Wave penetration in a tidal inlet system during a severe winter storm

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Motivation

- Improve SWAN model for determination of wave boundary conditions for Dutch sea defenses
- Perform hindcast studies to validate SWAN
- Investigate under-estimation of low-frequency wind wave energy by SWAN

Conclusions of storm hindcast

- Inclusion of wave effects improves the prediction of water levels in the Wadden Sea;
- Low-frequency wave penetration is under-estimated by SWAN
- Low-frequency waves in SWAN are 'redirected' from the tidal channels by refraction into shallow areas where they dissipate;
- The amount of low-frequency wave energy in the interior of the Wadden Sea can be improved by:
  - limiter on the refraction speed for low-frequencies (f < 0.2 Hz)
  - Freq. dependent surf breaking on bulk dissipation
  - Using lower JONSWAP bottom friction coefficient
- Currents effects in SWAN did not significantly influence the outcome of the hindcast, at least for this storm and these buoy locations.

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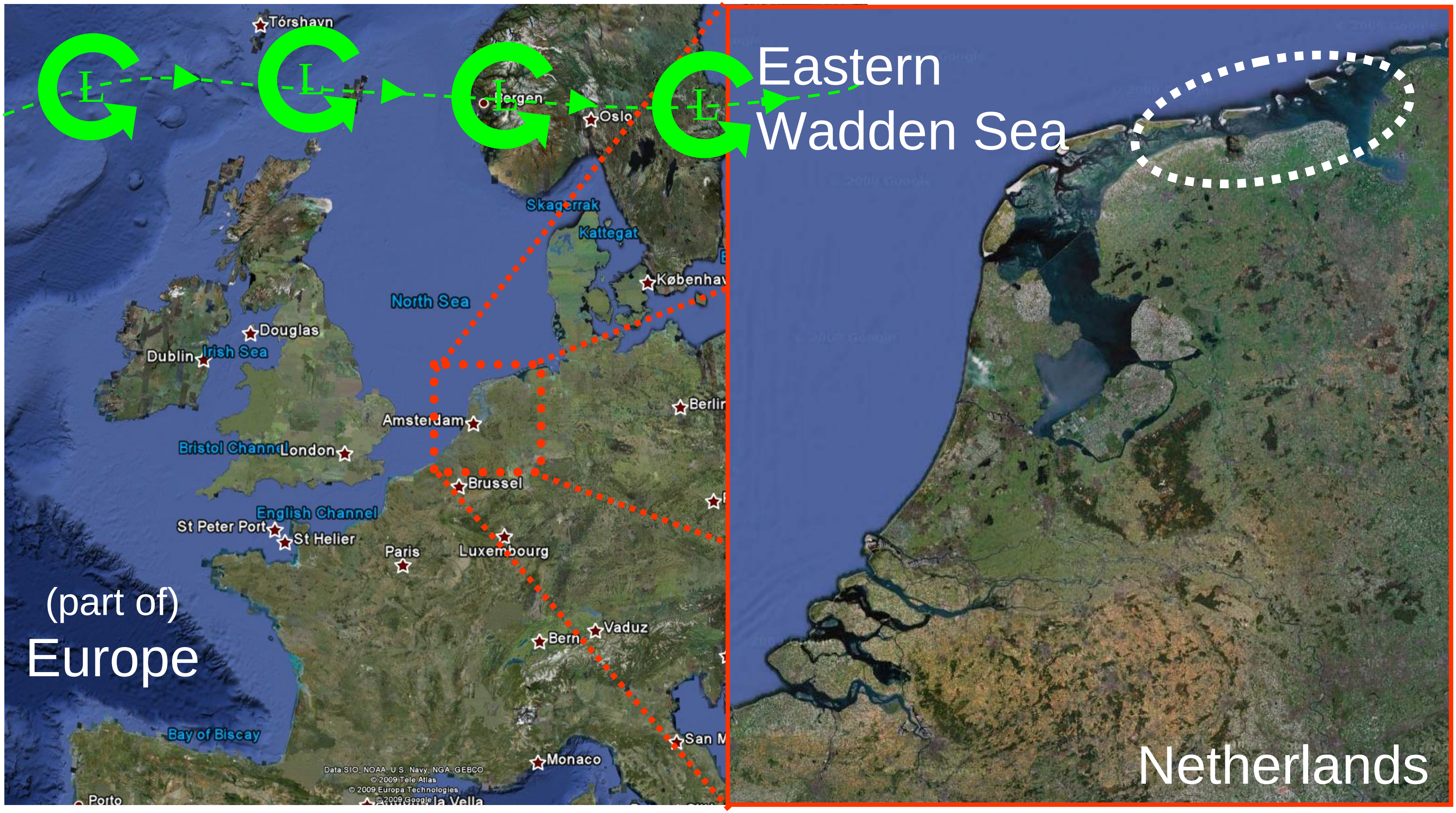
Storm trajectory
9 Nov. 2007

Geographic location
(Google Earth)

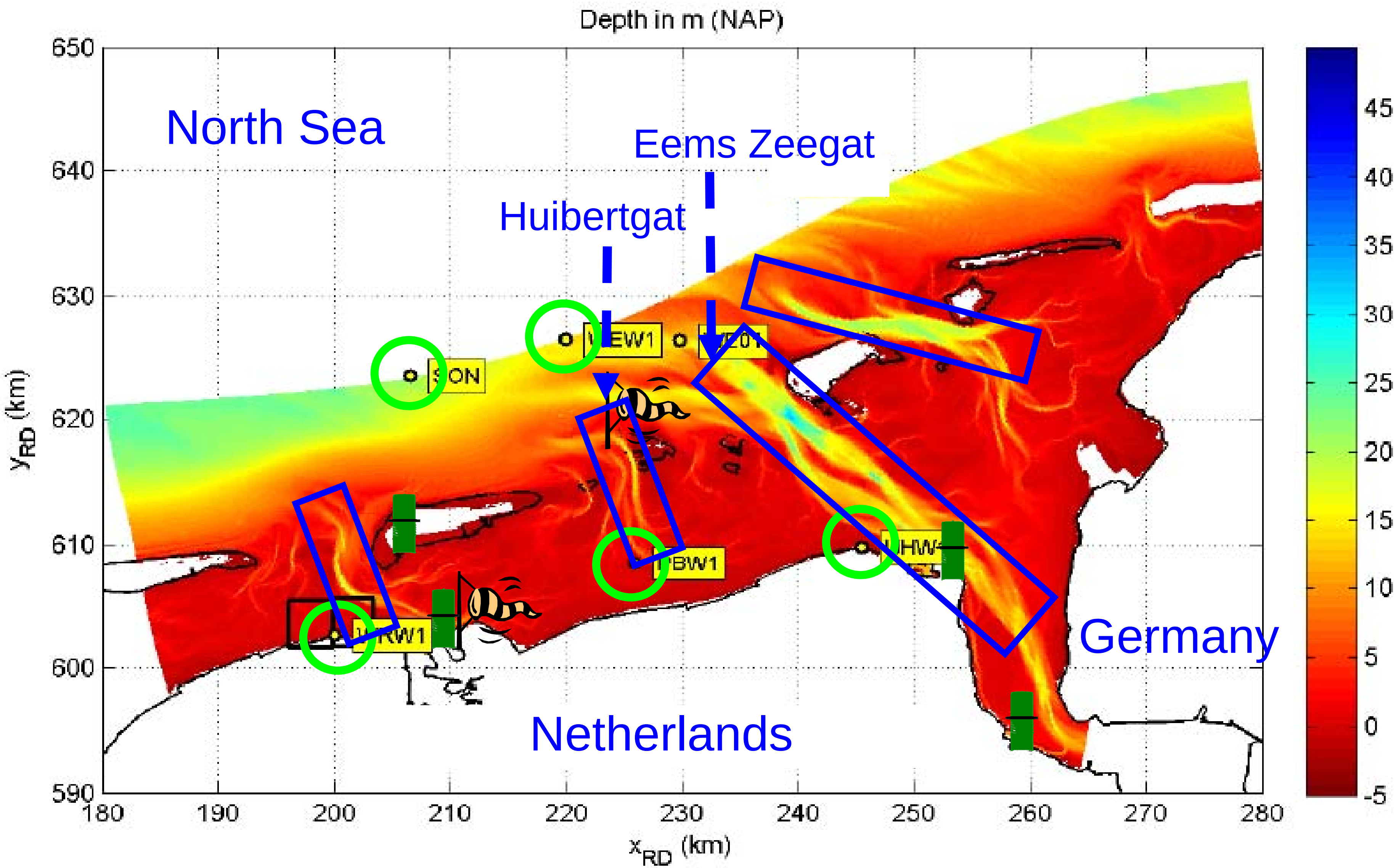


Purpose of hindcast

Assess performance of the SWAN model in the Eastern Wadden Sea. Points of attention:

- Penetration of low-frequency storm waves ($f < 0.2$ Hz)
- Wave heights in depth-limited situations (addressed by Van der Westhuysen)
- Effect of currents on waves

