ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

Geometric Characteristics Of Wave-Generated Sand Ripples
A Full-Scale Experimental Study

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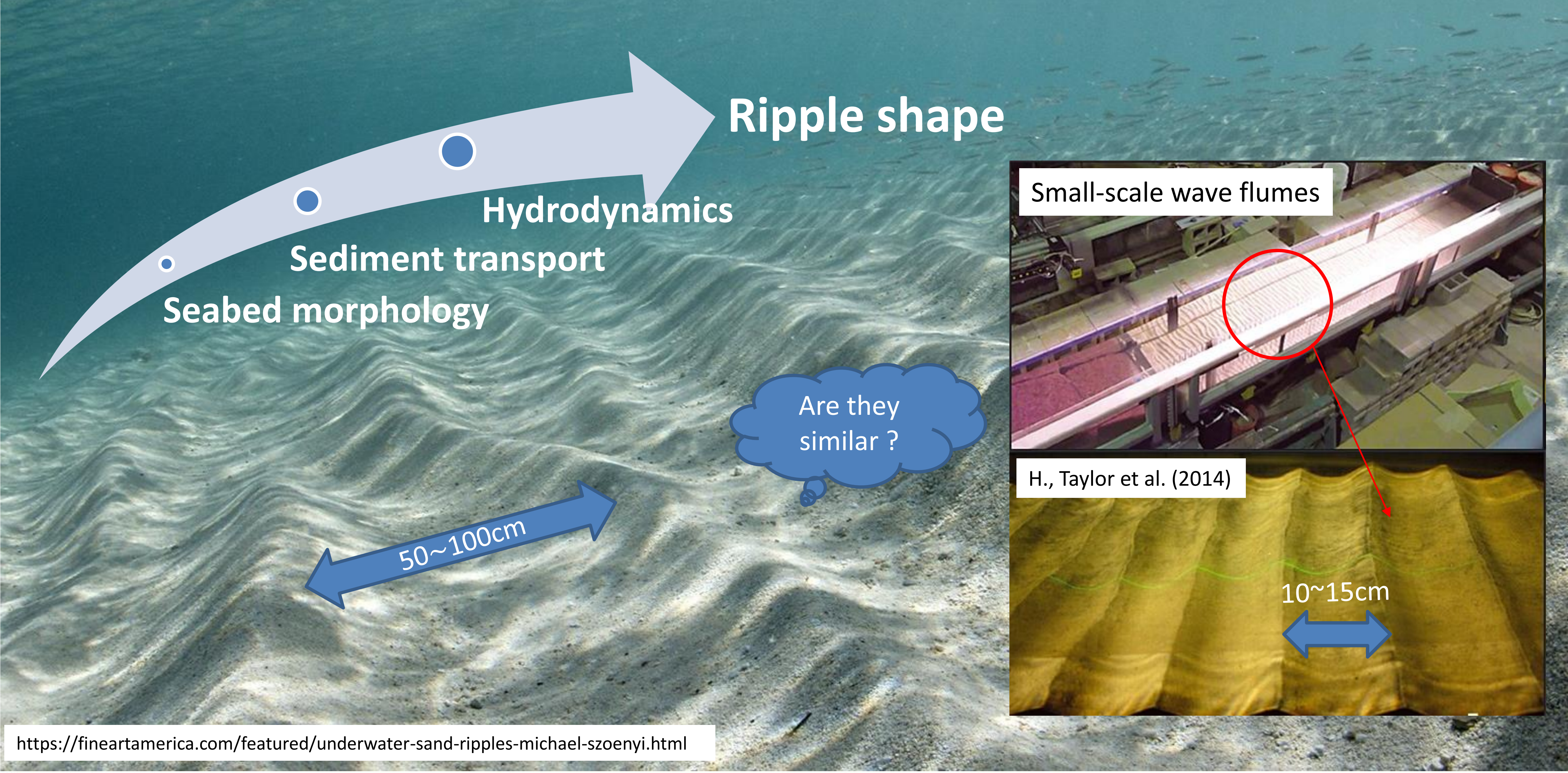
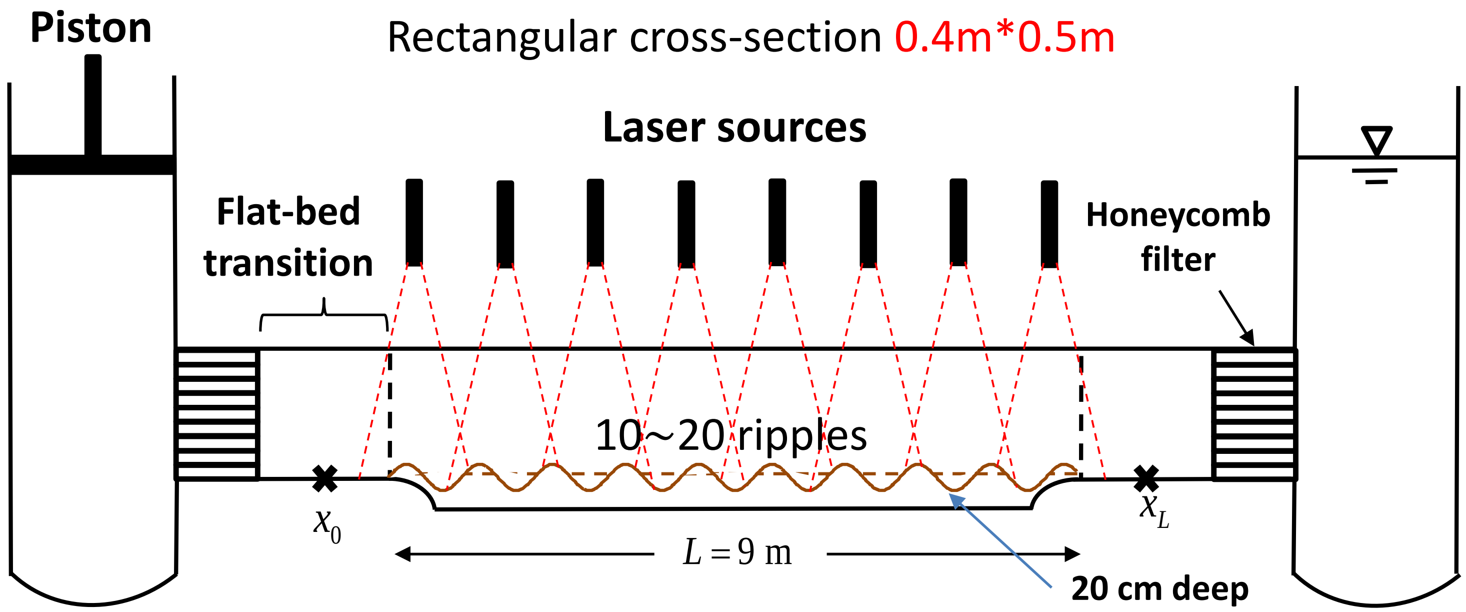
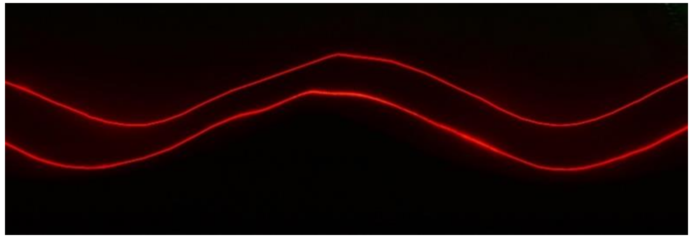
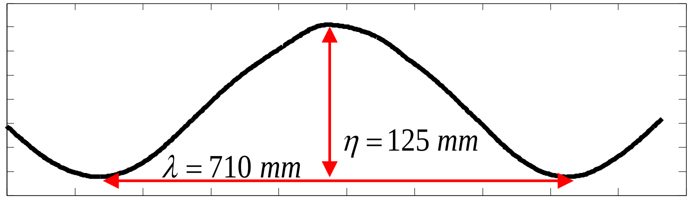

