Numerical Aspects and Source term Analysis of Wave Modeling in a Tidal Inlet

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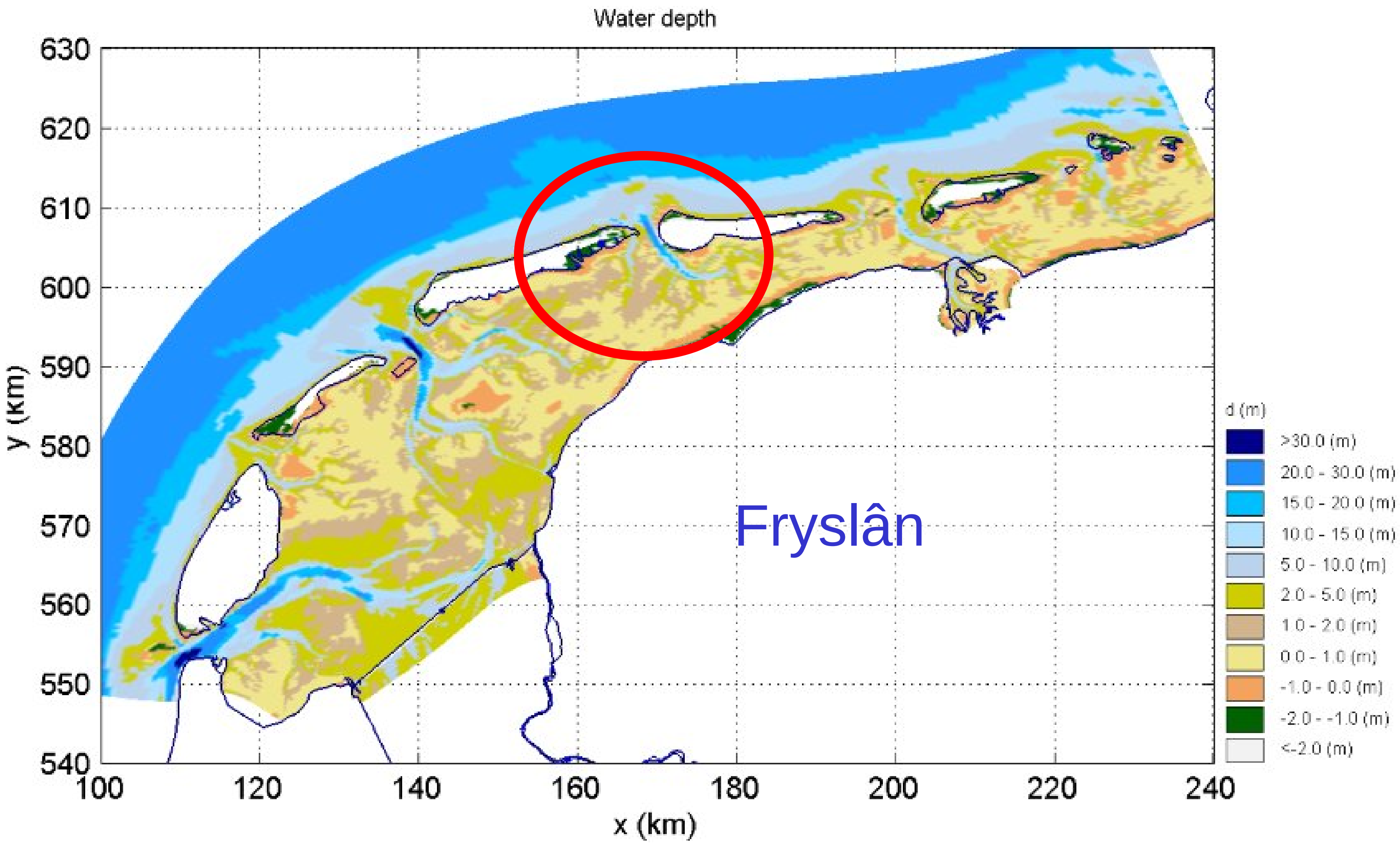
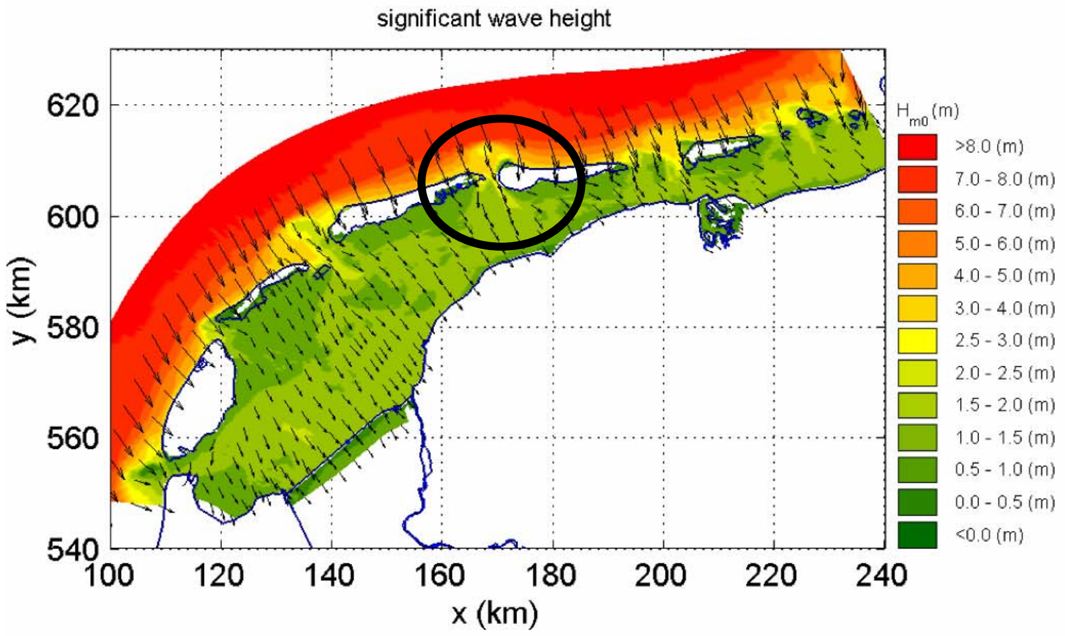
Wadden Sea


Water depth
630
620
610
600
590
580
570
560
550
540
y (km)
100
120
140
160
180
200
220
240
x (km)
Fryslân
d (m)
>30.0 (m)
20.0 - 30.0 (m)
15.0 - 20.0 (m)
10.0 - 15.0 (m)
5.0 - 10.0 (m)
2.0 - 5.0 (m)
1.0 - 2.0 (m)
0.0 - 1.0 (m)
-1.0 - 0.0 (m)
-2.0 - -1.0 (m)
<-2.0 (m)

