A hybrid method to combine wave penetration and local wave growth in large harbour basins

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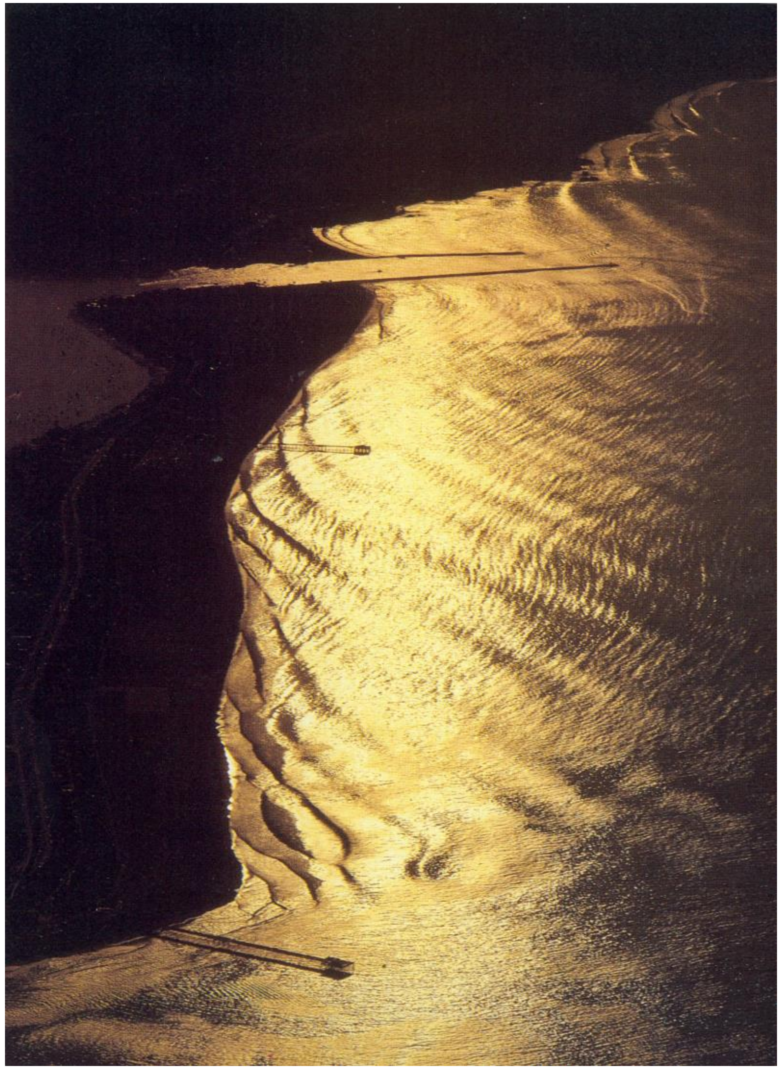


Problem

- Determination of design conditions in (large) harbour basins
  - Physical model experiments
  - Numerical modelling of wave penetration (BSQ, mild-slope, etc…)
- Design conditions associated with strong winds
- Wind effect can be significant !
- How to include wind wave growth?

Challenge

Compute wave conditions area in large harbour basins for design conditions

Wave penetration model: diffraction, no wind

Wind wave models: wind, no diffraction

Still, not one wave model exists accounting for both diffraction and local wave growth

Hybrid method in use for more than 20 years in the Netherlands to combine results of wave penetration and wave growth

Illustrated for Port of IJmuiden

Physical processes and model choice

- Propagation
  - Diffraction (breakwater, quayheads)
  - Transmission (breakwater, dams)
  - Reflection (dams, quays)
  - Refraction (access channel)

- Energy balance; growth and decay
  - Dissipation, breaking, bottom friction, whitecapping
  - Wind wave growth
  - Nonlinear interactions

- Choice of wave models
  - Wave penetration model mild slope (PHAROS, HARES,…) Boussinesq, (Mike21, Trition), non-hydrostatic (SWASH,…)
  - Spectral model for wind wave growth (SWAN,…)

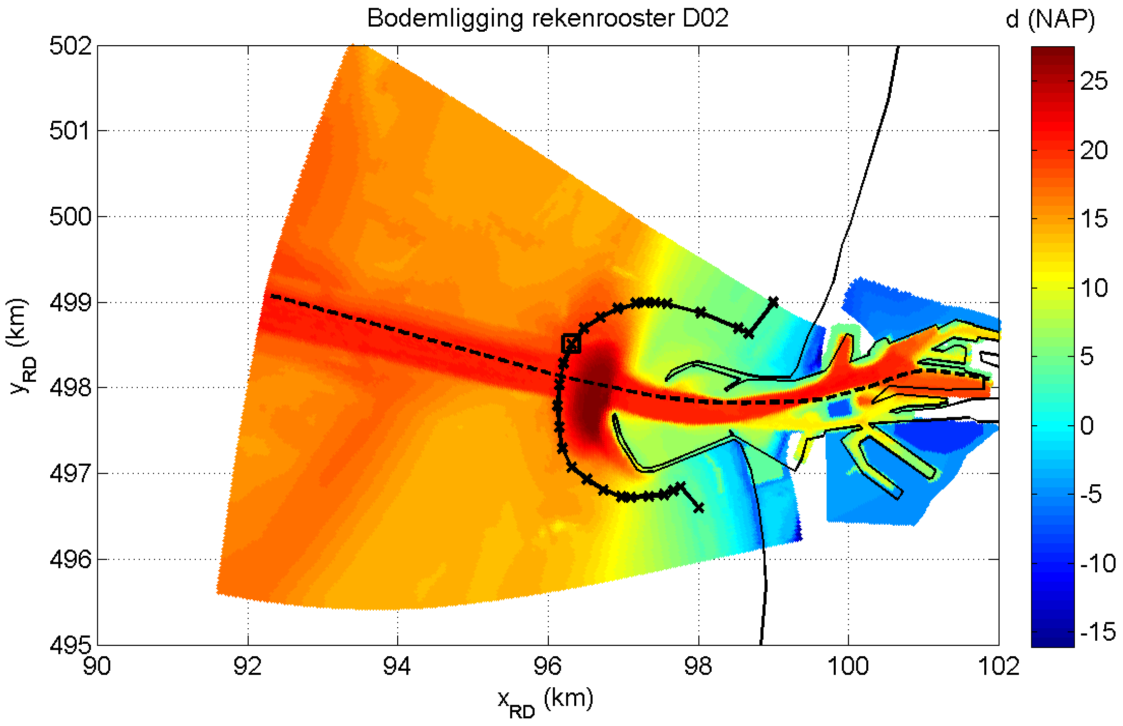
- Many processes depend on water level/relative freeboard

