Land-ocean interaction mediated by coastal upwelling and sea breeze: online coupling of atmosphere and ocean models

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General overview

Coastal upwelling is a wind-driven process which brings cold and nutrient-rich waters masses to the sea-surface, with the consequence of a substantial increase of primary production. In addition, the air-sea fluxes of momentum, heat and freshwater are strongly impacted by the reduced sea surface temperature, with significant feedbacks from the upper ocean to the lower atmosphere. Such dynamic feedbacks are generally not considered neither in atmospheric nor in ocean models, a neglect which has quantitative implications on the predictability of coastal ocean and regional atmospheric model systems. For regional studies, the consistent and interactive coupling of atmosphere and ocean models is carried out. The General Estuarine Transport Model (GETM) on the ocean side and the ICOsahedral Non-hydrostatic (ICON) modeling framework on the atmospheric side are utilized. As applications, the complex and episodic upwelling events in the Western Baltic Sea will be simulated with a fully two-way coupled exchange between ocean and atmosphere. ICON and GETM are coupled using the Earth System Modeling Framework (ESMF).

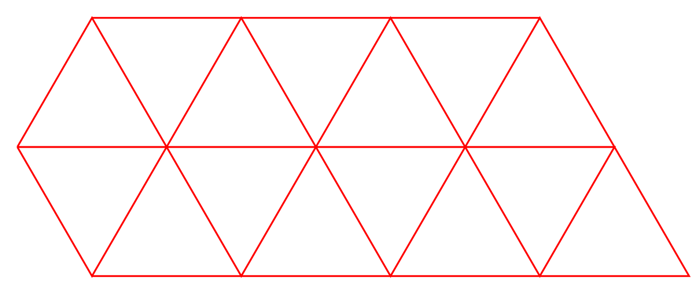
Modeling framework: ICON, GETM, ESMF

ICON (Zängl et al., 2015)

ICON is a joint project of the German Weather Service and the Max Planck Institute for Meteorology, targeting a unified modeling system for global numerical weather prediction and climate modeling.

- Main achievements: exact local mass conservation, mass-consistent tracer transport, a flexible grid nesting capability, use of non-hydrostatic equations on global domains
- Fully explicit two-time-level predictor-corrector scheme, except for the terms describing vertical sound-wave propagation

ICON: horizontal grid structure



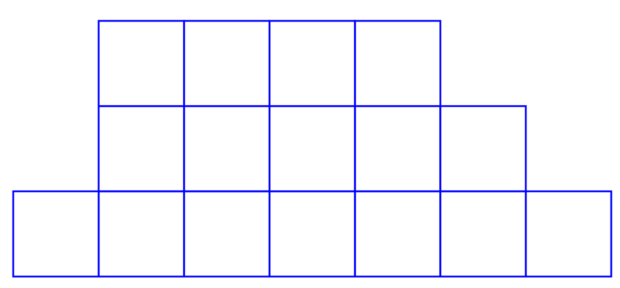
- Based on projection of the icosahedron on the sphere
- Refinement is obtained by iteratively bisecting of edges
- Triangle edges are arcs of great circles

GETM (Burchard et al., 2004)

GETM has been specifically designed for reproducing baroclinic, bathymetry-guided flows where the tidal range may exceed the mean water depth in large parts of the domain such that drying and flooding processes are relevant.

- High-order turbulence closure schemes guarantee proper reproduction of vertical exchange processes
- Implementation of generalized vertical coordinates, orthogonal curvilinear horizontal coordinates, high-order TVD advection schemes and stable drying and flooding algorithms

GETM: horizontal grid structure

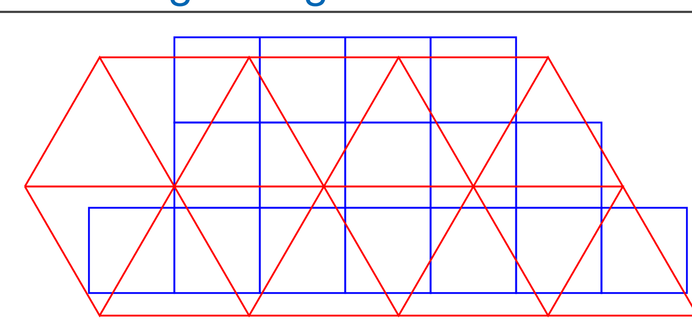


- Rectangular based structured grid
- Cells following the coastline

ESMF (Hill et al., 2004)

ESMF is a suite of software tools for developing high-performance, multicomponent Earth science modeling applications. Different components like ocean and atmosphere models are part of such an application.

