Modeling Coarse Sand Transport under Skewed Oscillatory Flow Using a CFD-DEM Approach

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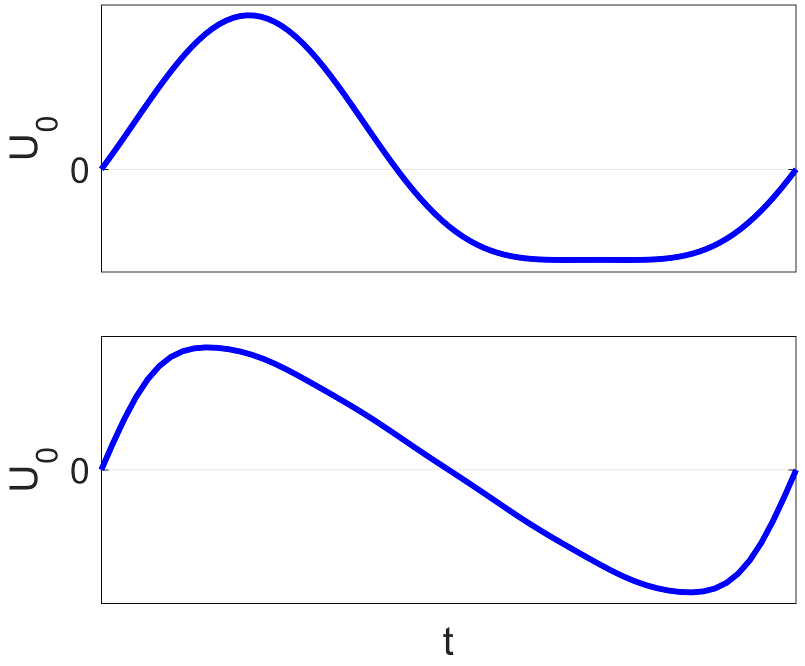
Introduction

- Goal: to better understand the effect of size gradation on wave-induced sediment transport

