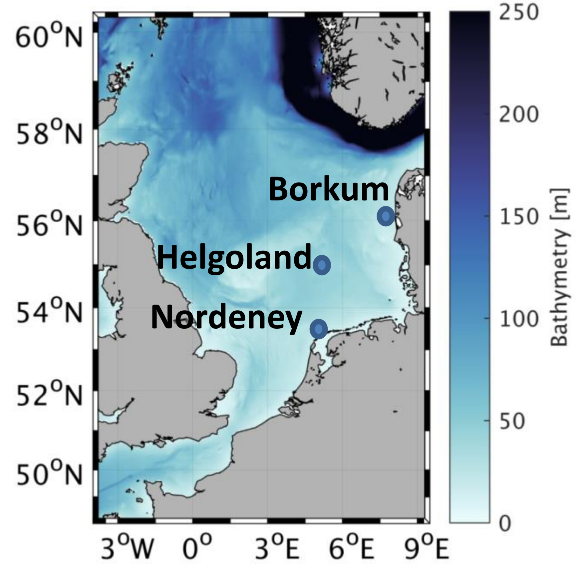

The role of wave-induced processes in particle drift modelling

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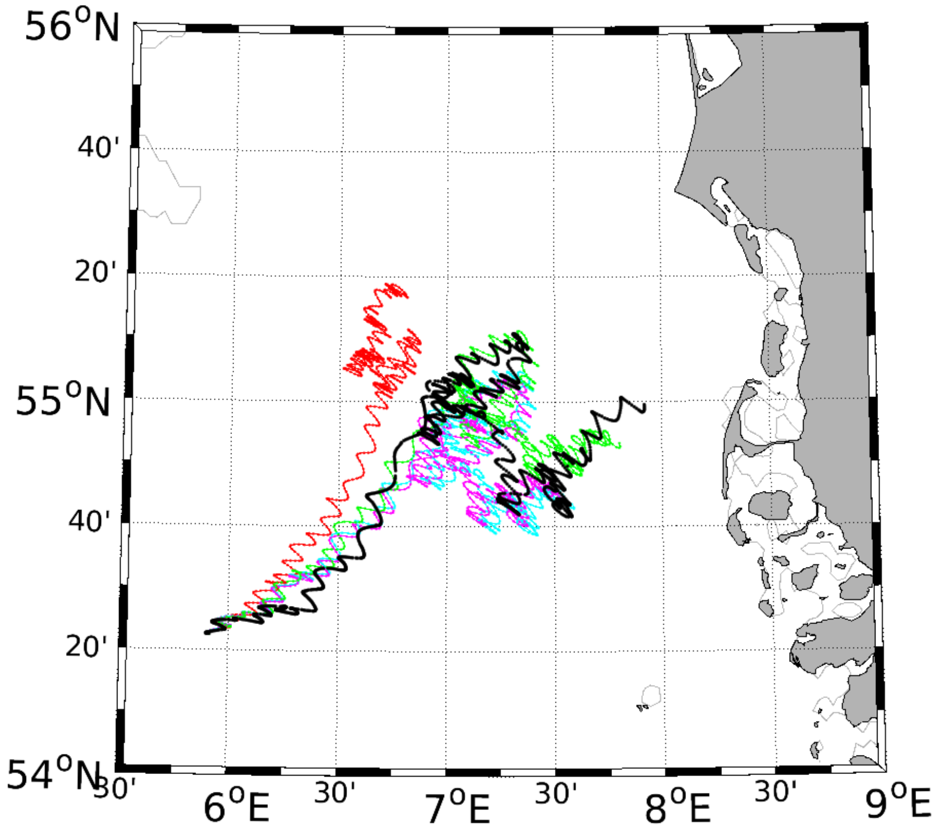