Process	PHAROS	SWAN
Propagation	x	x
diffraction	x	-
reflection	x	X
transmission	x	x
wave growth		x
dissipation	x	x
non-linear interactions	(x)	x

Port of IJmuiden, the Netherlands

Situation sketch

bathymetry and outline of computational grids



Hybrid method

Add wind effect **on top** of penetrated wave field

3 model runs for given offshore wave boundary condition

- 1 model run using **phase-resolving** model **p**enetration $E_P(x,y)$
- 1 model run using **phase-averaged** model with **w**ind $E_W(x,y)$
- 1 model run using **phase-averaged** model **n**o wind $E_N(x,y)$

Isolate effect of wind **G**rowth

$$E_G = E_W - E_N$$

Add wind effect to **P**enetrated wave field to obtain **T**otal wave condition

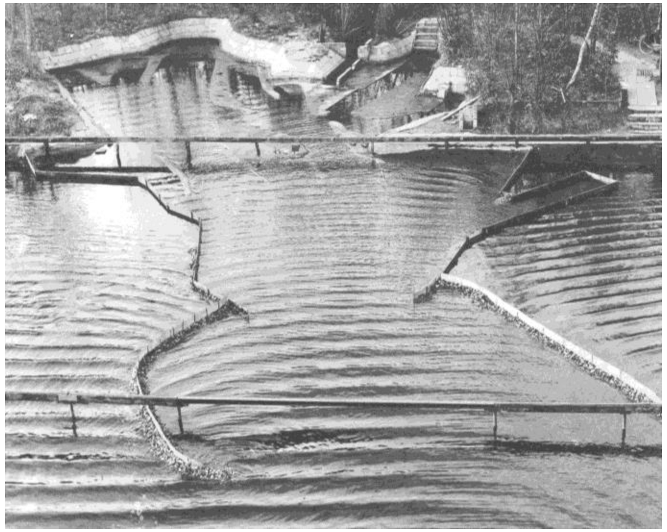
$$E_T = E_P + E_G$$

How to combine results of different model types?

Combination in terms of wave spectra

- Given offshore wave **b**oundary condition Hs, Tm, $\theta \rightarrow E_B(f, \theta)$

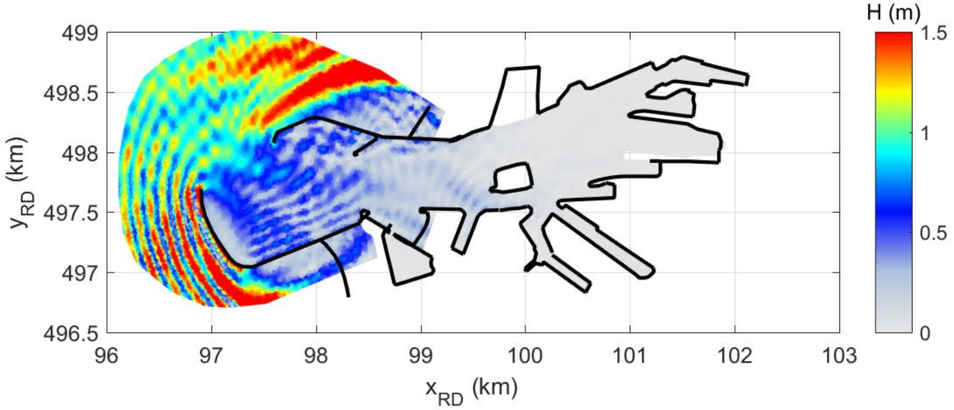
- Run PHAROS mild slope model for finite number of spectral components $\Sigma(f_i, \theta_j)$, compute spatial variation of unit amplitude $A=A(x,y|f, \theta)$



- Reconstruct wave spectrum $E(f, \theta)$ at each location using scaled summation

$$E_P(x,y\,|\,f,\theta) = \sum_{i,j} \underbrace{A\left(x,y\,|\,f_i,\theta_j\right)}_{scaling} \times \underbrace{E_B\left(f_i,\theta_j\right)}_{boundary\,spectrum}$$

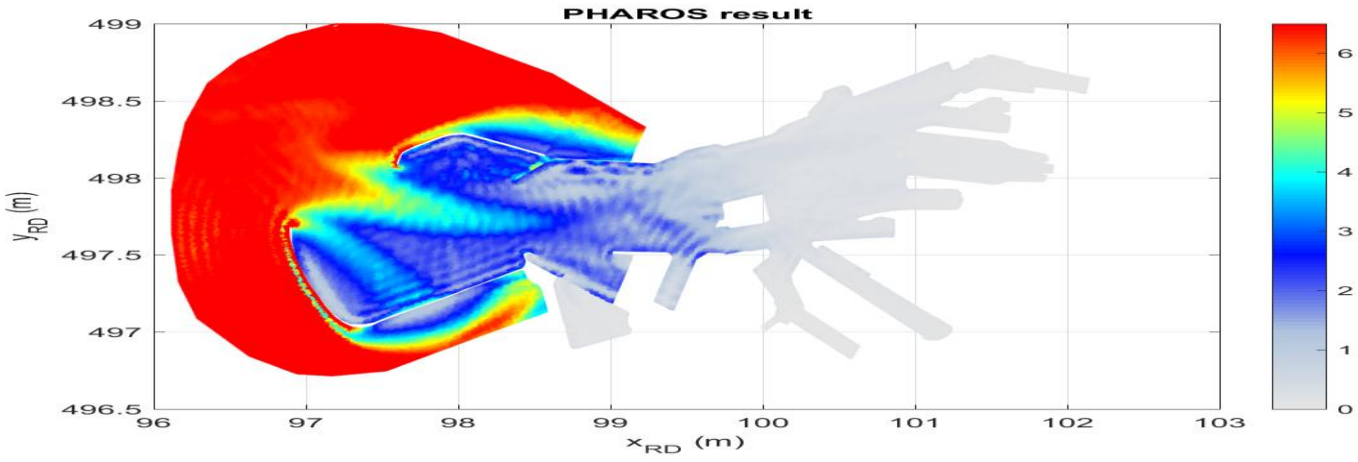
- Run phase-averaged SWAN wave model twice for given input spectrum $E(f, \theta)$, all components together, with wind E_W and without wind E_N

