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

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Relevance of atmosphere-ocean-wave coupling for coastal predictions

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- Reducing prediction errors at coastal scales (e.g., drift forecast), which in many cases are due to unresolved nonlinear feedback between wind-waves, circulation and atmosphere
- Study/understand 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
- Of particular importance in coastal areas where one has a lot of human activities

GCOAST Modell system

ESM
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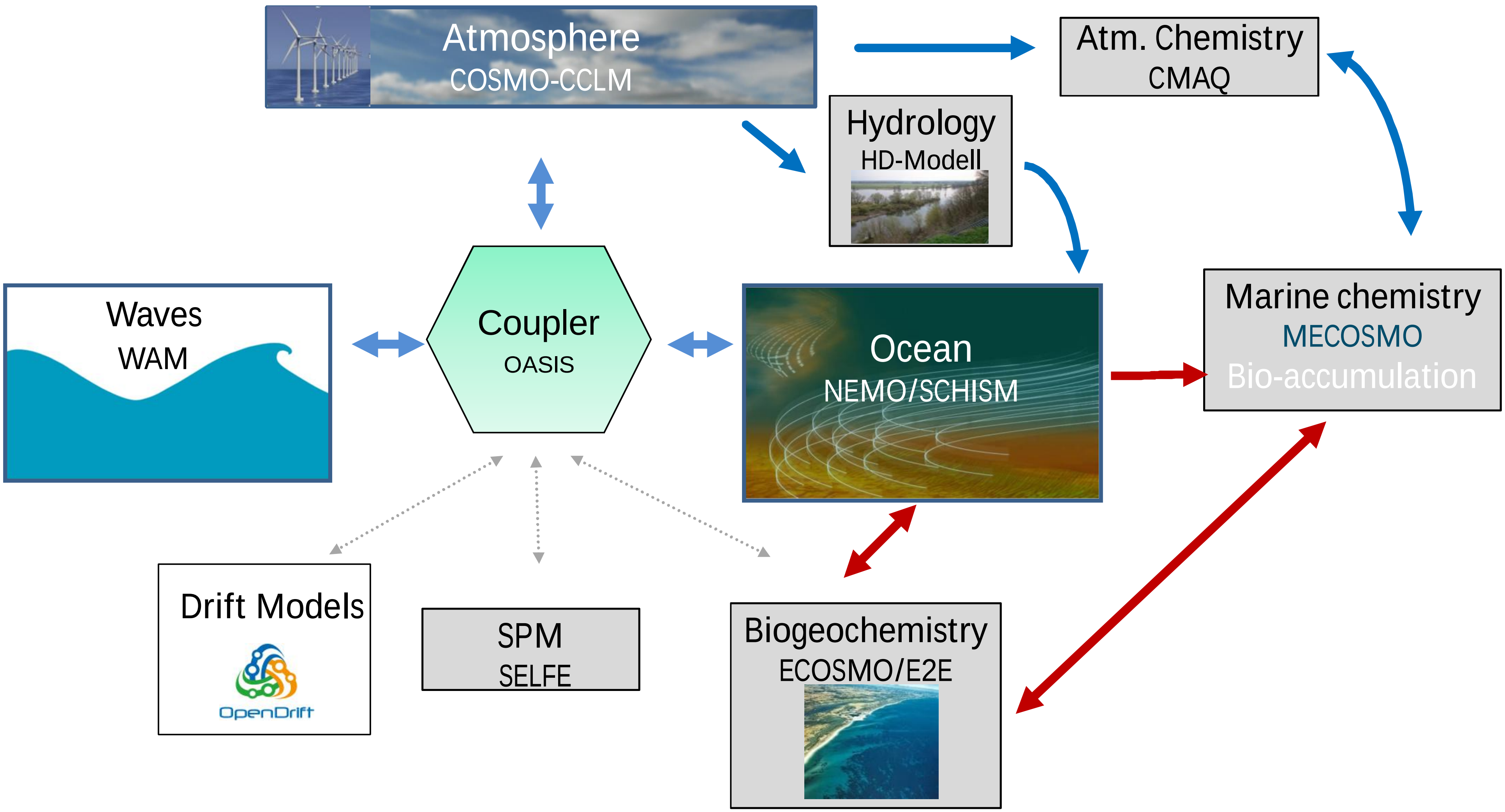

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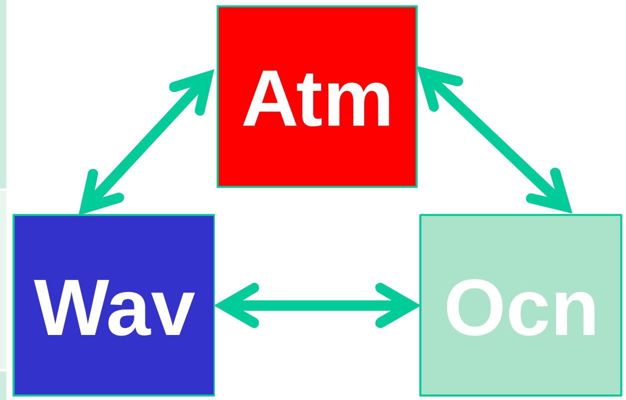
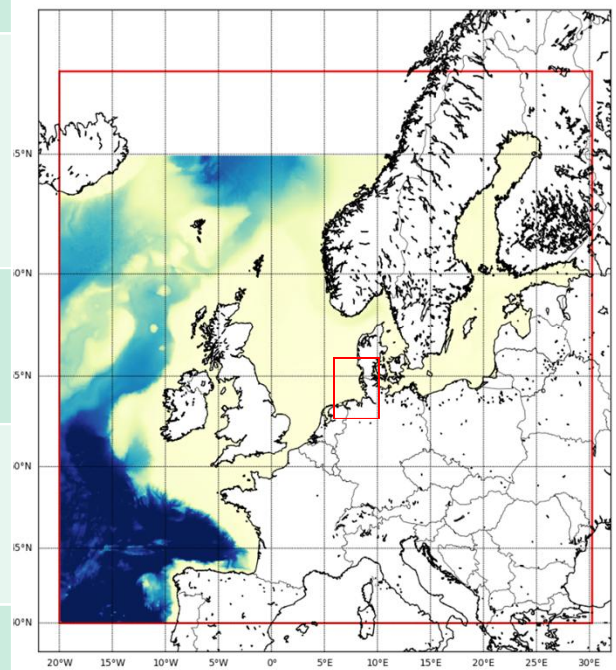
Coupled Model Setup

	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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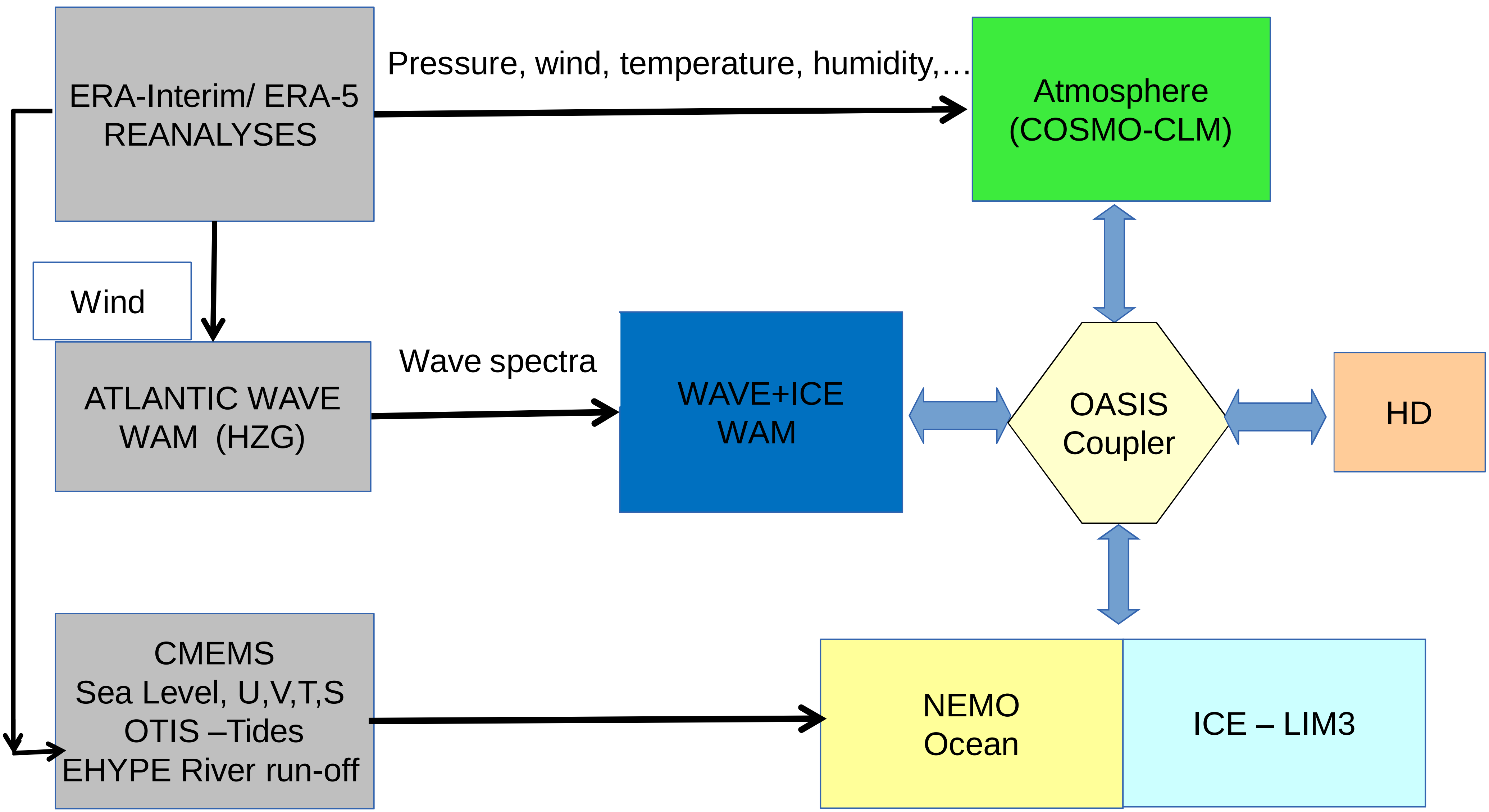

