

Swan and WEC Introduction

Delft3D FM Waves Model

Sam McWilliams
Craig Jones
Ashley Ellenson

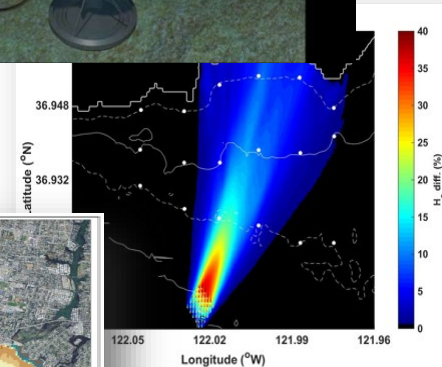
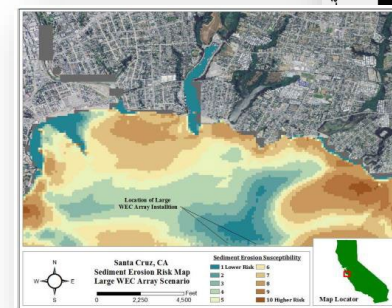
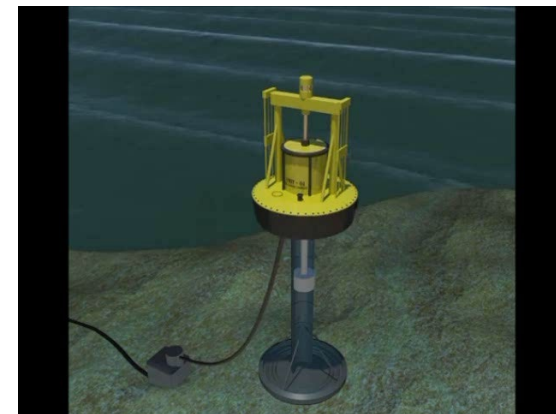
Day 3

Modeling Tools and Techniques for the Evaluation of
Physical and Environmental Marine Hydrokinetic (MHK)
Interactions



Objectives

- › Overview of SWAN
- › Overview of SNL-SWAN
- › WEC integration into SWAN
- › Setup SNL-SWAN

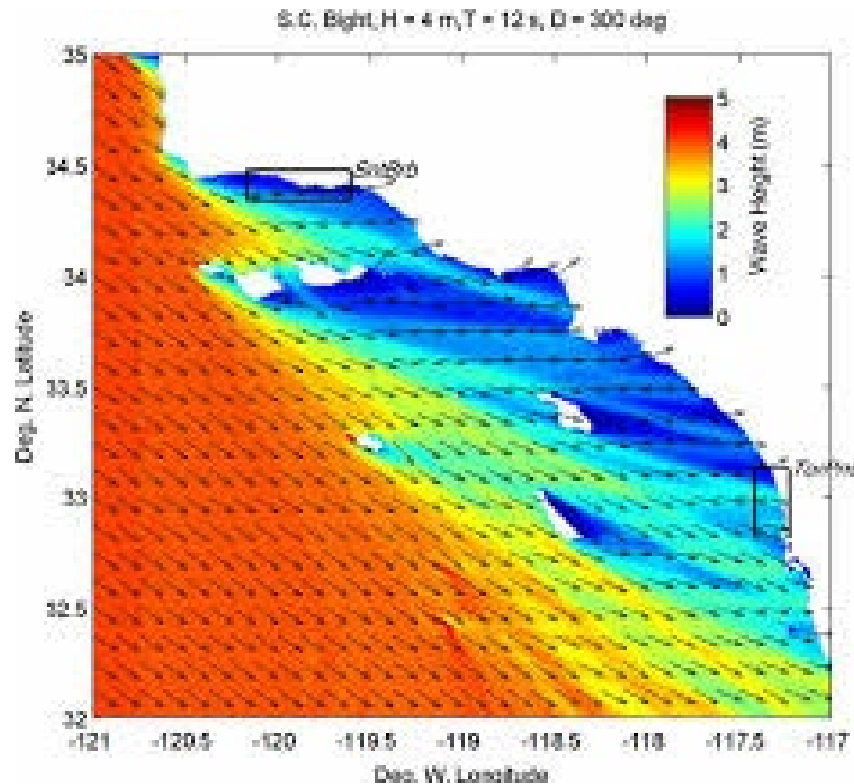


SWAN Modelling



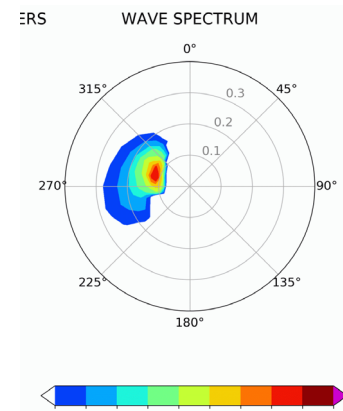
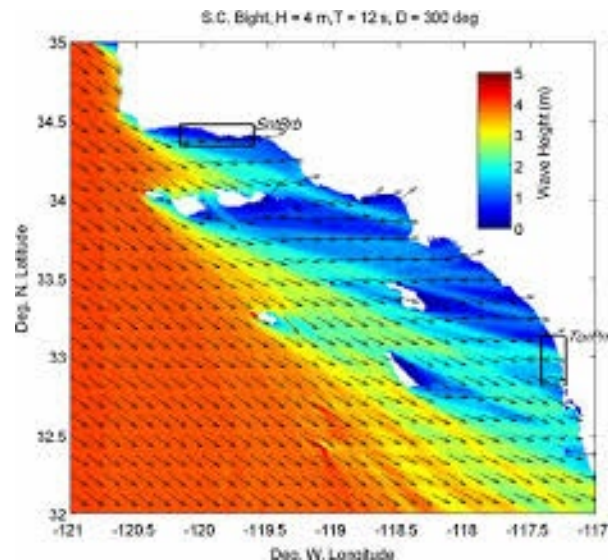
Presentation Outline

- › How does SWAN work?
- › Governing Equation
- › Bathymetry and Grid
- › Forcing Conditions
- › Putting it Together: Computation
- › Outputs



What is SWAN?

- › Simulating Waves Nearshore
- › The SWAN model simulates random, short-crested wind-generated waves in coastal regions and inland waters.
- › Fully spectral in frequencies and directions, meaning it can account for a wide range of wave frequencies and directions.



Wave Driven Circulation

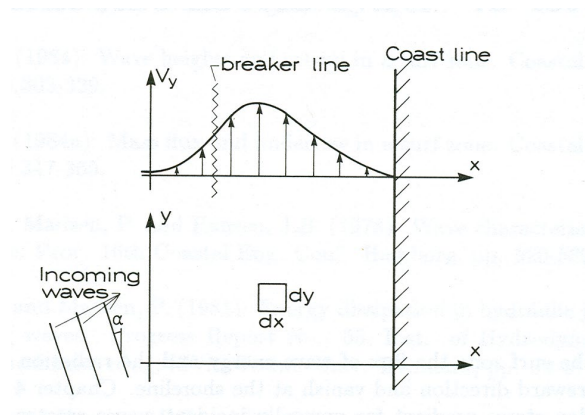
- › As waves move into nearshore regions, the energy gradients created cause nearshore circulation. The nearshore circulation affects sediment and nutrient transport



Processes Controlling Wave Driven Circulation

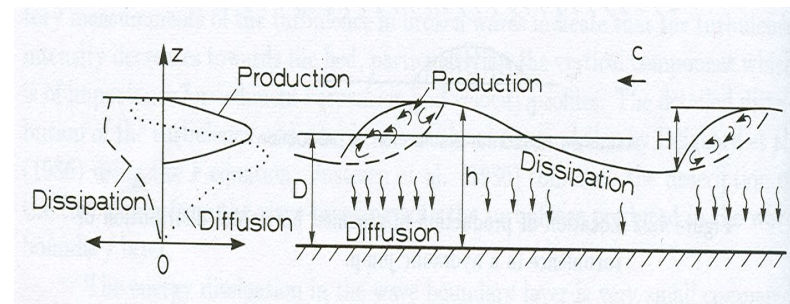
› Radiation Shear Stress

- Waves in the nearshore cause an excess flow of momentum defined as the radiation shear stress. The change in momentum as waves move towards shore is balanced by a pressure gradient (wave set-up) and wave induced velocities. (Longuet-Higgins, 1970)



› Energy Dissipation

- Energy dissipation is due to loss of energy in a wave from the wave boundary layer and wave breaking and happens in the form of turbulence generation. The turbulence generated governs the exchange of momentum in the nearshore.



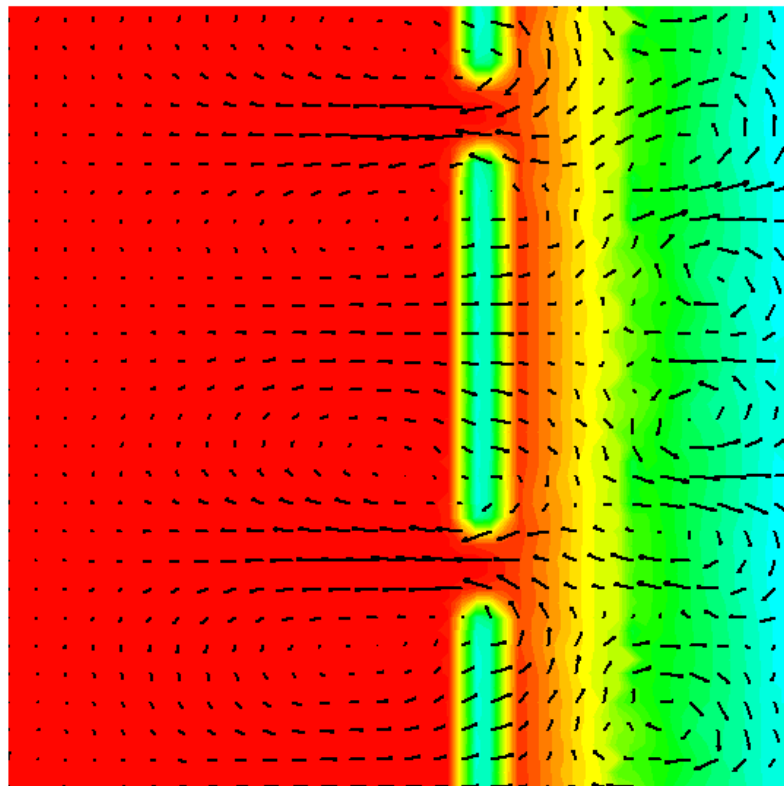
Modeling Wave Driven Circulation

› 3-D Hydrodynamic Model – Delft3d

- Delft3d solves the three-dimensional, vertically hydrostatic, free surface, turbulent equations for motions of a variable density fluid.

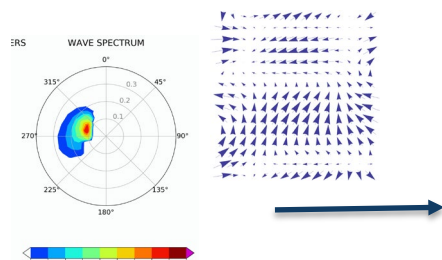
› Incorporation of Wave Effects

- Wave generated radiation shear stresses are incorporated as a source of shear into the X and Y momentum equations. The wave dissipation is incorporated as a source term in the turbulent transport equations.



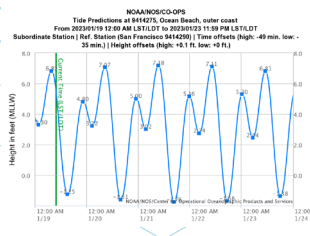
How does SWAN work?

