NUMERICAL SIMULATION OF IRREGULAR WAVE RUNUP ON A BEACH

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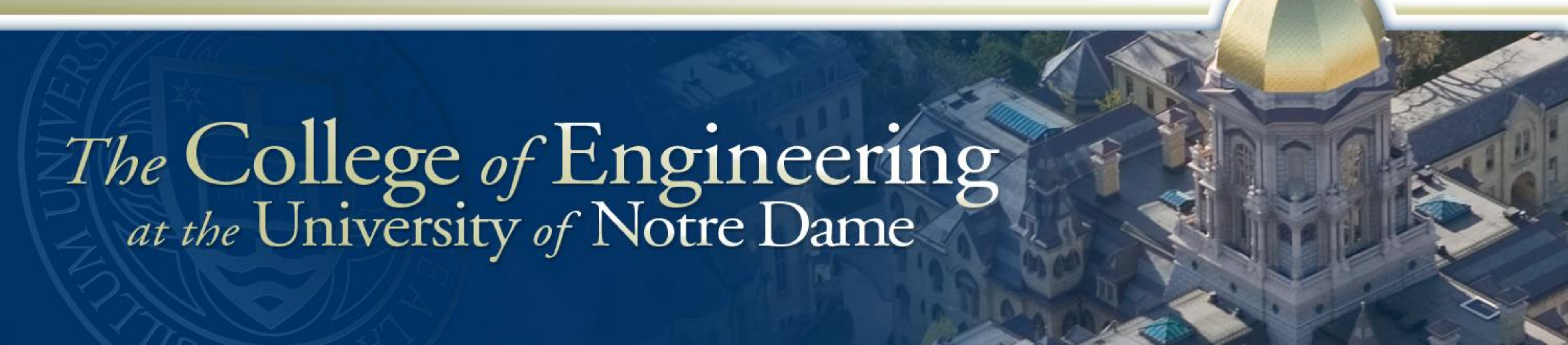

Outline

- **Introduction**
- Numerical Simulation
- Run-up Height Result
- Momentum Flux Result
- Summary and Conclusion

Introduction: Motivation

- Frequent extreme weather conditions due to climate change (Sea Level Rise, Hurricanes)
- As of 2010, 44 percent of the world population live 150 km or closer to the ocean water.
- Affect coastal infrastructure and people in coastal area. (Harvey 2017)

Objective

Investigate run-up process on an impermeable slope for different environmental conditions and propose a formula for design use

Extreme Run-up Height

Extreme Momentum Flux

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Overview of research

Wave Characteristics

H_0
5
8
10

T_p
9
12
15

Friction Coefficient

n
0.01
0.02
0.05

Bottom Slope

$tan\alpha$
0.01
0.02
0.04
0.06
0.1

Directional Spreading angle

σ_θ
0°
10°
20°
30°

Numerical Model: SWASH

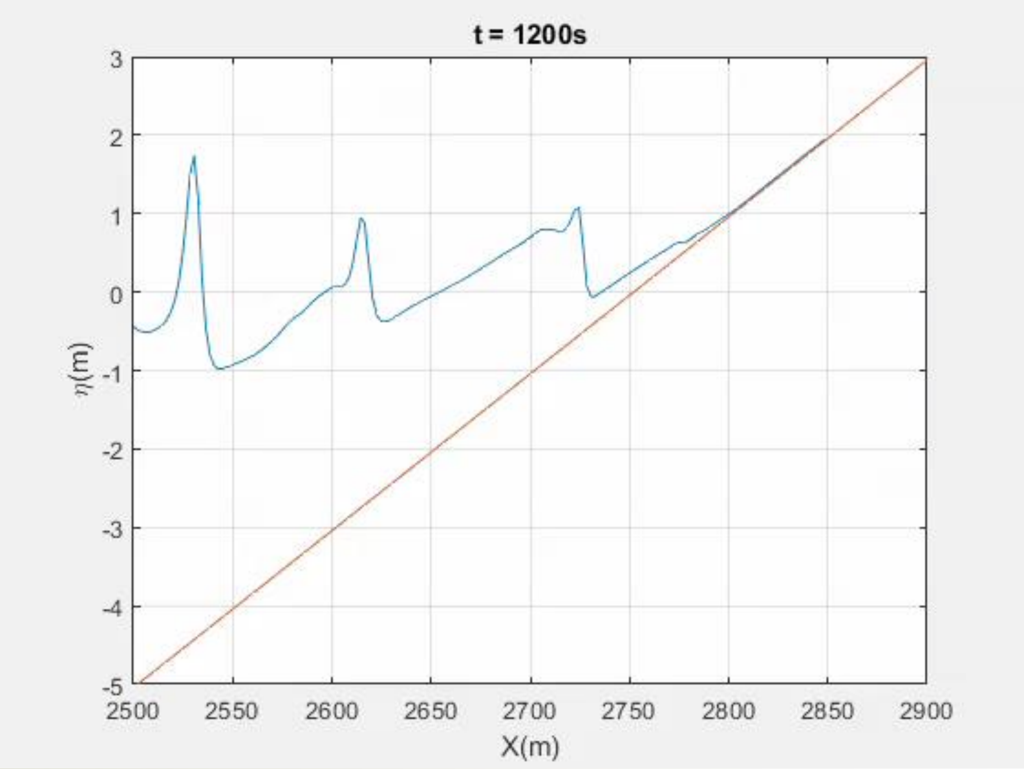
- SWASH(Simulating WAves till SHORE)
- Open source software developed and maintained by TU Delft.
- Euler equation with the non-hydrostatic pressure: $P = \rho(g(\eta - z) + q)$
- Achieve good dispersion relationship by dividing the vertical direction into several layers.
- More information available on http://swash.sourceforge.net/

Numerical Model: Simulation Set-up

Domain	2D and 3D	
Grid Size	$dx = 2.5m$, $\mathrm{dy} = 10m$ (in 3D domain)	
Initial Time Step	0.01s(adjusted by dynamic CFL conditions)	
Simulation Time	1 hour	
Boundary Conditions	Offshore	TMA Spectrum
	Onshore	Wet-Dry Scheme
	Side	Periodic Boundary Conditions
Wave Breaking	Threshold Wave slope	
SGS Model	Smagorinsky Coeficient	
Vertical Layers	3	

Number	100 2D	17 3D
Time	5 h	7d
Cores	Serial	24 Cores
Grid	500×360000	$500\times 90 \times 360000$
System	CRC, Athos, TACC	

