Source term balance of wind waves in the North Sea

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- Storm periods
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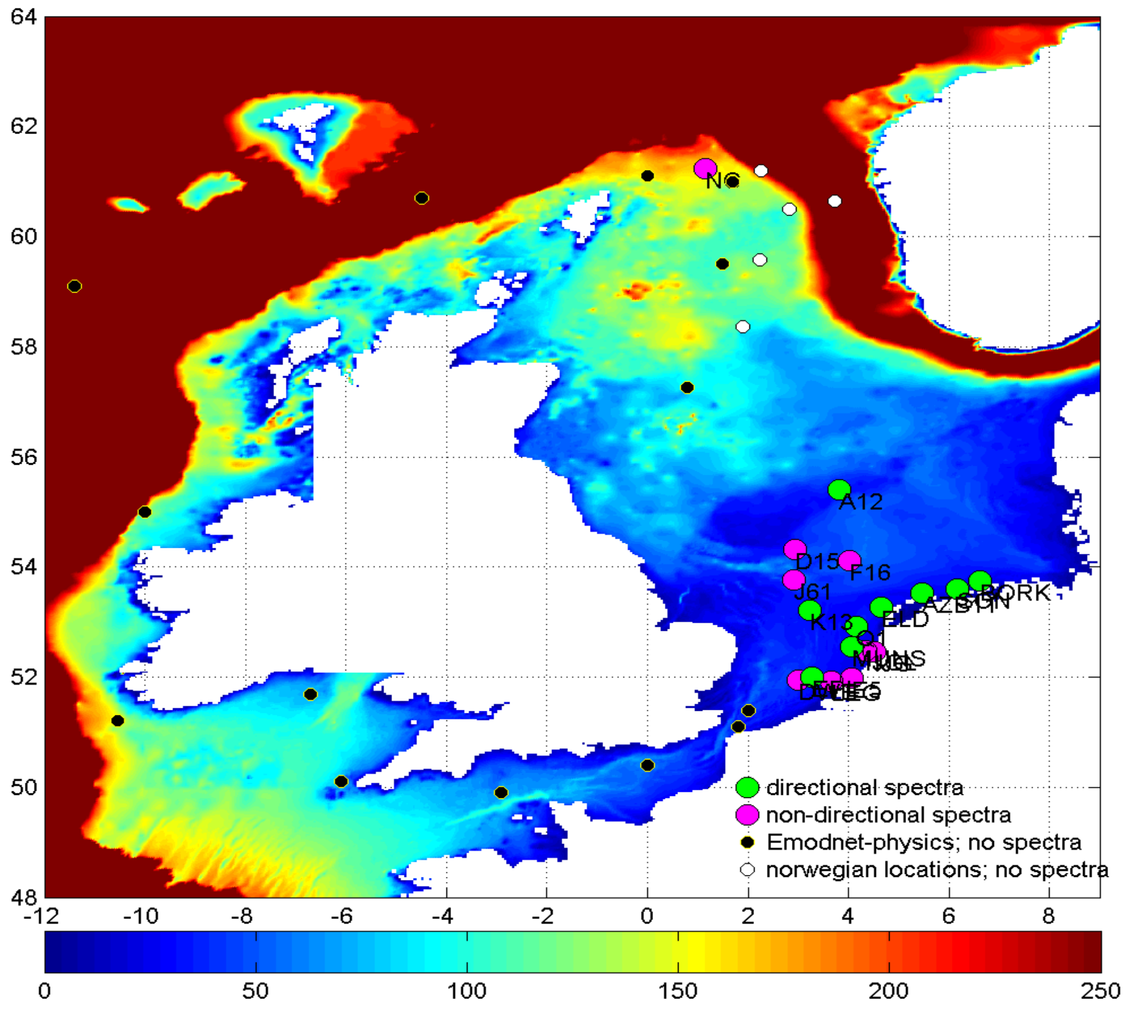
Motivation

- SWAN important for the design of sea defences in the Netherlands, storm surges and wave loads
- Improve prediction of low-frequency wave energy ($f<0.1$ Hz), needed for entrance windows of large ships to Port of Rotterdam (PRO-TIDE)
- Ongoing SWAN development at TU Delft
- Present results of NOPP project
- Implement and test new source terms
- Consistency of physics with WWIII, important when nesting SWAN in WWIII

North Sea and measurement locations

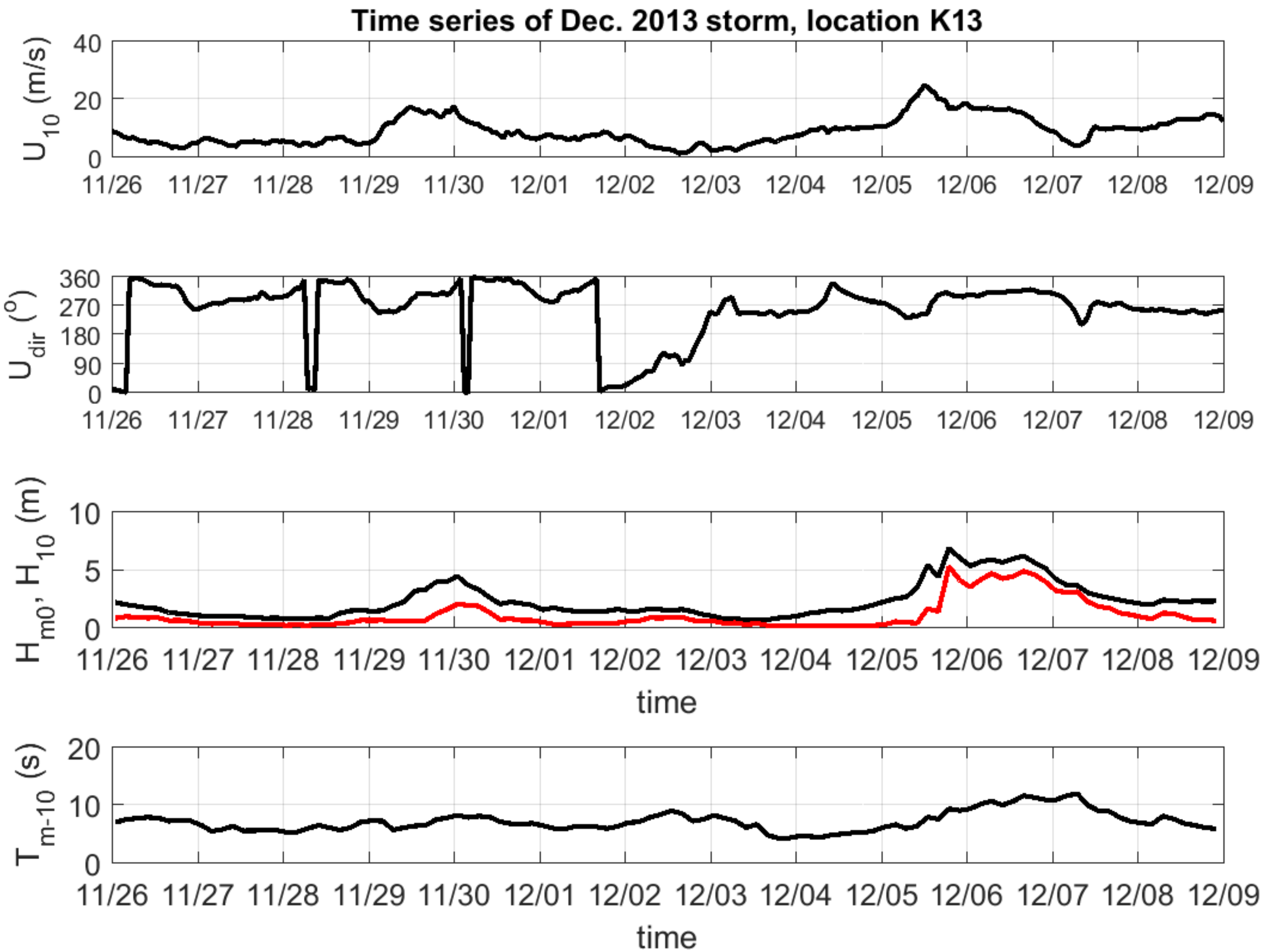


Storm periods

- 2013 Oct 25 - 2013 Oct 31
- 2013 Nov 26 - 2013 Dec 09
- 2014 Feb 03 - 2014 Feb 17
- 2013 Dec 31 - 2014 Jan 14
- 2014 Apr 10 - 2014 Apr 21

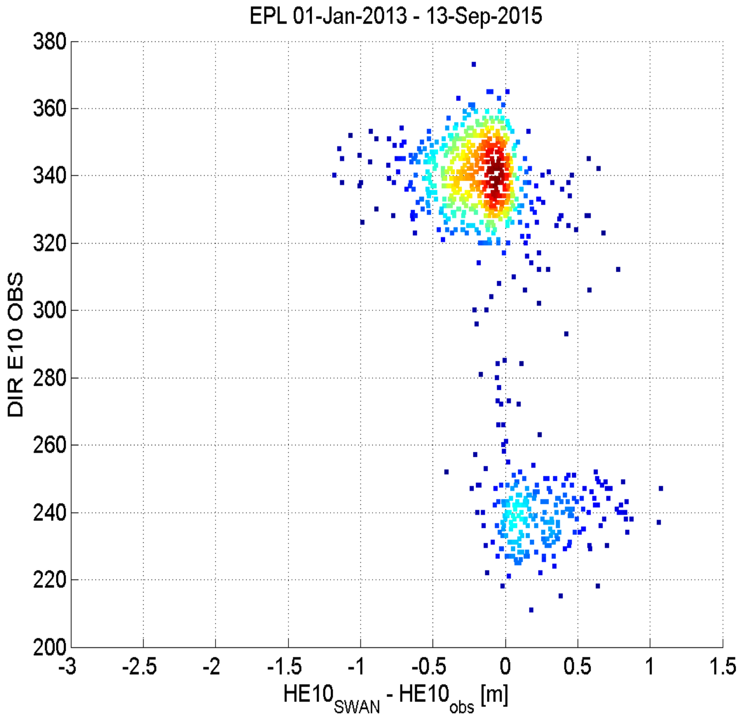
- Special attention for Dec. 2013 storm Sinterklaas (Santa Claus) bringing nasty winds and waves