Boundary Conditions



$$\frac{\partial N}{\partial t} + \nabla_{\vec{x}} \cdot [(\vec{c}_g + \vec{u})N] + \frac{\partial c_{\sigma} N}{\partial \sigma} + \frac{\partial c_{\theta} N}{\partial \theta} = \frac{S_{\text{tot}}}{\sigma}$$

**Wave Action
Balance**



**Bathymetry
and Grid**

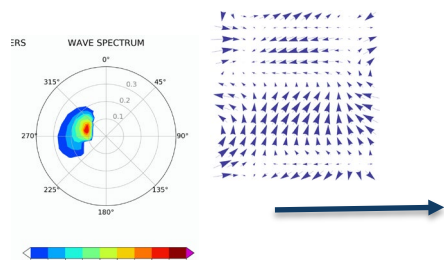
Numerical Methods (Finite Difference)

$$\begin{aligned} \frac{N^n - N^{n-1}}{\Delta t} \Big|_{i,j,l,m} + & \frac{[c_x N]_{i+1/2} - [c_x N]_{i-1/2}}{\Delta x} \Big|_{j,l,m}^n + \\ & \frac{[c_y N]_{j+1/2} - [c_y N]_{j-1/2}}{\Delta y} \Big|_{i,l,m}^n + \\ & \frac{[c_{\sigma} N]_{l+1/2} - [c_{\sigma} N]_{l-1/2}}{\Delta \sigma} \Big|_{i,j,m}^n + \\ & \frac{[c_{\theta} N]_{m+1/2} - [c_{\theta} N]_{m-1/2}}{\Delta \theta} \Big|_{i,j,l}^n, \end{aligned}$$

Governing Equation

Boundary Conditions

$$\frac{\partial N}{\partial t} + \nabla_{\vec{x}} \cdot [(\vec{c}_g + \vec{u})N] + \frac{\partial c_{\sigma} N}{\partial \sigma} + \frac{\partial c_{\theta} N}{\partial \theta} = \frac{S_{\text{tot}}}{\sigma}$$



Governing Equation: Wave Action Balance

$$\frac{\partial N}{\partial t} + \nabla_{\vec{x}} \cdot [(\vec{c}_g + \vec{u})N] + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_{\text{tot}}}{\sigma}$$

Action Density N $N = \frac{E}{\sigma}$

Energy density (E) over radial frequency
(σ)

Conserved during propagation along its
wave characteristic

Wave Action Balance Equation stipulates the rate of change of the action
density

Governing Equation: Wave Action Balance

$$\underbrace{\frac{\partial N}{\partial t} + \nabla_{\vec{x}} \cdot [(\vec{c}_g + \vec{u})N]}_{\text{1: Kinematic part}} + \underbrace{\frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta}}_{\text{2: Non-conservative source/sink term}} = \frac{S_{\text{tot}}}{\sigma}$$

1: Kinematic part

Change of wave energy in time, in physical space, and in spectral space (frequency and direction)

2: Non-conservative source/sink term that represents all physical processes that generate, dissipate or redistribute wave energy at a point.

Wind

Dissipation

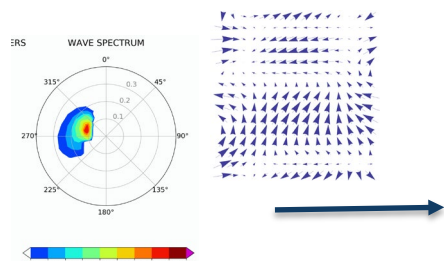
Wave-wave interactions

Wave damping

... and more

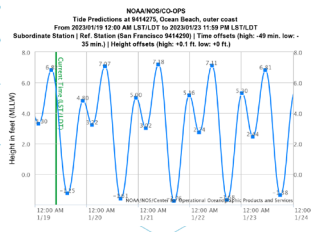
Governing Equation

Boundary Conditions



$$\frac{\partial N}{\partial t} + \nabla_E \cdot [(c_g + \bar{u})N] + \frac{\partial c_g N}{\partial \sigma} + \frac{\partial c_g N}{\partial \theta} = \frac{S_{ws}}{\sigma}$$

Wave Action Balance



Bathymetry and Grid

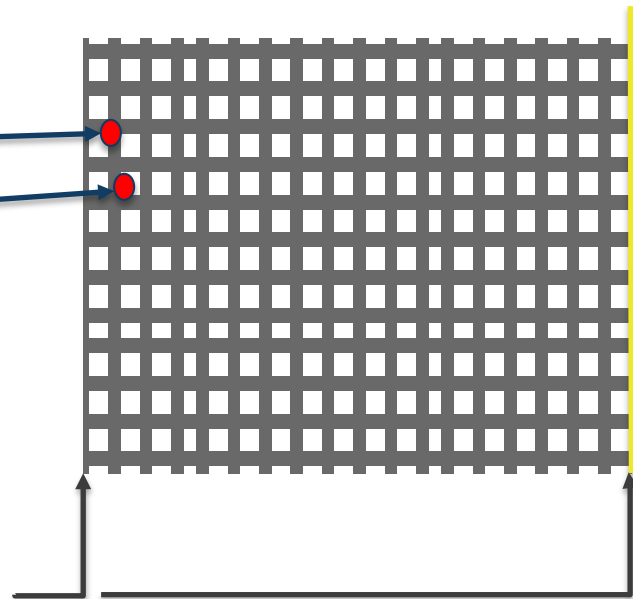
Numerical Methods (Finite Difference)

$$\frac{N^n - N^{n-1}}{\Delta t} \Big|_{i,j,l,m} + \frac{[c_x N]_{i+1/2} - [c_x N]_{i-1/2}}{\Delta x} \Big|_{j,l,m}^n + \frac{[c_y N]_{j+1/2} - [c_y N]_{j-1/2}}{\Delta y} \Big|_{i,l,m}^n + \frac{[c_\sigma N]_{l+1/2} - [c_\sigma N]_{l-1/2}}{\Delta \sigma} \Big|_{i,j,m}^n + \frac{[c_\theta N]_{m+1/2} - [c_\theta N]_{m-1/2}}{\Delta \theta} \Big|_{i,j,l}^n,$$

Bathymetry and Grid

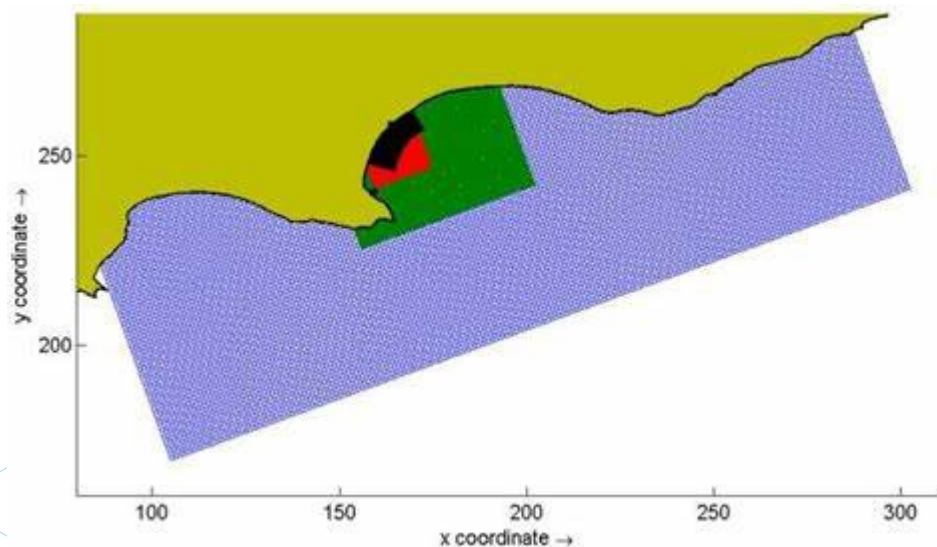
The grid - represent the physical space of the simulation area. The spectral action balance equation is solved at each grid point.

- Grid Points
- Grid Cells
- Grid Resolution – higher resolution, more points, more details, more time and processing power
- Grid Boundaries – start and end points



Bathymetry and Grid

- › Nested grids allow for varying resolution.
- › Information is passed only “into” nested grids
- › Recommended that resolution of innermost grid is \sim WEC size.

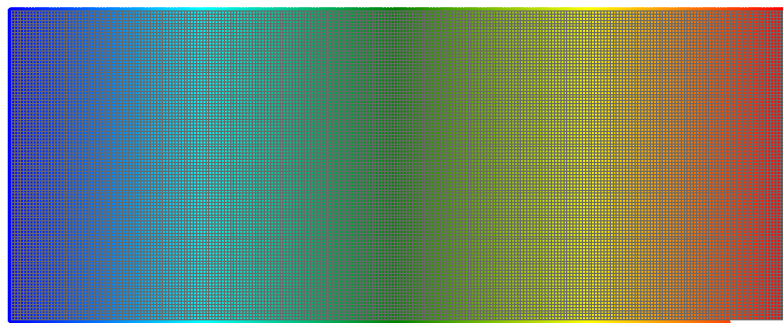
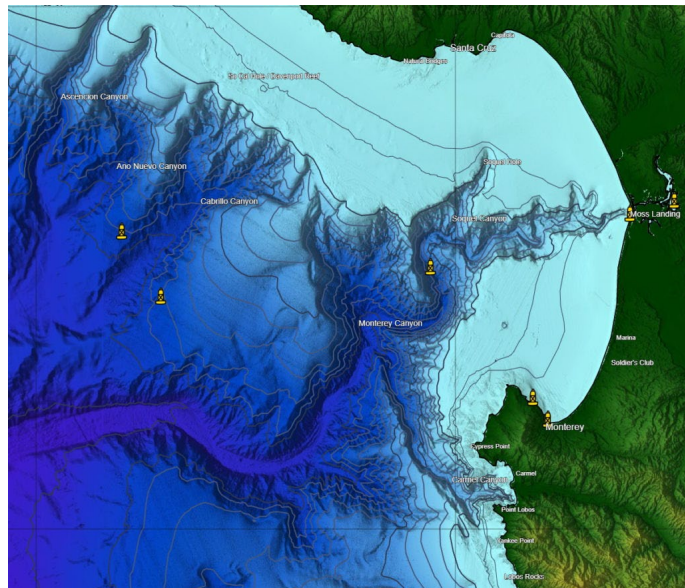


Bathymetry and Grid

Bathymetry

Underwater topography that determines wave transformation and behavior

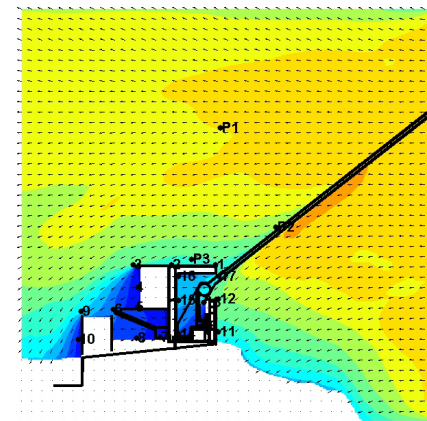
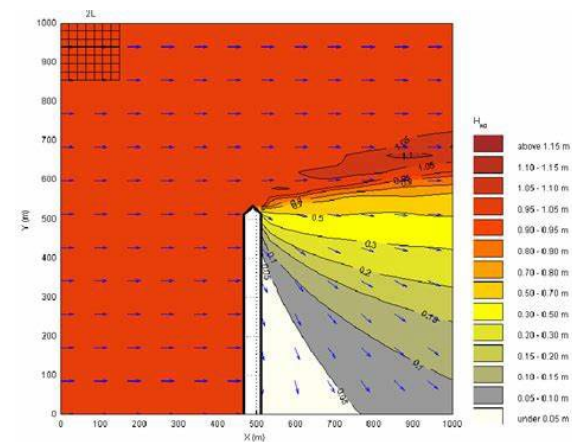
- › Bathymetry governs which the wave behavior domain
- › Deep water vs. Shallow water assumptions and governing equation simplifications



