Application of UnSWAN for wave hindcasting in the Dutch Wadden Sea

11th Waves Workshop

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Motivation

- In the past 10 years, a lot of SWAN studies have been carried out for e.g., the Dutch goverment
  - main motivations: assessing safety of sea defences and operational wave forecasting
  - studied areas: Scheldt estuaries, lakes (IJsselmeer) and coast (Petten)
  - currently, SBW project initiated at Deltares for studying tidal inlets in the Wadden Sea
- General conclusion: wave heights are good, but wave periods consistently underestimated
- Ask for some improvements in both accuracy and efficiency

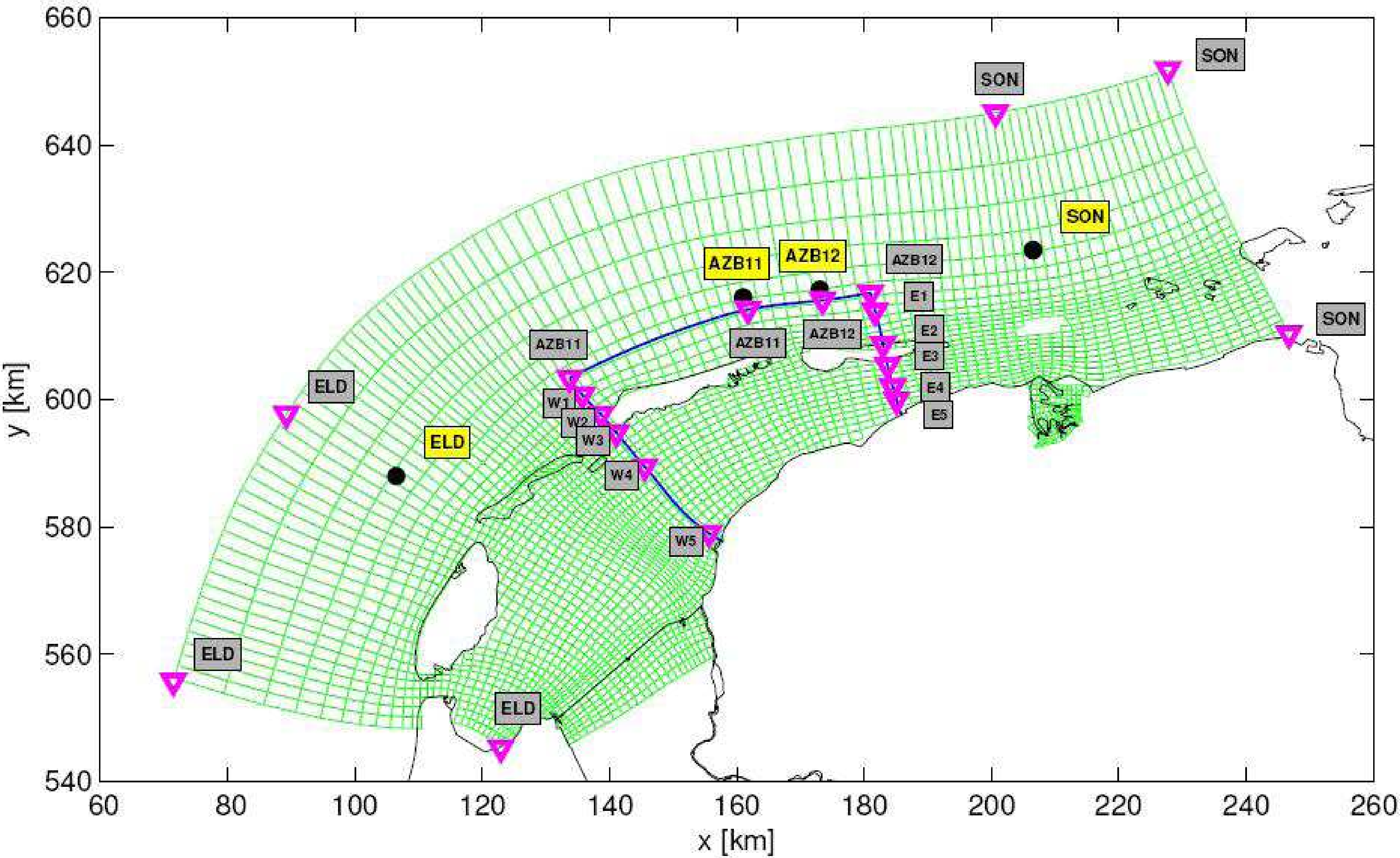
Methodology

- The *usual* SWAN approach is a finite difference, fixed, regular grid solution to the action balance equation employing the default third-generation formulations for deep and shallow water
- Recently, an unstructured-mesh procedure is implemented in SWAN
  - Would that be a *better* approach for modelling and understanding wave dynamics in tidal inlets?
- Recently, alternative source term parameterizations have been proposed in the literature
  - How about that? Are they useful?

Summary of conclusions

- The parallel, unstructured version of SWAN is a good alternative for tidal inlet studies
  - no nesting and no boundary condition issue
  - achieve good speedups
  - fully compatible with the regular-grid version
- SWAN should be applied with care, choose model settings accordingly
  - optimal settings is found for the Wadden Sea
  - skillful in prediction of wave height and periods over ebb-tidal delta and over shallow interior

