Minimizing errors in sub-regional scale wave modeling:

Design of a forecasting system for the Nearshore Canyon Experiment

Presented by:

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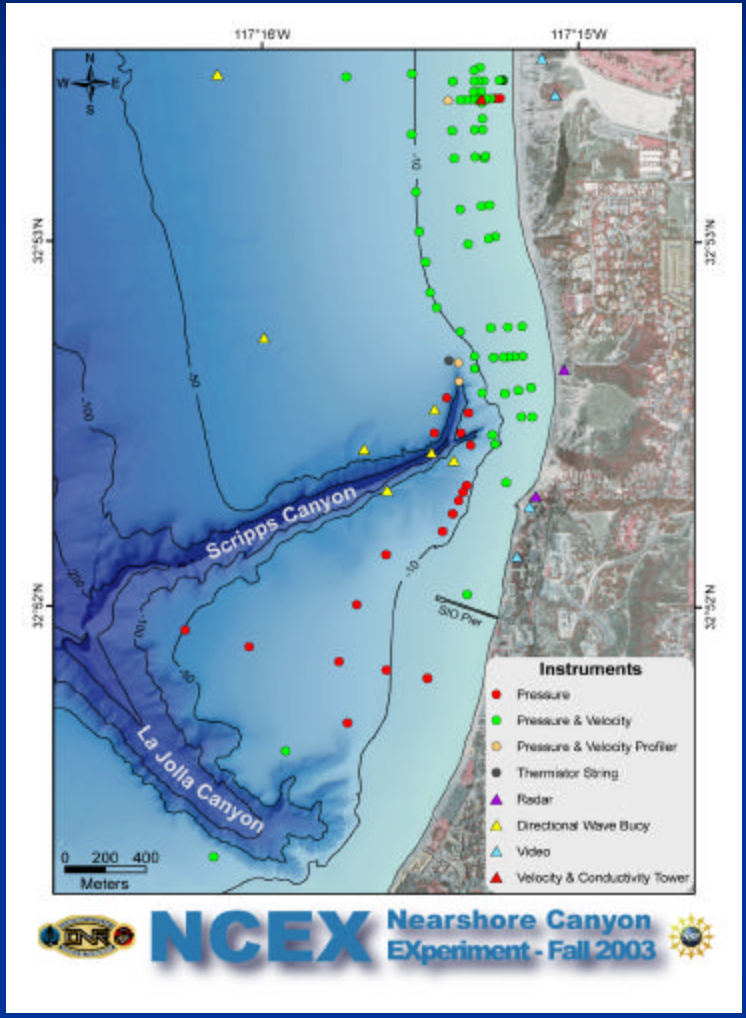
8th International Workshop on Wave Hindcasting and Forecasting

Nov. 14-19, 2004

[a pdf of this paper is available, also some hard copies]

Nearshore Canyon Experiment (NCEX) (Sponsor: ONR)



Graphic courtesy of Dr. Michele Okihiro, SIO

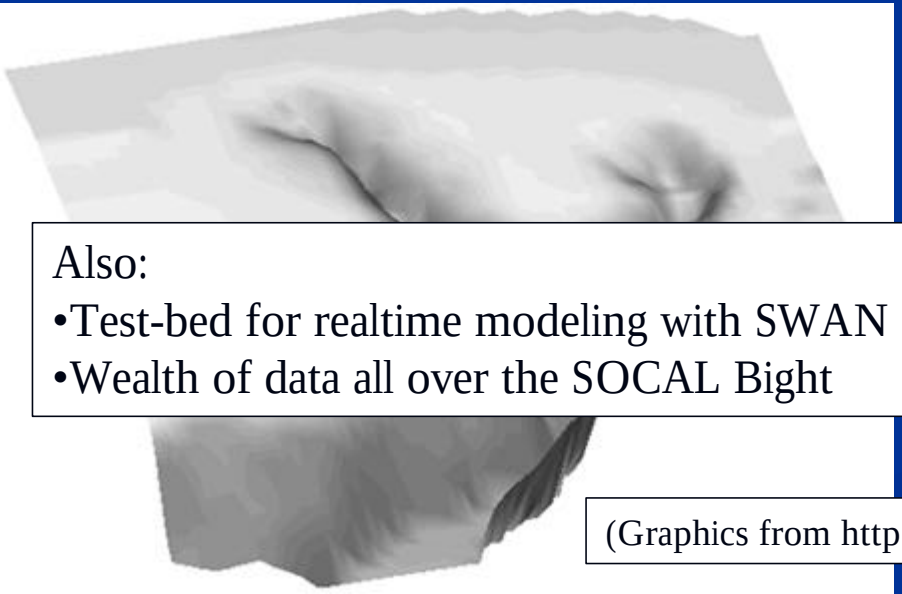
- Large, multi-investigator experiment located at Scripps Institution of Oceanography (CA), Sept.-Dec. 2003
- Primary locations of instrumentation: Black's Beach and Torrey Pines Beach
- Complex canyon bathymetry leads to severe wave refraction effects

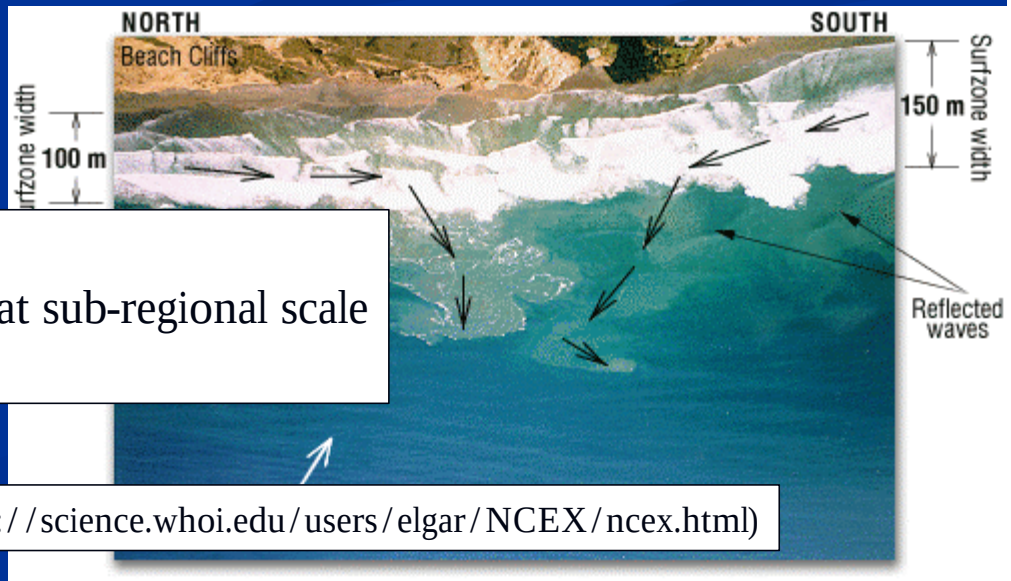
NRL's Wave Forecasting System for Nearshore Canyon Experiment (NCEX) (Sponsor: ONR)

In support of the Nearshore Canyon Experiment (NCEX)…

- **to help plan instrument deployment,**
- **gauge the arrival of interesting wave conditions, and**
- **anticipate the arrival of heavy surfer traffic to Black's Beach, the primary site of instrumentation for the experiment.**

http://www7320.nrlssc.navy.mil/NCEX/NCEX_mod.htm

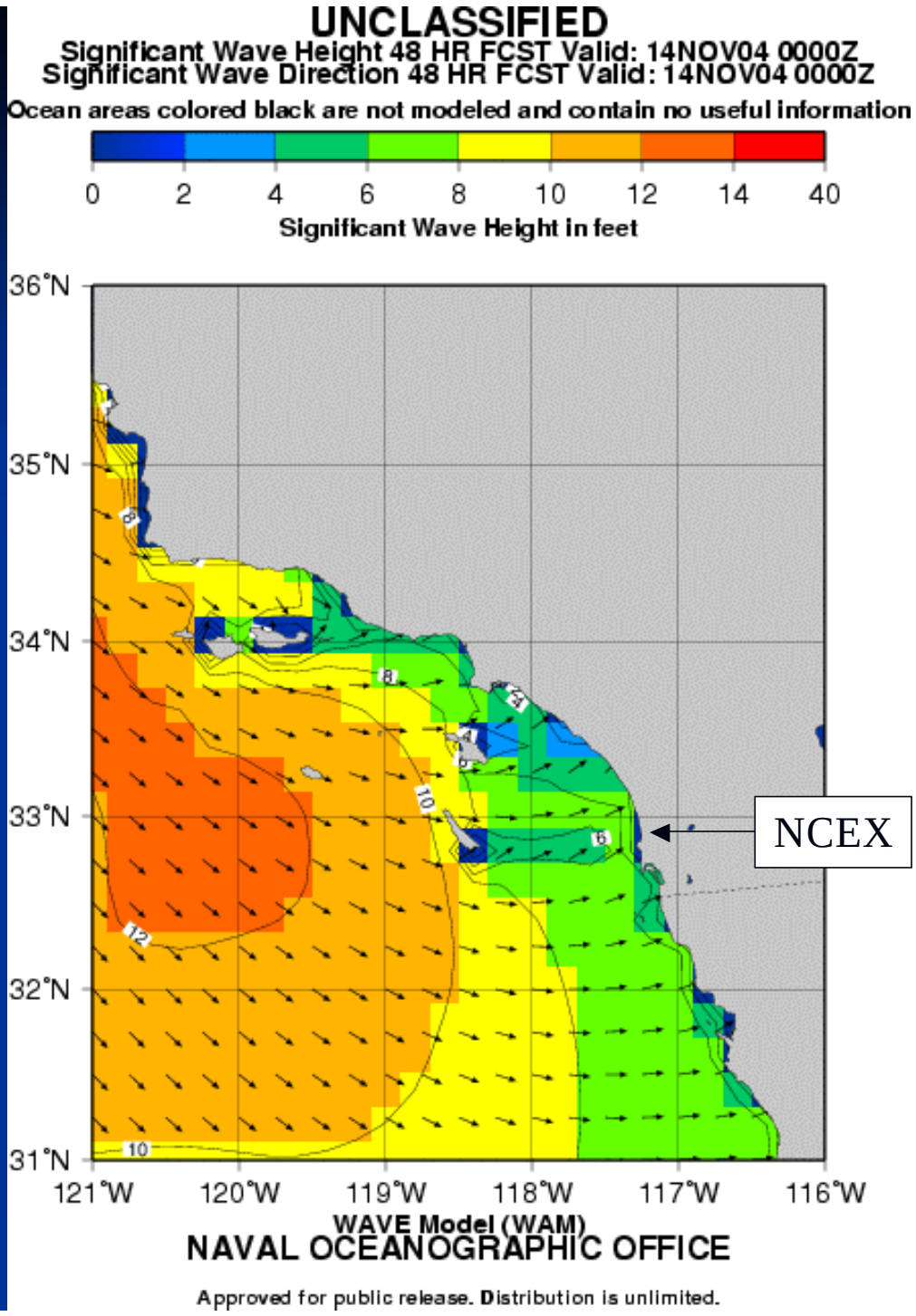




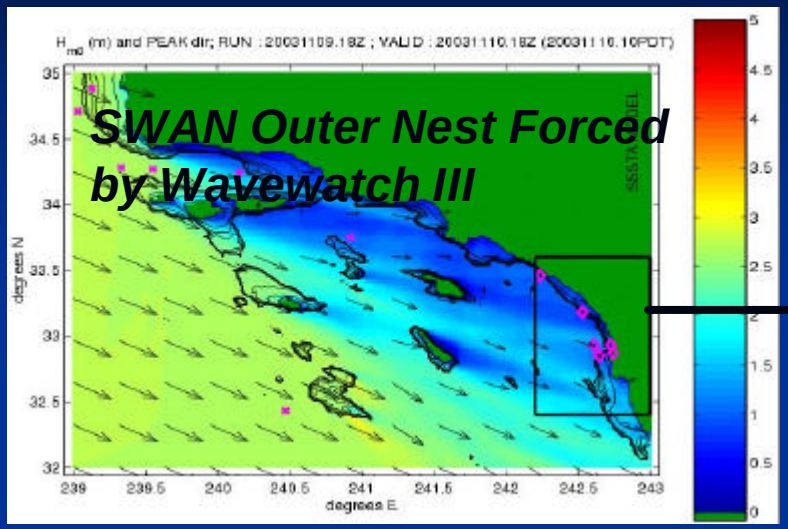
Also:
- Test-bed for realtime modeling with SWAN at sub-regional scale
- Wealth of data all over the SOCAL Bight

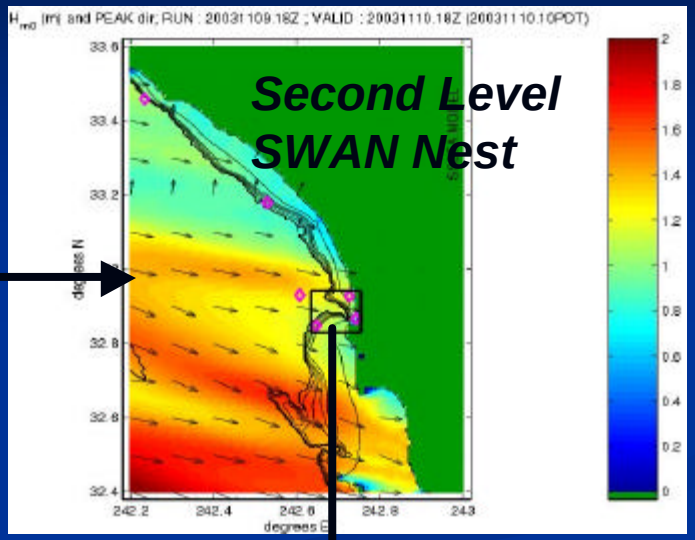
(Graphics from http://science.whoi.edu/users/elgar/NCEX/ncex.html)

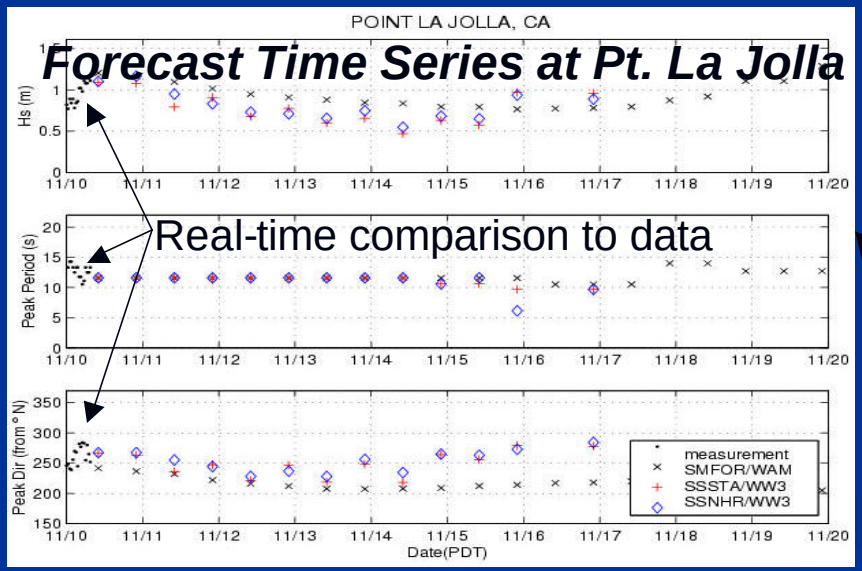
Pre-existing sub-regional Navy operational product: NAVO Southern California Bight WAM (too coarse?)