Idealized grid

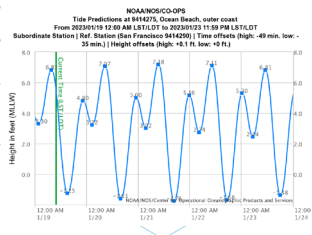
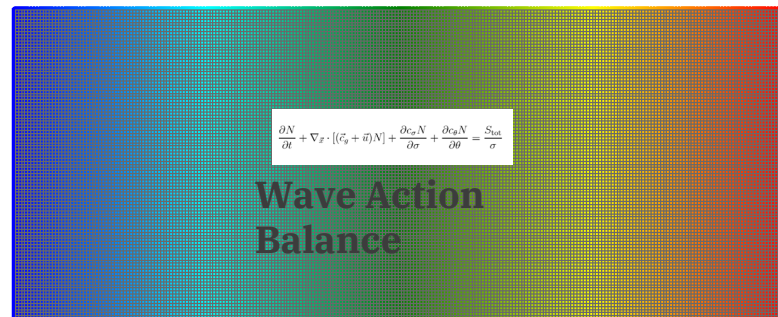
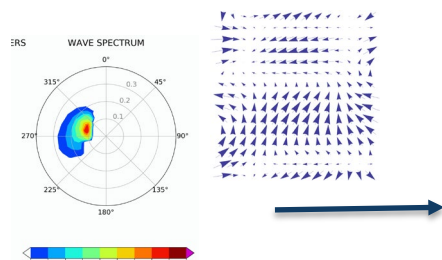
Obstacles

- › Physical structure that affects wave propagation (e.g., pier, breakwater, island)
- › WECs fall into this category



Governing Equation

Boundary Conditions



Bathymetry and Grid

Numerical Methods (Finite Difference)

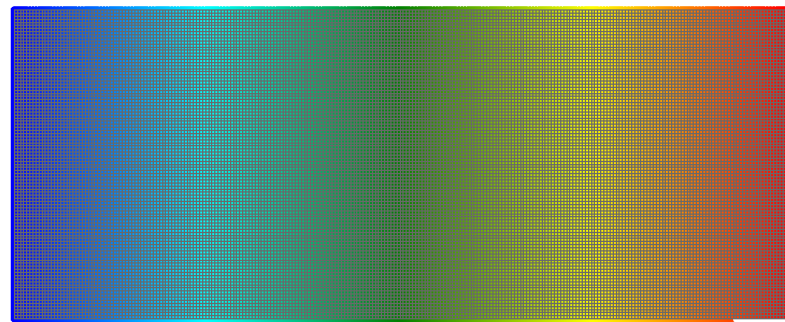
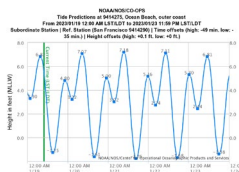
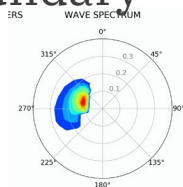
$$\frac{N^n - N^{n-1}}{\Delta t} \Big|_{i,j,l,m} + \frac{[c_x N]_{i+1/2} - [c_x N]_{i-1/2}}{\Delta x} \Big|_{j,l,m}^n + \frac{[c_y N]_{j+1/2} - [c_y N]_{j-1/2}}{\Delta y} \Big|_{i,l,m}^n + \frac{[c_\sigma N]_{l+1/2} - [c_\sigma N]_{l-1/2}}{\Delta \sigma} \Big|_{i,j,m}^n + \frac{[c_\theta N]_{m+1/2} - [c_\theta N]_{m-1/2}}{\Delta \theta} \Big|_{i,j,l}^n,$$

External Forcing Conditions: Boundary Conditions

Boundary conditions – applied at any boundary
 Can be just at the start or throughout the whole simulation
 Measured or Modelled
 Can also vary along the boundary

Wave Energy

- Bulk parameters to generate a wave spectrum of an assumed shape (e.g., JONSWAP)
- measured or modelled



Water Levels

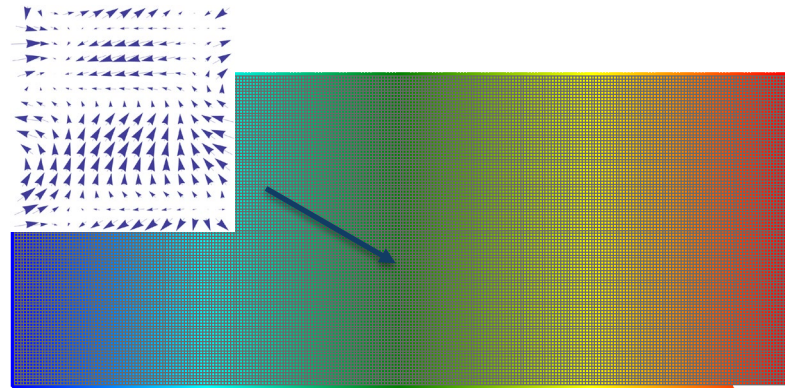
- Tides or storm surges

External Forcing Conditions: Gridded Data

Can be added once or throughout the simulation

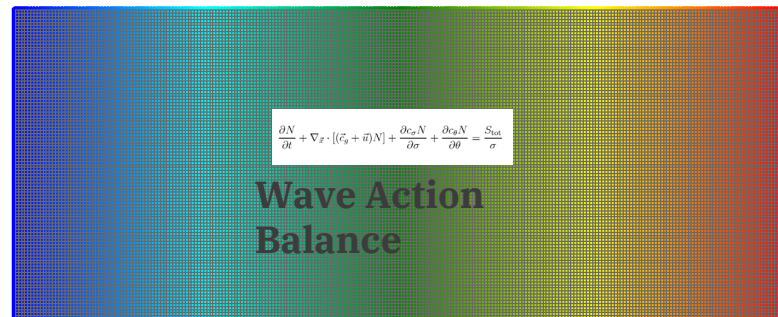
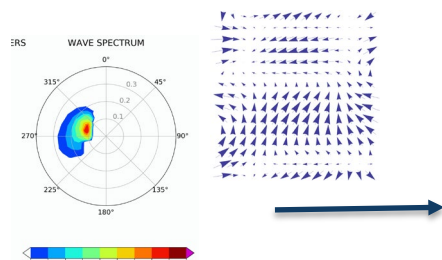
Wind

- Field of wind speed and direction
- Generates waves
- Usually modelled



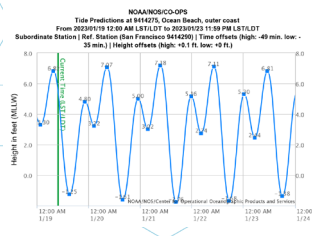
Putting it all together

Boundary Conditions



Numerical Methods (Finite Difference)

$$\frac{N^n - N^{n-1}}{\Delta t} \Big|_{i,j,l,m} + \frac{[c_x N]_{i+1/2} - [c_x N]_{i-1/2}}{\Delta x} \Big|_{j,l,m}^n + \frac{[c_y N]_{j+1/2} - [c_y N]_{j-1/2}}{\Delta y} \Big|_{i,l,m}^n + \frac{[c_\sigma N]_{l+1/2} - [c_\sigma N]_{l-1/2}}{\Delta \sigma} \Big|_{i,j,m}^n + \frac{[c_\theta N]_{m+1/2} - [c_\theta N]_{m-1/2}}{\Delta \theta} \Big|_{i,j,l}^n,$$



Bathymetry and Grid

Iterative Solving in SWAN

- › SWAN is an **implicit** solver
- › Requires iterations to reach a stable solution
- › Each iteration results in a more stable answer
- › Can define threshold value where accuracy is acceptable enough
- › Most important output is the final iteration

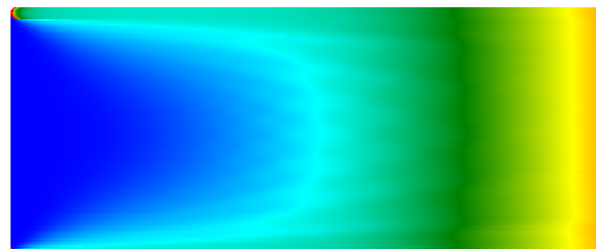
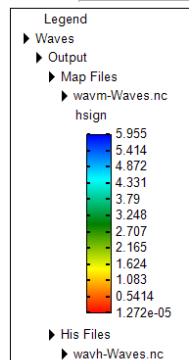
$$\frac{N^n - N^{n-1}}{\Delta t} \Big|_{i,j,l,m} + \frac{[c_x N]_{i+1/2} - [c_x N]_{i-1/2}}{\Delta x} \Big|_{j,l,m}^n + \frac{[c_y N]_{j+1/2} - [c_y N]_{j-1/2}}{\Delta y} \Big|_{i,l,m}^n + \frac{[c_\sigma N]_{l+1/2} - [c_\sigma N]_{l-1/2}}{\Delta \sigma} \Big|_{i,j,m}^n + \frac{[c_\theta N]_{m+1/2} - [c_\theta N]_{m-1/2}}{\Delta \theta} \Big|_{i,j,l}^n,$$

SWAN Outputs

Time series (at a point, 1-D) or gridded (2-D)

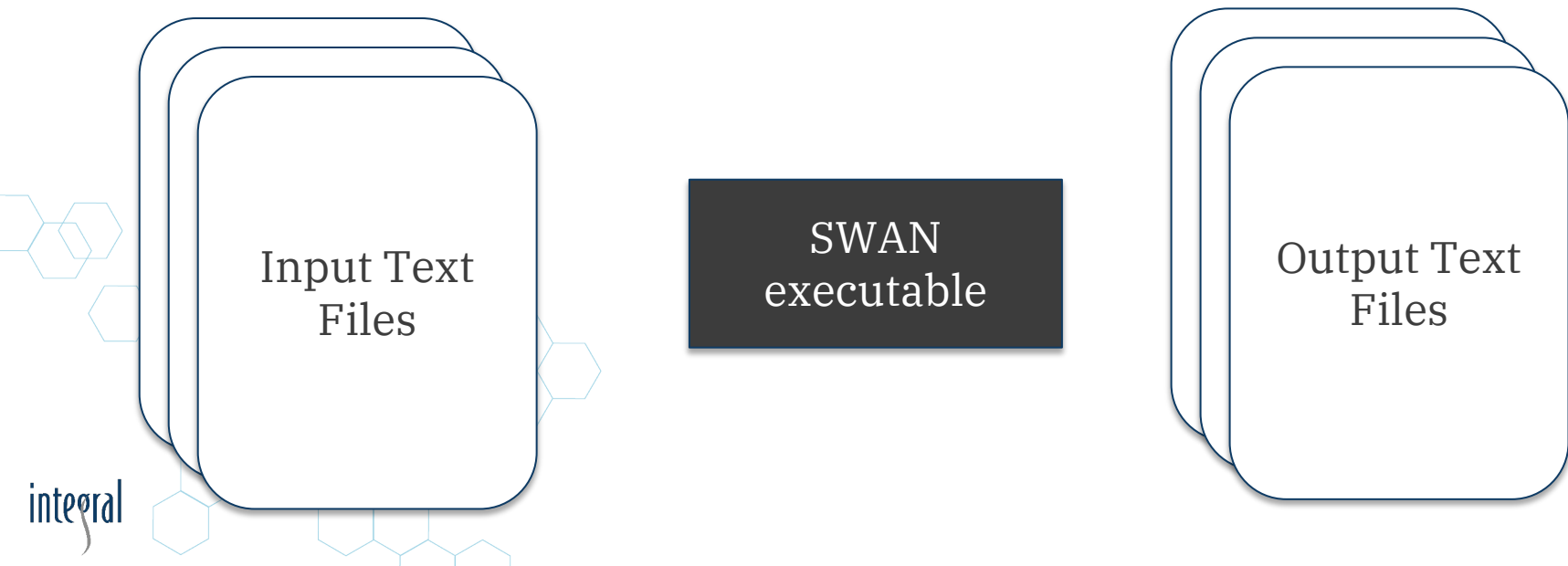
- Wave height
- Wave period
- Wave direction
- Wave energy
- Wave spectrum
- Wave propagation
- Wave breaking
- And more!

Example Hs Output



What do you need to run SNL-SWAN?

