The Influence of Vertical Current Structure on Wind-Driven Surges in the Nearshore Region

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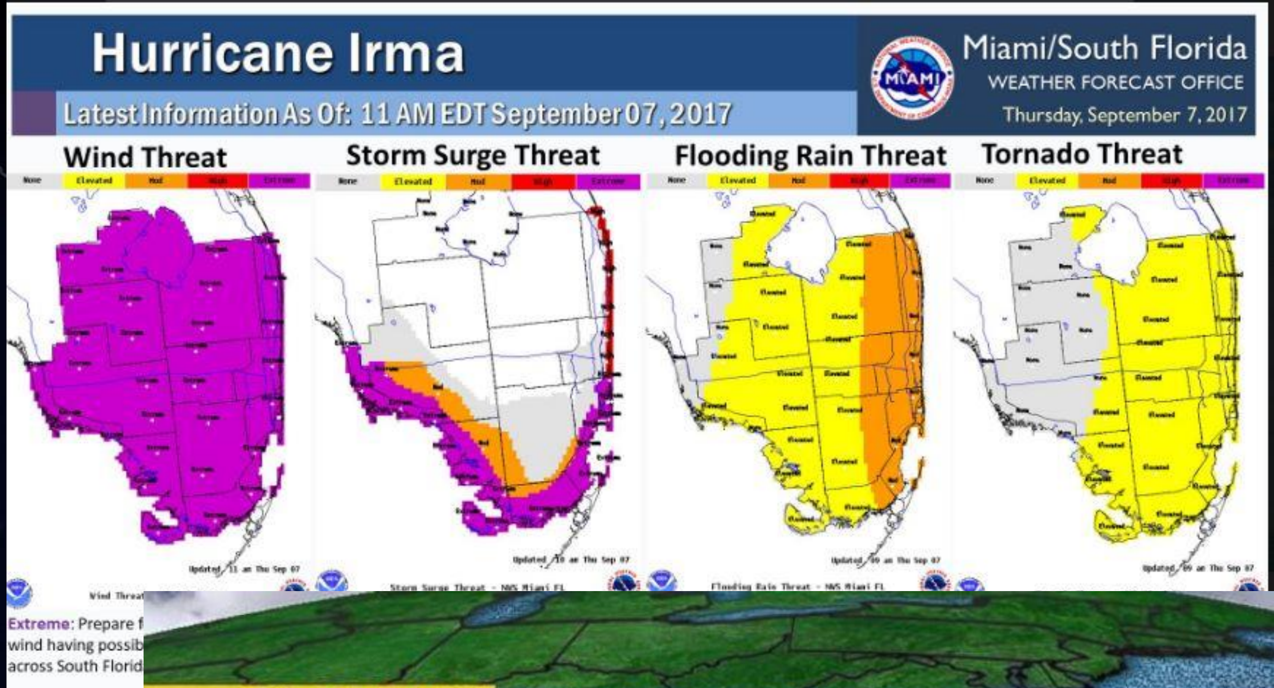

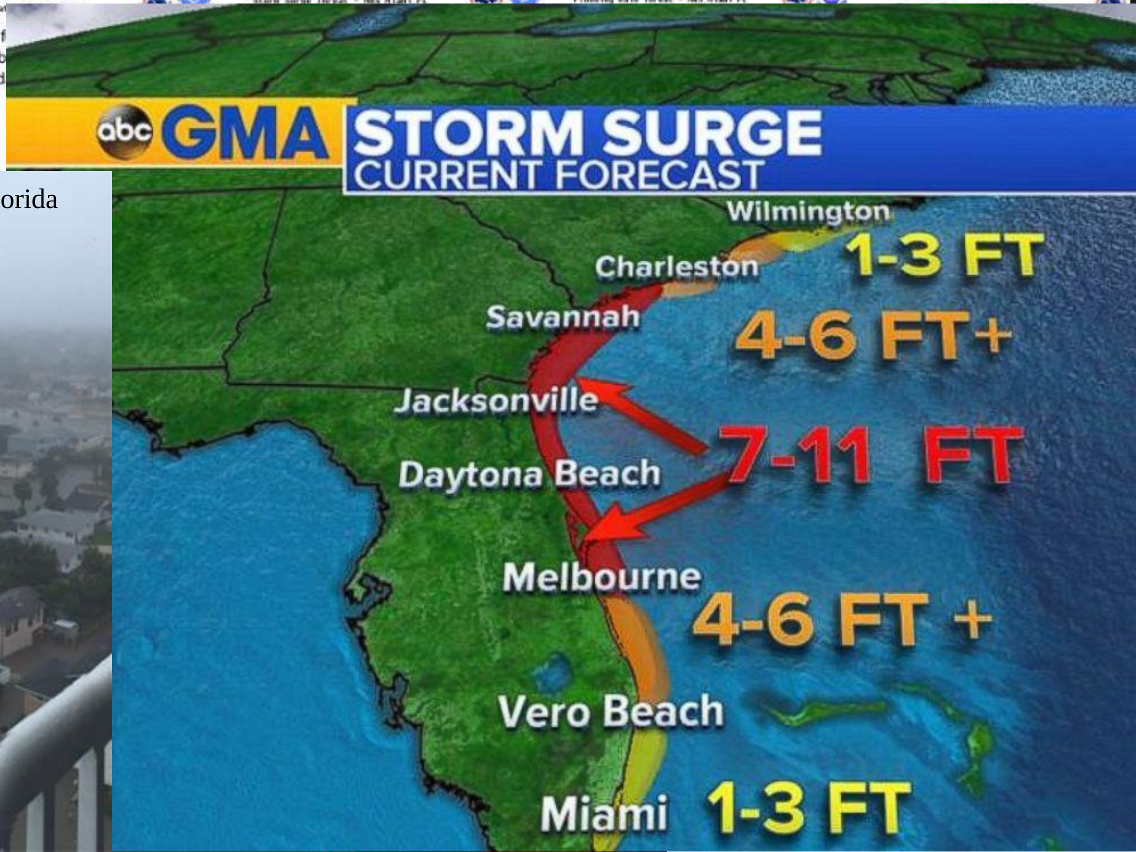

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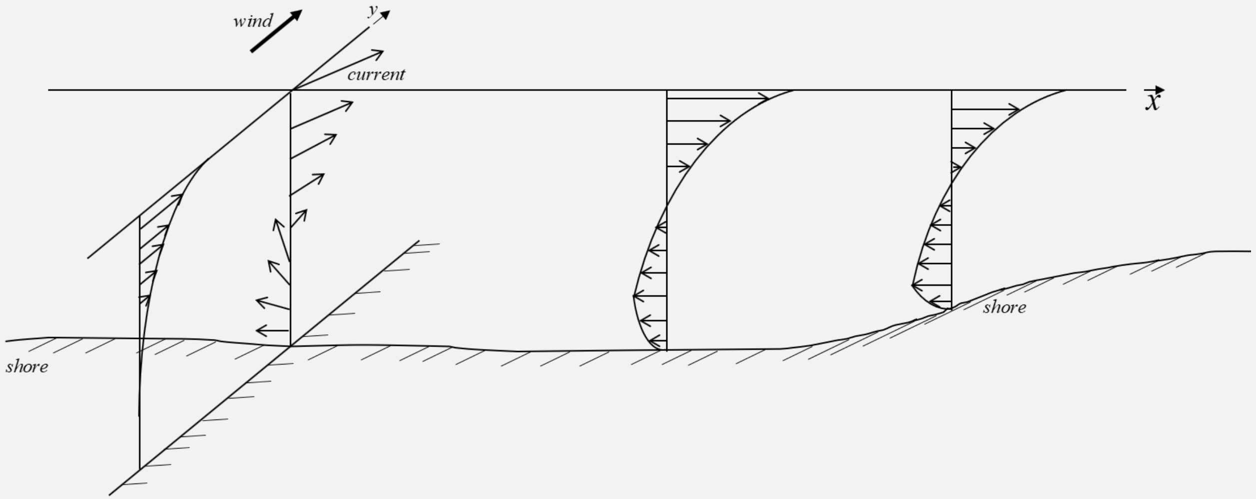
Background Review

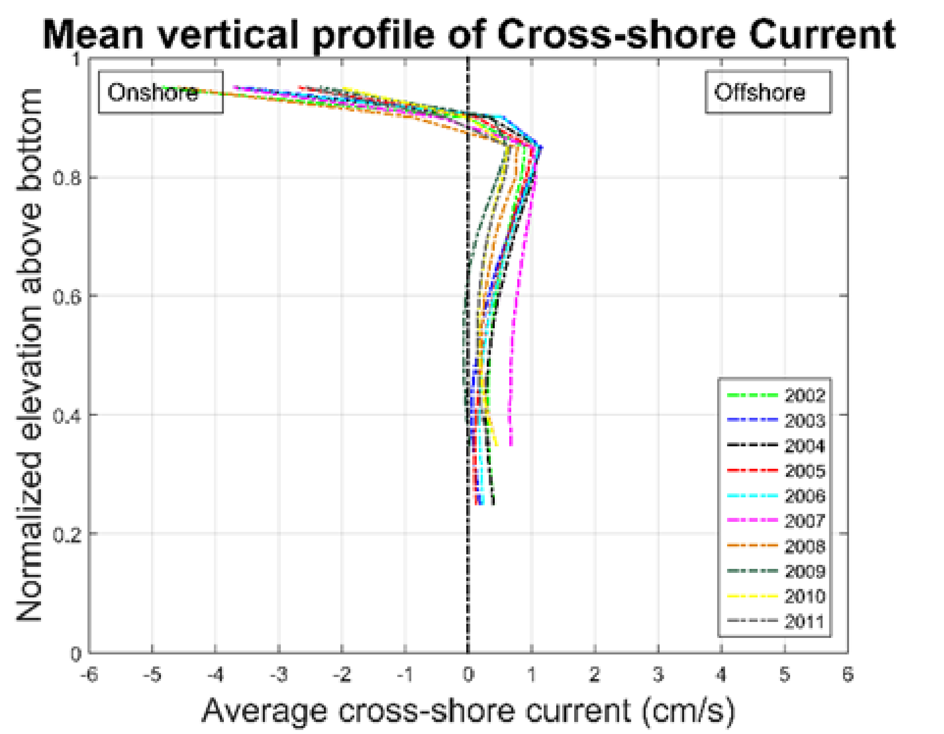
Vertical Structure – theory and observations.

Theory



Wind induced circulation in the nearshore open coast due to longshore winds, and the response in the current vertical structure.