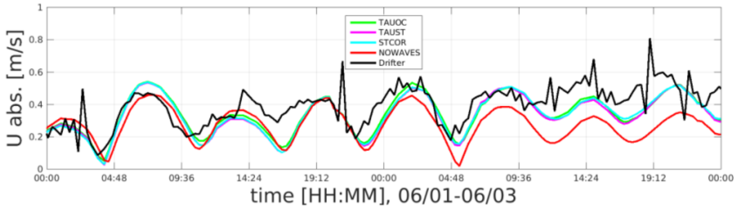
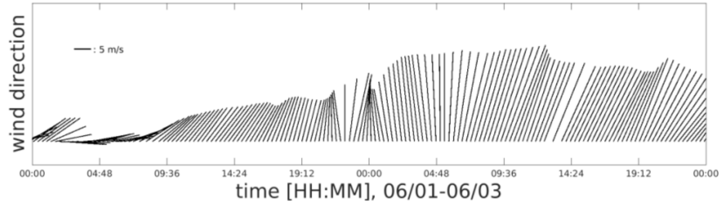
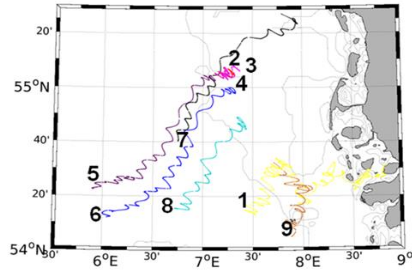
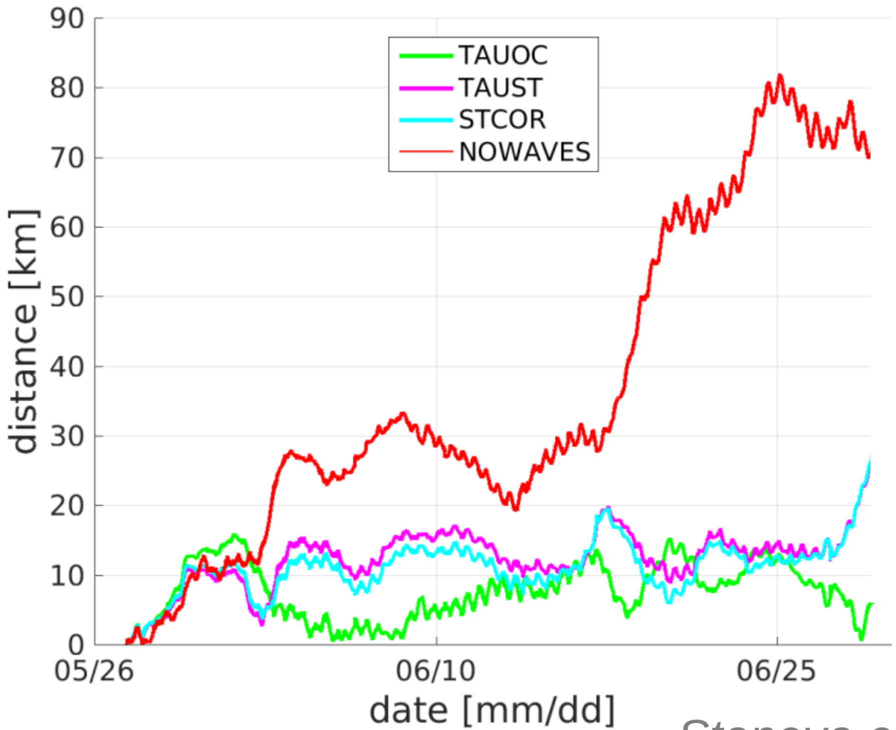
Drifter #5











