Wave Transformation Modeling with *Bottom Friction* Applied to the Southeast Oahu Reefs

Mary A. Cialone and Jane McKee Smith

Outline

- Objective
- Study Area
- STWAVE Friction Formulations
- Model Validation
- Summary

Objective

RSM Program Goal

An integrated approach of coastal, estuary, and river sediments on a regional scale in the planning and maintenance of water resource projects to achieve balanced and sustainable systems.

POH Goal

Develop an understanding of longshore sediment transport potential in the region and determine the likelihood of accretional/erosional areas within the project domain

ERDC/CHL Goal

To provide POH with a tool for understanding nearshore circulation in the study area

ERDC/CHL Task

Nearshore circulation and wave transformation modeling

ERDC/CHL Technical Tasks

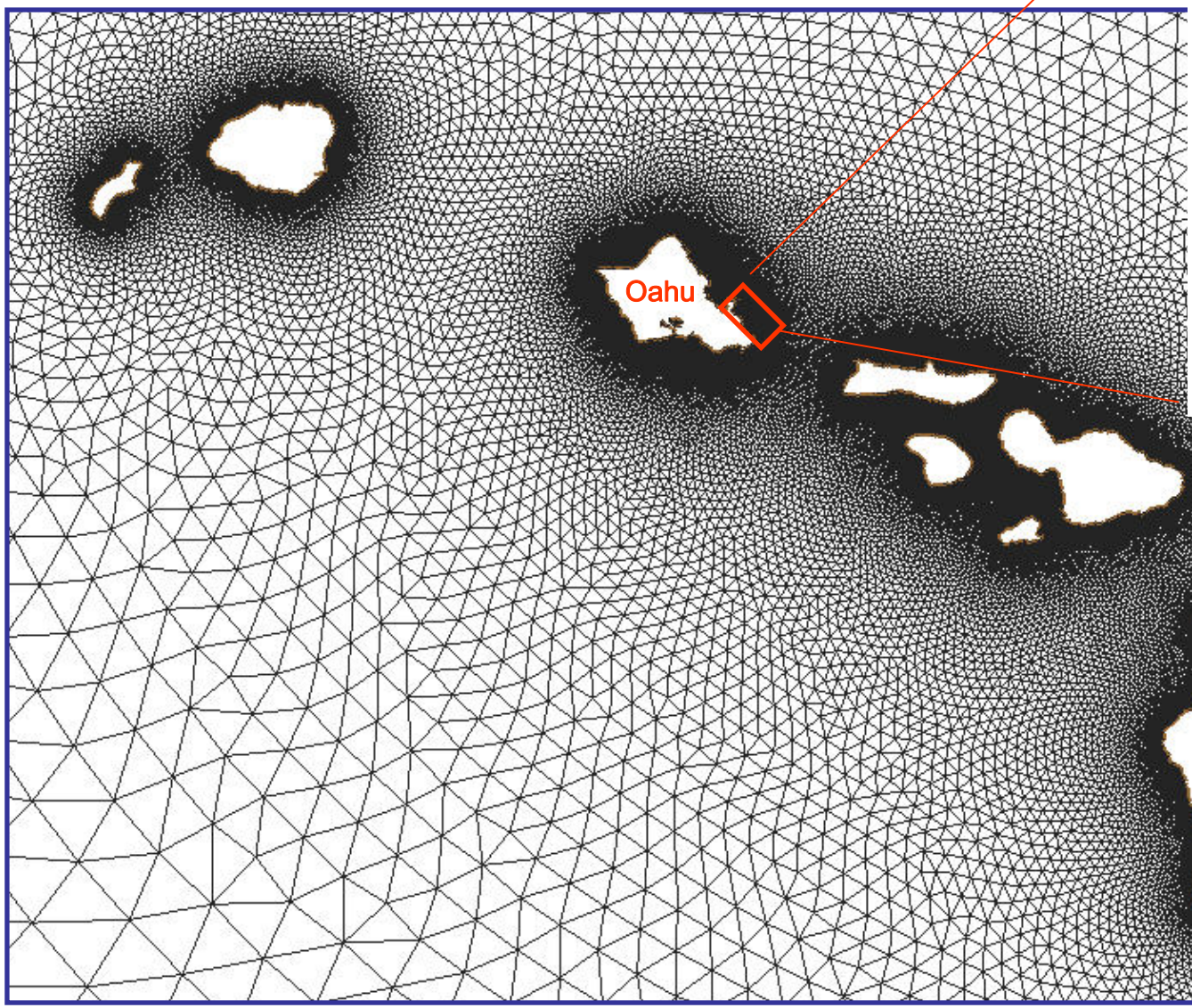
- Data collection/assessment
- Finite element and finite difference grid development
- Development of model forcing conditions
- Bottom friction formulation
- Model simulations
- Model validation
- Simulation analysis

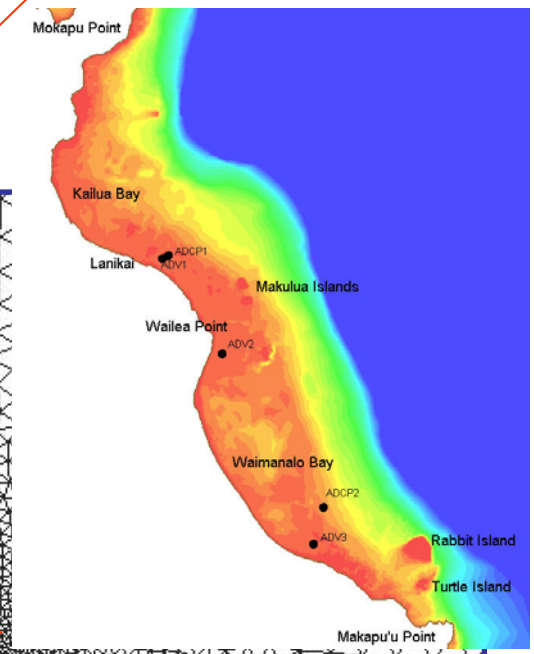
Final product: validated hydrodynamic and wave models for the project site

Outline

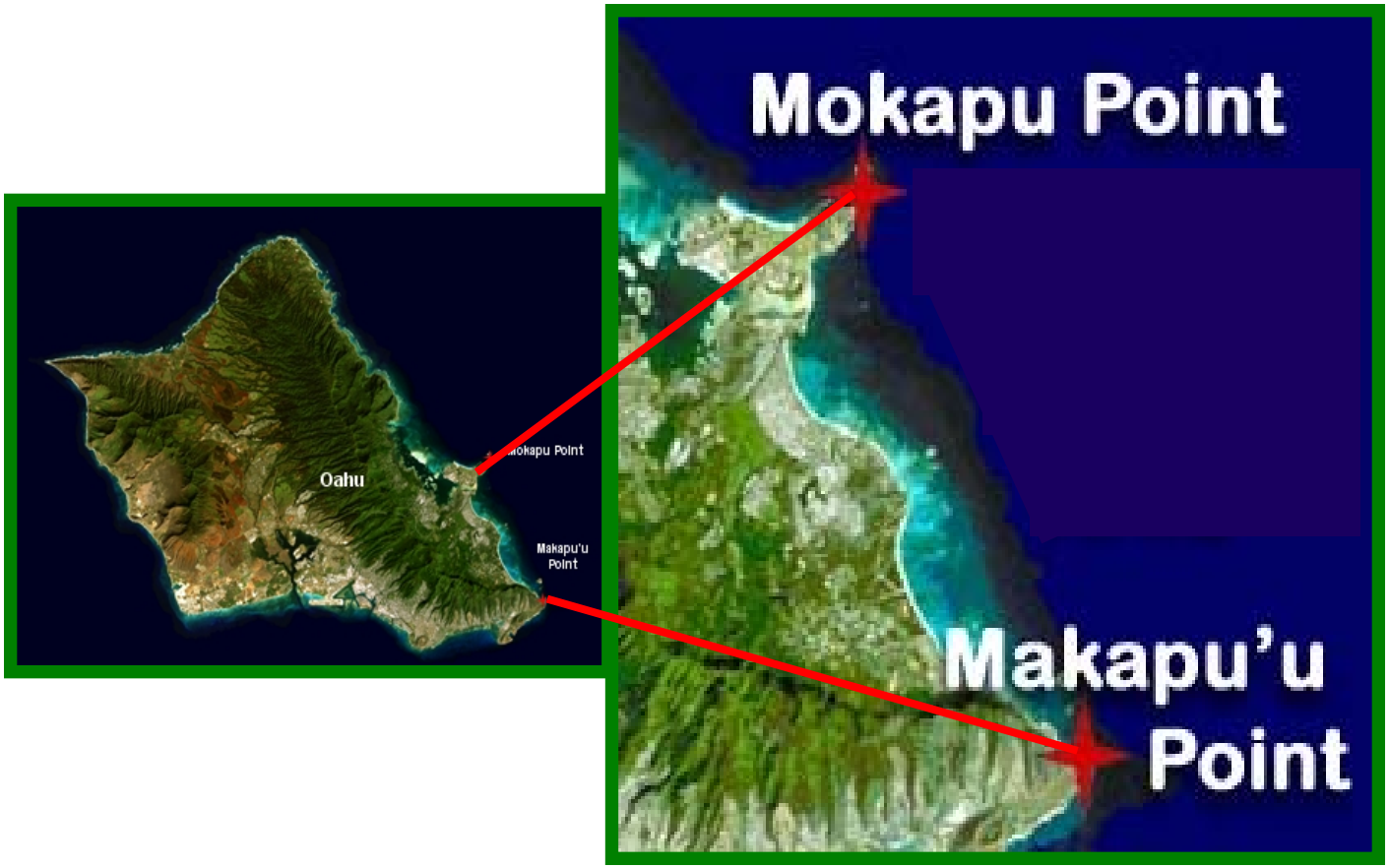
- Objective
- Study Area/Problem Areas
- STWAVE Friction Formulations
- Model Validation
- Summary

