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Enabling Delta Life

JONSMOD 2014

On the consistency of the drag between air and water in meteorological, hydrodynamic and wave models

Joana van Nieuwkoop, Peter Baas, Sofia Caires and Jacco Groeneweg

Acknowledgements:
Netherlands National Water Authority, Rijkswaterstaat

Outline

- Introduction
- Case ‘storm October/November 2006’
    - Methodology
    - Results
- Concluding remarks

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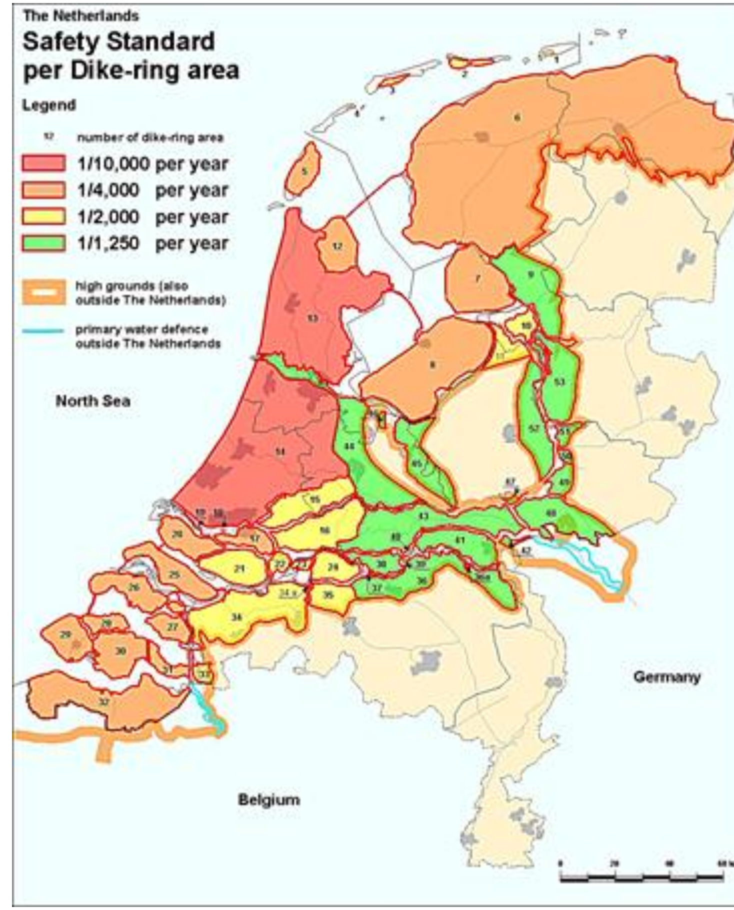
Introduction - motivation

- According to the Dutch Water Act ("Waterwet, 2009") the strength of the Dutch primary water defences must be checked with a certain periodicity for the required level of protection from loads with return periods varying from 1,250 to 10,000 years.

- The assessment is carried out using the: Hydraulic Boundary Conditions (HBC).



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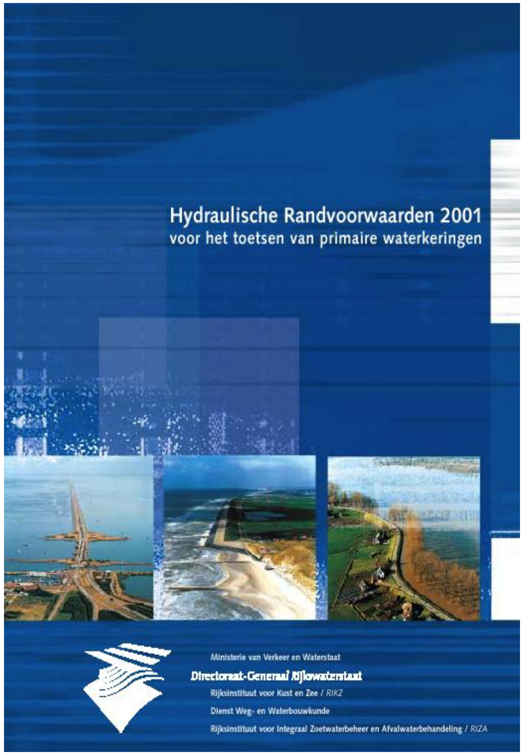
Introduction - motivation