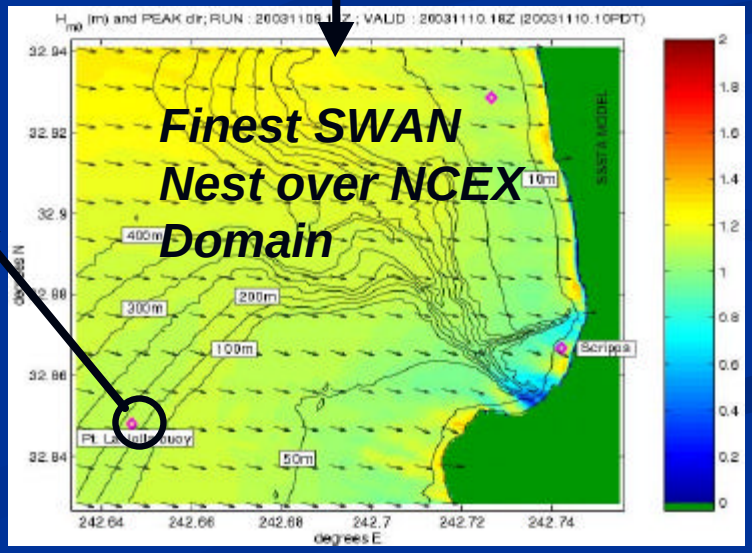


Wave Forecasting System for Nearshore Canyon Experiment (NCEX) (Sponsor: ONR)









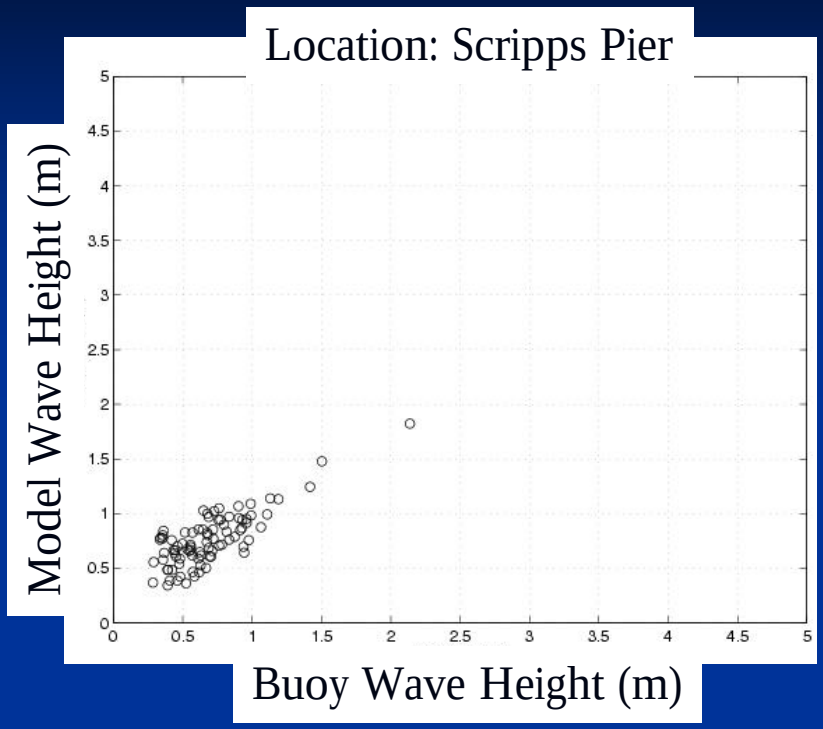
http://www7320.nrlssc.navy.mil/NCEX/NCEX_mod.htm

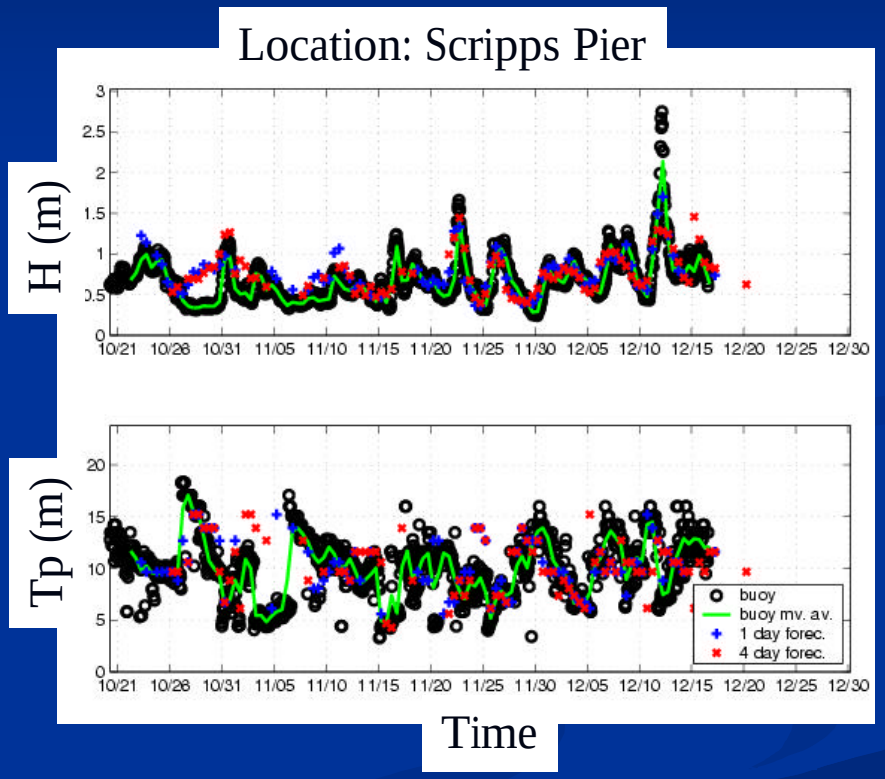
Wave Forecasting System for Nearshore Canyon Experiment (NCEX) (Sponsor: ONR)

1st (outermost) SWAN Nest

- **Boundary forcing from Wavewatch III : input spectra uniform along each boundary, from NCEP ENP wave model**
- **Geographic resolution: 1.67 ¢ (lat) ´ 2.0¢ (lon)**
- **Wind forcing from NCEP global model**
- **Computation Mode: Nonstationary**
  - **Time-lagging of swells is correctly represented**
  - **Expensive: (so run on 8 threads on 1.3 GHz IBM-P4 at NAVO MSRC using new OpenMP SWAN)**

Validation of Realtime System after NCEX ended





21 locations in all, wave height, peak period (and mean direction where available)
ftp://ftp7300.nrlssc.navy.mil/pub/rogers/NCEX/validation
See error statistics (for wave height) in the paper.

Minimizing Errors

- …but getting the job done within operational time constraints
- What shortcuts are ok? What are not?
- Not a question of tuning
  - Source/sink terms of wave generation secondary
- Accuracy of wind forcing also secondary
- Propagation is key

Idealized Cases

- Objective: Estimate penalty from two computational “shortcuts”:
  - Stationary computations
  - Coarse geographic resolution (e.g. of islands, shoals)
- Strategy: Simple cases + Measured time series of wind/wave conditions

Hindcasts description

- Four hindcasts. Only the outer SWAN Grid (SC1) is varied:
  1. SC1 at high resolution[1] and computed in nonstationary mode.
  2. SC1 at high resolution and computed in stationary mode.
  3. SC1 at low resolution[2] and computed in nonstationary mode.
  4. SC1 at low resolution and computed in stationary mode.
- This allows us to study the practical effect of two computational “short cuts”
  1. Using coarse resolution to describe propagation near island groups
  2. Using the stationary assumption for a regional scale model

[1]: $\Delta x = \Delta y = 1'$

[2]: $\Delta x = \Delta y = 3'$

Hindcasts description

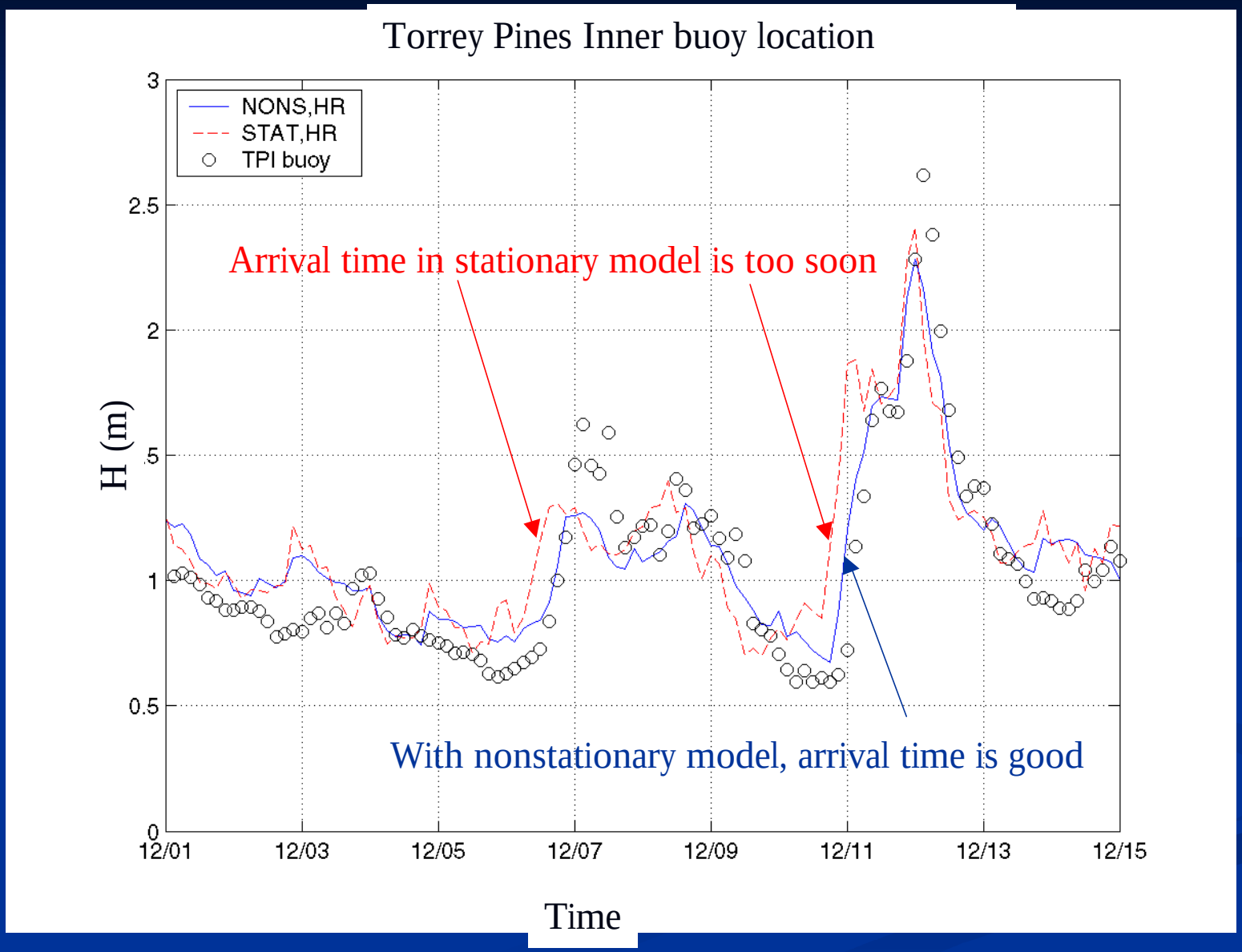
- 3 nested SWAN grids, as with realtime model
- Boundary forcing of outer grid:
  - CDIP spectra along west boundary (assumed uniform)
  - NCEP WW3 spectra along south boundary (assumed uniform, since only available at one point)
- Wind forcing: NWS global wind analyses

Error metrics (a typical result at a nearshore location)

Wave height RMSE (root mean square error) comparison at "Scripps Pier" (many more in paper)

Stationary		Non-stationary	
Low resolution	High resolution	Low resolution	High resolution
29 cm	28 cm	24 cm	24 cm

- Use of low resolution through islands of Bight has insignificant impact on RMSE
- Use of stationary assumption incurs penalty in RMSE