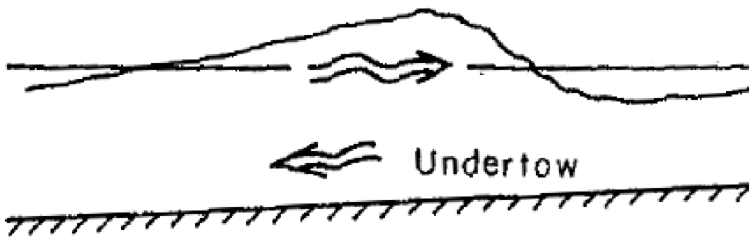
Wave-induced nearshore hydrodynamics

- Non-breaking waves → Velocity skewness



Acceleration skewness

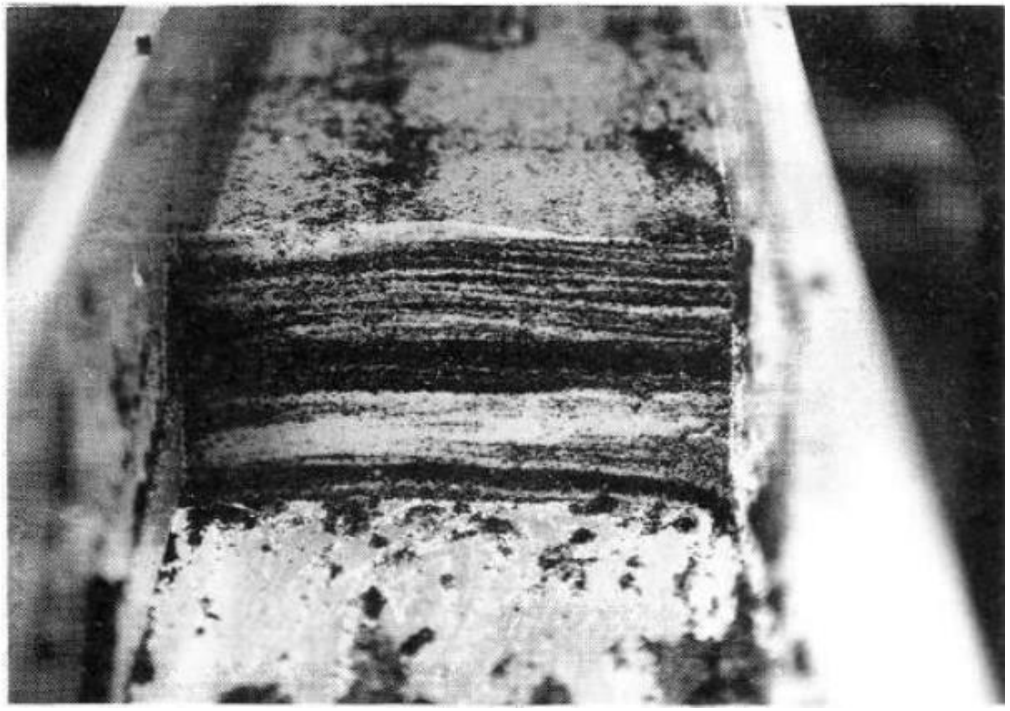
- Broken waves → Undertow current



Introduction

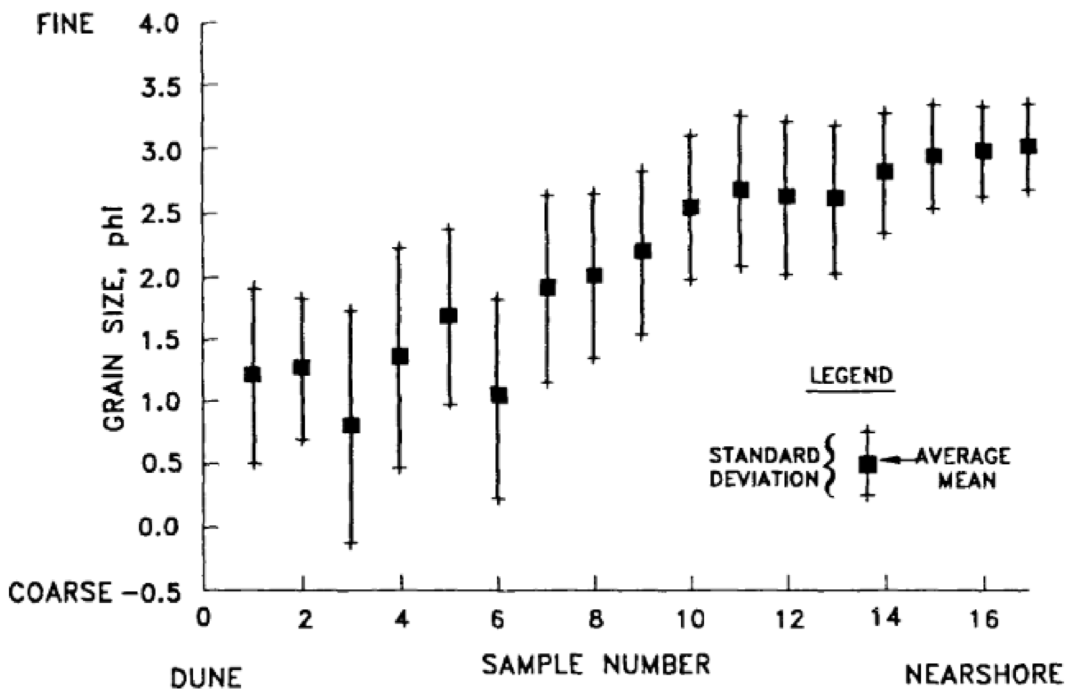
Sediment size gradation

Vertical sorting



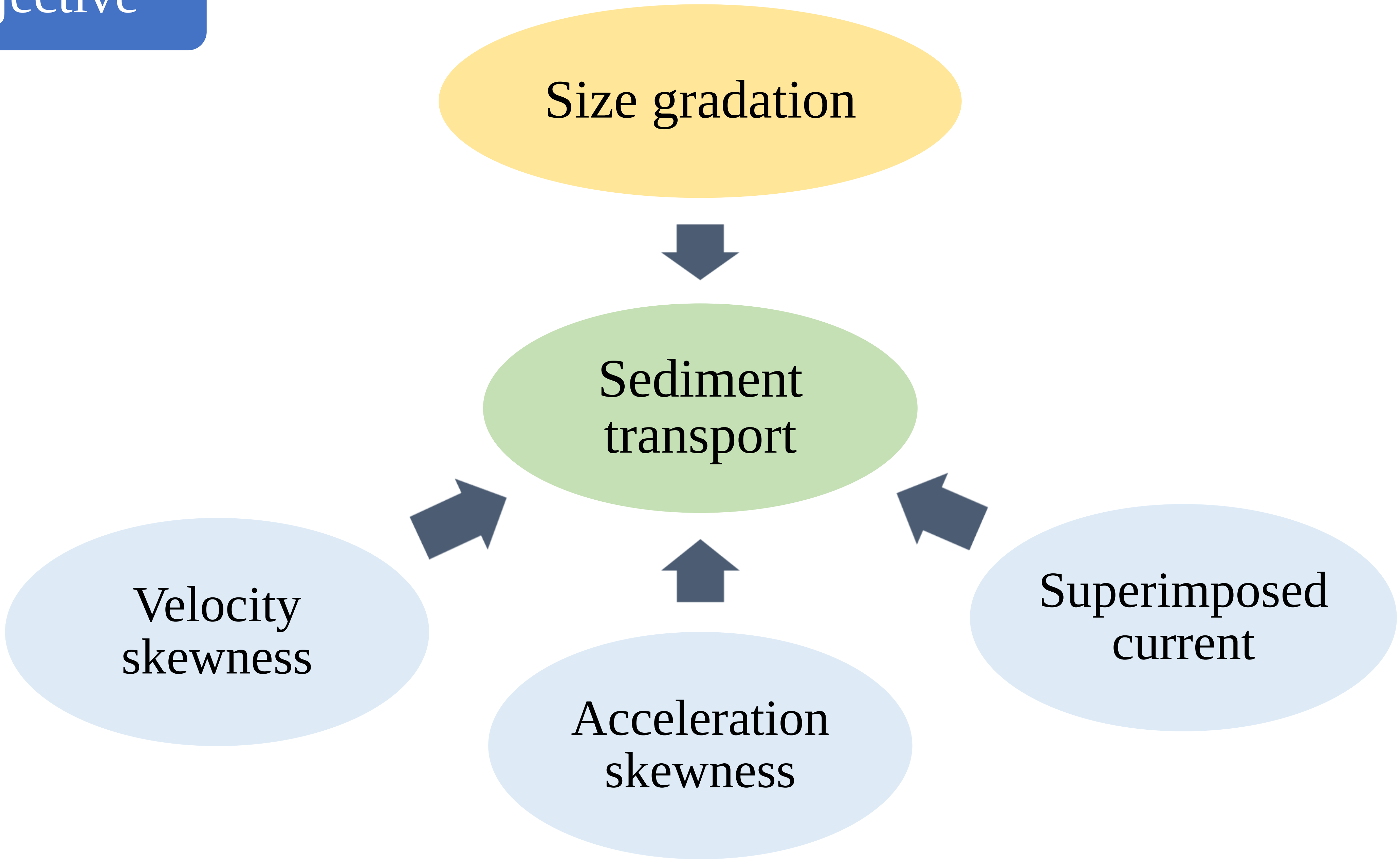
Julien et. al. (1998), CEN Tech. J.

Horizontal sorting



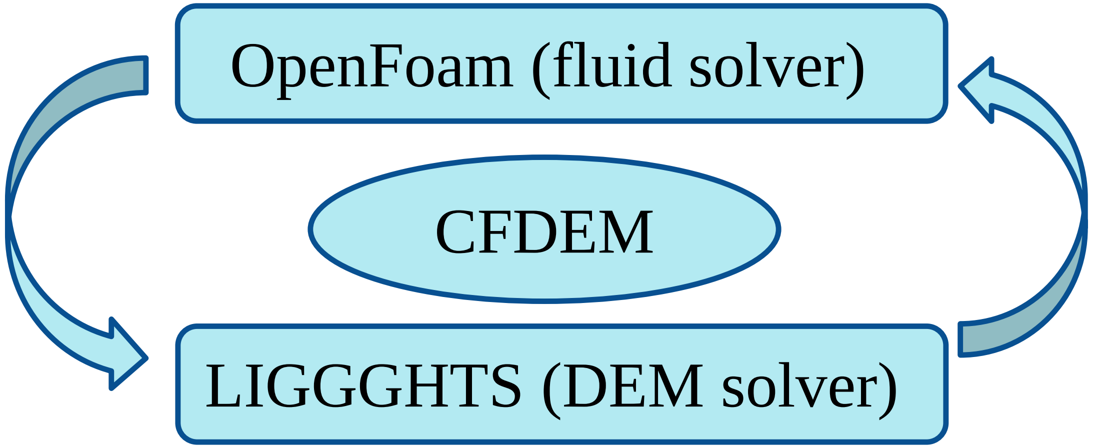
Stauble (1992), Tech. Rep. CERC-92-7

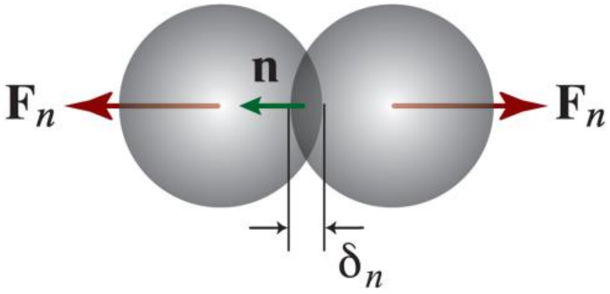
Objective

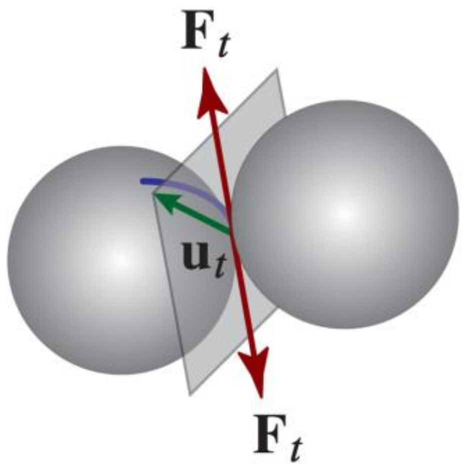

Size gradation
Sediment transport
Velocity skewness
Acceleration skewness
Superimposed current

