Effects of range bunching on modulation spectrum measured by a wave scatterometer

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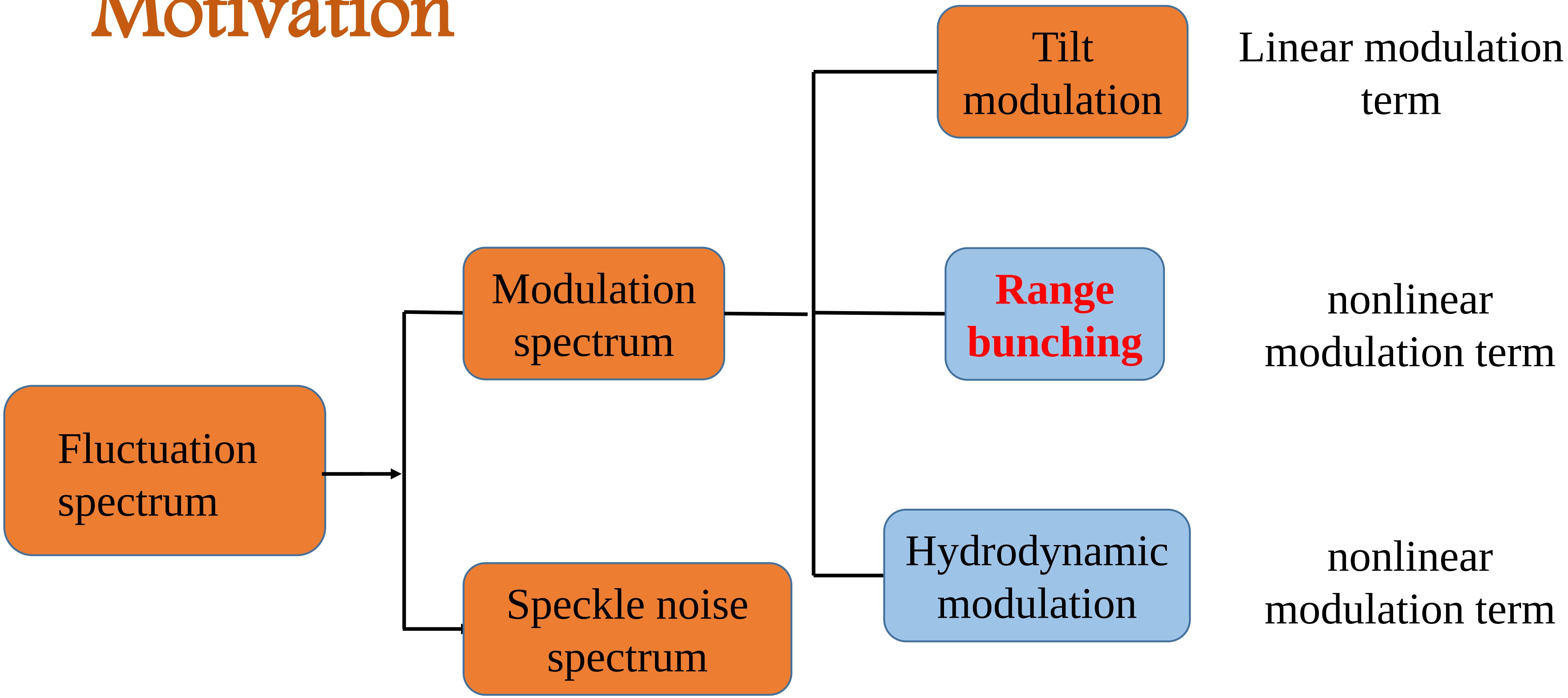
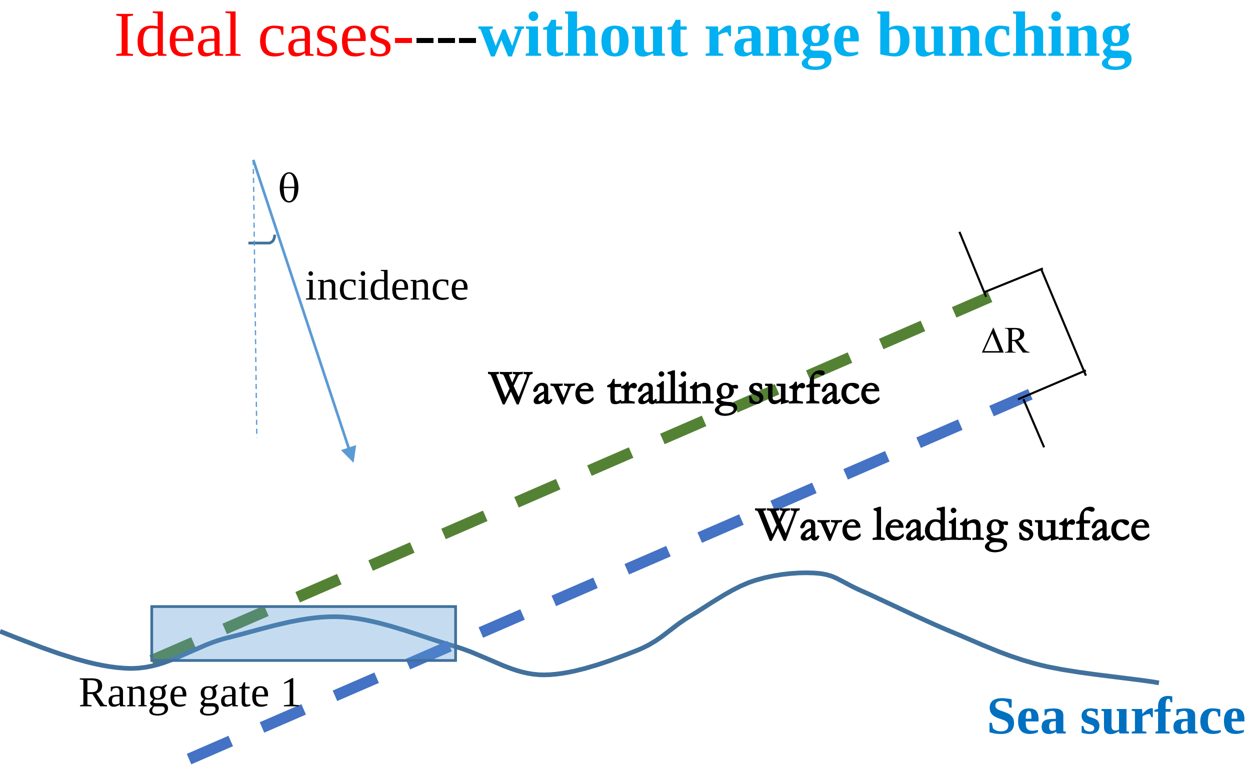
Motivation

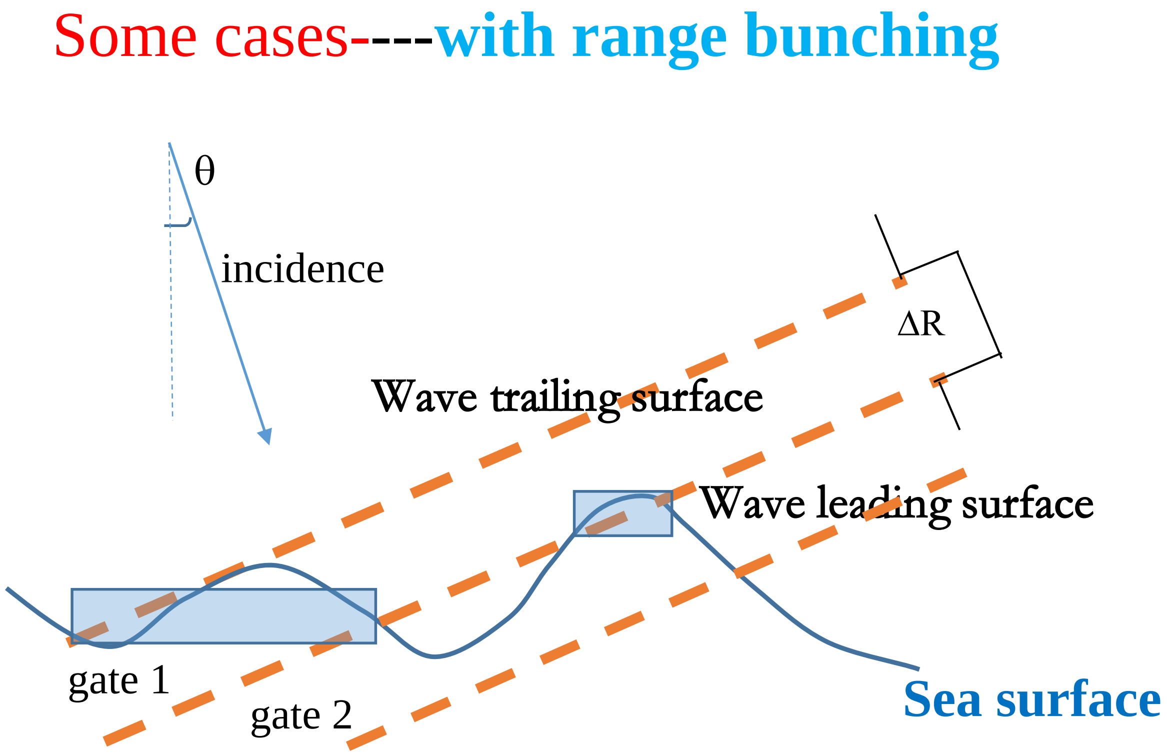

Fluctuation spectrum
Modulation spectrum
Speckle noise spectrum
Tilt modulation
Range bunching
Hydrodynamic modulation
Linear modulation term
nonlinear modulation term
nonlinear modulation term

Outlines

1. Range-bunching
2. A modulation spectrum model with range-bunching
3. Effects of range-bunching by the model
4. Conclusion

Part 1: What is range bunching?