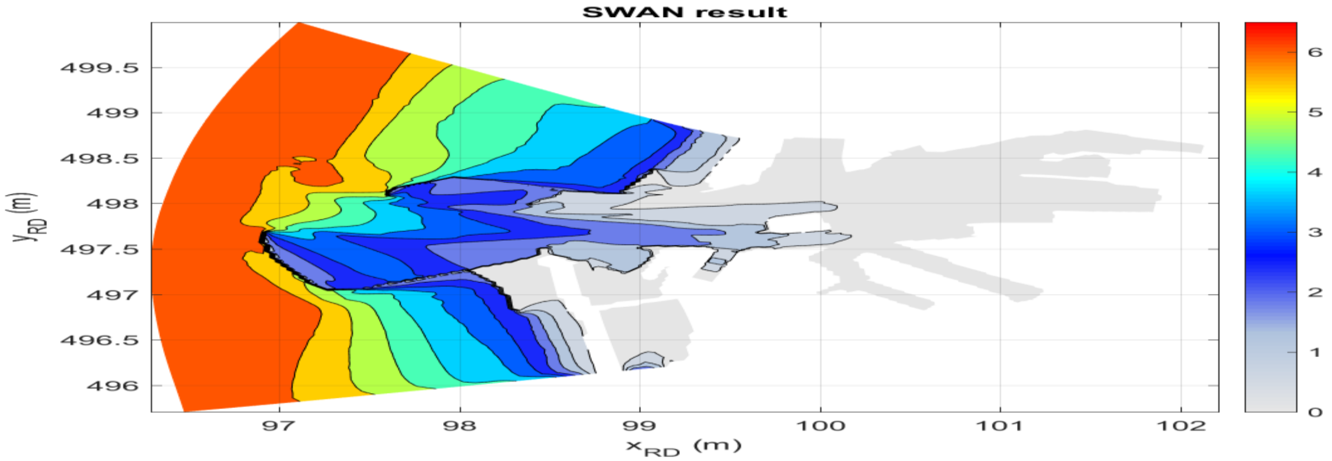


- $E_T = E_P+(E_W-E_N)$

- Compute wave parameters for design H_s, T_{m-10}, ….

Wave penetration using different models





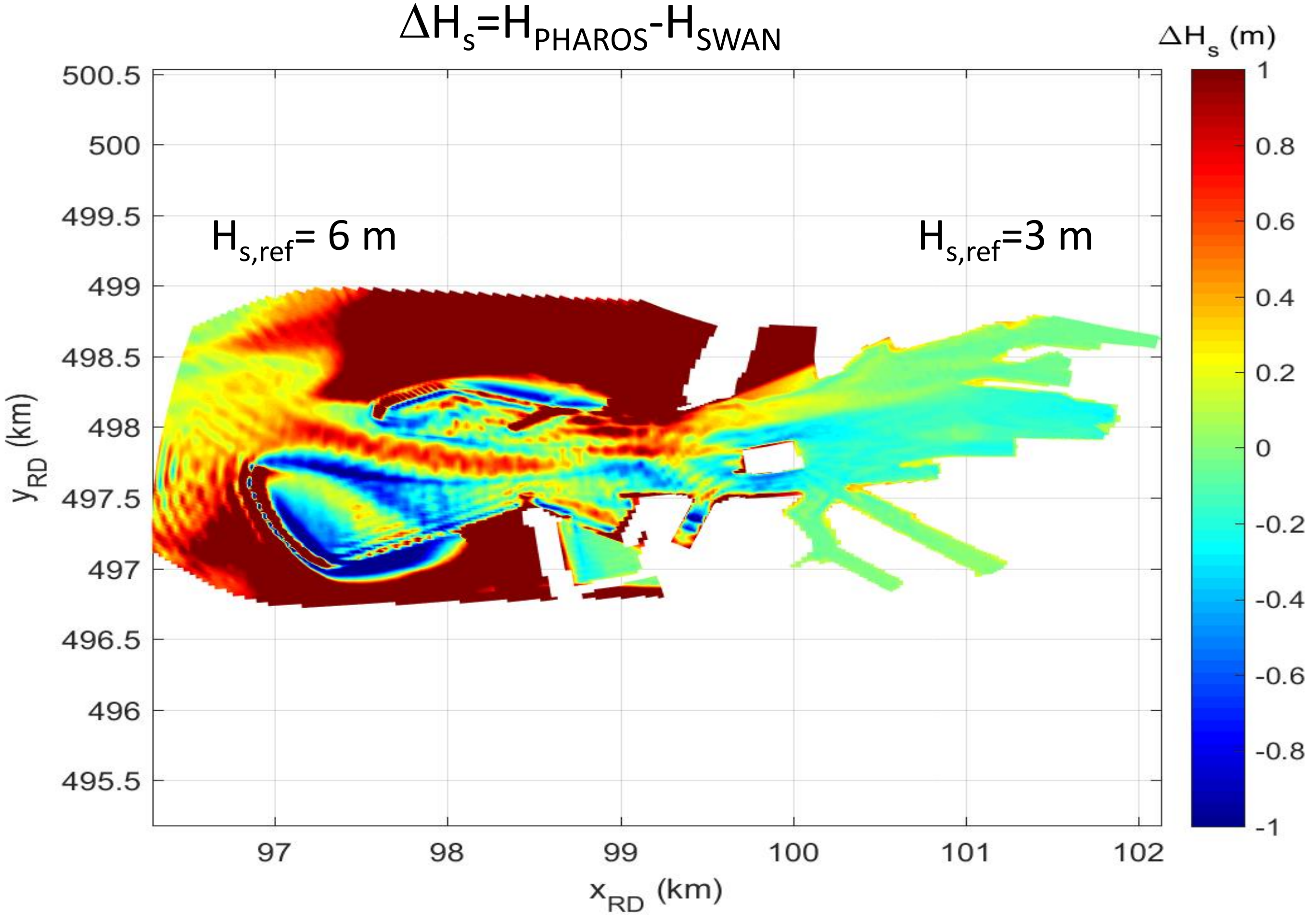
Typical design condition
U_{10} = 37 m/s
θ_w = 270 °N