Interpolation or regridding with ESMF



- ESMF provides various regridding methods: bilinear, high-order patch recovery, first order conservative and nearest neighbor interpolation

Problems

Different aspects have to be considered:

- Are there any differences in the land-sea-mask between the models? If so, how are these cells treated?
- How are the coastline overlapping cells handled, especially during the interpolation within the exchange of data?

Area of interest: Baltic Sea

Occasionaly, there are coastal upwelling events at the coast of Poland, such as from the 19th till 23rd of August 2015. The following figures show the sea surface temperature of the Western Baltic Sea for these dates. There has been a drop of about 5 to 10 K at the coast.

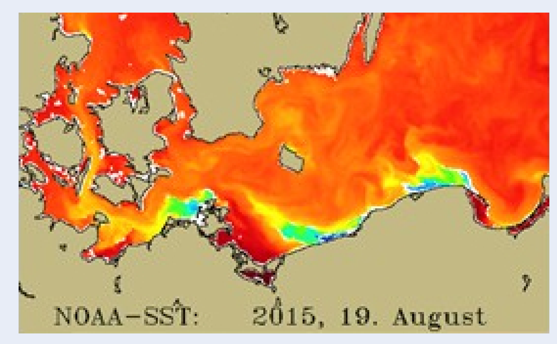


Figure 2: SST: 08/19/2015

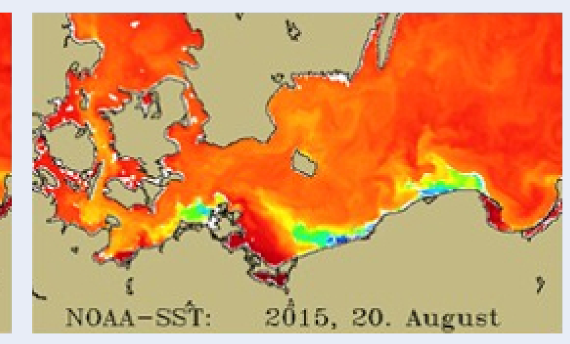


Figure 3: SST: 08/20/2015

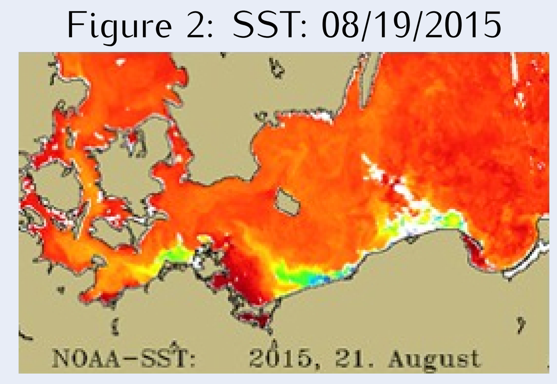


Figure 4: SST: 08/21/2015

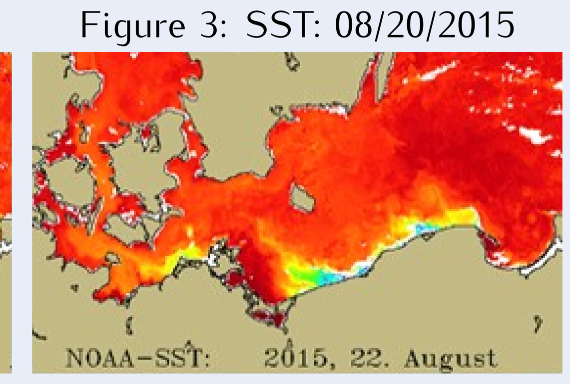
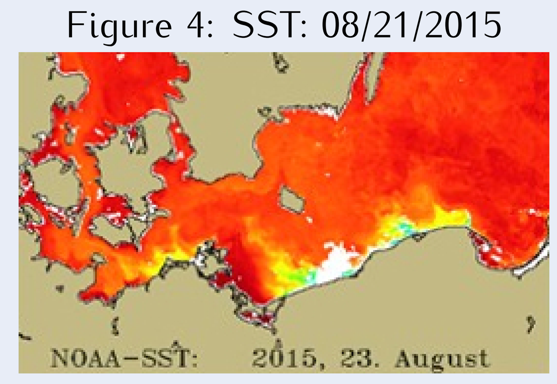
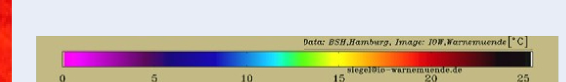


Figure 5: SST: 08/22/2015





This data has been provided by the national oceanic and atmospheric administration (NOAA) and assimilated by the federal maritime and hydrographic agency of Germany (BSH). Special thanks to Herbert Siegel (IOW), who prepared these figures.

