Deltares

Shallow water issues SWAN under extreme conditions

Jacco Groeneweg

Joana van Nieuwkoop

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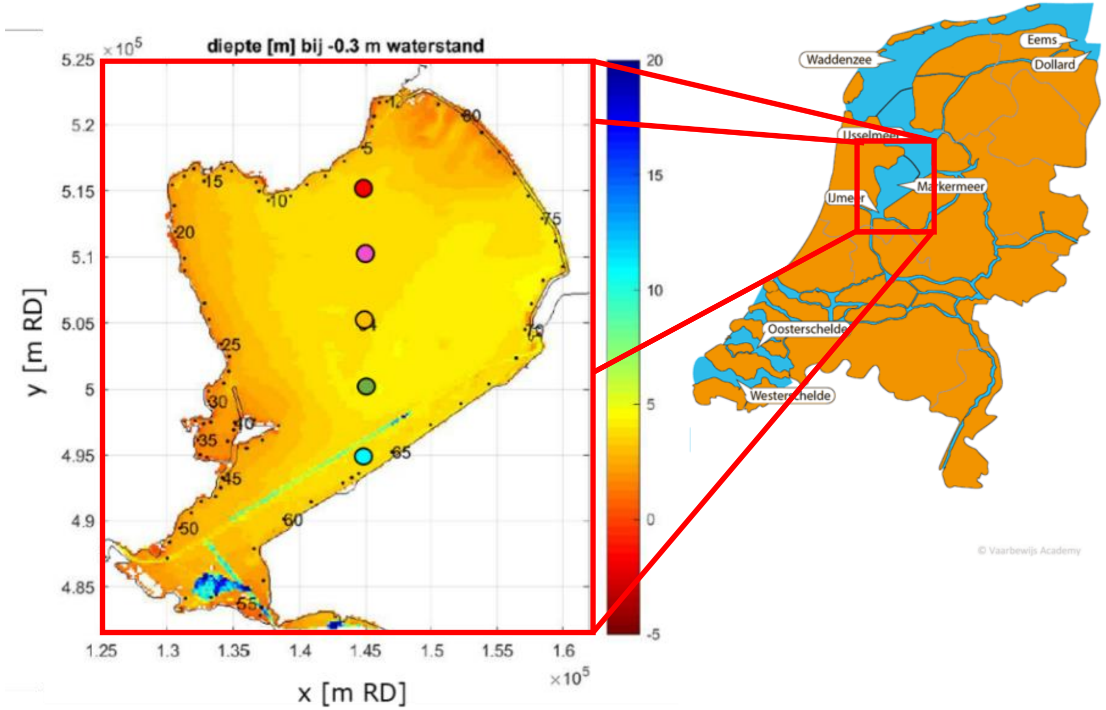
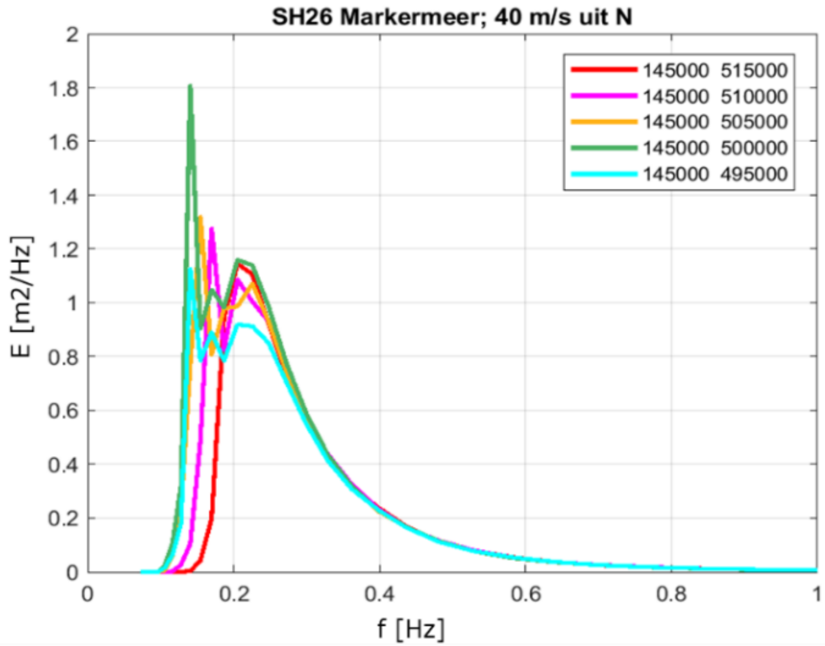
Background

- SWAN is part of design and safety instrumentation for levees along primary sea defences in the Netherlands

- Irregularities near spectral peak for strongly forced, growing waves over relatively flat bed.



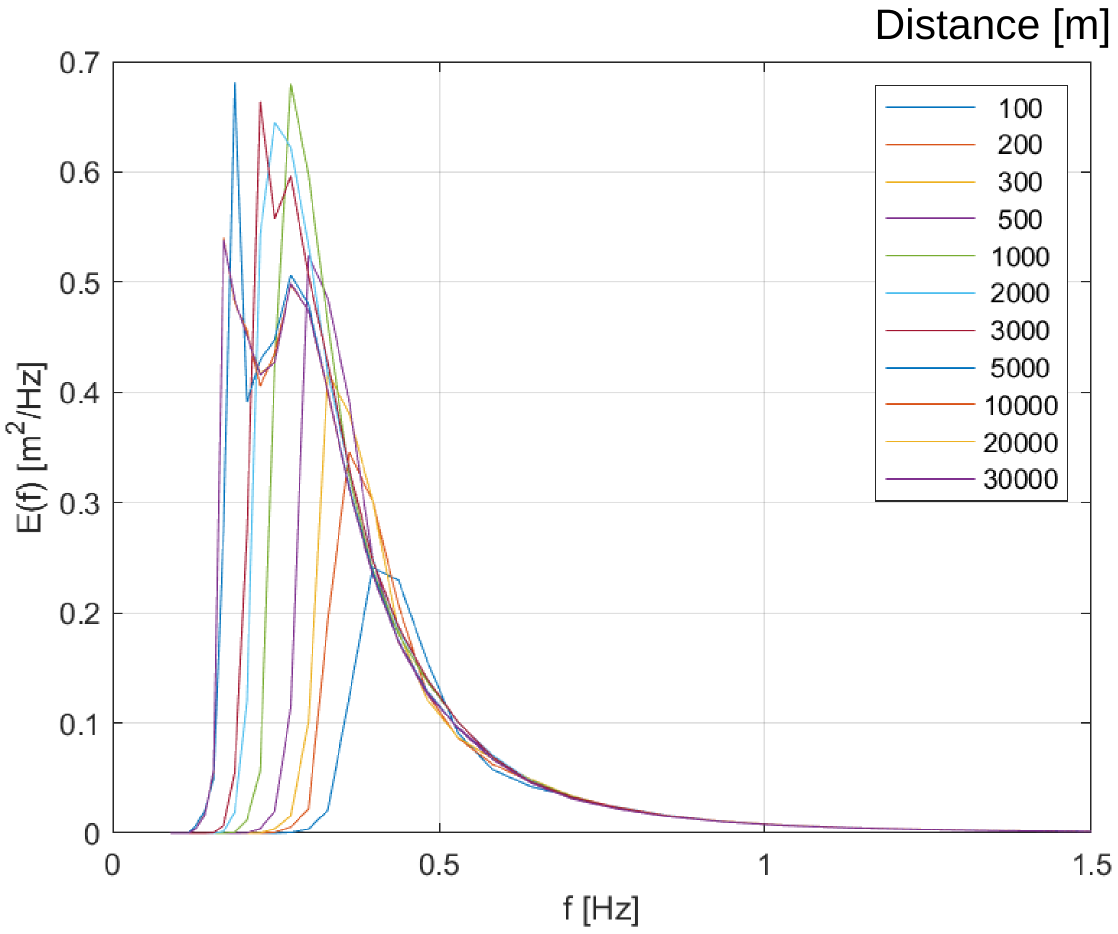


Brief analysis 1D case

Simplification to 1D case

- Channel: length = 30 km, depth = 2.5 m
- Wind speed = 40 m/s

- Physical settings:
  - Default wind generation/whitecapping (V.d. Westhuysen/Yan), quadruplets (DIA), bed friction (Jonswap)
  - Deth-induced breaking: V.d. Westhuysen (2011)
  - Triads: LTA-CCA (Salmon and Holthuijsen, 2015) with *trfac* = 0.8
- Numerical settings: 80 iterations