The Study Area

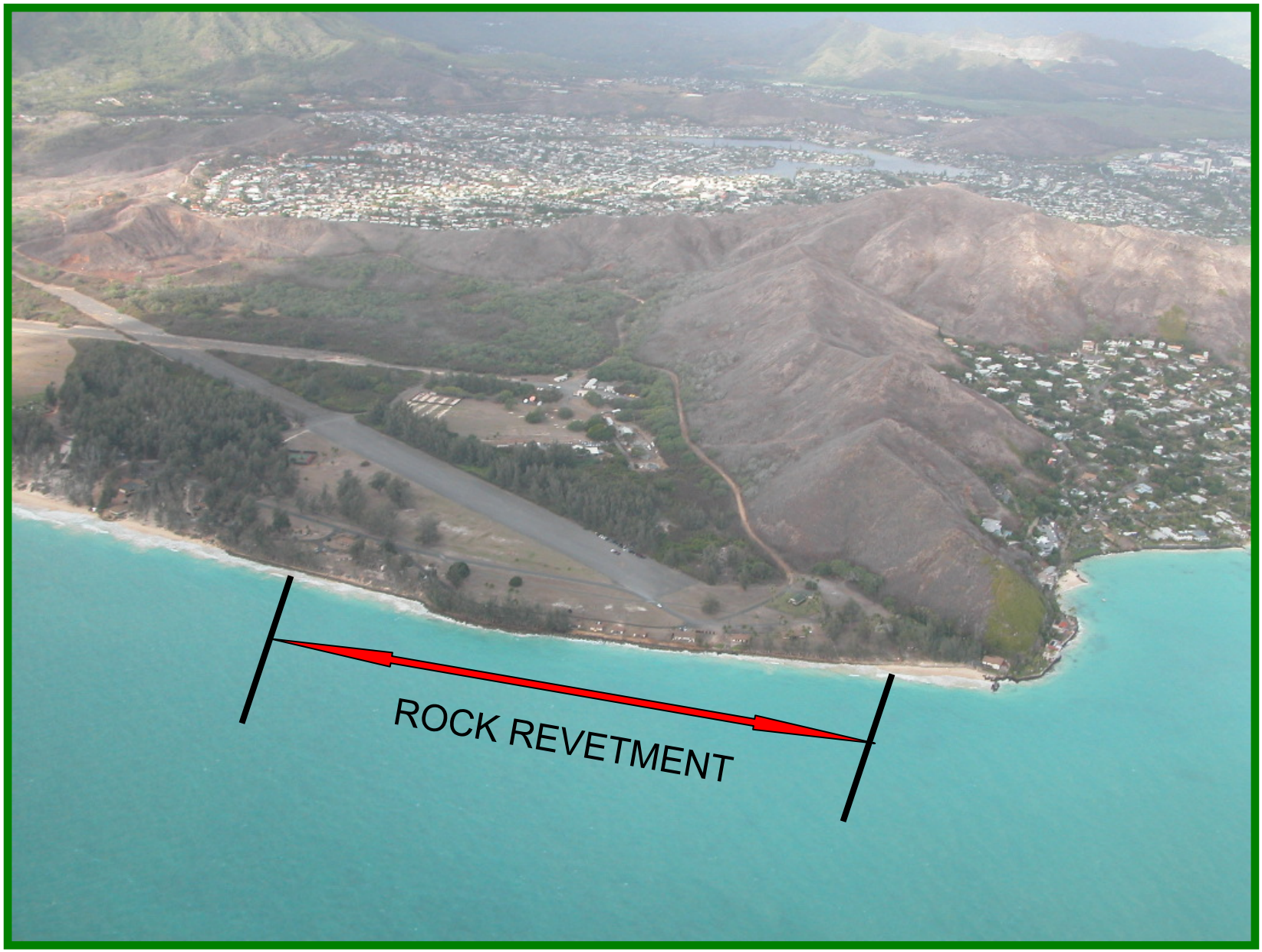




The Study Area



Bellows Air Force Station



Lanikai Beach looking north

Lanikai Beach looking south

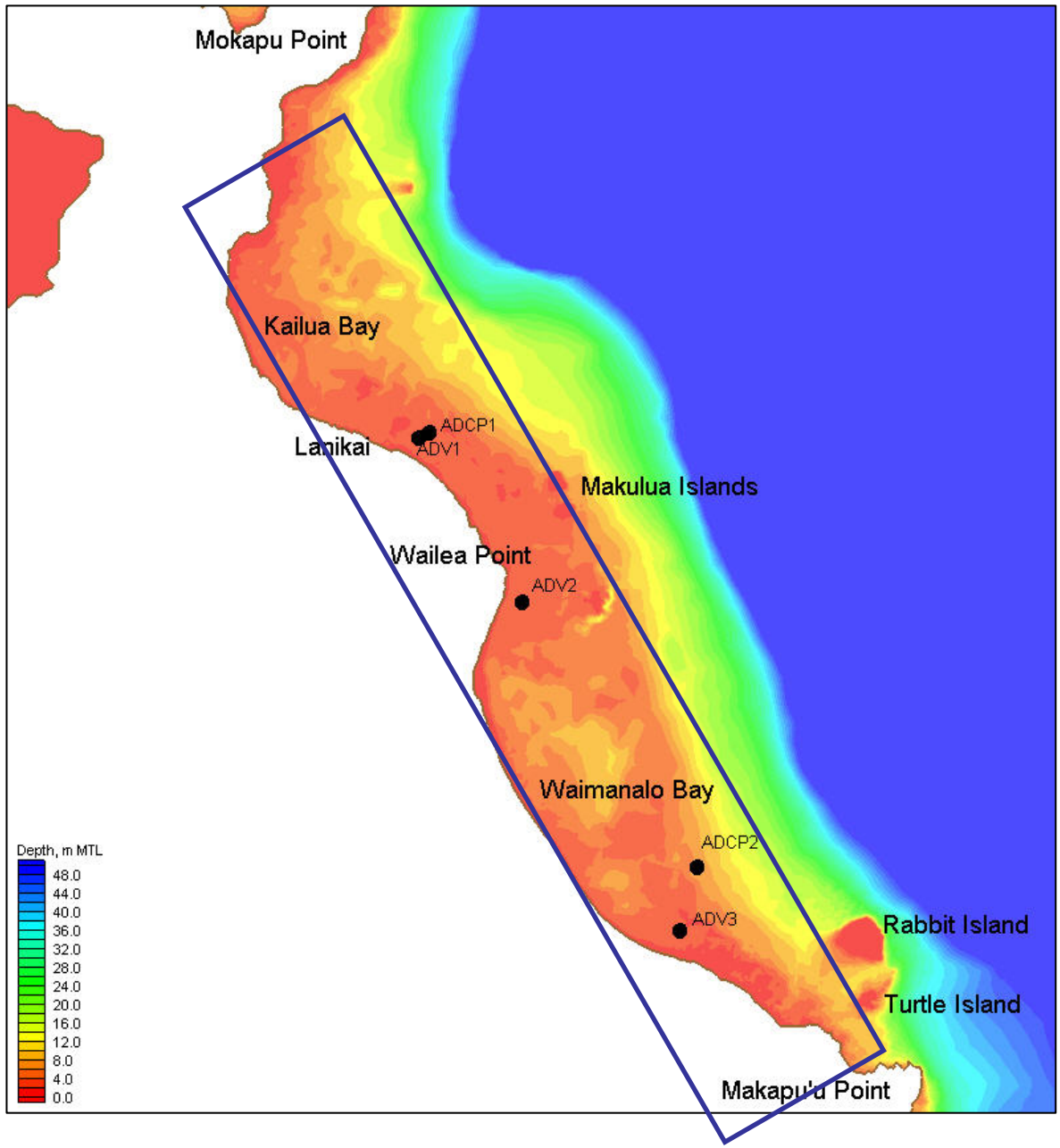
Lanikai Beach

Ka’elepulu stream looking makai

Ka’elepulu stream looking mauka

Ka’elepulu Stream

Extensive Reef



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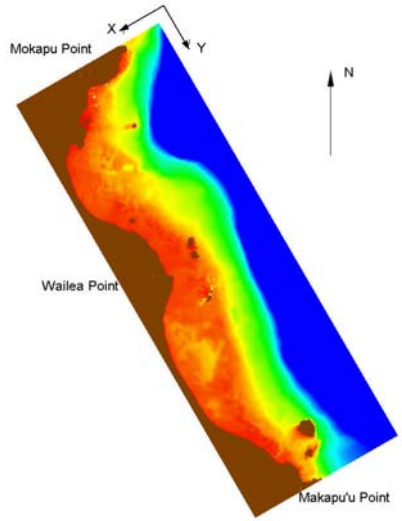
STWAVE Model Description

Steady-state spectral wave model

- Conservation of wave action
- Simplified diffraction
- Wave growth and white-capping
  - Wind input
  - Nonlinear transfers to low frequencies
  - Dissipation at high frequencies
- Depth and steepness-induced breaking
- Refraction and shoaling
- Wave-current interaction
- Bottom friction



Wave height, direction, period (bulk parameters and spectra), radiation stresses

JONSWAP friction formulation

$$S_{bf} = \frac{-1}{g} c_f \frac{\sigma^2}{\sinh^2 kd} E(f,\alpha)$$

S_{bf} : spectral energy loss from bottom friction

c_f : friction coefficient

σ : angular frequency

k and d : wave number and water depth

$E(f,\alpha)$: wave energy density function (divided by $(\rho_w g)$,

(f,α): wave frequency and wave direction

(Hasselmann et al. 1973, Padilla-Hernandez and Monbaliu 2001)

Manning friction formulation

$$S_{bf} = \frac{-1}{g}\left(\frac{gn^2}{d^{1/3}}\right)\frac{\sigma^2}{\sinh^2 kd}E(f,\alpha)u_{rms}$$

S_{bf} : spectral energy loss from bottom friction

n : friction coefficient

σ : angular frequency

k and d : wave number and water depth

$E(f,\alpha)$: wave energy density function (divided by $(\rho_w g)$,

(f,α) : wave frequency and wave direction

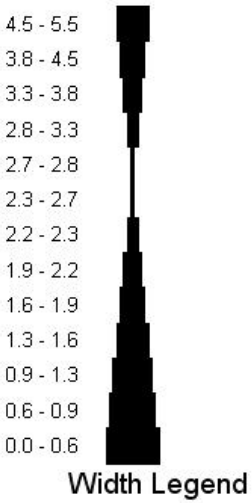
u_{rms} : root-mean-square bottom velocity

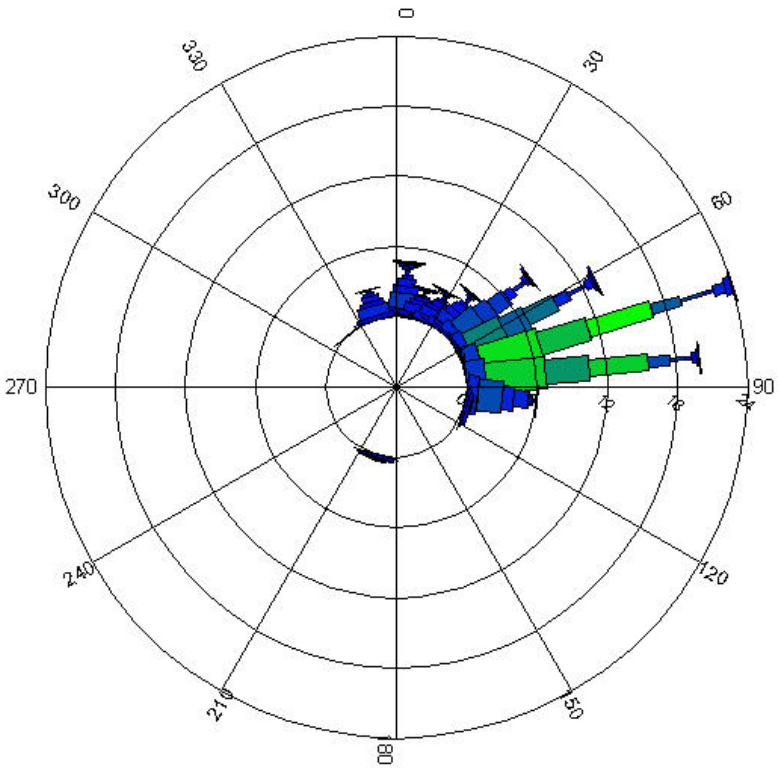
Holthuijsen (2007)

Offshore Wave Climate

CDIP Buoy Station 098

(2000-2004)

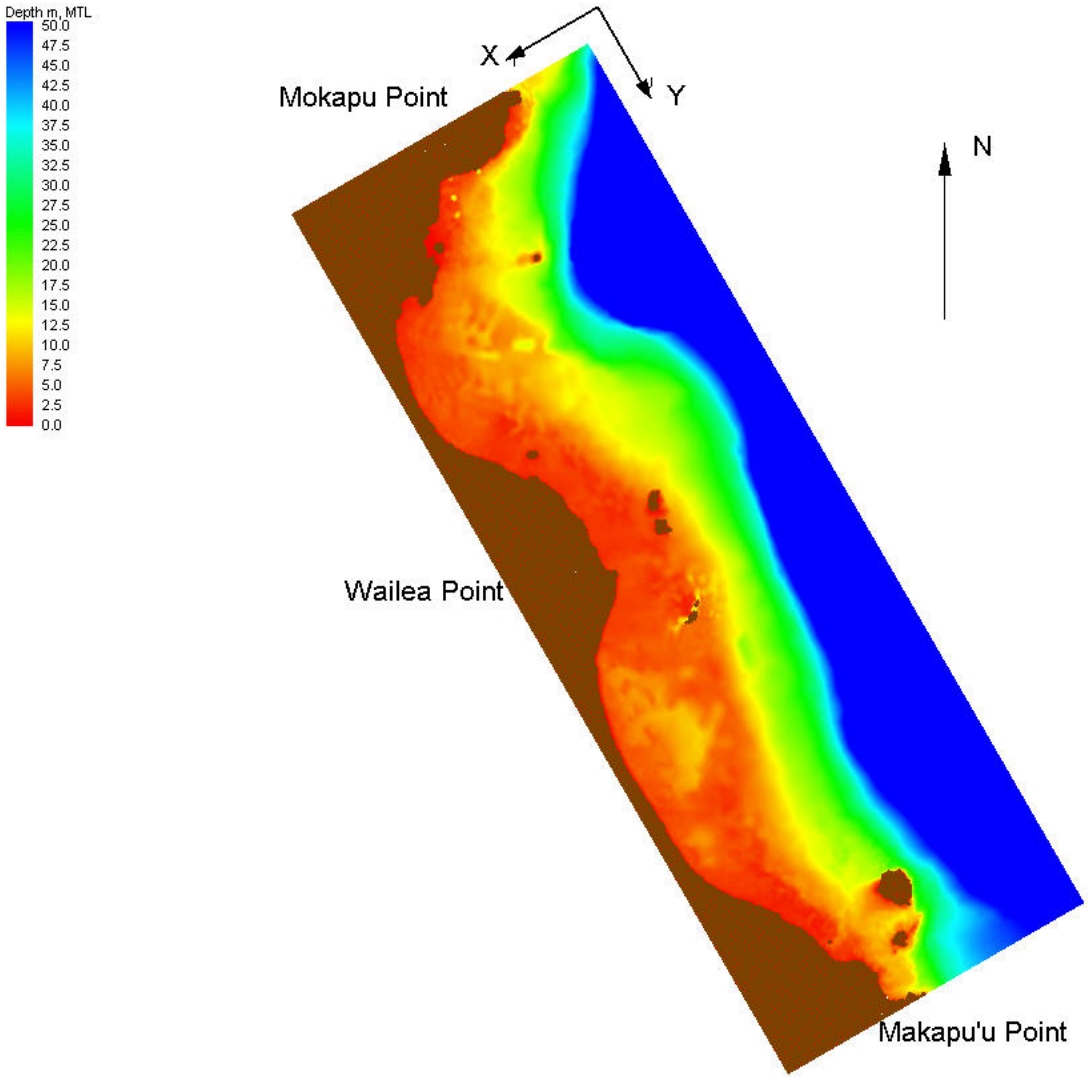


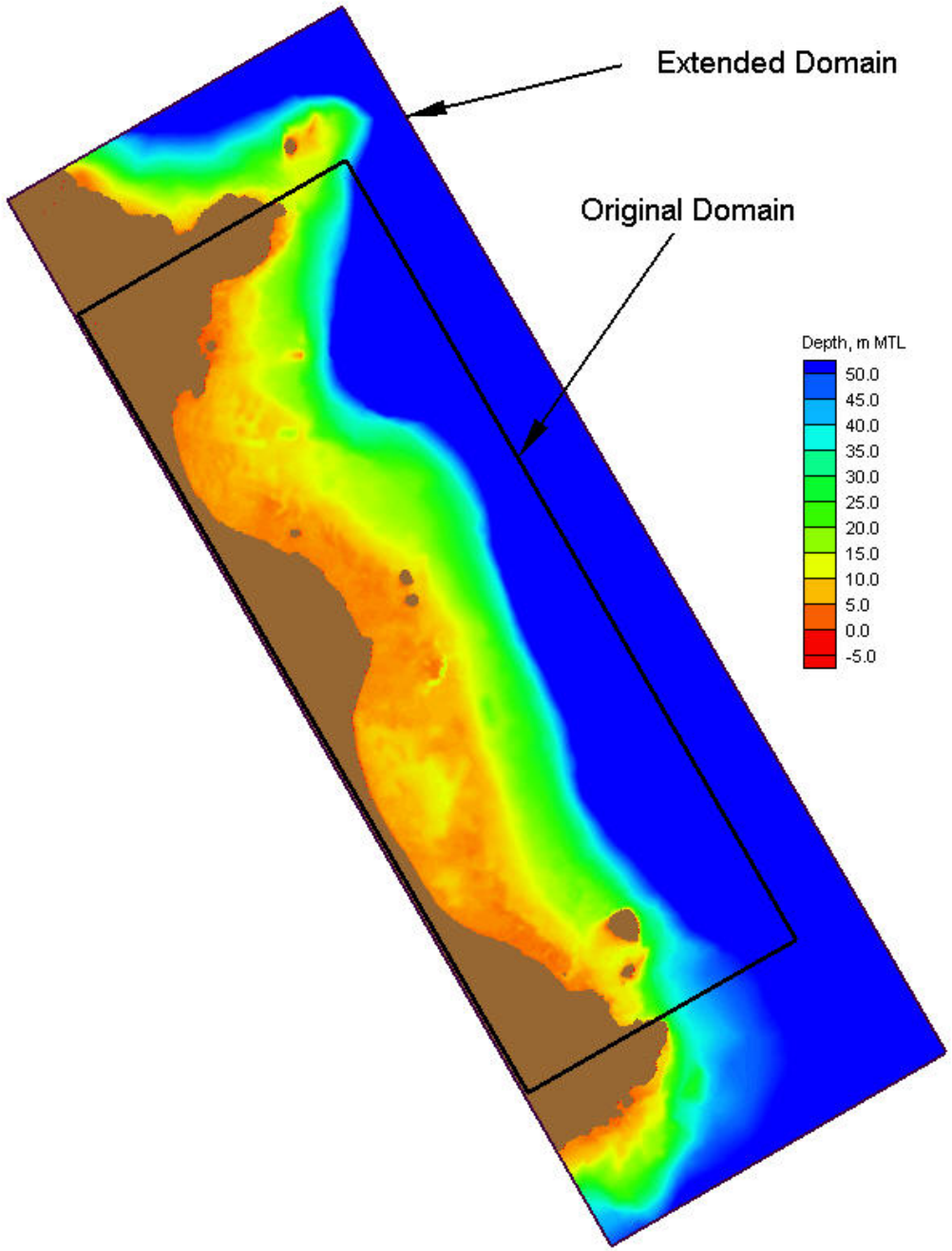


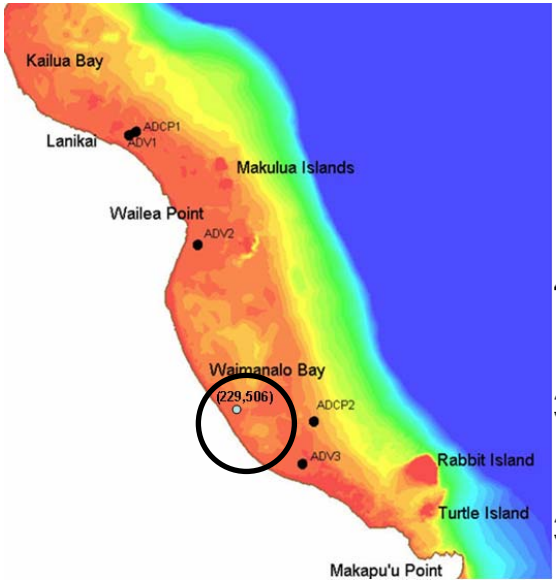
Initially discretized into 134 wave conditions

Significant Wave Height M	Wave Period sec	Wave Direction deg from North
	6	-22.5
0.75	8	
1.25	10	0
	12	
1.75	14	22.5
	16	
2.25		45
2.75		67.5
3.50		90

