Predicting wave conditions in a coral embayment from offshore directional spectral model input

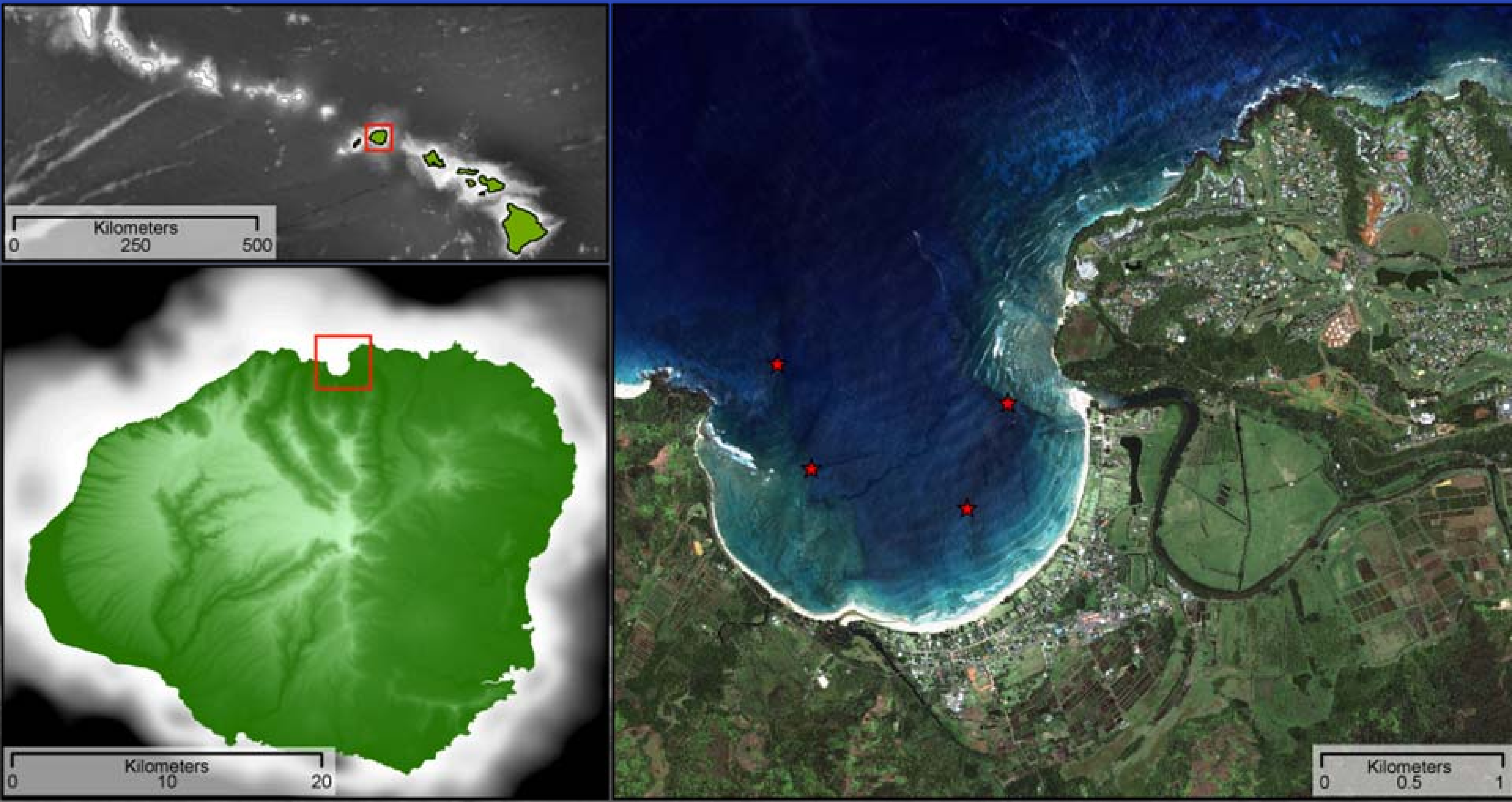
Ron Hoeke[1,2] and Curt Storlazzi[3]

[1]Coral Reef Ecosystem Division (CRED)
NOAA Pacific Islands Fisheries Science Center

[3]Coastal Marine Geology (CMG)
USGS Pacific Science Center

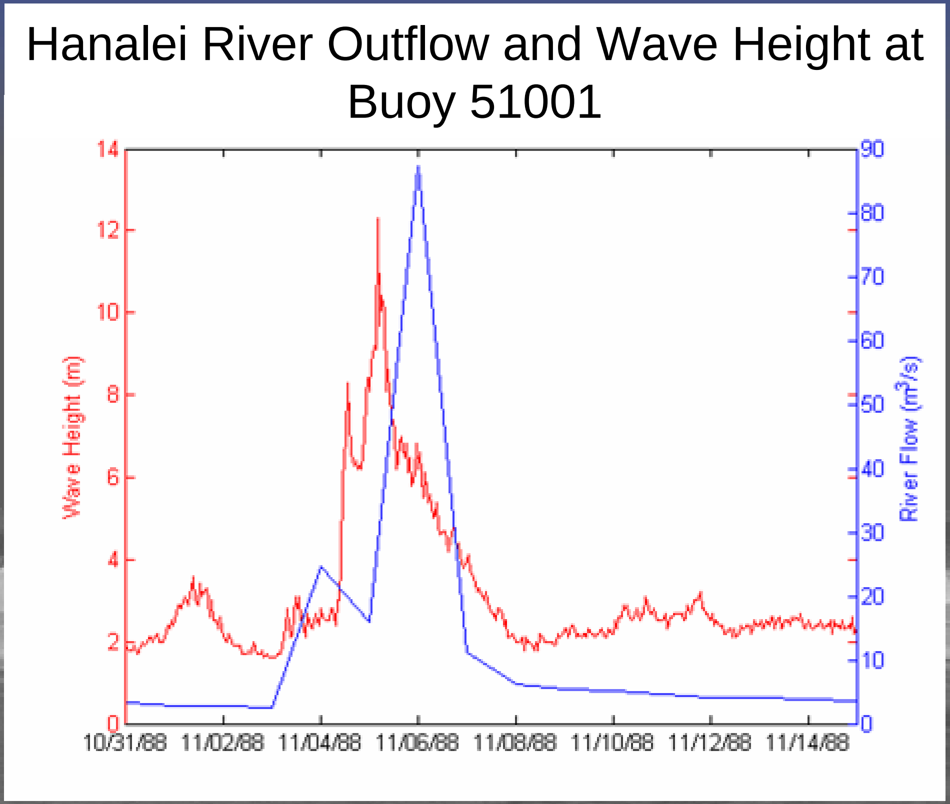
[2]School of Maths and Physics
James Cook University

Study Location Map:
Hanalei Bay, Island of Kauai, Hawaii



Hanalei Bay

- Dynamic Conditions
- Huge freshwater input, biggest waves and some of the smallest waves….. quite possibly the greatest range of conditions in the Hawaiian Islands.



Mt. Wai’ale’ale

1570m tall

Average Rainfall:

9400 mm y^{-1}

Hanalei Bay

- A major marine recreation area and famous tourist destination site. Its water uses include surfing, swimming, snorkeling, scuba, kayaking, sailing, outrigger canoe paddling, and fishing.
- 60% of Hawaii's taro (Poi) crop
- Traditional Hawaiian cultural area
- Listed in the Environmental Protection Agency's (EPA) 303d list of impaired waters
- One of the three priority ahupua`a for focused action by Hawai`i's Local Action Strategy (LAS) to address land-based pollution threats to coral reefs
- Hawaiian Islands Humpback Whale National Marine Sanctuary.