Purpose

- Improve prediction of wave conditions in the Wadden Sea
- Long (swell) waves may penetrate into the Wadden Sea and contribute to wave loads on dikes
- Analysis physical processes in tidal inlets
- Optimise computational requirements



1 November 2006

Offshore conditions

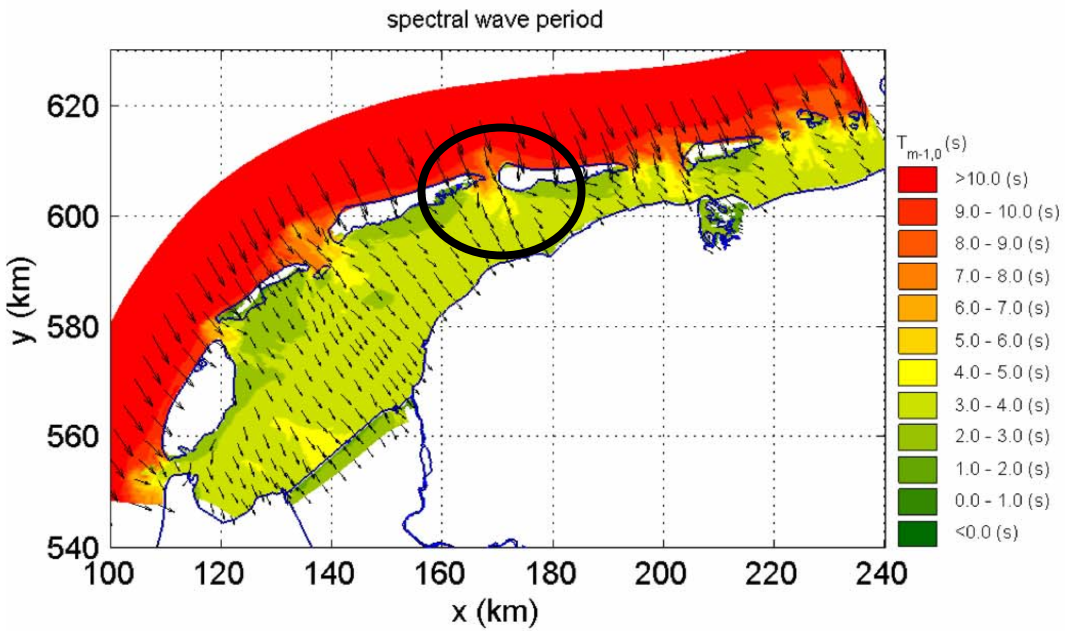
H_{m0} = 8 m

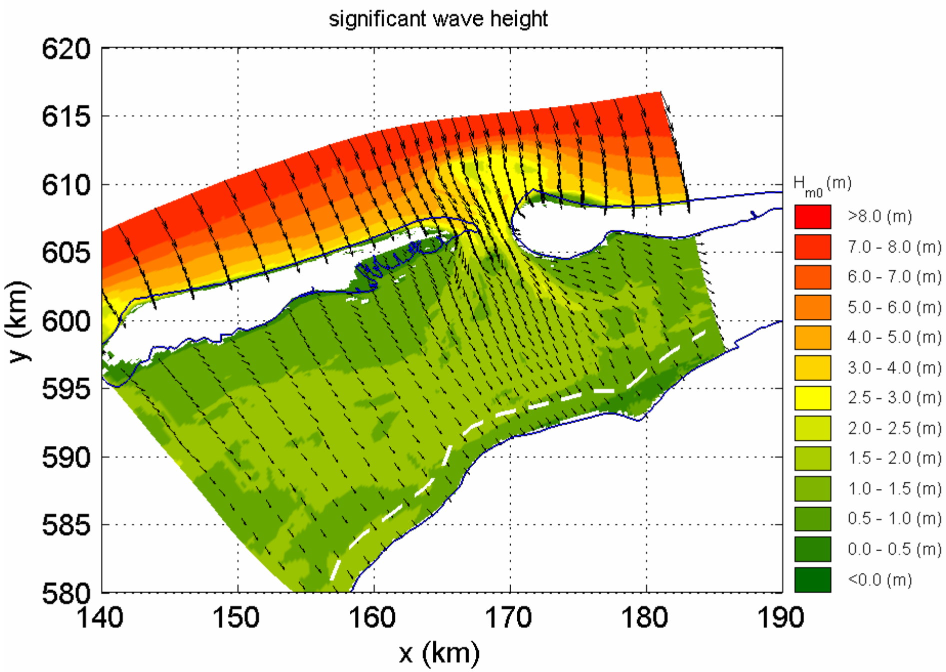
T_p = 14 s

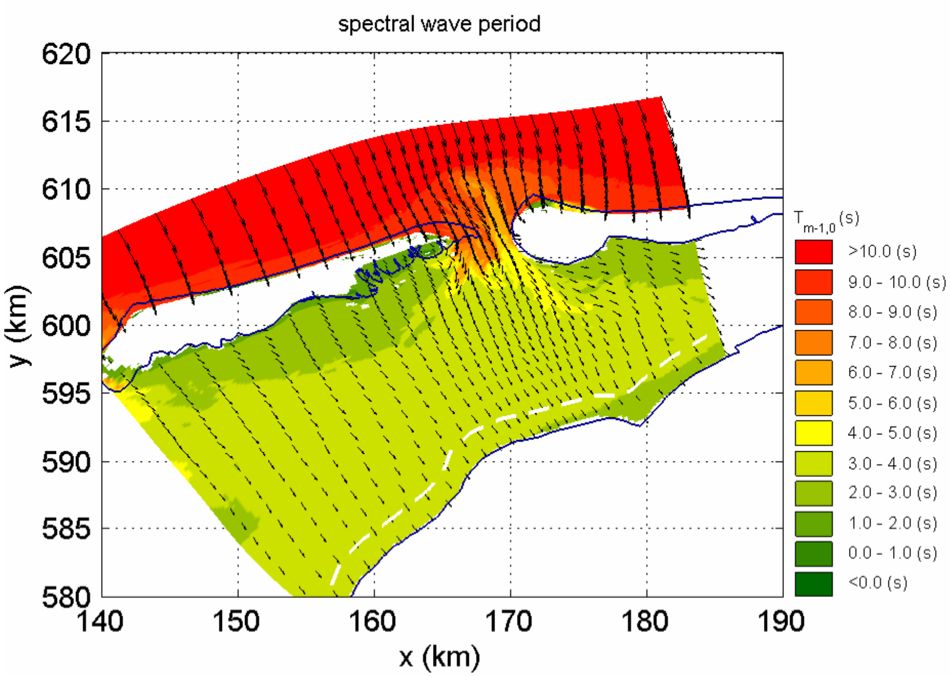