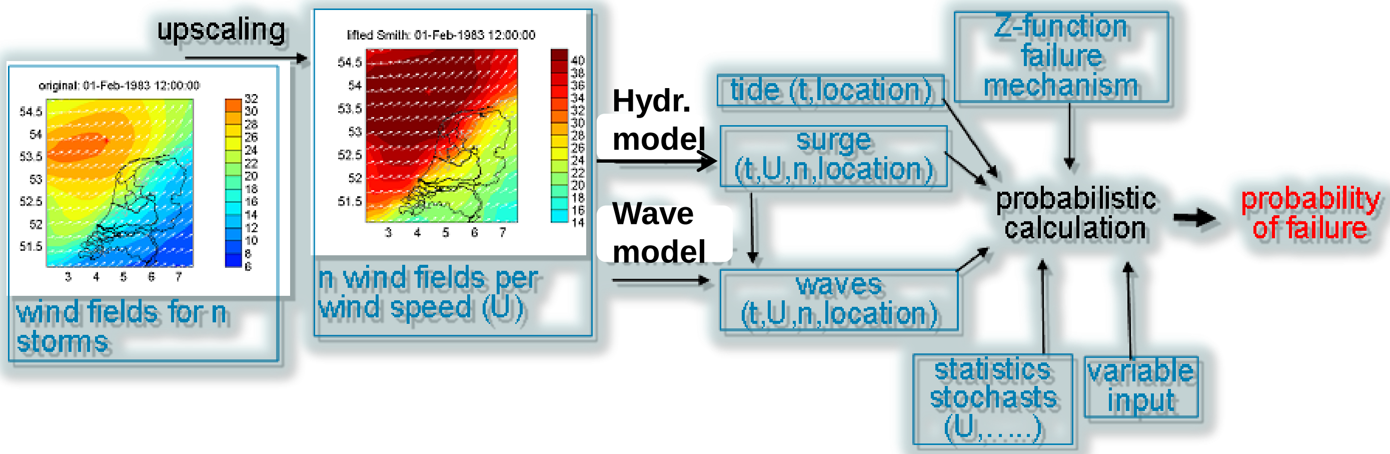
- The current computations of the HBC rely mostly on the statistical distribution of the basic variables at (solely) the peak of the storms.
- Depending on the failure mechanism under consideration, the combination of the values of the basic variables at the peak of the storm may lead to lower failure probabilities than the probabilities based on combinations at other instants around the storm peak.
- To improve the accuracy of the HBC time evolving hydraulic loads along the water defences are needed.



Introduction - motivation

To produce a set of time evolving hydraulic loads along the water defences the numerical models will in the future use time and space varying wind fields.

For further improvement of the quality of the numerical modeling, it is important that the atmospheric forcing is applied correctly.



Introduction – problem description

- Waves and surges are forced by wind stress.
- Input for the numerical models consists of 10-m wind velocities that are internally converted to wind stress by applying a particular drag relation.
- But the atmospheric model already used a particular drag relation to convert wind stress to 10-m wind velocity output.
- This procedure generally leads to inconsistencies and errors, since the hydrodynamic, wave and atmospheric models often apply different drag relations.
- Furthermore, a large uncertainty exists in the magnitude of the drag coefficient.

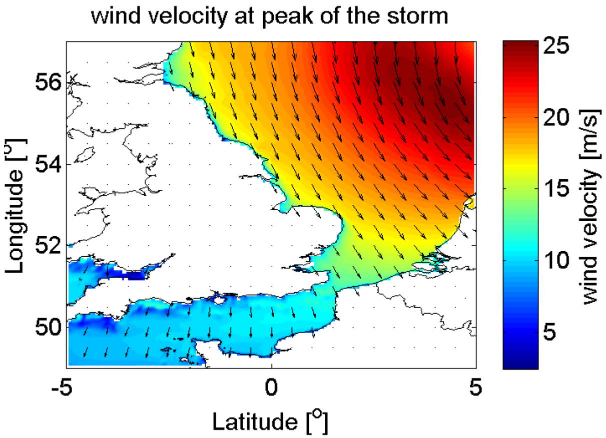
Introduction - objective


1. To explore the consequences of this inconsistency in the drag formulation in a case study of a North Sea storm hindcast of waves and surges.