Tidal inlet of Ameland connecting the North Sea with the Dutch Wadden Sea



Nested curvi-linear grids with offshore boundary conditions

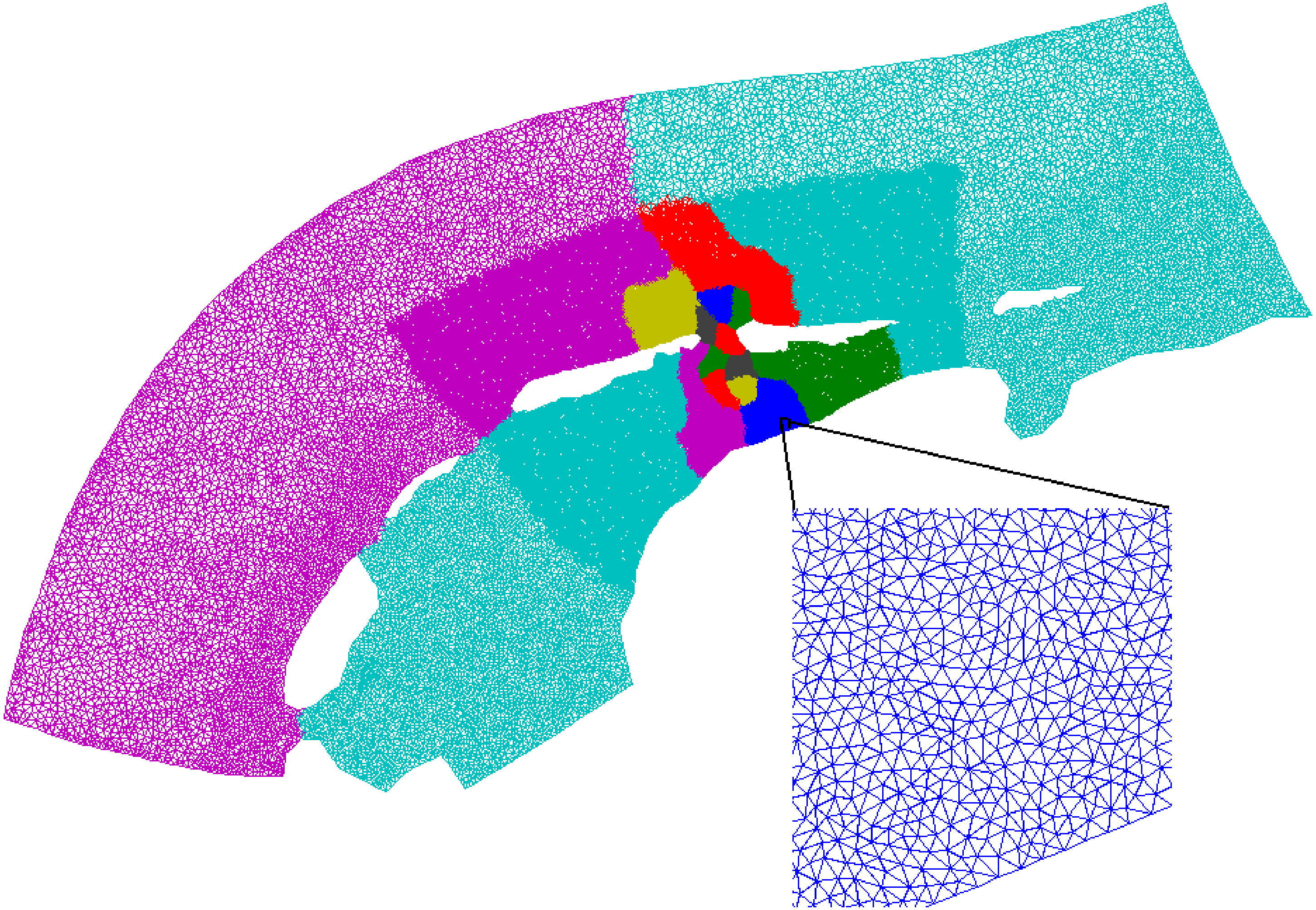
Why unstructured grids?

- Contrary to curvi-linear grids, more flexibility in generating grid as there are no restrictions (smoothness, orthogonality, cell-aspect ratio, etc.)
- Accurate representation of irregular shorelines and islands
- High variability in geographic resolution
- Can take into account large scales in deep water ($\sim 100km$) and small scales in surf zone ($\sim 10m$) in one mesh
- Nested grid problems in terms of correct dynamic coupling and boundary condition discretization accuracy can be avoided