Wind condition

U_{10} = 21 m/s

θ_w = 334°N







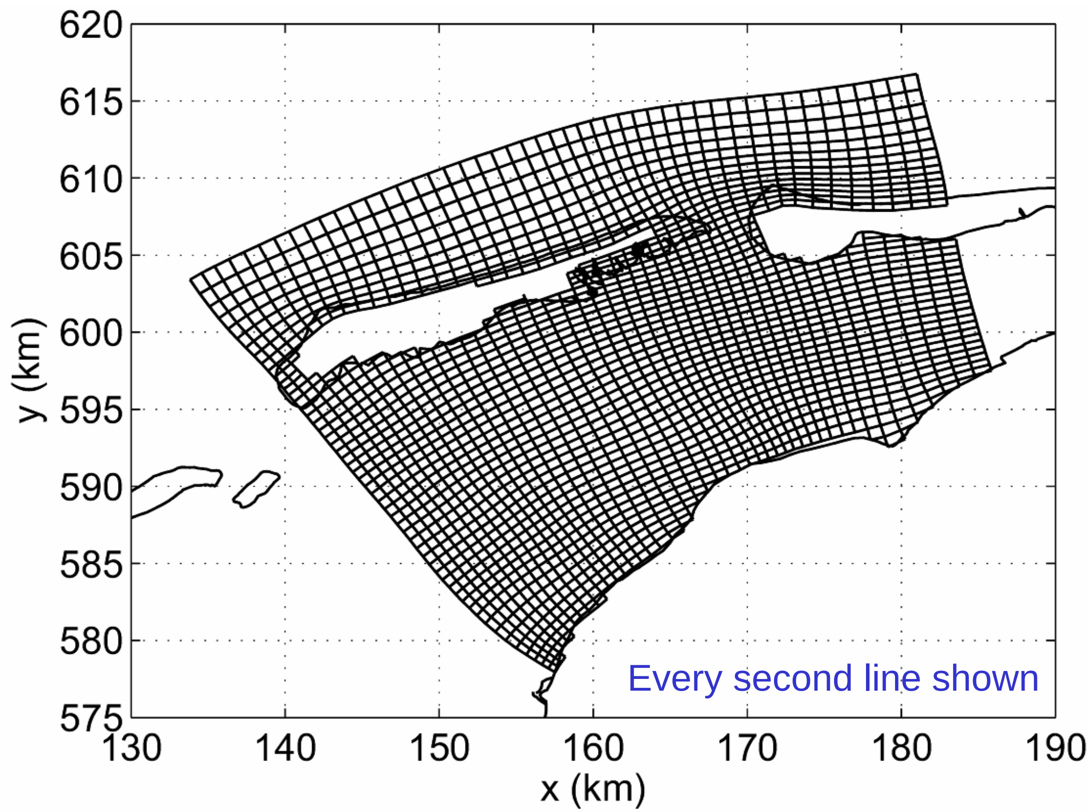
Tidal inlet of Ameland

Strong decay of wave height and wave periods

Cause of decay
'long' wave penetration

Computational grid

Section of curvi-linear grid from WAQUA flow model



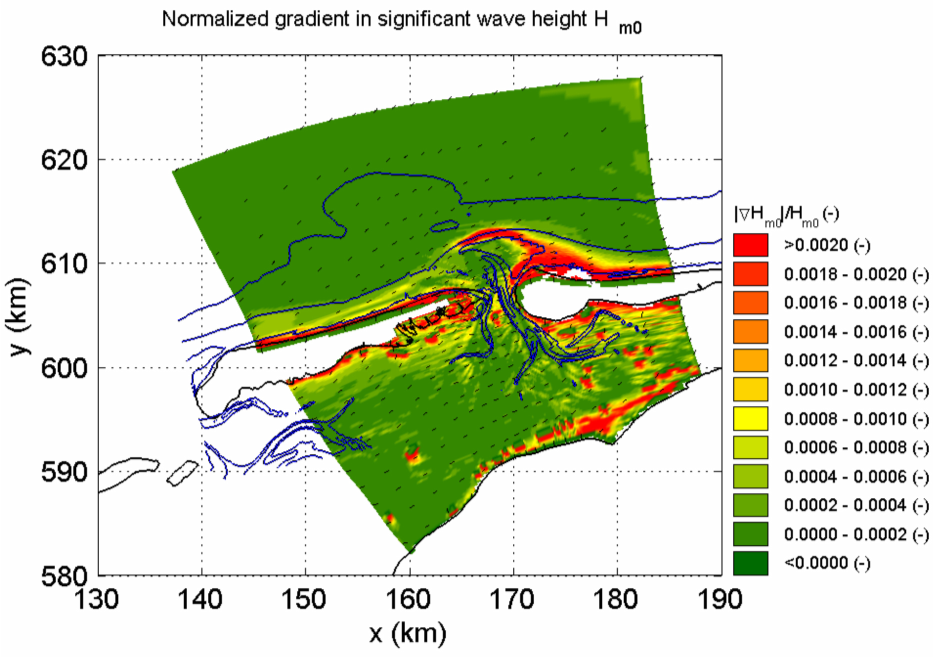
Requirements for flow model:

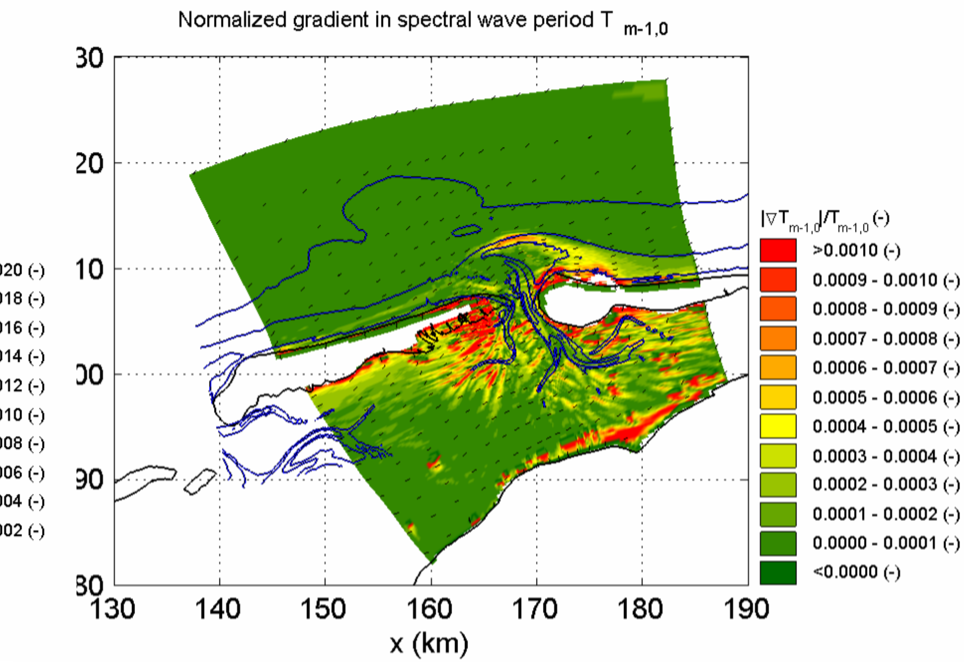
- orthogonal
- small variation cell size