Ripple shape
Hydrodynamics
Sediment transport
Seabed morphology
Are they similar ?
50~100cm
https://fineartamerica.com/featured/underwater-sand-ripples-michael-szoenyi.html
Small-scale wave flumes
H., Taylor et al. (2014)
10~15cm

Wave-Current-Sediment (WCS) Facility & Laser-based Bottom Profiler (LBP)





Laser line profile



Representative ripple profile

Well-sorted coarse sand

$$d_{50} = 0.51\text{mm}$$

$$\psi_{cr} = 0.032$$

Sinusoidal oscillatory flows

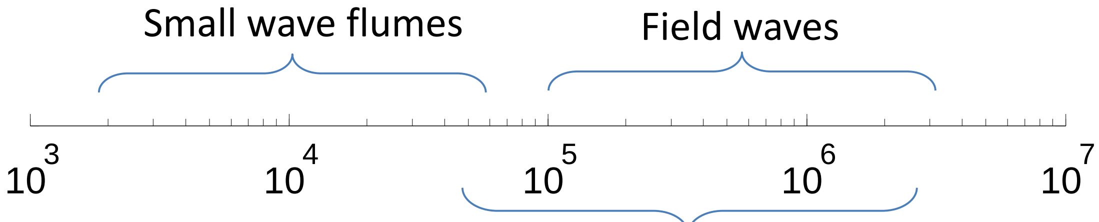
$$U_\infty = U_{bm} \cos \omega t$$

$$3.13s < T < 10.00s$$

$$0.064 < \psi_{wmd} < 0.695$$

Wave Reynolds number

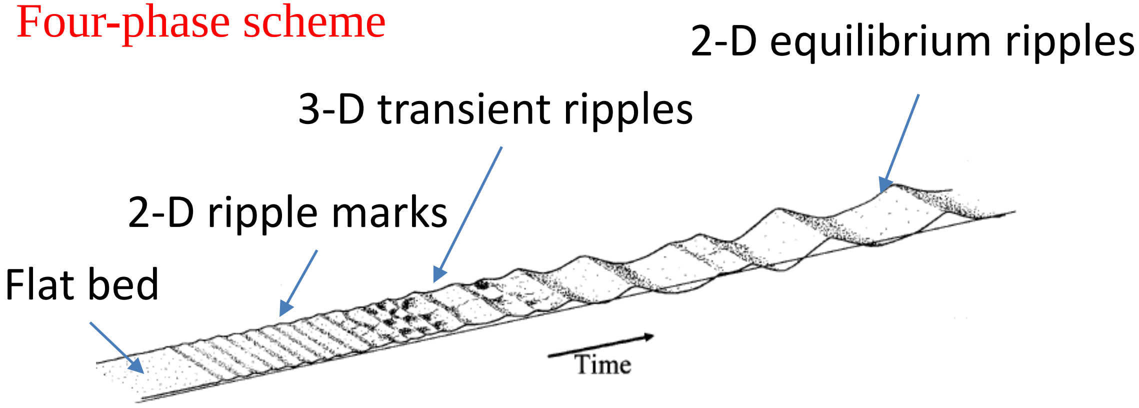
$$\mathrm{Re}_w = \frac{U_{bm} \cdot A_{bm}}{\nu}$$



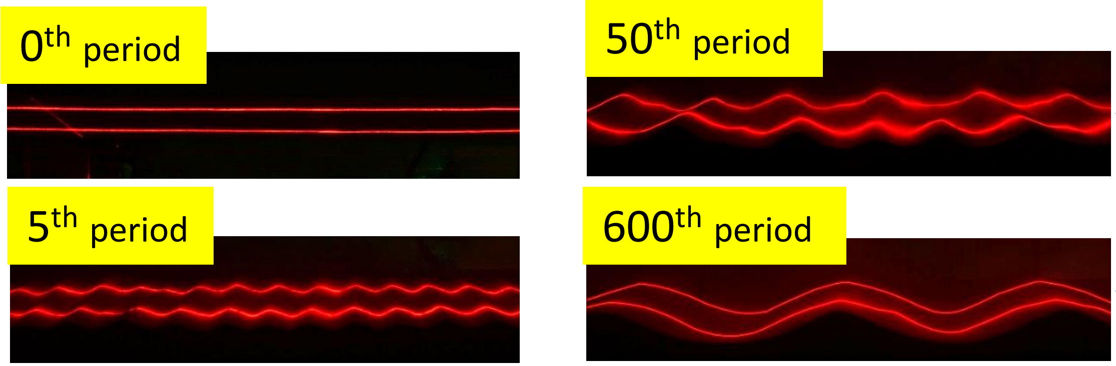
Our study $5.77 \times 10^4 \sim 1.39 \times 10^6$