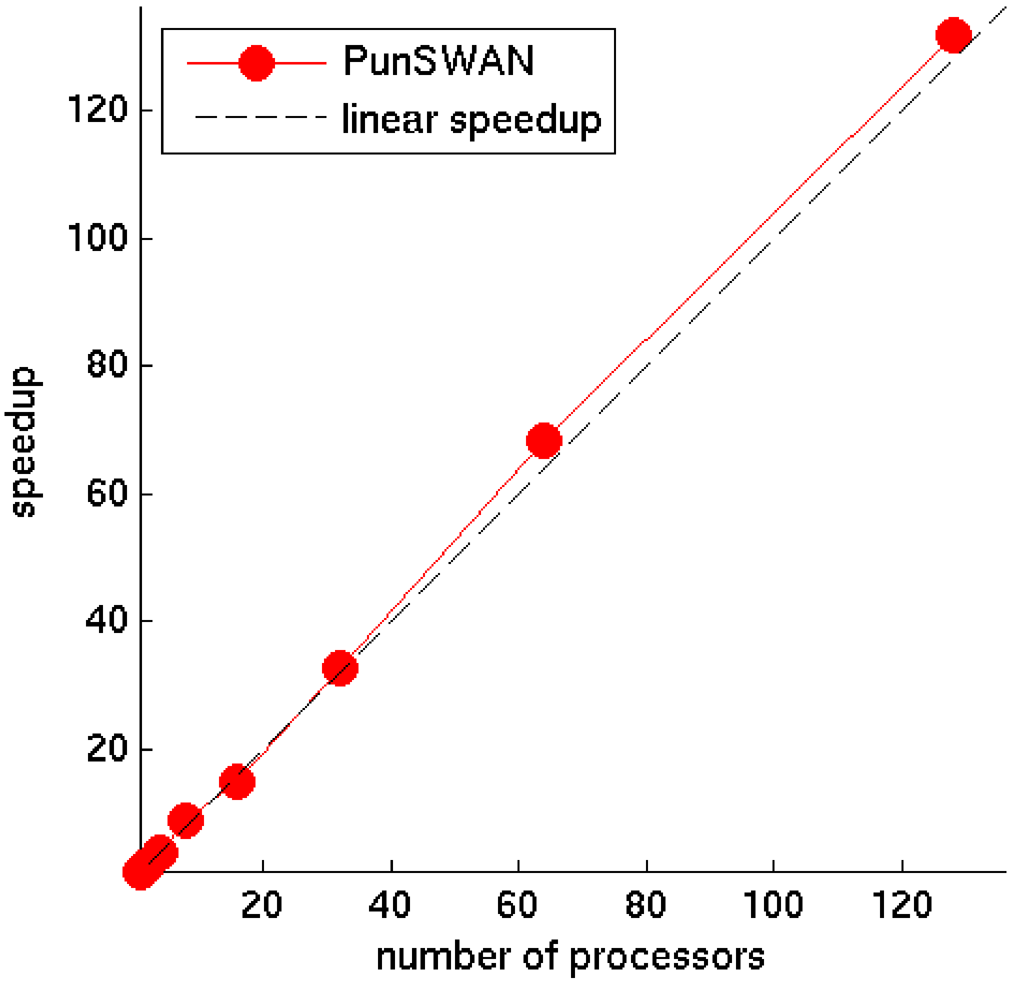
PUnSWAN

- implemented in the ADCIRC environment
- make use of the `adcprep` program:
  - controls domain decomposition for a parallel run
  - METIS is called to do the actual grid partitioning
  - creates sub-domain input files after decomposition
- make use of the ADCIRC module `messenger` and MPI for
  - local exchanging at subdomain interfaces
  - global reductions e.g., summation, maximum and minimum over all subdomains

Partitioned, unstructured mesh



Parallel efficiency - IBM Power6 cluster



Physics

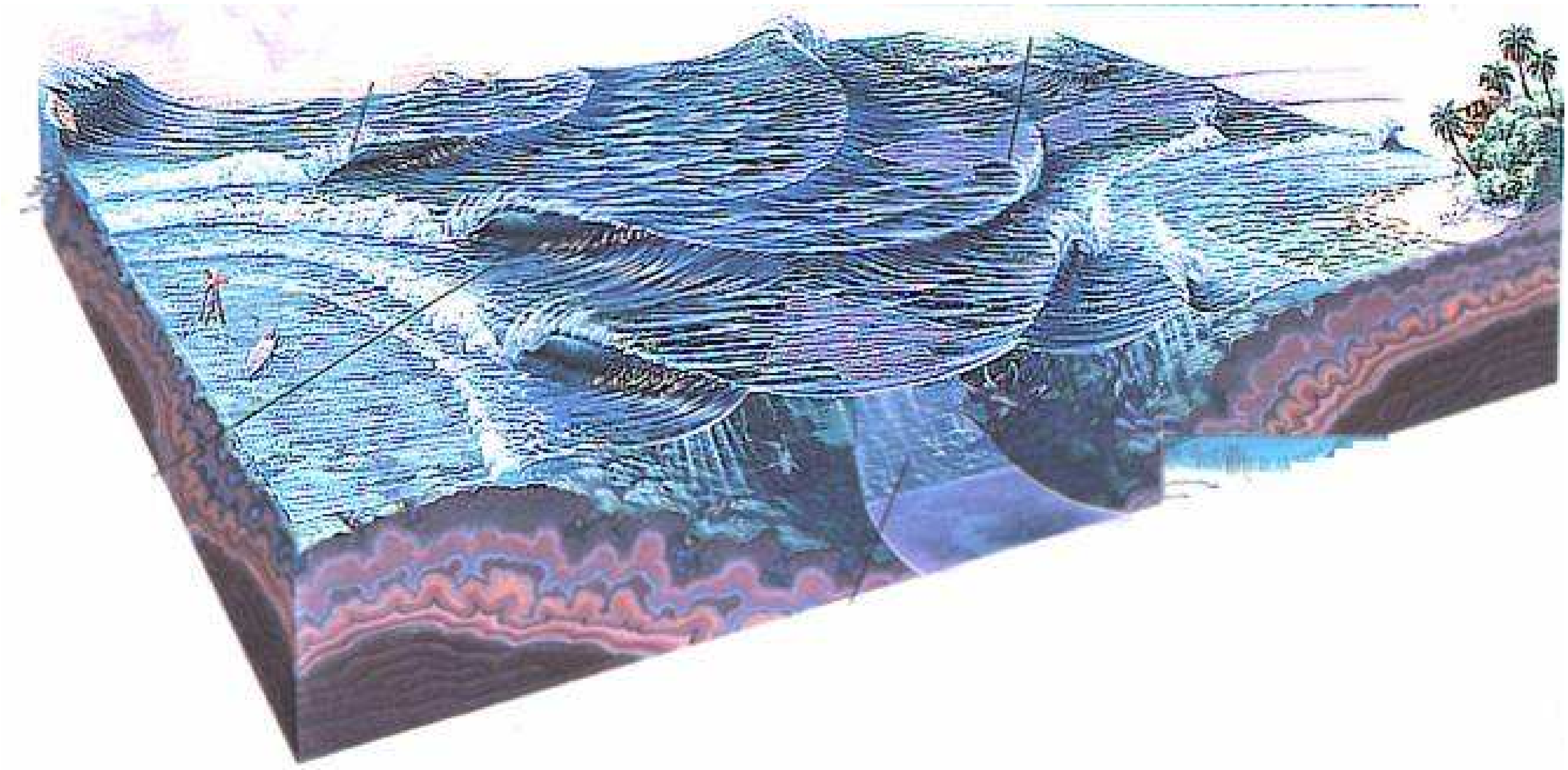
- General: underprediction of period measures in coastal waters
- Other (more specific) observed inaccuracies in tidal inlets:
  - Underestimation of penetration of low-frequency peak wave energy over ebb-tidal delta
  - Underestimation of finite depth wave growth in near-horizontal beds

Model formulation

- Wave energy represented by action density spectrum $N(x, y, t; \sigma, \theta)$
- Governed by the action balance equation:

$$\frac{\partial N}{\partial t} + \nabla_{\vec{x}} \cdot [(\vec{c}_g + \vec{U})N] + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_{\mathrm{tot}}}{\sigma}$$