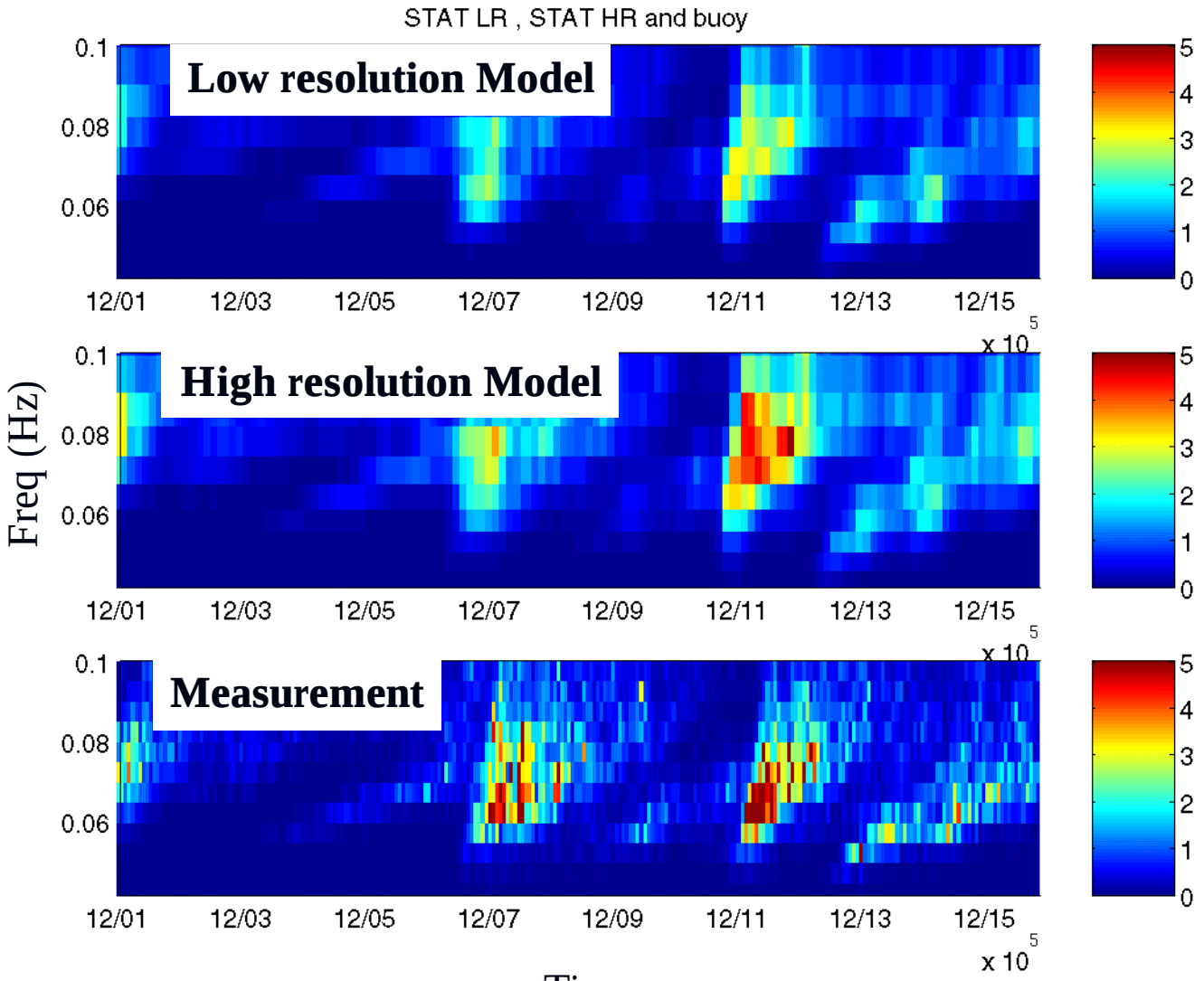


Dec 1-15 Case study: stationary assumption

December 1-15 Case Study

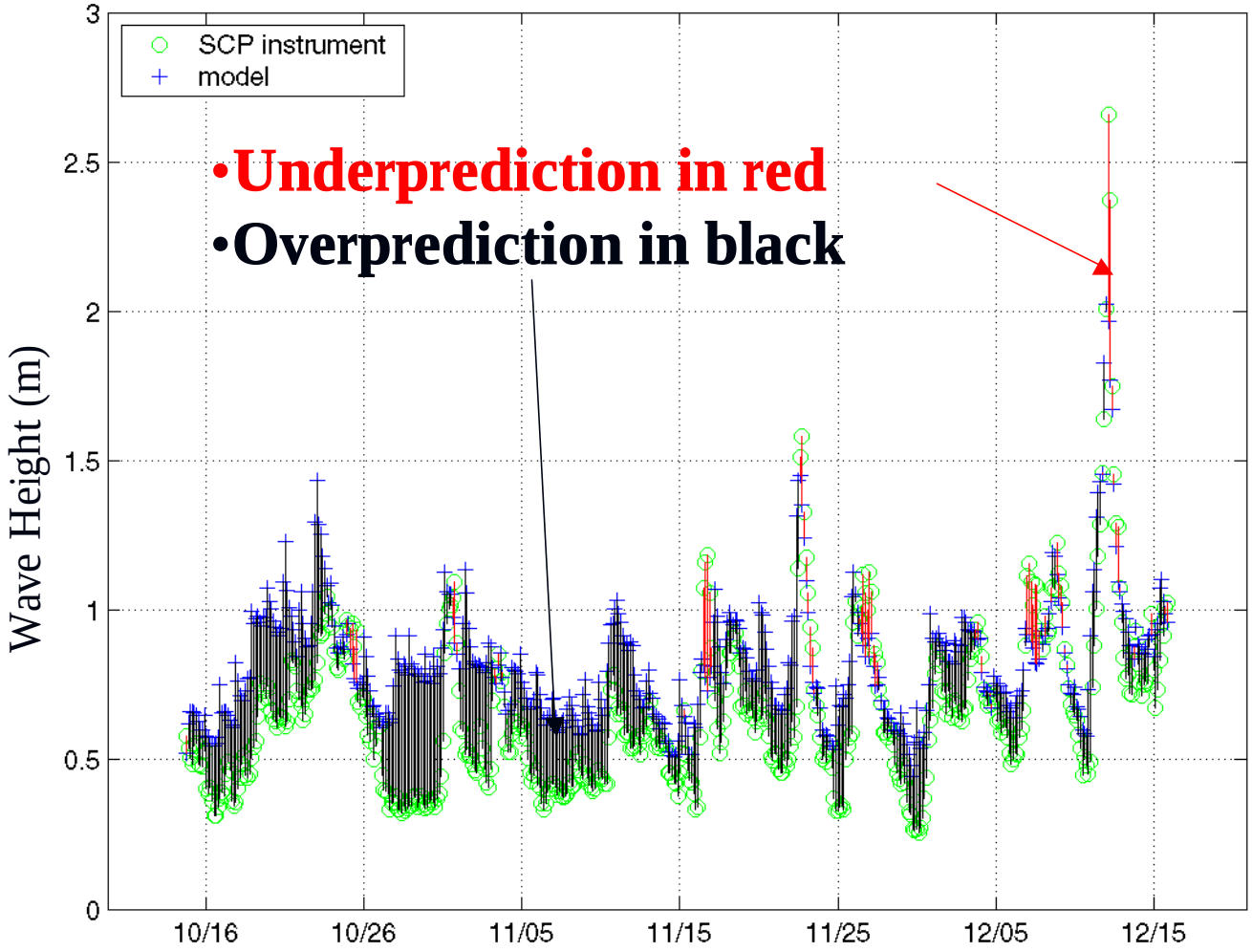
Conclusion:
Stationary assumption incurs noticeable penalty in RMSE due to incorrect arrival time of swells

High resolution model more energetic than low resolution model



Dec 1-15 Case study: impact of resolution

Nonstationary, high resolution hindcast

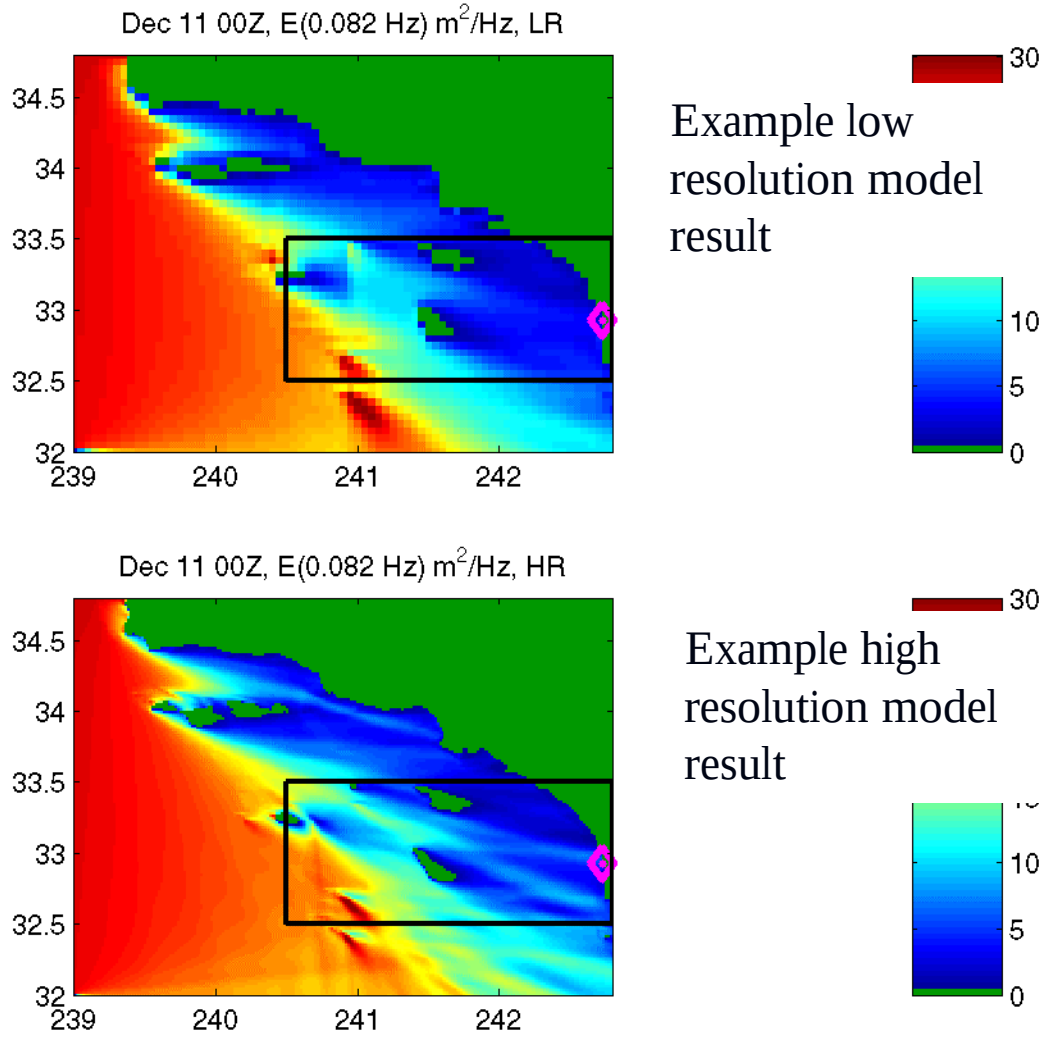


Comparison to measurements at Scripps: entire hindcast duration.

Consistent overprediction ➔ not associated with stationary assumption.

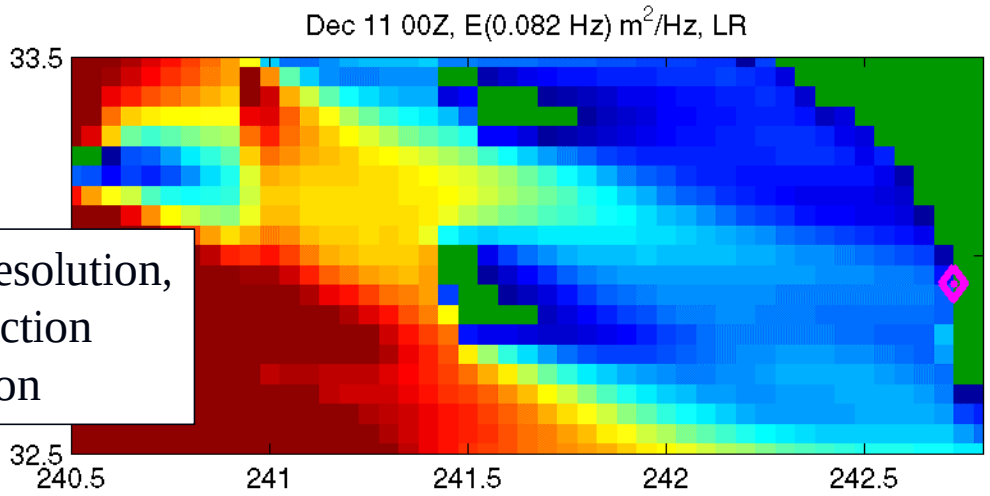
Since high resolution models tend to be more energetic at nearshore locations, there is apparent "penalty" for using high resolution!

The two high resolution models tend to allow more energy past the islands into the nearshore areas.

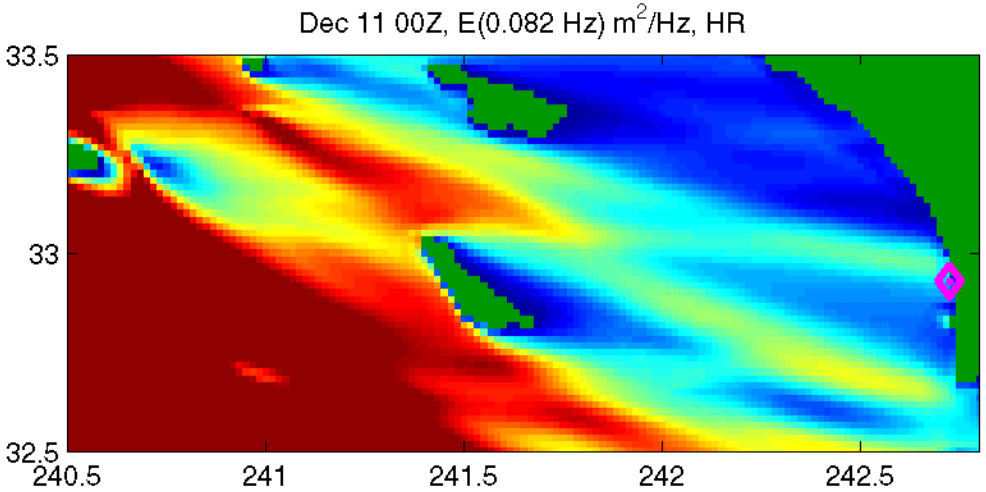


The two high resolution models tend to allow more energy past the islands into the nearshore areas.