2. To discuss different ways the atmospheric forcing can be applied.

Methodology – Case study

- Storm hindcast October/November 2006
  - north-westerly storm
  - Max. wind velocity ~ 25 m/s



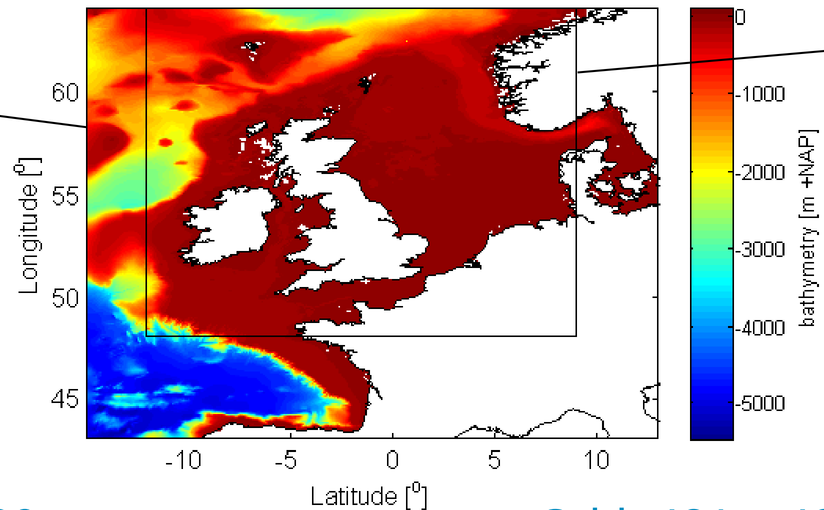
- Atmospheric model: high resolution numerical weather forecast model HARMONIE, used by Dutch meteorological institute (KNMI)
- Hydrodynamic model: shallow water flow model WAQUA (Netherlands National Water Authority Rijkswaterstaat)
- Wave model: spectral wave model SWAN (TU Delft)
- Using the Coastal Shelf Schematizations (DCSMv6) of both models

