(3)

Where Applied Mathematics, Hydrodynamics and Ocean Science meet: Predictive, Diagnostic & Sea Going Assessments of Water levels & Global- and Internal Tides

1: Dr. R. (Ramses) van der Toorn, Prof. Dr. A.W. Heemink, (TUD)
2: Dr. M. Verlaan (Deltares)
3: Dr. Th. Gerkema, Dr. H. van Haren (NIOZ)

Deltares (2)

(1) TU Delft

The Netherlands







The Netherlands: 18% water (area)

- 180 x 300 km^2; ~ 21% below sea
- population: 17 mln; ~ 30-40% below sea

The Netherlands

The Netherlands: water management





- 1953 flood: 1800 killed, 100000 lost home.

Oosterscheldekering
(finished 1986)







- Oosterschelde:
  - crucial eco-zone
  - ocean species breed here

The Netherlands

The Netherlands

- Rotterdam harbor:
  largest port in Europe





offshore







Petrochemicals

The Netherlands

The Netherlands

- Rotterdam harbor:
  largest port in Europe
- *Maeslantkering:*

storm surge protection:









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Water Level / Storm Surge Forecasting

Dutch Continental Shelf Model (DCSMv6)
Water Level Forecasting

- content:
  - *non-linear* shallow water dynamics
    - captures tide-surge interaction

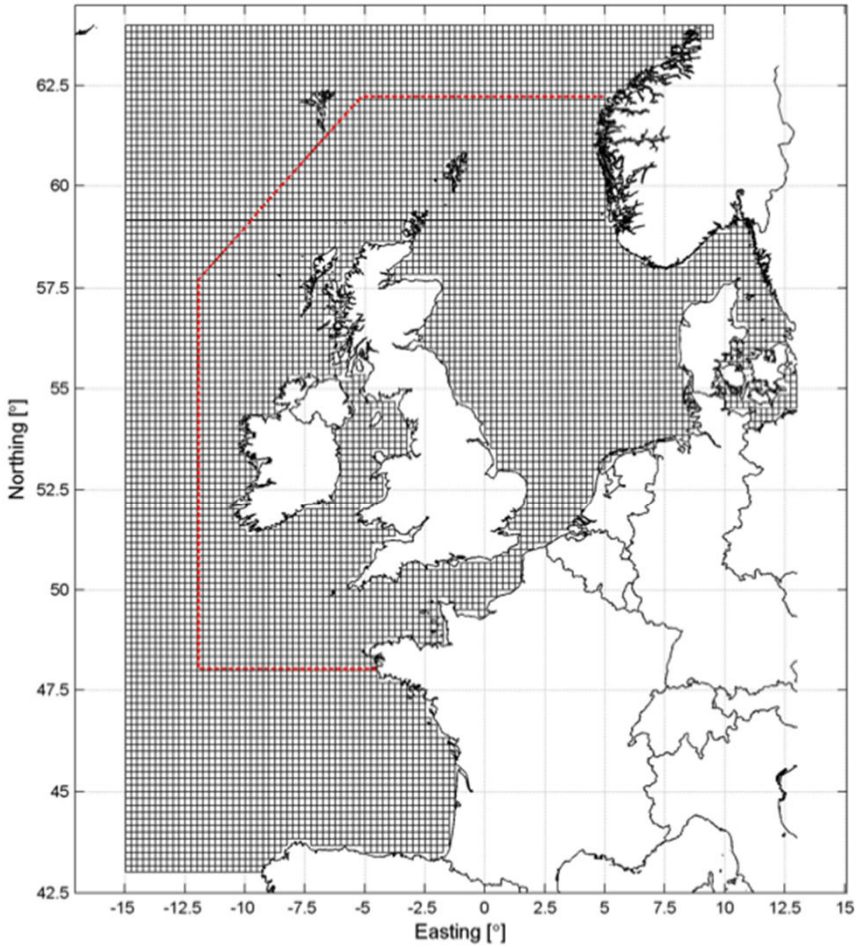


Figure 2.1 Overview of the DCSMv6 hydrodynamic model grid; every tenth grid line is plotted. The red, dashed line represents the DCSMv5 model extent.

Water Level / Storm Surge Forecasting

Dutch Continental Shelf Model (DCSMv6)
Water Level Forecasting

- content:
  - non-linear shallow water dynamics
    - captures tide-surge interaction
  - bathymetry

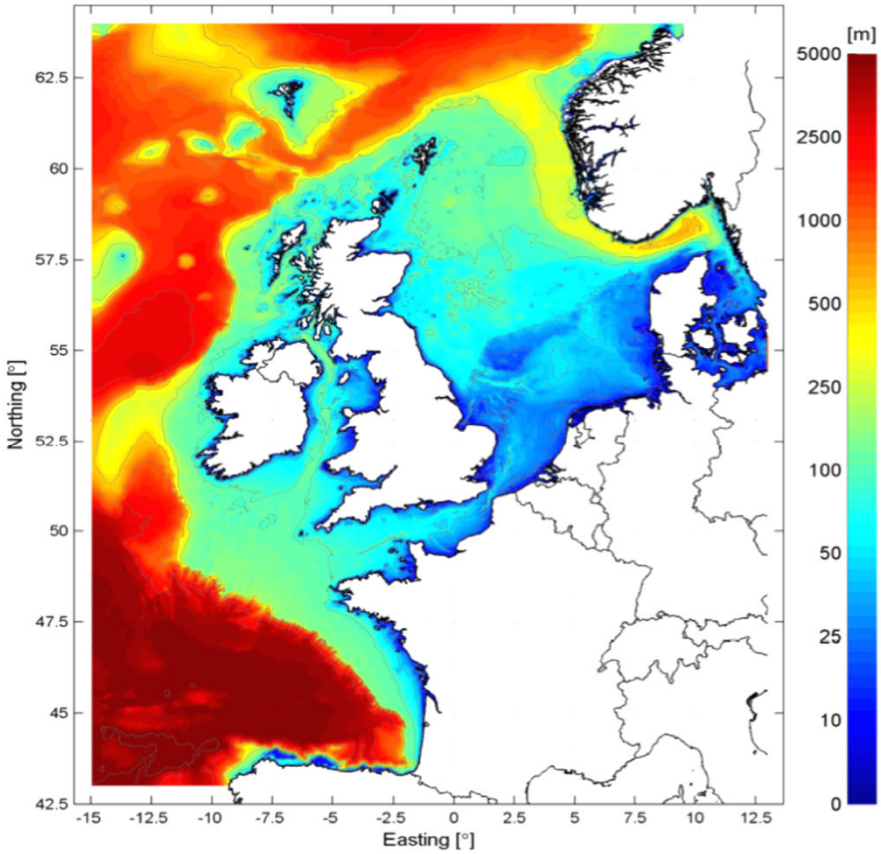
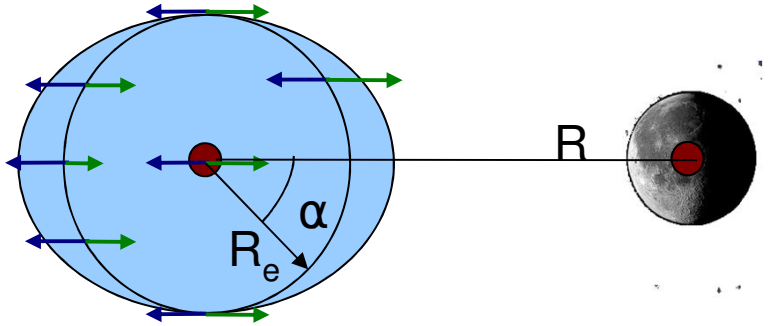


Figure 2.2 Overview of final DCSMv6 model bathymetry (depths relative to MSL).