With coarse resolution,
- More constriction
- More diffusion



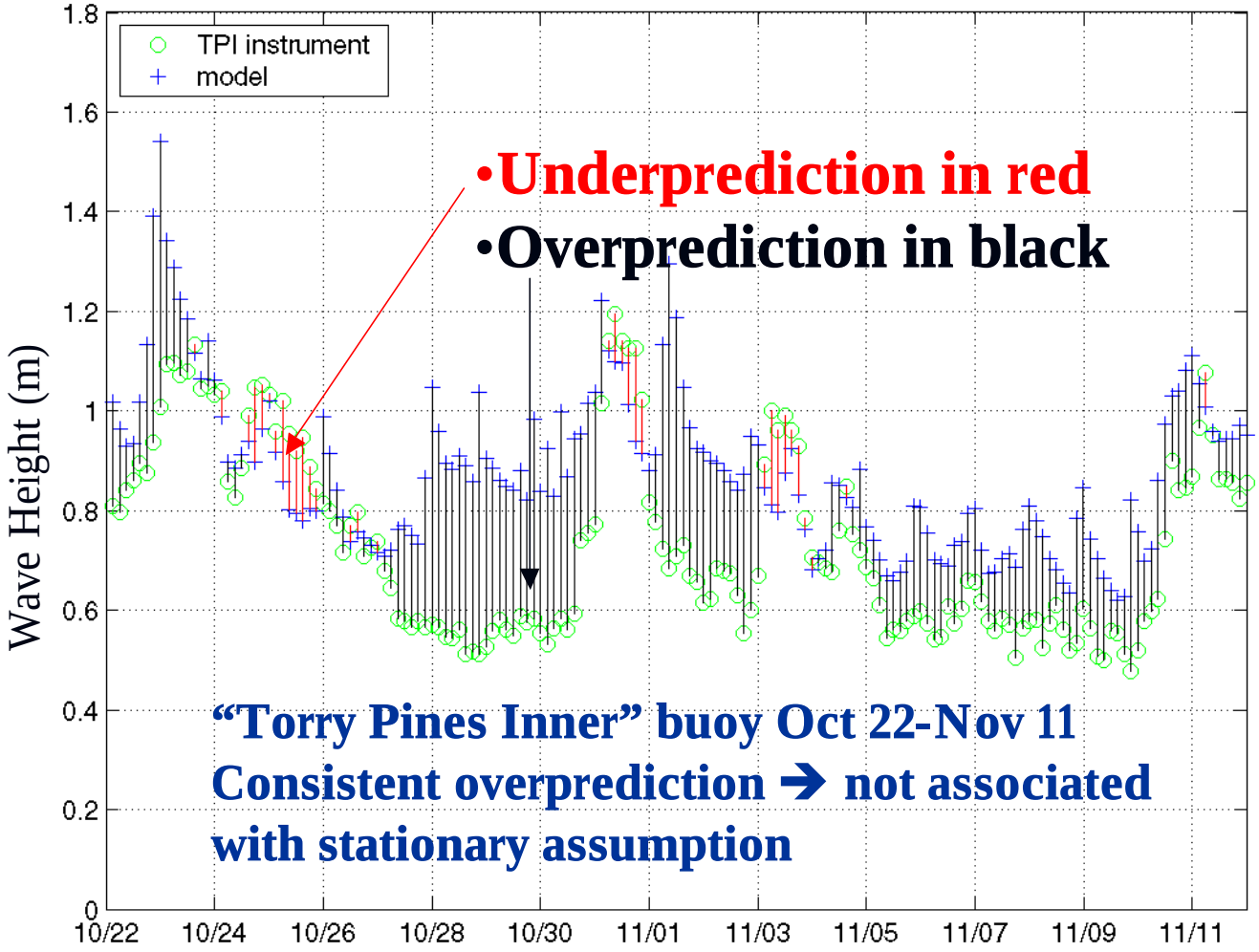
Example low resolution model result



Example high resolution model result

Oct. 22-Nov. 8 Case Study

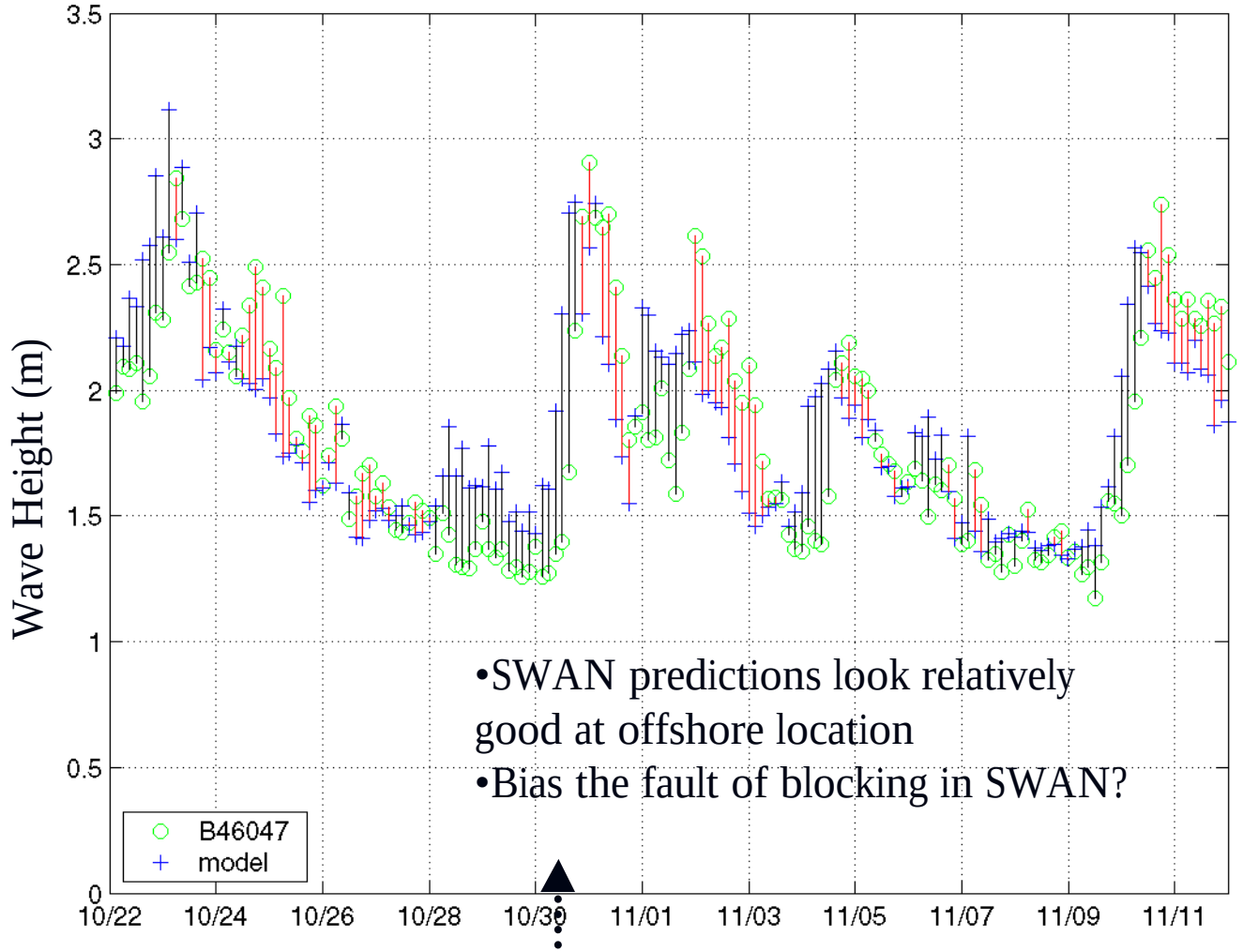
Nearshore Location



- **Underprediction in red**
- **Overprediction in black**

"Torry Pines Inner" buoy Oct 22-Nov 11
Consistent overprediction → not associated with stationary assumption

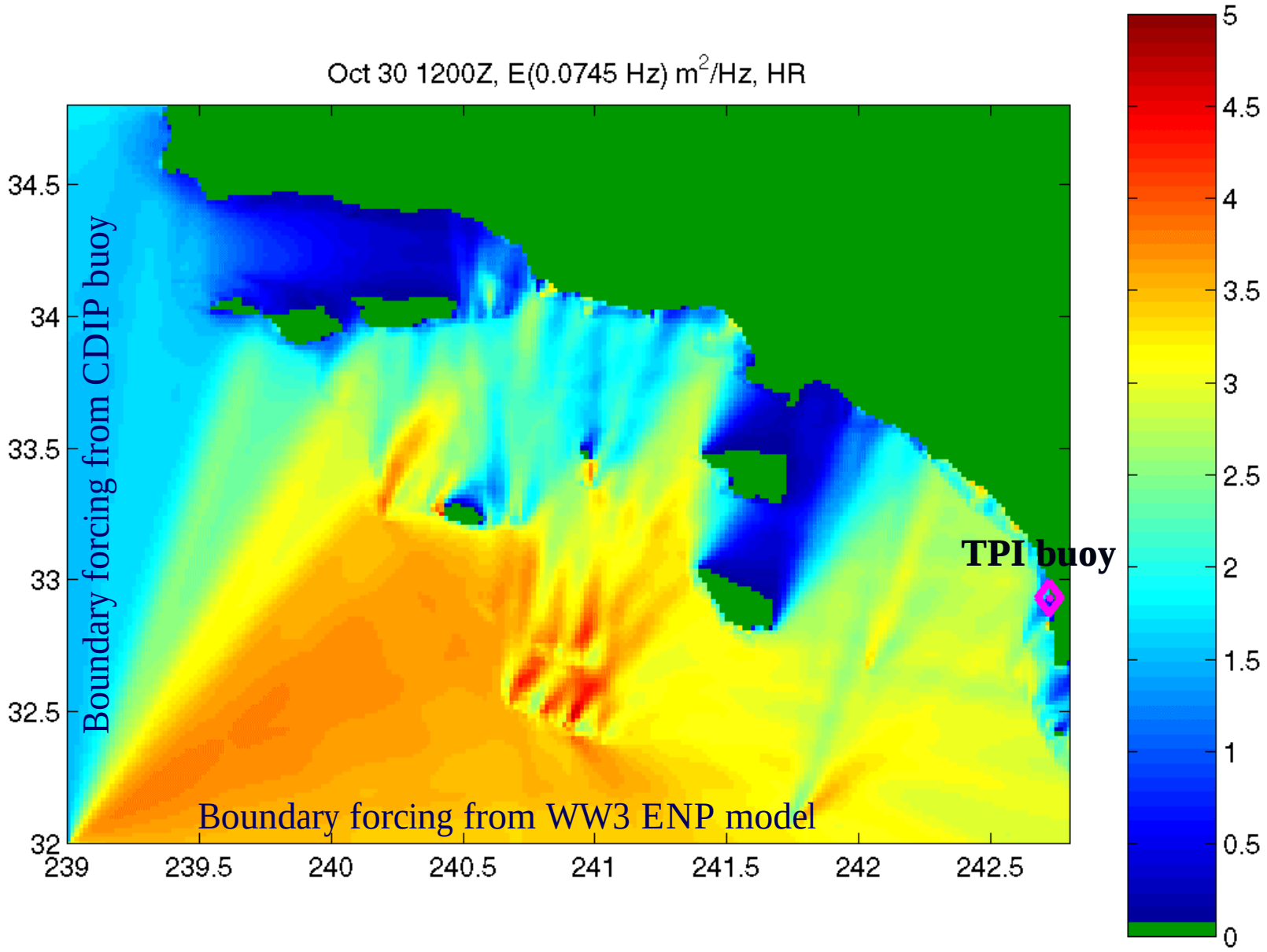
Offshore Location (46047)



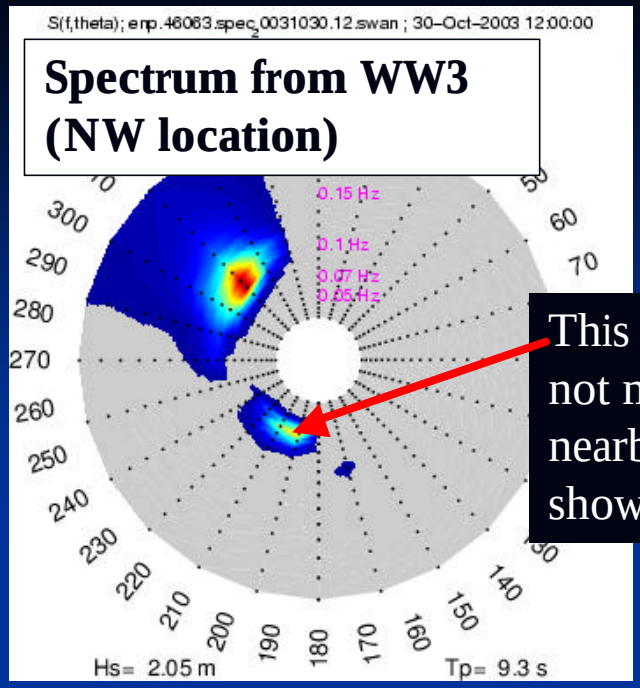
- SWAN predictions look relatively good at offshore location
- Bias the fault of blocking in SWAN?

Study Oct. 30 1200Z in greater detail

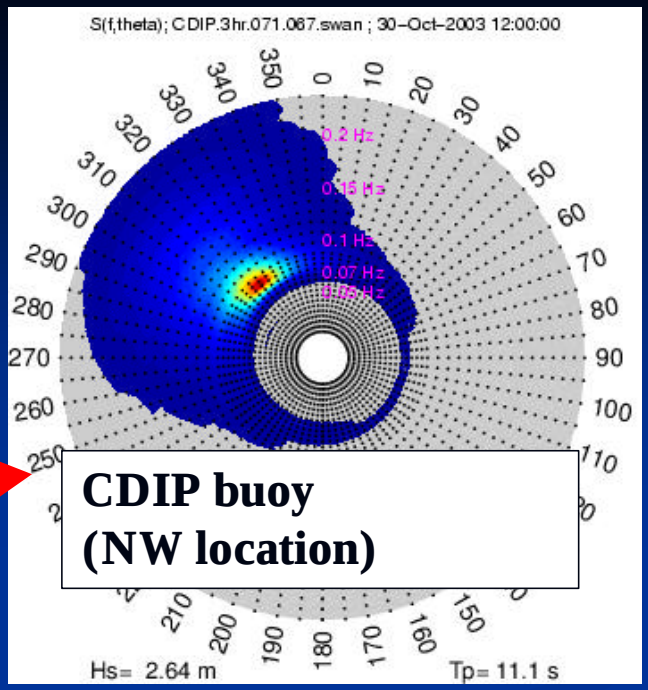
Oct 22 - Nov 8: study of swell forcing

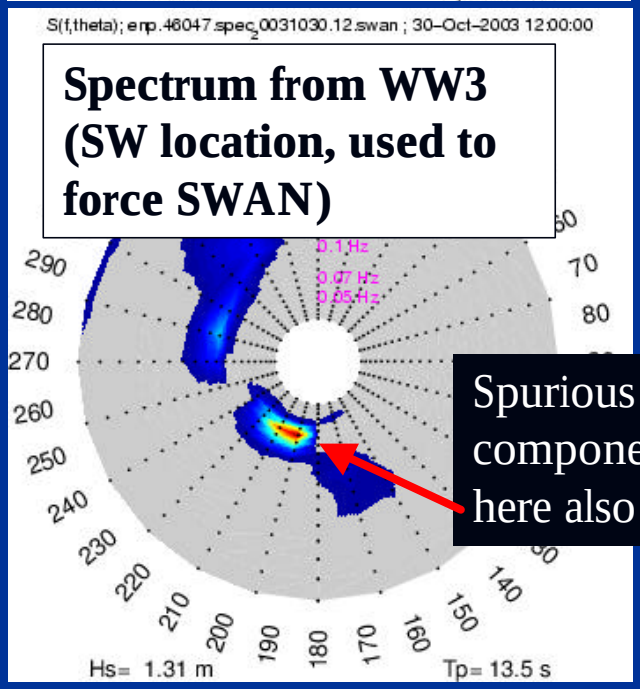


Alarming discrepancy, and a clue!