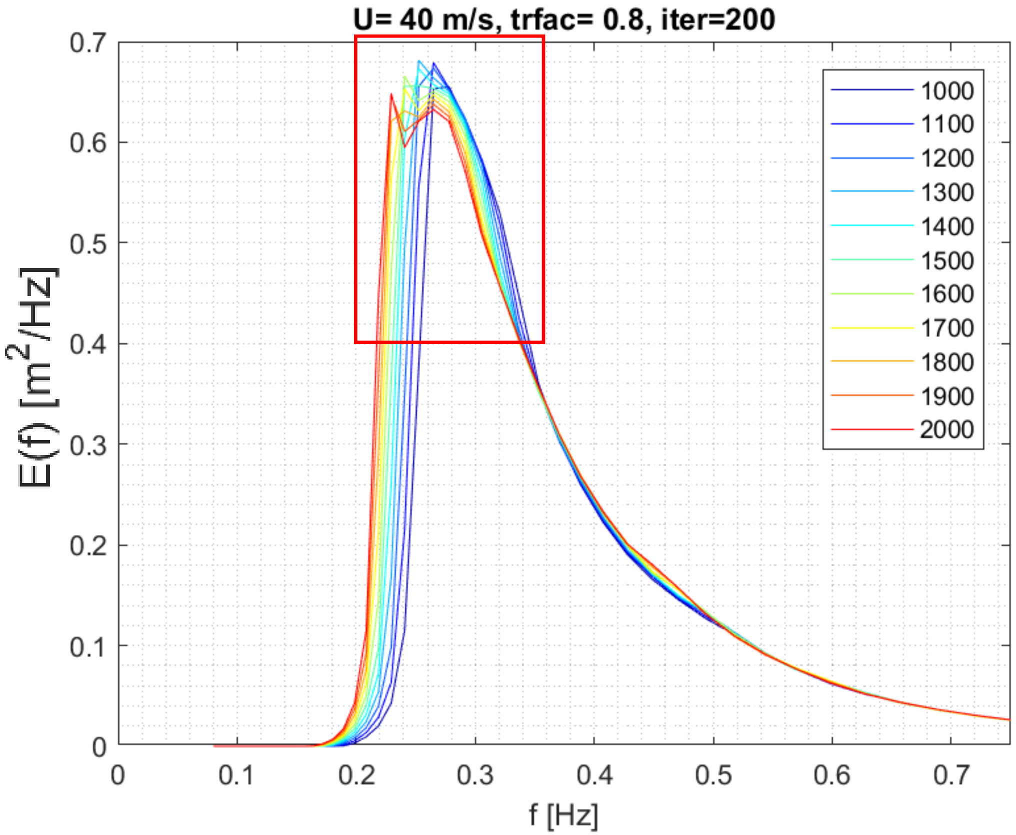
Numerical issues?

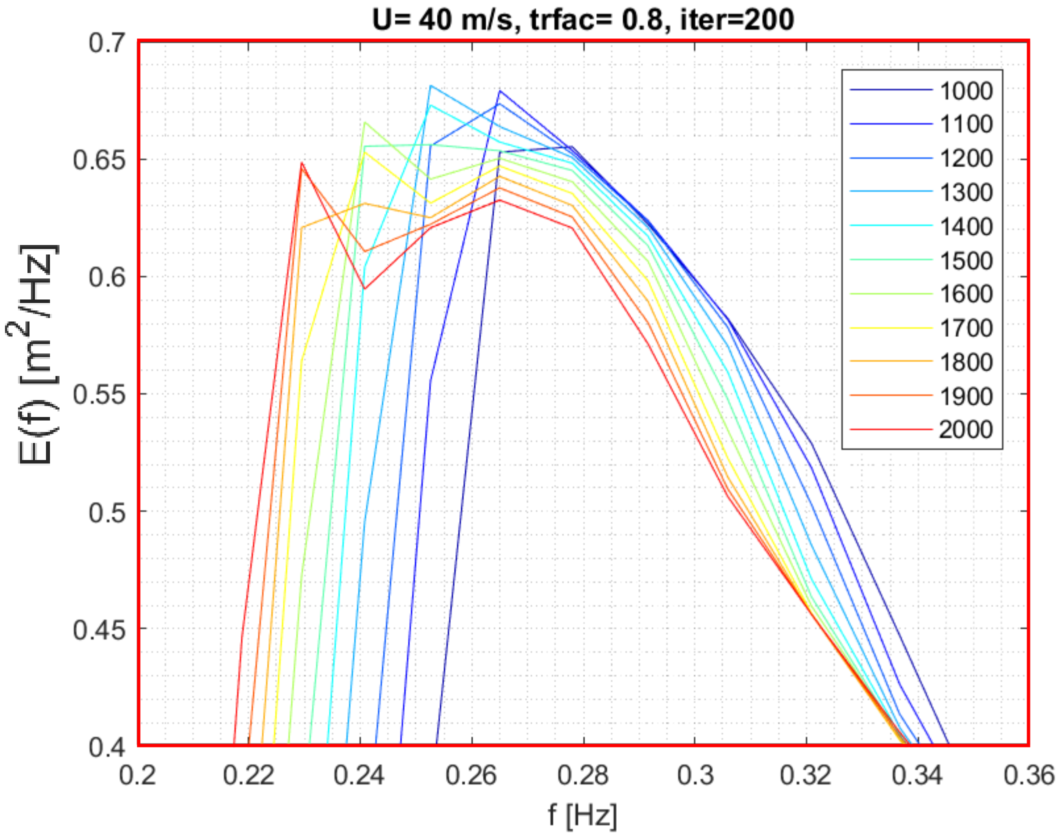
Numerical grid change:

- Δx = 30 m → 10 m; Δf/f = 0.1 → 0.05
- 200 iterations

No effect of numerical measures observed:

- Rescaling off
- Including under-relaxation (alfa = 0.01)
- Decreasing limiter

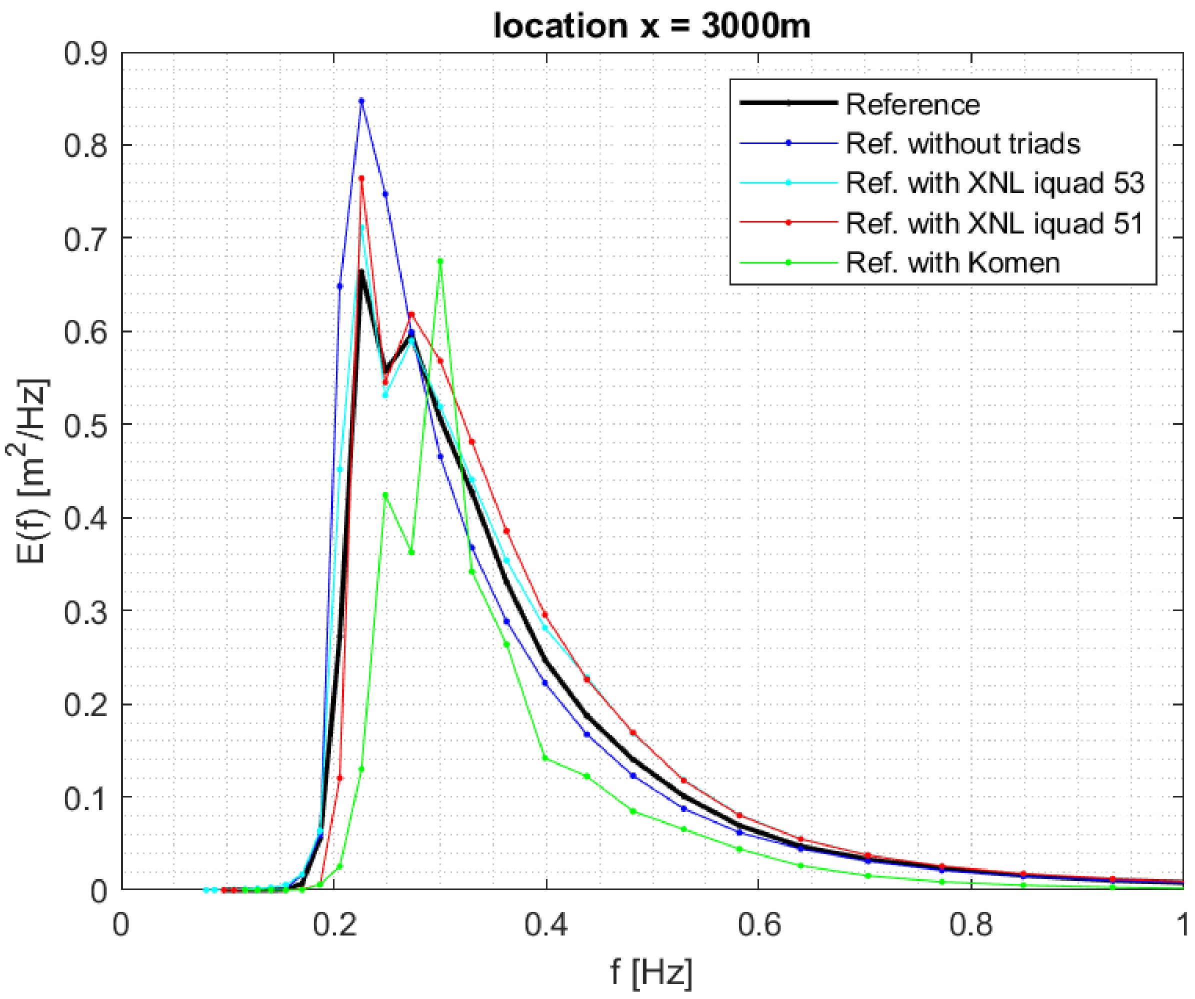




Sensitivity source terms

- Reference:
  - Default wind generation/whitecapping (V.d. Westhuysen/Yan), quadruplets (DIA), bed friction (Jonswap)
  - Deth-induced breaking: V.d. Westhuysen (2011)
  - Triads: LTA-CCA (Salmon and Holthuijsen, 2015) with *trfac* = 0.8

- XNL-quads, Komen wind/whitecapping: still irregularities
- No triads: no irregularities



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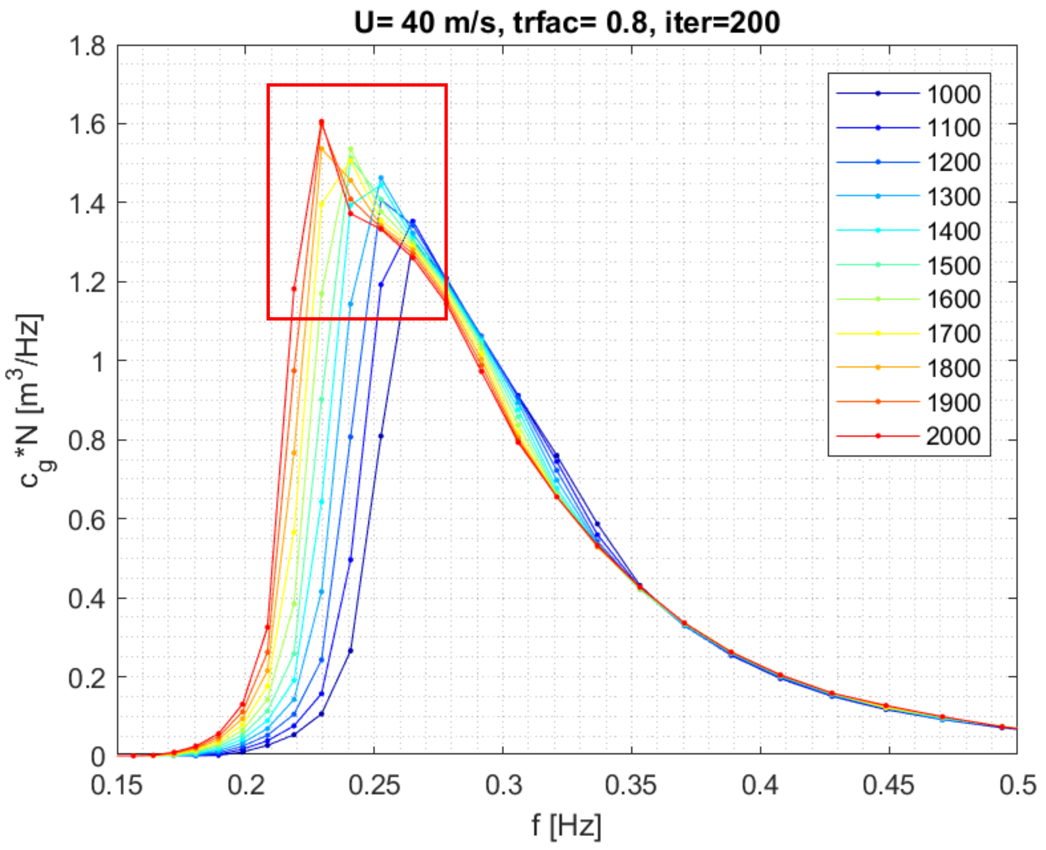
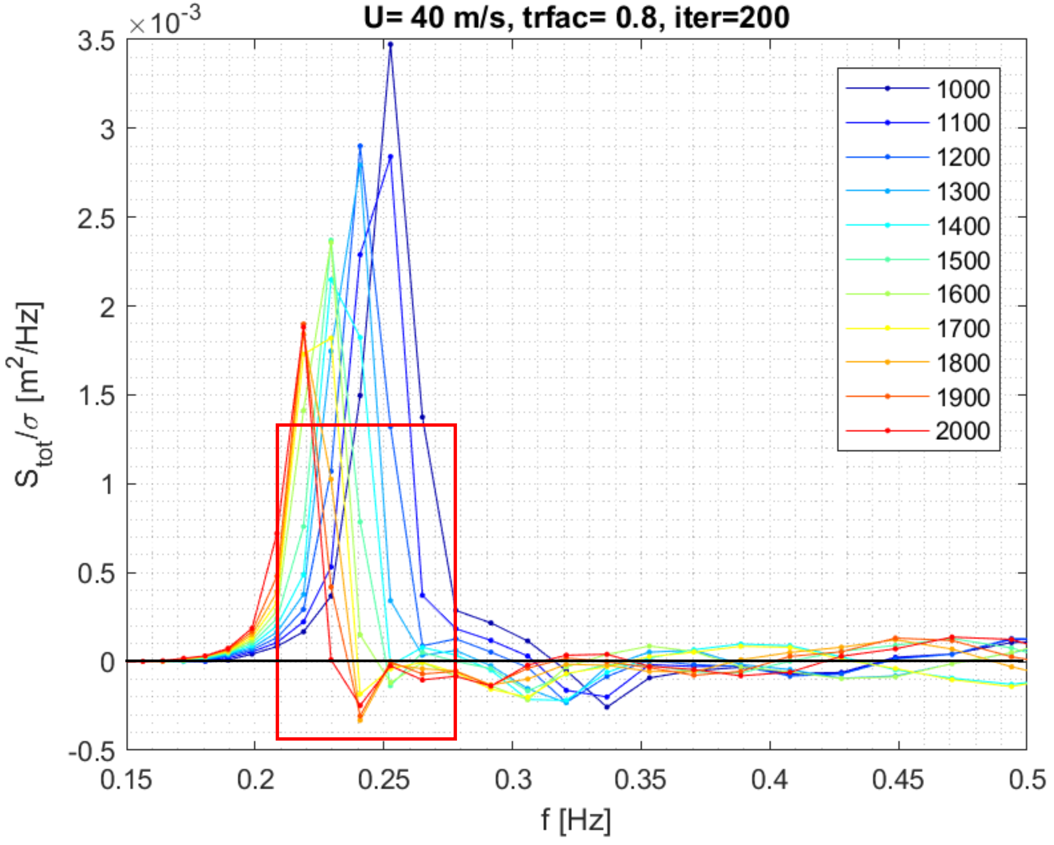
Detailed analysis source term balance (1D)

Action balance equation

$$\frac{\partial N}{\partial t} + \nabla_{\vec{x}} \cdot [(\vec{c}_g + \vec{u})N] + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_{\text{tot}}}{\sigma}$$