Regional Downscaling via OASIS

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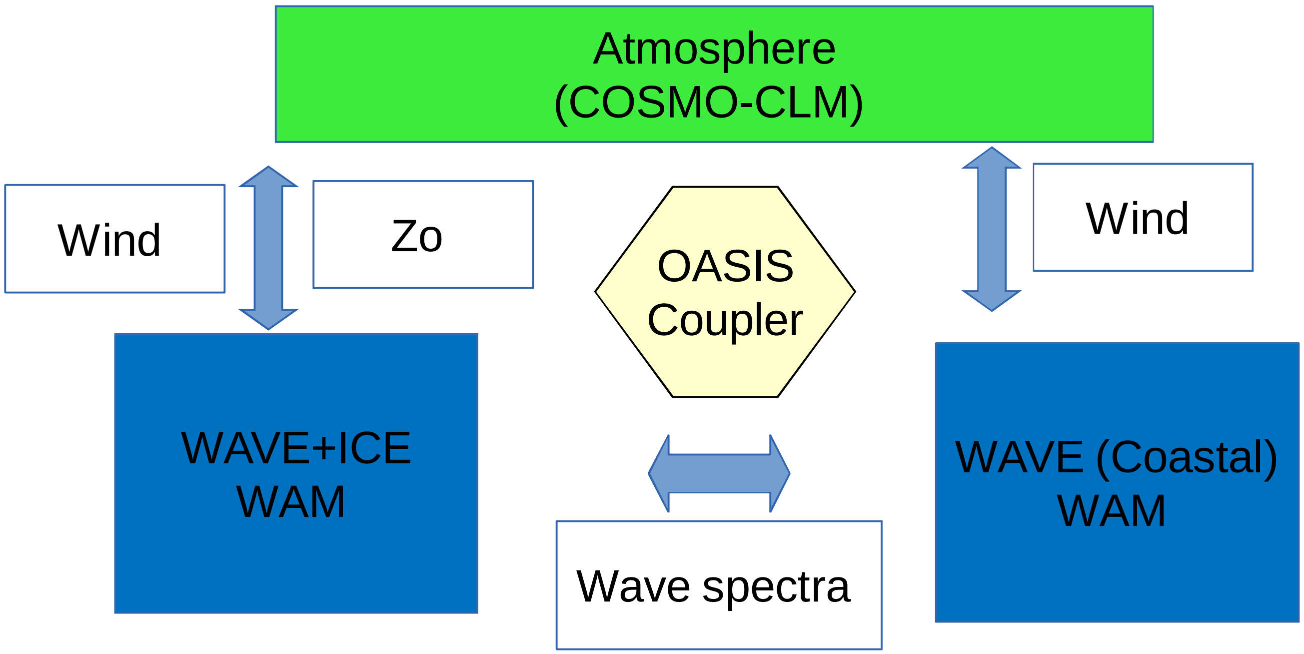
→Waves extract energy and momentum from the atmosphere.
→The effect is largest for young sea states and high wind speeds.



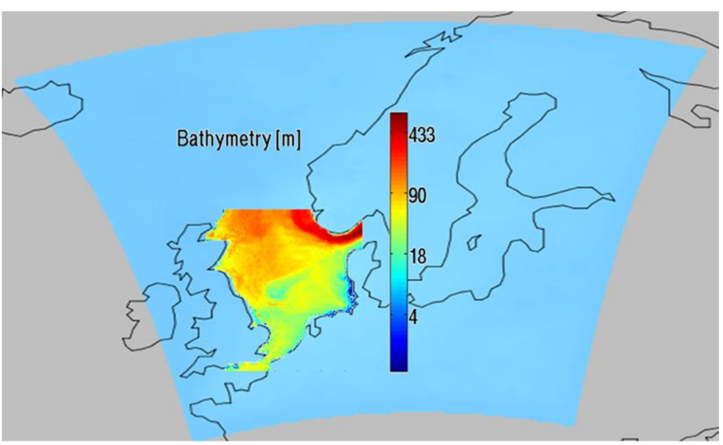
$$U(z) = \sqrt{\frac{\tau}{C_D(z)}}$$

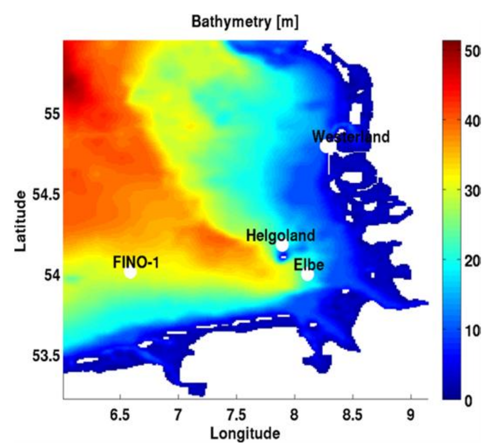
$$C_D(z) = \frac{\kappa^2}{ln^2(z/z_0)}$$

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

Charnock Relation

Wave dependent





Impact of two-way coupling between waves and atmosphere

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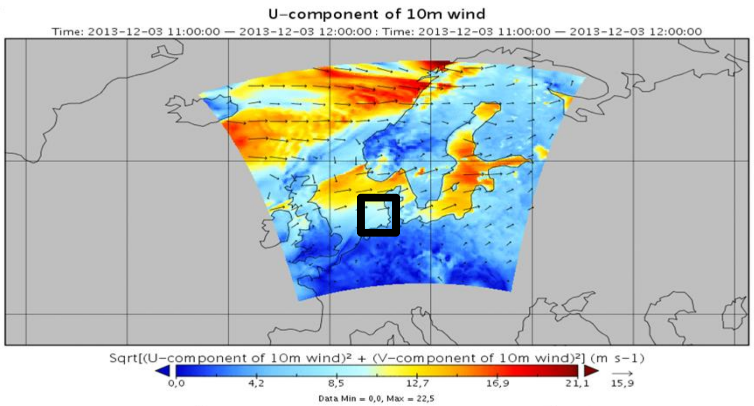
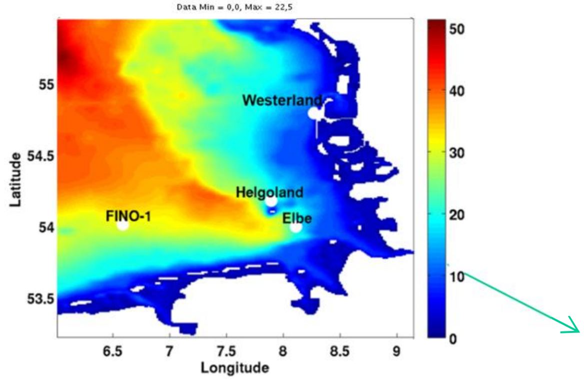
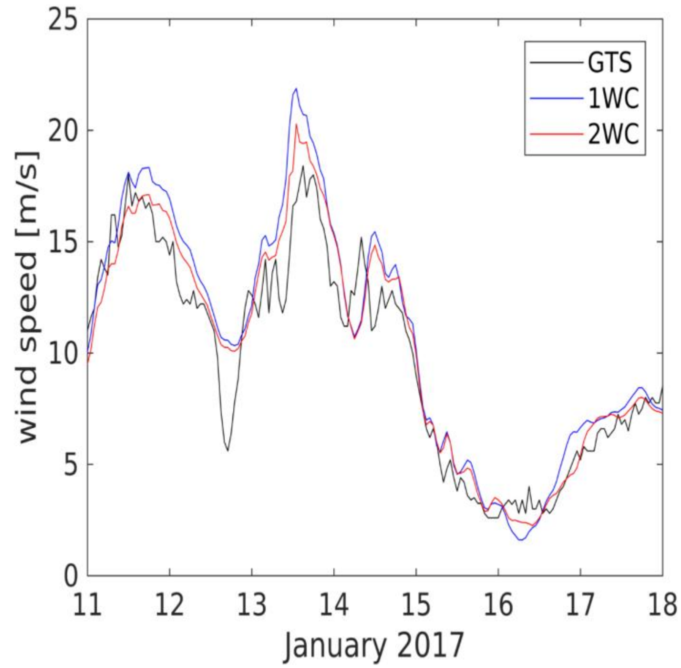
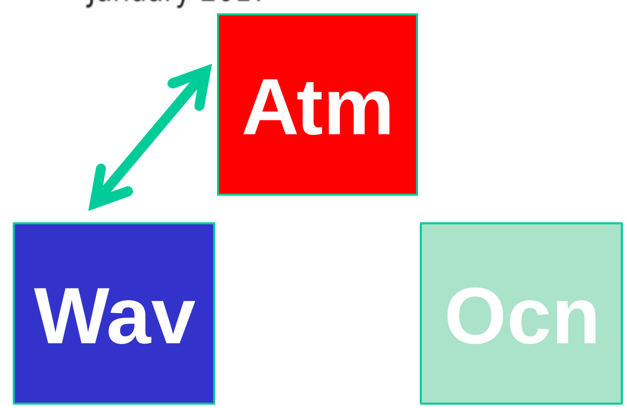




(b)



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),

MSLP, 10m wind speed, surface roughness

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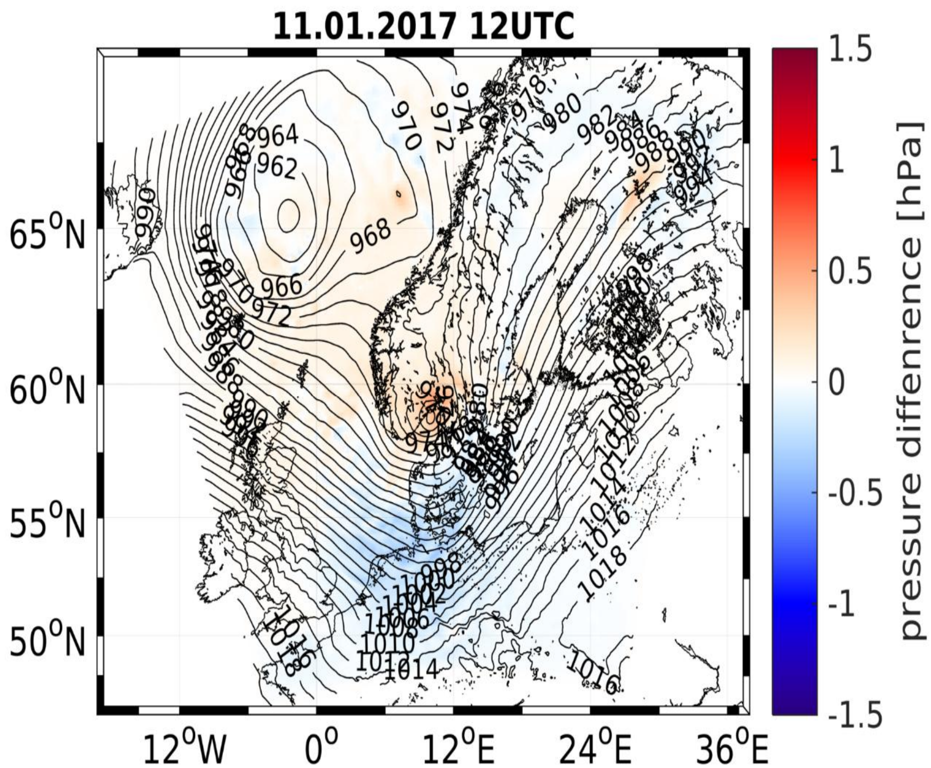