Requirements for wave model less strict. No diffusion in propagation scheme

Higher resolution in areas with high gradients in wave conditions

Normalized gradients of significant wave height H_{m0} and spectral period $T_{m-1,0}$

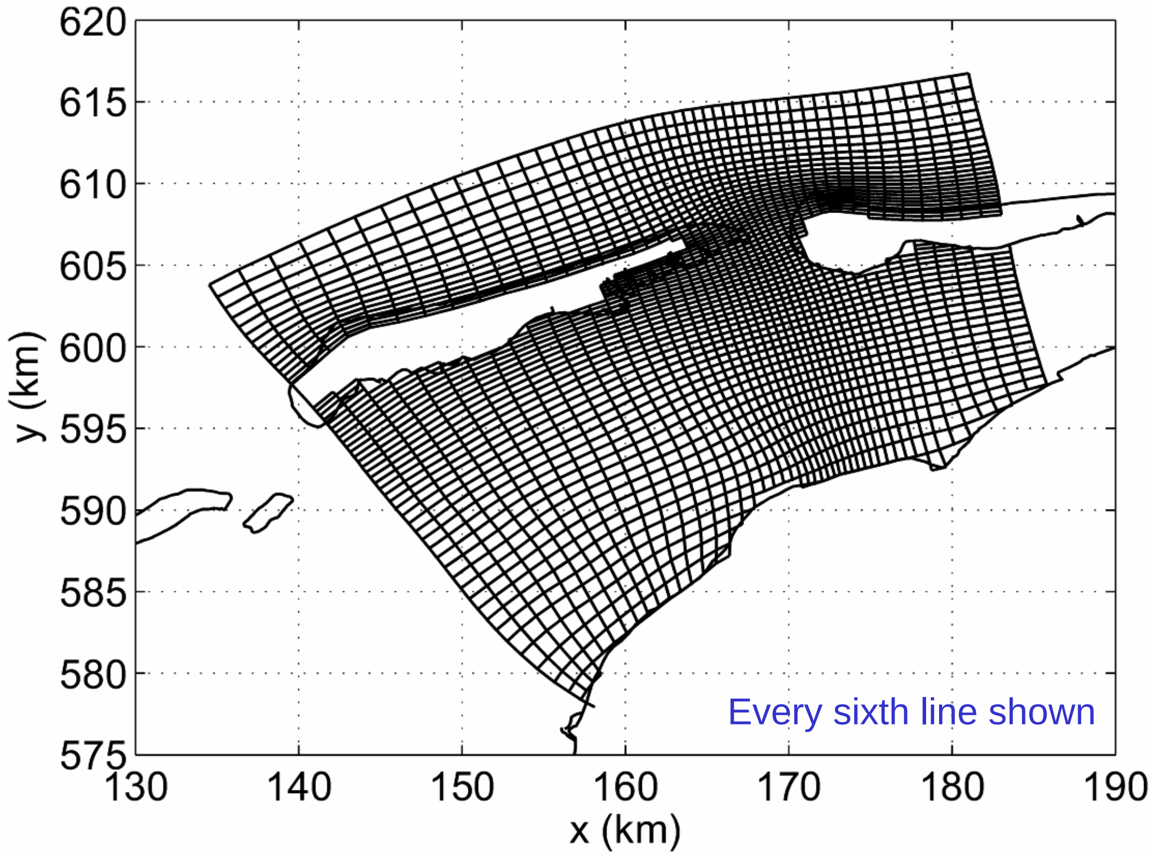




$\nabla H_{m0}/H_{m0}$

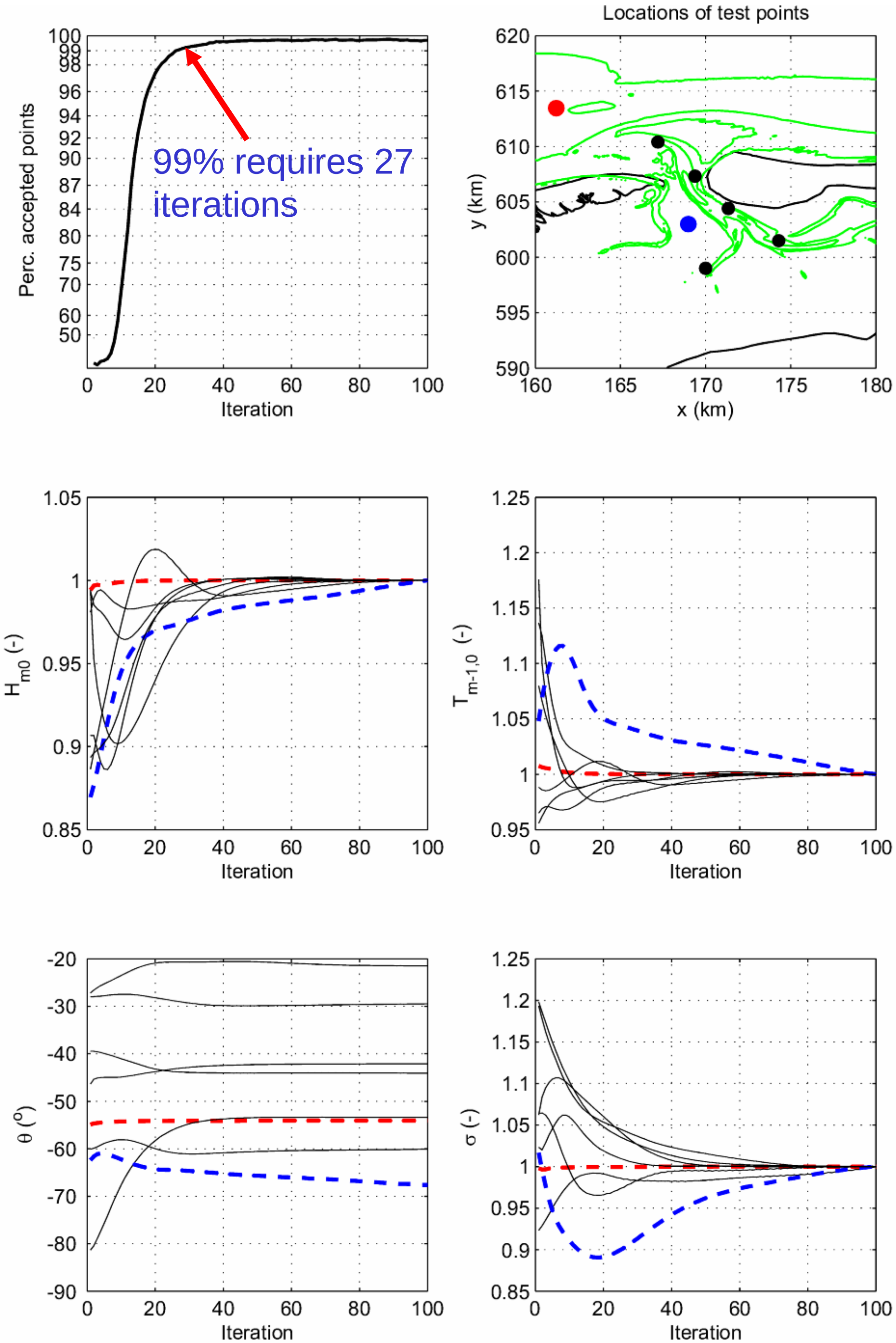
$\nabla T_{m-1,0}/T_{m,-1,0}$

Dedicated non-uniform grid for tidal inlet



Spatially varying resolution up to 50 m in central part of tidal inlet

Saves 50% grid points while retaining accuracy with respect to fine rectangular grid

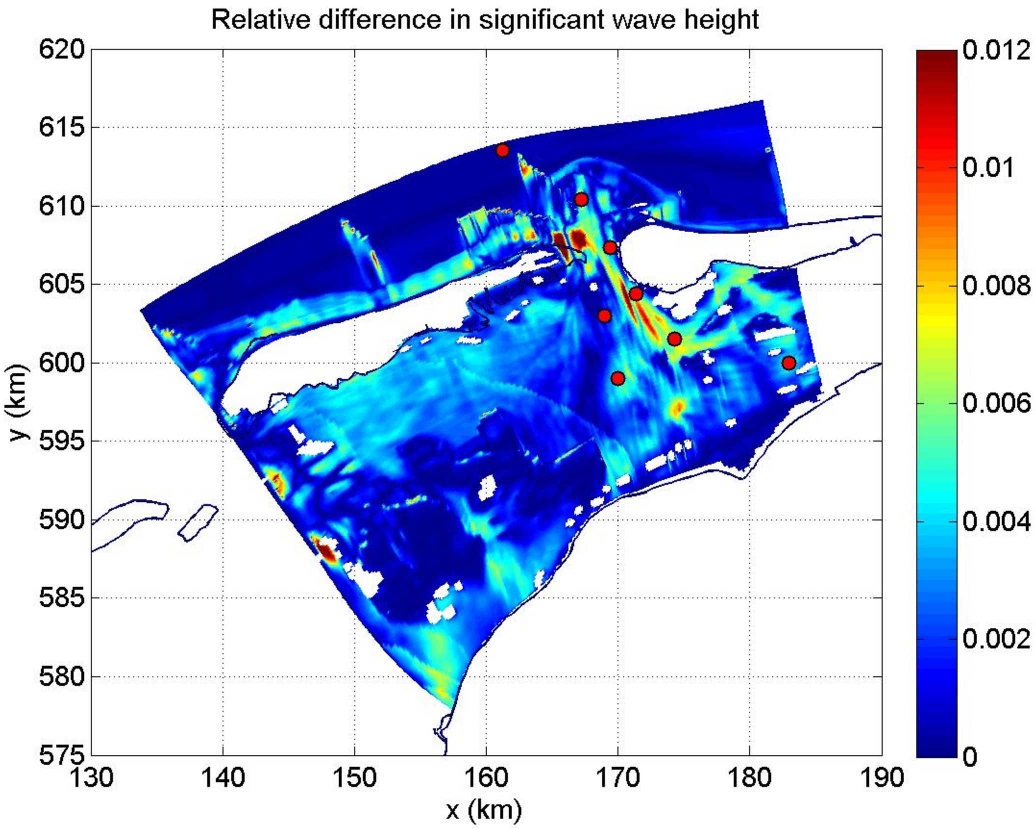


Convergence behavior SWAN

- SWAN solves action balance equation iteratively
- Overall convergence tracked by curvature criterion applied to H_{m0}