Movie for Two Dimensional Run



Visualization of two-dimensional results

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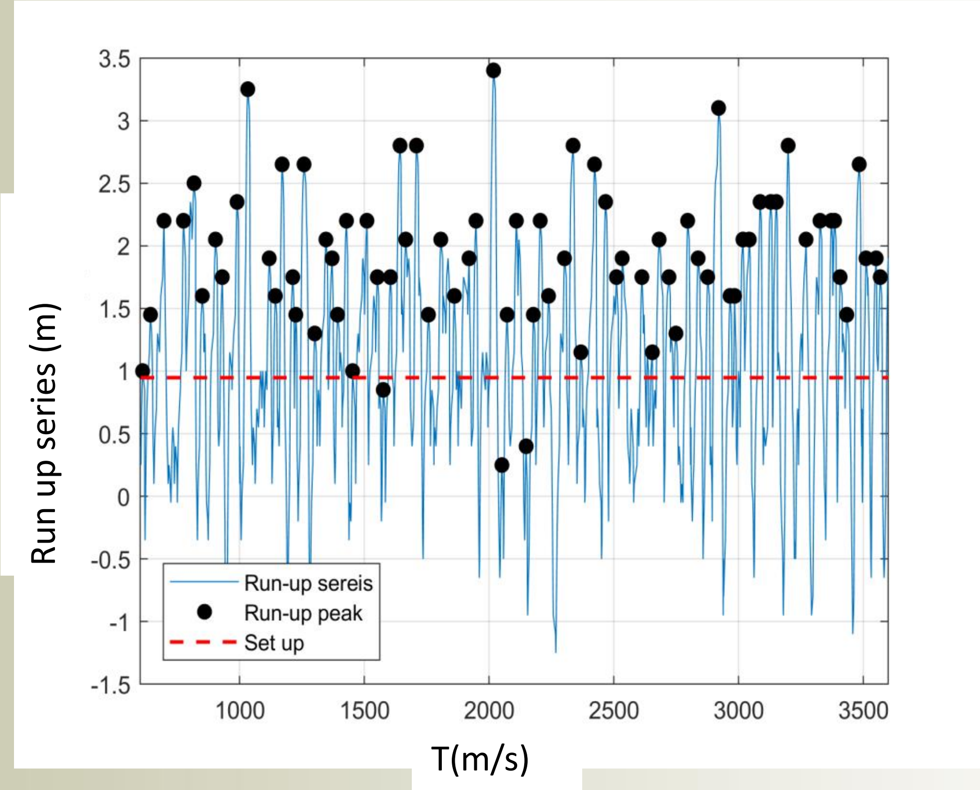
Dimensionless Parameters in Run-up Comparison

Iribarren Number	$\xi_0 = \frac{tan\alpha}{\sqrt{\frac{H_0}{L_0}}}$
Significant wave height	H_0
Dimensionless Run-up	$R_2 = \frac{R_{2\%}}{H_0}$

Run-up series and Run-up peaks

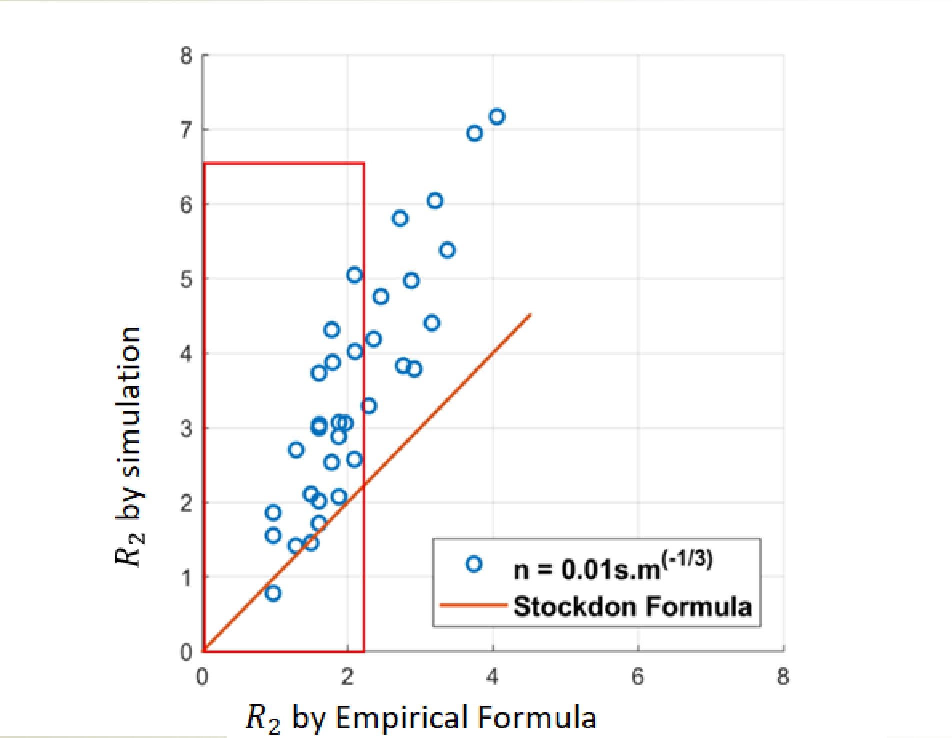


- Definition: Run-up is maximum of discrete wave peak.
- Run-up threshold 15cm

Run-up Height: Dimensional Expression

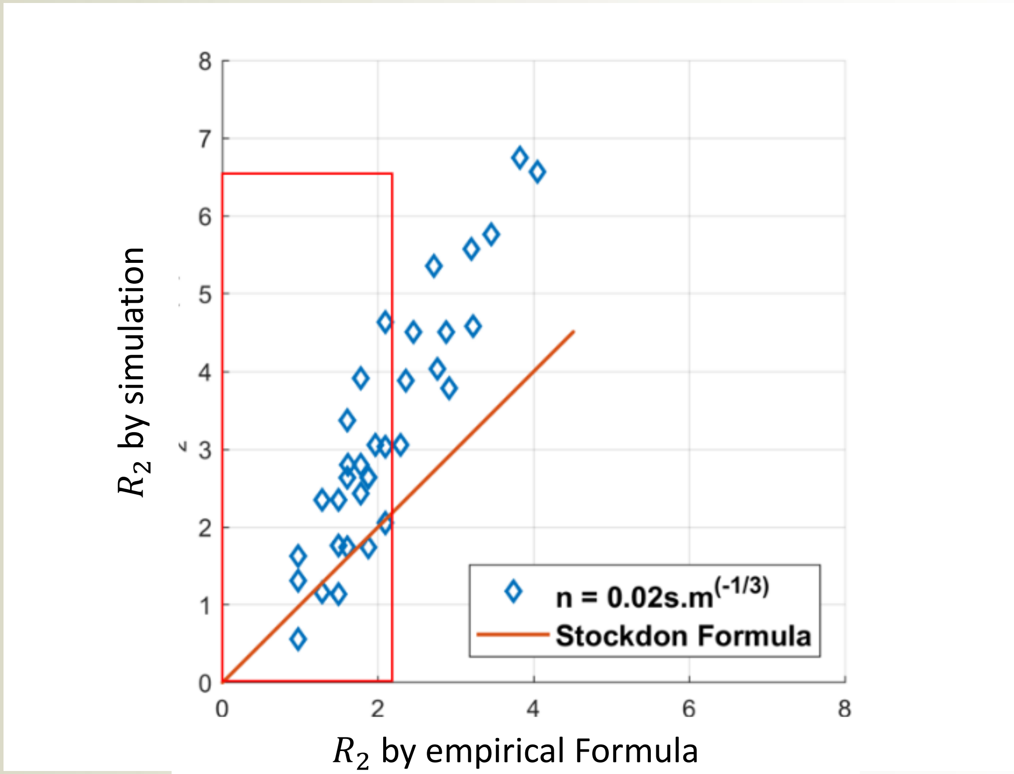
- $$R_2 = \begin{cases} 1.1\left(0.35\beta_f (H_0 L_0)^{\frac{1}{2}} \dfrac{\left[H_0 L_0 \left(0.563{\beta_f}^2 + 0.004\right)\right]^{\frac{1}{2}}}{2}\right), \xi_0 > 0.3 \\ 0.043(H_0 L_0)^{1/2}, \xi_0 < 0.3 \end{cases}$$

