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Improvements in turbulence model realisability for enhanced stability of ocean forecast and its importance for downstream components

Thorger Brüning, JONSMOD 2018, October 17th – 19th, Firenze

BSH: Tasks and services

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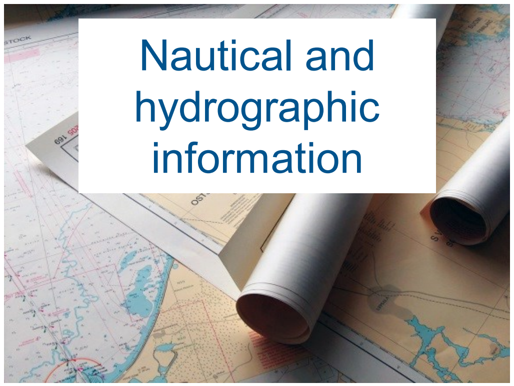

Nautical and hydrographic information


Services for maritime shipping

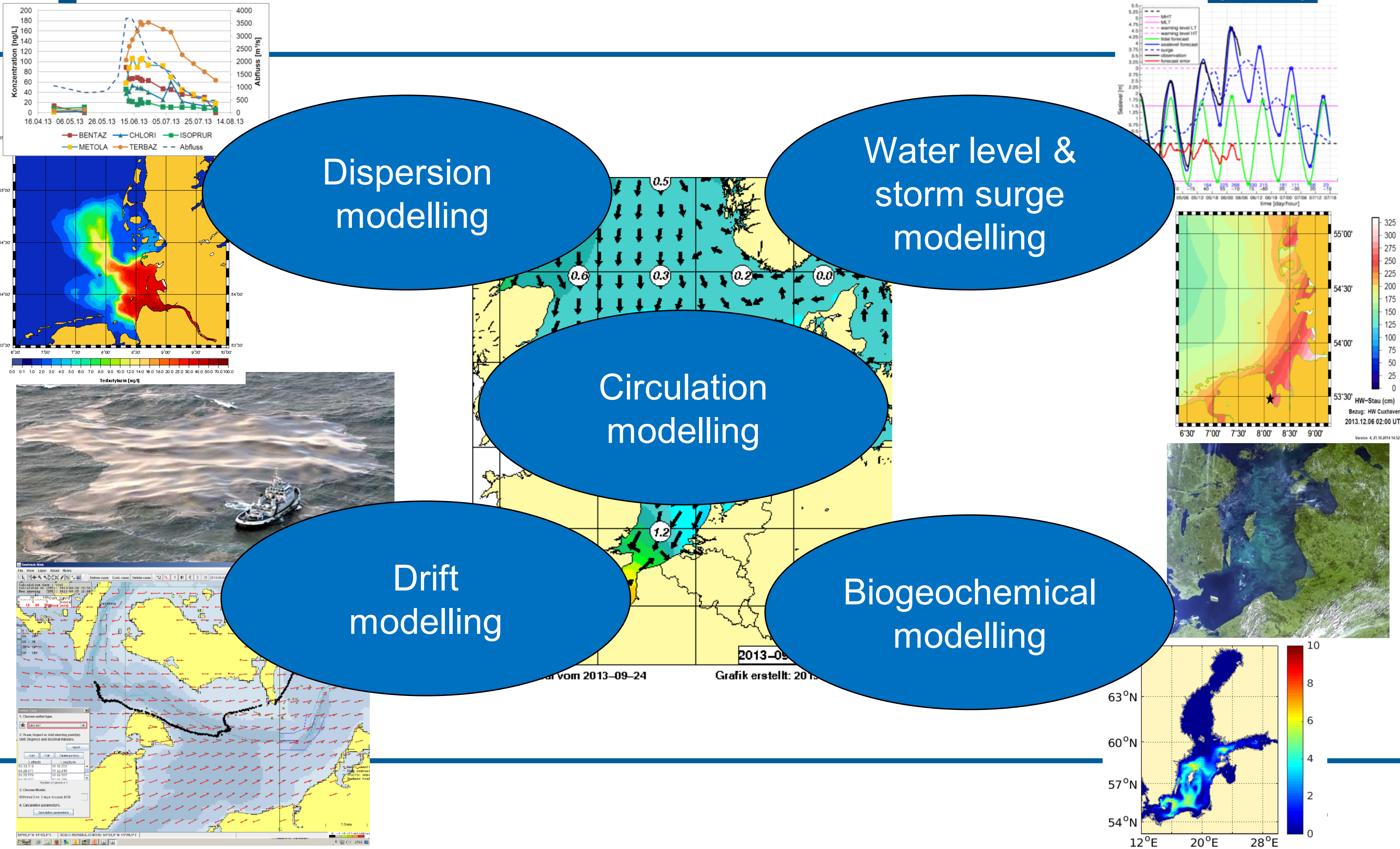

Marine monitoring


Maritime Forecasting Services


Order of the seas

National, supranational, international obligations to report

General overview: Operational model applications



Motivation – A problem with surface currents during a storm event in December 2013