- Source term S_{tot} describes physical modelling of wave generation, dissipation and redistribution wind whitecapping quadruplets



surf breaking friction triads

Whitecapping

Based on Hasselmann (1974) and can be expressed as

$$S_{\mathrm{wcap}} = -C_{\mathrm{ds}}\,\tilde{\sigma}\,\left(\frac{\tilde{s}}{\tilde{s}_{\mathrm{pm}}}\right)^{m}\left(\frac{k}{\tilde{\bar{k}}}\right)^{n}\;E(\sigma,\theta)$$

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$$n = \begin{cases} 1 & \text{Komen et al. (1984)} \\ 2 & \text{Rogers et al. (2003)} \end{cases}$$

The $n = 2$ setting effectively removes underprediction of periods observed with the $n = 1$ setting

Depth-induced breaking (1)

Modelled by the bore-based dissipation model of Battjes and Janssen (1978):

$$S_{\rm brk} = D_{\rm tot}\frac{E(\sigma,\theta)}{E_{\rm tot}}$$

with

$$D_{\rm tot} = -\frac{1}{4}\alpha_{\rm BJ}Q_b(\frac{\tilde{\sigma}}{2\pi})H_{\rm max}^2$$

and $\alpha_{\rm BJ} = 1$ and Q_b is fraction of breaking waves

Depth-induced breaking (2)

The maximum wave height $H_{\rm max}$ is given by

$$H_{\rm max} = \gamma_{\rm BJ} \; d$$

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where γ_{BJ} is the breaker parameter:

$$\gamma_{\mathrm{BJ}} = \begin{cases} 0.73 & \text{Battjes and Janssen (1978)} \\ 0.76 k_{\mathrm{p}} d + 0.29 & \text{Ruessink et al. (2003)} \end{cases}$$

Parameterization of Ruessink et al. (2003) improves finite depth results for a nearly horizontal bed

(Van der Westhuysen, 2009; SBW project)

Bottom friction

Bottom friction is modelled by the JONSWAP formulation (Hasselmann et al., 1973):

$$S_{\mathrm{bot}} = - \; C_{\mathrm{b}} \; \frac{\sigma^2}{g^2 \sinh^2(kd)} \, E(\sigma, \theta)$$

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where C_{b} is a tunable friction parameter:

$$C_{\mathrm{b}} = \begin{cases} 0.038 m^2 s^{-3} & \text{(swell)} \\ 0.067 m^2 s^{-3} & \text{(fully-developed sea)} \end{cases}$$

Now: $C_{\mathrm{b}} = 0.038 m^2 s^{-3}$ for both swell and low frequencies in wind-sea spectrum

Default settings

- Deep water source terms:
  - wind input based on Yan (1987)
  - saturation-based whitecapping of Alves and Banner (2003)
  - DIA for quadruplets (Hasselmann et al., 1985)
- Shallow water source terms:
  - LTA for triads (Eldeberky, 1996)
  - depth-induced breaking: $\gamma_{\mathrm{BJ}} = 0.73$ (Battjes and Janssen, 1978)
  - JONSWAP for bottom friction: $C_{\mathrm{b}} = 0.067 m^2 s^{-3}$ (Hasselmann et al., 1973; Bouws and Komen, 1983)

Optimal settings

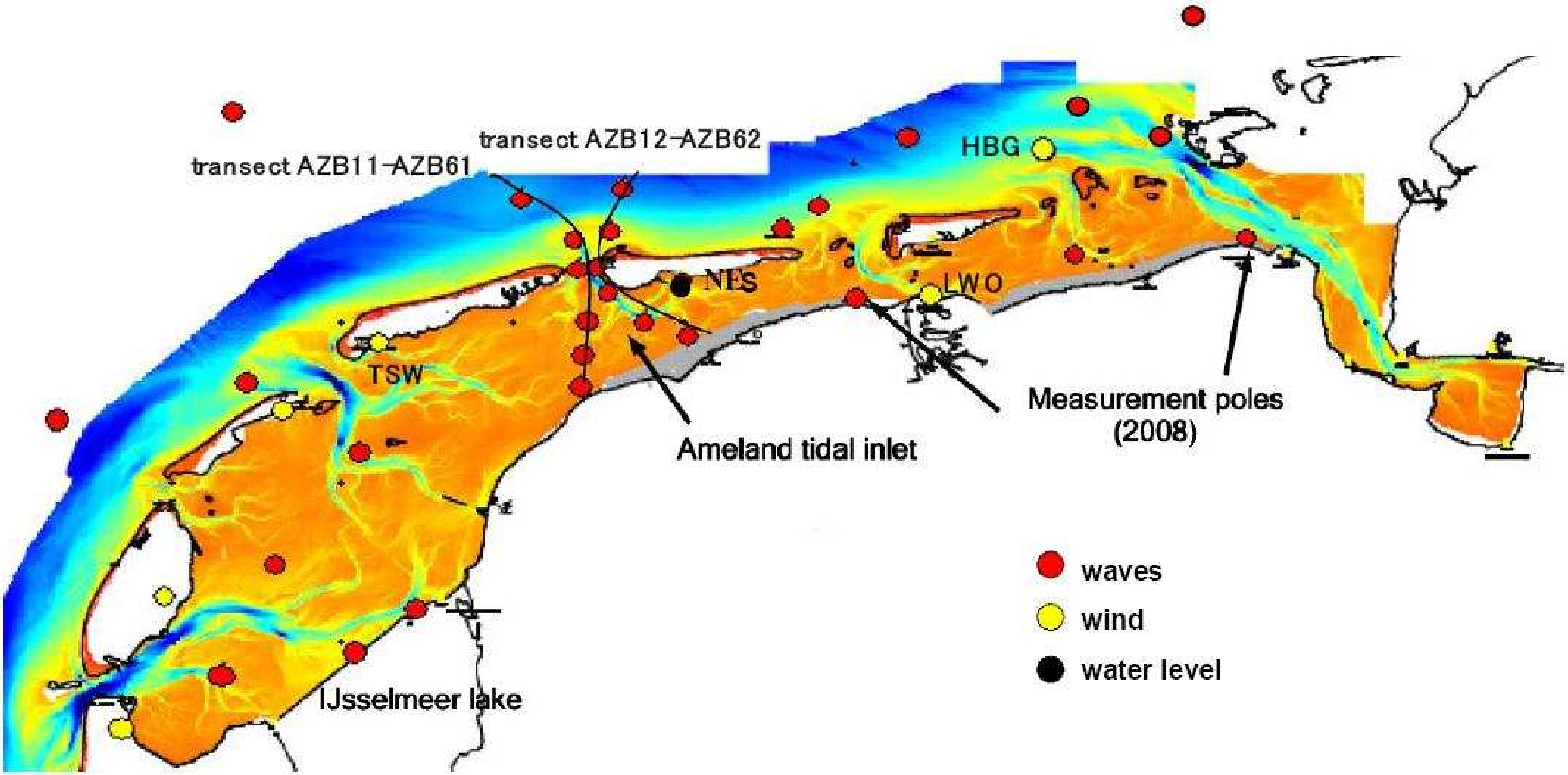
- Deep water source terms:
  - wind input based on Snyder et al. (1981)
  - modified whitecapping expression of Rogers et al. (2003)
  - DIA for quadruplets (Hasselmann et al., 1985)
- Shallow water source terms:
  - switch off LTA triads since transfer to higher frequencies often overestimated
  - depth-induced breaking of BJ78 with breaker index parameterization of Ruessink et al. (2003)
  - JONSWAP for bottom friction: $C_{\mathrm{b}} = 0.038 m^2 s^{-3}$ (Hasselmann et al., 1973)

