Coupling Alongshore Variations in Wave Energy to Beach Morphologic Change Using the SWAN Wave Model at Ocean Beach, San Francisco, CA

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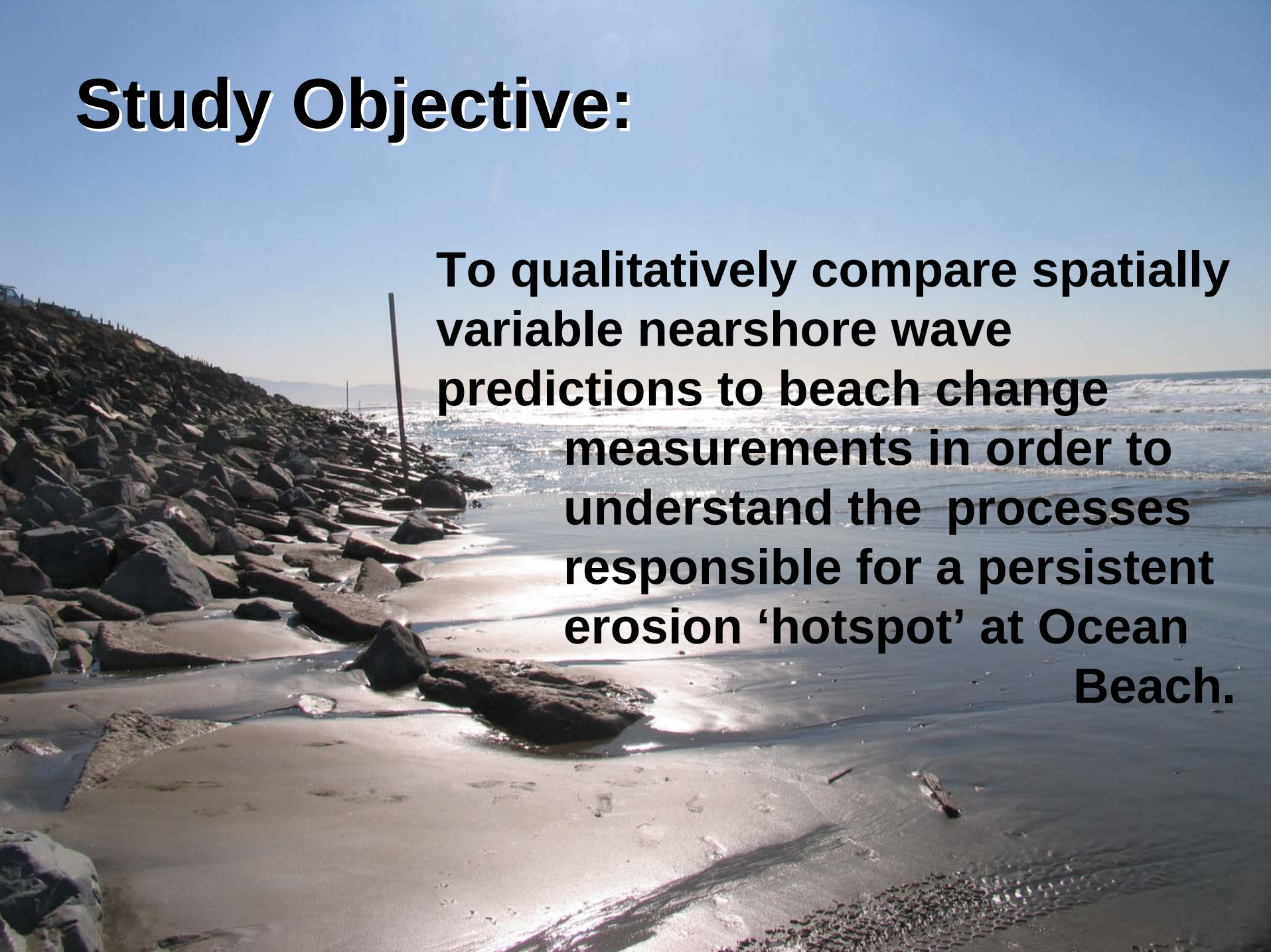
USGS science for a changing world

Study Objective:



To qualitatively compare spatially variable nearshore wave predictions to beach change measurements in order to understand the processes responsible for a persistent erosion 'hotspot' at Ocean Beach.

Methodology

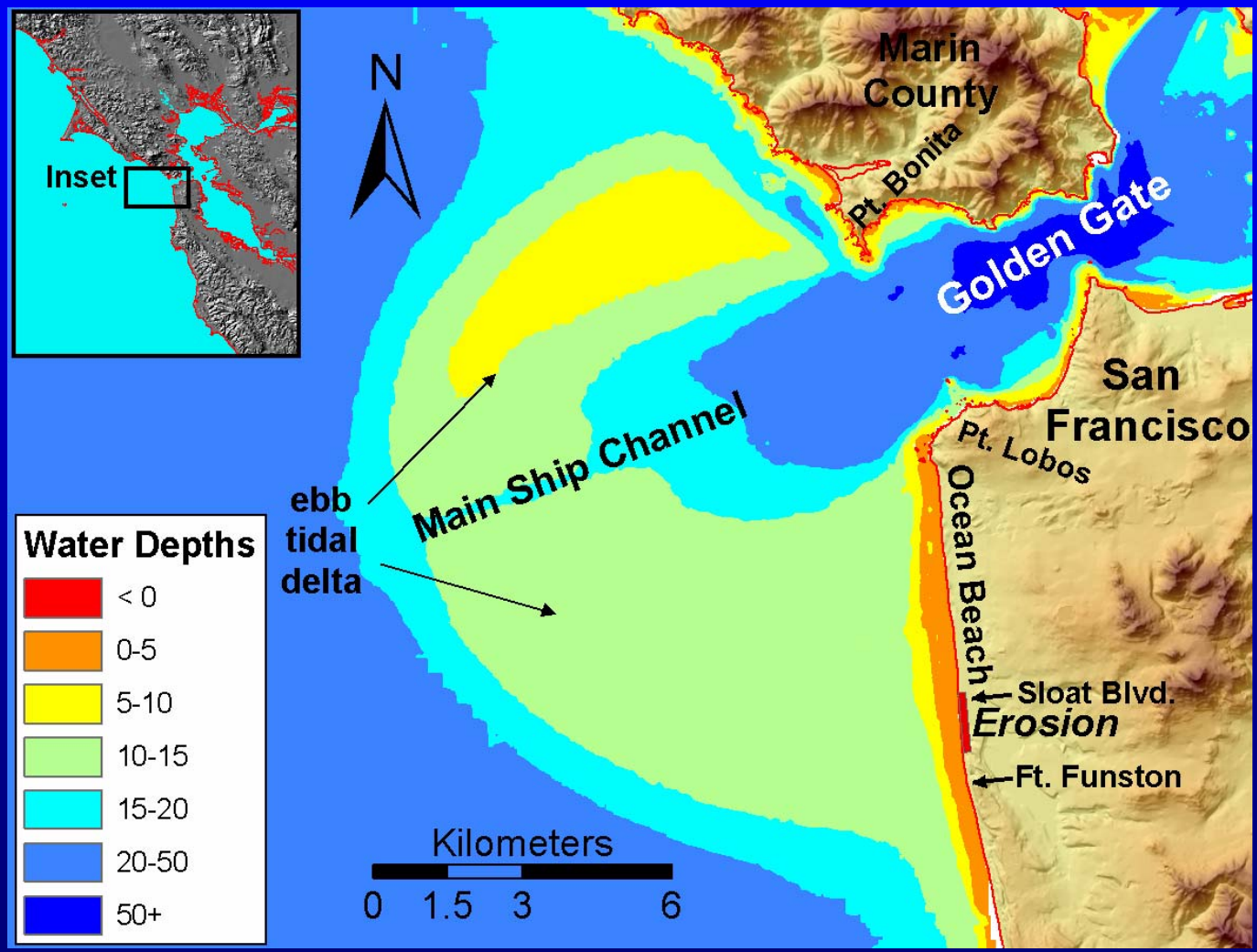
- Calibrate and validate SWAN wave model with local measurements
- Compute alongshore varying average beach change statistics from topographic survey and lidar data
- Run SWAN model for thousands of binned offshore wave conditions to isolate effects of offshore wave direction and period

Summary of Conclusions

- The wave model generally underestimates wave heights, but often because it overly dissipates the high frequency energy
- Changes in all beach parameters at the same alongshore location suggest that the bathymetry exerts a first order control over the location of the erosion hotspot
- Average wave height contour shapes can be grouped based on offshore incident angle relative to 270˚
- The erosion hotspot is not located where wave energy is focused, but south of the focus section where there are strong gradients in significant wave height alongshore