Eastern Wadden Sea & measurement locations

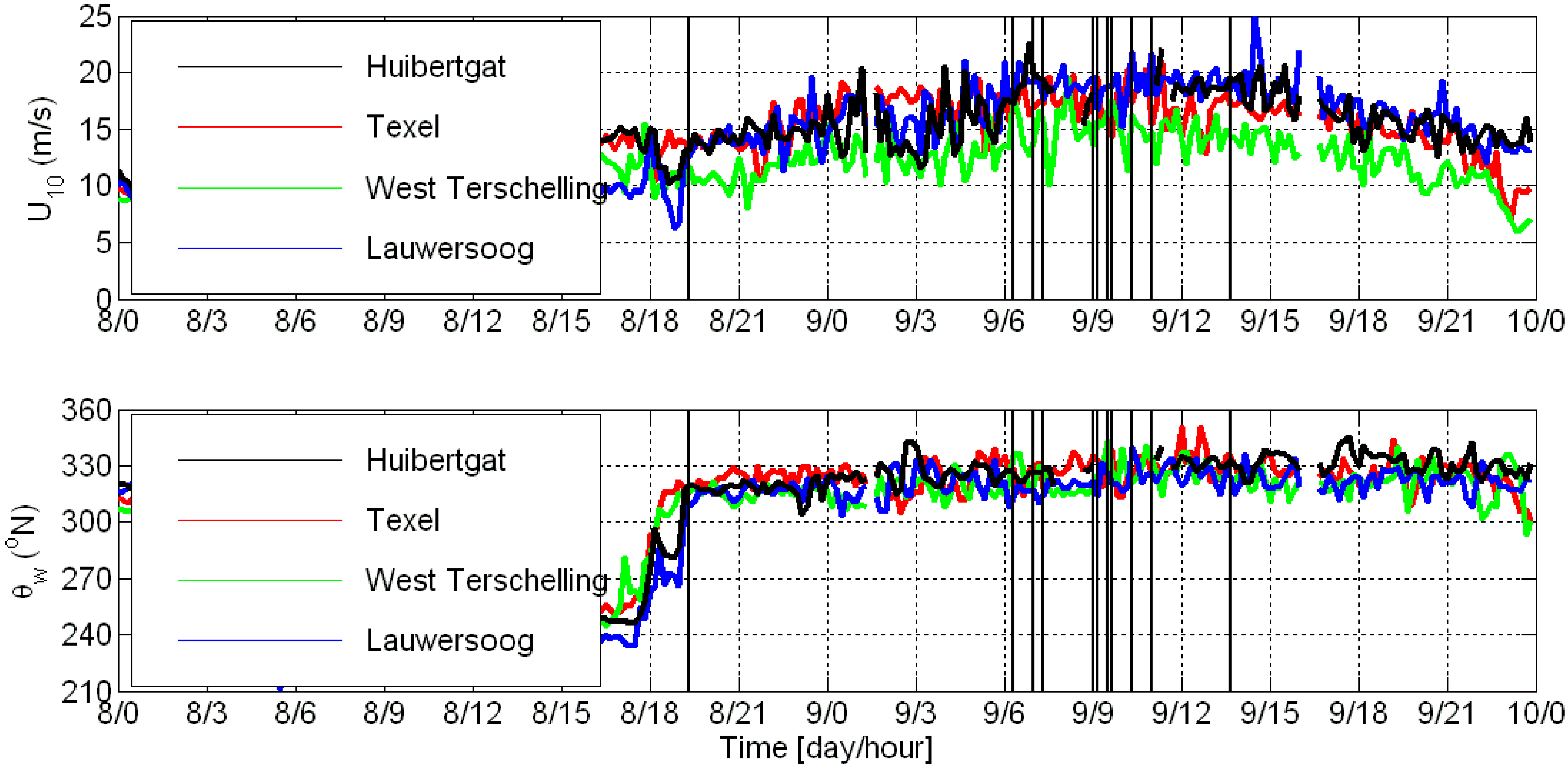


Phase 1: storm hindcast

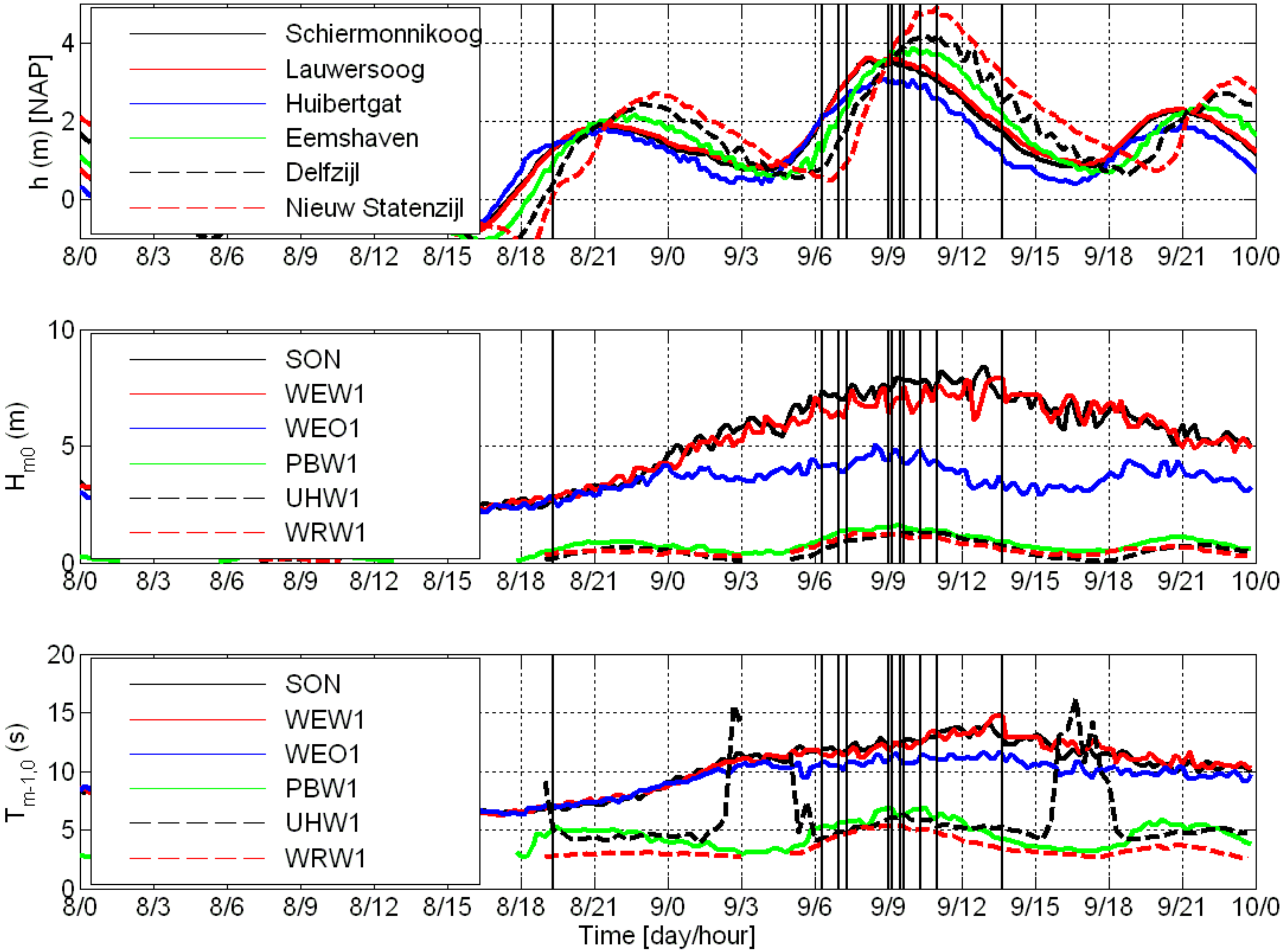
Variables:	*Model assumptions:*	*Measurements:*
Water level	▪ Astronomical tide (yearly) ▪ Domain nested in continental-shelf model (CSM)	▪ 5 locations ▪ every 10 minutes
Wind	▪ Drag coefficient	▪ 2 locations ▪ every 10 minutes
Current	▪ Influences wave propagation	▪ None
Waves	▪ 2 Offshore buoys as BC ▪ Stationary per interval ▪ Water level setup by wave dissipation	▪ 4 near shore buoys ▪ every 10 or 20 minutes