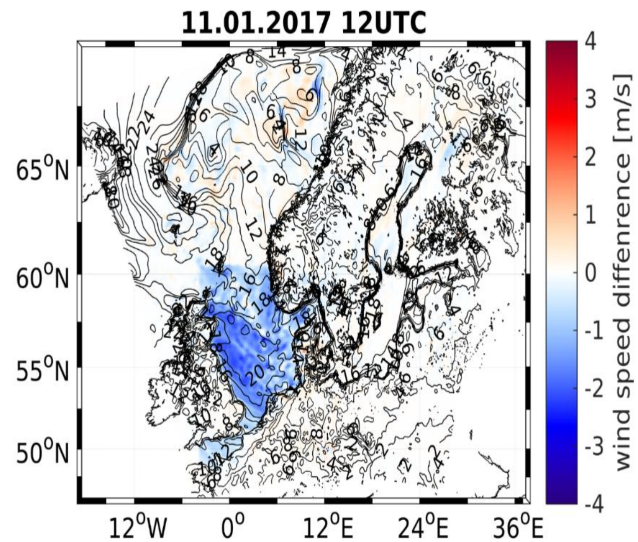

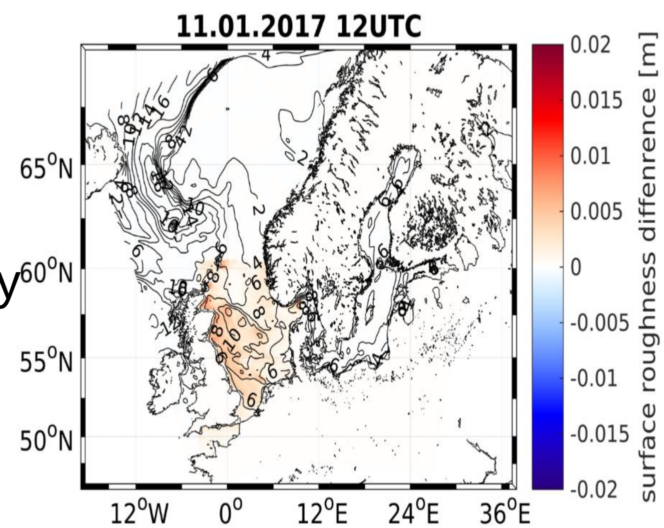

- Low pressure system between Island and Norway
- Secondary low around Oslo
- Reduced pressure gradient
- Enhanced surface roughness
- Reduced wind speed

MSLP, 10m wind speed, surface roughness

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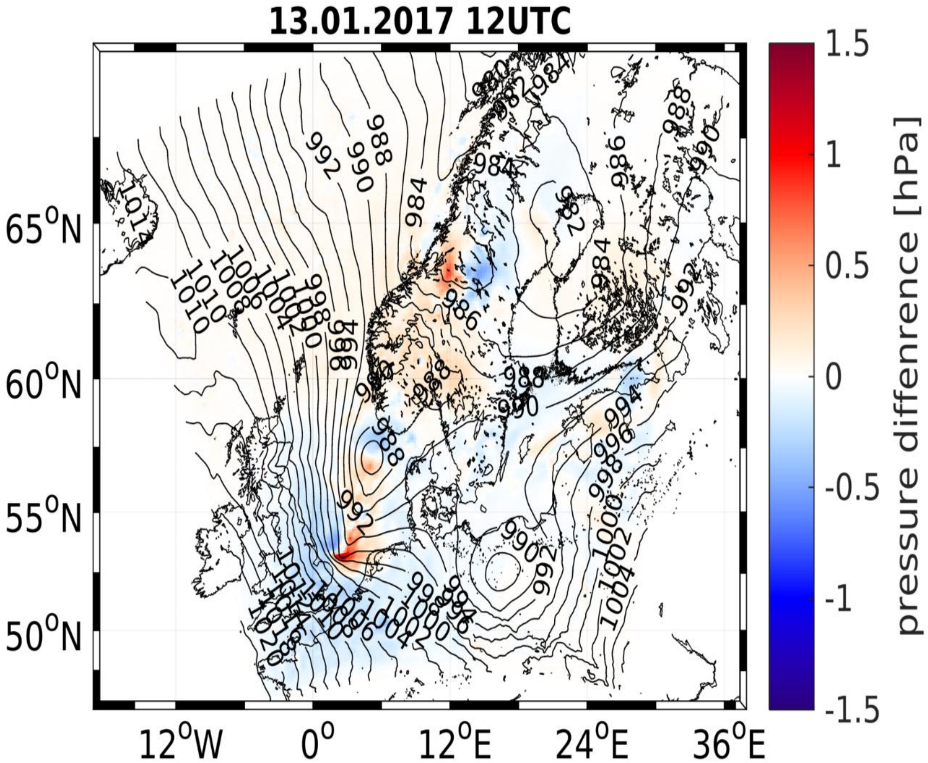
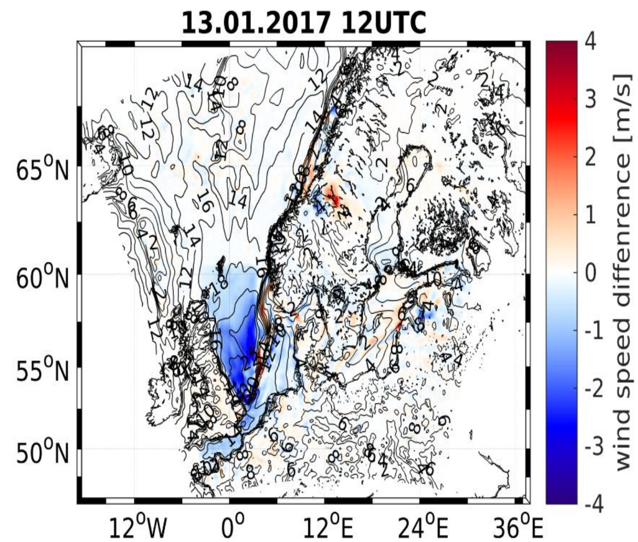
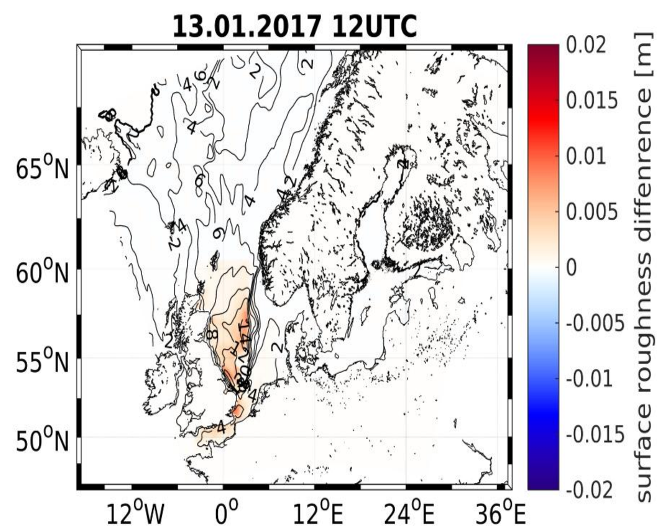






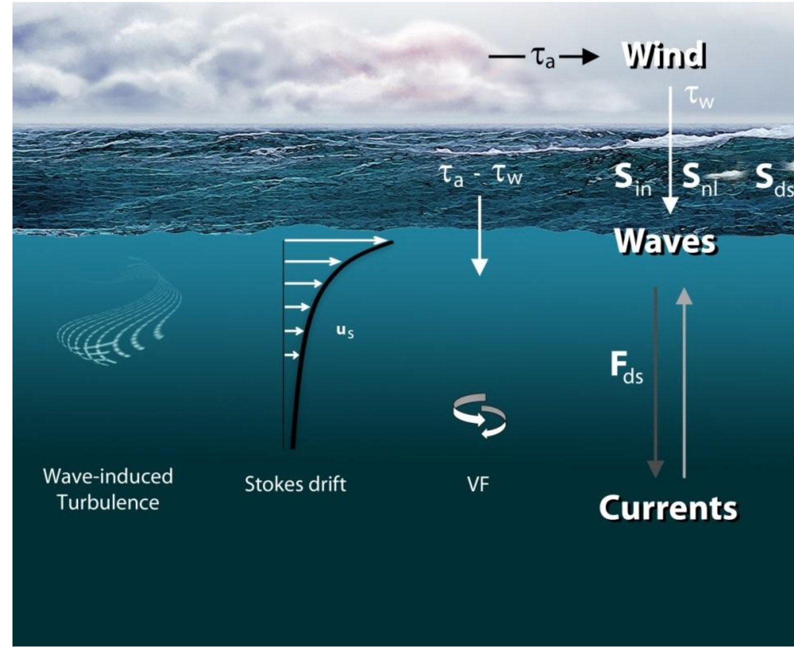
- Centre of low pressure system over North Sea
- Convergence Zone
- Enhaced wind speed at convergence zone
  → Further east in 2wc

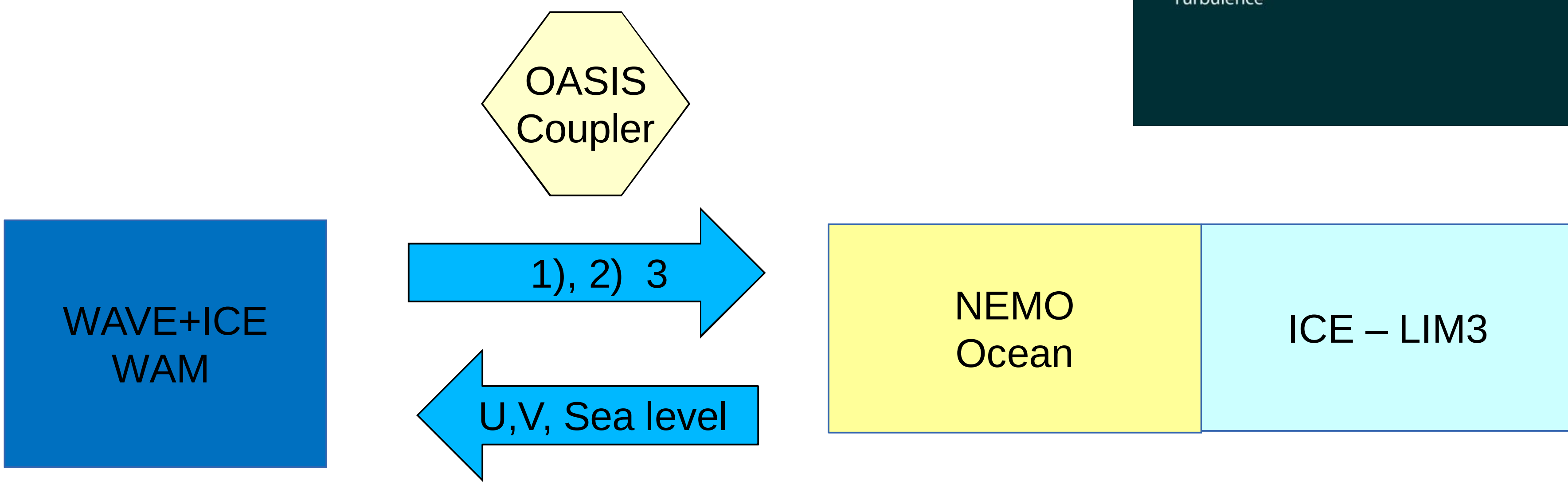
Wave-current interaction:

(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)





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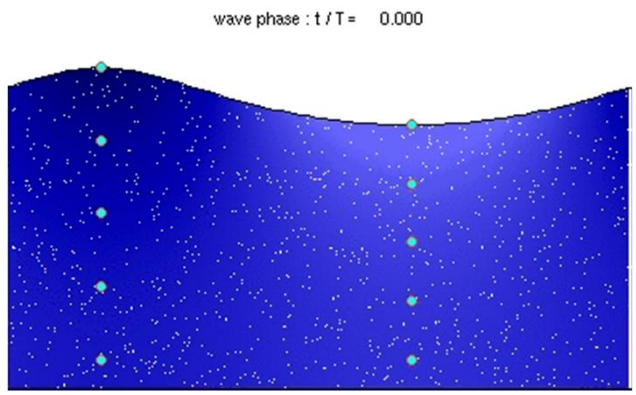
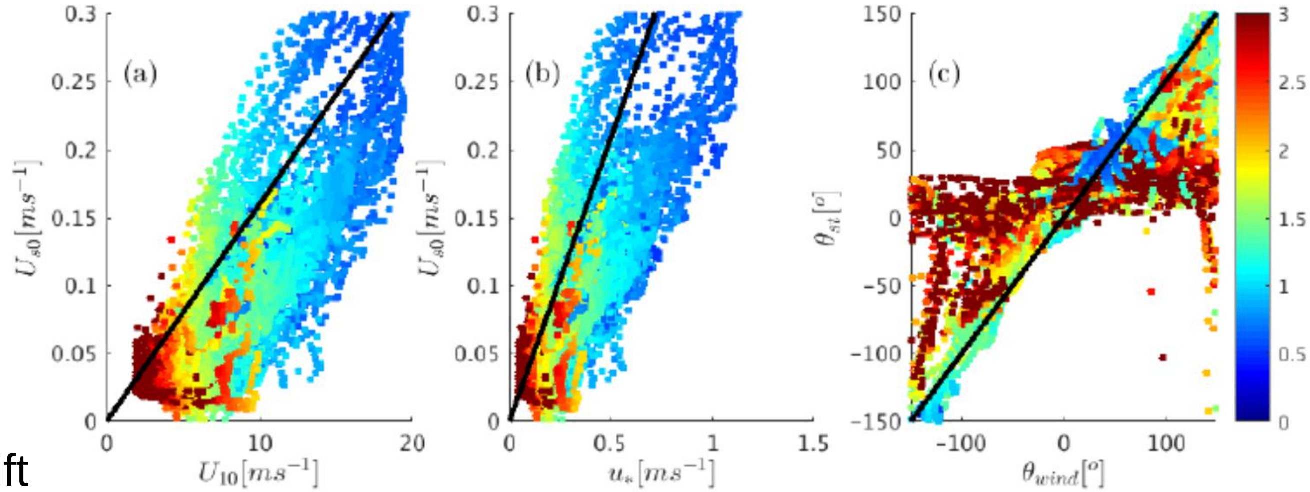
Stokes-Coriolis forcing



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



The Stokes drift –> WAM

Momentum equations

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

New adding Ust in advection terms

The relationship between U10 and the magnitude of the surface Stokes drift :

(a) black line represents the Ust =0:016 U10 (Li and Garrett, 1993);

(b) Ust = 0:377 Tau $^{1/2}$ (Madec et al., 2015);

(c) the surface Stokes drift direction and the direction of U10 The color represents the wave age

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

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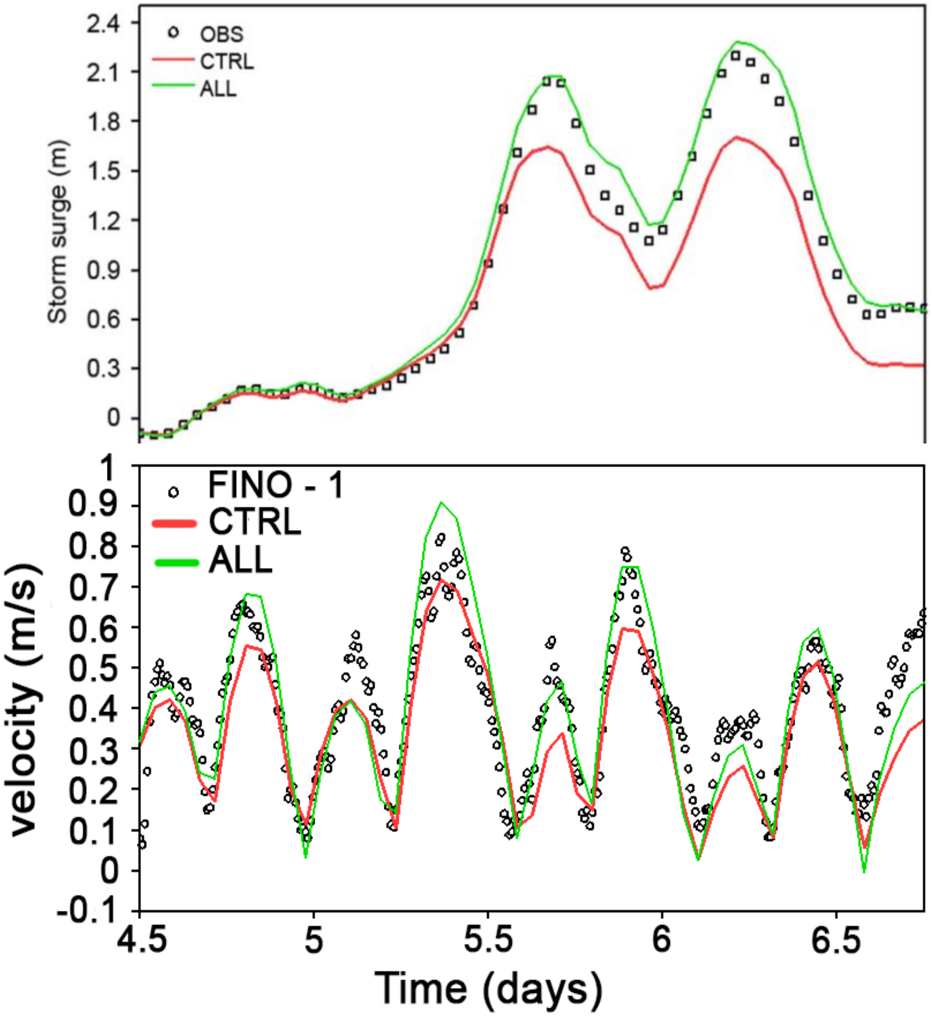
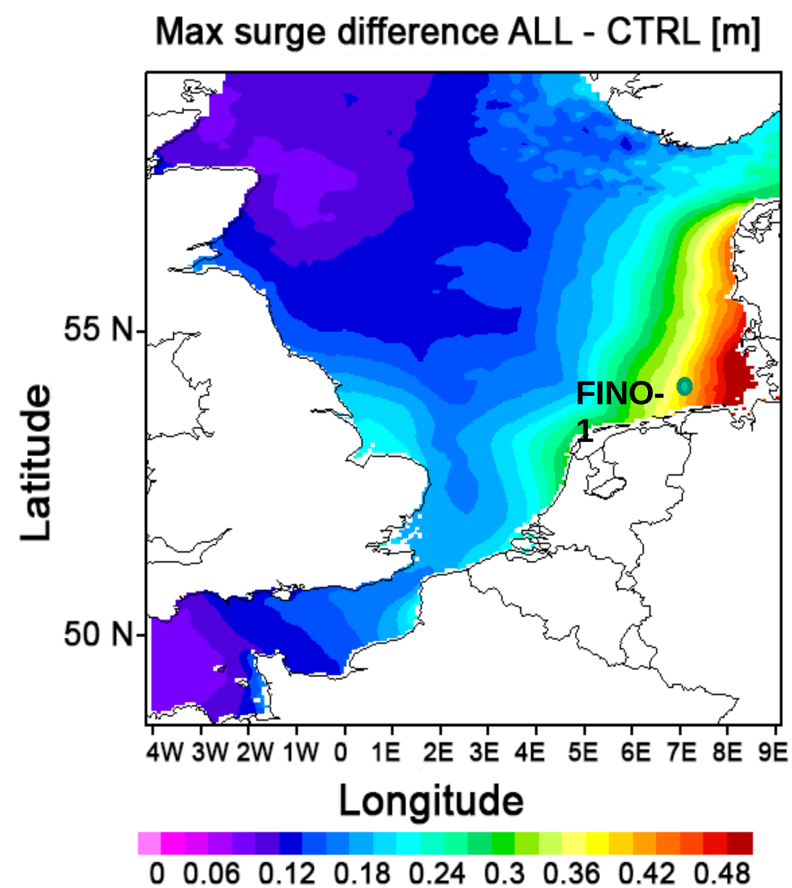


Uncoupled run

in-situ data

Wave-circulation coupled run

Maximum storm surge difference [m]
COUPLED-NEMO (Xaver, 5-6.12.2013)



(Staneva et al, 2017)