Observations



Burnette and Dally (2017)

Objectives

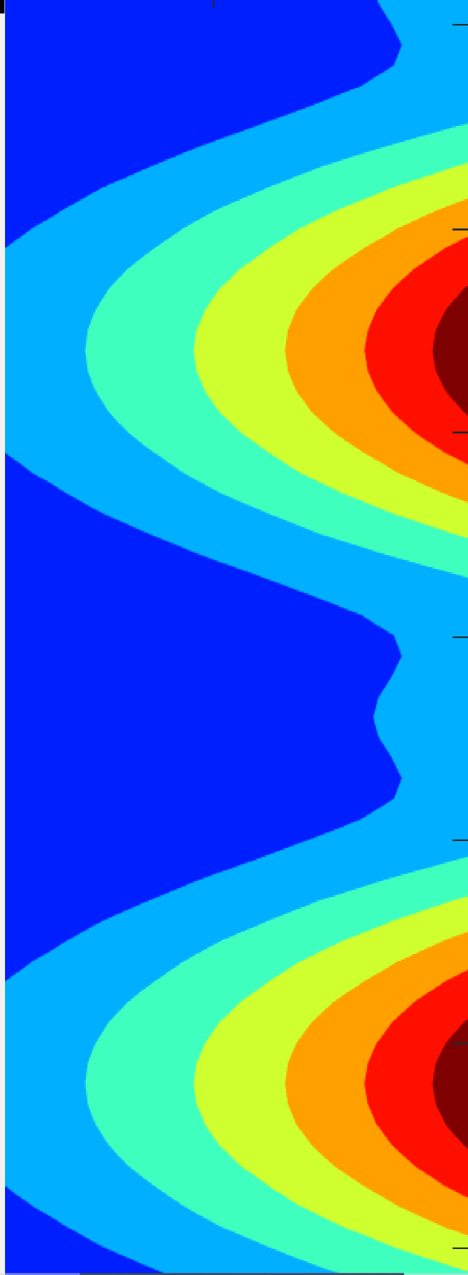
1. Implement turbulent closure equations within a 2-Dimensional Vertically-Resolving (2DVR) hydrodynamic model for coastal applications;

2. Implement depth averaged momentum and mass conservation equations within a 2DDI hydrodynamic model for coastal applications;

3. Make comparisons of the differences in surge estimation from 2DDI and 2DVR storm surge estimation simulations;

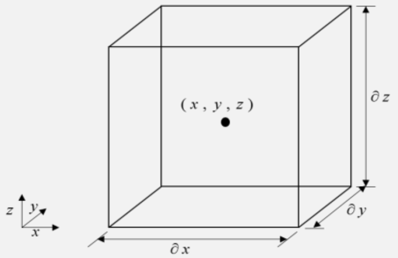
4. Investigate an effective means of including the 2DVR vertical momentum fluxes into the 2DDI codes and;

5. Suggest application of simple method for including 2DVR surge estimation solutions into a 2DDI model.

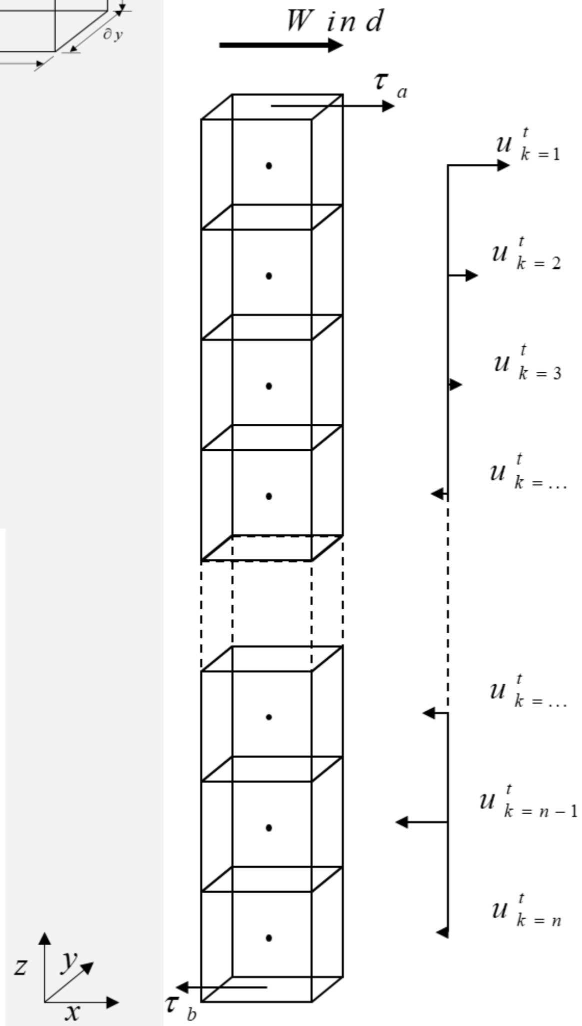


METHODS: *Development of Numerical Simulations*

2DVR Numerical Approach



- Vertical Momentum Equations **(2) & (3)**
  - Assume advection can be neglected;
  - Assume vertical momentum gradient >> horizontal momentum gradient
  - Assume the surface slope inversely defines the pressure gradient
- Initial Conditions:
  - Assume initial condition u & v = 0
  - Assume initial condition surface slope & pressure gradient = 0



$$\textbf{(2)}\quad \frac{\partial(\rho_w u)}{\partial t} = \frac{\partial}{\partial z}[\upsilon_{eff}\frac{\partial(\rho_w u)}{\partial z}] + f\rho_w v - g\rho_w\frac{\partial\eta}{\partial x}$$

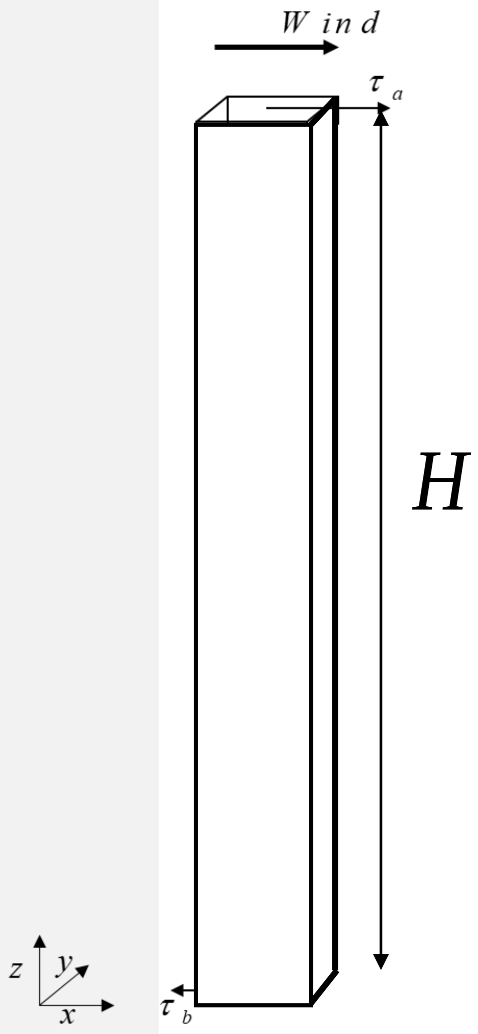
$$\textbf{(3)}\quad \frac{\partial(\rho_w v)}{\partial t} = \frac{\partial}{\partial z}[\upsilon_{eff}\frac{\partial(\rho_w v)}{\partial z}] - f\rho_w u - g\rho_w\frac{\partial\eta}{\partial y}$$

2DDI Numerical Approach

- Vertical Momentum Equations **(17) & (18)**
  - Assuming constant density
  - Neglecting advection
  - and average the tangential stress components.
- Initial Conditions:
  - Assume initial condition u & v = 0
  - Assume initial condition surface slope & pressure gradient = 0

$$\textbf{(17)} \qquad \frac{\partial U}{\partial t} = fV - gH\frac{\partial \eta}{\partial x} - \frac{\tau_{bx}}{\rho_w} + \frac{\tau_{ax}}{\rho_w}$$

$$\textbf{(18)} \qquad \frac{\partial V}{\partial t} = -fU - gH\frac{\partial \eta}{\partial y} - \frac{\tau_{by}}{\rho_w} + \frac{\tau_{ay}}{\rho_w}$$



Finite Difference Method (FDM)

- The FDM presented here uses the continuity and momentum conservation equations, and is similar to the method presented in Buttolph, et al., 2006.
  - Explicit method

(19)

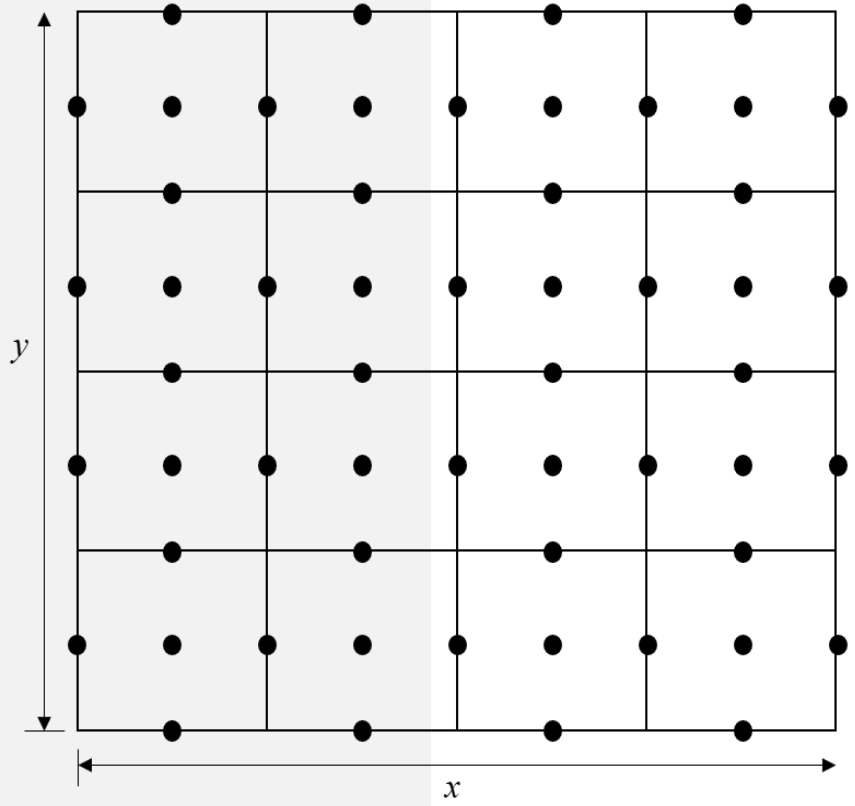
$$\Delta v_{i,j}^{k} = \Delta v_{i,j}^{k-1} +$$

