Quantifying Scour

Overview:

CFD

- Sea state is treated as the superposition of two monochromatic waves
- Can spatially map shear stress around the device, but cannot directly quantify scour
- Different device geometries can be treated
- Can identify shear stress hotspots due to certain elements of geometry

Empirical Formulations

- Sea state is treated as a uniform monochromatic wave
- Cannot spatially map shear stress around the device, but can quantify a general scour depth
- Simple geometries only
  - Global formulations are derived from studies on cylindrical piles
  - Local formulations not yet addressed here

Deployment observations

- Limited to 2-3 qualitative assessments by divers over the 2 week deployment
- Scour noted to beginning shortly after deployment
- Greatest scour in the latter days of deployment (Regime 4)
- Scour was confined to the the device ends and under the caissons at depths of ~ 15 cm
- Accretion was noted in the mid section along the edges ~15cm

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Plan for Quantifying Scour

Aim: Build on Ryan's analysis

Correlate CFD with empirical formulations

- Check that methods are consistent in estimating shear stress associated with undisturbed flow
- Global Scour/Shear stresses
  - Empirical formulations for block geometry
  - CFD for block geometry
- Relate CFD shear stress output to scour potential
  - CFD for caisson geometry (accounts for shear stresses that may cause local scour)
  - Local scour formulations using a characteristic element (like horizontal pipe in Ryan's analysis)
- Verify results are consistent with deployment observations
  - determine whether scour was more likely due to local, global, or both scour processes
  - determine appropriate empirical formulations for general application

Apply empirical formulations to 2014 conditions

- Identify some representative nominal and extreme 2014 conditions based on empirical scour results
- Employ CFD to provide corresponding shear stress estimates
- Infer scour potential from shear stress mapping

Empirical Formulations

- Text of reference: *The Mechanics of Scour in the Marine Environment* (Sumer and Fredsoe, 2014)
- Formulations based on undisturbed flow properties (nearby seabed) estimated using: H_{rms}, T_p, u_m, d_{50}, s, v, h, α
- Valid for live-bed conditions ($\theta > \theta_{cr}$) when undisturbed seabed velocities can cause sediment motion and contribute to the filling of scour holes downstream

Shields parameter under waves:

$$\theta = \frac{u_{fm}^2}{(s-1)gd_{50}} = \frac{\tau_b/\rho}{(s-1)gd_{50}}$$

Friction velocity:

$$u_{fm} = \sqrt{\frac{f_w}{2}} u_m$$

Wave friction factor (p. 201, text):

$$f_w = 0.035(Re)^{-0.16}$$

Boundary–layer Reynolds number:

$$Re = \frac{a\, u_m}{\nu}$$

Amplitude of orbital velocity

$$a = \frac{H_{rms}}{2}\left(\frac{1}{\sinh\,(k_p h)}\right)$$

Empirical Formulations (Global Scour)

- Empirical formulations were derived from those for cylindrical piles under waves.
- K factors expand formulation to account for sediment size, device shape, alignment with respect to waves, finite device height, and sea state exposure time.
- This multistep approach is supported in text, p.192

1. Scour under constant current:

$$\frac{S_c}{D} = K_I K_\delta K_d K_s K_\alpha K_h$$

K_I = 2.4 (initial factor: live-bed scour, uniform sediment size)
K_δ = 1 (boundary layer factor, NA – river flow)
K_d = 1 (sediment size factor, fig. 3.27 with D/d_{50} = 2.5/0.2E-03 = 1.3E04)
K_s = 1.11 (shape factor, rectangle with Length/Width = 9/2.5 = 3.6, Table 3.1)
K_α = case specific, ~2 - 3.7 for Sept 2014 (alignment factor , fig. 3.29)
K_h = 0.19 (finite device height factor, fig. 3.28 with h/D = 1.0/2.5)

$$KC = \frac{u_m}{D f_p} = \frac{\sqrt{2}\sigma_u}{D f_p}$$

2. Scour depth (vertical pile/waves only, Myrhaug/Ong 2013*, also p. 192 text):

$$\frac{S}{D} = \frac{S_c}{D}\{1 - \exp\left[-0.019(KC-3)\right]\};KC \geq 3, \quad 45^o \; square\ cross\ section \longleftarrow$$