- Convergence behaviour not uniform in space
- At some points convergence of H_{m0}, $T_{m-1,0}$, θ and σ lags behind
- Use sufficiently number of iterations

Spatial variation of iteration behavior of SWAN

$(H_{50}-H_{iteration\ 15})/H_{50} \times 100\%$



Speed of convergence not uniform in space

Large areas are already converged (dark blue)

Save time where solution hardly changes per iteration

Dynamical deactivating method developed, saving up to 40% in CPU

Physical processes in tidal inlet

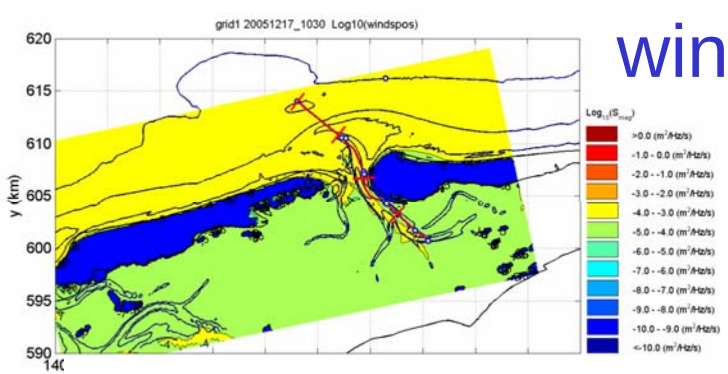
- Source terms reflect ‘model’ physics
- Spatial variation of their magnitude

$$M(\boldsymbol{x}) = \int_{f_{\min}}^{f_{\max}} \int_{0}^{2\pi} \left| S(f, \theta; \boldsymbol{x}) \right| df\, d\theta$$