Figure 6: SST: 08/23/2015

There are other upwelling events at the coast of Poland, i.e. from 05/24/2008 till 06/05/2008.

Nesting and interpolation

To understand the processes at the air-sea-interface in a local area, it is important to use high resolution grids up to one kilometer. Therefore, an appropriate atmospheric model such as the non-hydrostatic model ICON is utilized. Initializing the atmospheric model for a specific hindcast run is carried out with measured and reanalyzed data sets. The resolution of these data sets for the area of interest is between 13 km and 16 km. To avoid interpolation issues from 13 km to 1 km a reasonable number of nested grids with different resolutions is adjusted. In Figure 1 the green rectangle is the applied grid for GETM, while the yellow circle is the highest resolved grid for ICON.

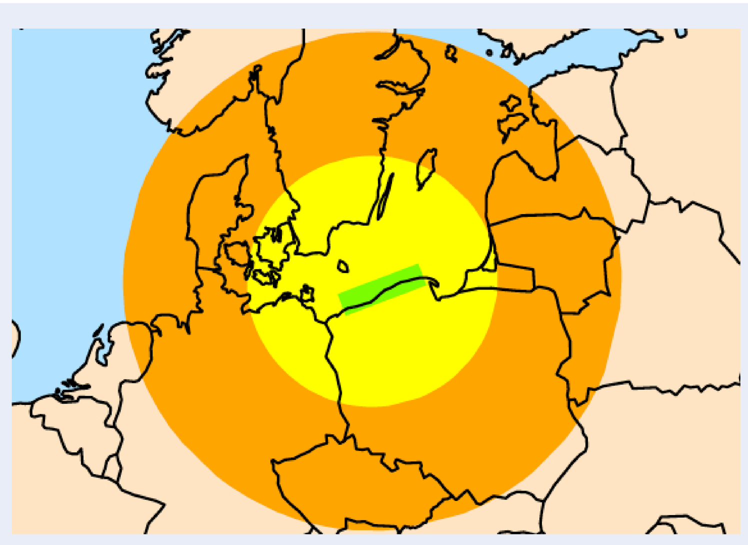


Figure 1: Nested Grids and Area of Interest

Furthermore, the coupled run is conducted as a limited area run. Therefore, the outer boundaries of the largest and smallest resolved grid is forced with reanalyzed data.

Description of applied runs

Planned runs

Various different (un-)coupled runs are planned to investigate the processes at the air-sea-interface. First of all, there is an uncoupled run of GETM with the so far used initializing data sets of the area of interest. Secondly, the same run is carried out except that the initializing data is given by a previous run of ICON. Furthermore, there is a one-way coupled run, where the air-sea-interface in GETM is forced by ICON and vice versa. Finally, a fully tow-way coupled run is applied. Using these numerous runs, the processes which are modelled by the coupling itself are describable and analyzable.

Considered numerical aspects

- Which time stepping schemes are applied for the models?
- When will be a data exchange at the air-sea-interface?
- Which numerical methods are going to be adapted for investigating the processes at the interface?

References

Burchard, Hans, Karsten Bolding, and Manuel Ruiz Villarreal (2004). "Three-dimensional modelling of estuarine turbidity maxima in a tidal estuary". In: *Ocean Dynamics* 54.2, pp. 250–265.

Hill, Chris et al. (2004). "The architecture of the Earth system modeling framework". In: *Computing in Science and Engineering* 6.1, pp. 18–28.

Zängl, Günther et al. (2015). "The ICON (ICOsahedral Non-hydrostatic) modelling framework of DWD and MPI-M: Description of the non-hydrostatic dynamical core". In: *Quarterly Journal of the Royal Meteorological Society* 141.687, pp. 563–579.

Outlook

- Thorough description of the physics at the air-sea-interface
- Investigation of numerical problems arising with the physics of coupling