Water Level / Storm Surge Forecasting

Dutch Continental Shelf Model (DCSMv6)
Water Level Forecasting

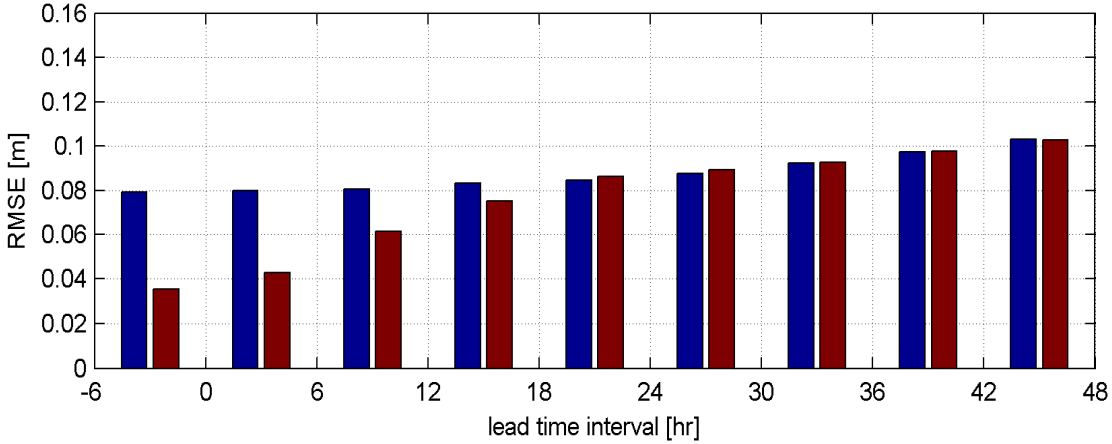
- content:
  - non-linear shallow water dynamics
    - captures tide-surge interaction
    - bathymetry
- forcing:
  - tidal (gravity field: sun, moon)*
  - meteorology (pressure, winds)



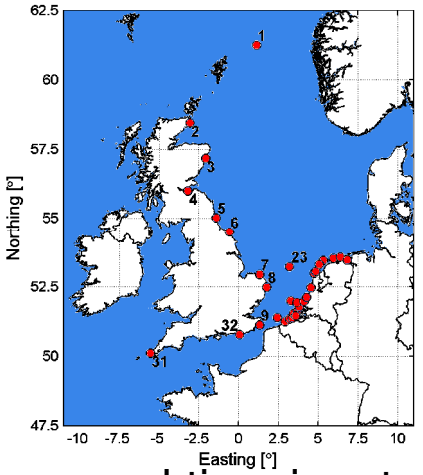
*Courtesy: E. Schrama, TU Delft

Water Level / Storm Surge Forecastin

Dutch Continental Shelf Model (DCSMv6)

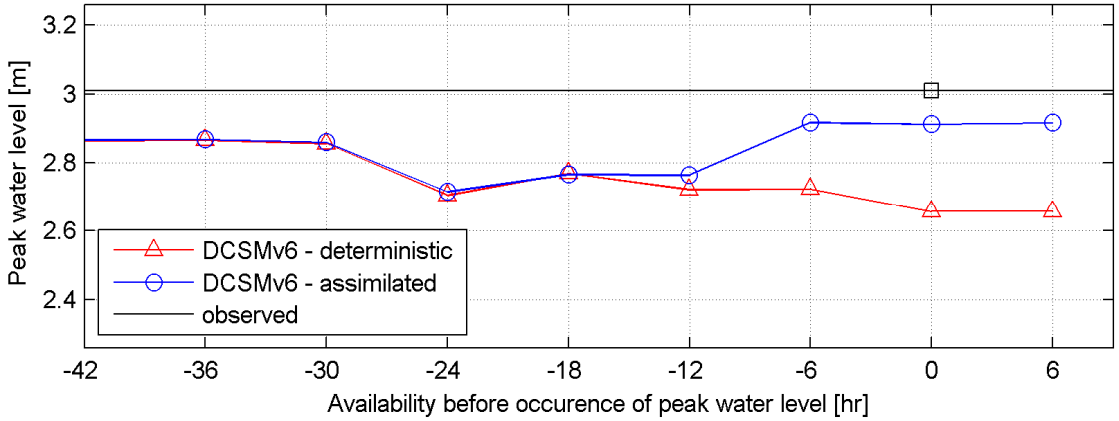


RMSE(m) a.f.o. lead time, **with** and **without** Kalman Filter



real time input data stations

- operation:
  - **data assimilation: Kalman Filtering**



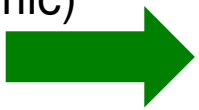
5/6 December 2013 storm surge event, Hoek van Holland

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Water Level / Storm Surge Forecasting

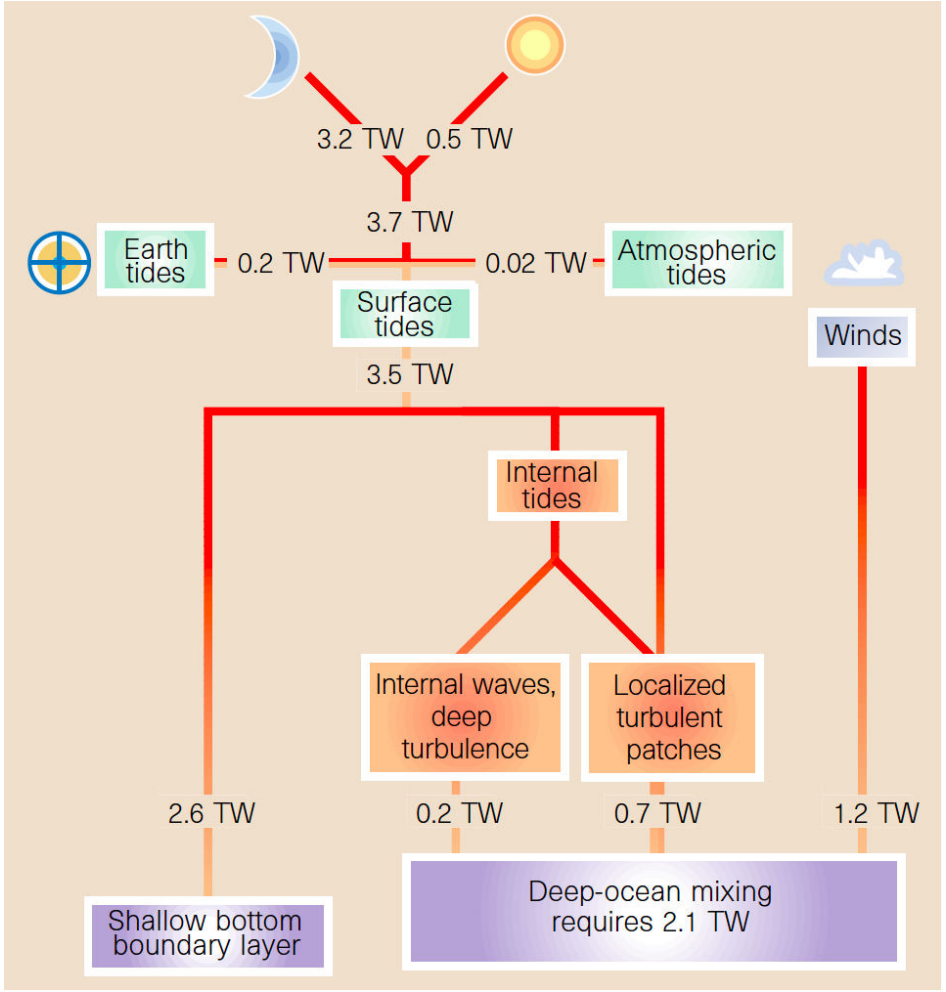
Dutch Continental Shelf Model (DCSMv6)
Water Level Forecasting

