Spectral wave modelling in tidal inlet seas: Results from the SBW project

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Flood protection in the Netherlands

The Netherlands without dikes

Dike rings and safety levels

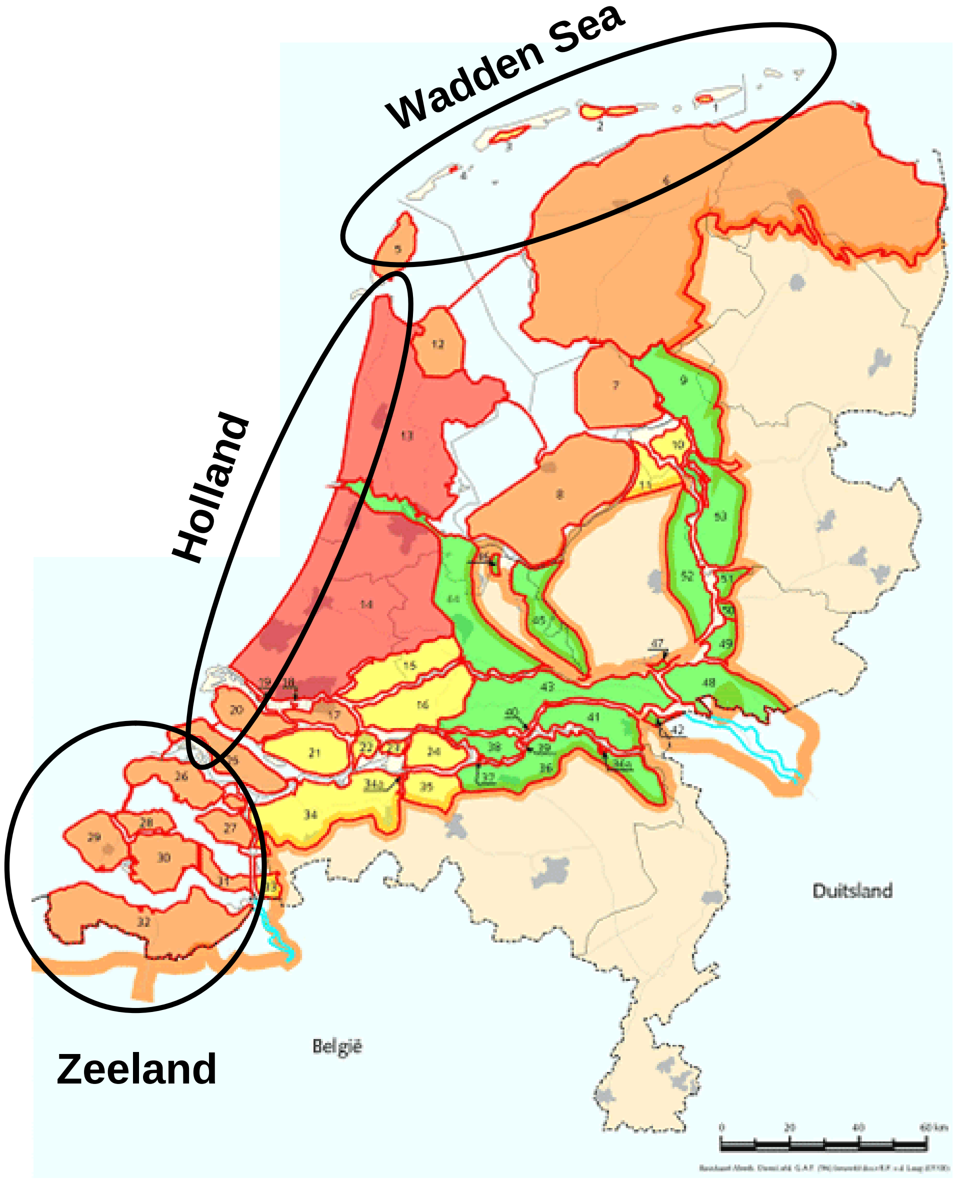
Project motivation

Safety level of Dutch Sea defenses
checked every 5-6 years

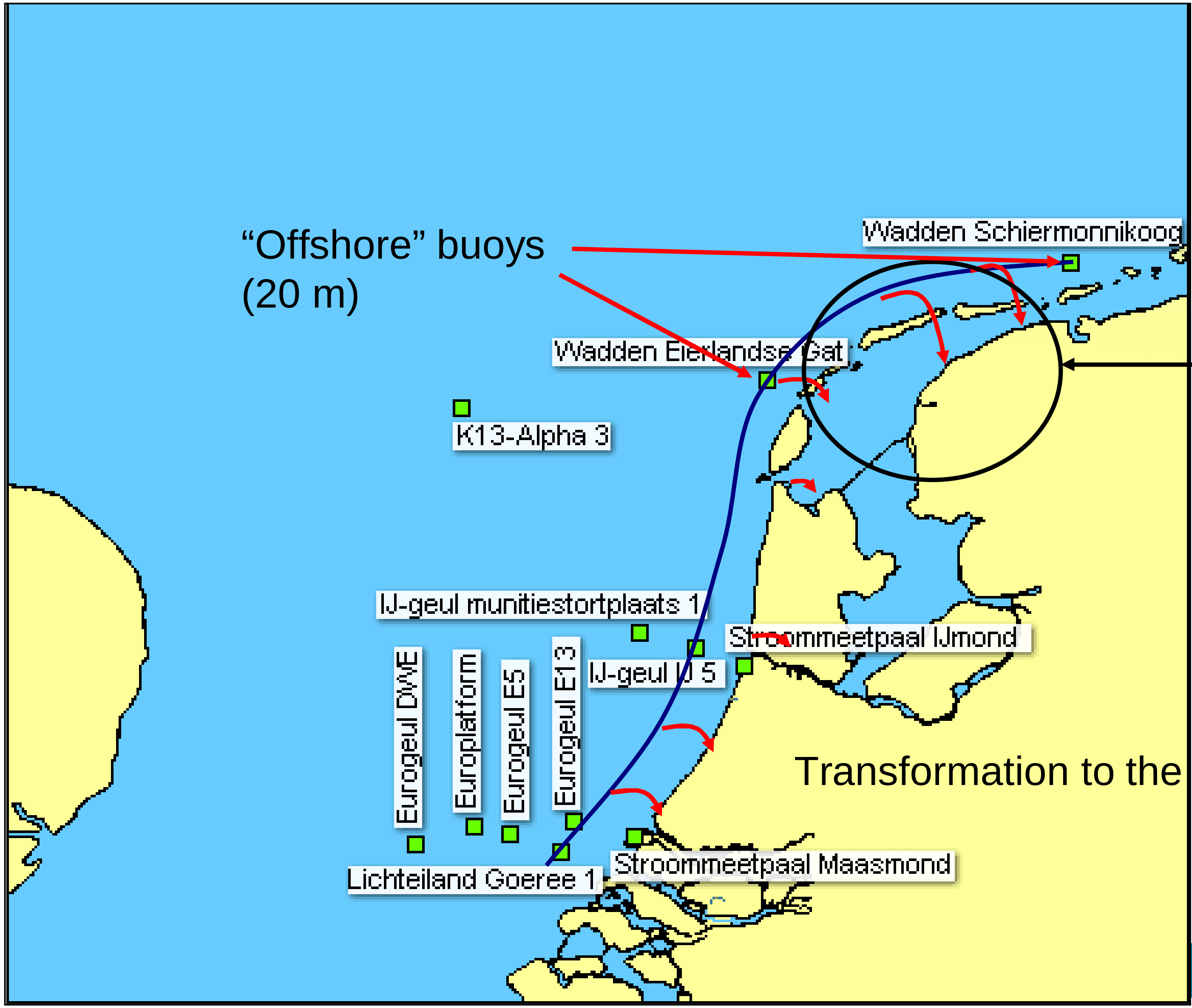
Need Hydraulic Boundary Conditions
(HBCs) at toe of dike

For Holland and Zeeland coasts
SWAN is used for wave
transformation offshore/nearshore

In Wadden Sea historic/design data
are used instead.



