The Importance of Vertical Structure to Open-Coast Surges and its Incorporation into Depth Averaged Models

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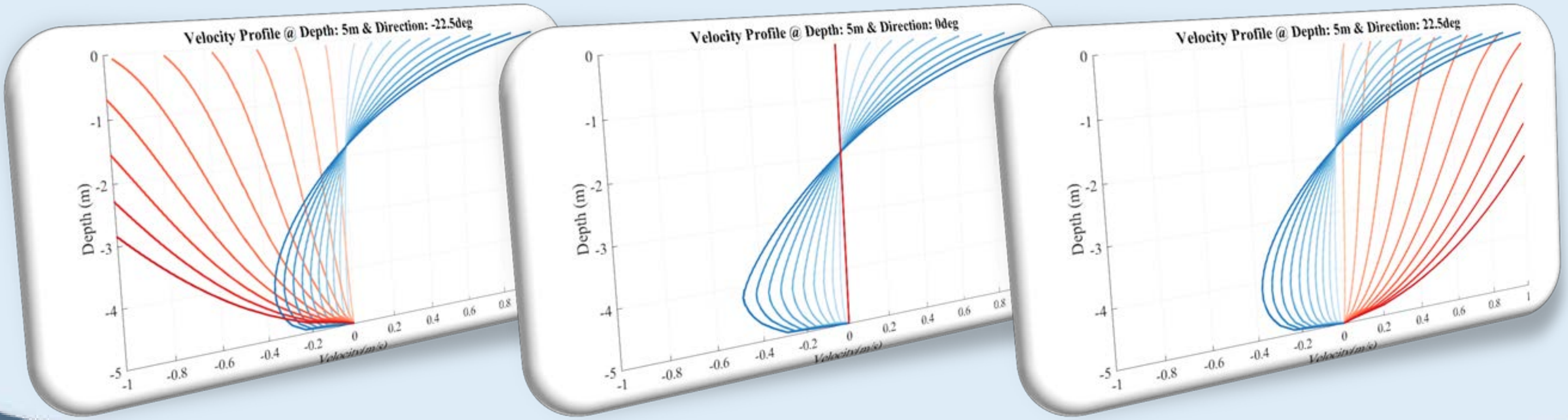

1st International Workshop on Waves, Storm Surges and Coastal Hazards
Liverpool, UK, 10-15 September 2017

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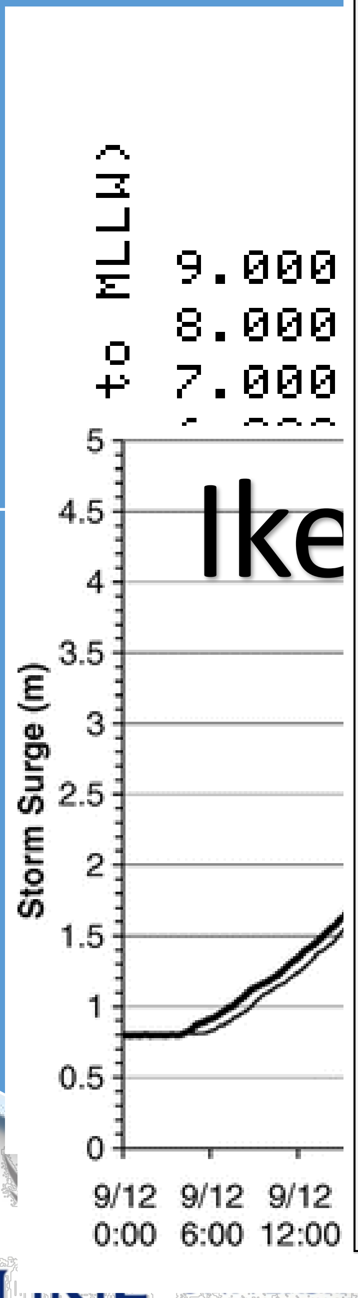

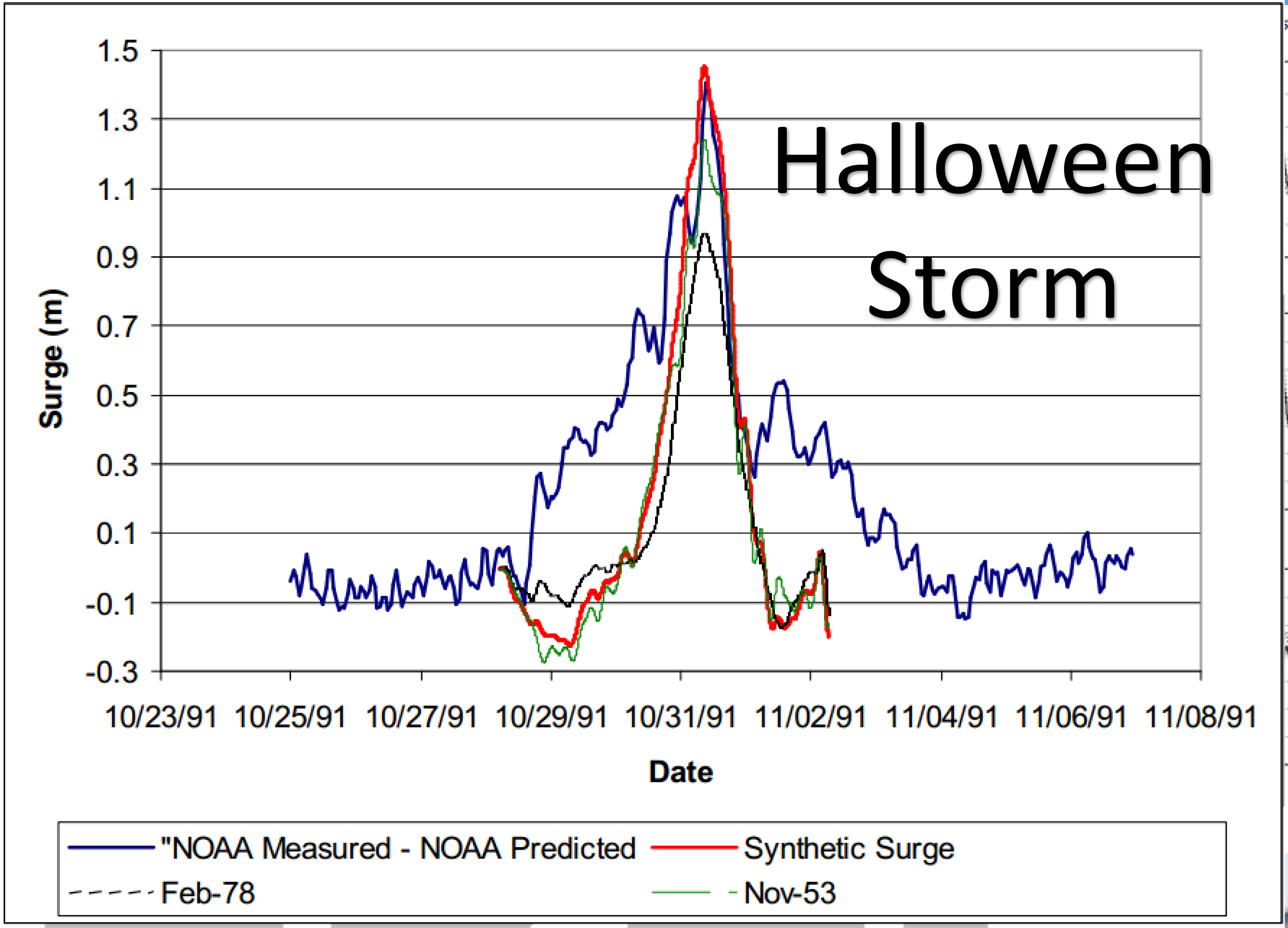

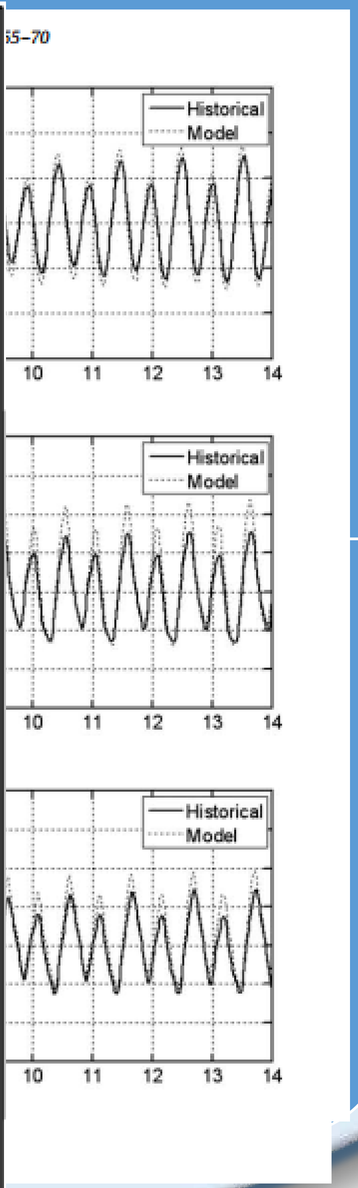

(USACE 2016)