Model Description

- Intergranular forces: Soft sphere model
- Fluid phase: RANS Model
- Fluid turbulence: k-ε Model
- Fluid and particle phase coupling: Drag force and pressure gradient
- Particle dispersion due to turbulence: Eddy Interaction Model



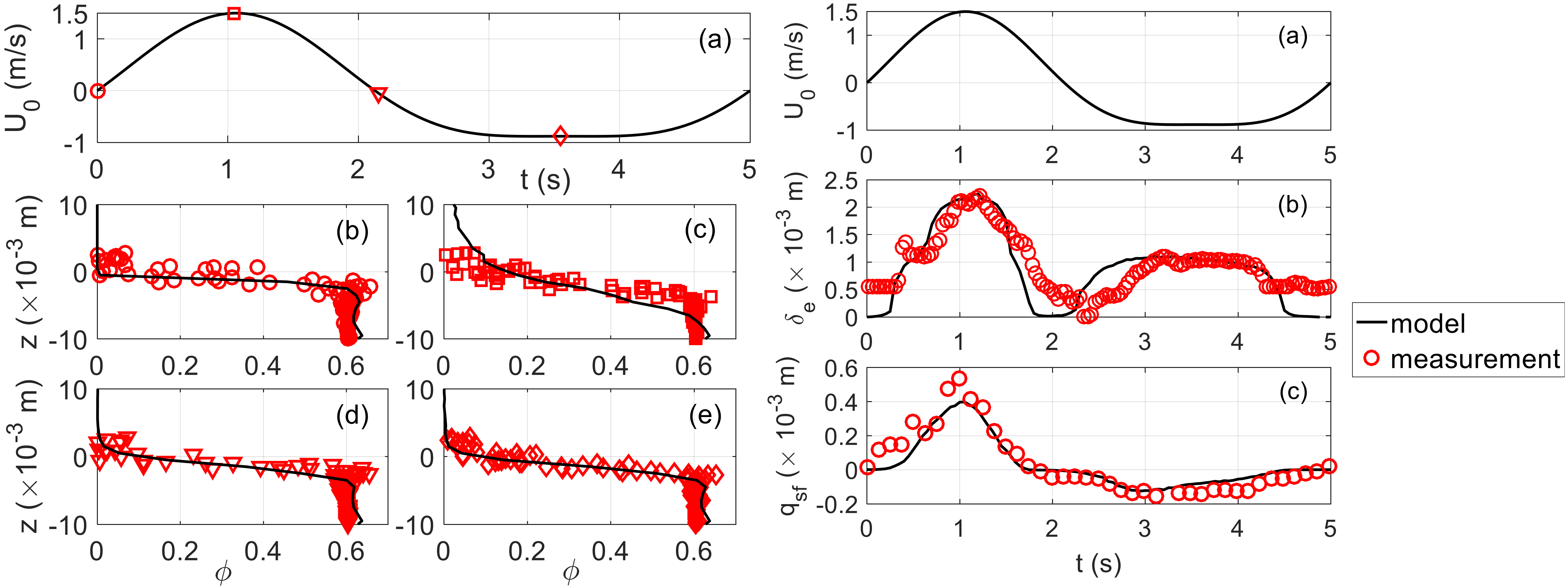




Cheng et. al. (2018). "Eddy Interaction Model for Turbulent Suspension in Reynolds-Averaged Euler–Lagrange Simulations of Steady Sheet Flow." Advances in Water Resources

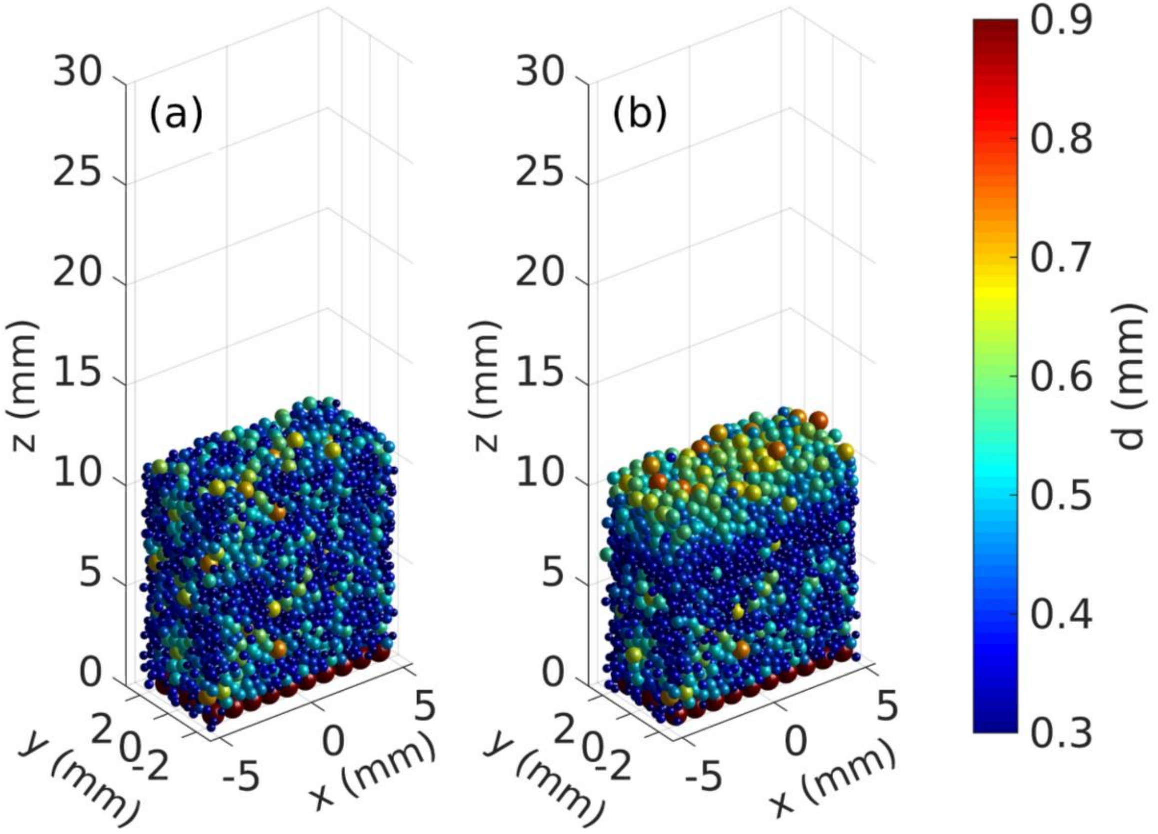
Model Validation

- O'Donoghue & Wright (2004), Coastal Engineering
- Well-sorted coarse sand: d_{10} = 0.36 mm, d_{50} = 0.51mm, d_{90} = 0.67mm