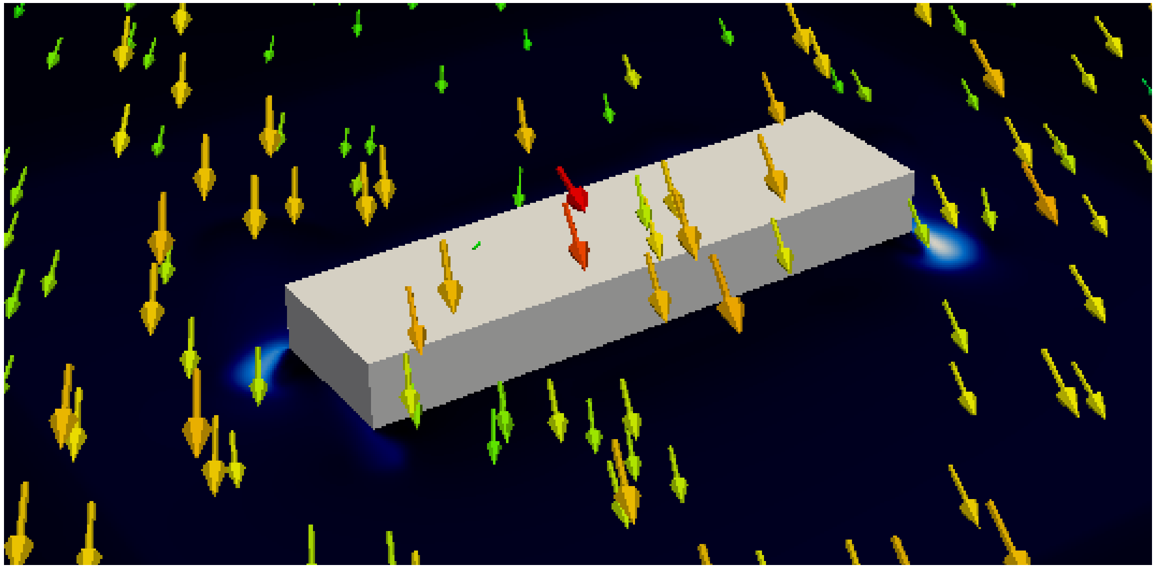
for KC < O(10) scour is due to lee-wake vortex shedding with an onset dependent upon KC and device geometry

3. *Time-scale of scour (Petersen, Sumer and Fredsoe, 2012), substituting S from step 2 for S_0 below and t = 0.5 hrs:

$$S_t = S_0\left(1 - \exp\left(-\frac{t}{\tau}\right)\right)$$

$$\tau = \frac{D^2}{\sqrt{g(s-1)d_{50}^3}} 10^{-6} \left(\frac{KC}{\theta}\right)^3 \left(\frac{1\ hr}{3600\ s}\right)$$

Empirical Estimates for September 2014 APEX deployment site and "block" geometry



Text recommends using u_m:

$$u_m = \sqrt{2}\,\sigma_u = \sqrt{2}\,u_{rms}$$

$$\sigma_u^2 = \int_0^\infty S_u(f)df$$

But since bimodal wave superposition occasionally results in greater seabed velocities, also considered using u_{sig}:

$$u_{sig} = 2\sigma_u = 2\,u_{rms}$$

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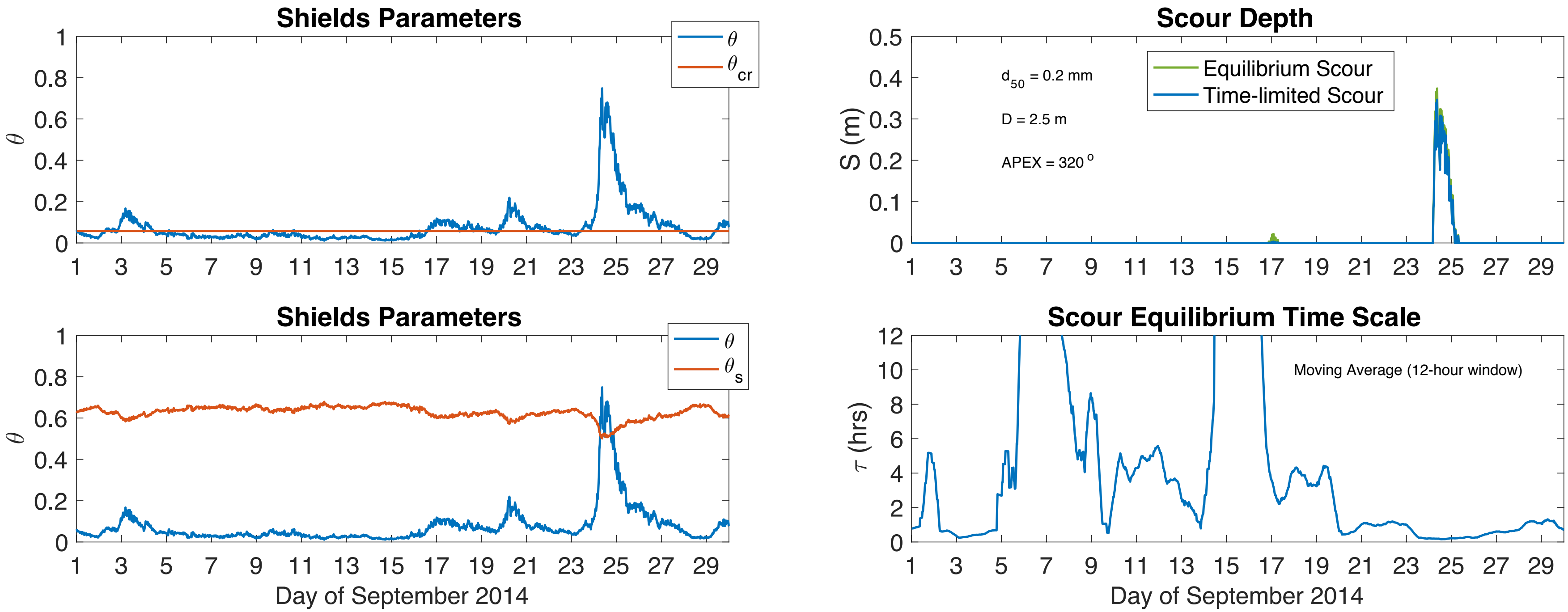
Empirical Estimates for September 2014 APEX deployment site