Part 2: Modulation spectrum model without/with range-bunching

Linear model (given by Jackson 81) ← Without range-bunching

$$P_m(\vec{K}) = MTF \cdot \boxed{K^2 F(\vec{K})}$$

$$MTF = \frac{\sqrt{2\pi}}{L_y}\alpha^2 \qquad \alpha = cot\theta - \frac{\partial ln\sigma^0}{\partial\theta}$$

Nonlinear model (given by Jackson 81) ← With range-bunching

$$P_m'(\vec{K}) = \frac{\sqrt{2\pi}}{L_y}\boxed{e^{-(\vec{K}\sigma cot\theta)^2}} \cdot (P_m(\vec{K}) + nonlinear\ term)$$

$$nonlinear\ term = \frac{1}{2}K^4 \cot^4\theta\, F(\vec{K}) * F(\vec{K}) + K^2 cot^2\theta\left(\frac{p_{\alpha\beta}}{p} + \frac{p_\alpha p_\beta}{p^2}\right)\overline{\vec{K}_\alpha F(\vec{K})} * \overline{\vec{K}_\beta F(\vec{K})}$$
$$+ \frac{1}{2}\frac{p_{\alpha\delta}p_{\beta\eta}}{p^2}\overline{\vec{K}_\alpha\vec{K}_\beta F(\vec{K})} * \overline{\vec{K}_\delta\vec{K}_\eta F(\vec{K})} - 2K^3\cot^3\theta\,\frac{p_\alpha}{p}F(\vec{K}) * \overline{\vec{K}_\alpha F(\vec{K})}$$
$$+ K^2\cot^2\theta\,\frac{p_\alpha p_\beta}{p^2}F(\vec{K}) * \overline{\vec{K}_\alpha\vec{K}_\beta F(\vec{K})} - Kcot\theta\left(\frac{p_\alpha p_{\beta\delta} + p_\beta p_{\alpha\delta}}{p^2}\right)\overline{\vec{K}_\delta F(\vec{K})} * \overline{\vec{K}_\alpha\vec{K}_\beta F(\vec{K})}$$

Part 3: Effects of range-bunching calculated by the model

Use the nonlinear/linear modulation spectrum model to simulate the modulation spectrum $P_m' \, / P_m$ with/without range-bunching in different sea surface conditions (swell and wind wave) with different incidence anlges (2°, 4°, 6°, 8°, 10°, 12°).

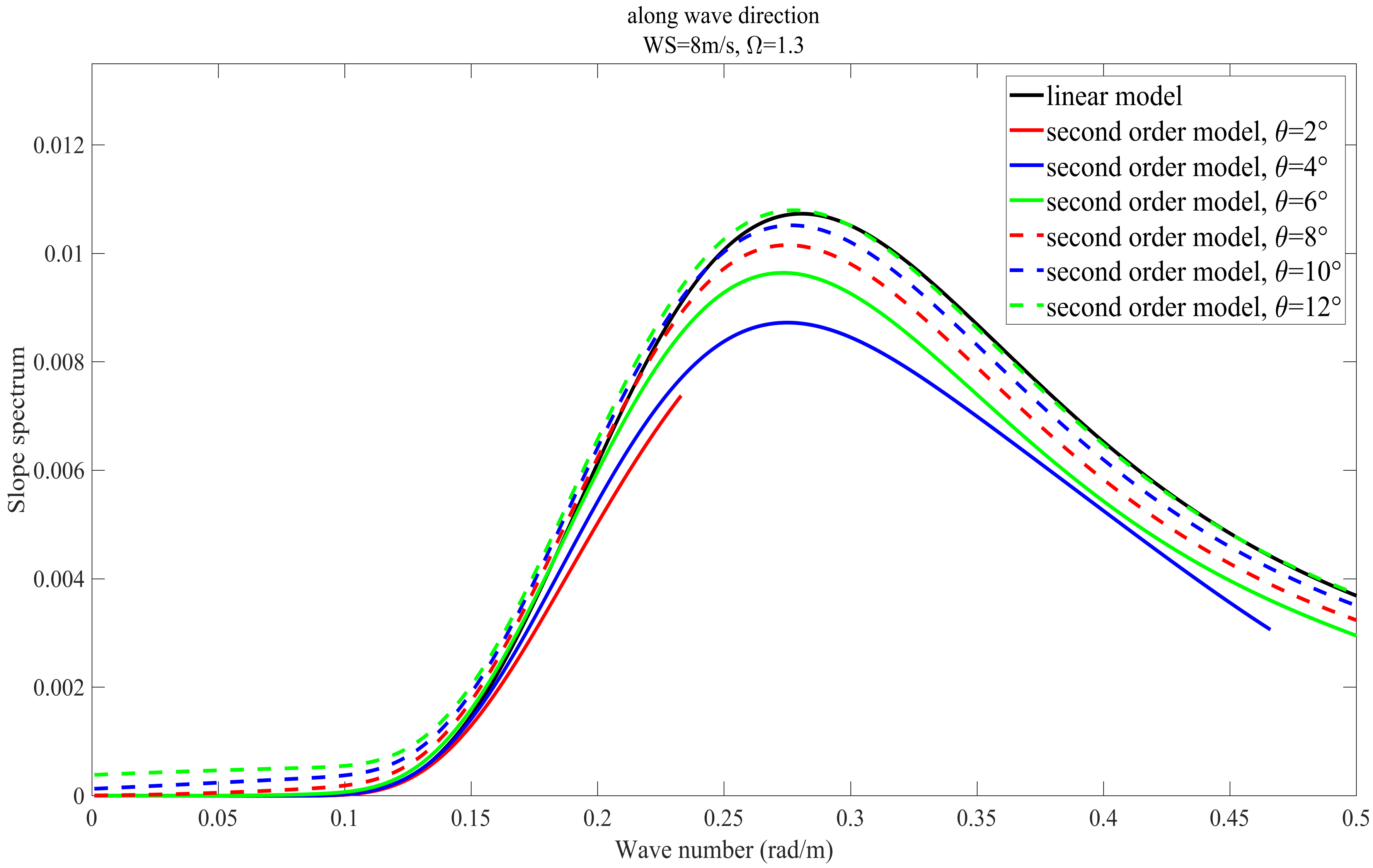
The slope spectrum S'/S is inverted from the P_m'/P_m according the linear method.

$$S' = P_m'/\mathrm{MTF},$$
$$S = P_m \, /\mathrm{MTF}$$

The wave height spectrum is calculated, and the significant height Hs and the peak wave length are obtained.