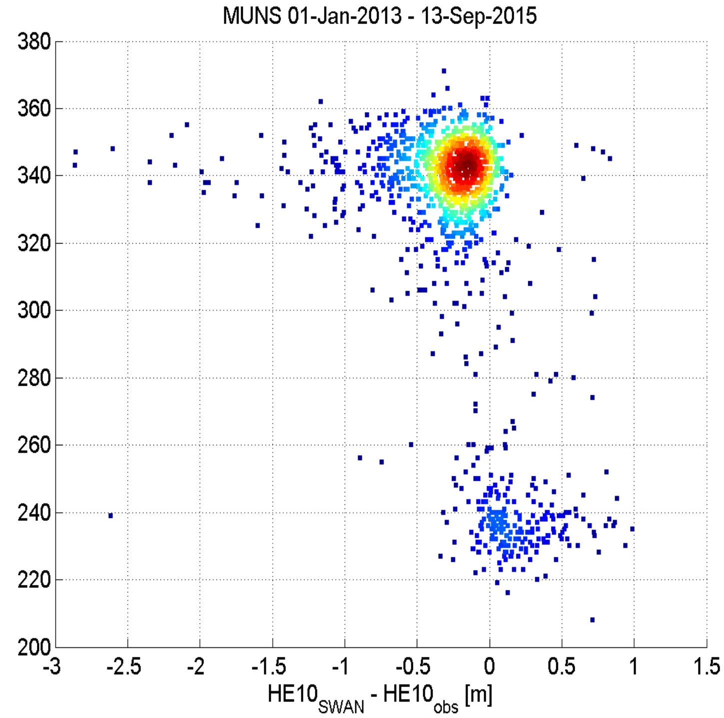
Storm profile Dec 2013



Direction dependent swell error

under-prediction for northerly swells
over-prediction for southerly waves





Components of prediction system

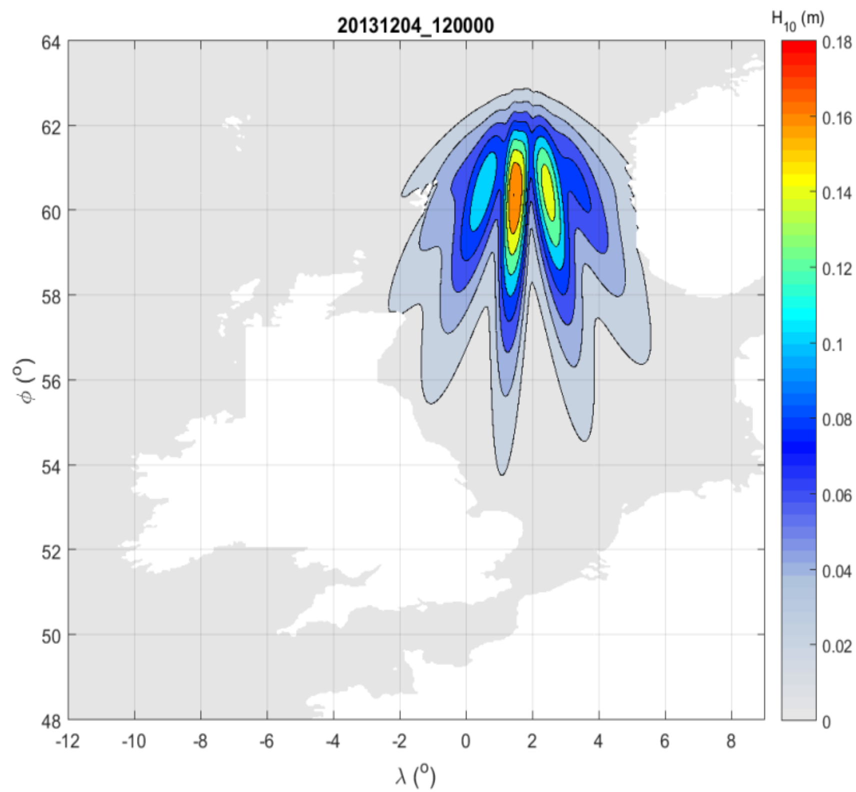
- Model error influenced by various groups of effects
- Hierarchy of important factors (Ardhuin & Roland, 2013)
  - Forcing (wind, currents, water level, boundary,)
  - Physics (source terms)
  - Numerics (propagation scheme, convergence, spatial and spectral resolution)

Propagation

- Accuracy of propagation scheme
  - First order upwind BSBT
  - Second order Stelling-Leendertse
  - Garden sprinkler effect
  - Artificial diffusion Booij and Holthuijsen (1987)
- Spectral resolution and time step
- Stability criterion
- Academic tests to highlight problem and solution

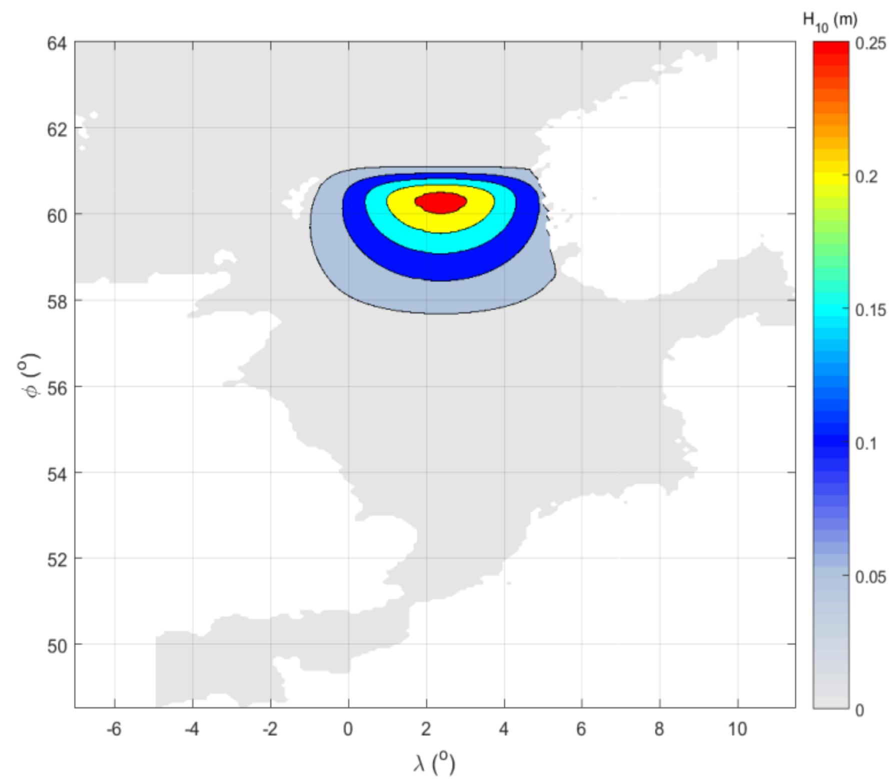
First order

- Initial condition: Small swell pulse travelling southwards Tp=12 s, Hs=1 m
- BSBT (Backward Space Backward Time)
- $\Delta\theta$=10°
- Δt =10 min
- Garden Sprinkler



Second order

- Stelling-Leendertse with artificial diffusion GSE
- Increase directional resolution and/or reduce time step (1minute)
- Wave age 1 day
- Stable solution
- Assess relative importance in conjunction with errors in forcing and source terms