Assuming "block" geometry

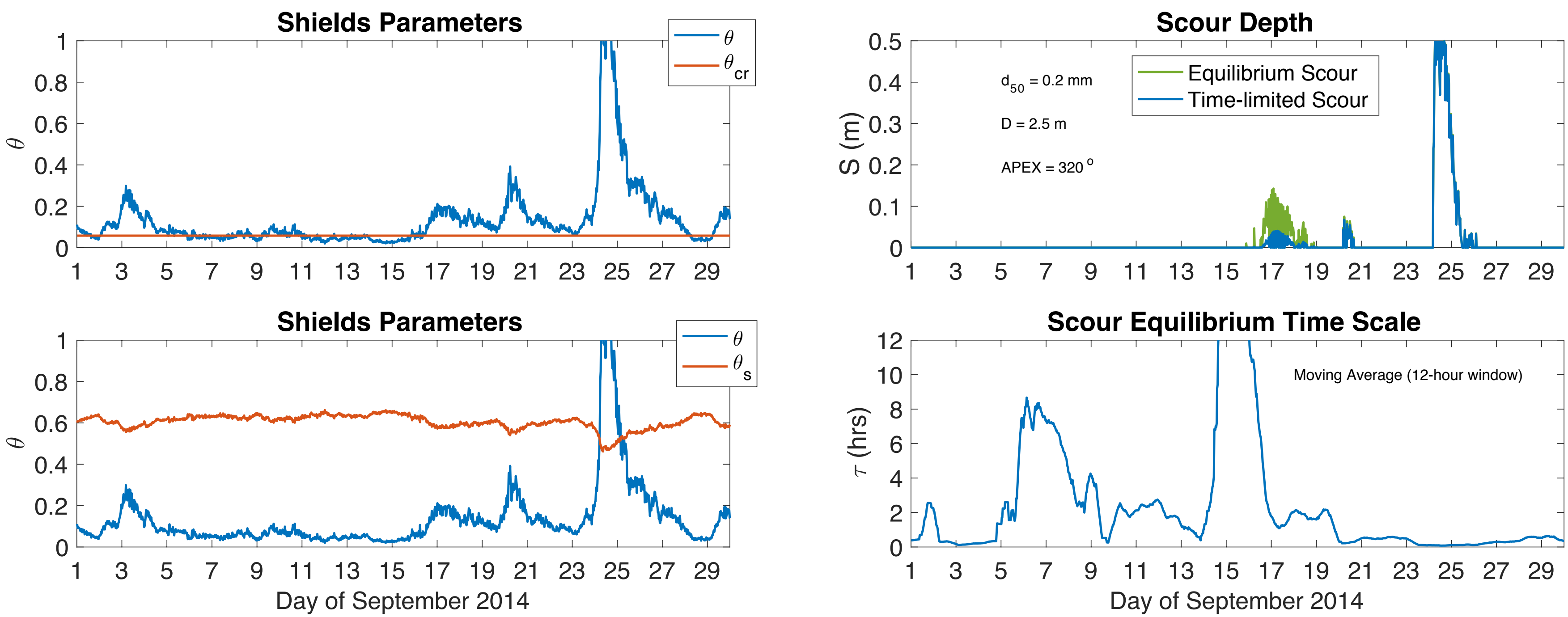


$$u_m = \sqrt{2}\,\sigma_u = \sqrt{2}\,u_{rms}$$

$$\sigma_u^2 = \int_0^\infty S_u(f)df$$

Possible Alternative
u_{sig} instead of u_m

Assuming "block" geometry



$$u_{sig} = 2\sigma_u = 2\, u_{rms}$$

*bimodal maximum seabed velocity is at times closer to u_{sig}
(u_{sig} = 0.52 m/s for Regime 4)