Measured winds Nov. 2007 storm

Max U_{10} at Huibertgat =22.6 m/s; θ_w=320°



Measured water level and wave conditions



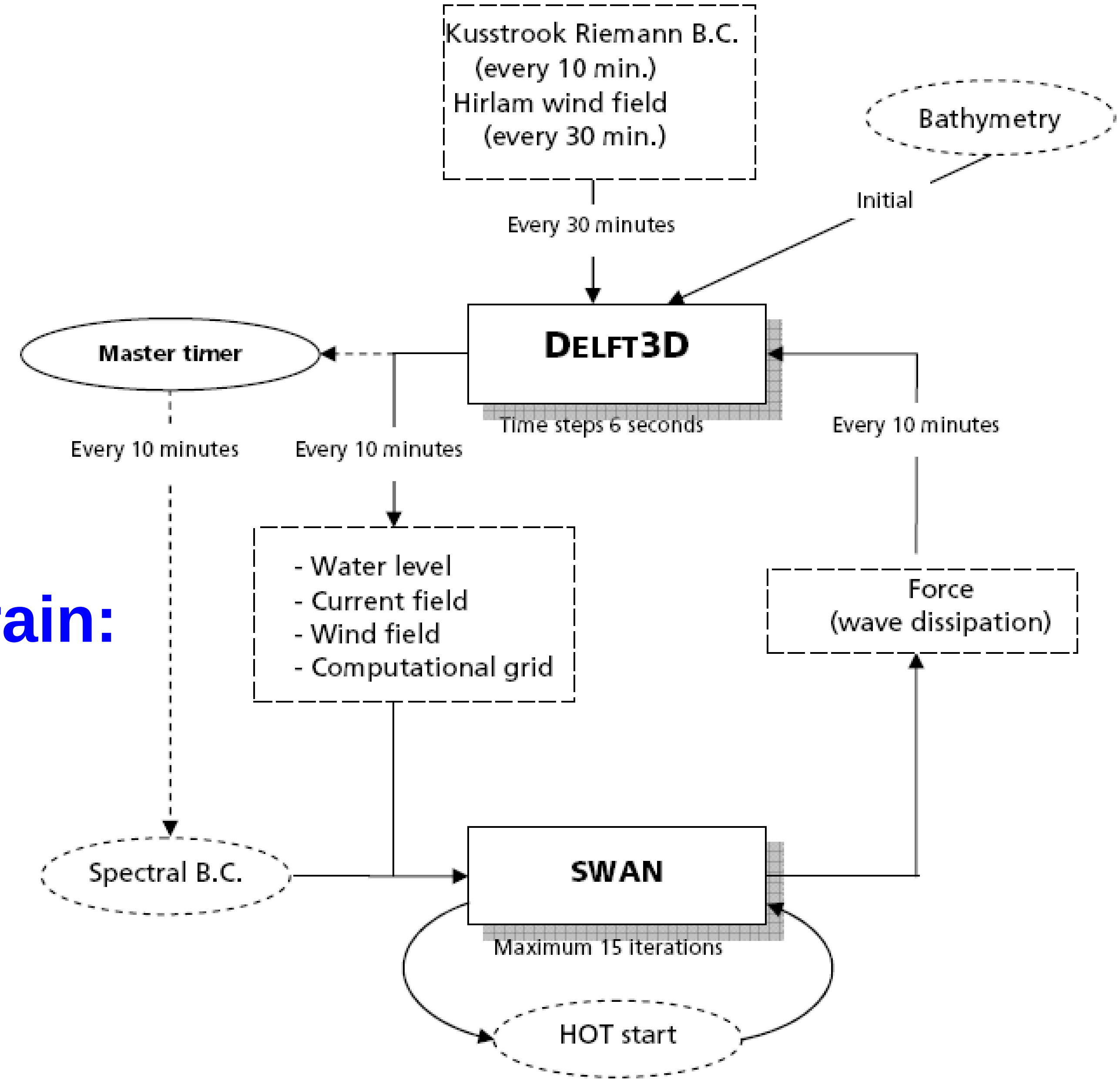
Huibertgat: max 3.3m

Delfzijl: max 4.2m

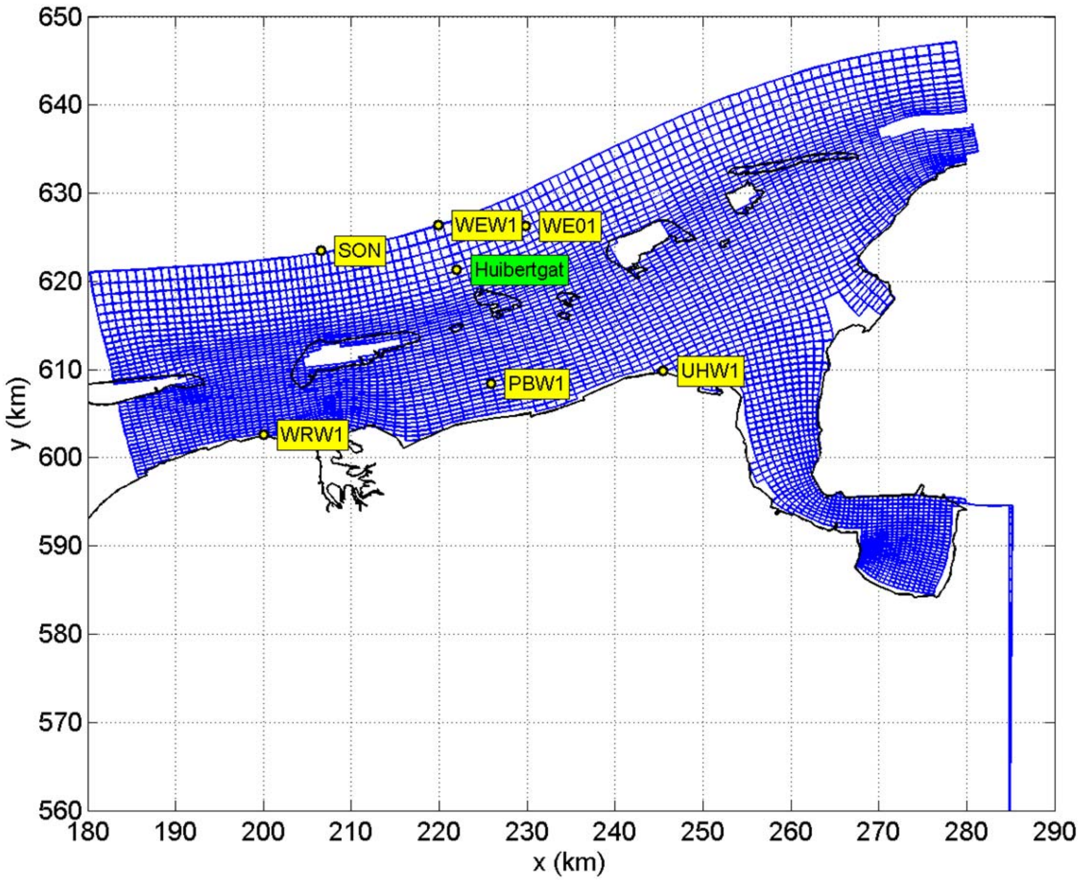
Max SON: 8.4m

1/100 years

Model train:

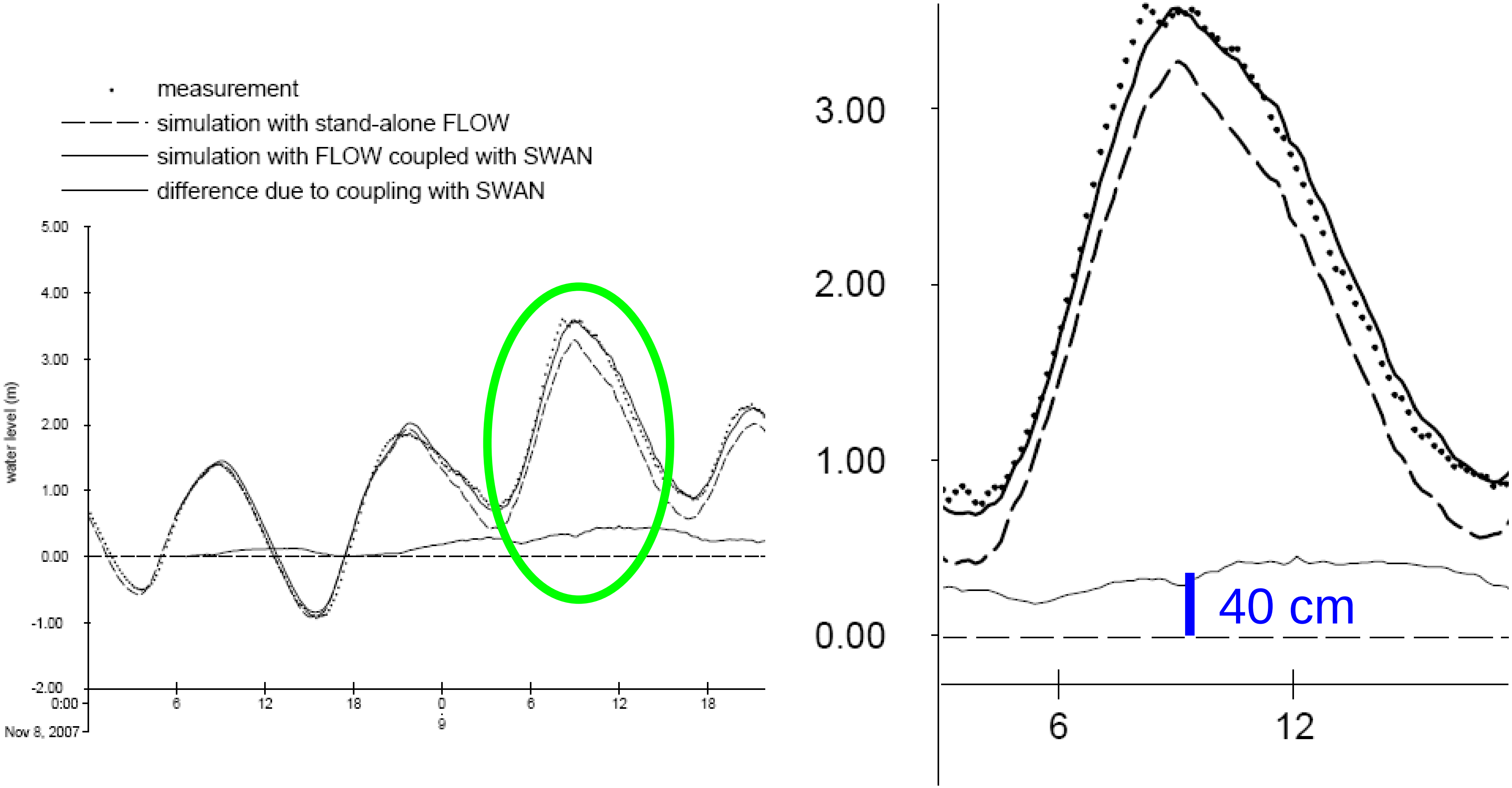

Kusstrook Riemann B.C.
(every 10 min.)
Hirlam wind field
(every 30 min.)
Bathymetry
Initial
Every 30 minutes
DELFT3D
Time steps 6 seconds
Master timer
Every 10 minutes
Every 10 minutes
Every 10 minutes
- Water level
- Current field
- Wind field
- Computational grid
Force
(wave dissipation)
Spectral B.C.
SWAN
Maximum 15 iterations
HOT start