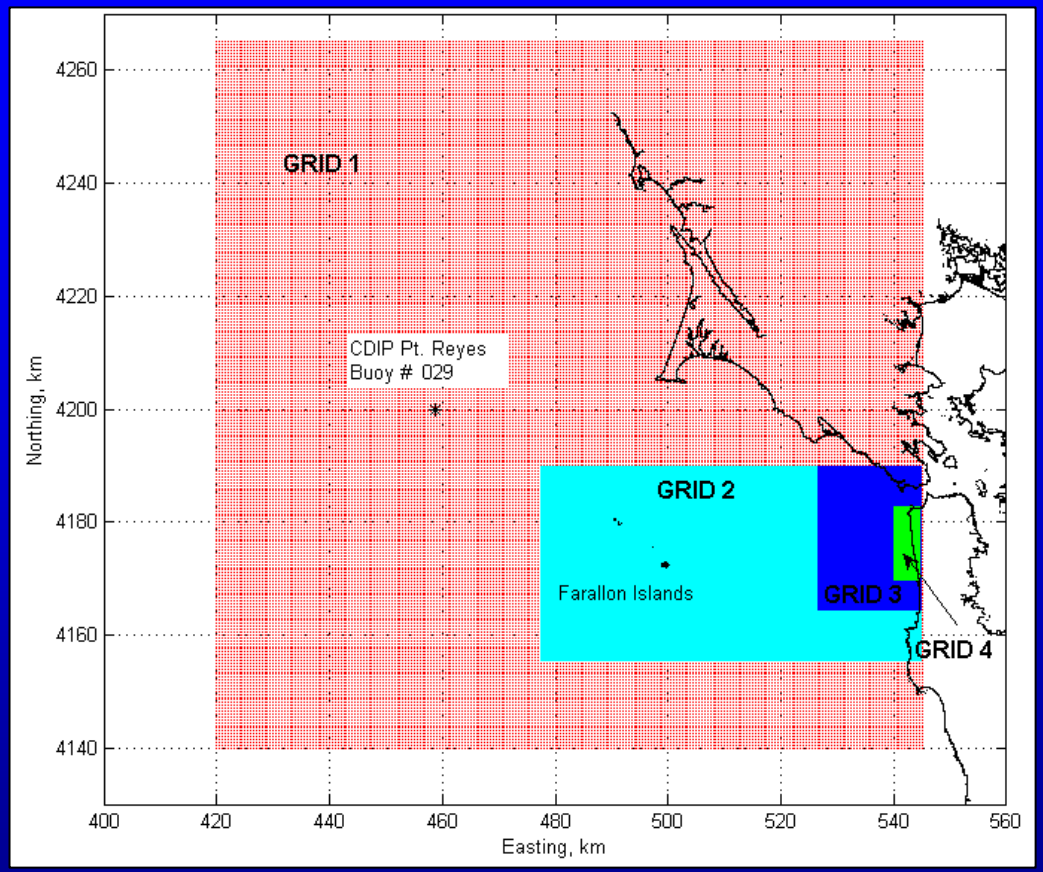
Study Location

San Francisco Bight in Central California



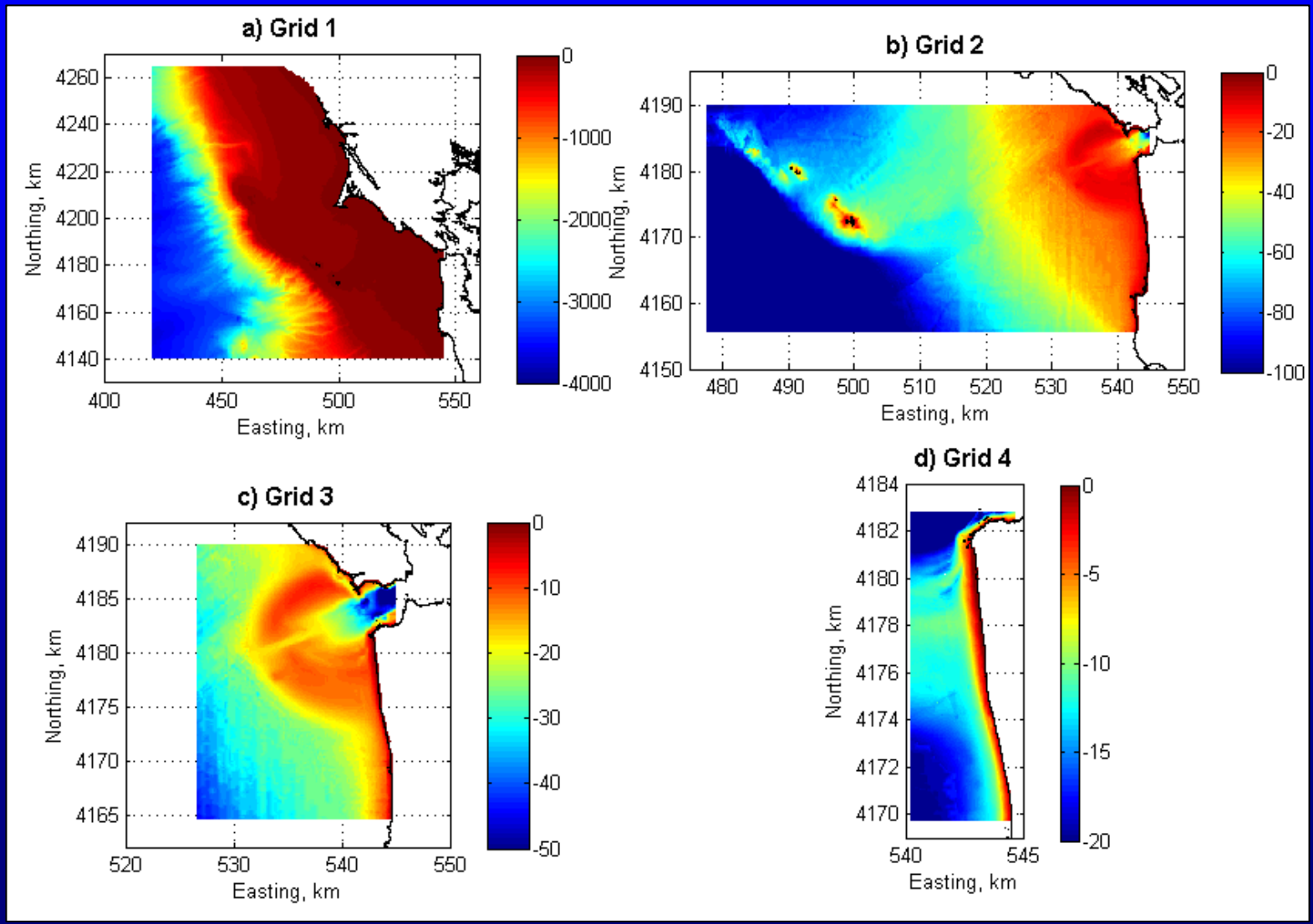
SWAN Setup

- Four nested grids with 500 m, 200 m, 100 m, and 25 m resolution
- CDIP buoy #029 data used to force model on 3 open boundaries (2D MEM Spectra)
- Current grid generated with Delft3D flow model

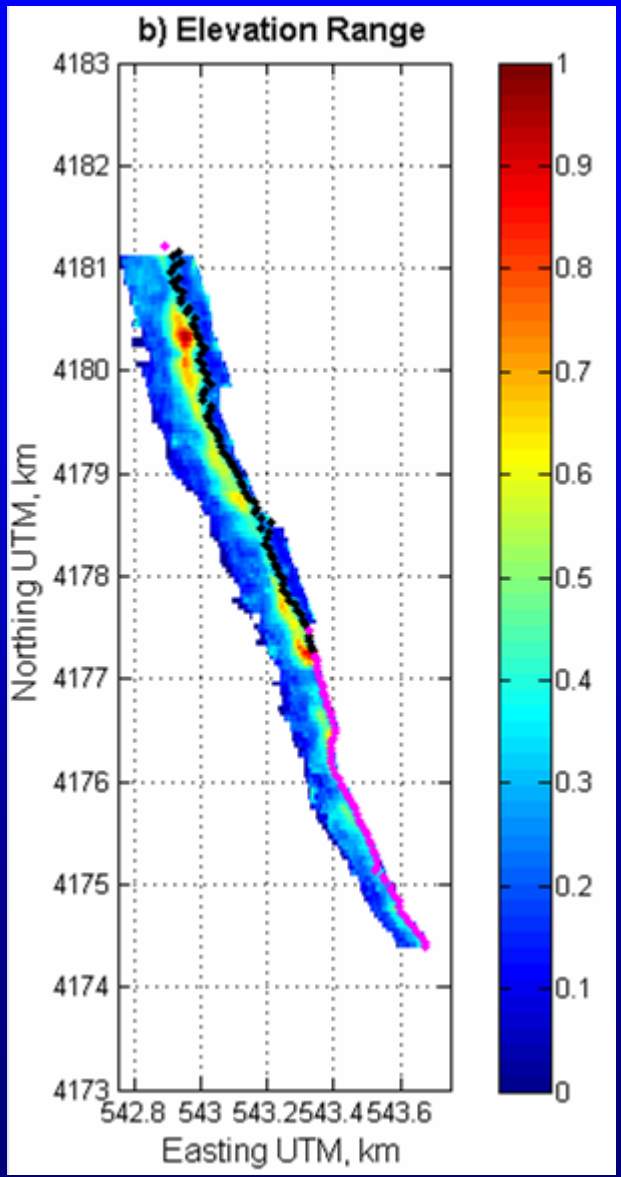


- Sensitivity analysis and friction calibration to determine detailed SWAN setup for version 40.51 in stationary mode.