Methodology - Hydrodynamic/ wave model

Hydrodynamic model: WAQUA

Wave model: SWAN

DCSMv6 model

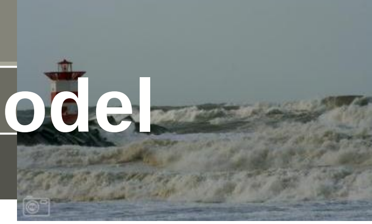


Hydrodynamic model: WAQUA

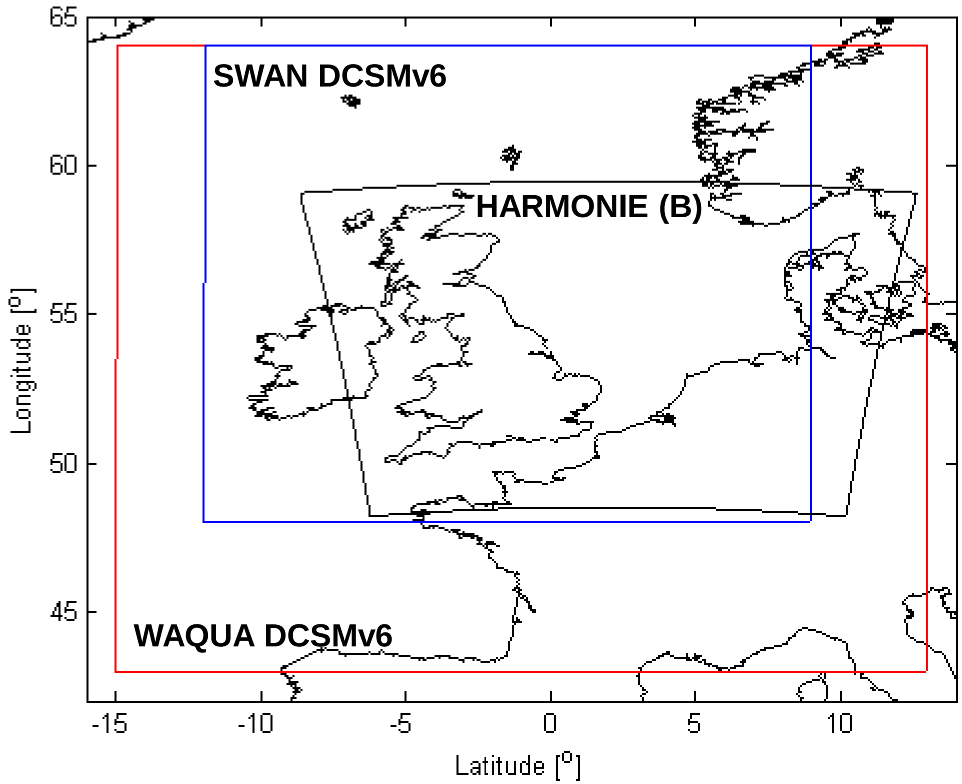
- Grid: 1260 x 1120
- Resolution: dx = 1/40°, dy = 1/60°
- Operational wind input: HIRLAM wind fields, dx = 1/10°, dy = 1/15°
- Wind drag formulation: Charnock

Wave model: SWAN

- Grid: 481 x 421
- Resolution: dx = 1/20°, dy = 1/20°
- Operational wind input: HIRLAM wind fields, dx = 1/10°, dy = 1/15°
- Wind drag formulation: Wu, 1982



Methodology - HARMONIE model



Constrains:

- resolution: 2.5 km
- max 500 x 500 grid points
- Extrapolated to cover DCSMv6 areas

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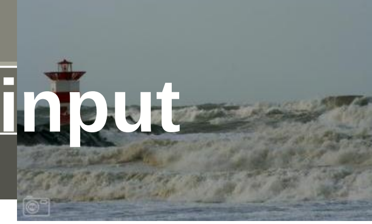
Methodology - wind velocity input



Atmospheric model HARMONIE

U_{10} (10 m wind vel.), τ(wind stress), U_* (friction vel.)

C_{d0} (drag coefficient) $\begin{cases} ECUME & - sea \\ Charnock & - fresh\ water \end{cases}$

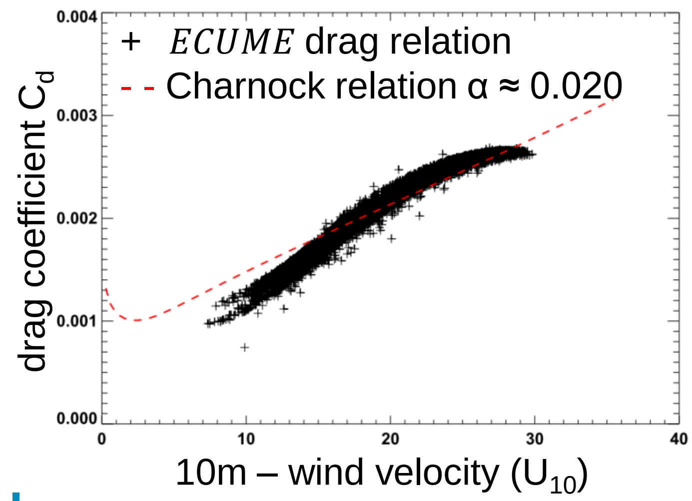
U_{10} U_{10}

hydrodynamic model WAQUA

$U_{10} \xrightarrow{C_{d1}} U_*$

wave model SWAN

$U_{10} \xrightarrow{C_{d2}} U_*$



$$U_* = \sqrt{C_{d1}}U_{10}$$

$$\frac{1}{C_{d1}} = \frac{1}{\kappa}\ln\left(\frac{10g}{\alpha_{ck}U_{10}^2 C_d}\right)$$

(Charnock drag formulation)