Recent SWAN model developments

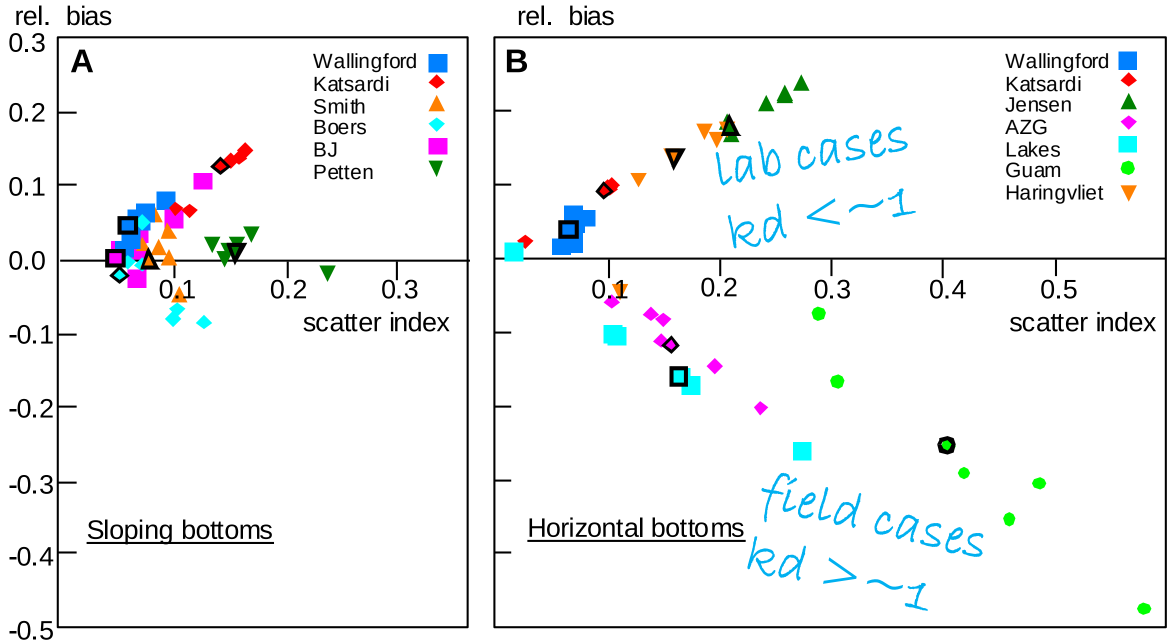
- Development of new source terms in NOPP project
  - WWIII: focus in deep water source terms
  - SWAN: focus on shallow water effects
- New breaker formulation Sbrk (Salmon et al. 2015)
- Test of new whitecapping ST6 formulation (Babanin, Rogers)
- New bottom friction Smith et al. (2012)
- Source term magnitudes
- Xnl settings

Shallow water wave breaking

- Bore based models
- Battjes and Janssen (1978), γ=0.73
- Van der Westhuysen (2010), bi-phase model
- Salmon et al. (2015), β-kd model
- Scaling of γ determining the onset of breaking

The problem

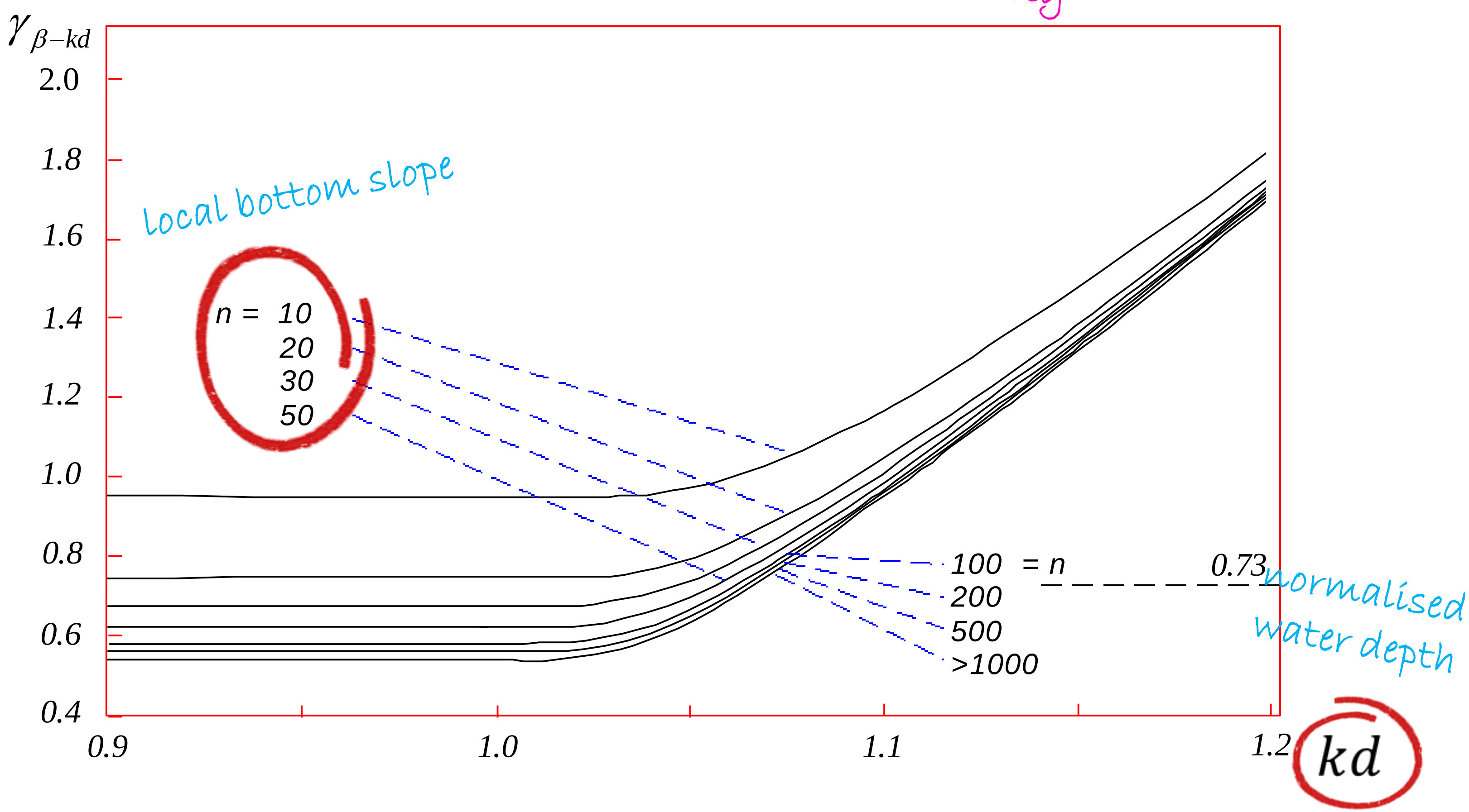
Depth-induced breaking source term (7 of 12 best alternatives applied to all data sets)



- Low correlation between SCI and RB for slopes; high correlation for horizontal bottoms
- Horizontal bottoms:
  - Locally generated = positive correlation
  - Non-locally generated = negative correlation

The β-kd model

+ modified dissipation for wave directionality



Calibrated over 79 laboratory cases with bathymetries ranging from horizontal to steep (1:10) and 5 observations of fully developed waves in shallow water

See: Salmon, Holthuisen, Zijlema, Van Vledder, Pietrzak, 2015: Ocean Modelling 87

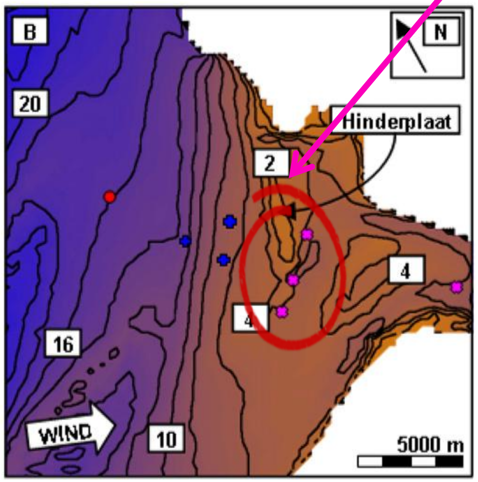
Results

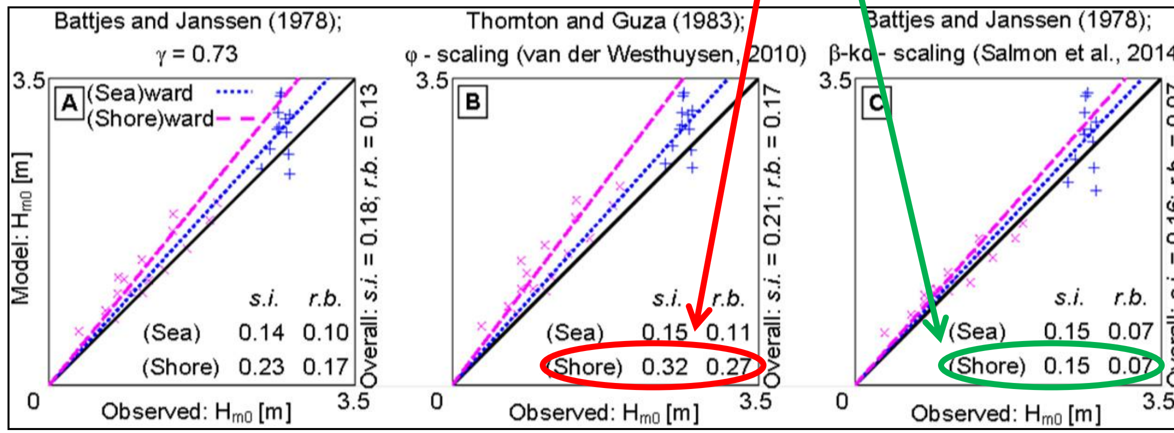
non-locally generated waves; horizontal bathymetry

decreased performance of φ

improved performance of β-kd

Haringvliet (1982)