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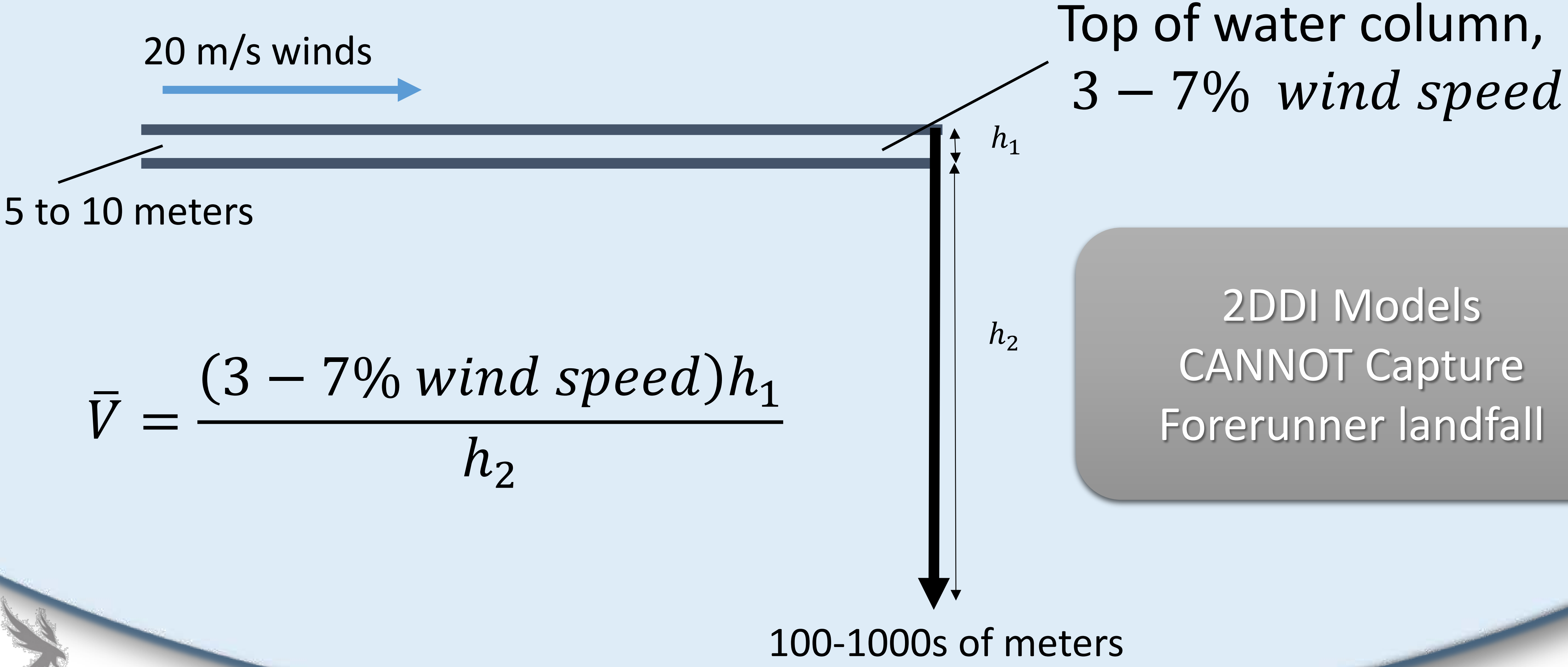
Investigation

What is the source of error in these depth integrated models?

Wind Stress → **Topography/ Bathymetry** → **Averaging Velocities** → **Vertical Structure** → **Bottom Friction**

- **Wind Stress**: Well Understood/ Captured
- **Topography/ Bathymetry**: Well Resolved
- **Averaging Velocities**: Reasonable Source…
- **Vertical Structure**: Not Captured in 2DDI
- **Bottom Friction**: Vector in Opposite Direction!

Theory - Advection (as it Affects Forerunners)



$$\bar{V} = \frac{(3 - 7\%\ wind\ speed)h_1}{h_2}$$

2DDI Models CANNOT Capture Forerunner landfall

Theory - Bottom Friction

$$\frac{\partial \eta}{\partial x} = \frac{\tau_w + \tau_{wave}}{gh}\left(1 + \boxed{\frac{\tau_B}{\tau_w + \tau_{wave}}}\right)$$