Mild slope PHAROS

Phase-averaged SWAN

Different computational grids, extent, unstructured <> regular

Difference between PHAROS and SWAN

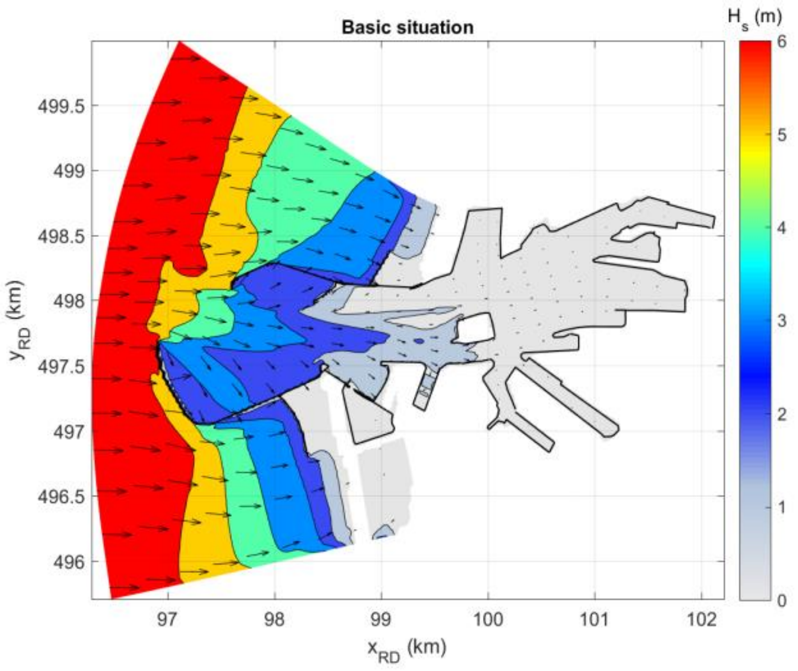


- Diffraction effects
  - Behind breakwater
  - In access channel
- In eastern part of basin
  - results equal
  - No diffraction points
  - Open water
  - Directional spreading

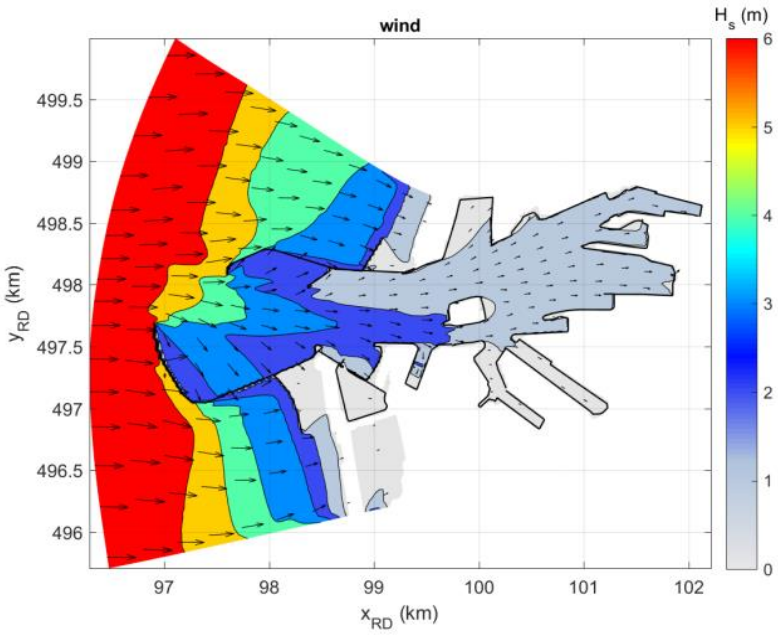
Hybrid method, added growth effect G

- Spatial variation of significant wave height
- Wave penetration only, no wind (left)
- Wave penetration and wind growth (right)