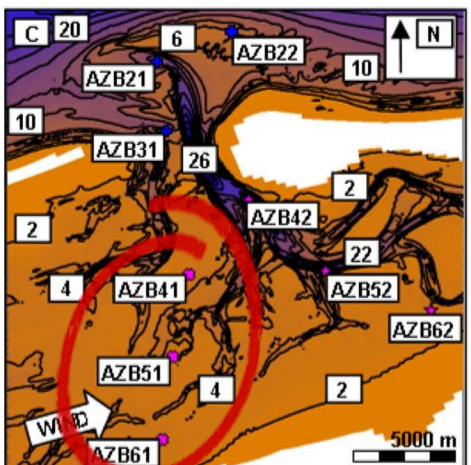


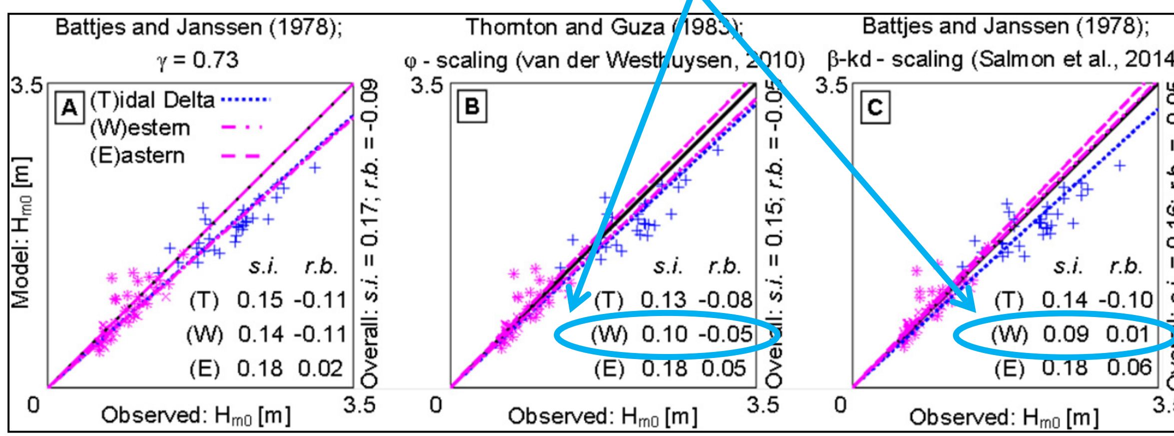


Amelander Zeegat (2007)

complex bathymetry!

similar improvements of φ and β-kd for locally generated waves over horizontal intertidal flats on the west

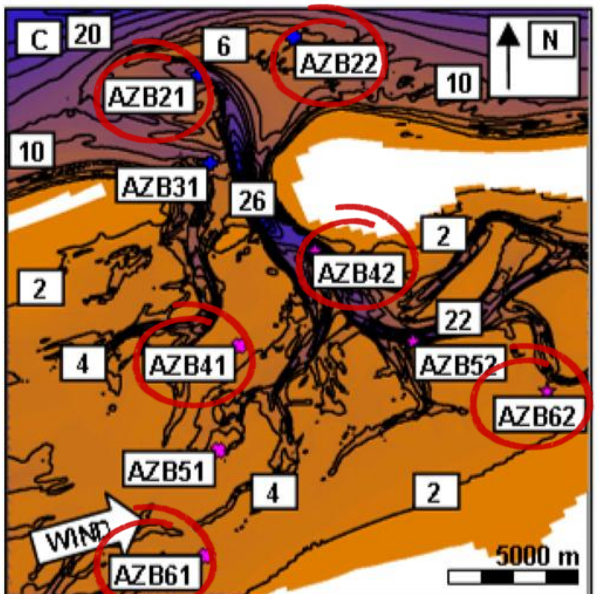


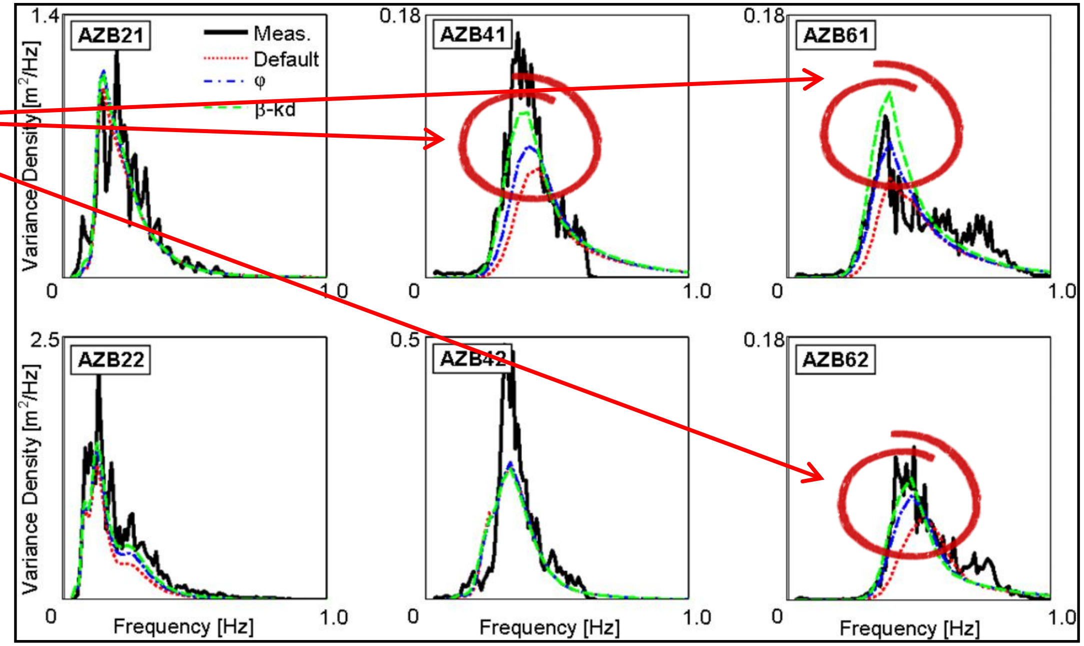


Results

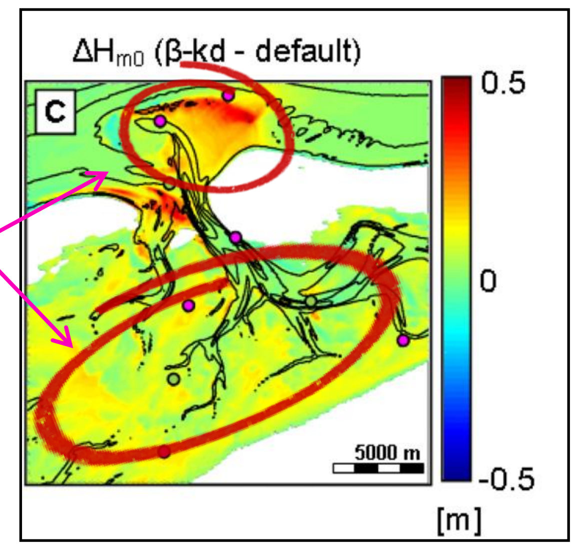
spectral peaks better reproduced over horizontal bottoms for both φ and β-kd

Amelander Zeegat (2007)





increased wave heights over tidal delta and intertidal flats with β-kd (and φ!)

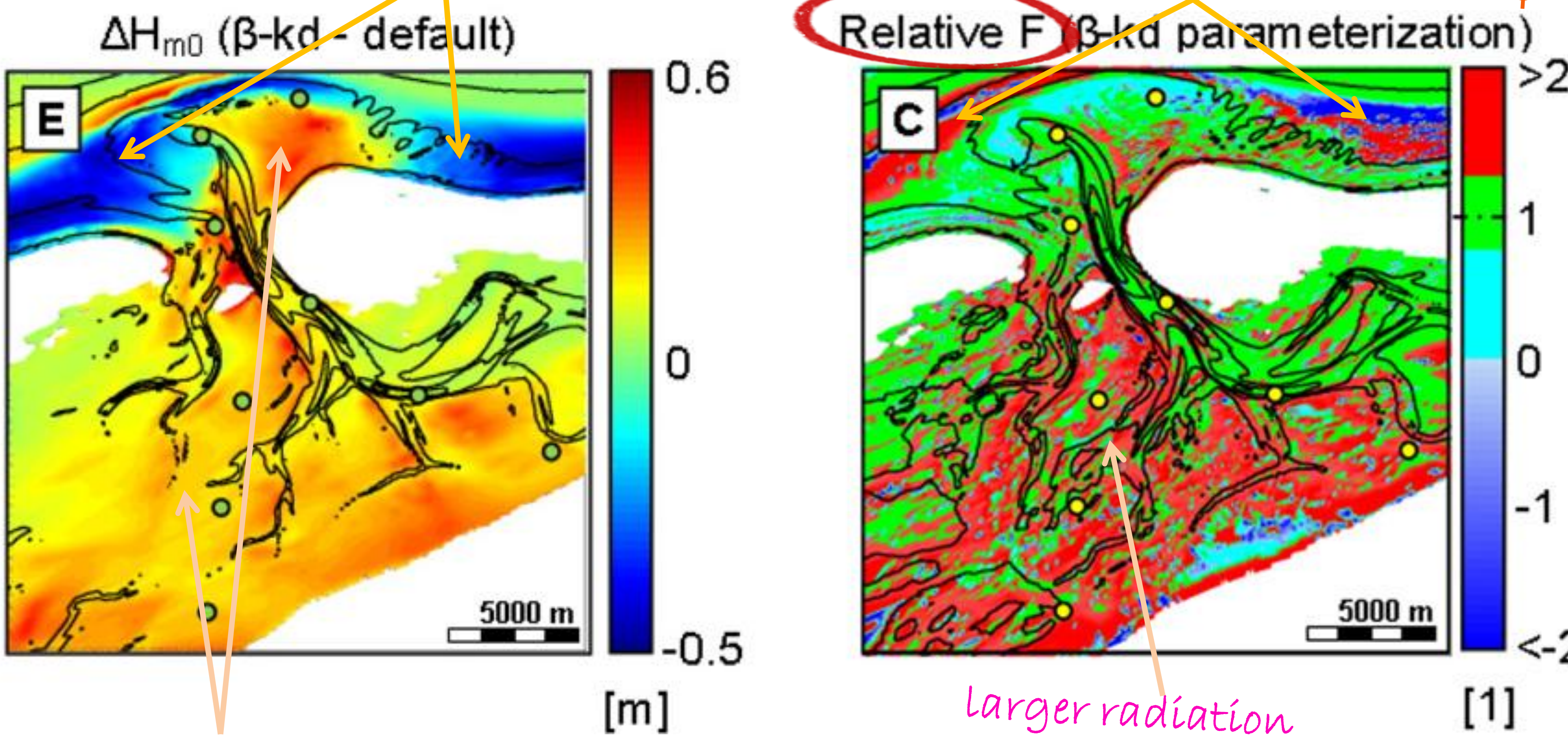


Design conditions (1 in 4000 storm)