Part 3: Effects of range-bunching calculated by the model

Observed along the wave direction



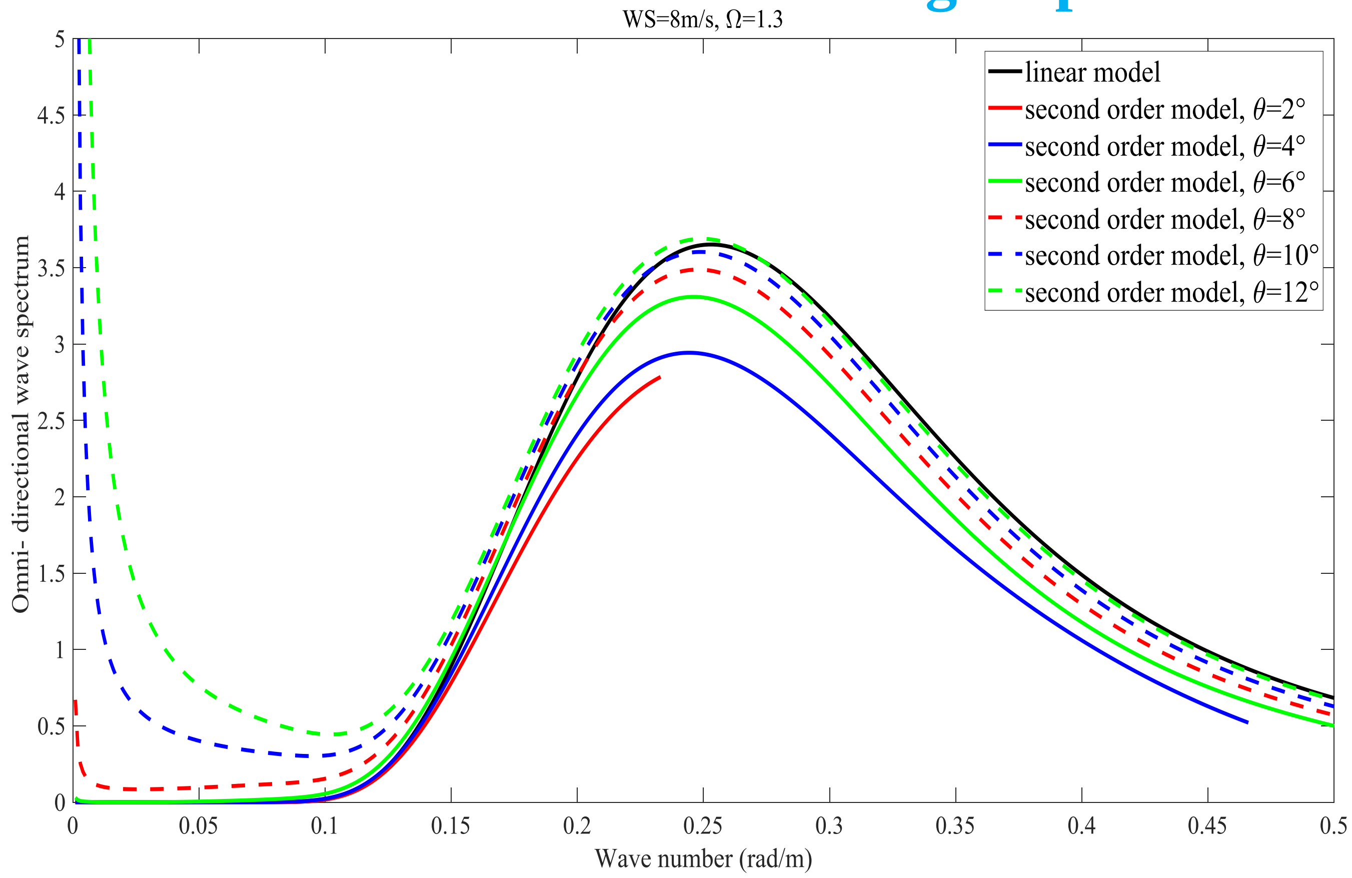
Developing wind wave

$U_{10} = 8\,m/s \quad \Omega = 1.3$

With the incidence angle decreasing, the attenuation of the spectrum become larger, the peak wavenumber shift to the left slightly

Part 3: Effects of range-bunching calculated by the model

Omnidirectional wave height spectrum



Developing wind wave

$$U_{10} = 8\ m/s \quad \Omega = 1.3$$

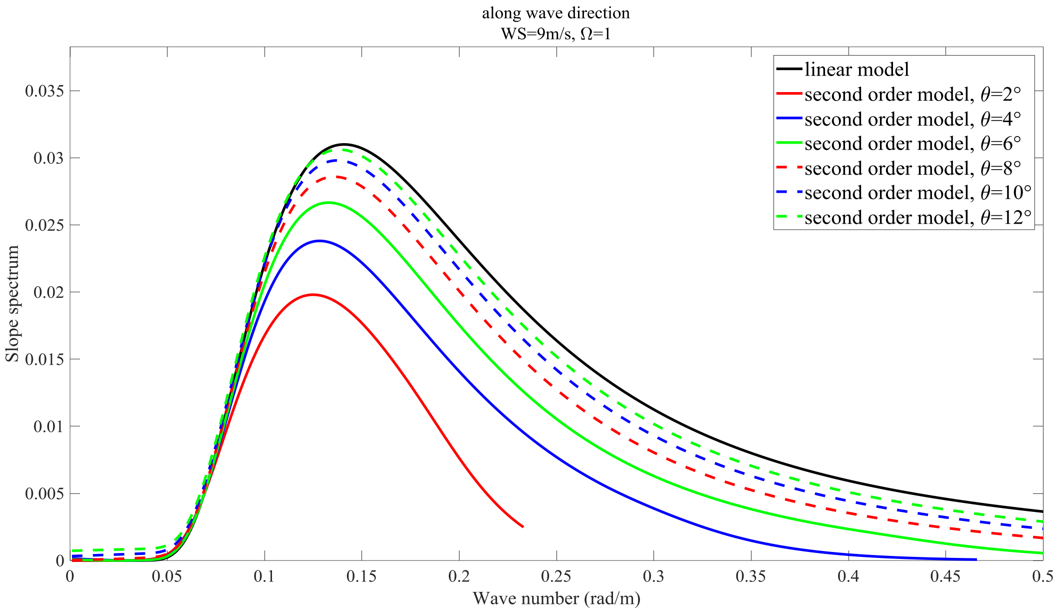
	Inversed Hs (m)	Relative error (%)	Inversed λ_p (m)	Relative error (%)
Linear model	0.72	~	24.8	~
2°	~	~	~	~
4°	~	~	25.8	+4.0
6°	0.64	-11.1	25.5	+2.8
8°	0.68	-5.6	25.3	+2.0
10°	0.73	+1.4	25.2	+1.6
12°	0.79	+9.7	25.2	+1.6

With the incidence angle decreasing, the attenuation of the spectrum become larger.

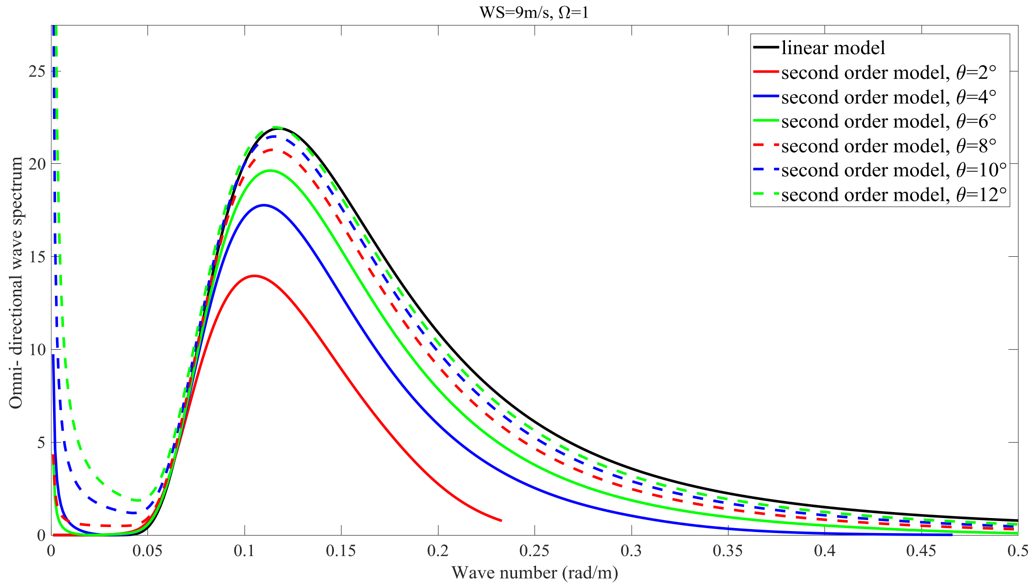
With the incidence angle increasing (above 8°), the parasitic peaks at low wave number become larger. **It shows that range-bunching is an important factor leading to parasitic peaks at low wave number in inverted wave height spectrum.**

The inverted Hs may be the result of the superposition of the pseudo-peak in low wave number and the spectral attenuation of other parts.