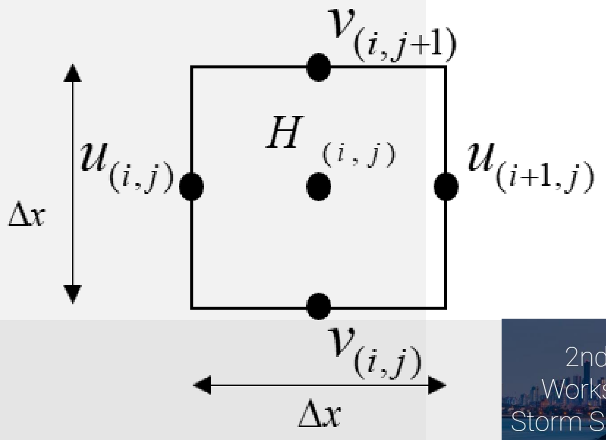
$$[\,f\,\frac{u_{i,j-1}^{k-1} + u_{i+1,j-1}^{k-1} + u_{i+1,j}^{k-1} + u_{i,j}^{k-1}}{4} + \frac{C_w \rho_a W^2 \sin(\theta)}{(H_{i-1,j}^{k-1} + H_{i,j}^{k-1})/2} + \frac{C_b \rho_w v_{i,j}^{k-1} \left| v_{i,j}^{k-1} \right|}{(H_{i-1,j}^{k-1} + H_{i,j}^{k-1})/2} + g\,\frac{\eta_{i-1,j}^{k-1} - \eta_{i,j}^{k-1}}{\Delta y}]\Delta t$$

(20)

$$\Delta u_{i,j}^{k} = \Delta u_{i,j}^{k-1} +$$

$$[-f\,\frac{v_{i-1,j}^{k-1} + v_{i,j}^{k-1} + v_{i,j+1}^{k-1} + v_{i-1,j+1}^{k-1}}{4} + \frac{C_w \rho_a W^2 \cos(\theta)}{(H_{i-1,j}^{k-1} + H_{i,j}^{k-1})/2} + \frac{C_b \rho_w u_{i,j}^{k-1} \left| u_{i,j}^{k-1} \right|}{(H_{i-1,j}^{k-1} + H_{i,j}^{k-1})/2} + g\,\frac{\eta_{i-1,j}^{k-1} - \eta_{i,j}^{k-1}}{\Delta x}]\Delta t$$





INVESTIGATION: *Numerical Test Cases & Analysis of Vertical Structure*

$$\textbf{(5)}\ \tau_{ax} = C_w \rho_a W^2 \cos(\theta)$$

$$\textbf{(6)}\ \tau_{ay} = C_w \rho_a W^2 \sin(\theta)$$

Where, if $\frac{\partial M_O}{\partial x}\frac{\partial x}{\partial t} = \frac{\iint \partial E(f,\theta)Cg}{\partial xC}\,\partial f \partial \theta$ then;

$$\textbf{(5)}\ \tau_{ax} = C_w \rho_a W^2 \cos(\theta) + \frac{\partial M_o}{\partial t}$$

$$\textbf{(6)}\ \tau_{ay} = C_w \rho_a W^2 \sin(\theta) + \frac{\partial M_o}{\partial t}$$

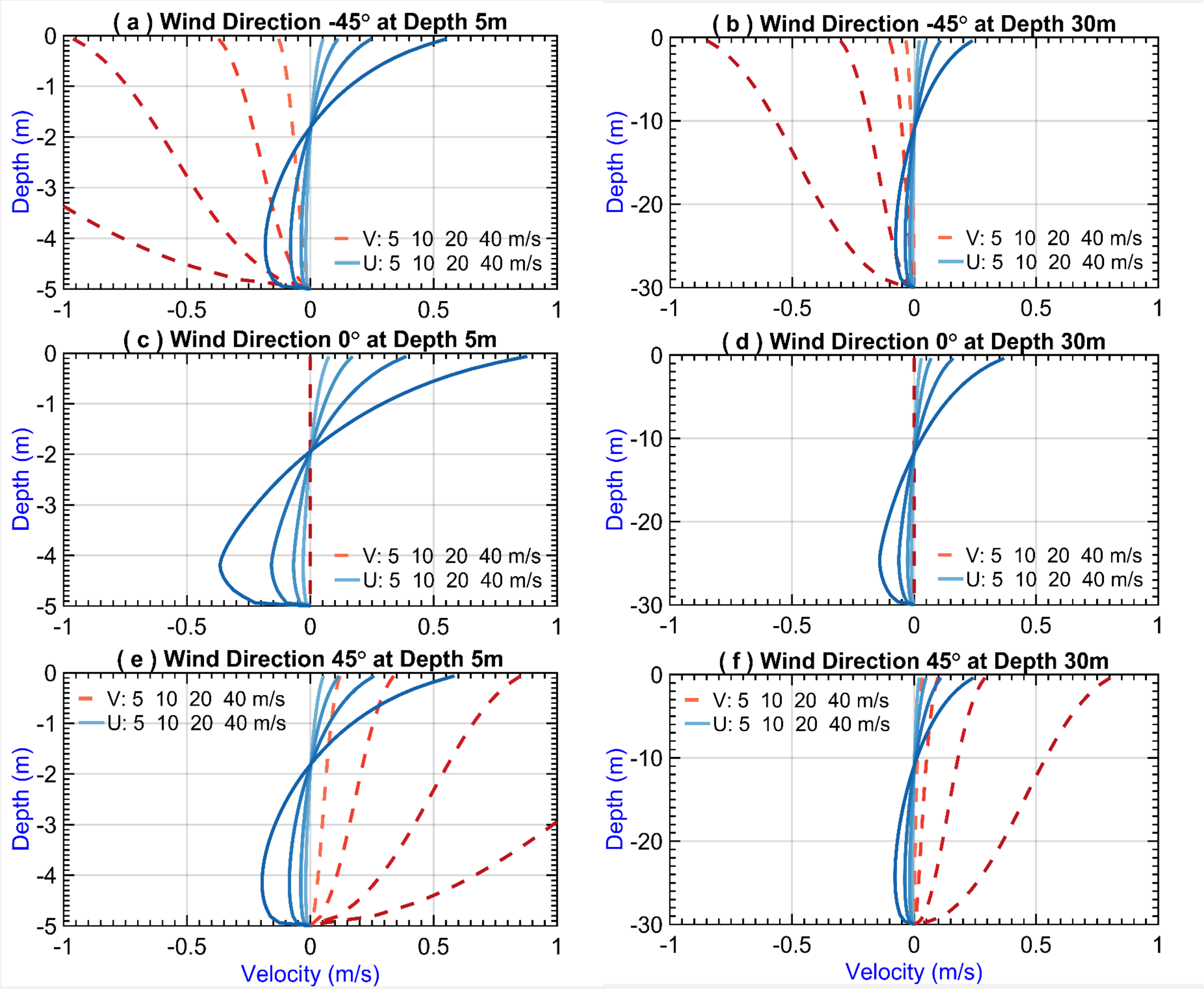
Investigation:

Though wind-driven currents are the focus of this work, it can be inferred that similar results would be found if waves are included as an equivalent wind stress.

NOTE: The wind parameter can represent both wind-driven and wave-driven surges.

THEREFORE: The <u>nearshore region</u> in this work represents an idealized open coast with constant bottom slope, spanning from a few to tens of meters in depth.

TEST CASE 1



24 selected simulations from test case 1:

(a) Simulated wind speed of 5, 10, 20, and 40 m/s blowing at a -45 degree angle onshore at 5 meters.

(b) Simulated wind speed of 5, 10, 20, and 40 m/s blowing at a -45 degree angle onshore at 30 meters.

(c) Simulated wind speed of 5, 10, 20, and 40 m/s blowing at a 0 degree angle onshore at 5 meters.

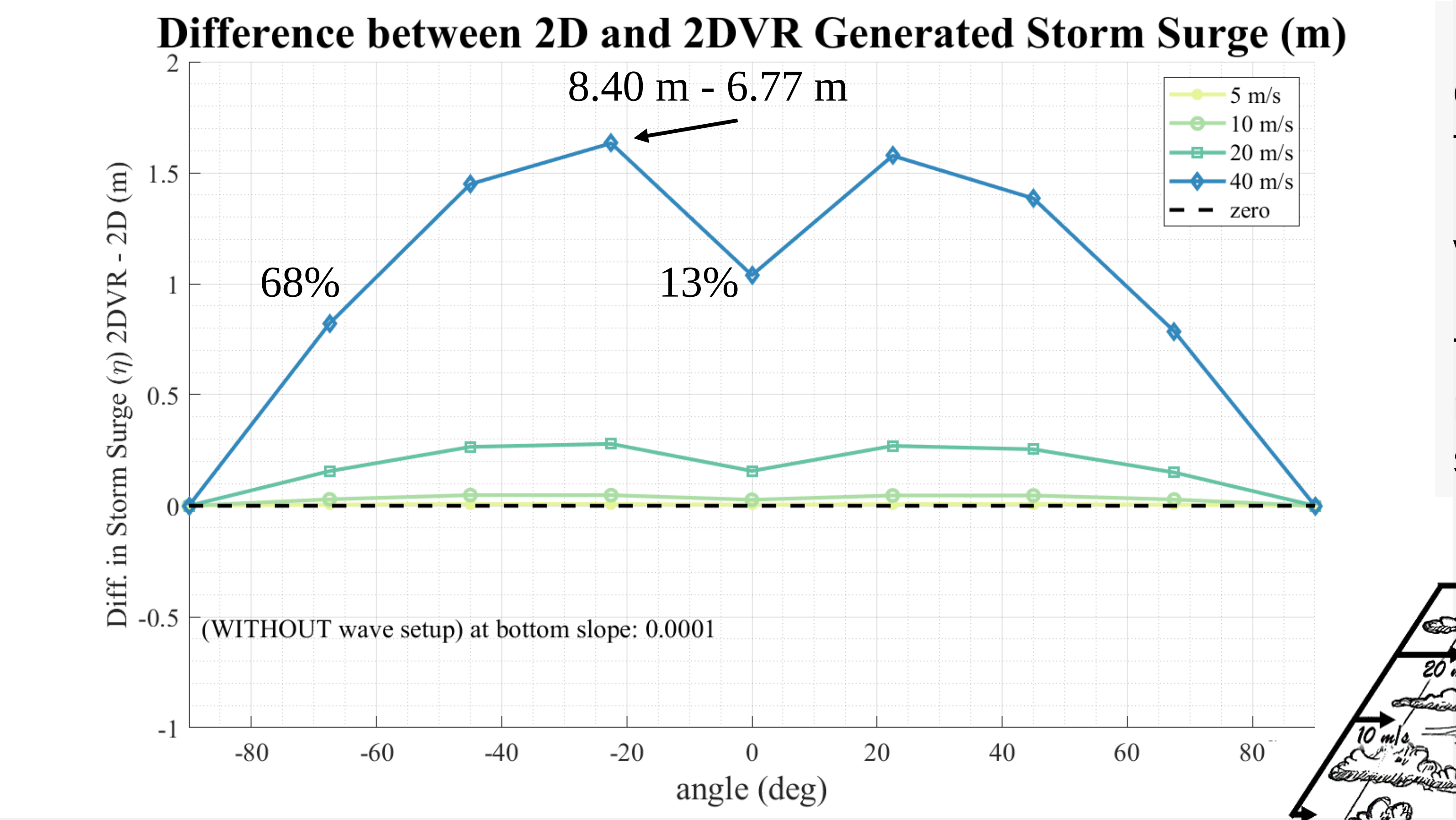
(d) Simulated wind speed of 5, 10, 20, and 40 m/s blowing at a 0 degree angle onshore at 30 meters.

