Wave Transformation, Prediction, and Analysis at Kaumalapau Harbor, Lanai, Hawaii

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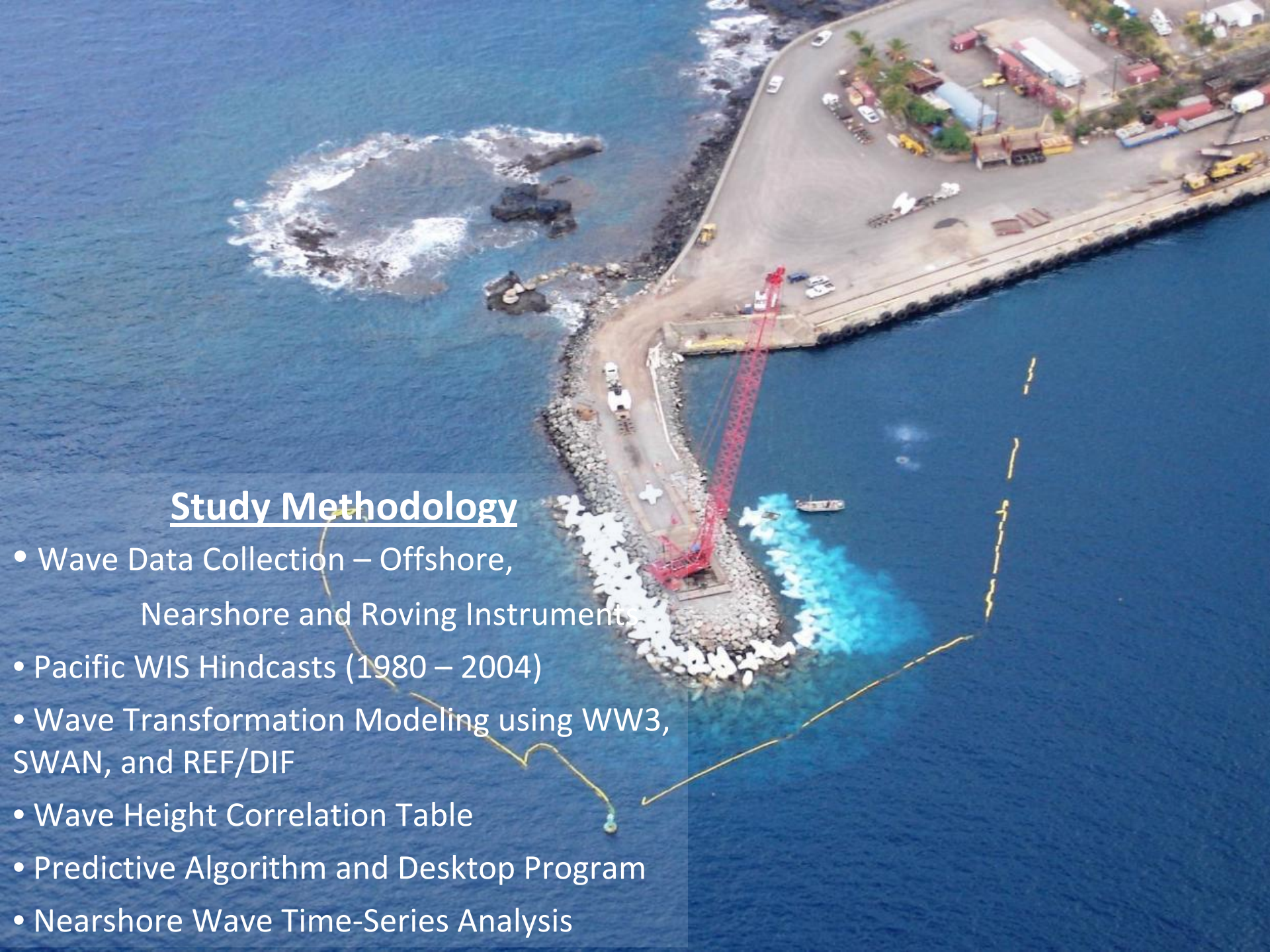
Study Motivation

Kaumalapau Harbor Breakwater Repair selected for monitoring under the USACE Monitoring of Completed Navigation Projects (MCNP) Program

Program Goals:

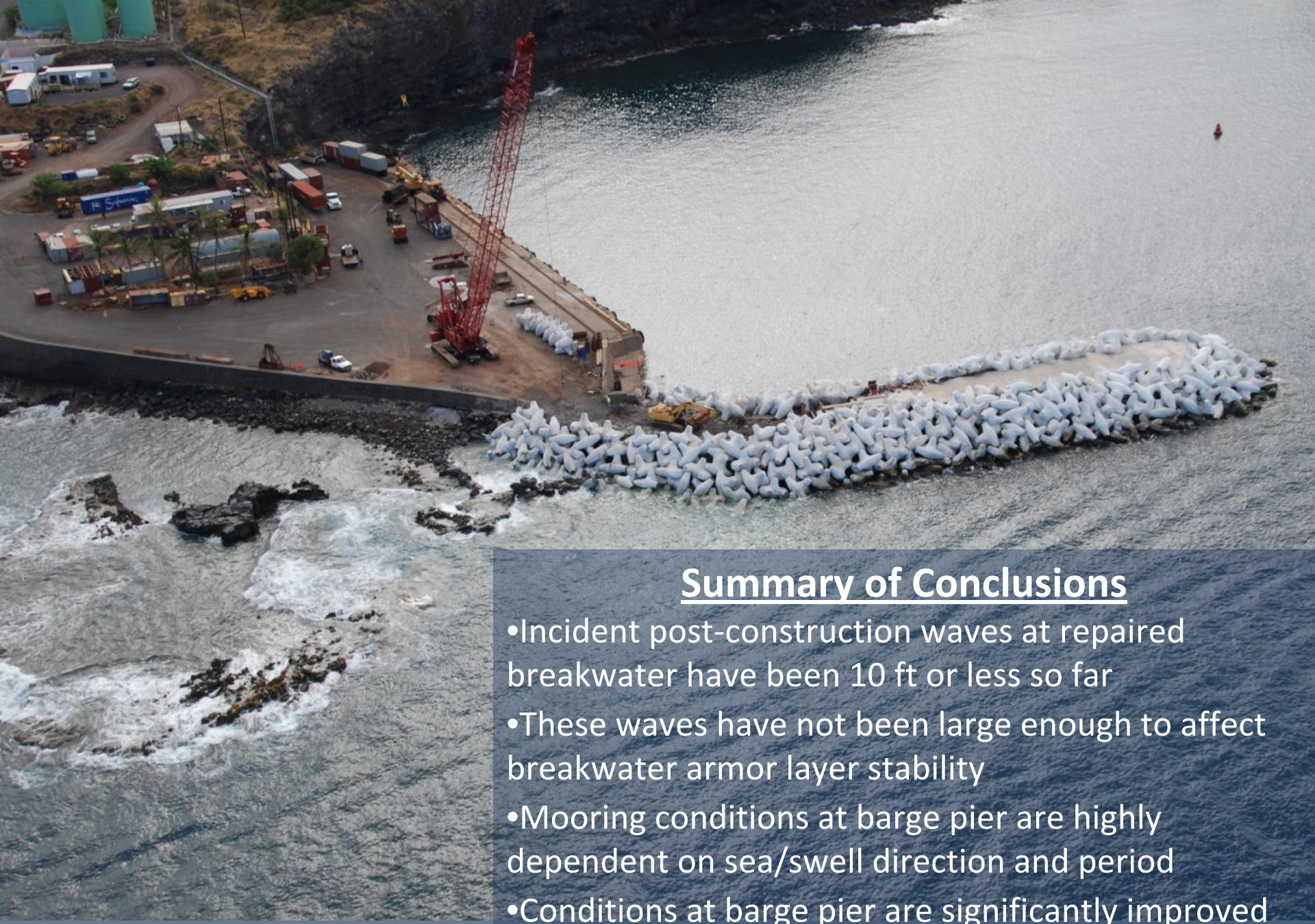
1) Measure waves at barge pier to determine repaired breakwater's effect on mooring conditions

2)Evaluate post-construction wave climate incident to breakwater for use in assessing structure stability and evaluating armor unit movement



Study Methodology

- Wave Data Collection – Offshore, Nearshore and Roving Instrument
- Pacific WIS Hindcasts (1980 – 2004)
- Wave Transformation Modeling using WW3, SWAN, and REF/DIF
- Wave Height Correlation Table
- Predictive Algorithm and Desktop Program
- Nearshore Wave Time-Series Analysis