Selected storm instants

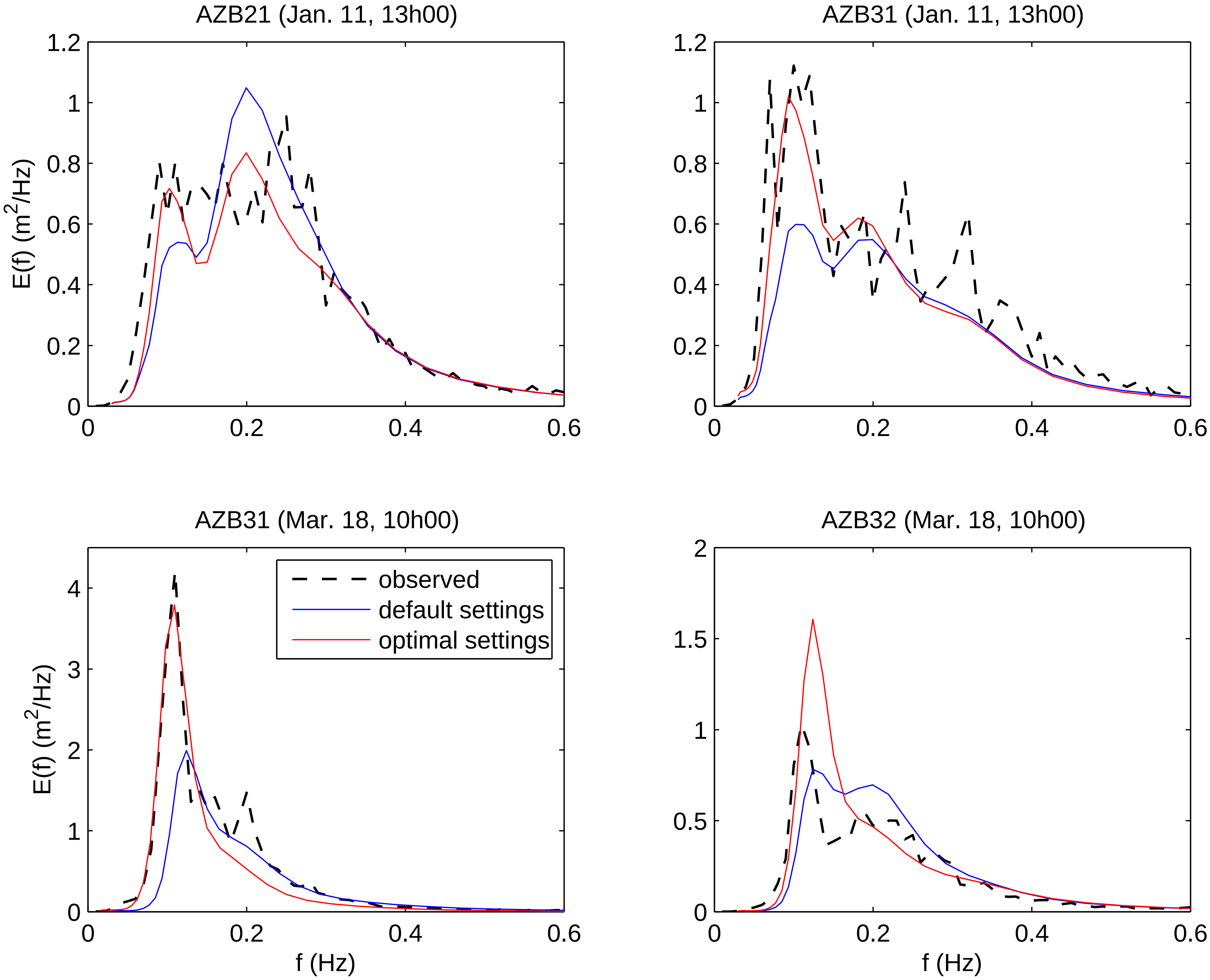
date and time	U_{10} (m/s)	U_{dir} (^{o}N)
11/01/2007, 13h00	19.6	228
11/01/2007, 22h40	19.6	279
18/01/2007, 14h00	20.4	263
18/03/2007, 10h00	14.3	279
18/03/2007, 14h40	18.5	266