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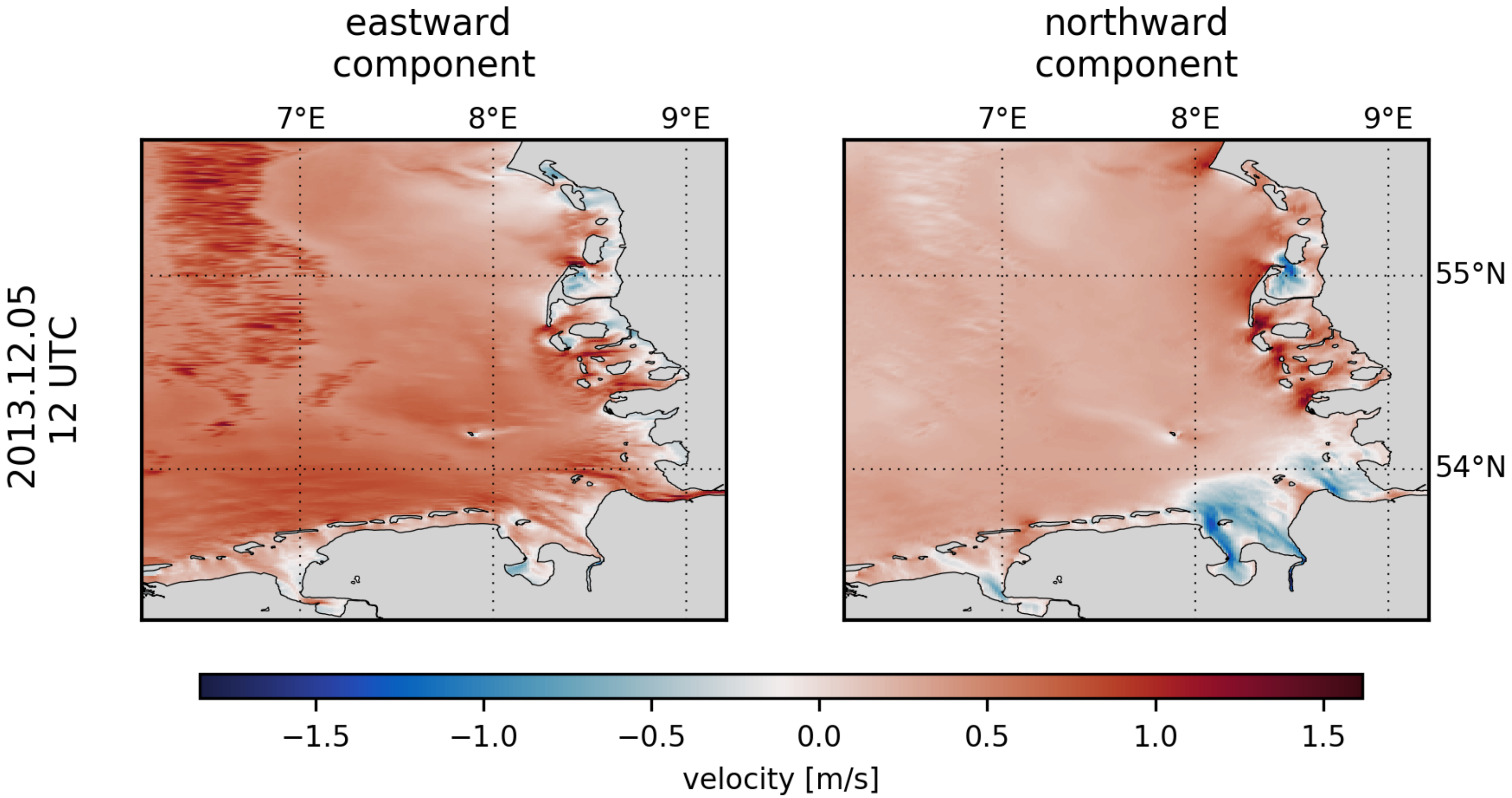

ε-tests

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- originally a pure technical test
- results of short model runs (e.g. 24 simulation hours) are compared
- only difference between these runs being the compiling of the source code.
  - It is done with different compilers
  - and/or with a different set of compiler flags
- results are compared point by point, maximum differences are the ε's
  - Small ε's indicate a both technically and physically stable code, providing reliable, portable and reproducible results.
  - Large ε's, indicate a stability problem in the code, which can have both technical and physical reasons.