SWAN Bathymetry



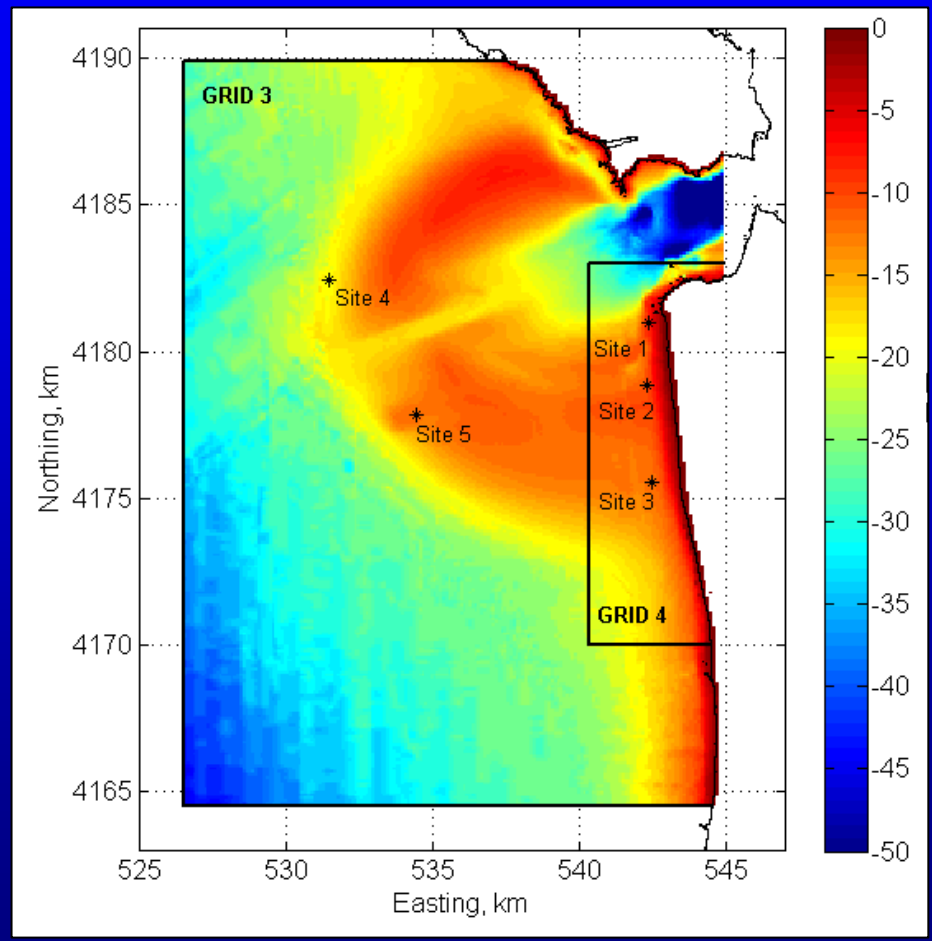
Defining Beach Statistics



- 34 topographic surveys (April 2004 – August 2006)
- 138 cross-shore profiles with 50m alongshore spacing
- Profile range defined by 30 cm below MSL and the upper swash limit
- Upper swash limit defined by standard deviation of elevation in the north and limit of survey coverage in the south
- Beach statistics include total beach width, sediment storage, beach slope and location of MHW line

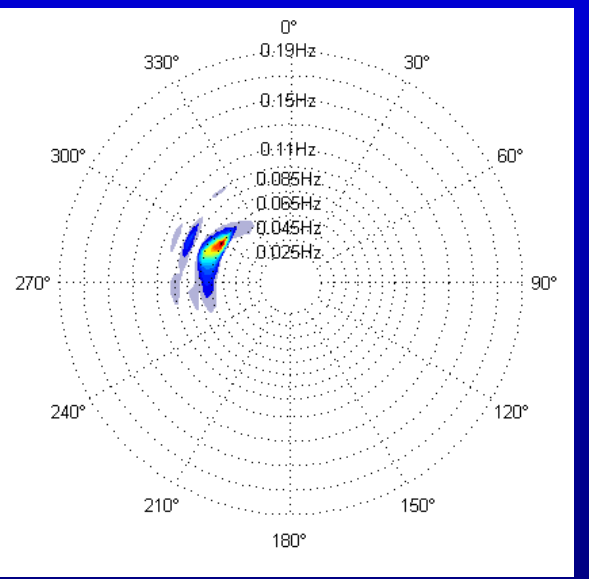
Instrument Measurements

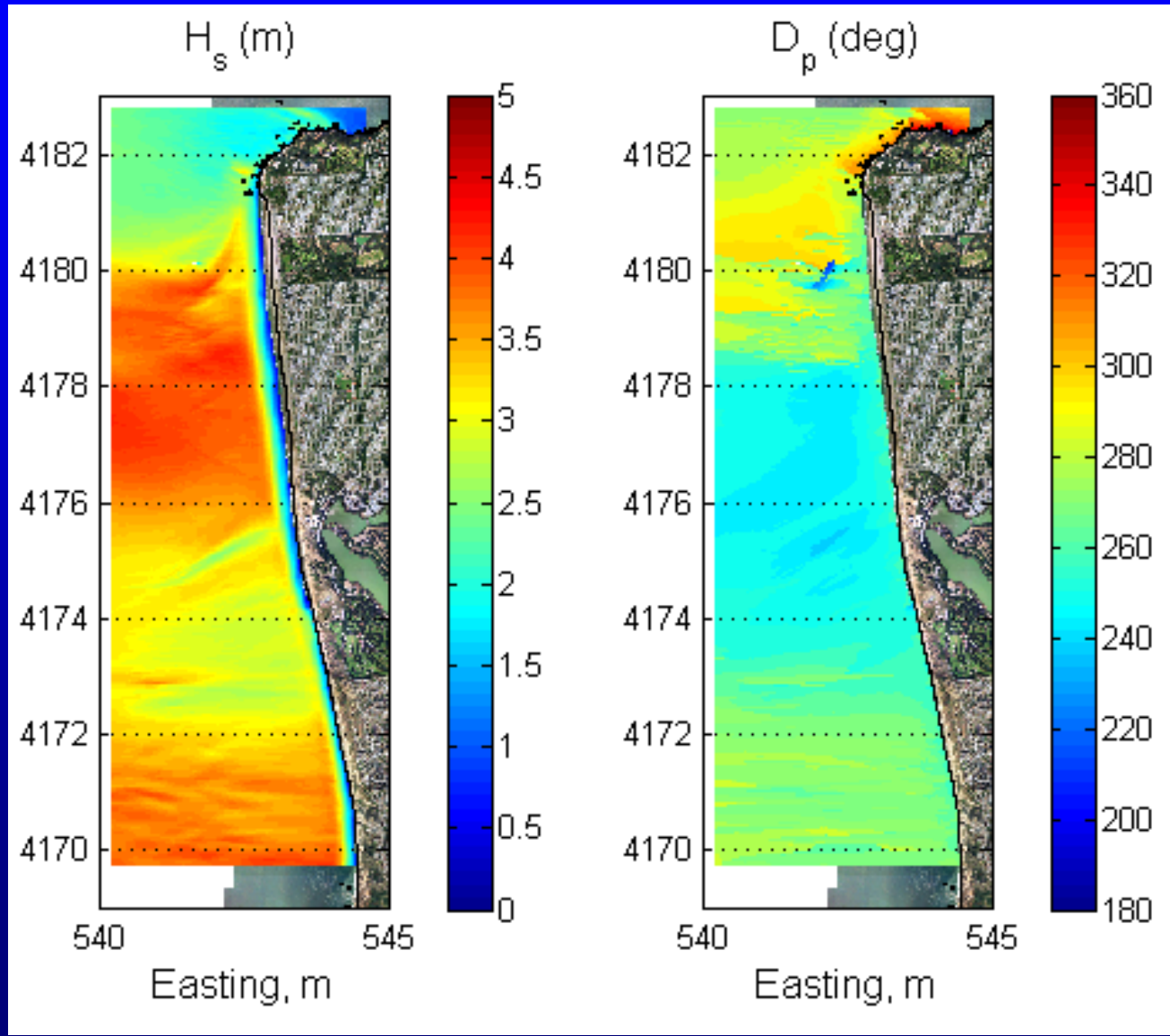
- Current profilers deployed at five locations off Ocean Beach
- Summer 2005 : Sites 1-4
- Winter 2006: Sites 3, 5
- Six test cases chosen for model validation (range of offshore conditions)