Observed along the wave direction



Omnidirectional wave height spectrum

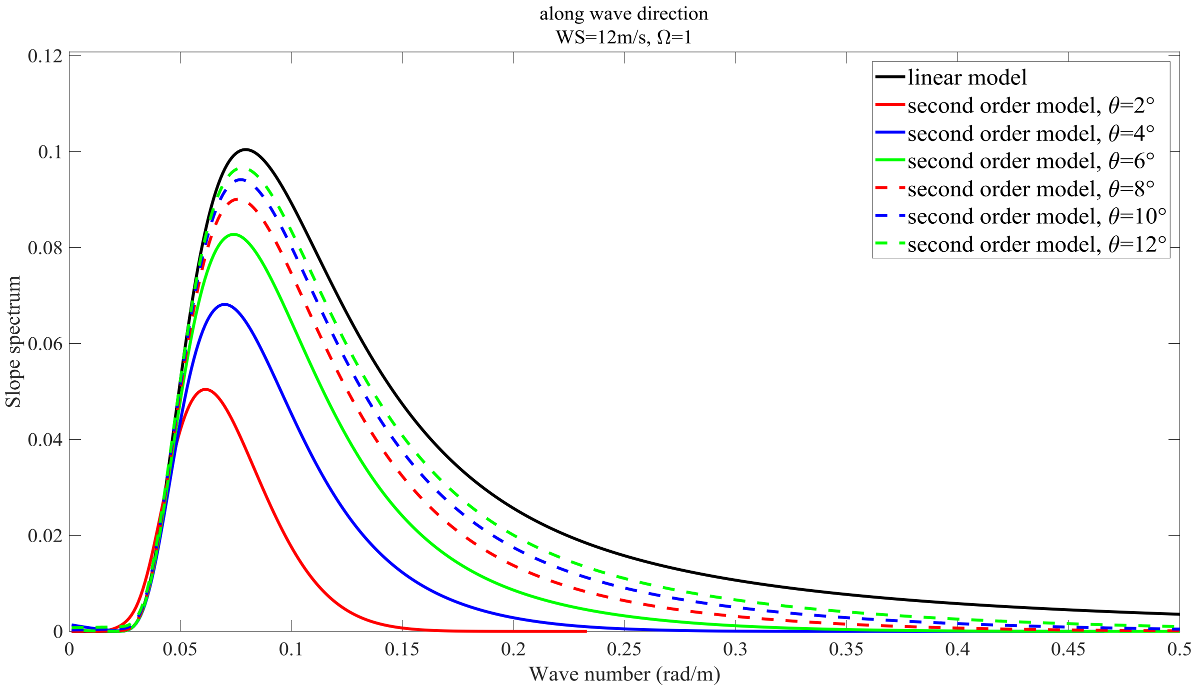


mature wind wave

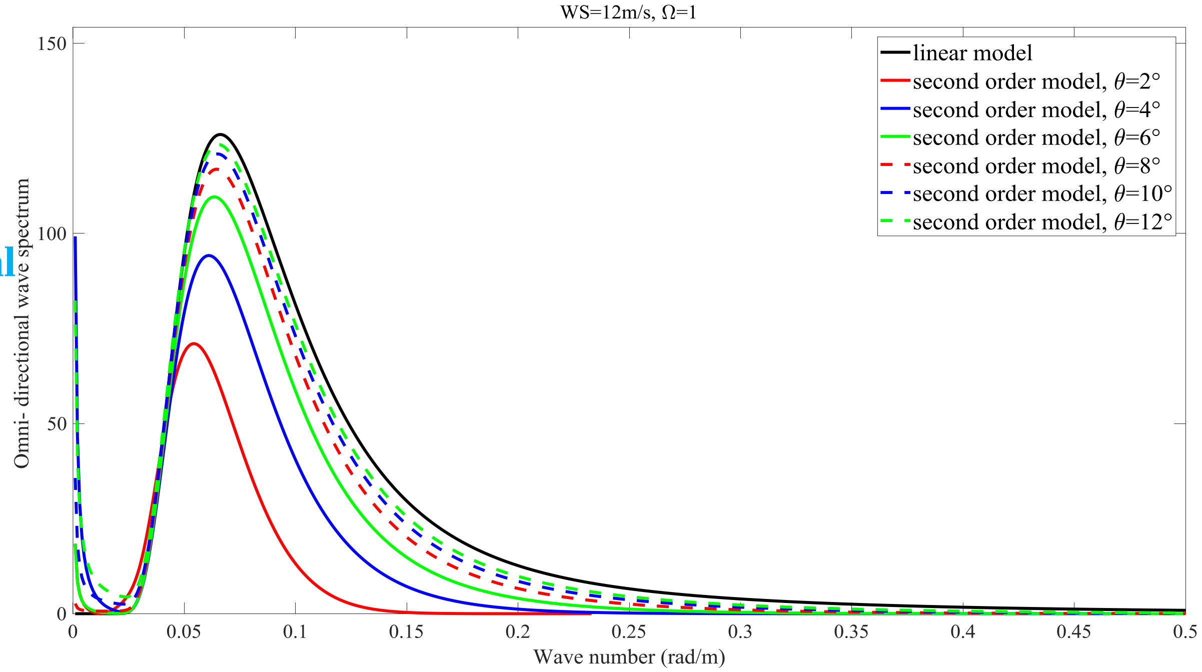
$$U_{10} = 9\, m/s \quad \Omega = 1$$

	Inversed Hs (m)	Relative error (%)	Inversed λ_p (m)	Relative error (%)
Linear model	1.38	~	53.2	~
2°	~	~	59.8	+ 12.4
4°	1.08	- 21.7	57.1	+ 7.3
6°	1.19	- 13.8	55.6	+ 4.5
8°	1.27	- 8.0	54.6	+ 2.6
10°	1.35	- 2.2	54.6	+ 2.6
12°	1.41	+ 2.2	54.2	+ 2.6

Observed along the wave direction



Omnidirectional wave height spectrum

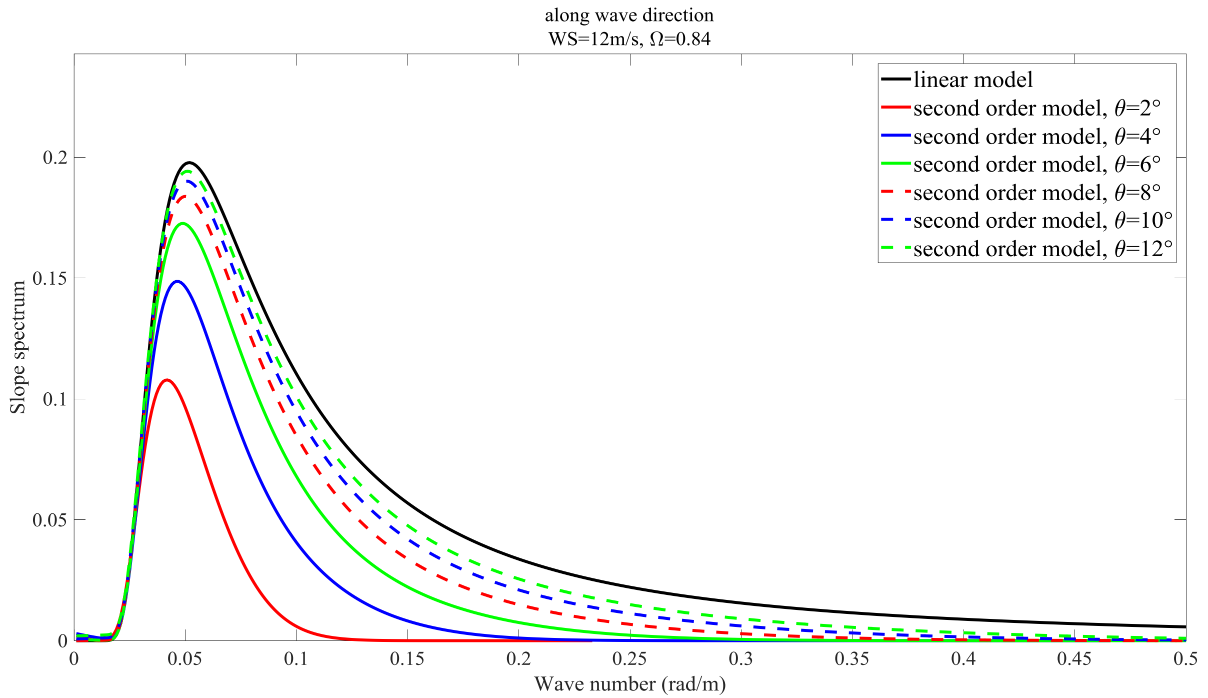


mature wind wave

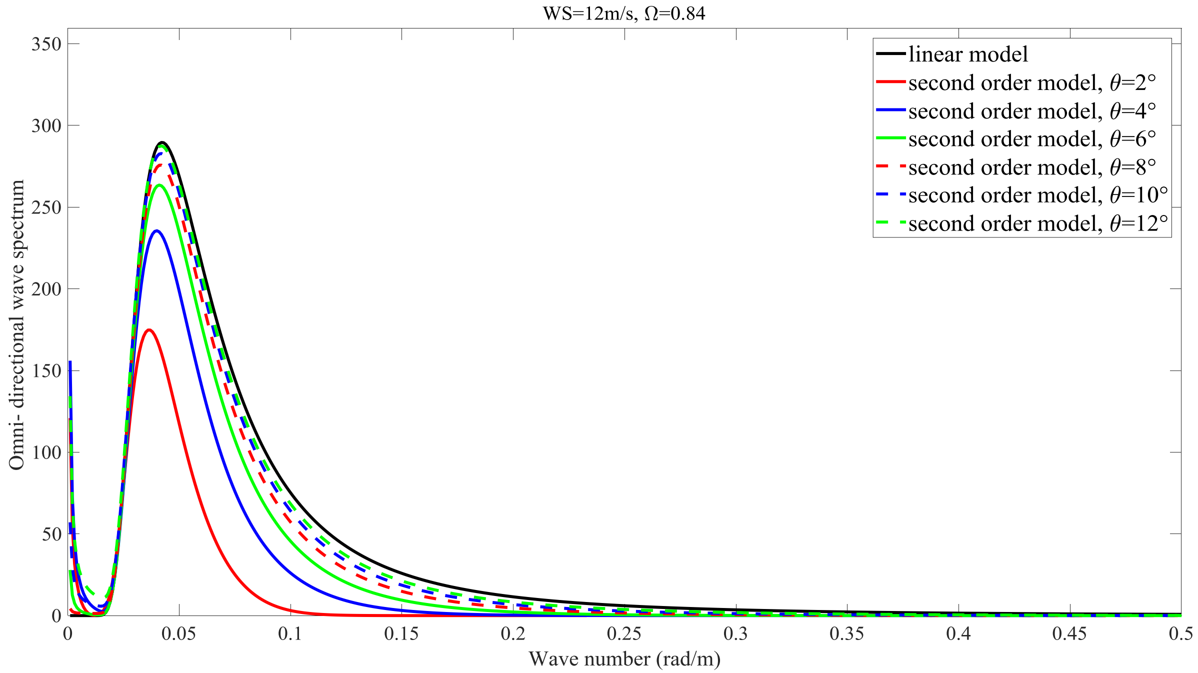
$$U_{10} = \mathbf{12}\ m/s \qquad \Omega = 1$$