Two Dimensional Result of R_2, $\sigma_\theta = 0^\circ$



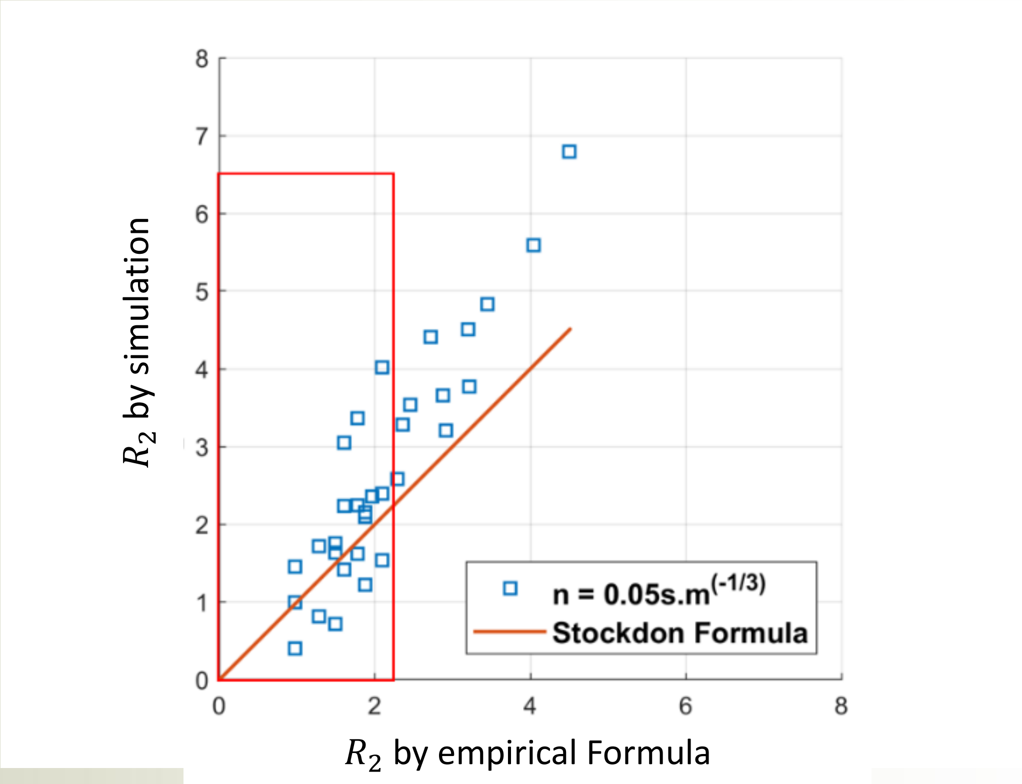
Run-up height comparison when
$C_s = 0.5$, n = $0.01s \cdot m^{-1/3}$

Two Dimensional Result of R_2, $\sigma_\theta = 0^\circ$



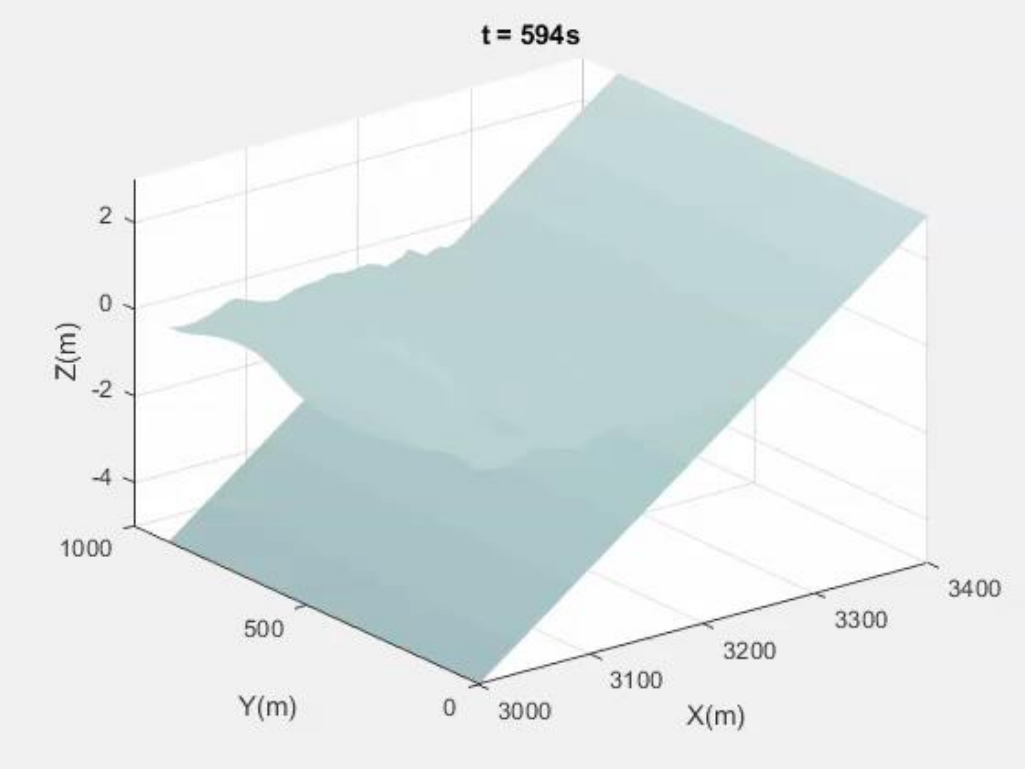
Run-up height comparison when
$C_s = 0.5$, n = $0.02s \cdot m^{-1/3}$

