The influence of the surfboard effect and hydrodynamic modulation effect on the performance of wave spectrum inversion

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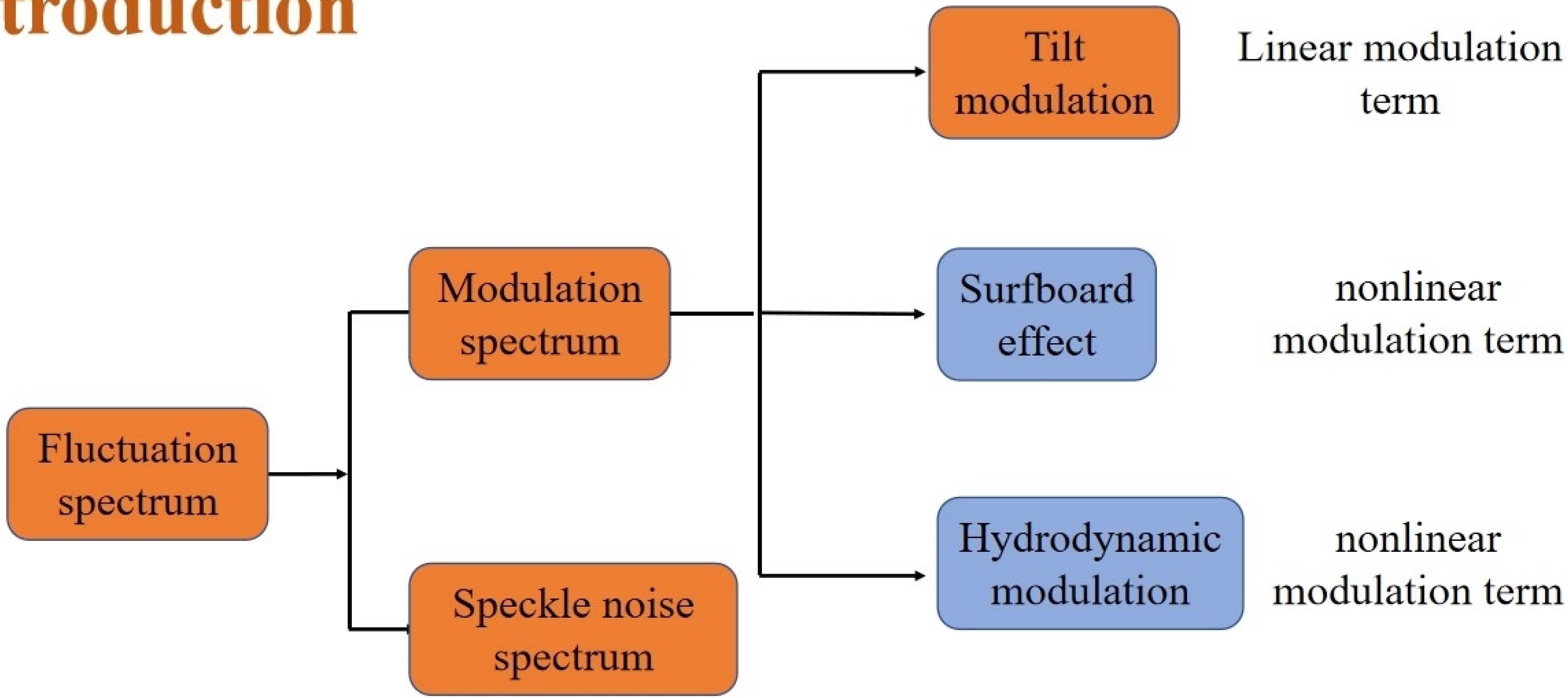
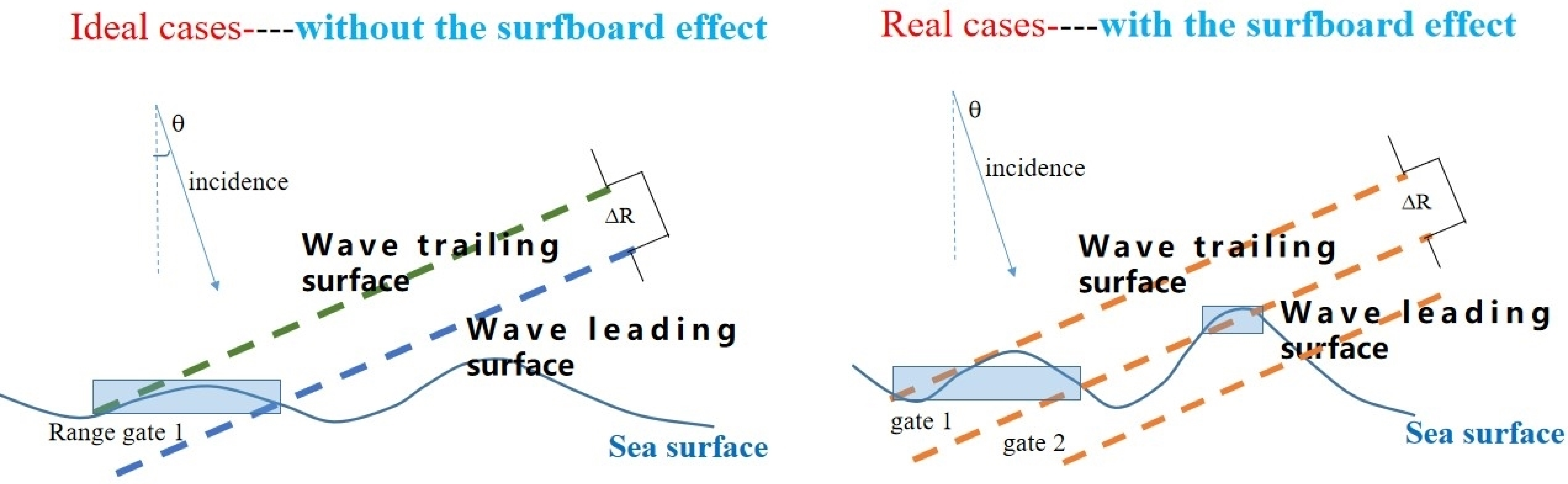
Introduction



Outlines

1. The surfboard effect
2. The hydrodynamic modulation
3. Simulation methods for considering the nonlinear modulations
4. Simulation results for the cases for wind waves
5. Comparison of the measured and simulation results
6. Conclusion

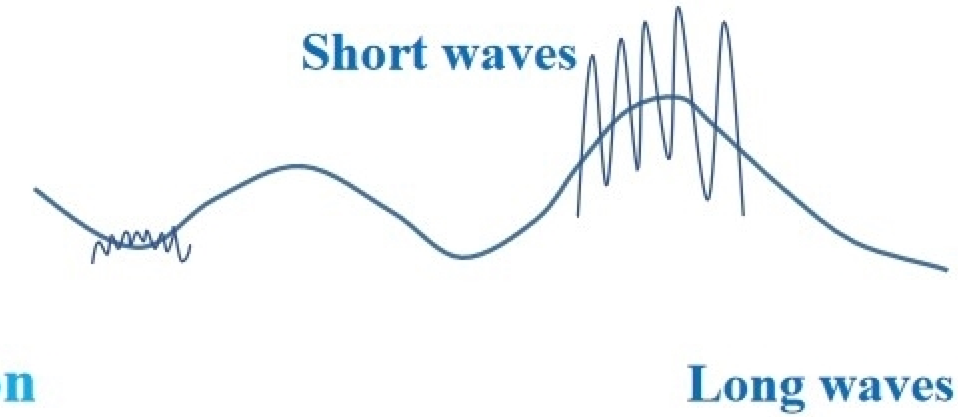
Part 1: What is the surfboard effect?



The backscattering received by the range gate includes not only the contribution of one surface element but also contributions of other intersecting surfaces elements.

Part 2: What is the hydrodynamic modulation?

Real cases----**with the hydrodynamic modulation**



Ideal cases----**without the hydrodynamic modulation**

The roughness of the short waves is larger at the wave crests and smaller at the troughs.

Part 3: Simulation method for considering nonlinear effects

Linear model ⟵ Without nonlinear effects

$$\sigma^0(\theta,\phi) = \frac{|R(0)|^2}{\cos^4\theta'} \cdot \frac{1}{2\sigma_u\sigma_c} \exp\left(-\frac{\tan^2\theta'}{mss}\right)$$

$$mss = 2\left[\left(\frac{\cos(\phi-\phi_0)}{\sigma_u}\right)^2 + \left(\frac{\sin(\phi-\phi_0)}{\sigma_c}\right)^2\right]^{-1}$$

Nonlinear model ← With nonlinear effects

Considering the hydrodynamic modulation

$$\sigma^0(\theta,\phi) = \frac{|R(0)|^2}{\cos^4\theta'} \cdot \frac{1}{2\sigma_u(\xi)\sigma_c(\xi)} \exp\left(-\frac{\tan^2\theta'}{mss(\xi)}\right)$$