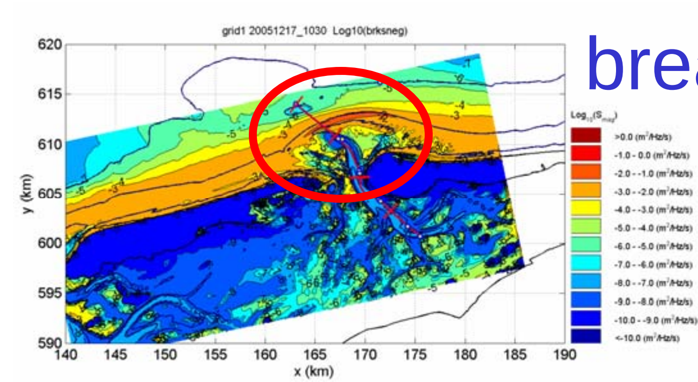
- Spatial variation of dimensional parameters (H_{10}/H_{m0}), $(T_{m01}/T_{m-1,0})$, kd, $s=H_{m0}/L$;

$$H_{10} = 4\left\{ \int_{0}^{0.1} E(f)\, df \right\}^{1/2}$$

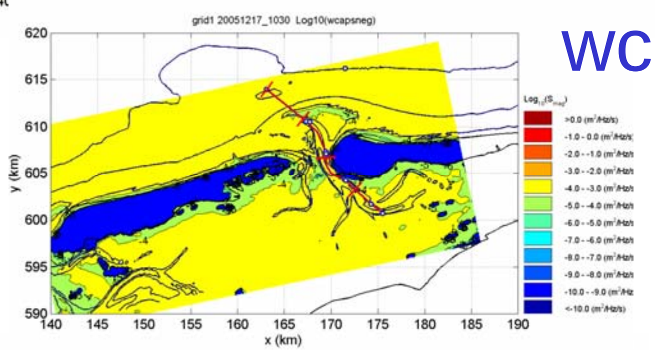
Physical processes, source term magnitudes
(plotted on log10-scale)