STWAVE Domain



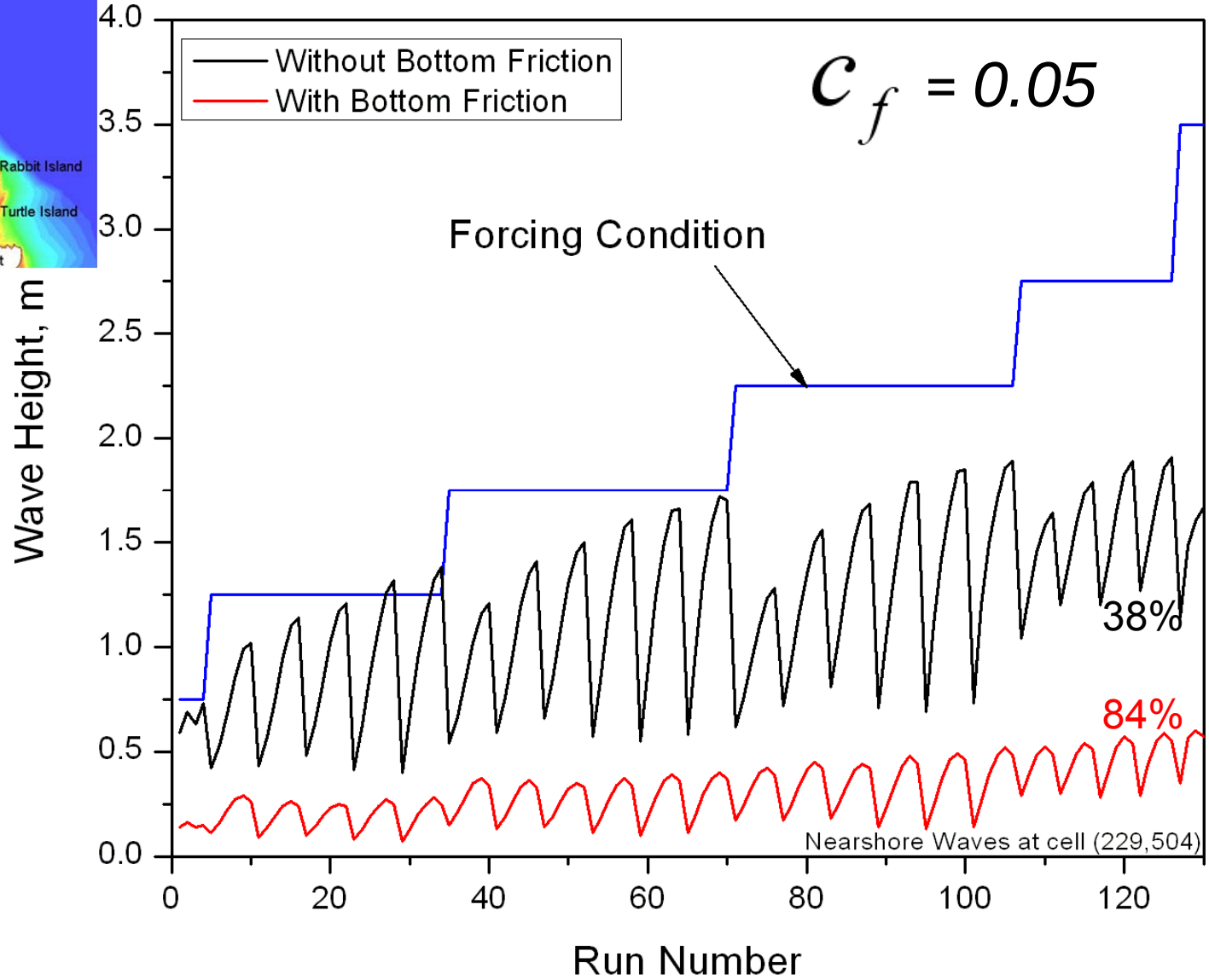

Extended Domain
Original Domain
Depth, m MTL
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0



Test Range

c_f 0.04 - 0.12

n 0.15 - 0.25



Adv1: cf 64-93%
n 62-80%

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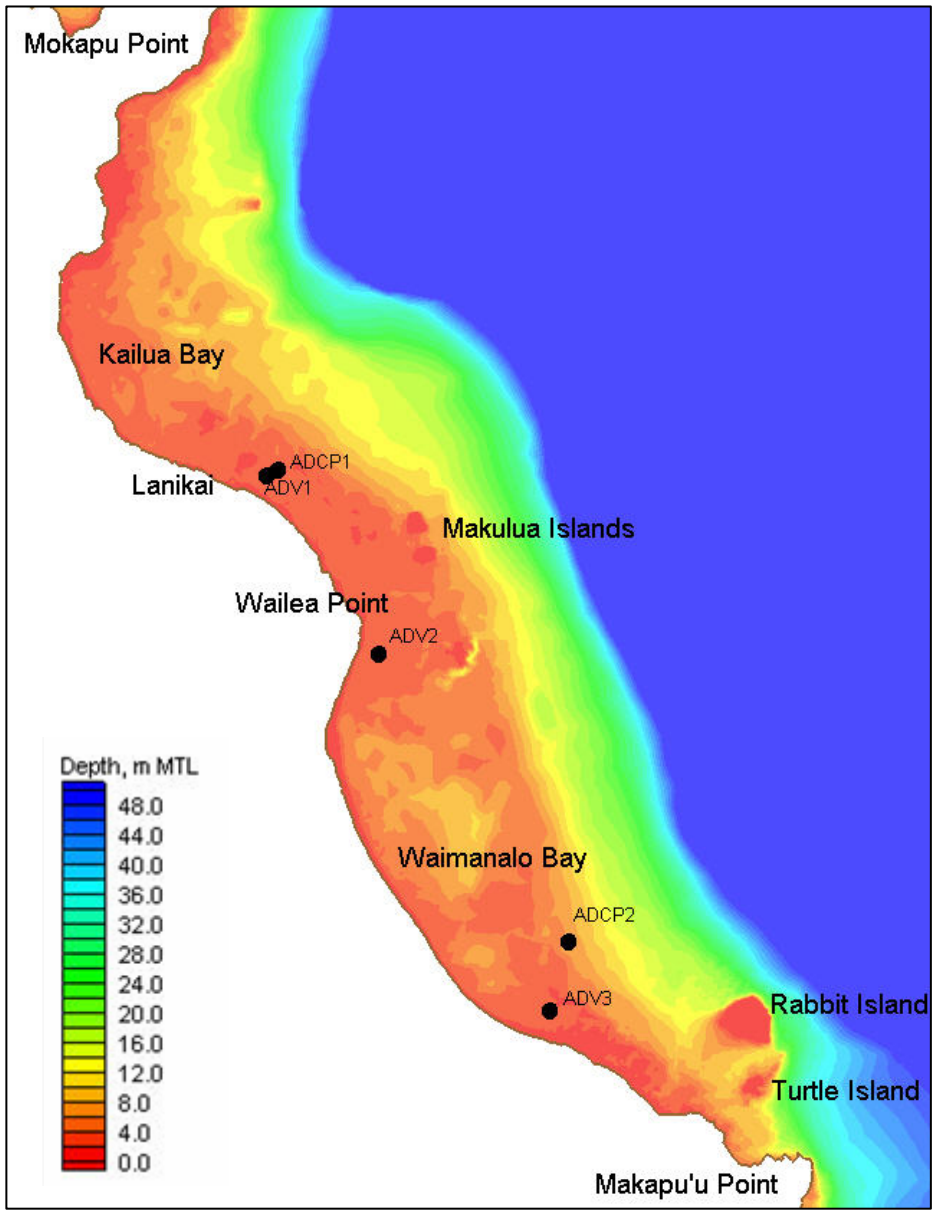
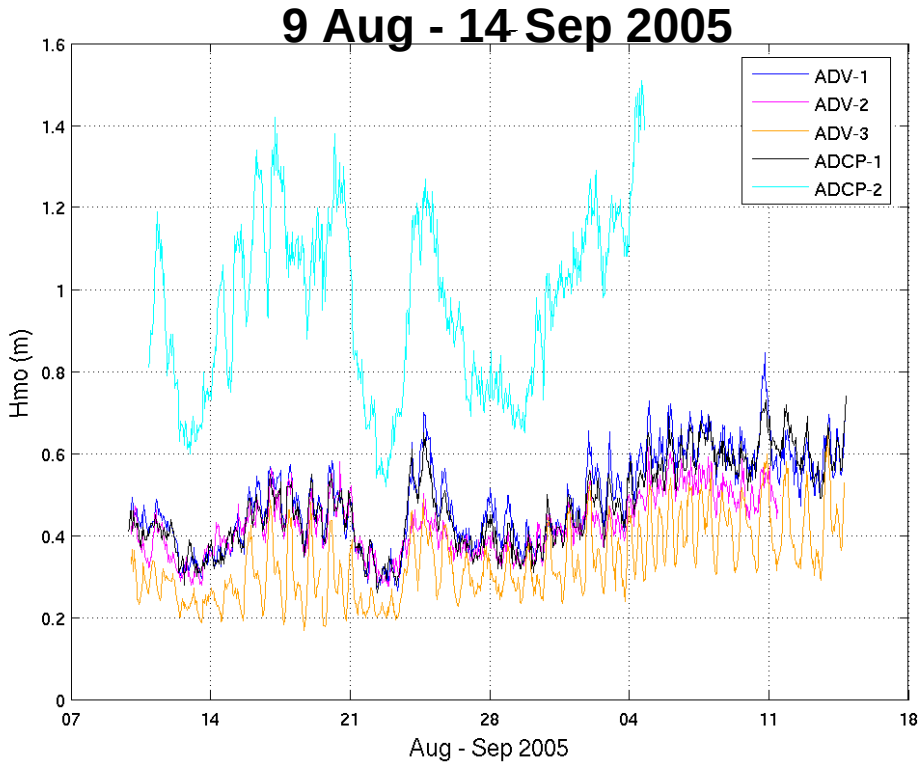
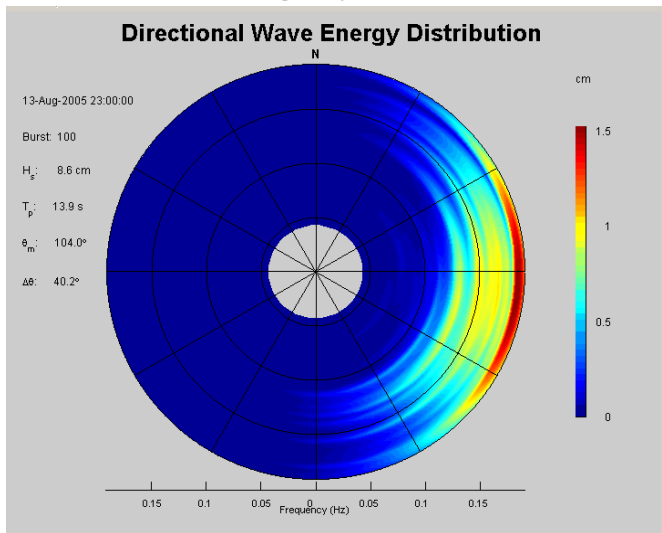
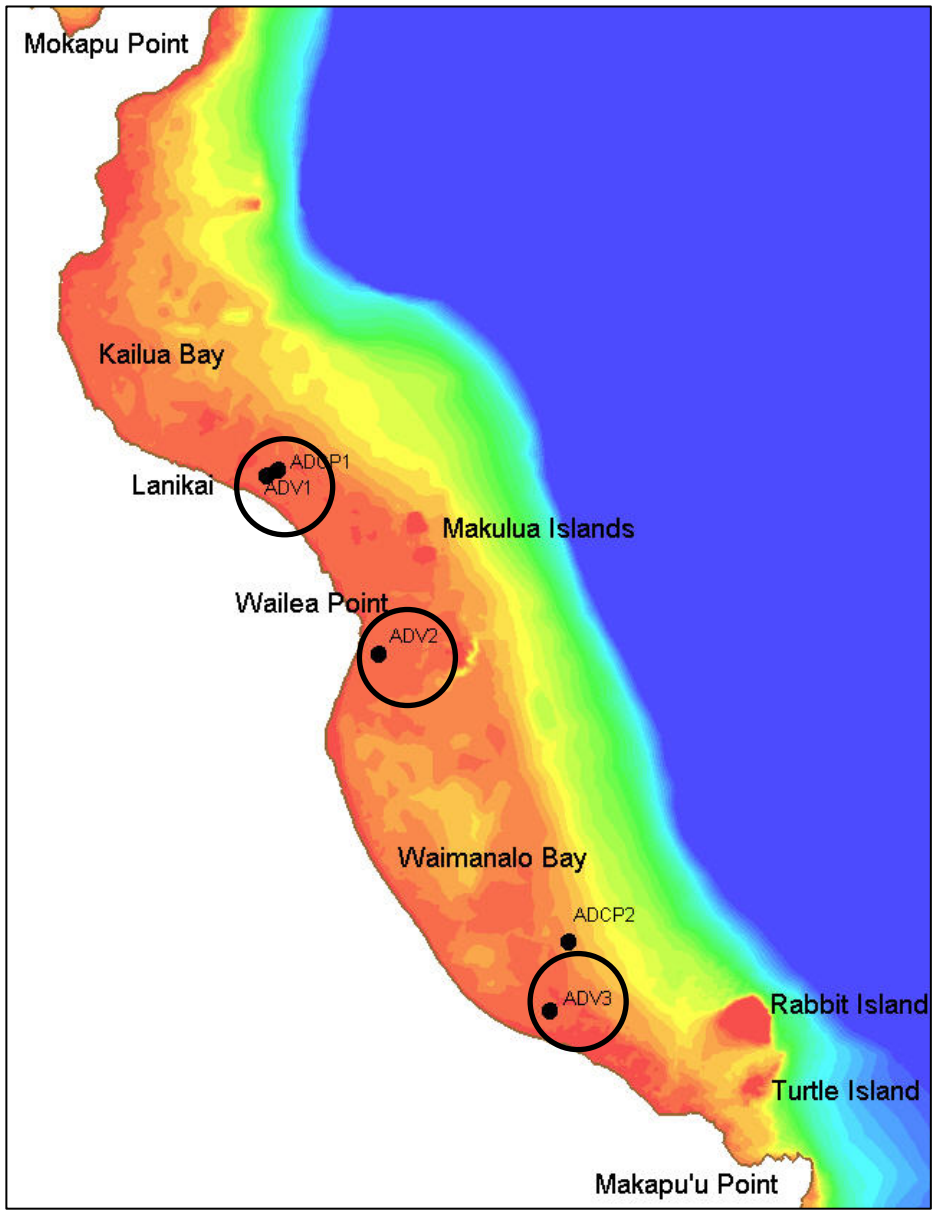
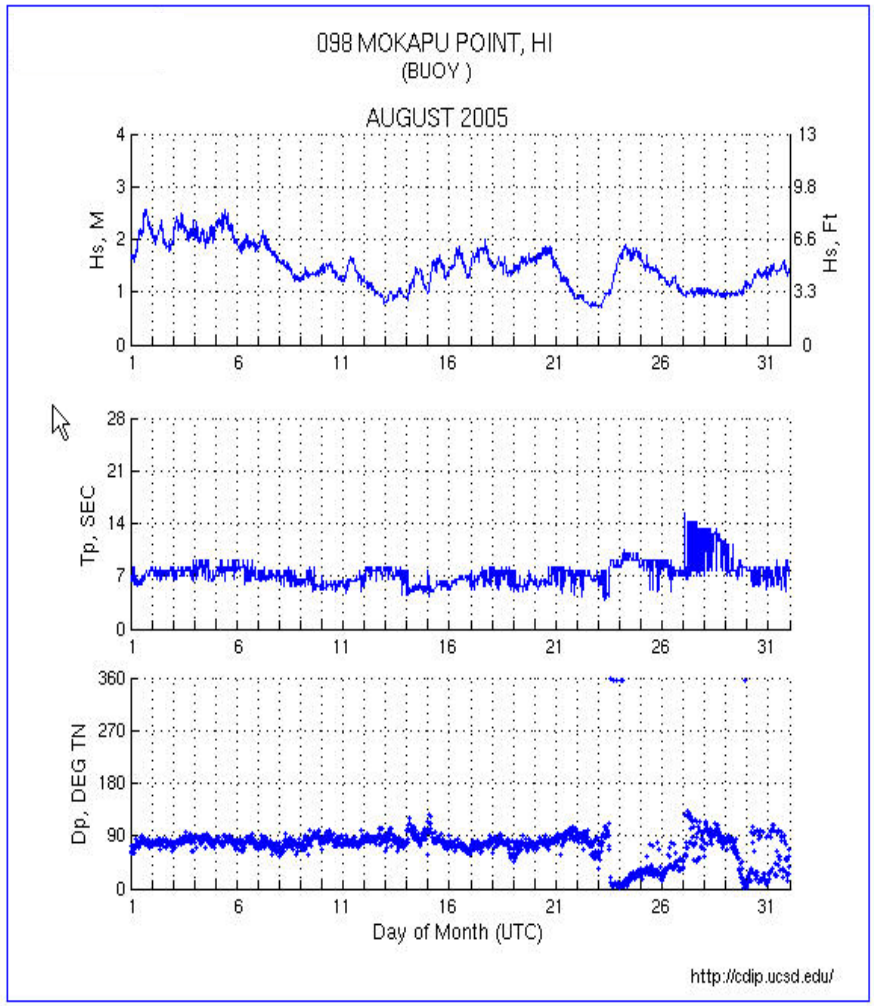
Field Data Collection