Baltic Sea: Impact of waves to Sea Surface Temperature

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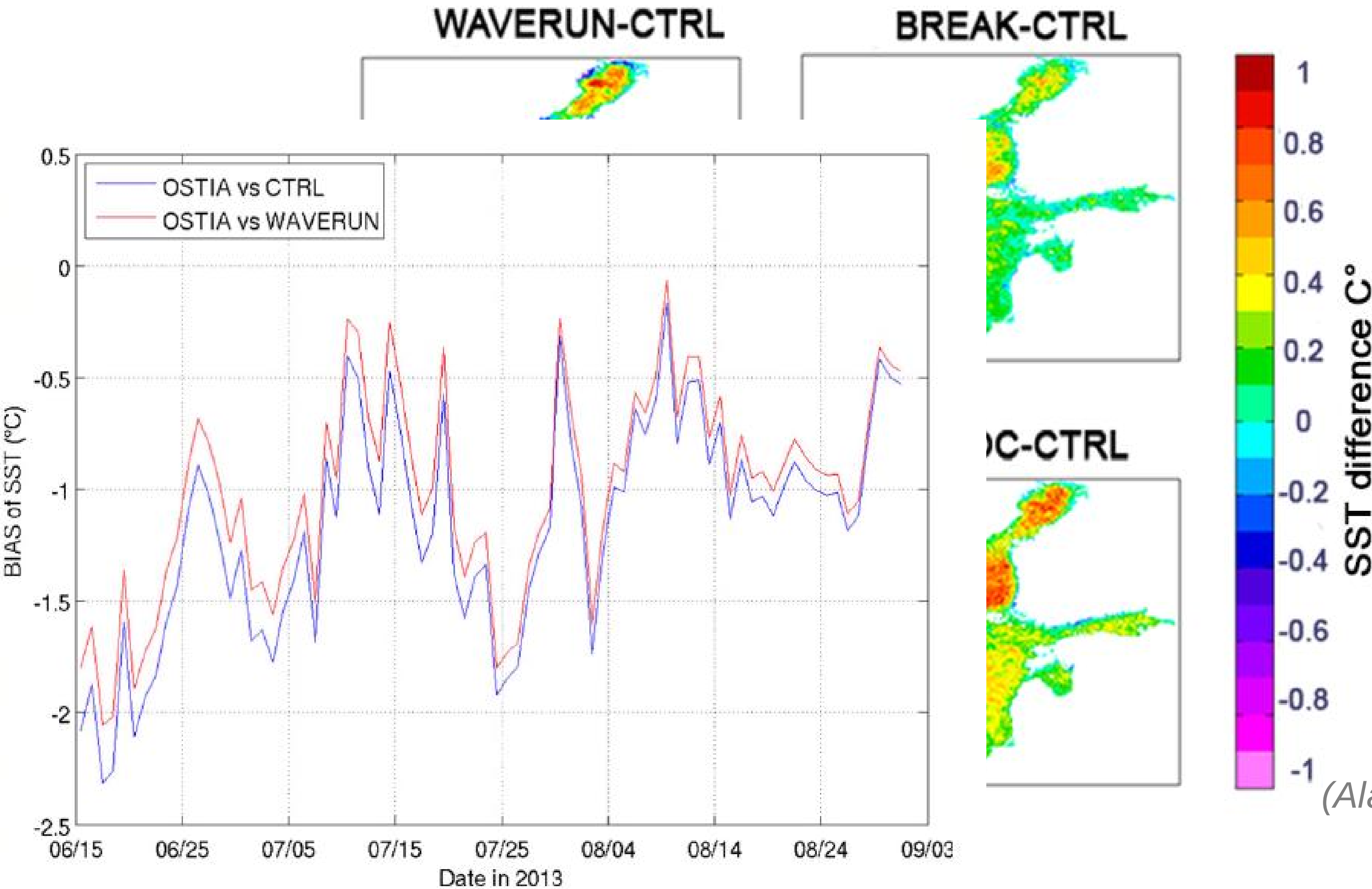
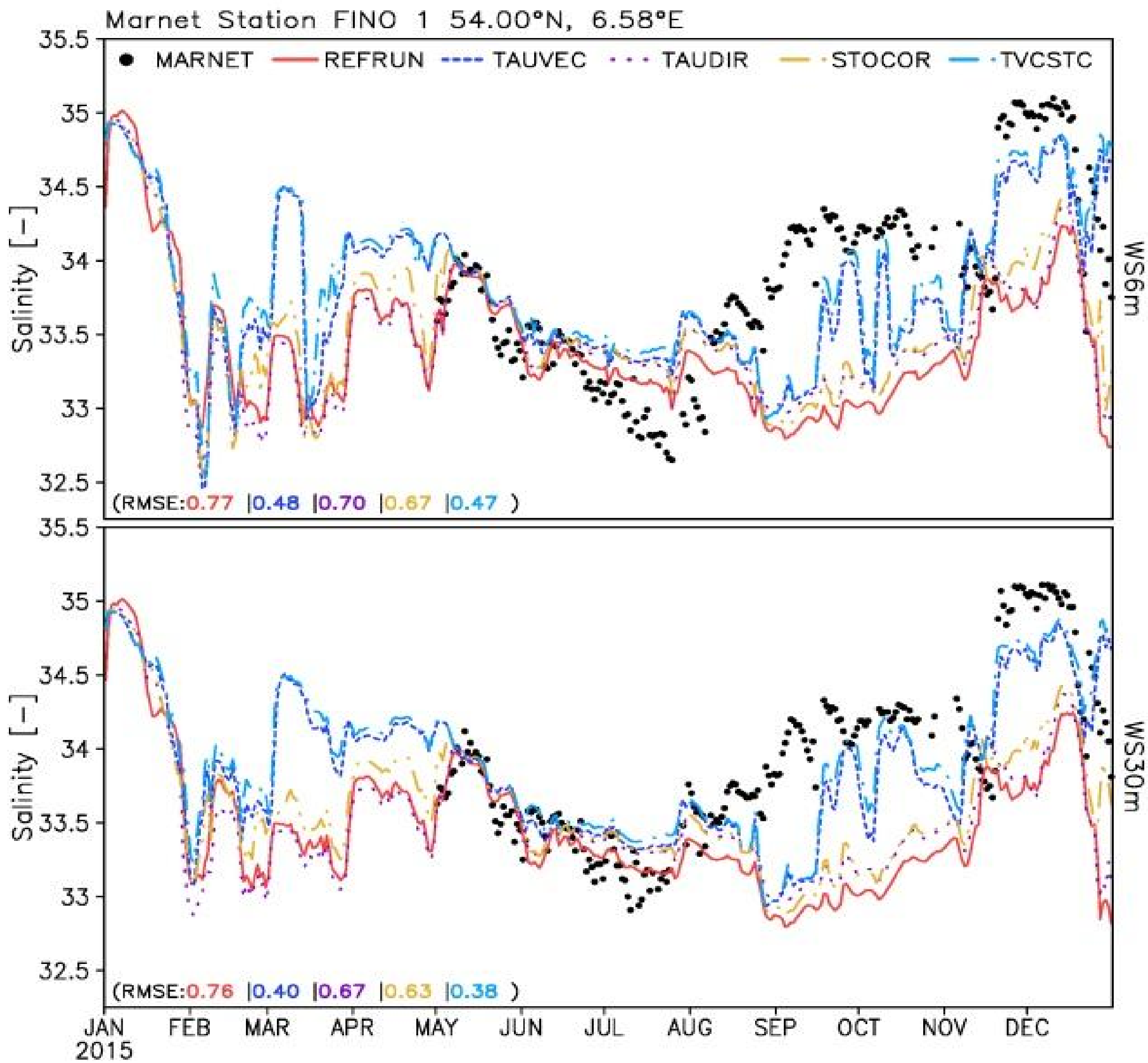
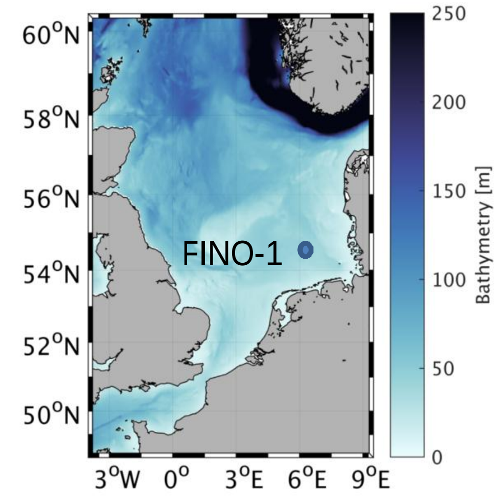
Summer SST Differences



(Alari et al., 2016)