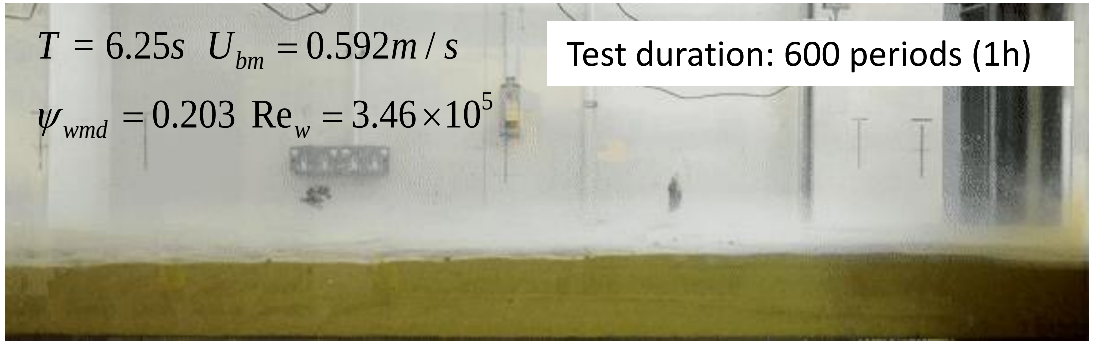
2-D Ripple development

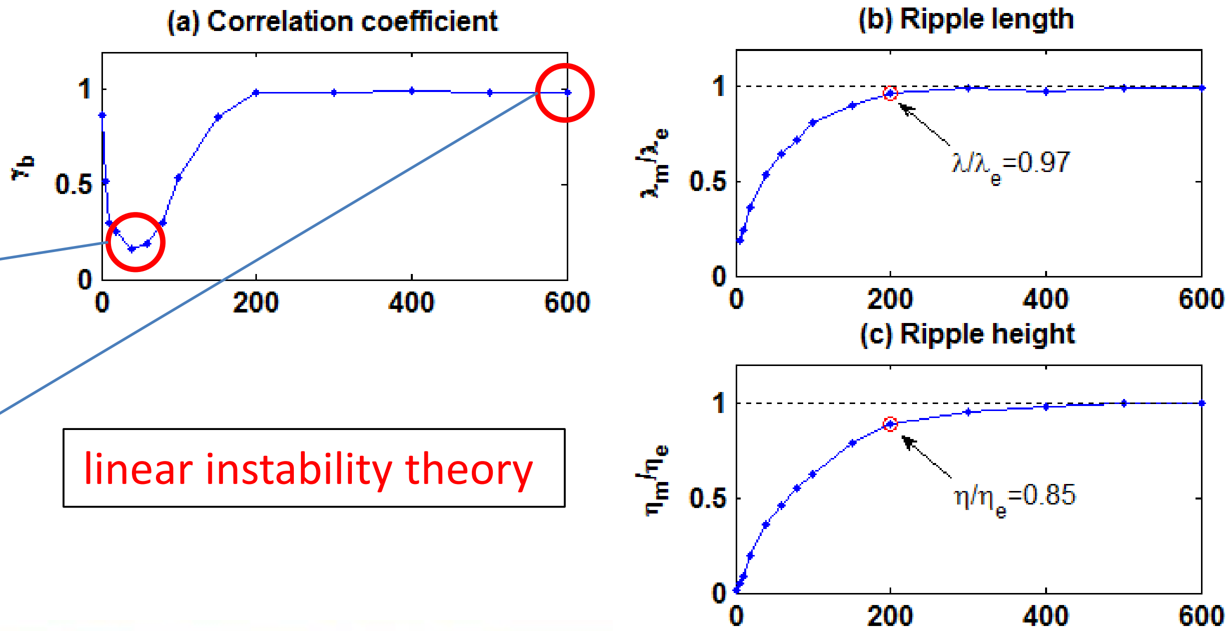
Four-phase scheme



Adopted from O'Donoghue, T. and G. S. Clubb (2001). "Sand ripples generated by regular oscillatory flow." Coastal Engineering 44(2): 101-115.