(e) Simulated wind speed of 5, 10, 20, and 40 m/s blowing at a 45 degree angle onshore at 5 meters.

(f) Simulated wind speed of 5, 10, 20, and 40 m/s blowing at a 45 degree angle onshore at 30 meters.

2DVR Bottom Stress Solutions for Idealized Cases (Latitude = 0)
with model run time of 3 hours (dt = 0.5 sec)

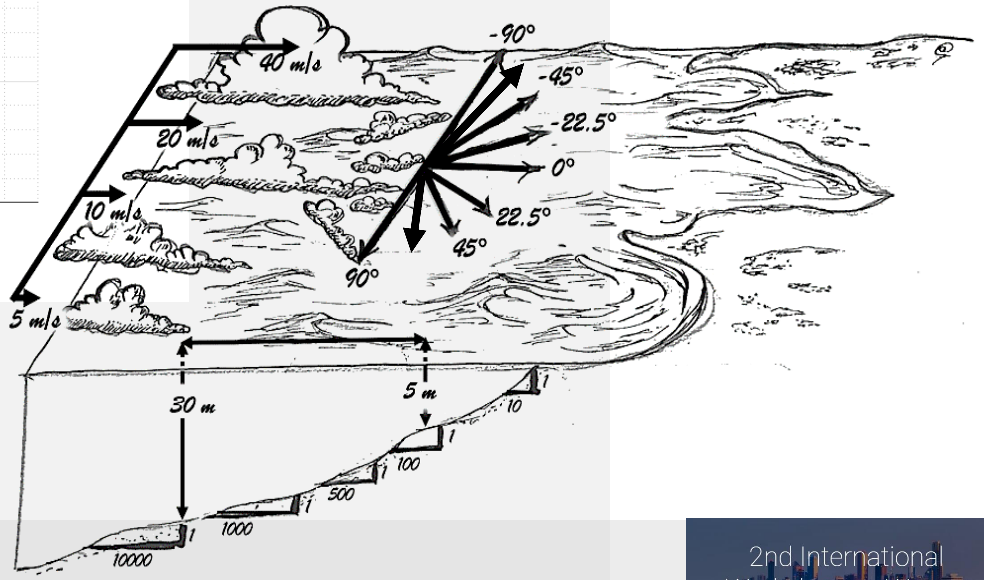
TEST CASE 2



Results showing the surface surge calculated at steady state generated for

vertically resolved - depth averaged

These runs were made from 30 to 5 meters of depth, for 4 different wind speeds, and 9 different wind angles.

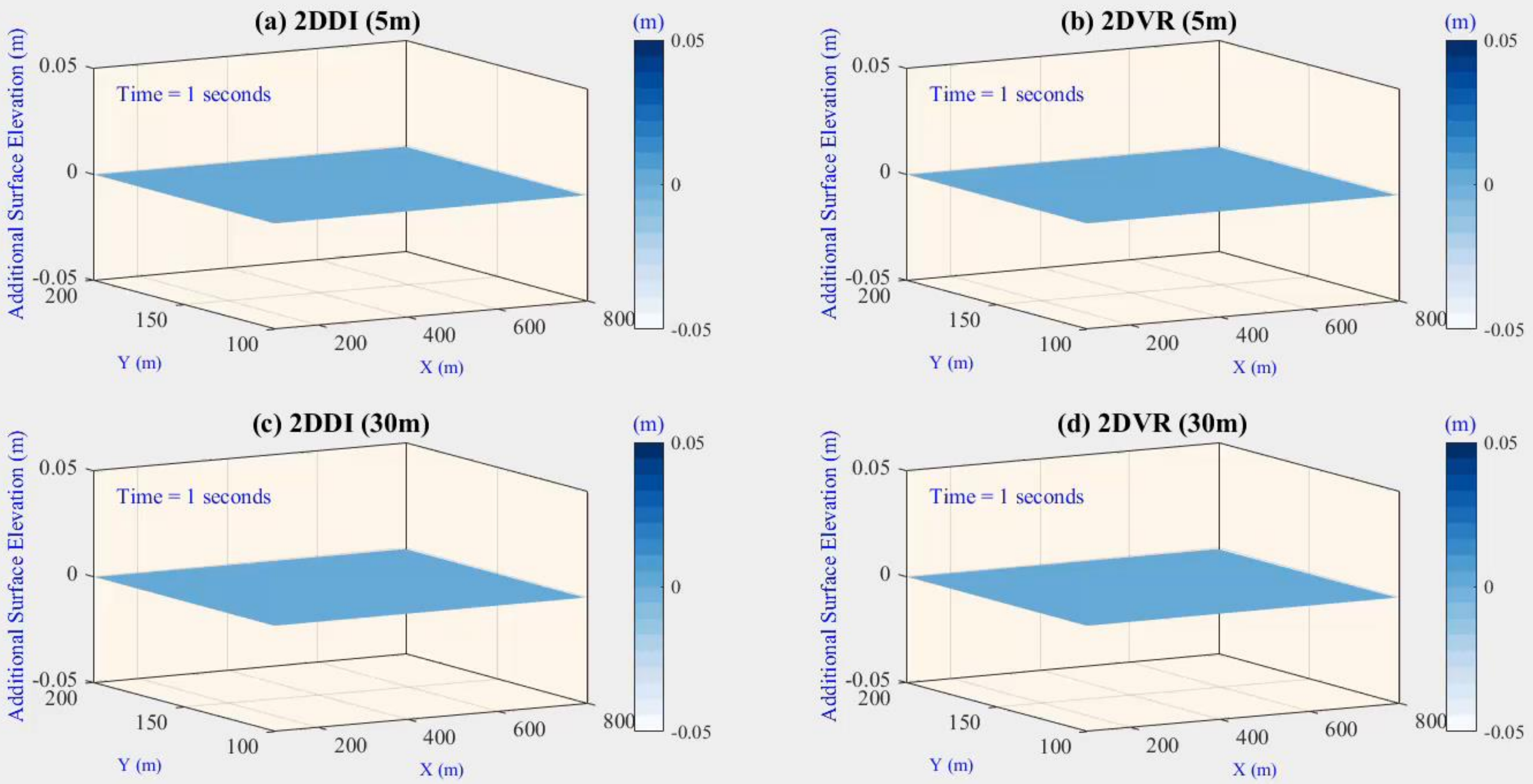


Approx. 24.1% additional storm surge.