This component not measured by nearby CDIP buoy shown here

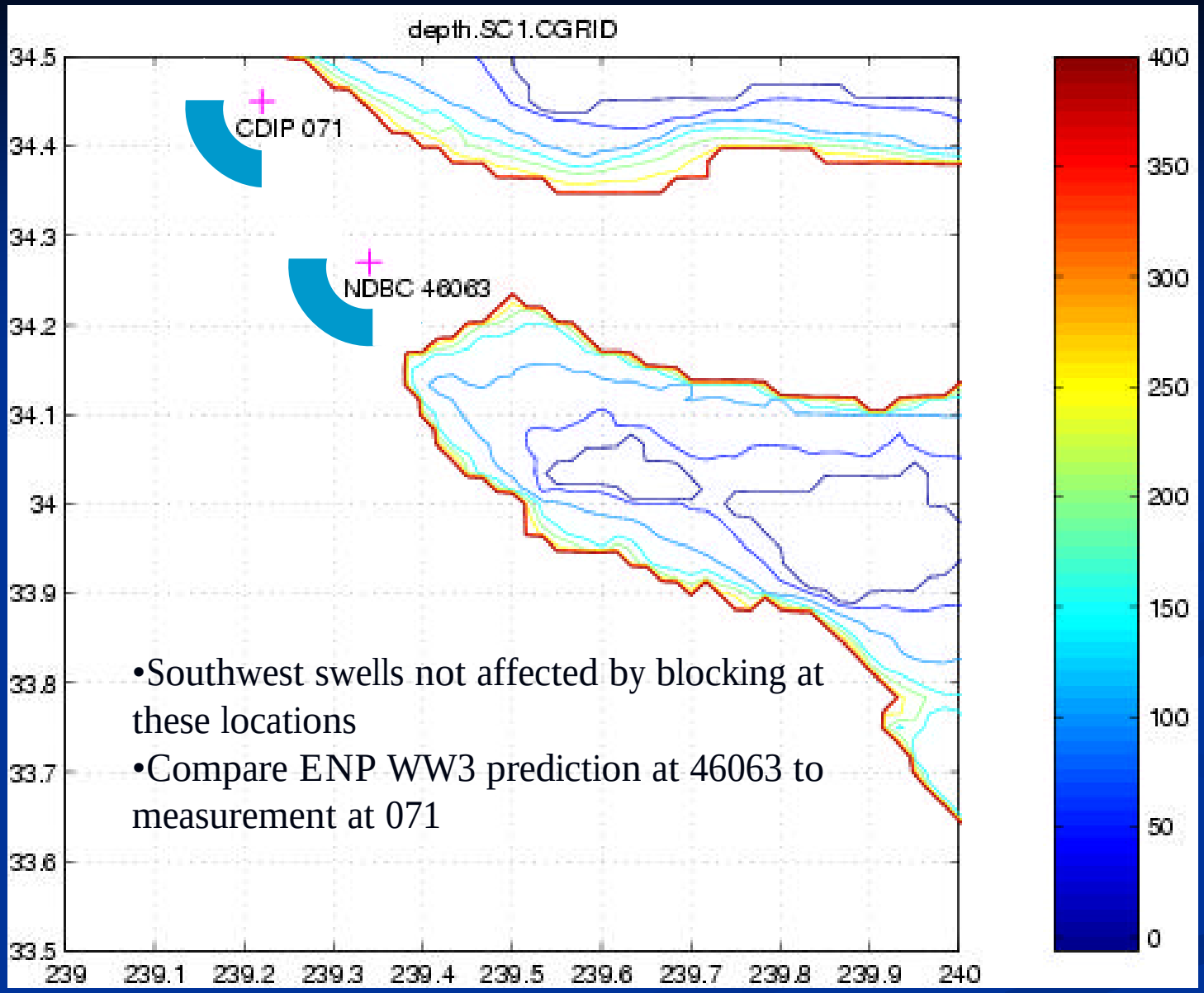




Spurious swell component exists here also

Spurious swell from southwest exists in the boundary forcing from WW3 ENP model

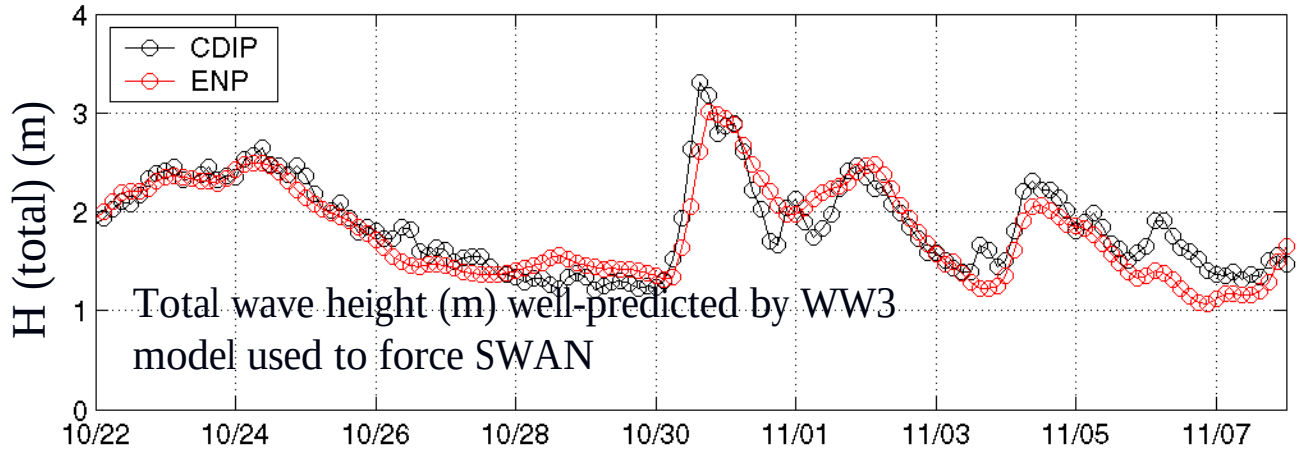
Oct 22 – Nov 8: study of swell forcing

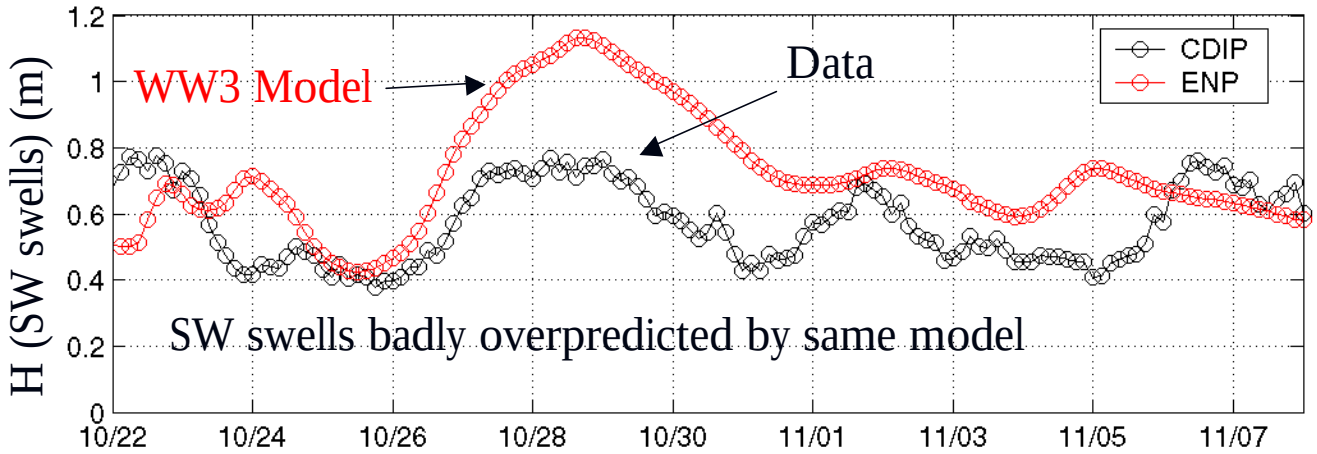


- Southwest swells not affected by blocking at these locations
- Compare ENP WW3 prediction at 46063 to measurement at 071

Oct 22 – Nov 8: study of swell forcing

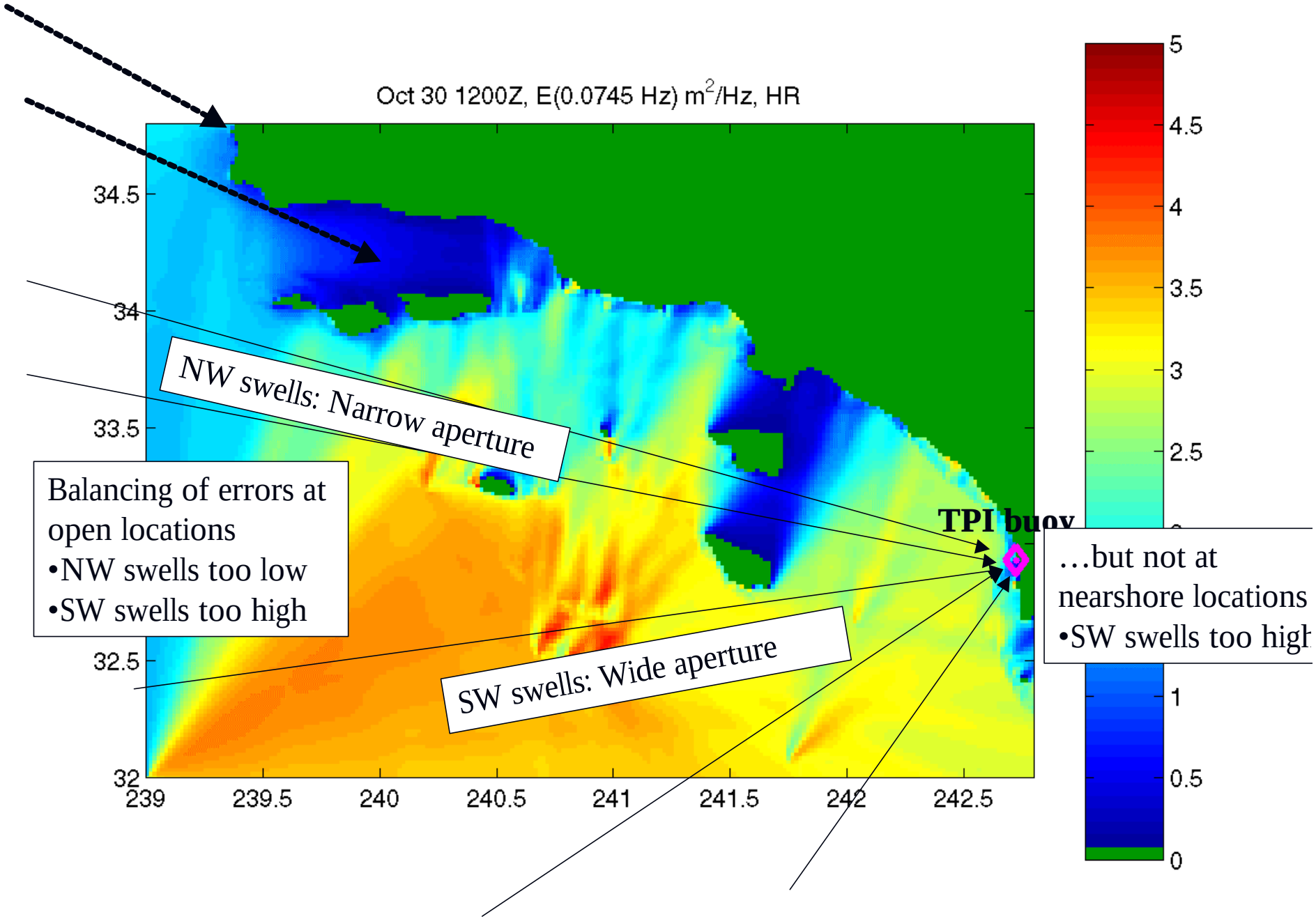
WW3 regional model (our boundary forcing) vs. measurements





So what?

Oct 22 – Nov 8: study of swell forcing



Oct 22 – Nov 8: study of swell forcing

Oct 22-Nov 8 case study

Swells from SW are small and if they are poorly specified, this will….

- have a minor impact on skill of total wave height prediction at those unsheltered locations
- have a major impact on skill of total wave height prediction at sheltered locations (inside Bight)

Discussion

- Blindfold realtime system vs. hindcast
- Model handoff

Conclusions

- (SCAL and similar cases) Accuracy of directional characteristics of boundary forcing critical
- SWAN now feasible for high resolution, nonstationary computations
- Coarse (Δx, Δy) computations for SCAL (SC1) grid ➔ no penalty in RMS error (and negative trend in bias)
- Stationary computations for SCAL (SC1) grid ➔ penalty in RMS error

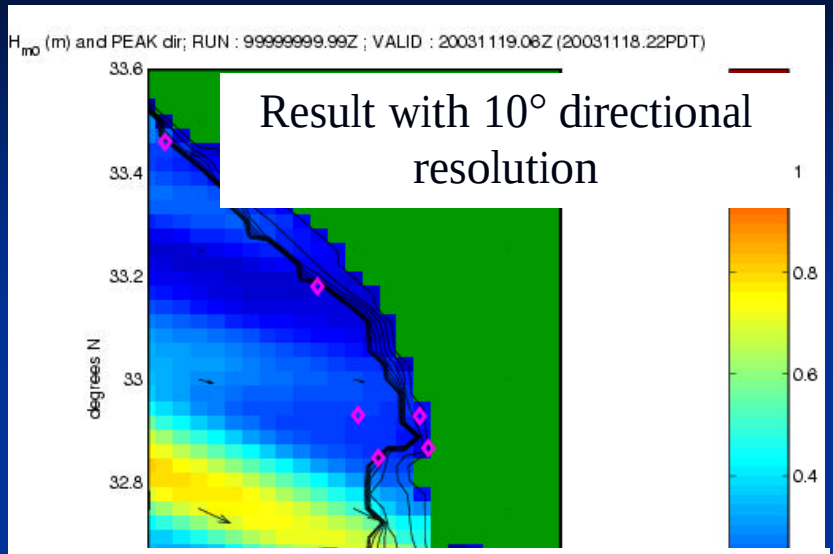
[a pdf of this paper is available, also some hard copies]

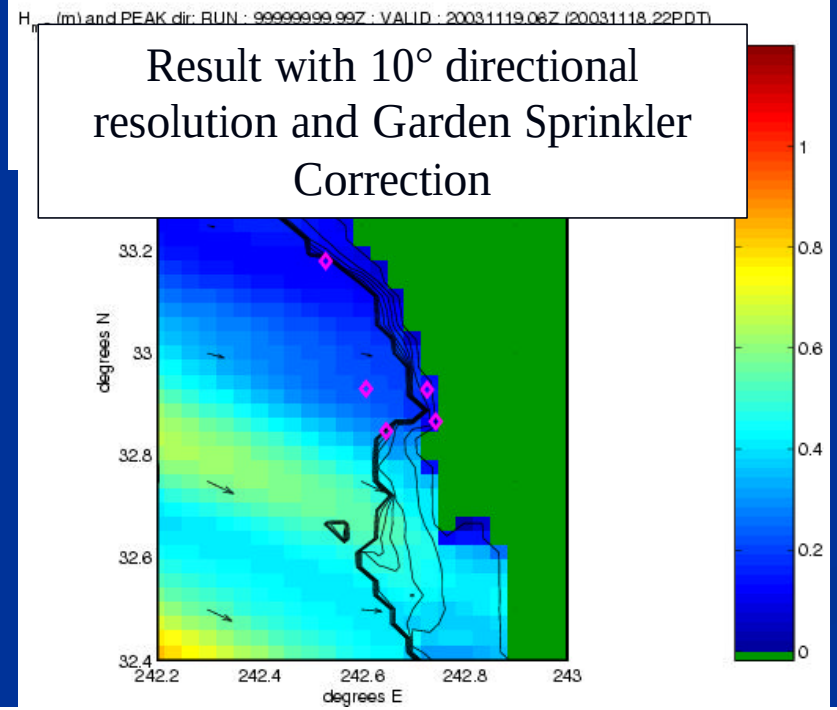
Some problems

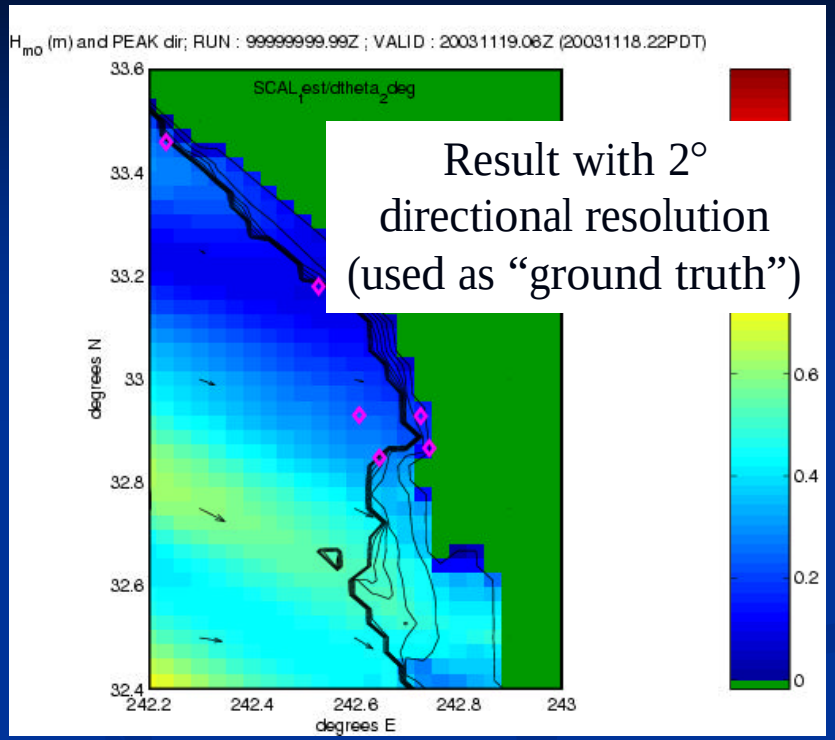
- Garden Sprinkler Effect
  - (a side effect of discrete representation of continuous spectrum)
- Refraction at coarse geographic resolution
- Underconvergence

Subtle yet significant → problematic, esp. for new SWAN users in Navy → A.I. required?