Coupled flow-wave system

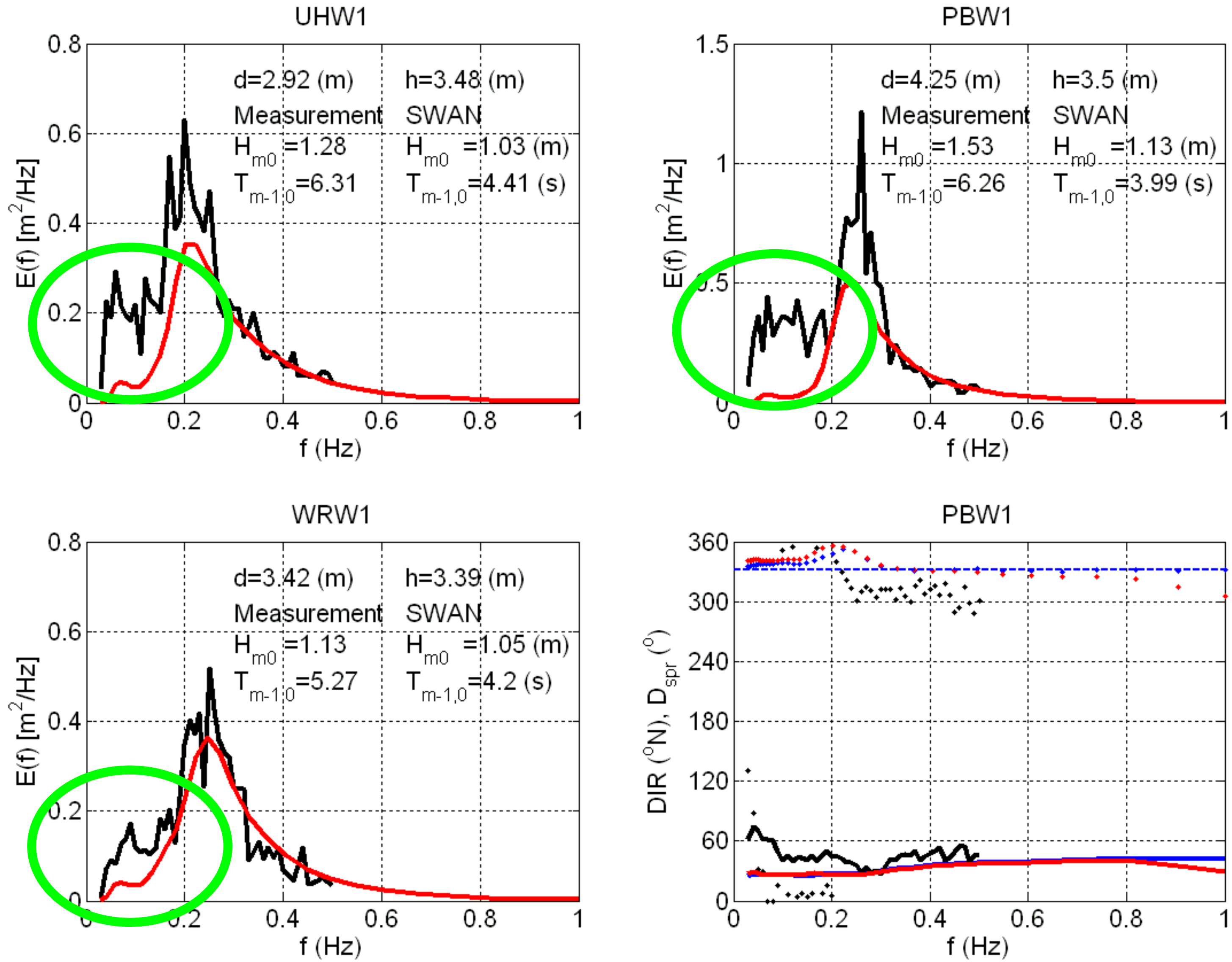


- Wind forcing with meas. winds from Huibertgat, applied as uniform fields
- Dynamic behavior more important than spatial variation of wind field
- Waves effects incorporated in flow model via radiation stresses

Storm hindcast: results



Spectra: 9 Nov. 2007: 9^40h (High water)



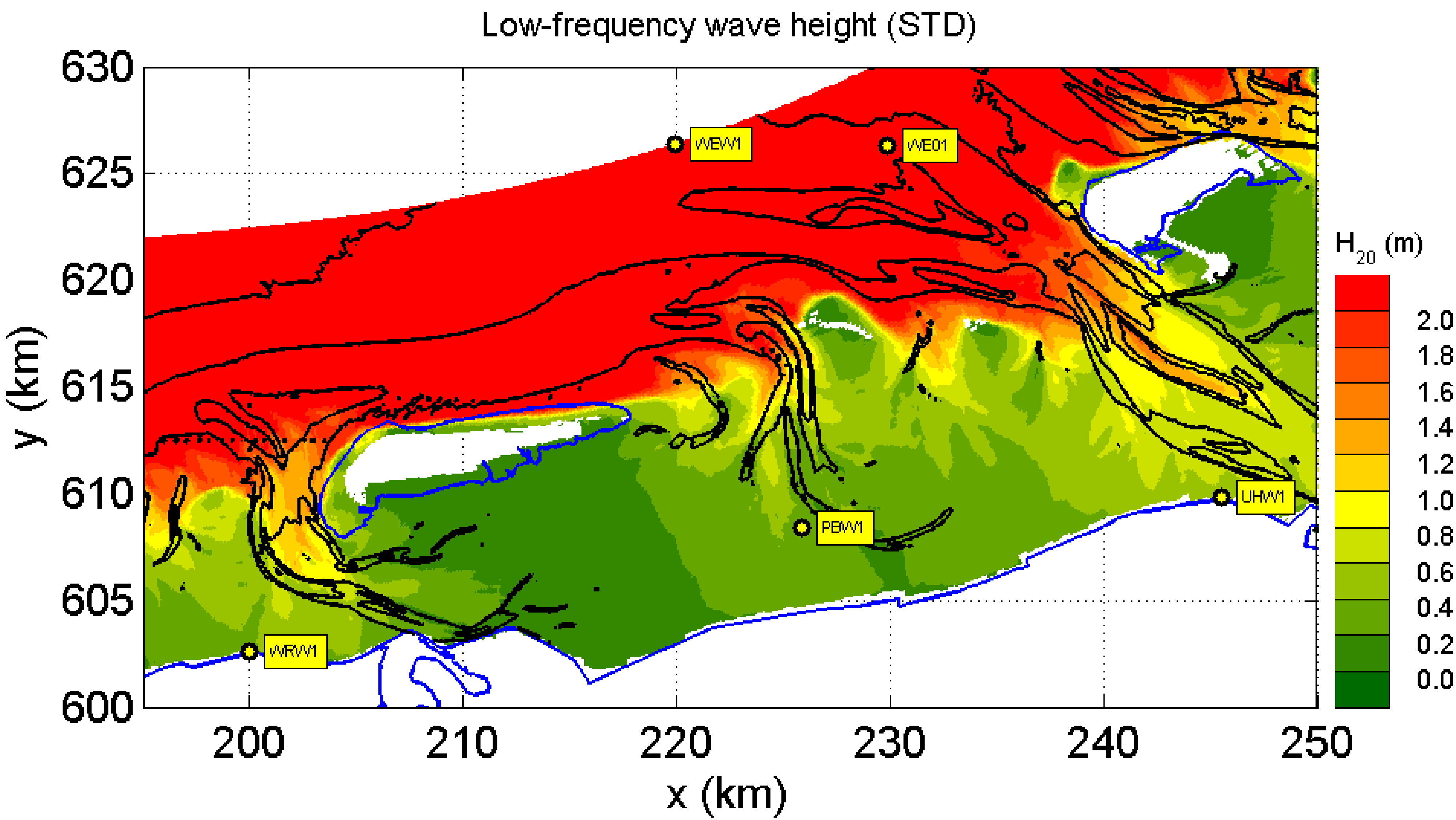
Conclusions hindcast

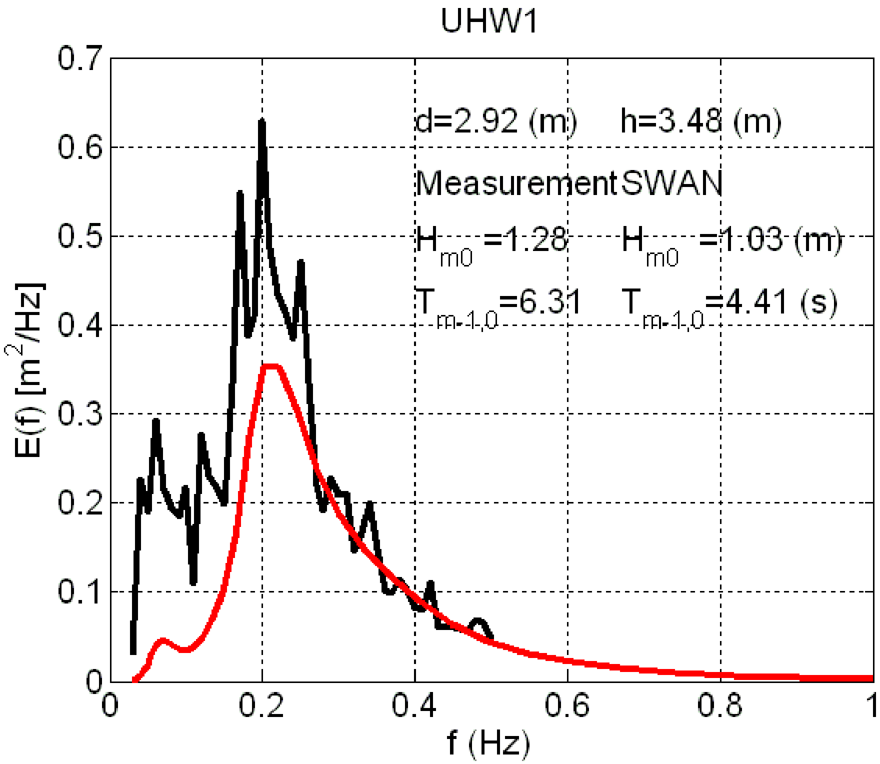
- Wave effects significantly affect water levels in the interior of the Wadden Sea
- Strong under-prediction of low-frequency wind wave energy
- Shallow water effects are significant
- Next phase, analysis of wave penetration & sensitivity analysis

Where does the LF-energy disappear?

