Transport and fate of toxic constituents of dumped munitions in the western Baltic Sea

Anja Eggert

Leibniz Institute for Baltic Sea Research Warnemünde (IOW)

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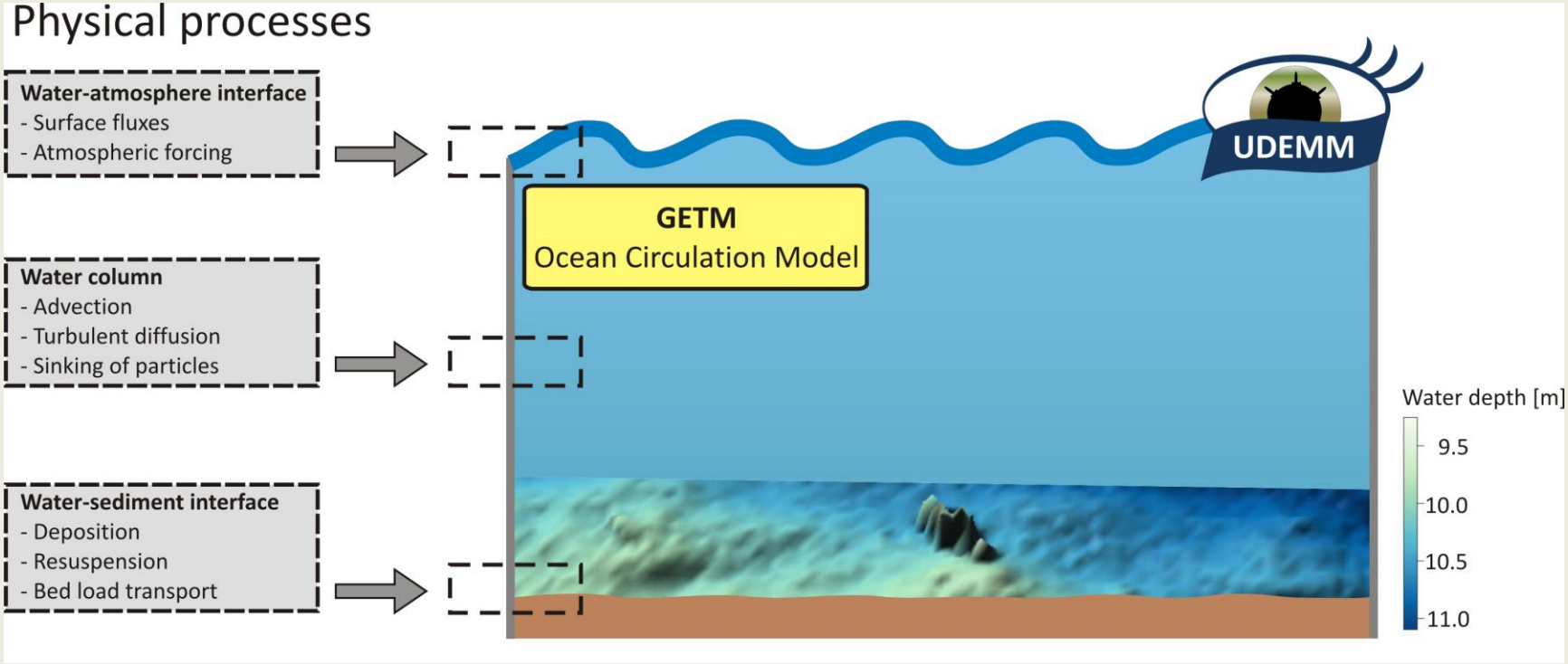
Application of the circulation model GETM

- **Simulation** of e.g. temperature, salinity, currents in 3D and over time

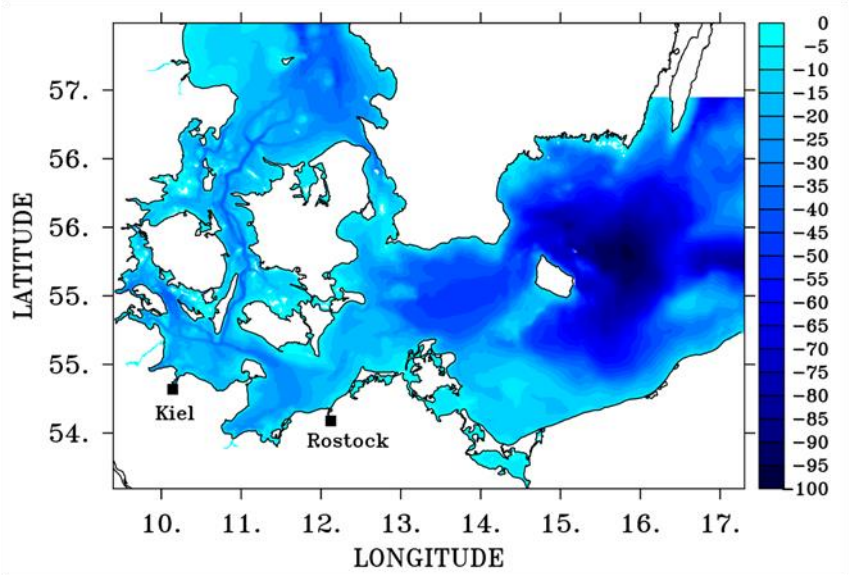


GETM model results were validated in numerous studies – and is now a workhorse.