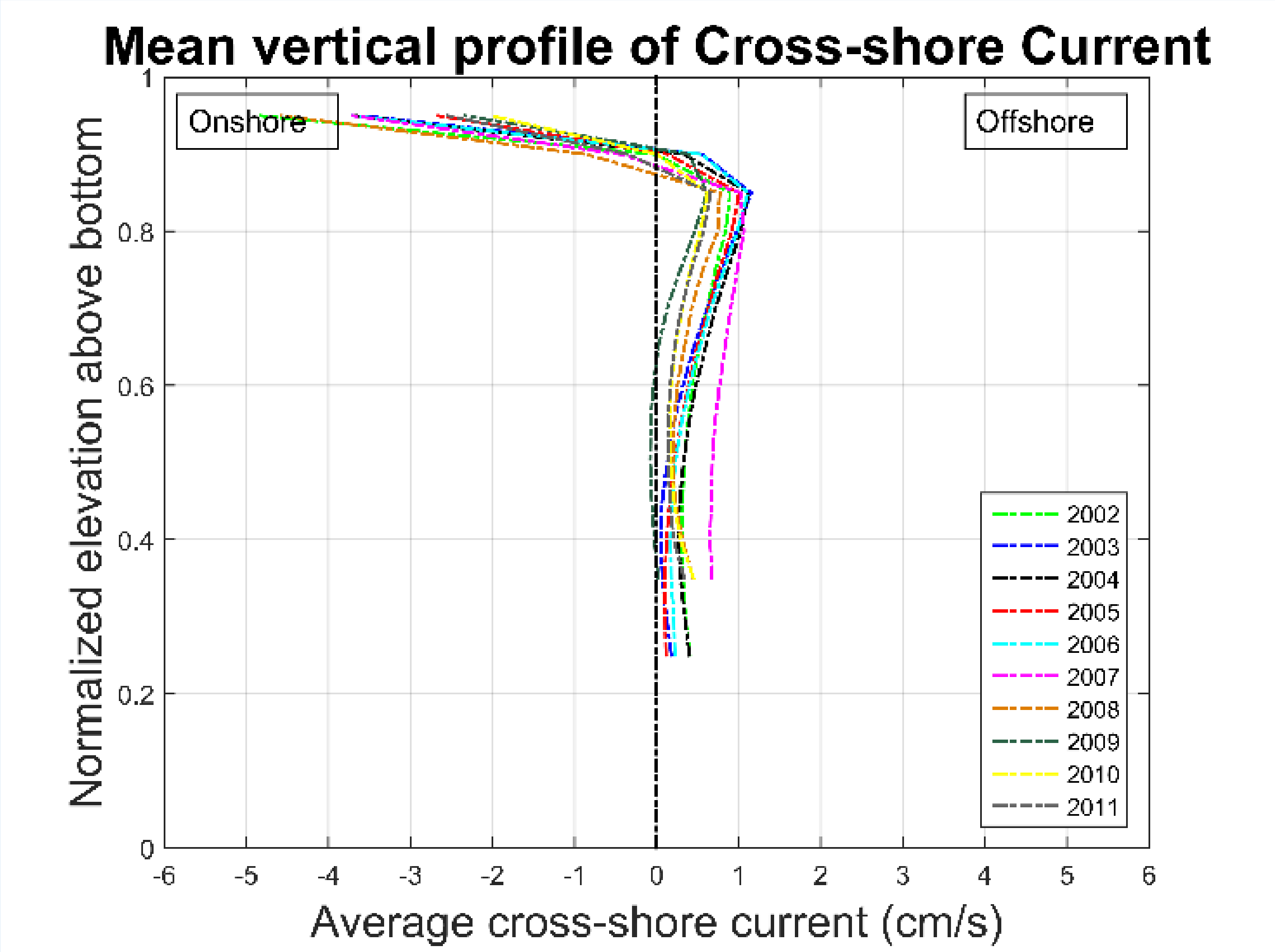
Difference

WAVE SET-UP *equivalent wind

Observations

ADCP CURRENT PROFILES IN OFFSHORE FROM MELBOURNE, FLORIDA

-DATA SUPPLIED BY DR. WILLIAM DALLY[1]



[1]UNIVERSITY OF NORTH FLORIDA, DEPARTMENT OF COLLEGE OF COMPUTING, ENGINEERING, AND CONSTRUCTION, JACKSONVILLE, FL, USA

Objectives

- Investigate the potential impact the vertical structure has on currents and surges in idealized coastal areas
- Capture the physics of the multilayer vertical structure using elementary numerical model
  - Build database of high resolution solutions
- Develop a method for embedding this structure in existing 2DDI models… Digital Stochastic Model

Fundamental Assumptions

- Momentum balance equation -> steady state

$$\frac{\tau_{wind}, \tau_{wave}, \tau_{bottom}}{gh} = surface\ slope$$

- Parametrization of turbulence -> K-Scaling

- Reynolds-averaged Naiver-Stokes equation -> U_*

Numerical Approach

- After the addition of both wind stresses and bottom friction equations were derived;

  - $U^{n+1} = U^n + \left[fV^n - g\frac{dh}{dx} + \left(\frac{\frac{\rho_a}{\rho_w} C_d U_w^2}{H} cos\theta\right) - \frac{C_b \bar{U}^2}{H}\right] dt$
  - $V^{n+1} = V^n + \left[-fU^n - g\frac{dh}{dy} + \left(\frac{\frac{\rho_a}{\rho_w} C_d U_w^2}{H} sin\theta\right) - \frac{C_b \bar{V}^2}{H}\right] dt$

Numerical Approach (with setup)

- After the addition of both wind stresses and bottom friction equations were derived;

- $U^{n+1} = U^n + \left[fV^n - g\frac{dh}{dx} + \left(\frac{\frac{\rho_a}{\rho_w} C_d U_w^2 + \boxed{\left(\frac{\partial M_o}{\partial t}\right)}}{H} \cos\theta \right) - \frac{C_b \bar{U}^2}{H} \right] dt$
- $V^{n+1} = V^n + \left[-fU^n - g\frac{dh}{dy} + \left(\frac{\frac{\rho_a}{\rho_w} C_d U_w^2 + \boxed{\left(\frac{\partial M_o}{\partial t}\right)}}{H} \sin\theta \right) - \frac{C_b \bar{V}^2}{H} \right] dt$

where $\frac{\partial M_o}{\partial t} = \frac{\iint \partial E(f,\theta) Cg}{\partial x C} \partial f \partial \theta$

Open Coast Current Investigation

2D and 3D runs for a 30-3 meter transects;

- Seven half-plane coordinate wind angles

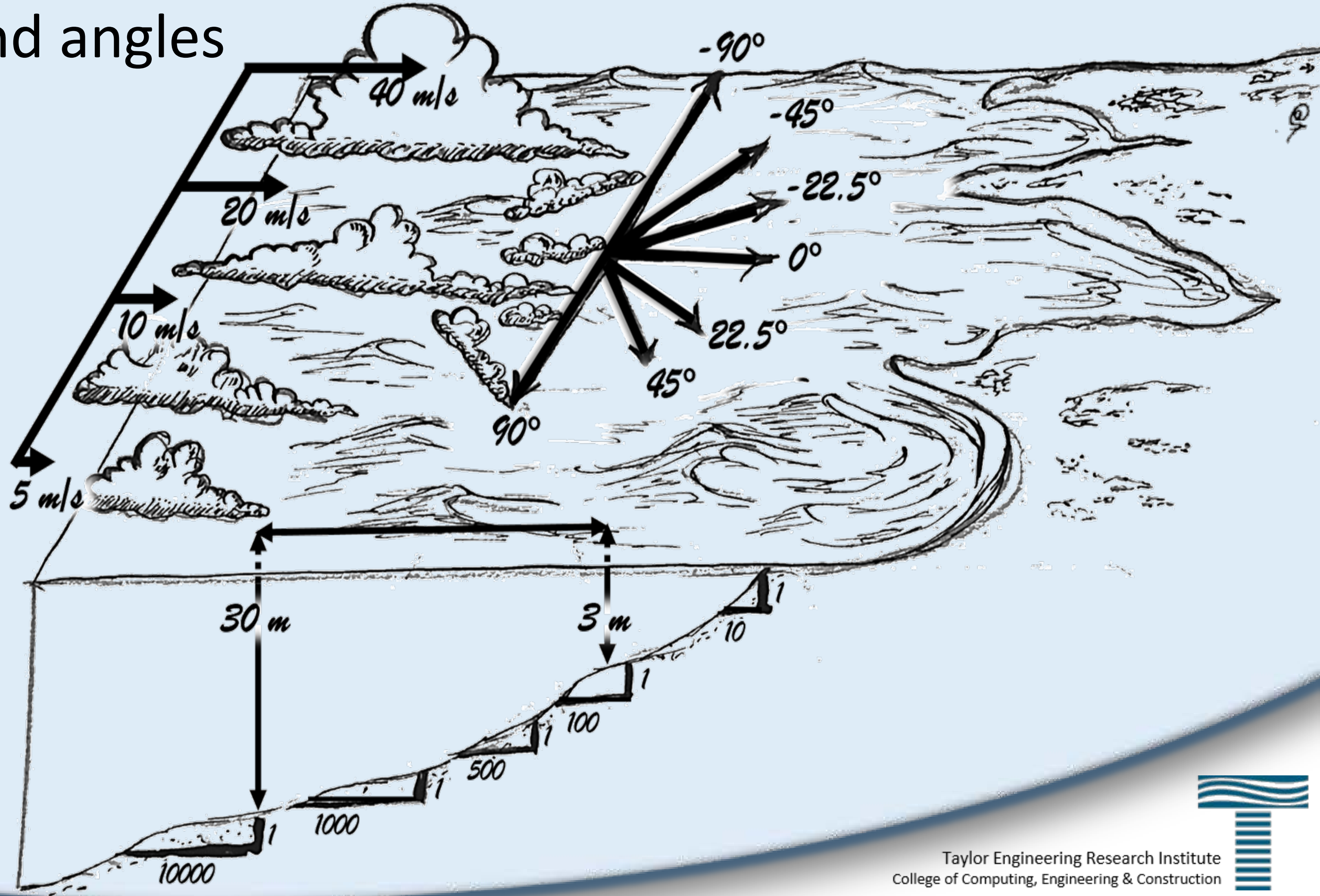
  (-90,-45,-22.5,0,22.5,45,90)