Wave transformation from offshore to the coast



SWAN
not used here
(up to 2006)

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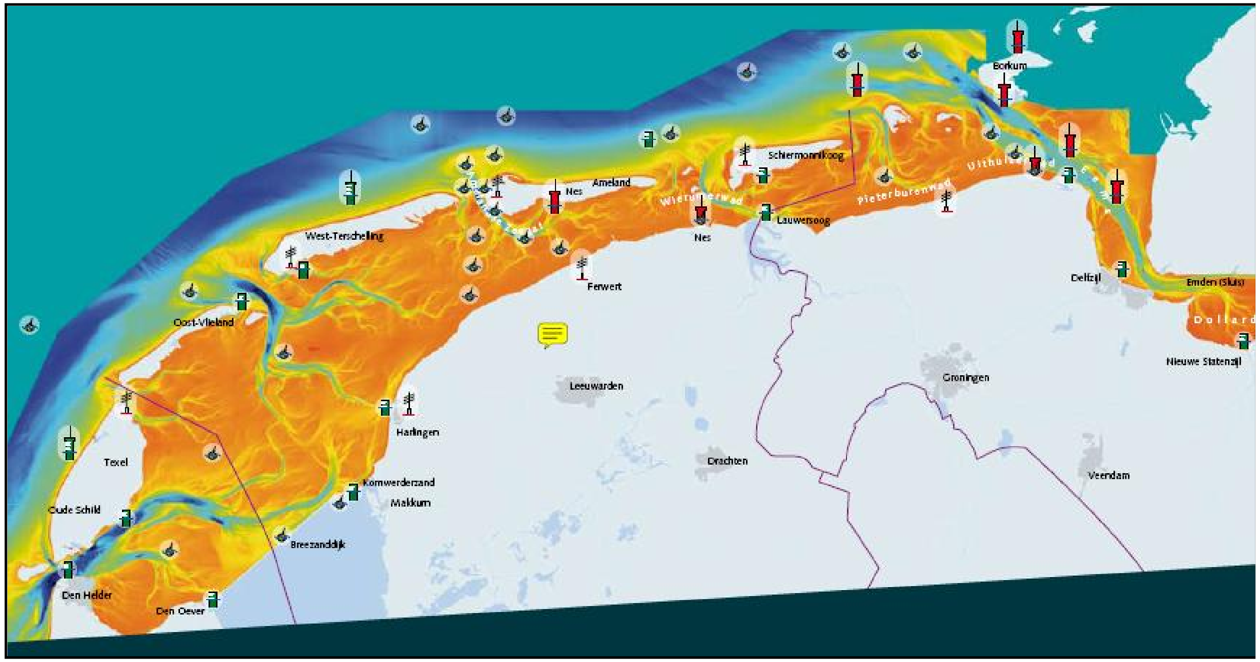
The problem with SWAN in Wadden Sea

- SWAN results are insufficient compared to observations in Norderneyer Seegat, especially wrt penetration of North Sea waves (Kaiser & Niemeyer 2001).

- No relevant verification wave data in Dutch part of the Wadden Sea.



Objective SBW-Waddenzee: a consistent, calibrated wave model + tools as part of the HBC chain to produce reliable HBC for the Wadden Sea in 2011 (and for other coastal areas and lakes) using Dutch and foreign field data.

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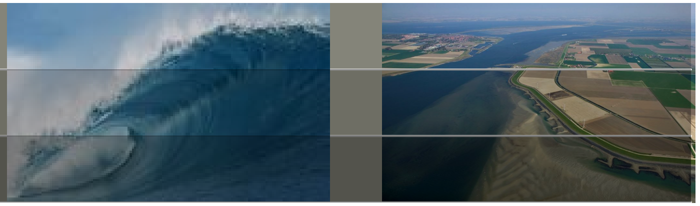
Measurement campaign

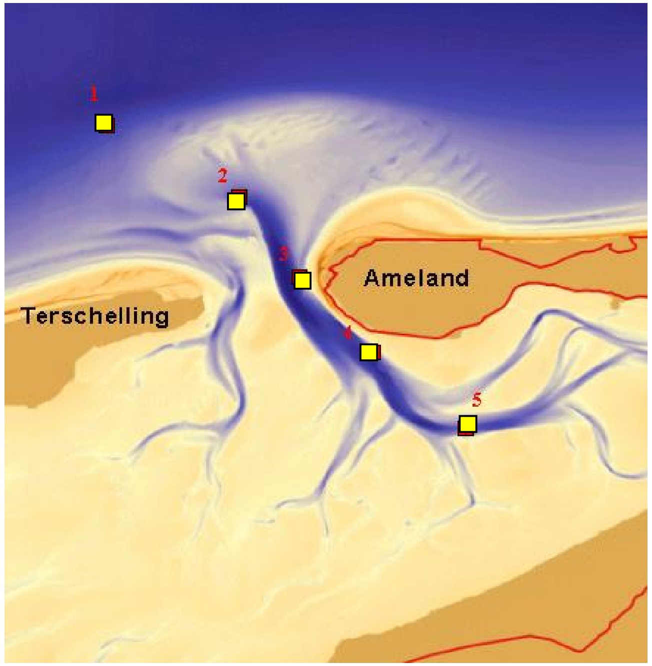


Bathymetry and buoy locations in tidal inlet of Ameland

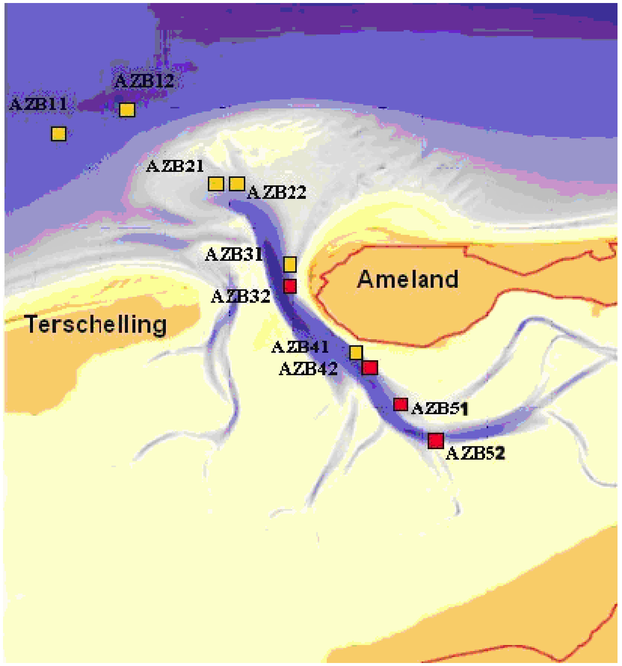
Wave riders:

- directional
- non-directional

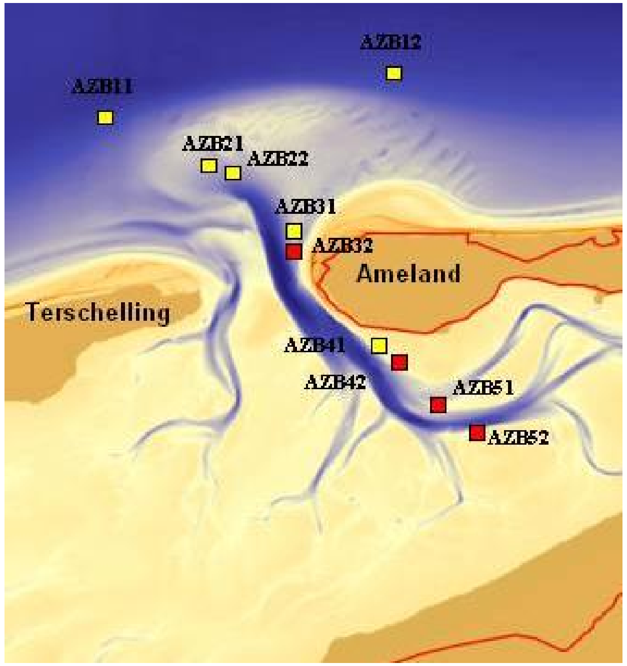
2003/2004



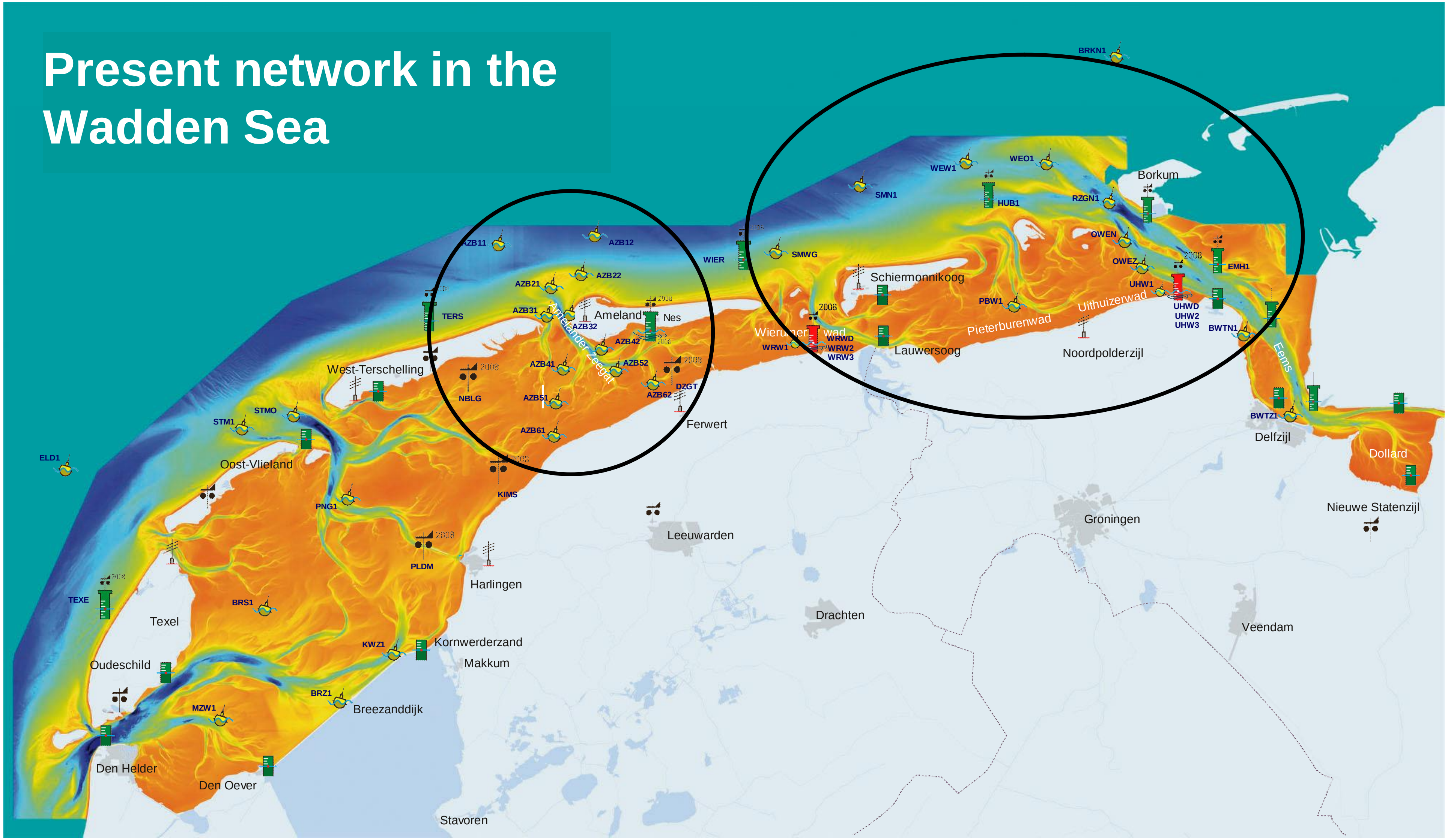
2004/2005

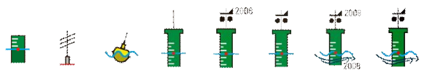


2005/2006



Present network in the Wadden Sea





- peilmeetstation
- meetpaal met zendverbinding
- meetpaal met zendverbinding (gerealiseerd binnen het SBW-project)
- golfmeetboei
- stromingsmeting
- waterstandsmeting
- waterstands- en golfmeting
- windmeting
- windmeting voorzien voor 2008
- ontvangstlokatie

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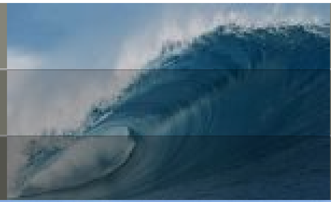
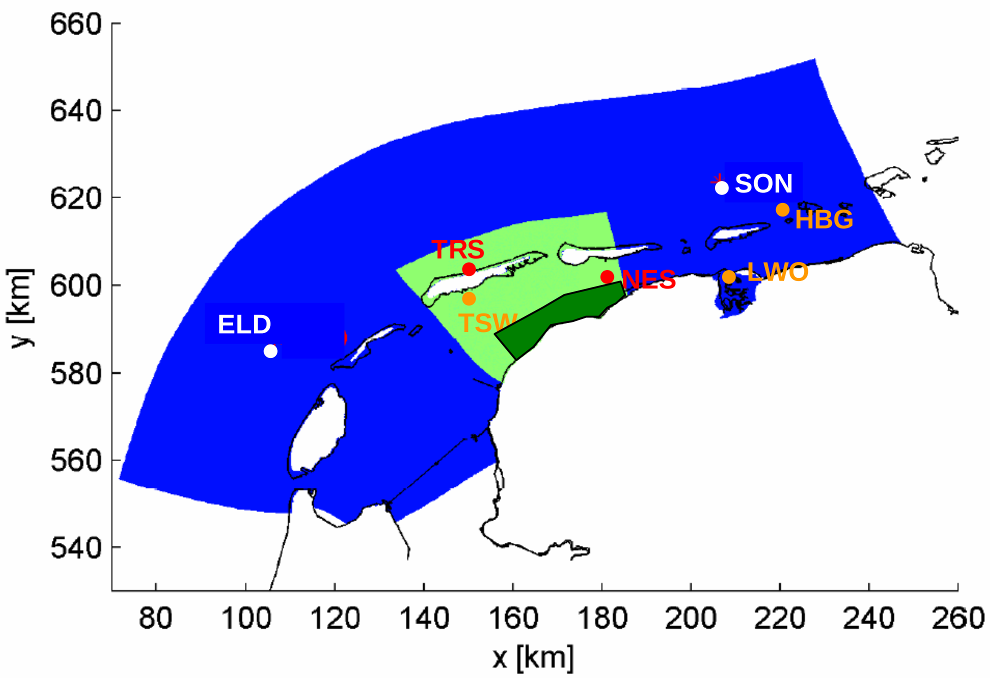
Observations at Uithuizerwad



Wave modelling with SWAN (input and grids)



Curvilinear grids :

- Overall (GridCL)
- Amelander Zeegat (AZG3A)
- Frisian coast (AK4A)

Measurement stations :

- Directional wave gauges at ELD, SON
- (Non-)Directional wave gauges in AZG
- Tidal gauges at NES, TRS
- Wind stations at TSW, LWO, HBG

Models for wind and current fields :

- Wind field from HIRLAM
- Wind field from downscaling technique
- Water level / current field from WAQUA

Bathymetry (based on soundings):

- Inlet of Ameland: yearly
- Elsewhere: 5-yearly

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Modelling approach: SWAN, source terms, numerics

Action balance equation:

$$\nabla_x \bullet \left[\left(\vec{c}_g + \vec{U} \right) N \right] + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_{tot}}{\sigma}$$

Wind input and whitecapping (vd Westhuysen et al., 2007):

$$S_{wc} = -C_{ds} \left[\frac{B(k)}{B_r} \right]^{p/2} \left[\tanh(kd) \right]^{\frac{2-p}{4}} g^{\frac{1}{2}} k^{\frac{1}{2}} E(\sigma,\theta)$$

Bottom friction (Hasselmann, 1973):

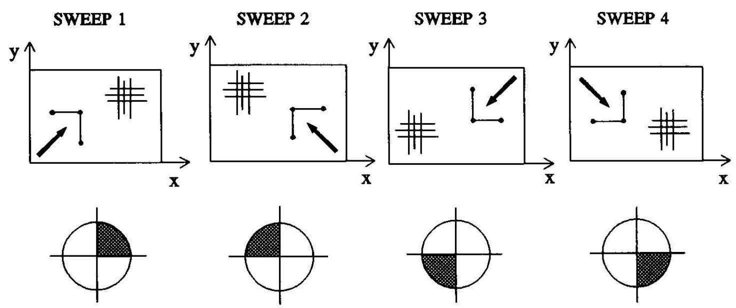
$$S_{bot} = -C_{JON} \frac{\sigma^2}{g^2 \sinh^2(kd)} E(\sigma,\theta)$$

Depth-induced breaking (Battjes & Janssen, 1978):

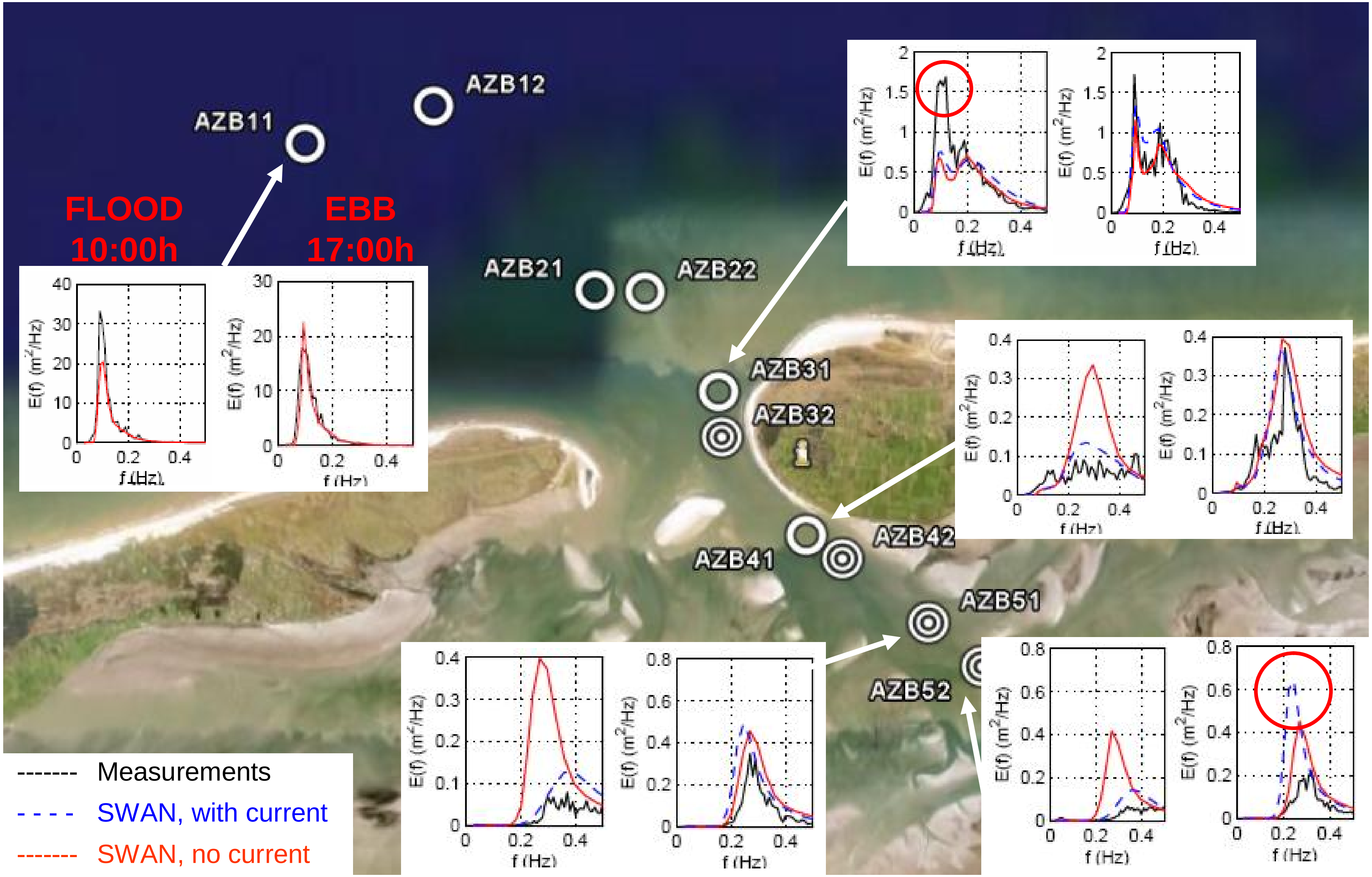
$$S_{brk} = D_{tot} \frac{E(\sigma,\theta)}{E_{tot}} \quad , \quad D_{tot} = -\frac{1}{4} \alpha_{BJ} Q_b \bar{f} H_m^{\ 2}$$