increased dissipation; reduced wave height compared to default and φ

magnitude of radiation stress gradient

location of depth-induced wave breaking moved offshore compared to default and φ



reduced dissipation; higher wave heights

larger radiation stress gradients over intertidal region

Summary of new breaking source term

- Performance is **comparable** to default settings (γ=0.73) on slopes and errors reduced for non-locally generated waves over horizontal bathymetries compared to default or φ
- Results over a field case with a **complex coastal bathymetry** shows the **improvements** over intertidal regions comparable to φ
- Under conditions of strong **local wave growth**, energy at the peak frequency are dissipated less
- For **design conditions** (1:4000), larger waves are predicted in the intertidal regions and increased dissipation in offshore regions

Xnl4 implementation

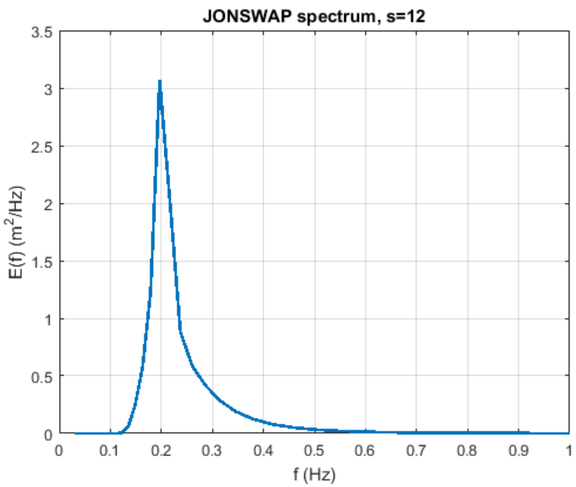
- WRT method implemented in Wavewatch III and SWAN (Van Vledder, 2006), also referred to as Xnl
- Xnl implementation has various internal settings not many users are aware of:
- Objective comparisons are recommended to reveal implications of such hidden features (Van Vledder and Hashimoto, 2013).
- Default settings were chosen to optimally work in most conditions
- Default settings can be modified using a (safe) backdoor, place file XNL4V5.CFG in working directory. See also subroutine Q_SETCONFIG

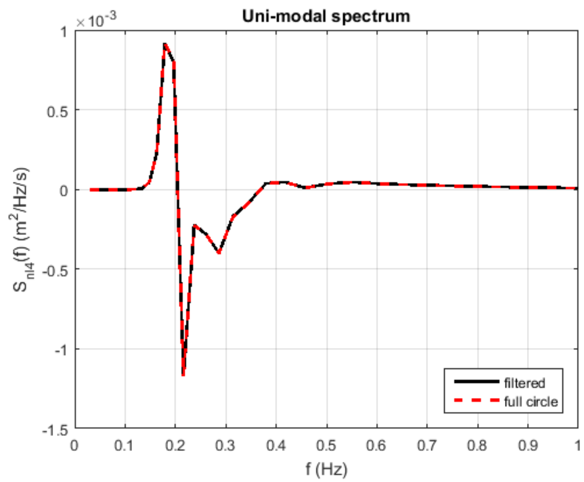
Some internal settings

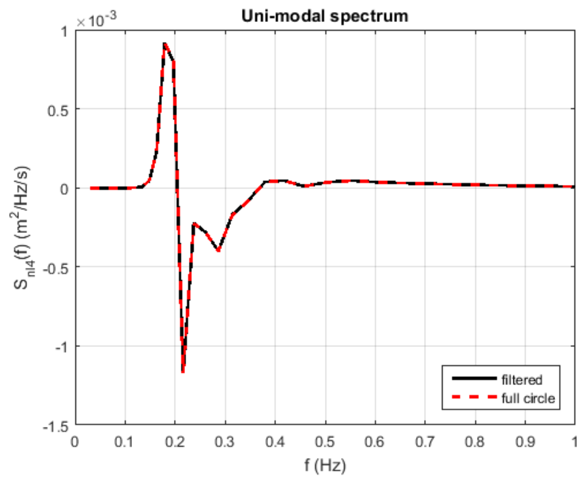
- NLOCUS Number of points on the locus
- INTEG Integration method, trapezoid or Gauss-Legendre
- TEST Generation of test output
- FILT Filtering of interactions in case $\mathbf{k}_1$ and $\mathbf{k}_3$ are too far separated in wave number space according to 2 criteria:
  $\max(k_1/k_3, k_3/k_1) <$ F_KRAT (default 2.5)
  $|\theta_1 - \theta_3| <$ F_DMAX difference (default 75°)

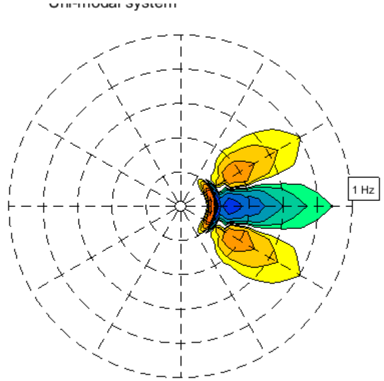
- Do these settings work for opposing spectra?
- Does filtering affects the result?
- Set-up for academic situation