H_{20} =LF sig. wave height

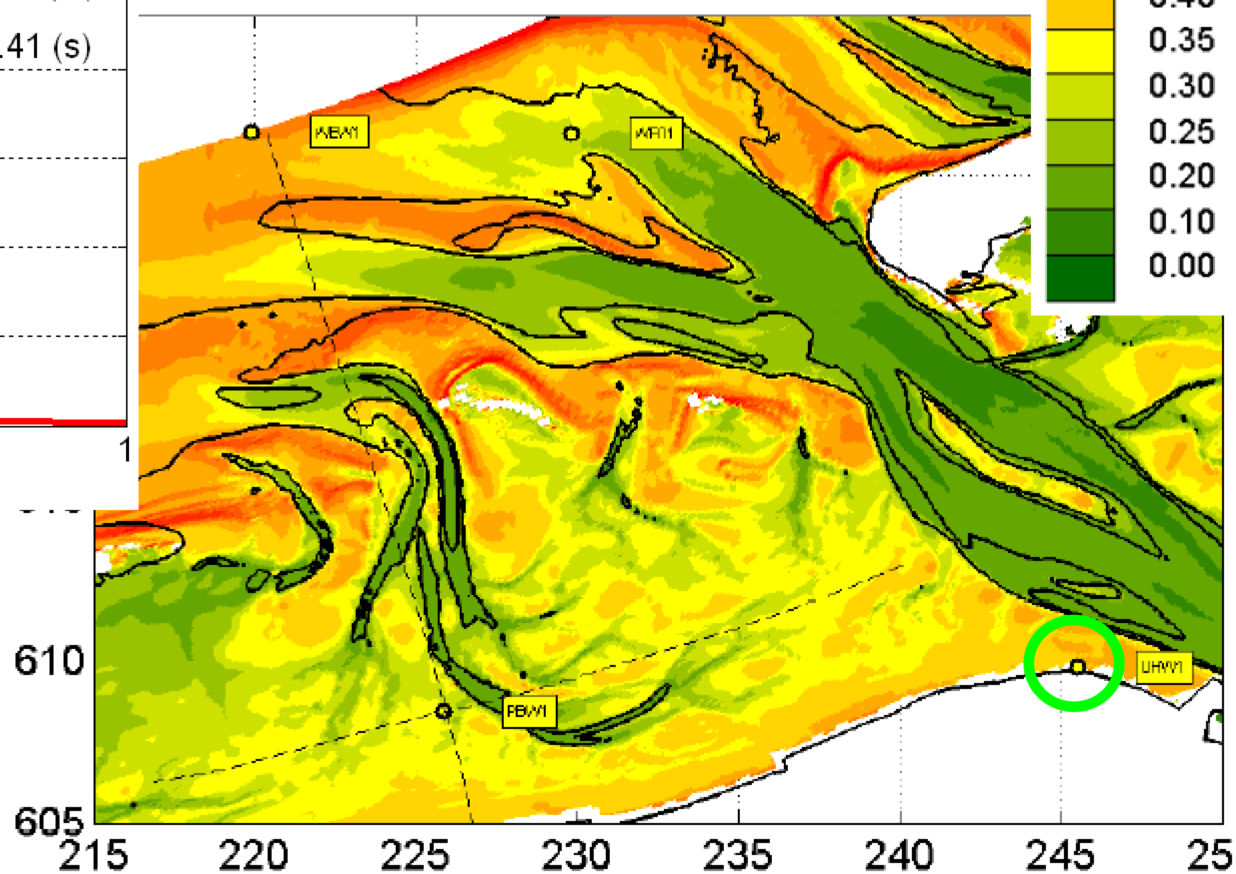
9 Nov. 2007: 9^{40h}



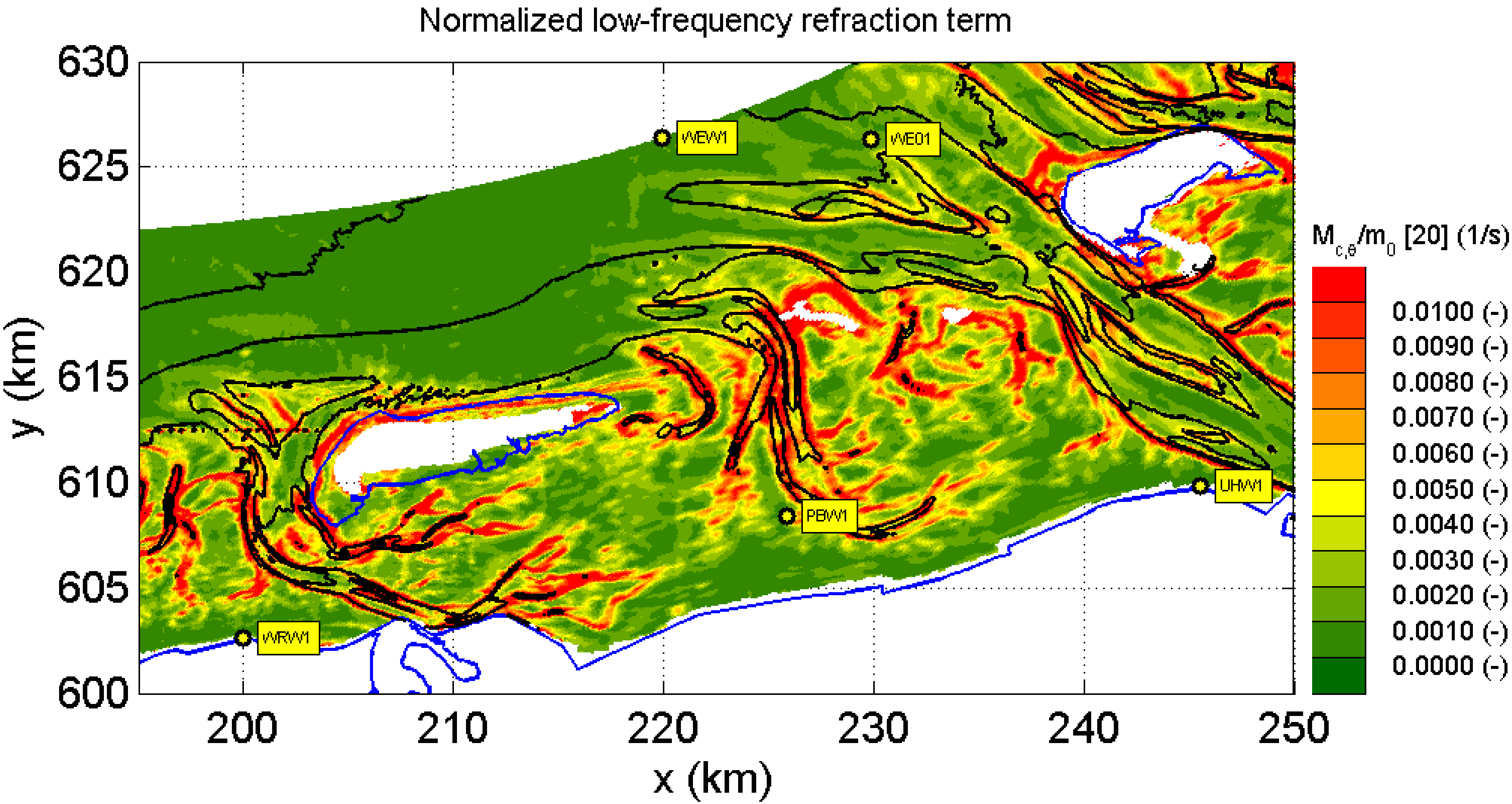


Depth limited waves

9 Nov. 2007: 6^{20h}



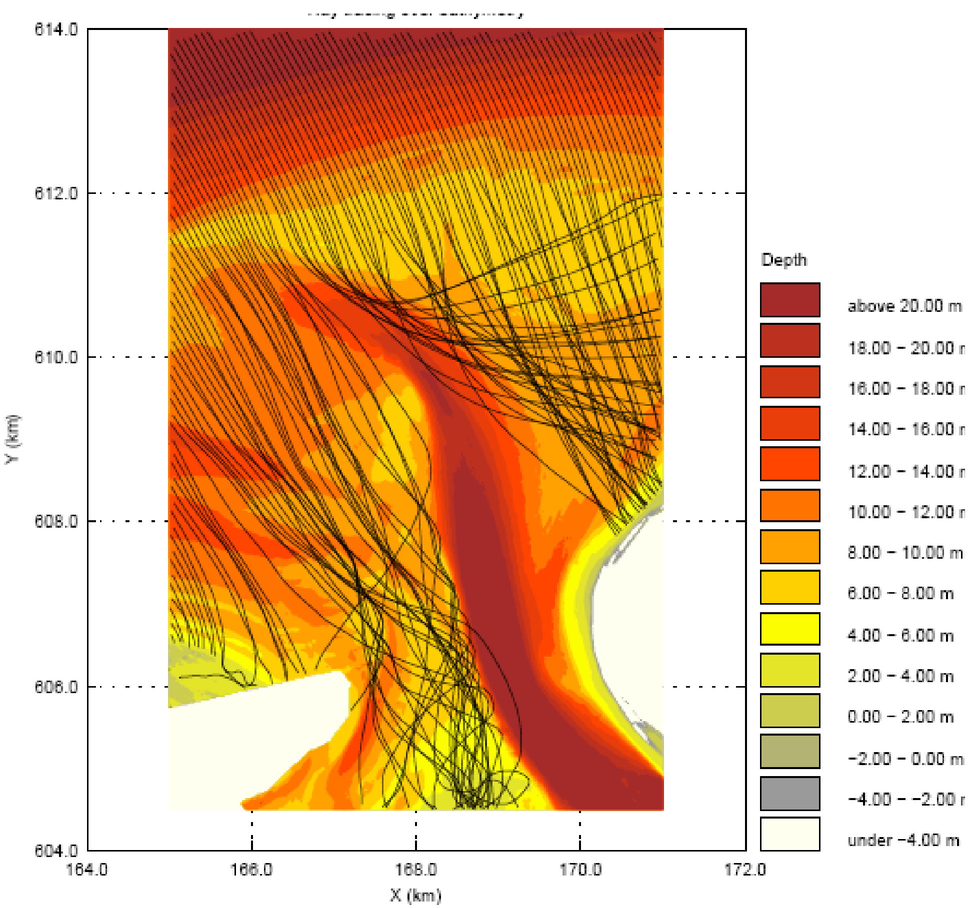
Role of refraction



Low-frequency wave propagation is strongly affected by refraction as shown by ray tracing (pure refraction)

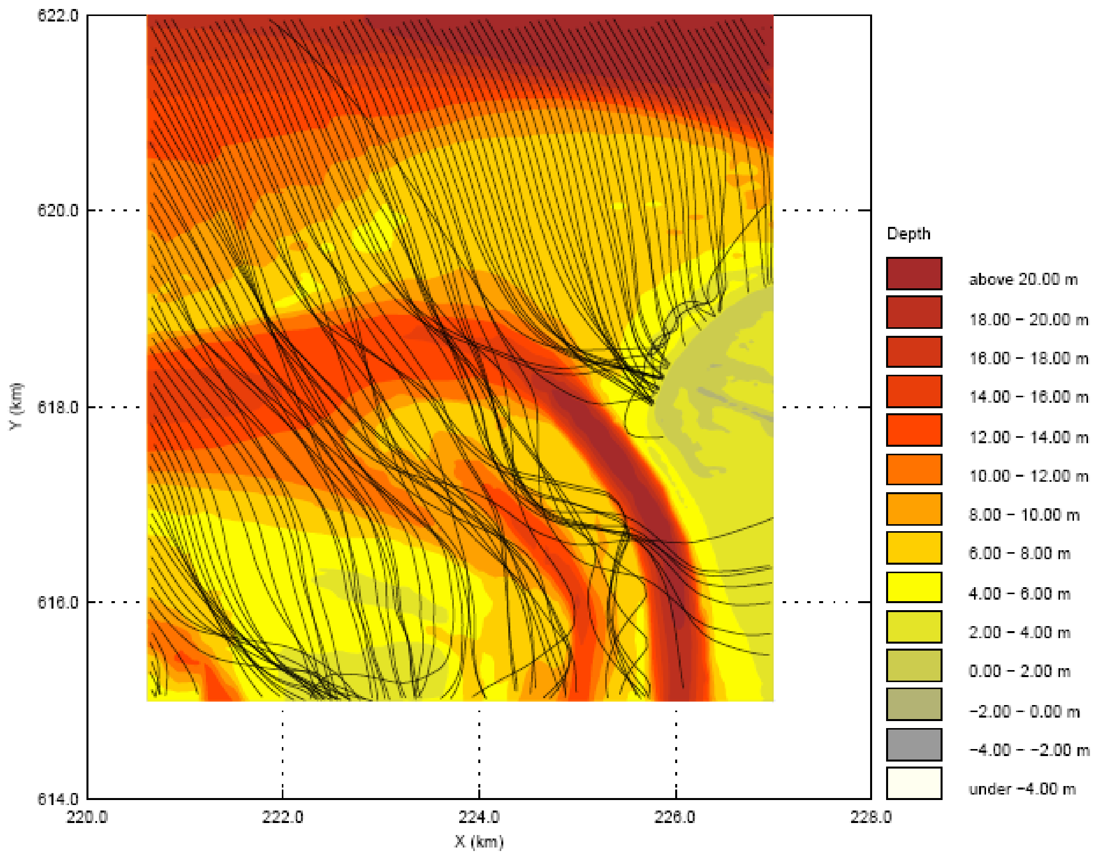
Amelander Zeegat

Tp = 12.9s; θ=330°N



Huibertgat

Tp = 14.3s; θ=330°N



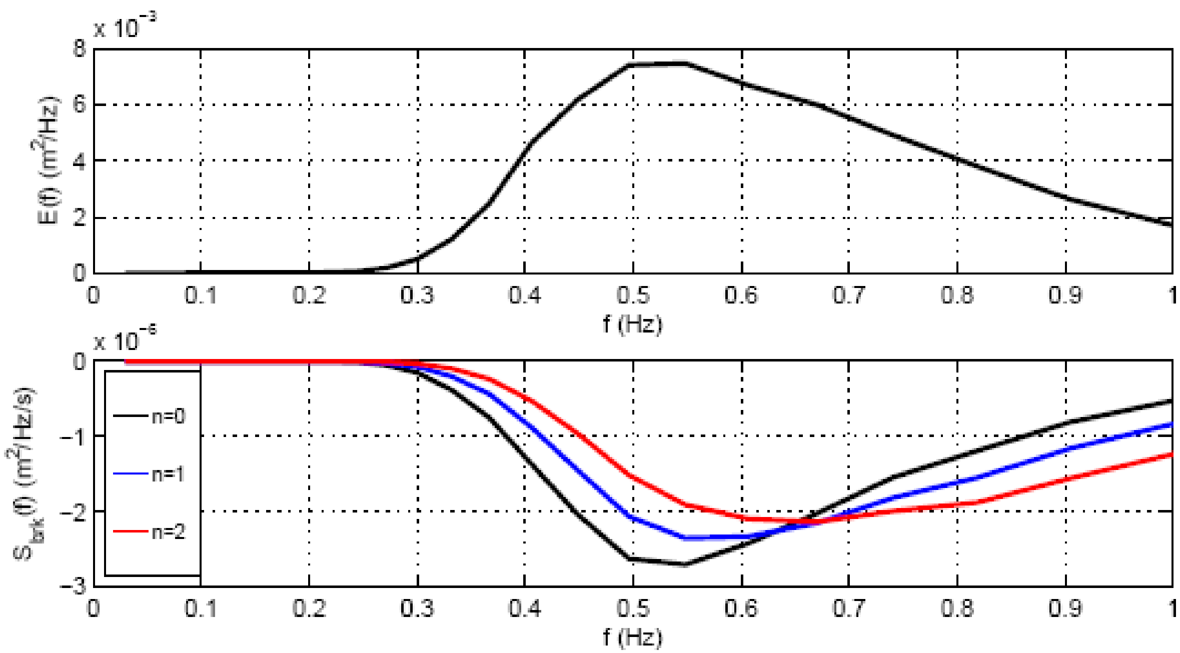
Sensitivity analysis of model settings