Quadruplets (DIA, Hasselmann. et al. 1985)

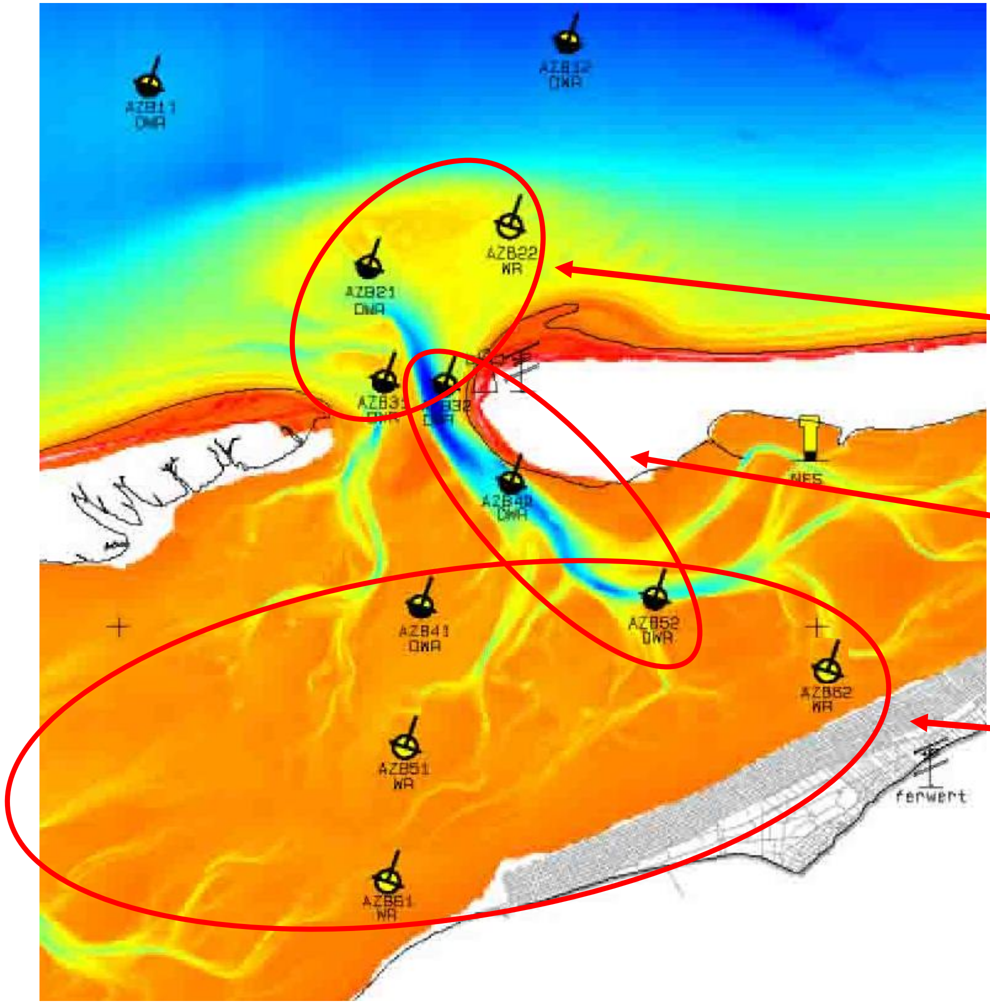
Triad interactions (LTA, Eldeberky 1996)



Performance default model (Ameland, 2 Jan 2005, flood&ebb)



Wave modelling challenges in the Wadden Sea



Configuration since Nov. 2006.

Focus of hindcasts on specific aspects:

Penetration of low-frequency energy from North Sea

Effect of wave-opposing and wave-following currents

Wave growth in depth-limited areas

Improved modelling of water levels and currents

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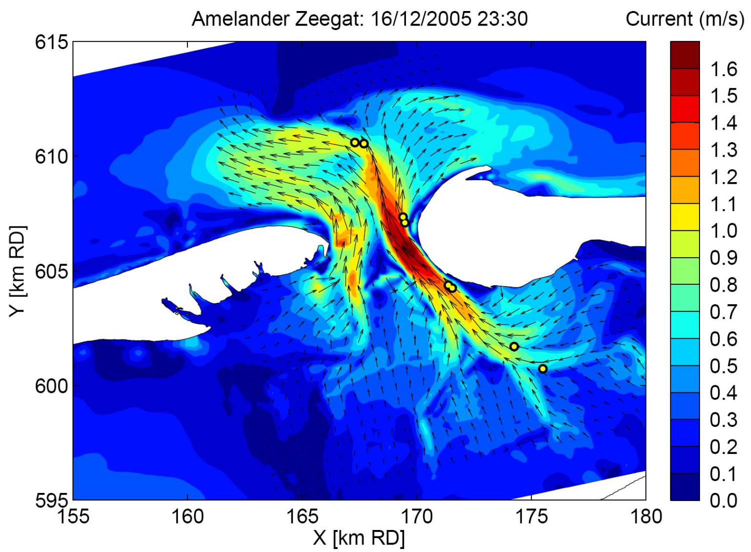
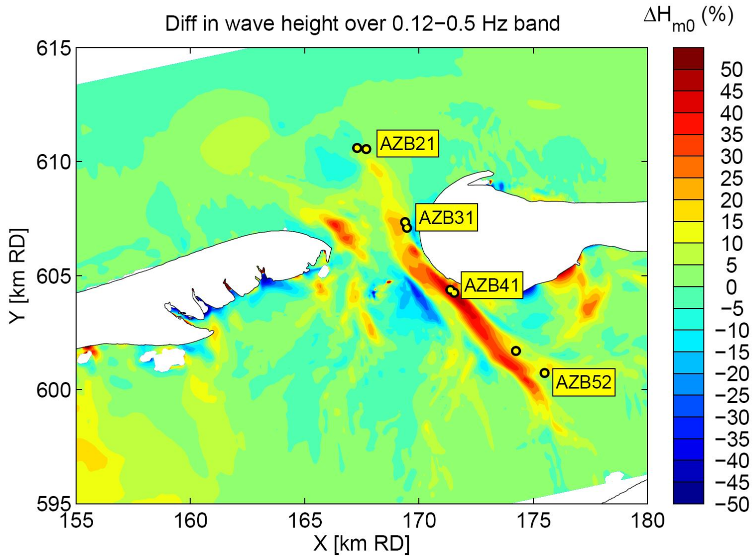
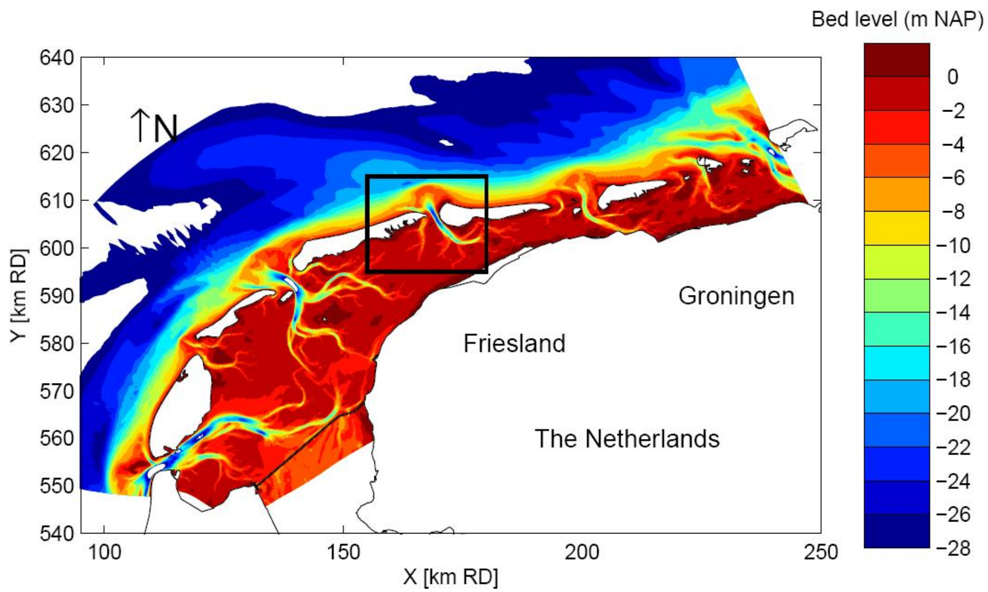
Wave-current interaction: Influence of opposing current