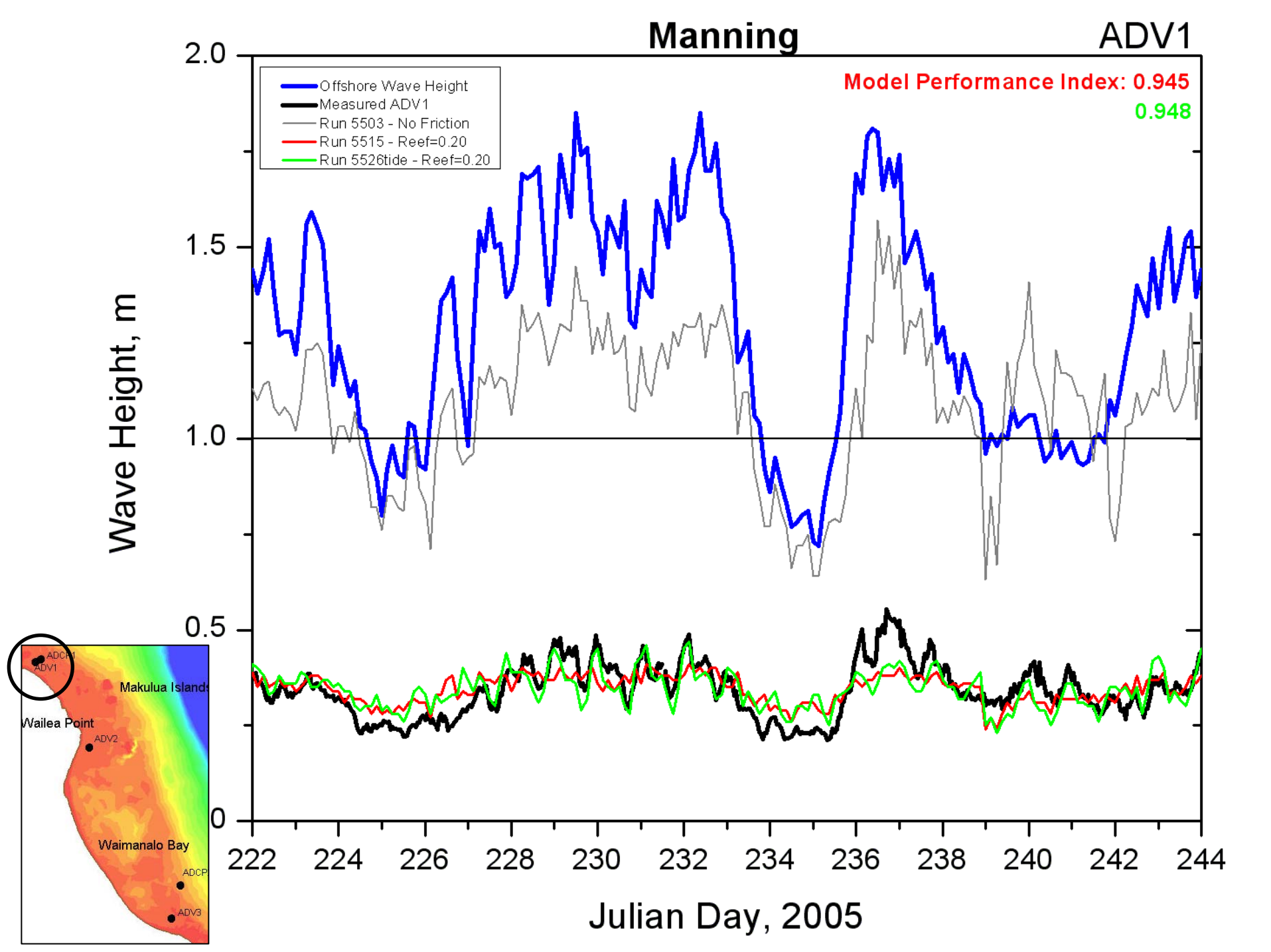







Mokapu Point
Kailua Bay
ADCP1
ADV1
Lanikai
Makulua Islands
Wailea Point
ADV2
Waimanalo Bay
ADCP2
ADV3
Rabbit Island
Turtle Island
Makapu'u Point


098 MOKAPU POINT, HI
(BUOY)
AUGUST 2005
Hs, M
Hs, Ft
Tp, SEC
Dp, DEG TN
Day of Month (UTC)
http://cdip.ucsd.edu/

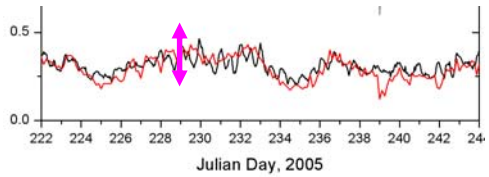

Manning
ADV1
Offshore Wave Height
Measured ADV1
Run 5503 - No Friction
Run 5515 - Reef=0.20
Run 5526tide - Reef=0.20
Model Performance Index: 0.945
0.948
Wave Height, m
2.0
1.5
1.0
0.5
0
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Islands
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

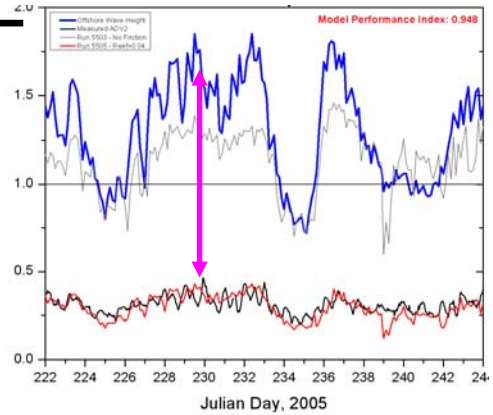
Model Performance Index

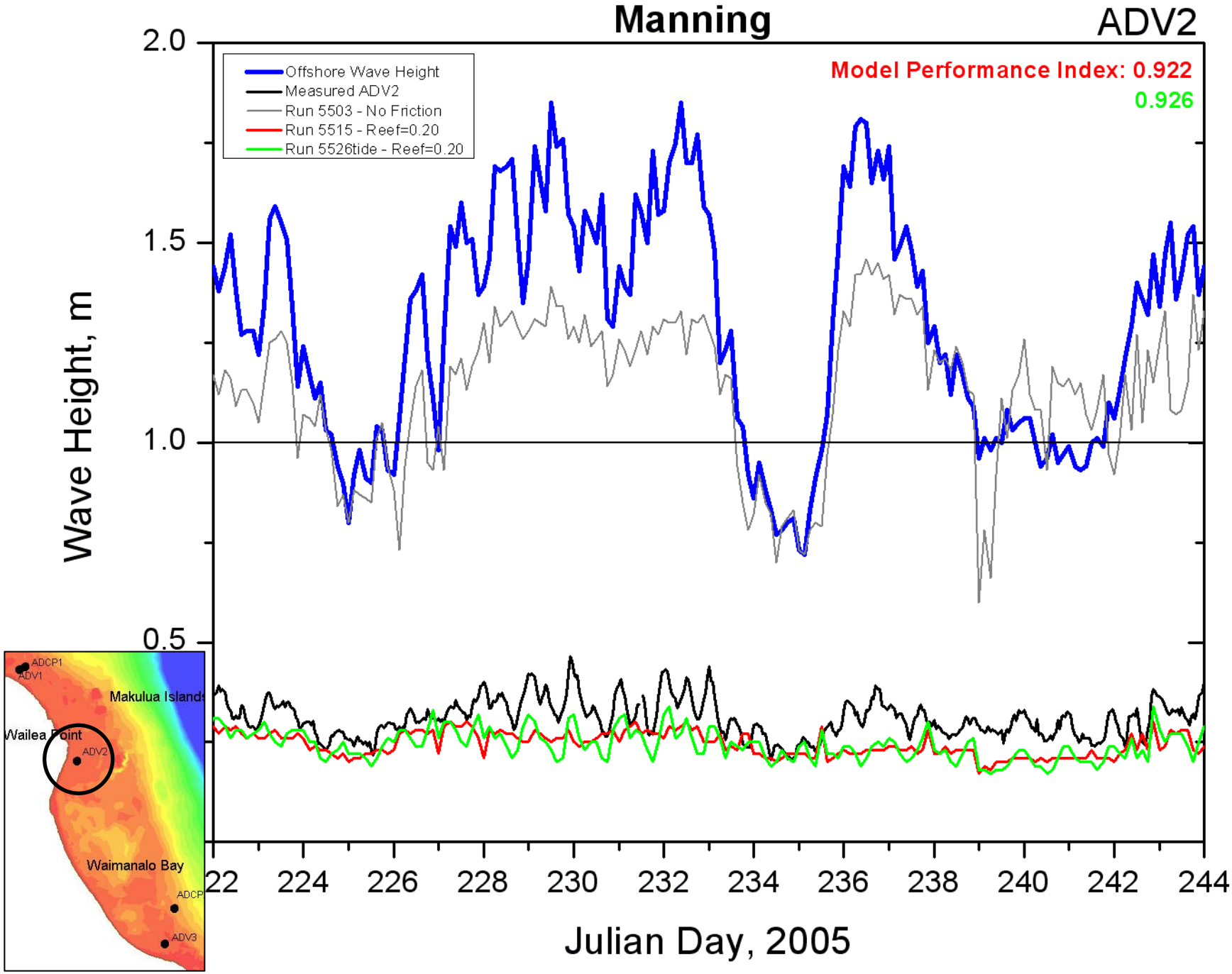
$$MPI = 1 - Error_{rms} / Changes_{rms}$$

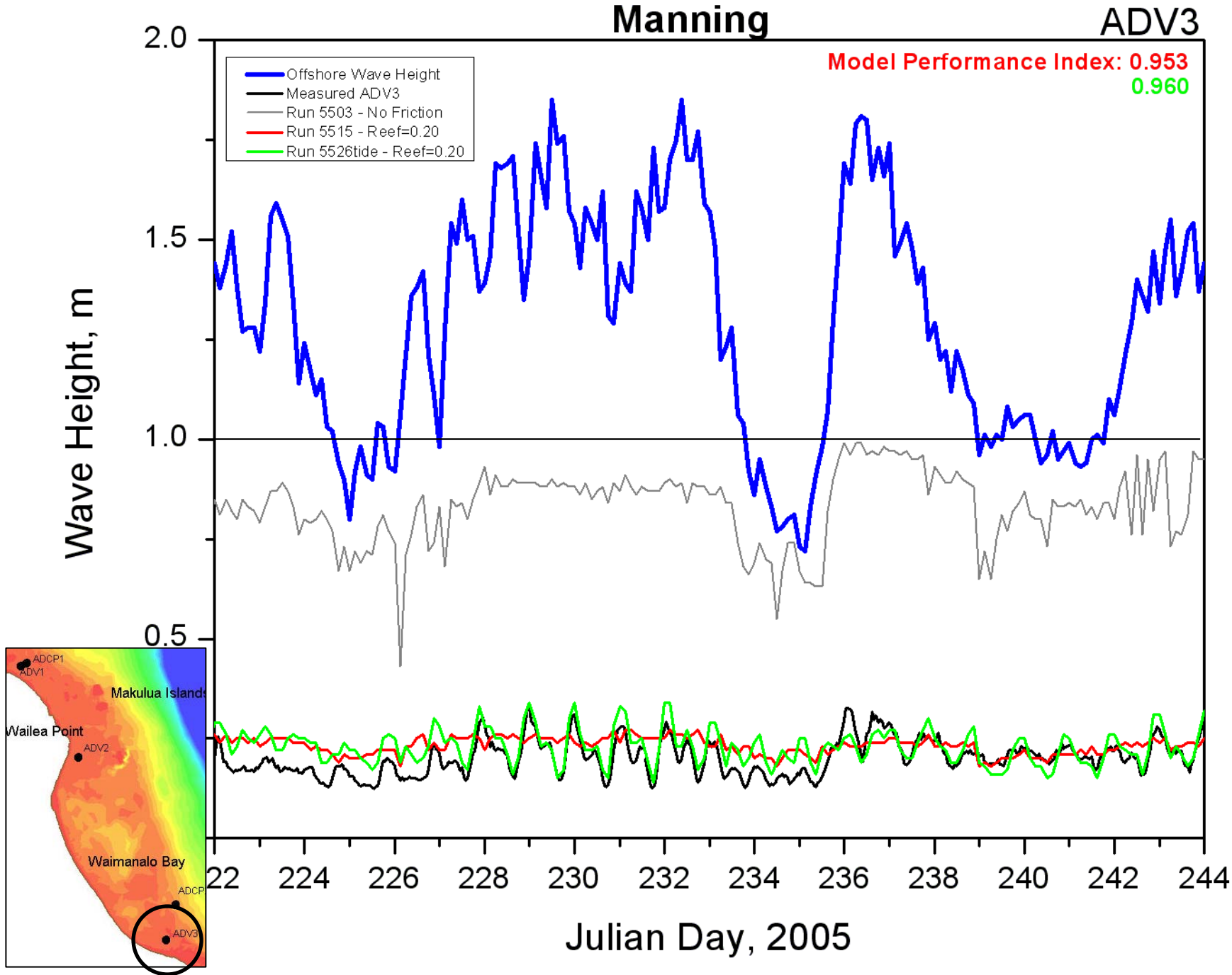
$$Error_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Model-Data)^2}$$