Wave height (m) predictions from outer SWAN grid, zoomed in on nearshore area



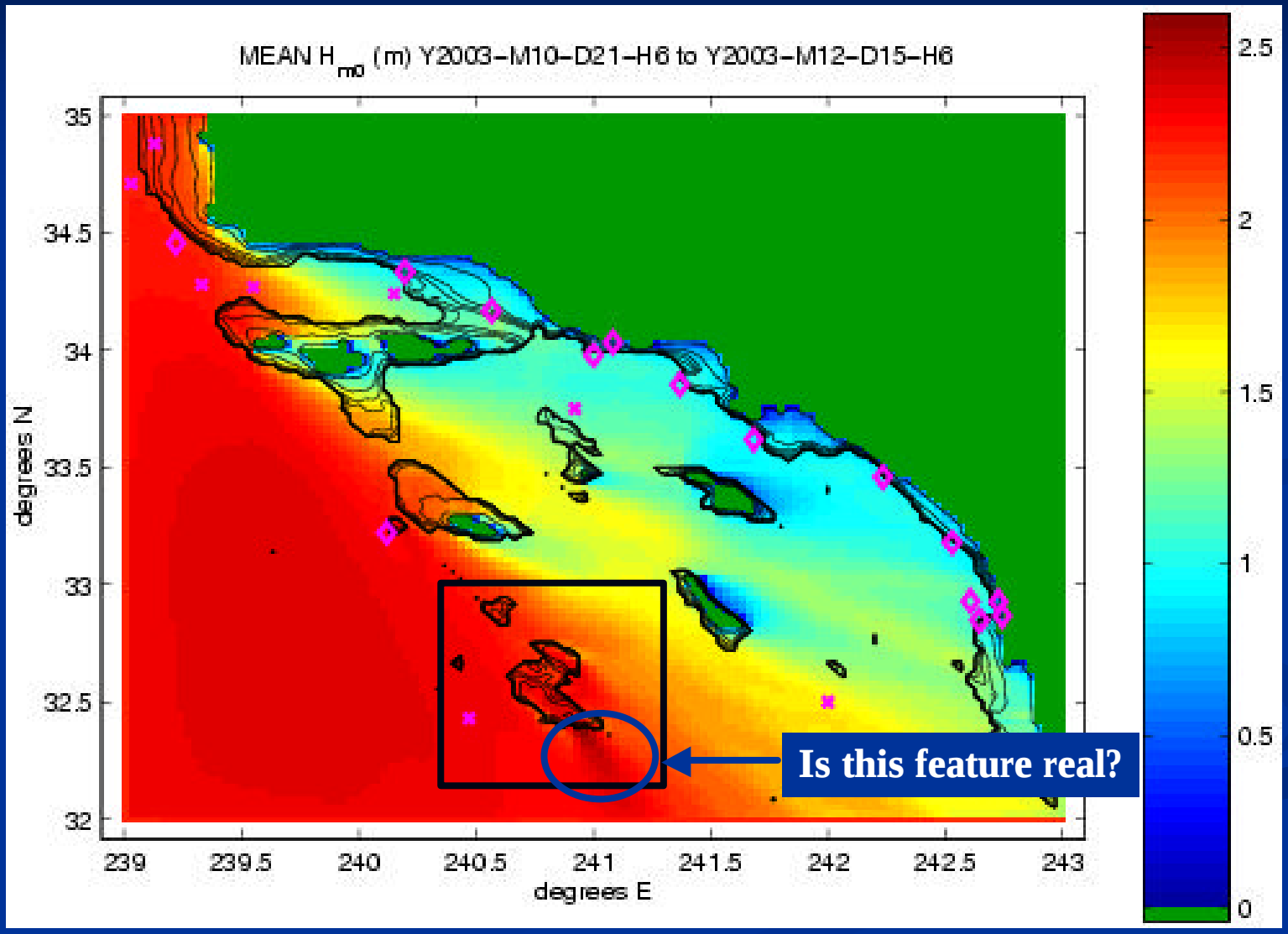




Different result indicates Garden Sprinkler Effect (a side effect of continuous s

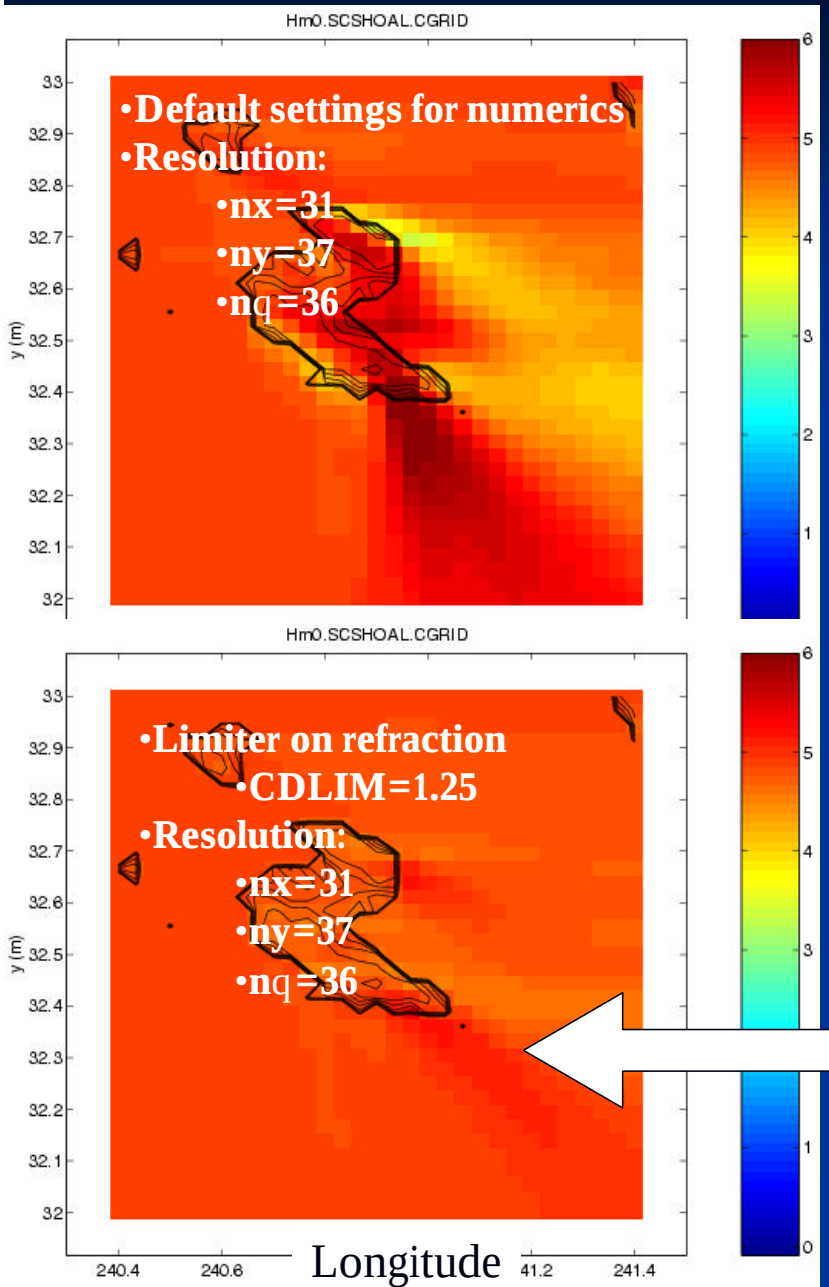
Unfortunately, correction is tuned for this “ground truth” and may not work as well for other cases and it makes our model conditionally stable.

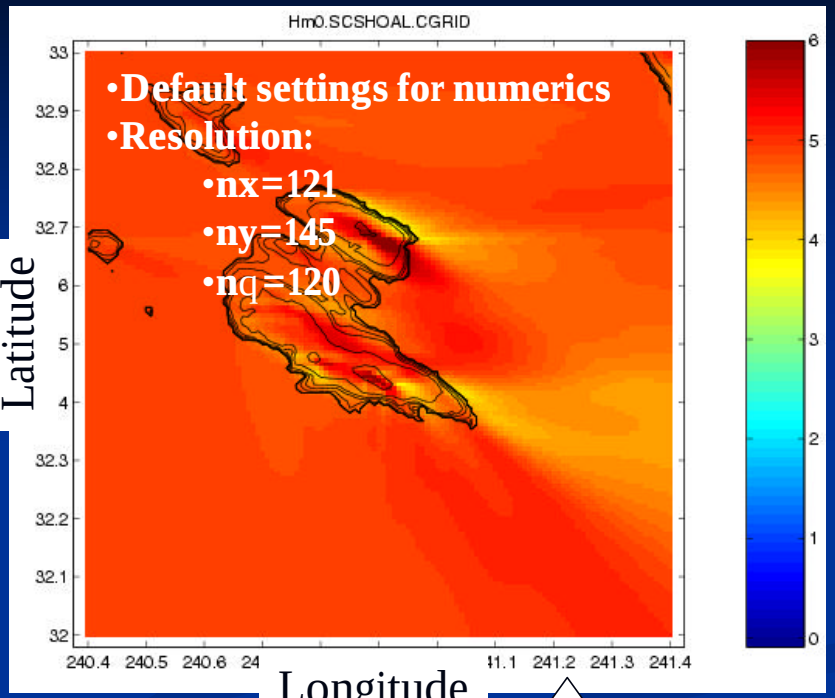
Climatology



Refraction in SWAN

Refraction at coarse resolution: H_{m0}(m) shown





Numerics can be adjusted via a limiter on refraction:
this limiter removes the artifact in coarse resolution model

Correct garden sprinkler effect
al
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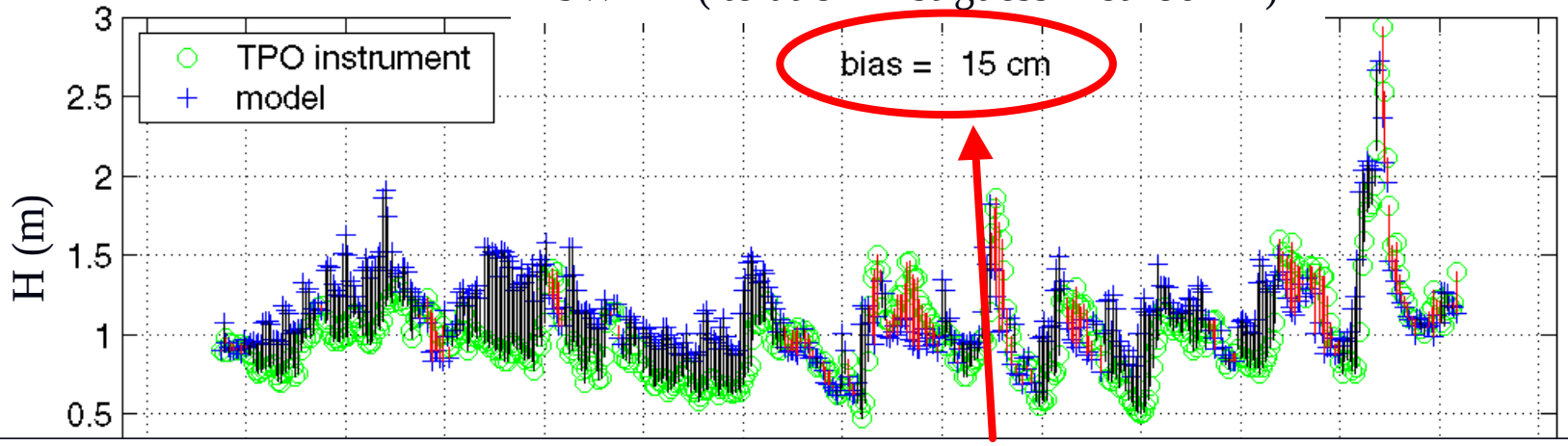
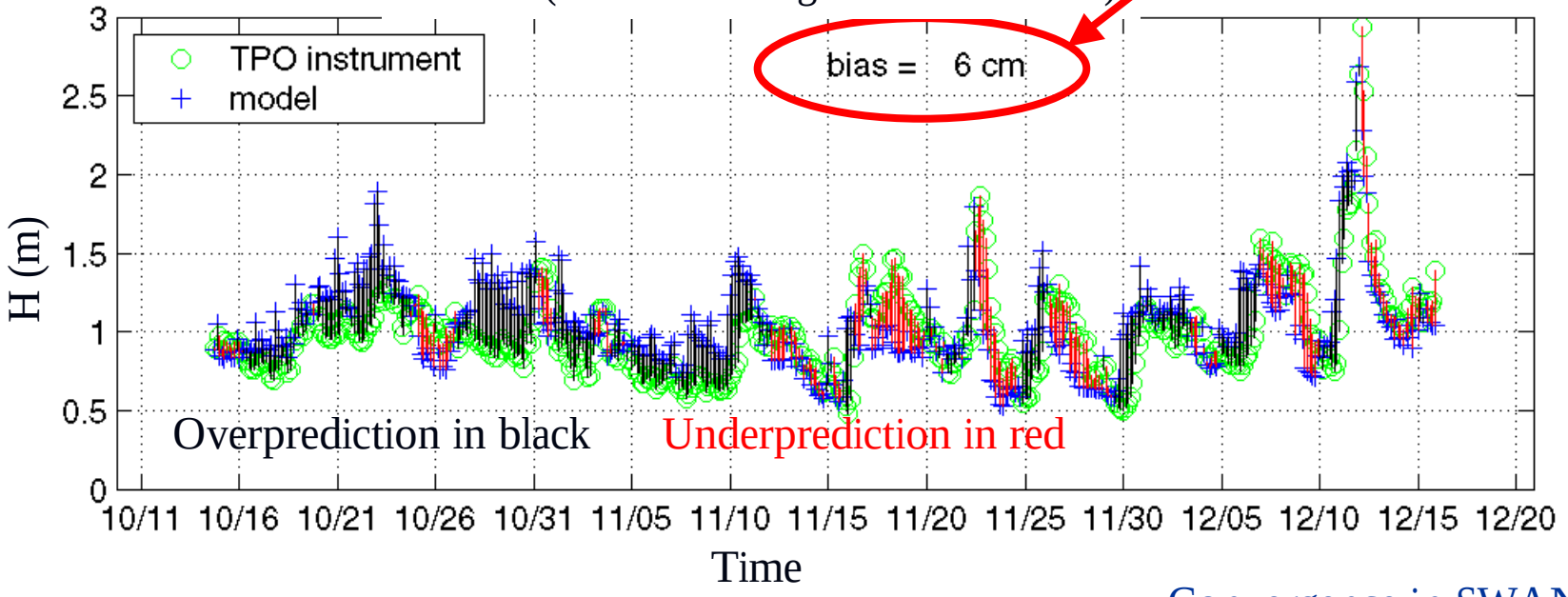
for adjusting numerics

SWAN (iteration first guess method #1)



Two cases identical except for method of initializing computations (at each time interval):
Dramatic difference in bias suggests stationary computations in SWAN are under-converged.