Do solutions exist to solve the under-prediction of LF-energy ($f < 0.2$ Hz) near the main land coast?

- Reducing JONSWAP bottom friction (Bouws and Komen, 1983)
- Limiter L on refraction term c_θ of low-frequency waves: $L = f/0.2$ for $f < 0.2$ Hz
- Frequency dependent wave breaking of bulk dissipation
- Higher water level

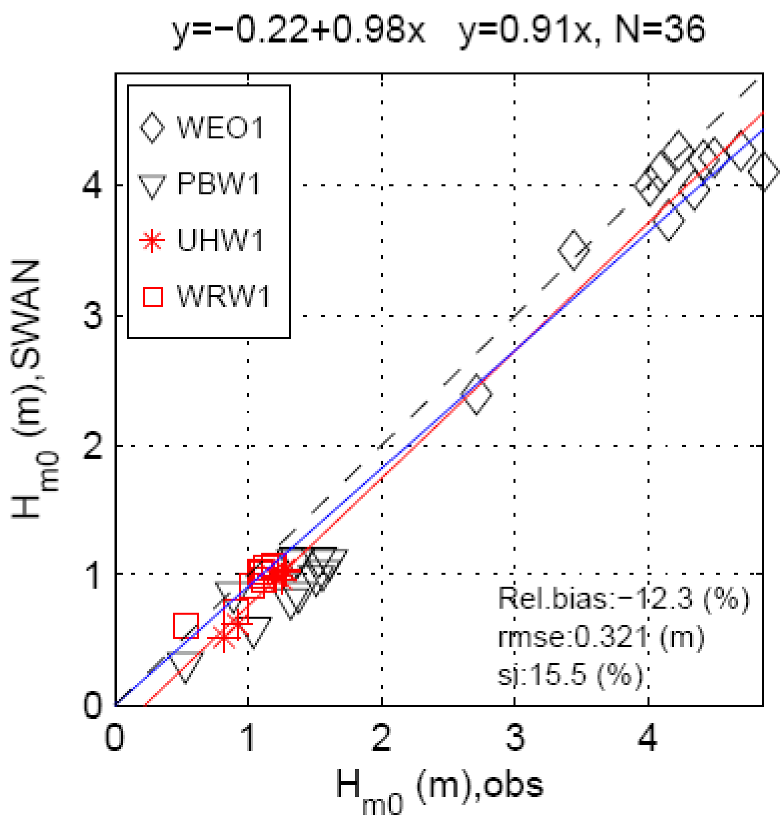
Frequency dependent breaking

- Chen et al., 1997
- $$S_{brk,2}\left(f,\theta\right)=D_{tot}\frac{m_0}{m_2}f^2\frac{E\left(f,\theta\right)}{E_{tot}}$$