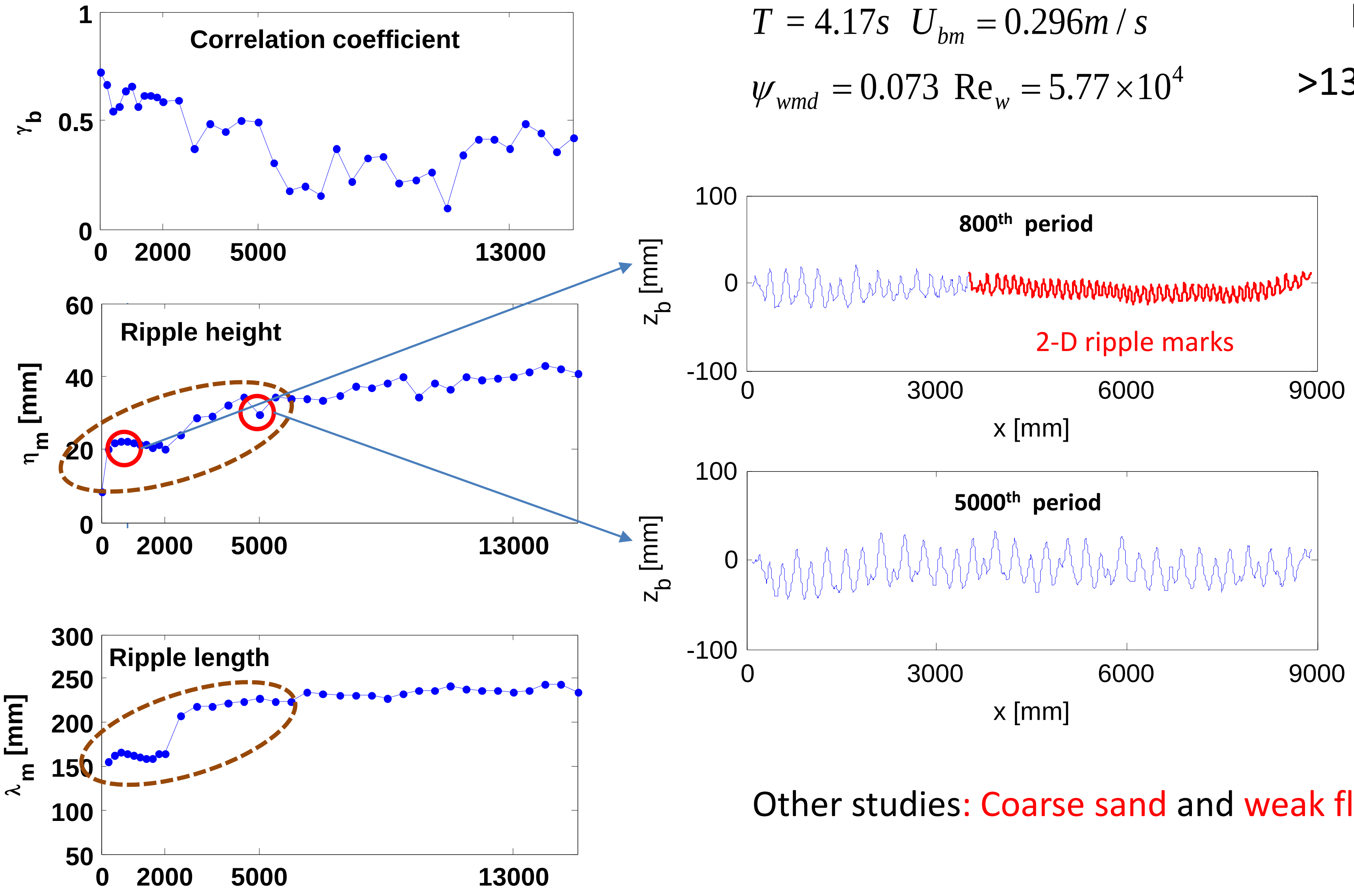
A case of 3-D ripples: development

$T = 4.17s \quad U_{bm} = 0.296 m/s$

$\psi_{wmd} = 0.073 \quad \mathrm{Re}_w = 5.77 \times 10^4$

Flow conditions: Tb030

>13000 periods ~ 15 hours!



Flat bed

↓

2-D ripple marks

↓ Much longer

3-D transient ripples

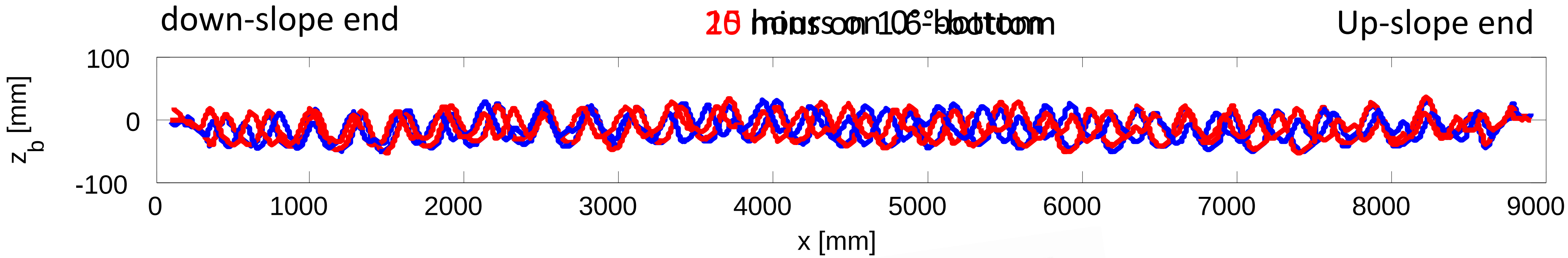
✗

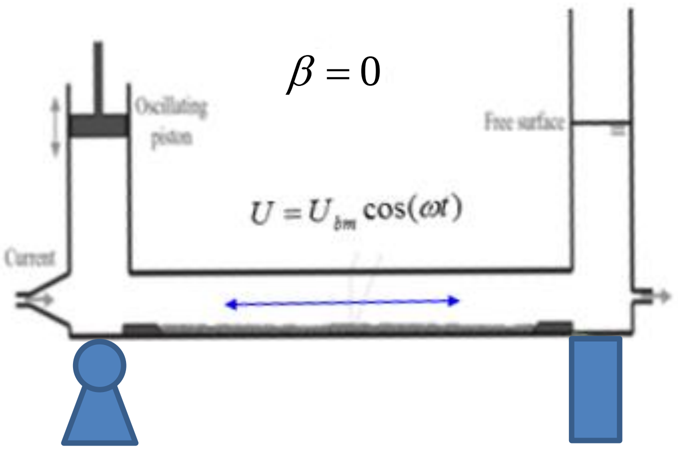
2-D equilibrium ripples

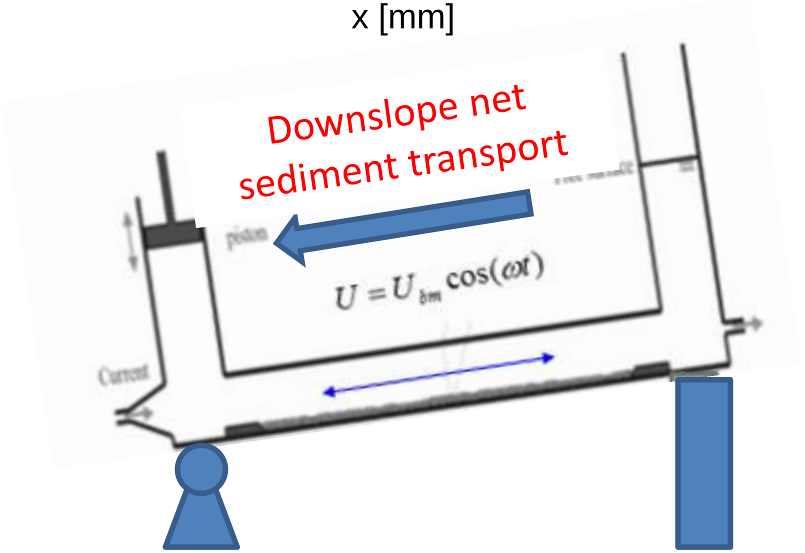
Other studies: Coarse sand and weak flow conditions → 2-D ripples

A case of 3-D ripples: planform geometry

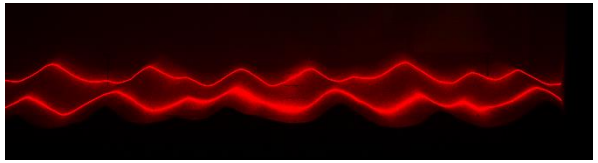
Flow conditions: Tb030 $T = 4.17\ s \quad U_{bm} = 0.296\ m/s \quad \psi_{wmd} = 0.073 \quad \mathrm{Re}_w = 5.77 \times 10^4$

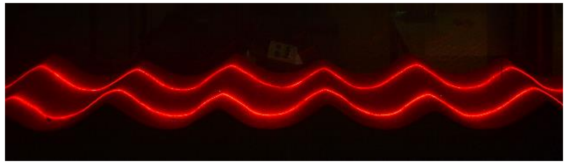






Other factors?