	Inversed Hs (m)	Relative error (%)	Inversed λ_p (m)	Relative error (%)
Linear model	2.51	~	95.2	~
2°	1.38	- 45.0	116.4	+ 22.3
4°	1.83	- 27.1	103.0	+ 8.2
6°	2.07	- 17.5	99.7	+ 4.7
8°	2.22	- 11.6	96.7	+ 1.6
10°	2.33	- 7.2	96.7	+ 1.6
12°	2.42	- 3.6	96.7	+ 1.6

Observed along the wave direction



Omnidirectional wave height spectrum

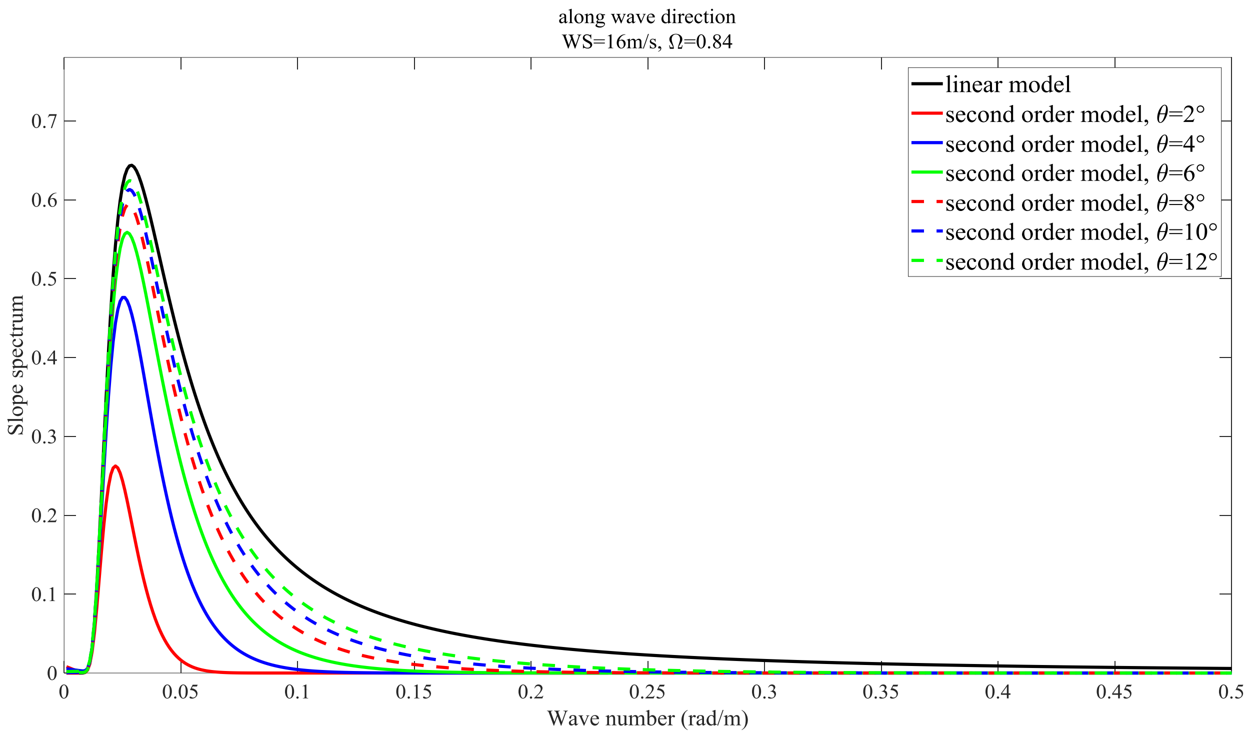


developed wind wave

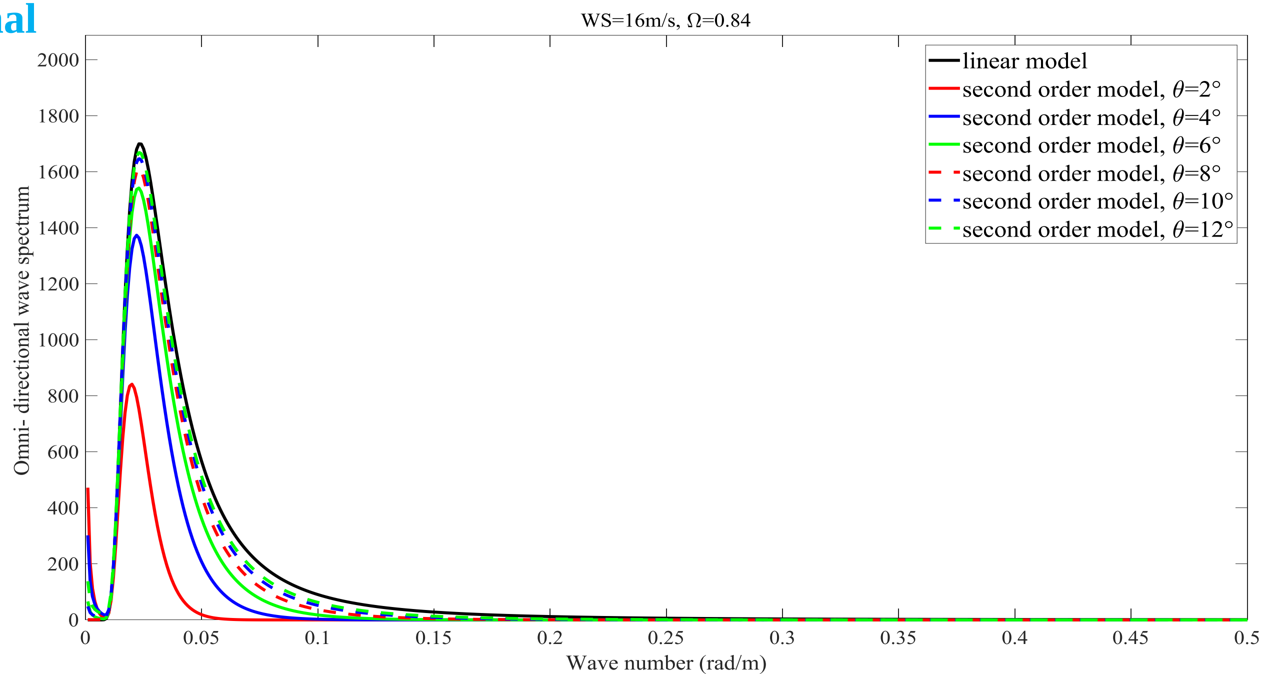
$U_{10} = \mathbf{12}\ m/s \qquad \Omega = 0.84$

	Inversed Hs (m)	Relative error (%)	Inversed λ_p (m)	Relative error (%)
Linear model	3.20	~	149.6	~
2°	1.85	- 42.2	174.5	+ 16.6
4°	2.44	- 23.8	157.1	+ 5.0
6°	2.72	- 15.0	153.2	+ 2.4
8°	2.89	- 9.7	149.6	0
10°	3.02	- 5.6	149.6	0
12°	3.12	- 2.5	149.6	0