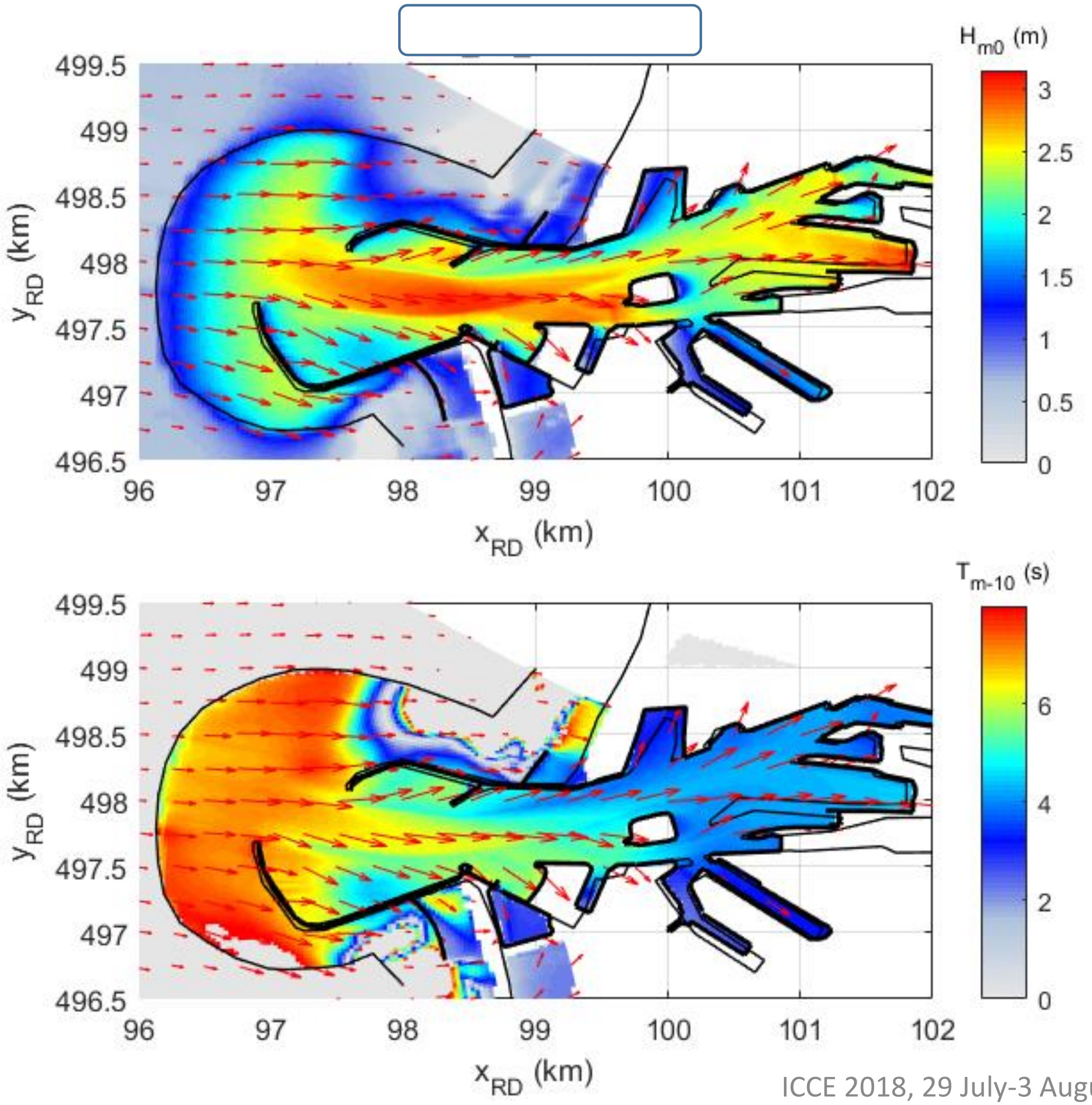
NO WIND E_N



WITH WIND E_W



Spatial variation of added growth in terms of H_{m0} and T_{m-10}



Wave growth E_G on top of penetrated wave field in PHAROS domain

Significant wave height H_{m0}

Increase to the east

Decrease behind island

Spectral period T_{m-10}

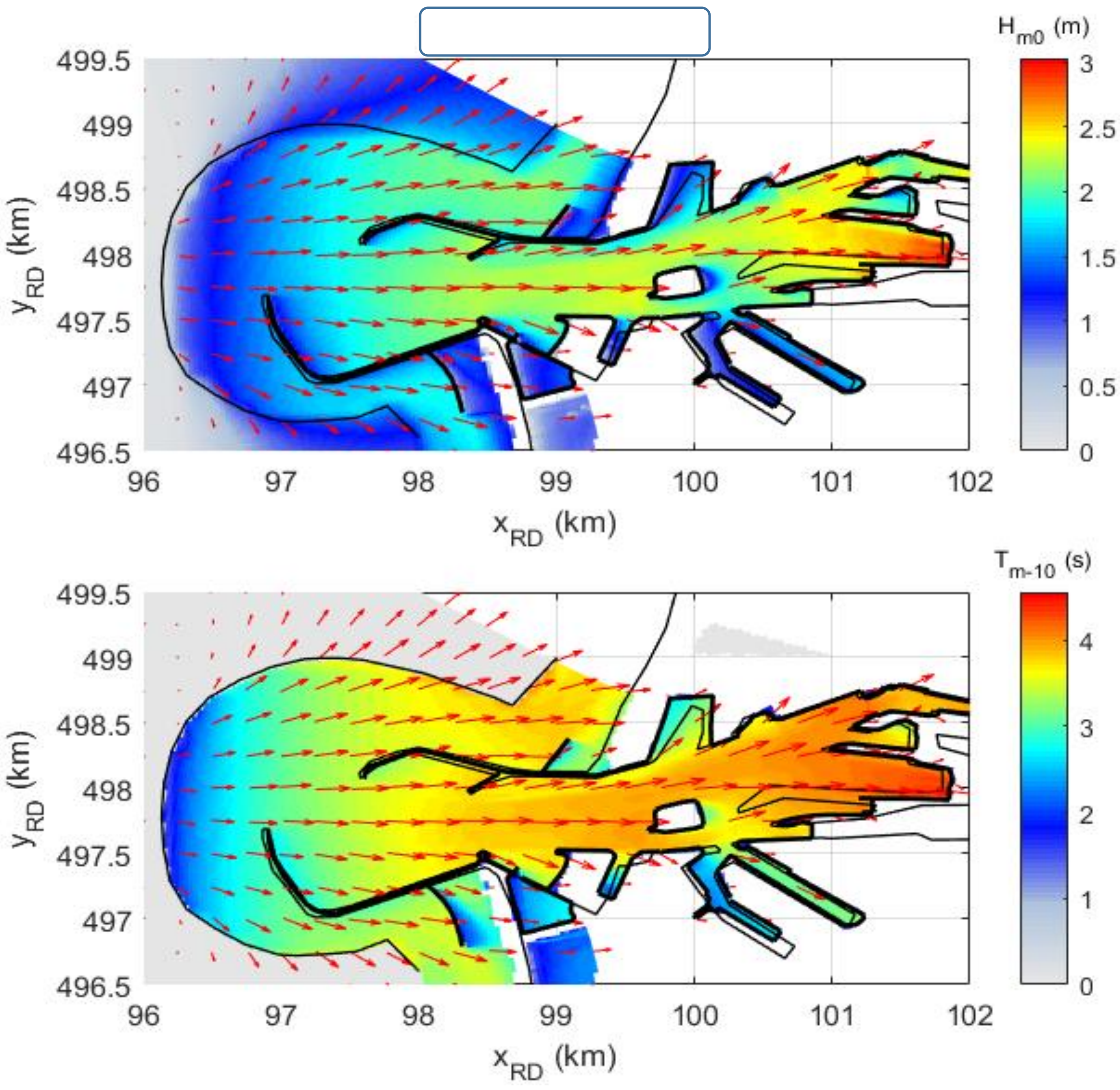
Initial decrease to the east

Followed by slight increase