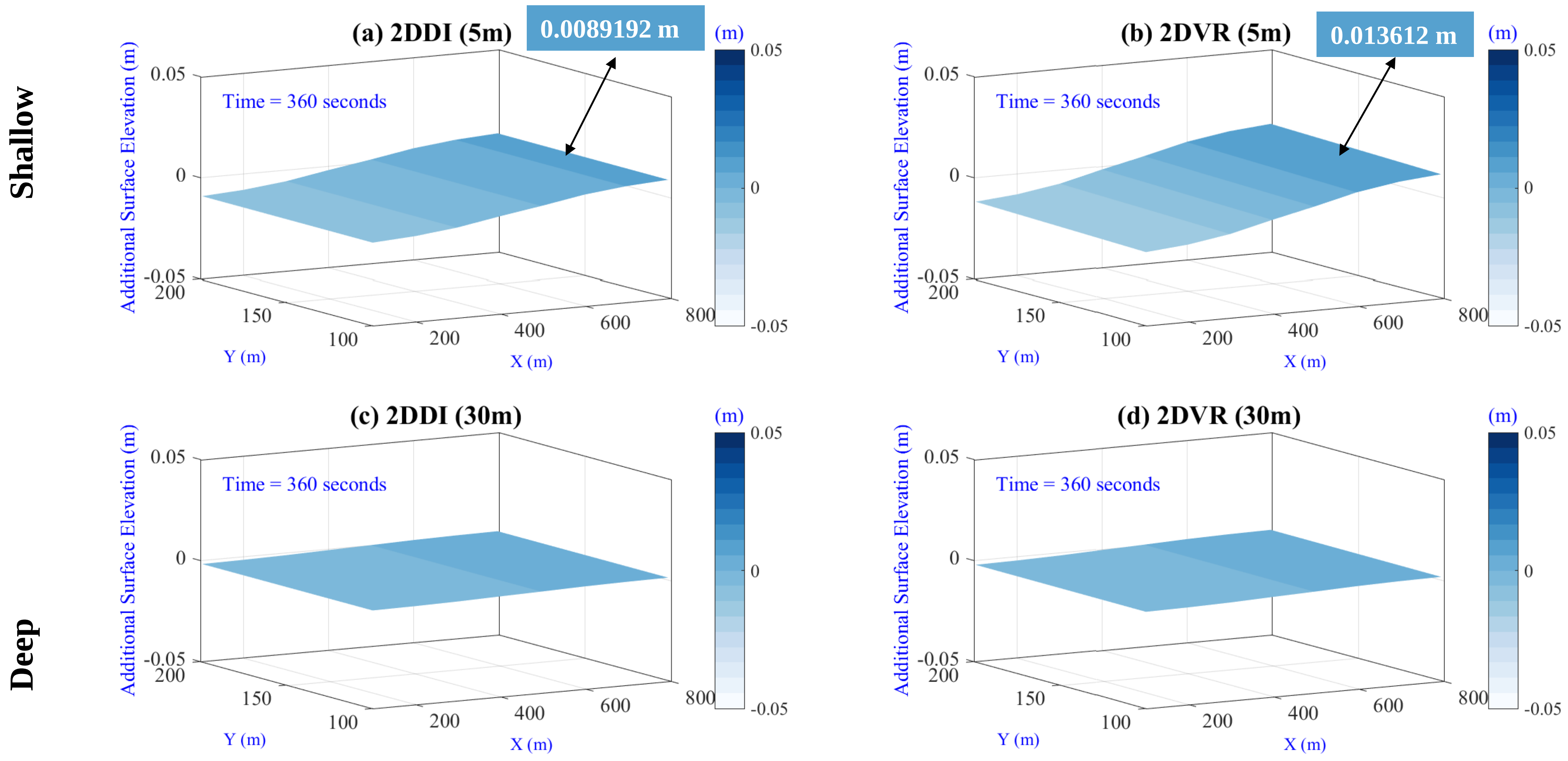
TEST CASE 3

Shallow

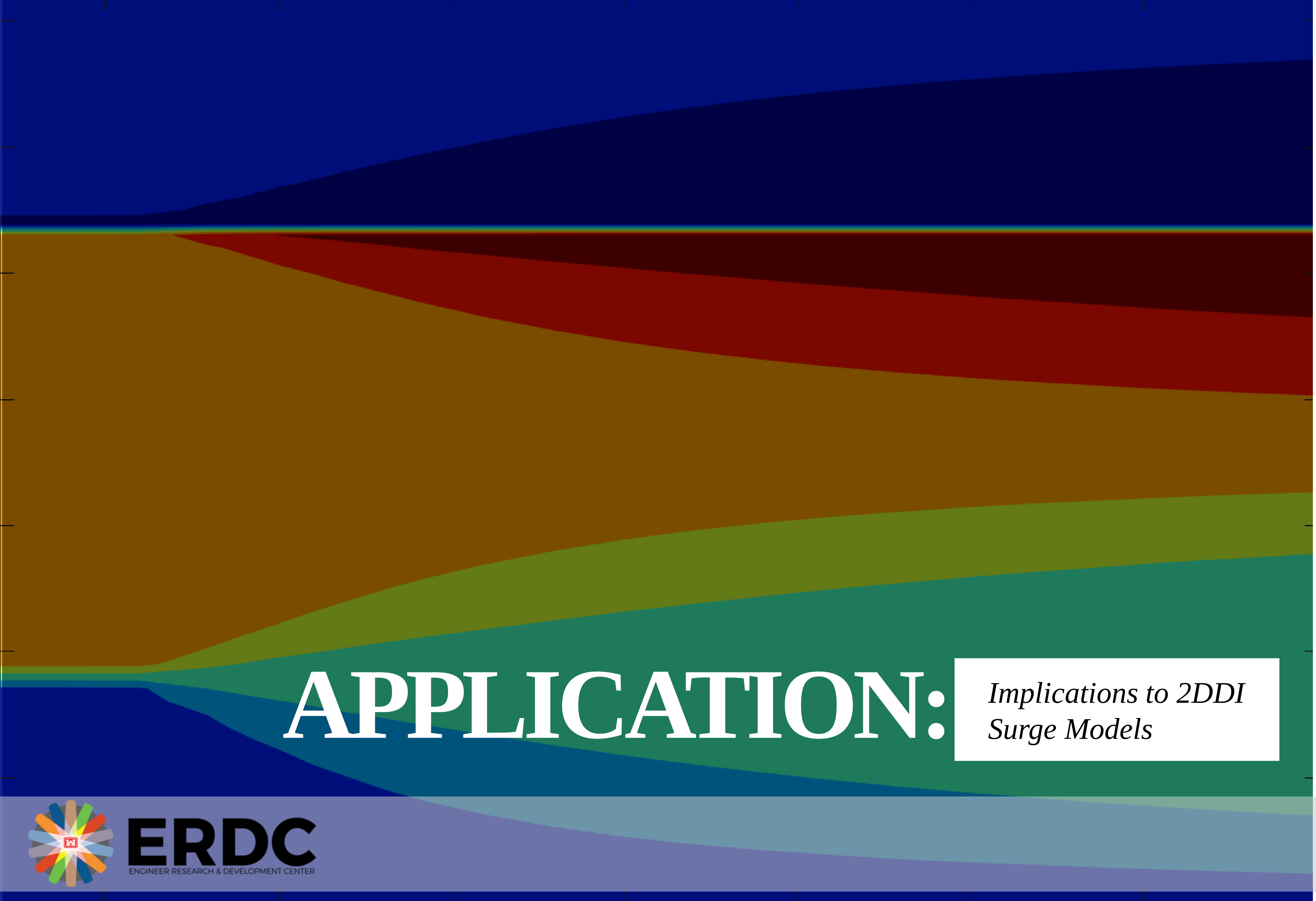
Deep



TEST CASE 3



Diff/2DDI = 0.5262

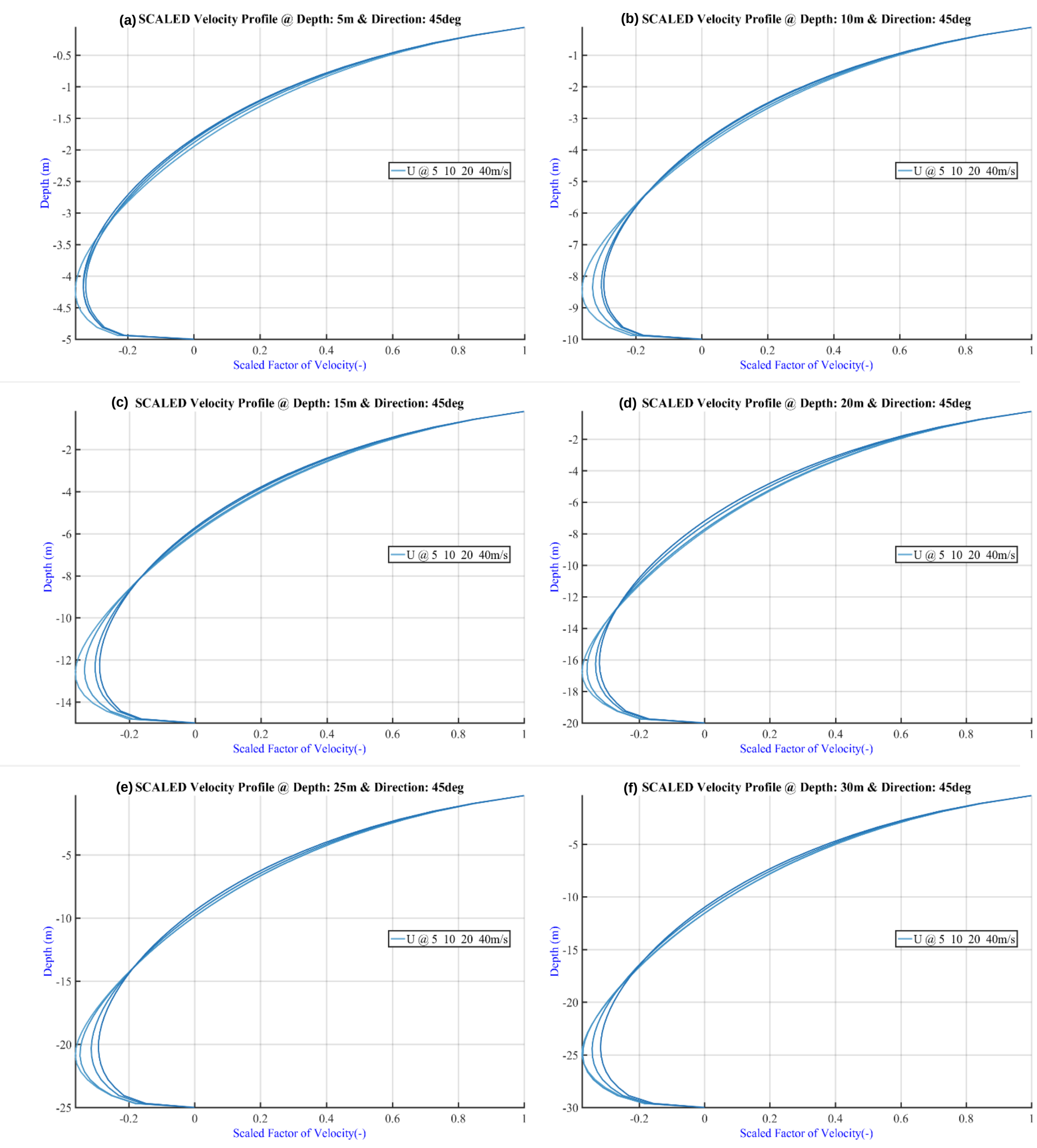


APPLICATION: *Implications to 2DDI Surge Models*

Scaled Analysis

The maximum velocity, at the top layer of the water column, is used to non-linearize the velocity profile through depth, for wind speeds of 5, 10, 20, and 40 m/s (where darker lines represent higher speeds), and a wind direction of 45 degrees.

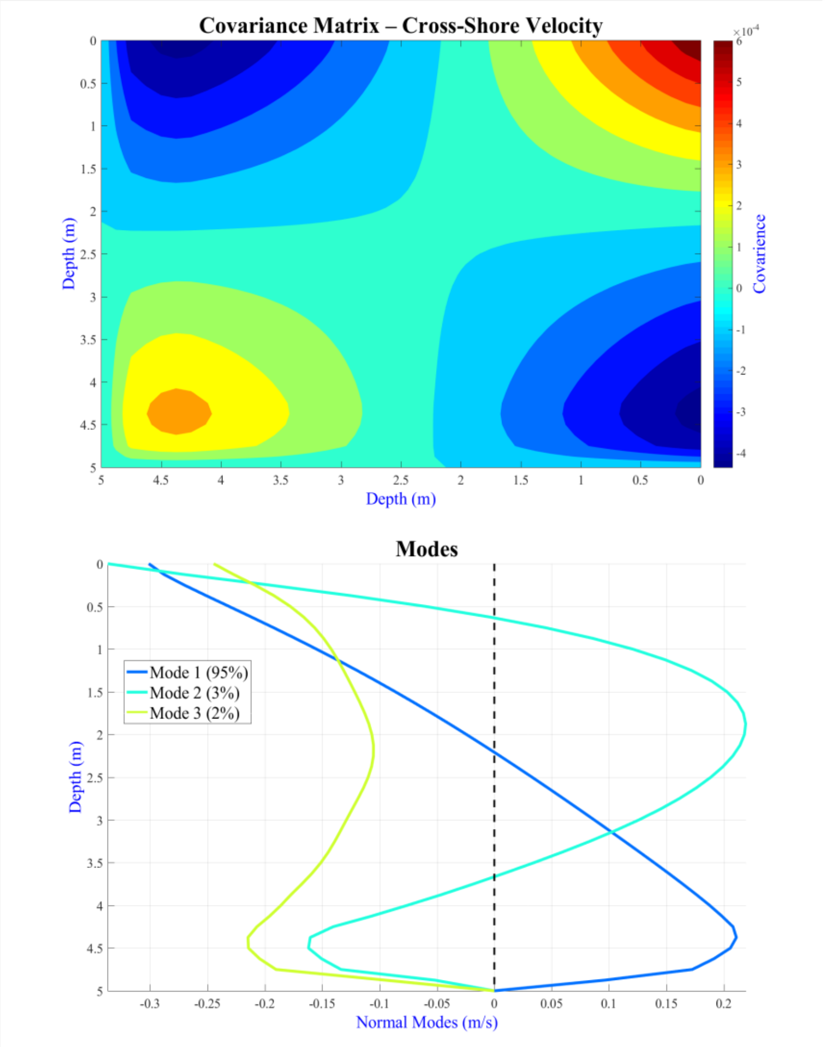
There is an approximate difference between
$-0.35 * max\ velocity$ and
$-0.4 * max\ velocity$
at $0.85 * water\ depth$.