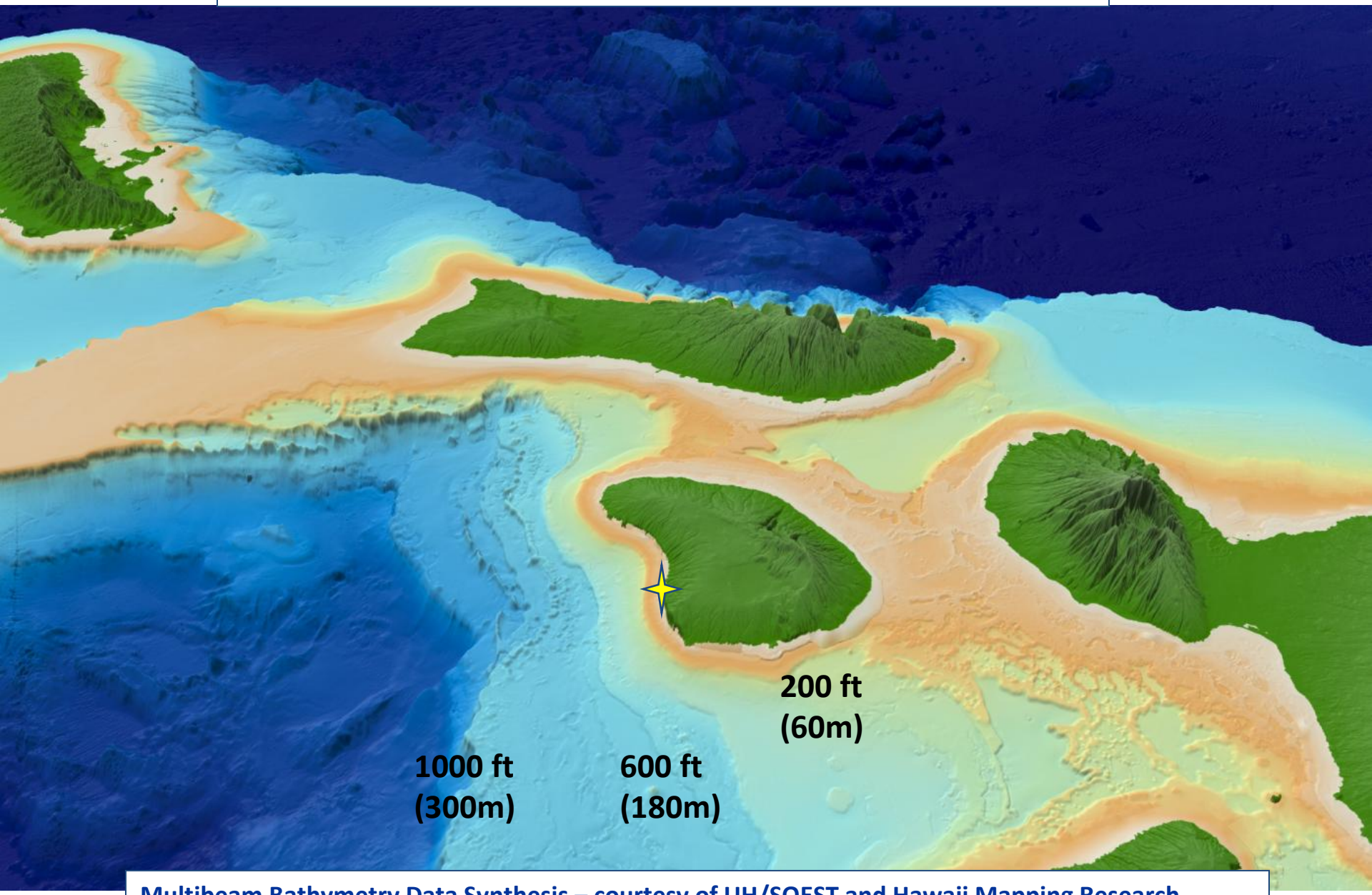


Summary of Conclusions

- Incident post-construction waves at repaired breakwater have been 10 ft or less so far
- These waves have not been large enough to affect breakwater armor layer stability
- Mooring conditions at barge pier are highly dependent on sea/swell direction and period
- Conditions at barge pier are significantly improved during the post-construction conditions observed

N
KAUAI
OAHU
MOLOKAI
MAUI
HAWAII
Pacific Ocean

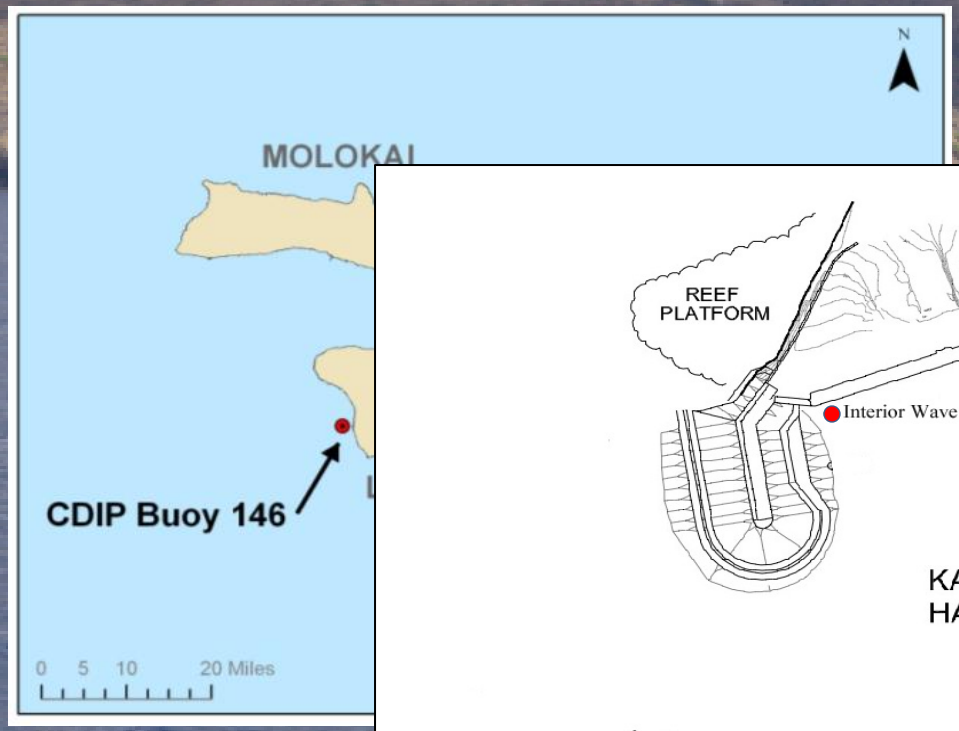
3D Bathymetry Near Kaumalapau Harbor

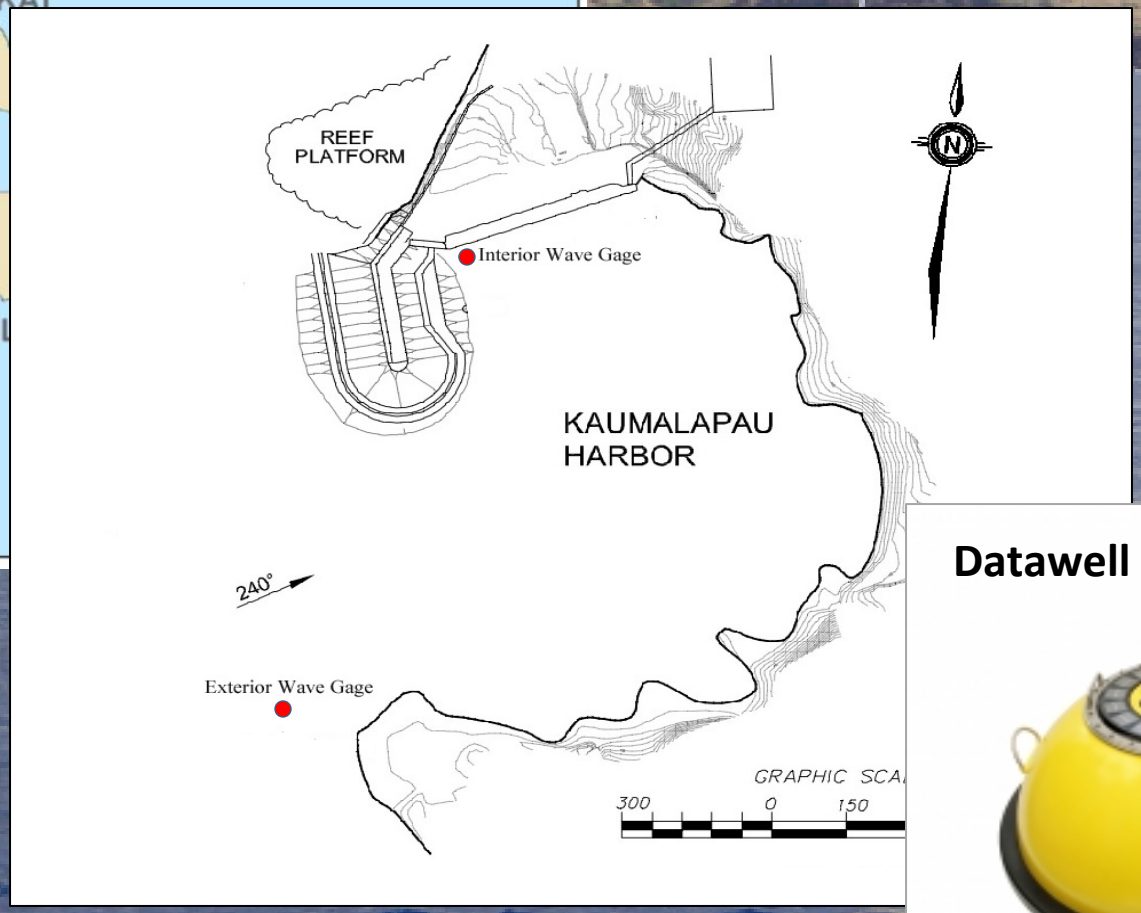


Multibeam Bathymetry Data Synthesis – courtesy of UH/SOEST and Hawaii Mapping Research Group