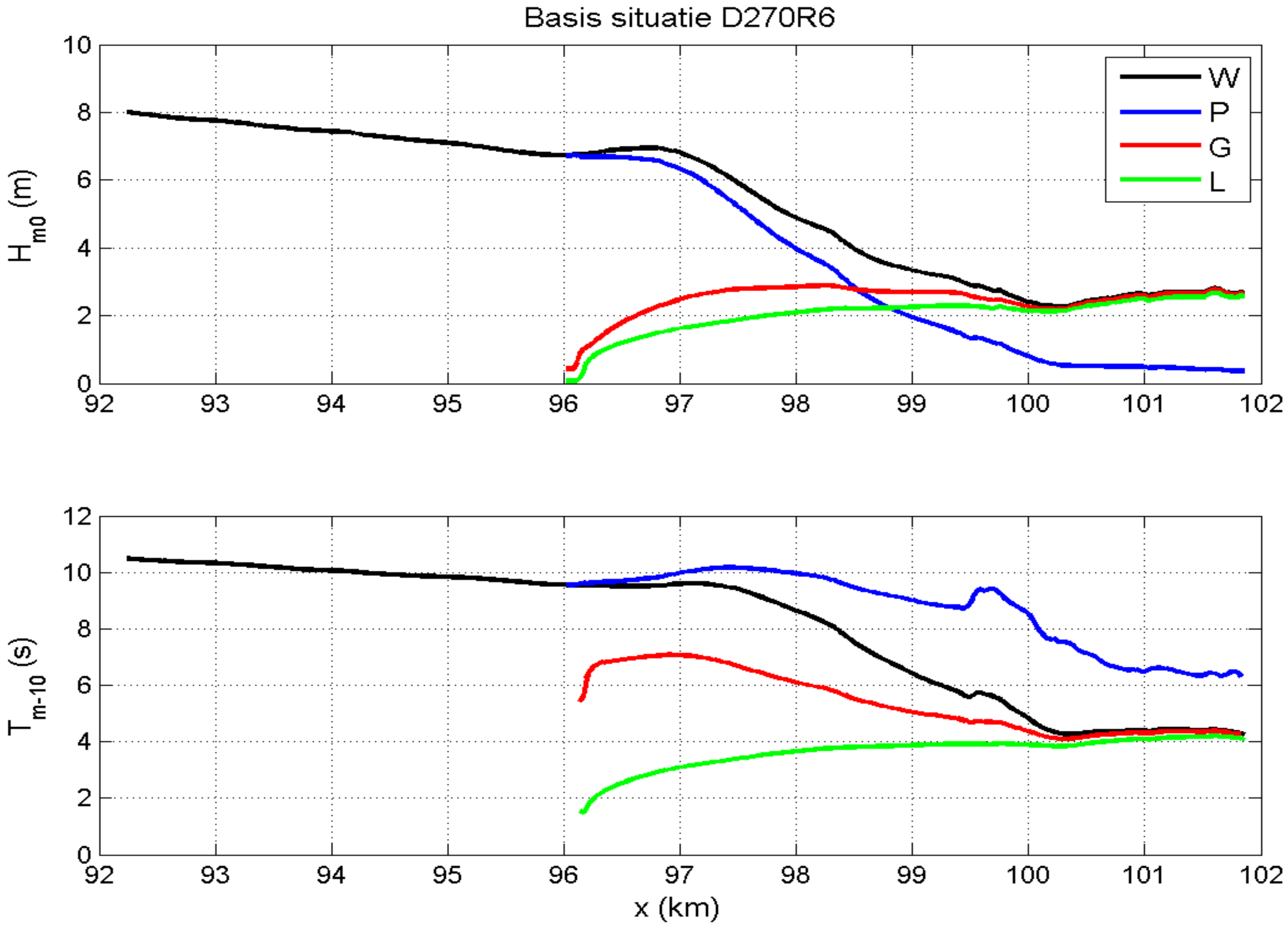
Local wave growth E_G

Local wave in area of wave penetration model growth E_L starting from boundary

U_{10} = 37 m/s
θ_w = 270 °N



Spatial variation H_{m0} and T_{m-10} along access channel axis IJmuiden



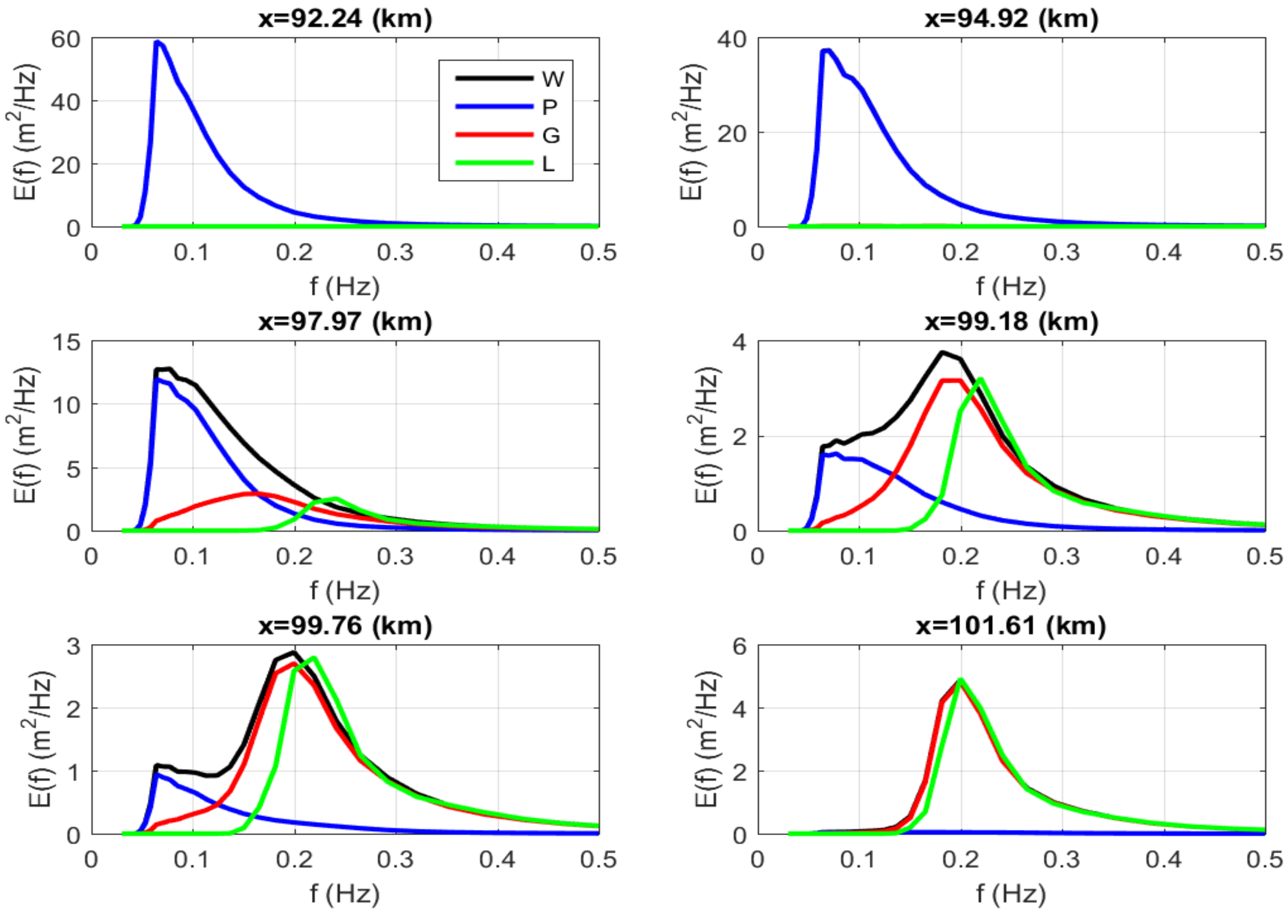
Wave penetration (blue)
- Strong decay of height into basin
- Periods slightly decrease (refraction)