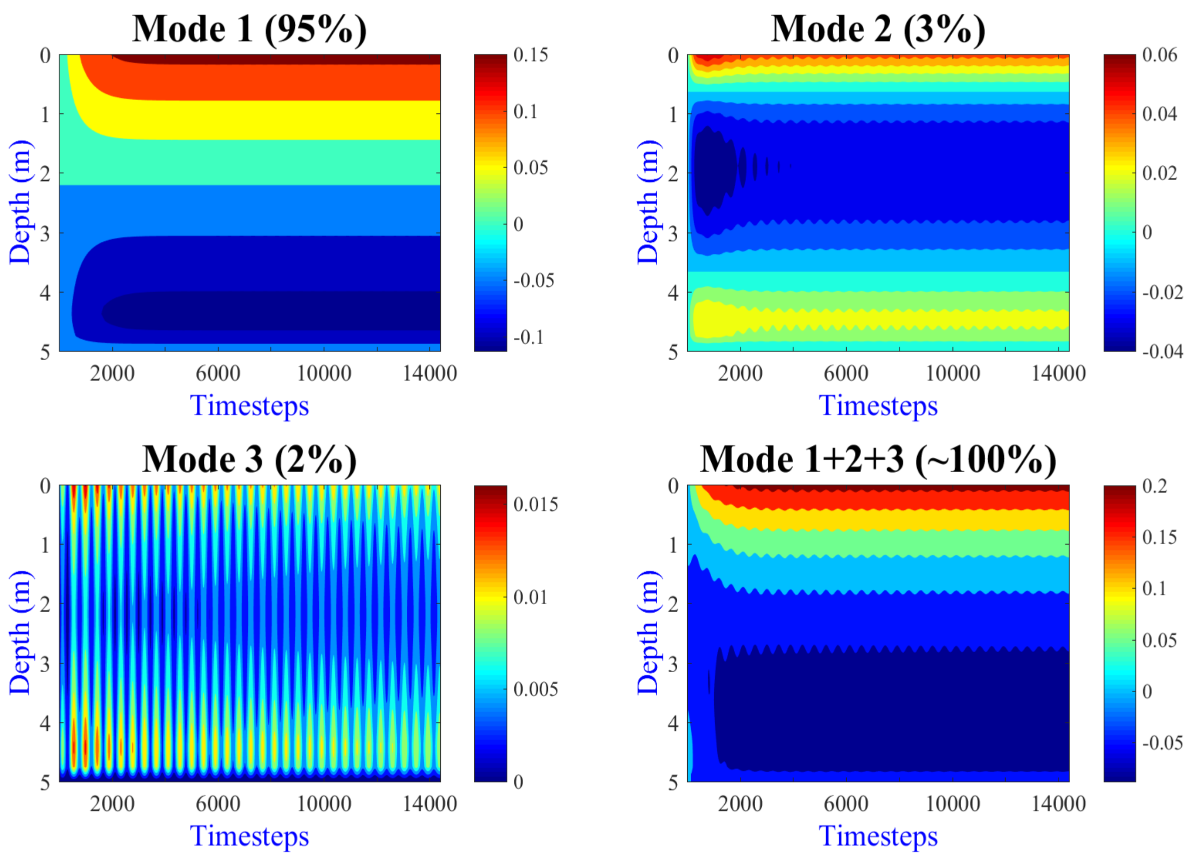
2DVR Bottom Stress Solutions for Idealized Cases (Latitude = 0)

Where;
(a) 5m
(b) 10m
(c) 15m
(d) 20m
(e) 25m
(f) 30m

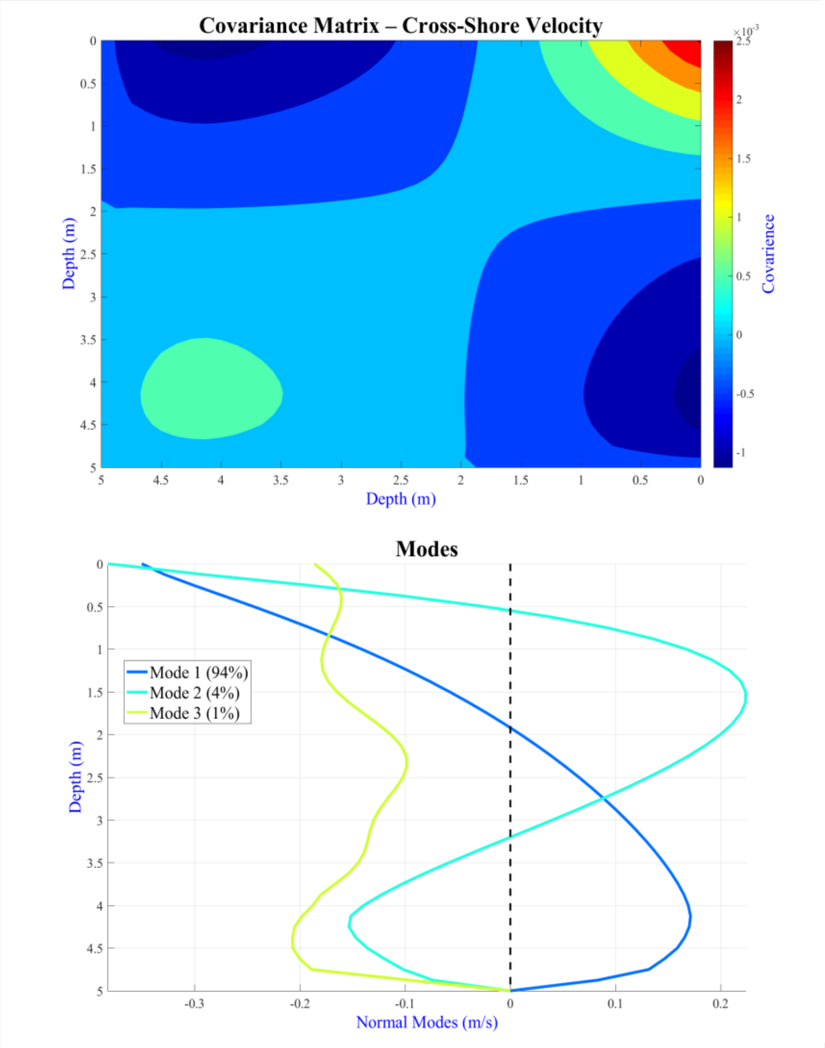
Multivariate Analysis – Principal Component Analysis



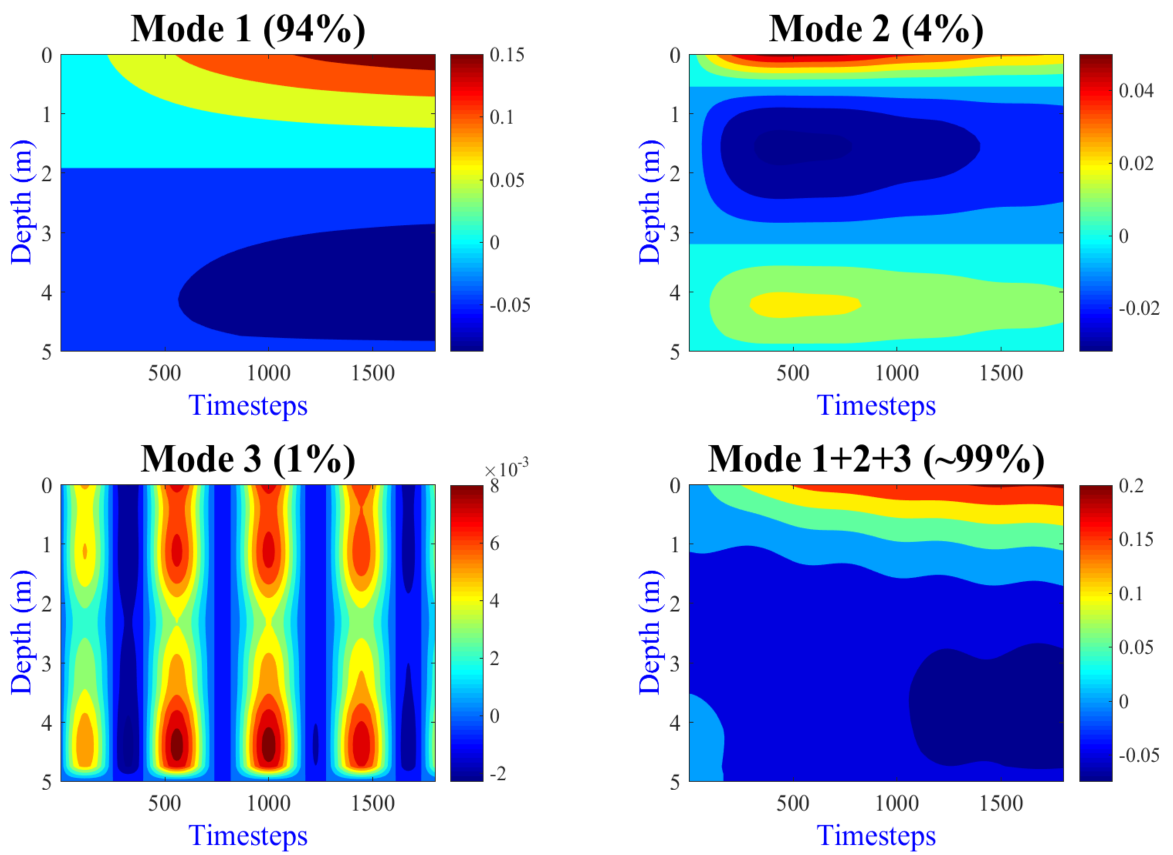
Depth: 5m & Winds: 20 m/s @ 0º Onshore
Run Time: 0 to 120 min (14400 Timesteps, dt = 0.5 sec)