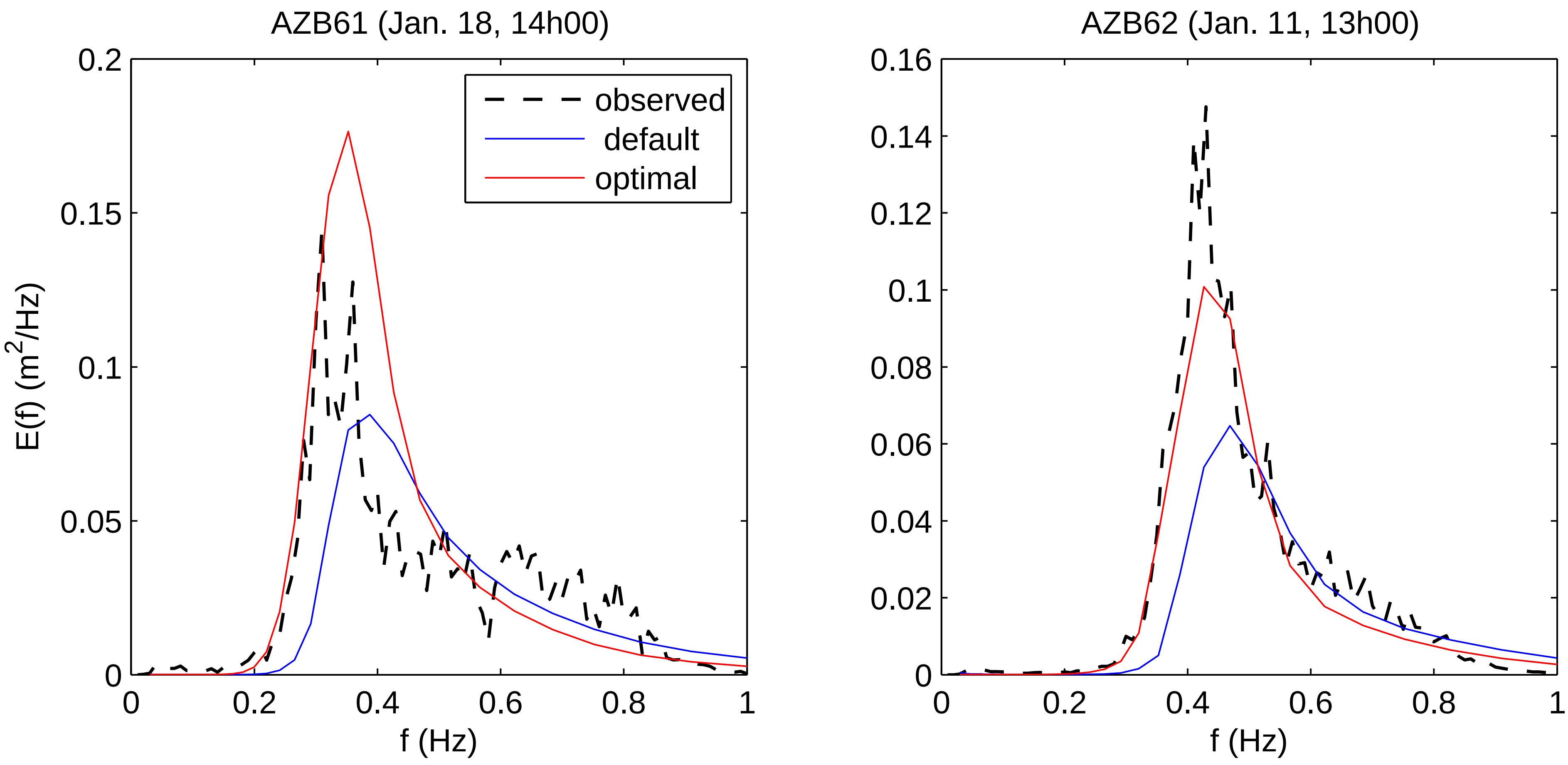
These instants are around the peak of the westerly storms with relatively high wind speeds