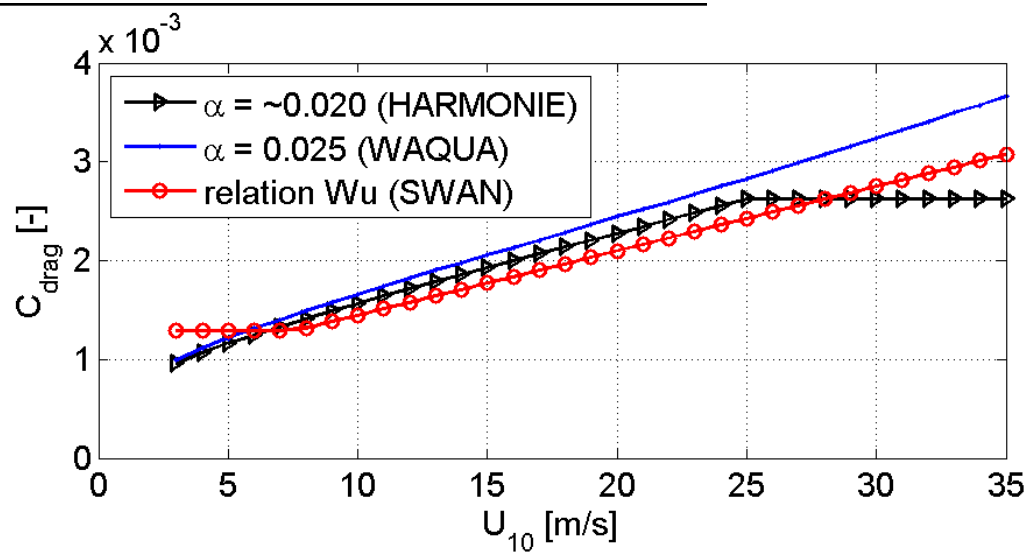
$$U_* = \sqrt{C_{d2}}U_{10}$$

$$C_{d2} = \begin{cases} 1.2875 \times 10^{-3} & for\ U_{10} < 7.5\ m/s \\ (0.8 + 0.065U_{10}) \times 10^{-3} & for\ U_{10} \geq 7.5\ m/s \end{cases}$$

(formulation Wu, 1982)

Methodology – drag coefficient

Model	Area	Charnock parameter α_{ck} [-]
WAQUA (DCSM model)	Lake and sea	0.025
SWAN (DCSM model: Wu,1982)	Lake and sea	~ 0.016 (Wu)
HARMONIE (Van den Brink et al., 2013)	Sea	~ 0.020 (ECUME)
HIRLAM (default)	Lake and sea	0.025



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Methodology - wind stress input

atmospheric model HARMONIE

U_{10} (10 m wind vel.), τ (wind stress), U_* (friction vel.)

C_{d0} $\begin{cases} ECUME & - sea \\ Charnock & - fresh\ water \end{cases}$

(drag coefficient)

τ

hydrodynamic model WAQUA

$\tau \rightarrow U_*$

$U_* = \sqrt{\tau/\rho_a}$

wave model SWAN

$\tau \rightarrow U_*$

$U_* = \sqrt{\tau/\rho_a}$

ρ_a : air density – also no consistent use between models!

- In WAQUA wind stress input was already an option
- In SWAN wind stress input was implemented into code