Observed along the wave direction



Omnidirectional wave height spectrum

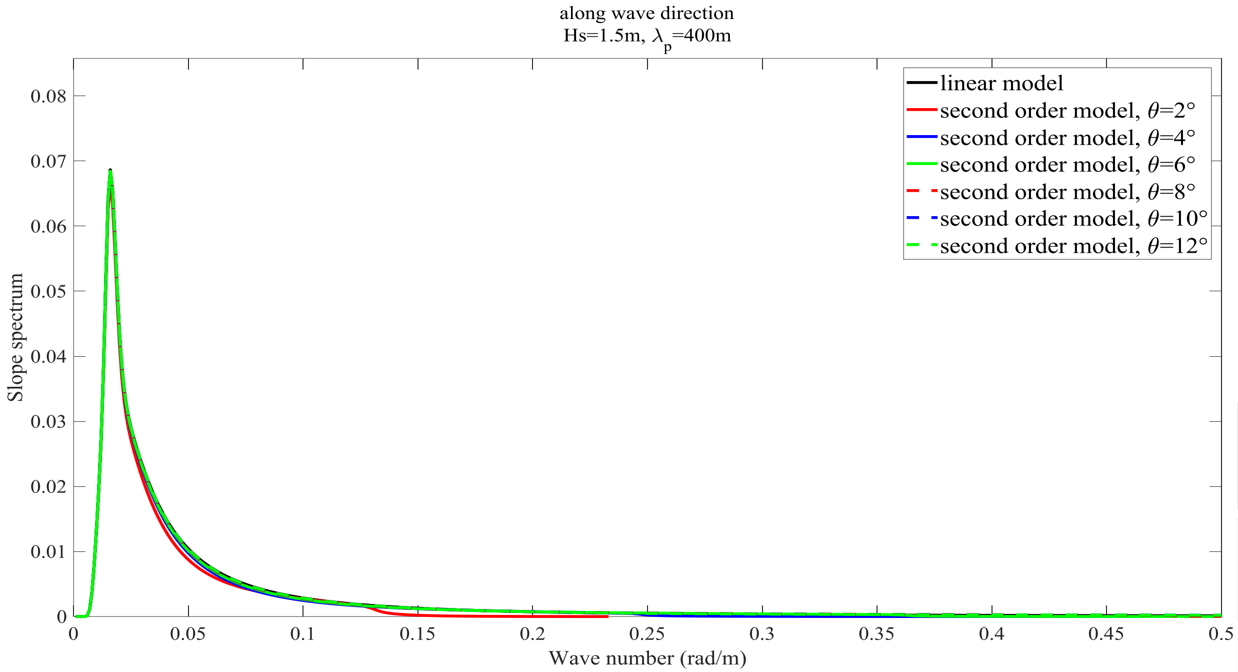


developed wind wave

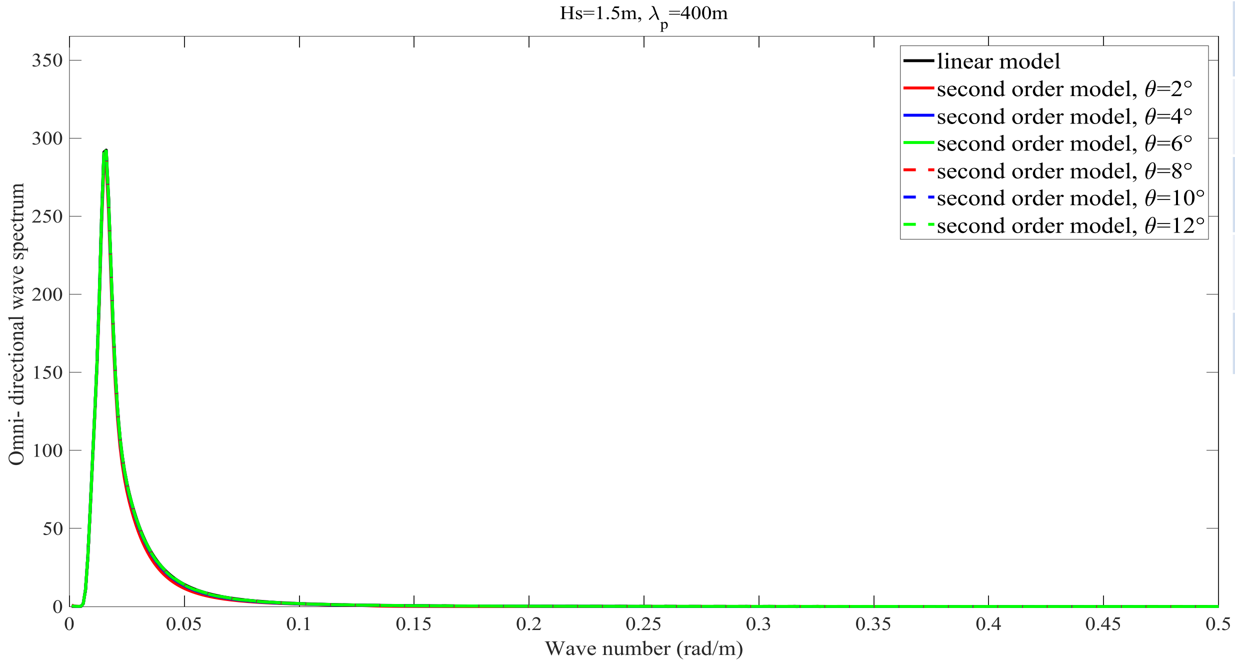
$$U_{10} = \mathbf{16}\ m/s \qquad \Omega = 0.84$$

	Inversed Hs (m)	Relative error (%)	Inversed λ_p (m)	Relative error (%)
Linear model	5.77	~	273.2	~
2°	2.88	- 50.1	314.2	+ 15.0
4°	4.28	- 25.8	285.6	+ 4.5
6°	4.85	- 15.9	273.2	0
8°	5.16	- 10.6	273.2	0
10°	5.35	- 7.3	273.2	0
12°	5.49	- 4.9	273.2	0

Observed along the wave direction



Omnidirectional wave height spectrum

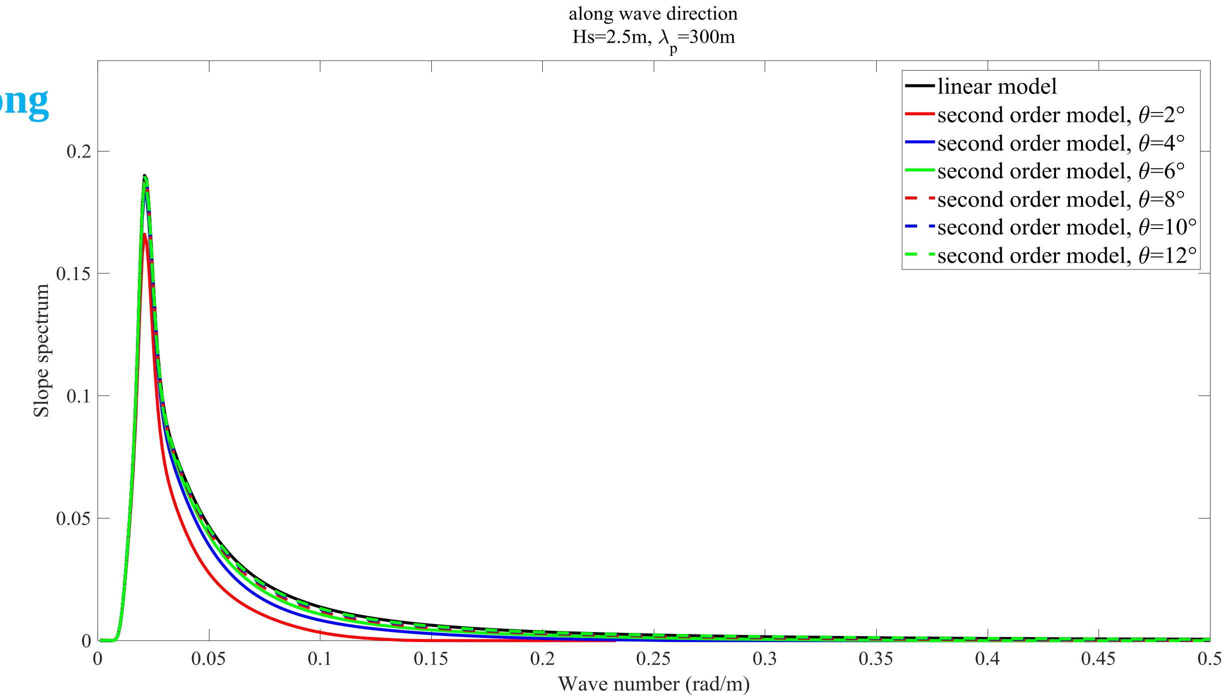


Swell

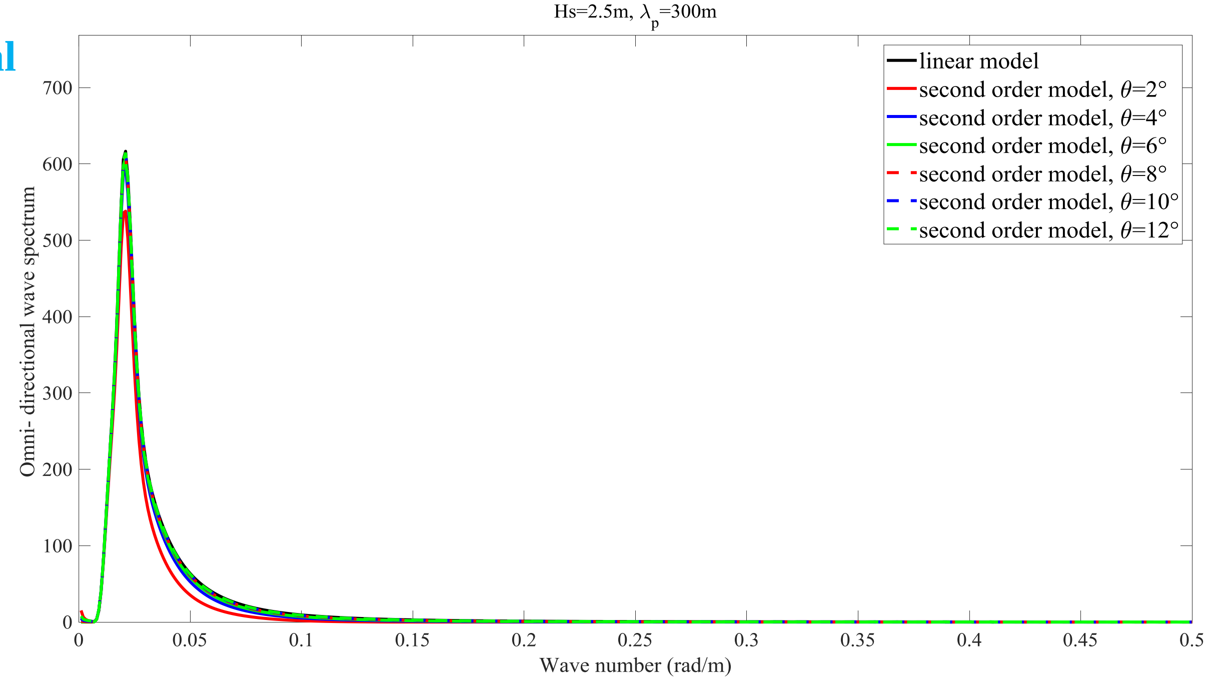
$Hs = 1.5\ m \qquad \lambda_p = 400\ m$

	Inversed Hs (m)	Relative error (%)	Inversed λ_p (m)	Relative error (%)
Linear model	1.50	~	392.7	~
2°	1.45	- 3.3	392.7	0
4°	1.48	- 1.3	392.7	0
6°	1.49	- 0.7	392.7	0
8°	1.50	0	392.7	0
10°	1.50	0	392.7	0
12°	1.50	0	392.7	0