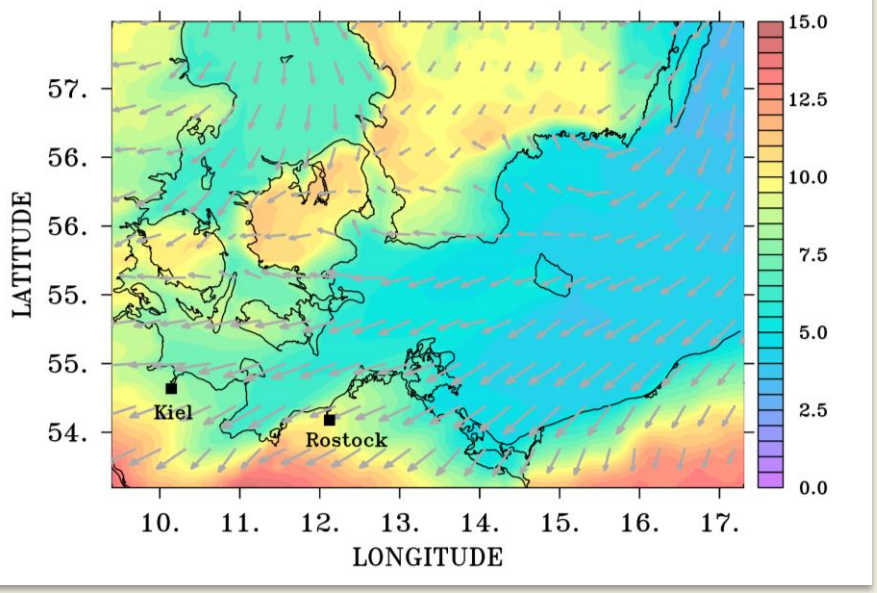
Realistic model runs: 2007-2016

- **Model area:** western Baltic Sea from the Kattegat to Bornholm Basin
- **Horizontal resolution:** ~600 m
- **Vertical resolution:** 42 vertically adaptive, topography-following layers
  → in 10-20 m water depth: 25-50 cm resolution
- **Realistic atmospheric forcing** (data from German Weather Service)