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





The role of wave-induced processes in particle drift modelling

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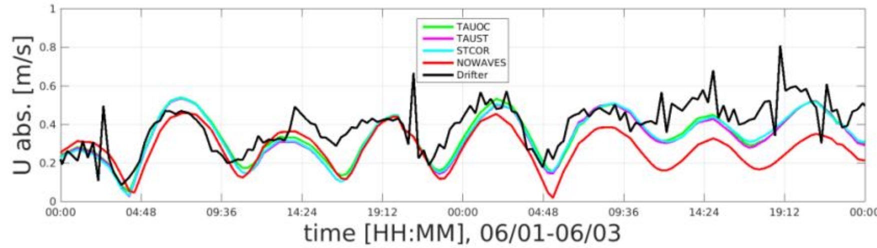
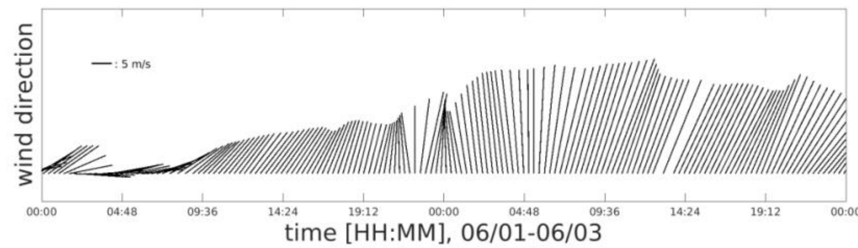
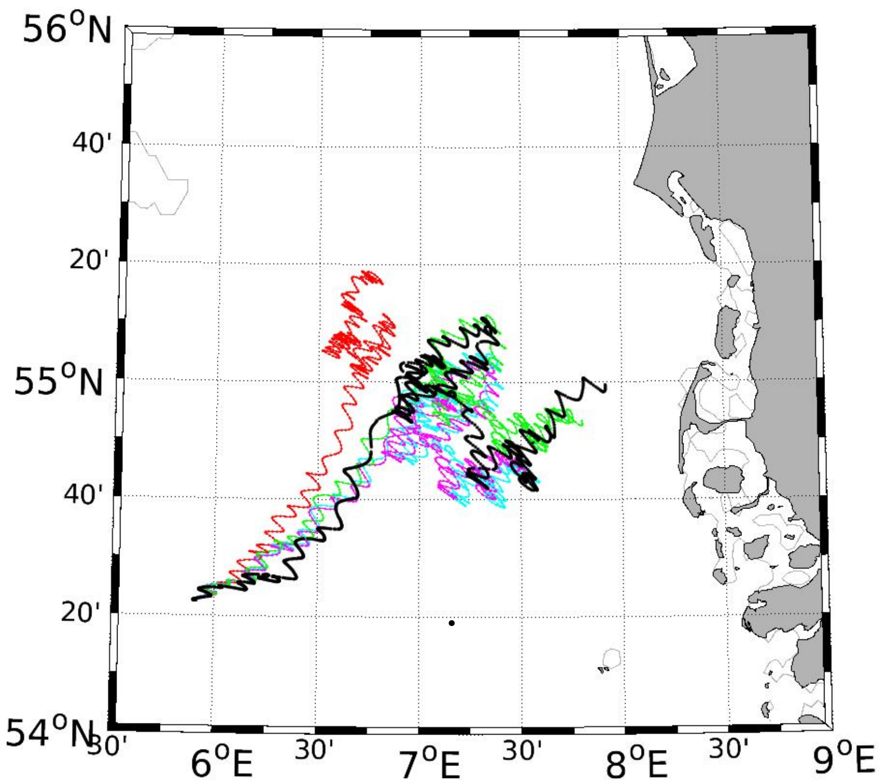
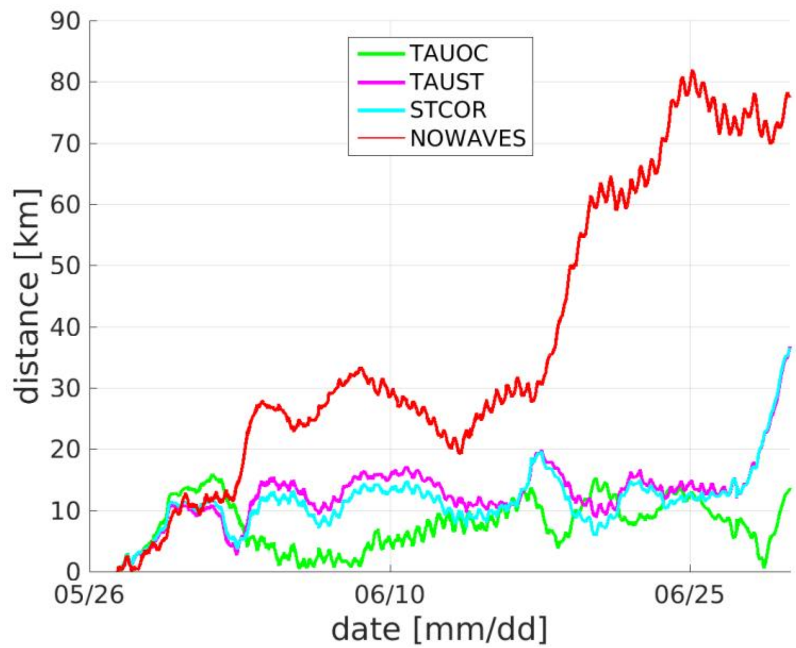
Drifter #5









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.
- Paves the road to more realistic simulations in both operational forecasting systems and climate studies in the coastal regions (➔ CMEMS, WAVE2NEMO, Offshore Windfarming, Suitable Observations ?).

Publications:

Helmholtz-Zentrum Geesthacht
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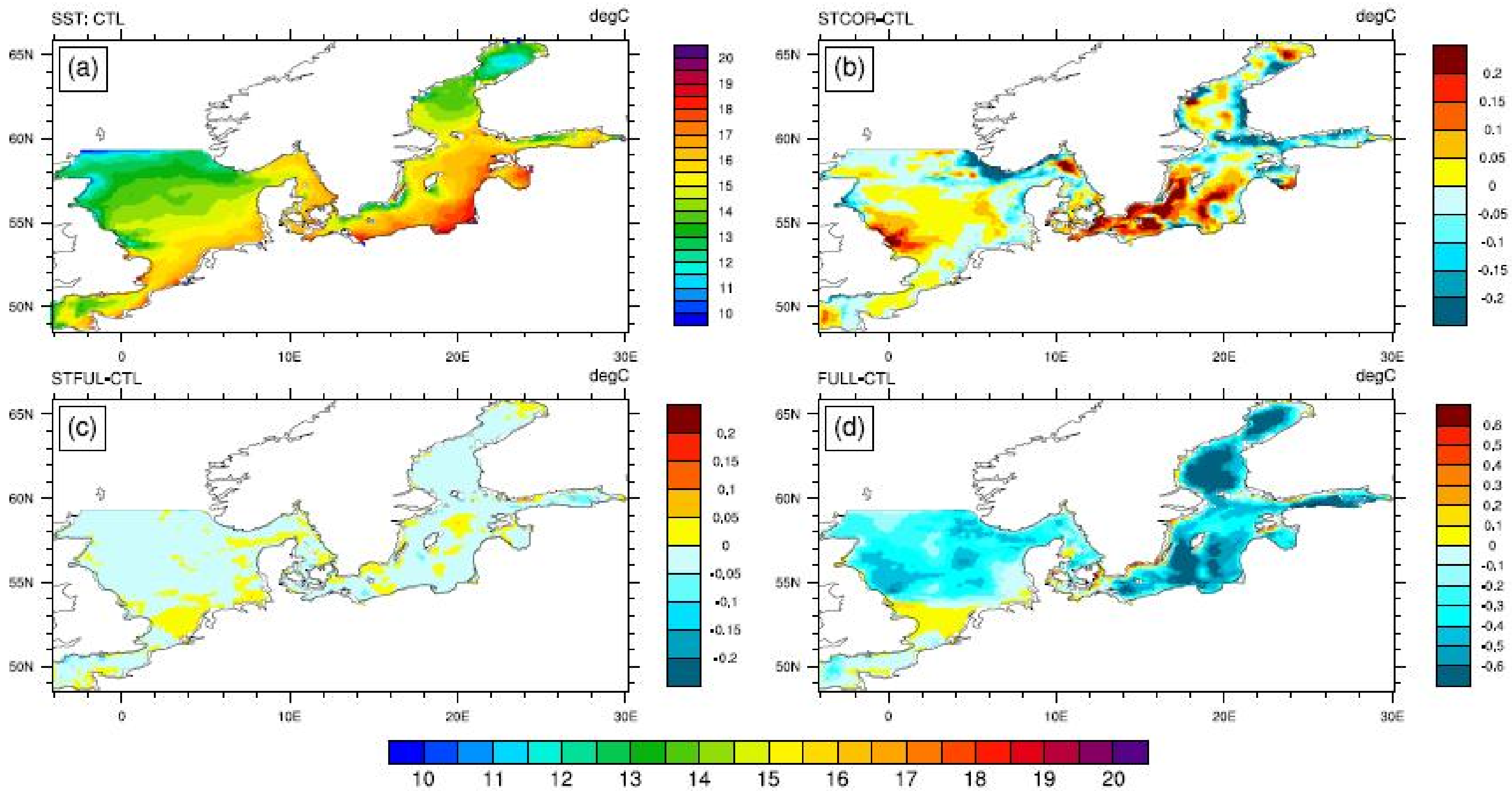
- Alari V, Staneva J, Breivik O, Bidlot JR, Mogensen K and Janssen PAEM (2016). Response of water temperature to surface wave effects in the Baltic Sea: simulations with the coupled NEMO-WAM model. Ocean Dynamics, DOI 10.1007/s10236-016-0963-x
- Breivik, O, J-R Bidlot, P A Janssen (2016). A Stokes drift approximation based on the Phillips spectrum, Ocean Model, 100, pp 49-56, doi:10.1016/j.ocemod.2016.01.005
- Stanev E., Schulz-Stellenfleth J., Staneva J., Grayek S, Grashorn S., Behrens A, Koch W., and Pein J. (2016). Ocean forecasting for the German Bight: from regional to coastal scales, Ocean Sci., 12, 1105–1136, 2016, doi:10.5194/os-12-1105-2016
- 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 coupling with waves on SST (JJA)



Wu et al (2018)

Impact of coupling with waves on SST (NDJ)