Harbor Layout

Wave Data Collection

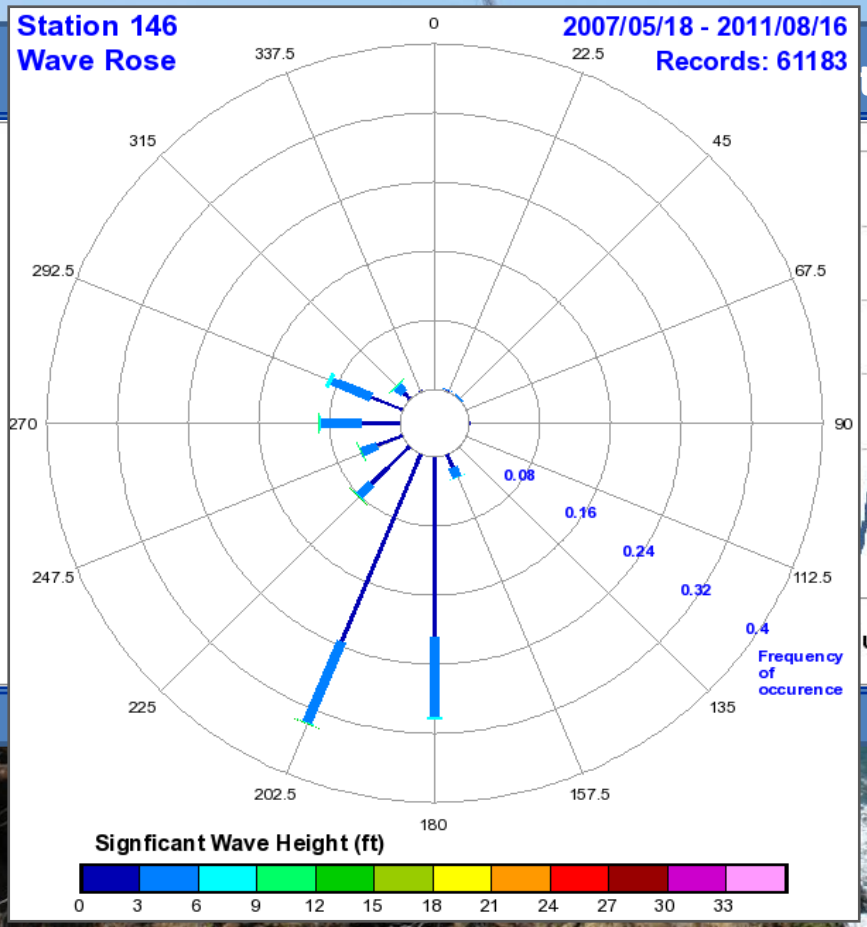


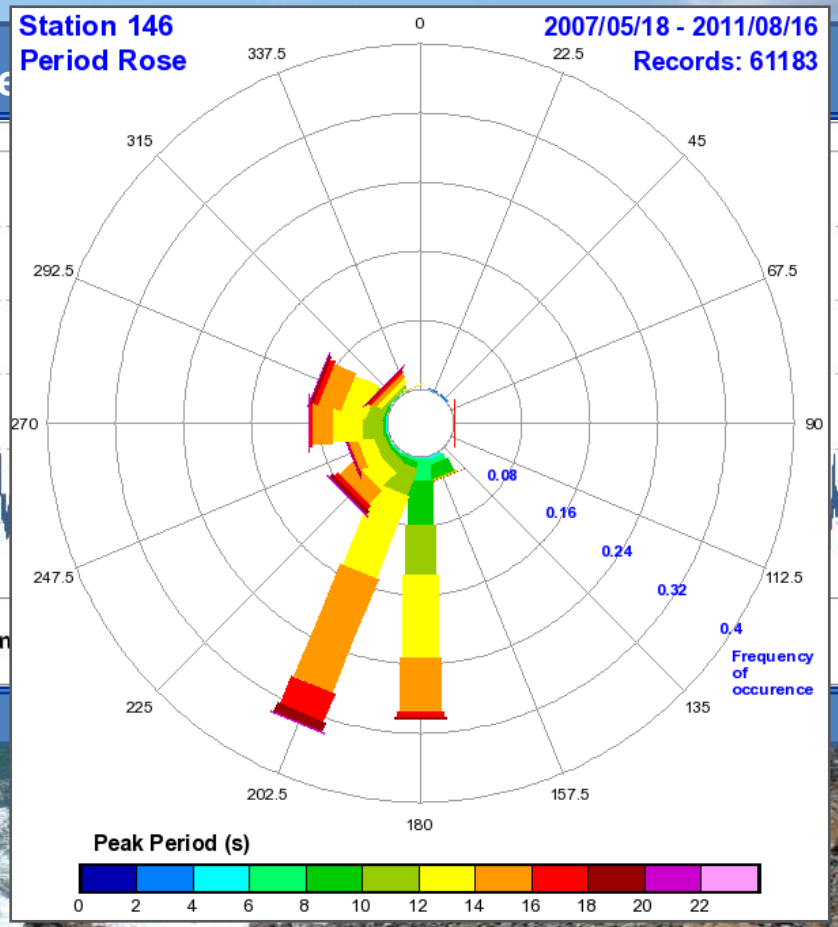


Datawell Roving Buoy

Wave Data Collection

Offshore CDIP Buoy

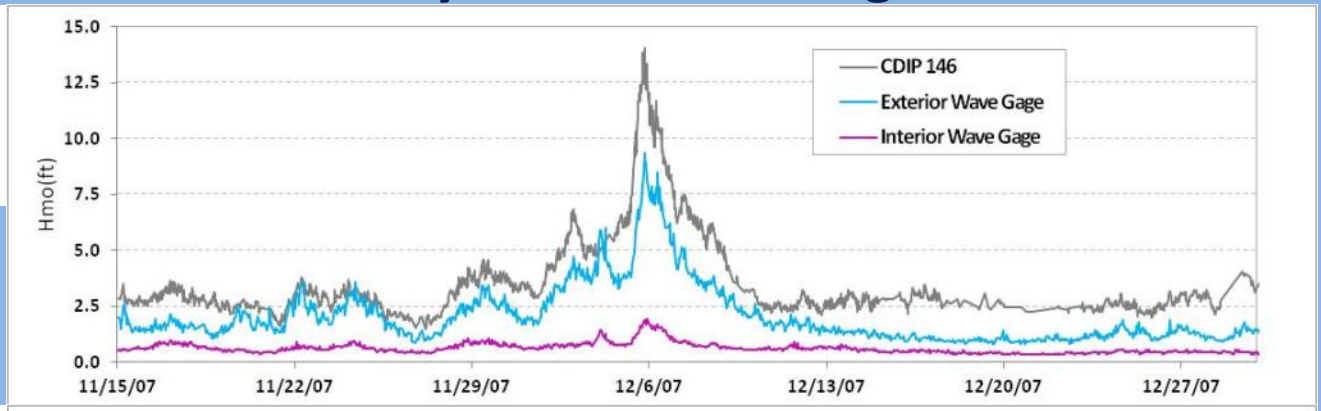




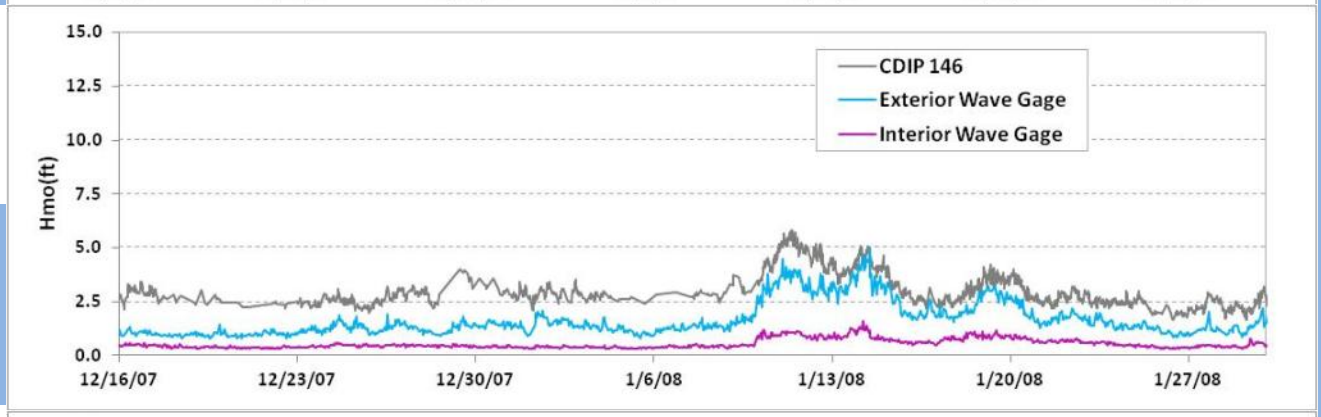
Wave Data Collection

Offshore CDIP Buoy and Harbor Gages

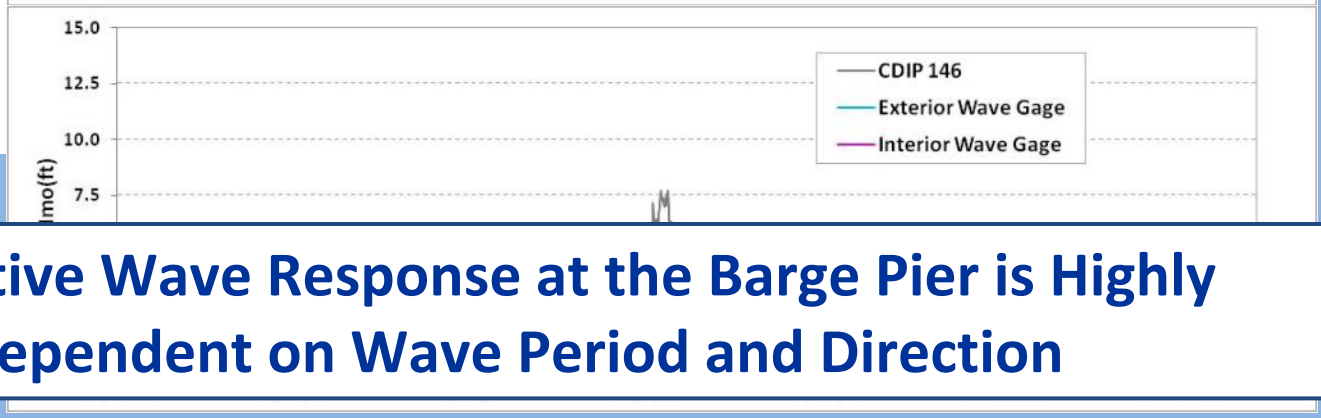
December 2007 Kona Storm:
Tp = 8.3 s
Dir = 224 TN (SW)



January 2008 W-NW Swells:
Tp = 15.4 s
Dir = 298 TN (NW) &
281 (W-NW)