Two Dimensional Result of $R_2, \sigma_\theta = 0^\circ$

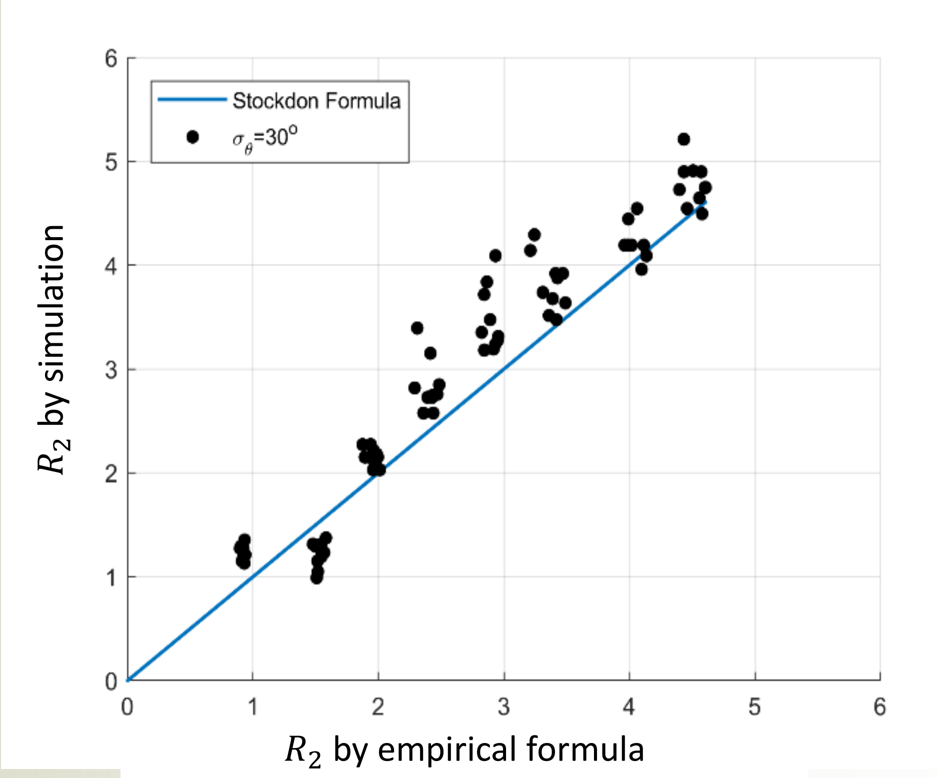


Run-up height comparison when
$C_s = 0.5$, **n =** $0.05s \cdot m^{-1/3}$

Movie for Three Dimensional Case



Three Dimensional Result of R_2, $\sigma_\theta = 30^\circ$



Run-up height comparison with
$\boldsymbol{\sigma_\theta = 30^\circ, C_s = 0.5}$

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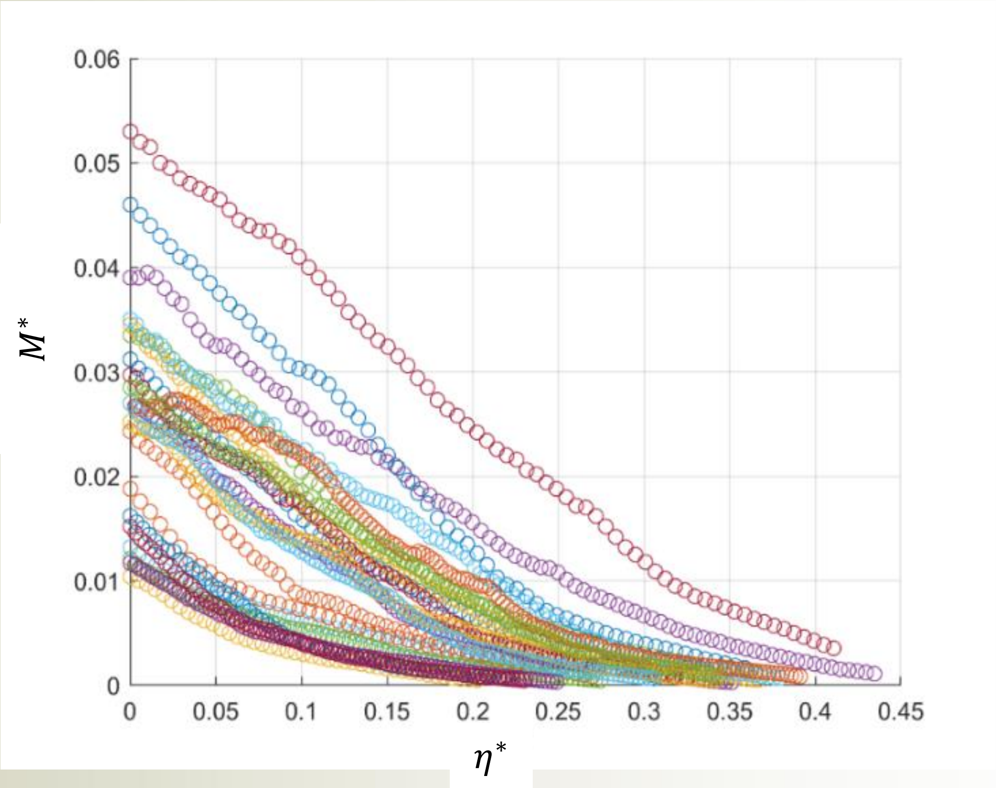
Momentum Flux Analysis

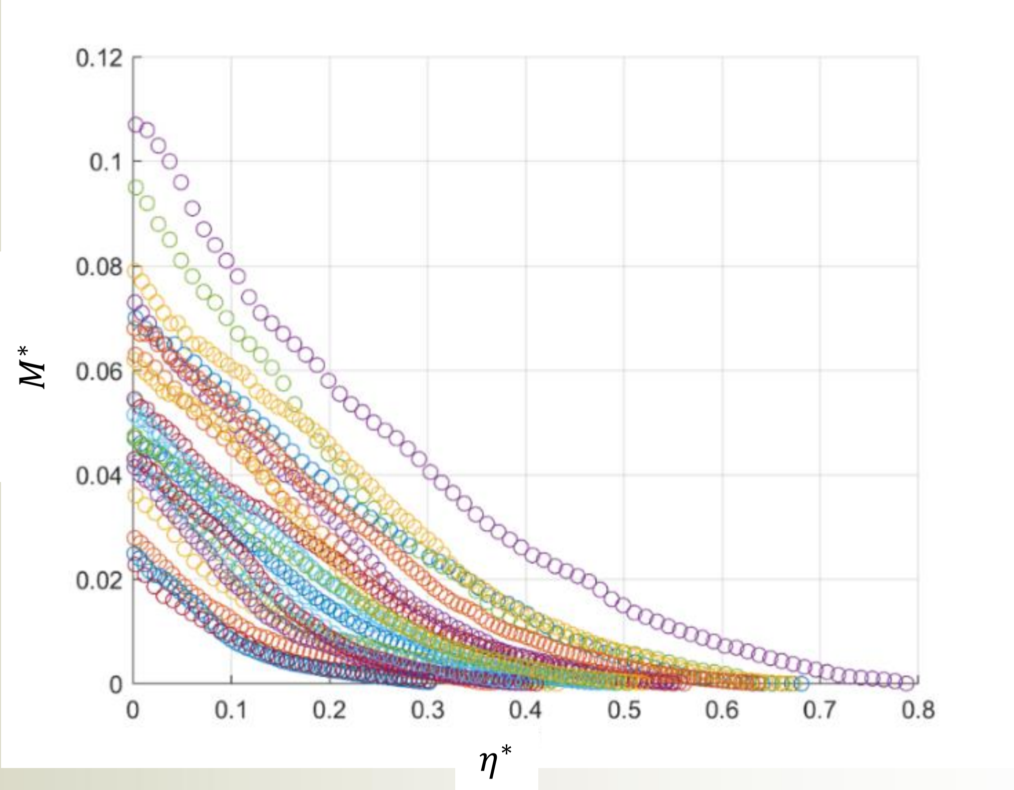
Dimensionless Elevation	$\eta^* \equiv \dfrac{\eta}{H_0},$
Normalized Dimensionless Elevation	$\eta_0^* \equiv \dfrac{\eta^*}{\eta_{max}^*}$
Dimensionless Momentum Flux	$M^* = \dfrac{u\|u\|(d+\eta)}{gH^2}$
Normalized Dimensionless Momentum Flux	$M_0^* \equiv \dfrac{M^*}{M^*\|_{\eta=0}}$

Visualization of Momentum Flux, $\sigma_\theta = 0^\circ$



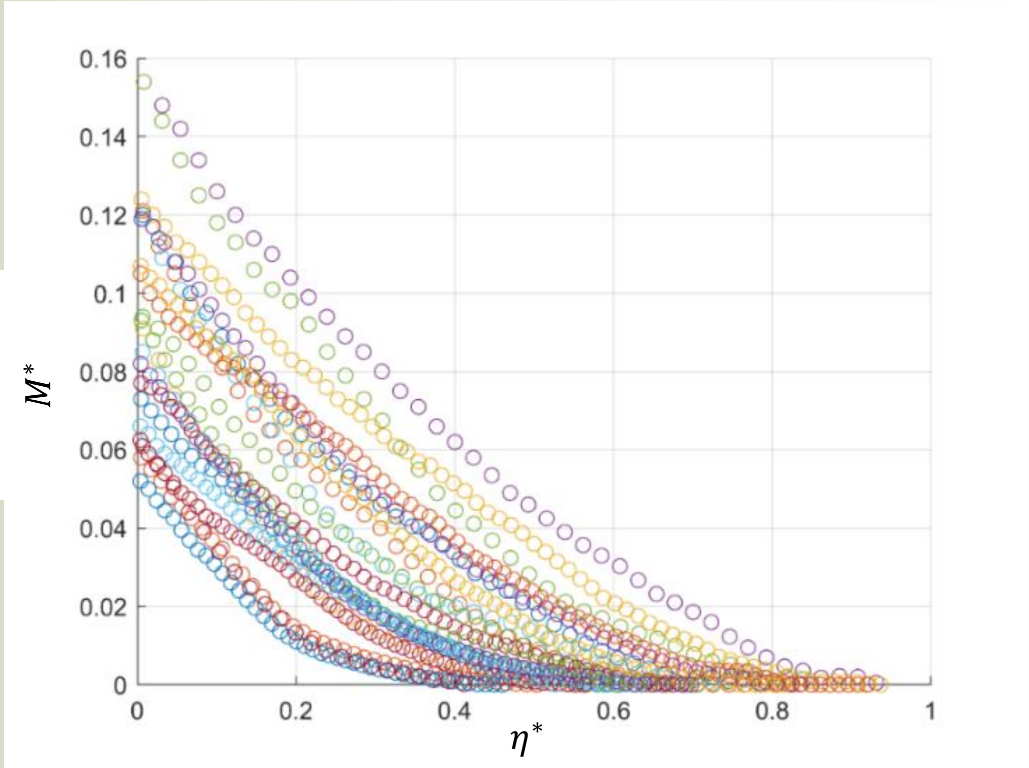
Momentum Flux variation against elevation on bottom slope $tan\alpha = 0.01$