- content:
  - non-linear shallow water dynamics
    - captures tide-surge interaction
    - bathymetry
- forcing:
  - tidal (gravity field: sun, moon)
  - meteorology (pressure, winds)
- operation:
  - data assimilation:
    Kalman Filtering (dynamic)
  - **calibration (parametric)** 
    - comes *first* in real life
    - comes *last* this presentation:
      link to oceanography & science!

Global Ocean Mixing As Driven by Mechanics

Abyssal Recipes II:
Energetics of Tidal and Wind Mixing
Walter Munk & Carl Wunsch
Deep Sea Res., 1998

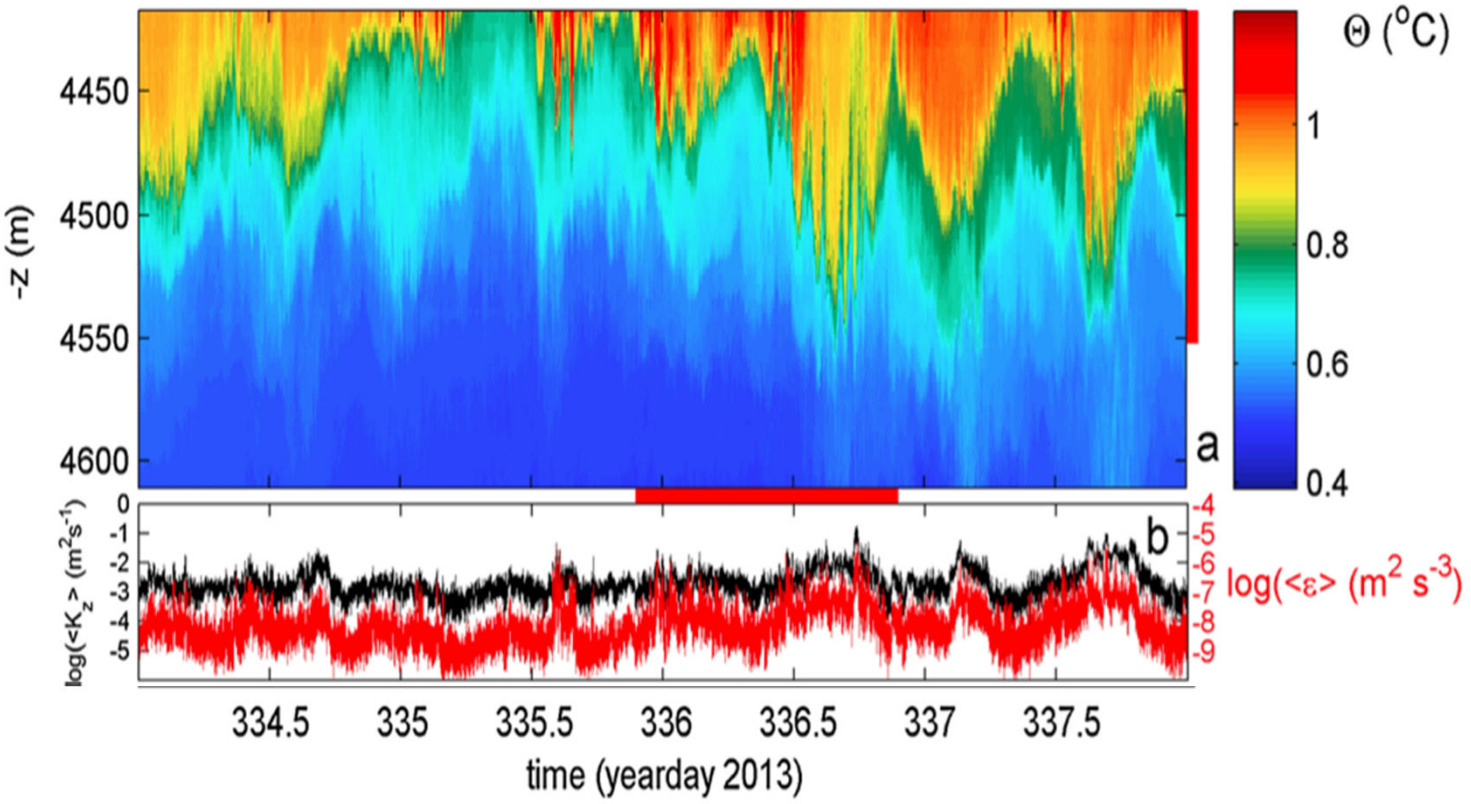
Something Stirs in the Deep
Peter Killworth
Nature, December 1998

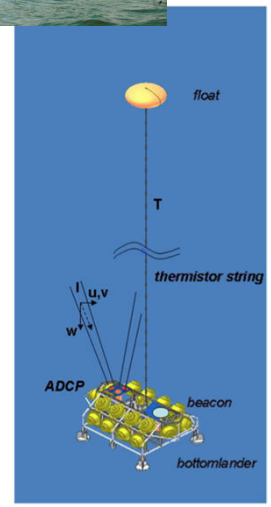


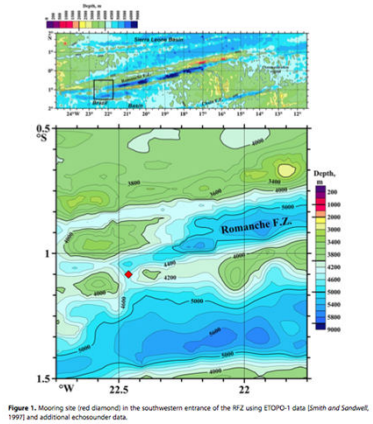
Mixing in Action..



Kelvin-Helmholtz billows,







"Extremely long Kelvin-Helmholtz billow trains in the Romanche Fracture Zone"
Hans van Haren, Louis Gostiaux, Eugene Morozov & Roman Tarakanov
Geophys. Res. Lett., Dec. 2014

Mixing in Action..

Kelvin-Helmholtz billows ..
shear induced overturning..