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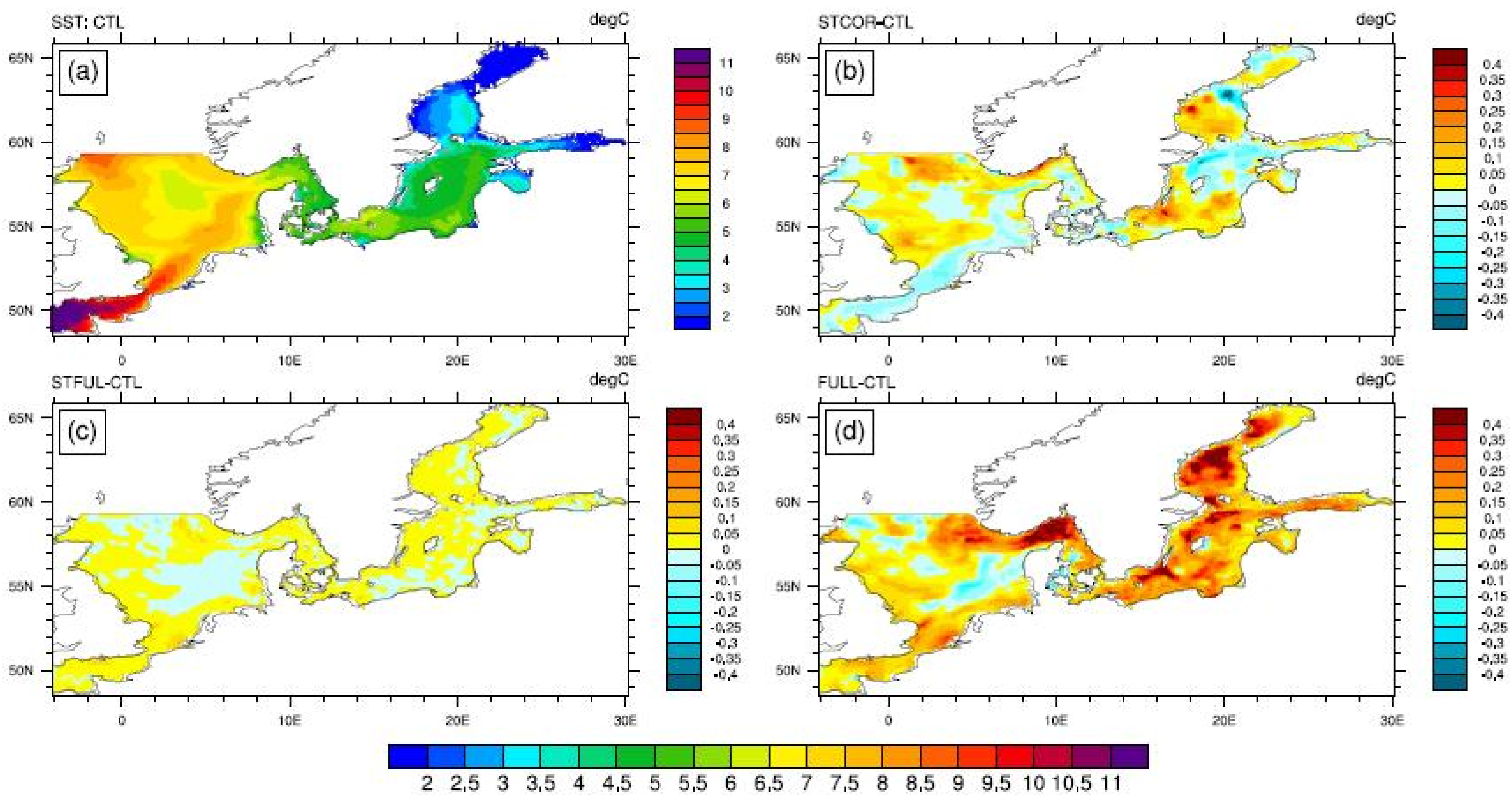
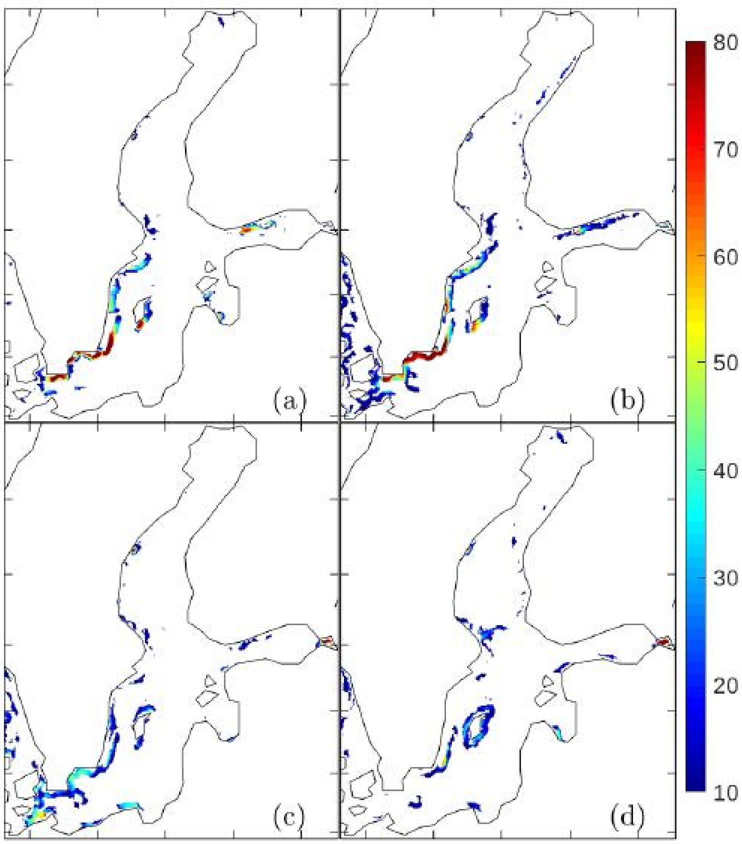


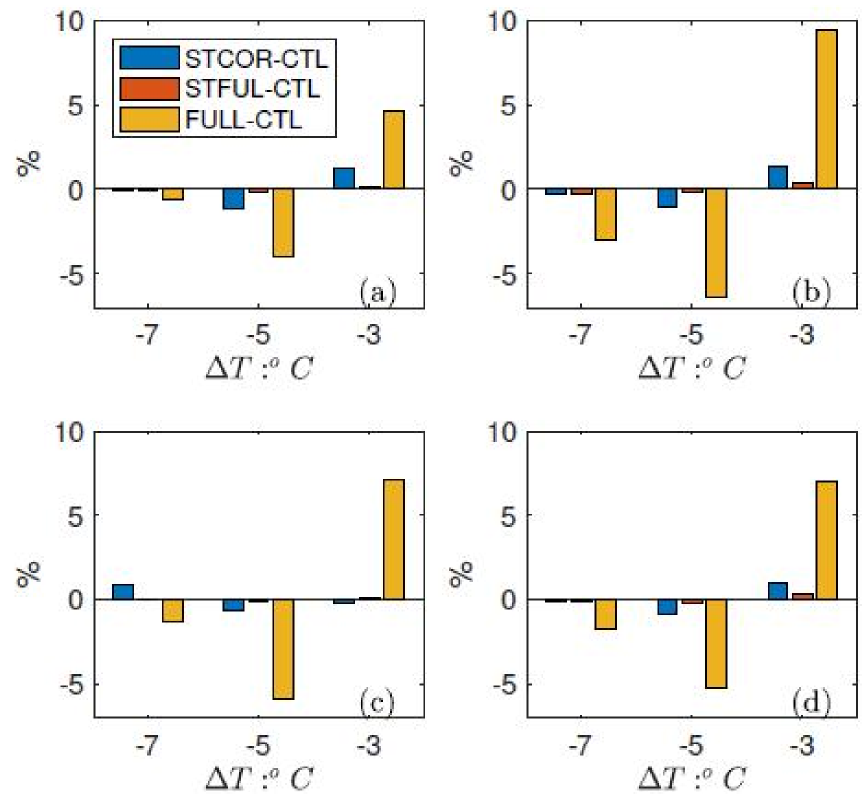
Wu et al (2018)

Impact of coupling on UPWELLING

The frequency of upwelling in the CR of June (a), July (b), August (c) and September (d), 2015 (%). The criteria for upwelling are fulfilled when the SST difference from the zonal mean temperature is greater than 2.5



The wave effect on the distribution of the upwelling intensity in (a) June, (b) July, (c) August, and (d) September 2015.



Wu et al (2018)

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

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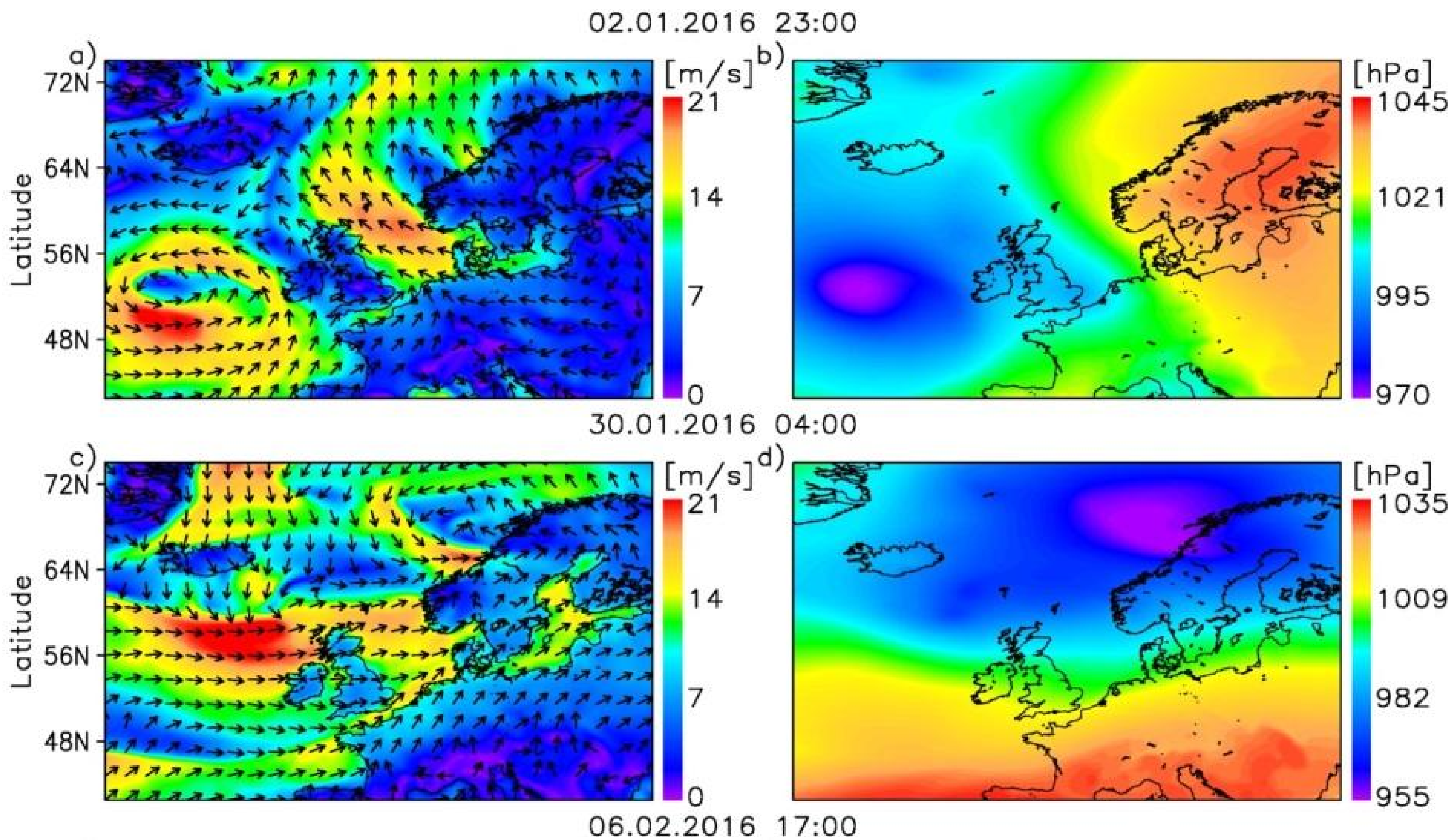

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Staneva et al., (2018)