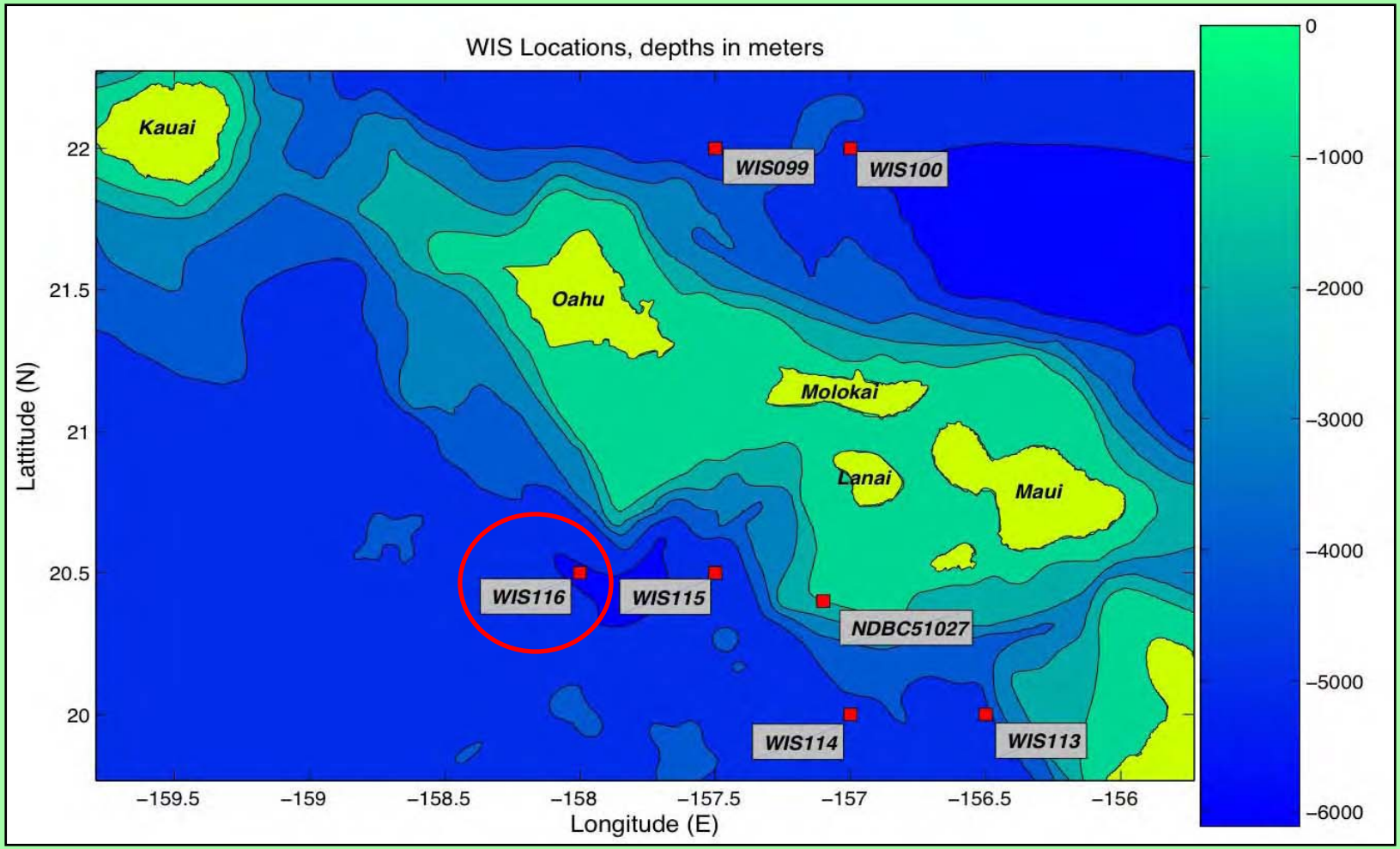


November 2007 South Swell:
Tp = 16.7 s
Dir = 190 TN (S-SW)



➢ **Relative Wave Response at the Barge Pier is Highly Dependent on Wave Period and Direction**

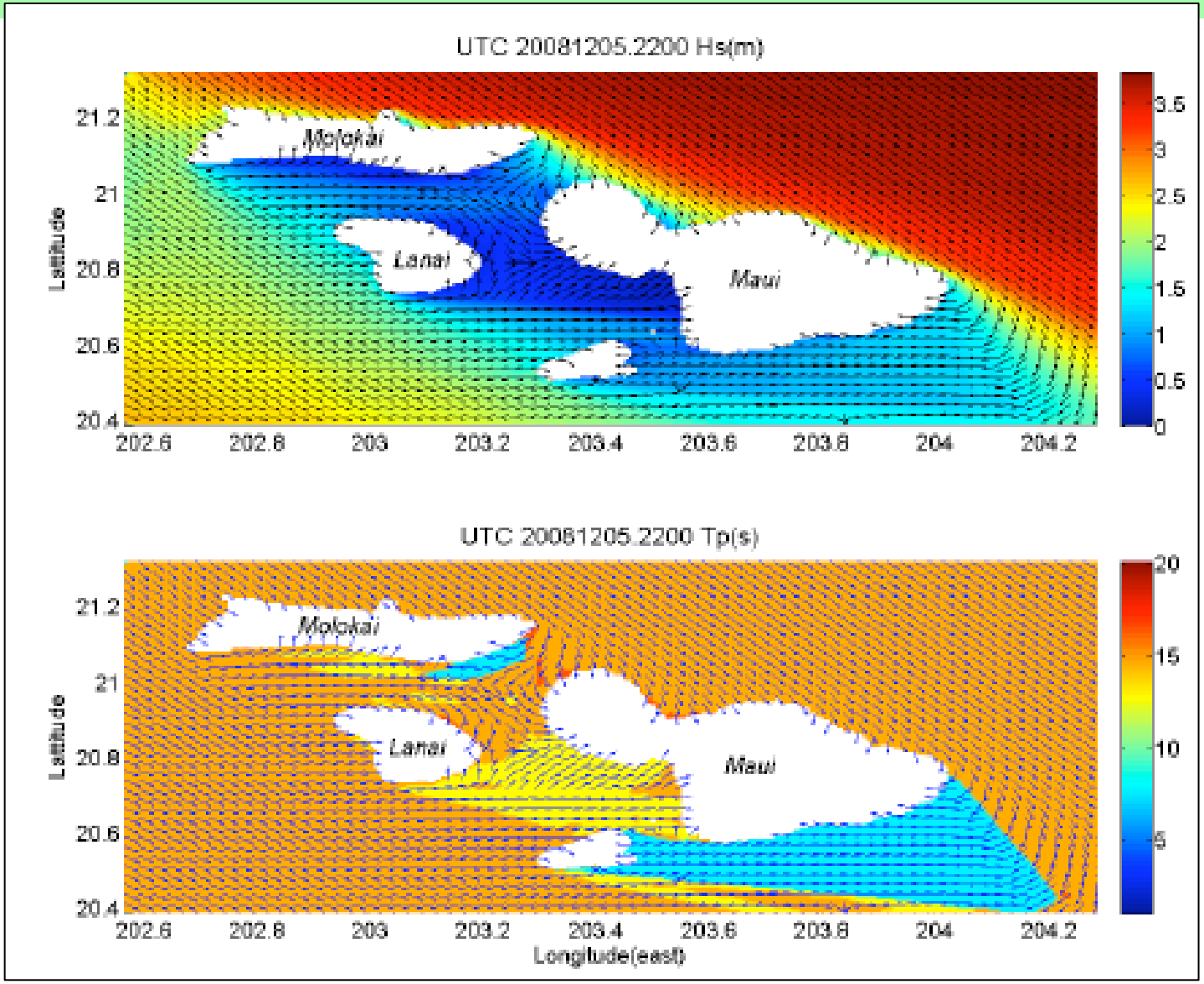
Wave Transformation
WIS Hindcast Data



- **WIS Pacific Hindcast available for 1980 – 2004**
- **Stations 113, 114, 115,116 compared to 1 year of buoy data at NDBC 51027**
- **WIS Station 116 had best fit overall for Tradewind, South Swell and NW Swell**