Visualization of Momentum Flux, $\sigma_\theta = 0^\circ$



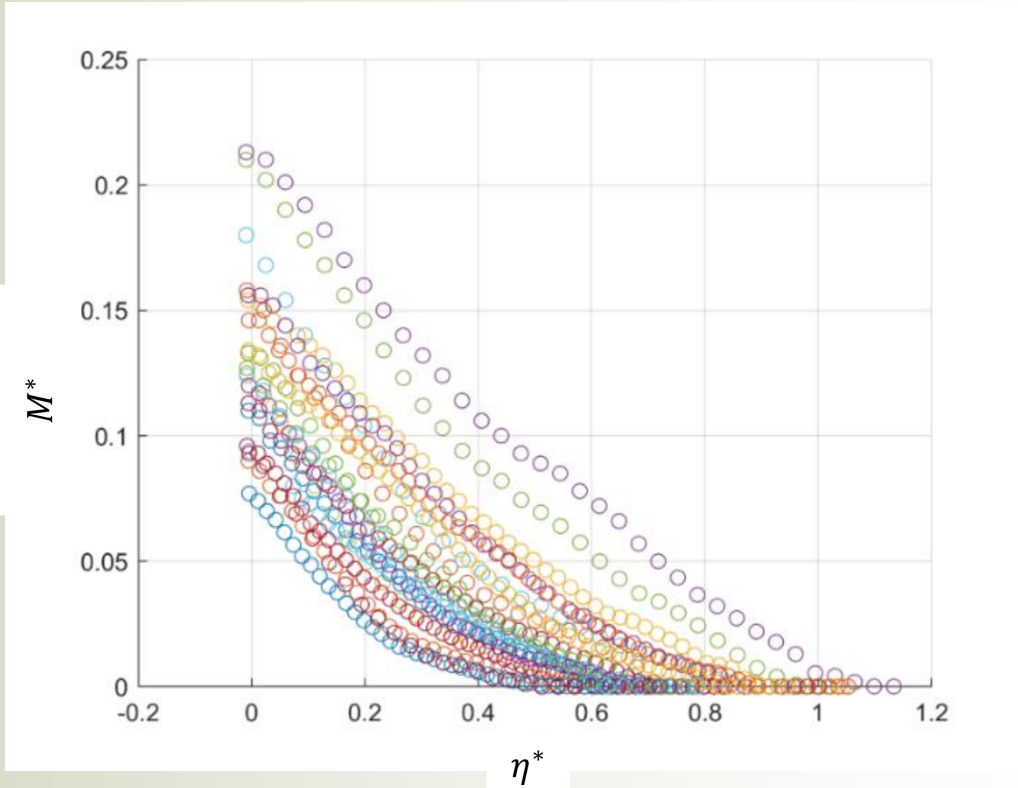
Momentum Flux variation against elevation on bottom slope $tan\alpha = 0.02$

Visualization of Momentum Flux, $\sigma_\theta = 0^\circ$



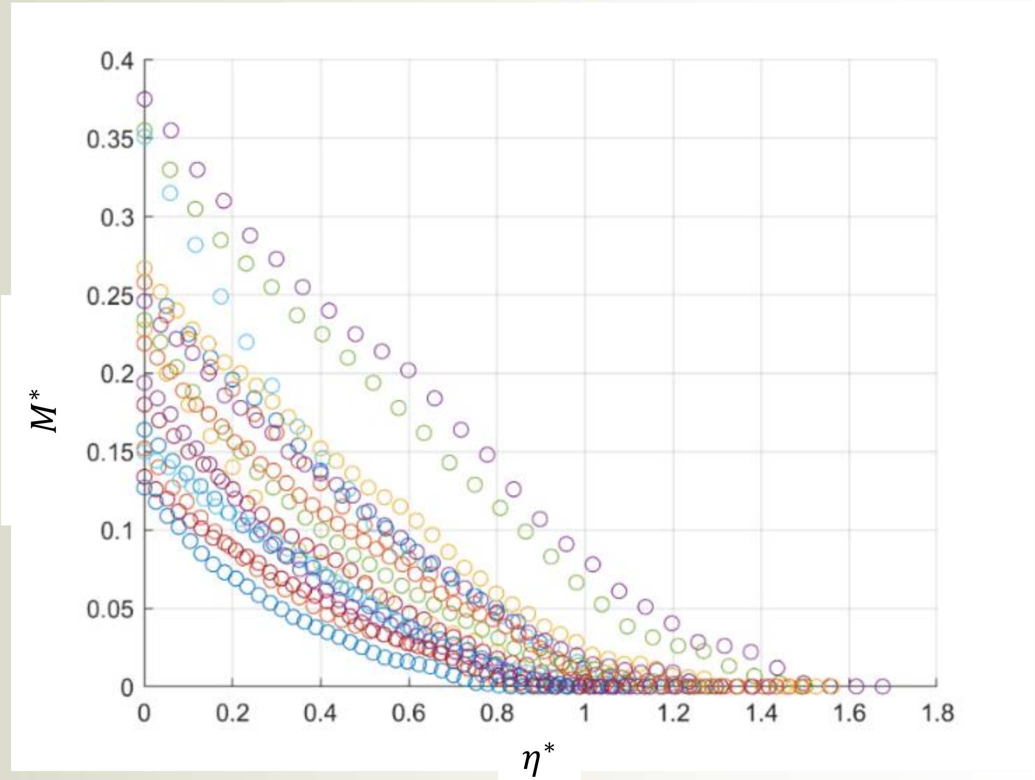
Momentum Flux variation against elevation on bottom slope $tan\alpha = 0.04$