- › SWAN is an executable
- › Grid, boundary conditions are input files – text files



Input Files

*.mdw

Dep file
Bathymetry

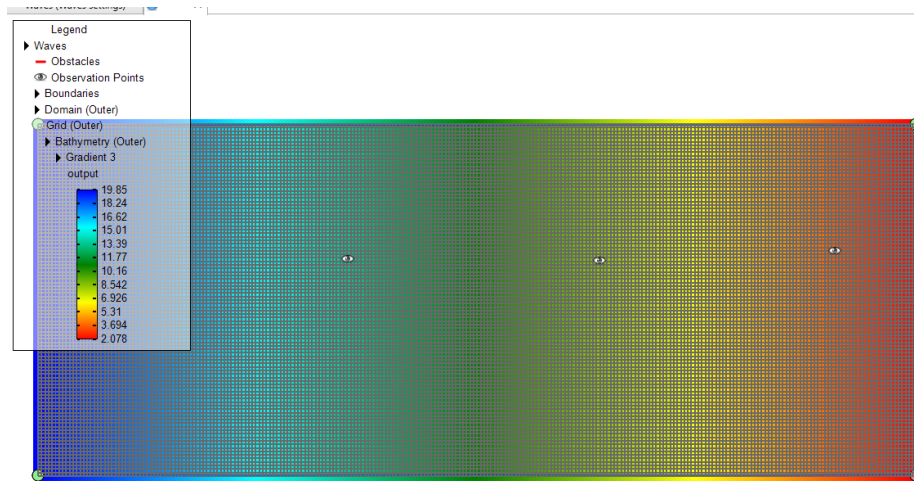
Grid file
Grid info

Obt file
Output
locations

Loc file
Output
locations

Master file
General info
Boundary
Conditions
Wave physics
more

Example Bathymetry, grid and observation points



Output files

Map files

Gridded files

Hs

Tp

Peak Period

His files

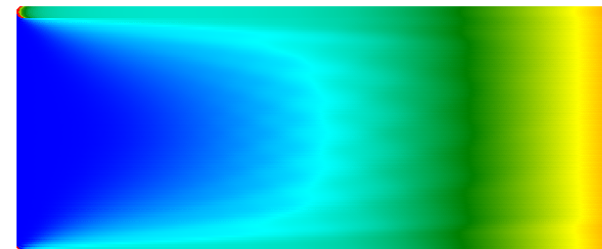
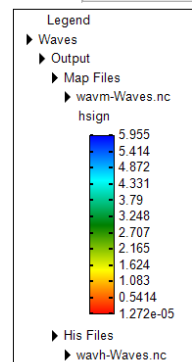
Time series

Hs

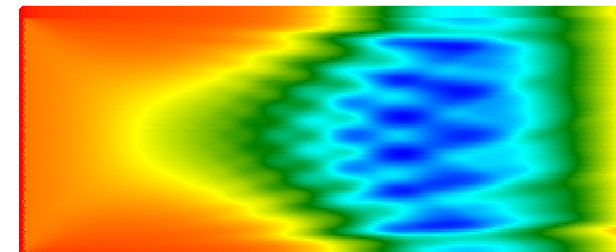
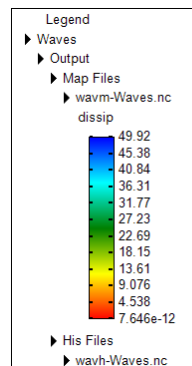
Tp

Peak Period

Example Hs Output



Example Dissipation Output

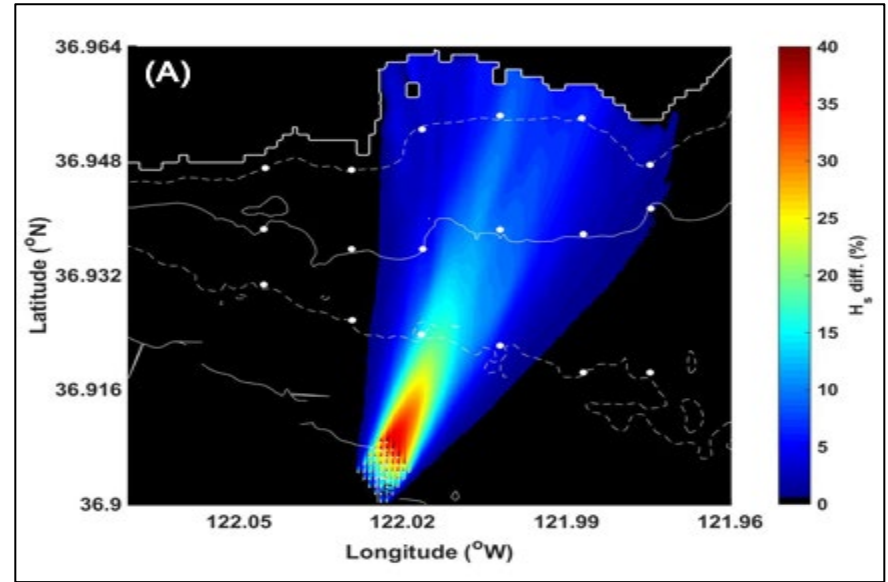


WEC Module Implementation in SWAN



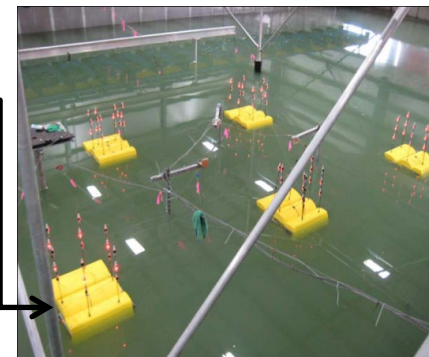
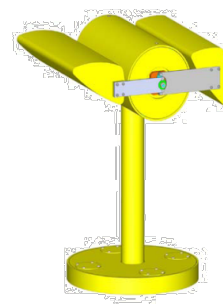
SNL-SWAN WEC Module

- › WEC module added to SWAN to accurately represent energy removal by WECs



SNL-SWAN Validation: Laboratory

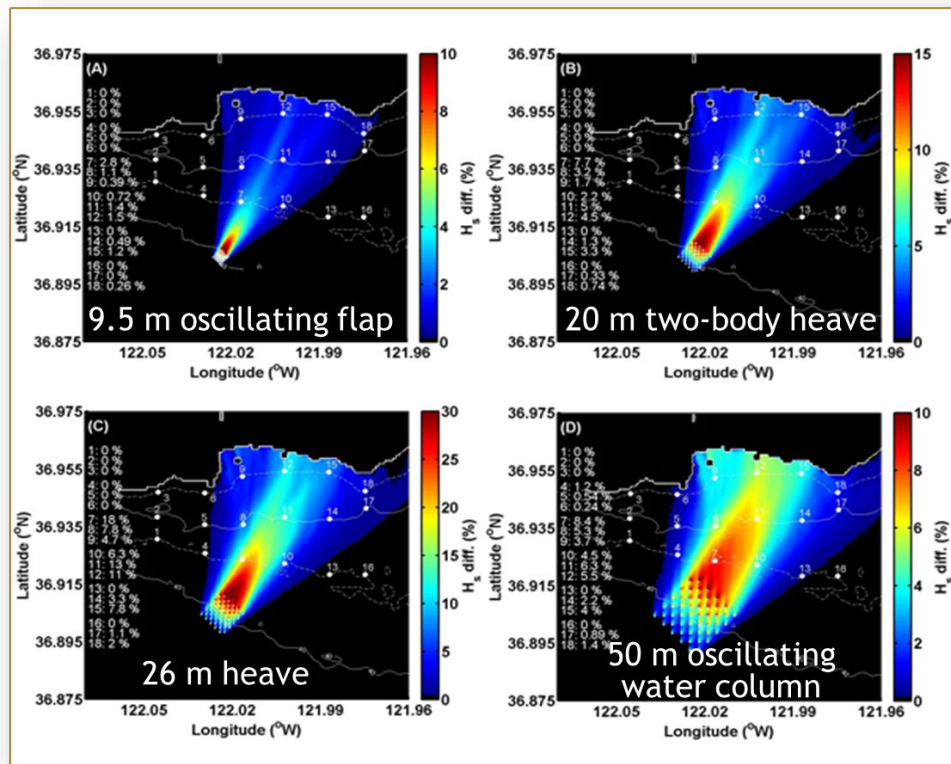
- › SNL-SWAN by comparison to array testing data
- › Columbia Power Technologies 1/33 scale Manta 3.1
- › Testing at OSU Hinsdale Directional Wave Basin in 2011
- › High performance for 3/5 experiments
 - The different types of experiments representing
 - One output



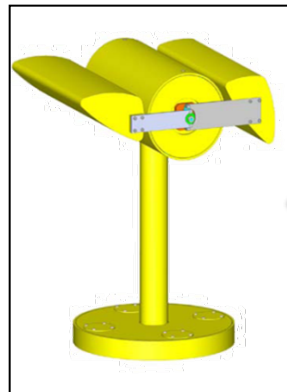
SNL-SWAN Sensitivity: Open Ocean

Determine sensitivity to:

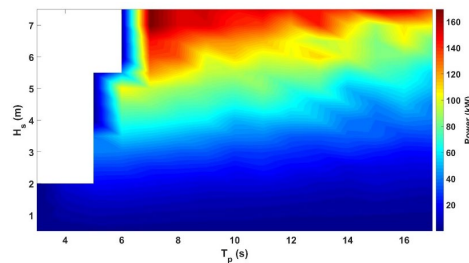
- WEC device type
- Number of WECs in array
- WEC spacing



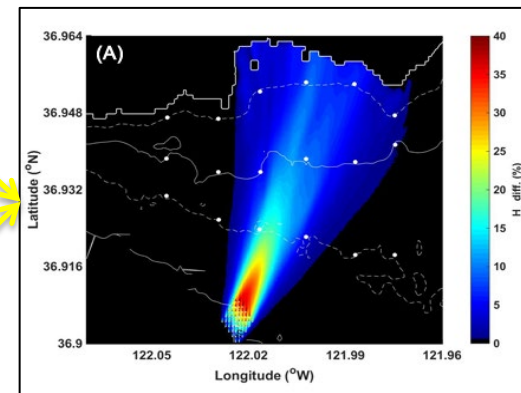
SNL-SWAN WEC Module



Obstacle info



Power Information



What do you need to run SNL-SWAN?