$$\sigma_i(\xi) = \sigma_i\left(1 + m_1\frac{\xi}{h_l}\right)$$

where m_1 represents the modulation strength

h_l is the height standard deviation of long waves

ξ is the height of the large-scale wave

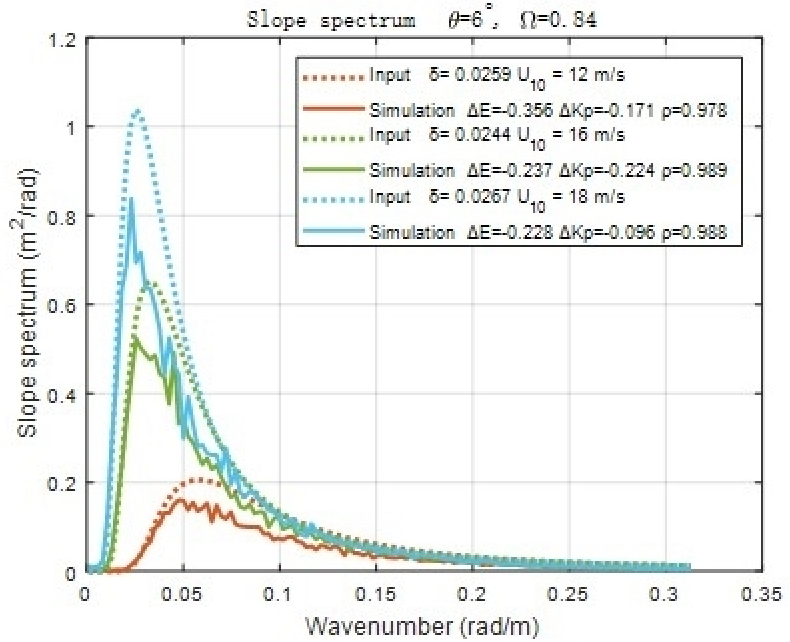
Considering the surfboard effect

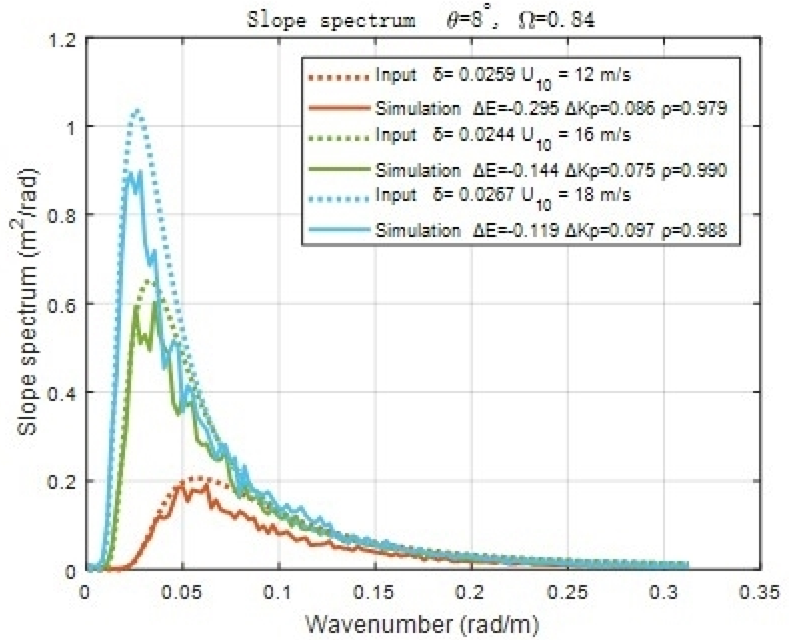
$$\sigma = \sum_{i=1}^{n} \sigma_i^0 S_i$$

S_i represents the actual illumination area of surface element i within the range gate.

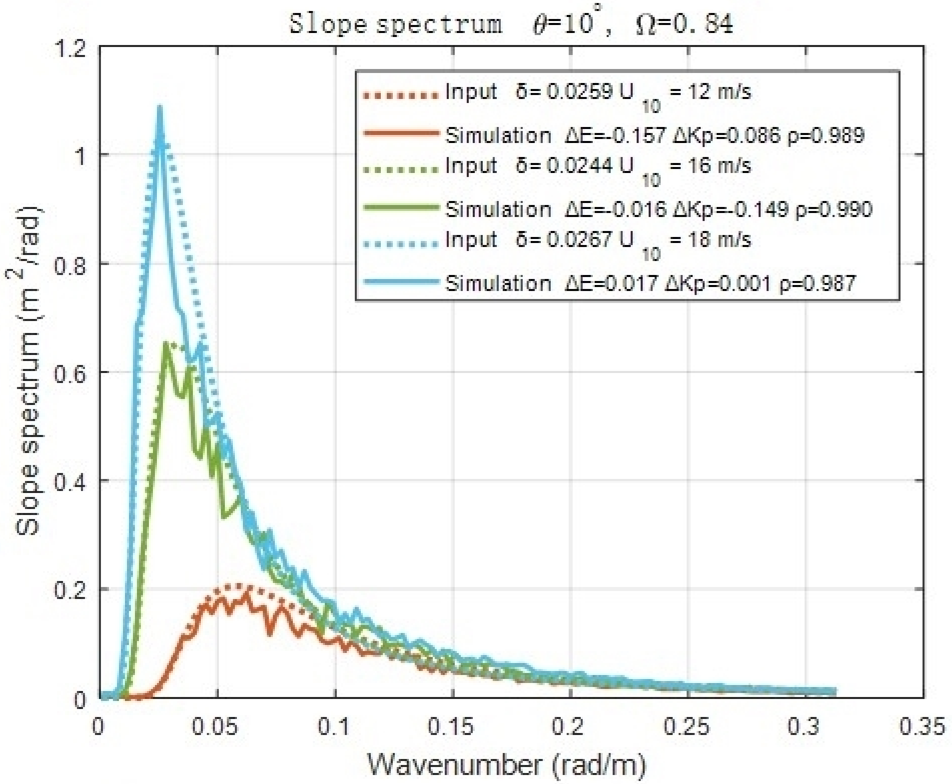
Part 4: Simulation results for the case of wind waves

--only considering the surfboard effect



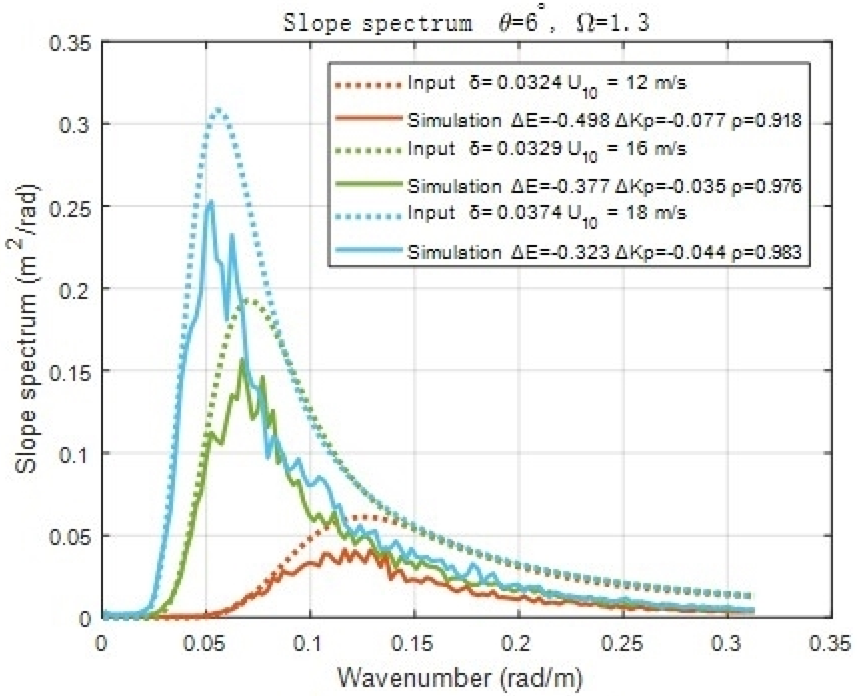


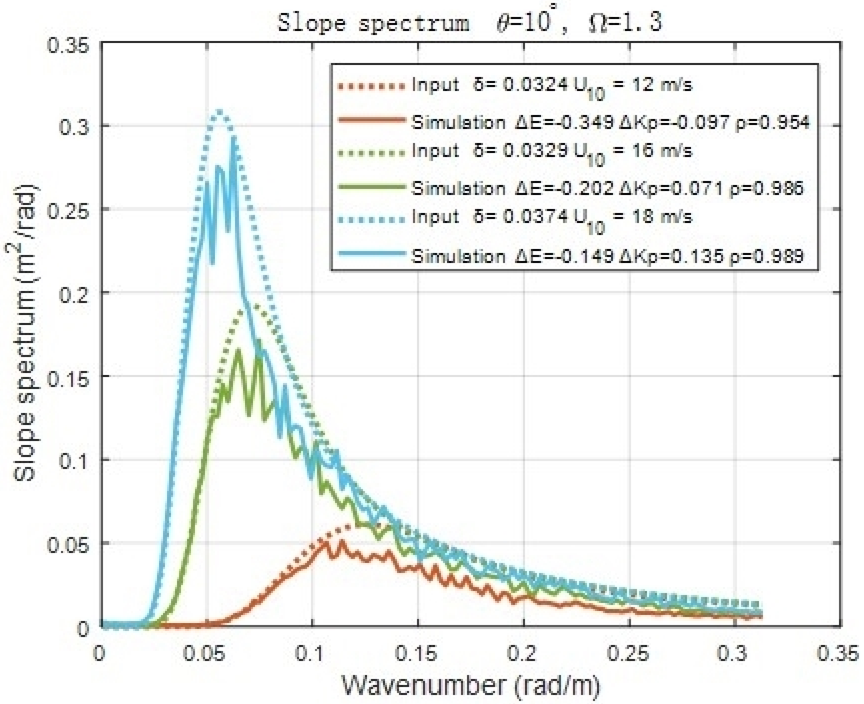
Observed along the wave direction, Fully developed wind wave

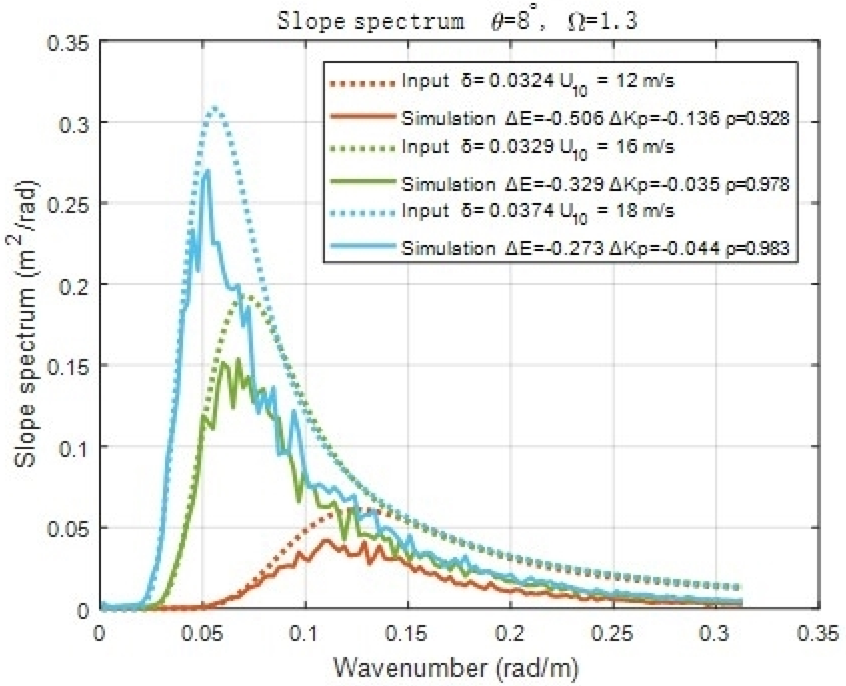


The surfboard effect will cause the value near the peak wavenumber to be underestimated and the peak wavenumber will be left-shift compared with the input spectrum.