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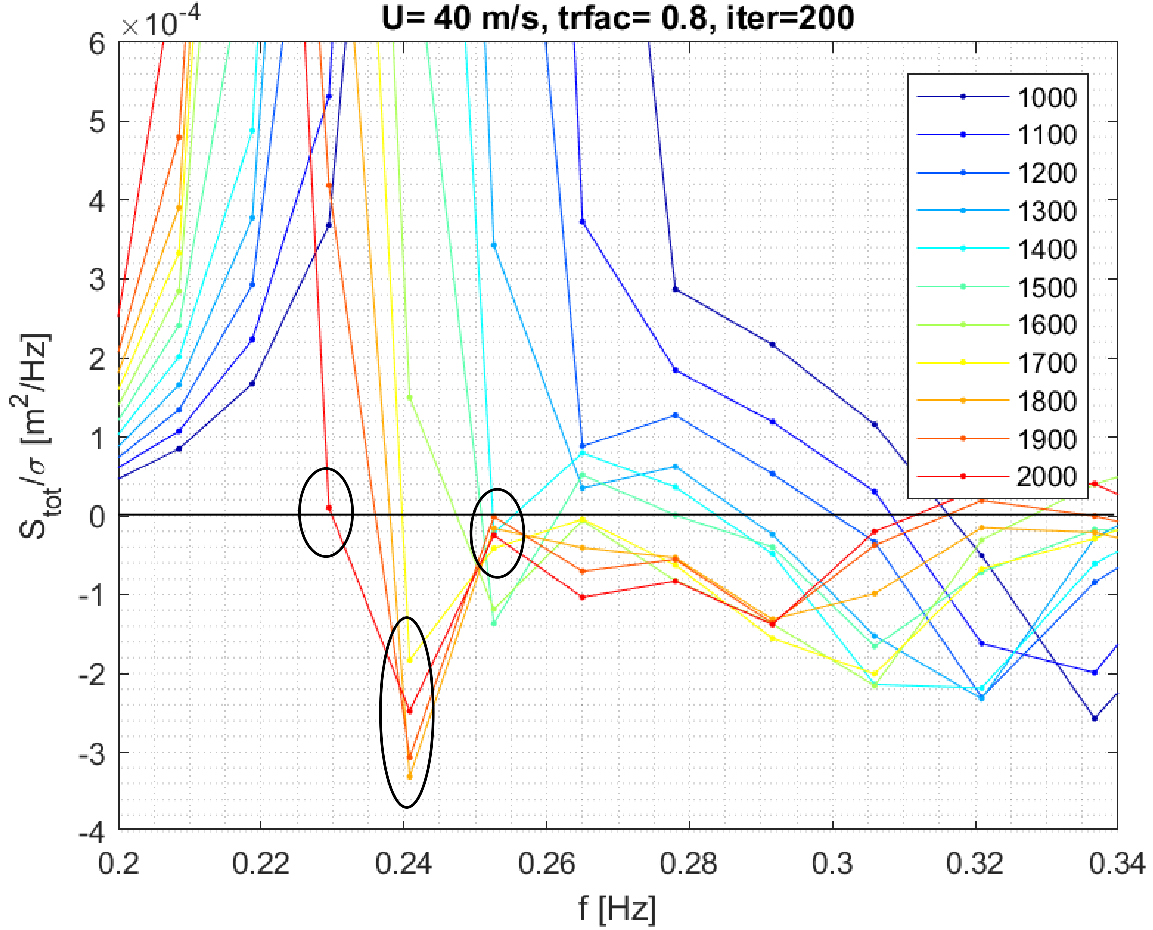
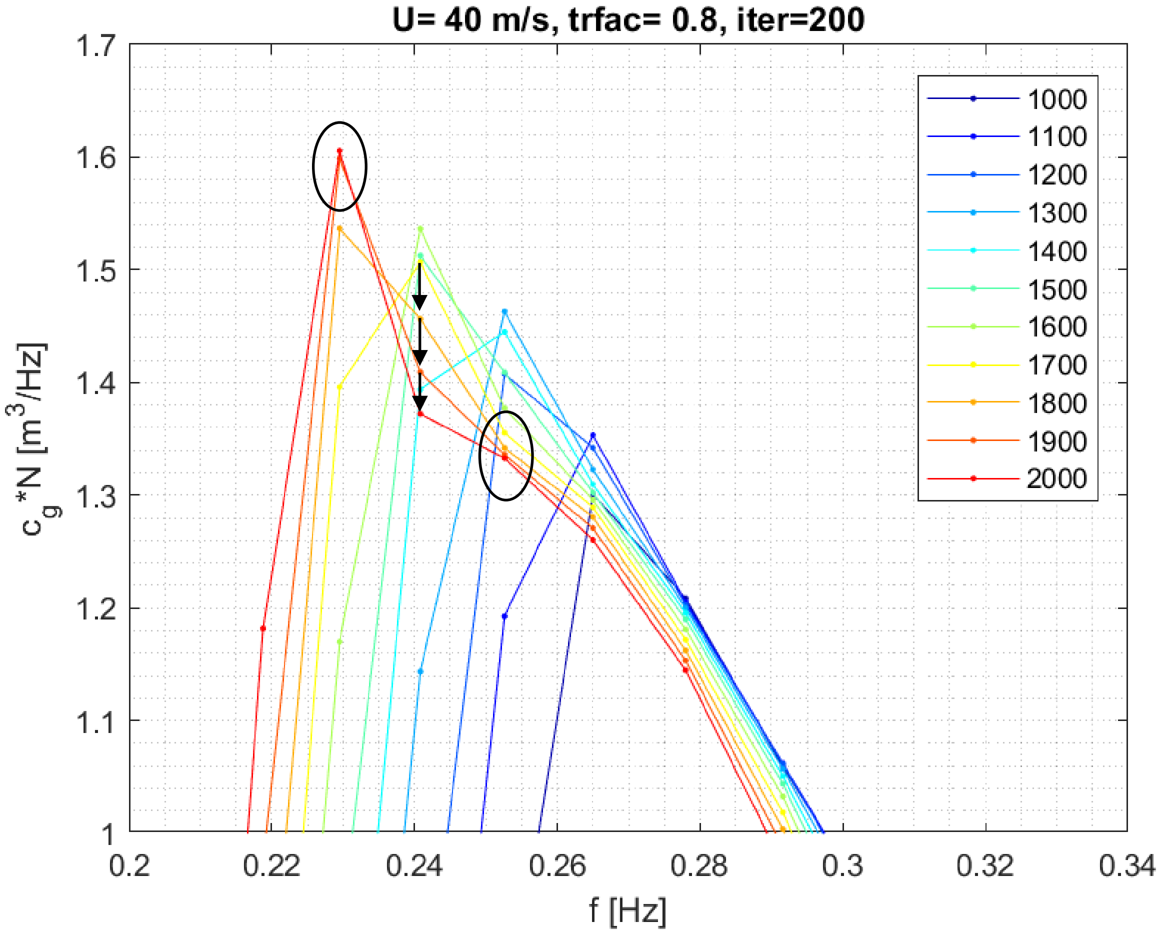
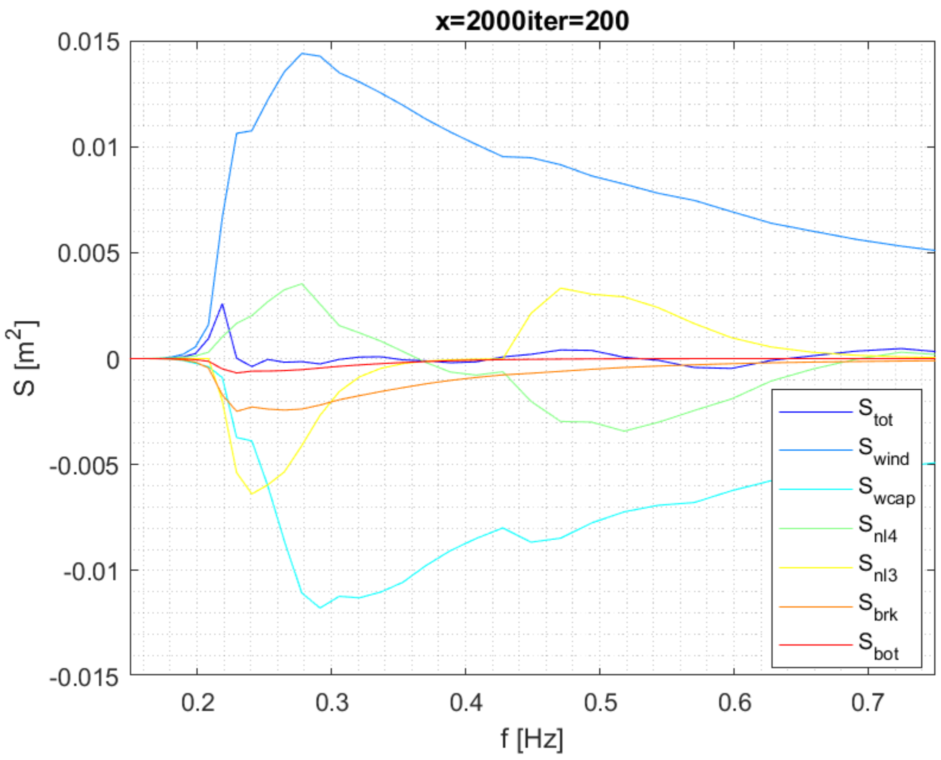
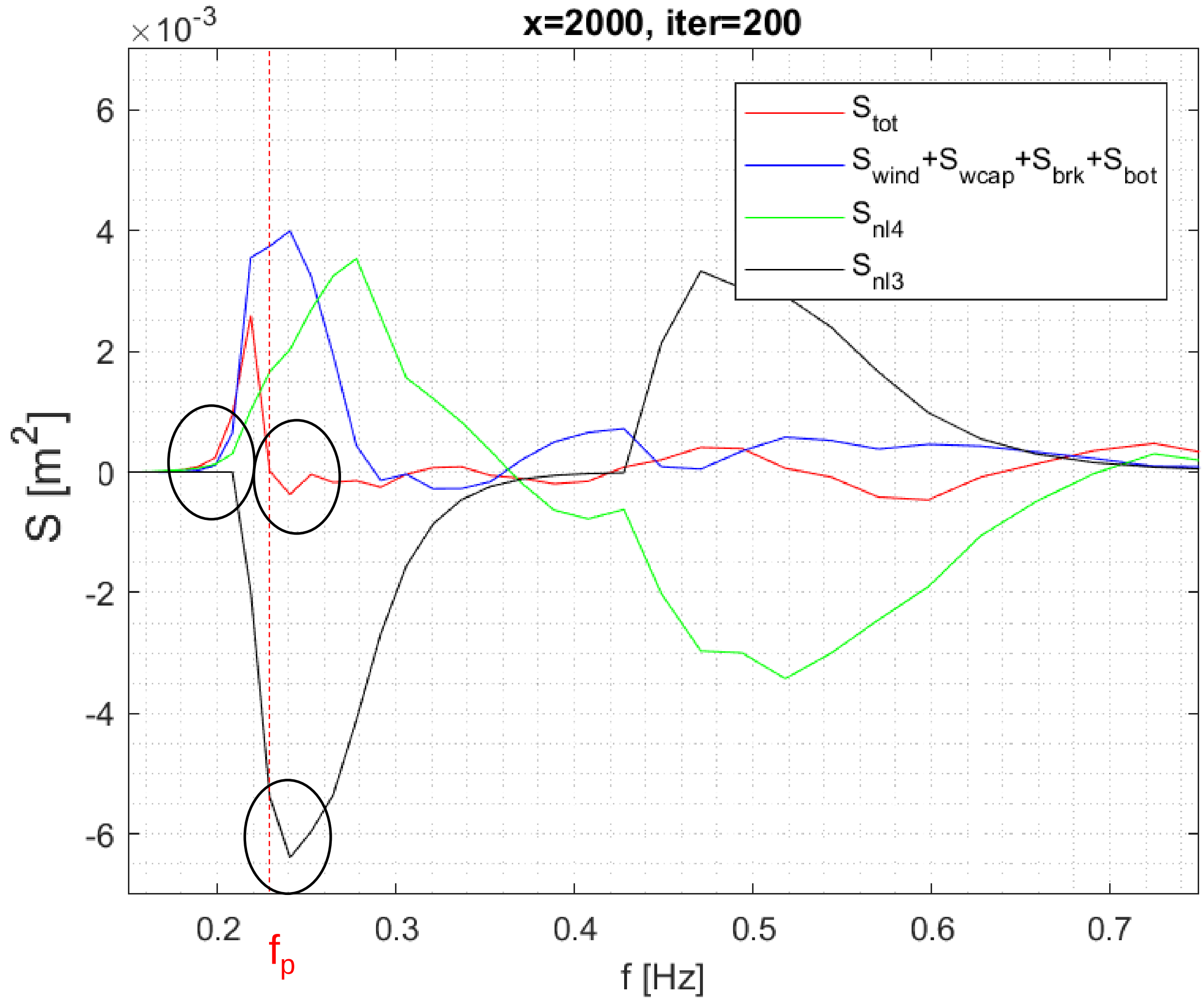