Hypothesis: Net sediment transport rate affects the planform geometry

2-D Equilibrium Ripples: General Shape

Sinusoidal profile $z_* = \frac{1}{2}\cos(2\pi x_*) \quad |x_*| \le \frac{1}{2}$

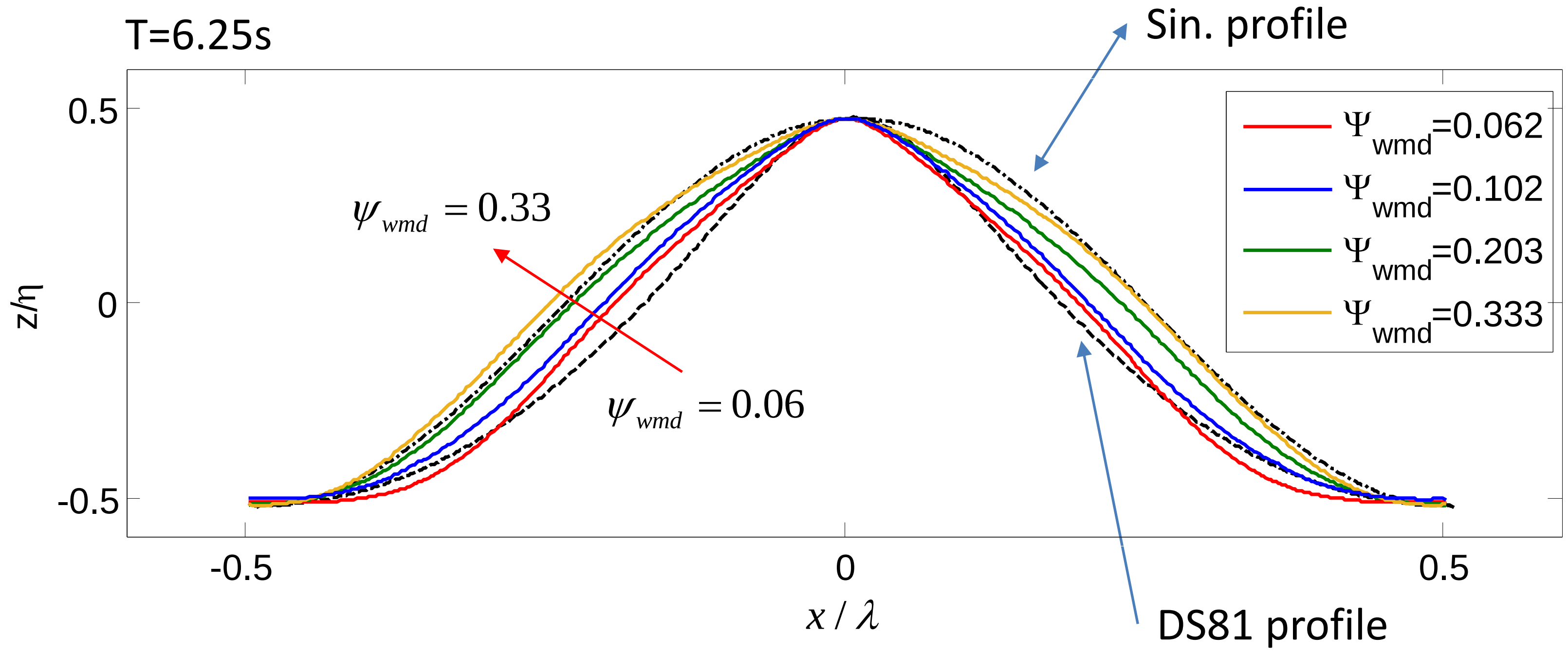
Theoretical profile proposed by Du Toit and Sleath (1981)

$$\begin{cases} x_* = \frac{\xi}{\lambda} - \frac{1}{2}\frac{\eta}{\lambda}\sin(2\pi x_*) \\ z_* = \frac{1}{2}\cos(2\pi \frac{\xi}{\lambda}) \end{cases} \quad \xi \le \left|\frac{\lambda}{2}\right|$$