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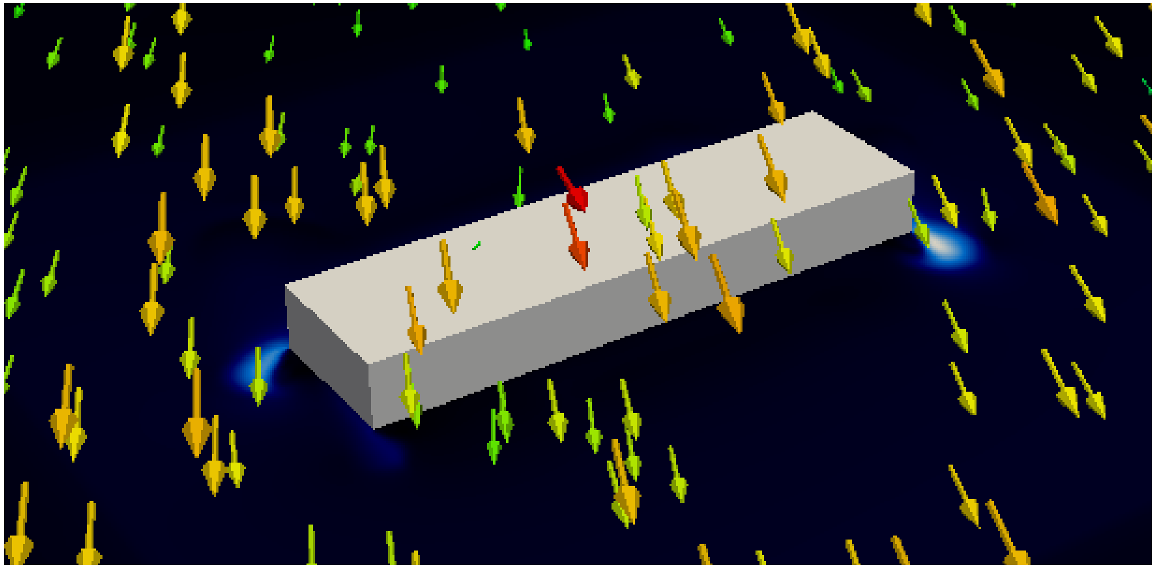
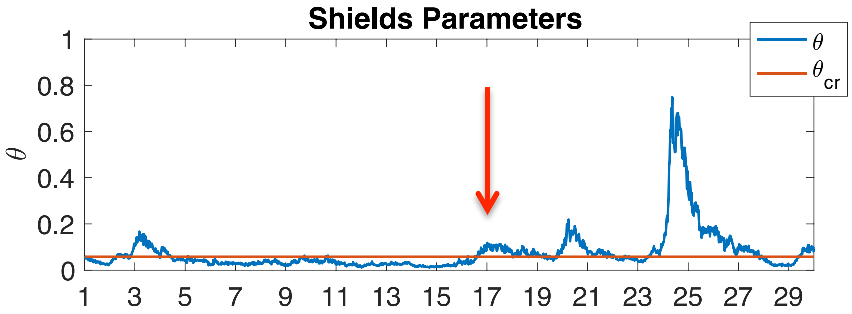
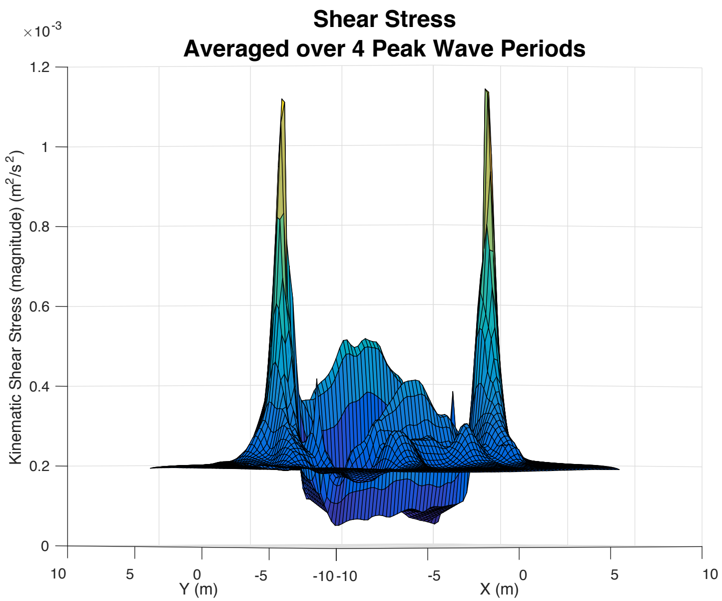
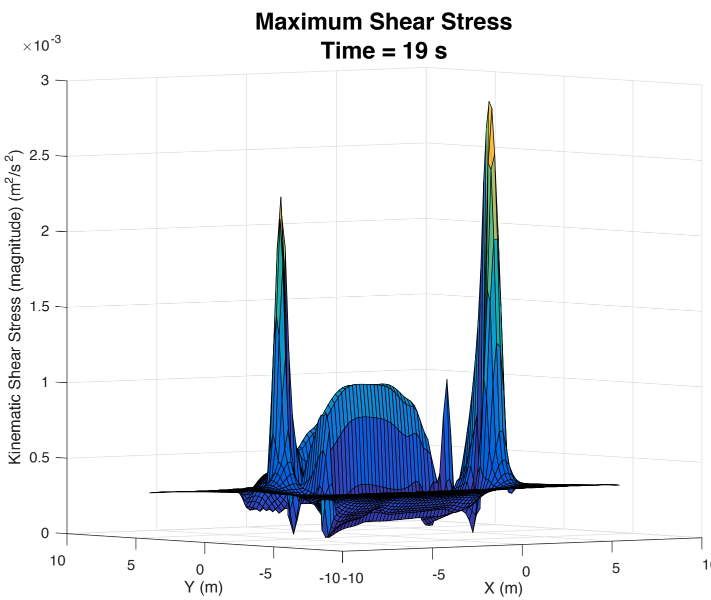
CFD for September 17 (Regime 4)
APEX deployment site and "block" geometry