Observed along the wave direction
Developing wind wave



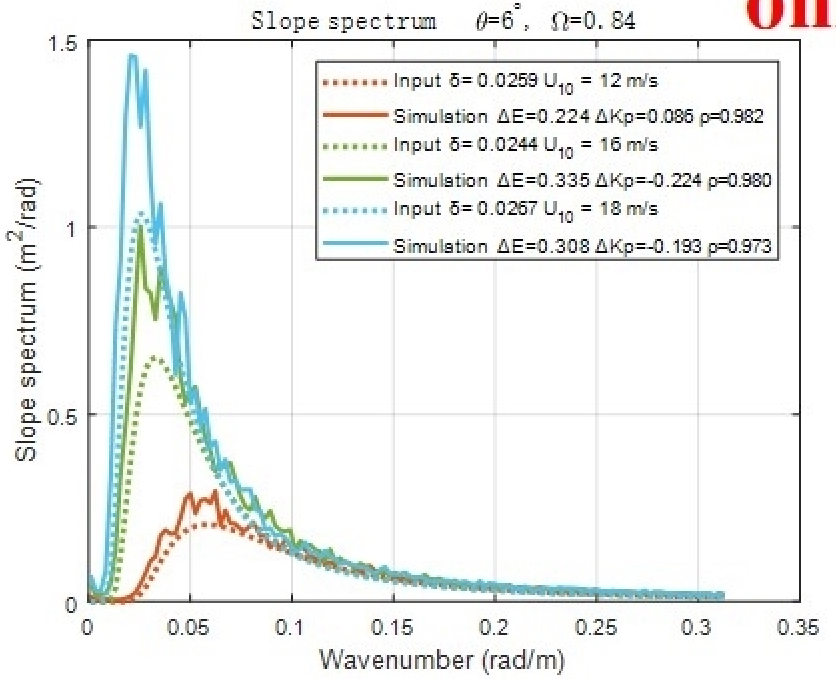


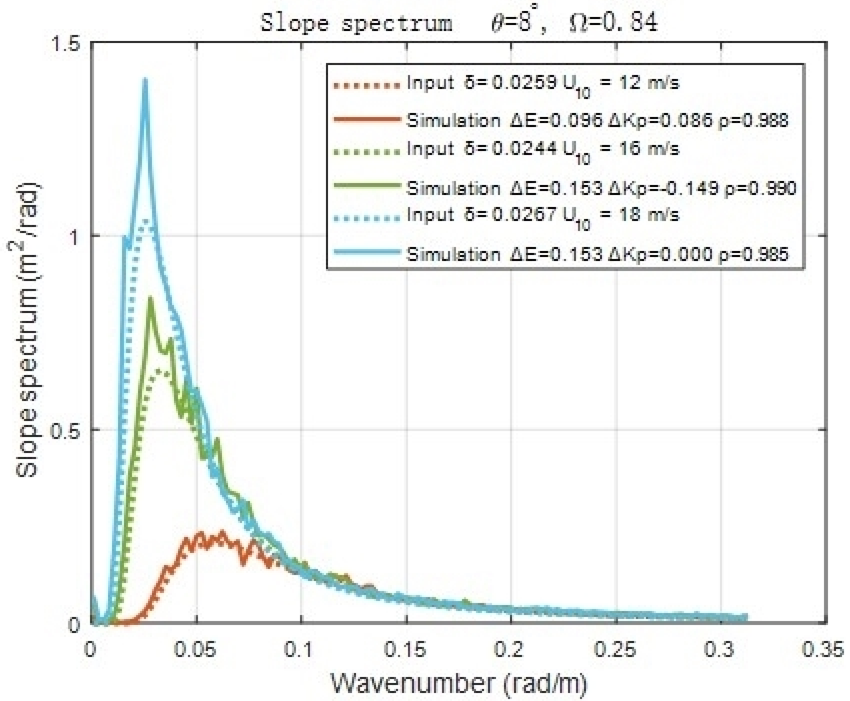


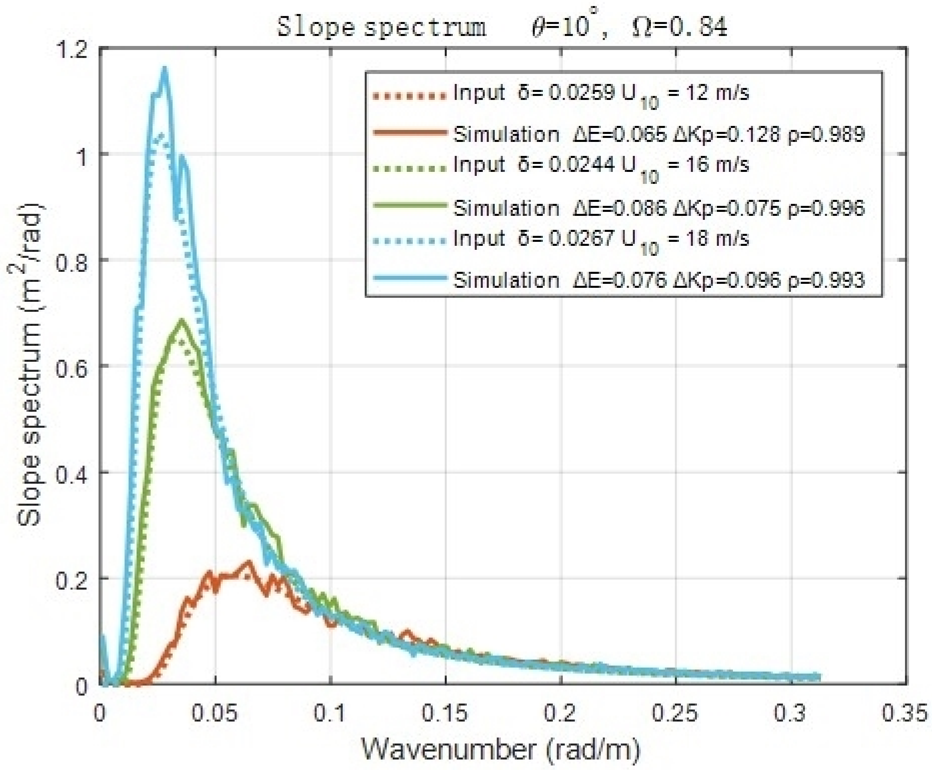
The younger the wave is and the smaller the incident angle is, the more obvious the surfboard effect is.