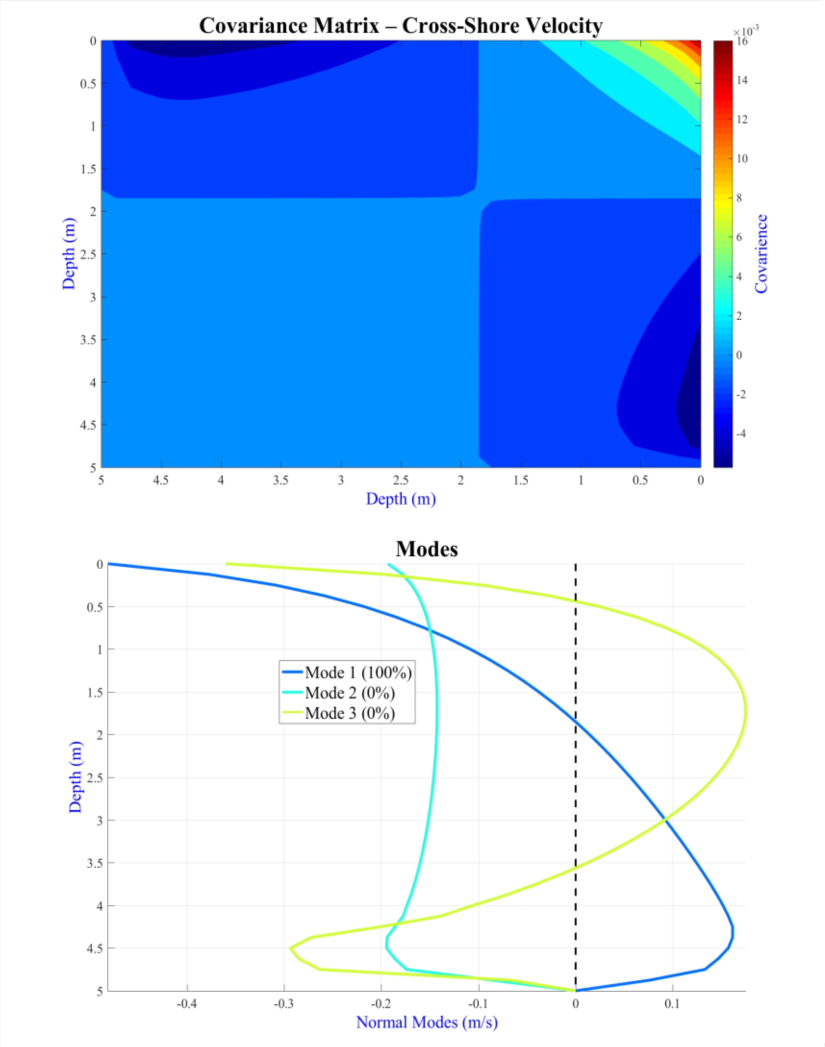
Multivariate Analysis – Principal Component Analysis



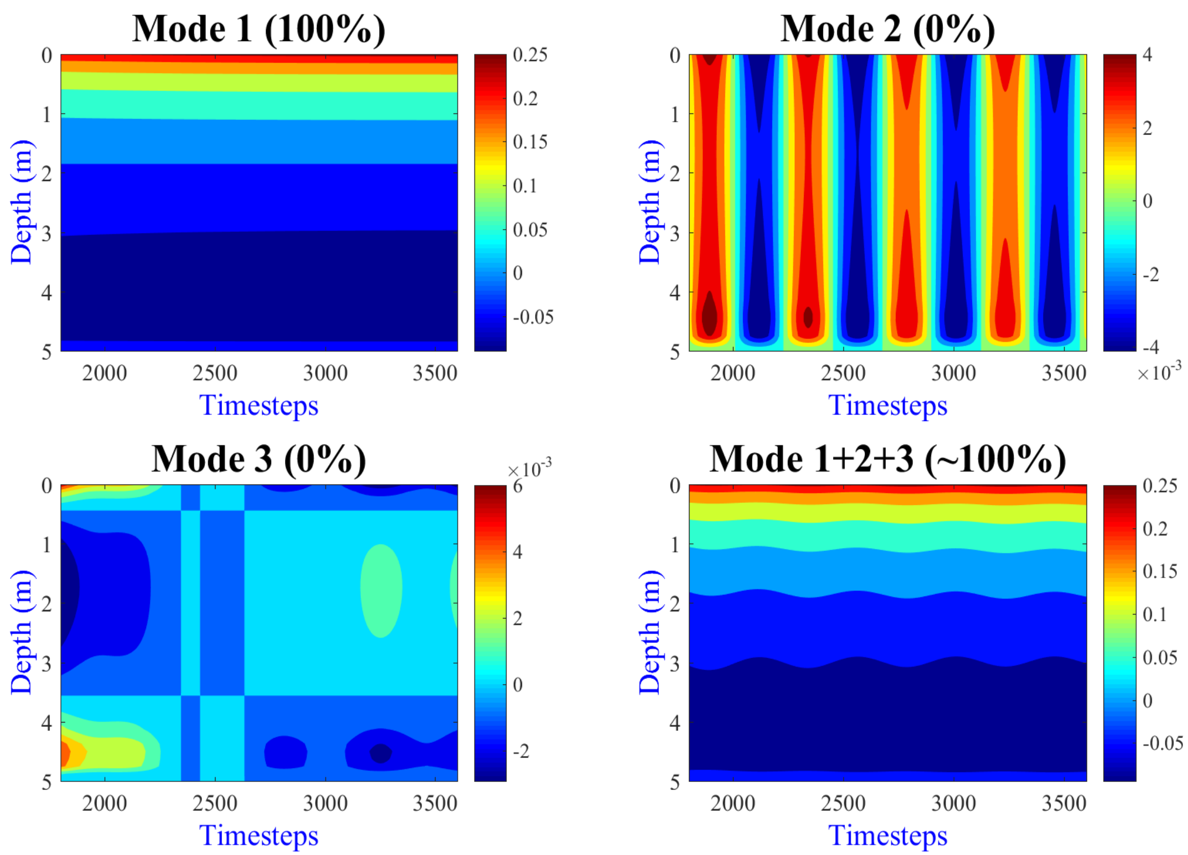
Depth: 5m & Winds: 20 m/s @ 0° Onshore
Run Time: 0 to 15 min (1800 Timesteps, dt = 0.5 sec)



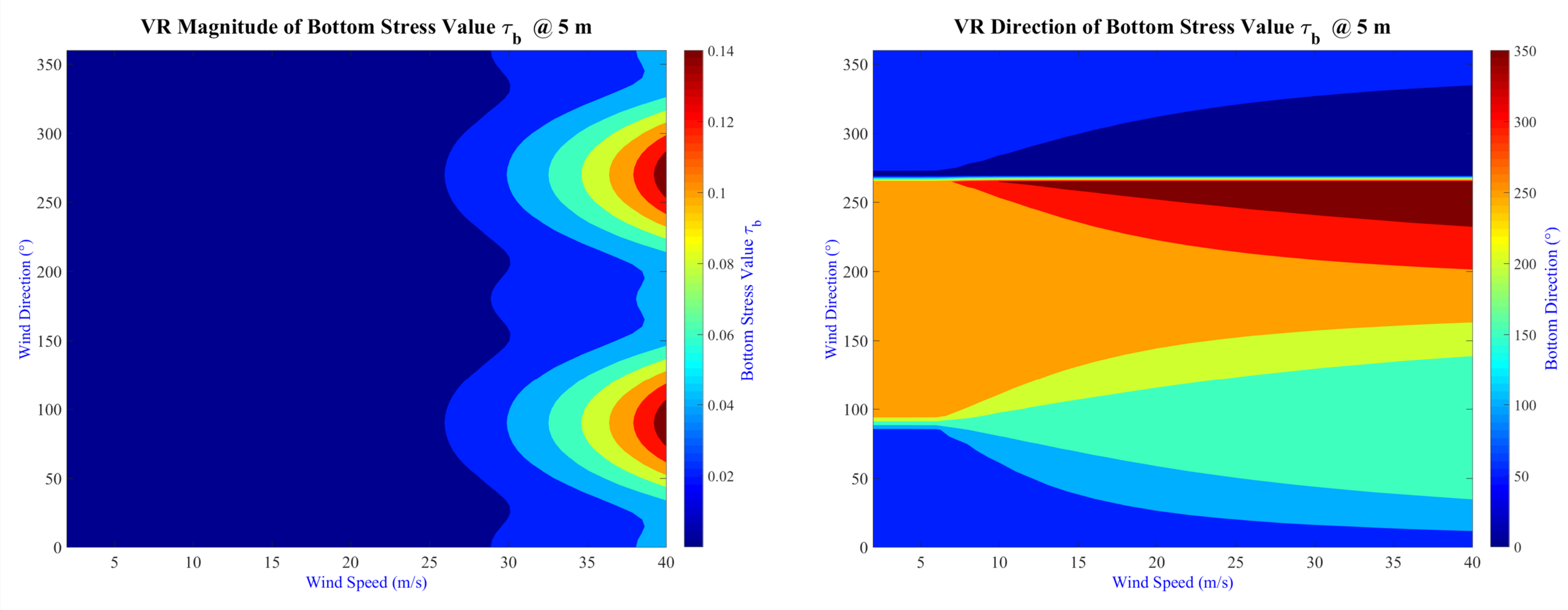
Multivariate Analysis – Principal Component Analysis



Depth: 5m & Winds: 20 m/s @ 0° Onshore
Run Time: 15 to 30 min (1800 Timesteps, dt = 0.5 sec)

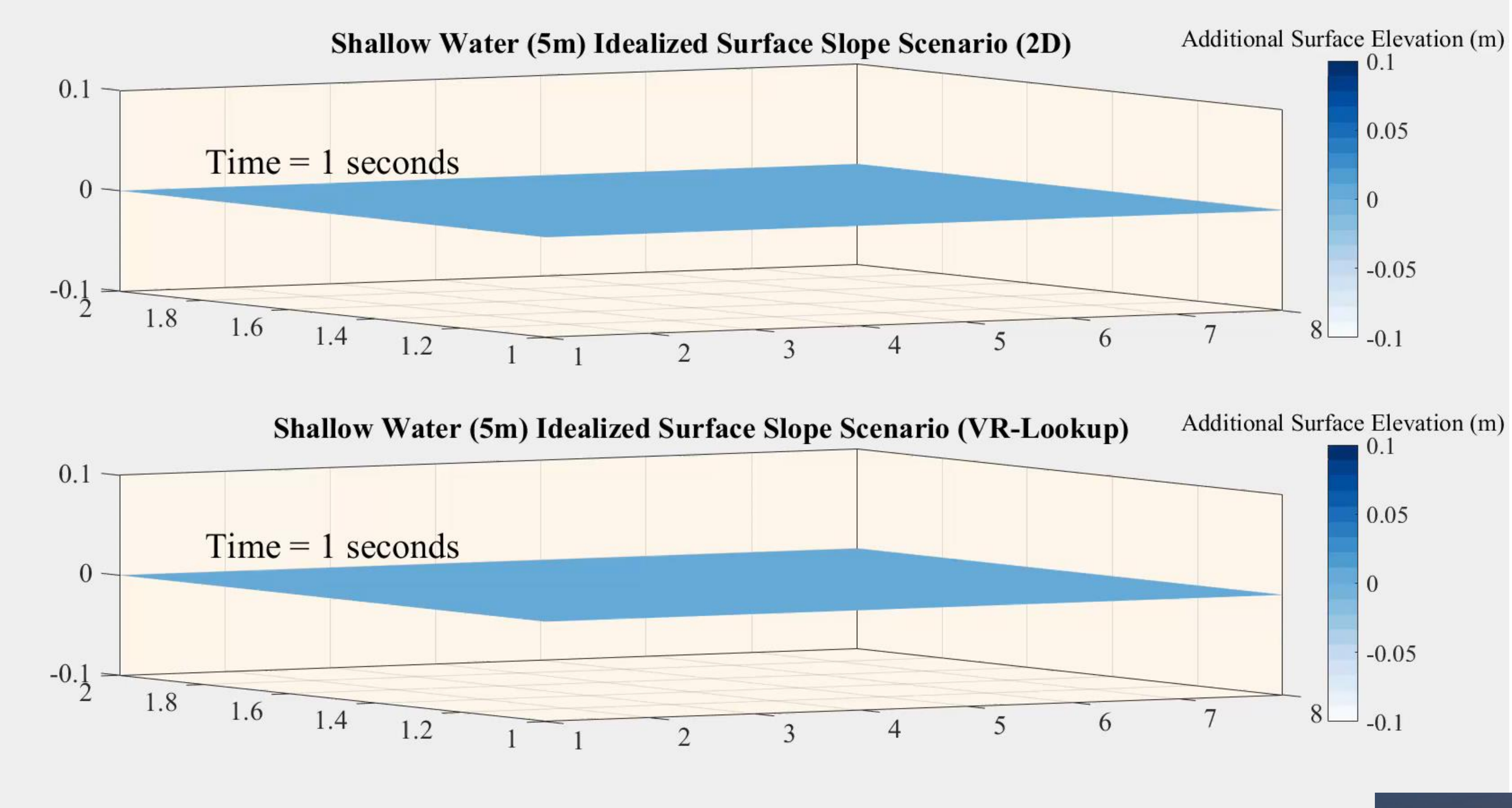


Example Look Up Table (latitude = 0)



Bottom Stress solution for estimated wind speeds and wind directions at 5 meters depth.
Where (right) is the magnitude of the stress component and
(left) is the direction of the stress component.