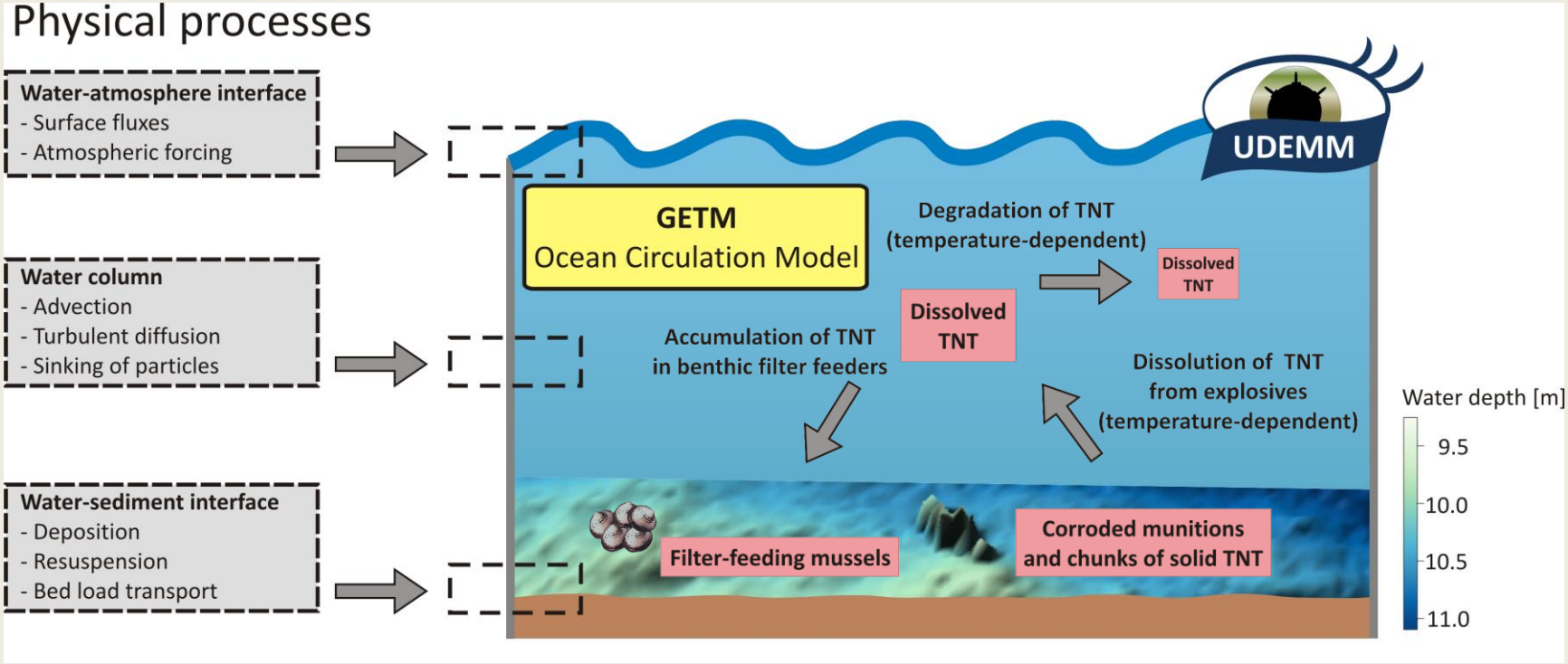
TOPOGRAPHY OF THE WESTERN BALTIC SEA



E.G. AIR TEMPERATURE AND WIND ON 3 APRIL 2014



Simulating the transport and fate of TNT in the western Baltic Sea



TNT module developed in UDEMM in close cooperation with other WPs !

→ e.g. TNT dissolution + degradation rates

Dissolution and degradation of TNT - parameterizations in the model -

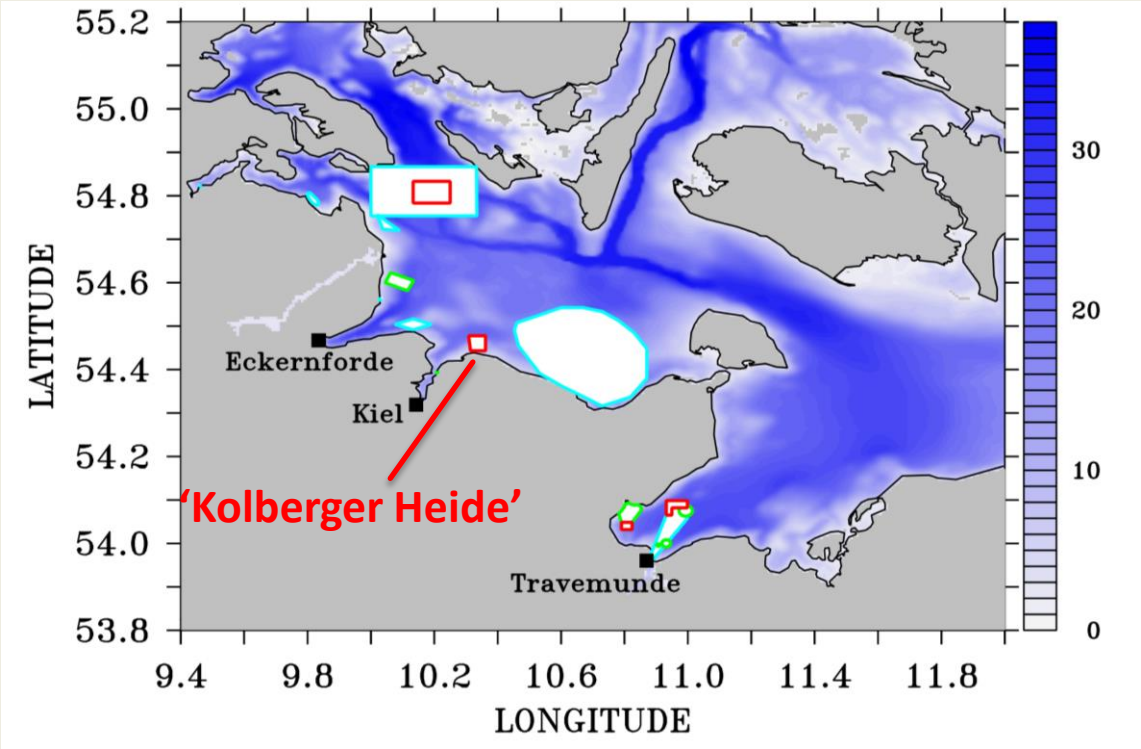
Arrhenius-equation:

$$k = A \cdot e^{-\frac{E_a}{R \cdot T}} \leftrightarrow \ln(k) = \ln(A) - \frac{E_a}{R} \cdot \frac{1}{T}$$

- Temperature-dependent reaction rate k [mol m^{-2} d^{-1} or mol mol^{-1} d^{-1}]
- Pre-exponential factor A [mol m^{-2} d^{-1} or mol mol^{-1} d^{-1}]
- Activation energy E_a [J mol^{-1}]
- Universal gas constant R = 8.31446 [J mol^{-1} K^{-1}]
- Absolute temperature T [K]

Experimental determination of A and E_a → **Temperature-dependence of *k*** → **Temperature-dependence of TNT dissolution and degradation**

Regional analysis (19 sites)



Geographic database at State office of Energy, Agriculture, the Environment and Rural Areas (Schleswig-Holstein), http://amucad.egeos.de

Munitions dumping site (~100 km²)