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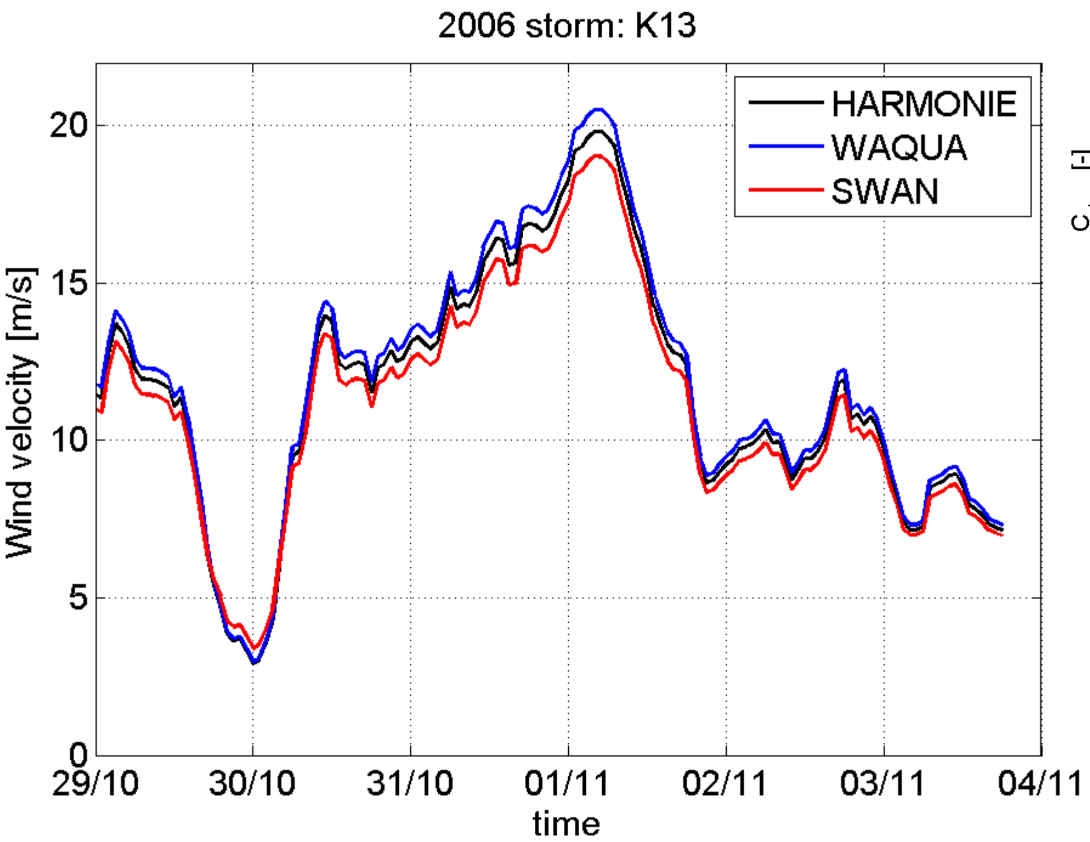
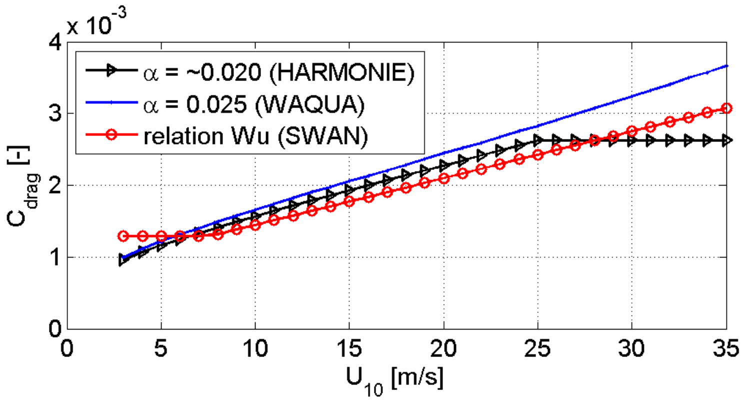
Methodology - overview

1. The HARMONIE wind stress is directly imposed on the SWAN and WAQUA.
2. The SWAN and WAQUA models are also forced with the wind velocities.
3. The results of the models using both forcings and measurements are compared.