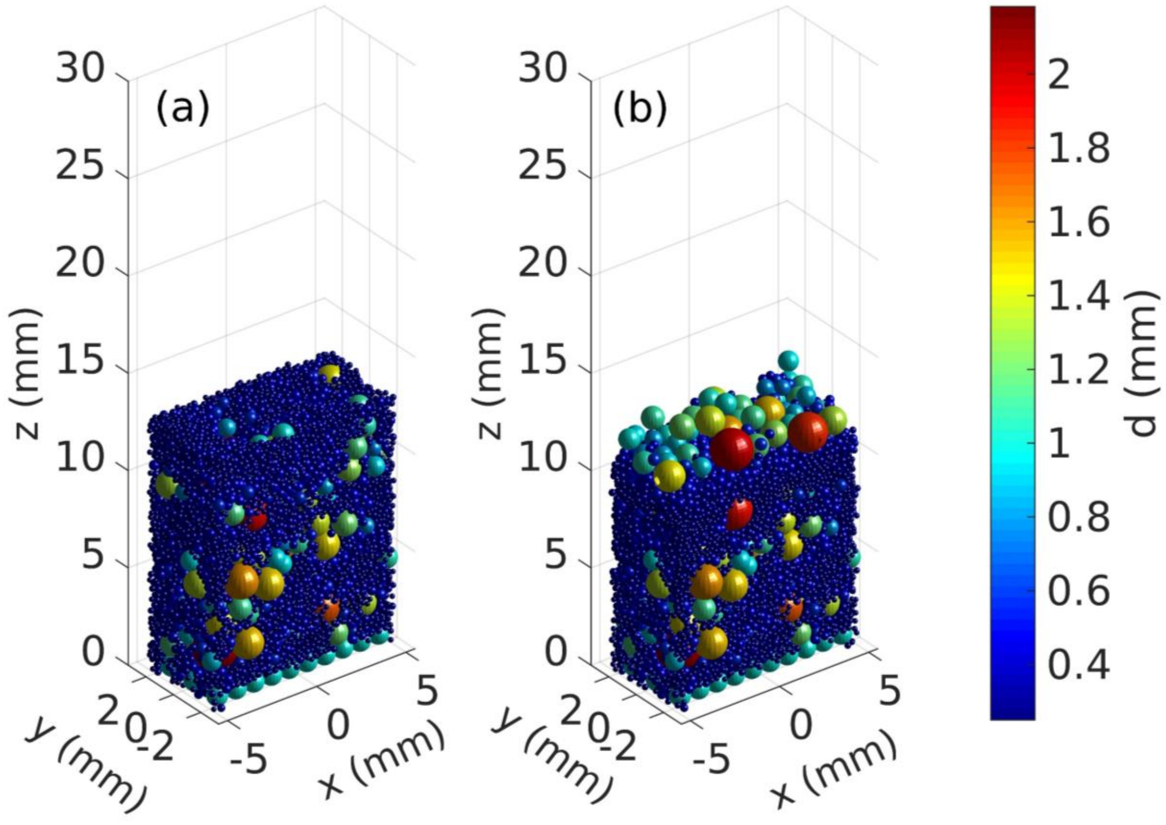
Model Result

Well-sorted sand:
d_{50} = 0.51 mm, d_{90}/ d_{10} = 1.86



Initial bed 10^{th} wave bed

Poorly-sorted sand:
d_{50} = 0.51 mm, d_{90}/ d_{10} = 5.96



Initial bed 10^{th} wave bed

Model Results

Effect of size gradation

- State of the art parameterization: van der A et. al. (2013), Coastal Engineering

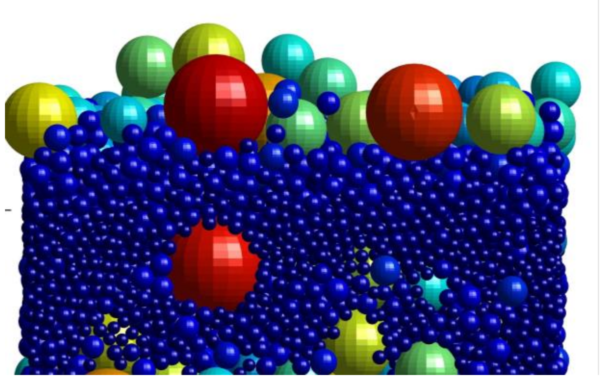
$$\vec{\Phi} = \frac{\vec{q_s}}{\sqrt{(s-1)gd_{50}^3}} = \frac{\sqrt{|\theta_c|}T_c\left(\Omega_{cc} + \frac{T_c}{2T_{cu}}\Omega_{tc}\right)\frac{\vec{\theta_c}}{|\theta_c|} + \sqrt{|\theta_t|}T_t\left(\Omega_{tt} + \frac{T_t}{2T_{tu}}\Omega_{ct}\right)\frac{\vec{\theta_t}}{|\theta_t|}}{T}$$

- Size gradation

$$\frac{q}{\sqrt{(s-1)gd_{50}^3}} = \sum_{j=1}^{M} p_j \frac{q_j}{\sqrt{(s-1)gd_j^3}}$$