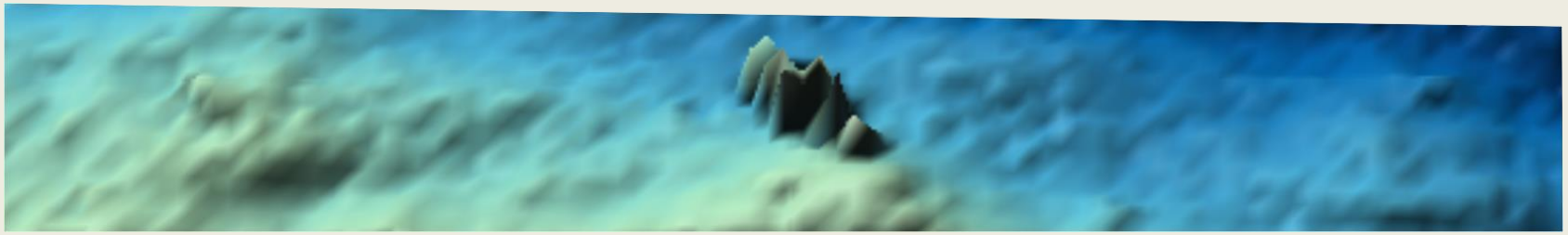
Munitions contaminated area (~50 km²)

Munitions suspected area (~850 km²)

→ **Amount/type of munition?**
→ **Its state of corrosion?**
→ **Open TNT surface?**

Estimates of open TNT surfaces

Munitions dumping site ‚Kolberger Heide':
Video analyses and hydroacoustic mapping



DATA: HYDROACOUSTIC MAPPING IN UDEMM-WP1

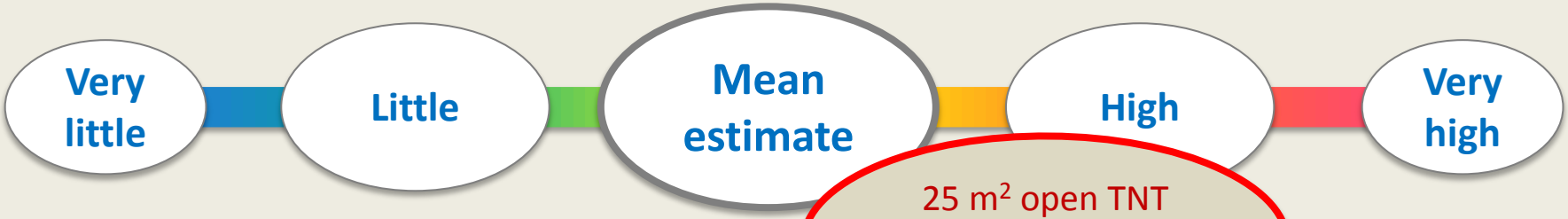
- **UDEMM-results:**
  - 300 contacts on 1260 ha (=35 grid cells)
  - TNT is leaking out from 100 corroded bombs

VIDEO ANALYSIS IN UDEMM-WP1

How large is the total open TNT surface in 'Kolberger Heide' ?

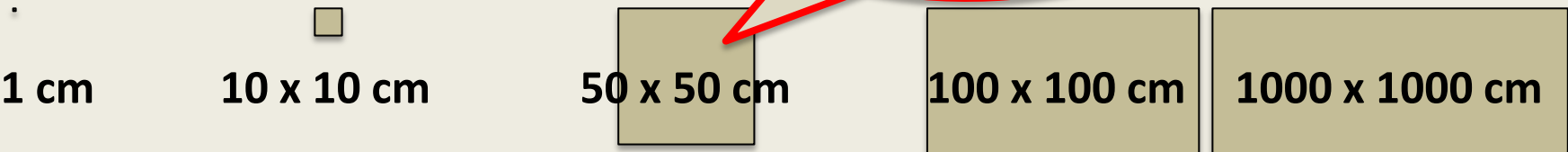
Uncertainties are very, very high !!

Sensitivity study across 5 orders of magnitude



25 m^2 open TNT surface in ‚Kolberger Heide'

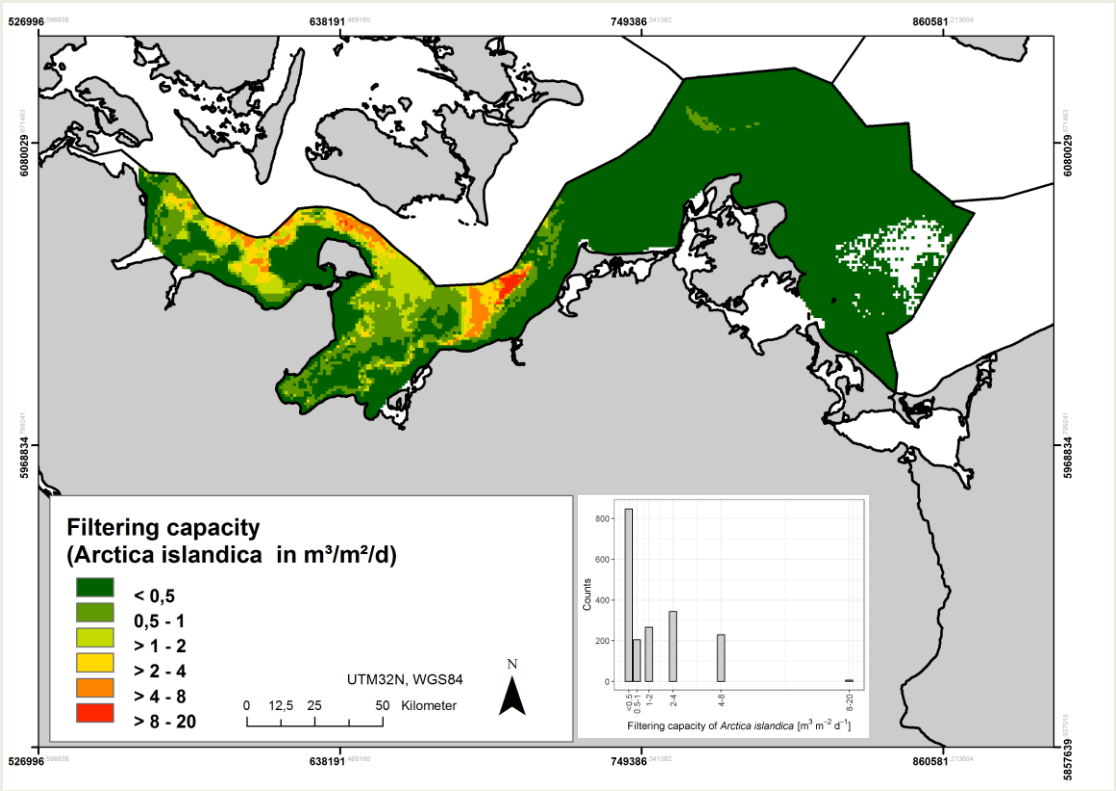
Open TNT surface per corroded bomb:



Three types of munition disposal sites:

- Munitions dumping site -> 100% ('Kolberger Heide')
- Munitions contaminated area -> 10%
- Munitions suspected area -> 1%

TNT-accumulation in filter-feeding mussels



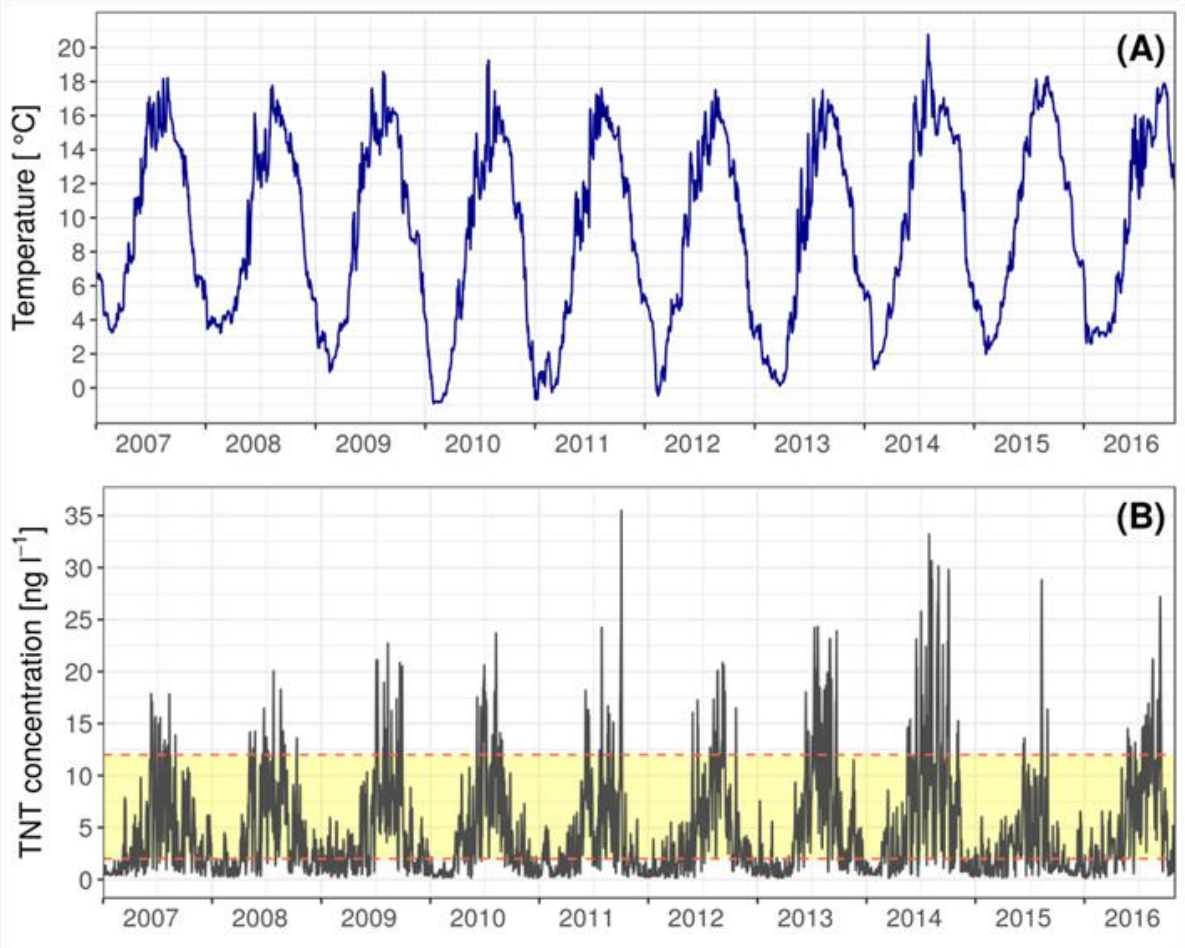
ALEXANDER DARR, WG ECOLOGY OF BENTHIC ORGANISMS, IOW

Arctica islandica (ocean quahog)