Enhanced dissipation on counter current

Default whitecapping (saturation-based):

$$S_{wc}(\sigma,\theta) = -C_{ds}\left[\frac{B(k)}{B_r}\right]^{p/2} g^{\frac{1}{2}}\, k^{\frac{1}{2}}\, E(\sigma,\theta)$$

(V/d Westhuysen 2007, based on Alves & Banner 2003)

Bore-based enhanced dissipation (Ris and Holthuijsen 1996):

$$S_{diss,cur}(\sigma,\theta) = -C'_{ds} Q_b \left(\frac{s_{\max}}{\tilde{s}}\right)^2 \tilde{\sigma}\frac{k}{\tilde{k}} E(\sigma,\theta) \quad , \quad \frac{1-Q_b}{\ln Q_b} = -8\frac{E_{tot}}{H_m^2} \quad \text{and} \quad H_m = \frac{2\pi\, s_{\max}}{\tilde{k}}$$

Saturation-based enhanced dissipation:

$$S_{diss,cur}(\sigma,\theta) = -C''_{ds} \max\left[\frac{c_\sigma(\sigma,\theta)}{\sigma}, 0\right]\left[\frac{B(k)}{B_r}\right]^{p/2} E(\sigma,\theta) \quad , \quad \frac{\Delta s(\sigma,\theta)}{s(\sigma,\theta)} = \frac{\partial s}{\partial t}\Big/ s = \frac{c_\sigma(\sigma,\theta)}{\sigma}$$

$$\Rightarrow \quad \boxed{S_{diss} = S_{wc} + S_{diss,cur}}$$

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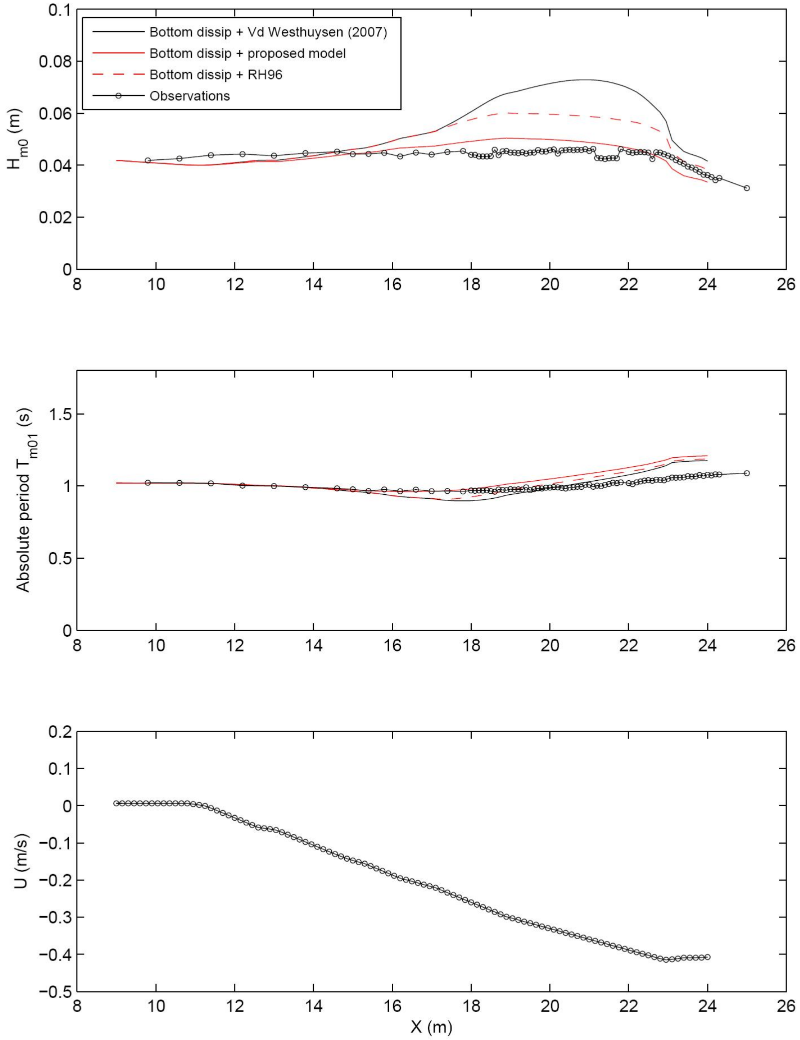
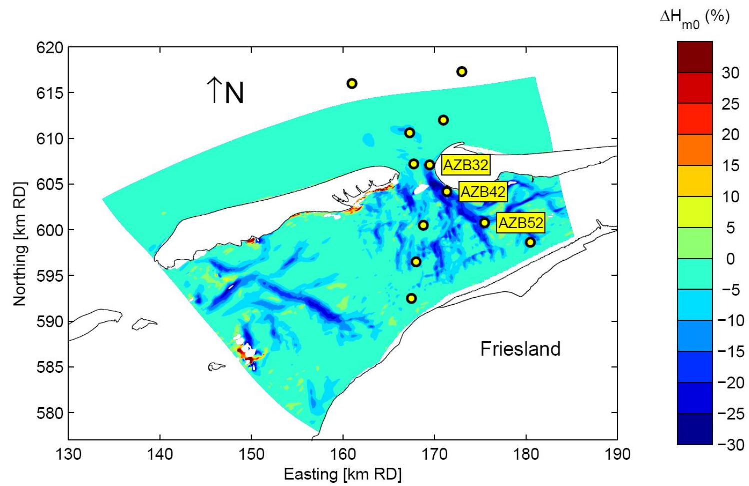
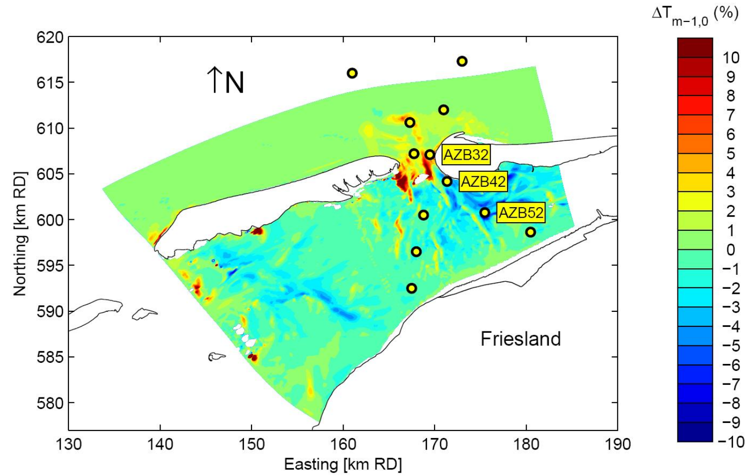
Wave-current interaction: Results