Source terms





- Triad magnitude seems responsible for negative ‘wiggle’
- Triad minimum one bin next to f_p
- Triads inactive at low frequencies where energy is present (threshold in code?)

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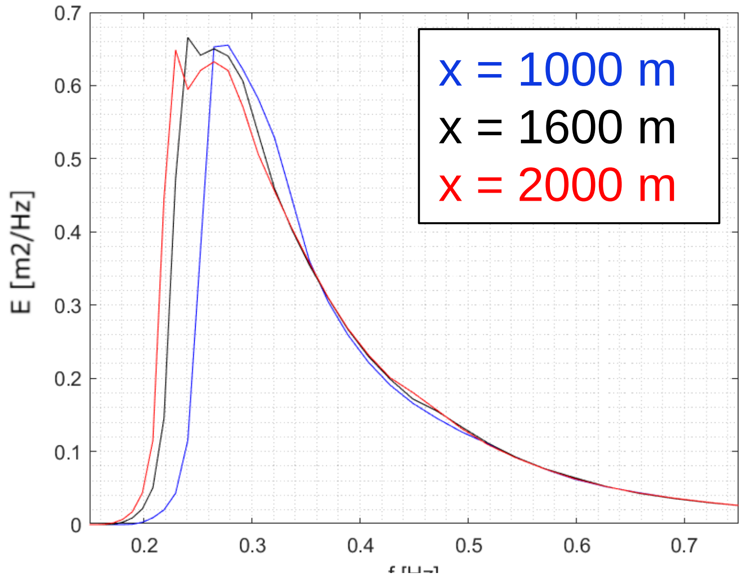
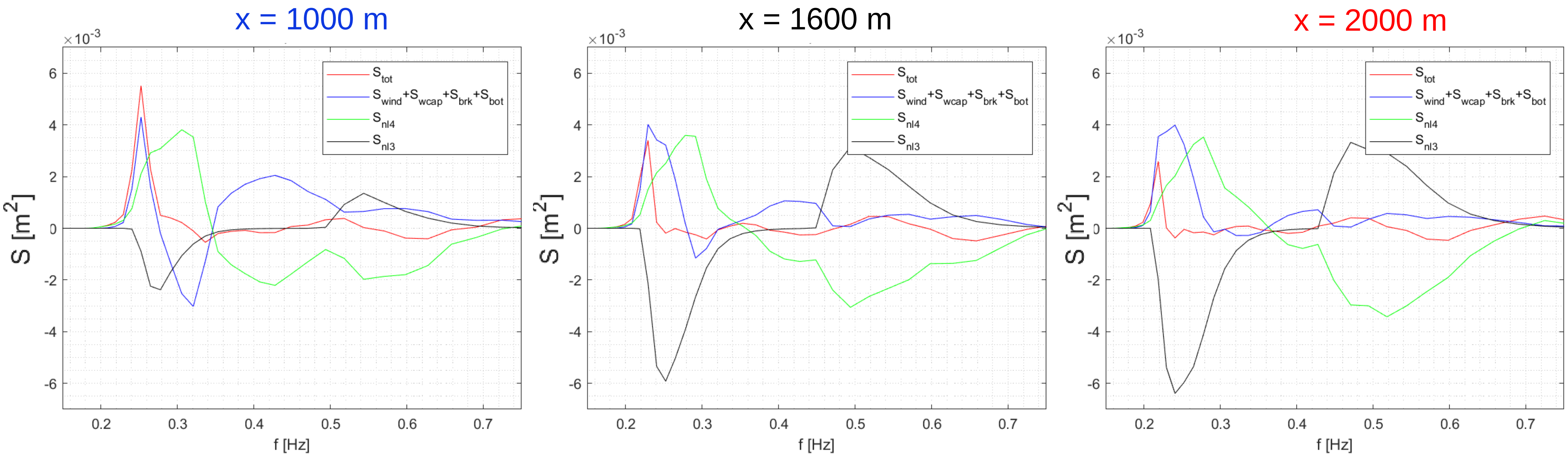
Source term evolution

- Wiggles occur when triad and quad source terms are of comparible size
- Is the magnitude of triad source term realistic?