- with four wind speeds

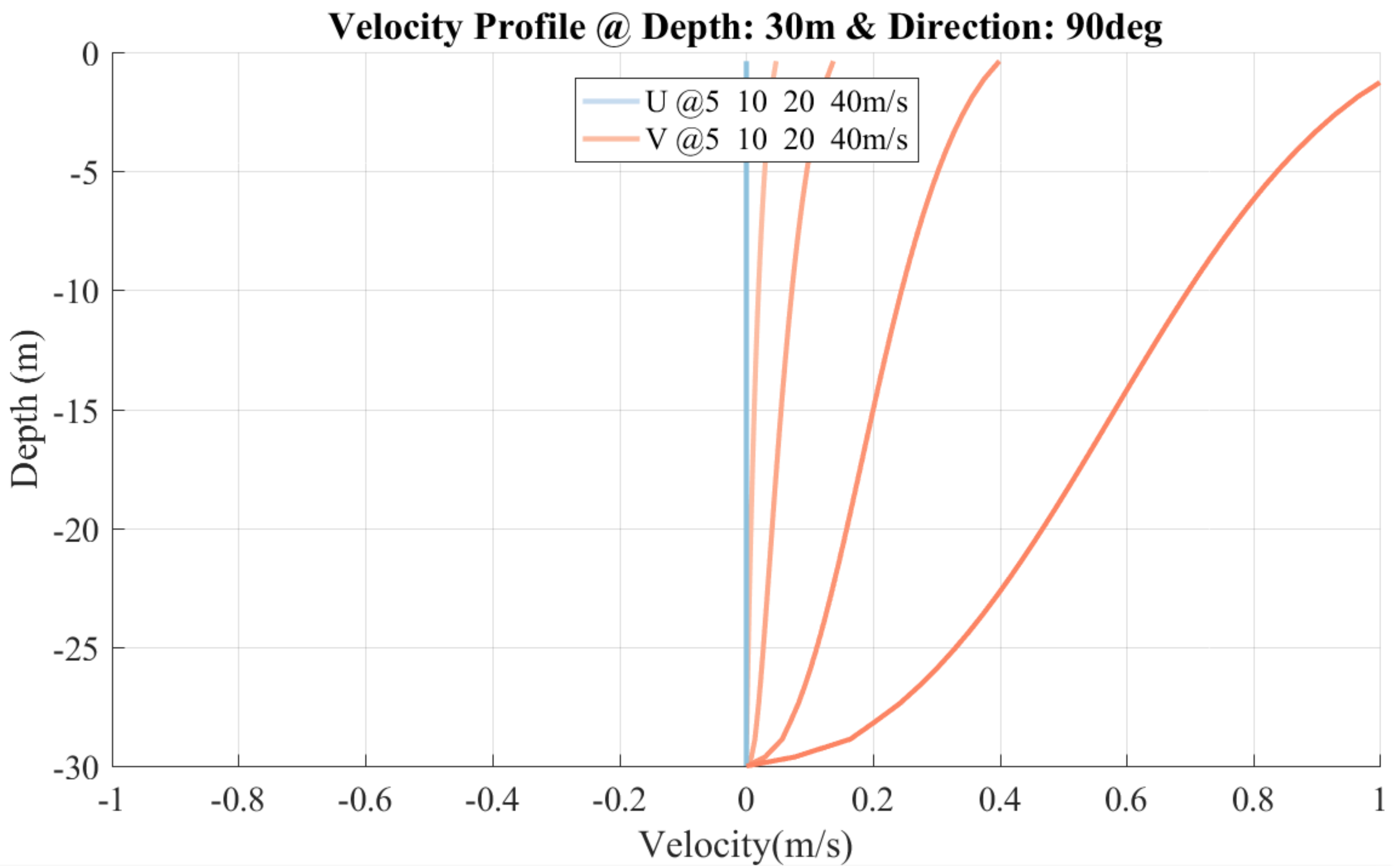
  (5 m/s, 10 m/s, 20 m/s, 40 m/s)

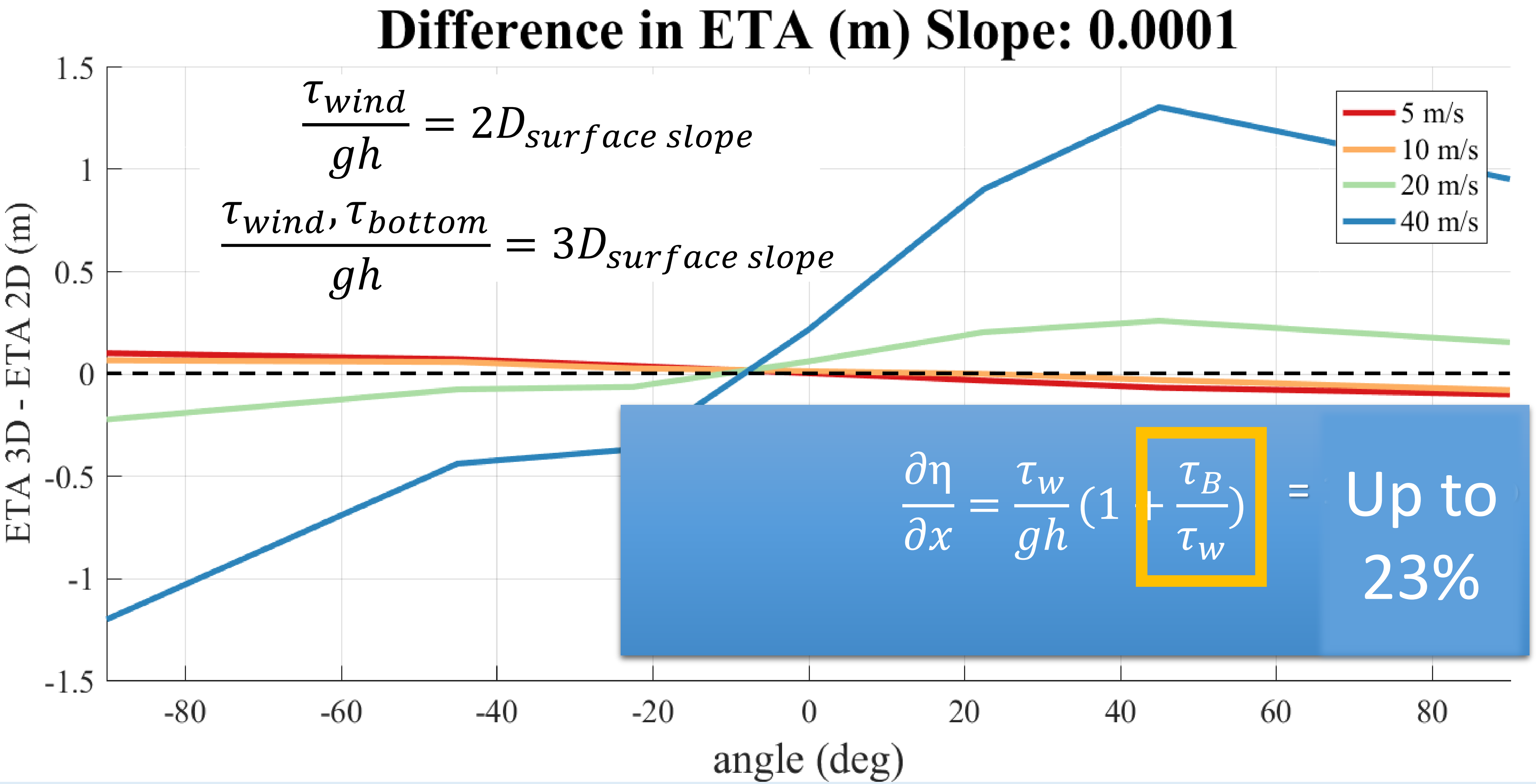
- at five bottom slopes

  (1/10,1/100,1/500,1/1000,1/10000)