Suastika (2004) flume, partial blocking

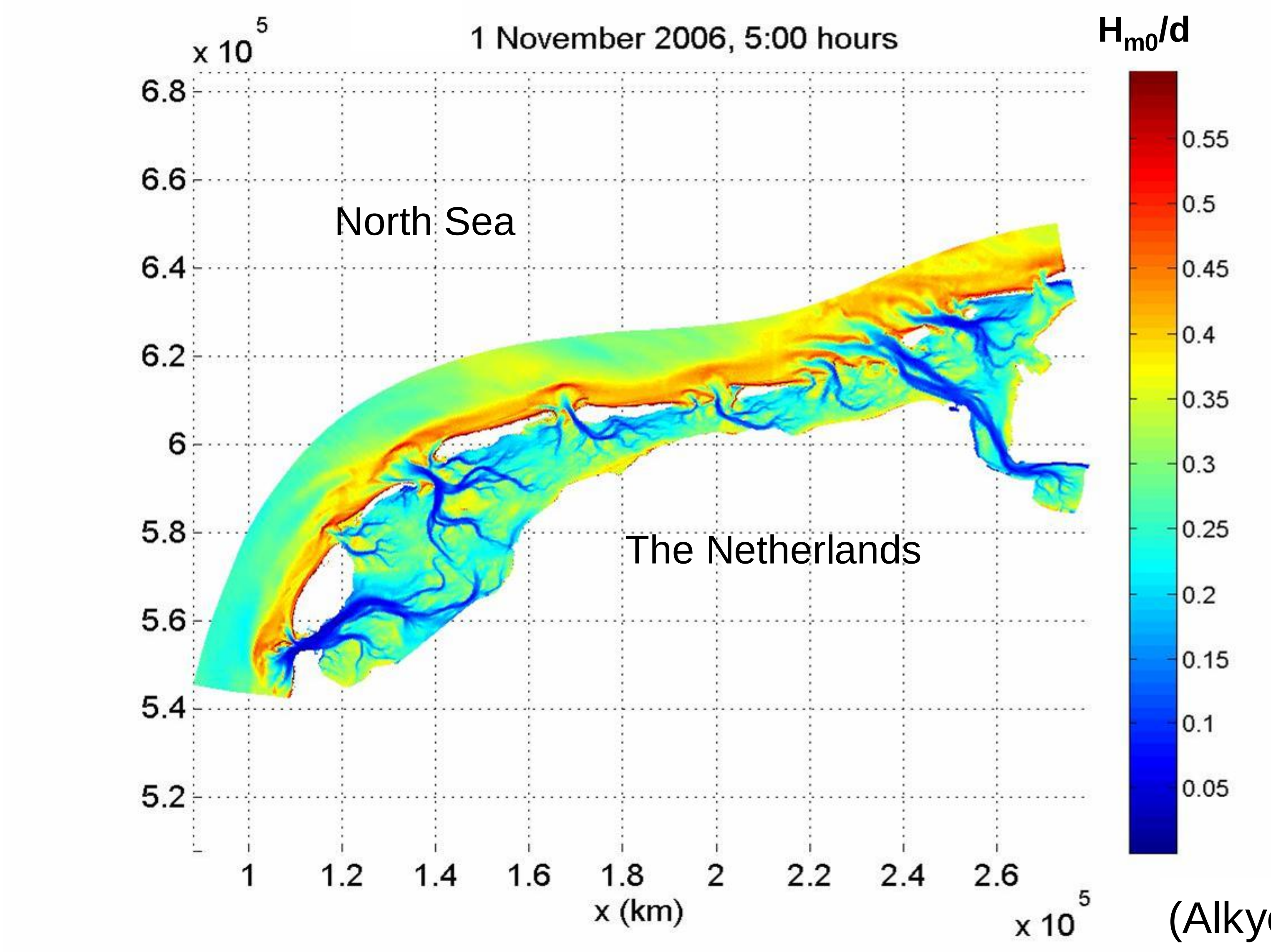


AZG 18/03/2007 at 14:40 (ebb)
Diff. proposed & default models





Wave growth in finite-depth areas: Depth limitation



(Alkyon 2008)

Depth breaking based on shallow water nonlinearity

From Thornton & Guza (1983):

$$D_{tot} = -\frac{B^3}{4}\frac{f_{m01}}{d}\int_0^\infty H^3 p_b(H)\,dH$$

$$p_b(H) = W(H)\,p(H)$$

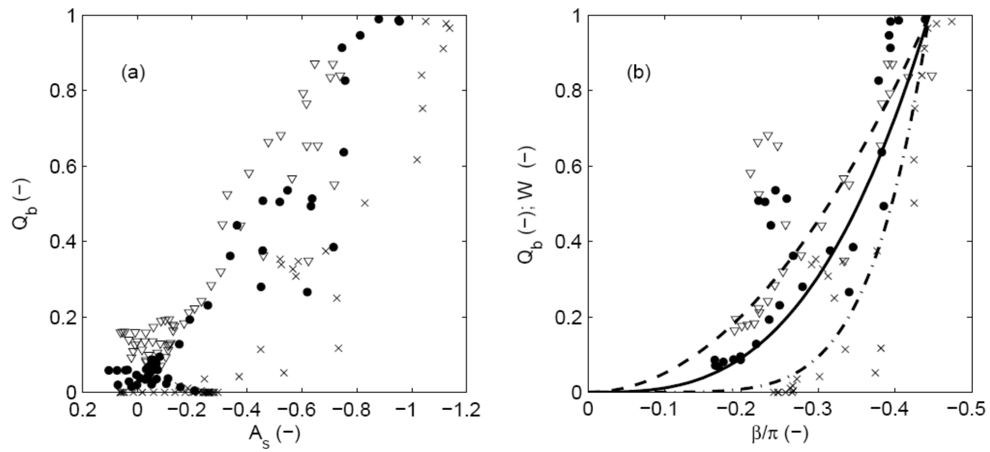
Introduce a biphase-dependent weighting function on the pdf:

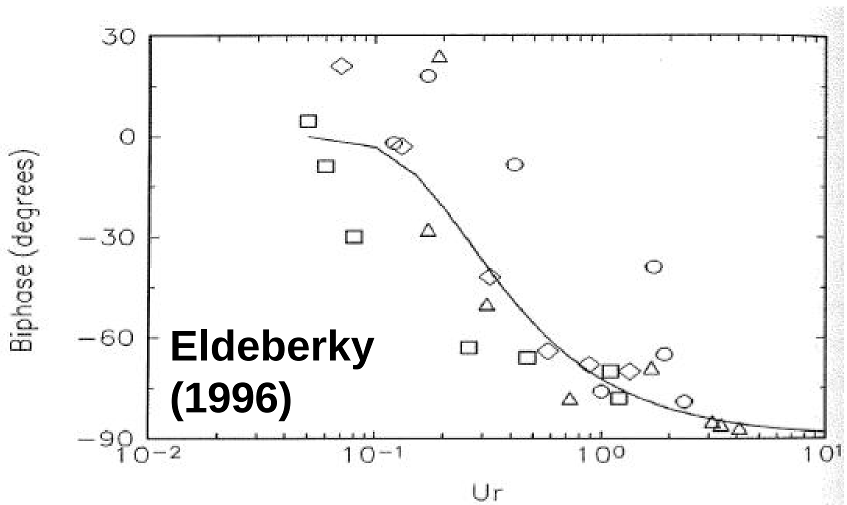
$$W(H) = \left(\frac{\beta}{\beta_{ref}}\right)^n \quad , \quad \beta_{ref} \quad -\frac{4\pi}{9}$$

$$n = 4 - \frac{4}{\pi}\arctan\left[\nu\left(S_{\text{loc}} - \tilde{S}_{\text{loc}}\right)\right]$$

$$D_{tot} = \frac{3\sqrt{\pi}}{16}\frac{B^3 f_{m01}}{d}\left(\frac{\beta}{\beta_{ref}}\right)^n H_{rms}^{\ 3}$$

Boers (1996):





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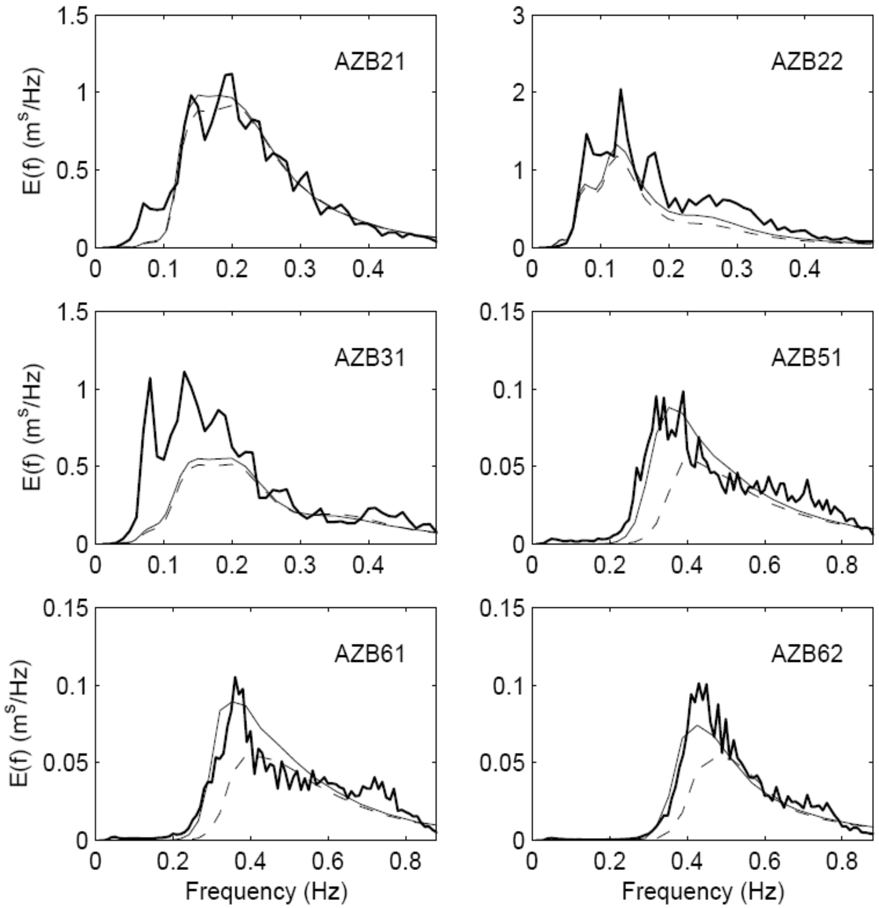
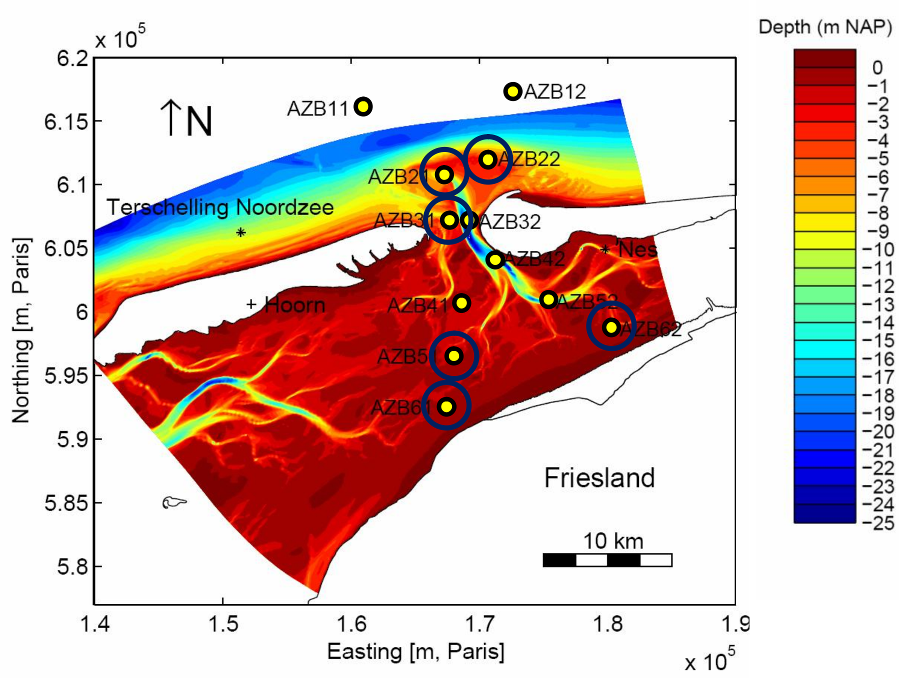
Wave growth in finite-depth areas: Results