- › SWAN is an executable
- › Grid, boundary conditions are input files – text files
- › Additional files about device – power and obstacle



WEC Module Components

› Obstacle Information

- **Obstacle Characteristics (Kt, Kr, and more)**
- **Obstacle Location**
- **Best Practices for Grid Implementation**

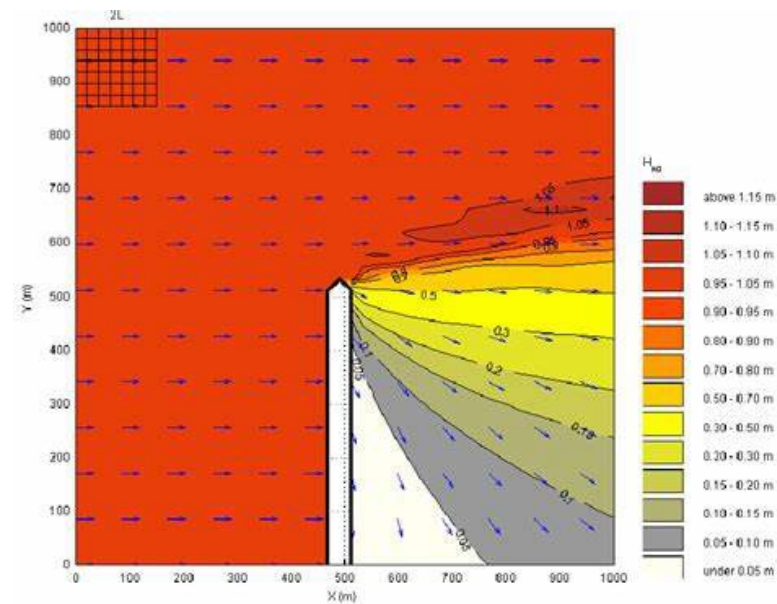
› Defining Kt: WEC Power Performance

› OBCASE Parameterization

› Output

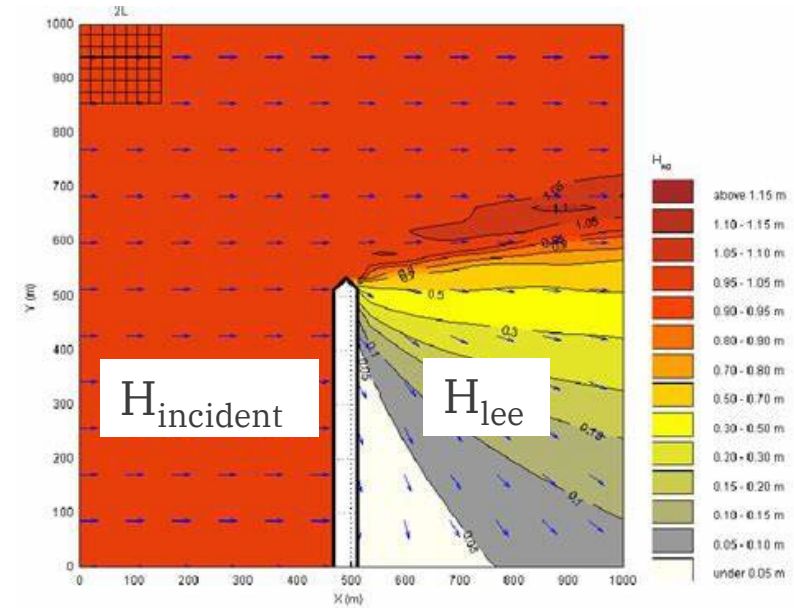
Obstacle Information

- › WECS are represented in SNL-SWAN as obstacles.
- › Define where the devices are located with specification files
- › Define characteristics of device



Defining transmission coefficient (K_t)

$$K_t = \frac{H_{lee}}{H_{incident}}$$



File 1: Obstacle Parameters

- › **Kt:** Transmission Coefficient. How much wave energy passes through (0-1)
- › **Kr:** Reflection Coefficient. How much wave energy reflects back.
- › **Diffraction:** how waves bend around the obstacle
- › **Height:** physical height of the obstacle

Obstacles X								
Name	Δ	Type	Transmission Coefficient	Height	Alpha	Beta	Reflection Type	Reflection Coefficient
Obstade01		Sheet	0.5				No	
Obstade02		Sheet	0.5				No	
Obstade03		Sheet	0.5				No	
Obstade04		Sheet	0.5				No	
Obstade05		Sheet ▼	0.5				No	

Best Practice: WEC Transmission vs Reflection

- › Transmitted + reflected + absorbed energy cannot be greater than the incident wave energy
 - $1 - k_t + k_r > 0$
- › Check this for all frequencies.
- › SNL-SWAN will produce an error message if energy is not conserved in this way.

File 1: Obstacle Parameters – “.obt” file

“.obt” file defines obstacle parameters

```
[ObstacleFileInformation]
  FileVersion   = 02.00
  PolylineFile  = case_2_obs_new.pol
[Obstacle]
  Name          = Obstacle 1
  Type          = sheet
  TransmCoef    = 5.00000000e-001
  Reflections   = no
[Obstacle]
  Name          = Obstacle 2
  Type          = sheet
  TransmCoef    = 5.00000000e-001
  Reflections   = no
[Obstacle]
  Name          = Obstacle 3
  Type          = sheet
  TransmCoef    = 5.00000000e-001
  Reflections   = no
```

File 1

Defines Obstacle
characteristics (Kt, Kr,
etc.)

File 2: Location of Obstacles – “.pol” file

File 2

Defines obstacle locations
in space

Two X,Y points per
obstacle

“.pol” file defines location of obstacles

Obstacle 1

2 2

235.85975 44.68599

235.86035 44.68599

← endpoints
←

Obstacle 2

2 2

235.85975 44.68859

235.86035 44.68859

Obstacle 3

2 2

235.85975 44.69118

235.86035 44.69118

Obstacle Files

“.obt” file defines obstacle parameters

```
[ObstacleFileInformation]
  FileVersion  = 02.00
  PolylineFile = case_2_obs_new.pol

[Obstacle]
  Name        = Obstacle 1
  Type        = sheet
  TransmCoef  = 5.00000000e-001
  Reflections = no

[Obstacle]
  Name        = Obstacle 2
  Type        = sheet
  TransmCoef  = 5.00000000e-001
  Reflections = no

[Obstacle]
  Name        = Obstacle 3
  Type        = sheet
  TransmCoef  = 5.00000000e-001
  Reflections = no
```

“.pol” file defines location of obstacles

```
Obstacle 1
2 2
235.85975 44.68599
235.86035 44.68599

Obstacle 2
2 2
235.85975 44.68859
235.86035 44.68859

Obstacle 3
2 2
235.85975 44.69118
235.86035 44.69118
```

endpoints

WEC Module Components

› Obstacle Information

- Obstacle Characteristics (K_t , K_r , and more)
- Obstacle Location
- Best practices for grid implementation

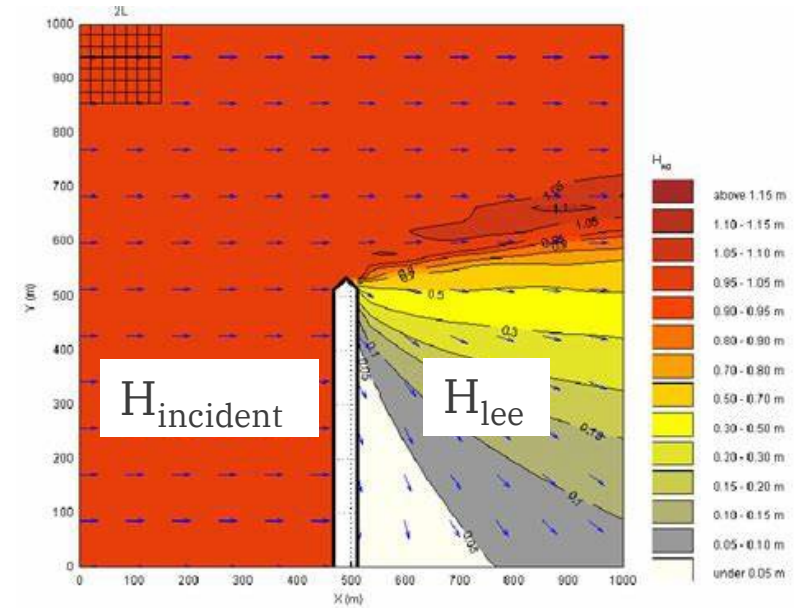
› **Defining K_t : WEC Power Performance**

› OBCASE Parameterization

› Output

Defining transmission coefficient (K_t)

$$K_t = \frac{H_{lee}}{H_{incident}}$$



Defining K_t with the WEC Power Absorption

Using wave power information from the WEC where the WEC absorbs different amounts of energy at different frequencies

$$K_t^2 = \frac{P_{Lee}}{P_{Incident}} = \frac{P_{Incident} - P_{Absorbed}}{P_{Incident}} = 1 - \frac{P_{Absorbed}}{P_{Incident}}$$

Kt with Power Performance

- WEC energy absorption defined in two ways: power matrix or relative capture width

$$K_t^2 = \frac{P_{Lee}}{P_{Incident}} = \frac{P_{Incident} - P_{Absorbed}}{P_{Incident}} = 1 - \frac{P_{Absorbed}}{P_{Incident}}$$

Power Matrix

Defines $P_{absorbed}$
for different
frequencies

Relative Capture Width (RCW)

Defines $\frac{P_{absorbed}}{P_{incident}}$ for different
frequencies

Kt Definition Options

- › Kt itself provided
- › Kt defined with power matrix
- › Kt defined with Relative Capture Width

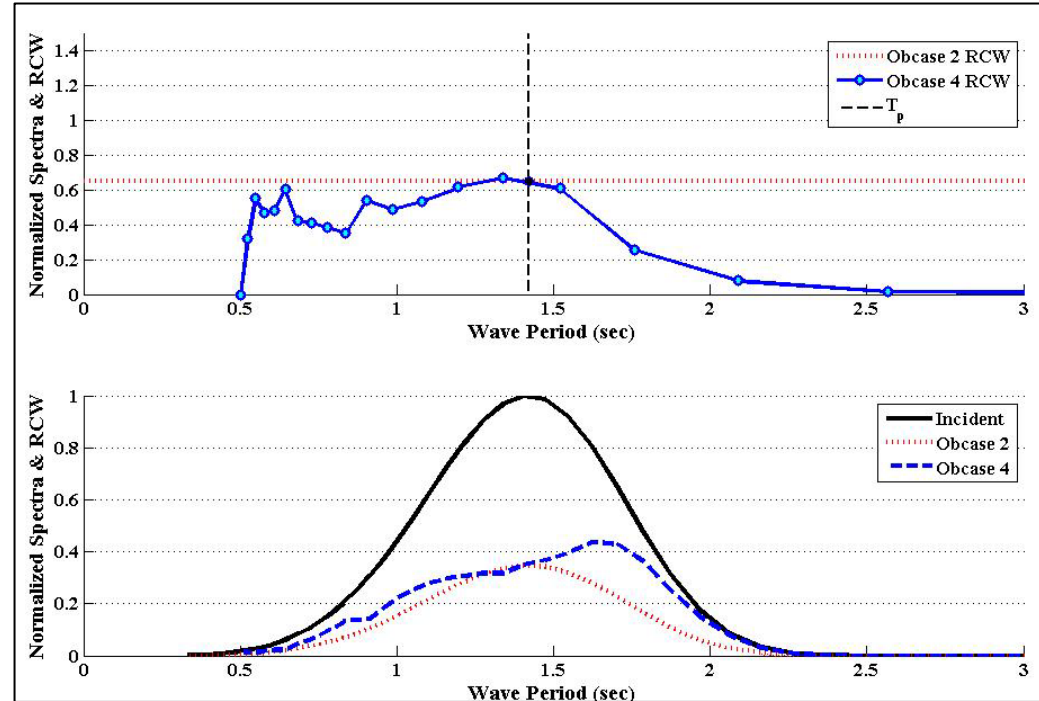
Kt itself by frequency

› Frequency specification

- Apply a frequency-dependent Kt from whole spectra Hs

OR

- Determine effective wave height at each frequency and determine frequency-dependent Kt



Kt define by Relative Capture Width (RCW)

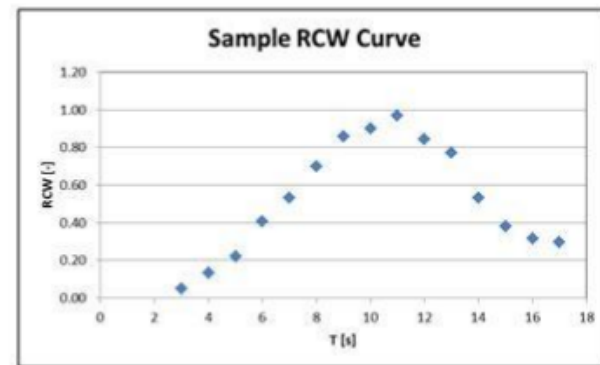
- › The relative capture width curve is a table of absorbed power ratios by a WEC device at varying wave periods.
- › May be estimated experimentally or numerically.
- › Saved as Relative_Capture_Width.txt
- › RCW should be between 0 and 1.0