Based on the measurements with Re_w= 6.3×10^3~ 5.6×10^4

close to two-parabolas profile but rounded crest

T=6.25s



Not self-similar

Shields parameter is a controlling variable

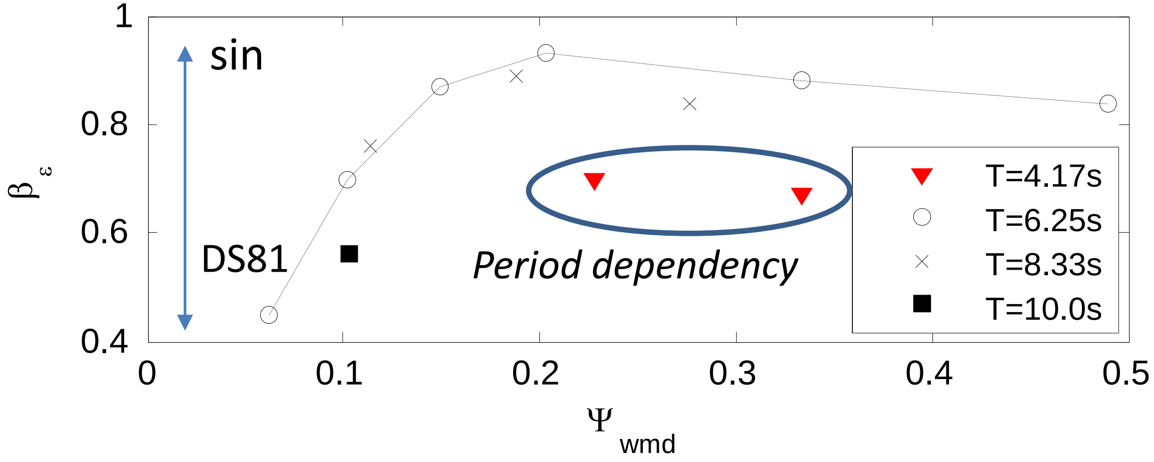
2-D Equilibrium Ripples: General Shape

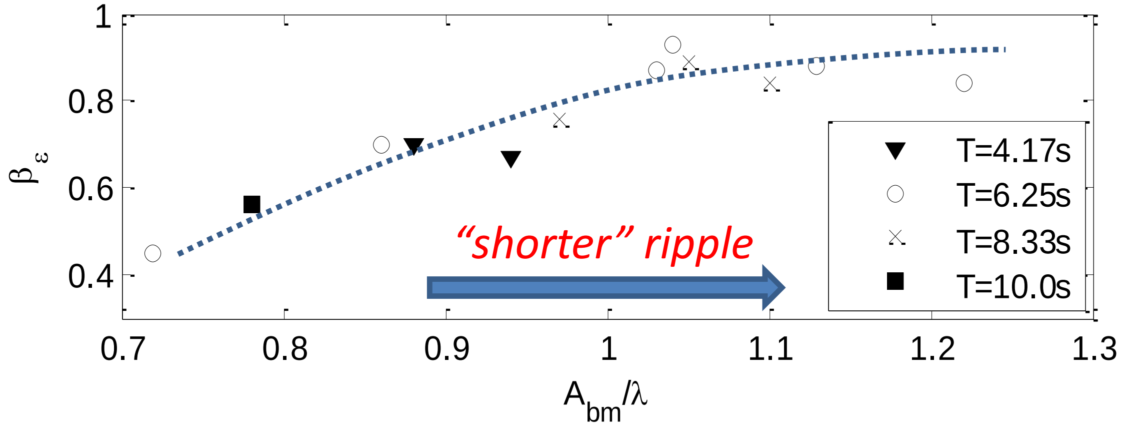
Root-mean-square error

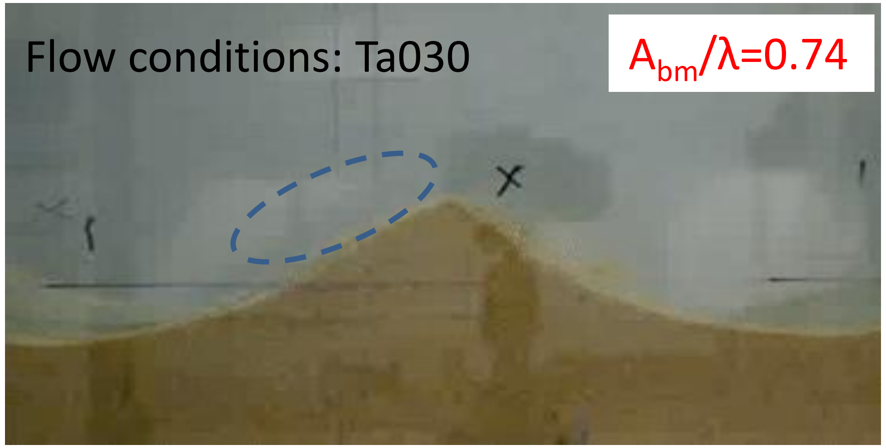
$$\varepsilon = \sqrt{\int_{-1/2}^{1/2} \left(z_{*m}(x_*) - z_{*t}(x_*)\right)^2 dx}$$

Similarity index

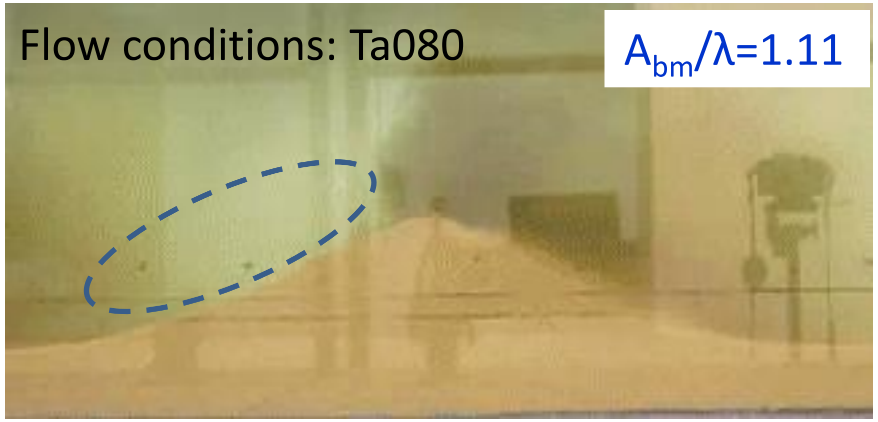
$$\beta_\varepsilon = \frac{\varepsilon_{DS}}{\varepsilon_{DS} + \varepsilon_{\sin}}$$







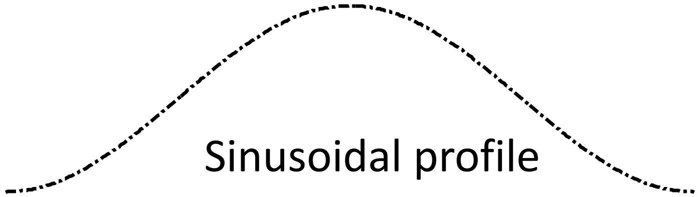
$\psi_{wmd} = 0.062$ $\mathrm{Re}_w = 8.66\times10^4$ $A_{bm} = 30\ cm$ $\lambda = 39.8\ cm$



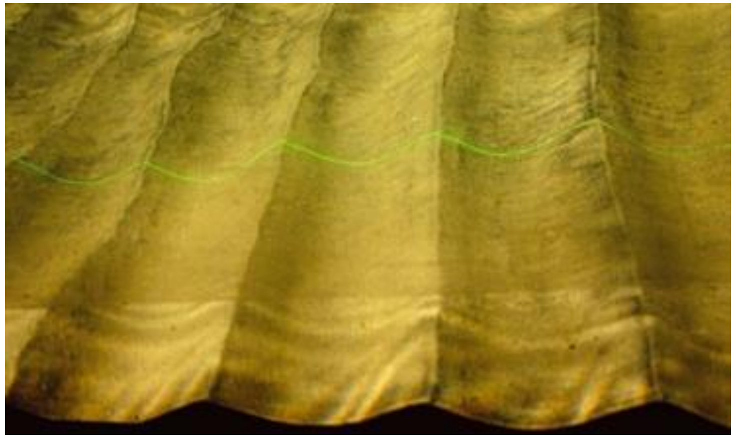
$\psi_{wmd} = 0.333$ $\mathrm{Re}_w = 6.16\times10^5$ $A_{bm} = 80\ cm$ $\lambda = 71\ cm$