Large Onshore Winter Swell – Test Case 6

2D Spectral Forcing
(From CDIP buoy #029)
Hs = 5.7 m
Tp = 15.4 sec
Dp = 293 deg





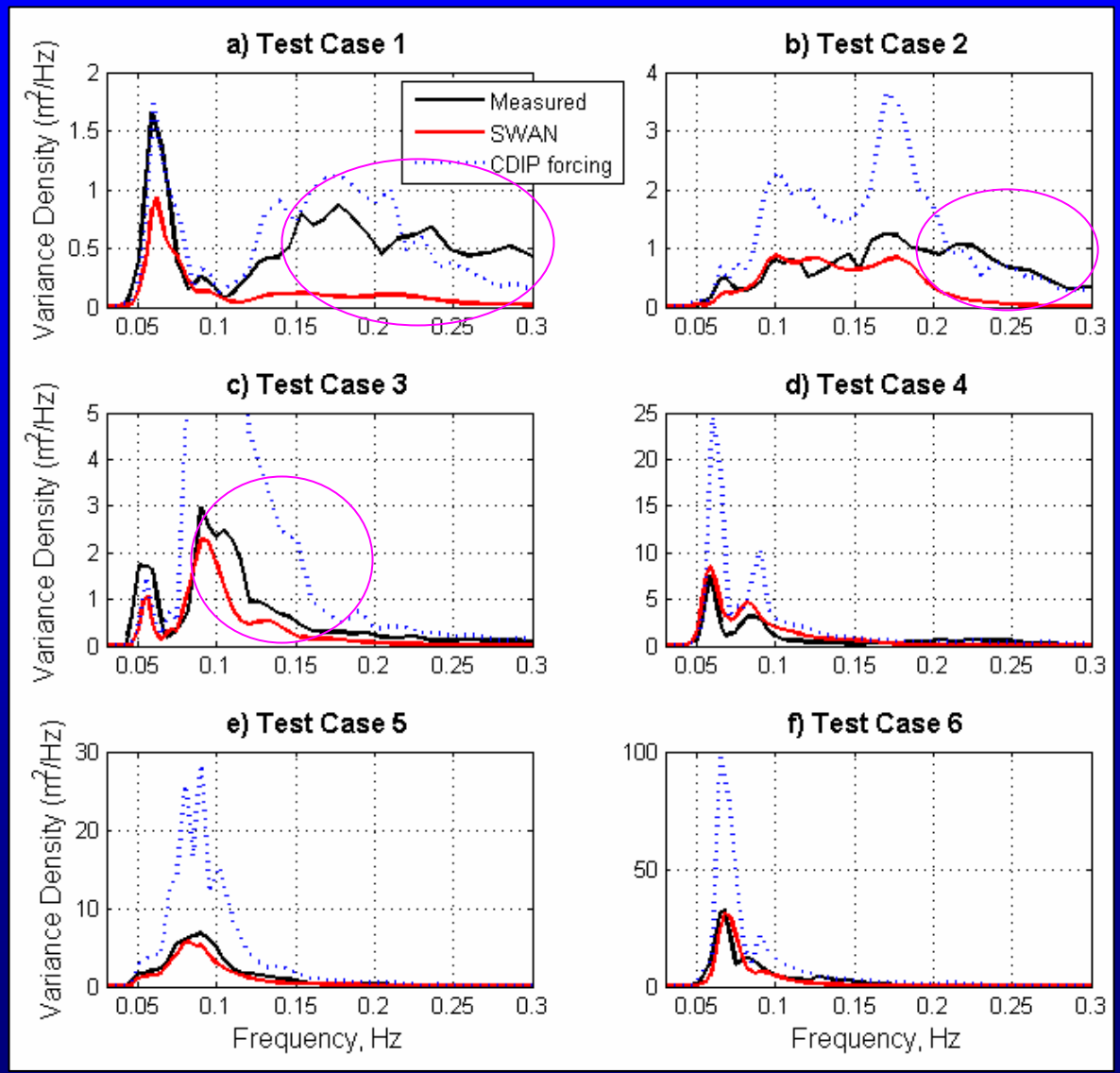
Model-Data Comparisons (Site 3)

Test Case	Meas Time	Model Time	Hs (m), Meas	Hs (m), Model	Tp (sec) Meas	Tp (sec) Model	Dp (deg) Meas	Dp (deg) Model
1	6/27/05 08:26:00	6/27/05 08:00:00	1.51	0.75	18.2	16.6	220	213
2	7/11/05 22:56:00	7/11/05 22:00:00	1.70	1.25	5.8	10.3	289	288
3	7/15/05 00:56:00	7/15/05 00:00:00	1.65	1.23	11.6	10.9	286	298
4	1/13/06 22:00:00	1/13/06 22:00:00	1.90	2.17	18.2	16.3	228	243
5	1/29/06 18:30:00	1/29/06 18:00:00	2.36	2.00	11.6	12.5	279	248
6	2/5/06 07:00:00	2/5/06 06:00:00	3.77	3.32	16.0	14.8	238	238

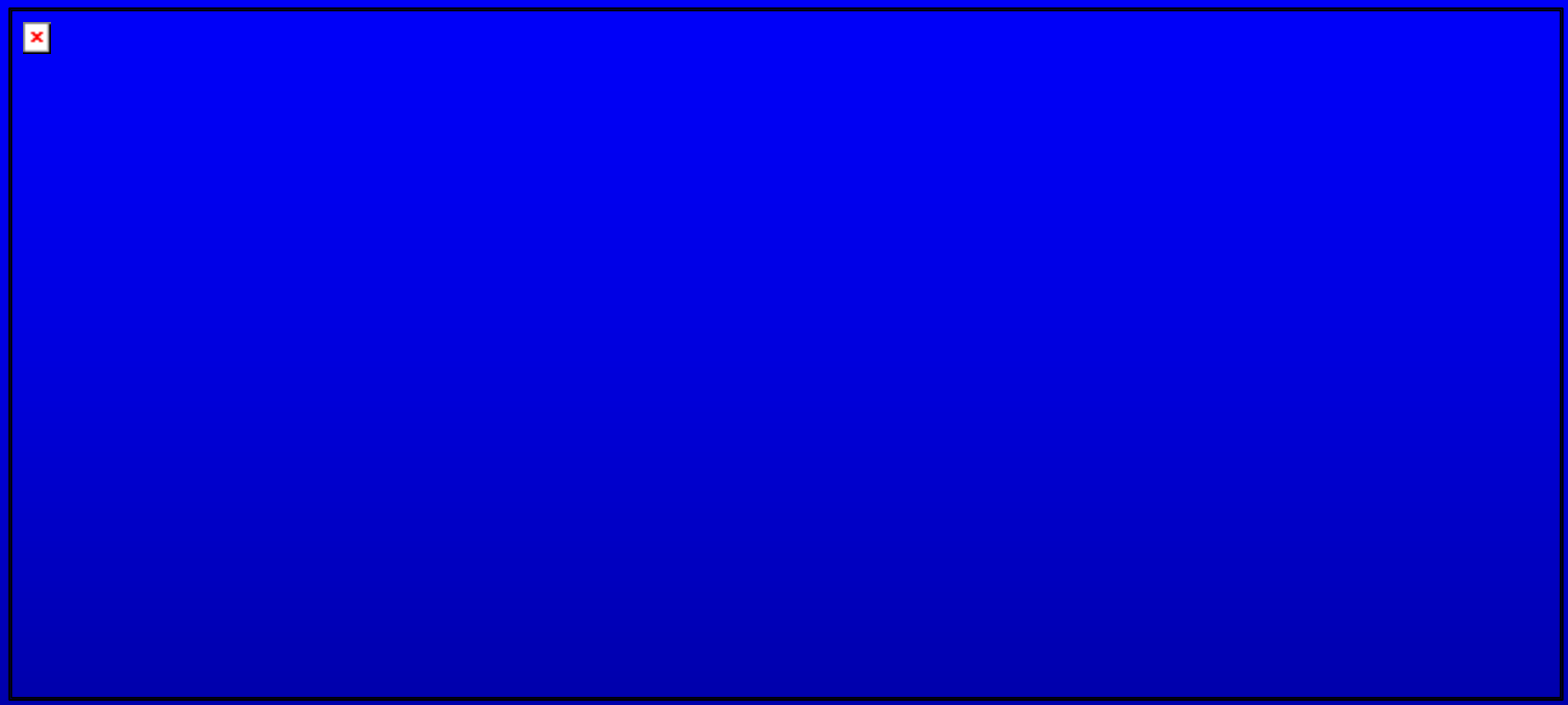
red = model comparison to measurement (>±20% difference)
orange = model comparison to measurement (>±10% and <±20% difference)
green = model comparison to measurement (<±10% difference)