Wave Transformation

SWAN Model

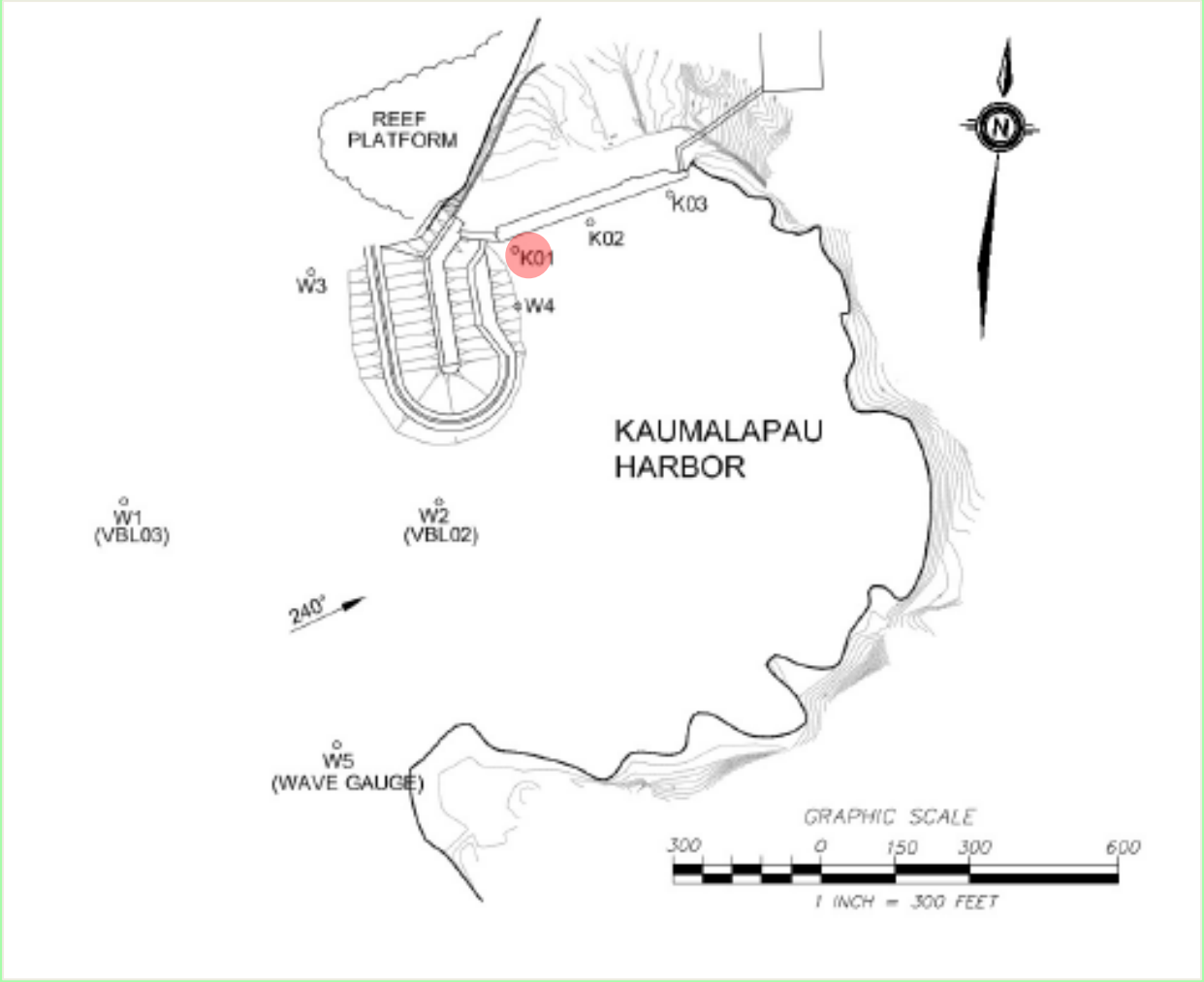


18 Aug 2007 – 28 October 2007

Wave Transformation
REF/DIF Model

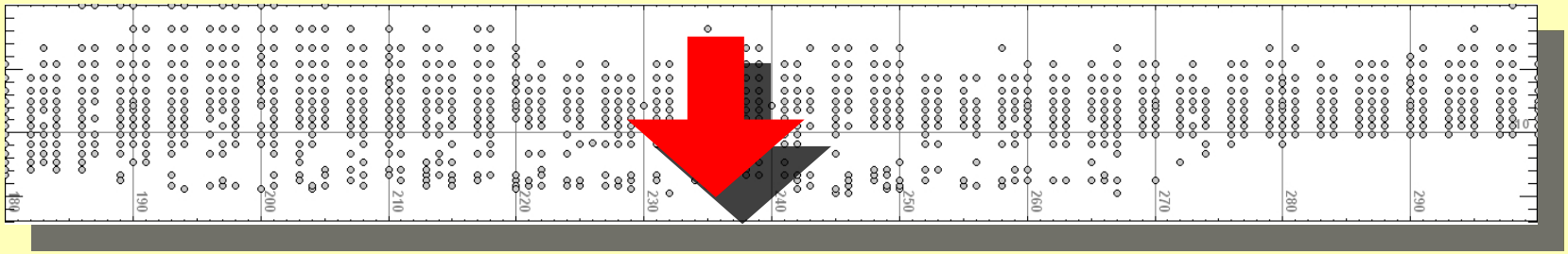
CDIP 146 Buoy

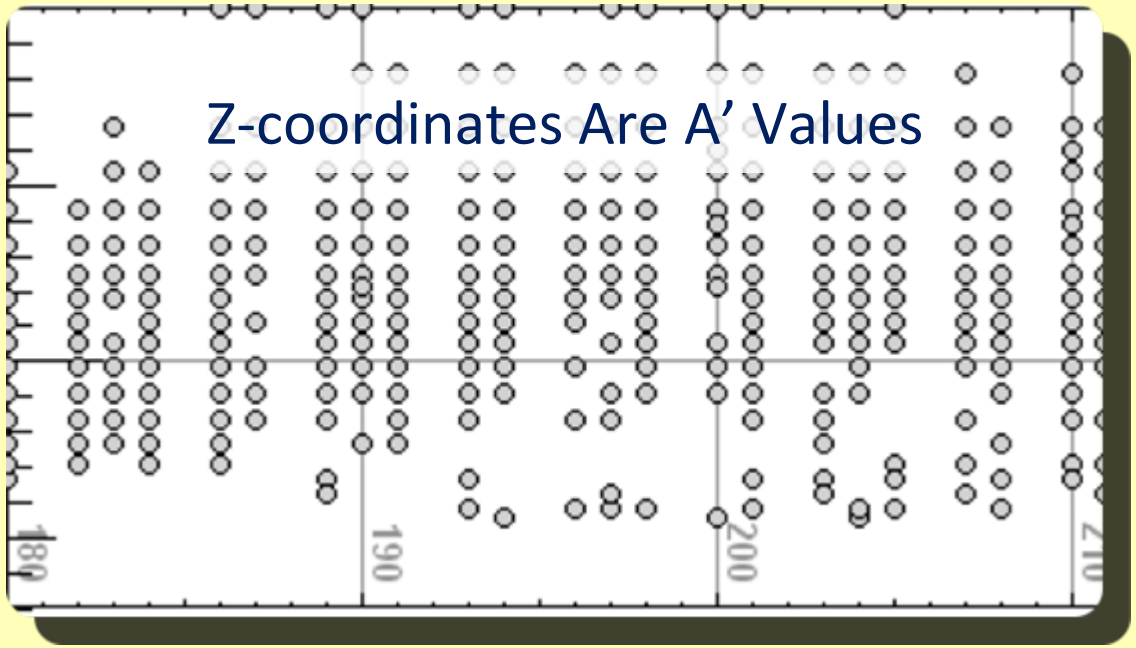
- REF/DIF used to transform SWAN output into harbor (tradewind cases dropped)
- Eight observation stations
- Model validation through comparison of A' with 3D physical model data (1998) => negative bias
- A' relationship at observation stations for 119 discrete wave conditions



Wave Prediction

Surface Plots and KPWAVE



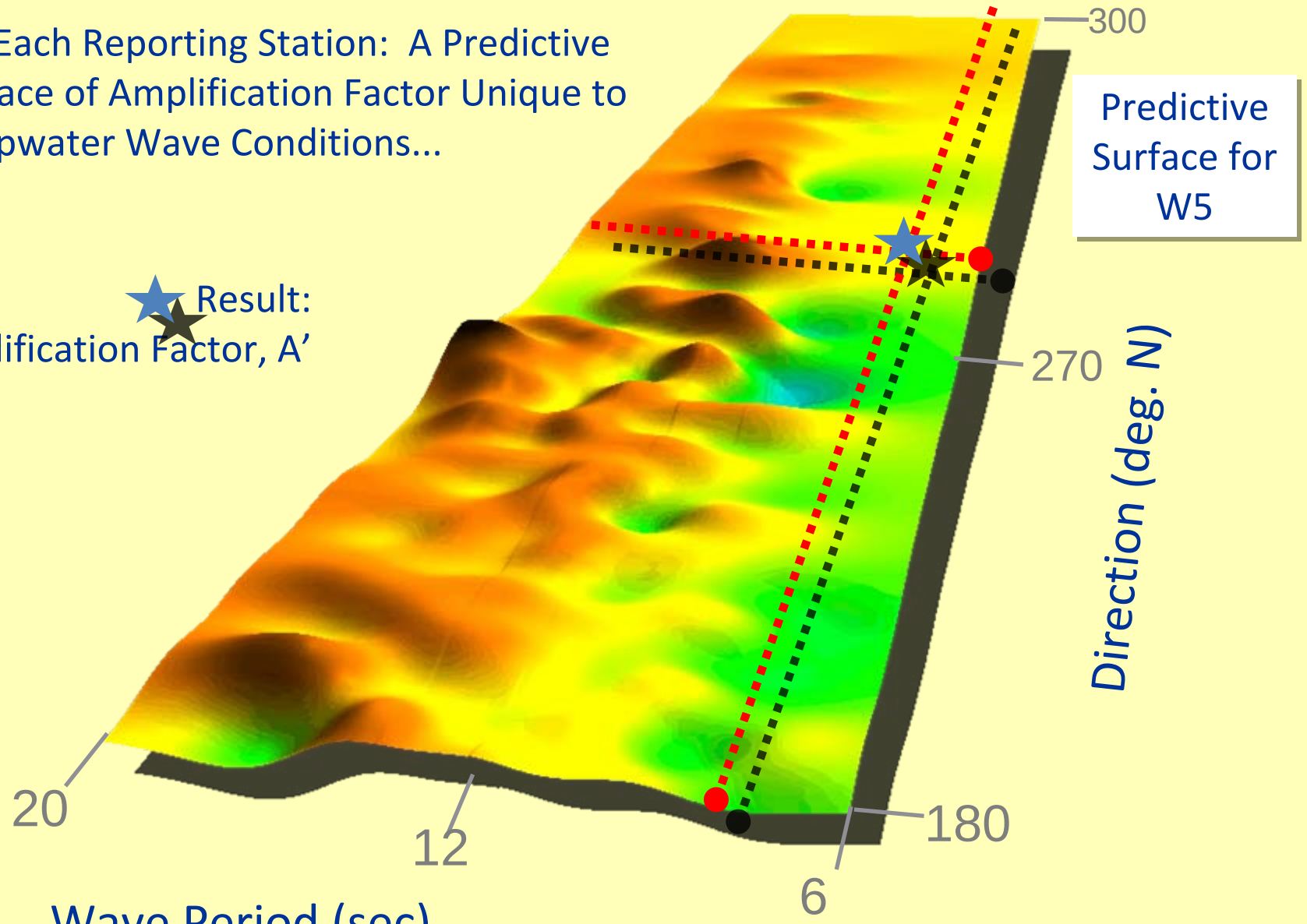


Time Series Data Sets Were Used to Calculate Amplification Factor for Each Measured Set of Conditions, Yielding a tabulation of 'x,y,z' values (direction, period, A' coefficient)

Wave Prediction
Surface Plots and KPWAVE

For Each Reporting Station: A Predictive Surface of Amplification Factor Unique to Deepwater Wave Conditions...