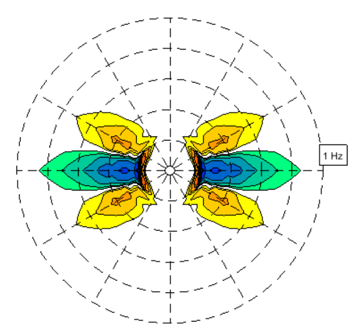
Effect on double peaked spectrum

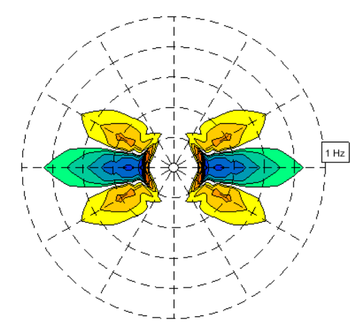








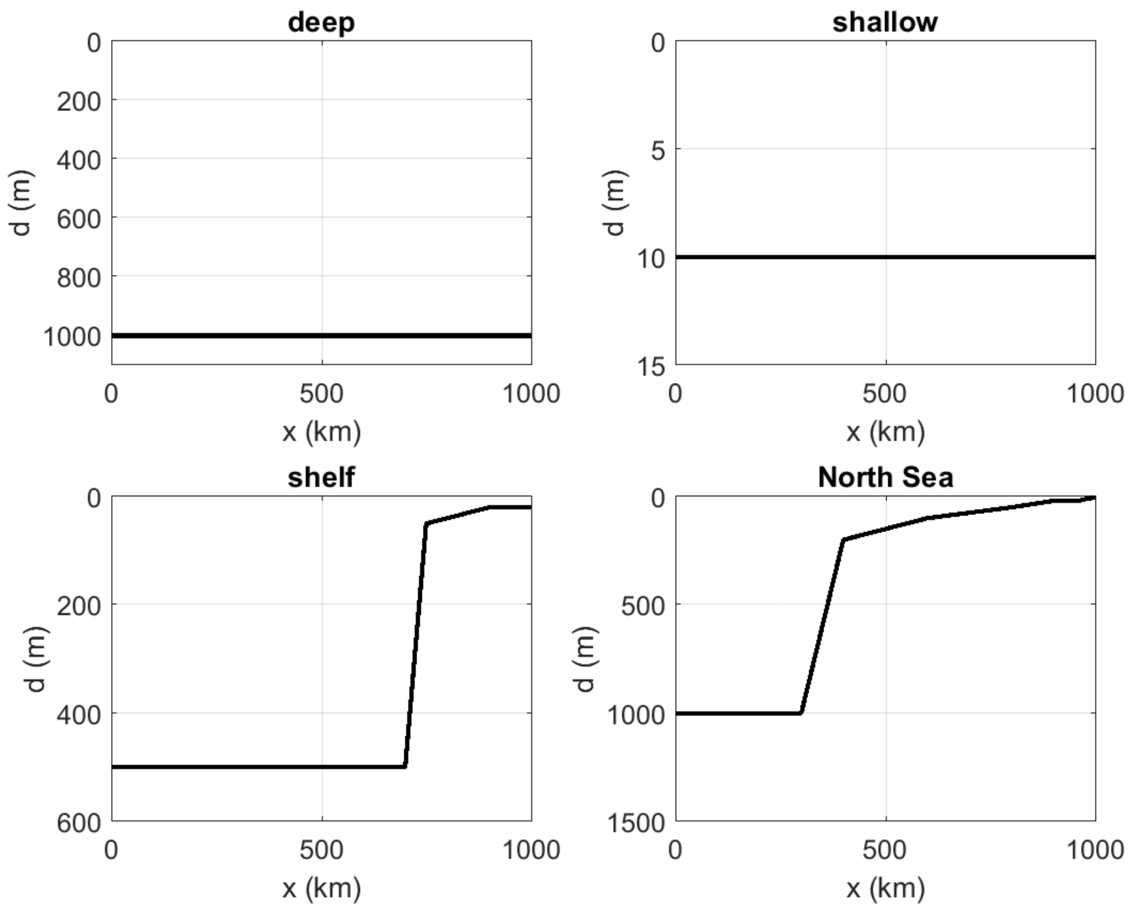




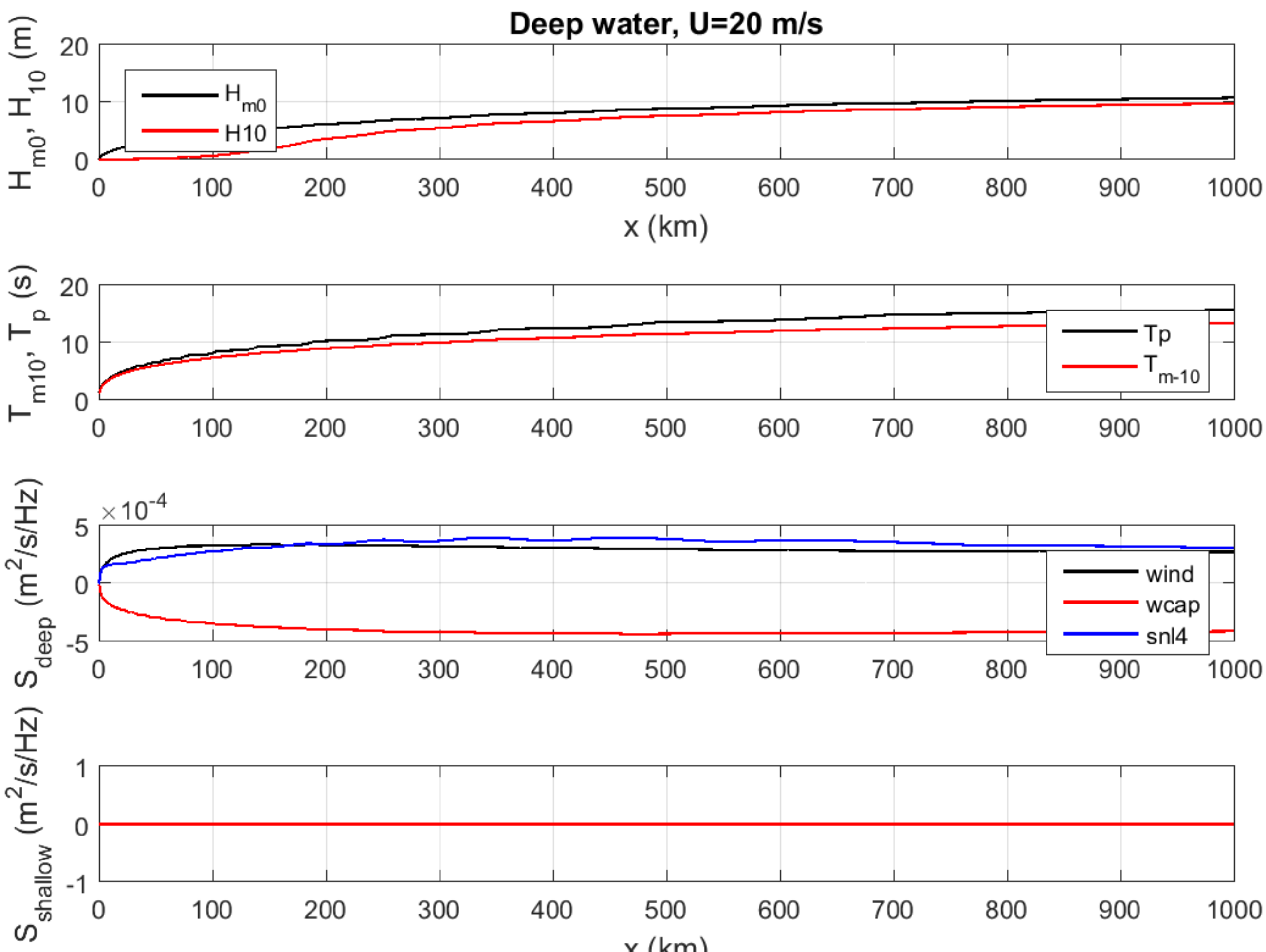
Conclusion: filtering does not affect Snl result for opposing spectra