Visualization of Momentum Flux, $\sigma_\theta = 0^\circ$



Momentum Flux variation against elevation on bottom slope $tan\alpha = 0.06$

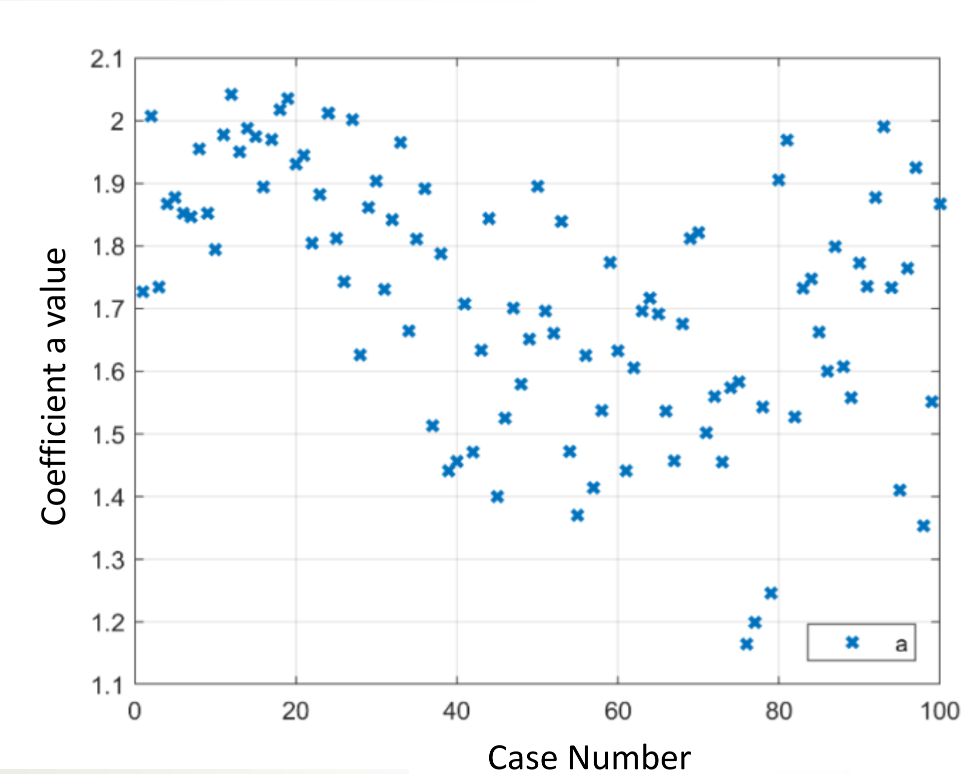
Visualization of Momentum Flux, $\sigma_\theta = 0^\circ$



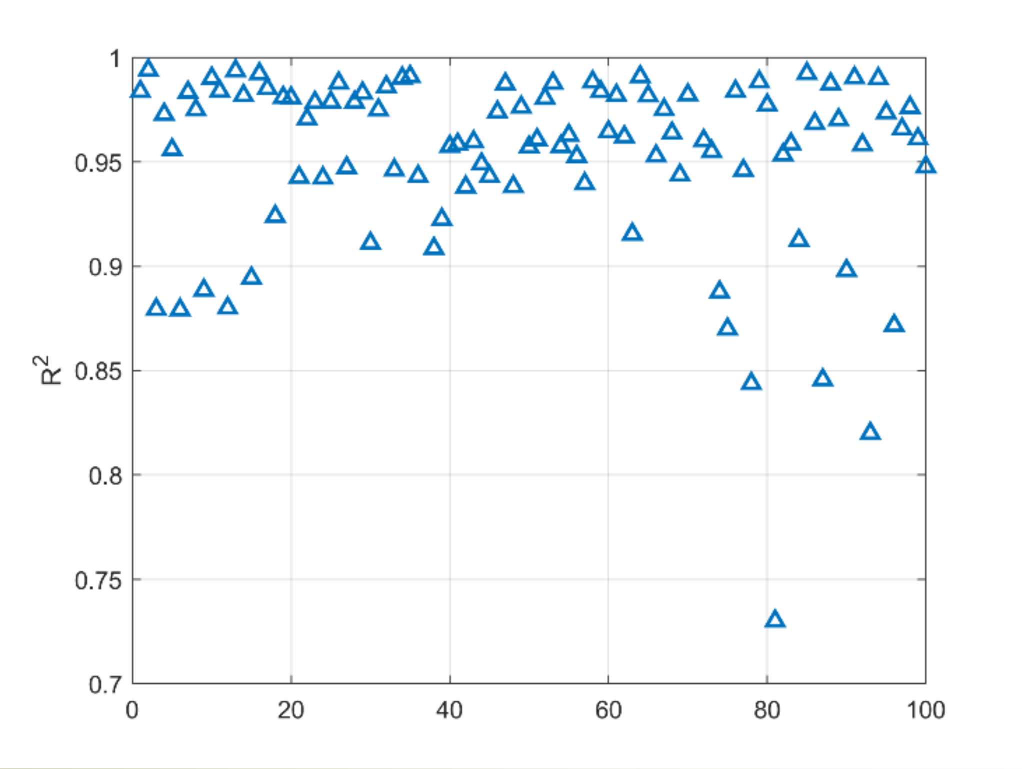
Momentum Flux variation against elevation on bottom slope $tan\alpha = 0.1$

Expression for M_0^* and actual parameter a value

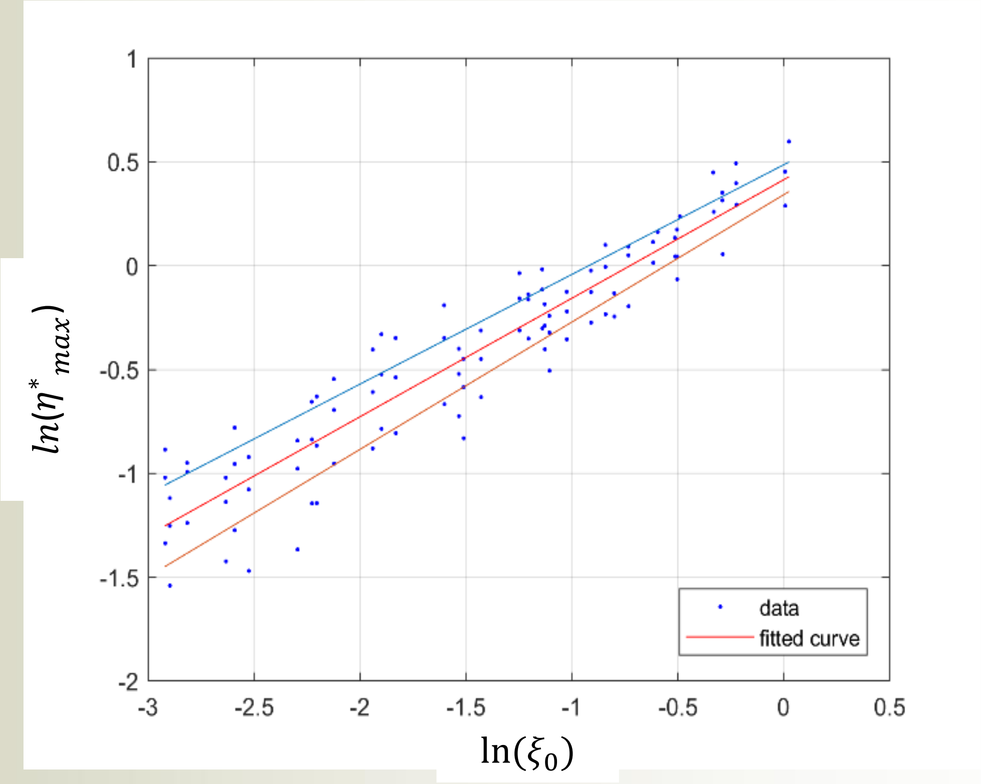
- $\log_{10}^{(M_0^*)} = -a \cdot {\eta_0^*}^2$
- $M_0^* \equiv \frac{M^*}{M^*|_{\eta=0}}$
- $\eta_0^* \equiv \frac{\eta^*}{\eta_{max}^*}$