$$\varepsilon_{eff,j} = \left(\frac{d_j}{d_{50}}\right)^{0.25}$$

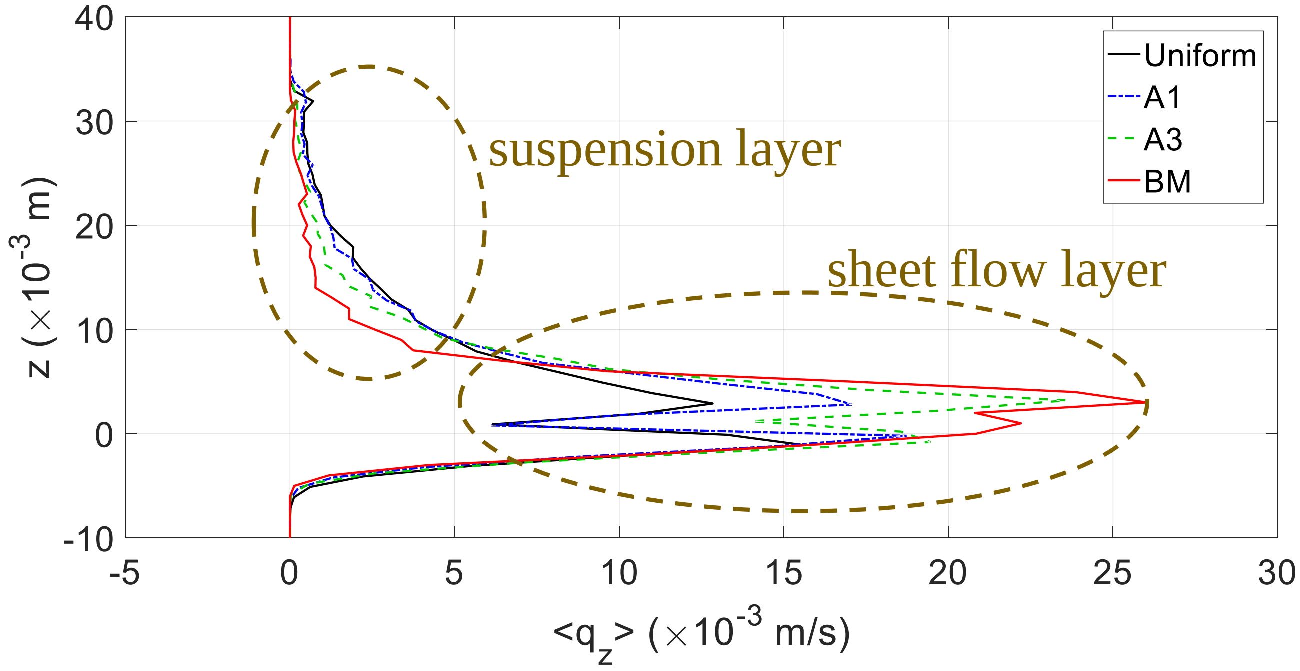
- Exposure
- Armoring

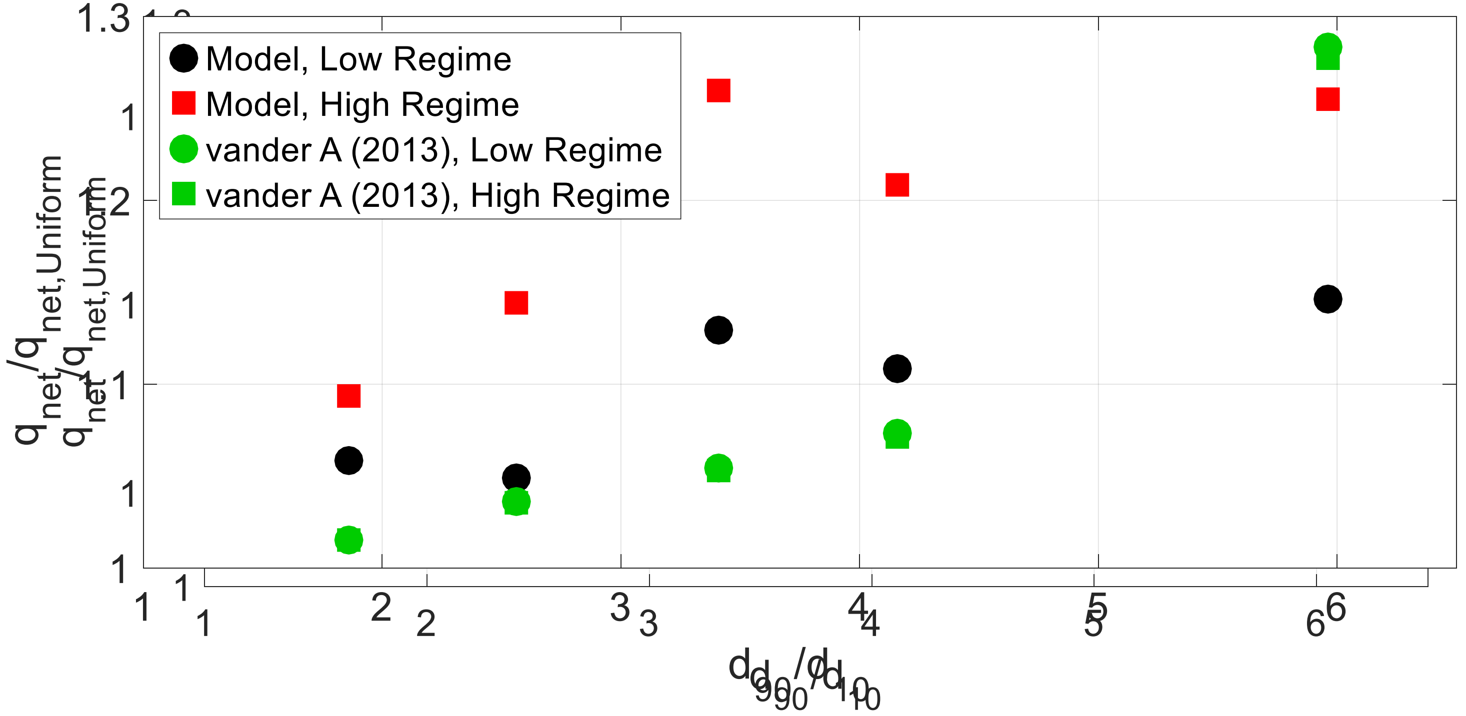


Size Distribution

Sand type	d_{90}/d_{10}	Category
Uniform	1	uniform
A1	1.86	very well-sorted
A2	2.56	well-sorted
A3	3.41	moderately-sorted
A4	4.16	moderately-sorted
BM	5.96	poorly-sorted