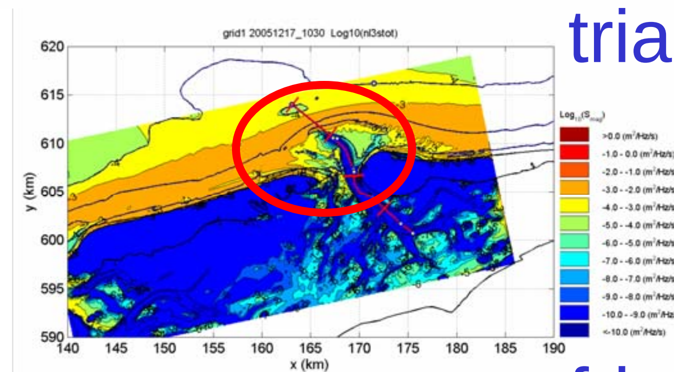
wind



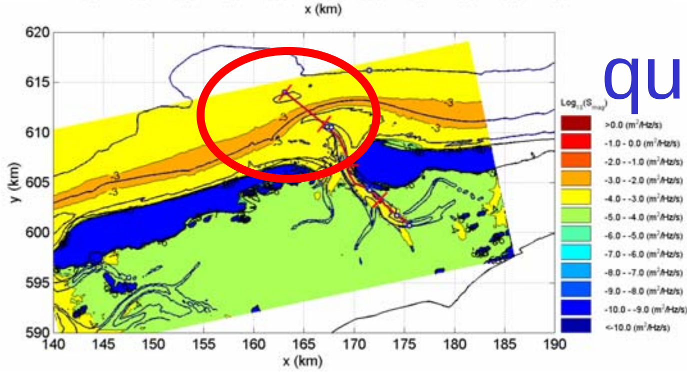
breaking



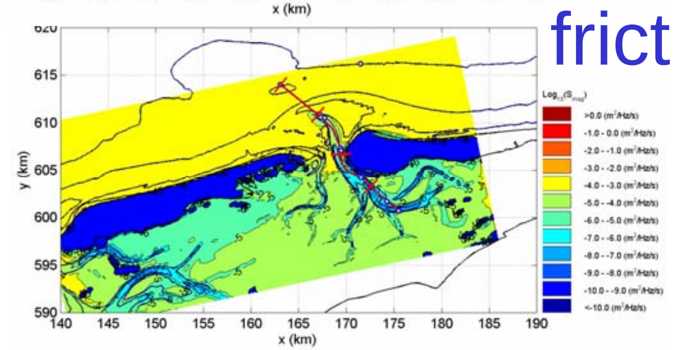
wcap



triads

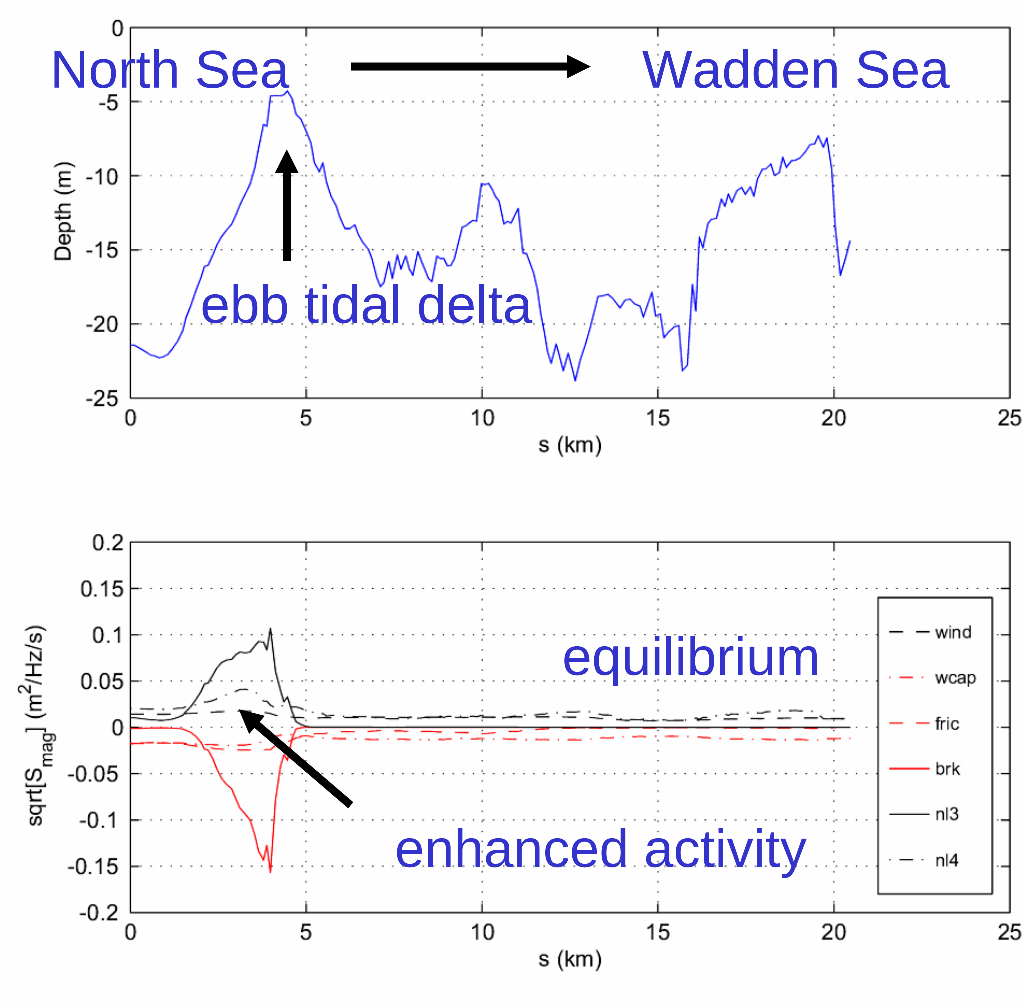


quads



friction

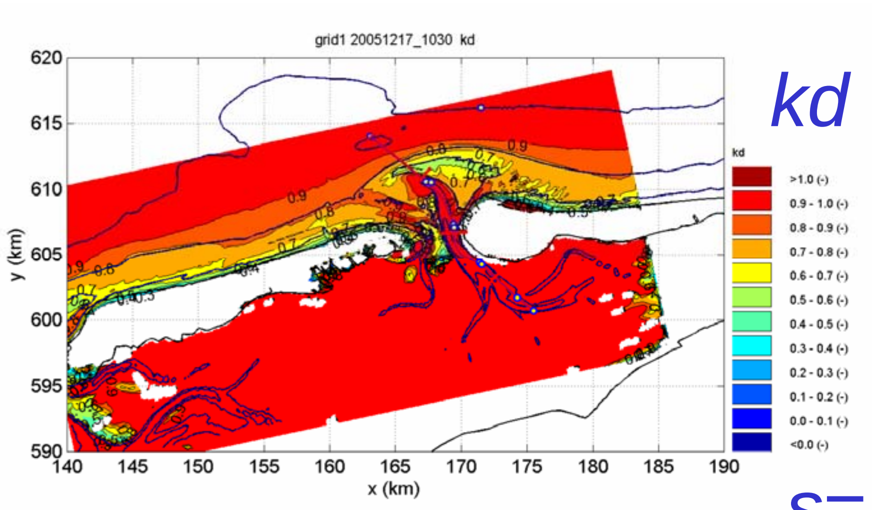
Magnitude of physical processes in main output ray



Surf breaking and triads dominant on outer banks of ebb tidal delta

Wind input, whitecapping and quadruplets dominant in Wadden Sea

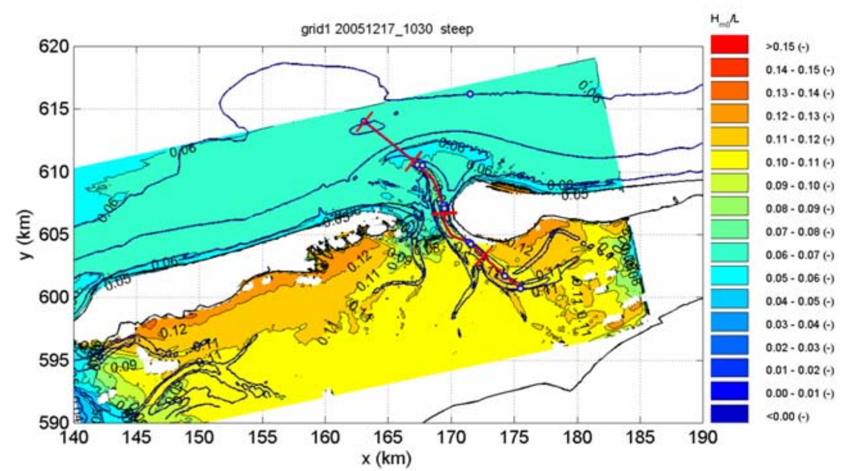
Dimensionless water depth and mean wave steepness



kd

kd dimensionless water depth, down to 0.5 (!)