Motivation:

HANALEI WATERSHED HUI
E Malama Kumu Wai

Management concerns require estimates of:

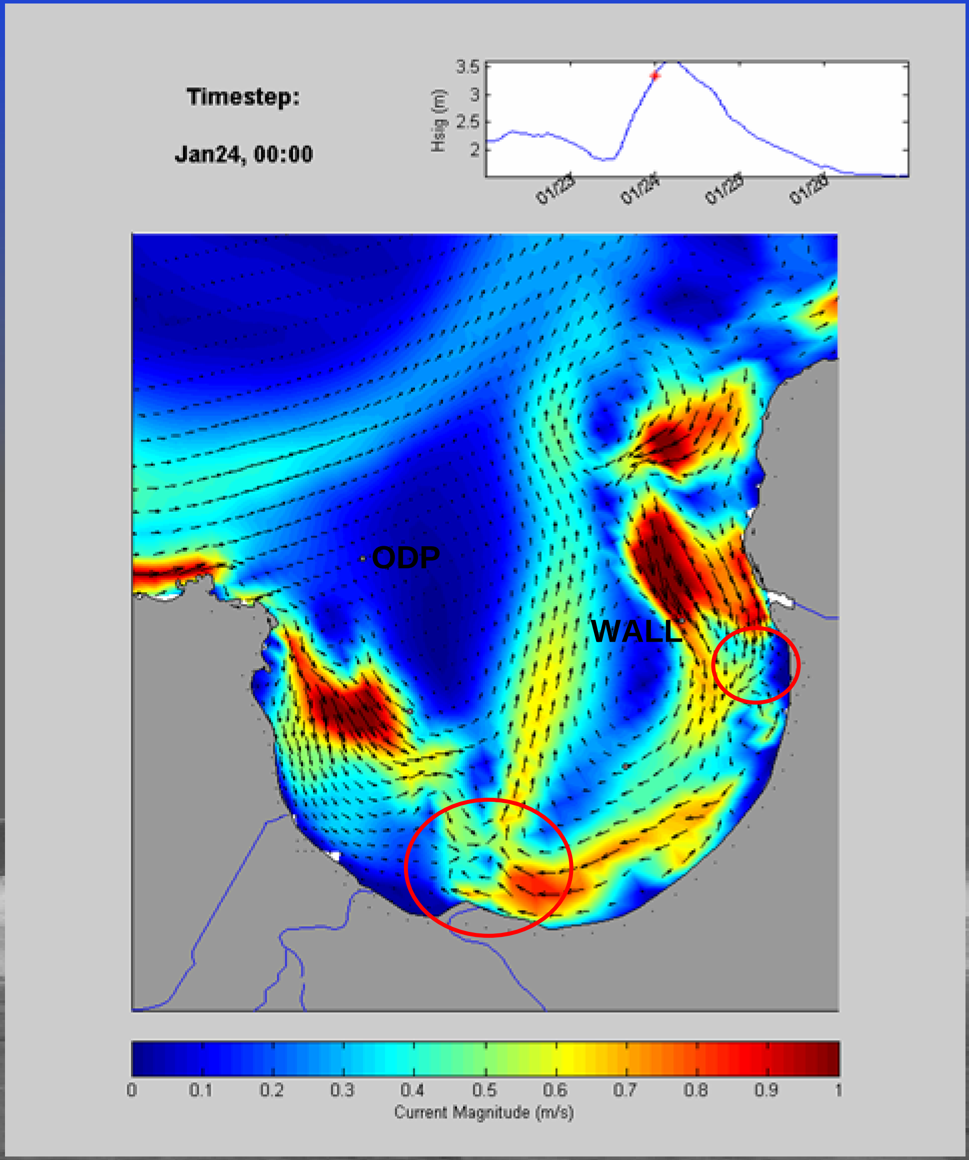
Flushing and overall circulation
1. Water quality/watershed management
2. sediment load/sediment transport
3. search and rescue

Bed shear stress:
1. distribution of benthic habitats
2. catastrophic storm damage
3. nutrient availability

Goal:
implement a coupled wave/circulation model for Hanalei Bay

Preliminary Results – Modeled Data

Location of rips:



Location of rips:

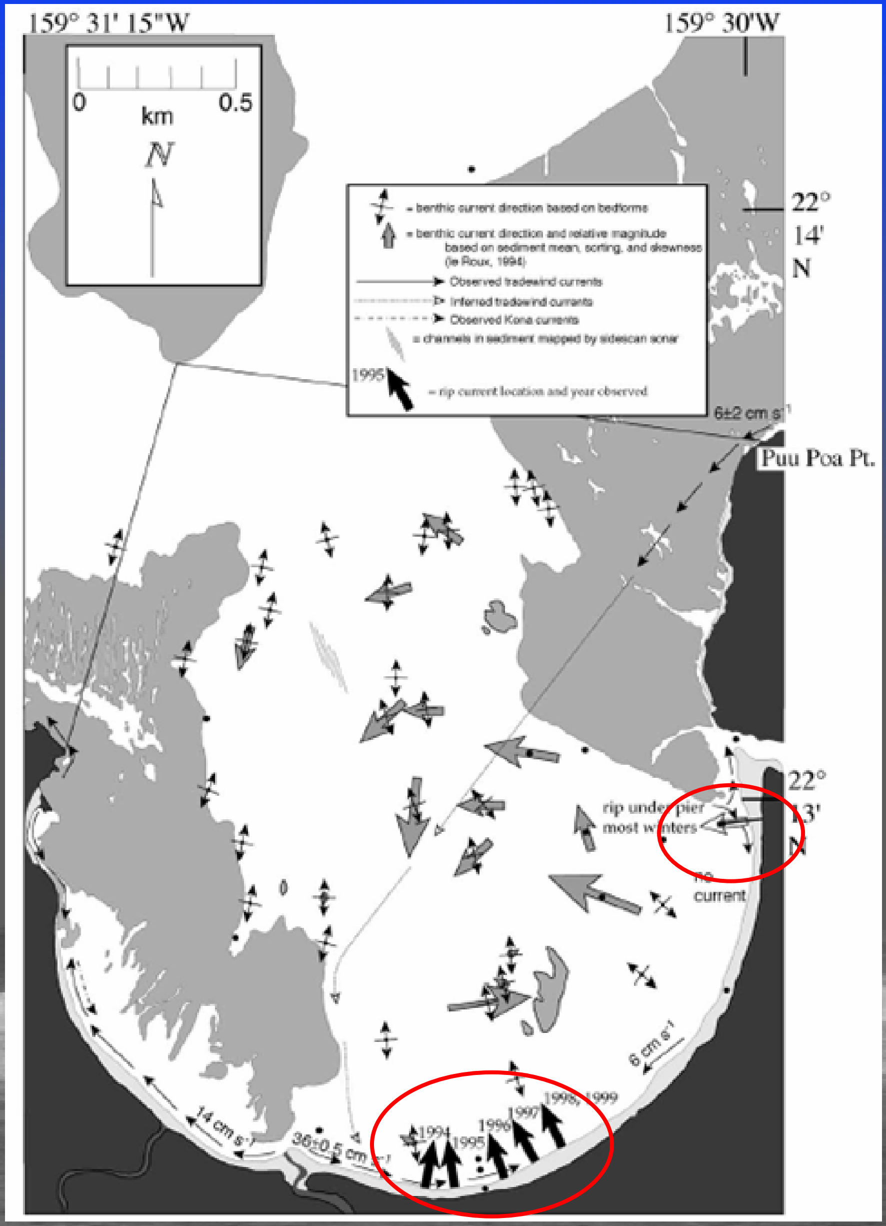
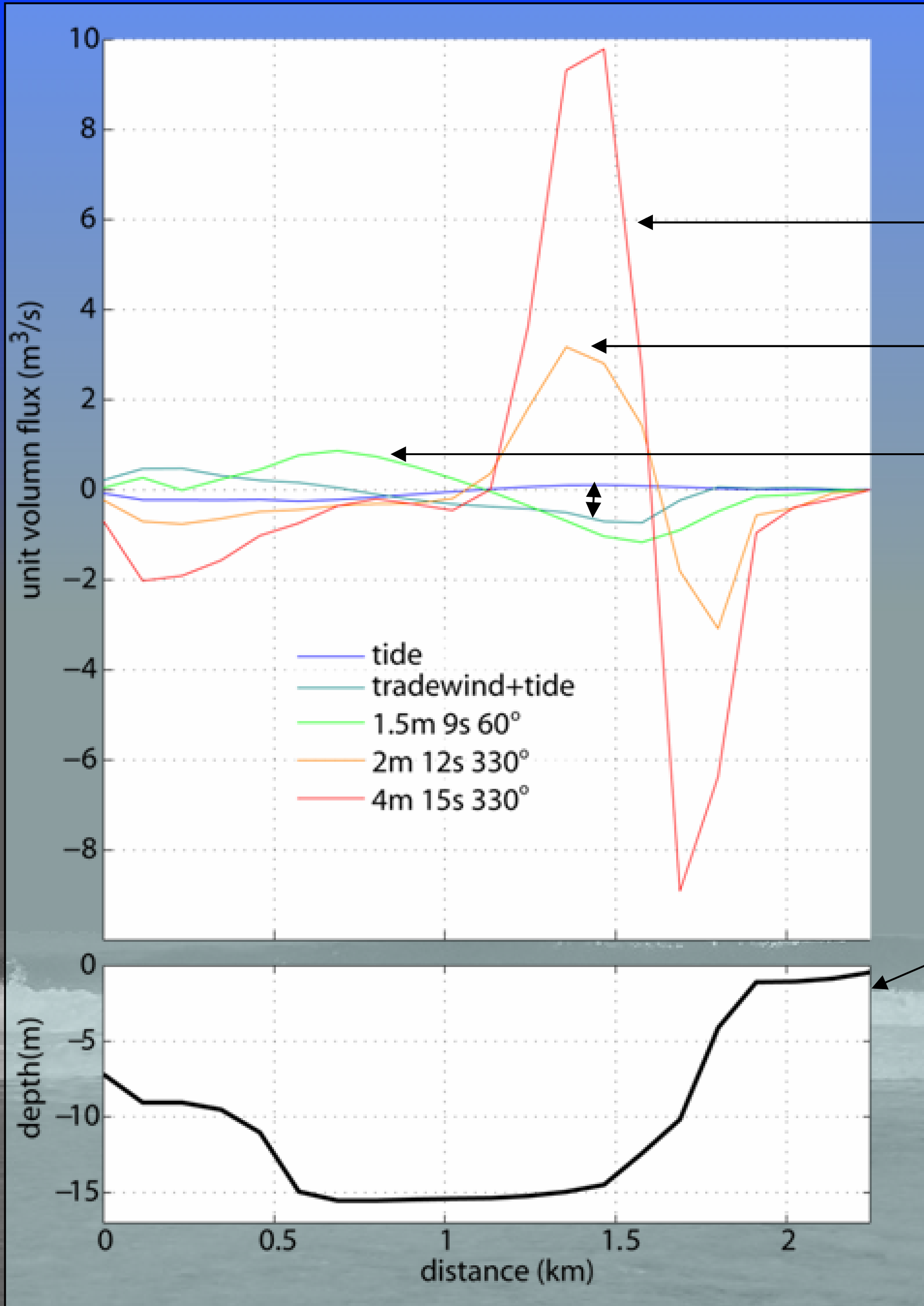