Amelander Zeegat (18/01/07, 12:20)



B&J 1978 (dashed); proposed (solid)



Van der Westhuysen (2010, JGR)

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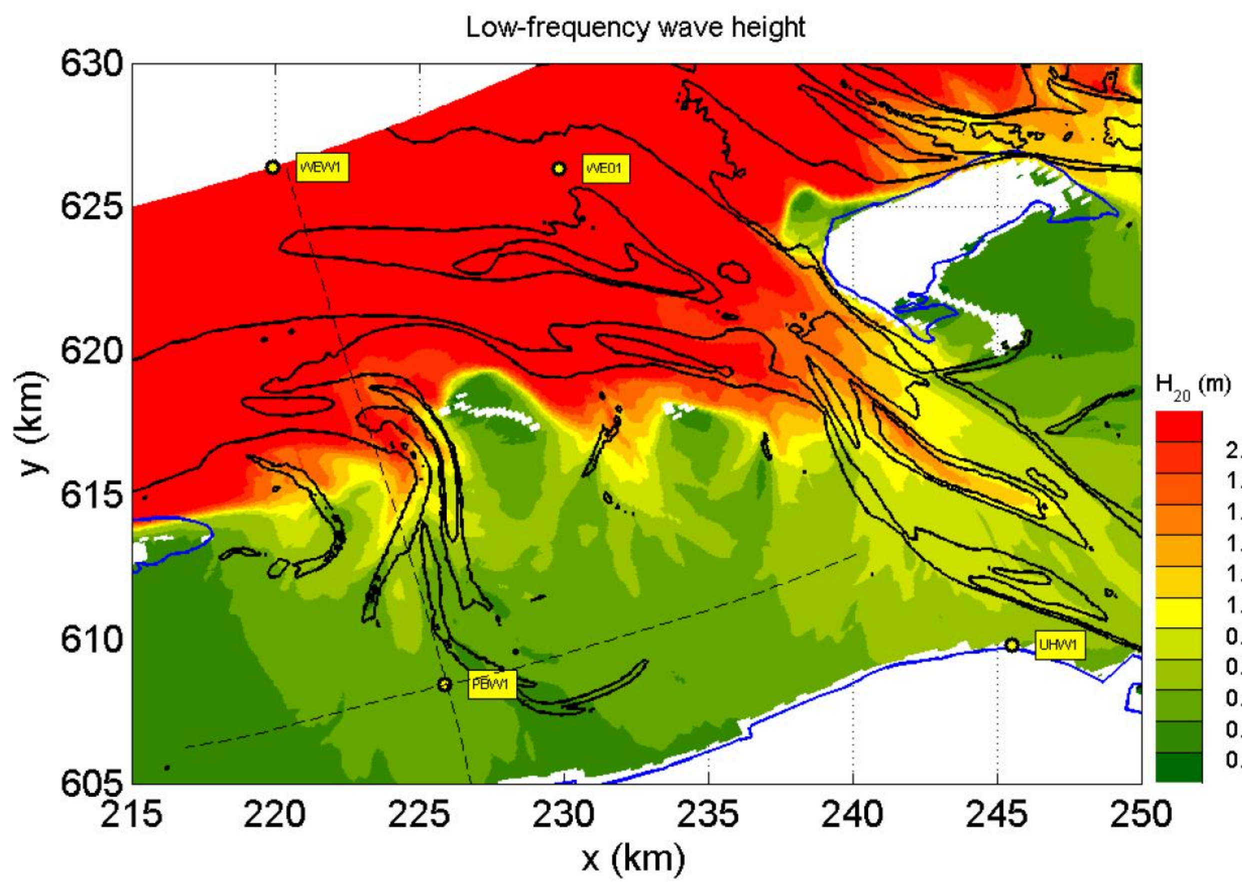
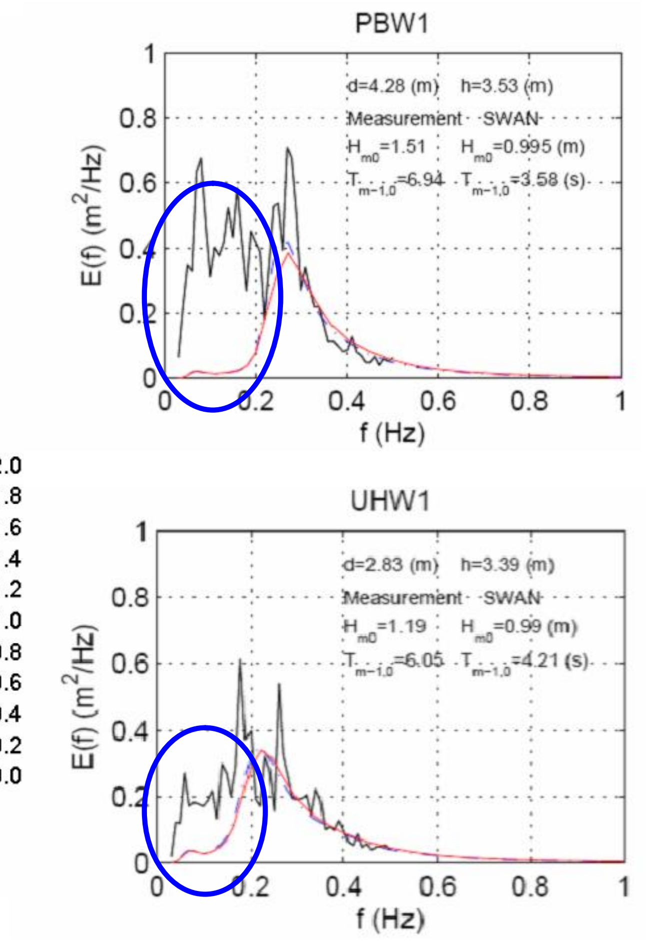
Swell penetration into the Wadden Sea interior