Staneva et al. (2018)

Discussion

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- A coupled WAM-COSMO-NEMO model has been implemented and applied for the North Sea Baltic Sea and new parameterizations added and tested.
- Coupling of COSMO-WAM showed better agreement with observations during extremes (reduced wind speed and thus wave heights)
- Effects of considering sea state and introducing wave-induced forcing on simulated temperature are not negligible.
- Storm surge and circulation of the NEMO-WAM model are improved for the coupled model compared with stand-alone NEMO.
- The using of a coupled model system reveals that the newly introduced wave effects are important for the drift-model performance.
- Paves the road to more realistic simulations in both operational forecasting systems and climate studies.

Thank you for your attention!

Publications:

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

- 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
- Breivik, O, J-R Bidlot, P A Janssen (2016). A Stokes drift approximation based on the Phillips spectrum, Ocean Model, 100, pp 49-56, doi:10.1016/j.ocemod.2016.01.005
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- Staneva J., Alari V., Breivik O, Bidlot J.-R. and Mogensen K., (2016). Effects of wave-induced forcing on a circulation model of the North Sea. Ocean Dynamics, DOI 10.1007/s10236-016-1009-0
- 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
- Wahle K., Staneva J, Koch W., Fenoglio-Marc L., Ho-Hagemann H., and Stanev E. (2016). An atmosphere-wave regional coupled model: improving predictions of wave heights and surface winds in the Southern North Sea. Ocean Sci. Discuss., doi:10.5194/os-2016-51, 2016

Impact of wave-induced forcing on Sea Level
Different meteoconditions during 2016

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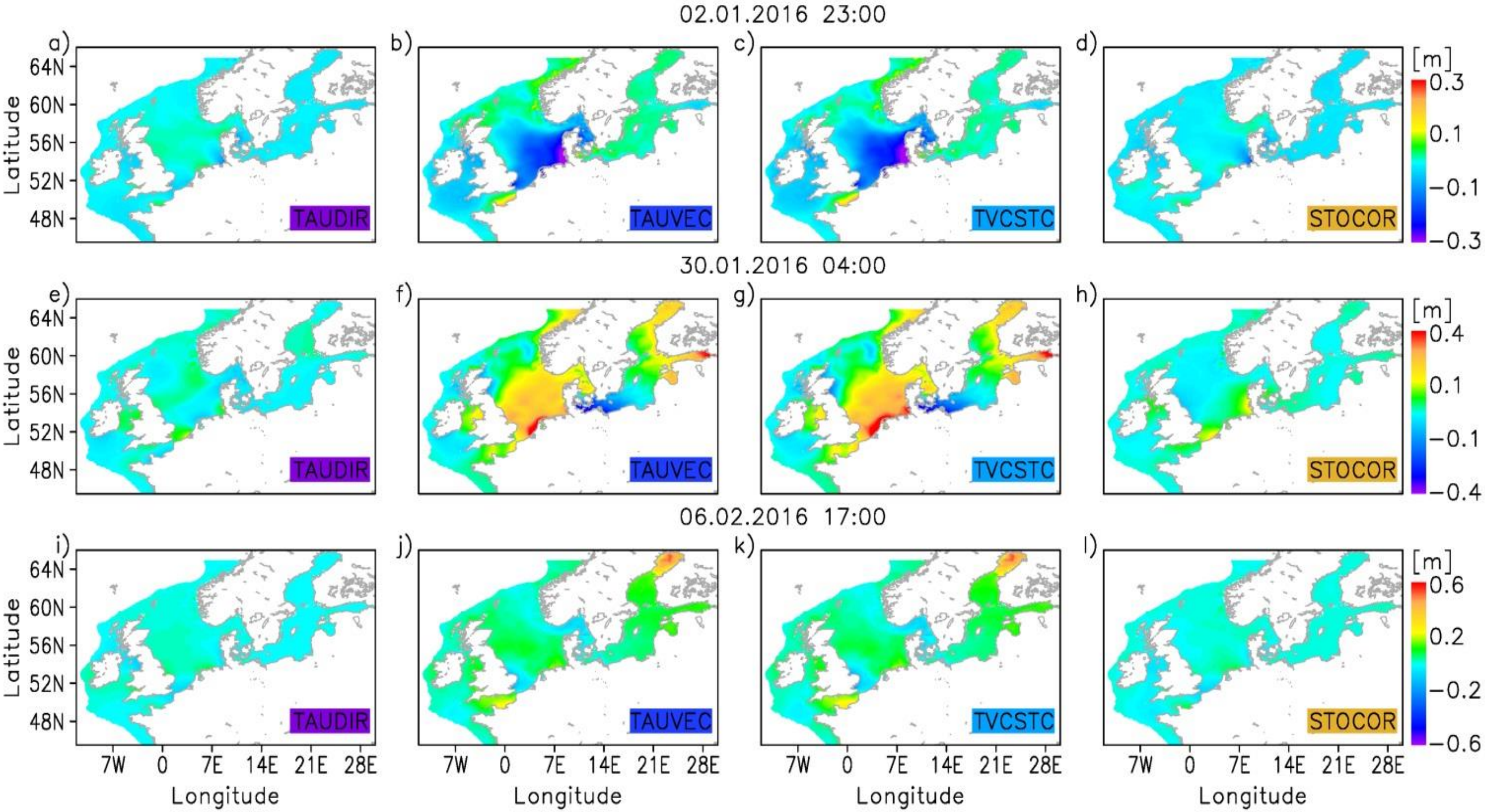

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