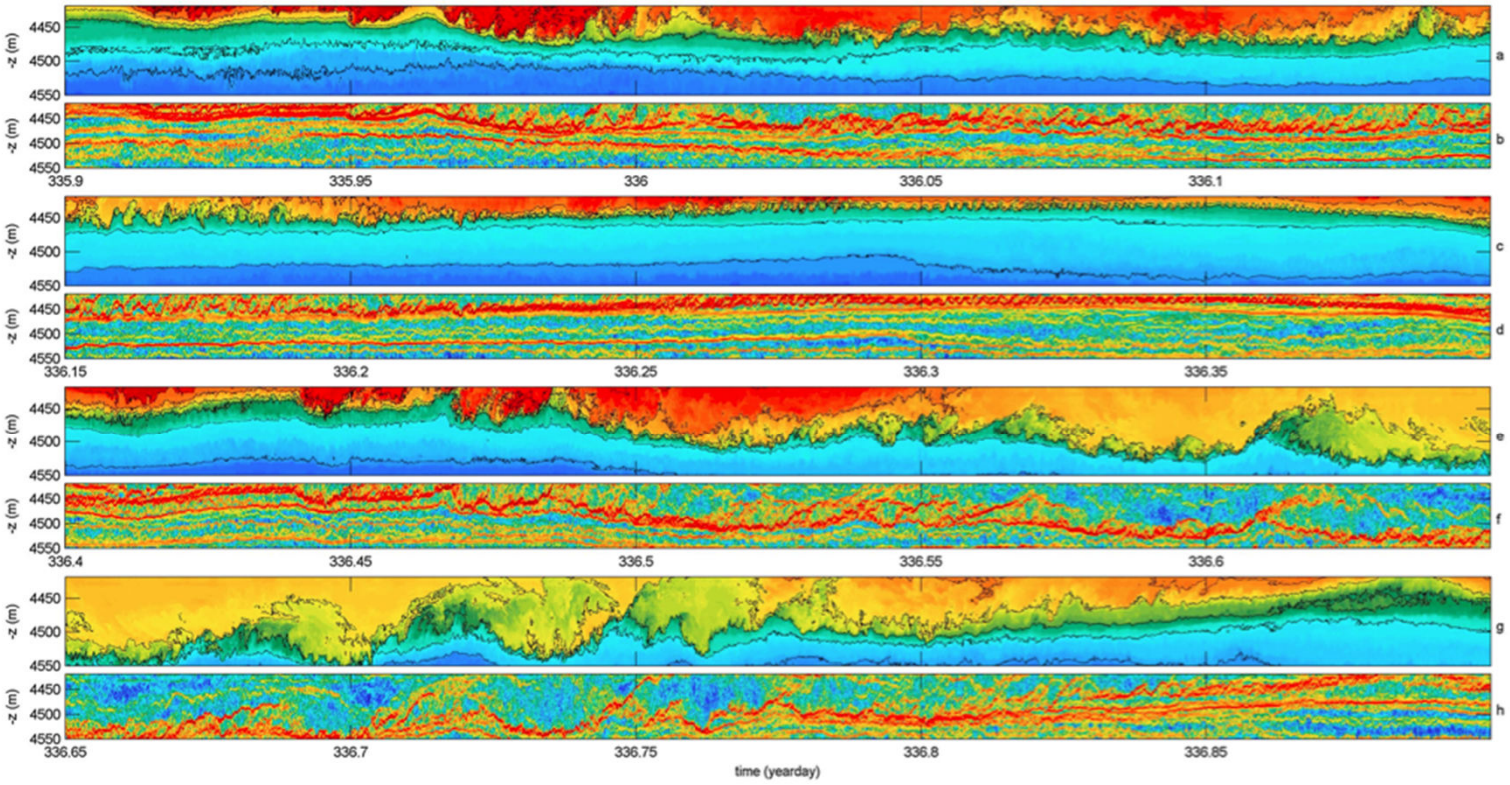
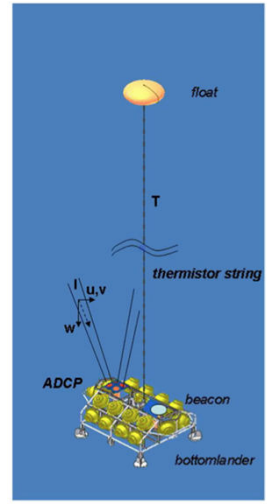
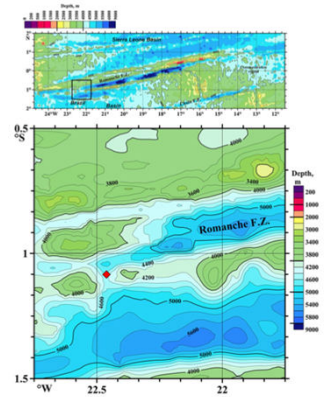


Figure 4. One day detail in four consecutive parts showing shear-induced overturning. (a, c, e, and g) Conservative temperature, with the same color scheme as in Figure 3a and contours every 0.1°C in black. (b, d, f, and h) Buoyancy frequency computed from the data in Figure 4a, sorted per time step in a statically stable profile. The color range [blue, red] is on a log-scale for [−4, −2.4] (which corresponds to a linear range of $[10^{-4}, 4\times10^{-3}]$ s^{-1}).





"Extremely long Kelvin-Helmholtz billow trains in the Romanche Fracture Zone"
Hans van Haren, Louis Gostiaux, Eugene Morozov & Roman Tarakanov
Geophys. Res. Lett., Dec. 2014

Mixing in Action..

wave breaking and turbulence, over sea-mount slopes..