Units:
Seconds

Units:
Unitless capture
width ratio

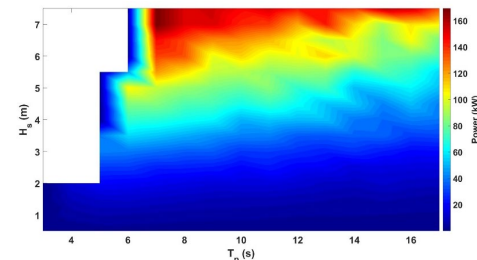
T [s]	RCW [-]
3	0.05
4	0.13
5	0.22
6	0.41
7	0.53
8	0.70
9	0.86
10	0.90
11	0.97
12	0.84
13	0.77
14	0.53
15	0.38
16	0.32
17	0.30

$$K_t^2 = 1 - \frac{P_{\text{Absorbed}}}{P_{\text{Incident}}} = 1 - \text{RCW}$$



Kt defined by WEC Power Matrix

- › The WEC power matrix should be defined in kW absorbed by the WEC.
- › Normalization Width of the WEC must be known.
- › Typically given in terms of bulk seastate parameters (H_s , T_p)



		T_p														
H_s (m)	MEAN	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	0.5	4.44	5.07	7.97	12.15	16.77	17.14	11.94	9.16	6.57	4.39	4.00	3.00	2.86	1.95	1.71
	1	16.65	19.00	29.48	46.94	56.61	52.38	37.14	28.73	19.84	16.62	12.94	9.33	7.29	7.40	4.49
	1.5	0.00	41.54	63.14	92.37	110.74	109.49	64.96	55.91	38.49	29.09	22.06	19.26	12.74	11.21	11.50
	2	0.00	66.29	99.03	150.67	200.97	164.91	105.27	85.30	58.63	52.31	40.56	28.76	24.22	19.31	17.57
	2.5	0.00	0.00	160.23	241.82	261.83	226.36	166.20	117.65	83.09	69.87	57.47	39.24	28.51	26.20	23.73
	3	0.00	0.00	212.52	319.26	372.09	327.17	210.96	151.98	116.43	93.66	75.42	66.09	44.81	42.09	30.83
	3.5	0.00	0.00	270.15	436.02	503.15	407.75	292.71	208.22	148.33	115.49	92.63	74.81	57.97	44.27	41.16
	4	0.00	0.00	0.00	553.82	540.26	521.33	355.46	260.73	191.66	144.19	122.78	84.04	81.01	55.80	53.24
	4.5	0.00	0.00	0.00	645.46	746.22	586.83	378.72	302.18	236.42	189.64	154.41	105.88	89.58	74.26	55.78
	5	0.00	0.00	0.00	796.15	926.13	694.67	485.91	341.08	287.07	211.41	167.83	135.72	111.21	93.81	77.53
	5.5	0.00	0.00	0.00	939.38	954.73	807.95	603.12	429.61	343.03	231.19	201.49	150.14	120.29	96.75	89.90
	6	0.00	0.00	0.00	0.00	1161.42	956.67	642.03	480.81	329.09	289.47	212.26	171.77	145.82	110.89	100.85
	6.5	0.00	0.00	0.00	0.00	1476.47	1039.27	702.04	487.62	396.60	311.56	236.66	203.88	153.43	120.26	102.25
	7	0.00	0.00	0.00	0.00	1664.93	1197.05	820.77	612.40	465.98	384.59	251.62	222.70	180.55	146.28	131.44
	7.5	0.00	0.00	0.00	0.00	1608.45	1407.61	922.63	703.98	508.65	373.47	325.45	229.49	190.53	151.78	149.26

Hs Bins

WEC's physical dimension
(meters)

Wave Heights (meters)

Wave Periods (seconds)

Power Matrix (units kW)

Tp Bins

```

50 # obstacle width
15 # number of significant wave height entries
0.5 # list of wave height entries
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
15 # number of peak period entries
3 # list of period values
4
5
6
7
8
9
10
11
12
13
14
15
16
17 # power matrix table is entered below
4.44 5.07 7.97 12.15 16.77 17.14 11.94 9.16 6.57 4.39 4.00 3.00 2.86 1.95 1.71
16.65 19.00 29.48 46.94 56.61 52.38 37.14 28.73 19.84 16.62 12.94 9.33 7.29 7.40 4.49
0.00 41.54 63.14 92.37 110.74 109.49 64.96 55.91 38.49 29.09 22.06 19.26 12.74 11.21 11.50
0.00 66.29 99.03 150.67 200.97 164.91 105.27 85.30 58.63 52.31 40.56 28.76 24.22 19.31 17.57
0.00 0.00 160.23 241.82 261.83 226.36 166.20 117.65 83.09 69.87 57.47 39.24 28.51 26.20 23.73
0.00 0.00 212.52 319.26 372.09 327.17 210.96 151.98 116.43 93.66 75.42 66.09 44.81 42.09 30.83

```

Hs

Tp

WEC Module Components

› Obstacle Information

- Obstacle Characteristics (K_t , K_r , and more)
- Obstacle Location
- Best Practices for Grid Implementation

› Defining K_t : WEC Power Performance

› **OBCASE Parameterization**

› Output

Obcase

- › Short for “WEC Obstacle Case”
- › Method for determining Obstacle transmission (K_t) is determined by selecting Obcase 0, 1, 2, 3, or 4.
 - 0: Baseline (TU Delft) SWAN. K_t set in INPUT file.
 - 1: K_t based on Power Matrix and incident wave field (H_s , T_p). Equal across wave periods.
 - 2: K_t based on RCW value at peak incident wave period. Equal across wave periods.
 - 3: K_t based on Power Matrix and incident wave spectra. Varying across wave periods.
 - 4: K_t based on RCW curve. Varying across wave periods.

OBCASE options

- › The OBCASE determines how what parameterization for the wec is used.

WEC Performance Information	Frequency-variable Kt	Frequency-constant Kt
No Information	N/A	Obcase 0
Power Matrix (real seas, peak period)	N/A	Obcase 1
Power Matrix (regular waves and amplitude)	Obcase 3	N/A
RCW Curve	Obcase 4	Obcase 2

OBCASE options

- › Using OBCASE equal to 3 or 4 is only appropriate when information is available about individual frequencies.
- › OBCASE 1 and 2 are more appropriate when information is available about average sea states.



WEC Module Components

› Obstacle Information

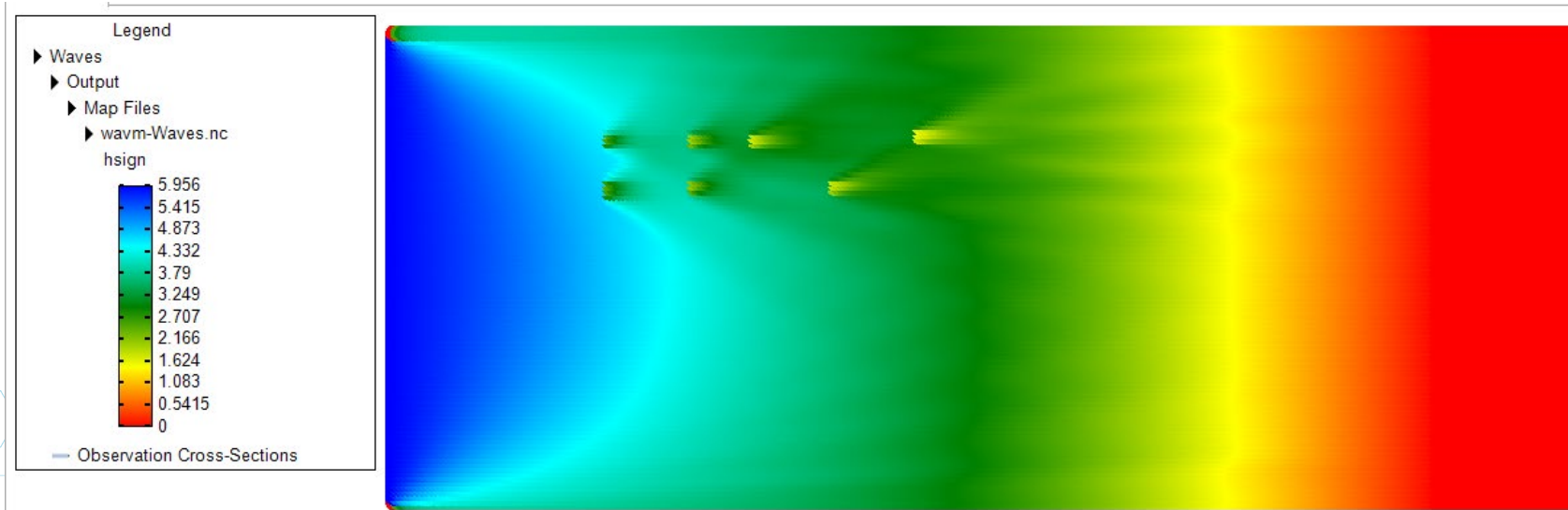
- Obstacle Characteristics (K_t , K_r , and more)
- Obstacle Location
- Best Practices for Grid Implementation

› Defining K_t : WEC Power Performance

› OBCASE Parameterization

› **Output**

Output Figures



Power Generation

- Power output is saved in a “POWER_ABS.OUT” file in the project folder.

This shows the watts generated for each obstacle (wec).

POWER_ABS.OUT				
1	Iteration:	1		
2	Power absorbed by obstacle	1 =	767394.7500000	W
3	Power absorbed by obstacle	2 =	570529.7500000	W
4	Power absorbed by obstacle	3 =	385894.8437500	W
5	Power absorbed by obstacle	4 =	192941.5937500	W
6	Power absorbed by obstacle	5 =	44051.6210938	W
7	Iteration:	2		
8	Power absorbed by obstacle	1 =	789945.8125000	W
9	Power absorbed by obstacle	2 =	605252.3125000	W
10	Power absorbed by obstacle	3 =	414473.2500000	W
11	Power absorbed by obstacle	4 =	206304.6562500	W
12	Power absorbed by obstacle	5 =	44921.4765625	W
13	Iteration:	3		
14	Power absorbed by obstacle	1 =	805410.0000000	W
15	Power absorbed by obstacle	2 =	644134.6250000	W
16	Power absorbed by obstacle	3 =	456051.7812500	W
17	Power absorbed by obstacle	4 =	229791.0937500	W
18	Power absorbed by obstacle	5 =	46864.5468750	W
19	Iteration:	4		
20	Power absorbed by obstacle	1 =	812230.8750000	W
21	Power absorbed by obstacle	2 =	669341.5625000	W
22	Power absorbed by obstacle	3 =	490437.6250000	W
23	Power absorbed by obstacle	4 =	253578.8281250	W
24	Power absorbed by obstacle	5 =	49318.8476562	W
25				

SNL-SWAN set up



Setup SNL-SWAN

- › If you haven't already, take a minute to setup SNL-SWAN.
- › SNL-SWAN can be run as a standalone package similar to previous versions of SWAN.
- › Can also replace the integrated SWAN executable in Delft3D-Wave.
 - Useful for coupling to flow model for comprehensive modeling of system dynamics.

SNL-Swan Integration

- › Copy the existing “swan” folder (C:\Program Files\Deltares\Delft3D FM Suite 2024.01 HMWQ\plugins\DeltaShell.Dimr\kernels\x64) and rename swan_ori.
- › Copy the file “snl-swan-win-ser-ifort.exe” into the folder ...\x64\swan\bin
- › Edit line 5 in the swan.bat file in “...\x64\swan\scripts”
 - from : set swanexec=%~dp0\..\bin\swan_omp.exe
 - to : set swanexec=%~dp0\..\bin\snl-swan-win-ser-ifort.exe

```
8 rem set swanexec=%~dp0\..\bin\swan_omp.exe  
9 set swanexec=%~dp0\..\binsnl-swan-win-ser-ifort.exe
```

- › Save the .bat file

SNL-Swan Integration Cont.