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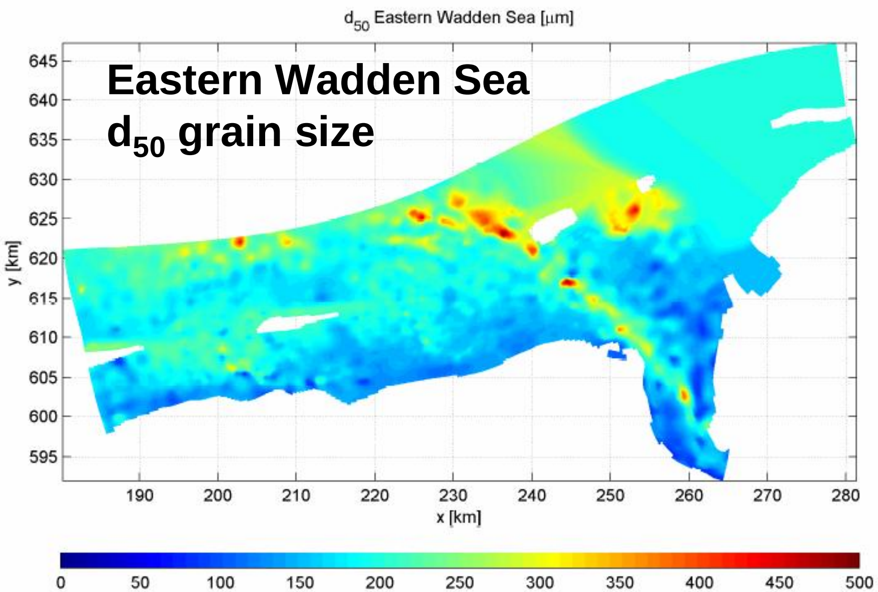
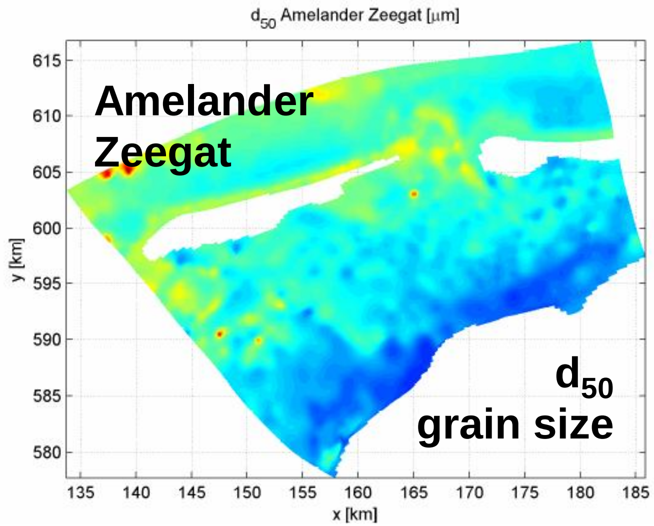
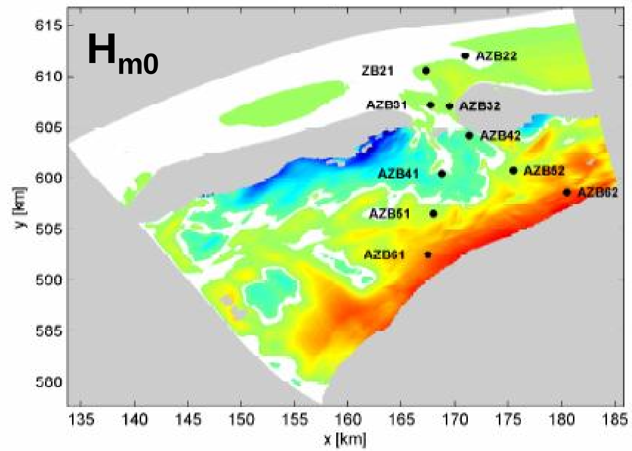
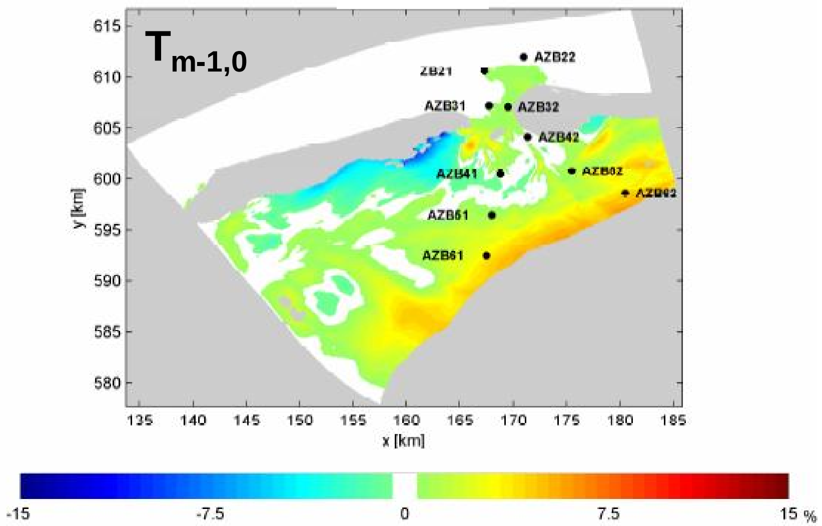
Swell penetration: Reduced bottom friction





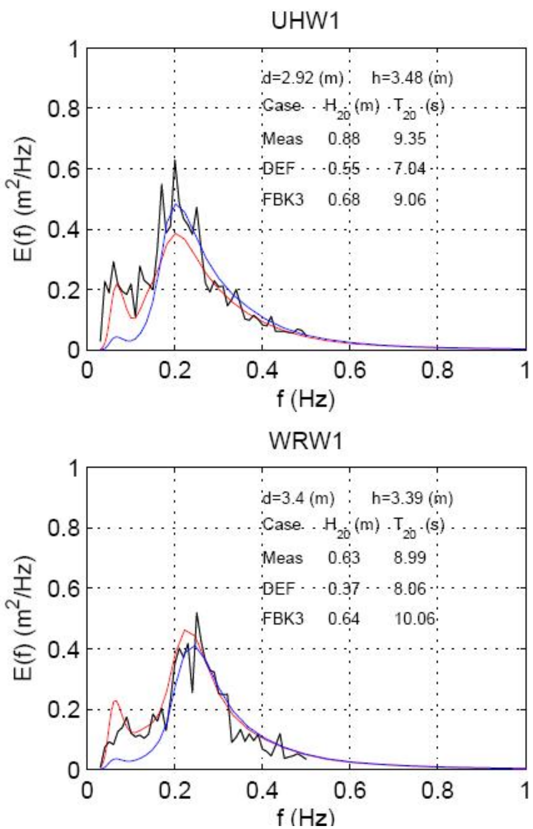
Madsen (1988) vs. JONSWAP (18/03/07 19:20)

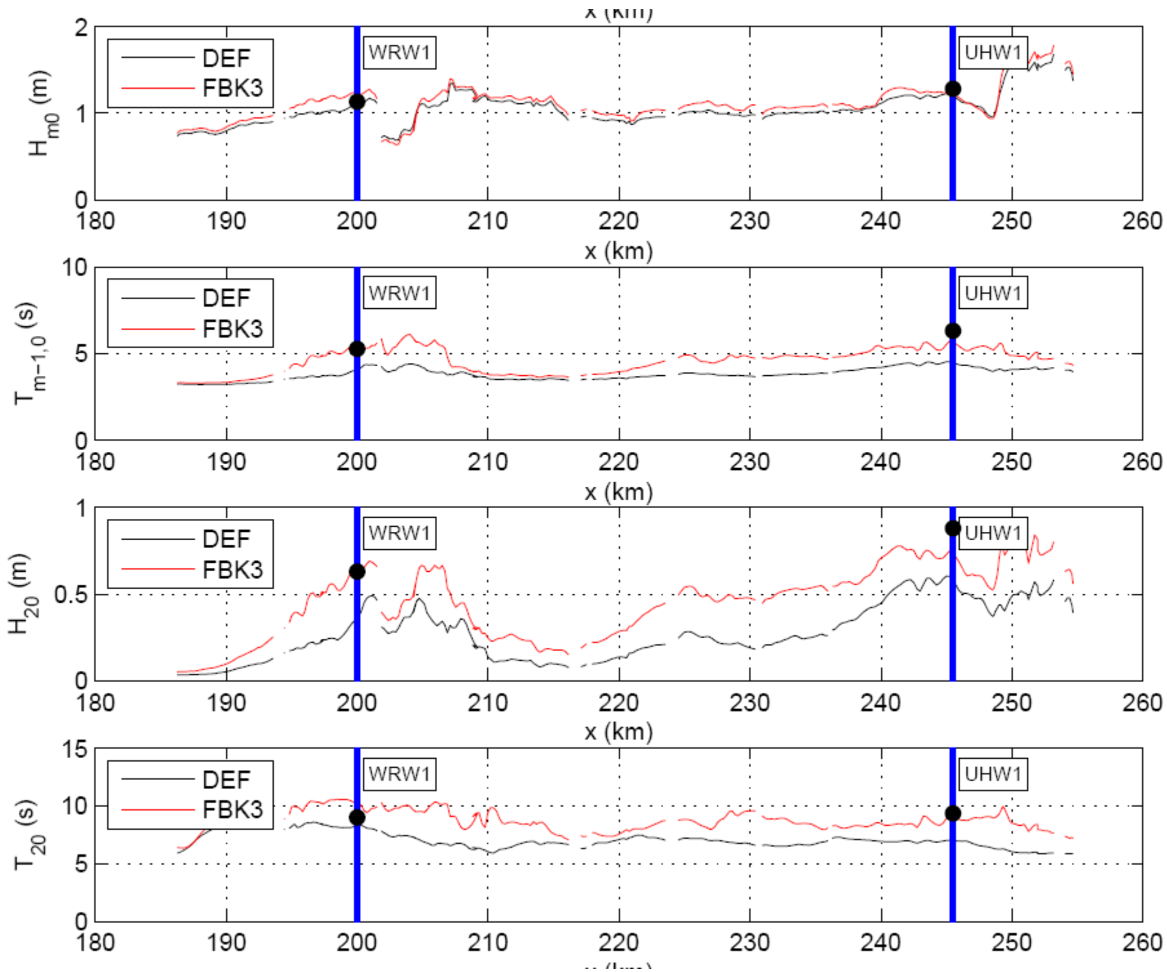




Swell penetration: Bottom friction and limit on refraction

- Largest improvement in H_{20} and T_{20} and integral parameters.
- H_{m0} and $T_{m-1,0}$ predicted within 10% accuracy





Overall Conclusions

1. Three modelling challenges in the Wadden Sea identified: (a) waves on opposing current, (b) depth-limited wave growth over the flats and (c) swell penetration.

2. New expression developed for dissipation on counter current. Improvement for counter current; no deterioration for no-current and following current situations.

3. Depth-induced breaking related to shallow water nonlinearity. Proposed model corrects underestimation over horizontal beds (finite-depth growth conditions), and maintains good results over sloping beds.

4. Bottom friction and propagation play important part in penetration of swell waves. Spatial information of bottom characteristics provides valuable insights.

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