1-d wave model experiments

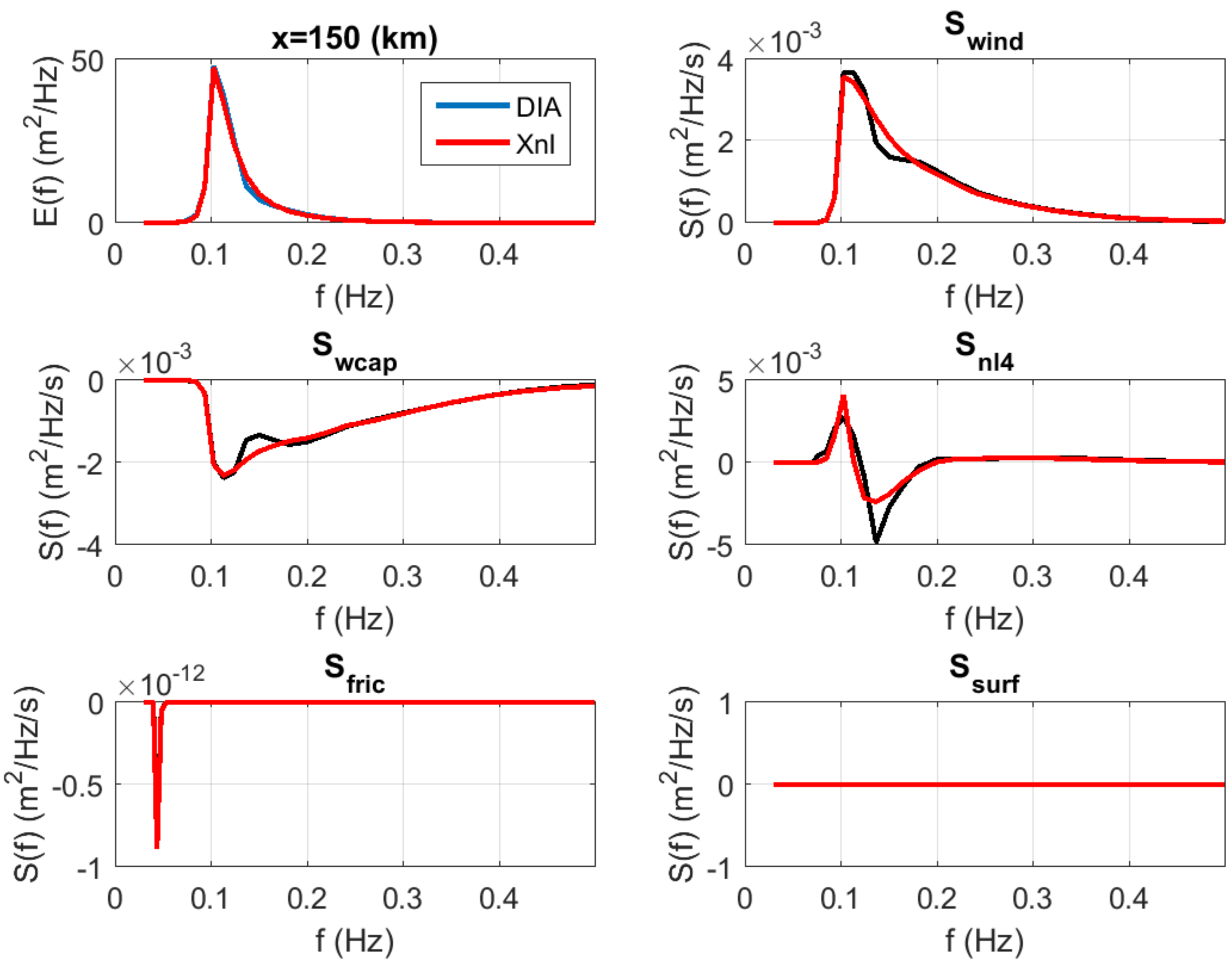
4 typical bathymetries



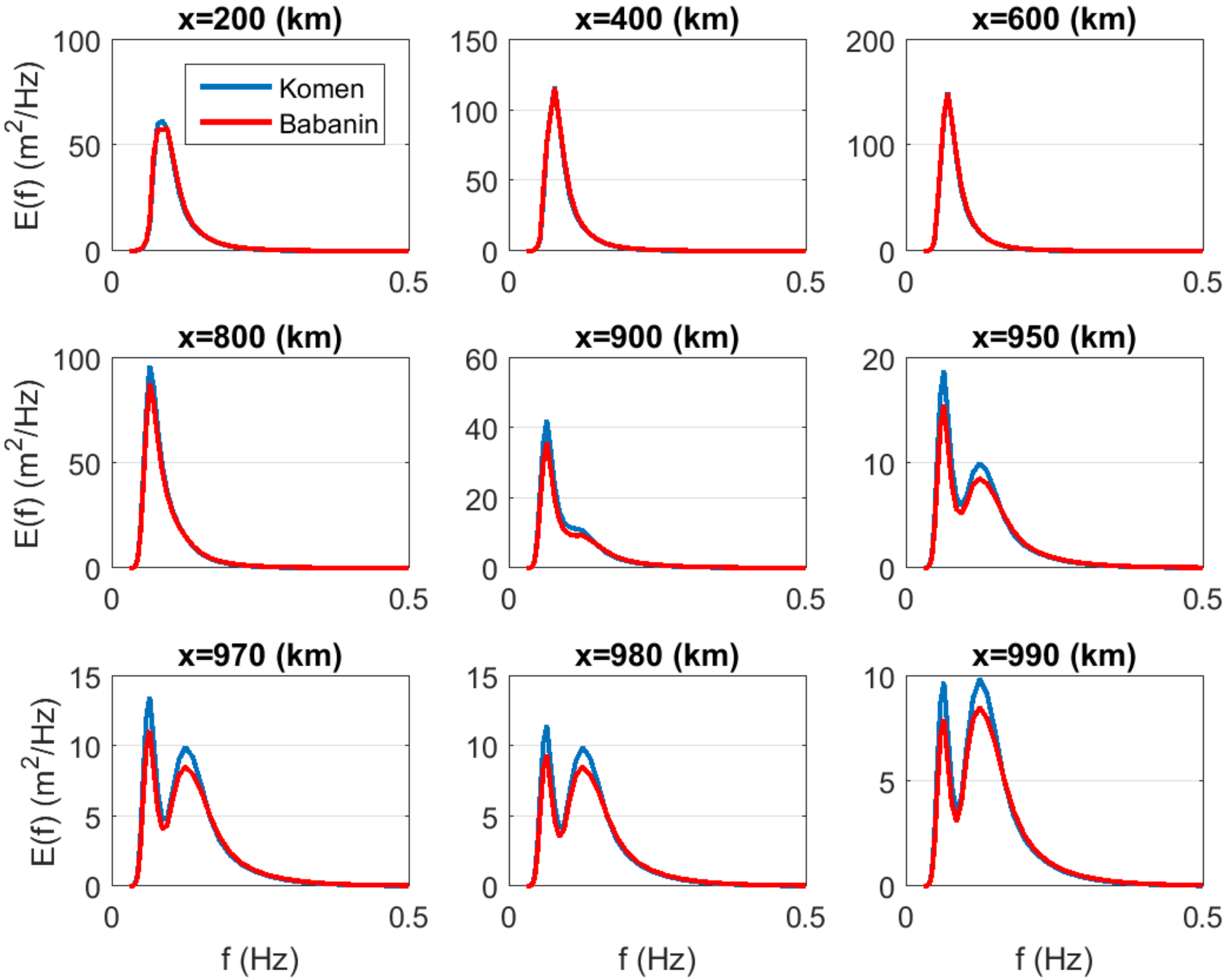
Deep water source term balance



Snl4 (DIA – Xnl, deep water)



S_{wcap} (Komen – ST6), shelf



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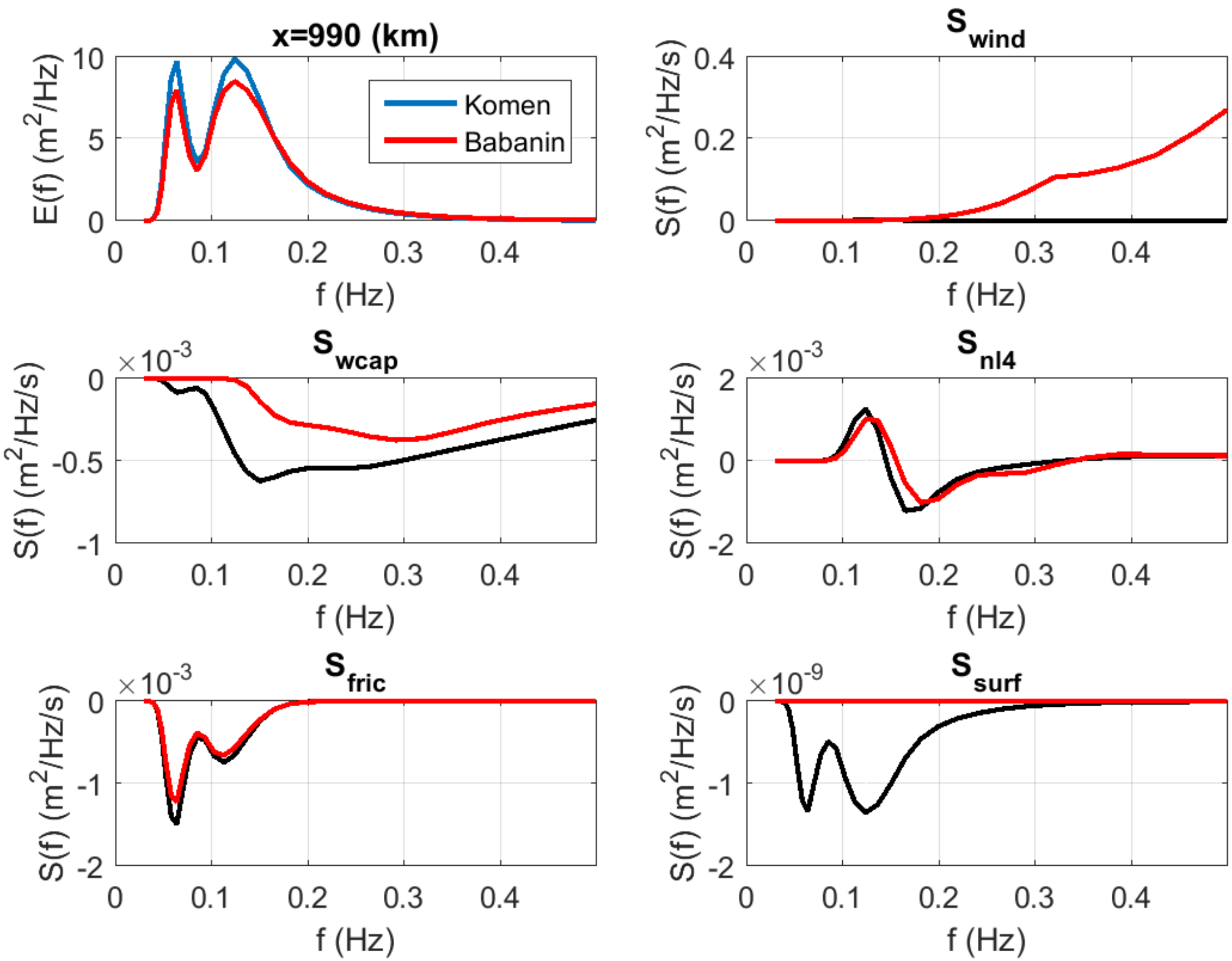
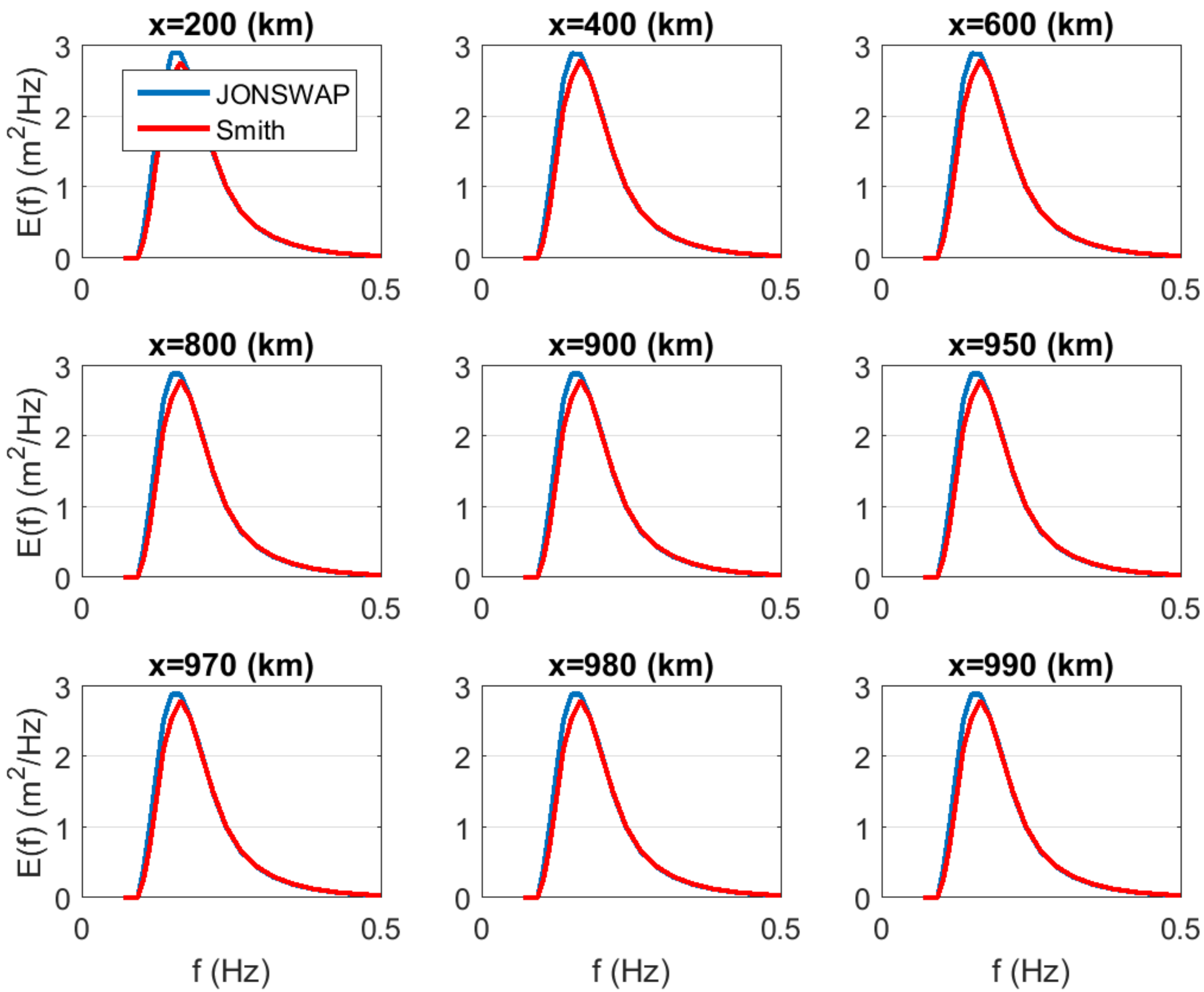
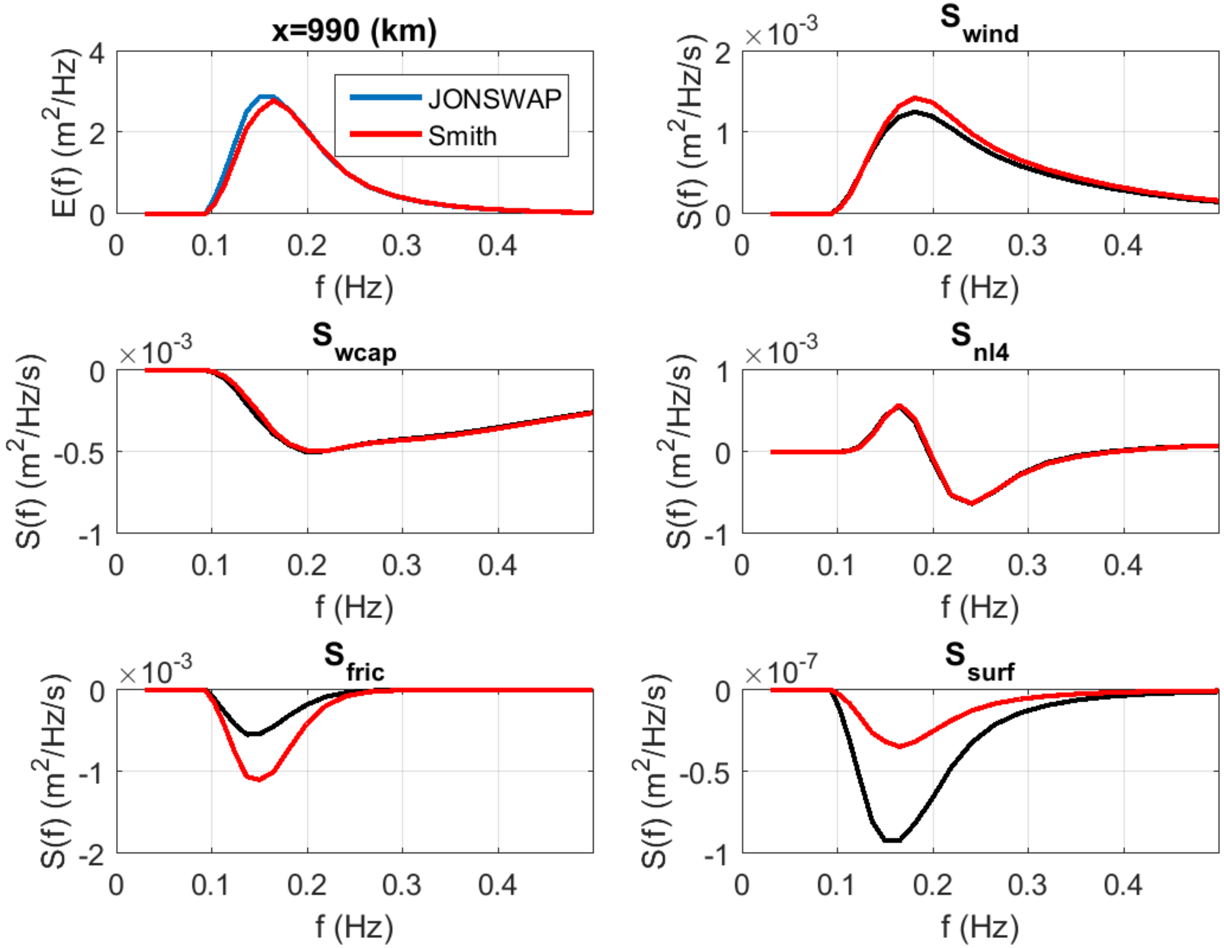