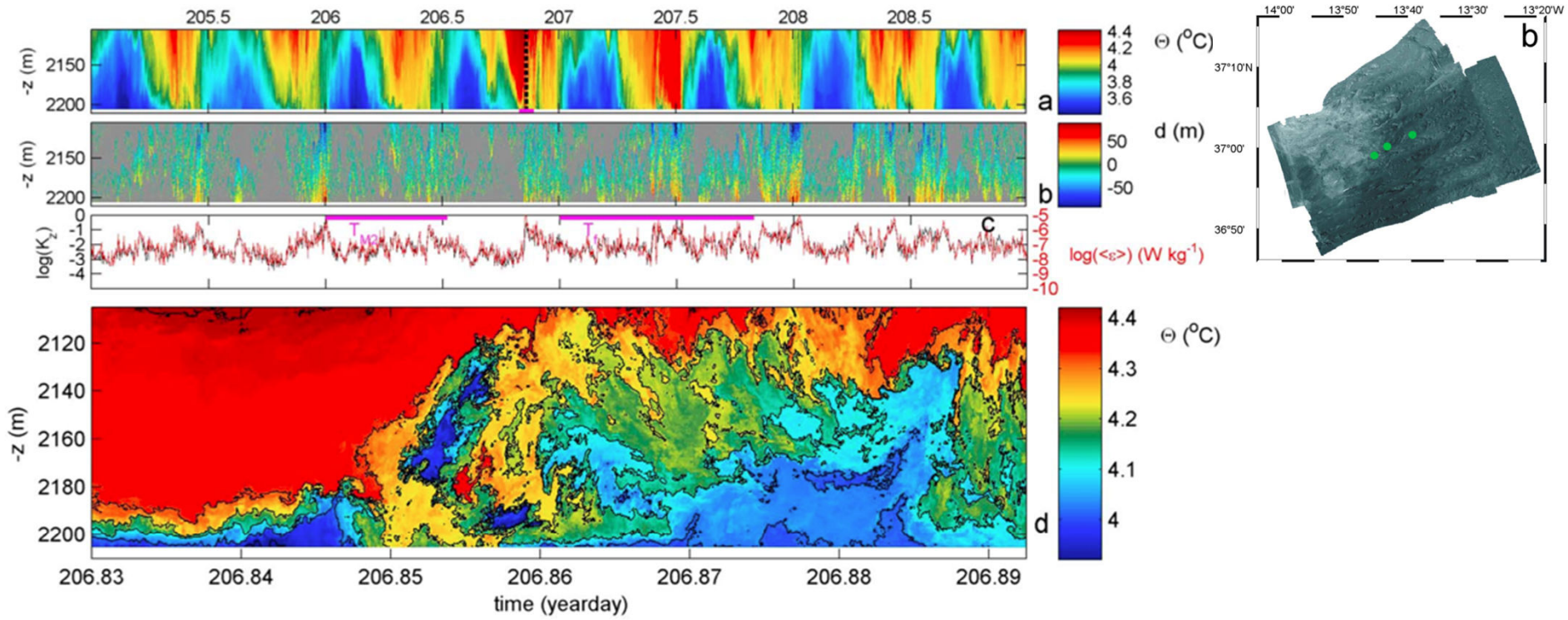
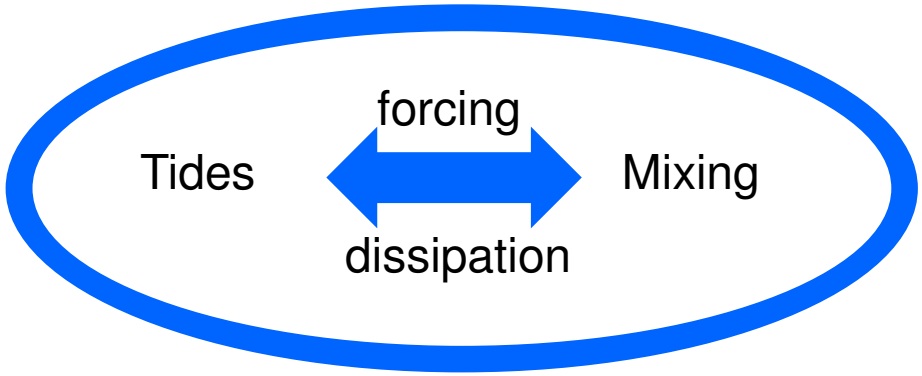


Figure 3. Four days of internal wave motions and turbulence observed at site A. (a) Depth-time series of conservative temperature. The black dashed line indicates the period in Figure 3d. (b) Turbulent displacements computed after sorting data in Figure 3a to stable profiles every time step. (c) Time series of logarithm of vertically averaged dissipation rate and diffusivity. Purple bars indicate semidiurnal tidal "T_{M2}" and inertial "T_f" periods. (d) One-and-a-half-hour sample detail of Figure 3a, with solid black contours every 0.1°C.

"Where large deep-ocean waves break"
Hans van Haren, Andrea Cimatoribus and Louis Gostiaux
Geophys. Res. Lett., April 2015

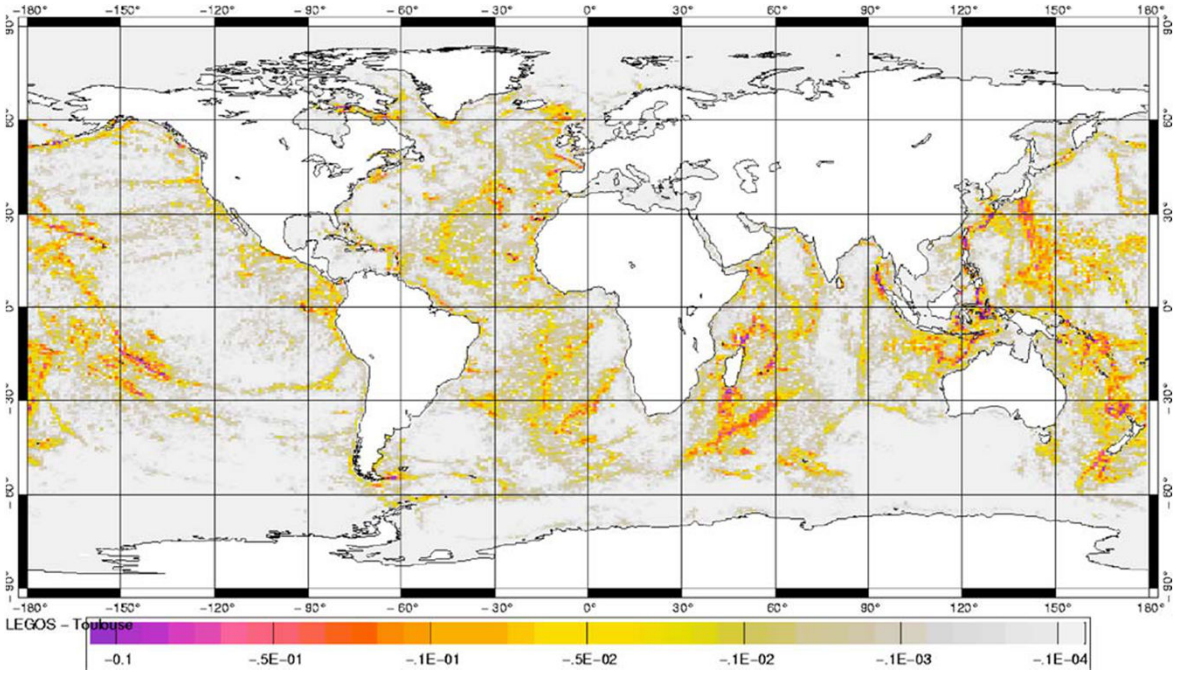
Relations global tides and mixing



Global tide models can *distinguish* between impact/significance of

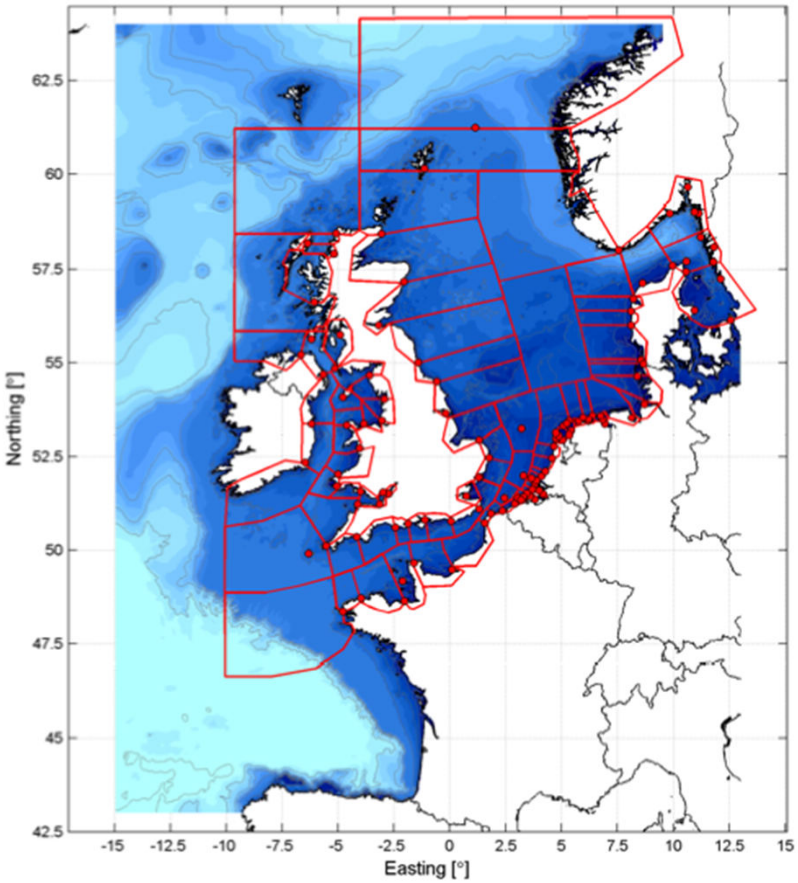
- *bottom friction* dissipation
- *wave drag* dissipation (parameterized generation by tide-topography interaction):