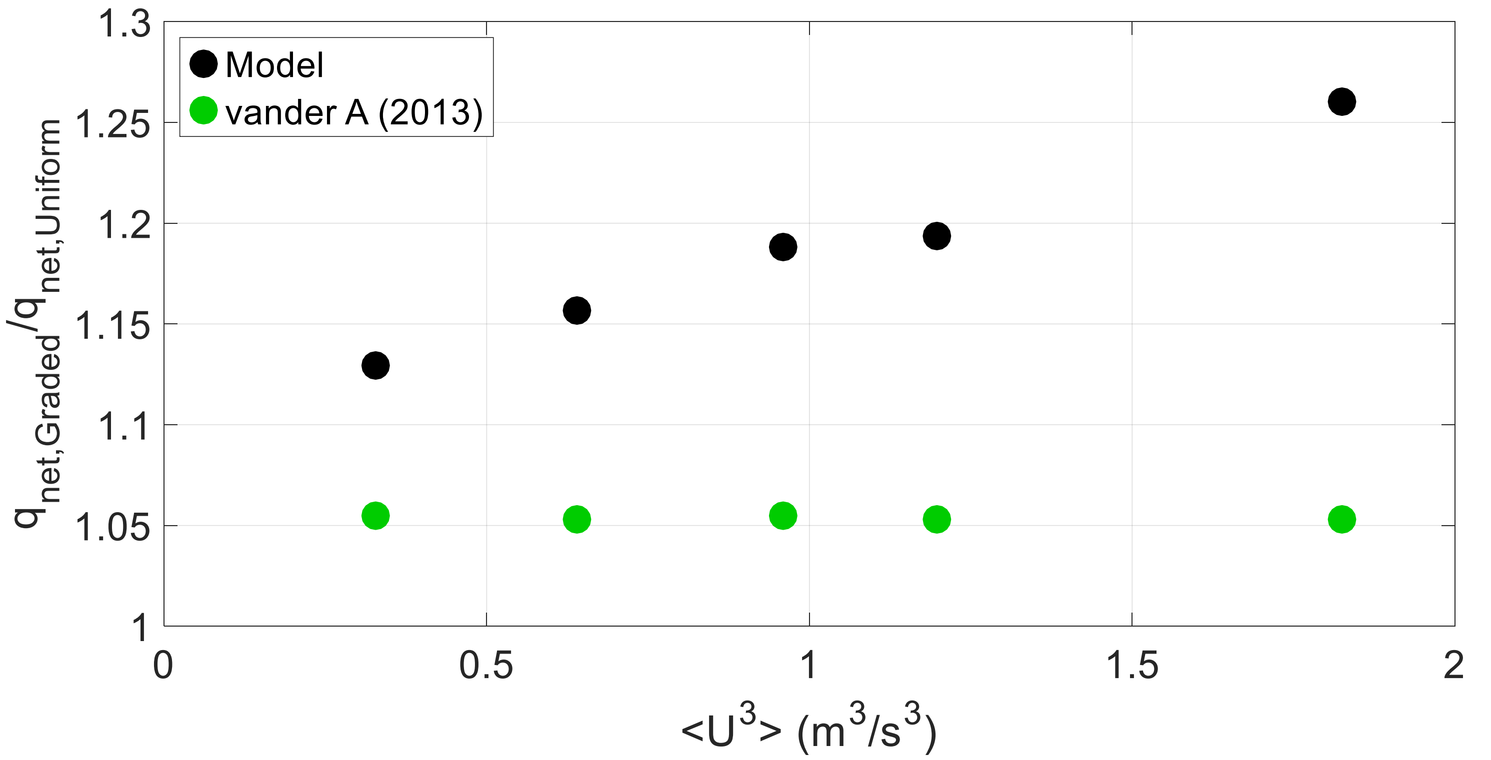
Flow	U_{rms} (m/s)	S
VSI88S63 (Low Regime)	0.88	0.63
VSI109S78 (High Regime)	1.09	0.78

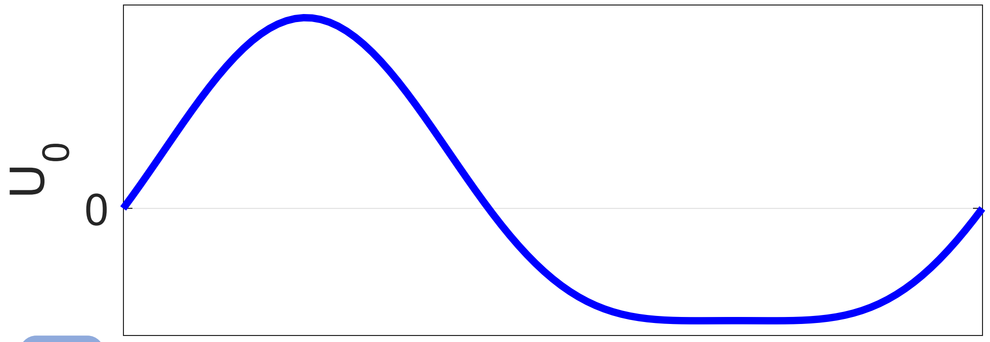




Velocity skewness

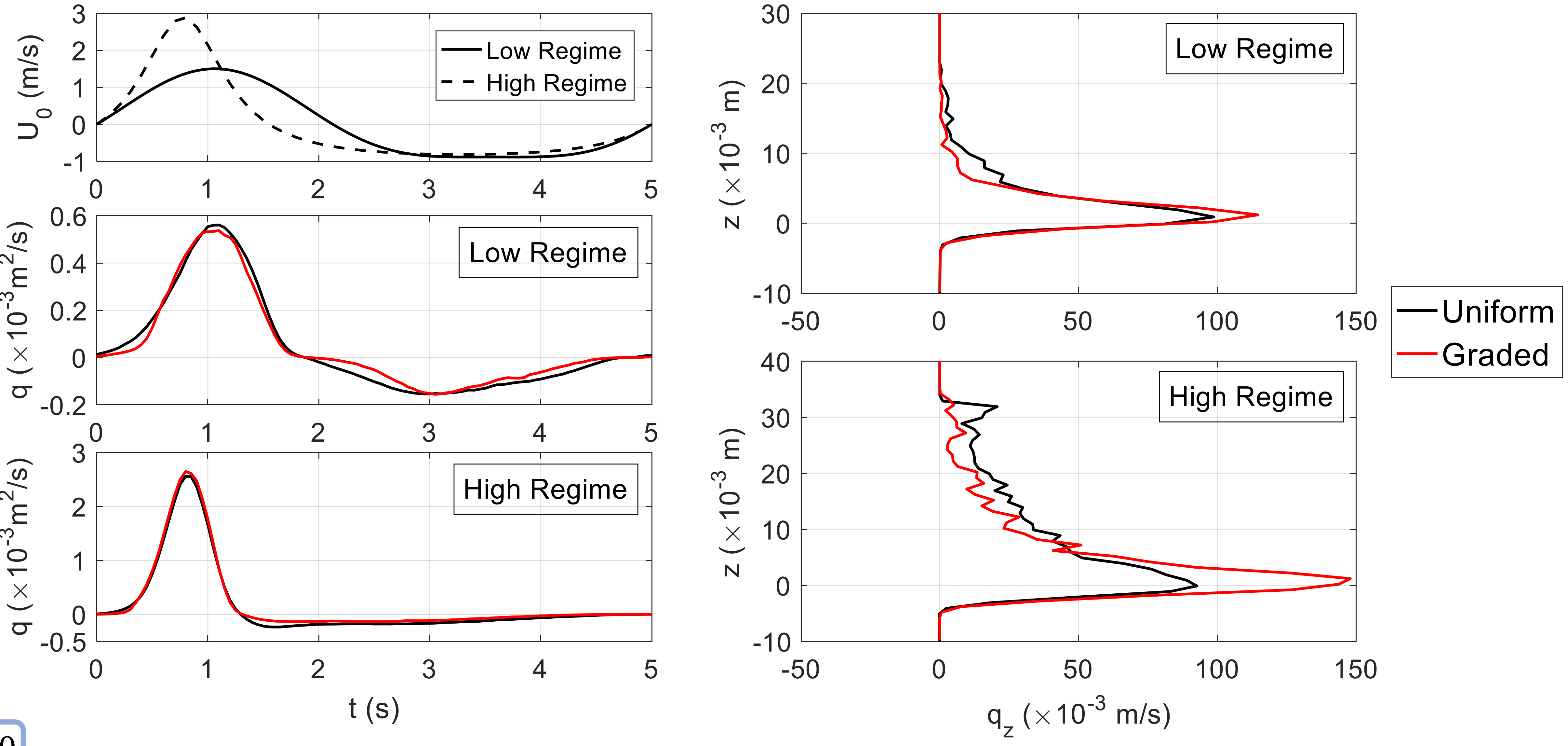
Flow	U_{rms} (m/s)	S	$\langle U^3 \rangle$ (m^3/s^3)
VSI88S63	0.88	0.63	0.33
VSI88S78	0.88	0.78	0.96
VSI109S63	1.09	0.63	0.64
VSI109S70	1.09	0.70	1.20
VSI109S78	1.09	0.78	1.82