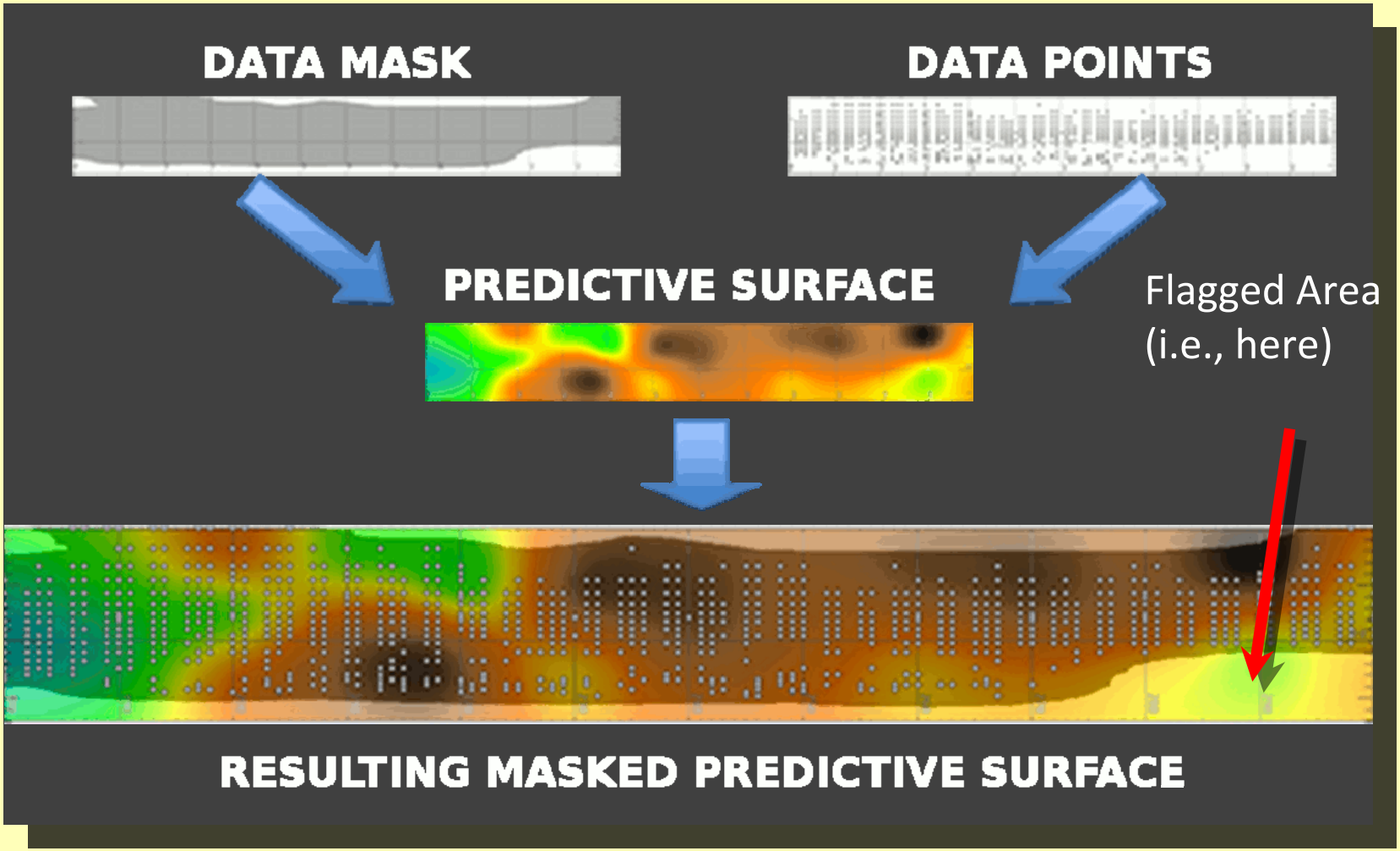
Result:
Amplification Factor, A'



Predictive Surface for W5

Wave Prediction

Surface Plots and KPWAVE



The Predictive Surface is Filtered to Identify Values That Are Too Far From Real Data Points (Points of Low Confidence)

Wave Prediction
Surface Plots and KPWAVE

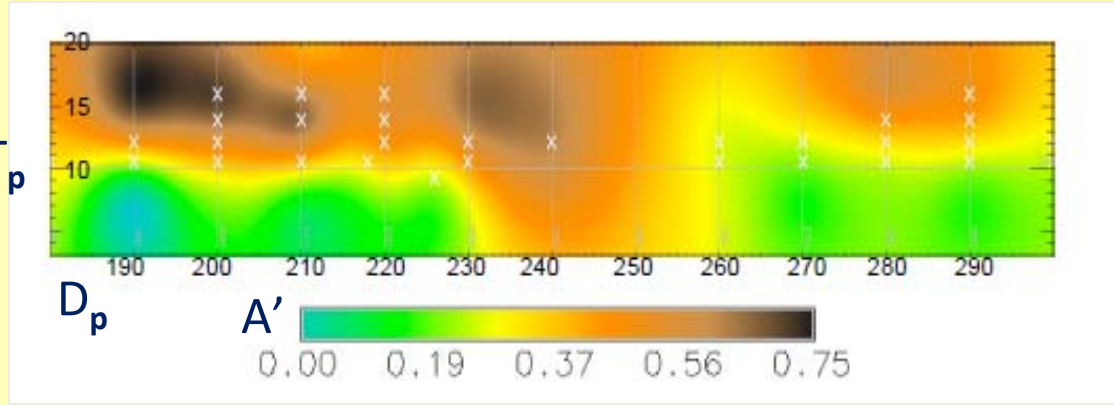
- Difference between *predicted* and *measured* A' at Location K01:

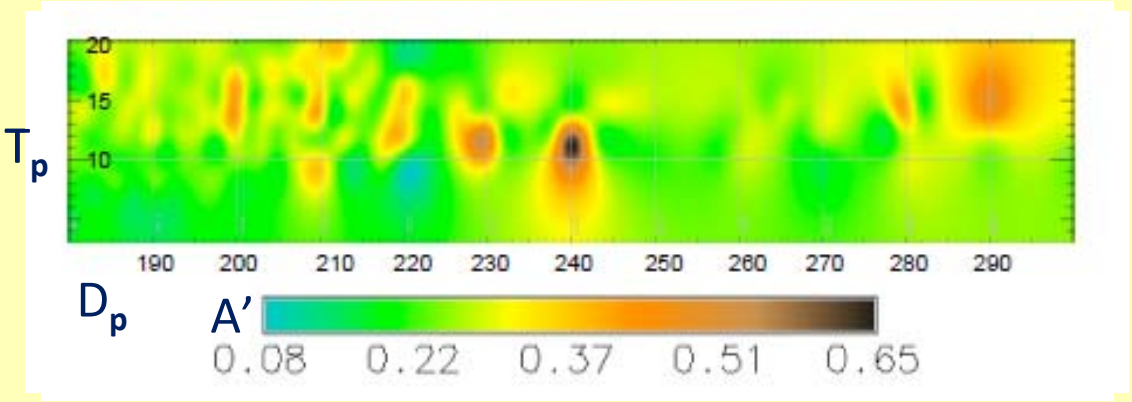
+0.49 (over predicted) for wave periods 15 - 20 seconds coming from S through SSW(180 – 215 TN)

-0.21 (under predicted) for shorter wave periods (5-10s) coming from the south (190 TN).

- Predictive Surfaces (based only on model output) created at K02, K03, W2, W3, W4, and W5 output wave stations also

3D Surface Plot of Amplification Factor at Location K01 (Model Data)