Measurement locations in Wadden Sea

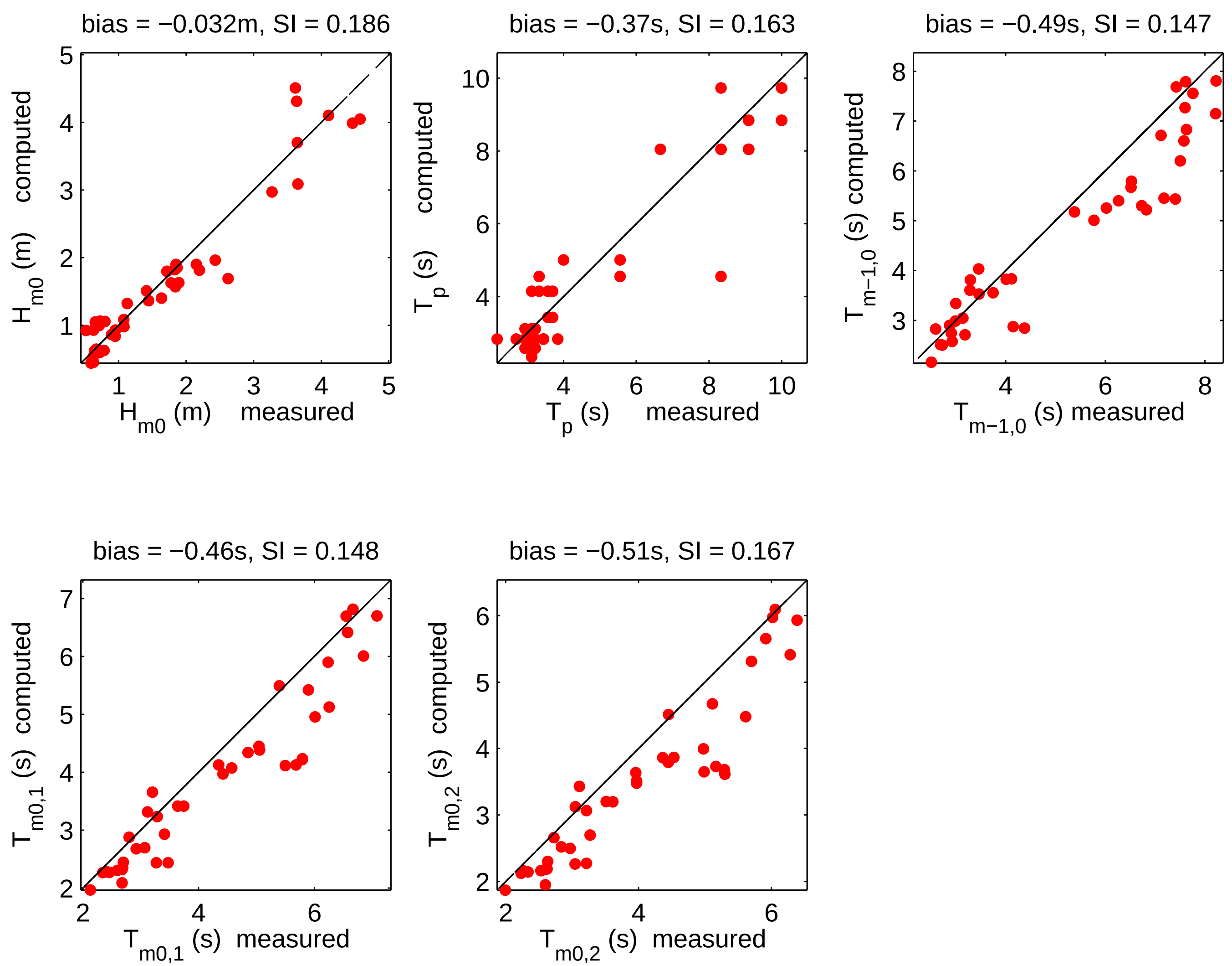


Courtesy of Deltares, The Netherlands

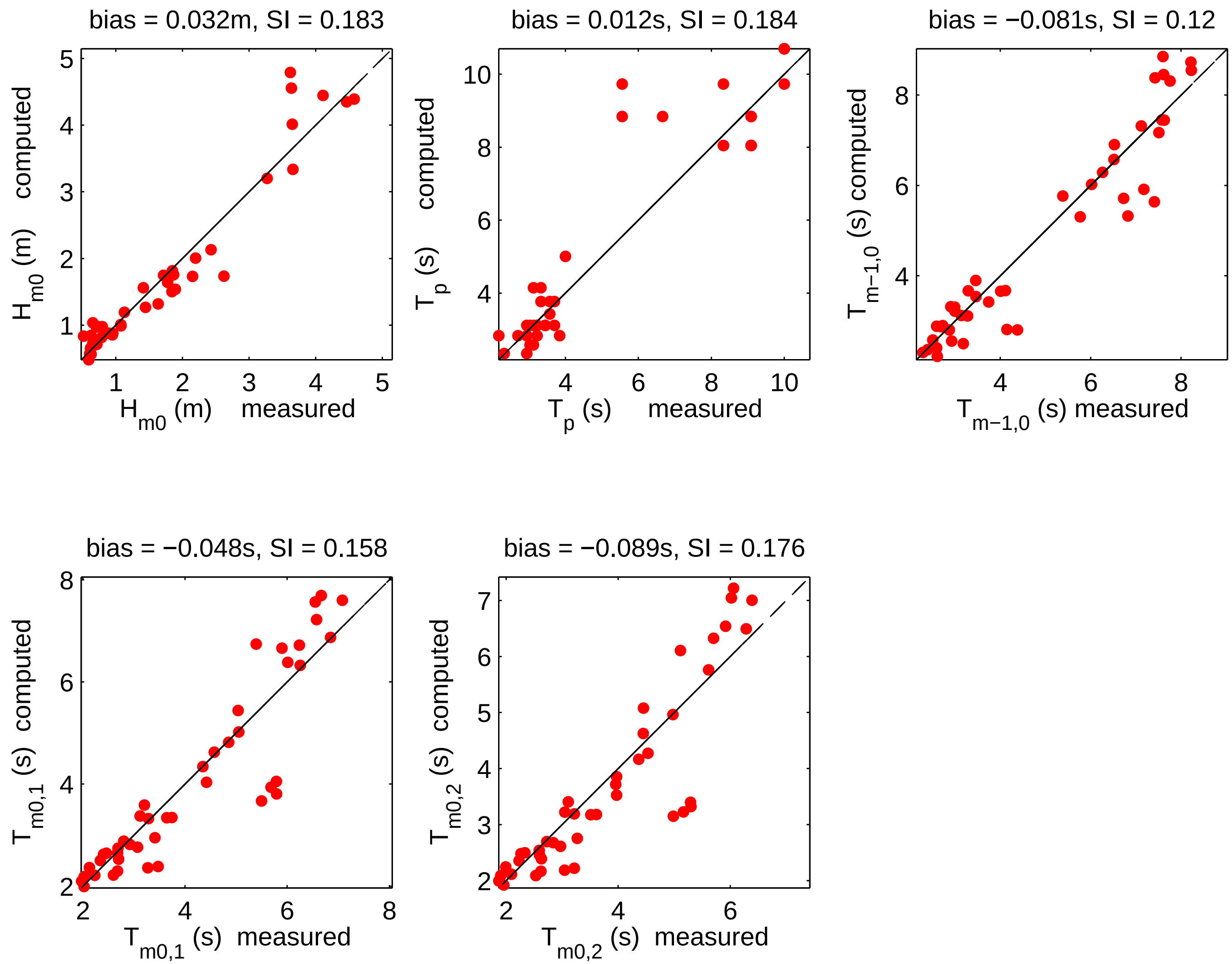

AZB21 (Jan. 11, 13h00)
AZB31 (Jan. 11, 13h00)
AZB31 (Mar. 18, 10h00)
AZB32 (Mar. 18, 10h00)
E(f) (m2/Hz)
f (Hz)
observed
default settings
optimal settings
0
0.2
0.4
0.6
0.8
1
1.2
1.5
2
3
4