1-D Spectral Comparisons

- Model successfully captures refraction patterns, energy changes
- Overly dissipates the high frequency energy for Summer test cases
- Model does a good job of transferring energy in large winter swell events



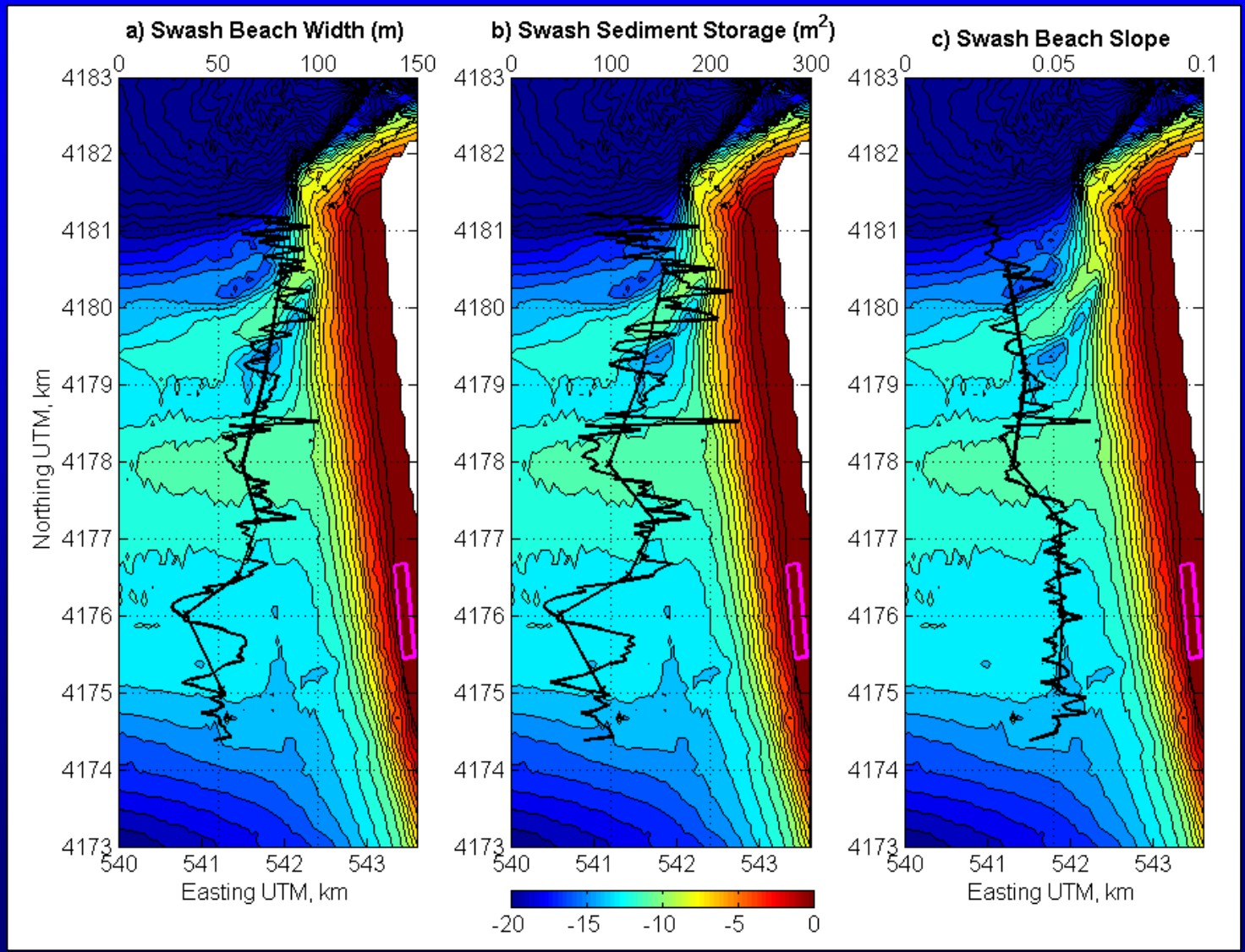
Shoreline Change



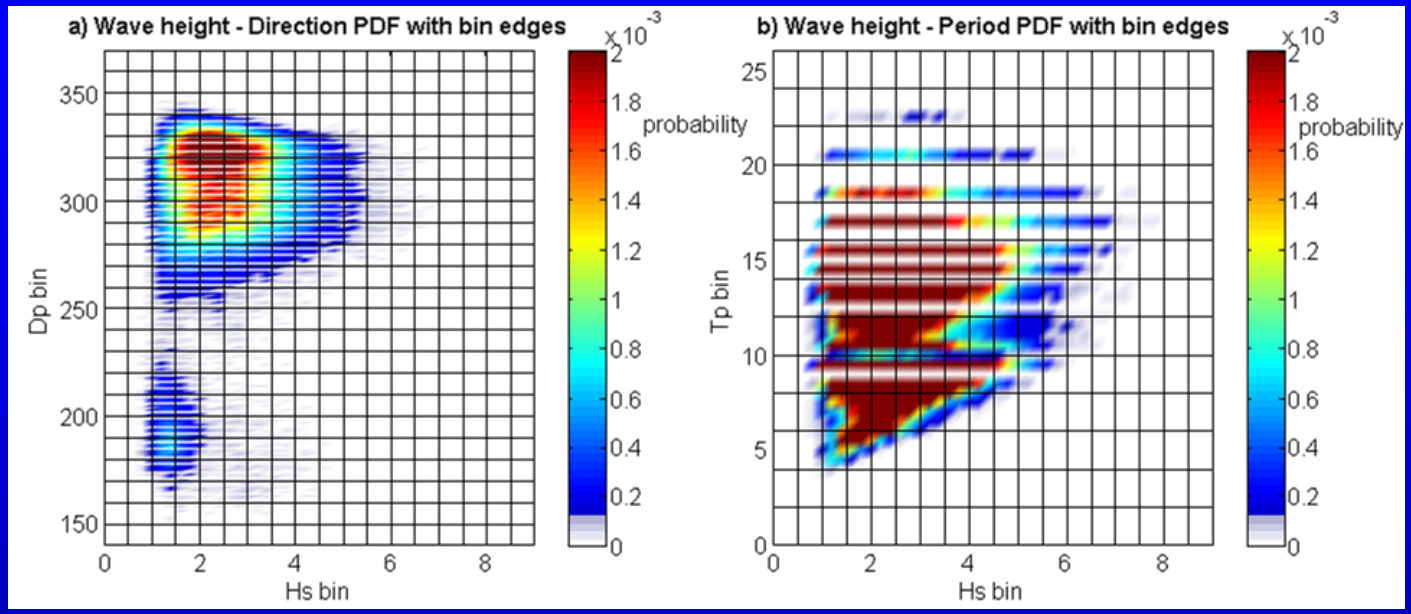
- Seasonal shoreline change rates switch from accretion to erosion at profile 80
- Profile 80 is in reach 4, just north of the 4177 km northing location
- Average shoreline change rates for April 1997 – 2006
    - Profiles 1-79: 1.1 m/yr
    - Profiles 80-138: -0.9 m/yr