$$Changes_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Off-Data)^2}$$



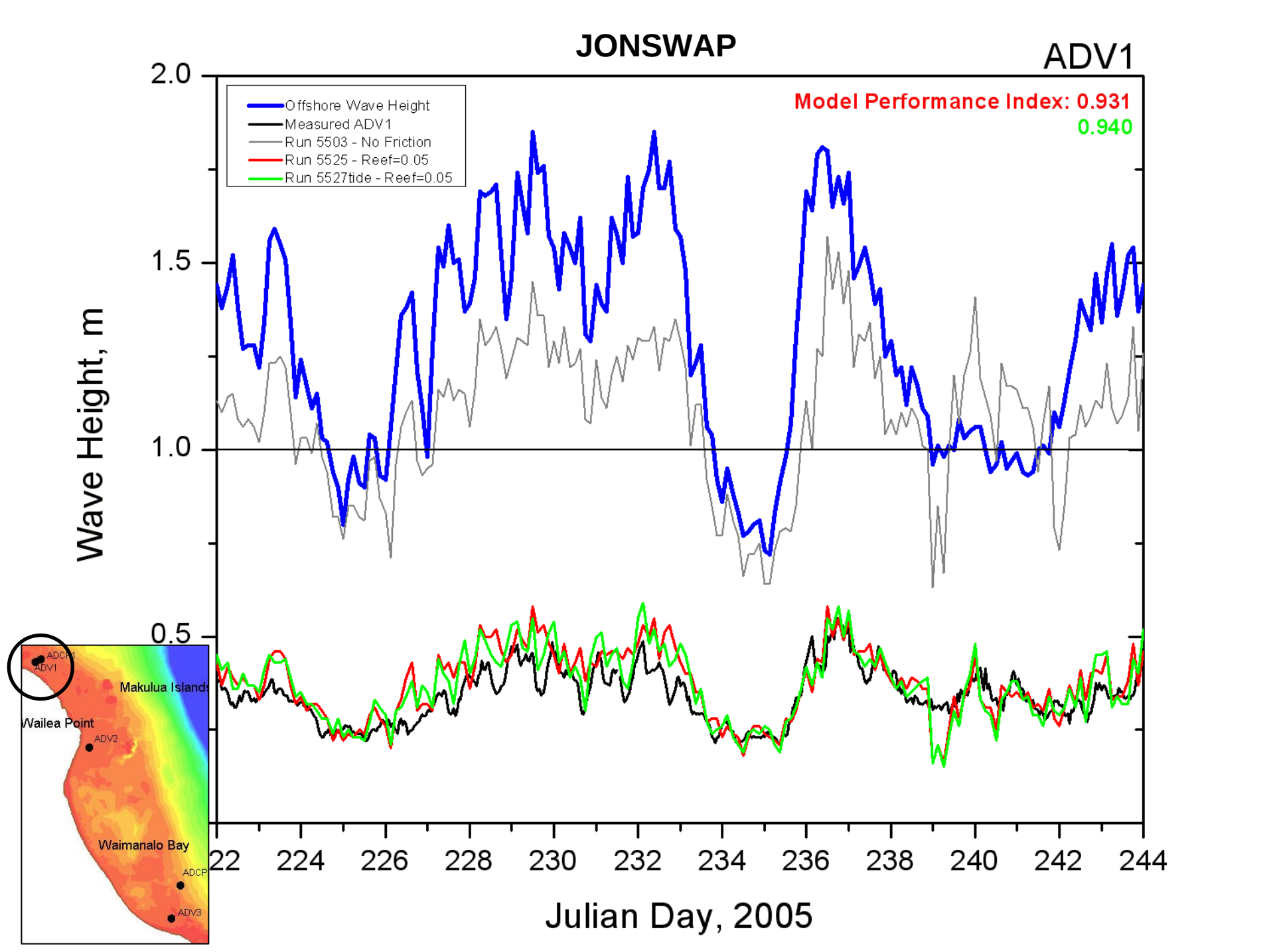


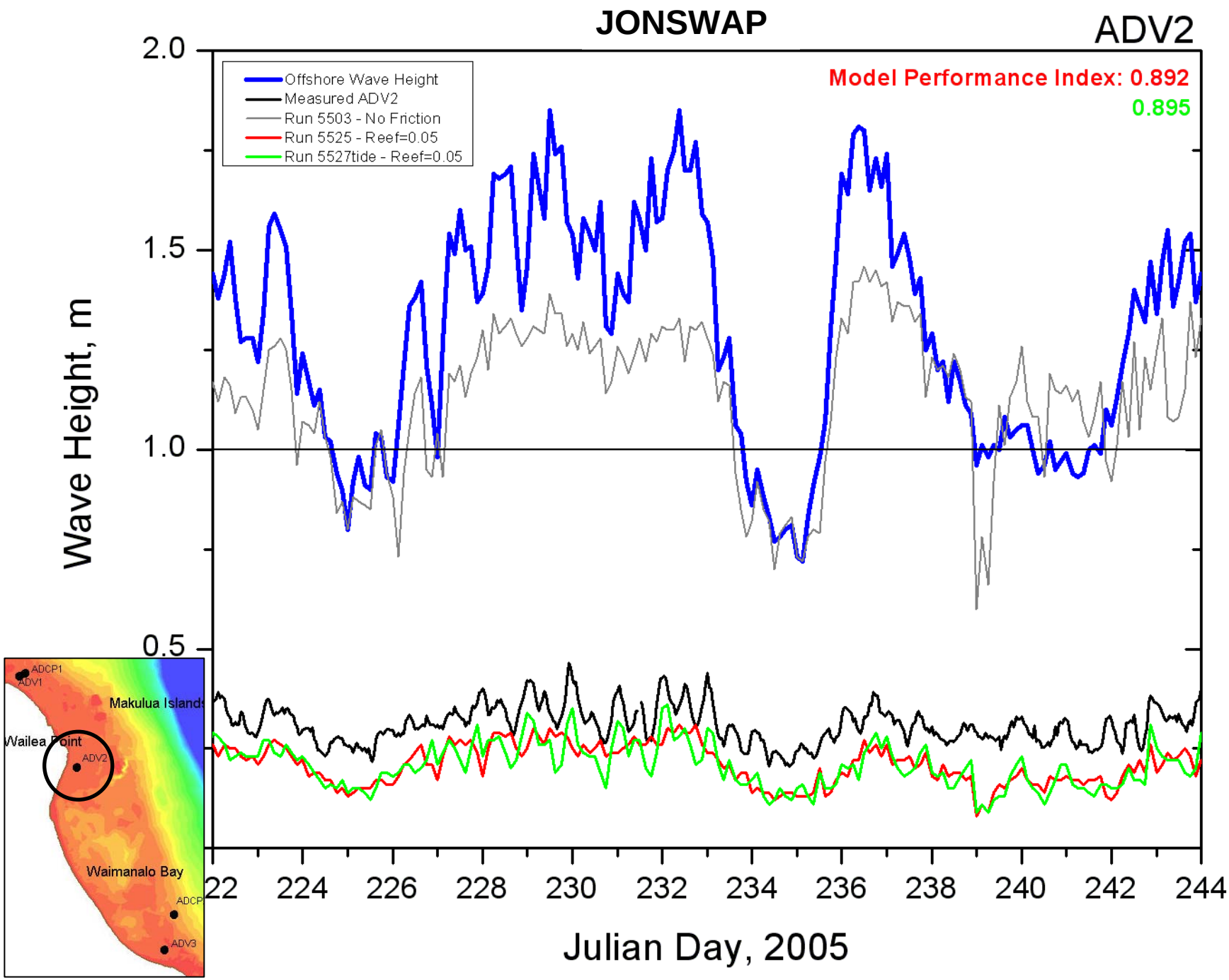

Manning
ADV2
Offshore Wave Height
Measured ADV2
Run 5503 - No Friction
Run 5515 - Reef=0.20
Run 5526tide - Reef=0.20
Model Performance Index: 0.922
0.926
Wave Height, m
2.0
1.5
1.0
0.5
22
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Islands
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

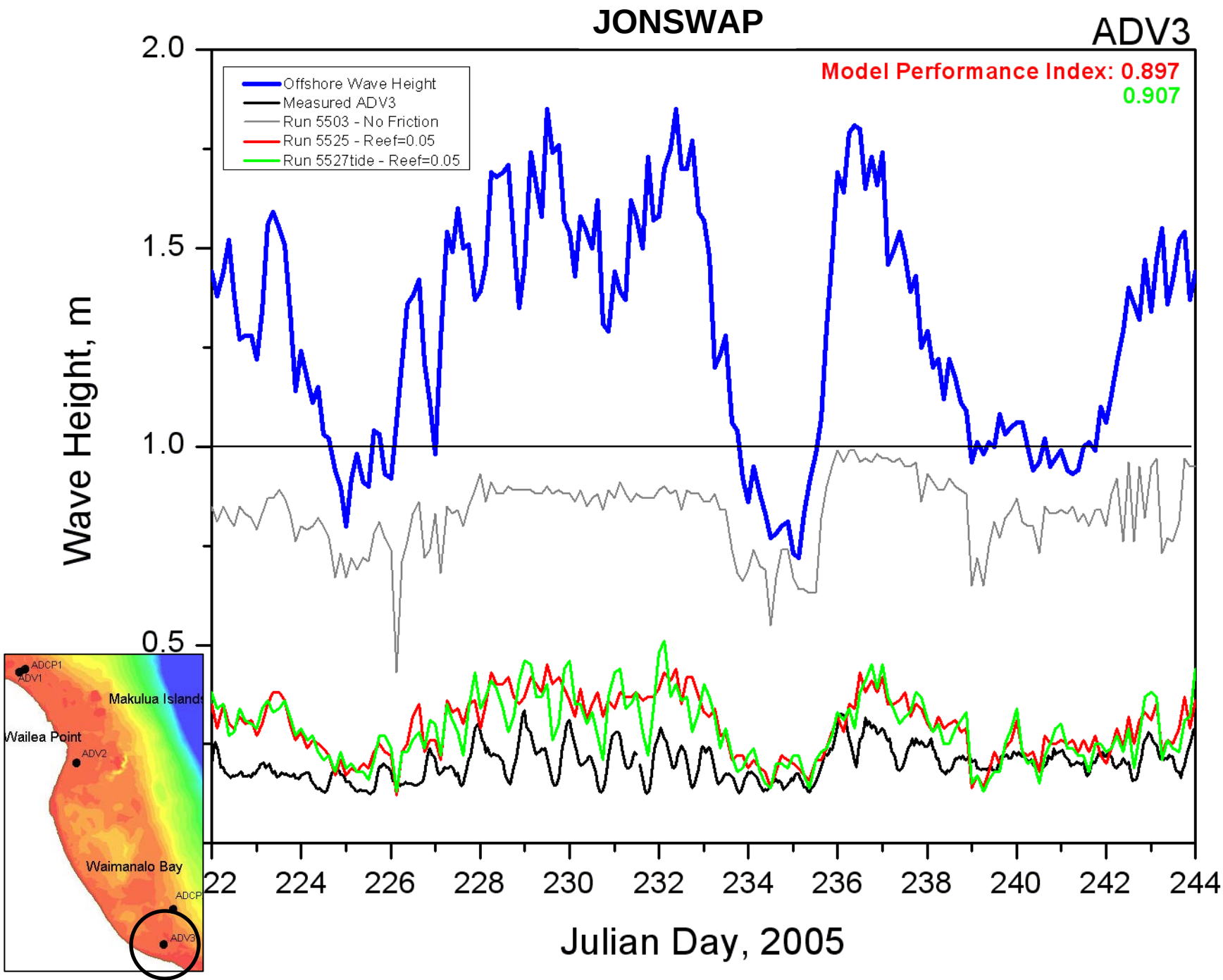

Manning
ADV3
Model Performance Index: 0.953
0.960
Offshore Wave Height
Measured ADV3
Run 5503 - No Friction
Run 5515 - Reef=0.20
Run 5526tide - Reef=0.20
Wave Height, m
2.0
1.5
1.0
0.5
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Islands
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

Model Performance Index Manning

	n 0.20	n 0.20 with tide
ADV1	0.945	0.948
ADV2	0.922	0.926
ADV3	0.953	0.960

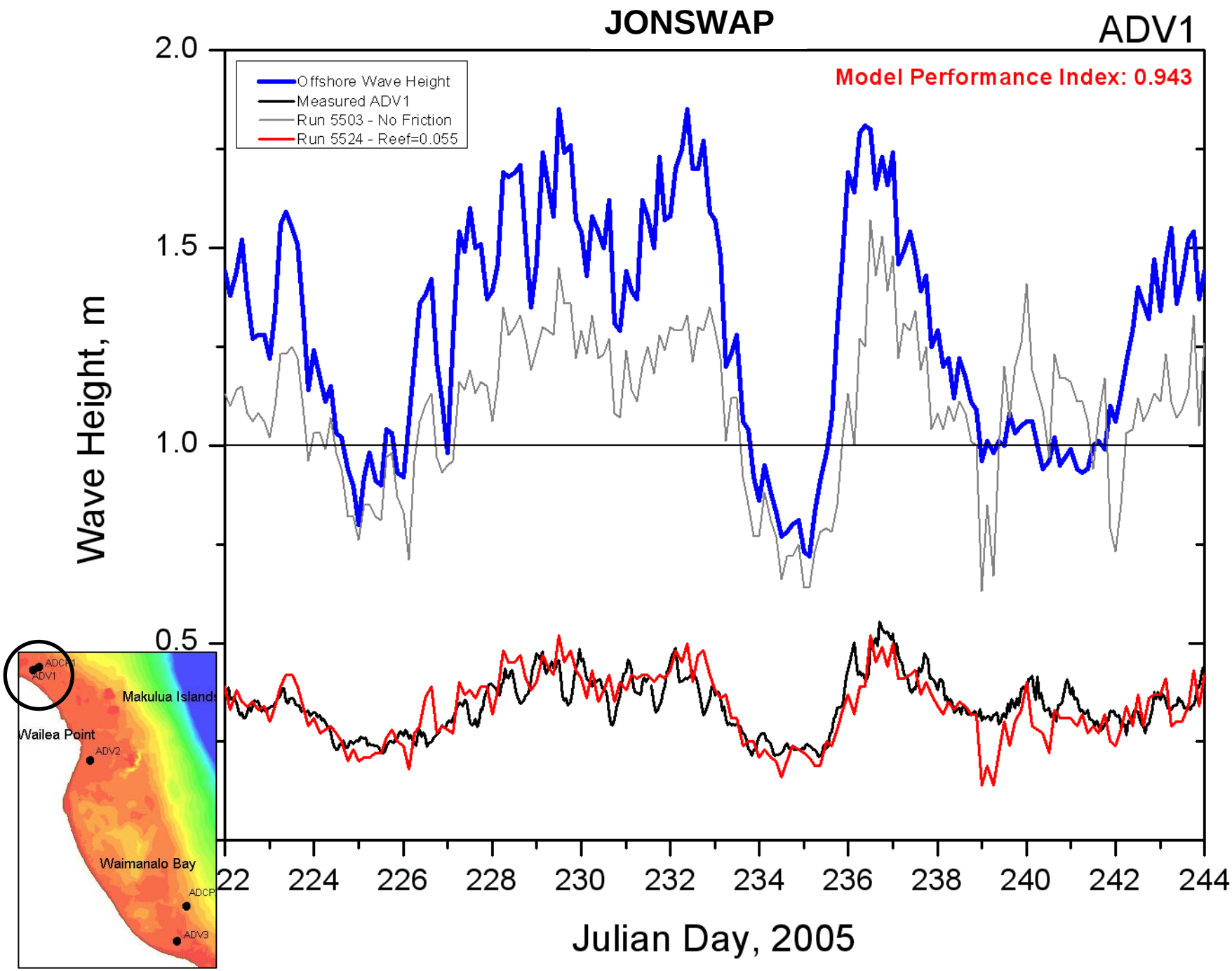

JONSWAP
ADV1
Offshore Wave Height
Measured ADV1
Run 5503 - No Friction
Run 5525 - Reef=0.05
Run 5527tide - Reef=0.05
Model Performance Index: 0.931
0.940
Wave Height, m
2.0
1.5
1.0
0.5
22
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Islands
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