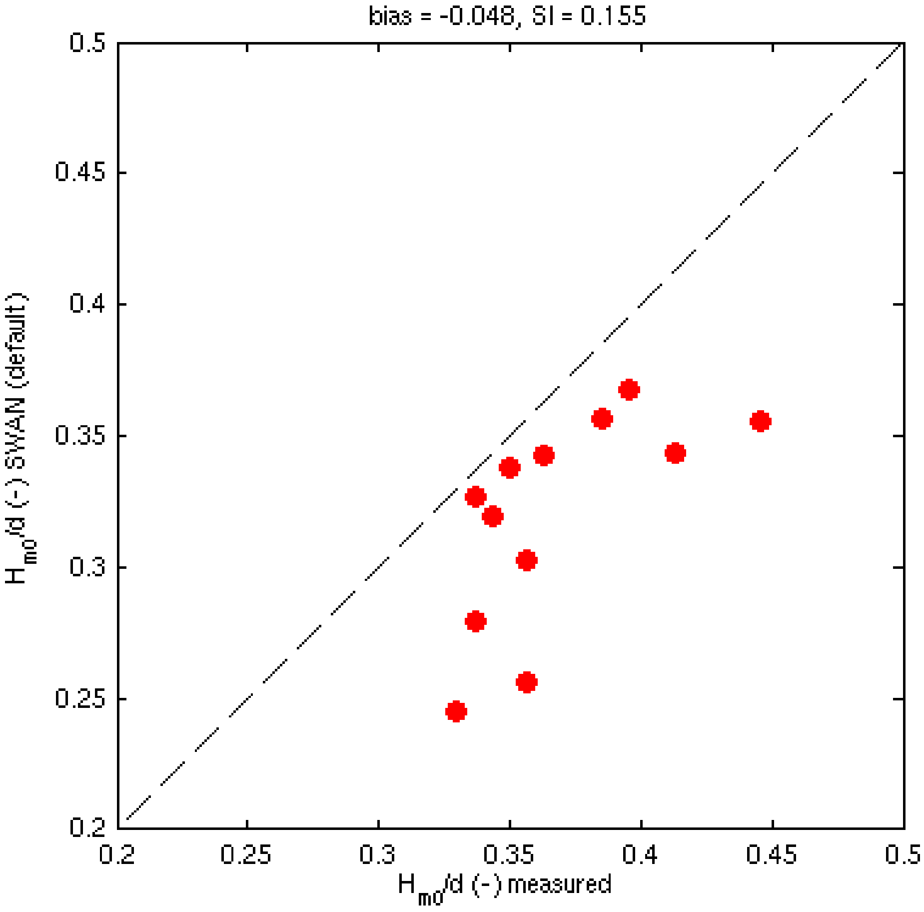

AZB61 (Jan. 18, 14h00)
AZB62 (Jan. 11, 13h00)
observed
default
optimal
E(f) (m^2/Hz)
f (Hz)
0
0.05
0.1
0.15
0.2
0.02
0.04
0.06
0.08
0.12
0.14
0.16
0.4
0.6
0.8
1

Model vs. measured: default settings

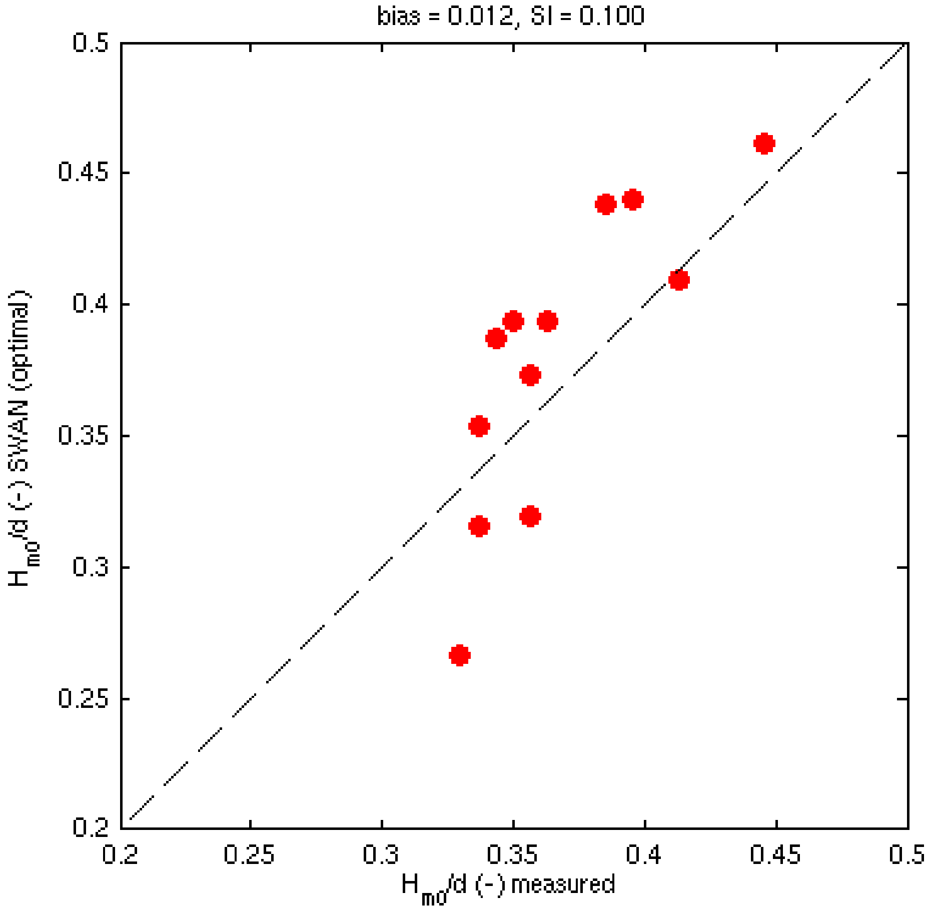


Model vs. measured: optimal settings





default settings



optimal settings

Concluding remarks (1)

- Use of UnSWAN for e.g.,
  - determination of wave climates and
  - hindcasting and forecasting storms
- As computational codes evolve with improvements in computer hardware, we should
  - add new or better physics to match the computational capabilities and accuracy
  - develop algorithms to handle multiscale physics and increasing grid resolution
- More focus on wave features associated with irregular bathymetry, e.g. surf zones

Concluding remarks (2)

- A parallel, unstructured version of SWAN has been developed and tested on Linux clusters
- Many known laboratory and field cases have been verified and validated and have shown
    - comparable results to that of regular grids and
    - expected results as indicated by the for SWAN typical bias and SI values
- Achieve good speedups and is scalable
- UnSWAN is available in the official release, version 40.72 see website www.swan.tudelft.nl