Beach Morphology Change

Average Profile Statistics



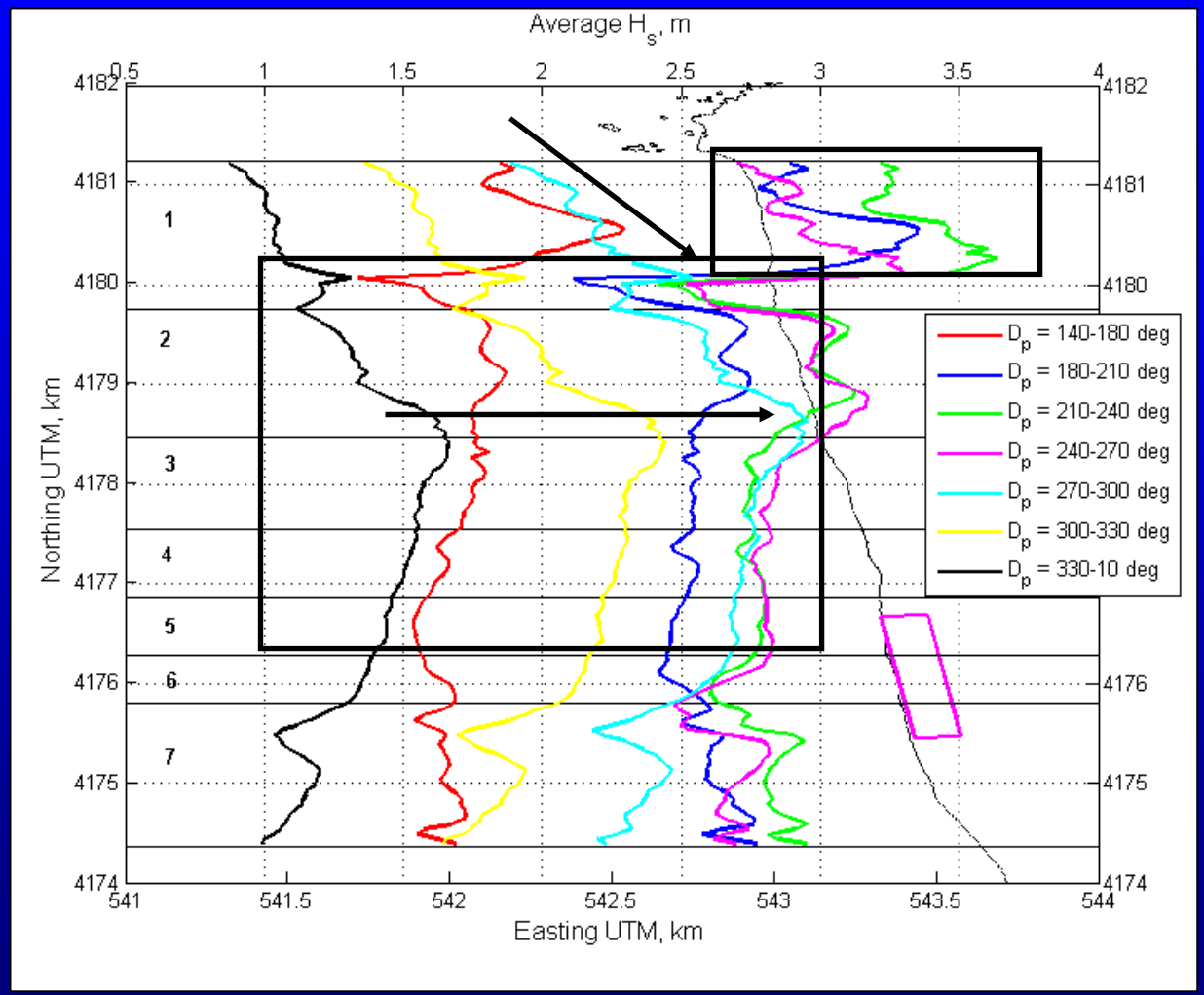
Binned Model Runs



- Bins of Hs, Tp and Dp generated based on available record at CDIP buoy #029
- Equally spaced bins: 0.5 m resolution for Hs, 10 deg for Dp, and 2 sec for Tp
- SWAN model run for each possible binned combination: 4577 runs
- Results compiled in a look-up table: gives bulk wave parameter output at each profile location along the 10 m contour
- Constant parameterized forcing was applied on all boundaries

Impact of Incident Wave Angle

- Strong gradients in wave height alongshore
- Average wave height contour shapes can be grouped based on offshore angle relative to 270˚
- Bins > 270 ˚ (cyan, yellow, black)
- Bins < 270 ˚ (red, blue, green, magenta)
- More onshore directed angles give greater wave height output at Ocean Beach



Concluding Remarks

- The wave model captures complicated refraction patterns and changes in energy from offshore conditions well, but generally underestimates wave heights at OB
- The shoreline change rate and beach statistics all show a change at profile 80, which is just south of where the ebb tidal delta connects to shore. The erosion hotspot is <1km south of this location.
- Southerly incident wave angles show different spatial variation and focus energy on the entire beach, whereas northerly angles focus energy on central reaches
- The erosion hotspot is located south of the focus section where there are strong gradients in significant wave height alongshore