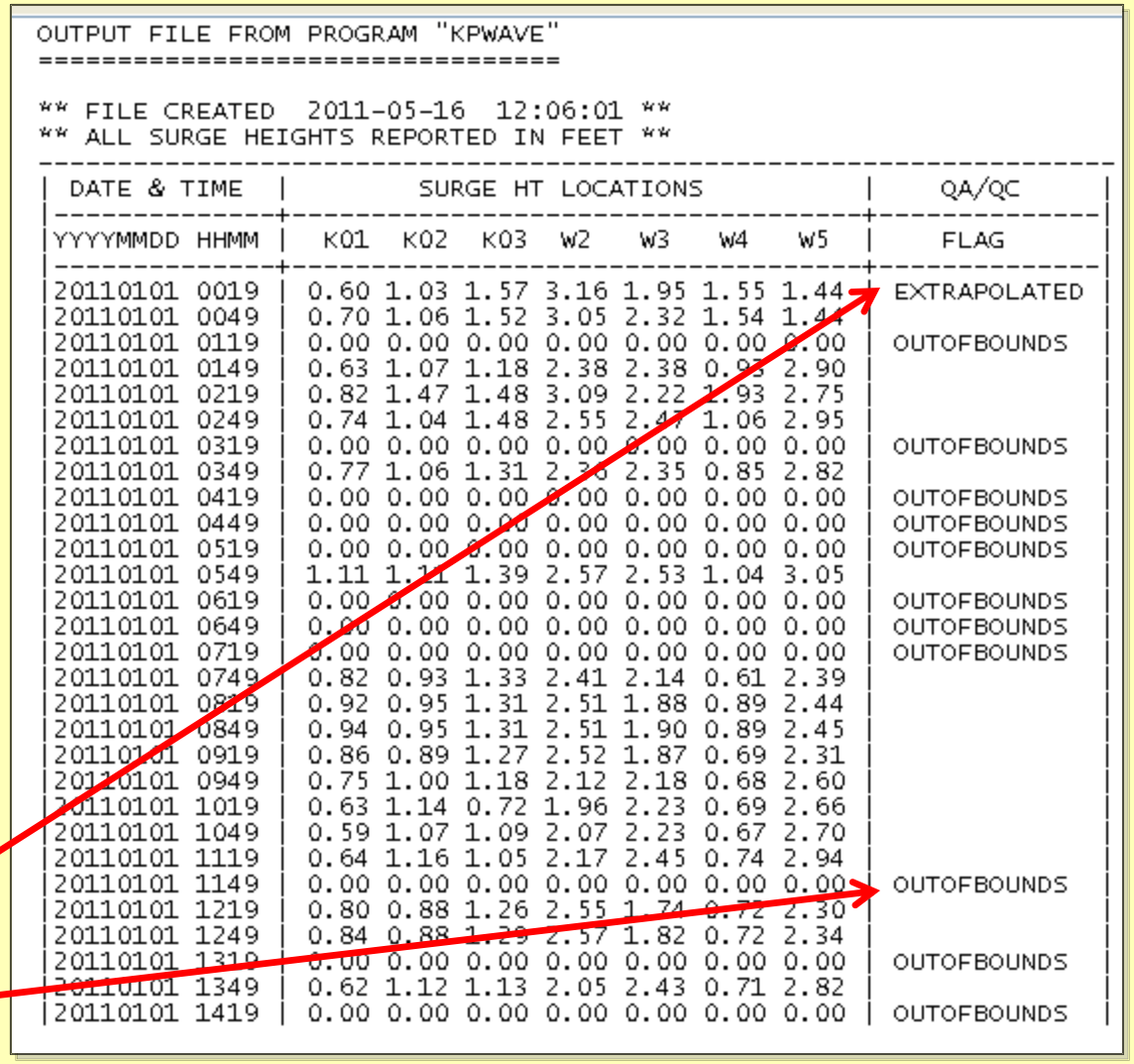




3D Surface Plot of Combined A' (Measured/Model Data)

Wave Prediction
Surface Plots and KPWAVE

- KPWAVE – a Fortran program that uses predictive algorithms to estimate wave amplification factor based on wave direction and period
- User can enter parameters manually or use time series input file from the CDIP buoy website (up to 1 year)
- Creates an output file of the corresponding time series at 7 output locations
- Flags for “Extrapolated” values or “Out of Bounds”



OUTPUT FILE FROM PROGRAM "KPWAVE"

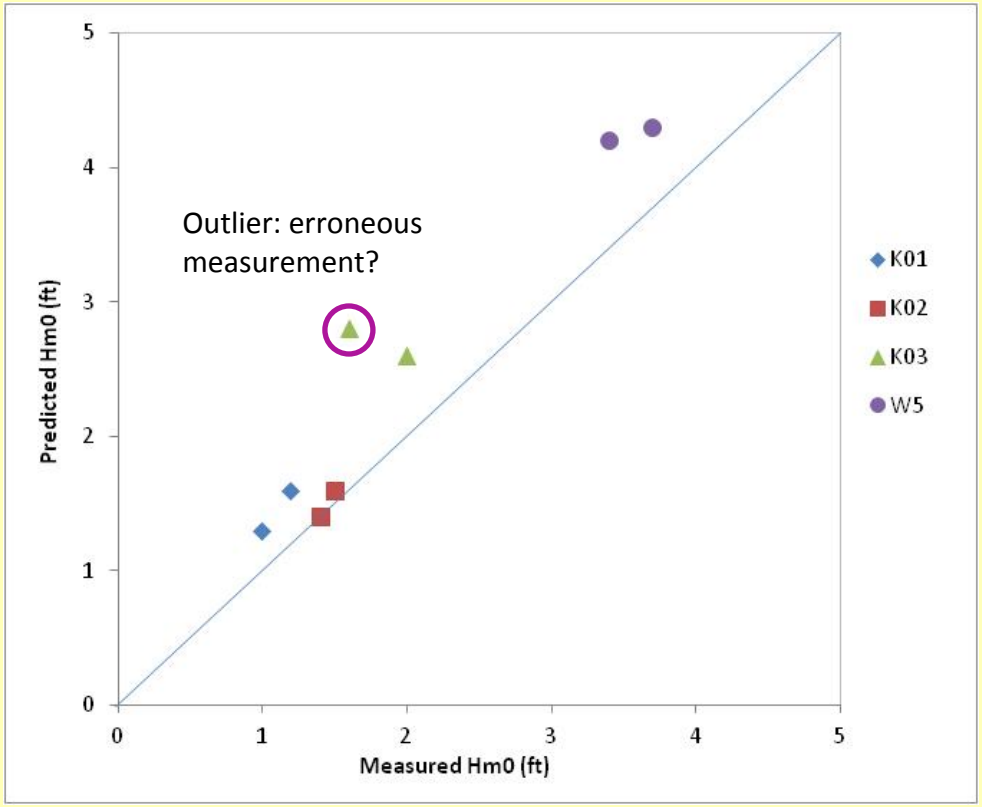
** FILE CREATED 2011-05-16 12:06:01 **
** ALL SURGE HEIGHTS REPORTED IN FEET **

DATE & TIME	SURGE HT LOCATIONS							QA/QC
YYYYMMDD HHMM	K01	K02	K03	W2	W3	W4	W5	FLAG
20110101 0019	0.60	1.03	1.57	3.16	1.95	1.55	1.44	EXTRAPOLATED
20110101 0049	0.70	1.06	1.52	3.05	2.32	1.54	1.44	
20110101 0119	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 0149	0.63	1.07	1.18	2.38	2.38	0.93	2.90	
20110101 0219	0.82	1.47	1.48	3.09	2.22	1.93	2.75	
20110101 0249	0.74	1.04	1.48	2.55	2.47	1.06	2.95	
20110101 0319	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 0349	0.77	1.06	1.31	2.36	2.35	0.85	2.82	
20110101 0419	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 0449	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 0519	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 0549	1.11	1.11	1.39	2.57	2.53	1.04	3.05	
20110101 0619	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 0649	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 0719	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 0749	0.82	0.93	1.33	2.41	2.14	0.61	2.39	
20110101 0819	0.92	0.95	1.31	2.51	1.88	0.89	2.44	
20110101 0849	0.94	0.95	1.31	2.51	1.90	0.89	2.45	
20110101 0919	0.86	0.89	1.27	2.52	1.87	0.69	2.31	
20110101 0949	0.75	1.00	1.18	2.12	2.18	0.68	2.60	
20110101 1019	0.63	1.14	0.72	1.96	2.23	0.69	2.66	
20110101 1049	0.59	1.07	1.09	2.07	2.23	0.67	2.70	
20110101 1119	0.64	1.16	1.05	2.17	2.45	0.74	2.94	
20110101 1149	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 1219	0.80	0.88	1.26	2.55	1.74	0.72	2.30	
20110101 1249	0.84	0.88	1.29	2.57	1.82	0.72	2.34	
20110101 1319	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS
20110101 1349	0.62	1.12	1.13	2.05	2.43	0.71	2.82	
20110101 1419	0.00	0.00	0.00	0.00	0.00	0.00	0.00	OUTOFBOUNDS

Wave Prediction
Surface Plots and KPWAVE

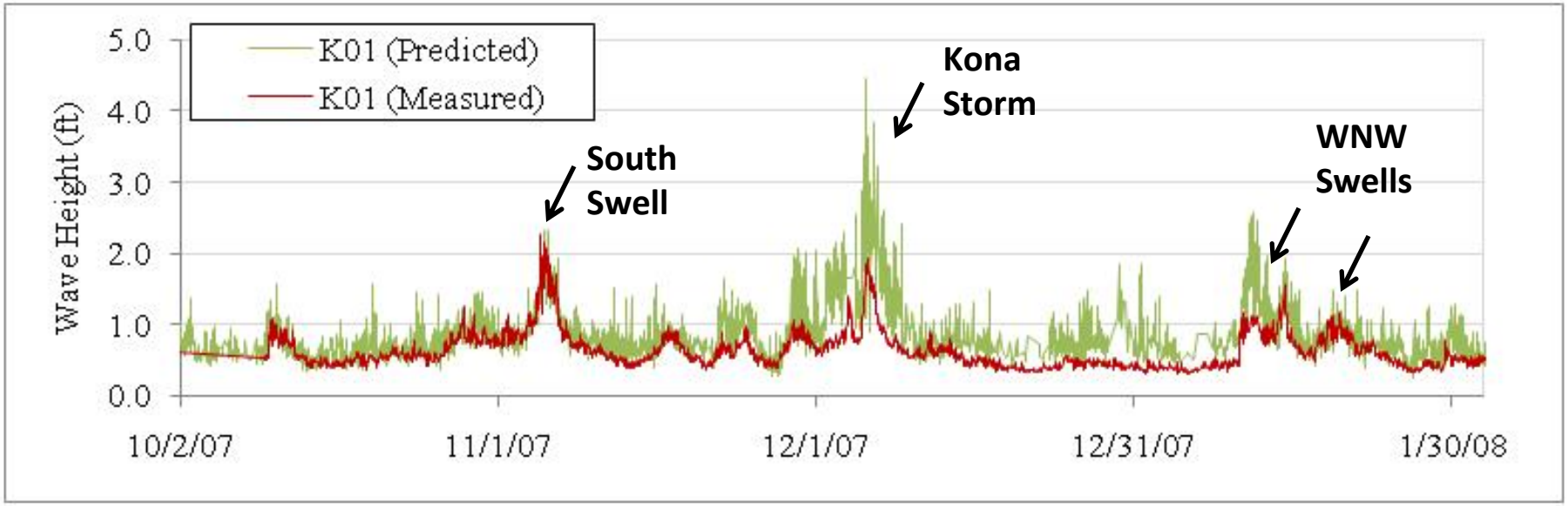
- Comparison of predicted H_s from modeling to roving buoy data on 5 Dec 08 at barge pier stations and harbor entrance
- Positive bias in modeled data
- One potential erroneous point
- Sensitivity to Tp and Dp