Test Case 3 – with VR Look Up Table



VR Bottom Stress for Idealized Cases

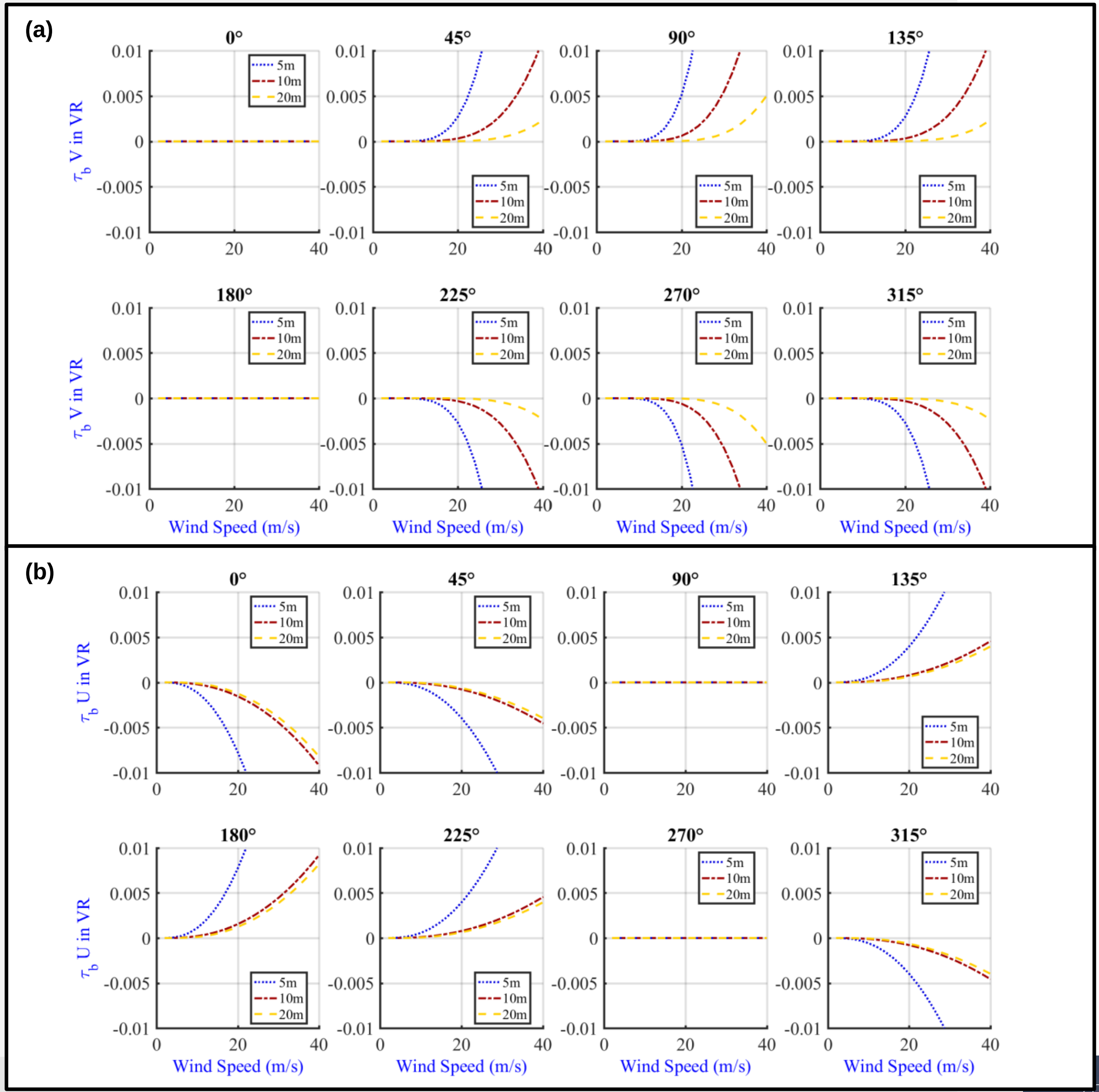
(Latitude = 0)

Example of bottom stress solutions for estimated wind speeds and wind directions by the steady state 2DVR numerical simulation at a depth of 5m.

Where;

(a) is bottom stress in the **along-shore** direction and
(b) is bottom stress in the **cross-shore** direction.

Latitude was set to zero in these numerical simulations, to ensure symmetry in the solutions, for validation purposes.



2DVR Bottom Stress Solutions for Idealized Cases (Latitude = 0)

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Bottom stress concepts in 2DDI surge models neglect the vertical current structure, which often varies significantly in direction and magnitude of the stress associated with the mean current.

By applying improved bottom stress physics in the boundary layer approximation, it is likely that the need to refine and adjust models on a storm by storm and location by location basis will be reduced.

It appears that 2DDI models combined with the vertical structure numerically simulated in this investigation will be sufficient for accurate results in most coastal storms, whereas 3D and quasi-3D model configurations are typically too coarse (due to computer restraints) to resolve the bottom boundary layer effectively.

CONCLUSION:

Findings, Discussion, & Future Work

THANK YOU

Amanda Tritinger

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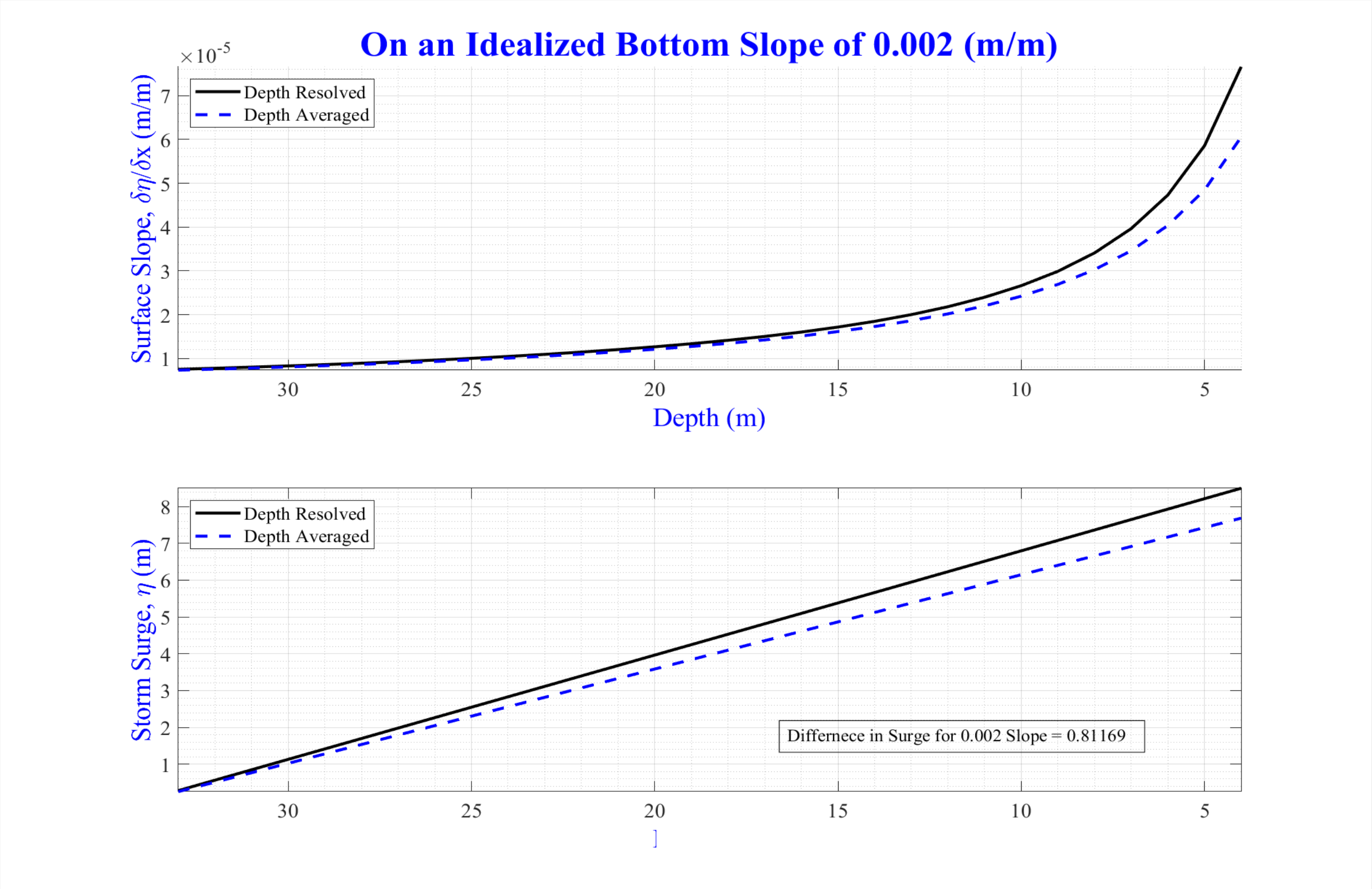
QUESTIONS?

UF
UNF

Why Bottom Friction Matters:



Depth Resolved:

$$U_s^2 = C_d \frac{\rho_a}{\rho_w} U^2 * C_b \rho_a U_b^2$$

Depth Averaged:

$$U_s^2 = C_d \frac{\rho_a}{\rho_w} U^2$$

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