Figure 6 from Calhoun, Fletcher, and Harney, 2002.

Preliminary Caclulations:

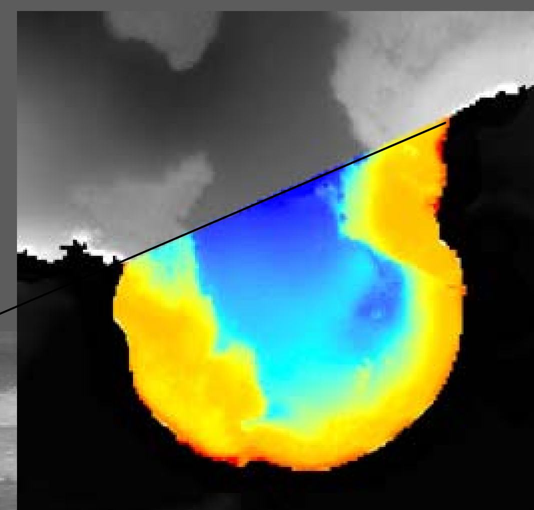
Estimation of volume flux



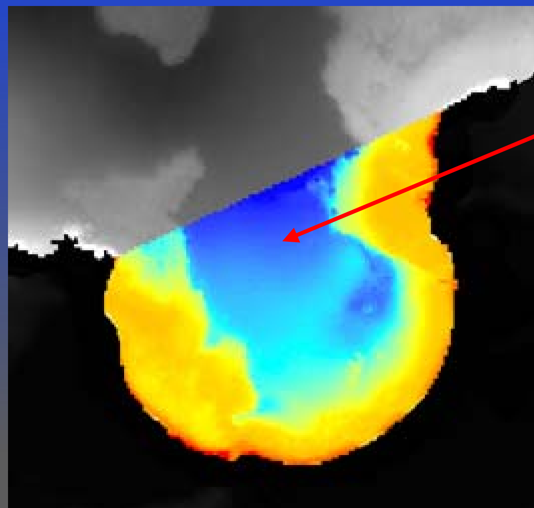
4m NW swell

2m NW swell

tradewind swell



Preliminary Calculations: Estimation of flushing time



Volume:
$V = 1.9 \times 10^7$ m3

Flushing (residence) time:
$R = V/U$

	volume flux	flushing time
tides alone	55.2 $m^3\ s^{-1}$	3.98 days
tides + winds	232 $m^3\ s^{-1}$	0.95 days
Tradewind waves	467 $m^3\ s^{-1}$	11.3 hours
Modal NW Swell	1062 $m^3\ s^{-1}$	5.0 hours
NW Swell	2816 $m^3\ s^{-1}$	1.9 hours

Preliminary Results: Estimation of "Dislodgment Mechanical Threshold (DMT)*"

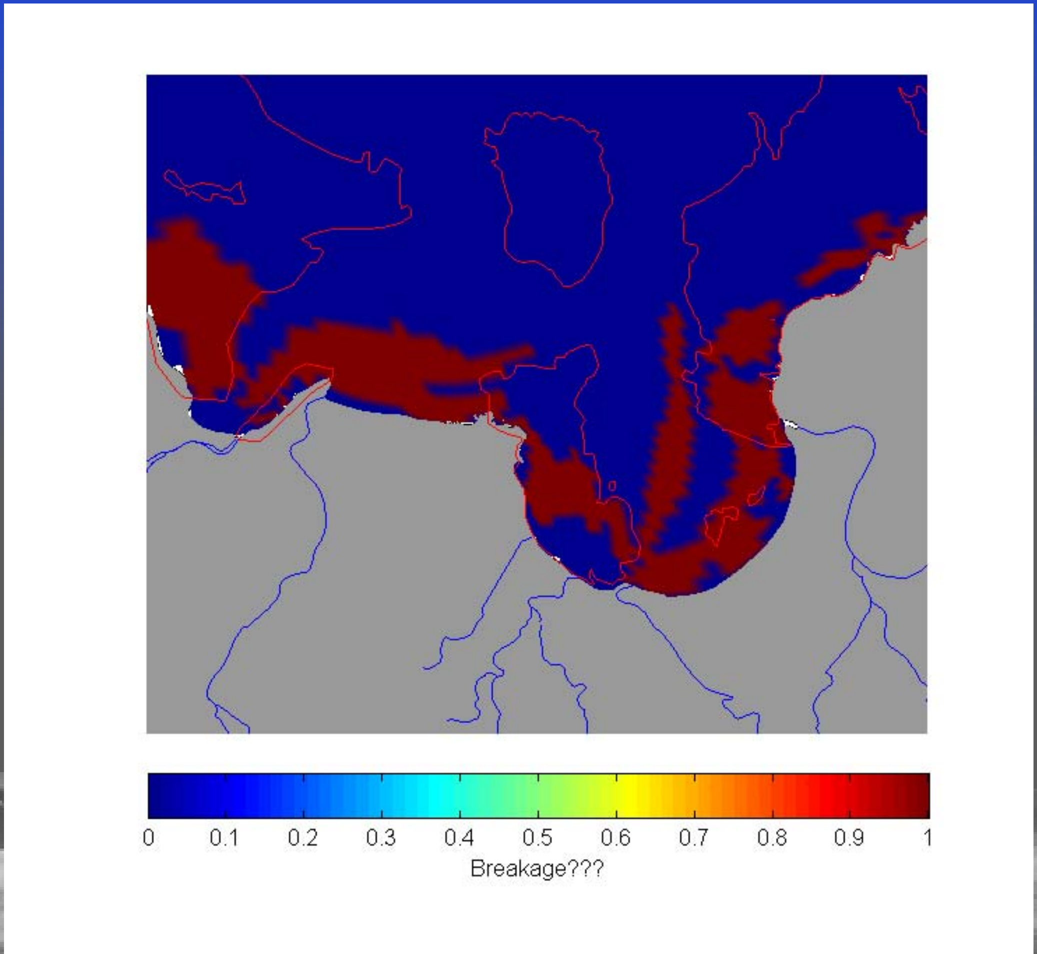
$$DMT = \frac{\sigma_s}{U^2 \rho}$$

$$\sigma_s = 2 \cdot 10^5 \, N \cdot m^{-2}$$

Breakage occurs when "Colony Shape Factor(CSF)"* exceeds DMT:

$$DMT \leq CSF$$

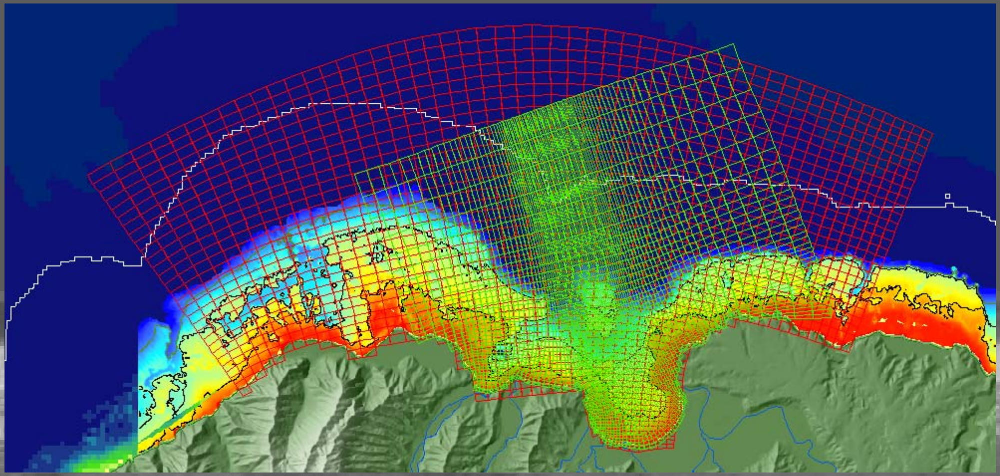
CSF ~ 300



* Madin JS and Connelly SR, 2006. Ecological consequences if major hydrodynamic disturbances on coral reefs. *Nature* **444**: 477-480.

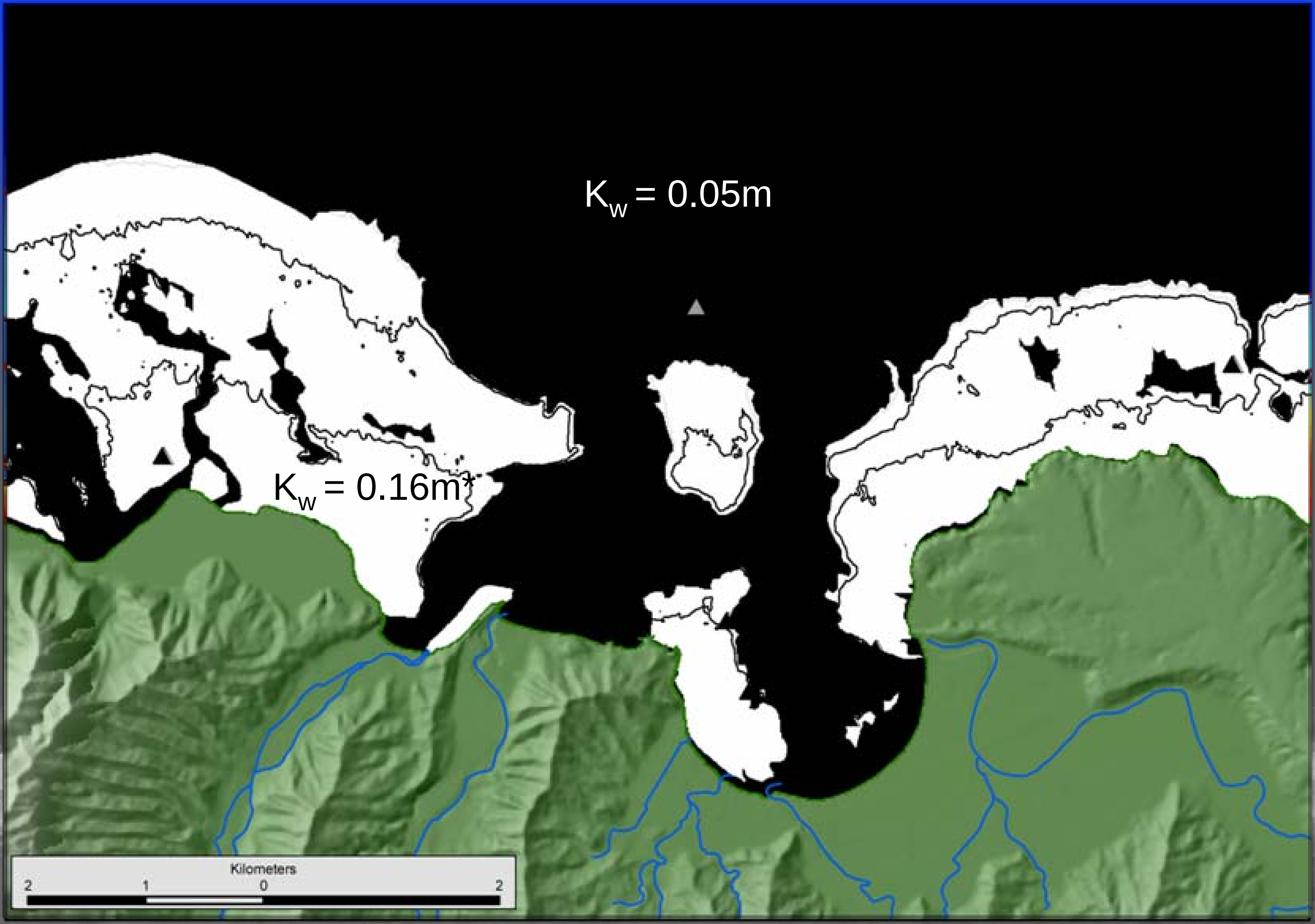
Muck with the models:

1. Measure tidal constituents at boundaries
2. Develop realistic spatially heterogeneous roughness grid
3. Refine grid and take careful consideration of shoreline and depth datum
4. Domain decomposition?
5. 2D -> 3D?