Added wind growth (red)
- Rapid growth
- Periods show decay (refraction effect, growth of younger waves)

Local wave growth (green)
- Strong growth
- Lags behind added wave growth

In the east equilibrium wind effect dominant

Spectral development along entrance channel axis



Development of local wind sea

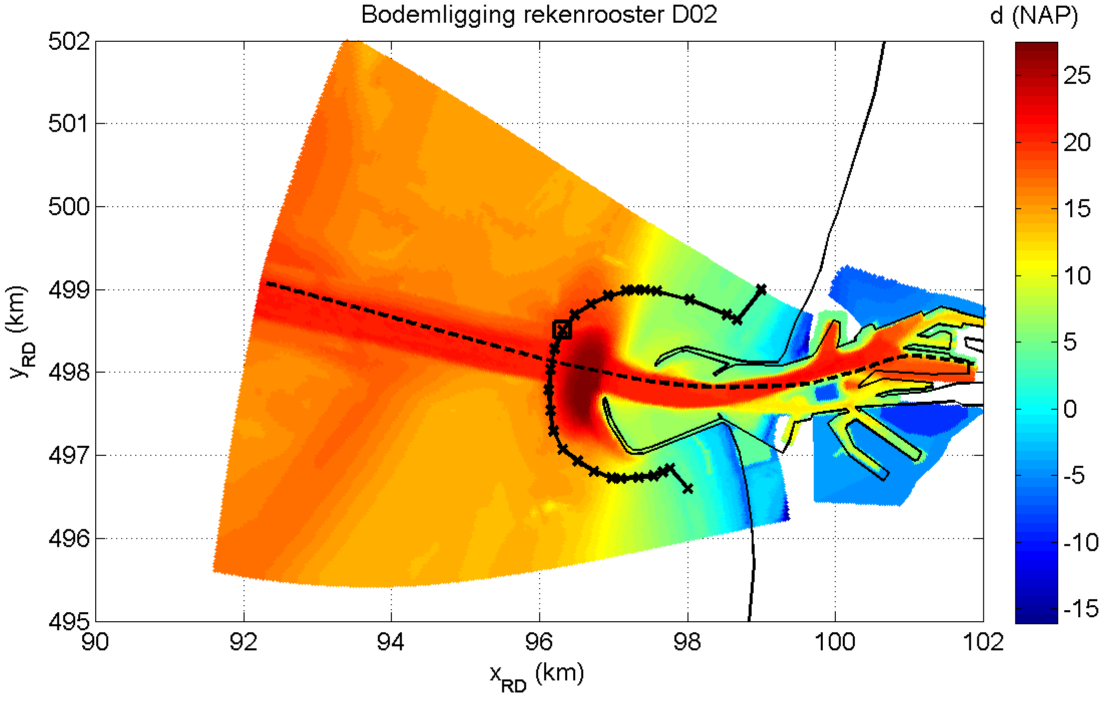
Uni-model and bi-modal spectra

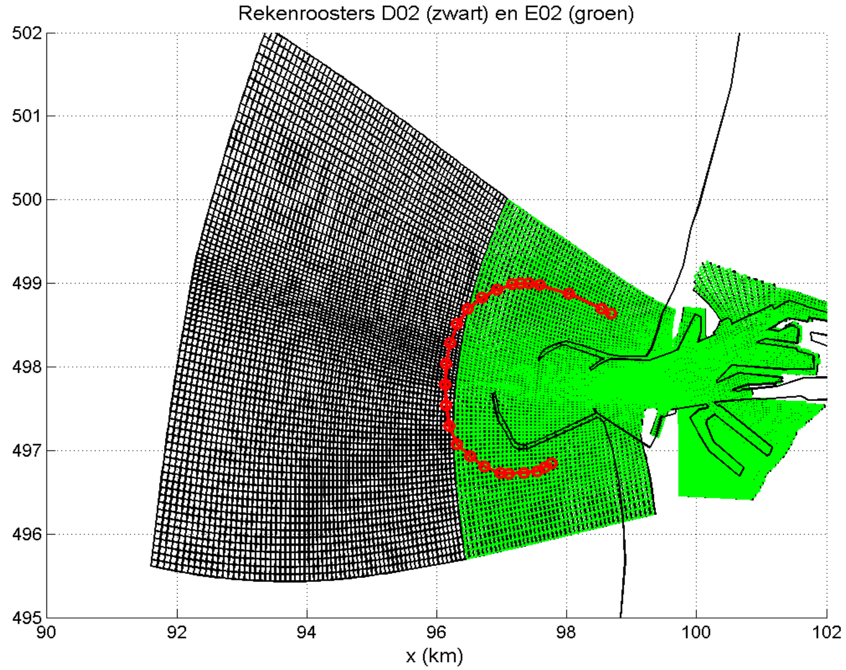
Transition area

Careful in choice of whitecapping formulation (Komen, Westhuysen, Ardhuin ST4, Rogers and Babanin ST6)