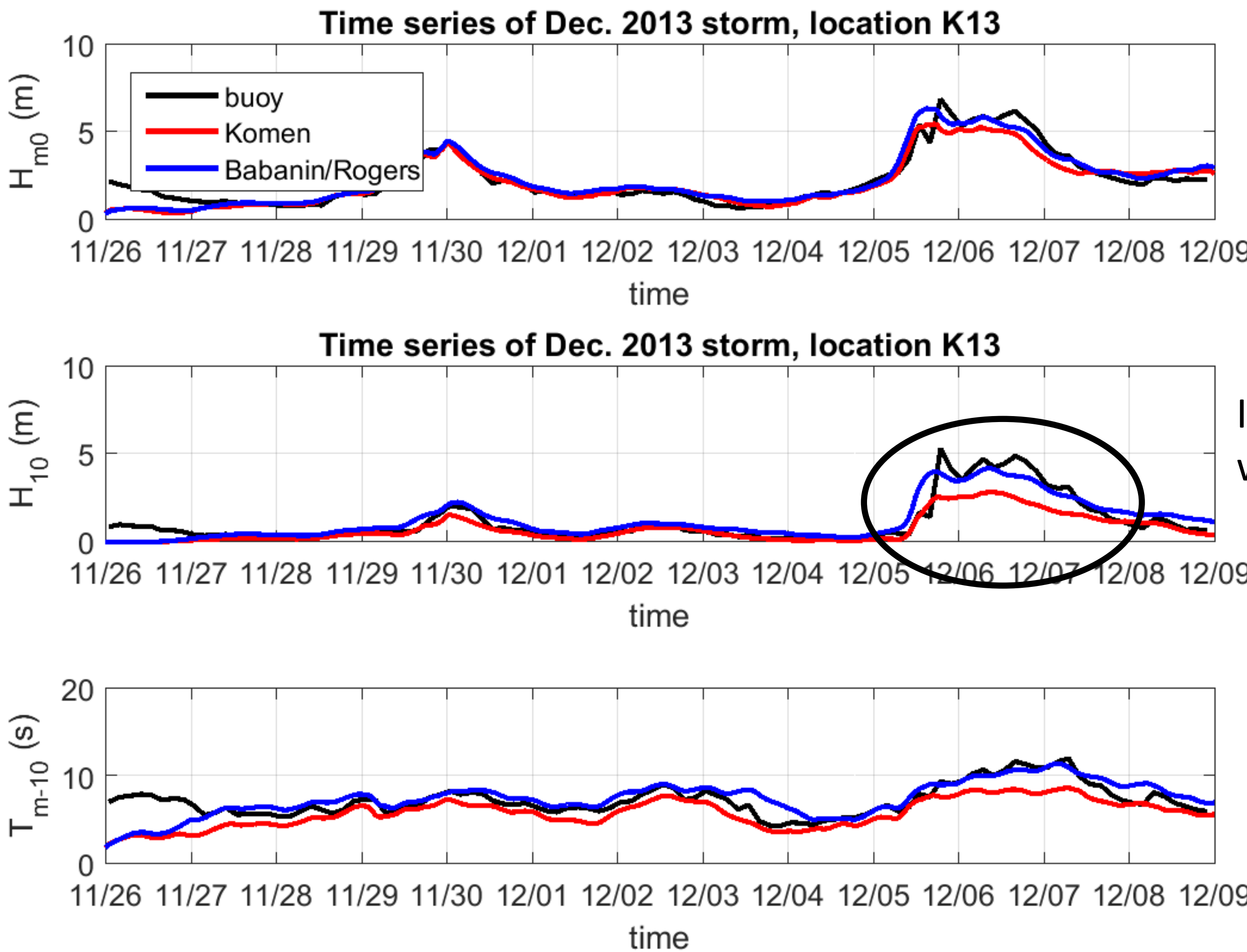
S_{fric} (JONWAP – Smith), shallow



S_{fric} (JONWAP – Smith), shallow



Storm dec 2013



Improves swell waves

- Conclusions
  - New source terms implemented in SWAN
  - Improved wave breaking (β-kd model)
  - Initial test whitecapping (ST6) encouraging
  - New bottom friction (Smith et al. 2011)
  - Improved prediction of H10 (new physics ST6)
- Further work
  - Test settings of ST6
  - Implement ST4
  - Snl4, LQA development
  - Implement new triad formulations
  - Implications of new breaking on storm surges
  - Include spectral partitioning

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