M2 *wave drag* dissipation



Modelling the global tides: modern insights from FES2004
F.Lyard, F. Lefevre, T. Letellier; Oc. Dyn. (2006)

Water Level Forecasting



Dutch Continental Shelf Model (DCSMv6)
Water Level Forecasting

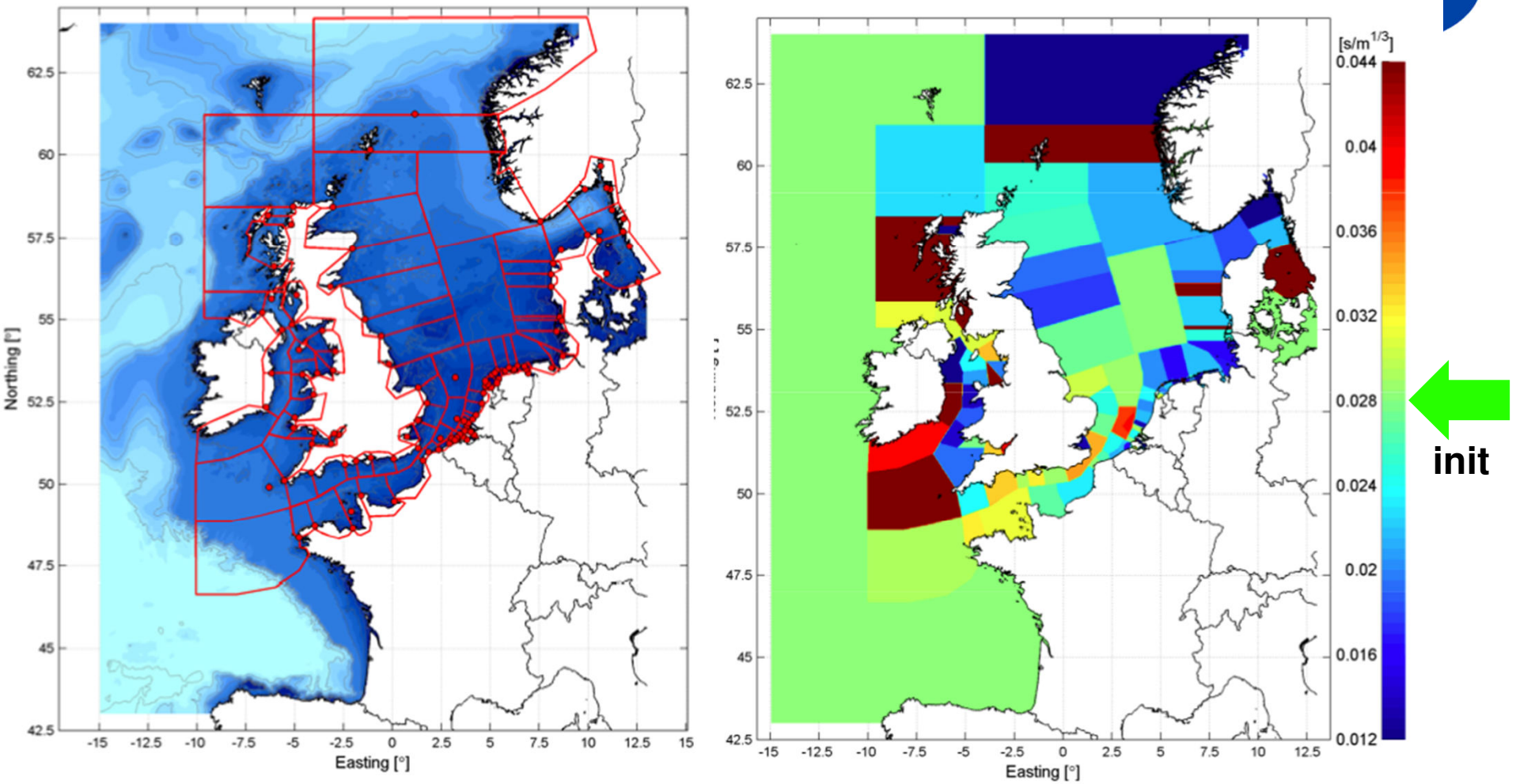
- content:
  - non-linear shallow water dynamics
    - captures tide-surge interaction
    - bathymetry
- forcing:
  - tidal (gravity field: sun, moon)
  - meteorology (pressure, winds)
- operation:
  - data assimilation:
    Kalman Filtering (dynamic)
    - real time adjustment of dynamic fields
  - **calibration (parametric)**
    - ***optimization of model parameters for model accuracy***
      - ***bathymetry***
      - ***bottom roughness***

"(..) water-level forecasting (..) through direct modeling of tide, surge and non-linear interaction"
F.Zijl, M. Verlaan, H. Gerritsen, Ocean Dyn. (2013) 63

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Segmentation for Calibration



left: segmentation for calibration of bottom roughness and bathymetry
right: calibrated bottom roughness