only considering the hydrodynamic modulation

Observed along the wave direction
Fully developed wind wave

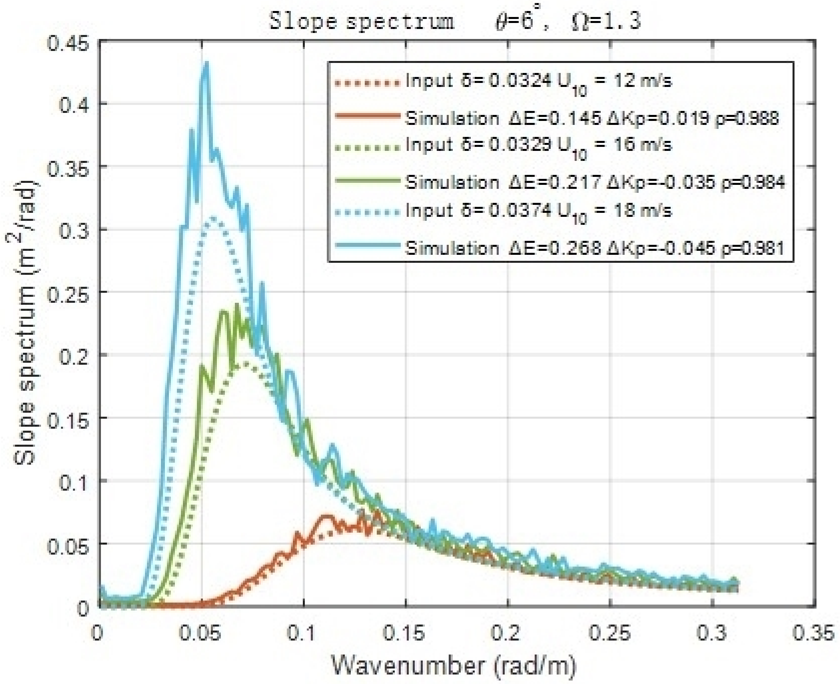


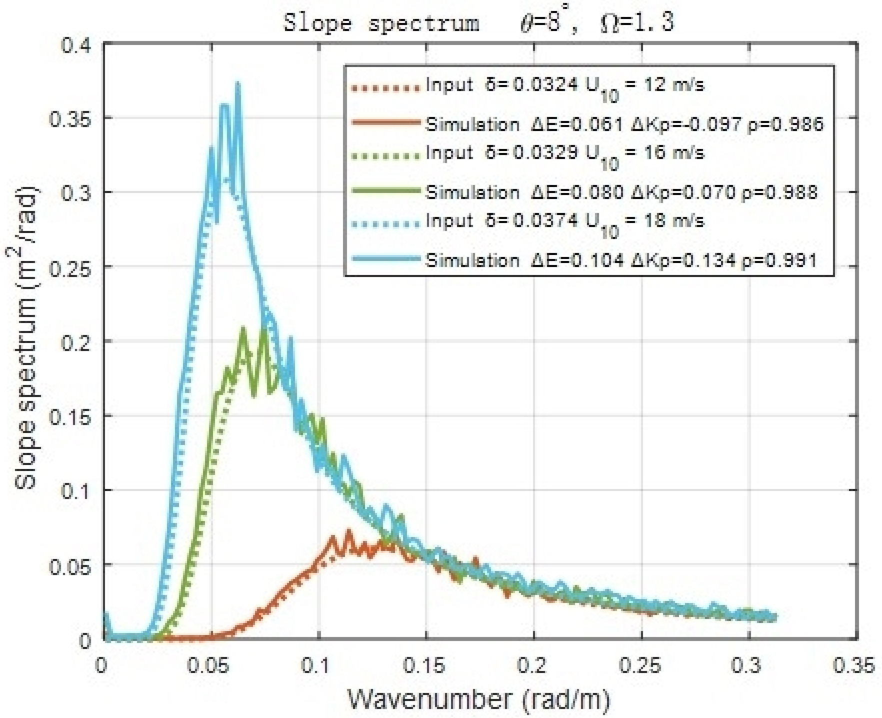


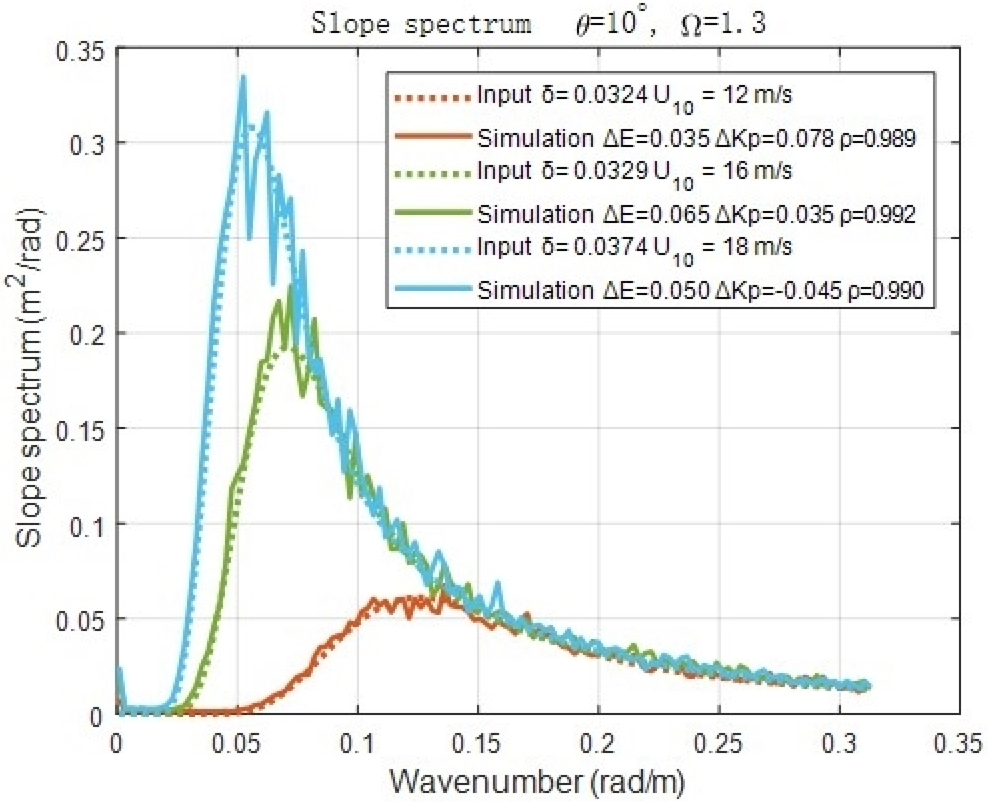


The hydrodynamic modulation will cause the slope spectrum to be overestimated, especially in the region near the peak wavenumber.

Observed along the wave direction
Developing wind wave

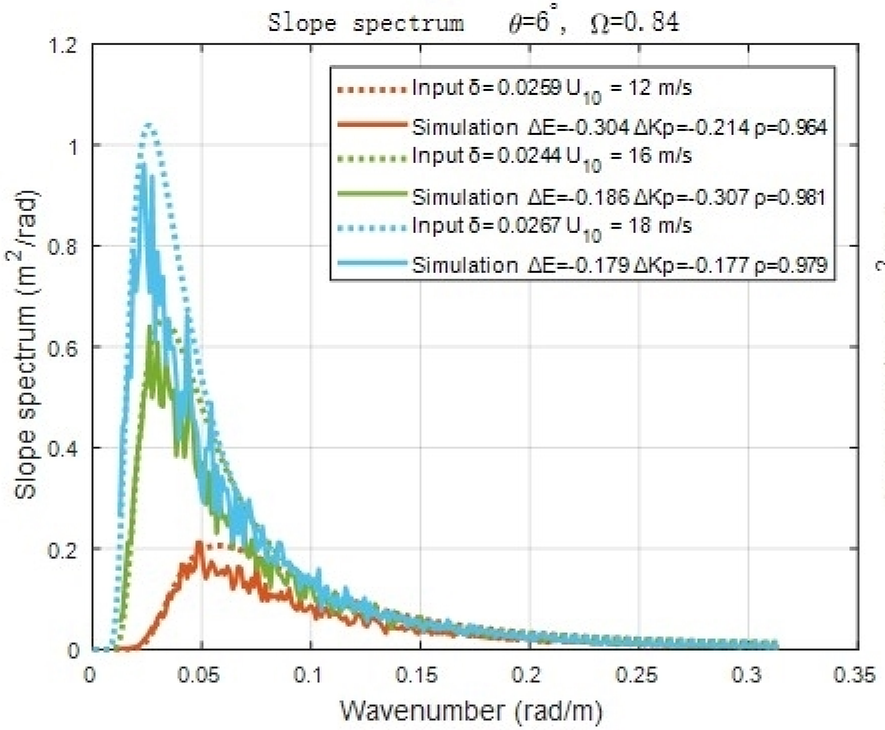


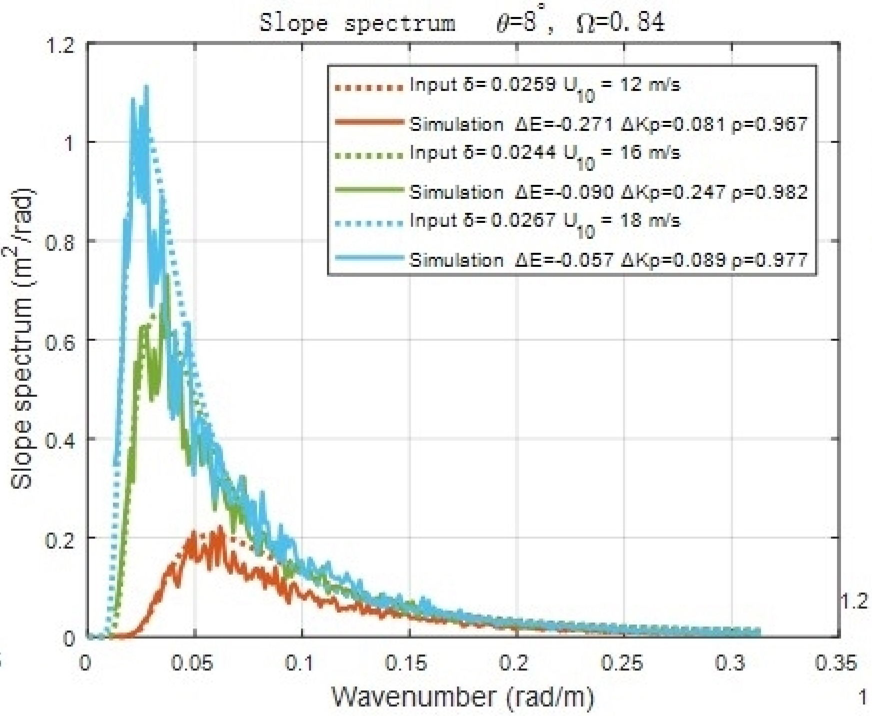




The smaller the incident angle and the larger the wind speed, the greater the influence of hydrodynamic modulation.

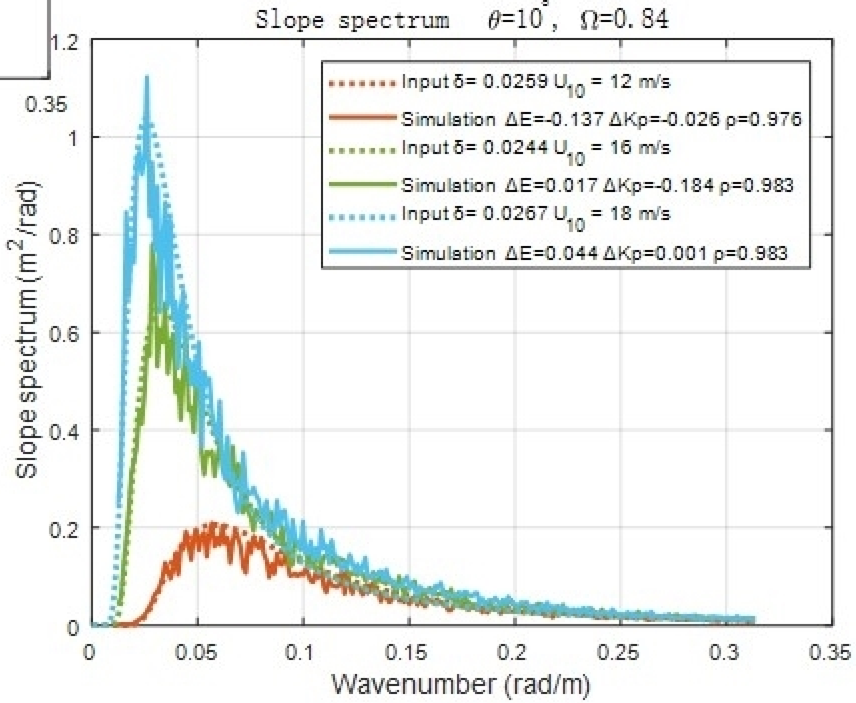
considering both the surfboard effect and hydrodynamic modulation