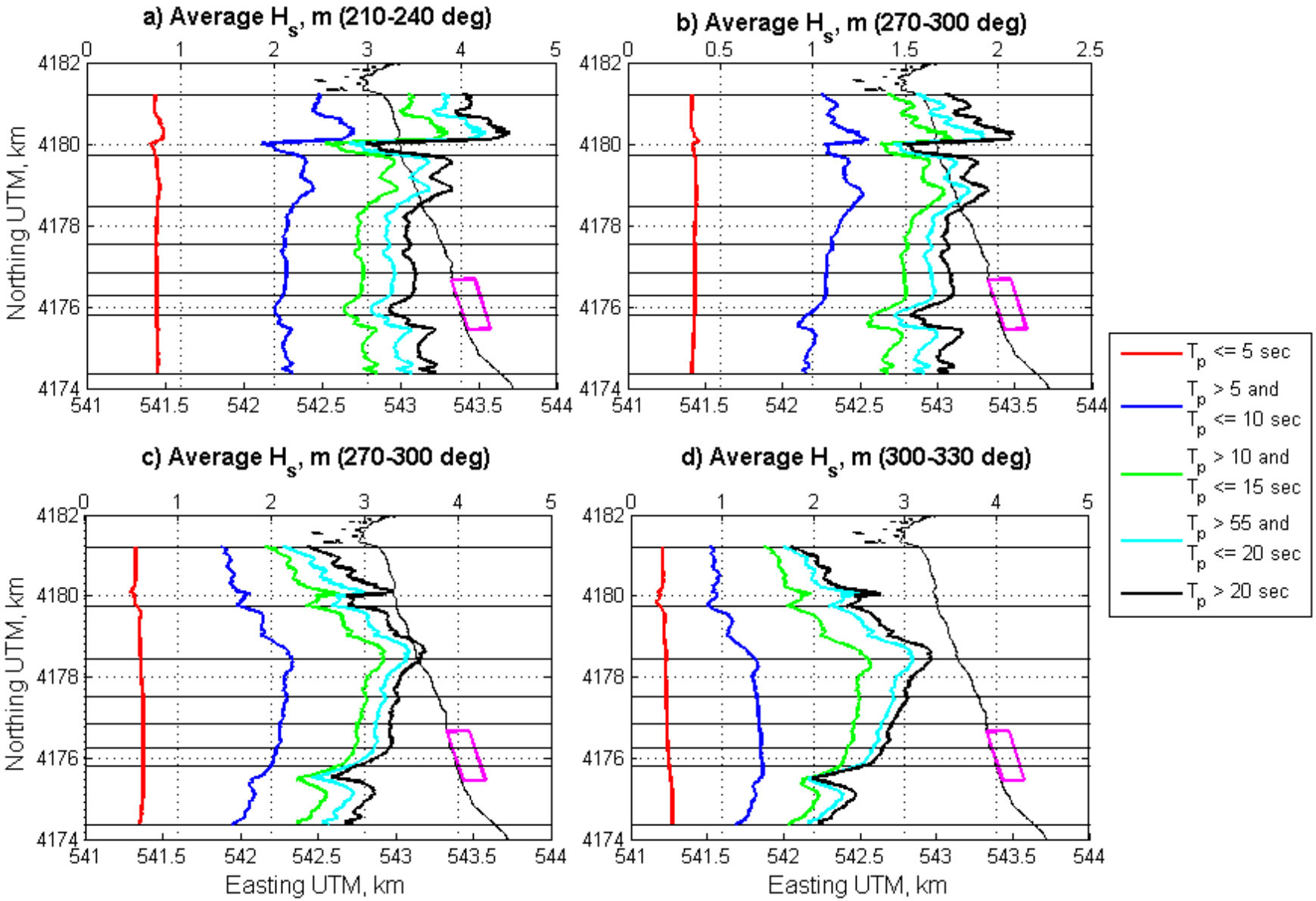
Future Work

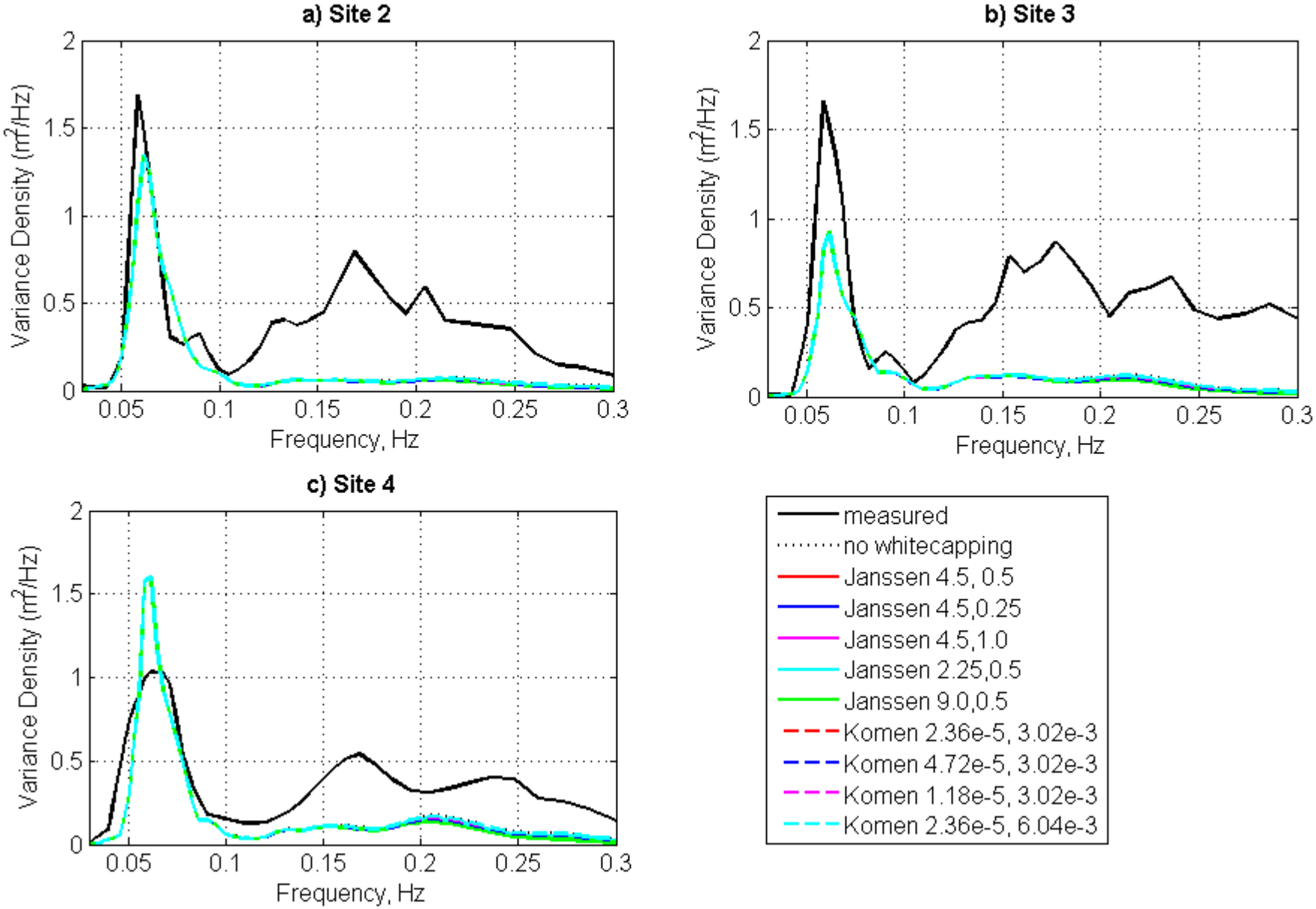
- Incorporate the wave model into a full 2D circulation model to look at varied sediment transport patterns along the beach.

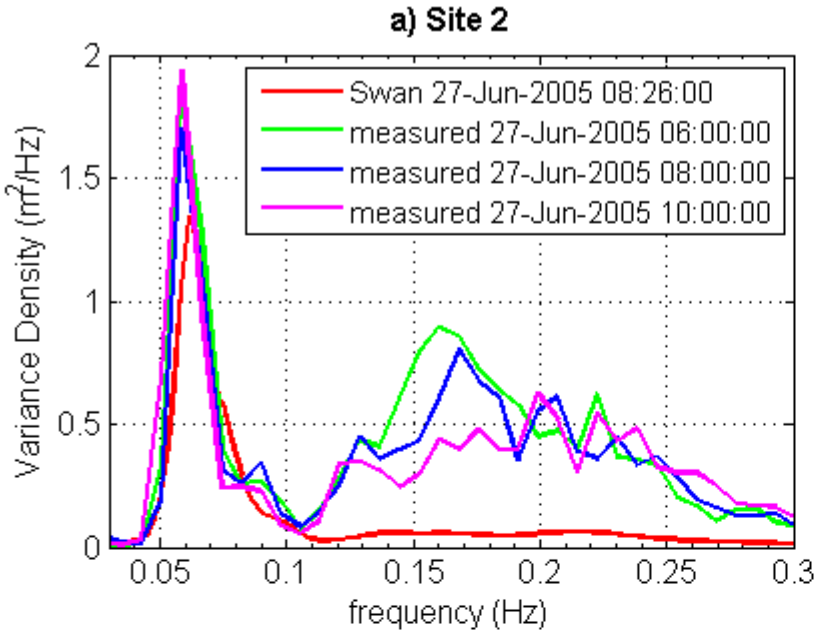
- Look up table can be used as input for probabilistic shoreline change modeling for coastal hazard assessment similar to technique used by Ruggiero et al (2006) on the Washington coast.

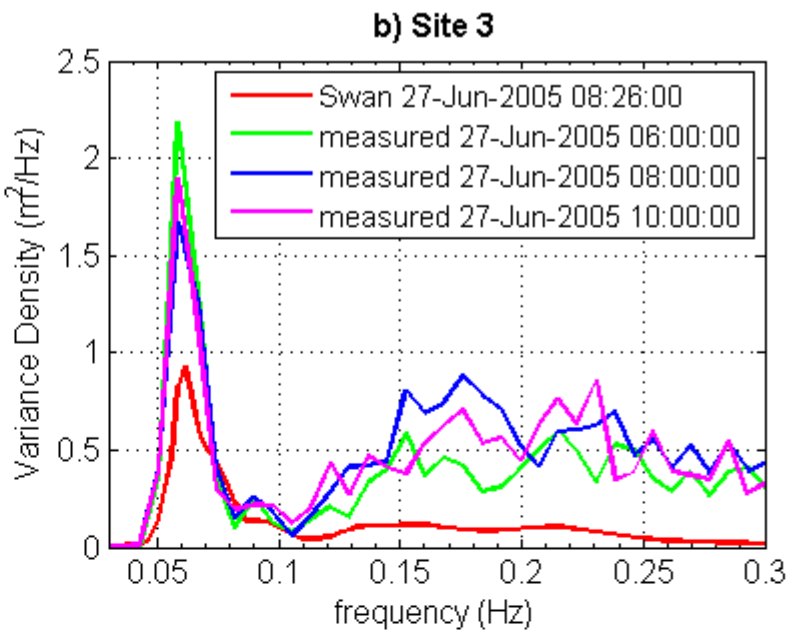

Questions?