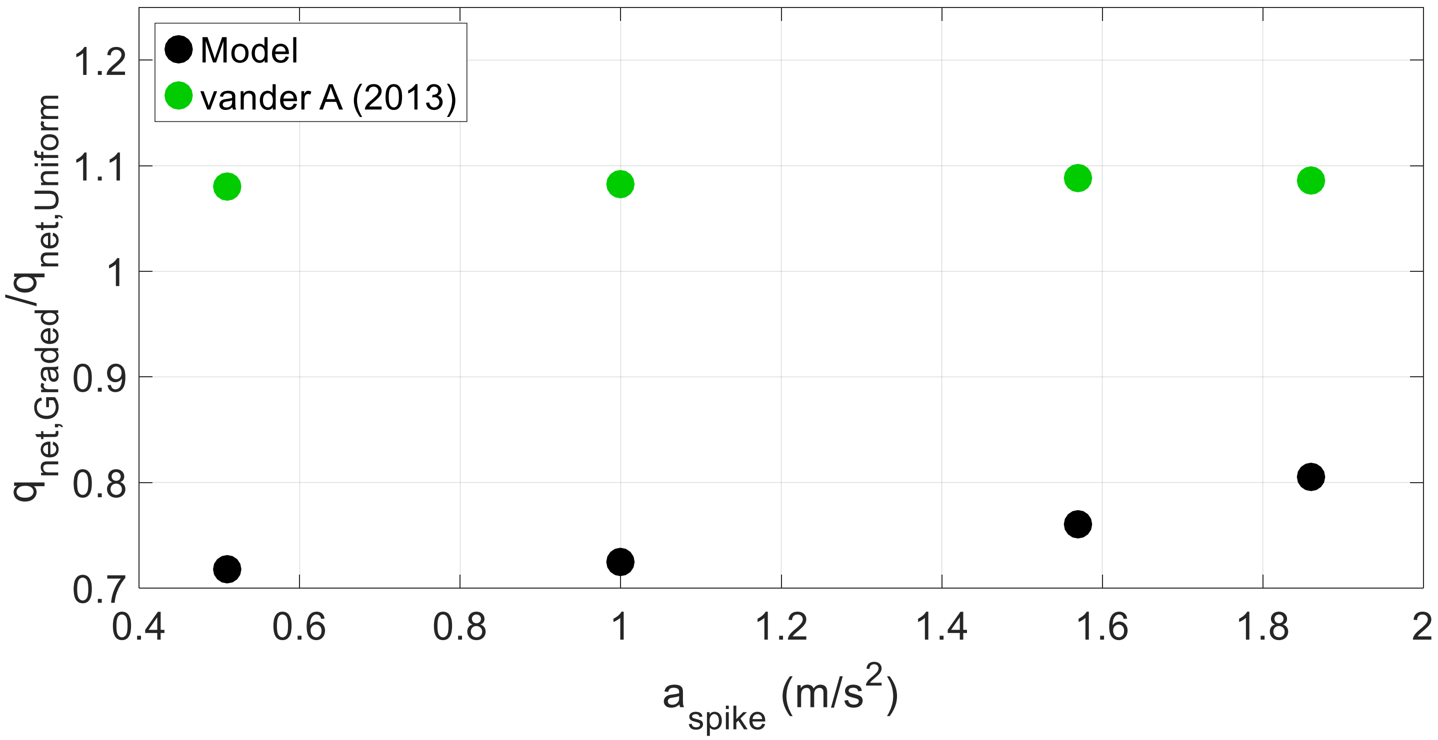
$$S = \frac{U_{max}}{U_{max} - U_{min}}$$

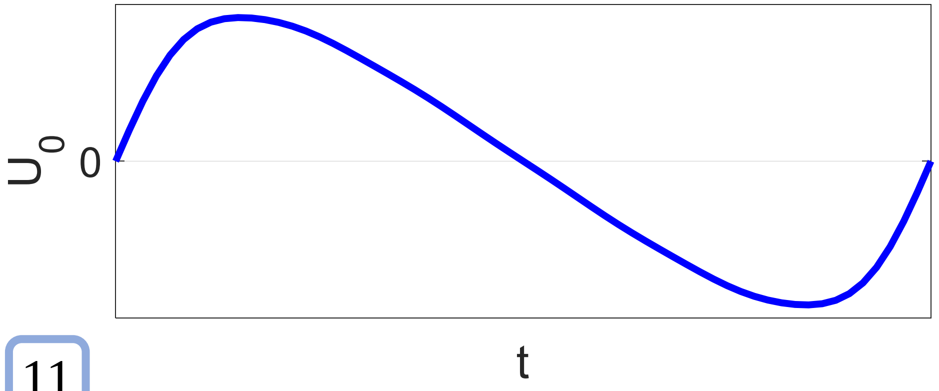
Velocity skewness



Acceleration skewness

Flow	U_{rms} (m/s)	R	a_{spike} (m/s^2)
ASI92S62	0.92	0.62	0.51
ASI92S71	0.92	0.71	1.00
ASI92S78	0.92	0.78	1.57
ASI109S78	1.09	0.78	1.86