ε-test
on 5 December 2013 at 12 UTC of surface eastward velocity (optimazation level O2 vs O3)

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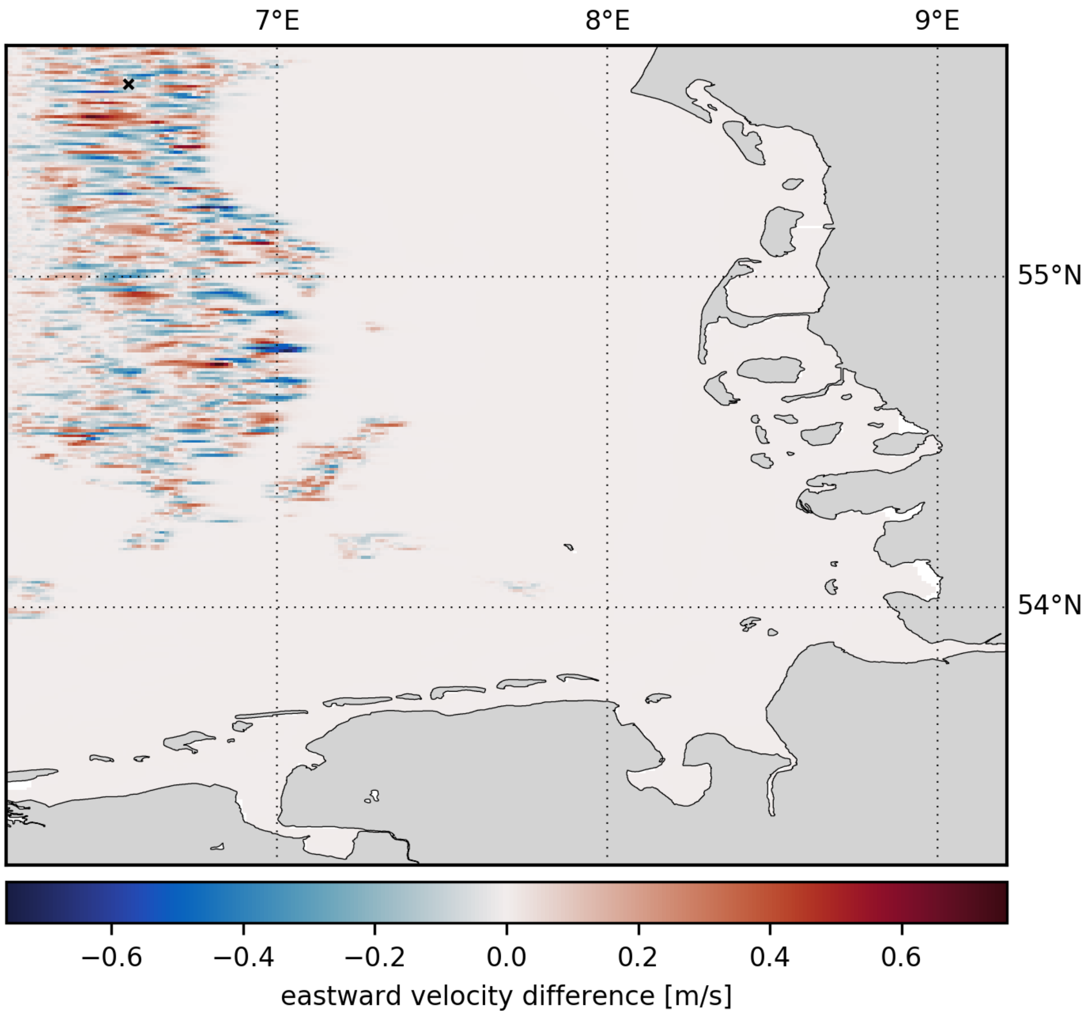

unrealistic current / diffusivity profile (at 55° 35' N / 6° 33' E)