- dominates soft bottom in Kiel Bight
- lives in dense communities below the sediment surface (~100 individuals per m²)

- Filter-feeding benthic organisms accumulate contaminants, i.e. are useful bioindicator species (SEE **UDEMM-WP4**)
- Mean filtering capacity of *A. islandica* in western Baltic: 1.5 $m^3\ m^{-2}\ d^{-1}$

Seasonal signal in TNT concentration in the bottom water of 'Kolberger Heide'

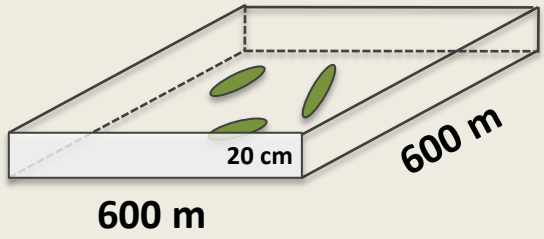


Very little

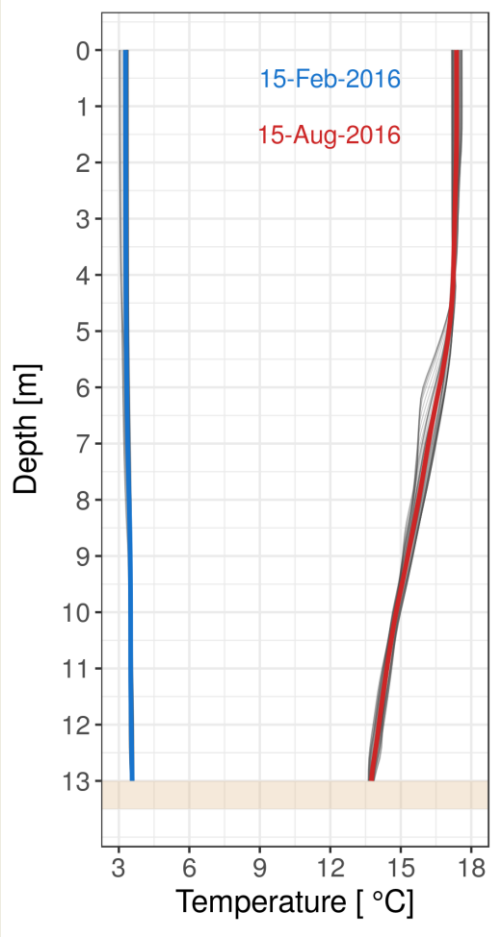
1 x 1 cm

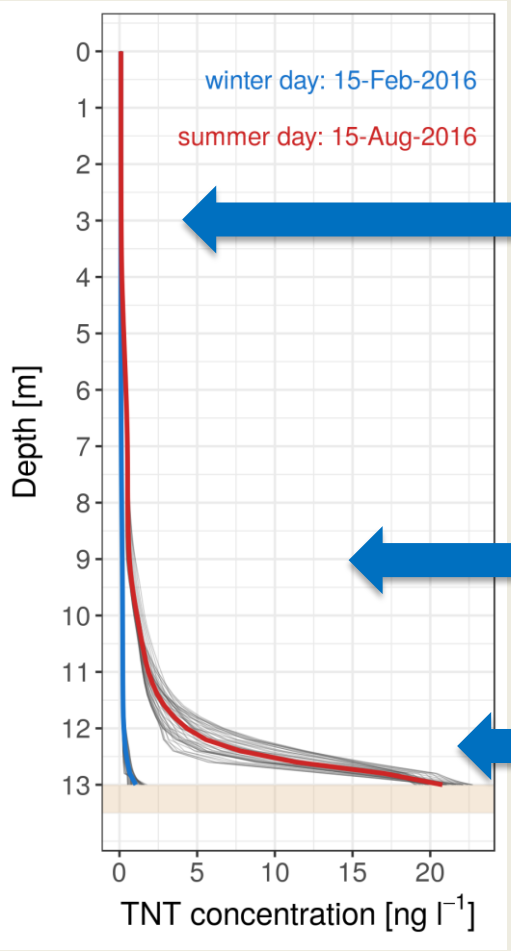
Open TNT surface per corroded bomb

1 model grid cell with 3 corroded bombs:



Depth-profiles of TNT concentration

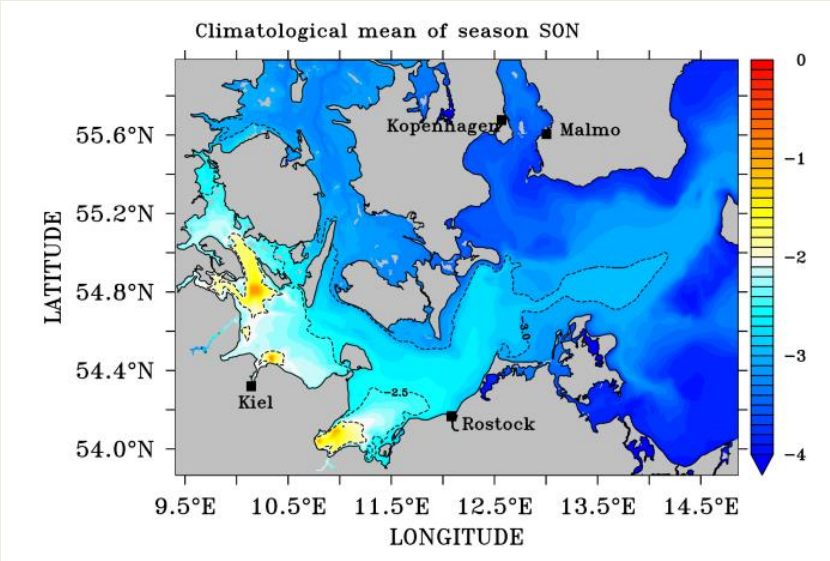


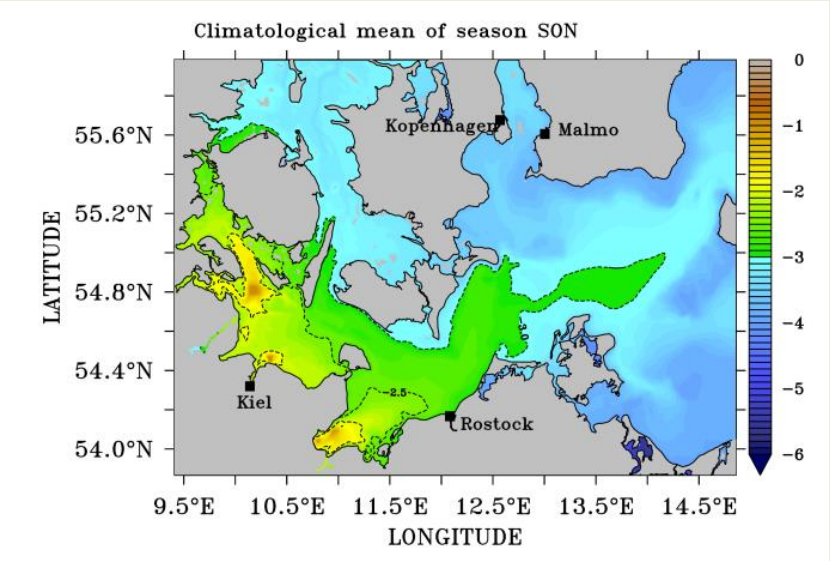


- Not necessarily high concentrations in the surface water in summer
- Faster degradation of TNT in the water column in summer
- Maximal TNT-concentrations at the seafloor
- Higher concentrations in summer