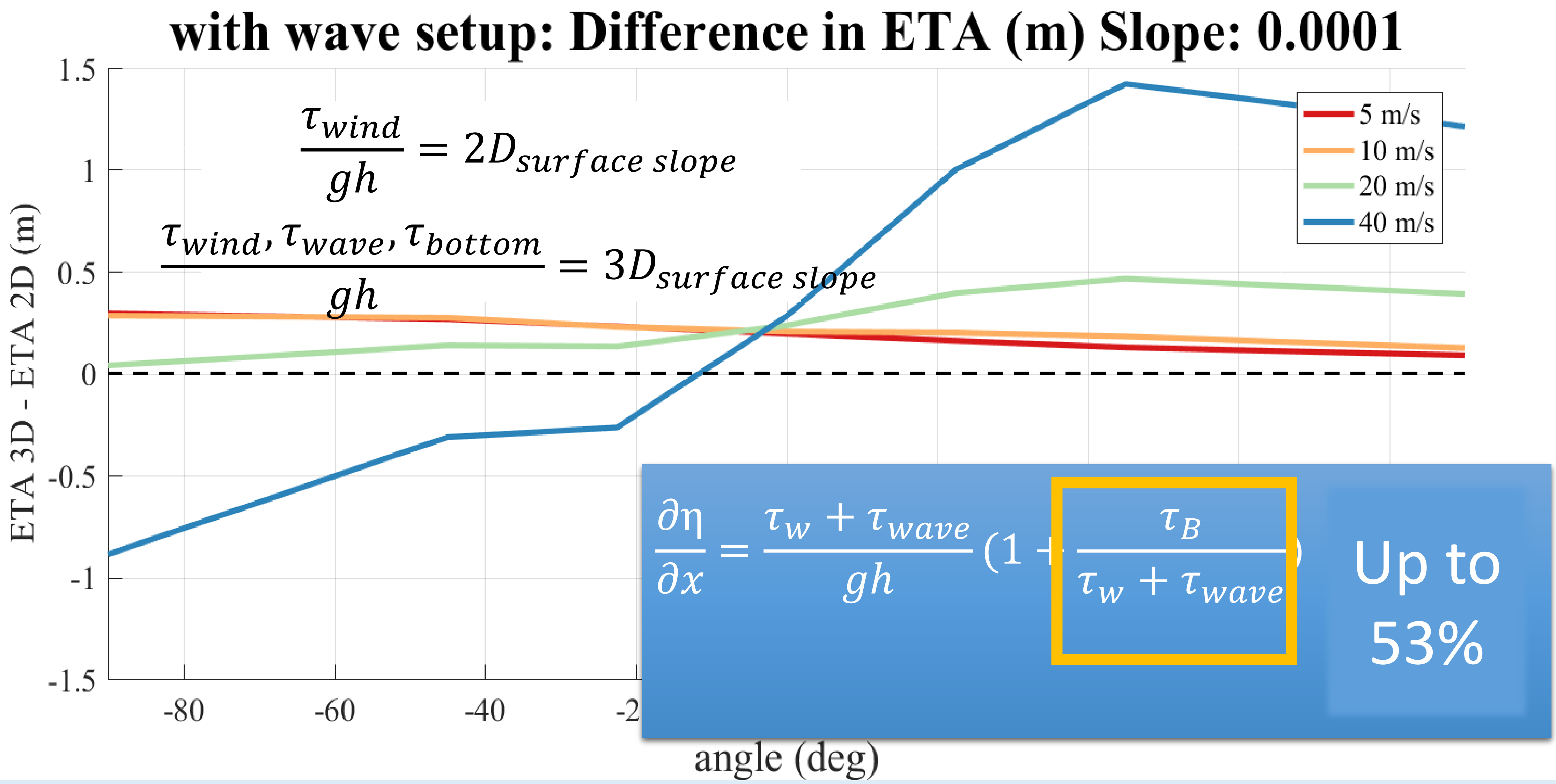


Open Coast Current Investigation





Findings – Generated Surface Elevation



$$\frac{\tau_{wind}}{gh} = 2D_{surface\ slope}$$

$$\frac{\tau_{wind}, \tau_{wave}, \tau_{bottom}}{gh} = 3D_{surface\ slope}$$

$$\frac{\partial \eta}{\partial x} = \frac{\tau_w + \tau_{wave}}{gh}\left(1 + \boxed{\frac{\tau_B}{\tau_w + \tau_{wave}}}\right)$$

Up to 53%

Findings- Consider Wave Setup

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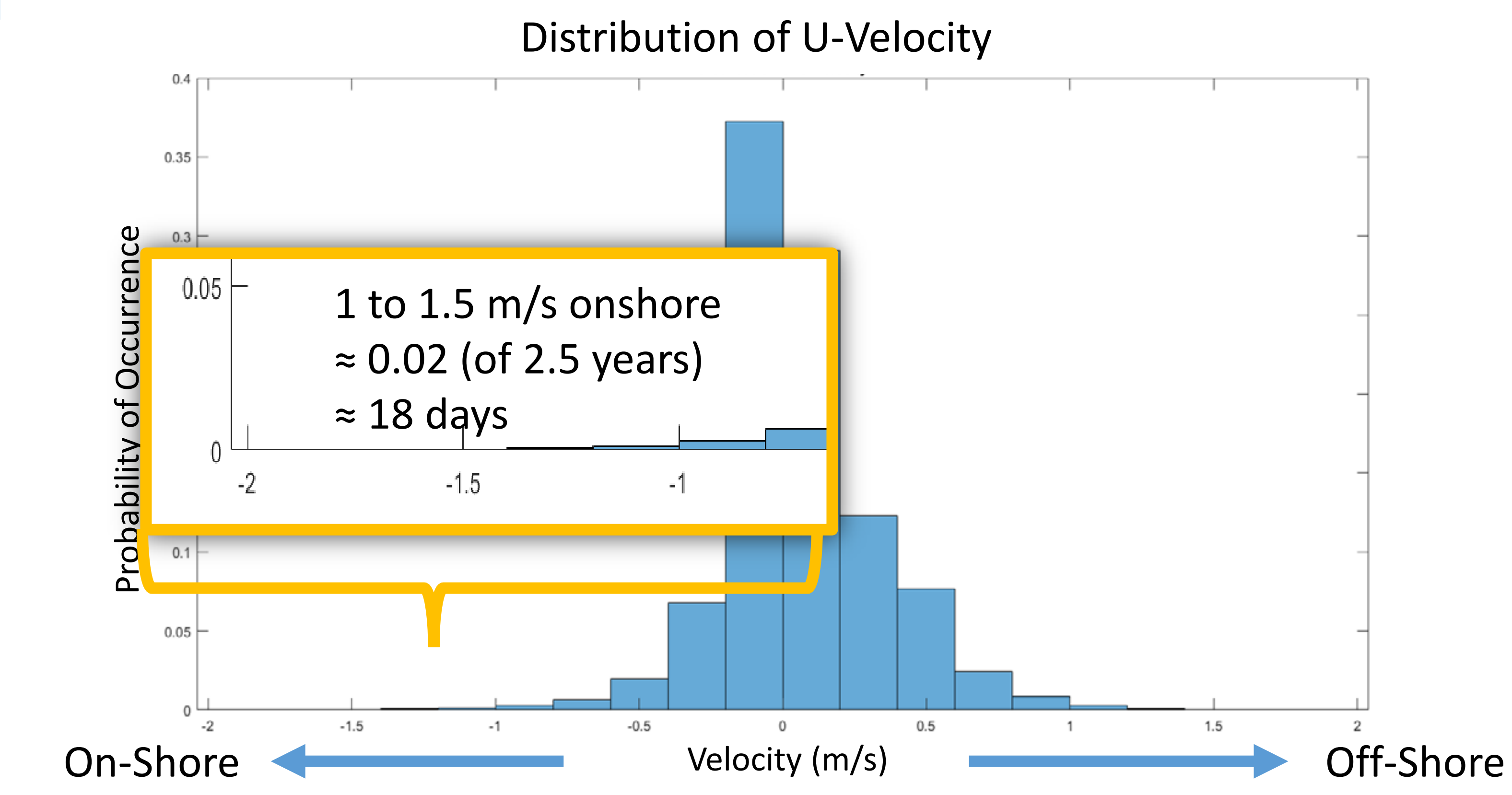
Scaling and Observations

$$\tau_{wind} -> C_d \frac{\rho_a}{\rho_w}(U - U_s)^2$$

In these strong storm events



"Application of current moments for the prediction of beach erosion and recovery" - Nikole Ward[1]