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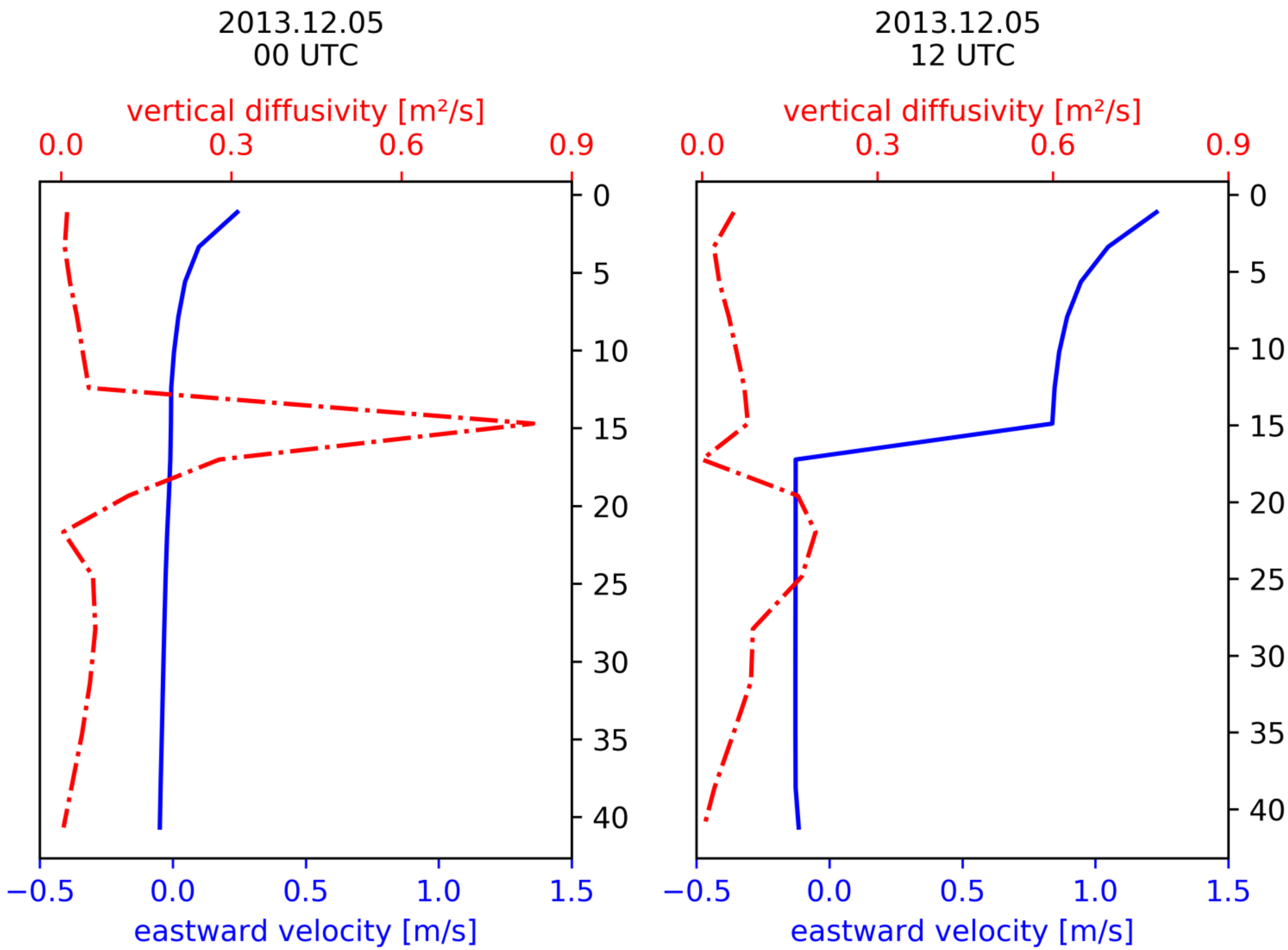

Stability and Realisability – Introduction into Turbulence model

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The vertical diffusivities are defined as follows:

$$K_i = 2\frac{k^2}{\epsilon}S_i$$

with structure/stability or closure functions

$S_i = S_i(a_m, a_h, a_s)$ with double diffusion

$S_i = S_i(a_m, a_n)$ without double diffusion

which depends on dimensionless shear, heat, salinity and buoyancy number: $a_m = (\tau\Sigma)^2$, $a_h = \tau^2 R_h$, $a_s = \tau^2 R_s$, $a_n = (\tau N)^2$ with the dynamic dissipation time scale $\tau = 2\frac{k}{\epsilon}$, the mean shear Σ, the buoyancy N^2, $R_h = a_T\,{}^{\partial T}/_{\partial z}$ and $R_s = a_S\,{}^{\partial S}/_{\partial z}$ wherby $\alpha_{T,S} = -\frac{1}{\rho}\frac{\partial\rho}{\partial(T,S)}$ denotes the thermal/ haline concentration coefficient and $N^2 = R_h - R_s$

Stability and Realisability – The criteria (stated in Umlauf and Burchardt (2005)

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(1) $K_i \geq c_i \geq 0$ with c_i being a constant

(2) To guarantee increasing effective vertical shear anisotropy with increasing dimensionless vertical shear number we have $\frac{1}{2}\partial_{a_m}\left(K_m(a_m, a_n)a_m{}^{1/2}\right) \geq 0$

(3) $a_n \geq a_n^*$ whereby a_n^* describes the value of a_n in shear-free convective conditions for the turbulence equilibrium, in which buoyancy production equals dissipation rate

(4) To prevent oscillation between two mathematically solutions, monotonicity of ${}^{K_n(a_m,a_n)}/_{a_n}$ with respect to a_n must be insured for negative a_n : $-\partial_{a_N}\left({}^{K_n(a_m,a_n)}/_{a_n}\right) > 0$

(5) The velocity variances must be positive, with the only critical condition being $< w', w' > \leq 2k$ whereby $< w', w' >$ is the vertical velocity variance.