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LTA source term, including biphase

LTA source term for triads (Eldeberky, 1996)

$$S_{nl3}(\sigma) = S_{nl3}^{+}(\sigma) + S_{nl3}^{-}(\sigma)$$

$$S_{nl3}^{+}(\sigma) = \max\left[0, \alpha c_{\sigma} c_{g,\sigma} J^2 \sin(-\beta)\{E^2(\sigma/2) - 2E(\sigma/2)E(\sigma)\}\right]$$

$$S_{nl3}^{-}(\sigma) = -2S_{nl3}^{+}(2\sigma)$$

Biphase

Proportionality coefficient *trfac*

- Two implementations of LTA:
  - Original Collinear Approximaton (OCA)
  - Consistent collinear approximation (CCA): improvement over OCA for narrow directional spread sea (Salmon and Holthuijsen, 2015)

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Calibration of LTA - *trfac*

- Calibration based on **laboratory experiments** by Beji & Battjes (1993) and Boers (1996)
    - OCA: V.d. Westhuysen (2007): *trfac* = 0.05
        - Visual calibration
        - Value confirmed by Gautier (2010)
    - CCA: Salmon (2016): *trfac* = 0.8
        - Minimization of scatter index H_{m0} and T_{m02}.
        - Focus on narrow directional spread

- Notes:
    - Field cases are not narrowly spread, so why not different values for *trfac*?
    - De Wit (2022) showed strong dependency of bed slope on optimal *trfac*
    - Applying CCA with *trfac* = 0.05 showed NO irregularities (but value not based on calibration)

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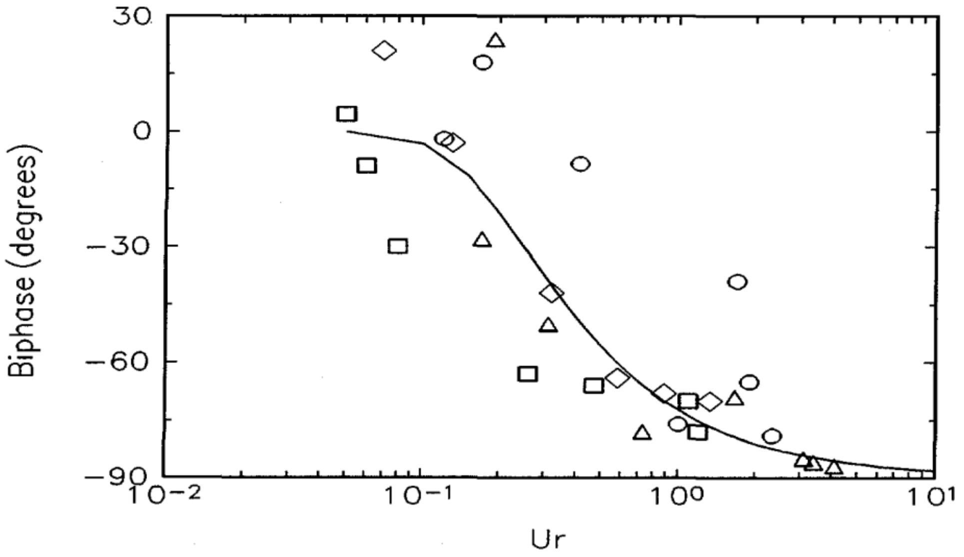
Biphase in LTA

- Eldeberky (1996) used laboratory experiments to determine simple biphase relation: short waves, steep slope

- Relevant for long waves on gentle slope, or even flat bed ?

- Alternatives:
  - Doering and Bowen (1995): $U_{r,\mathrm{crit}} = 0.63$ based on field measurements
  - De Wit (2022): $\beta = \beta_c \sqrt{\tanh U_r}$ with β_c depending on local bed slope and local peak wave period



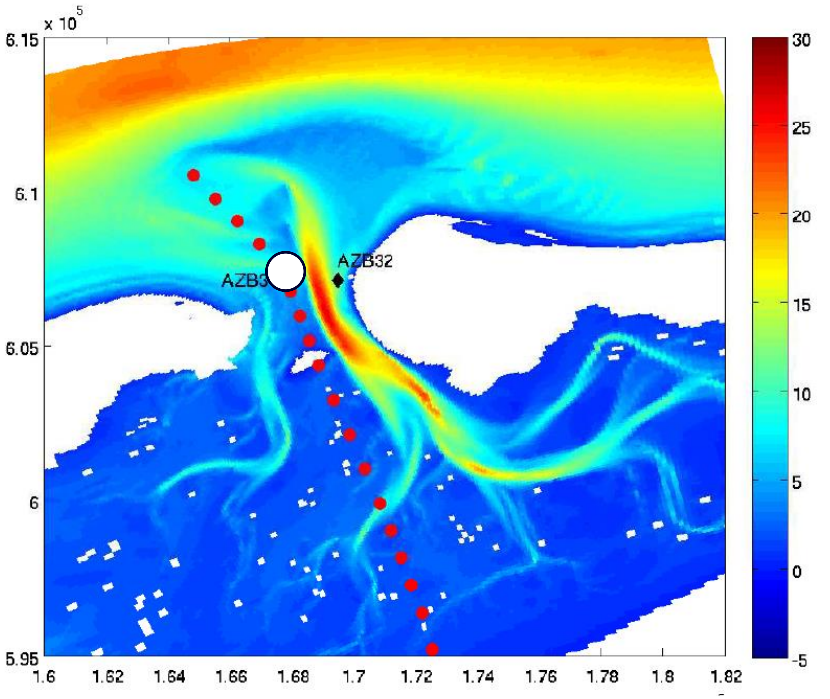
$$\beta(f_p, f_p) = -\frac{\pi}{2} + \frac{\pi}{2} \tanh\left(\frac{U_{r,\mathrm{crit}}}{U_r}\right)$$

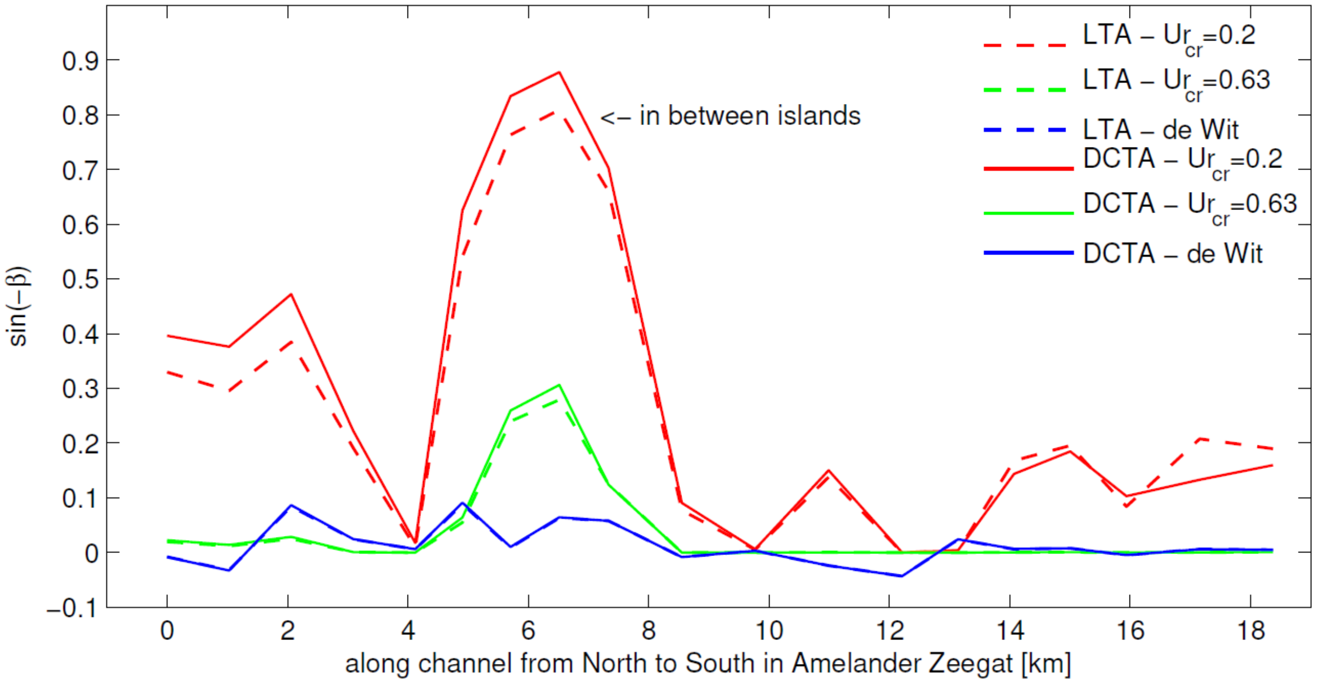
$$U_{r,\mathrm{crit}} = 0.2$$

Sensitivity biphase

- Tidal inlet between two Wadden islands
- Also comparison two triad formulations (LTA and DCTA)
- Courtesy: Marcel Zijlema (Delft Univ.)