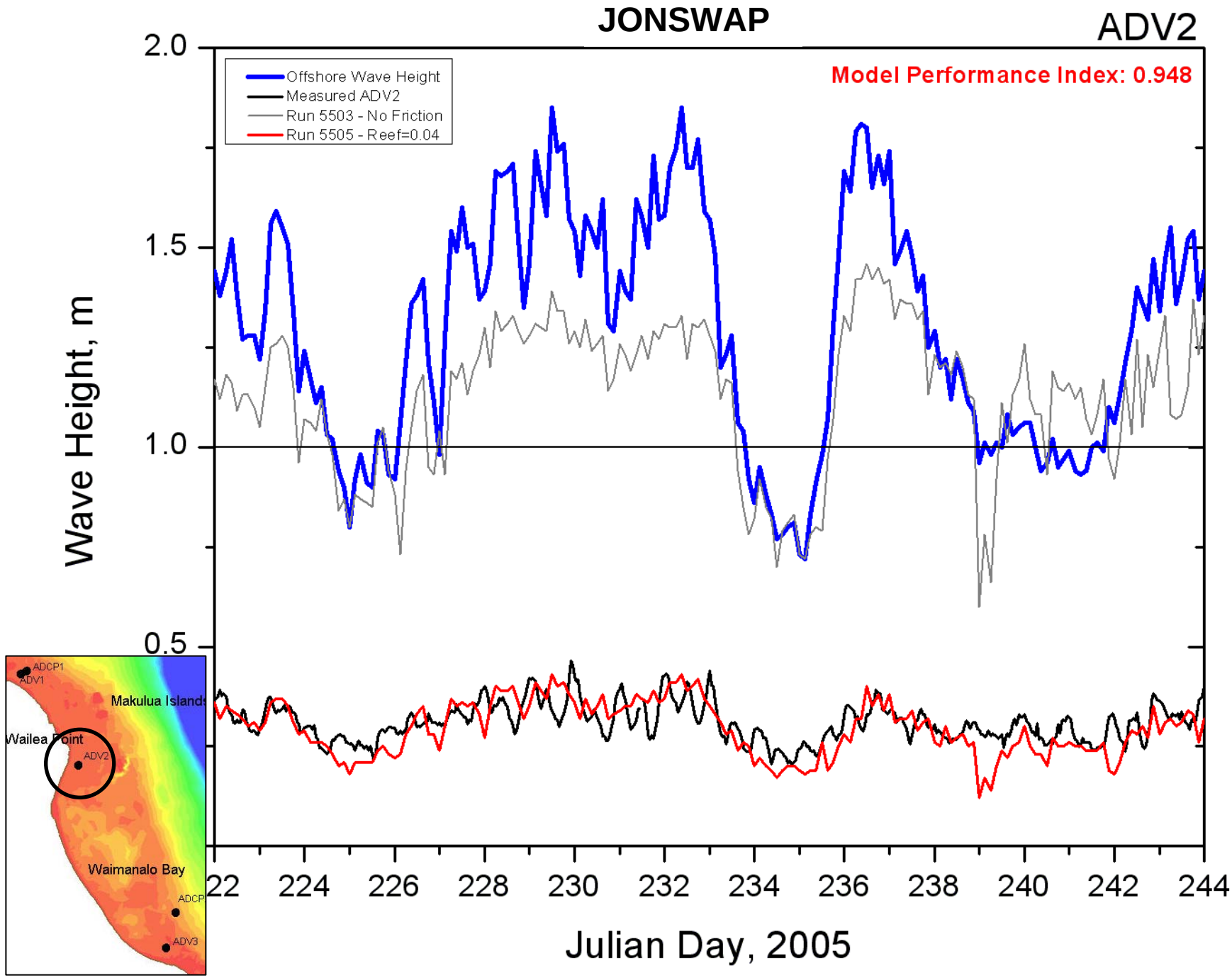

JONSWAP
ADV2
Offshore Wave Height
Measured ADV2
Run 5503 - No Friction
Run 5525 - Reef=0.05
Run 5527tide - Reef=0.05
Model Performance Index: 0.892
0.895
Wave Height, m
2.0
1.5
1.0
0.5
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Island
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

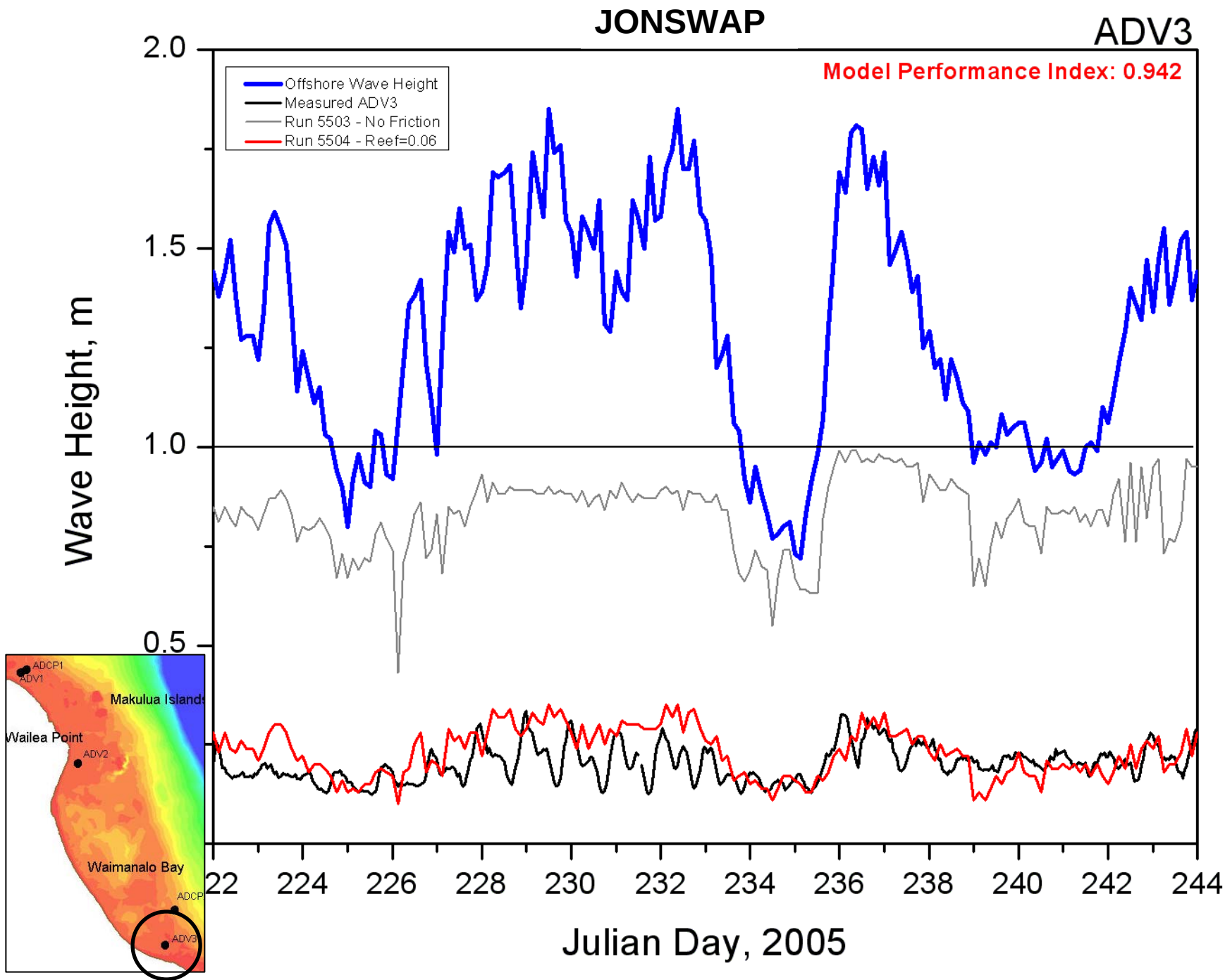

JONSWAP
ADV3
Model Performance Index: 0.897
0.907
Offshore Wave Height
Measured ADV3
Run 5503 - No Friction
Run 5525 - Reef=0.05
Run 5527tide - Reef=0.05
Wave Height, m
2.0
1.5
1.0
0.5
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Islands
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

Model Performance Index
JONSWAP

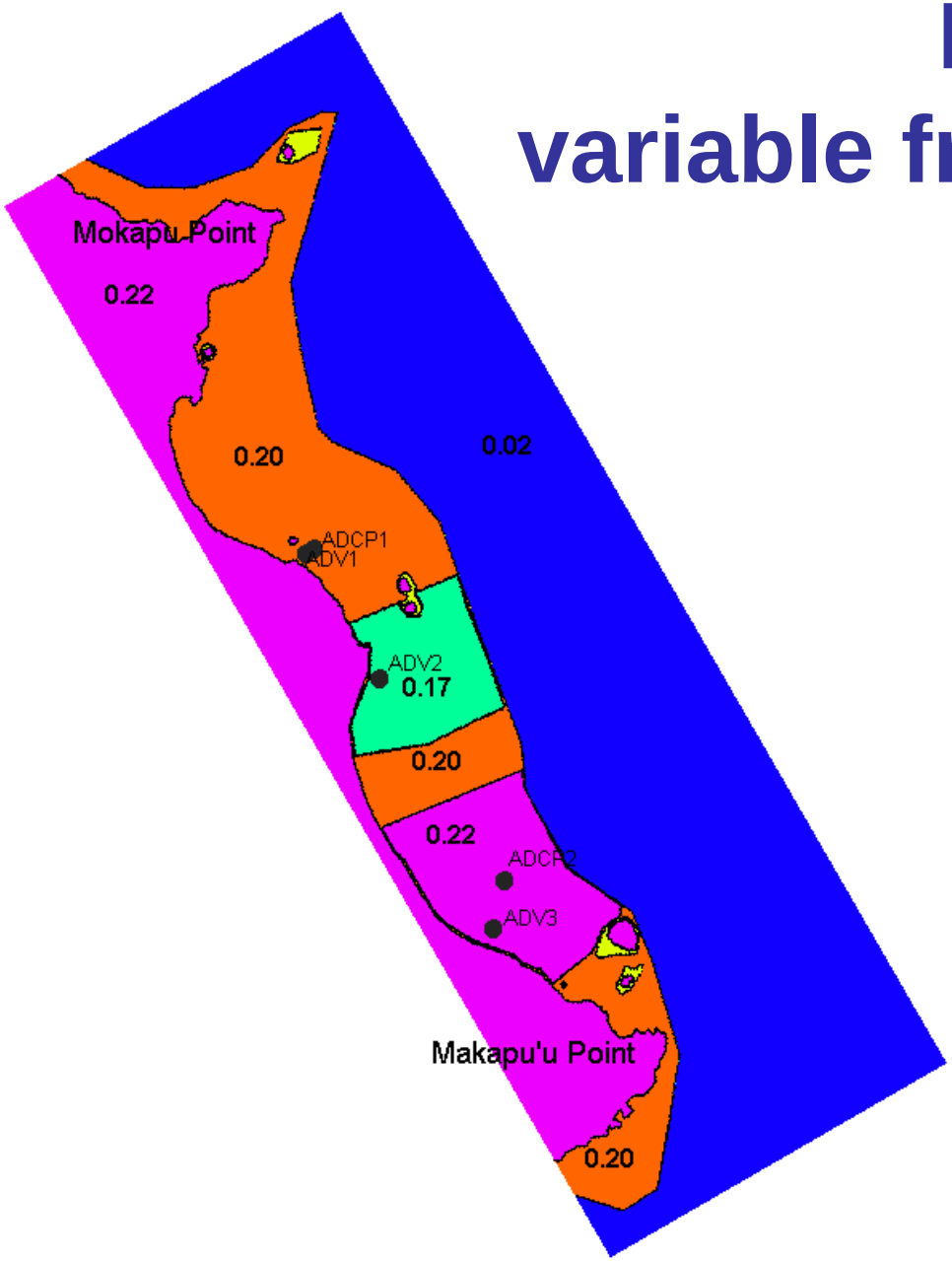
	c_f 0.05	c_f 0.05 with tide
ADV1	0.931	0.940
ADV2	0.892	0.895
ADV3	0.897	0.907

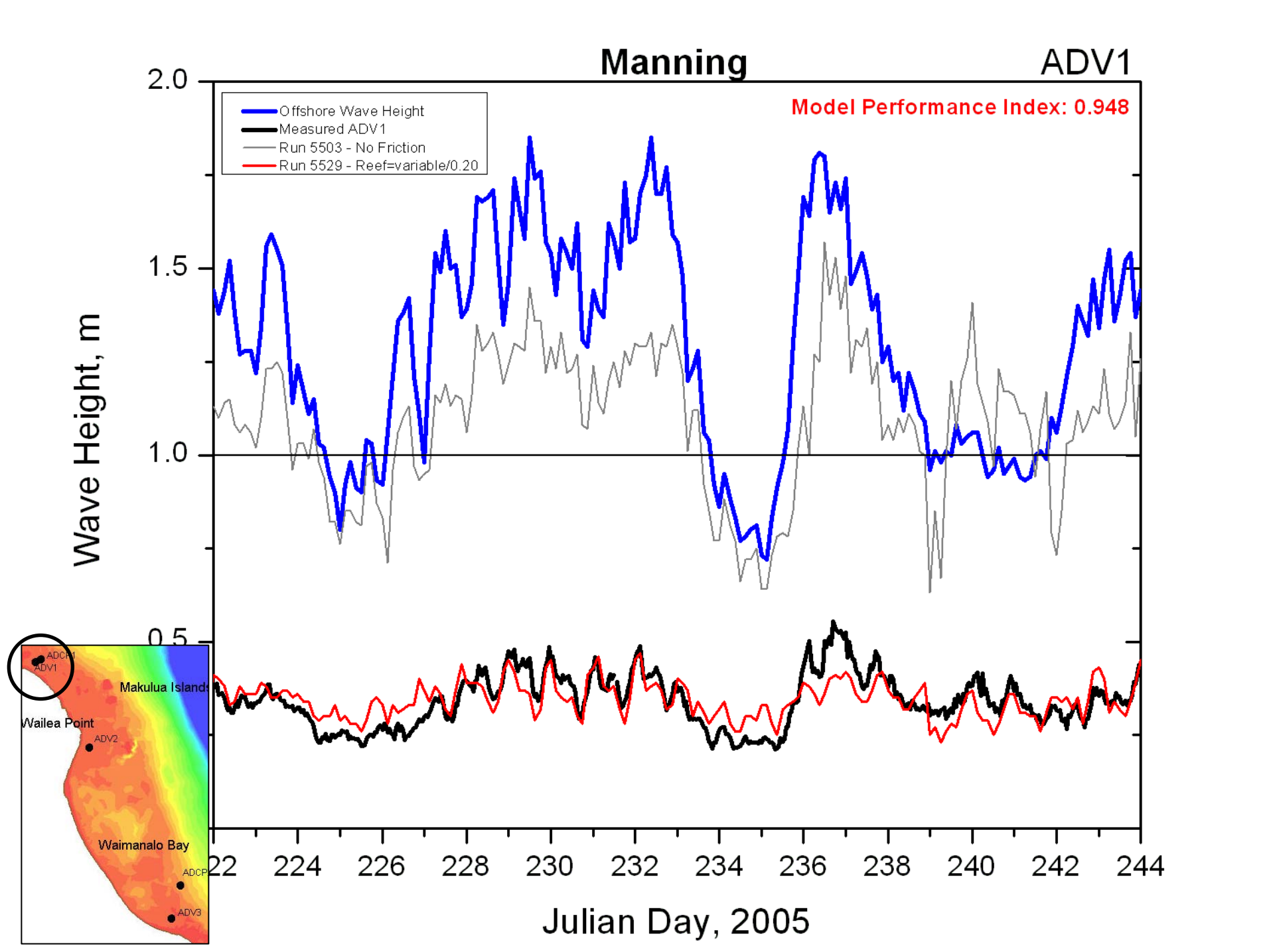

JONSWAP
ADV1
Model Performance Index: 0.943
Offshore Wave Height
Measured ADV1
Run 5503 - No Friction
Run 5524 - Reef=0.055
Wave Height, m
2.0
1.5
1.0
0.5
22
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Island
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