SWAN (iteration first guess method #2)



The End.

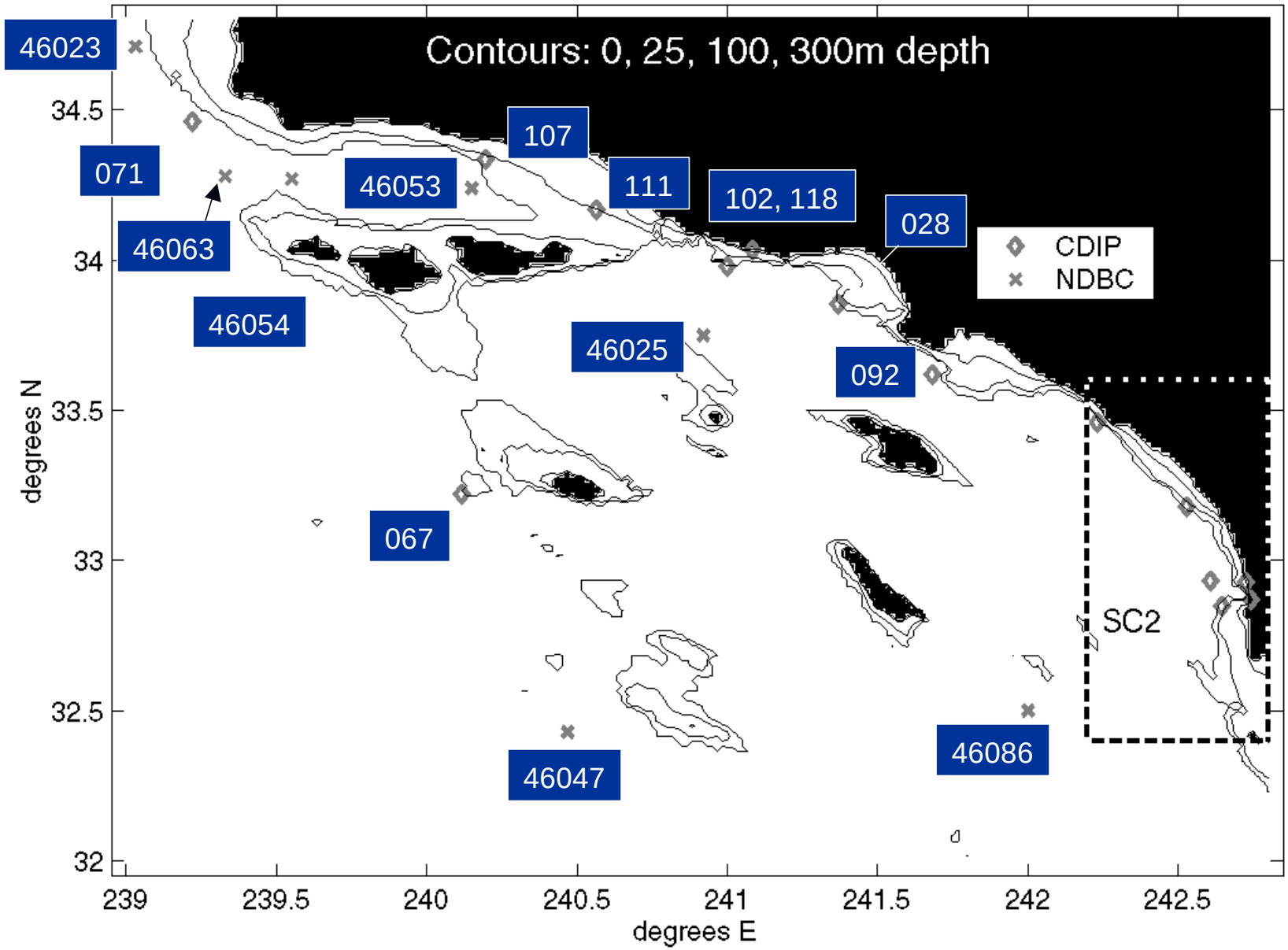
Extra slides

Summary

- Refraction computations at coarse resolution
- Garden Sprinkler Effect

Discussion

- Model handoff
- Output interval
- Blending of model and buoy spectra for southern boundary forcing
- Dissipation
- More comprehensive metrics
- Other forcing sets


Contours: 0, 25, 100, 300m depth
46023
071
46063
46053
107
111
102, 118
028
CDIP
NDBC
46054
46025
092
067
SC2
46086
46047
34.5
34
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degrees N
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239.5
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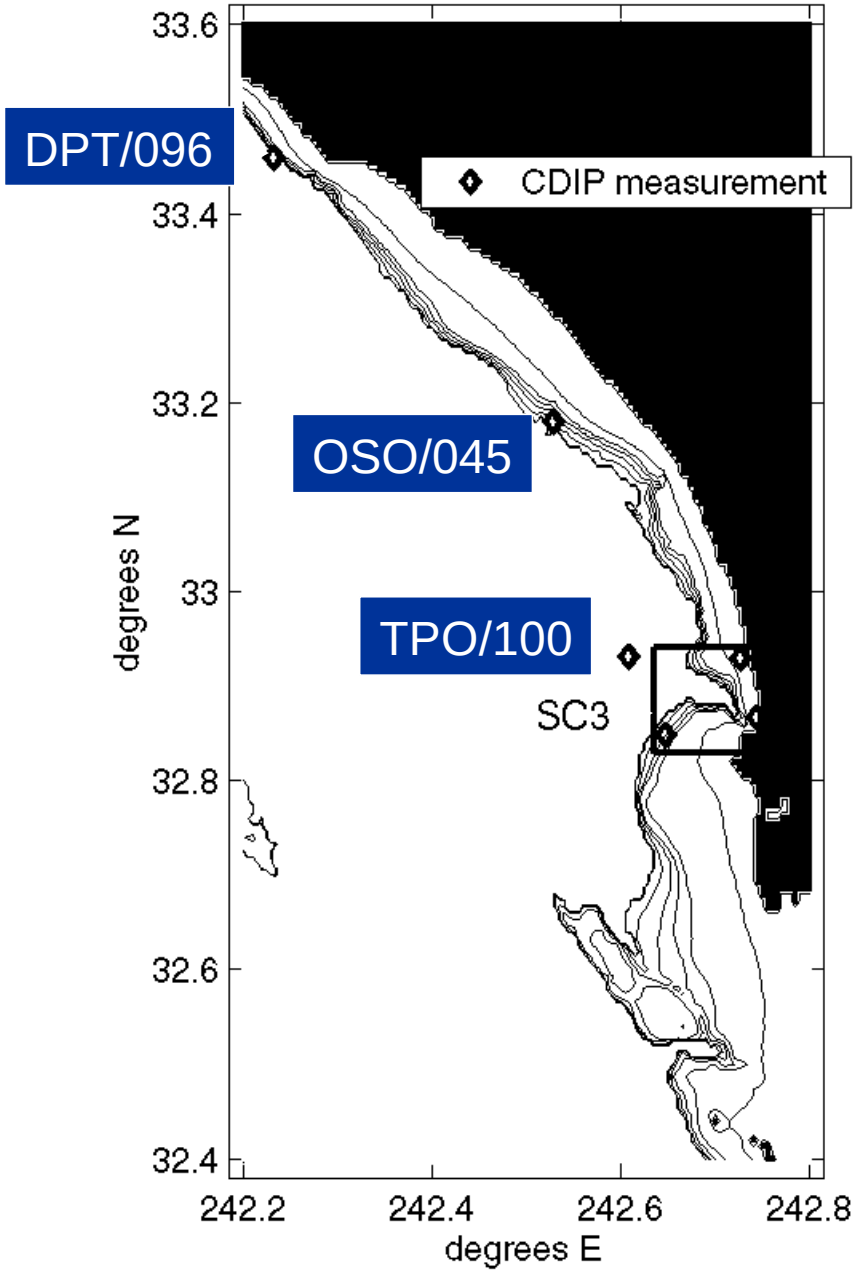
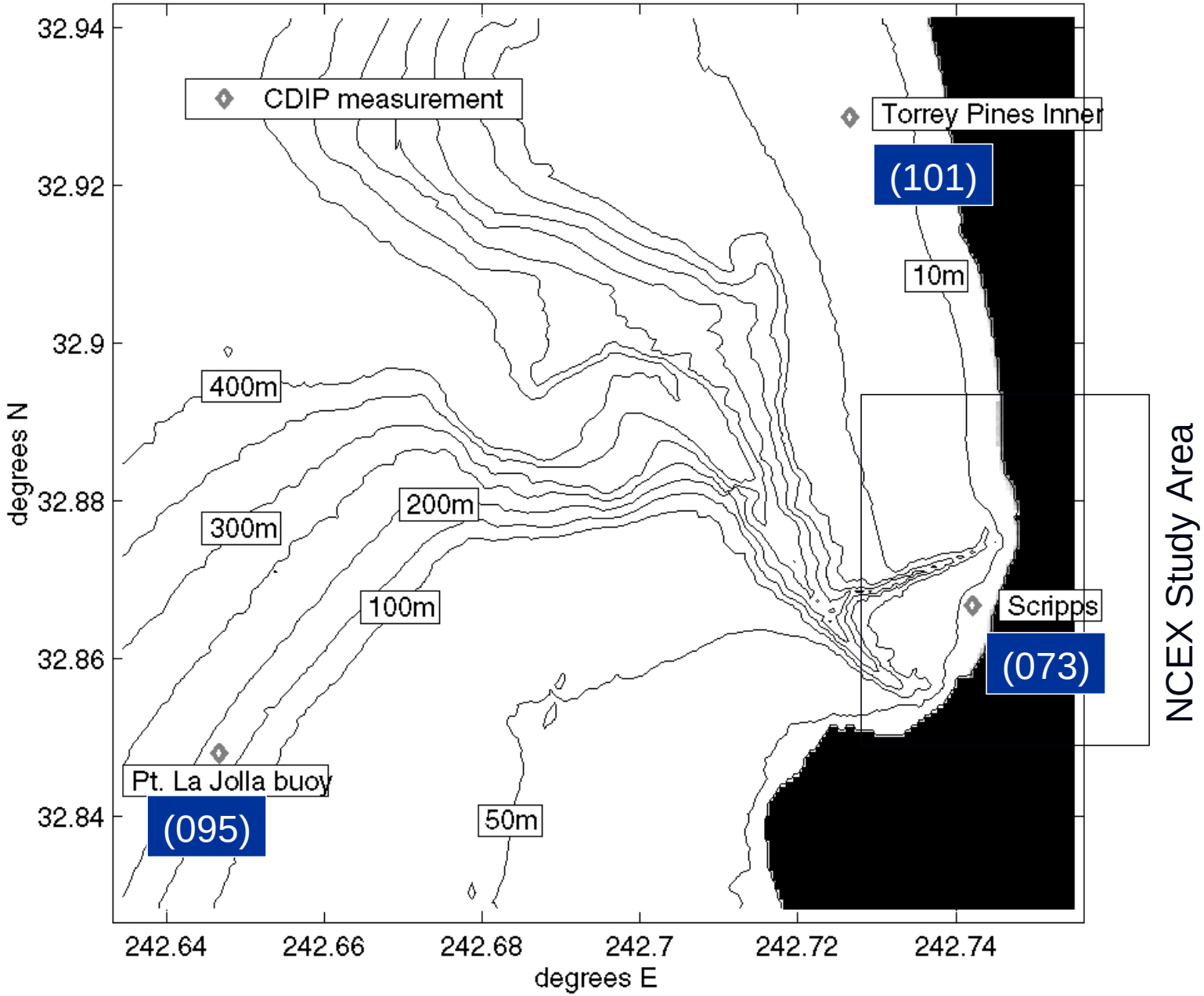
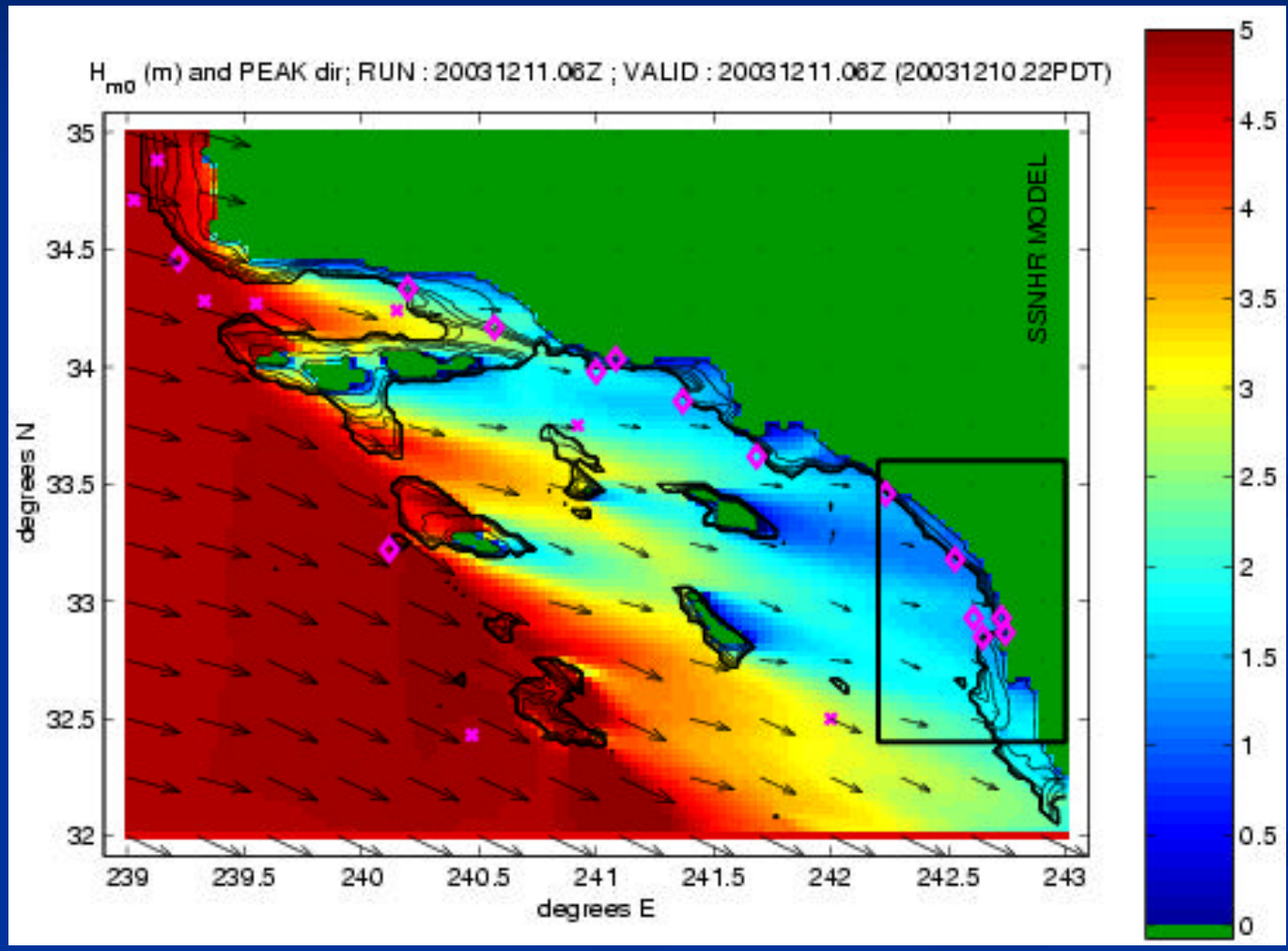
242
242.5
degrees E