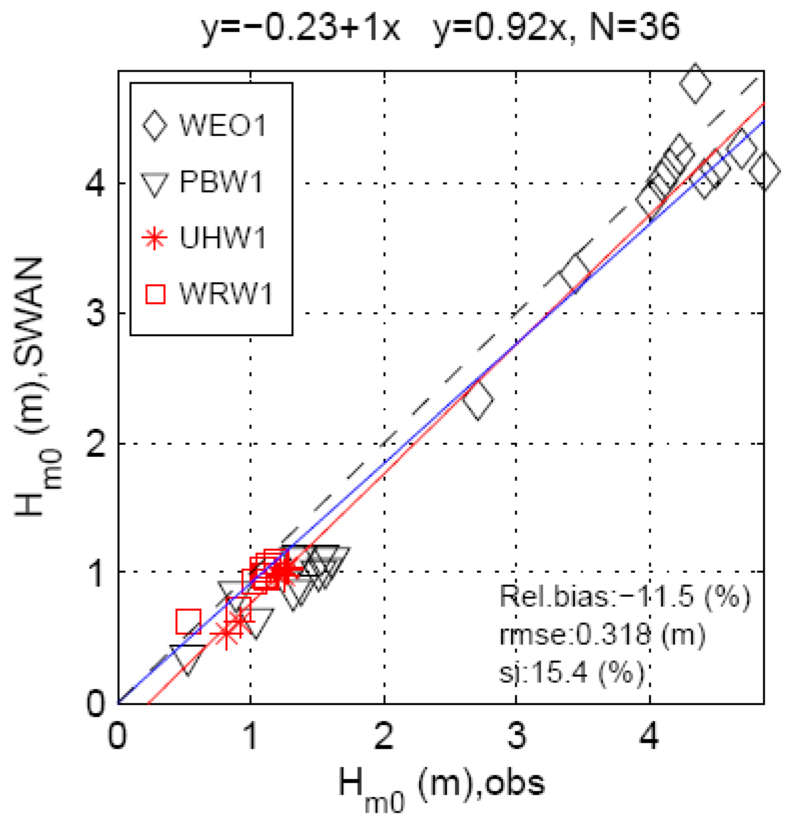


Effect of currents (in SWAN)