Observed along the wave direction



Omnidirectional wave height spectrum

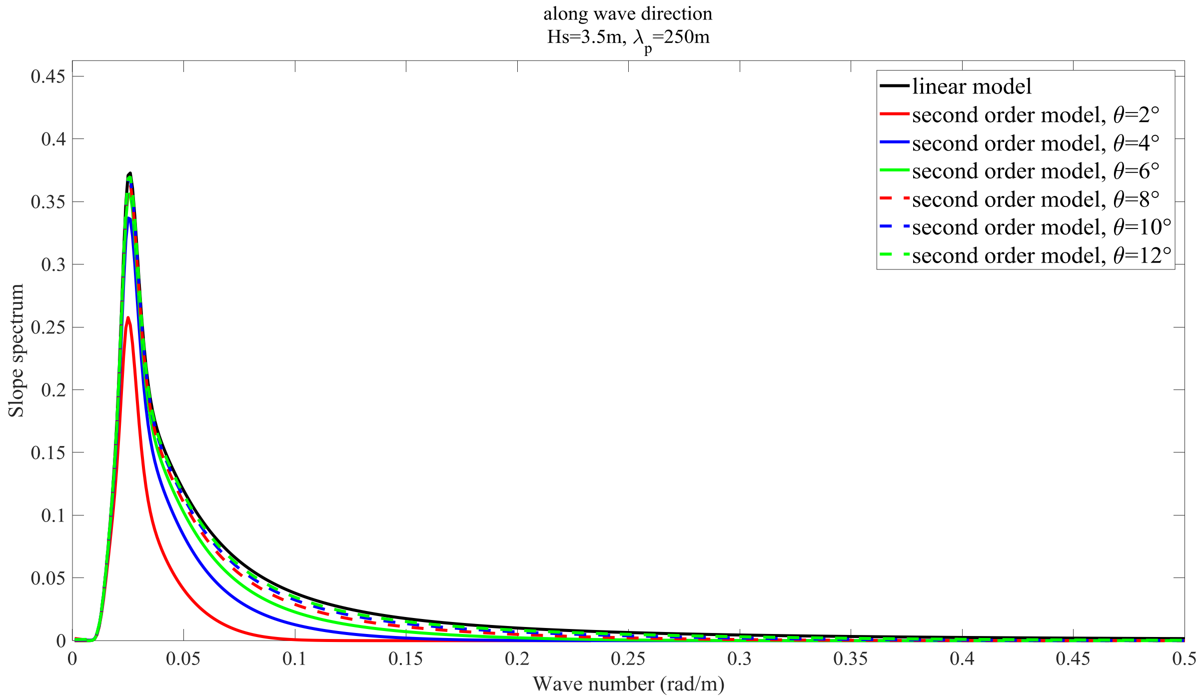


Swell

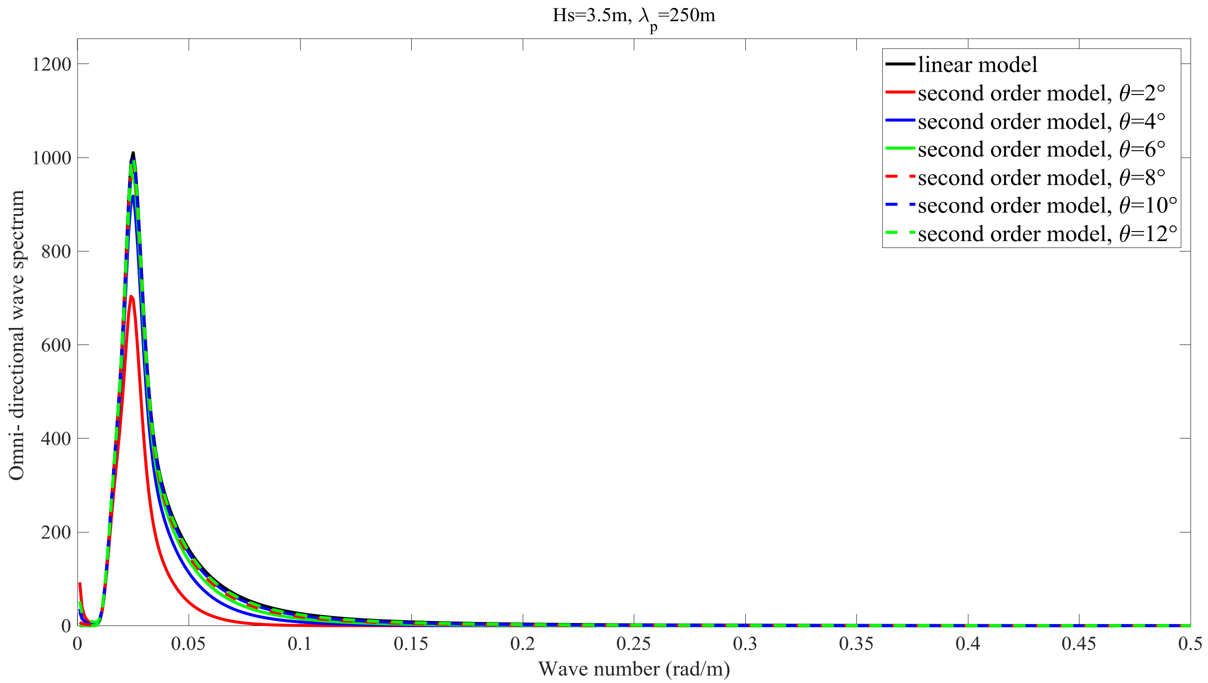
$$Hs = 2.5\ m \qquad \lambda_p = 300\ m$$

	Inversed Hs (m)	Relative error (%)	Inversed λ_p (m)	Relative error (%)
Linear model	2.51	~	299.2	~
2°	2.17	- 13.5	299.2	0
4°	2.37	- 5.6	299.2	0
6°	2.44	- 2.8	299.2	0
8°	2.47	- 1.6	299.2	0
10°	2.48	- 1.2	299.2	0
12°	2.49	- 0.8	299.2	0