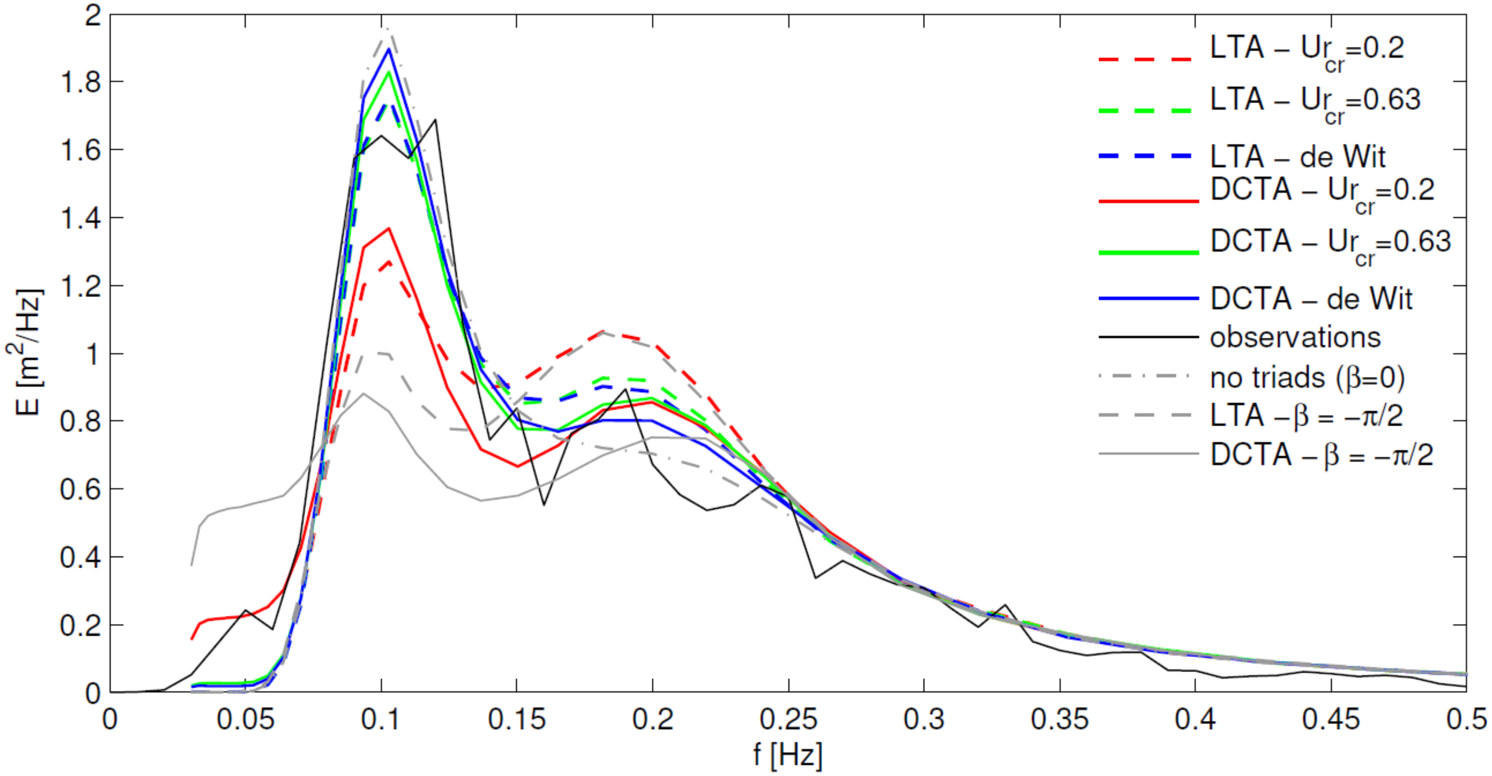
- Biphase based on $U_{r,\mathrm{crit}} = 0.2$ is strongly exaggerated in the channel