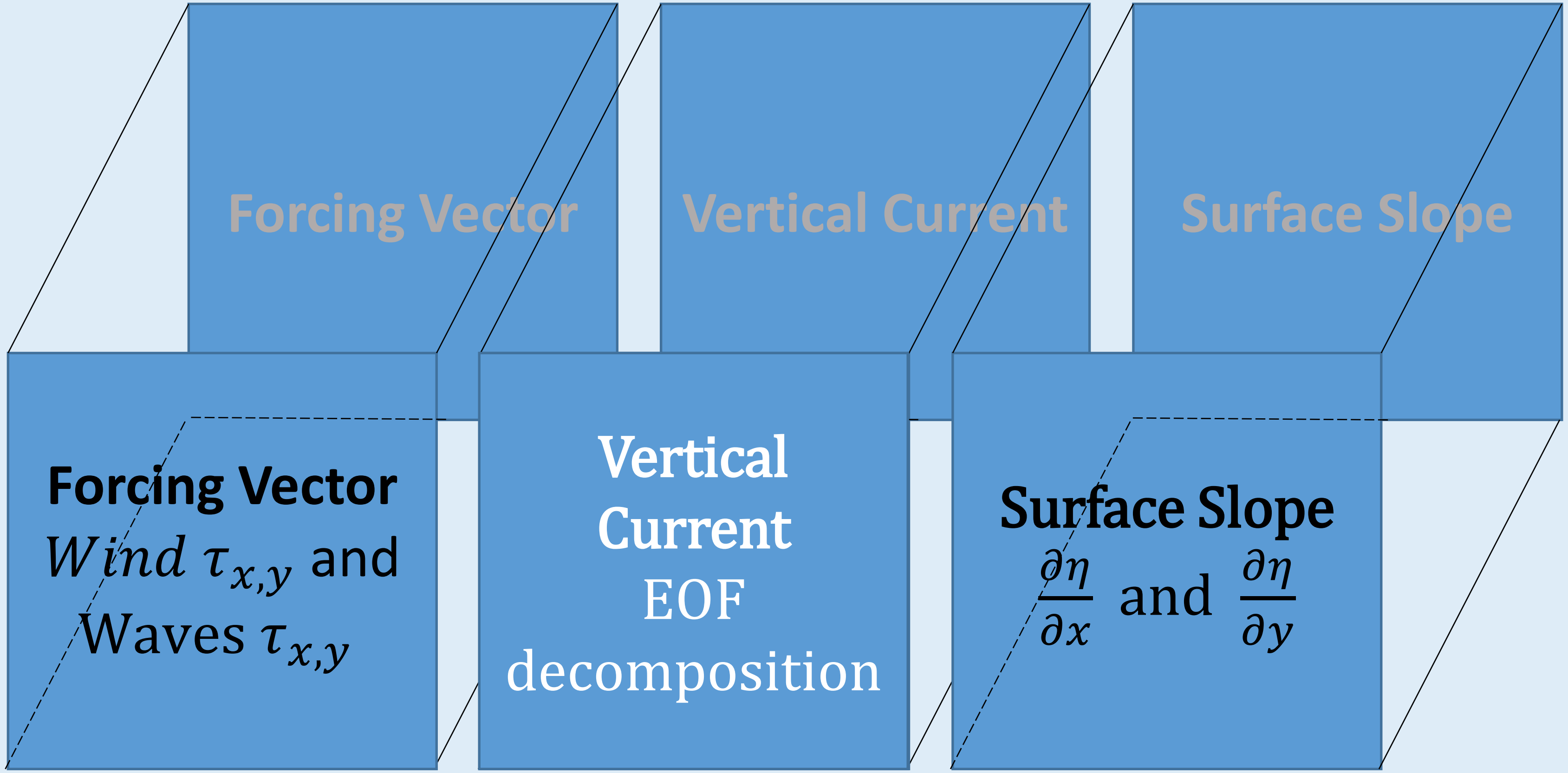
[2]Masters Student. University of North Florida, Department of College of Computing, Engineering, and Construction, Jacksonville, FL, USA

Evolution Towards Fully Time-Dependent Model

- Introduce stochastic dependence
- Arbitrary initial state to future state
- Transients are modeled using the full equation
- Mapped into multi-dimensional reference system

(Digital Stochastic Model)