TNT distribution (bottom water) & potential TNT accumulation in benthic mussels

Analysis of realistic model runs 2007-2016

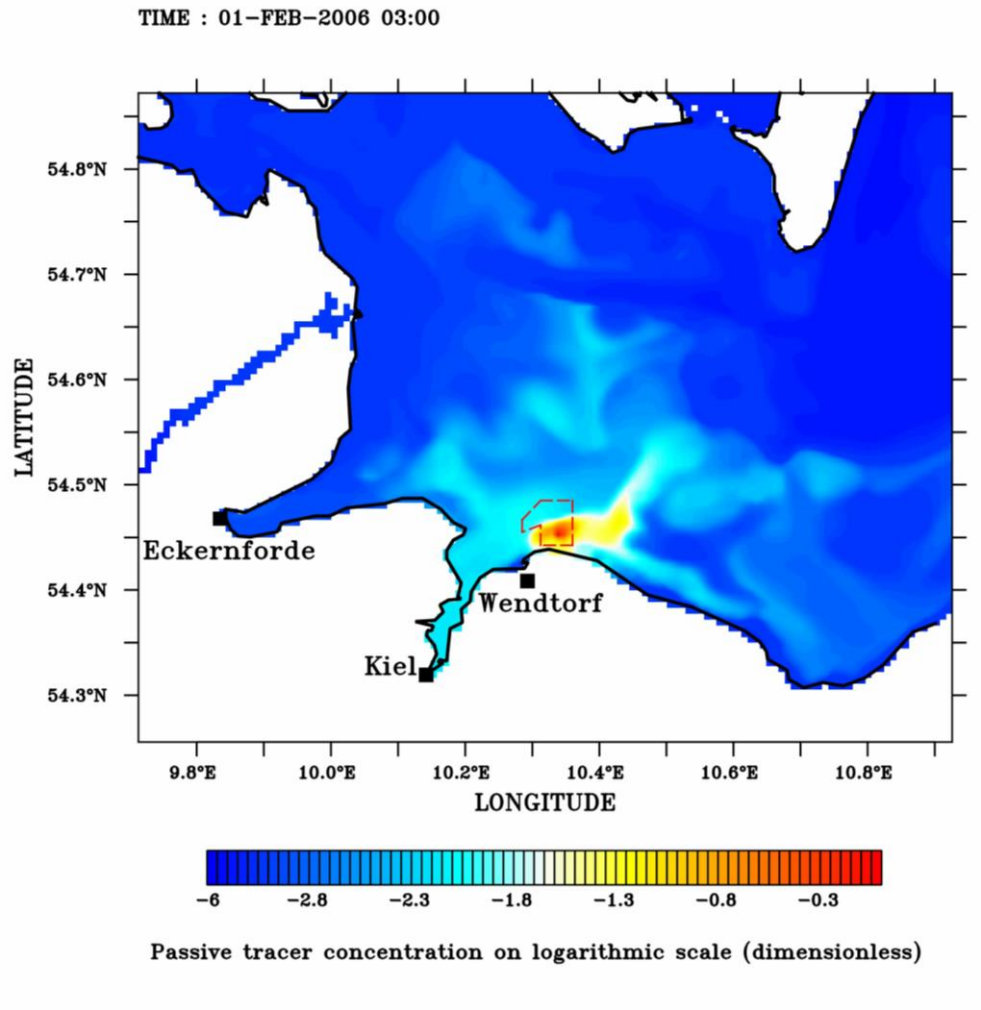




relative concentrations = -2
→ 1:100 dilution

- TNT accumulation in µg m^{-2} day^{-1}
- -2 → 0.01 µg m^{-2} day^{-1}
- with 100 mussels per 1 m^2 → 0.1 ng $indiv^{-1}$ day^{-1}

Thank you very much for your attention!



Release of a

passive tracer

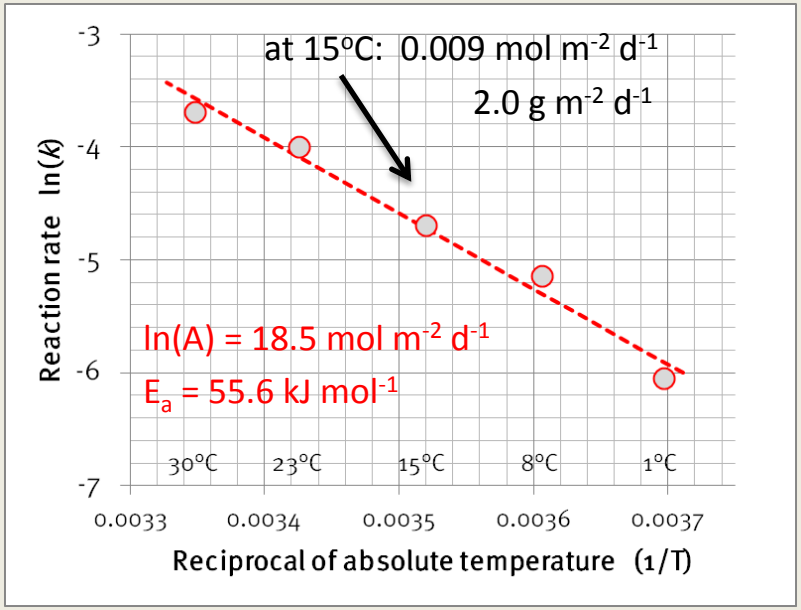
in the munitions

dumping site

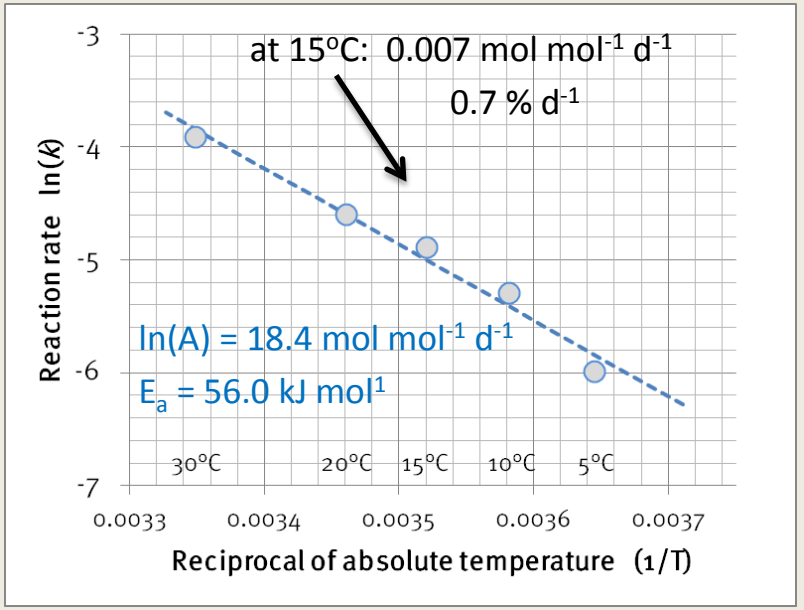
'Kolberger Heide'

Experiments: temperature dependence of TNT dissolution + degradation

TNT dissolution in to Baltic seawater



TNT degradation in Baltic seawater



CHEMICAL ANALYSES IN UDEMM-WP3

- **‚Kolberger Heide' (100 corroded bombs, 1260 ha, mean estimate)**

  25 m^2 open TNT surface -> 50 g day^{-1} TNT dissolved into the water

  -> 0.35 g day^{-1} TNT chemically degraded in the water