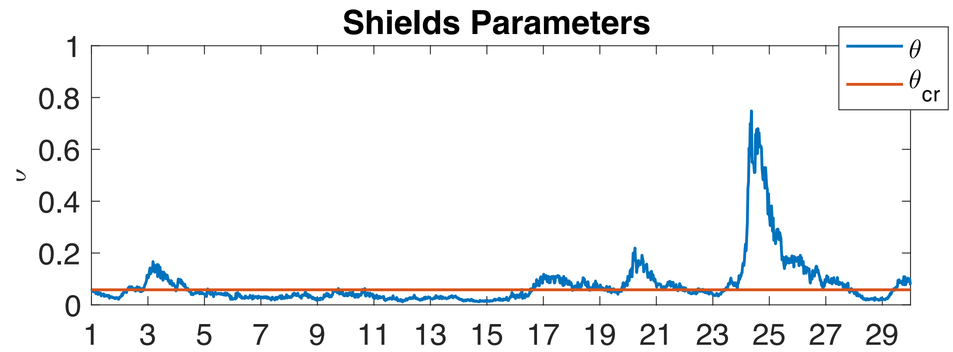
CFD





Empirical Formulation

Regime 4
Sept 17, 2014

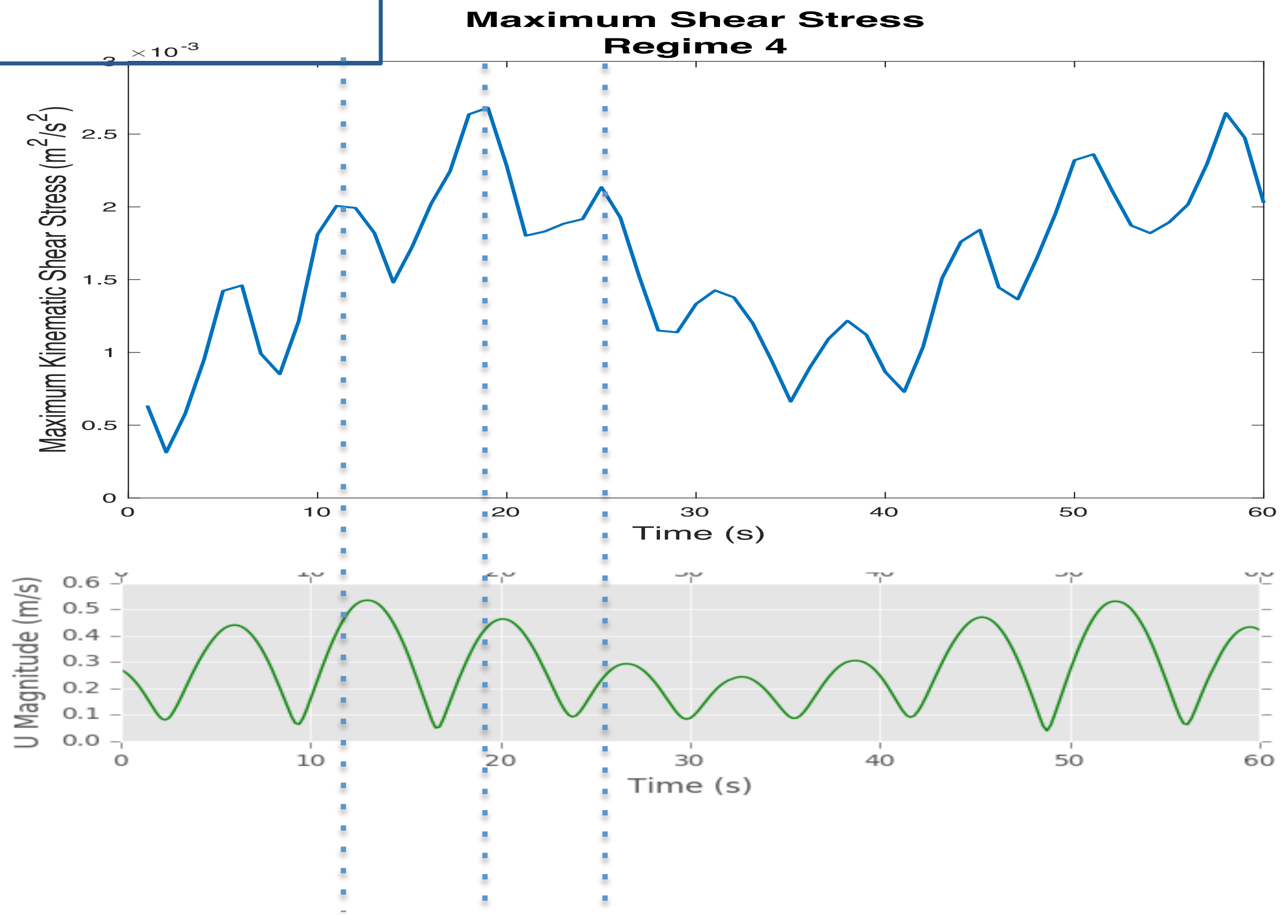


Above:
H_{rms} = 1.2 m
T_p = 13.1 s
u_m = 0.37 m/s
f_w = 0.0047
u_{fm} = 0.018 m/s
$\tau_w = u_{fm}^2 = 0.32\text{x}10^{-3}\ m^2/s^2$
Sh = 0.10
KC = 1.9 < 3, no scour

CFD (sampled undisturbed seabed)
u_m ~ 0.44 m/s (3cm above floor)
τ_w ~0.35 x $10^{-3}\ m^2/s^2$
u_{fm} = sqrt(τ_w) = 0.019 m/s

*max shear stress at device seems to occur just before undisturbed maxima when gradients across the domain are high

Regime 4
Sept 17, 2014



empty domain sampled at center, 5 cm above floor

What would be the more appropriate way to define U_m for empirical estimates?