Case study - wind velocity at K13





- Difference of ~ 1 m/s wind velocity at the peak of the storm

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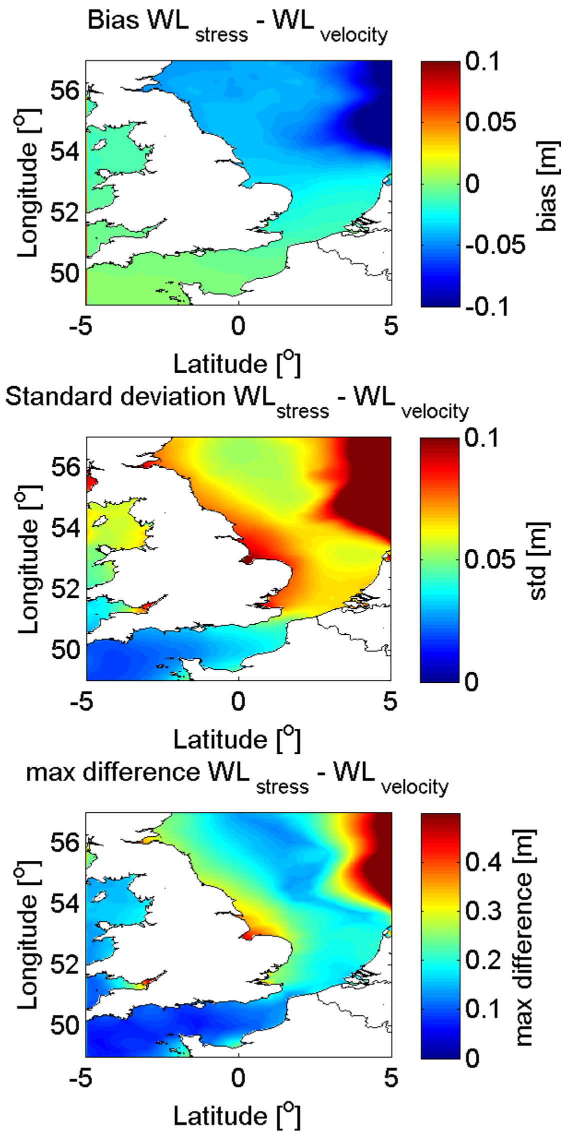
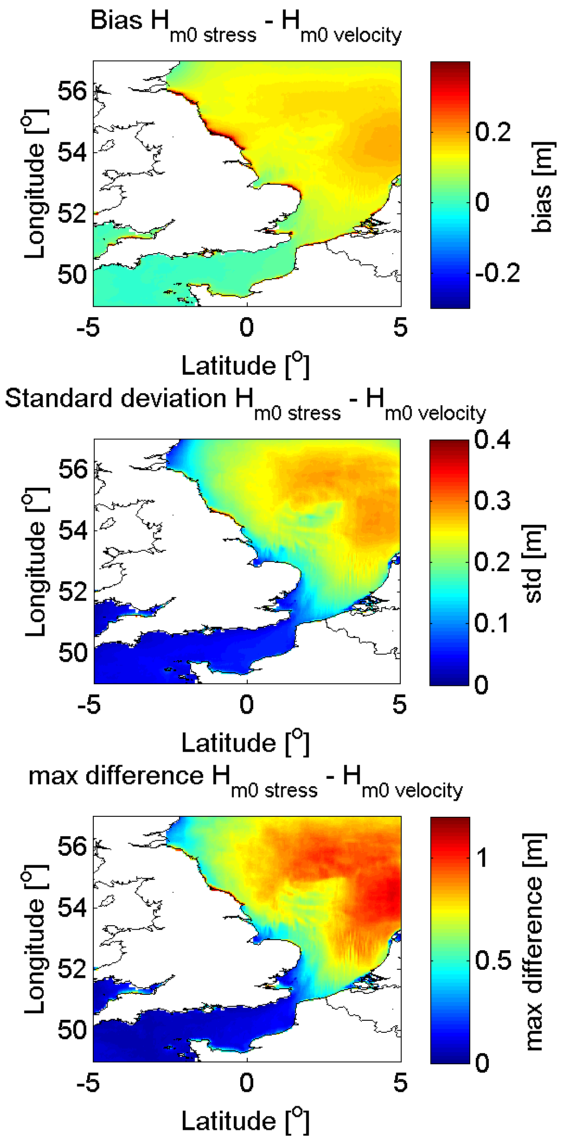
Case study – diff. stress input minus wind input statistics