Stability and Realisability – The adapted criteria for double diffusion

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(1) $K_i \geq c_i \geq 0$ with c_i being a constant **was already implemented**

(2) To guarantee increasing effective vertical shear anisotropy with increasing dimensionless vertical shear number we have $\frac{1}{2}\partial_{a_m}\left(K_m(a_m, a_n)a_m{}^{1/2}\right) \geq 0$ **extended to** $\frac{1}{2}\partial_{a_m}\left(K_m(a_m, a_h, \boldsymbol{a_s})a_m{}^{1/2}\right) \geq 0$

(3) $a_n \geq a_n^*$ whereby a_n^* describes the value of a_n in shear-free convective conditions for the turbulence equilibrium, in which buoyancy production equals dissipation rate

(4) To prevent oscillation between two mathematically solutions, monotonicity of ${}^{K_n(a_m, a_n)}/_{a_n}$ with respect to a_n must be insured for negative a_n : $-\partial_{a_N}\left({}^{K_n(a_m, a_n)}/_{a_n}\right) > 0$ **NOT NEEDED (implied by (3))**

(5) The velocity variances must be positive, with the only critical condition being $< w', w' > \leq 2k$ whereby $< w', w' >$ is the vertical velocity variance. **NO PROBLEM to implement**

Stability and Realisability – The adapted criteria for double diffusion

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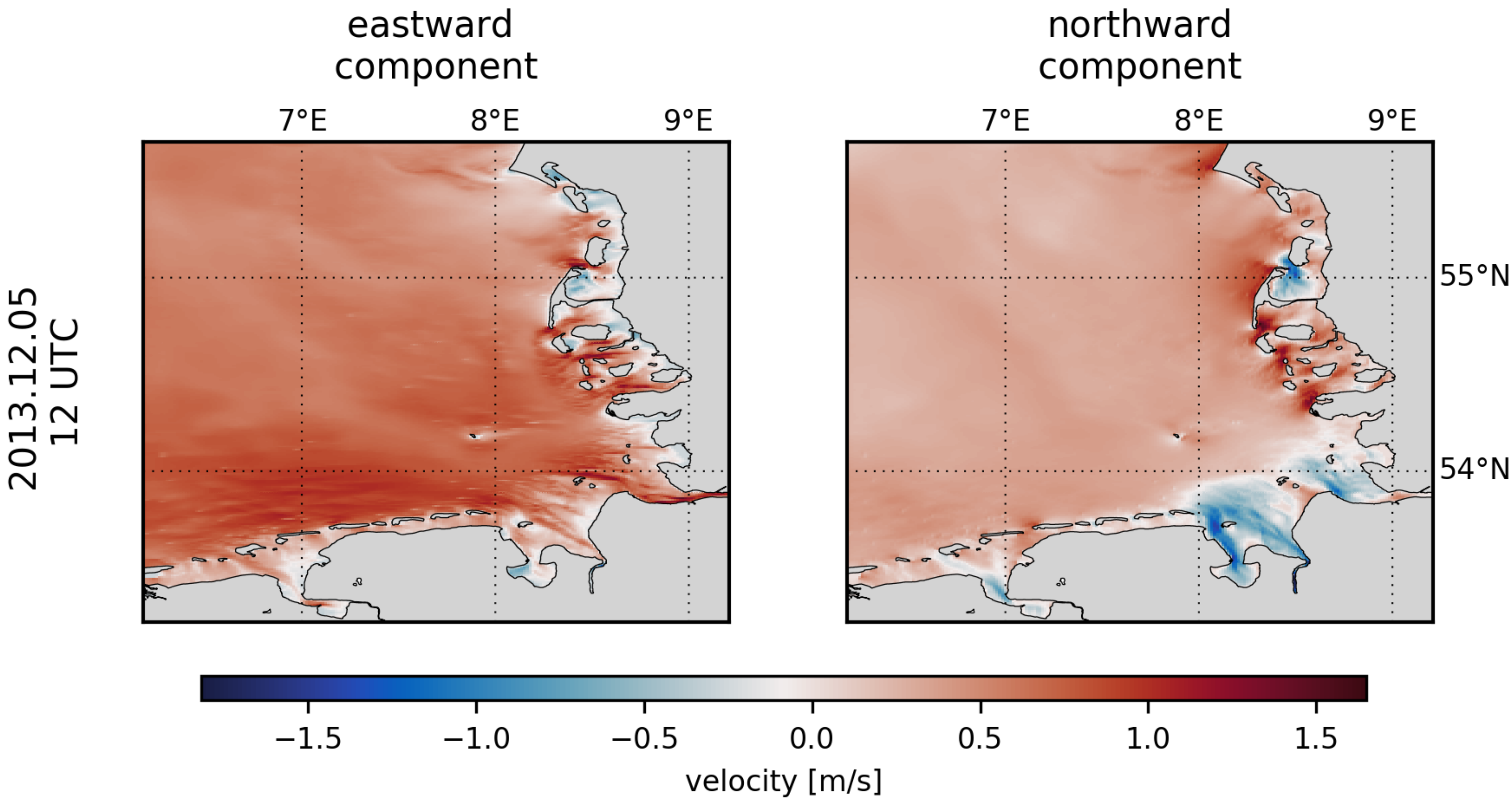
(3) $a_n \geq a_n^*$ whereby a_n^* describes the value of a_n in shear-free convective conditions for the turbulence equilibrium, in which buoyancy production equals dissipation rate

To generalize this, the shear-free convection case once without vertical temperature differences (heat number = 0) and once without vertical salinity differences (salinity number = 0) is considered. We get values a_h^* and a_s^* .