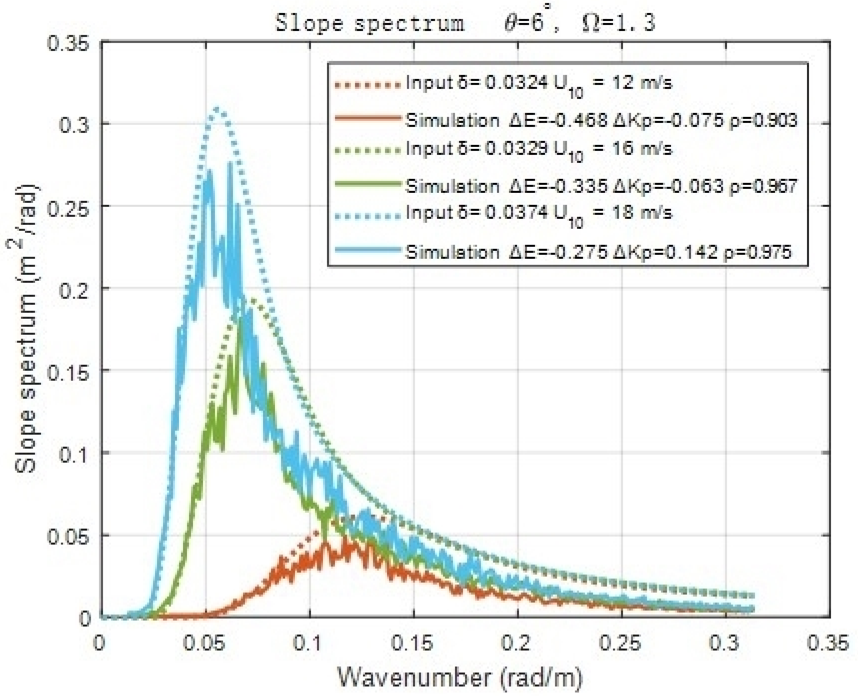


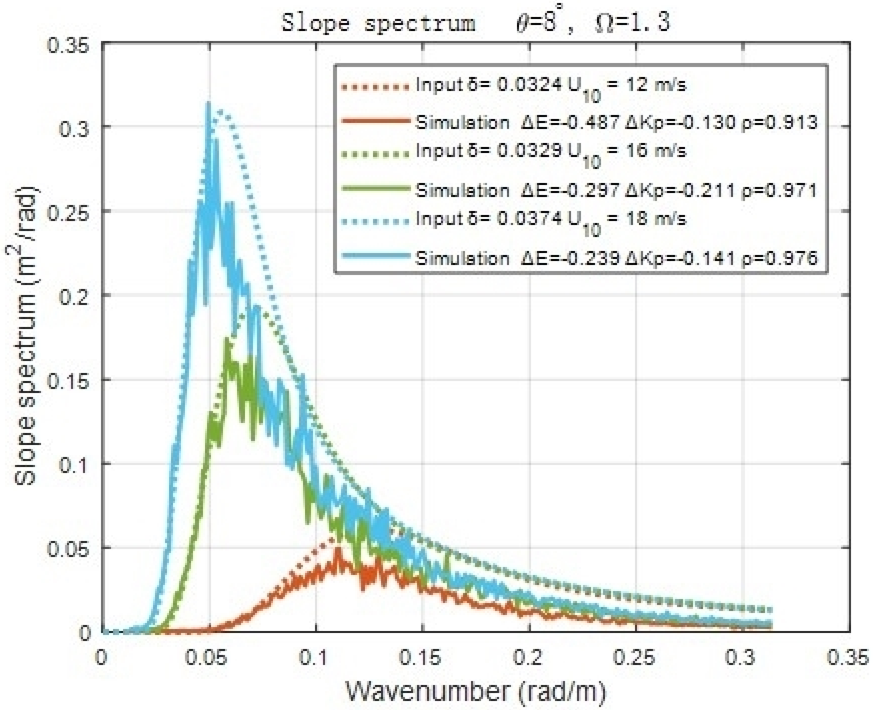
Observed along the wave direction

Fully developed wind wave

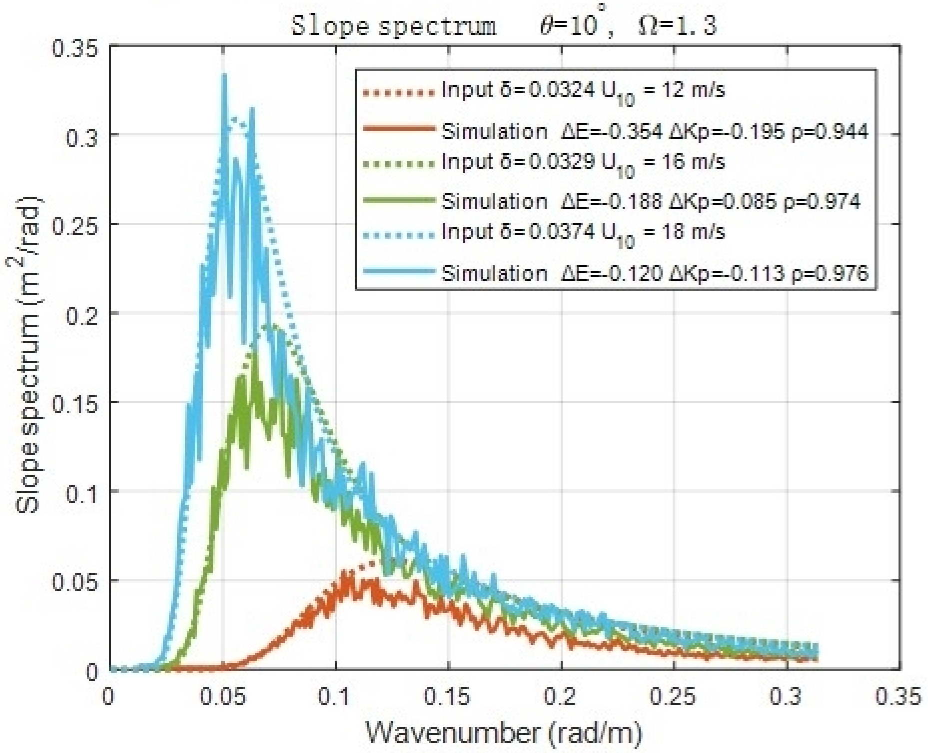


Comparing the effects of surfboard alone (reducing the spectral peak) and hydrodynamic modulation alone (increasing the spectral peak), the superposition of the two nonlinear effects reduces the deviation between the simulated slope spectrum and the input spectrum.





Observed along the wave direction
Developing wind wave



In the case of developing sea waves, because the surfboard effect is very significant, the superposition of the two nonlinear effects still shows obvious surfboard effect.

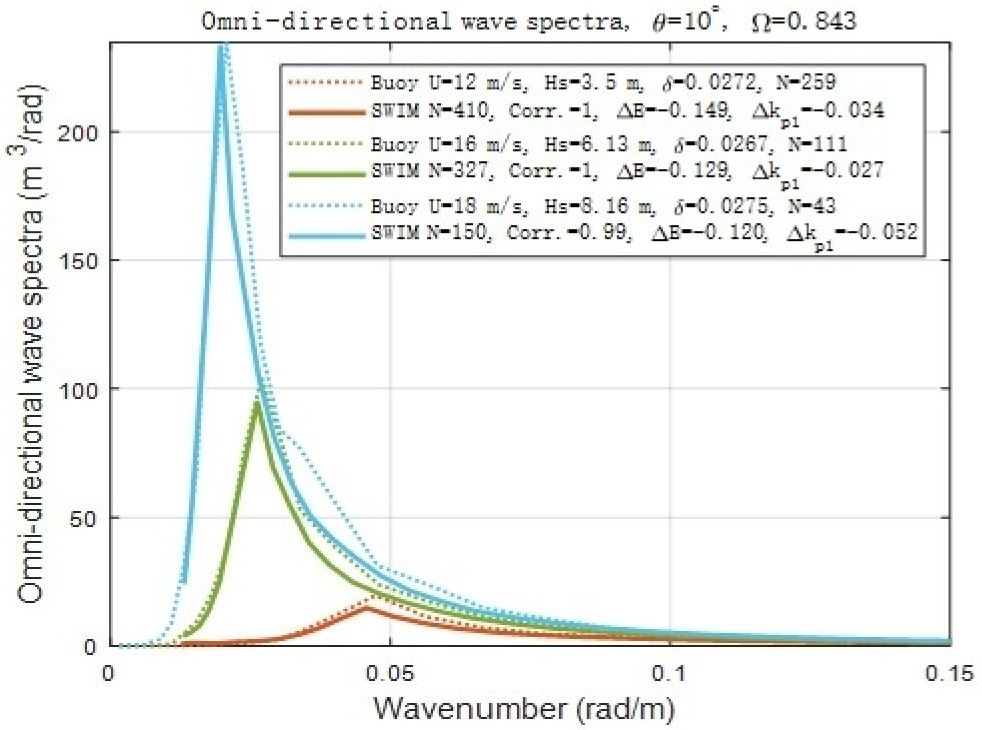
Part 5: Comparison of the measured and simulation results

In order to validate the simulation results, we study the comparison of the directional wave spectrum by SWIM and by buoy. Since the measured value of the buoy direction function is still not accurate enough, so the referred spectrum along the dominate direction by buoy is difficult to obtain. In the following only the omnidirectional wave spectrum comparison between SWIM and buoy is shown.

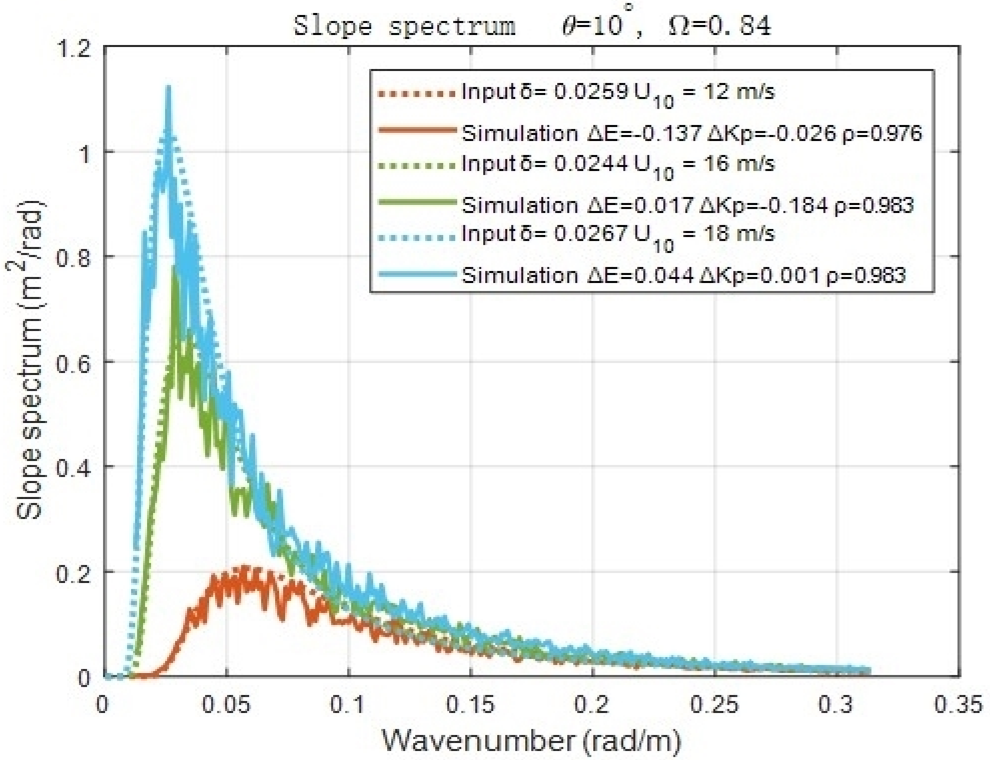
Because the wave spectrum inversion simulation considering the surfboard effect costs lots of time, only the simulation results of the slope spectrum along the wave direction are obtained and displayed in the following.