With Current

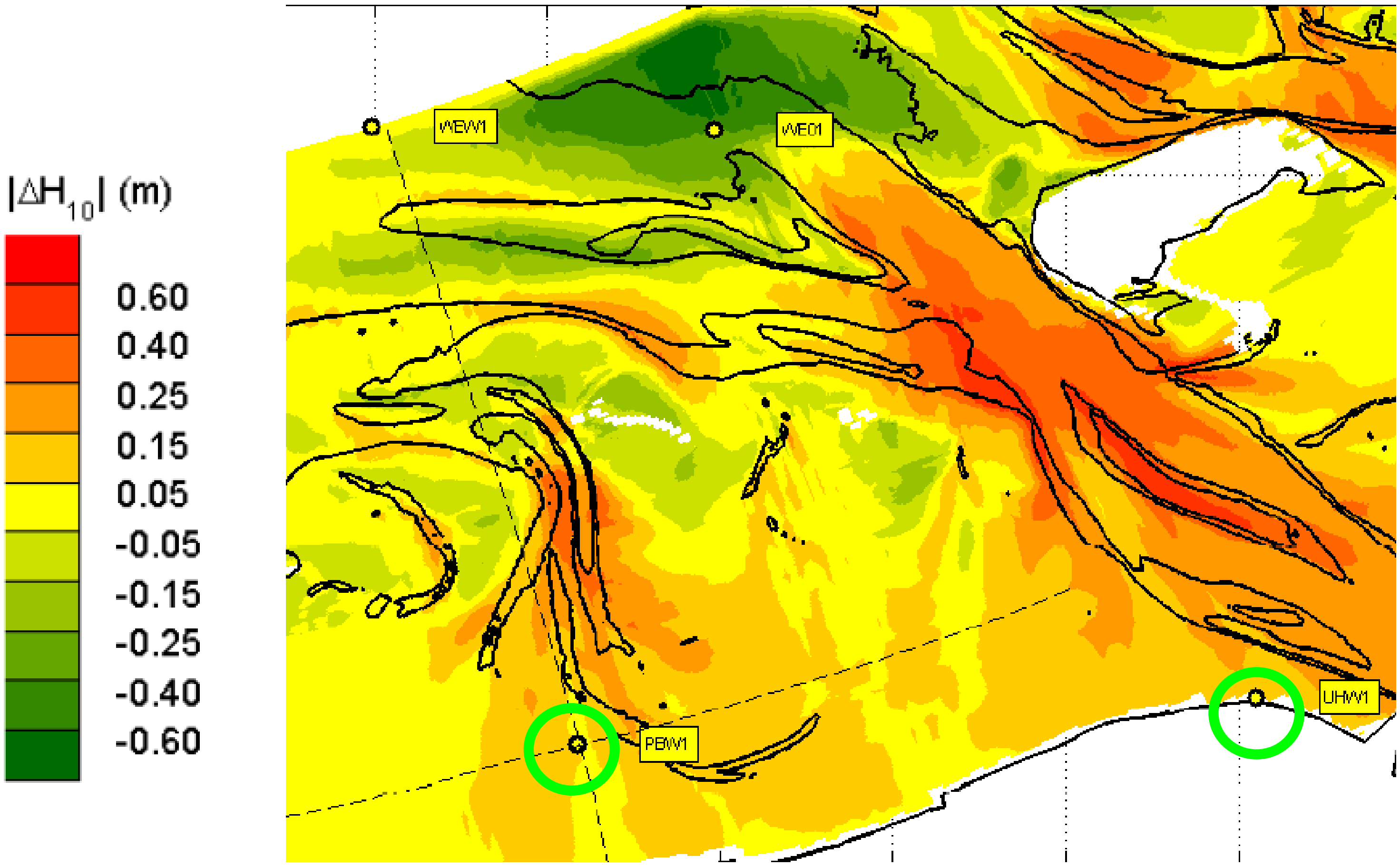


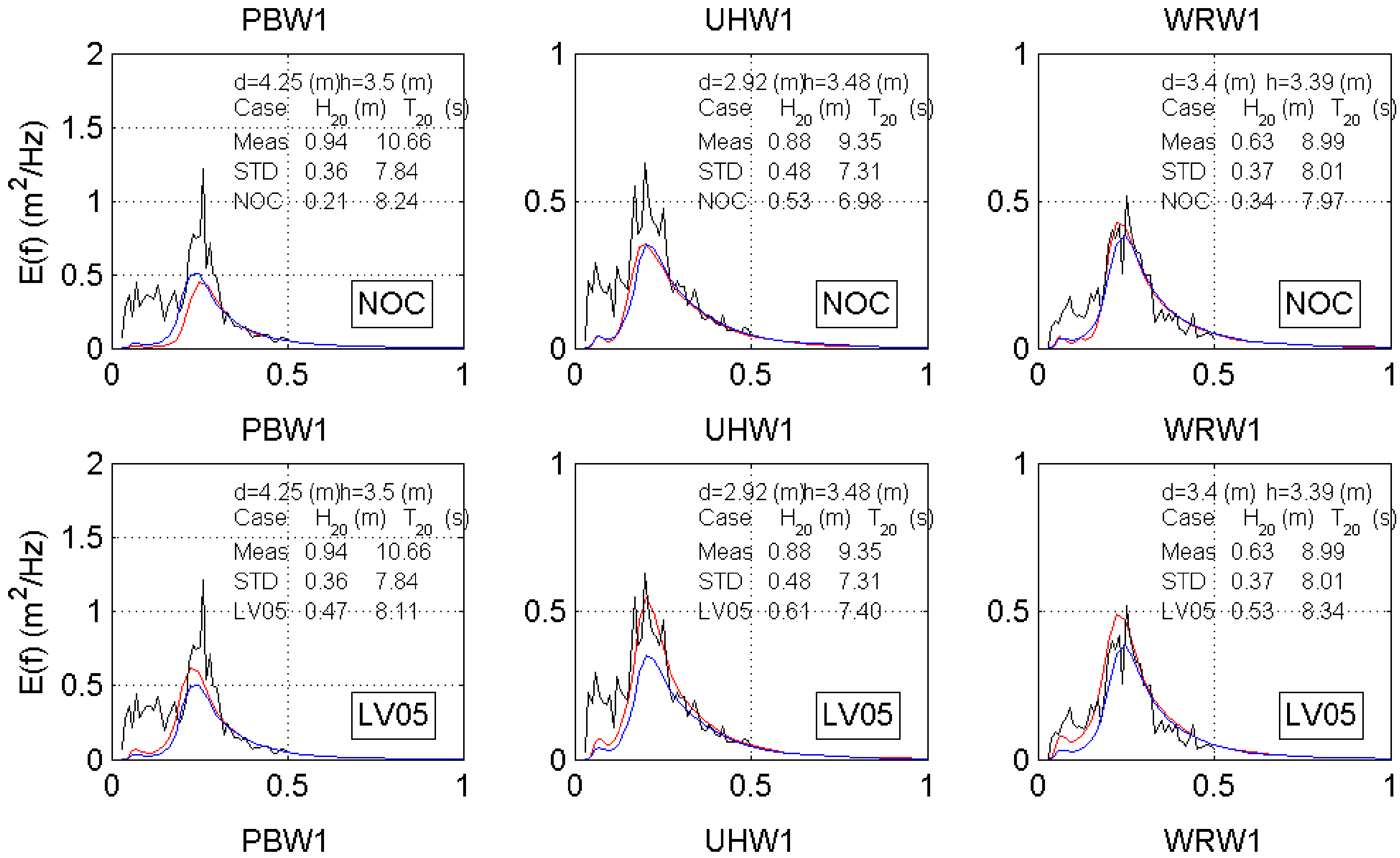
No Current



Linear low-frequency limiter on refraction

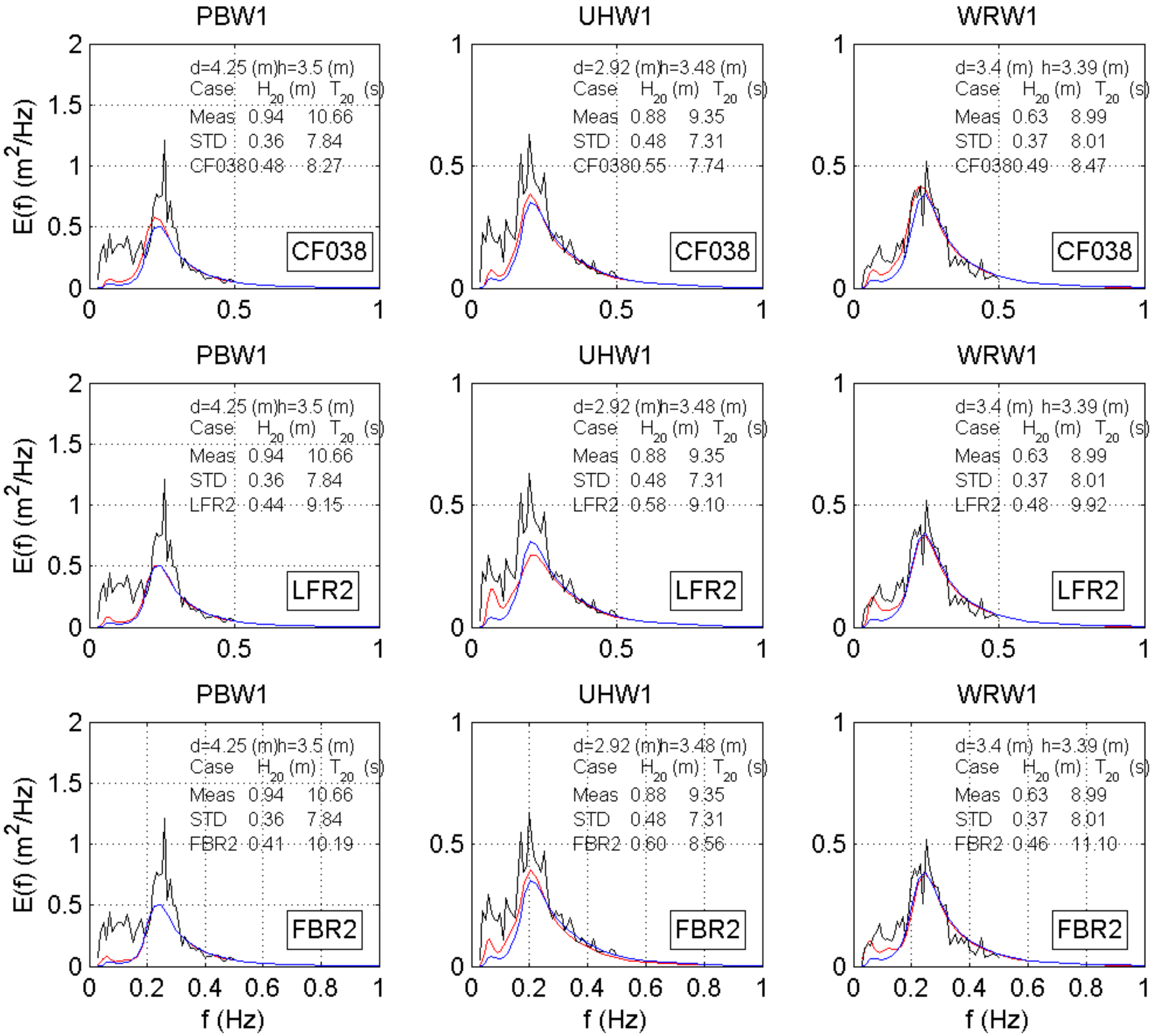
(artificial, but better results)





Effect of currents: small at buoy locations

Strong effect of higher water level (by 0.5 m)

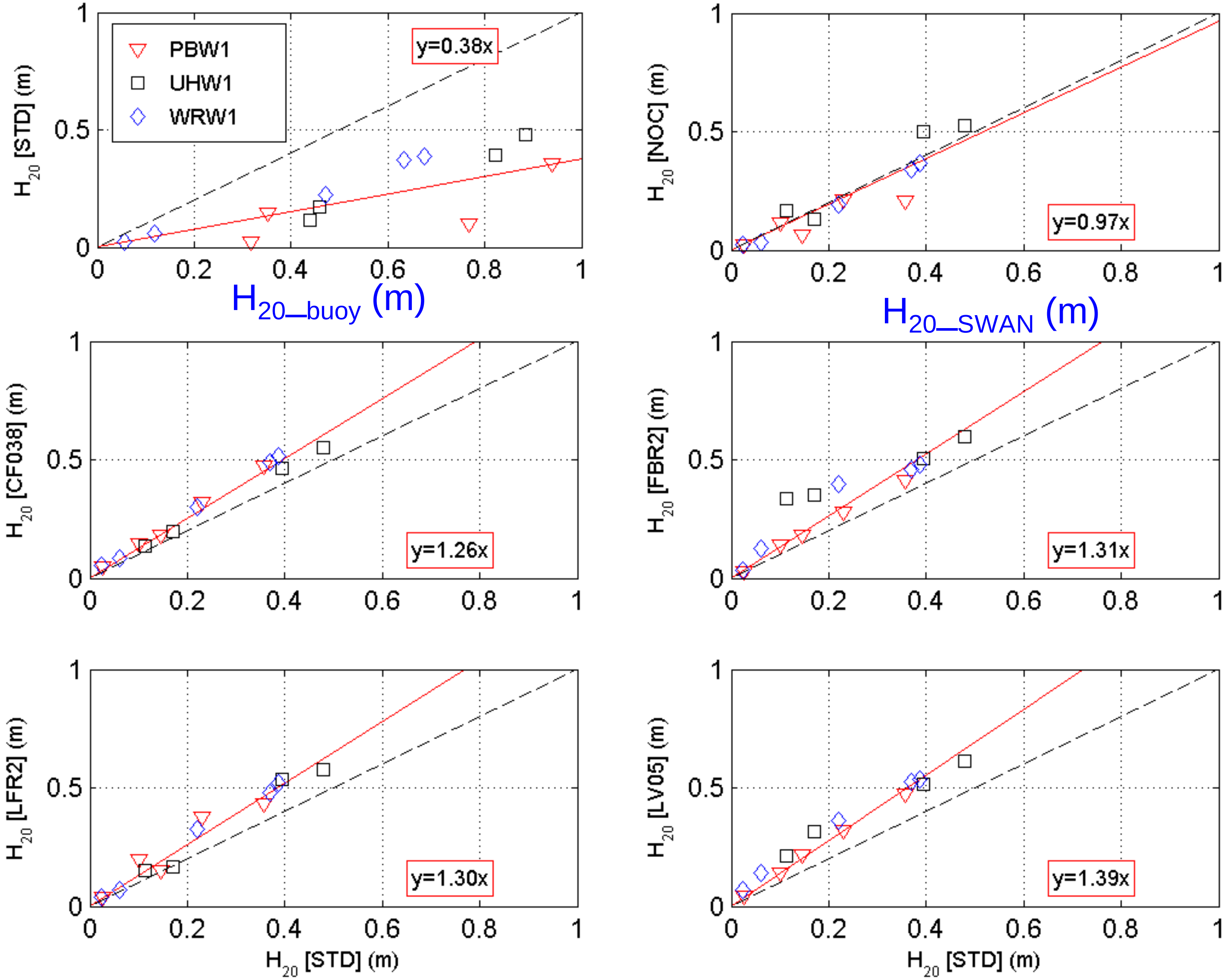


Overall increase of LF with lower bottom friction

More LF-waves with limiter on refraction

More LF-waves with f^2 distribution of bulk dissipation

Statistical analysis



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Recommendations

- Extend number of wind measurement locations to better represent spatial variation of wind field
- (local) current, water level & wave measurements are required in the interior of the Wadden Sea to improve flow/wave modeling
- Extend buoy/gauge array to better track the evolution of LF-wave energy as it propagates into the Wadden Sea
- Collect and analyze more ‘similar’ datasets to study the propagation of LF-energy in areas with a complicated bathymetry