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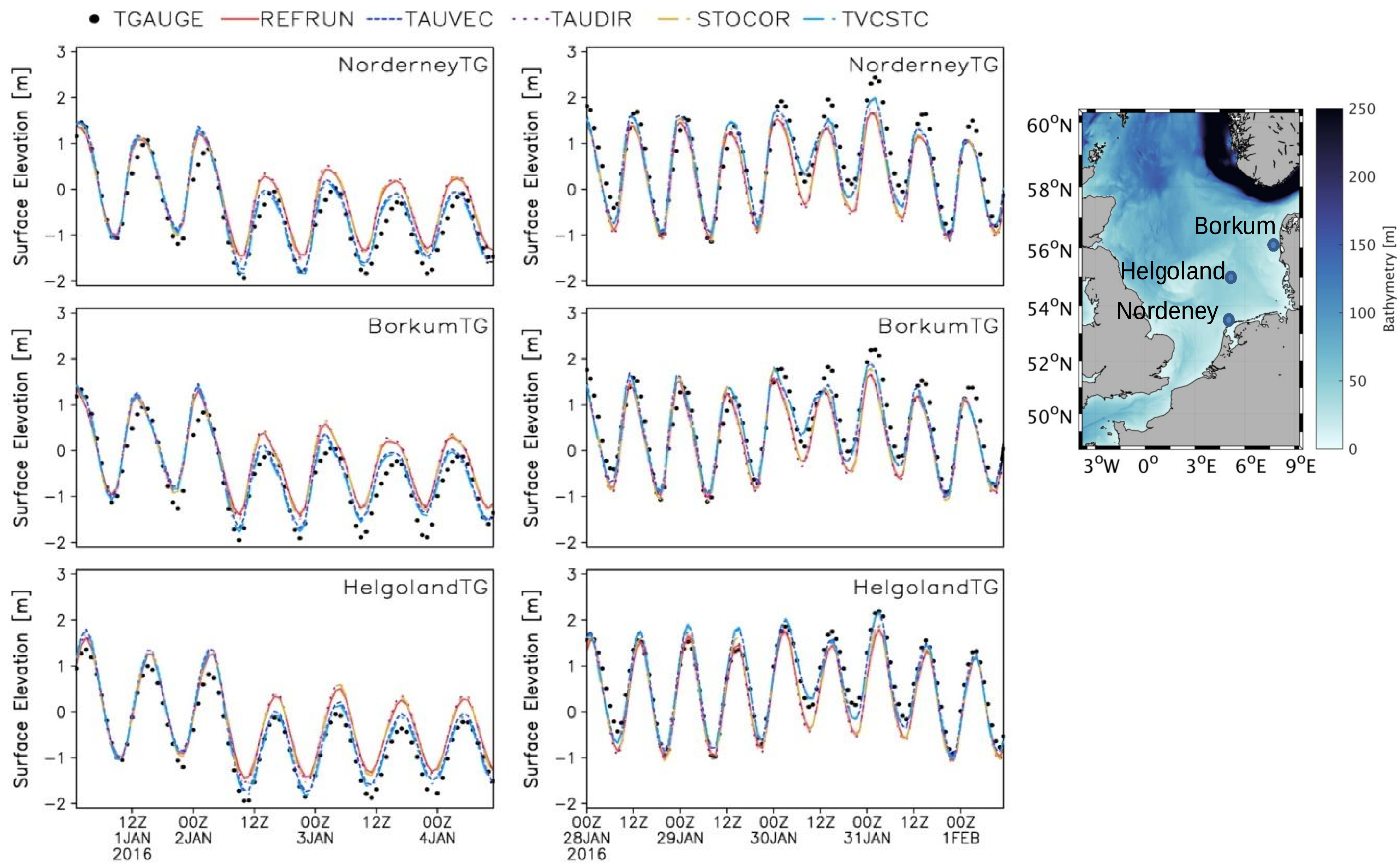

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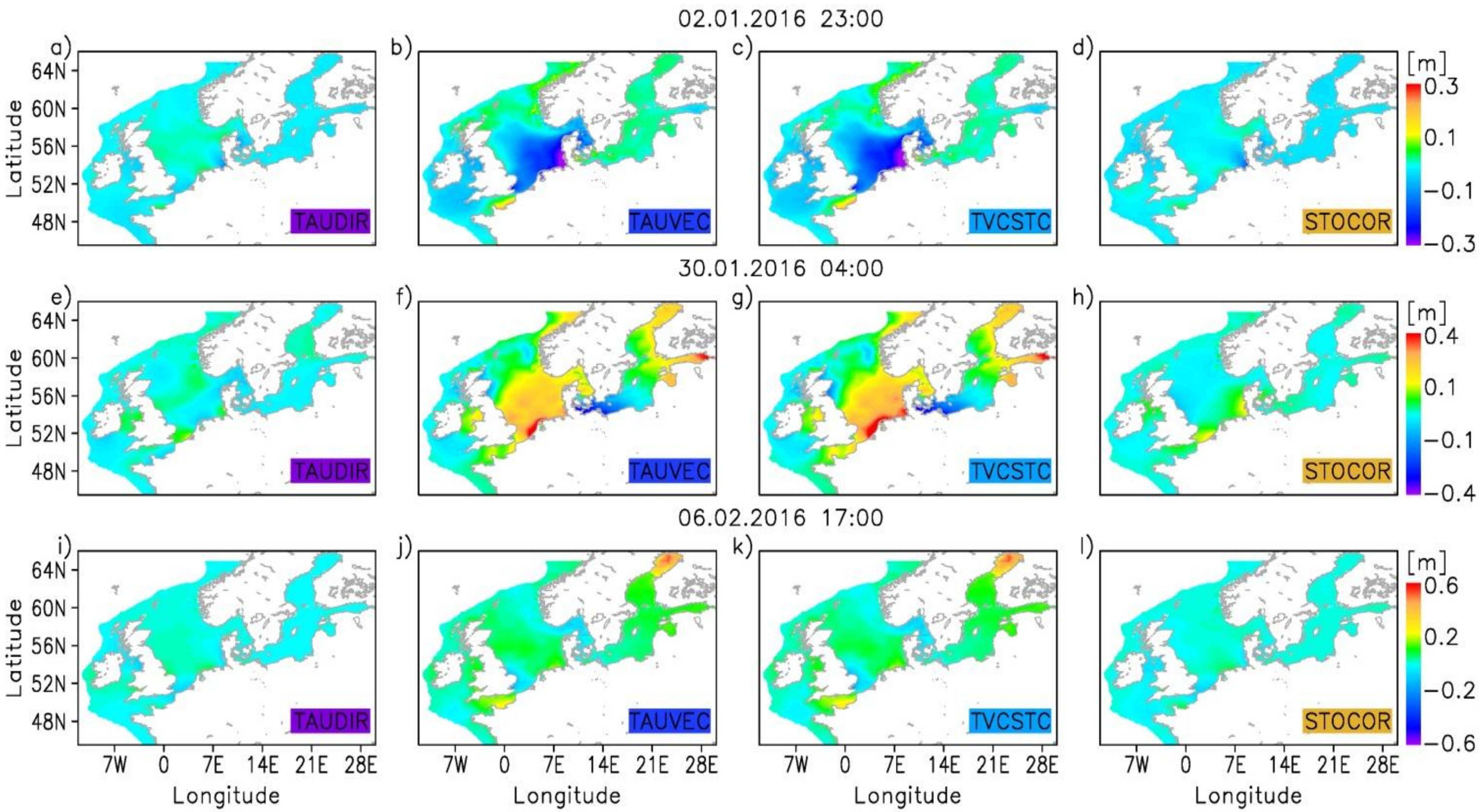


TAUOC **TAUVEC** **ALLWAVE** STCOR

Thank you
for your attention!

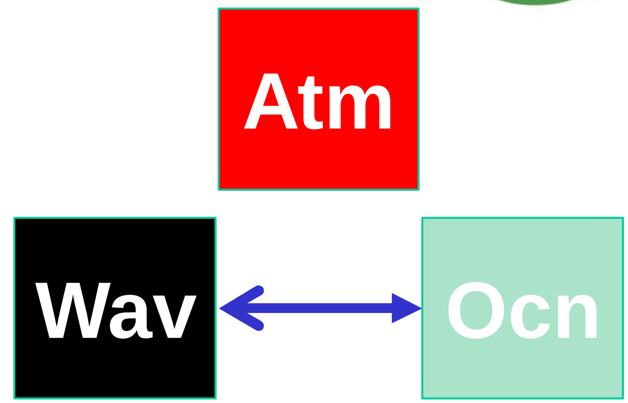
Wave-current interaction:

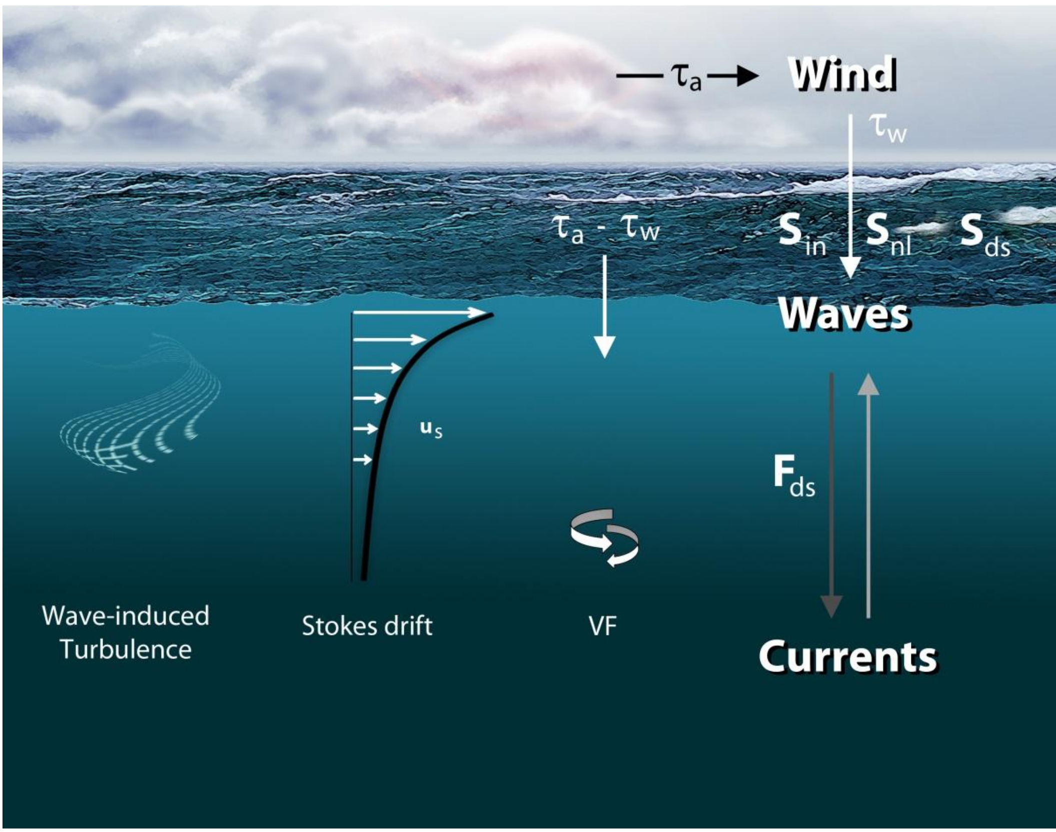
The ocean model takes into account the following wave effects:

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

(2) Sea state dependent momentum flux (Janssen, 1989; Janssen, 2012, Staneva et al., 2017);

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





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