Part 5: Comparison of the measured and simulation results

Beam 10° , fully developed wind wave



Omni-directional spectrum be measured by SWIM and by buoy

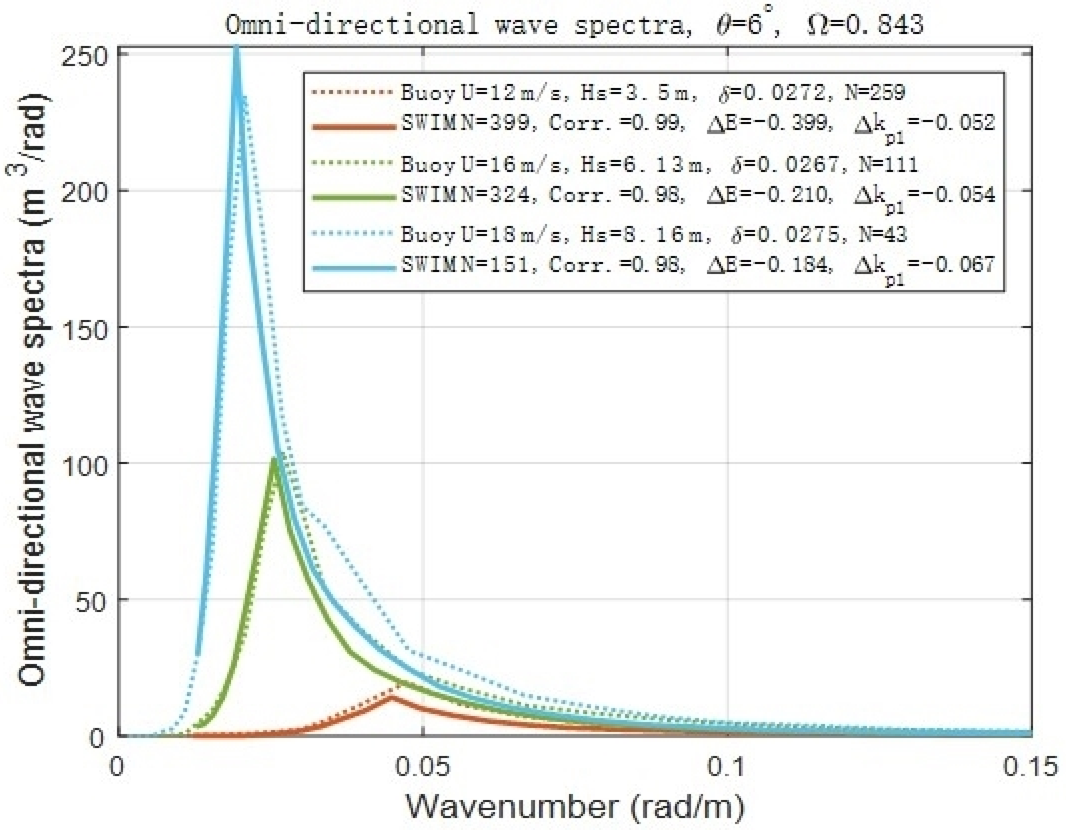


Slope spectrum along the dominate direction by the simulation for considering the two nonlinear modulaitons

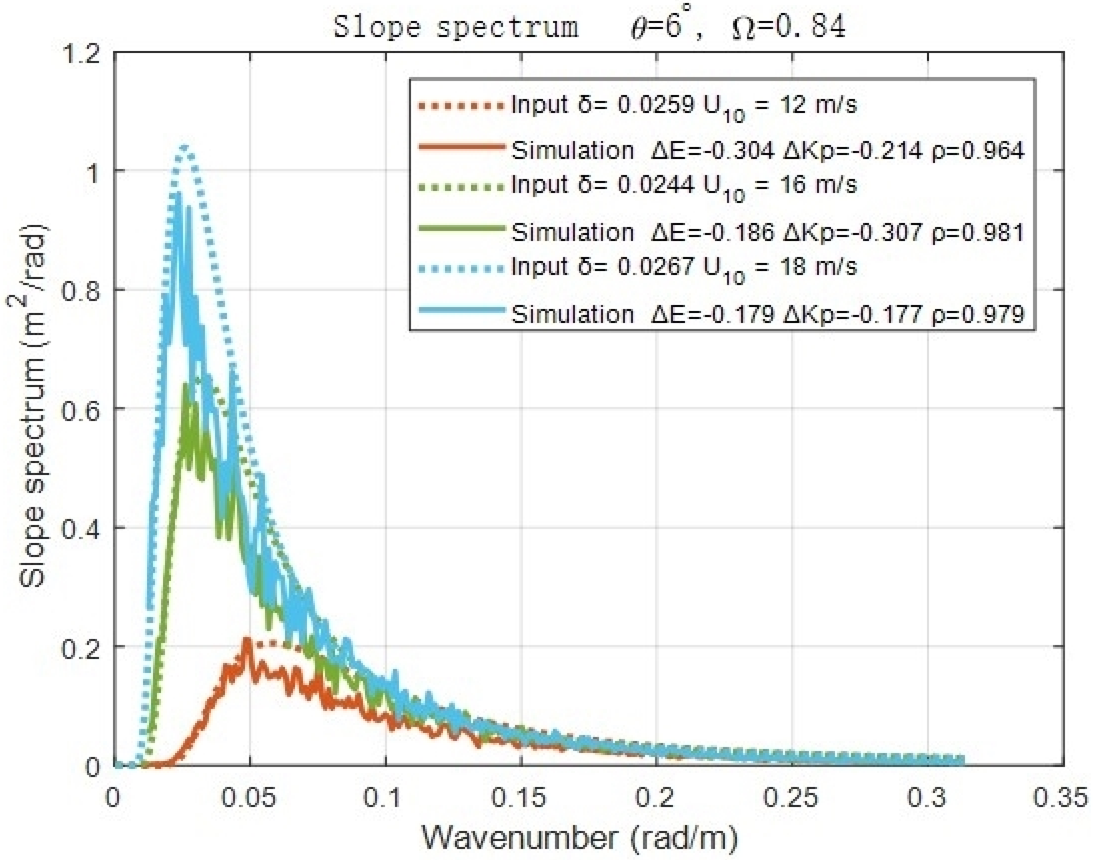
Because the two nonlinear effects are equivalent for the beam 10° and fully developed wind wave, so the superposition of the two nonlinear modulations makes the deviation between the slope spectrum and the input spectrum small, which is consistent with the comparison results of the measurements by SWIM and by buoy.

Part 5: Comparison of the measured and simulation results

Beam 6° , fully developed wind wave



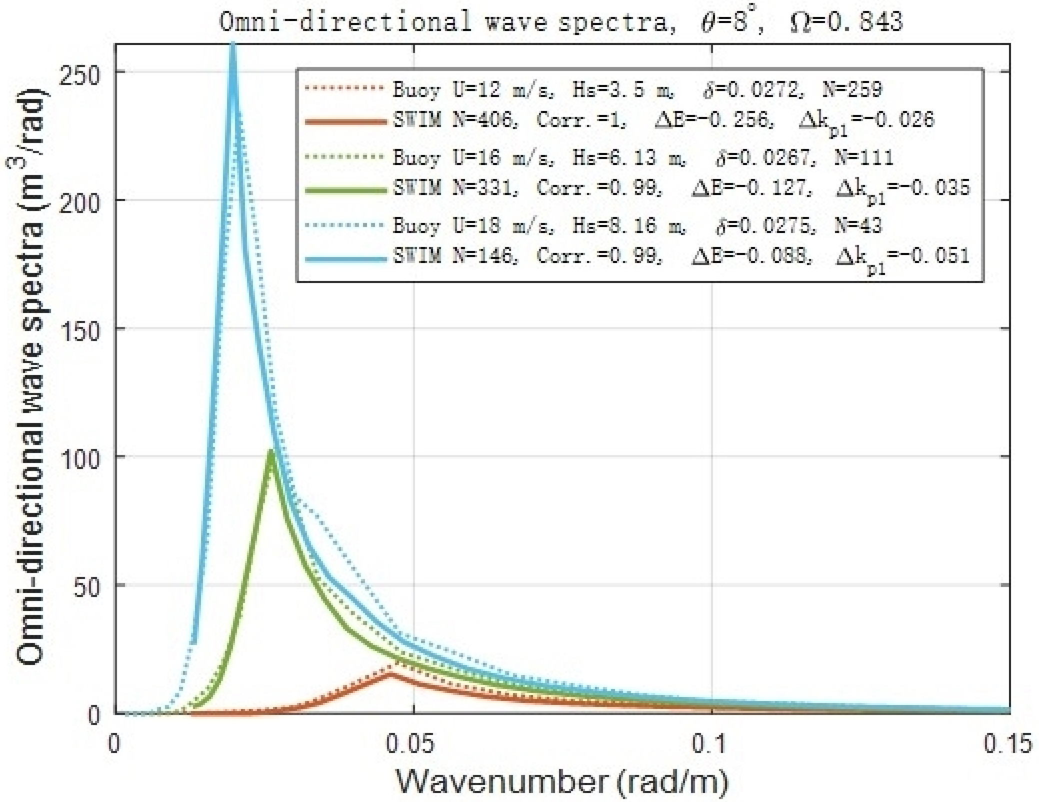
Omni-directional spectrum be measured by SWIM