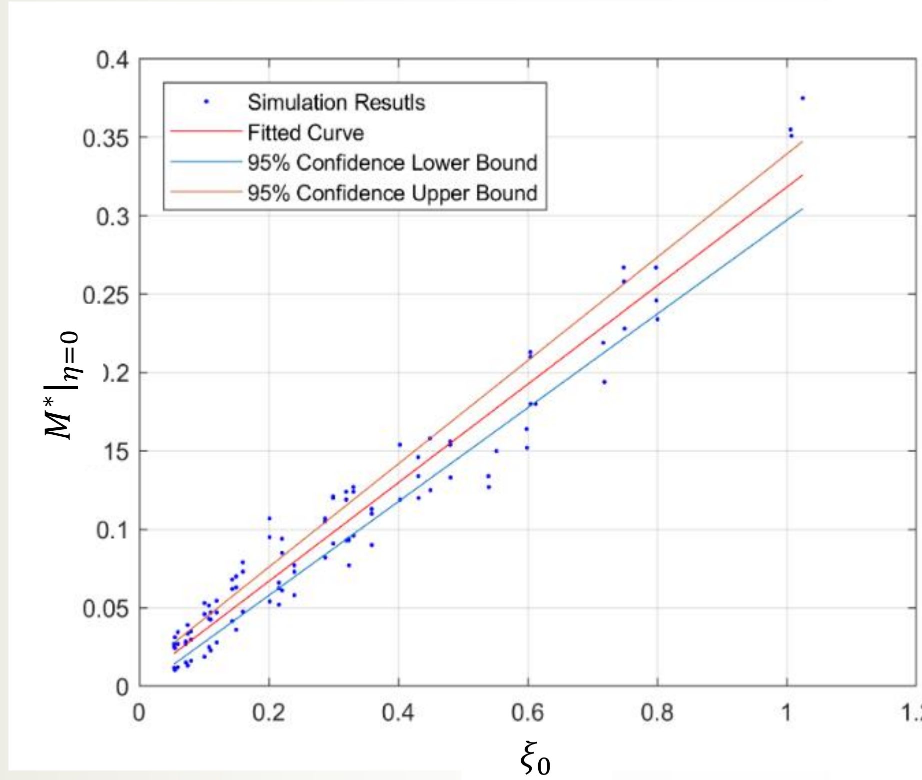
Parameter ‘a’ for two dimensional cases


1
0.95
0.9
0.85
0.8
0.75
0.7
R2
0
20
40
60
80
100

Regression results

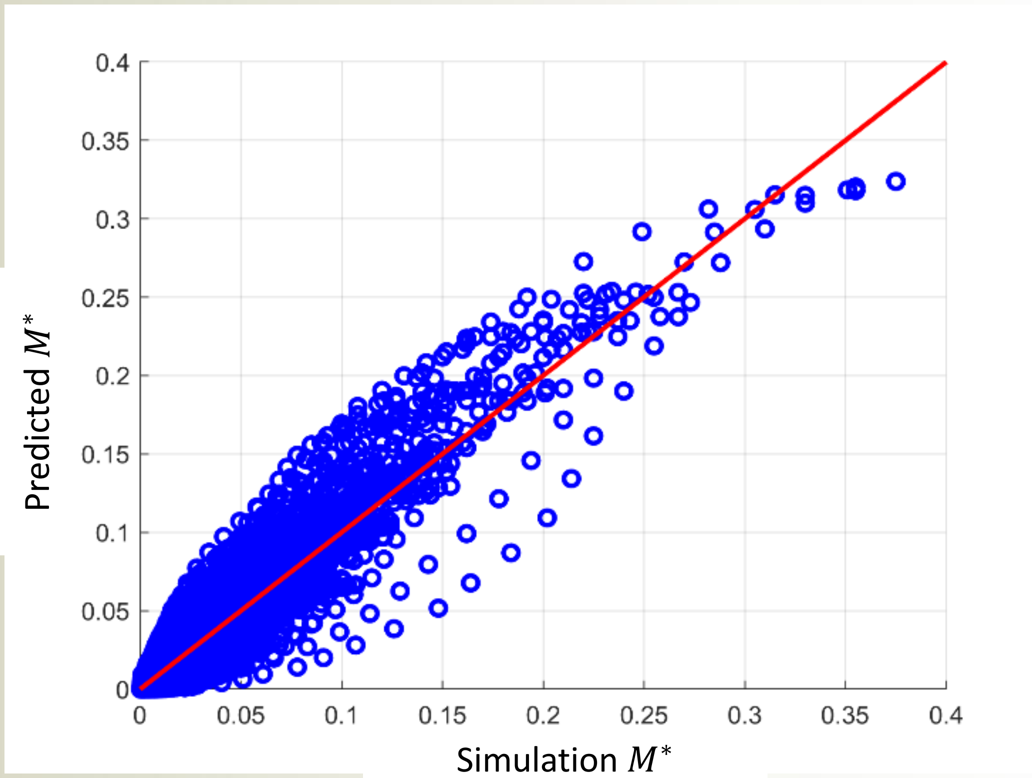


Regression results

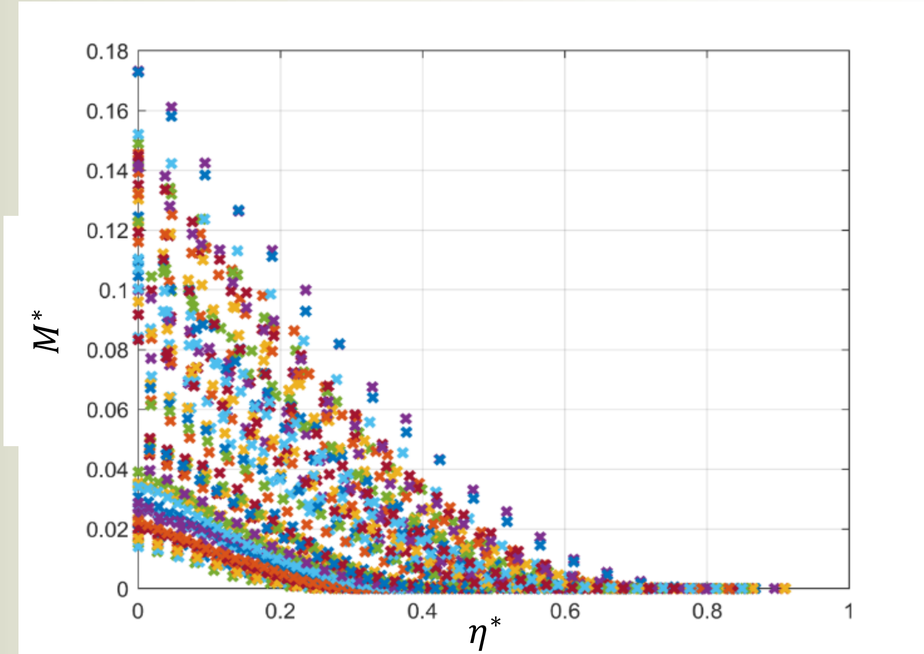


Predictive Variable	Response Variable	Slope m	Intercept b	R^2
$\ln(\xi_0)$	$\ln(\eta^*_{max})$	0.5705(0.528,0.613)	0.4138(0.3417,0.4859)	0.8786
ξ_0	$M^*\|_{\eta=0}$	0.3124(0.2971,0.3277)	0.003733(−0.002346,0.009813)	0.9436

$$M^* = \underbrace{(0.3124\xi_0 + 0.003733)}_{M^*|_{\eta=0}} \cdot \left(10^{\overbrace{-2.67}^{a}\cdot\left(\frac{\eta^*}{\underbrace{1.5126\cdot\xi_0^{0.5705}}_{\eta^*_{max}}}\right)^2}\right), \eta^* < 1.5126 * \xi_0^{0.5705}$$