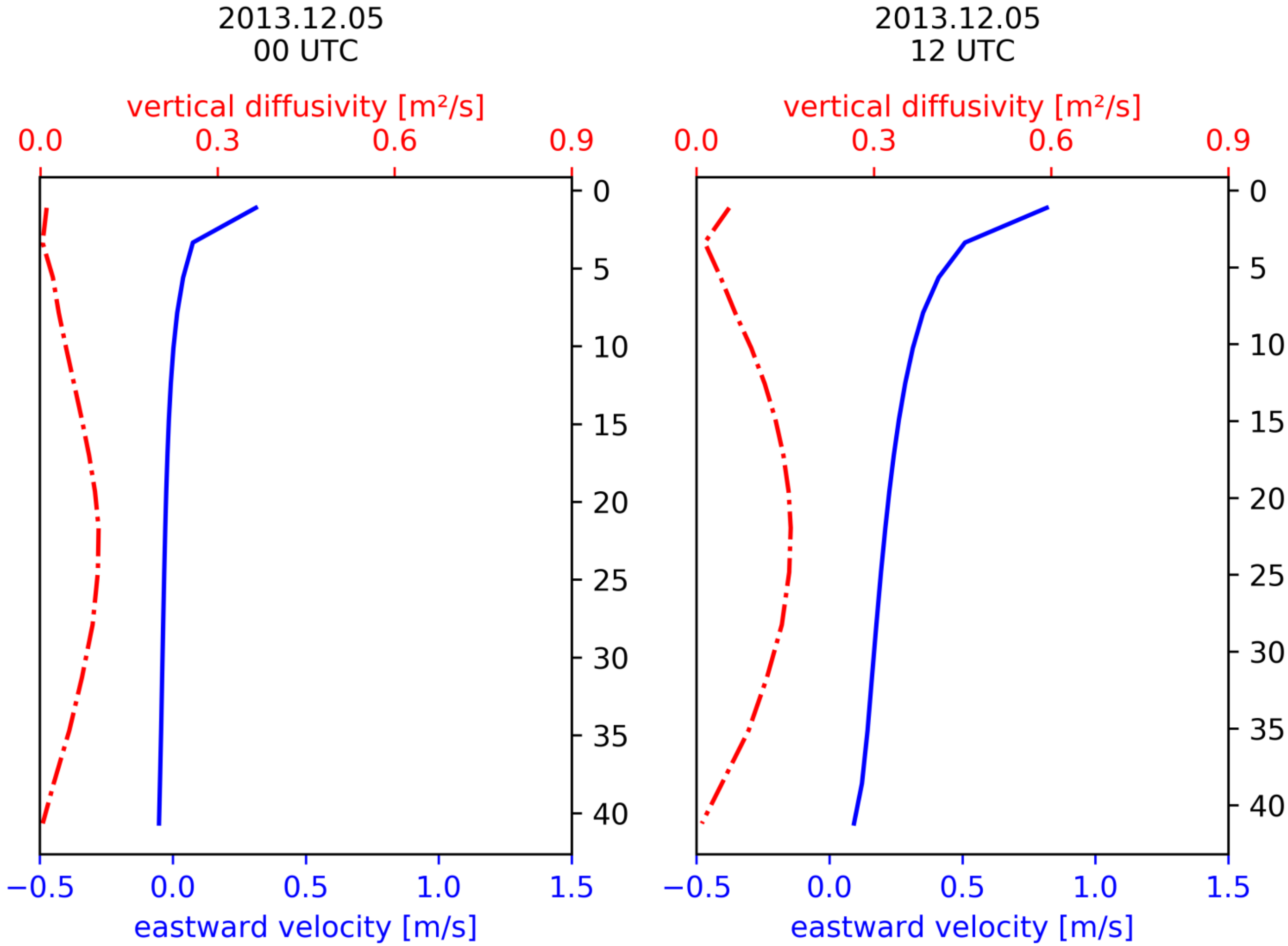
Due to symmetry, we get $a_h^* = a_s^* = a_{h,s}^*$