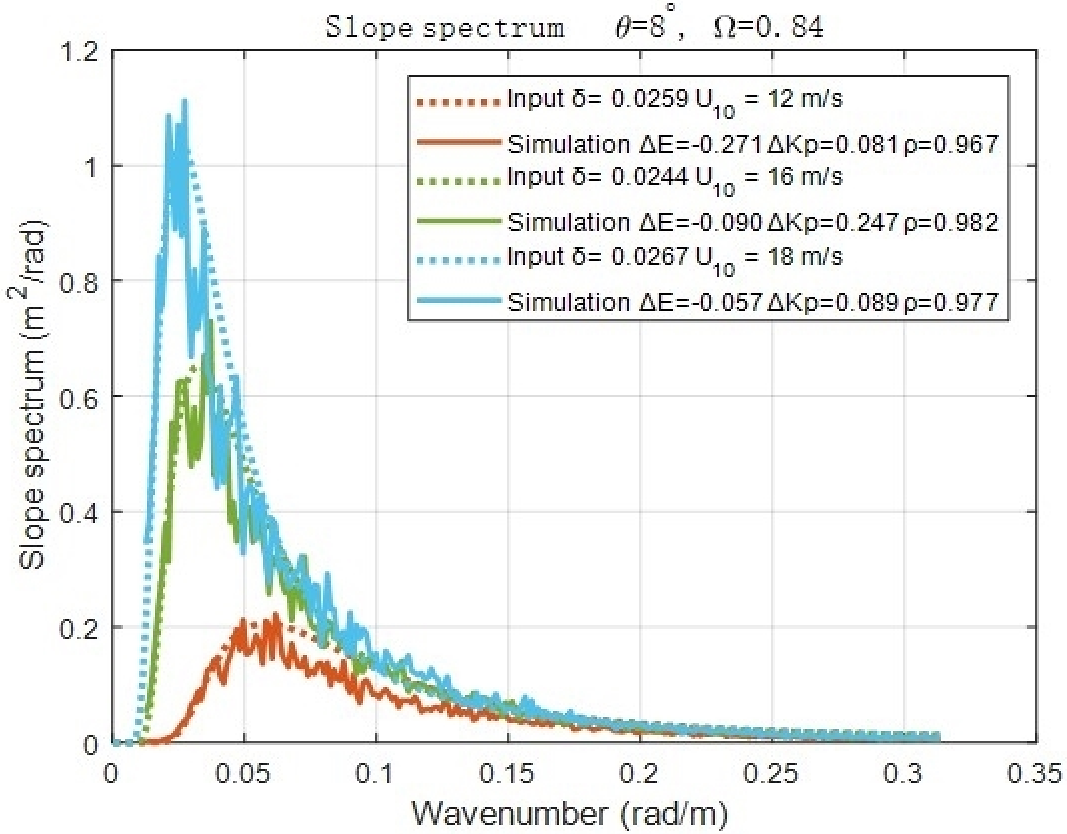
Slope spectrum along the dominate direction by the simulation for considering the two nonlinear modulaitons

Part 5: Comparison of the measured and simulation results

Beam 8° , fully developed wind wave



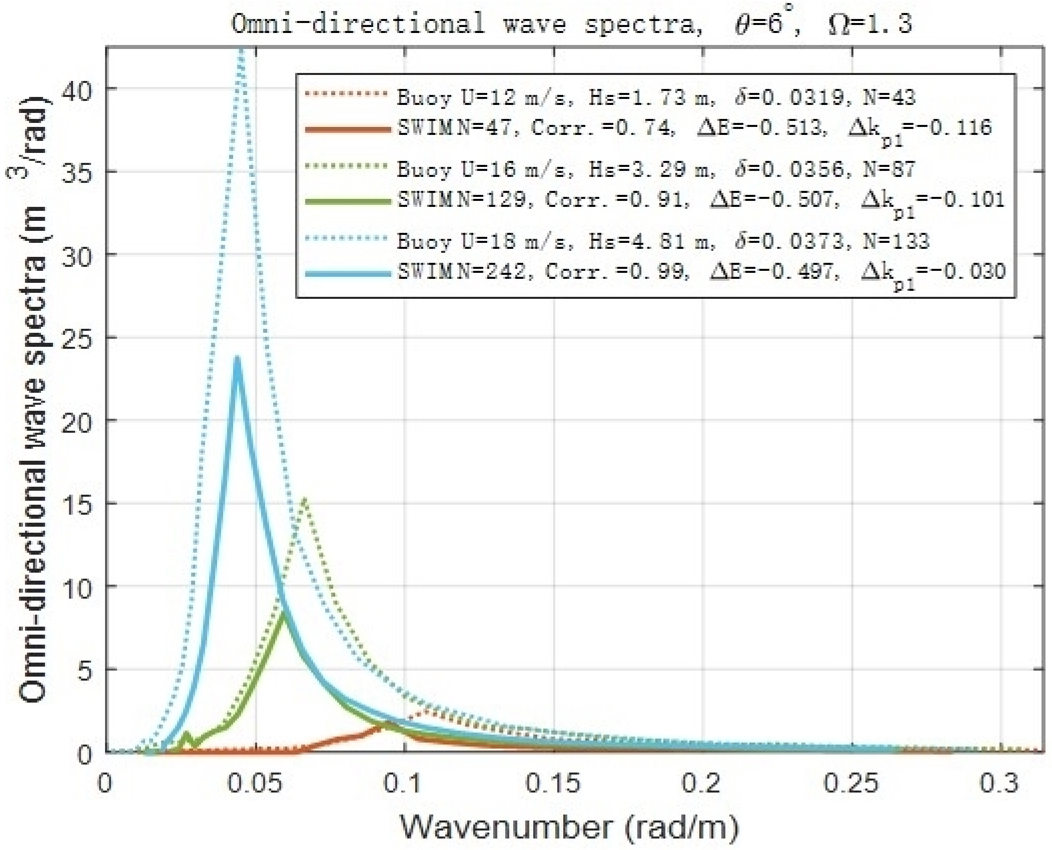
Omni-directional spectrum be measured by SWIM



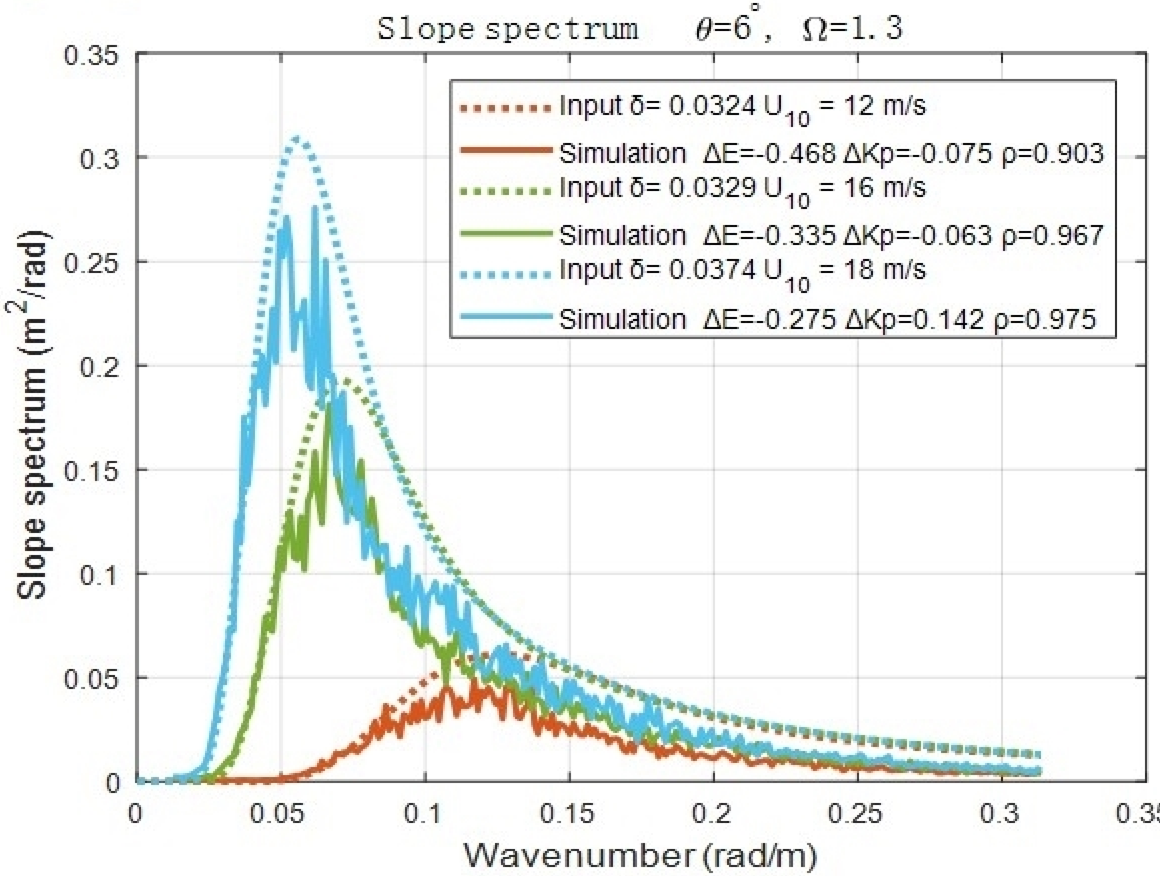
Slope spectrum along the dominate direction by the simulation for considering the two nonlinear modulaitons

Part 5: Comparison of the measured and simulation results

Beam 6° , developing wind wave



Omni-directional spectrum be measured by SWIM

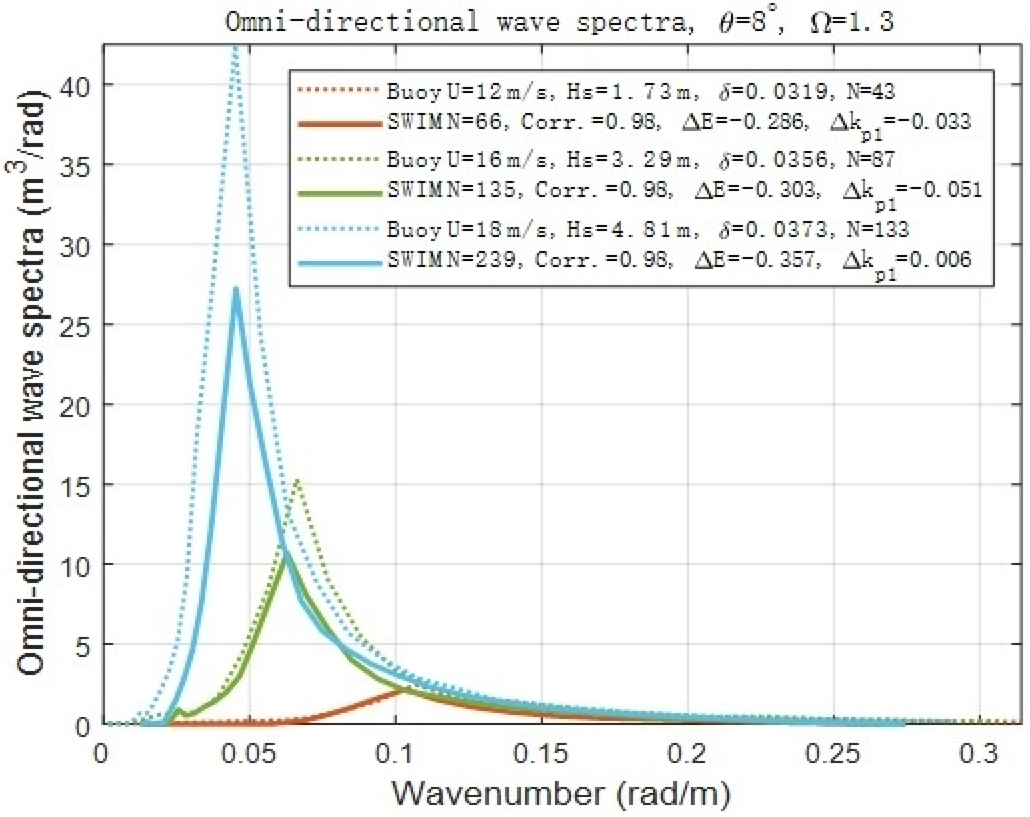


Slope spectrum along the dominate direction by the simulation for considering the two nonlinear modulaitons