Comparison of Measured vs. Predicted H_s for 5 Dec 2008 at Specified Locations



Moderate NW Swell Conditions:
Ho = 3.7 – 4.3 ft, Tp = 13.8 – 15.4 s, Dir = 267-286 TN

Time-Series Analysis
KPWAVE vs. Gage Data at Barge Pier



Measured vs. Predicted Wave Height at K01

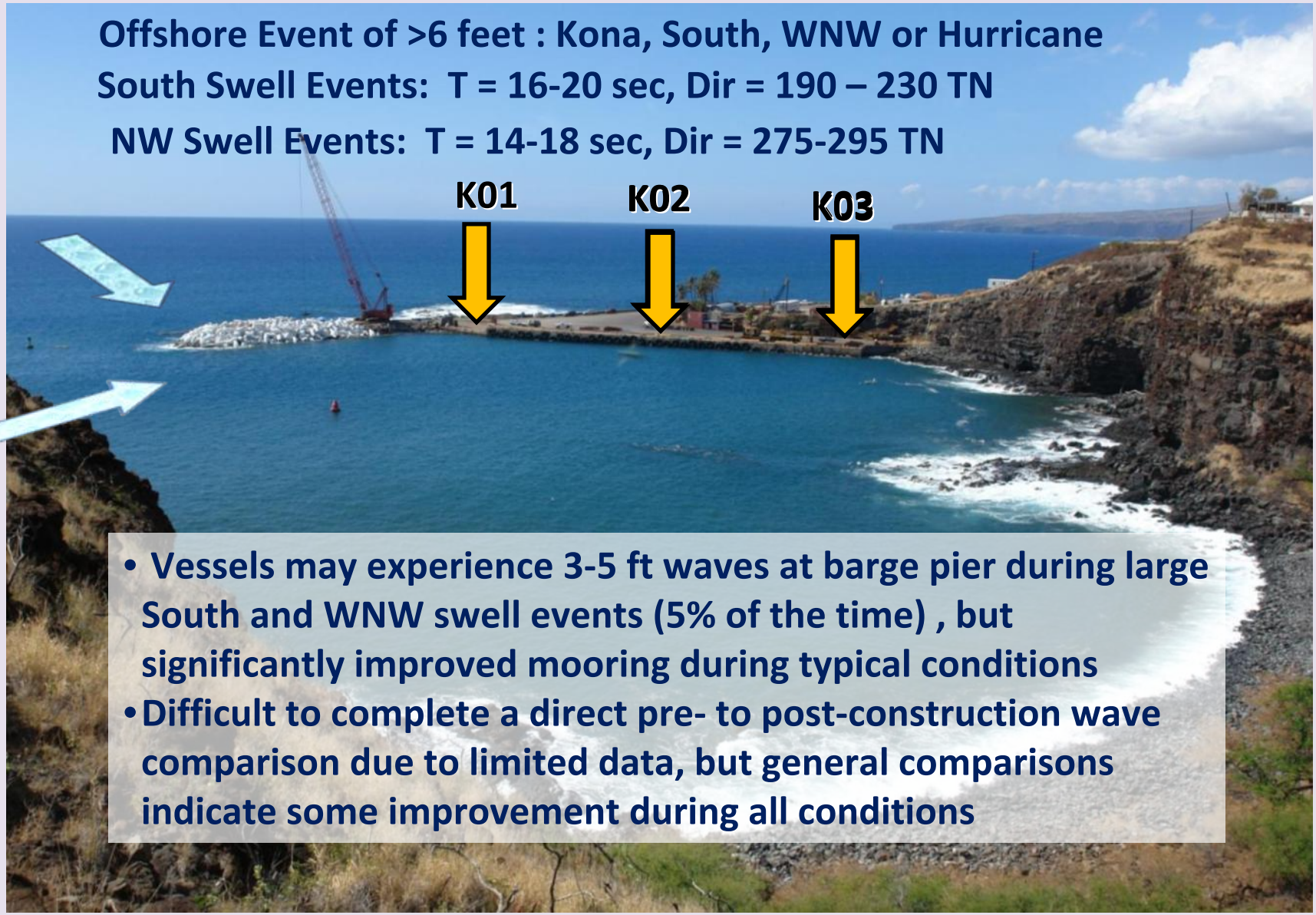
- Good agreement for South Swell and W-NW "Swell 2"

Possible reasons for overprediction during Kona storm and W-NW "Swell 1":

- Kona/WNW wave conditions were not adequately represented in the model runs completed to create the lookup table (requiring extrapolation by KPWAVE)
- Limited wave gage measurements from K01 that were incorporated into this predictive surface for augmentation did not include these conditions
- REF/DIF not accurately representing the diffraction occurring in the lee of the breakwater under these conditions – further calibration required?

Time-Series Analysis

Predicted Waves along Barge Pier



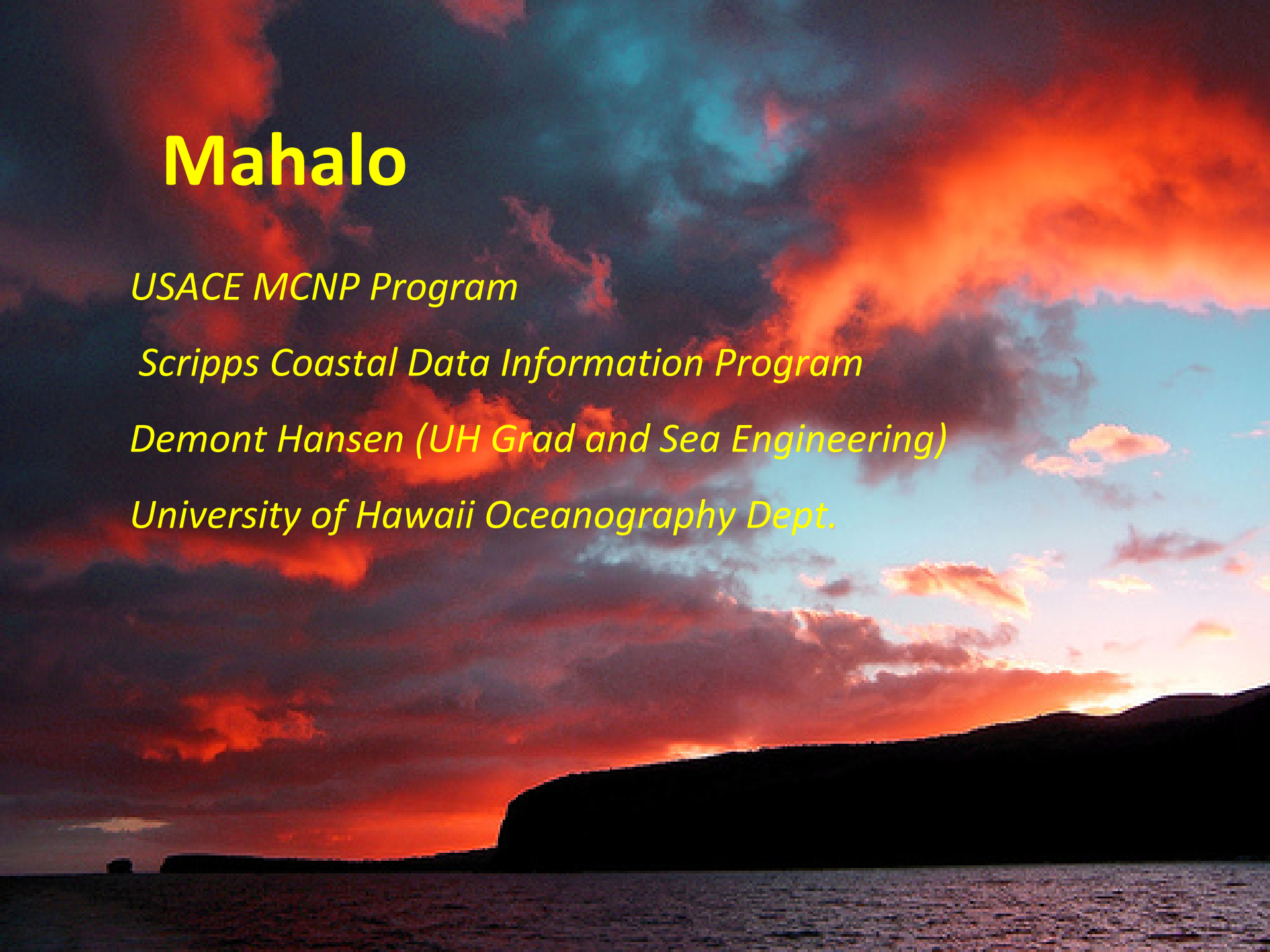
- Vessels may experience 3-5 ft waves at barge pier during large South and WNW swell events (5% of the time) , but significantly improved mooring during typical conditions
- Difficult to complete a direct pre- to post-construction wave comparison due to limited data, but general comparisons indicate some improvement during all conditions

Time-Series Analysis

Incident Wave at Breakwater

Conclusions

- Wave data collected in deep water and in lee of completed breakwater have documented wave climate inside/outside harbor
- Automated method to determine wave heights within harbor based on permanent CDIP Station and numerical modeling => KPWAVE (also beneficial to harbor users)
- Wave response and mooring conditions at barge pier are highly dependent on wave direction and wave period
- Long period waves (15 – 20s) from WNW and SSW, and Kona storms will still result in wave energy and surge in harbor
- The breakwater has improved mooring conditions within the harbor thus far, especially during moderate NW swells
- Nothing close to design wave has been experienced since completion of breakwater (largest recorded deep water Hs = 14 feet) => not large enough to affect breakwater armor layer stability


Mahalo
USACE MCNP Program
Scripps Coastal Data Information Program
Demont Hansen (UH Grad and Sea Engineering)
University of Hawaii Oceanography Dept.


Thank You