So that we finally have $a_h \geq a_{h,s}^*$ and $a_s \geq a_{h,s}^*$

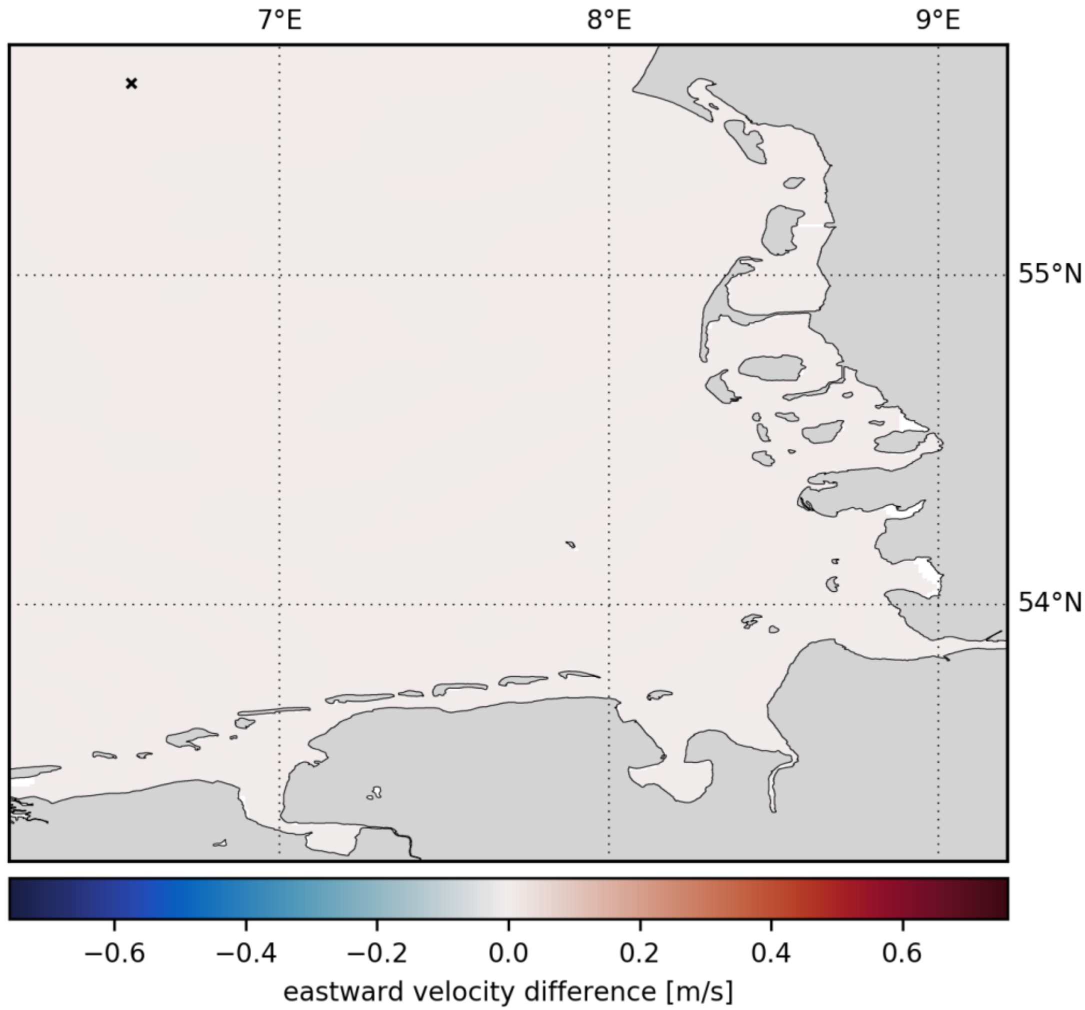
New surface currents during storm event in December 2013



New (now realistic) current / diffusivity profile (at 55° 35‘ N / 6° 33‘ E)



ε-test (with additional stability/realisibility checks) on 5 December 2013 at 12 UTC of surface eastward velocity (optimazation level O2 vs O3)



Drift of an object
from 5 December 10 UTC to 8 December 10 UTC (3 days)