› Note:

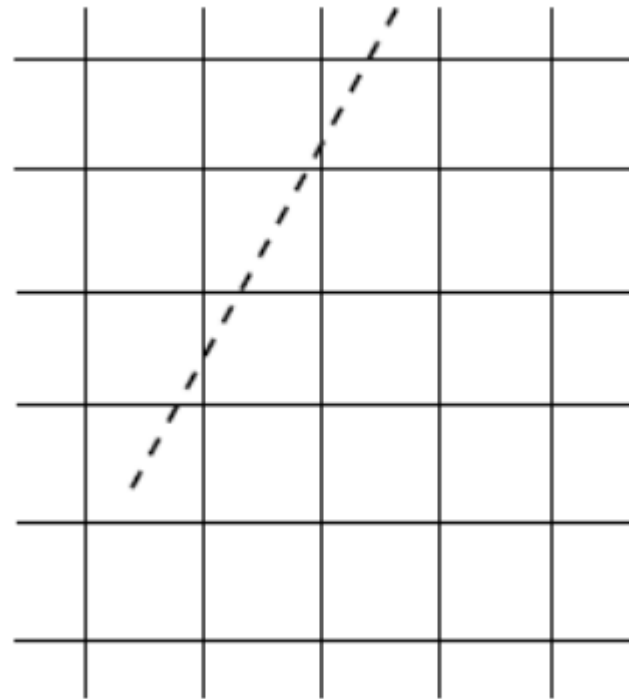
- If you cannot save the .bat file due to administrator restrictions, save the file to another folder (e.g.: Documents).
- Rename the existing swan.bat file to swan_ori.bat
- Copy the new swan.bat file to the “...\x64\swan\scripts” directory.

Next Steps

- › Next, we will set up a simple planar beach wave model in Delft3D FM Suite.

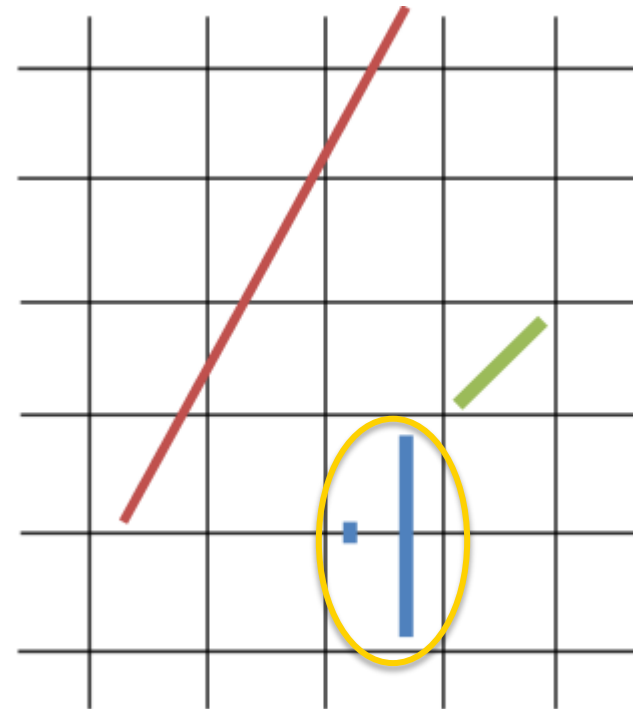
Location: Best Practice with Grids

- Obstacles are treated as lines running through the computational grid.
- When calculating the action density flux from one grid point to its neighbors, SWAN first determines if the connecting grid line crosses an obstacle line.
- If and only if a grid line is crossed by an obstacle line, the transmission coefficient applied to the flux between those nodes.



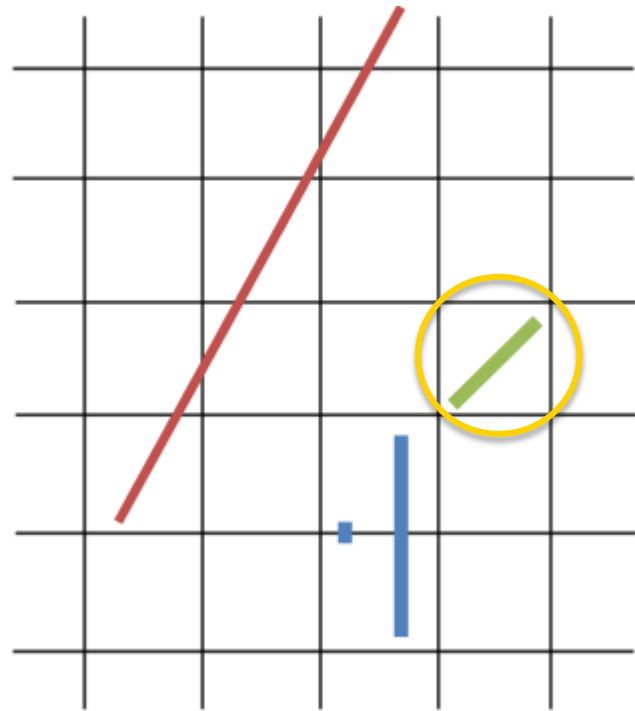
Location: Best Practice with Grids, cont'd

- › The two blue obstacles shown will have the exact same influence on the model solution, even though they have much different widths.
- › Both obstacles cross the same computation grid line, SWAN will apply their transmission coefficient the same volumetric fluxing face.
- › Both obstacles correspond to the same face, and thus their obstacle coefficients will have the same impact on the model calculation.



Location: Best Practice with Grids, cont'd

- › Due to grid discretization, the green obstacle does not intersect the computational grid lines. In this situation it will have no effect.



Location: Best Practice with Grids, cont'd

- › Most WEC types can capture Energy from all directions.
 - Define an obstacle at an angle to cross two perpendicular grid lines.
- OR
- Define two perpendicular obstacles that both cross grid lines. Power extracted for each obstacle must be summed.



Grid Size

- Make sure the grid size corresponds with the WEC's physical dimension specified in the Power Matrix
- SWAN will normalize by the size of the grid cell
- The power in the table is extracted every 50m in this example

$$P_{abs} = \frac{P_{matrix}}{W} N \Delta x$$

```
50 # obstacle width
15 # number of significant wave height entries
0.5 # list of wave height entries
```

```
50 # obstacle width
15 # number of significant wave height entries
0.5 # list of wave height entries
```

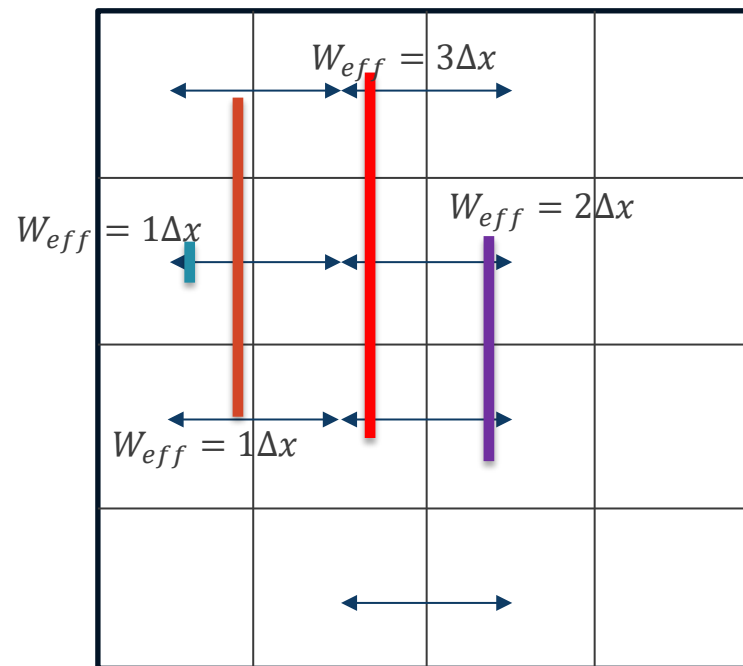
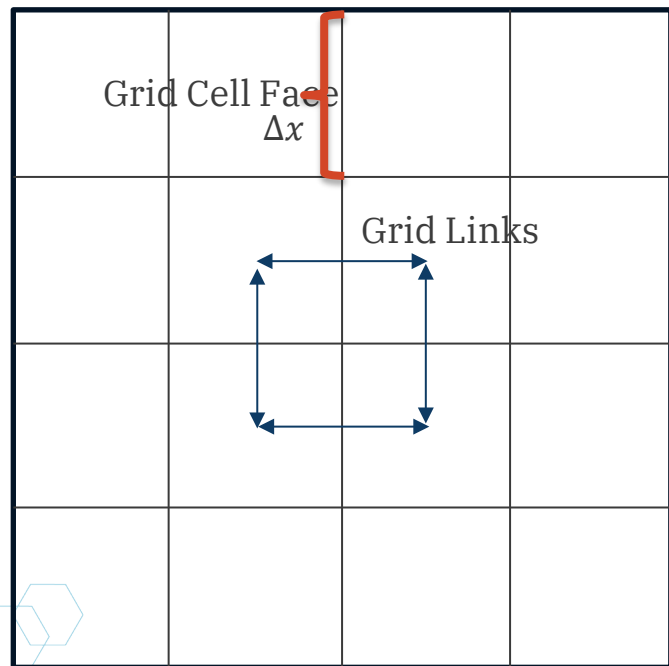
```
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
15 # number of peaks
3 # list of periods
4
5
6
7
8
9
10
11
12
13
14
15
16
17 # power matrix table is entered below
4.44 5.07 7.97 12.15 16.77 17.14 11.94 9.16 6.57 4.39 4.00 3.00 2.86 1.95 1.71
16.65 19.00 29.48 46.94 56.61 52.38 37.14 28.73 19.84 16.62 12.94 9.33 7.29 7.40 4.49
0.00 41.54 63.14 92.37 110.74 109.49 64.96 55.91 38.49 29.09 22.06 19.26 12.74 11.21 11.50
0.00 66.29 99.03 150.67 200.97 164.91 105.27 85.30 58.63 52.31 40.56 28.76 24.22 19.31 17.57
0.00 0.00 160.23 241.82 261.83 226.36 166.20 117.65 83.09 69.87 57.47 39.24 28.51 26.20 23.73
0.00 0.00 212.52 319.26 372.09 327.17 210.96 151.98 116.43 93.66 75.42 66.09 44.81 42.09 30.83
```


Questions?



Extra Slides





Δx - Width of one cell face

N - Number of grid links crossed by an obstacle

$W_{eff} = N * \Delta x$ - Effective width of the WEC, which is the obstacle width $\pm \Delta x$

Variance Spectrum $E(\sigma, \theta)$ -- units m^2

Action Density $N(\sigma, \theta) = \frac{1}{\sigma} E(\sigma, \theta)$ -- units $\frac{m^2}{s^{-1}}$

$$P_{inc} = \int \rho g C_g \sigma N(\sigma, \theta) d\sigma d\theta$$

Incident Power Flux

$$= \int \rho g C_g E(\sigma, \theta) d\sigma d\theta$$

$$\text{Units } \frac{Kg}{m^3} \frac{m}{s^2} \frac{m}{s} m^2 = \frac{Kg \cdot m}{s^3} = \frac{W}{m} \text{ Power per meter width}$$

Absorbed Power Calculation:

$P_{matrix} = f[H_s, T_p]$ WEC Power rating (units kilowatts) is a lookup value from the supplied Power.dat

Anticipated power absorbed with the given WEC width

$$\frac{P_{matrix}}{W} = P_{sink} \text{ Power Sink is the power rating per meter width (units kilowatts/meter)}$$

$$\text{Transmission Coefficient } K_t = \frac{P_{inc} - P_{sink}}{P_{inc}} = 1 - \frac{P_{sink}}{P_{inc}}$$

Complete transmission (1.0) if $P_{sink} = 0$, Complete blockage (0.0) if $P_{sink} = P_{inc}$

$$K_t = \frac{P_{inc} - P_{sink}}{P_{inc}} \text{ The ratio of transmitted power to incident power through each grid link}$$

Total Power Absorbed

$$P_{abs} = \int \int \rho g C_g (1 - K_t) \sigma N(\sigma, \theta) d\sigma d\theta dw$$

$$= \int \int \rho g C_g (1 - K_t) E(\sigma, \theta) d\sigma d\theta dw$$

Power absorbed is the Integral over the cell faces of the power flux **NOT** transmitted

Discretely, this is:

$$P_{abs} = \sum_N \int \rho g C_g (1 - K_t) E(\sigma, \theta) d\sigma d\theta \Delta x$$

$$= (1 - K_t) \sum_N \int \rho g C_g E(\sigma, \theta) d\sigma d\theta \Delta x$$