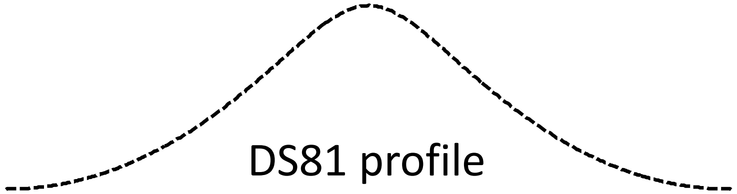
2-D Equilibrium Ripples: General Shape

Filed condition
our OWT experiments (large Re_w)



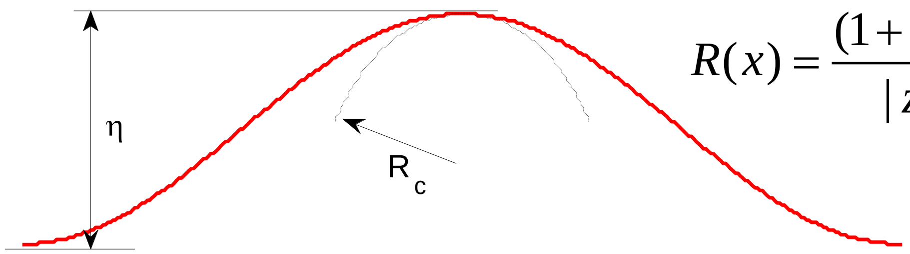
Small wave flumes
our OWT experiments (small Re_w)





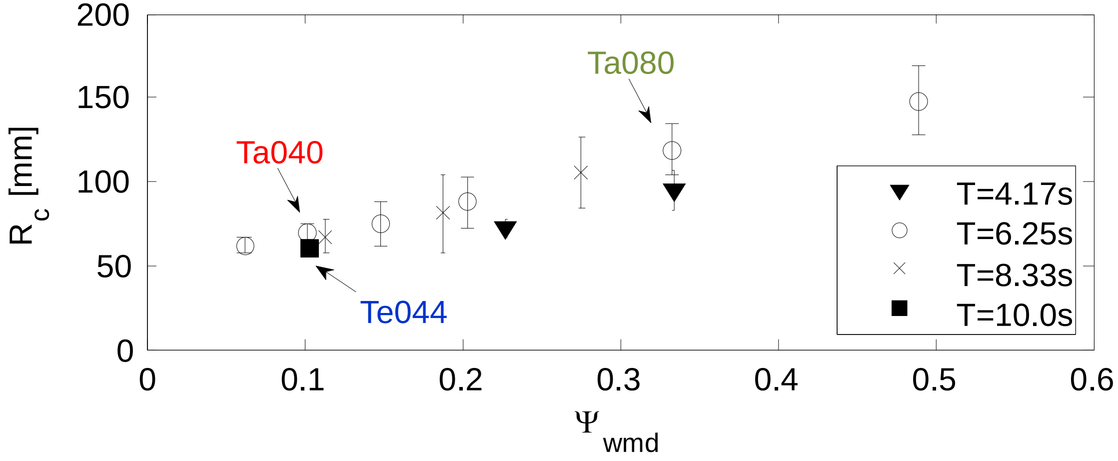
T = 6-10 s
$\Psi_{wmd} > 0.15$ → Full-scale flow conditions ($Re_w \sim 10^5$) → Larger A_{bm}/λ → Vortex can affect larger area of ripple flank → **Sinusoidal**

What does the crest look like : Crest Roundness

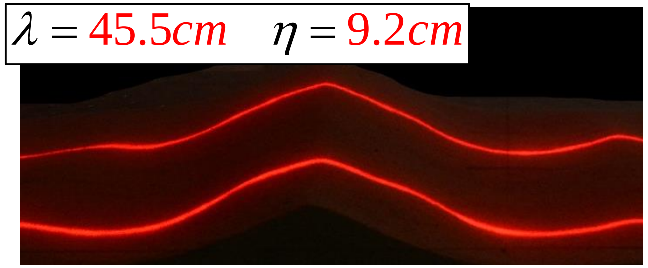


$$R(x) = \frac{(1 + z_b'(x)^2)^{\frac{3}{2}}}{|z_b''(x)|}$$

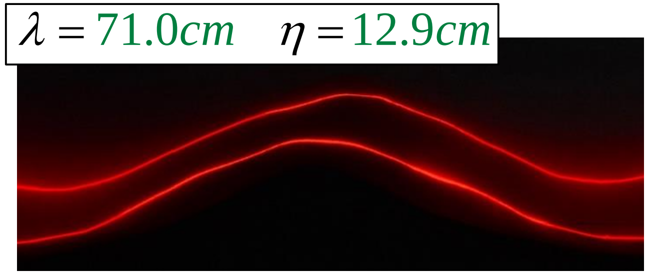
R_c Radius of curvature at the ripple crest



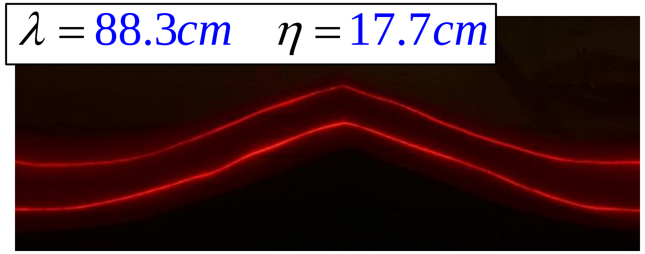
- larger Shields parameters larger Rc
- Shields parameter → roughness = d_{50}
- Crest roundness is controlled by the local flow conditions



$Ta040 \quad U_{bm} = 0.40 m/s \quad T = 4.17\ s \quad \psi_{wmd} = 0.102$



$Ta080 \quad U_{bm} = 0.80 m/s \quad T = 6.25\ s \quad \psi_{wmd} = 0.333$



$Te044 \quad U_{bm} = 0.44 m/s \quad T = 10.00\ s \quad \psi_{wmd} = 0.103$

Conclusion

- A Full-scale OWT experimental study on geometry of coarse-sand vortex ripples (ripple development and equilibrium ripple shapes).