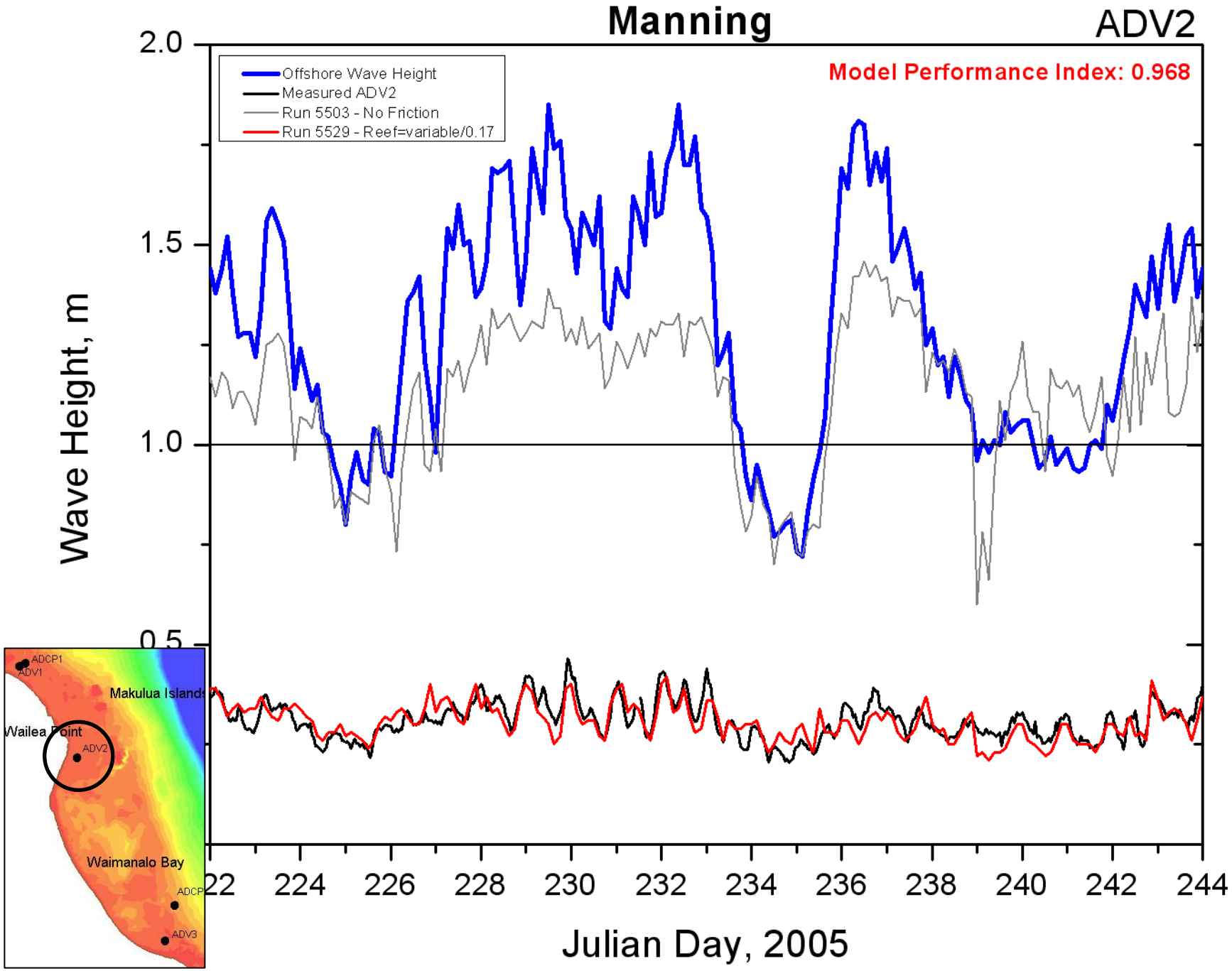

JONSWAP
ADV2
Offshore Wave Height
Measured ADV2
Run 5503 - No Friction
Run 5505 - Reef=0.04
Model Performance Index: 0.948
Wave Height, m
2.0
1.5
1.0
0.5
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Island
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

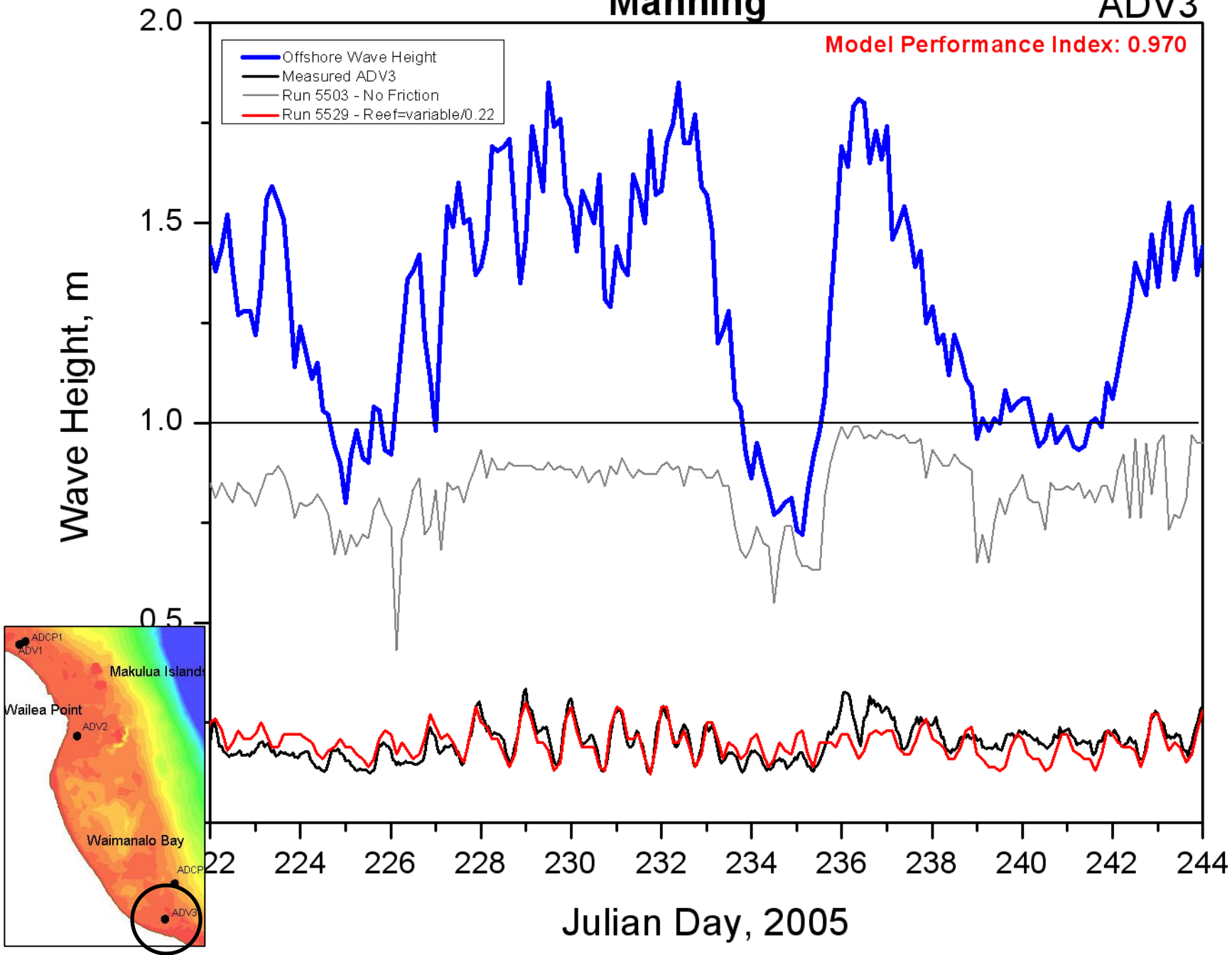

JONSWAP
ADV3
Model Performance Index: 0.942
Offshore Wave Height
Measured ADV3
Run 5503 - No Friction
Run 5504 - Reef=0.06
Wave Height, m
2.0
1.5
1.0
0.5
22
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Islands
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

Manning
variable friction coefficients

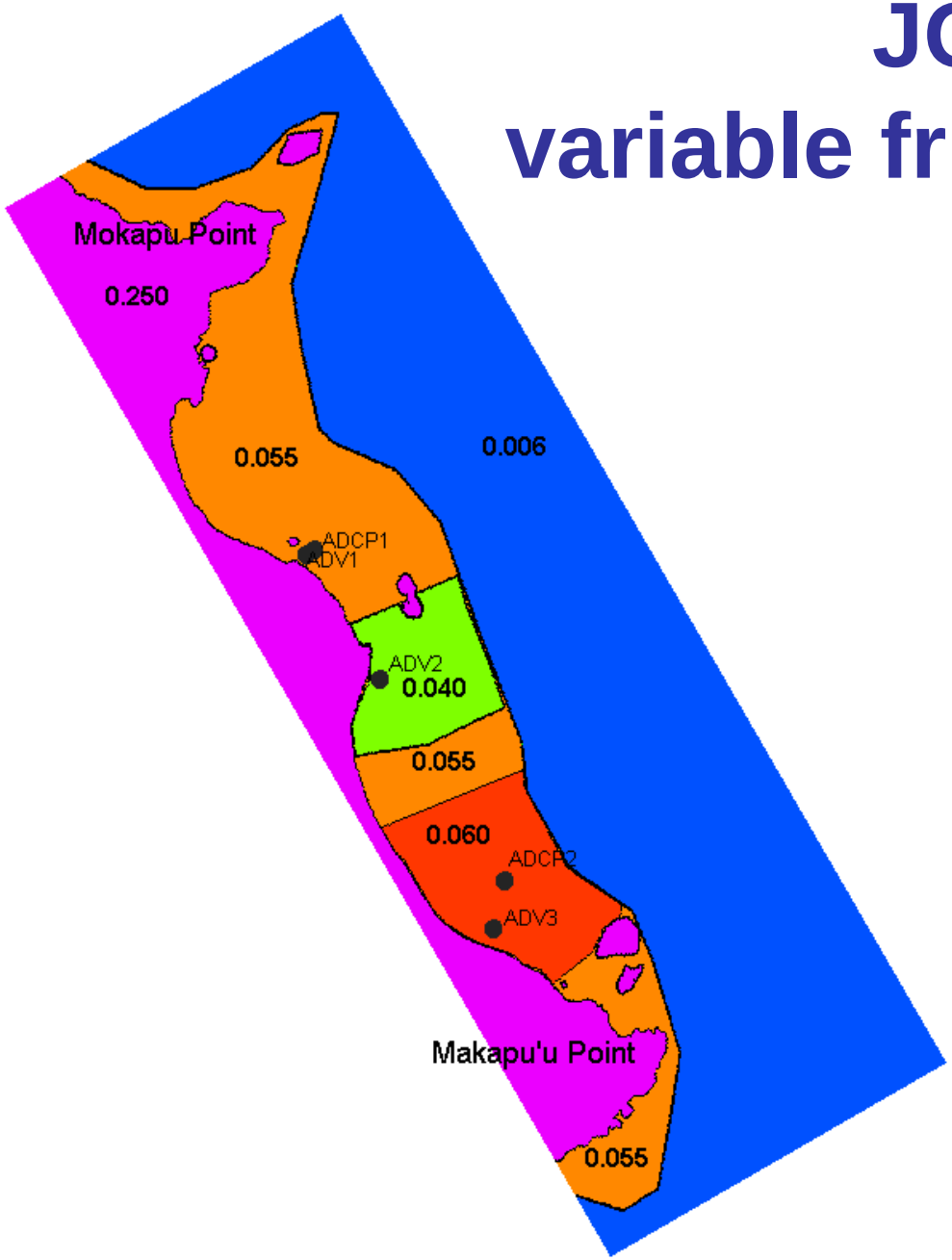


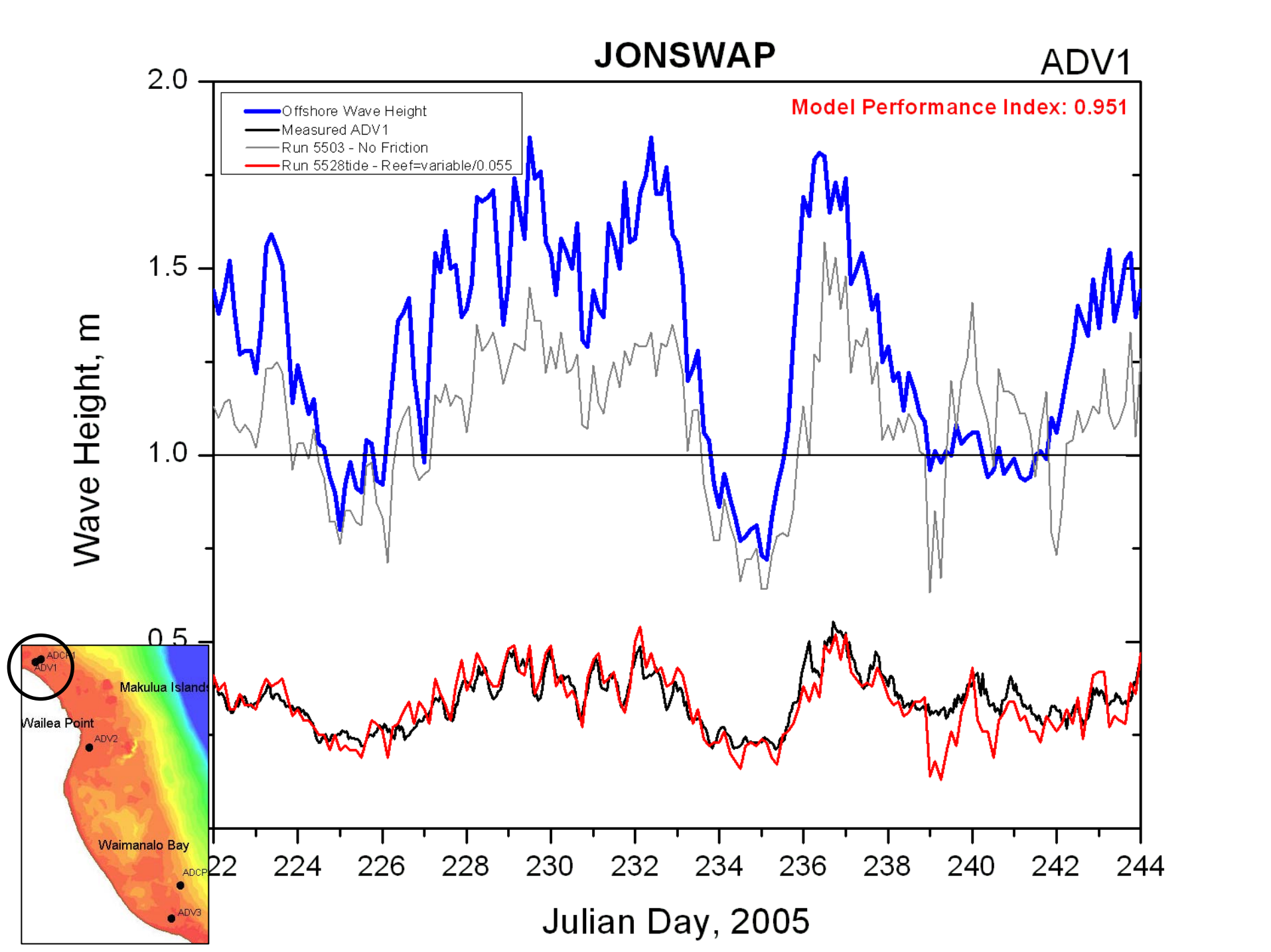

Manning
ADV1
Model Performance Index: 0.948
Offshore Wave Height
Measured ADV1
Run 5503 - No Friction
Run 5529 - Reef=variable/0.20
Wave Height, m
2.0
1.5
1.0
0.5
22
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Island
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