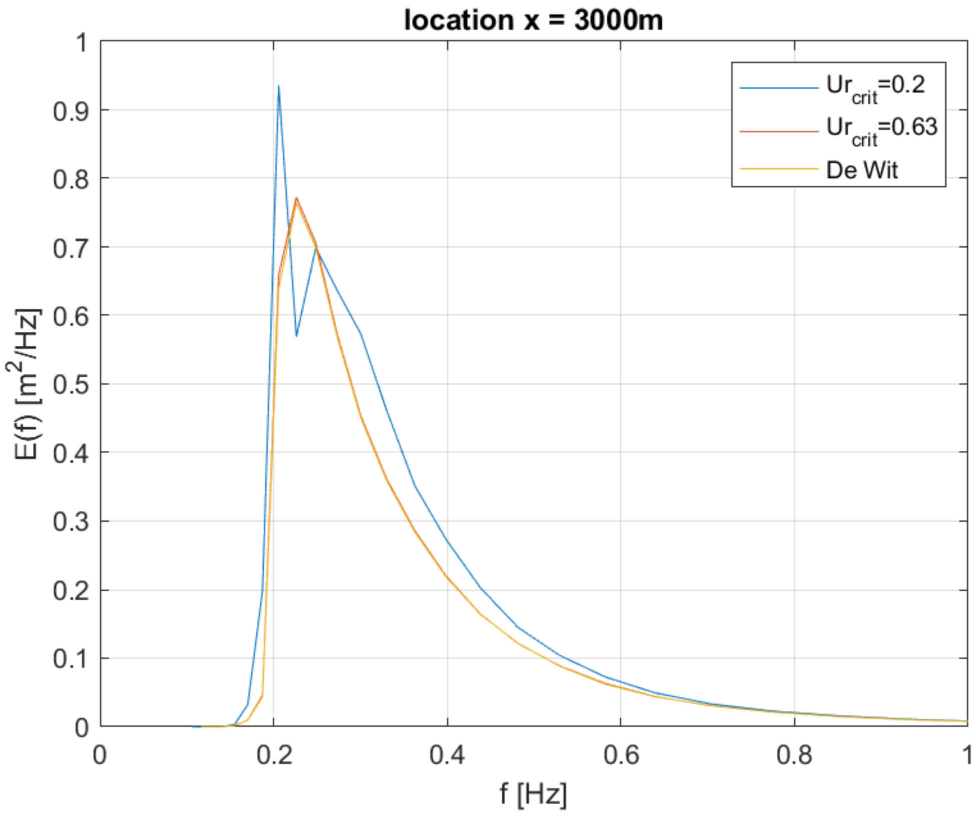
Sensitivity biphase

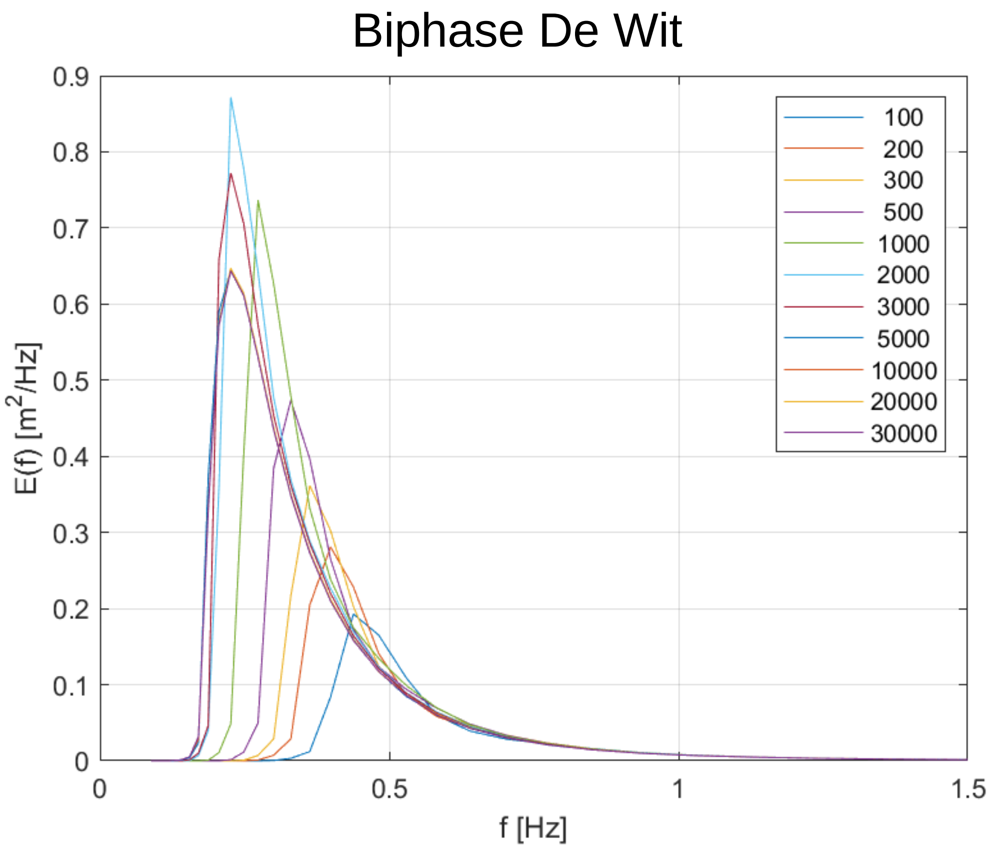
- Low critical Ursell number (0.2) induces excessive level of triad interactions
- Remedy: increase critical Ursell number or apply De Wit's biphase parametrisation
- Differences in predictive ability between LTA and DCTA of secondary importance



Changing biphase in 1D case

- Irregularities disappear





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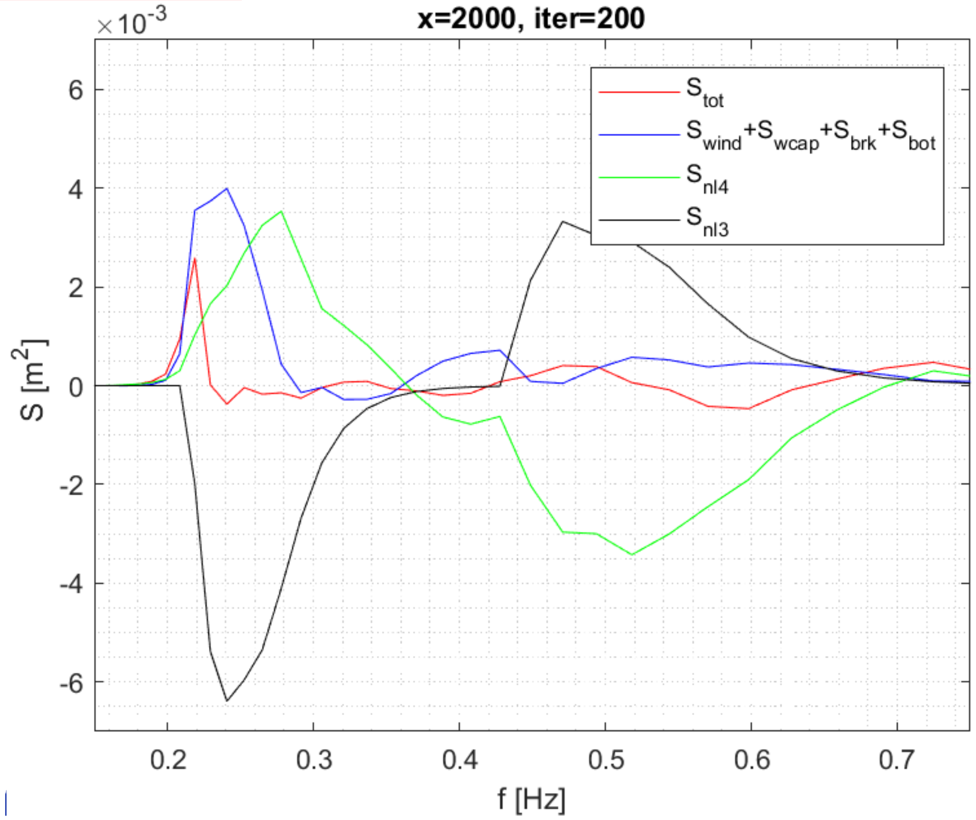
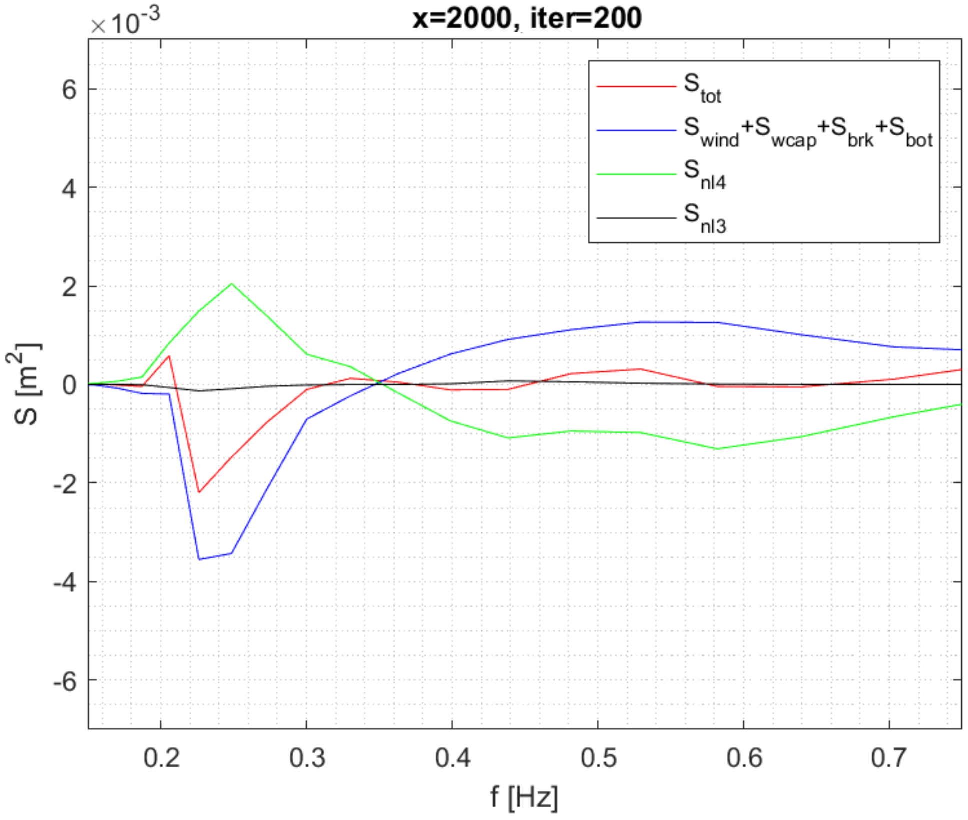
Changing biphase in 1D case

- Magnitude triad source term decreases significantly

$U_{r,\mathrm{crit}} = 0.2$



$U_{r,\mathrm{crit}} = 0.63$



Conclusions and recommendations

Conclusions and recommendations

For strongly forced waves over relatively flat bed:

- Large magnitude of triad source term (LTA-CCA) leads to wiggle(s) in the sum of the source terms and consequently to irregularities in the spectrum at the peak
- Using alternative biphase formulation (original with $U_{r,crit}$ = 0.63 or De Wit) decreases triad source term magnitude – no irregularities

- Recalibrate LTA-CCA, including field cases
- (Re-)Analyse Eldeberky's biphase relation in general, but for relevant lake cases in particular
- Note: breaker formulation of Van der Westhuysen (2011) also depends on biphase !!!

Contact

www.deltares.nl

info@deltares.nl

@deltares

@deltares

linkedin.com/company/deltares

facebook.com/deltaresNL