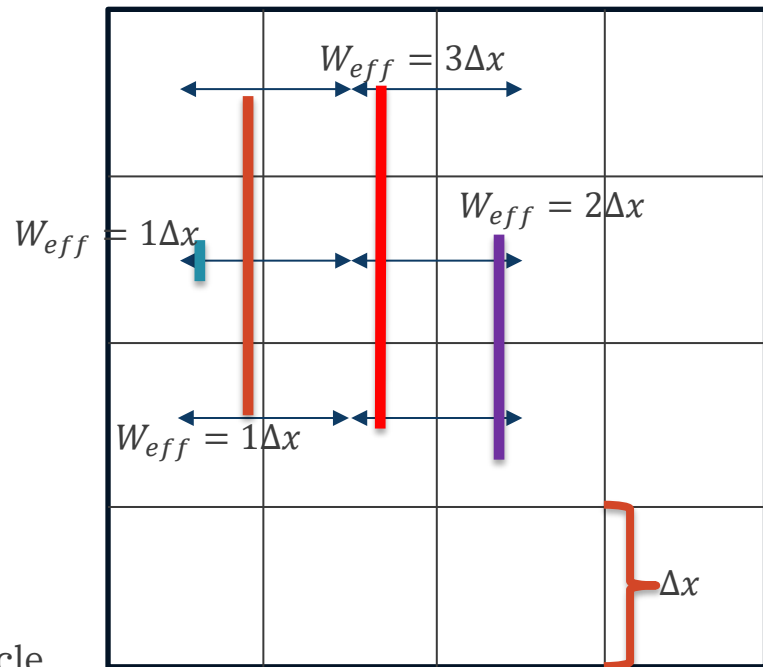
$$= (1 - K_t) \sum_N P_{inc} \Delta x$$

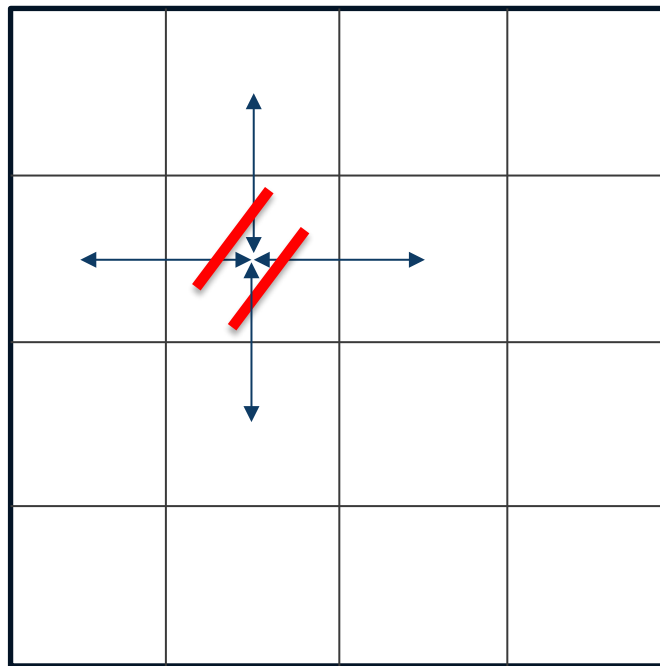
$$= (1 - K_t) P_{inc} N \Delta x$$

$$= \frac{P_{matrix}}{W} N \Delta x$$

Δx - Width of one cell face

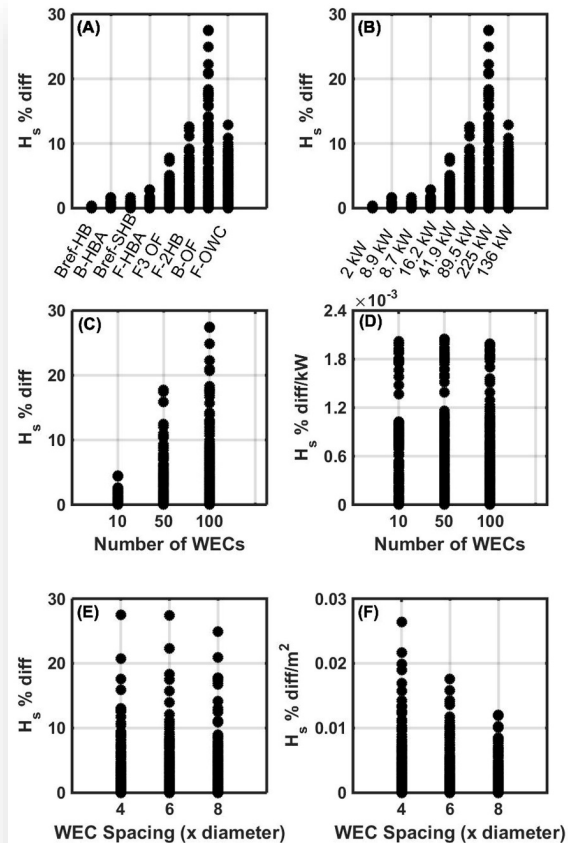
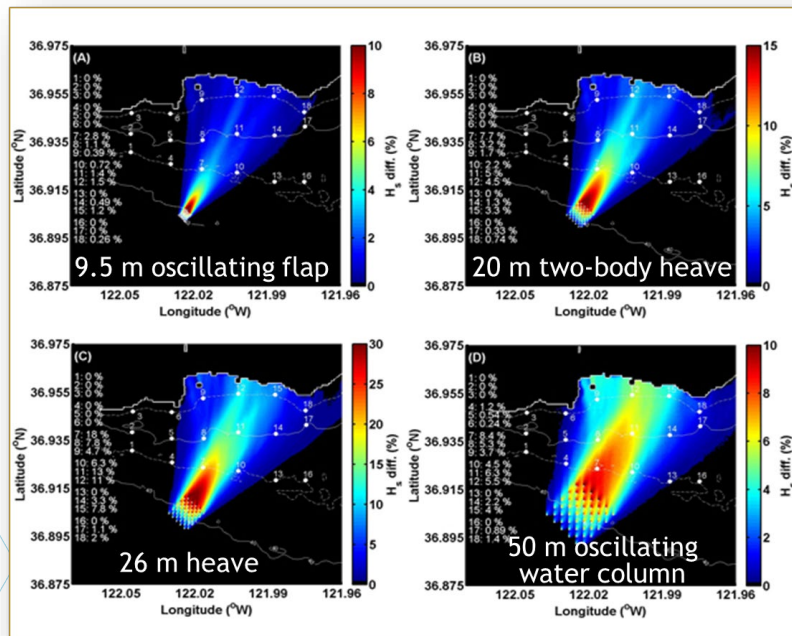
N - Number of grid links crossed by an obstacle





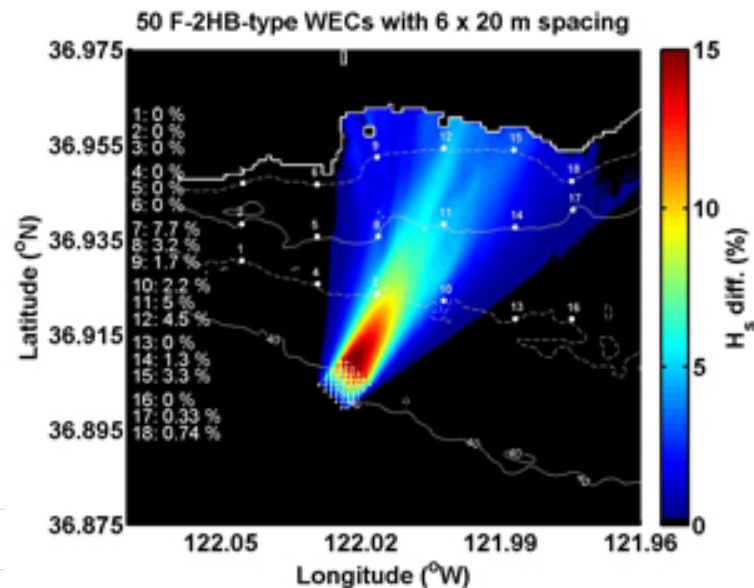
The more I think about it, this is probably the cleanest way to make an omni-directional point absorber, but it requires you to know the grid point locations first

Sensitivity to Device Type

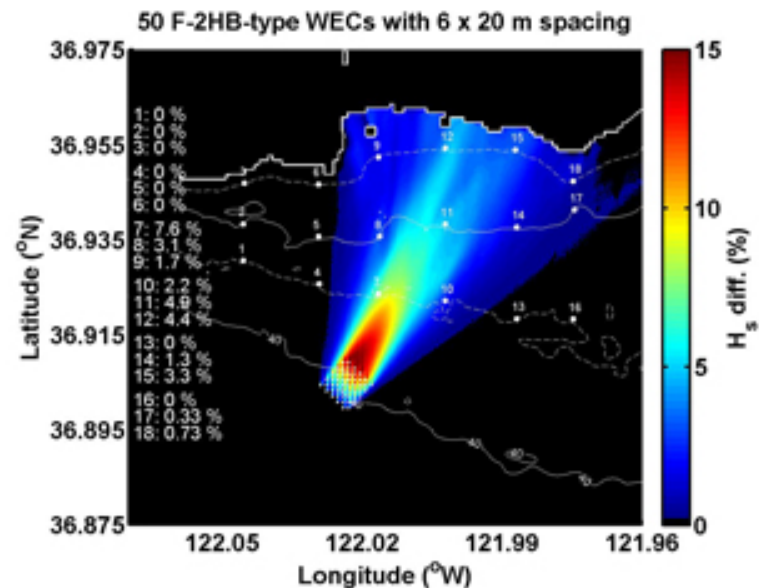


Open Ocean Sensitivity Testing

Interpolation Schemes for Power Matrix



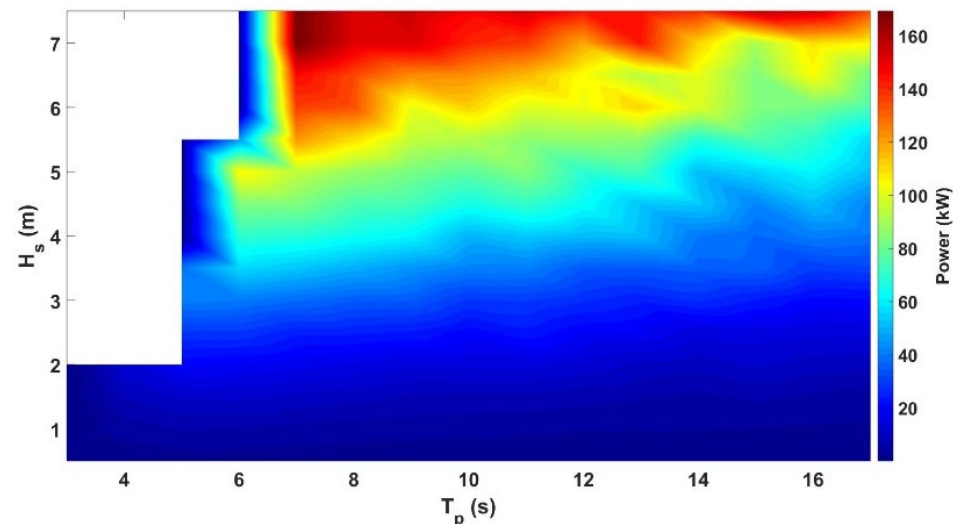
RCW Method



Power Matrix Method

Define WEC Power Performance

- › If Power Matrix is available for discrete wave periods (frequencies) and amplitudes, Obcase 3 may be used.
- › This is calculated for each time step and at each obstacle.
- › In SNL-SWAN this is represented by a *POWER.txt* file shown on the following page.



Babarit, A., J. Hals, M.J. Muliawan, A. Kurniawan, T. Moan, and J. Krokstad (2012) Numerical benchmarking study of a selection of wave energy converters, *Renew. Energ.*, 41, 44-63.