Observed along the wave direction



Omnidirectional wave height spectrum



Swell

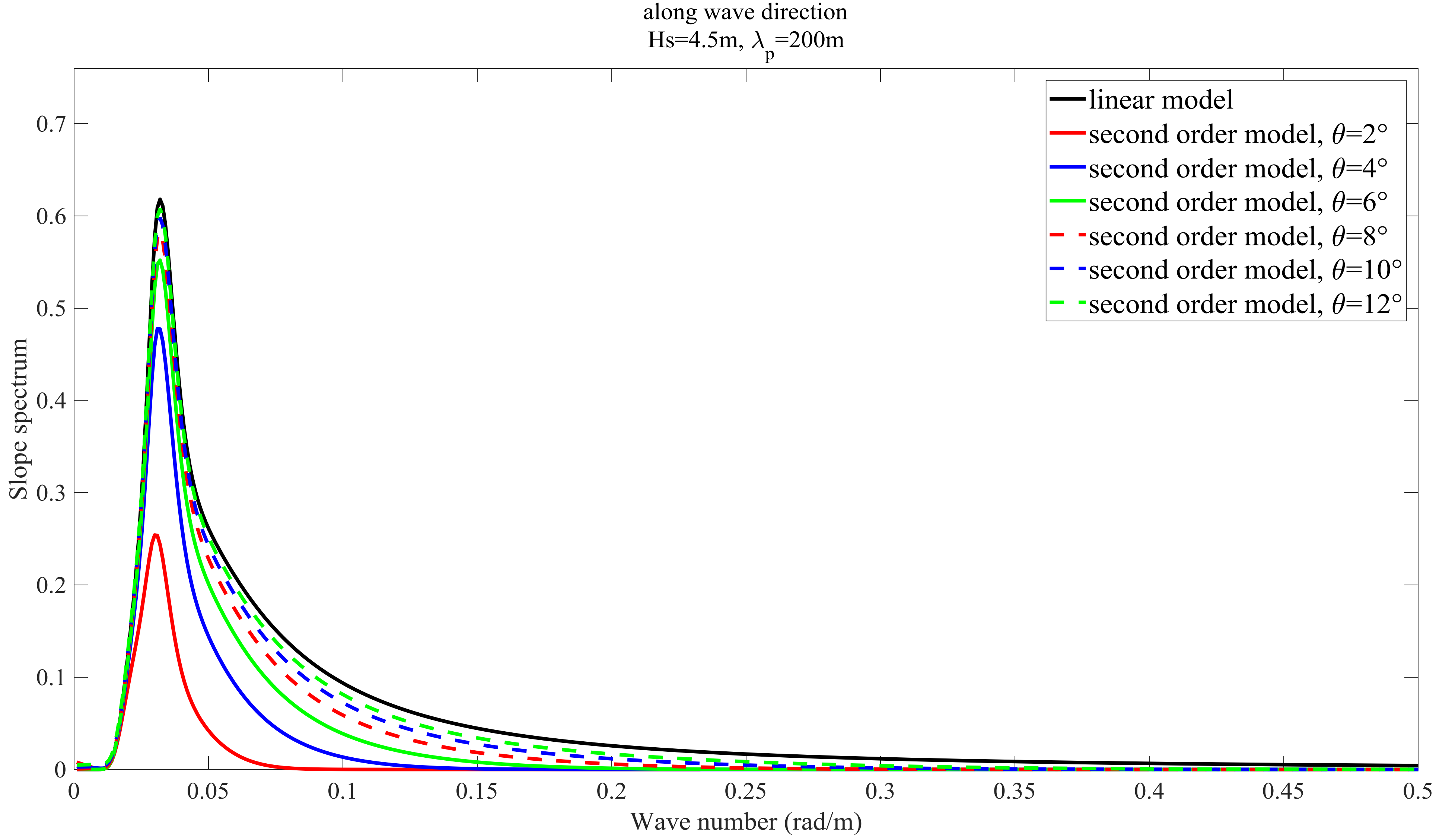
$$Hs = 3.5\, m \qquad \lambda_p = 250\, m$$

	Inversed Hs (m)	Relative error (%)	Inversed λ_p (m)	Relative error (%)
Linear model	3.51	~	251.3	~
2°	2.56	- 27.1	261.8	+ 4.2
4°	3.11	- 11.4	251.3	0
6°	3.29	- 6.3	251.3	0
8°	3.38	- 3.7	251.3	0
10°	3.43	- 2.3	251.3	0
12°	3.47	- 1.1	251.3	0

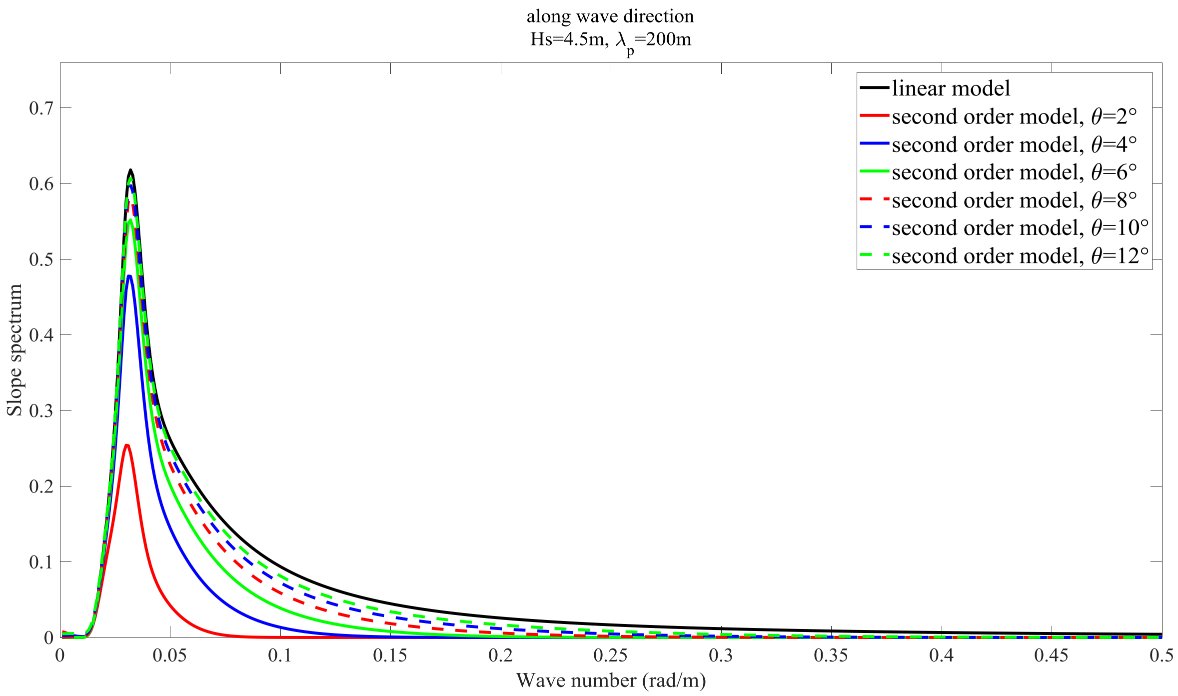
Swell

Observed along the wave direction

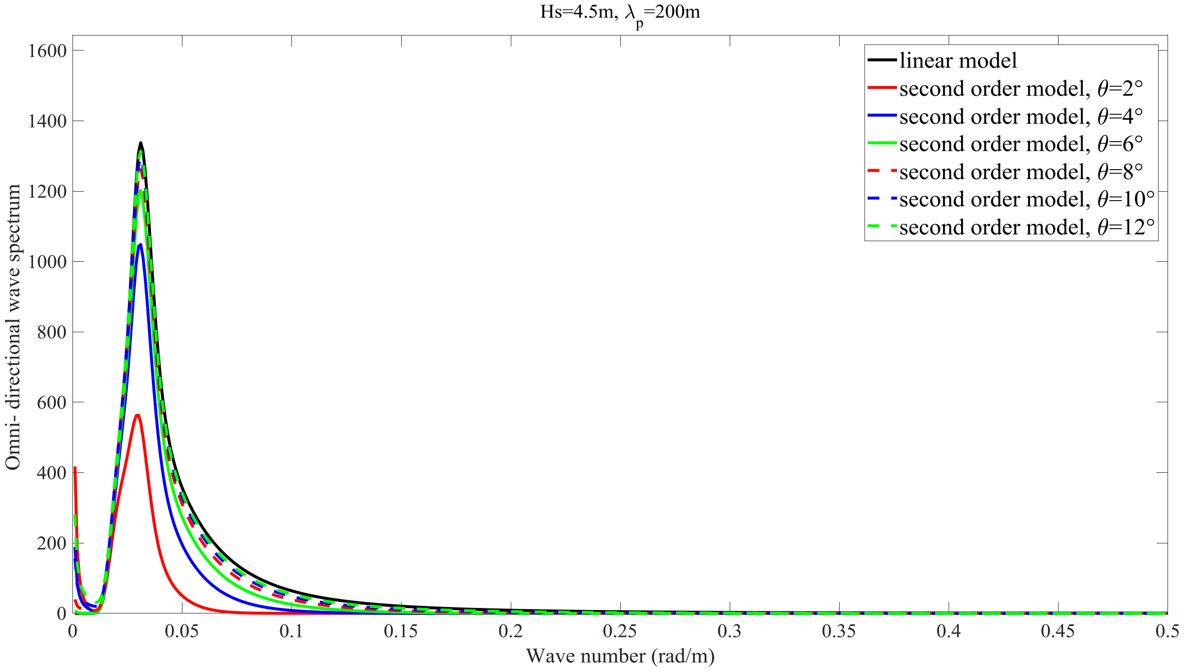
$Hs = \mathbf{4.5}\ m$ $\qquad \boldsymbol{\lambda_p} = 200\ m$



Observed along the wave direction



Omnidirectional wave height spectrum



Swell

$Hs = \mathbf{4.5}\ m \qquad \boldsymbol{\lambda_p} = 200\ m$

	Inversed Hs (m)	Relative error (%)	Inversed λ_p (m)	Relative error (%)
Linear model	4.51	~	202.7	~
2°	2.52	- 44.1	209.4	+ 3.3
4°	3.55	- 21.3	202.7	0
6°	3.94	- 12.6	202.7	0
8°	4.17	- 7.5	202.7	0
10°	4.32	- 4.2	202.7	0
12°	4.43	- 1.8	202.7	0

Conclusion

The effects of range bunching are studied by a theoretical nonlinear modulation model.

The range bunching will lead to the attenuation in the wave number domain where useful signal covers, in meanwhile, also lead to parasitic peaks at low wave number in modulation spectrum.

The effects of range bunching will be pronounced decreasingthe incidence angle, increasing wind speed, increasing Hs.

Range-bunching is an important factor leading to

- parasitic peaks at low wave number in inverted wave height spectrum
- Underestimation of inverted Hs under large sea surface conditions