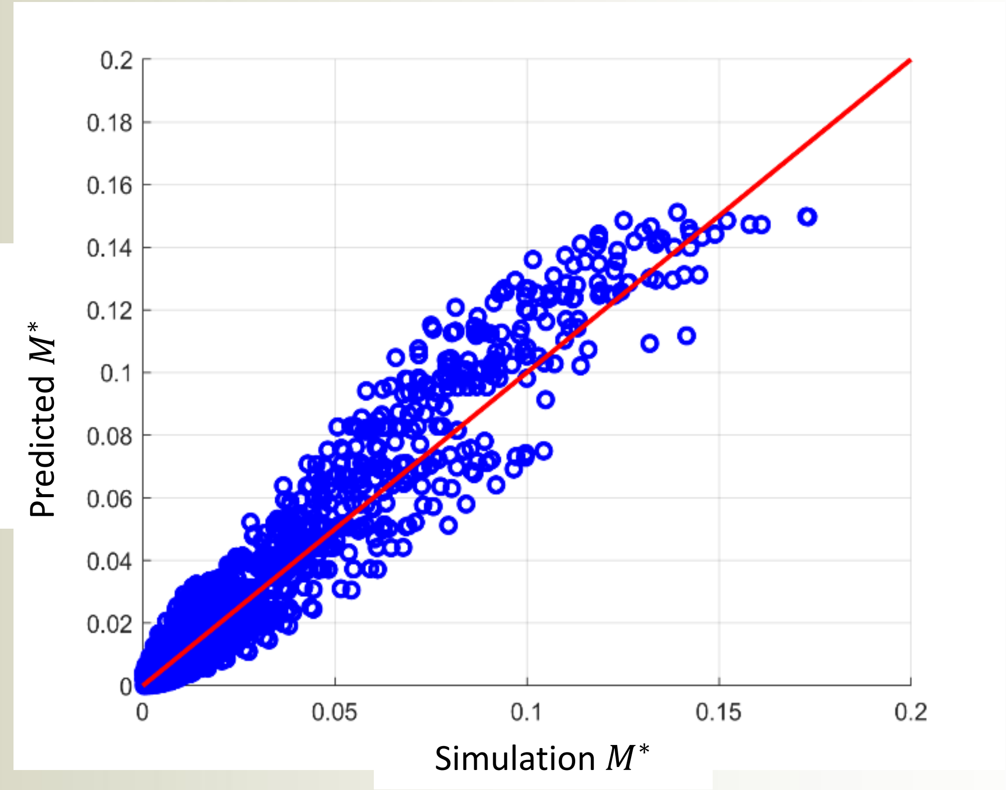


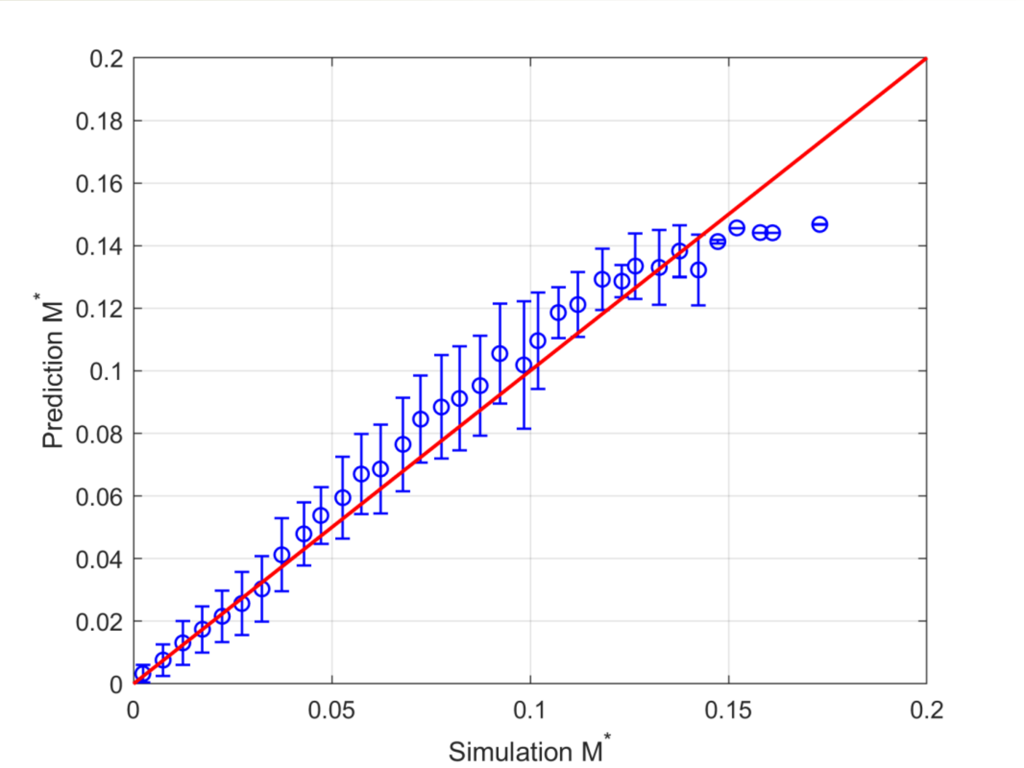
Visualization of Momentum Flux, $\sigma_\theta = 30^\circ$

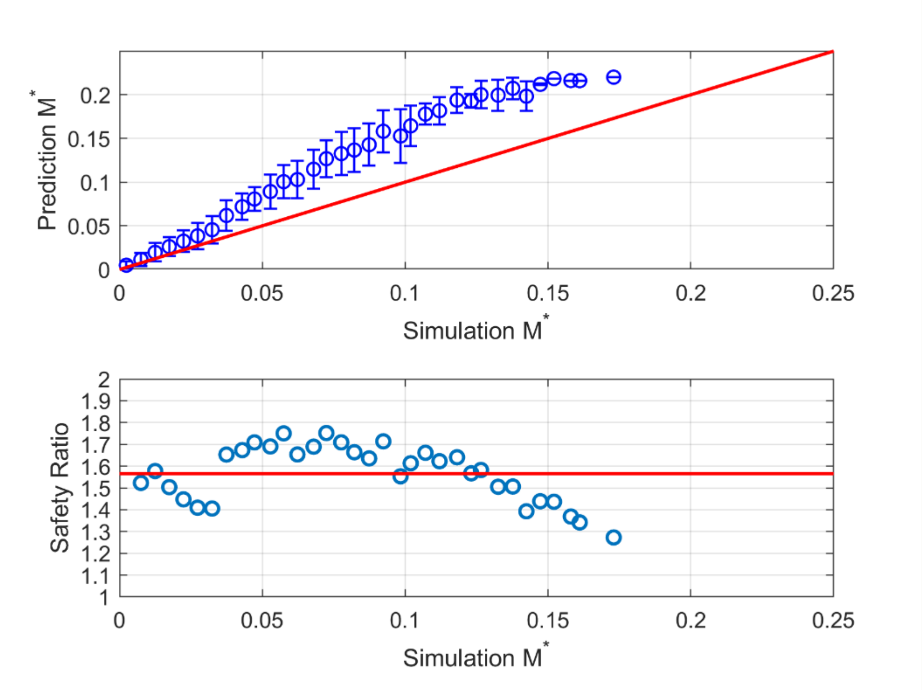


Momentum flux variation against elevation in three dimensional cases

$$M^*|_{\sigma_\theta=30^\circ} = \underbrace{(0.2071\xi_0 - 0.0217)}_{M^*|_{\eta=0}} \cdot \left(10^{\overbrace{-2.63}^{a}\cdot\left(\frac{\eta^*}{\underbrace{1.1018\cdot\xi_0^{0.4967}-0.0452}_{\eta^*_{max}}}\right)^2}\right)$$




Prediction M*
Simulation M*
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.05
0.1
0.15
0.2


0.2
0.15
0.1
0.05
0
Prediction M*
0
0.05
0.1
0.15
0.2
0.25
Simulation M*
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
Safety Ratio
Simulation M*

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Summary and conclusion

- Reproduce empirical formula by considering directional spreading effects.
- Simple model to predict 0.5 percent exceedance momentum flux.
- Applying a safety factor for design use

Acknowledgement

- CRC
- Athos
- TACC

- Thank you