- With respect to H_{rms} (since recommended by text assuming single-mode spectra)
- With respect to H_{sig} (since bimodal spectra result in occasional higher maxima than would be seen for single-mode)

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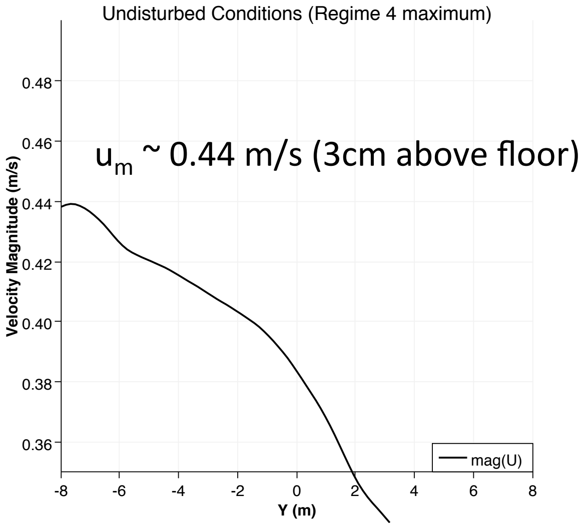
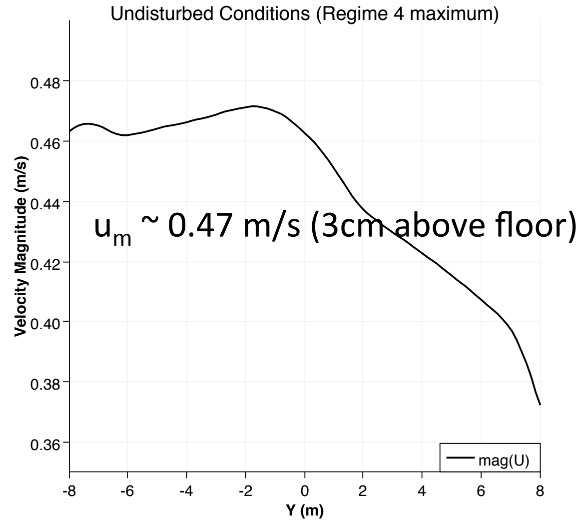
CFD sampling of undisturbed seabed