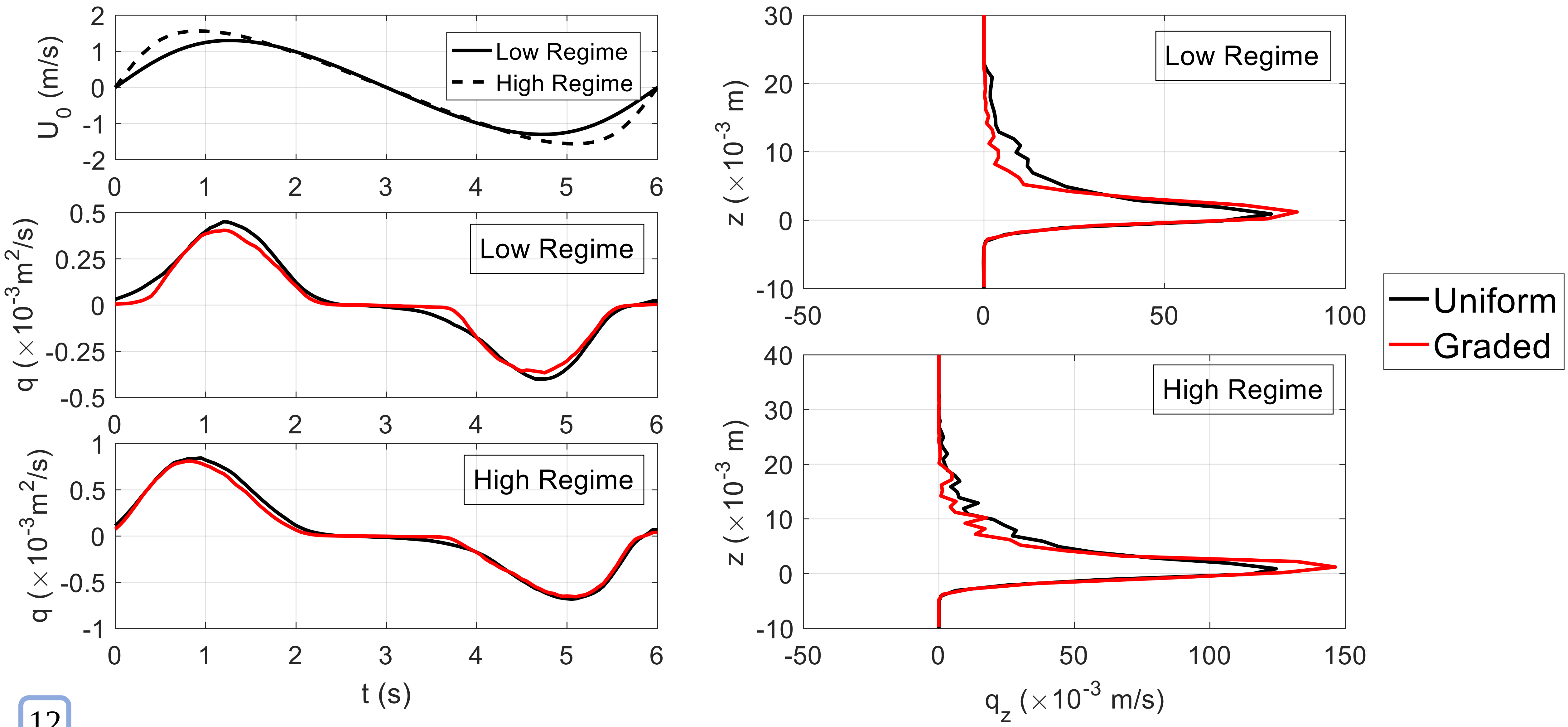




$$R = \frac{a_{max}}{a_{max} - a_{min}}$$

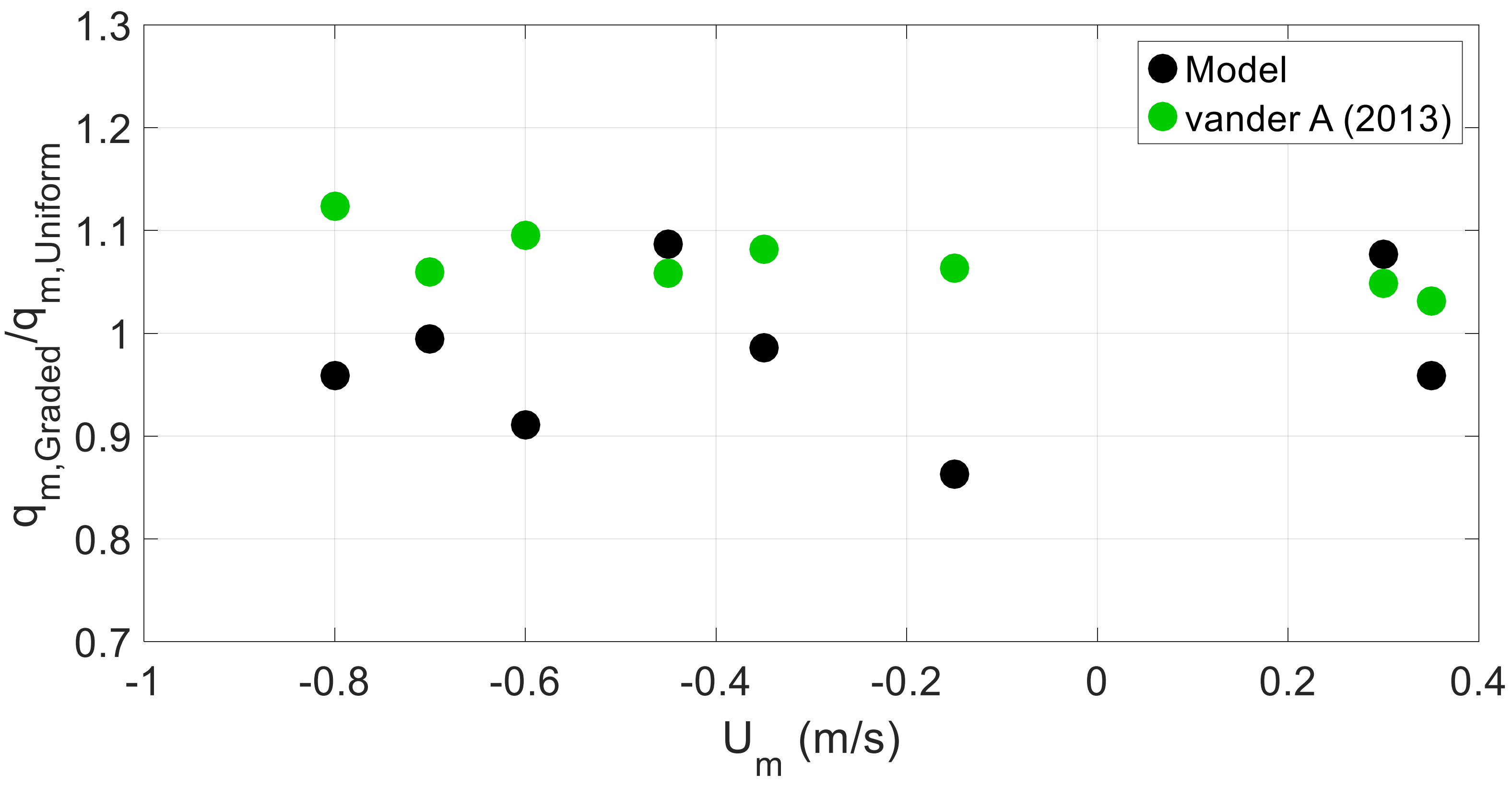
$$a_{spike} = \frac{< a^3 >}{< a^2 >}$$

Acceleration skewness



Superimposed current

Flow	U_{rms} (m/s)	U_m (m/s)
C15NI88S63	0.88	-0.15
C45NI88S63	0.88	-0.45
C70NI88S63	0.88	-0.70
C30PI88S63	0.88	+0.3
C35NI109S78	1.09	-0.35
C60NI19S78	1.09	-0.60
C80NI109S78	1.09	-0.80
C35PI109S78	1.09	+0.35



Summary

- 42 runs performed to investigate the effect of coarse sand size gradation on sediment transport rate under different flow conditions
- Size distributions wider that d_{90}/d_{10} = 3.5 do not influence the net transport rate.
- Size gradation increases transport rate corresponding to velocity skewness by 10-25%
- Size gradation reduces transport rate corresponding to acceleration skewness by 20-30%
- Size gradation has negligible effect on the current-induced transport rate (within 10%)

Thank you for your attention

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Thanksgiving, 2017

Field Trip, 2017