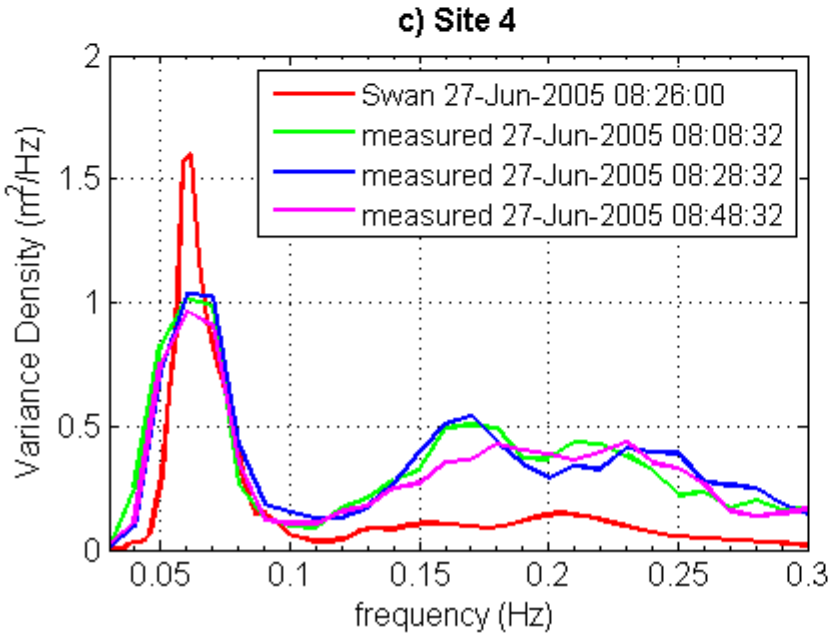
Impact of Wave Period

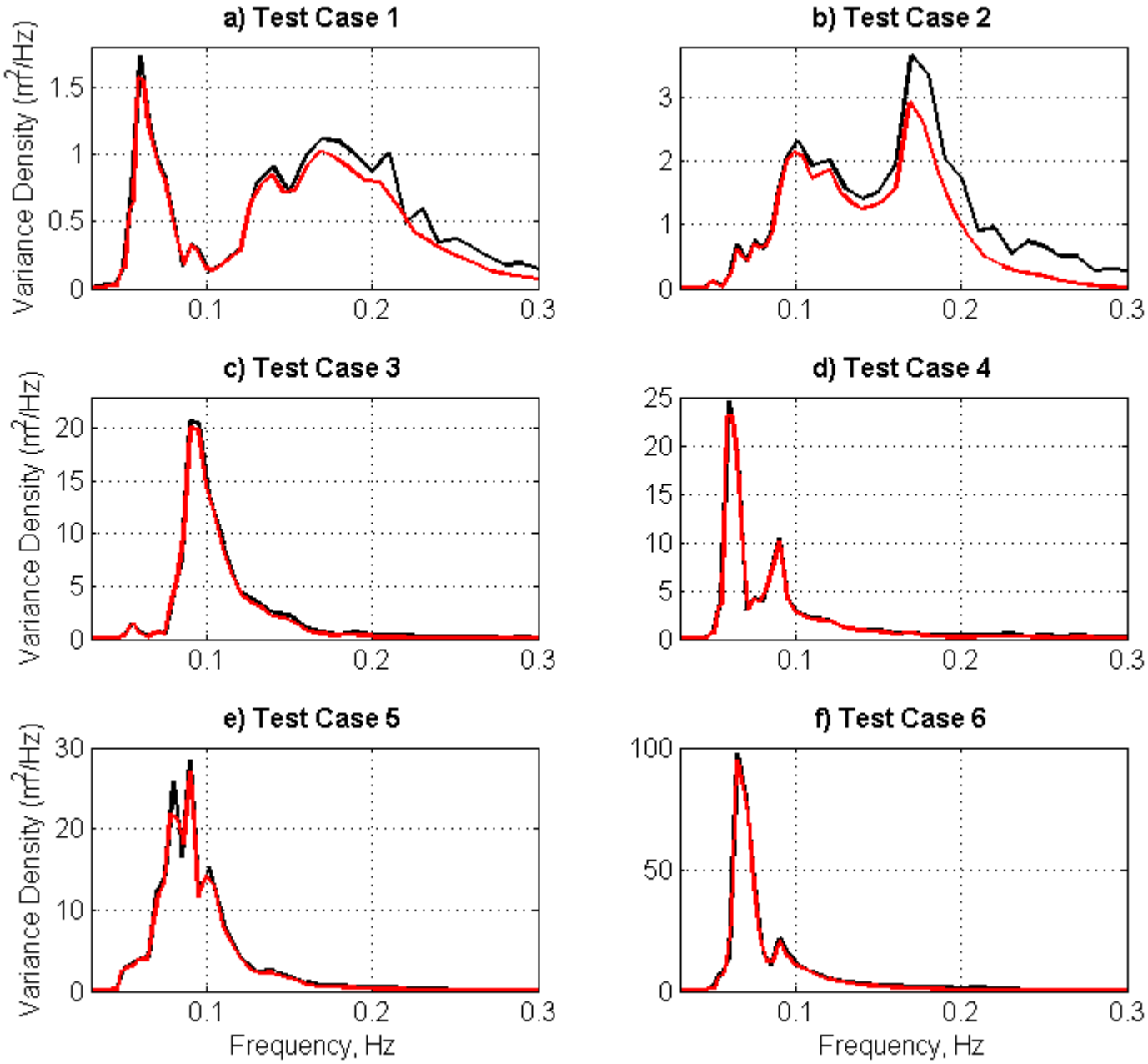


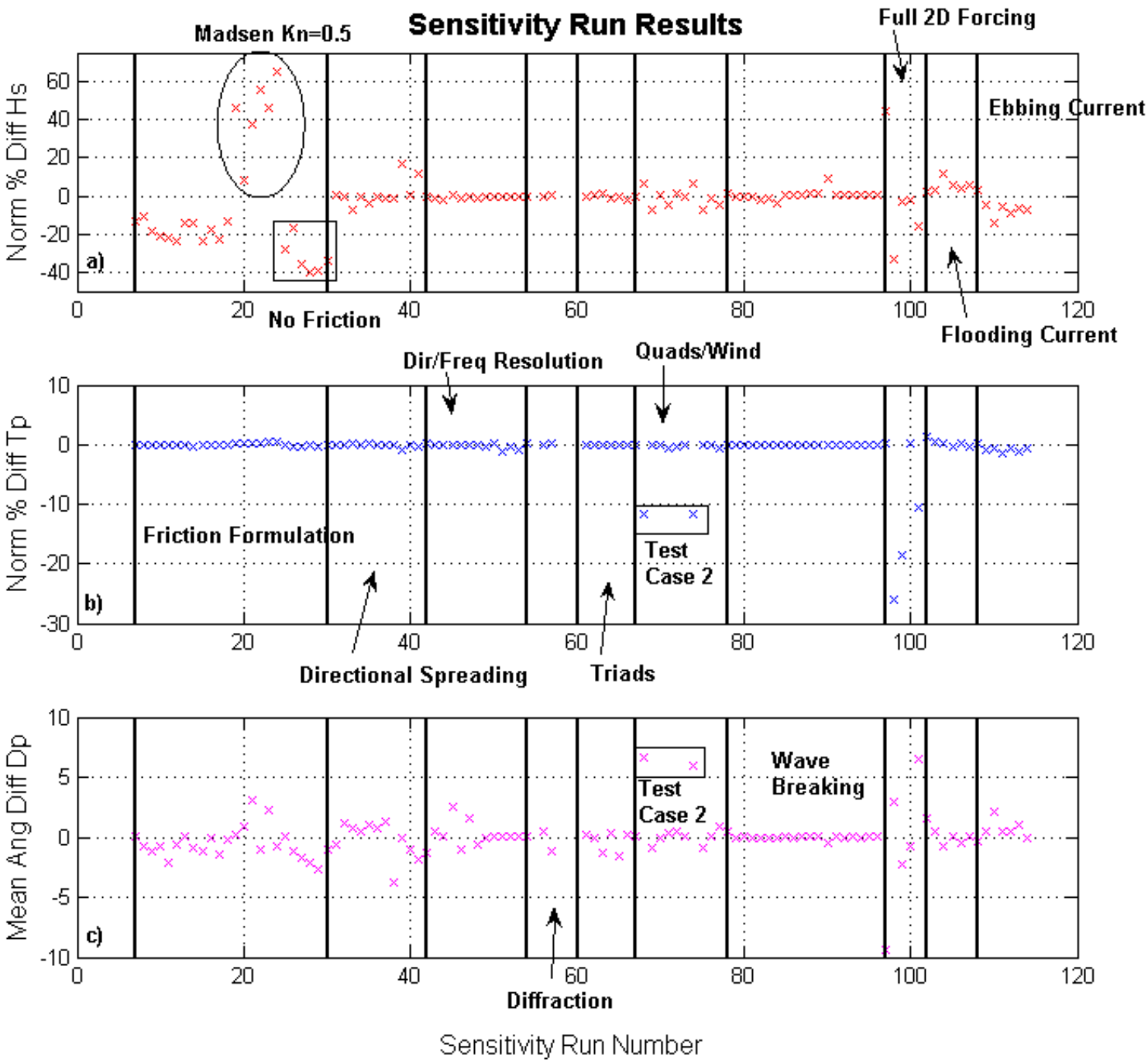

a) Site 2
b) Site 3
c) Site 4
Variance Density (m²/Hz)
Frequency, Hz
0
0.5
1
1.5
2
0.05
0.1
0.15
0.2
0.25
0.3
measured
no whitecapping
Janssen 4.5, 0.5
Janssen 4.5,0.25
Janssen 4.5,1.0
Janssen 2.25,0.5
Janssen 9.0,0.5
Komen 2.36e-5, 3.02e-3
Komen 4.72e-5, 3.02e-3
Komen 1.18e-5, 3.02e-3
Komen 2.36e-5, 6.04e-3


a) Site 2
Swan 27-Jun-2005 08:26:00
measured 27-Jun-2005 06:00:00
measured 27-Jun-2005 08:00:00
measured 27-Jun-2005 10:00:00
Variance Density (m²/Hz)
frequency (Hz)
0
0.5
1
1.5
2
0.05
0.1
0.15
0.2
0.25
0.3


b) Site 3
Swan 27-Jun-2005 08:26:00
measured 27-Jun-2005 06:00:00
measured 27-Jun-2005 08:00:00
measured 27-Jun-2005 10:00:00
Variance Density (m²/Hz)
frequency (Hz)
0
0.5
1
1.5
2
2.5
0.05
0.1
0.15
0.2
0.25
0.3


c) Site 4
Swan 27-Jun-2005 08:26:00
measured 27-Jun-2005 08:08:32
measured 27-Jun-2005 08:28:32
measured 27-Jun-2005 08:48:32
Variance Density (m²/Hz)
frequency (Hz)
0
0.5
1
1.5
2
0.05
0.1
0.15
0.2
0.25
0.3


a) Test Case 1
b) Test Case 2
c) Test Case 3
d) Test Case 4
e) Test Case 5
f) Test Case 6
Variance Density (m²/Hz)
Frequency, Hz
0
0.1
0.2
0.3
0.5
1
1.5
2
3
5
10
15
20
25
30
50
100


Sensitivity Run Results
Madsen Kn=0.5
Full 2D Forcing
Ebbing Current
Flooding Current
No Friction
Norm % Diff Hs
a)
Dir/Freq Resolution
Quads/Wind
Friction Formulation
Test
Case 2
Directional Spreading
Triads
Norm % Diff Tp
b)
Wave
Breaking
Test
Case 2
Diffraction
Mean Ang Diff Dp
c)
Sensitivity Run Number

Strong Tidal Currents Influence Wave Period

(Summer Southern Swell – June 27, 2005)