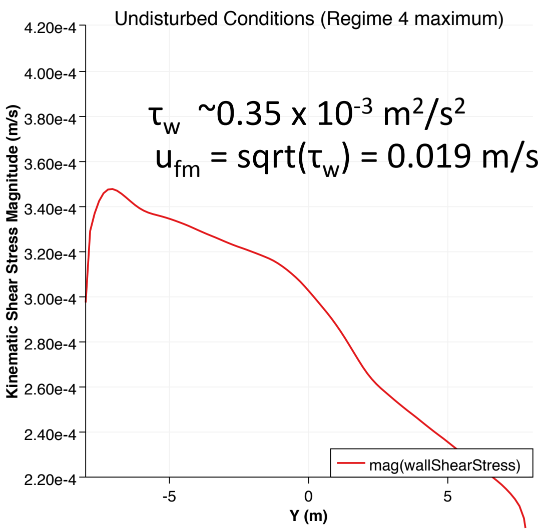
Regime 4
Sept 17, 2014

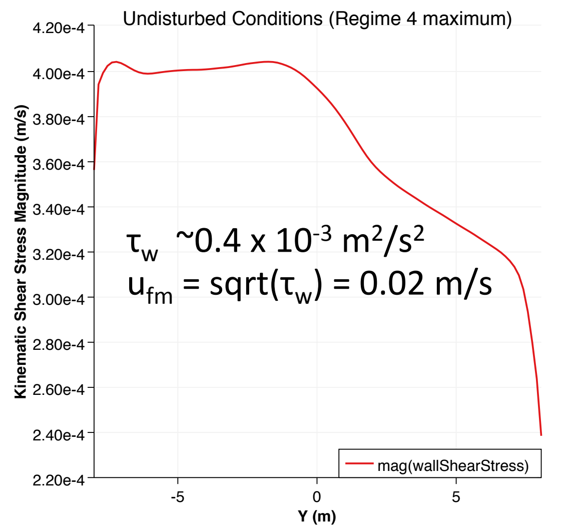


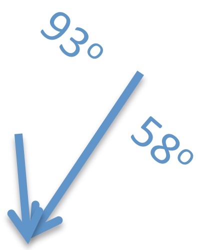
t = 19 s
max shear stress at device

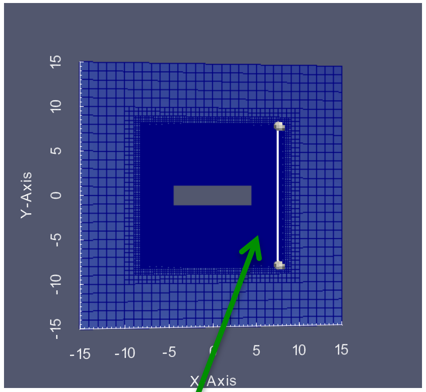


t = 20 s
max undisturbed conditions





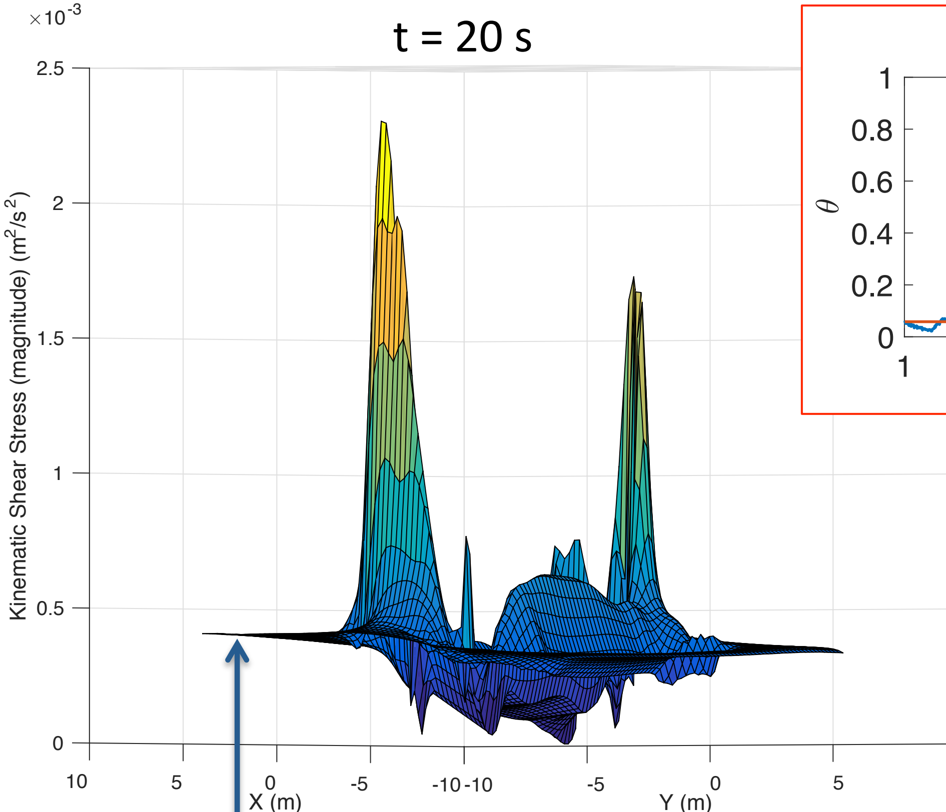




sampling along line

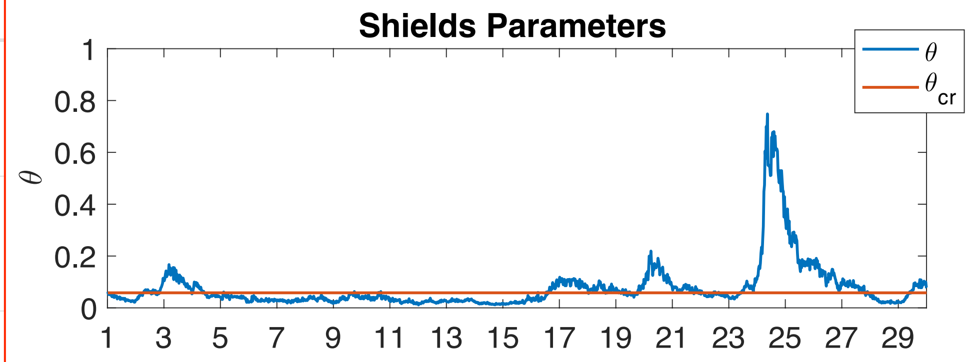
CFD

Undisturbed Flow Maxima
t = 20 s



Empirical Formulation

Regime 4
Sept 17, 2014



Above (Sept 17):
H_{rms} = 1.2 m
T_p = 13.1 s
u_m = 0.37 m/s
f_w = 0.0047
u_{fm} = 0.018 m/s
u_{fm}/u_m = 0.046
$\tau_w = u_{fm}^2 = 0.32 \times 10^{-3}\ m^2/s^2$
Sh = 0.10
KC = 1.9 < 3, no scour

(Cylindrical pile, Ryan):
H_s = 1.66 m
T_p = 13.1 s
*u_m = 0.6 m/s
*f_w = 0.0022
*u_{fm} = 0.02 m/s
u_{fm}/u_m = 0.033
$\tau_w = u_{fm}^2 = 0.4 \times 10^{-3}\ m^2/s^2$
Sh = 0.13
KC = 3.2 < 6, no scour

CFD (sampled undisturbed maxima)