Calibrated Energy Dissipation vs. bathymetry

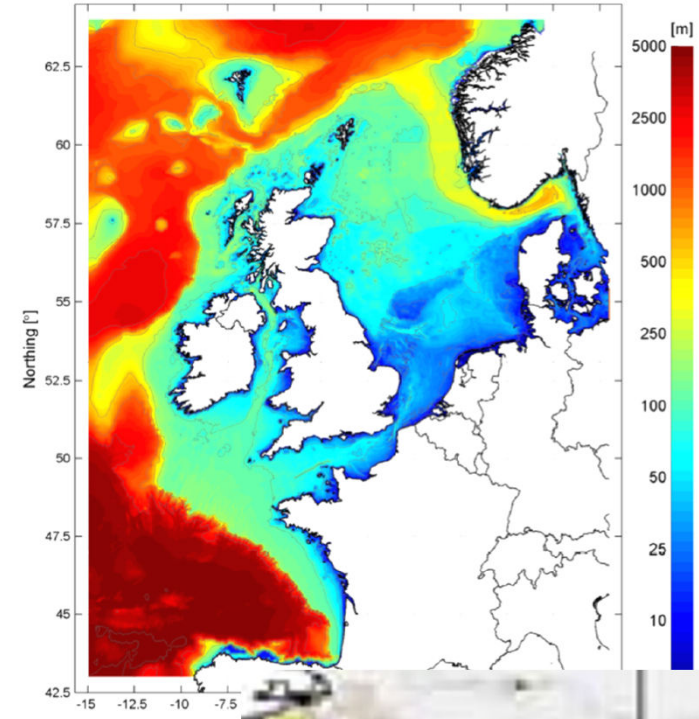
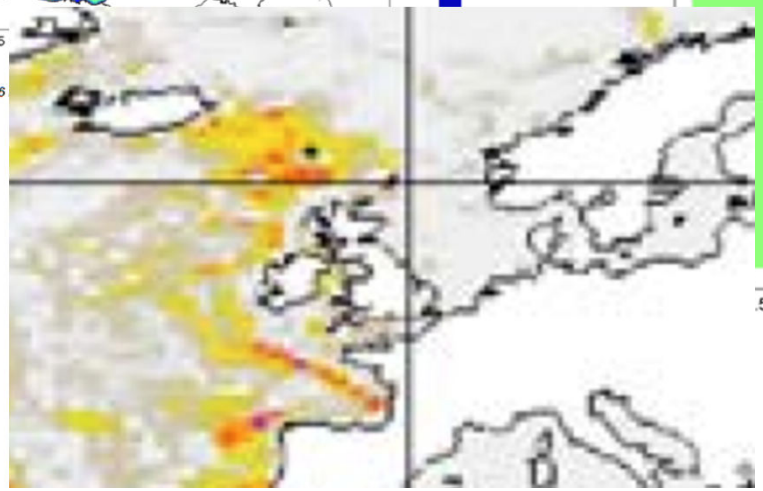
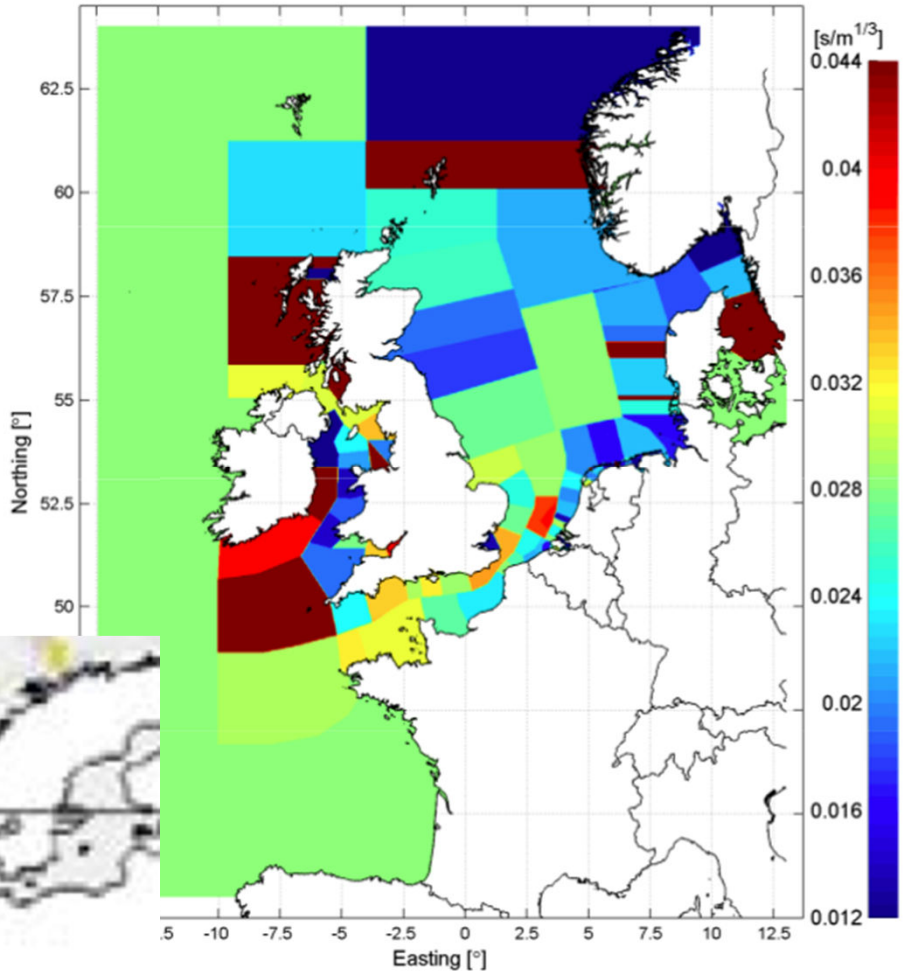


Figure 2.2 Overview of final DCSMv6

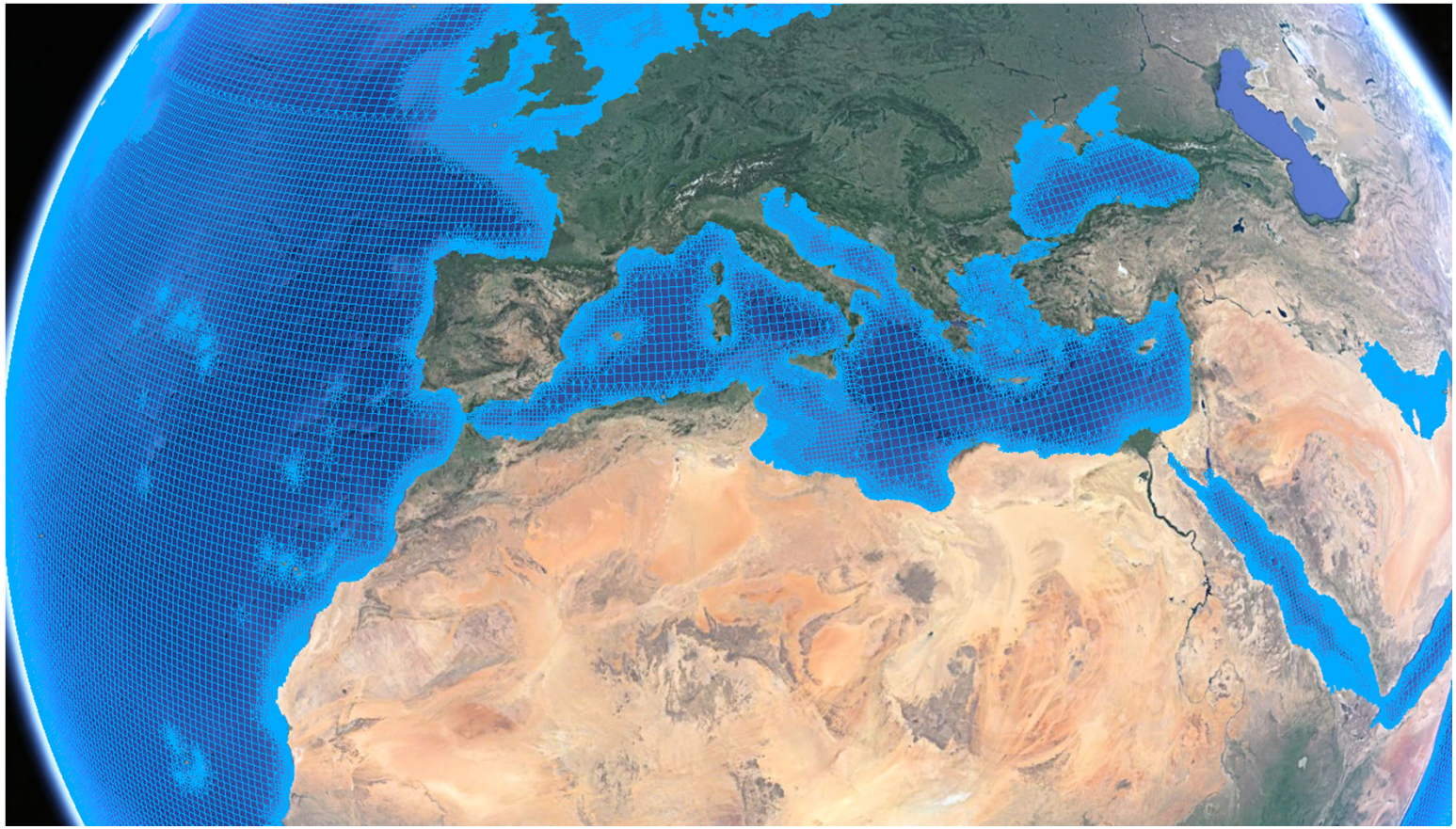




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The next step (in progress)