Discretized Modeling of Transients



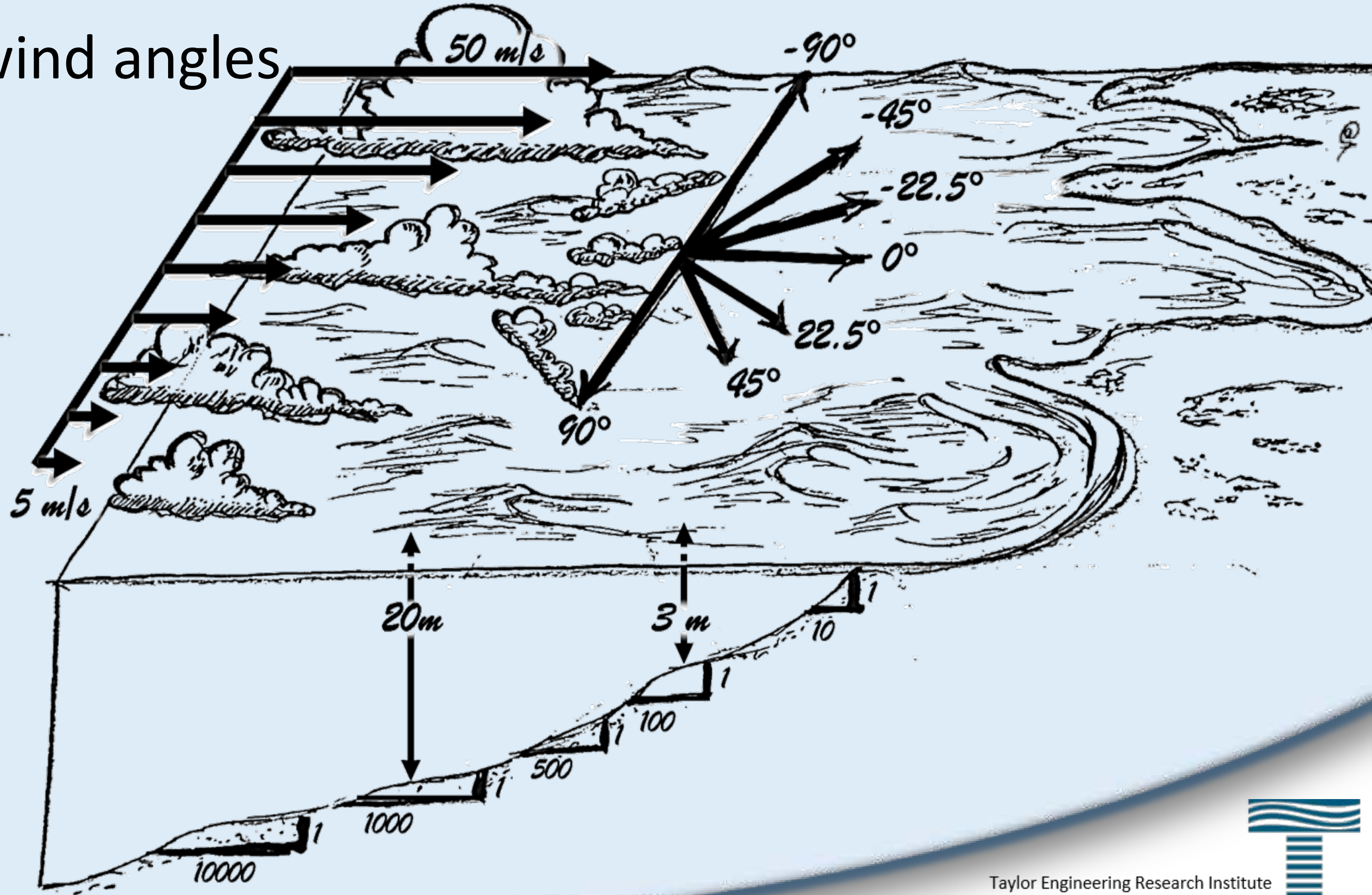
Stochastic Development Investigation

350 Runs @ 20 meters of depth & 350 Runs @ 3 meters of depth;

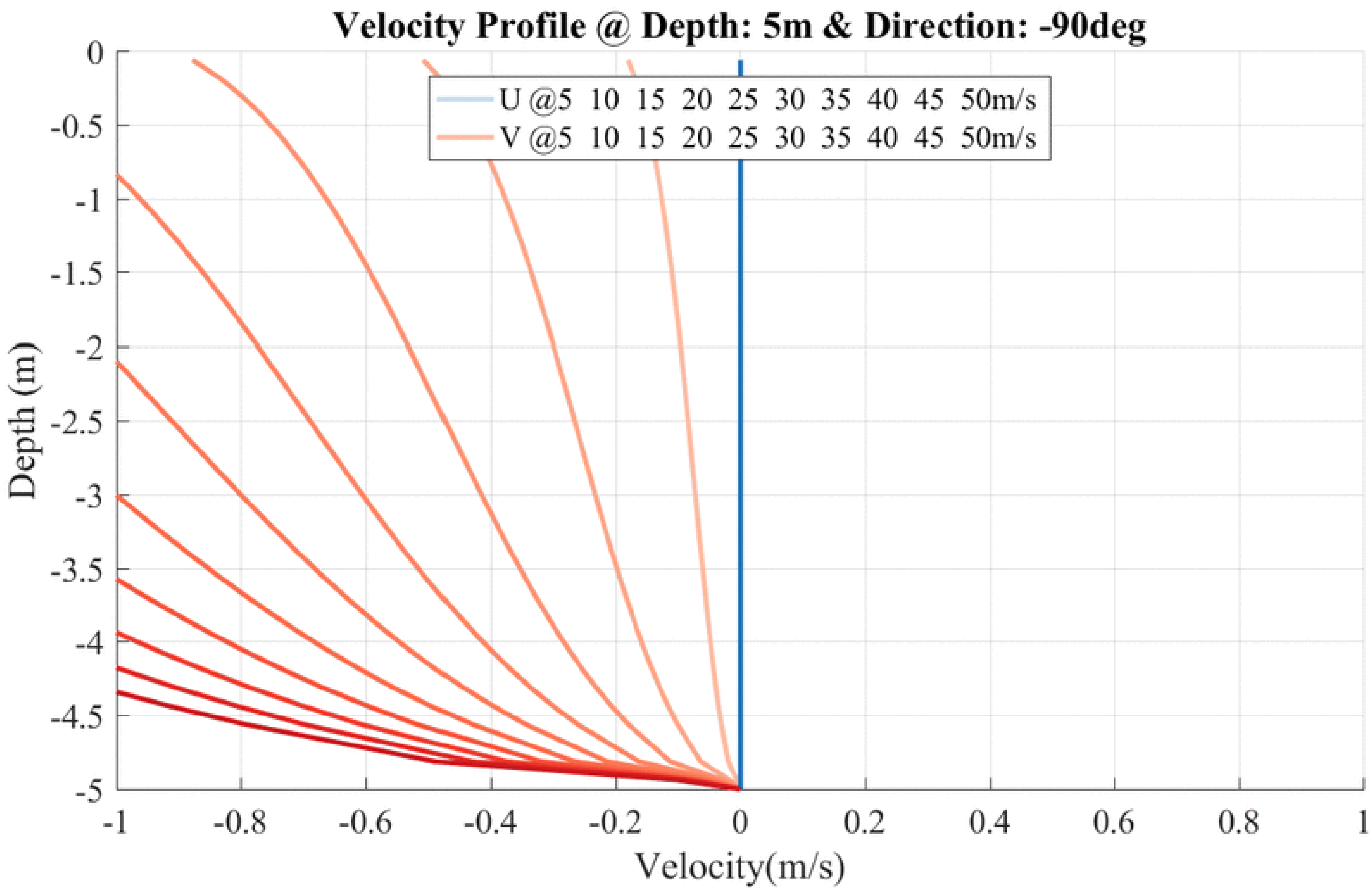
- Seven half-plane coordinate wind angles
  (-90,-45,-22.5,0,22.5,45,90)

- Ten wind speeds
  (5 m/s, 10 m/s, 15 m/s, 20 m/s, 25 m/s, 30 m/s, 35 m/s, 40 m/s, 45 m/s, 50m/s)

- Five bottom slopes
  (1/10,1/100,1/500,1/1000,1/10000)