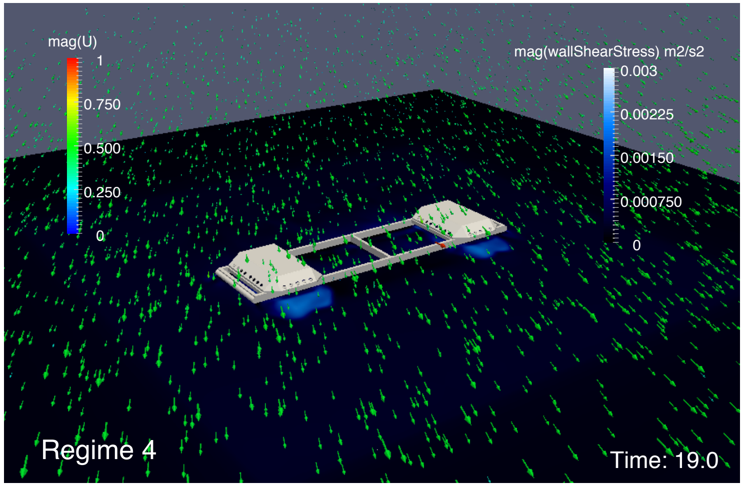
	t = 20	t=19
u_m (m/s)	~ 0.47	~0.44
τ_w (m^2/s^2)	~ 0.40 x 10^{-3}	~0.35 x 10^{-3}
u_{fm} (m/s)	~ 0.020	~ 0.019
u_{fm}/u_m	~ 0.043	~ 0.043
Sh	~ 0.13	~ 0.11

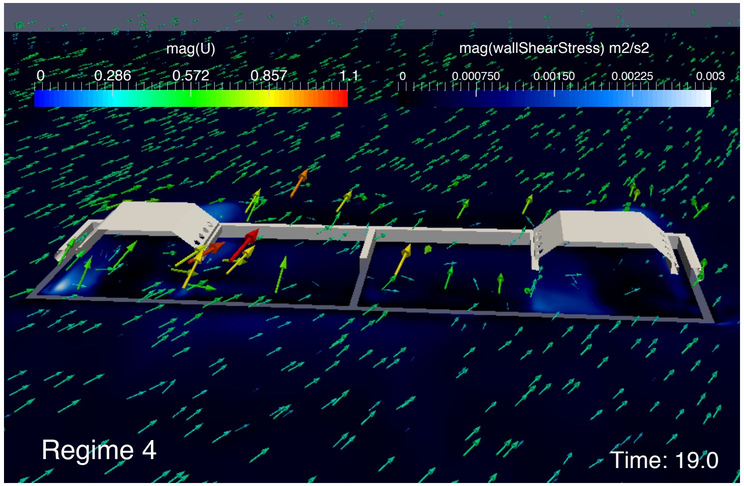
Alternative (Above, but $u_m = u_s$):
H_s = 1.66 m
T_p = 13.1 s
u_m = 0.52 m/s
f_w = 0.0042
u_{fm} = 0.024 m/s
u_{fm}/u_m = 0.046
$\tau_w = u_{fm}^2 = 0.65 \times 10^{-3}\ m^2/s^2$
Sh = 0.18
KC = 2.7 < 3, no scour

Regime 4
Sept 17, 2014

Scour was noted by divers for caisson geometry, especially for Regime 4 conditions

- How do we relate empirical scour estimates to shear stress map?





Notable hotspots from

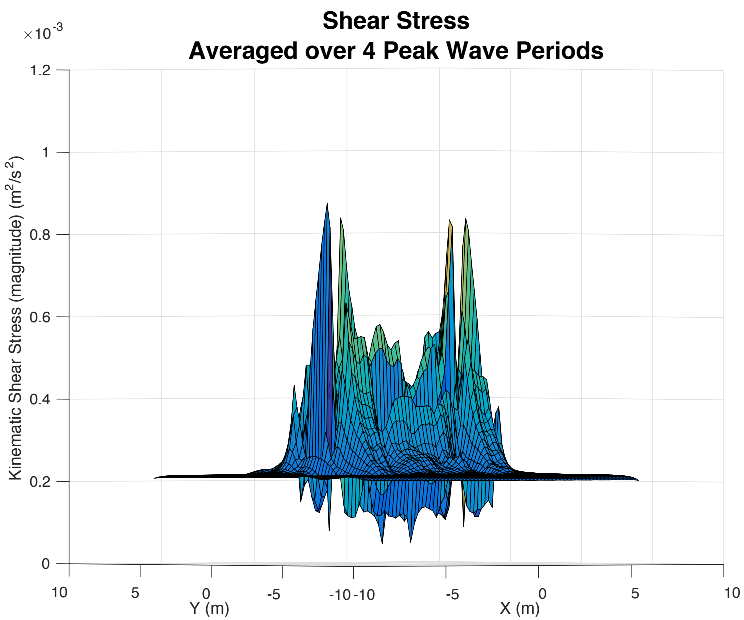
- Plunging over the caissons
- Interior caisson corners (interior vortex?)

Regime 4
Sept 17, 2014

CFD: Average shear stress of caisson geometry versus block geometry

- Since shear stresses are generally smaller for caisson geometry, could we infer that local scour would be less significant than global scour in this instance?
- Or perhaps things would look different if we averaged shear stress components instead of overall magnitudes

Caisson geometry
(local and global shear stress)



Block geometry
empirical global scour estimates apply