Global tide model

Global flood risk and intervention analyzer

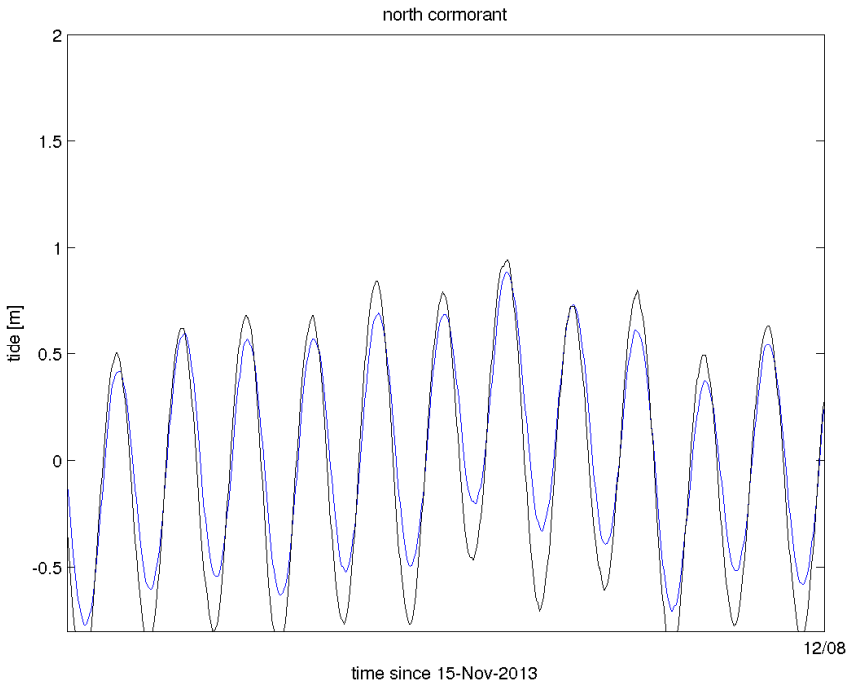
Starts in 2015

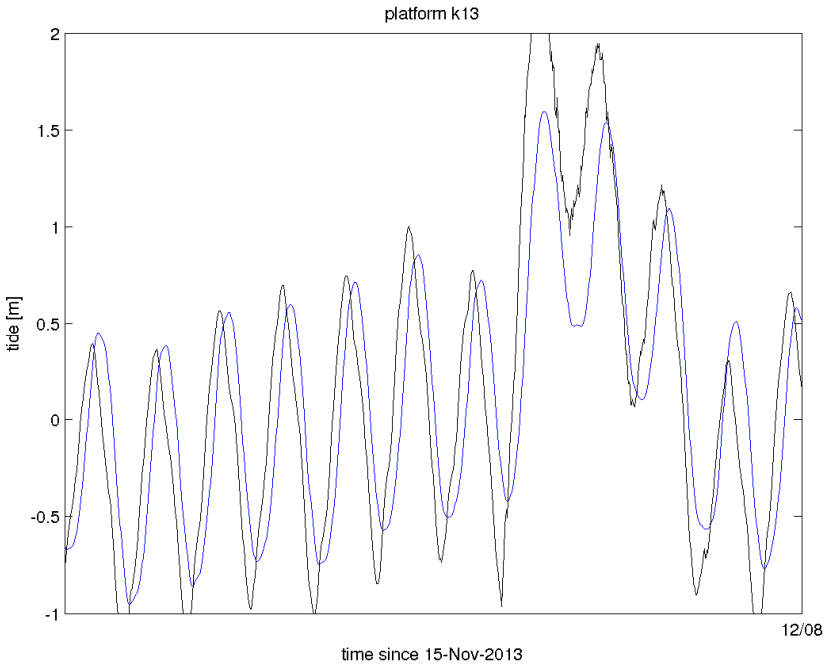
PL: Hessel Winsemius



Case: Storm December 5 2013

- again: tide *&* surge





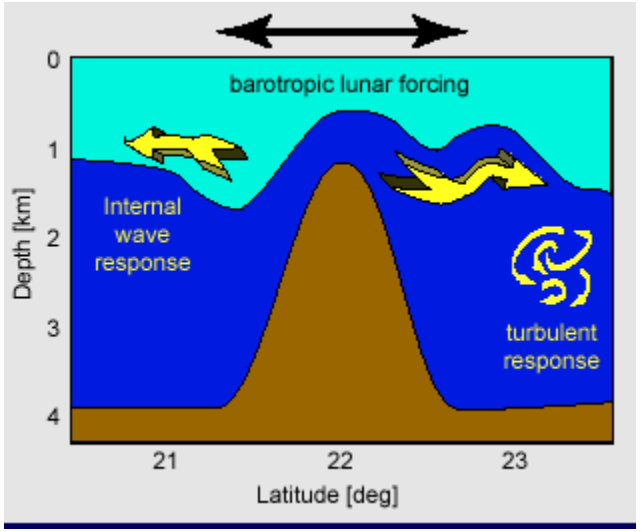
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Necessary improvements (in progress!)

- **Self attraction and loading**
  - **Tides modify the gravity potential as well**
- **Internal tides**
  - **Tides create internal tide where there is stratification and steep bathymetry**
  - **This creates dissipation (roughly ¼ of total tidal dissipation on global scale)**

$$f_x = \beta g \frac{\partial h}{\partial x}$$



$$N = \sqrt{\frac{-g}{\rho_0}\frac{\partial \rho}{\partial z}}$$

Depends on stratification

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Conclusion

- Ocean Science: Global effort ongoing, inspired by the vision of Munk & Wunsch '98, to construct & verify a detailed picture of the ocean's distributions & dynamics
    - complementary approaches:
        - theory & observations of mixing & dissipation processes
        - global circulation models (not in this presentation)
        - tidal modeling
            - modeling of dynamics
            - satellite data assimilation
- Hydrology:
    - water-level forecasting (tide & surge)
        - physics based simulation of dynamics
        - parameter tuning & Kalman filtering => data assimilation
    - improving forecasts thanks to increased physical content..
    - .. to the extent that engineering meets science:
    - *tuning* forecast models *hinted* where increased dissipation occurs in the ocean
    - => to be explored and continued..



Thank you

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