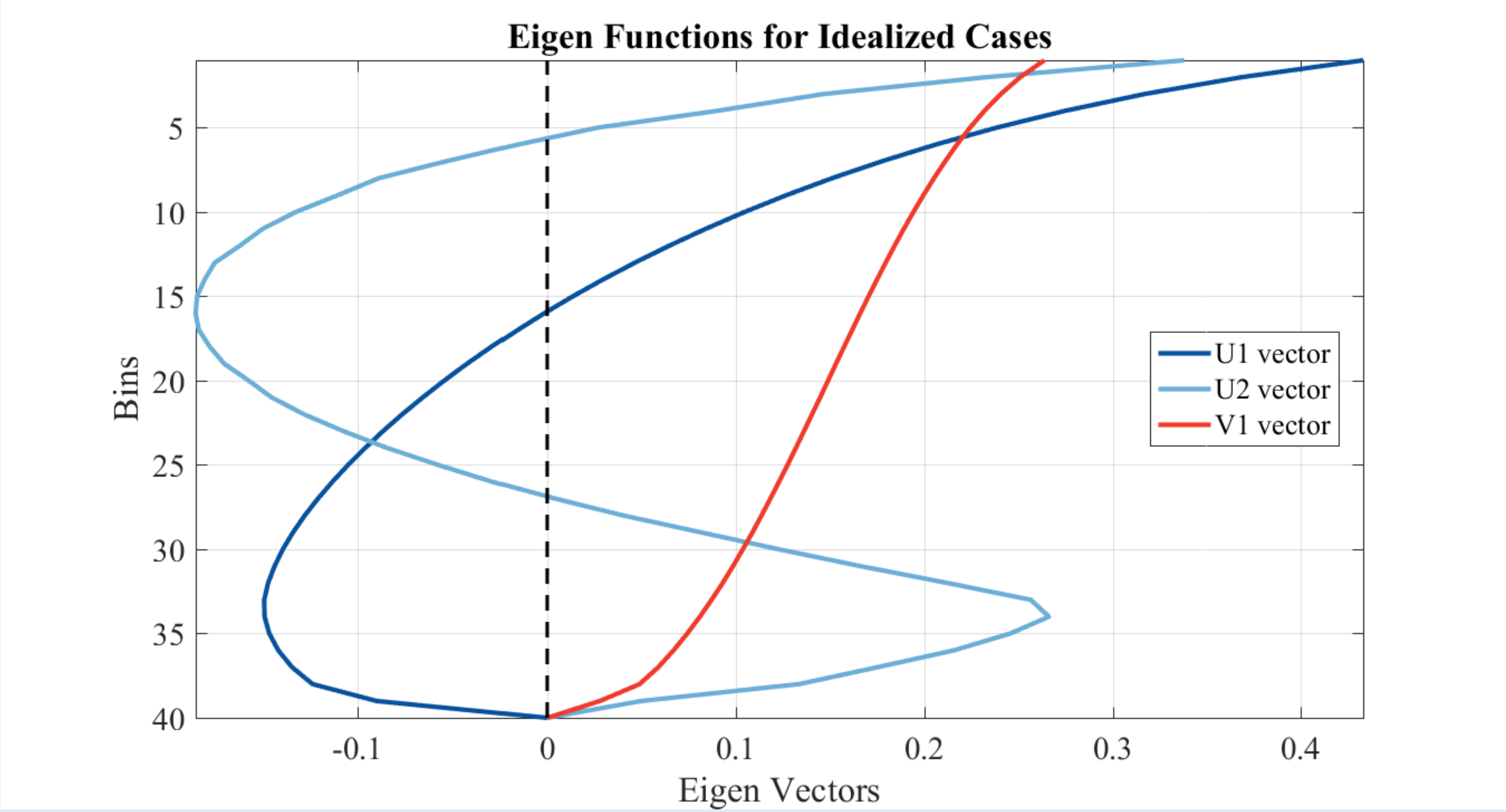
Self Similarity



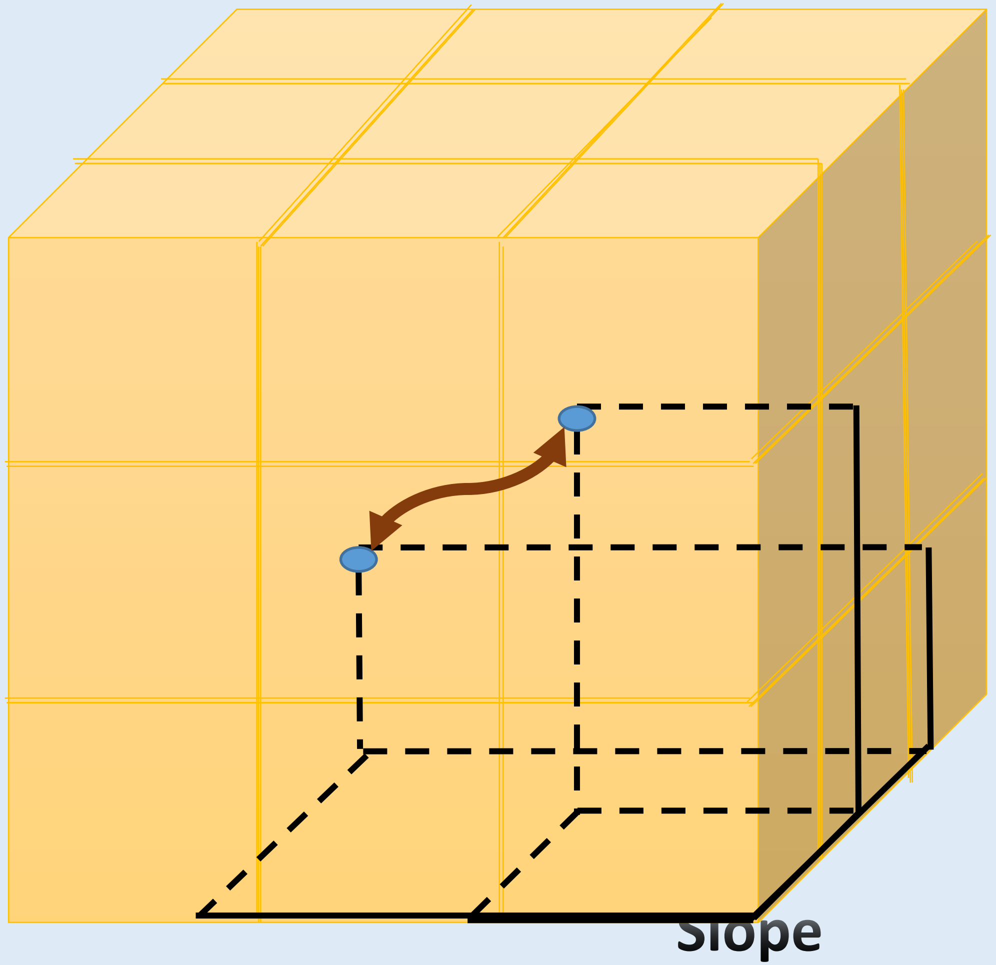
EOF Analysis …

EOF ANALYSIS

- Represent up to 100% Structure with 1 - 2 functions



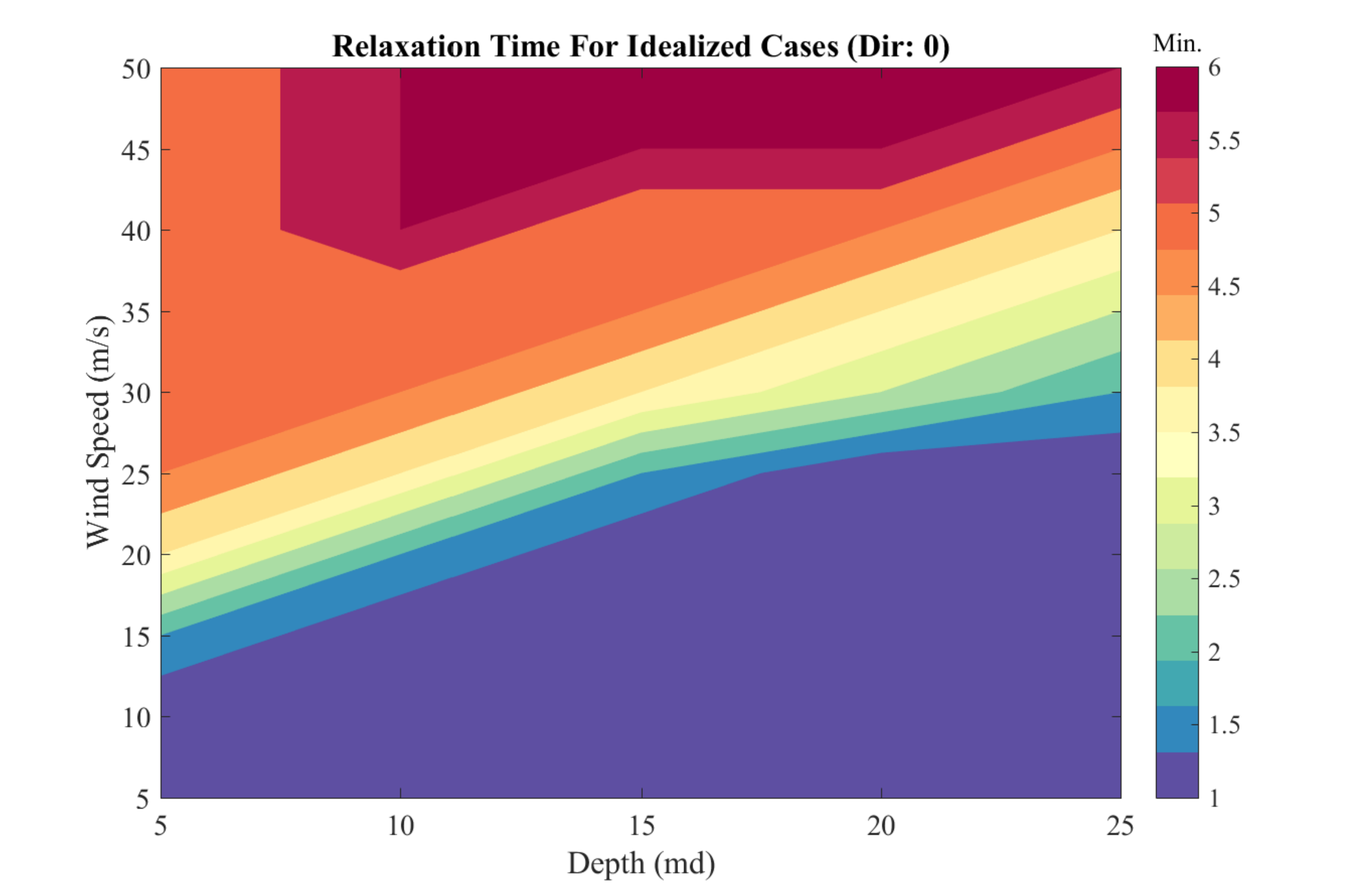
Transition Matrices



Relaxation Time

- In both directions, a sigma value is computed to represent the difference between the current time step, and the last time step.

  - $\boldsymbol{\sigma_U = \sum_{i=1,height}^{j=time} \left(U_{i,last} - U_{i,j}\right)^2}$
  - $\boldsymbol{\sigma_V = \sum_{i=1,height}^{j=time} \left(V_{i,last} - V_{i,j}\right)^2}$



$$\boldsymbol{\sigma_V \,\&\, \sigma_U < 1\frac{cm}{s}\ of\ accuracy}$$

Conclusion

- Two layers are needed to capture open-coast vertical structure
- Our numerical model captures this structure
- Digital Stochastic Model developed to be integrated into existing 2DDI storm surge models

- What's Next?
  - Utilization (can be added to any existing models, with less computation overhead)

Any Questions?

Thank you.

Curriculum:

Funding:

Email: atritinger@gmail.com

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