$s=H_{m0}/L$

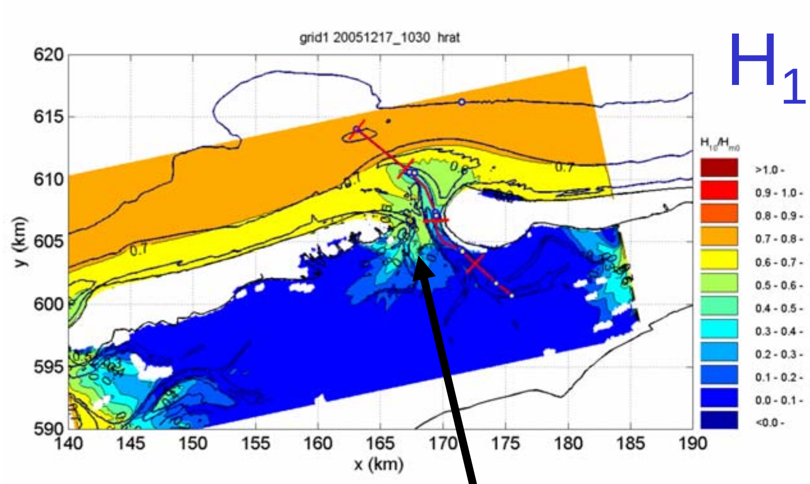


Mean wave steepness exceeds 0.12 (!). Problem with source term balance

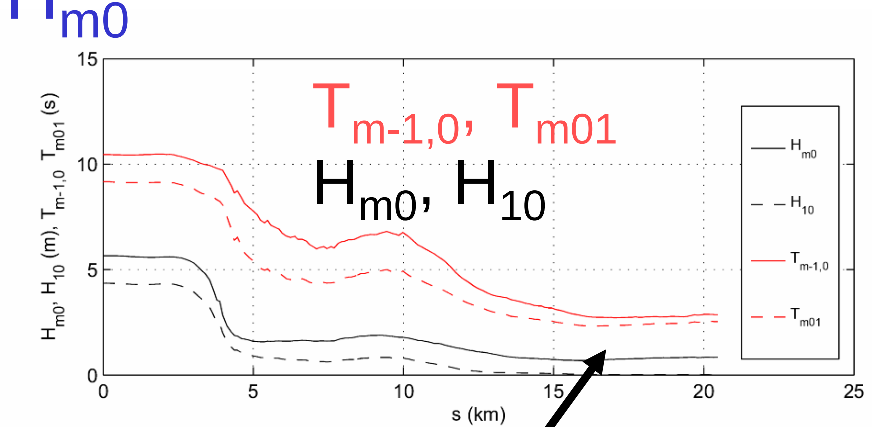
Wave penetration into the Waddensea

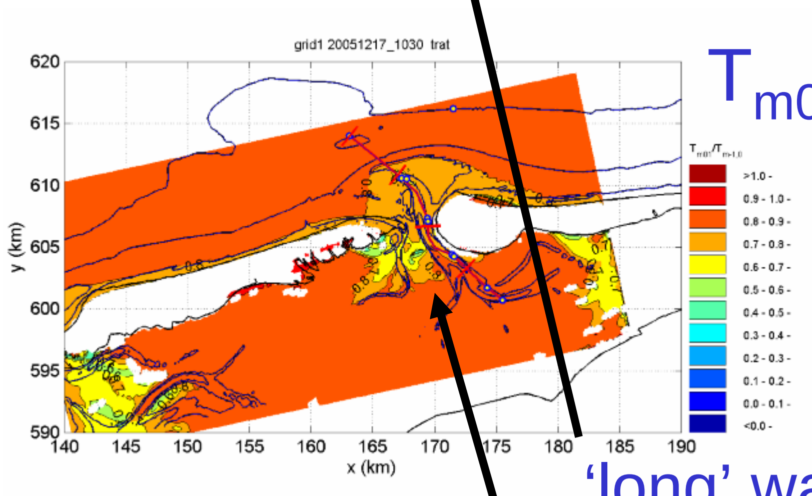
- How far do ‘long’ North Sea waves penetrate into the Waddensea ?
- Long waves: $f < 0.1$ Hz, $T > 10$ s
- Ratio of ‘long wave’ height H_{10} and total wave height H_{m0}
  (small values indicate lack of long waves)
- Ratio of spectral period measures $T_{m01}/T_{m-1,0}$
  (small values indicate surplus of long waves)

‘Long’ wave (f<0.1 Hz) penetration



H_{10}/H_{m0}





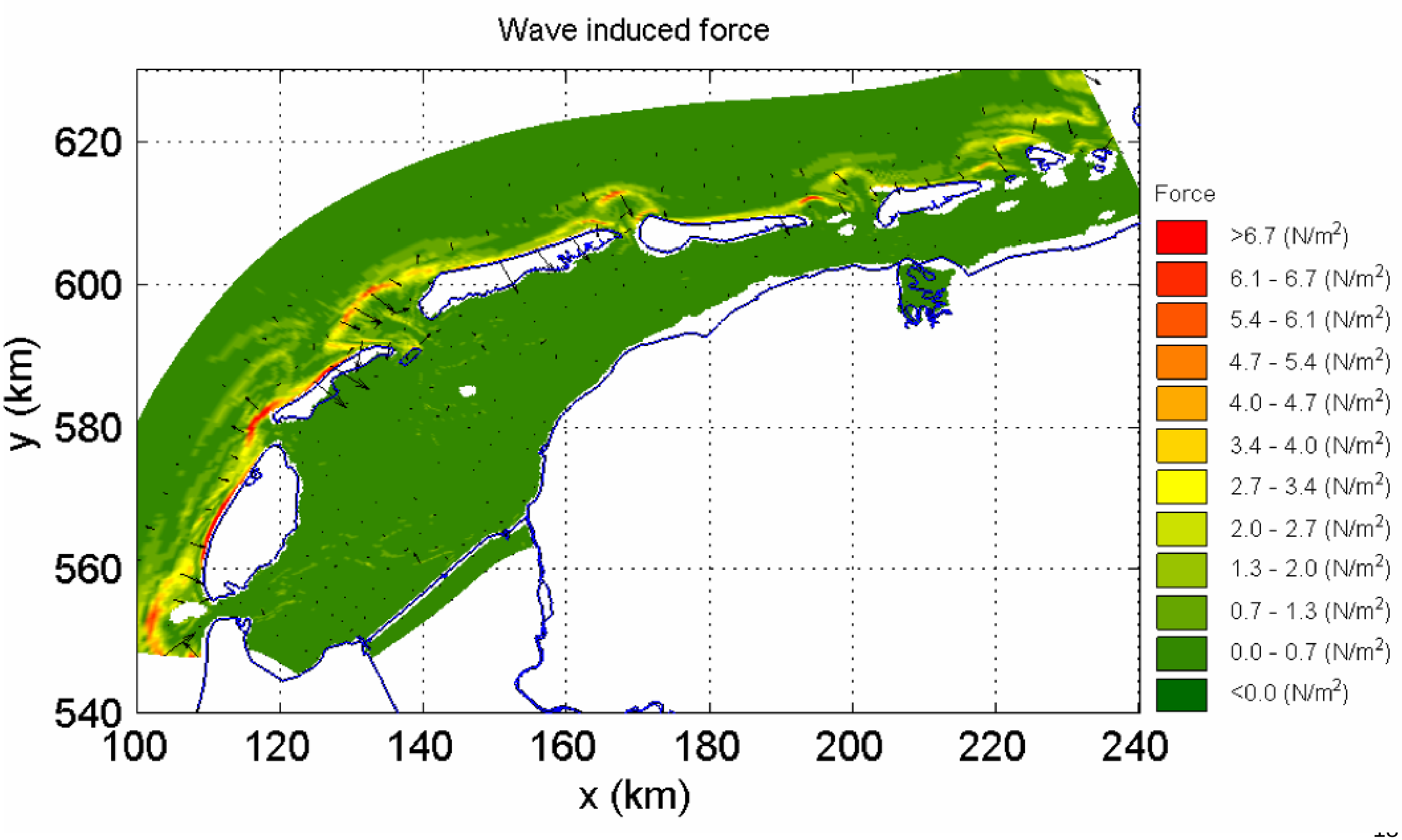
$T_{m01}/T_{m-1,0}$

‘long’ waves have disappeared by refraction and dissipation

‘long’ waves west of main tidal channel, not measured by buoys !

Wave induced forces

Small effect on water levels in Wadden Sea



Summary and conclusions

- Ebb tidal delta effectively blocks North Sea waves;
- Wave conditions in Wadden Sea locally determined;
- ‘Long’ waves not measured in channels, they refract out of channels, relocate buoys;
- Some SWAN source terms possibly applied outside assumed range of applicability in ebb tidal delta;
- Dedicated non-uniform grid saves CPU;
- Convergence (too) slow, more iterations needed;
- Dynamical deactivation of grid points saves up to 40% in CPU

Further developments

- Regeneration of long waves in coastal zone
- Determine role of wave induced set-up on water levels
- Ongoing validation
- Relocation of buoys
- Island effects on wind

- Improve modeling of physical processes
- New first guess developed for SWAN
- Enhanced modeling flexibility by unstructured grids in SWAN