- 3-D ripples become 2-D on sloping bed: net sediment transport rate also control the planform geometry.

- Full-scale ($Re_w \sim 10^5$) vortex ripples: ~ sinusoidal shape.

- Flow with larger shields parameter tend to form rounded-crest ripples.

Thank you !

Q&A

WANG D. and YUAN J., (2018), "Bottom-slope-induced net sediment transport rate under oscillatory flows in the rippled-bed regime." Journal of Geophysical Research: Oceans(under minor revision)

WANG D. and YUAN J., (2018), "Geometric Characteristics of Coarse-sand Ripples Generated by Oscillatory Flows: A Full-Scale Experimental Study." Coastal Engineering (submitted)

Planform Geometry

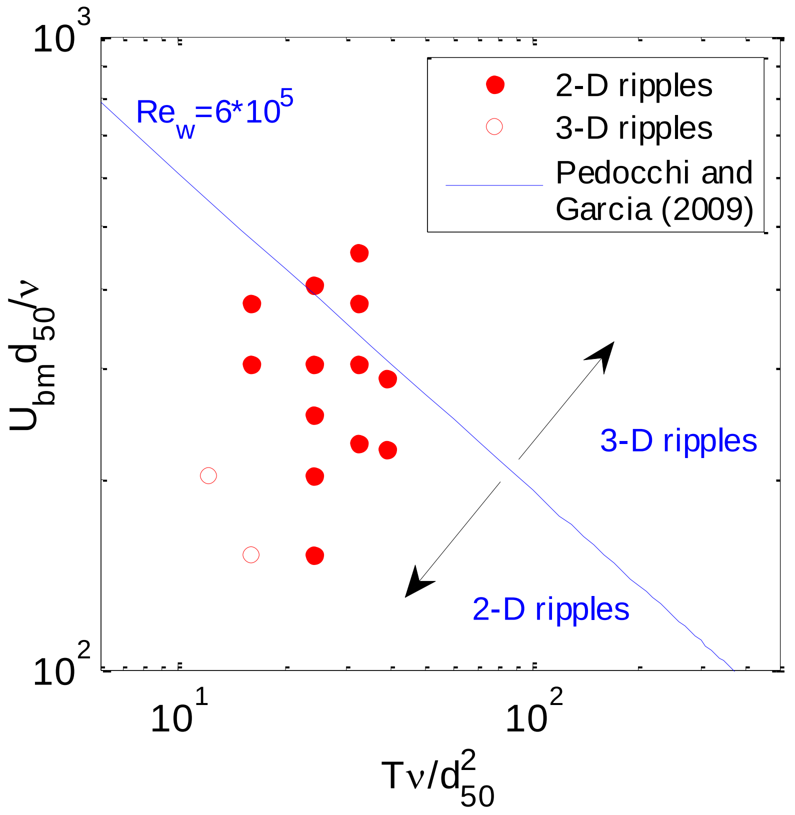
3-D ripples:

- Finer sand d_{50}
- Longer excursion amplitude A_{bm}
- Larger excursion velocity U_{bm}

Pedocchi and Garcia (2009)

$$\frac{\sqrt{g(s-1)gd_{50}}d_{50}}{\nu} < 0.06\sqrt{\frac{U_{bm}A_{bm}}{\nu}}$$

Small sand   Strong flow conditions



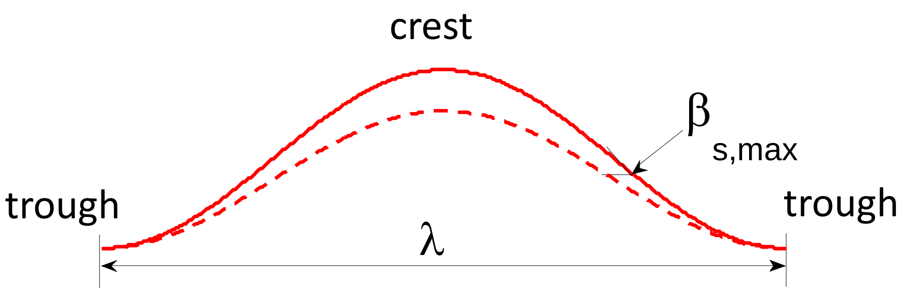
Tunnel width: 40 cm

Measured λ of 2-D ripples: 44.7cm-90.4cm

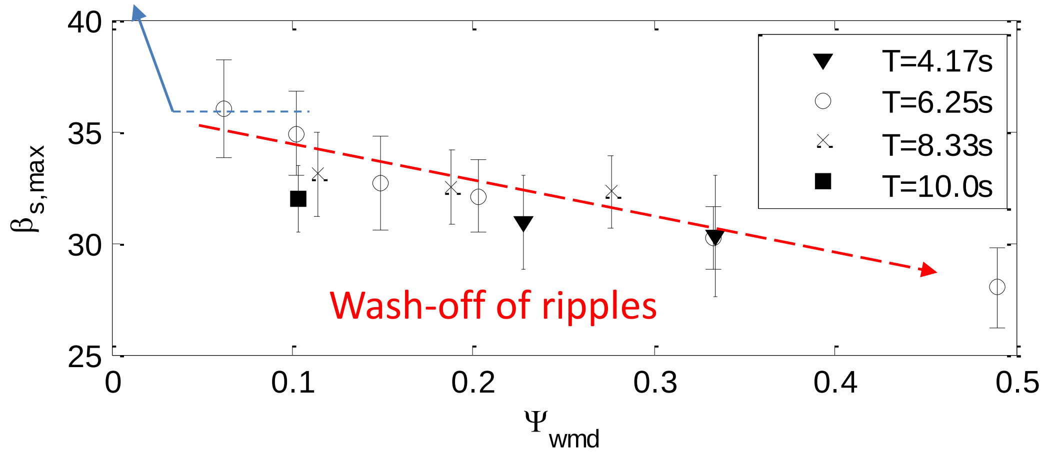
λ of 2-D ripples in the field: 50cm-100cm
e.g.,Traykovski, Hay et al. (1999)

Our study: Given *T* Longer A_{bm} or larger U_{bm} → 2-D ripples

What does the flank look like : Maximum Local Slope



$\beta_{s,max}$ Maximum slope between tough and crest



weak suspension

deposit

Angle of repose

strong suspension

Flattens the ripples: η/λ ↓

$\beta_{s,max}$ decreasing