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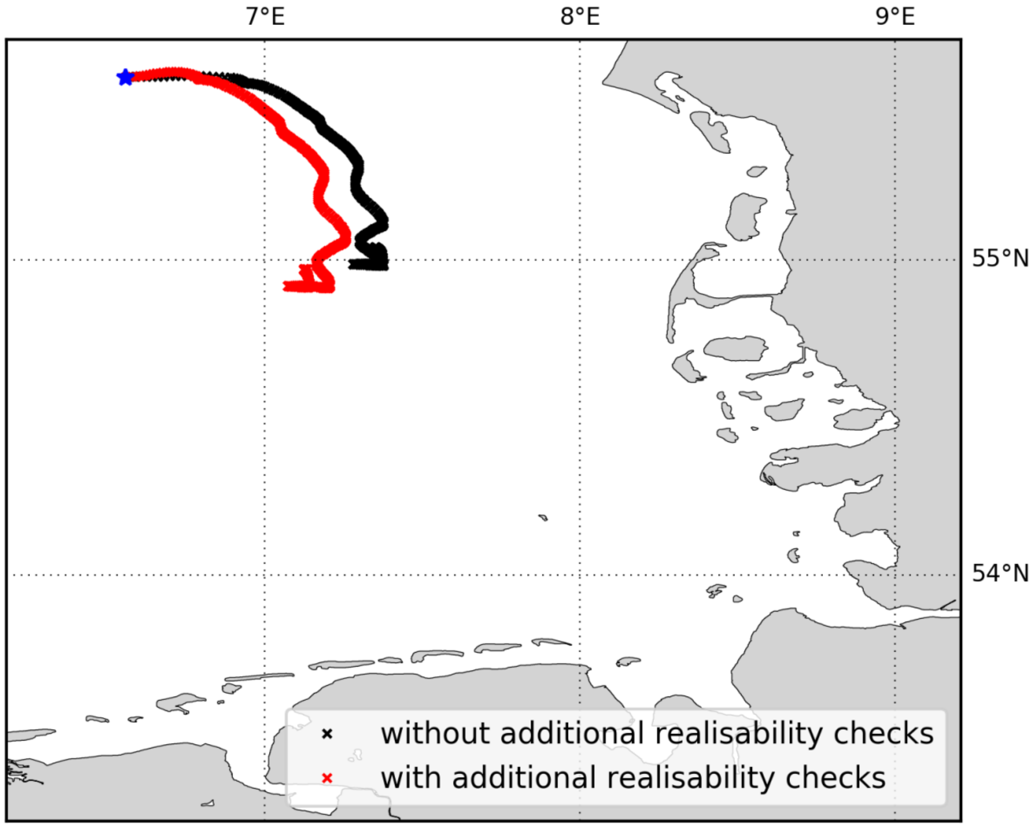

Particle cloud of a drift simulation of a fictitious oil accident with 15000 t of oil

on 8 December 10 UTC (after 3 days)

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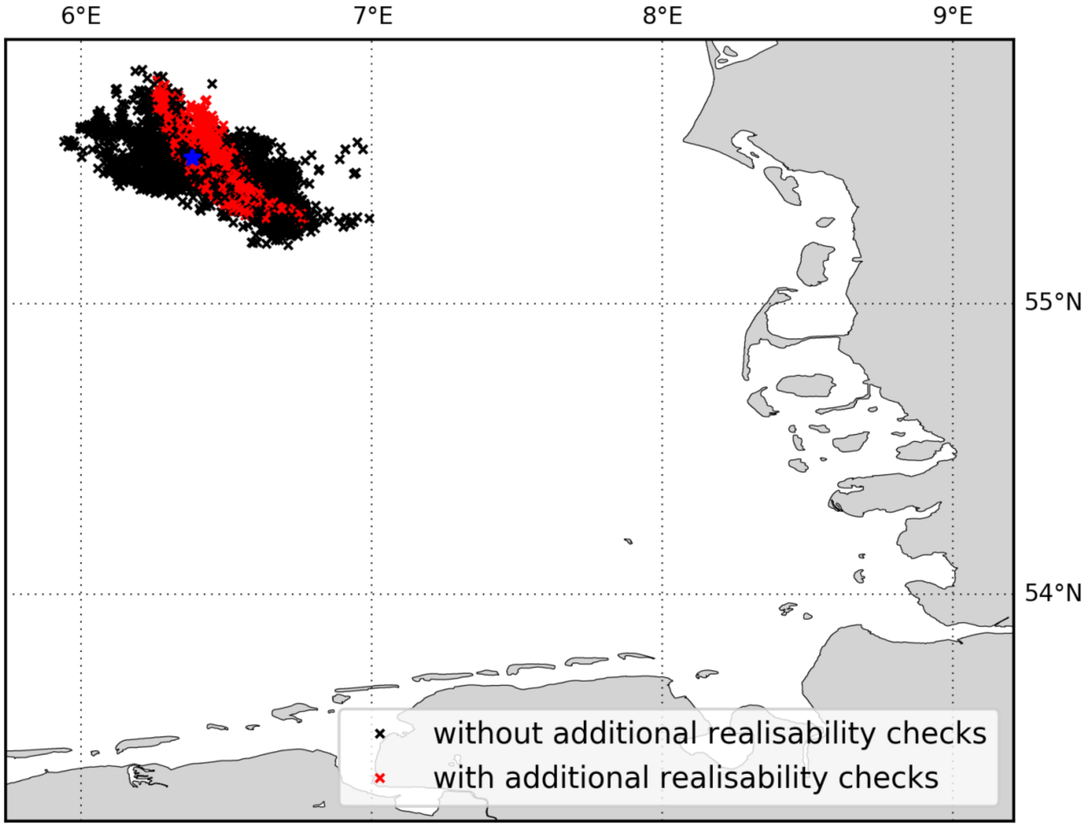

conclusions

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- Explicit realisability is a must in every turbulence model!
  - For those not using double diffusion criteria were well known
  - We presented an extension of these criteria to turbulence models using double diffusion
- Even very intensive physical validation (especially statistical validation) is not able to detect all temporally and spatially limited instabilities -> a look at specific individual events should always be part of the validation
- Technical validation is a useful tool and a good supplement to physical validation, which can also detect physical instabilities

Questions?