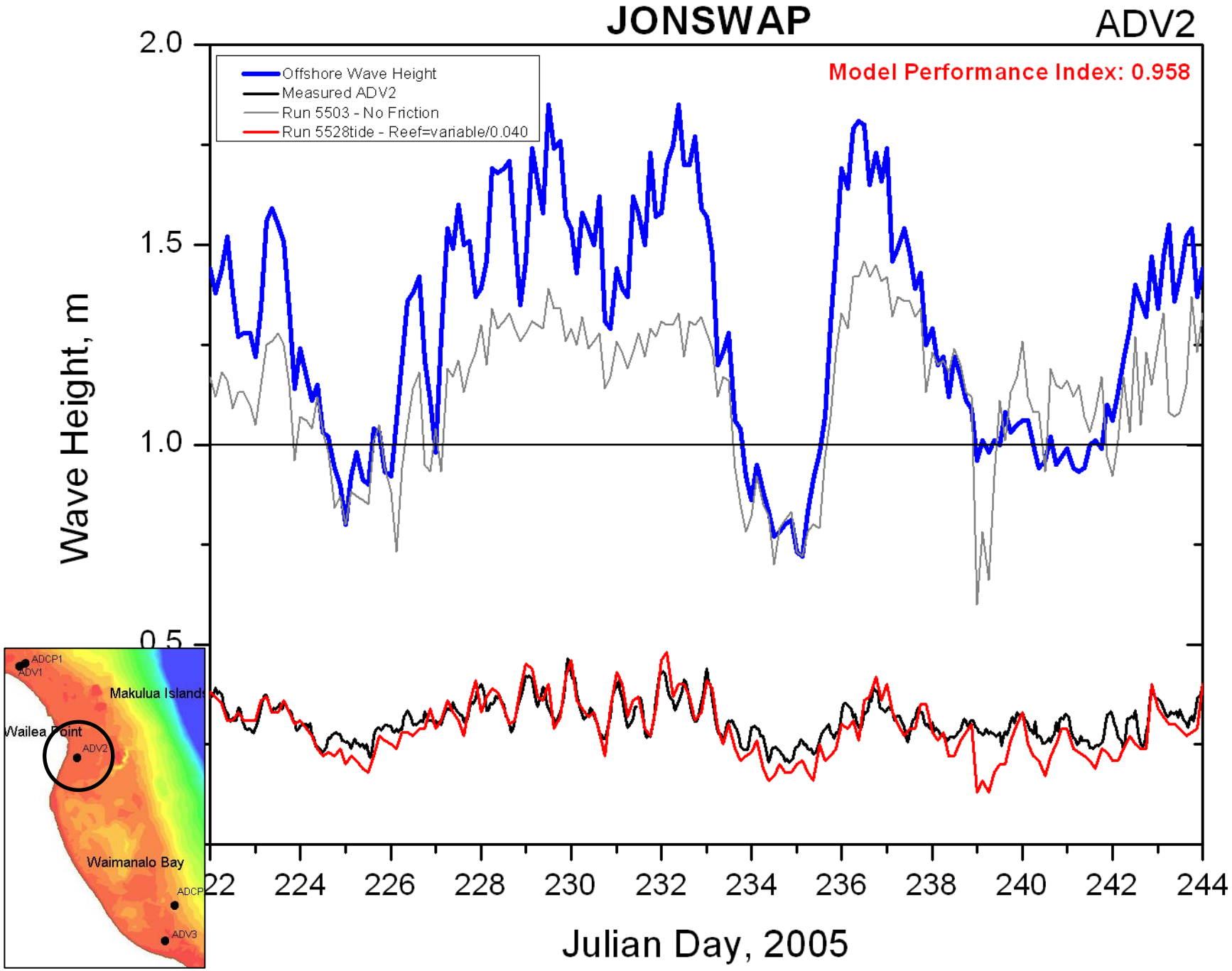

Manning
ADV2
Offshore Wave Height
Measured ADV2
Run 5503 - No Friction
Run 5529 - Reef=variable/0.17
Model Performance Index: 0.968
Wave Height, m
2.0
1.5
1.0
0.5
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Island
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

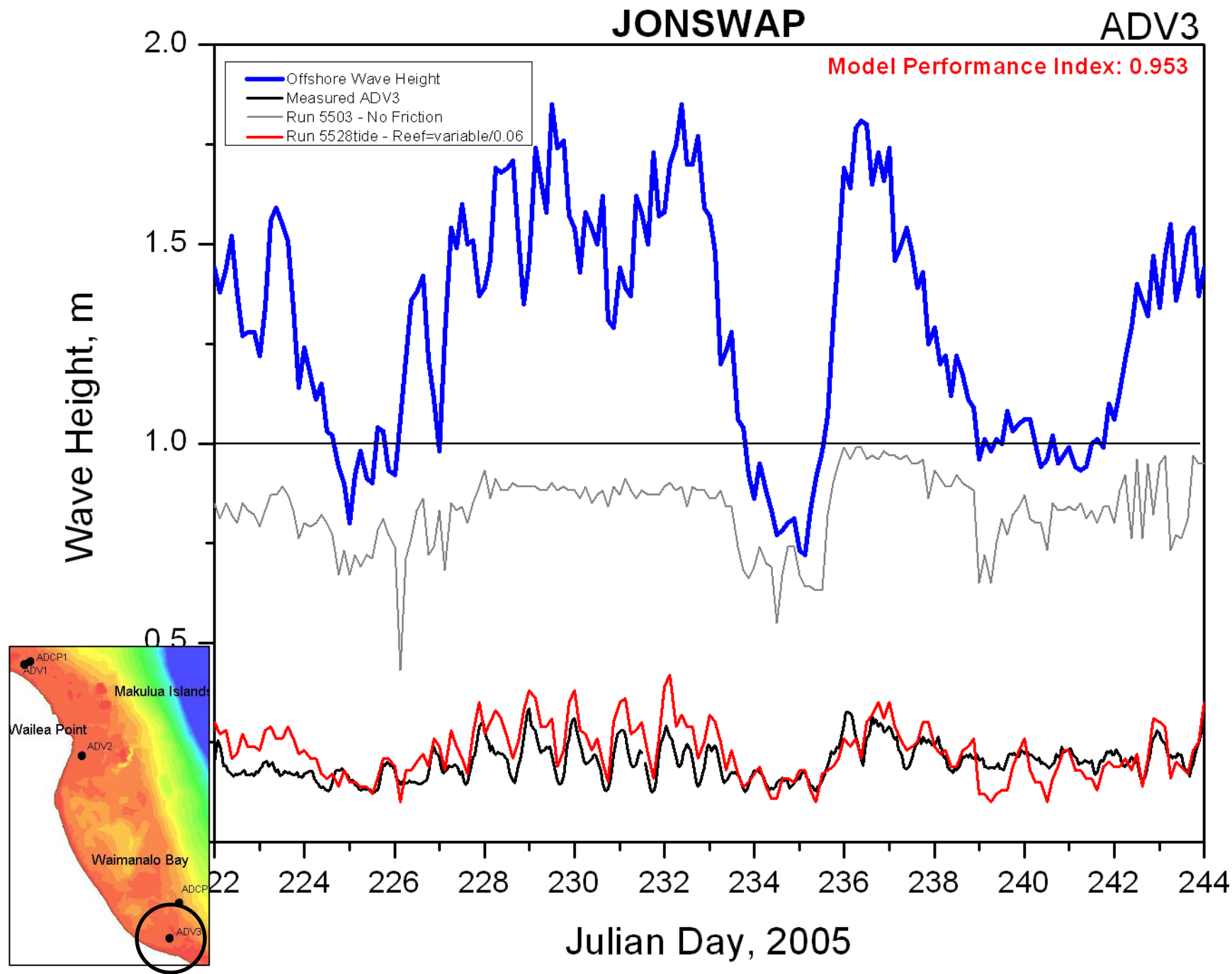

Manning
ADV3
Model Performance Index: 0.970
Offshore Wave Height
Measured ADV3
Run 5503 - No Friction
Run 5529 - Reef=variable/0.22
Wave Height, m
2.0
1.5
1.0
0.5
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Island
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

JONSWAP
variable friction coefficients



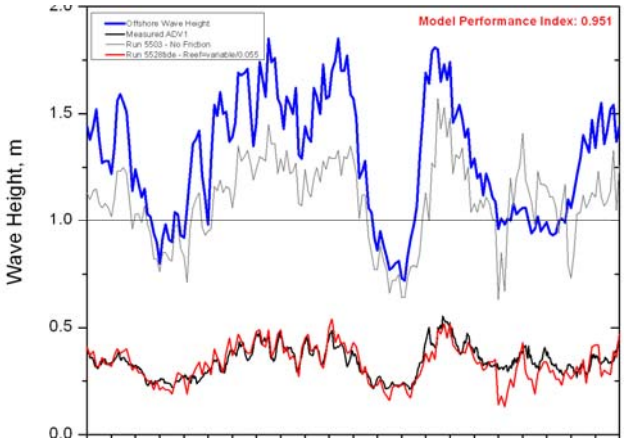

JONSWAP
ADV1
Model Performance Index: 0.951
Offshore Wave Height
Measured ADV1
Run 5503 - No Friction
Run 5528tide - Reef=variable/0.055
Wave Height, m
2.0
1.5
1.0
0.5
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Island
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

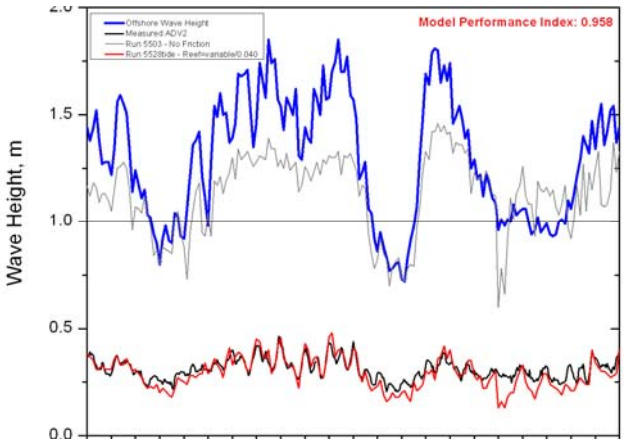

JONSWAP
ADV2
Model Performance Index: 0.958
Offshore Wave Height
Measured ADV2
Run 5503 - No Friction
Run 5528tide - Reef=variable/0.040
Wave Height, m
2.0
1.5
1.0
0.5
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Island
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

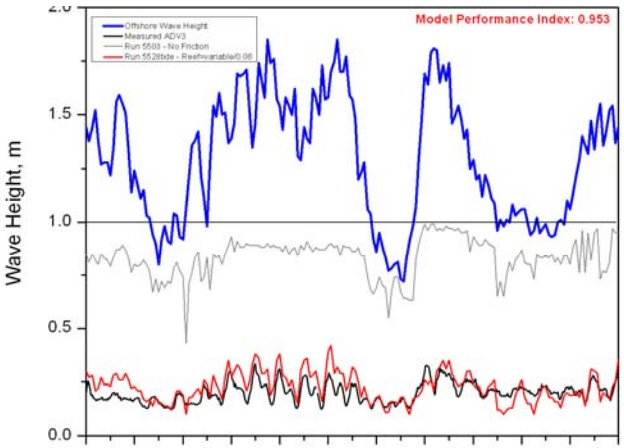

JONSWAP
ADV3
Model Performance Index: 0.953
Offshore Wave Height
Measured ADV3
Run 5503 - No Friction
Run 5528tide - Reef=variable/0.06
Wave Height, m
2.0
1.5
1.0
0.5
222
224
226
228
230
232
234
236
238
240
242
244
Julian Day, 2005
ADCP1
ADV1
Makulua Island
Wailea Point
ADV2
Waimanalo Bay
ADCP
ADV3

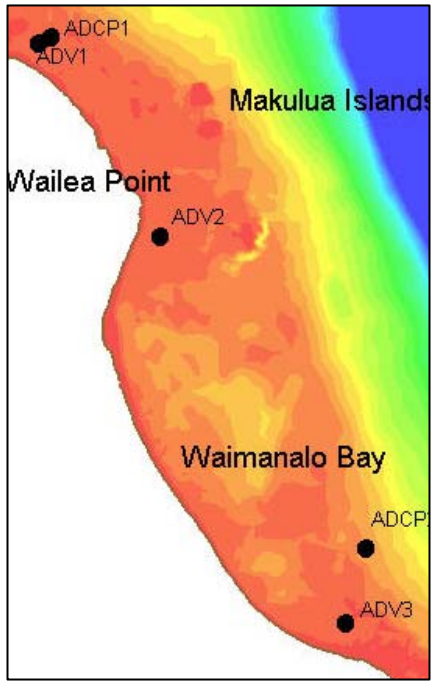
JONSWAP

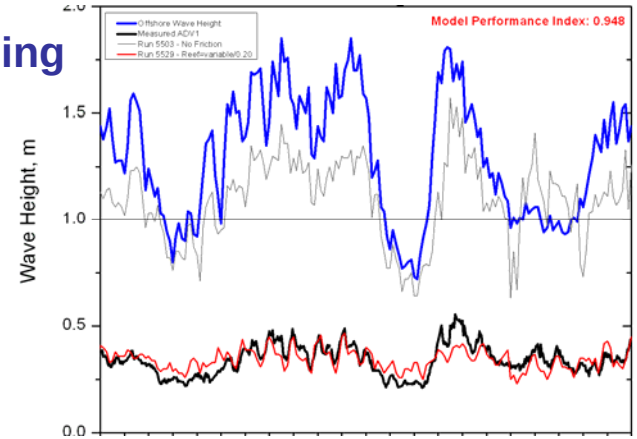
Manning

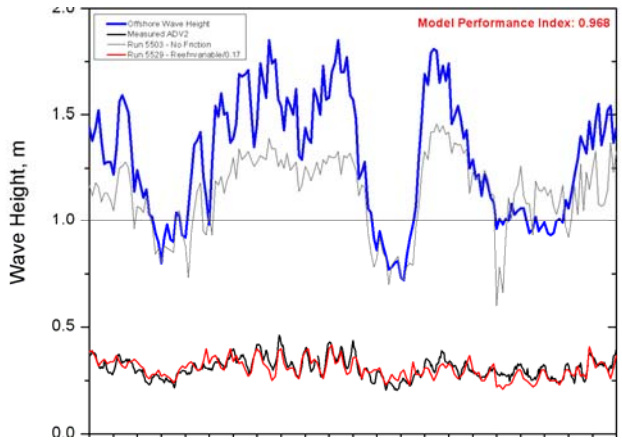


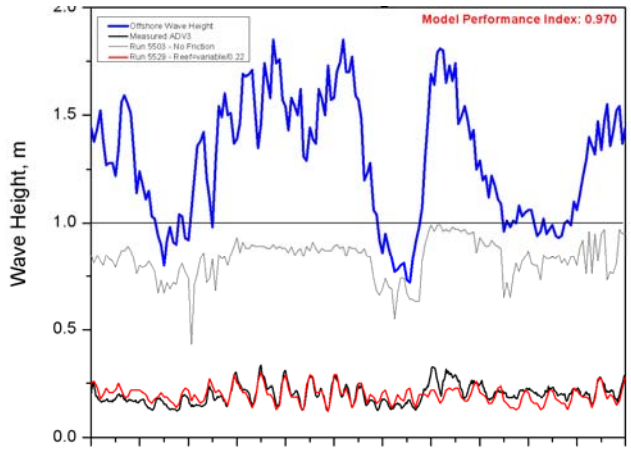












MPI
0.948 - 0.970

Outline

- Objective
- Study Area
- STWAVE Friction Formulations
- Model Validation
- Summary

Summary

- Bottom friction implemented in STWAVE
- Applied range of JONSWAP and Manning friction coefficients
- Validated to 2005 field data
- Included tidal fluctuation

- STWAVE with bottom friction captures the large reduction in wave height from the offshore to the nearshore
- An attempt at simulating the variability in reef condition was made by varying the friction coefficient in patches
- Model Performance Index values of ~0.95 indicate the model is capturing wave transformation/dissipation over the reef

Questions?