WAQUA
water level

Up to 20 cm difference in WL near the Dutch coast

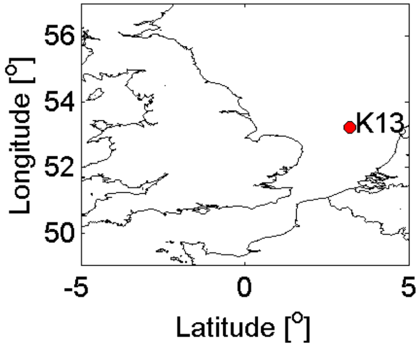




SWAN
H_{m0}

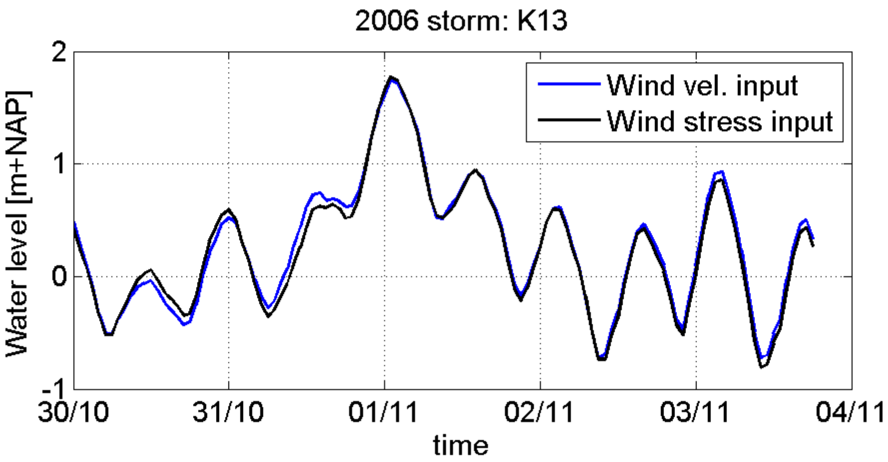
H_{m0} with stress input can be up to ~ 1 m higher

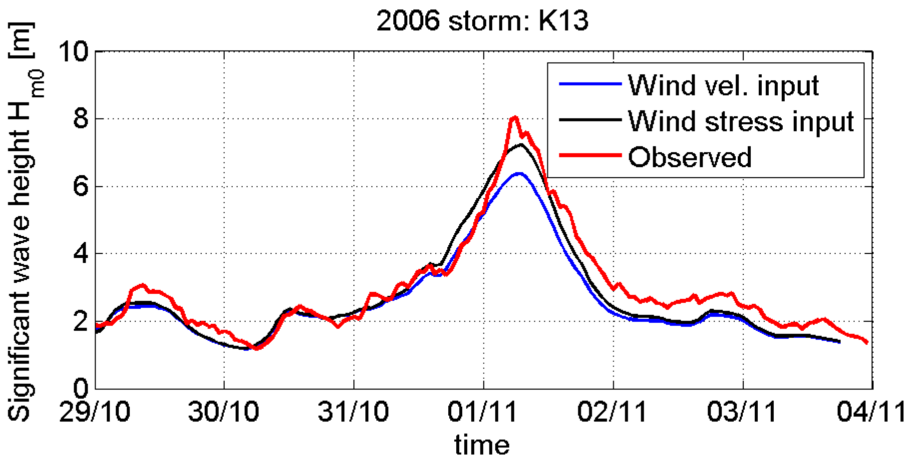
Case study - timeseries



WAQUA
water level

SWAN
H_{m0}





Concluding remarks

- Significant differences between the waves and water levels computed with wind stress input and wind velocity input.

- This means that the use of consistent drag relations in meteorological and hydrodynamic and wave models is very important.

- The use of wind stress is preferable above the use of U_{10} wind velocity, as no drag relation is needed. However, wind stress does not allow for an intuitive interpretation. ‘Pseudo wind’, which is a translation of the wind stress to the 10-m wind speed using a reference drag relation, could offer an alternative.

Pseudo-wind

$$U'_{10} = \sqrt{\tau_{HARMONIE}/(\rho_a C_{d\_ref})}$$

Concluding remarks

- The drag is not only dependent on the wind speed, but also on the wave state. Therefore, proper modelling of the drag between air and sea can in our opinion only be achieved if hydrodynamic, wave and atmospheric models are coupled

Thank you for your attention

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