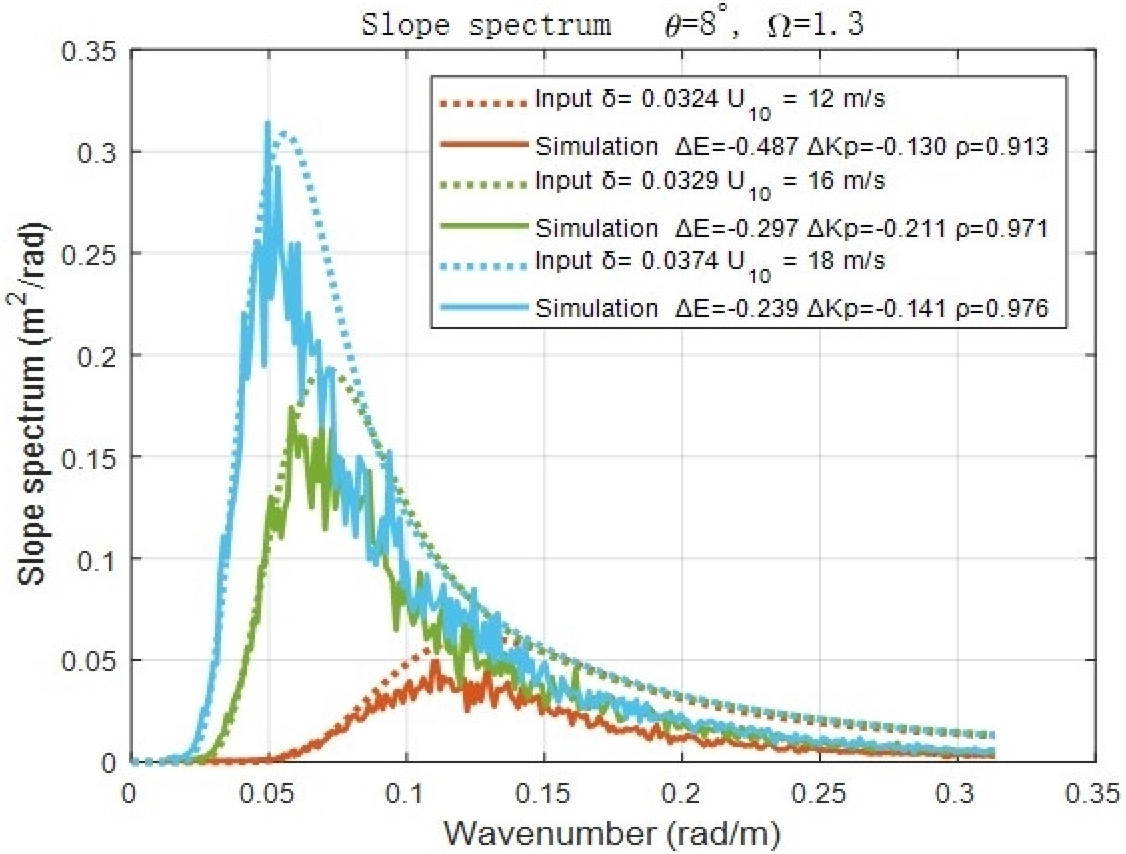
In the case of developing sea waves and for beam 6°, because the surfboard effect is very significant, the superposition of the two nonlinear effects still shows obvious surfboard effect, which agrees with the comparison between SWIM and buoy.

Part 5: Comparison of the measured and simulation results

Beam 8° , developing wind wave



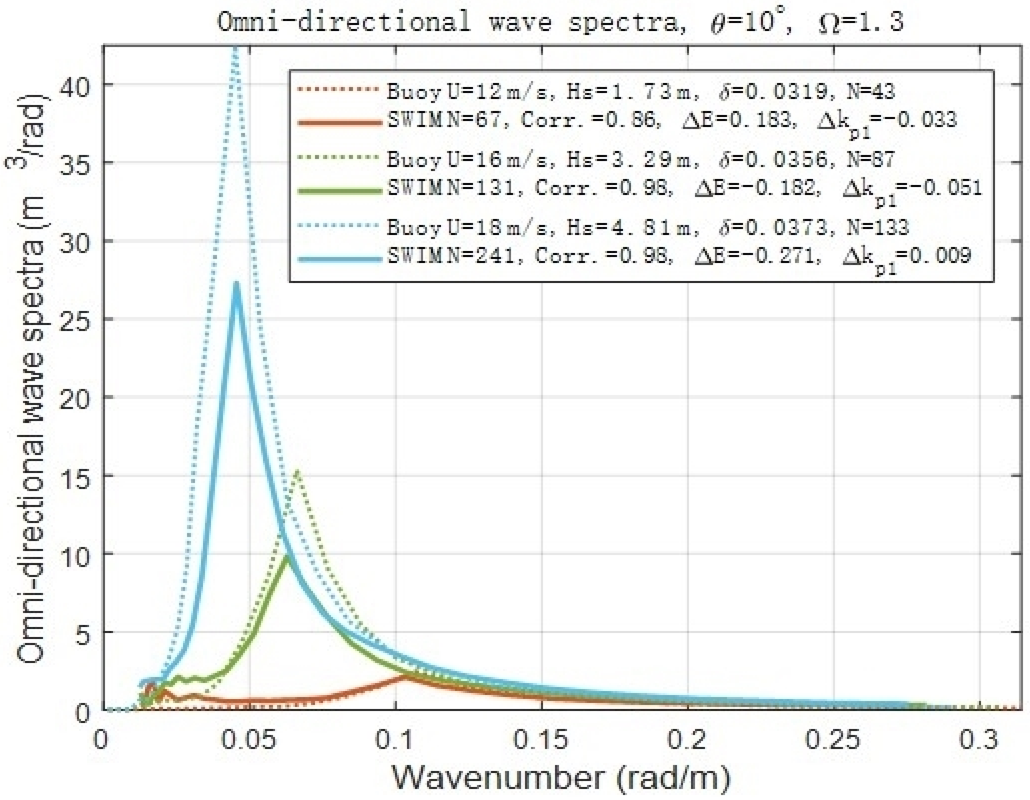
Omni-directional spectrum be measured by SWIM



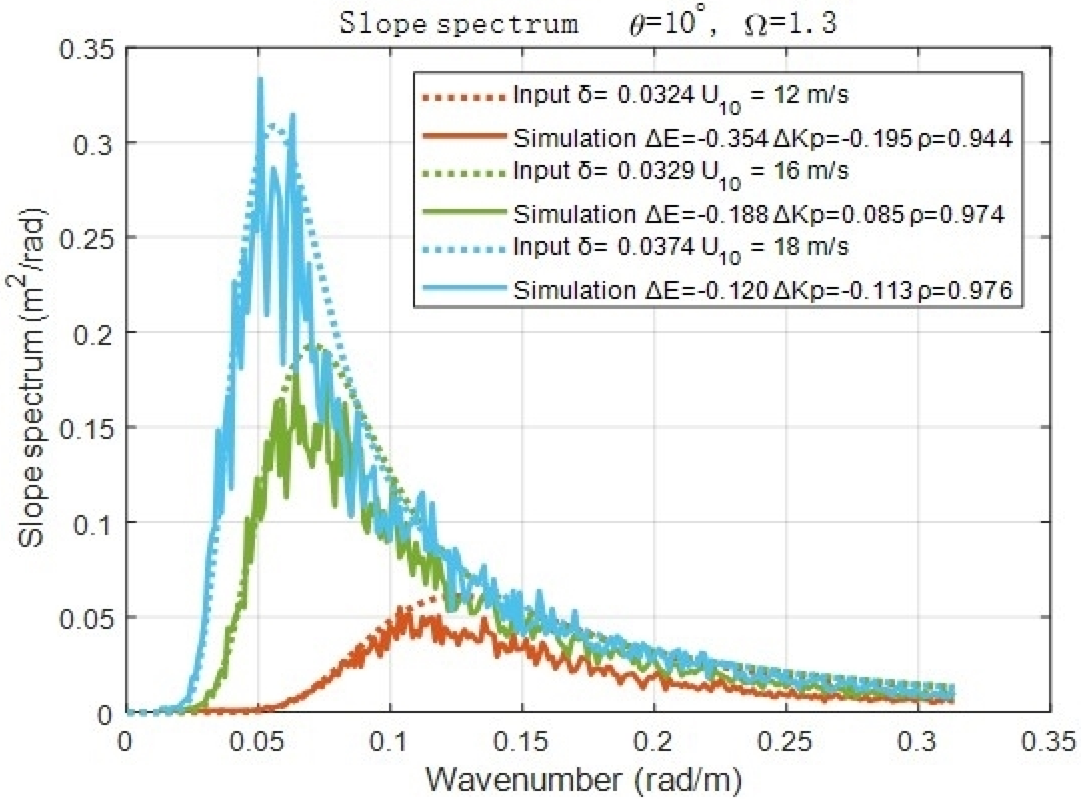
Slope spectrum along the dominate direction by the simulation for considering the two nonlinear modulaitons

Part 5: Comparison of the measured and simulation results

Beam 10° , developing wind wave



Omni-directional spectrum be measured by SWIM



Slope spectrum along the dominate direction by the simulation for considering the two nonlinear modulaitons

Part 6: Conclusion

The influence of nonlinear modulation effect on wave spectrum inversion is studied through the simulation of wave spectrum detected by wave scatterometer considering both surfboard effect and hydrodynamic modulation. The simulation results show:

1. The surfboard effect alone will cause the value near the peak wavenumber to be underestimated and the peak wavenumber left-shift compared with the input spectrum. The younger the wave is and the smaller the incident angle is, the more obvious the surfboard effect is.
2. The hydrodynamic modulation alone will cause the slope spectrum to be overestimated, especially in the region near the peak wavenumber. The smaller the incident angle and the larger the wind speed, the greater the influence of hydrodynamic modulation.
3. When the two nonlinear effects are taken into account, the hydrodynamic modulation offsets part of the influence of the surfboard effect, but for developing wind waves and low incidence angle, the surfboard effect occupies a dominant position, which is consistent with the measured results.

Future works

- Extending the simulation study to the case of swell
- Direct comparison of omni-directional wave spectrum between the simulation and the measurement results