Different computational domains

- No wind area in SWAN should match extent of PHAROS model
  - Overlap of grids (green within red boundary of PHAROS)
  - Deactivate wind in PHAROS domain





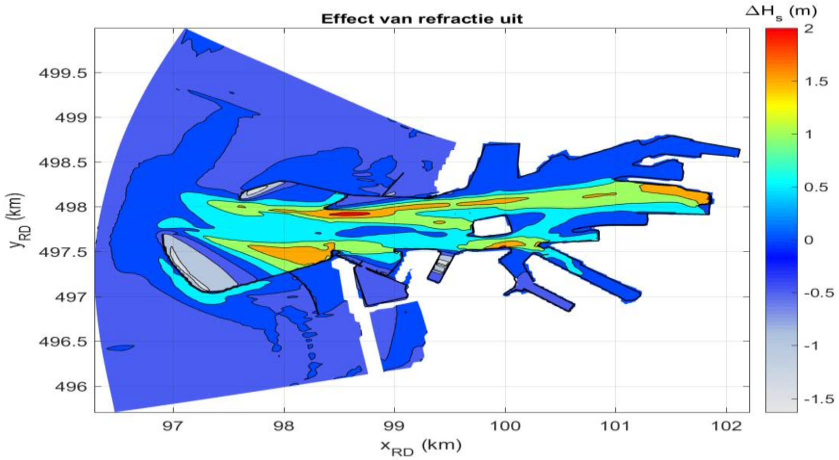
Role of refraction in wave penetration

Deactivate refraction in SWAN model

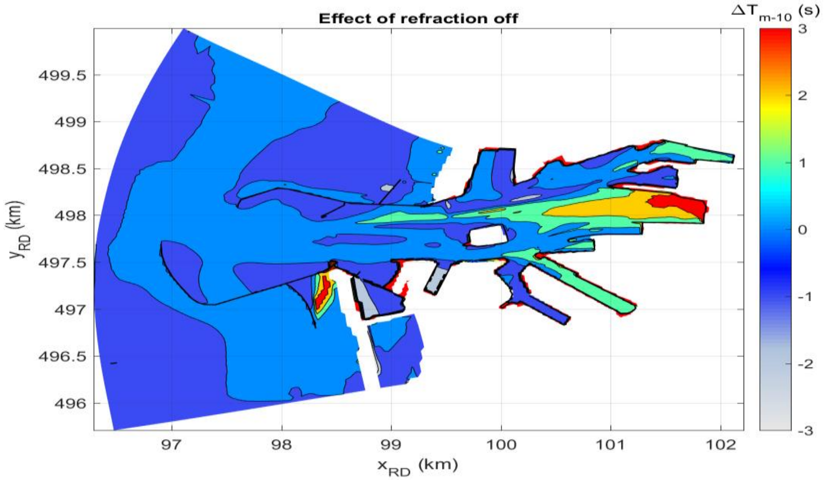
Significant increase of wave penetration

Increase of heights and periods in access channel

Access channel works as effective filter



ΔHs (m)



ΔTm (s)

Hybrid method, considerations

- Assumptions
  - For estimation of local wave growth: $E_{P,PHAROS} = E_{P,SWAN}$
  - Diffraction not affected by local wave growth
  - Local wave growth not affected by diffraction
  - No wind area should match area of wave penetration model

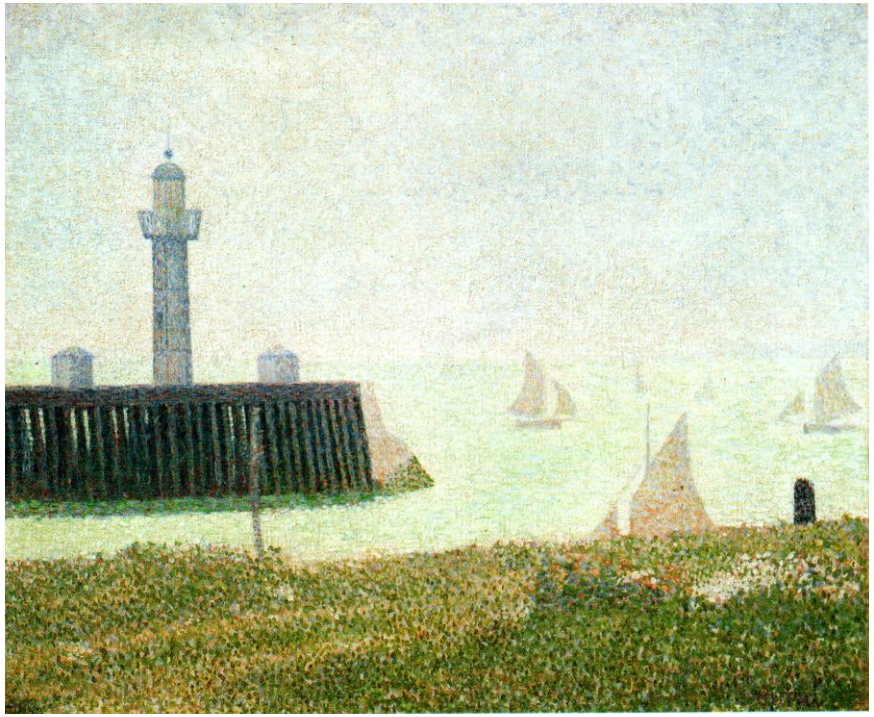
- Computational grids
  - Outline of grids should match, or
  - Deactivate wind for SWAN computation in region of PHAROS domain
  - Interpolation due to different kinds of grids (unstructured <> regular)

- Validation
  - Wave measurements for verification of hybrid method scarse
  - During storms no ship traffic

Conclusions and outlook

- In large harbour basins local wind effect cannot be neglected
- Different areas where either penetration or wind wave growth is dominant
- Refraction along access channel acts as effective filter

- Wave measurements in harbour basins under storm conditions required for validation
- Develop wave model with both diffraction and wind wave growth



Acknowledgements

Hybrid method has a long and poorly documented history

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