Collect/analyze in-situ observations and compare to the model

Study Location Overview:

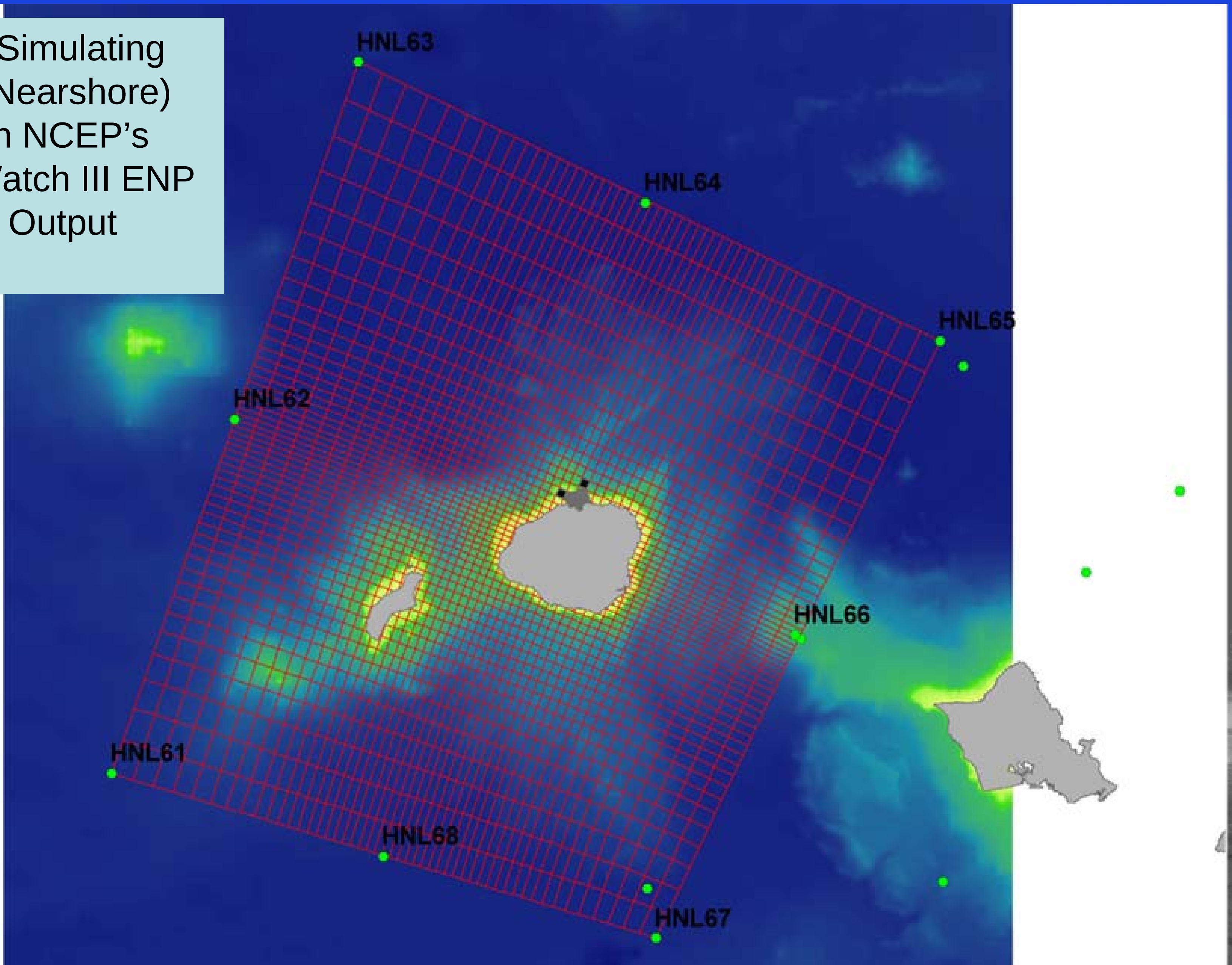


LOWE, et al., 2005. Spectral wave dissipation over a barrier reef. *Journal of Geophysical Research* 110(C04001).

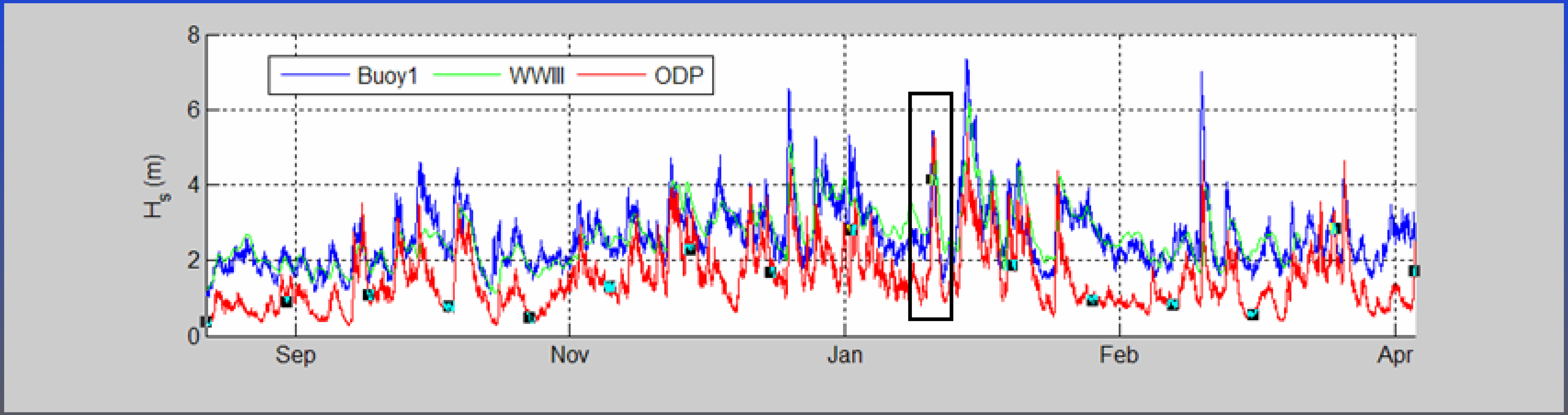
HEARN, et al., 2001. A physical derivation of nutrient-uptake rates in coral reefs: Effects of roughness and waves, *Coral Reefs*, 20, 347–356.

Methods: ***SWAN Kauai Grid Domain***

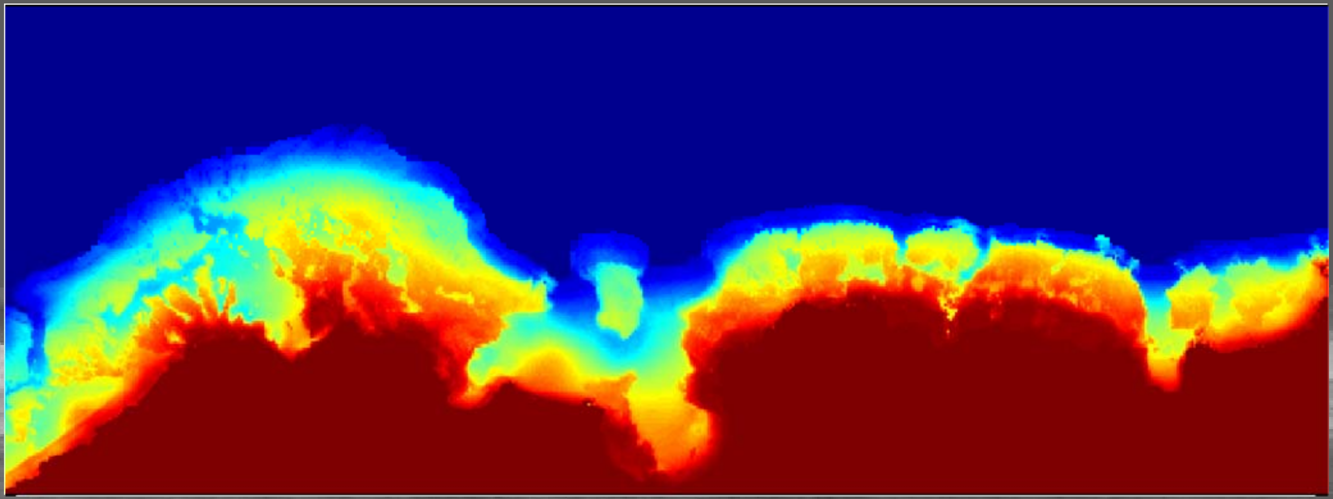
SWAN (Simulating WAves Nearshore) nested in NCEP's Wave Watch III ENP Spectral Output Nodes



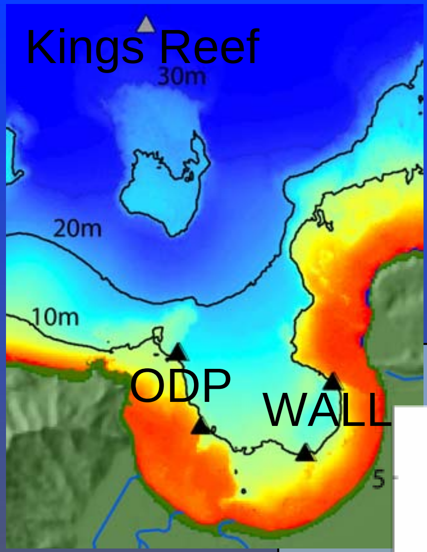
Preliminary Results: ***In-Situ Data***

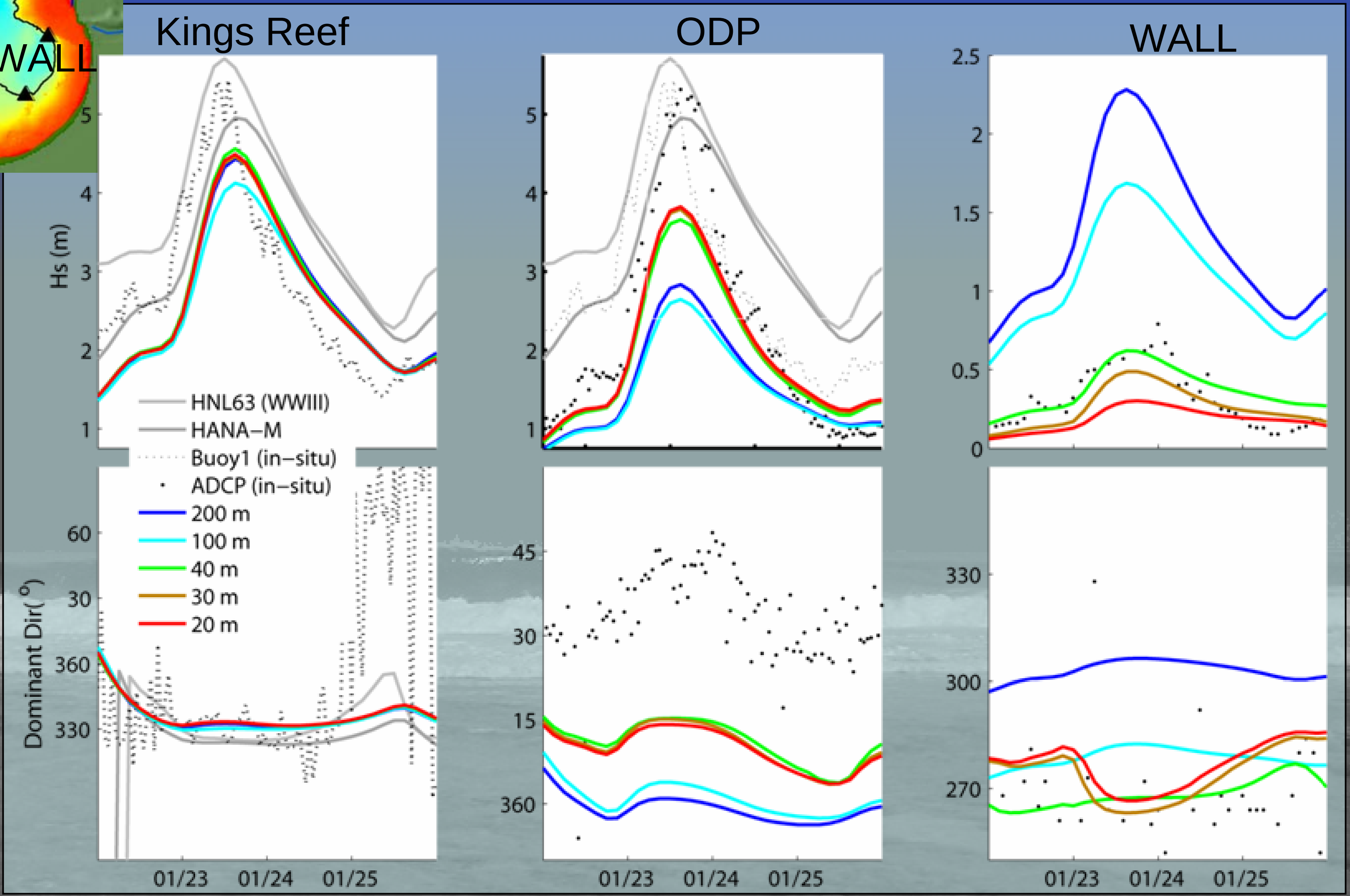


Spatial grid resolutions:
200m
100m
40m
30m
20m

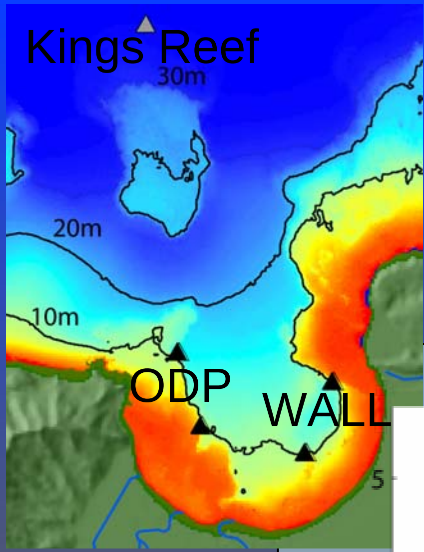


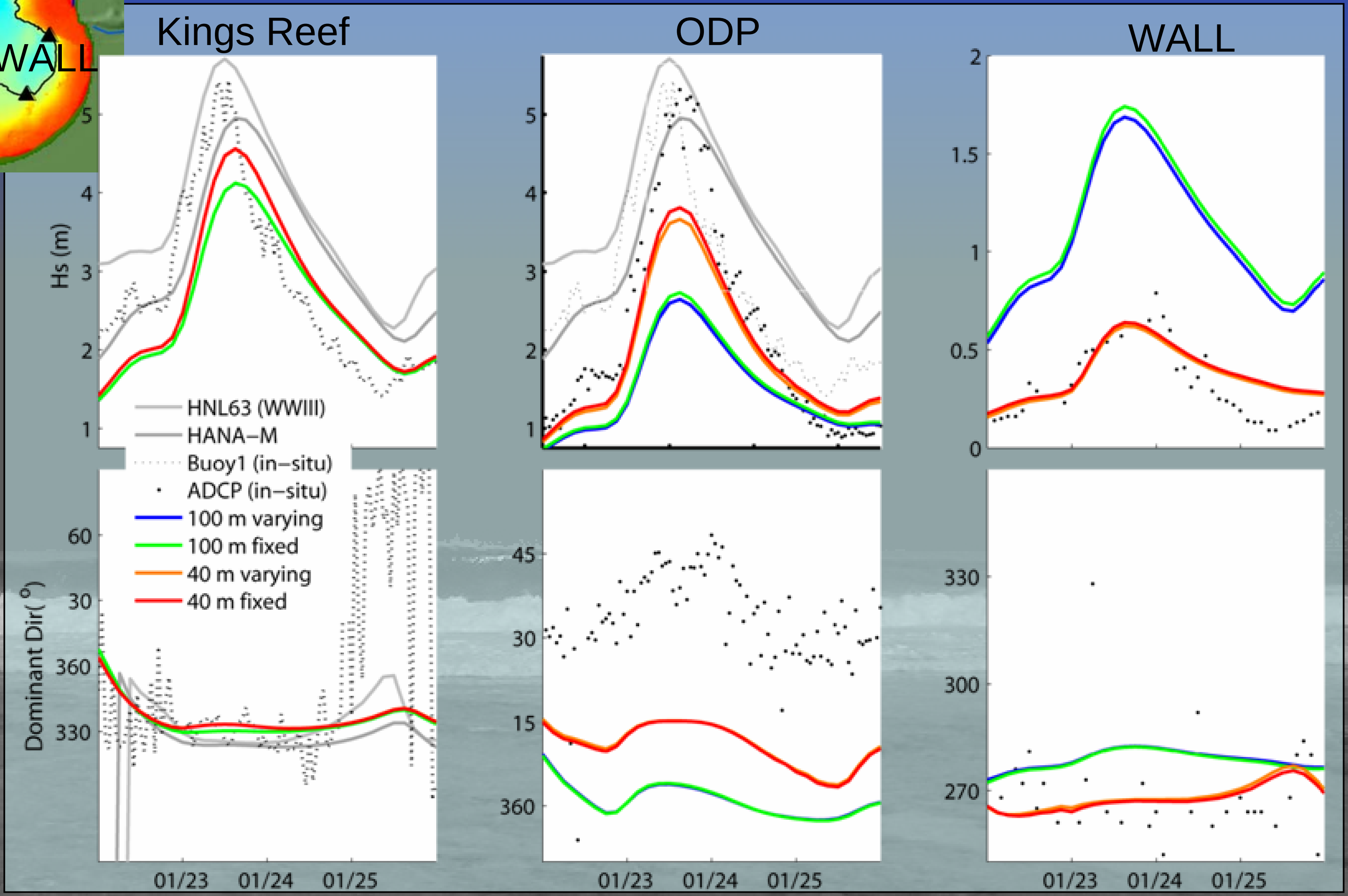
Comparison of different spatial resolutions:

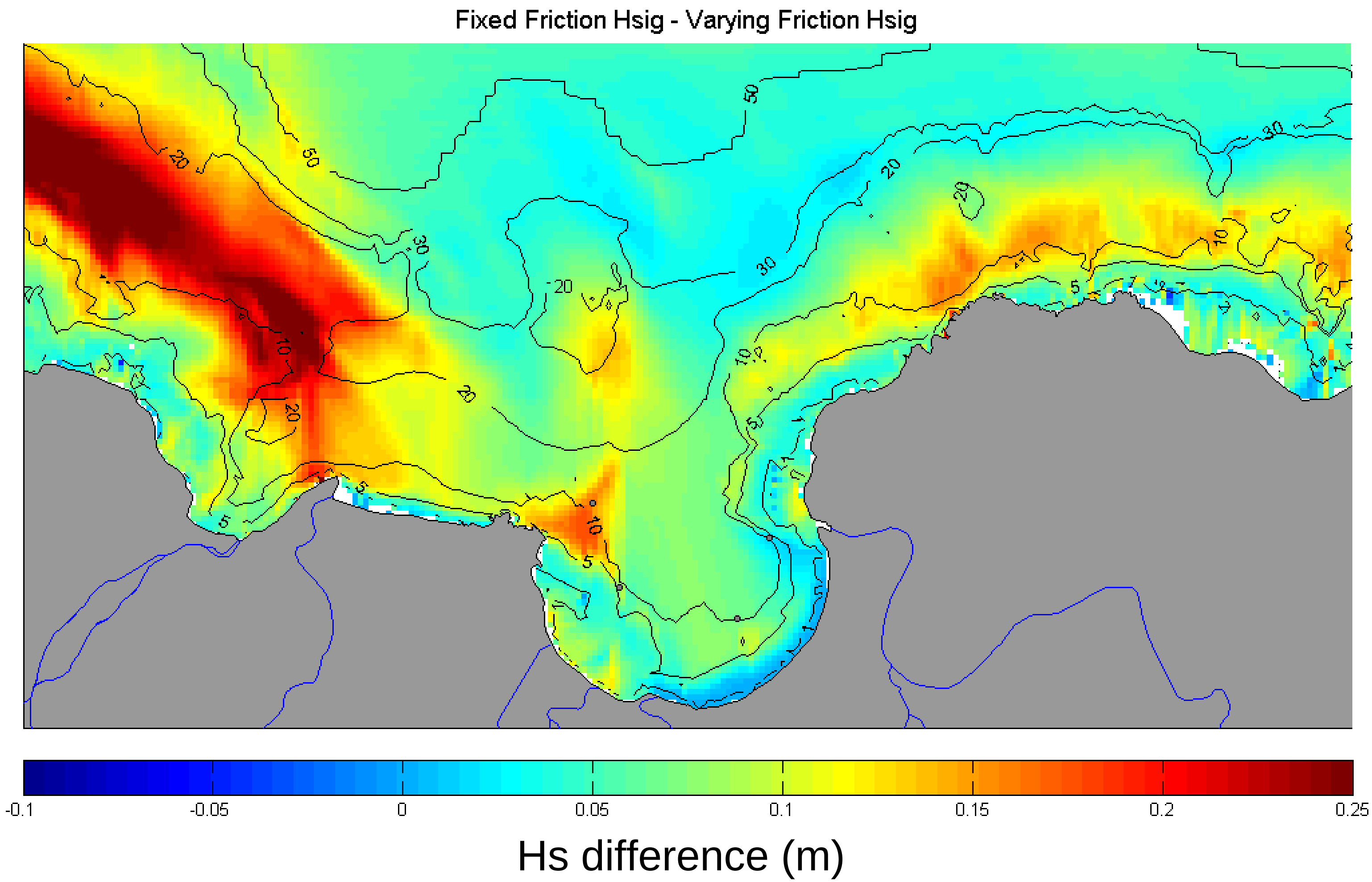




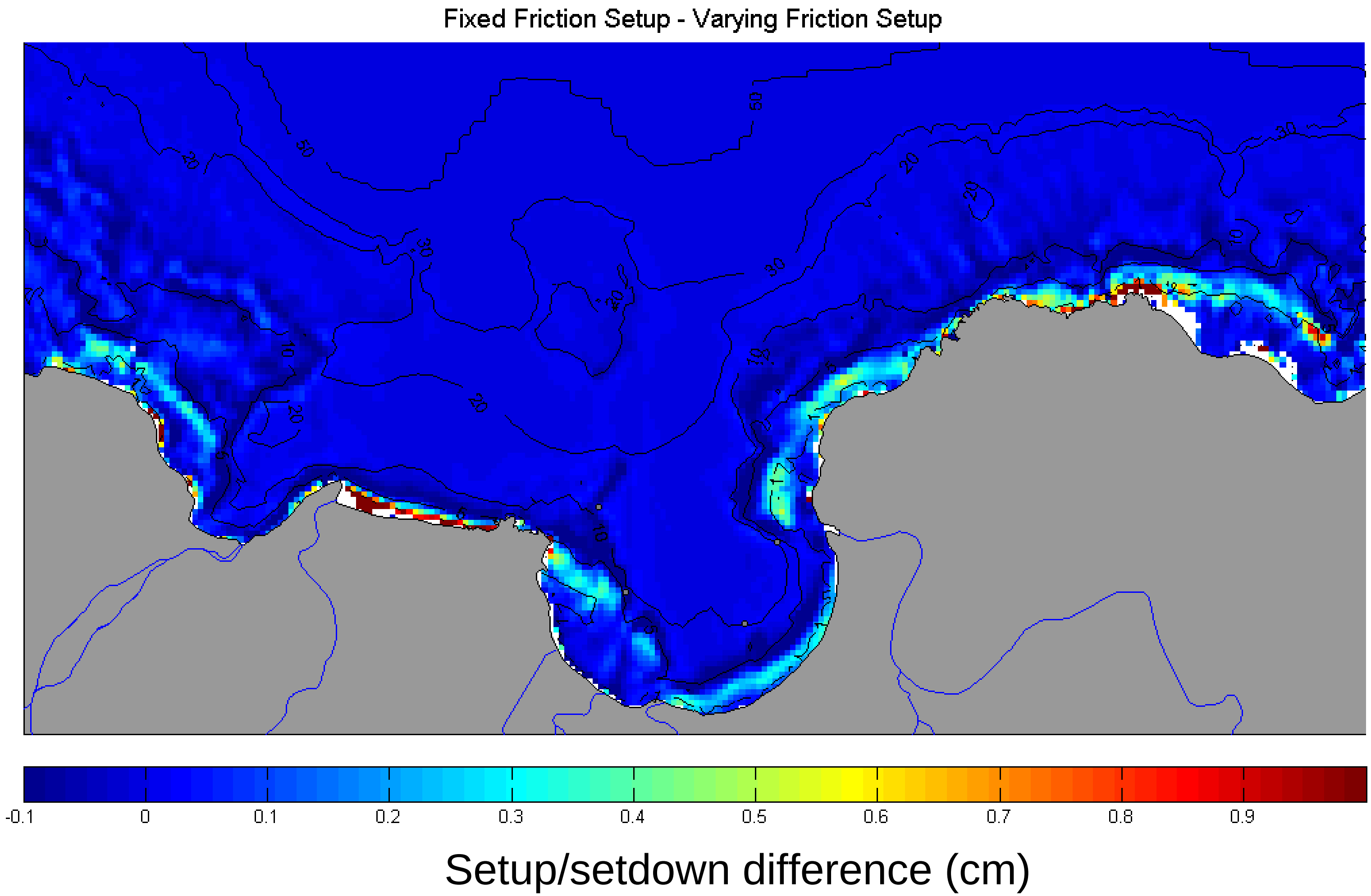
Comparison of different roughness schemes:



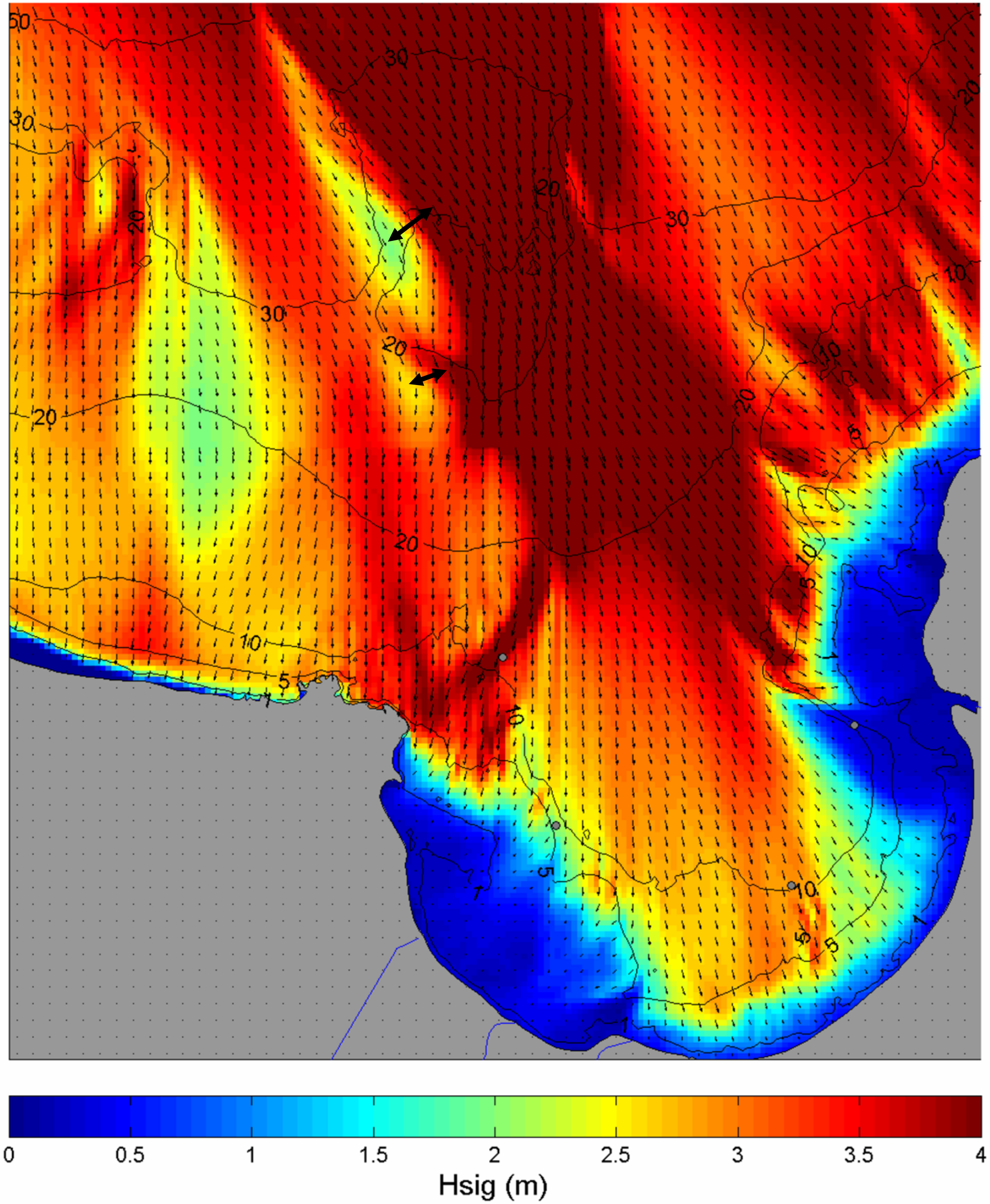




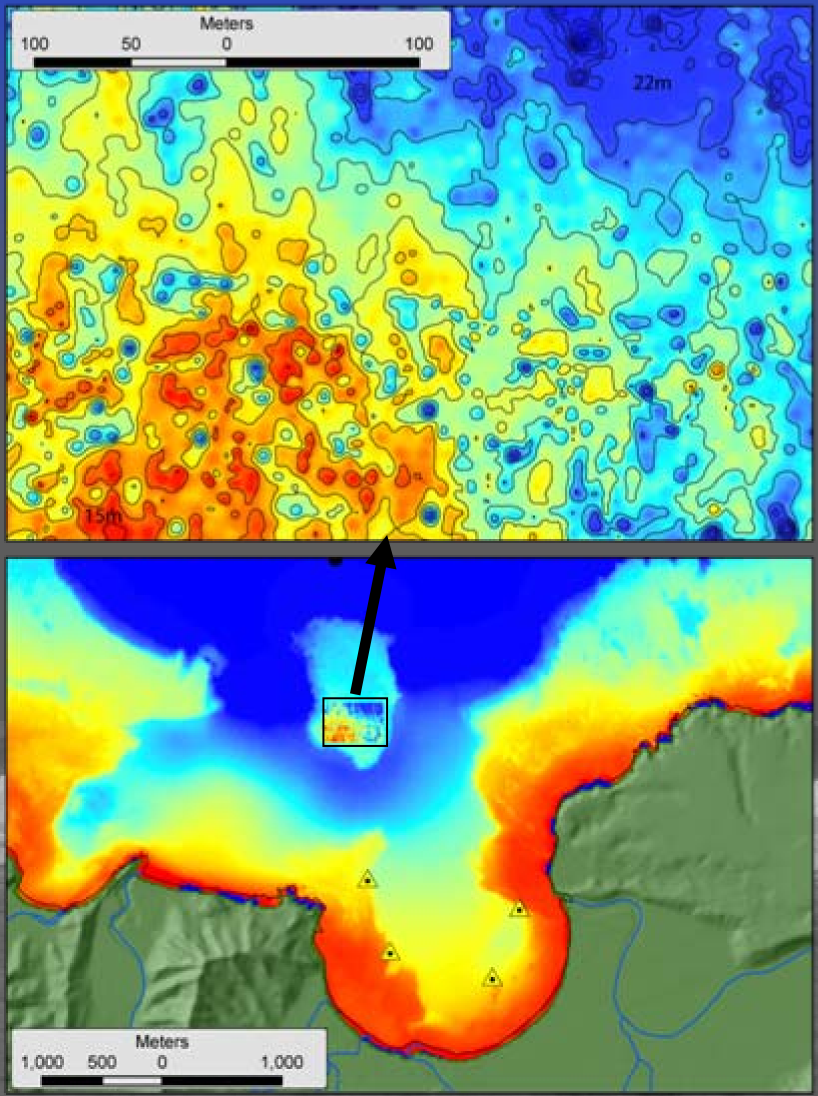
Fixed Friction Hsig - Varying Friction Hsig
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
Hs difference (m)


Fixed Friction Setup - Varying Friction Setup
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Setup/setdown difference (cm)

Hs - 20m grid



Typical Hawaiian forereefs: lots of different roughness scales



Conclusions:

1. Refraction/diffraction effects are especially important over coral reefs – and poorly modeled with existing phase-averaged models

2. At tested spatial scales, SWAN's solutions consistently under predict near-shore wave height and refraction – but improve with increasing spatial resolution

3. Spatially varying bottom roughness is essential for realistic results – but how best to go about it?

CAN waves on coral reefs be modeled at spatial resolutions lower than the individual roughness elements on the reef (e.g. 0.5-5m)?