DPT/096
CDIP measurement
OSO/045
TPO/100
SC3
33.6
33.4
33.2
33
32.8
32.6
32.4
degrees N
242.2
242.4
242.6
242.8
degrees E


CDIP measurement
Torrey Pines Inner
(101)
10m
400m
300m
200m
100m
50m
Scripps
(073)
Pt. La Jolla buoy
(095)
NCEX Study Area
32.94
32.92
32.9
32.88
32.86
32.84
degrees N
242.64
242.66
242.68
242.7
242.72
242.74
degrees E

Wave Forecasting System for Nearshore Canyon Experiment (NCEX) (Sponsor: ONR)

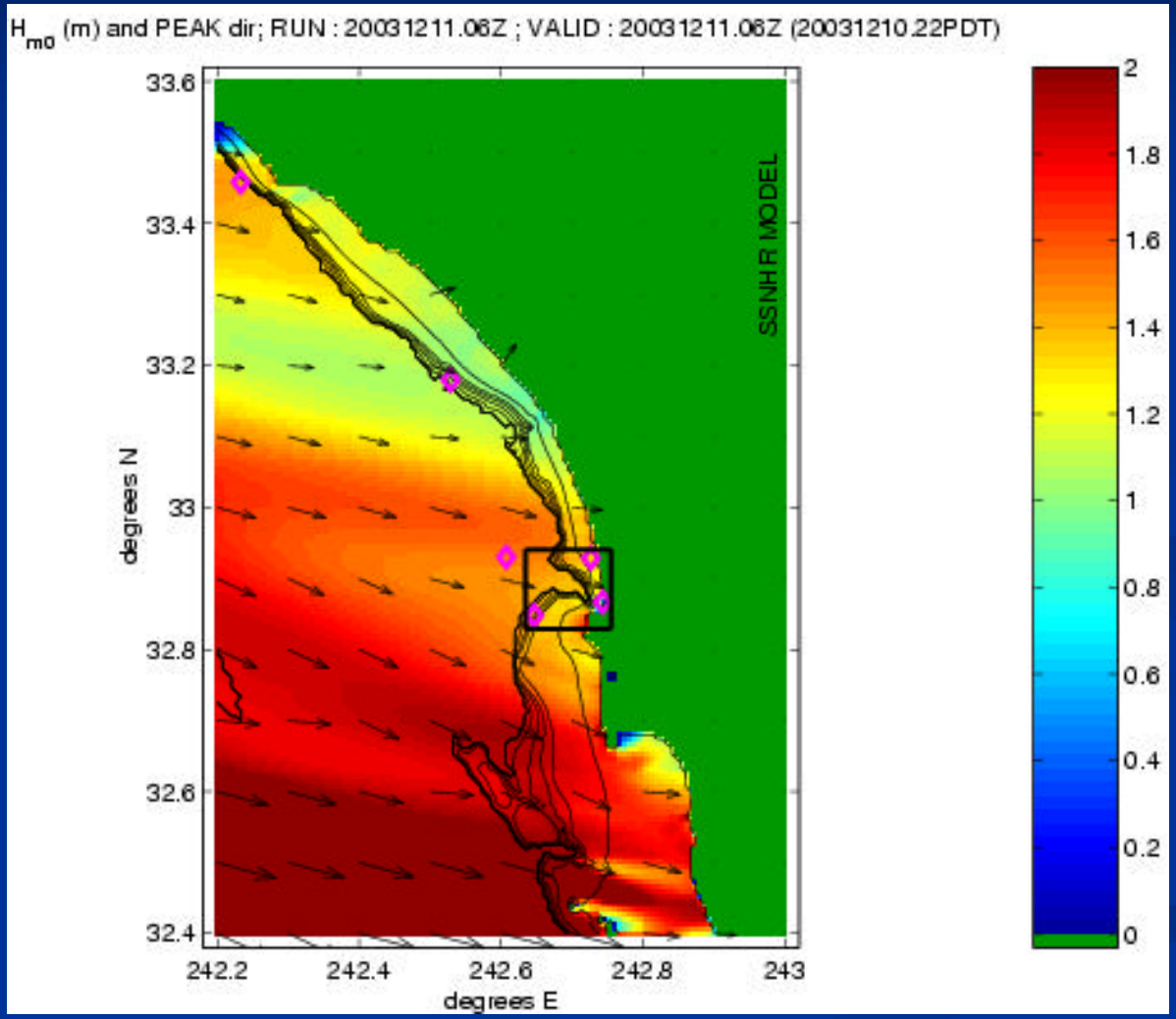
1st (outermost) SWAN Nest



http://www7320.nrlssc.navy.mil/NCEX/NCEX_mod.htm

Wave Forecasting System for Nearshore Canyon Experiment (NCEX) (Sponsor: ONR)

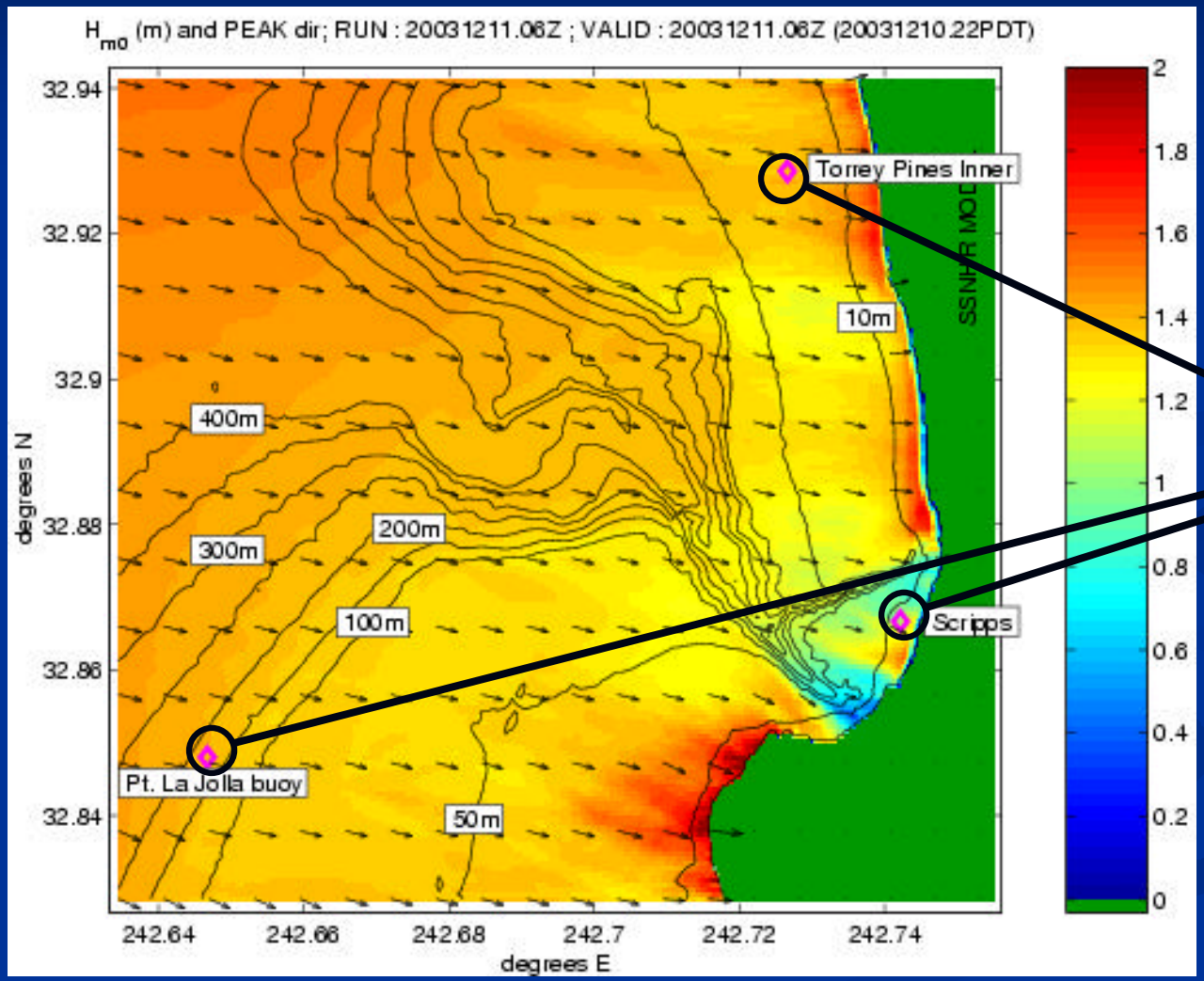
2nd SWAN Nest



http://www7320.nrlssc.navy.mil/NCEX/NCEX_mod.htm

Wave Forecasting System for Nearshore Canyon Experiment (NCEX) (Sponsor: ONR)

3rd (innermost) SWAN Nest (corresponds to NCEX region)



Time series comparisons at three instrument locations

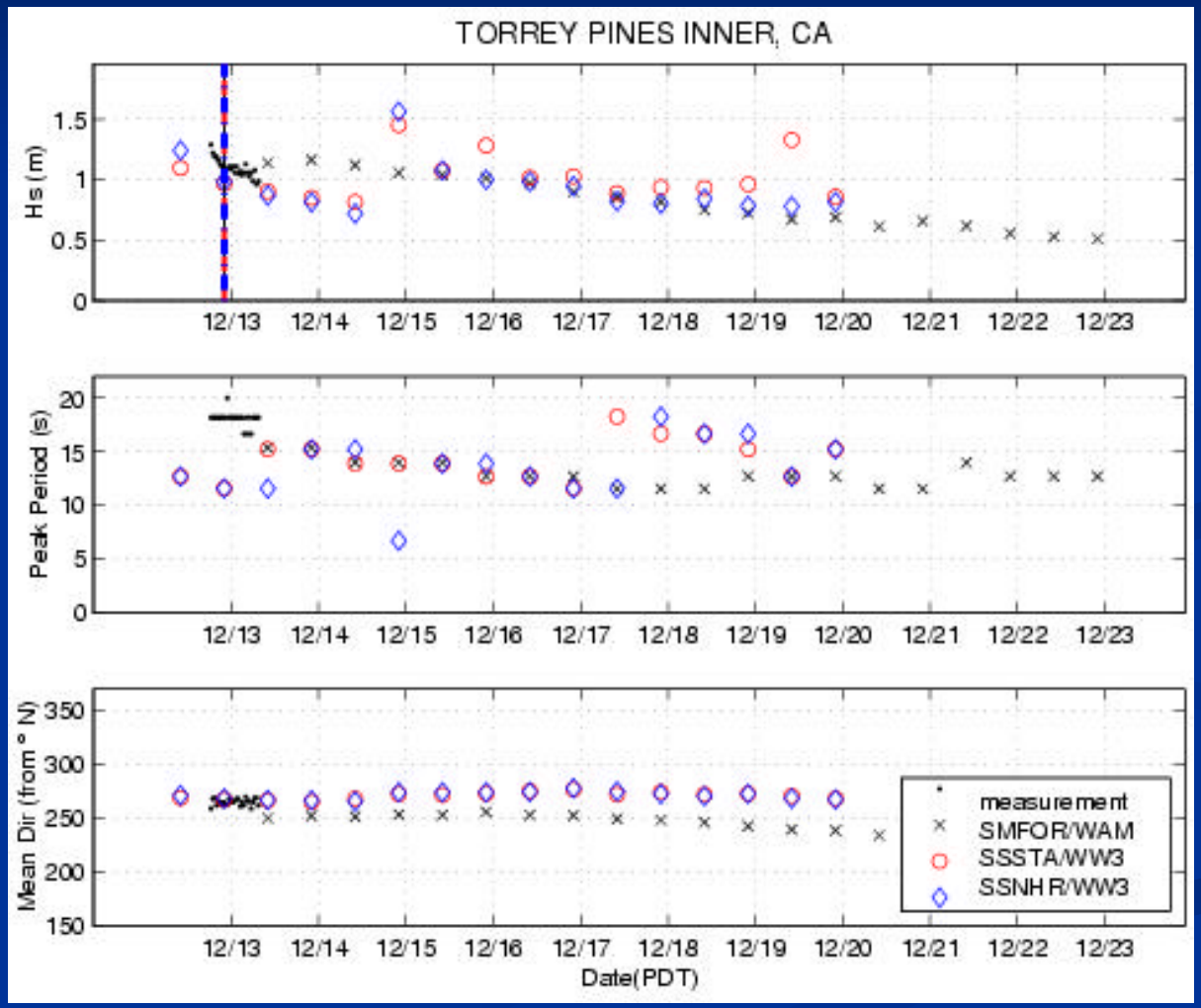
http://www7320.nrlssc.navy.mil/NCEX/NCEX_mod.htm

Wave Forecasting System for Nearshore Canyon Experiment (NCEX) (Sponsor: ONR)

Realtime Time Series Comparisons to Data

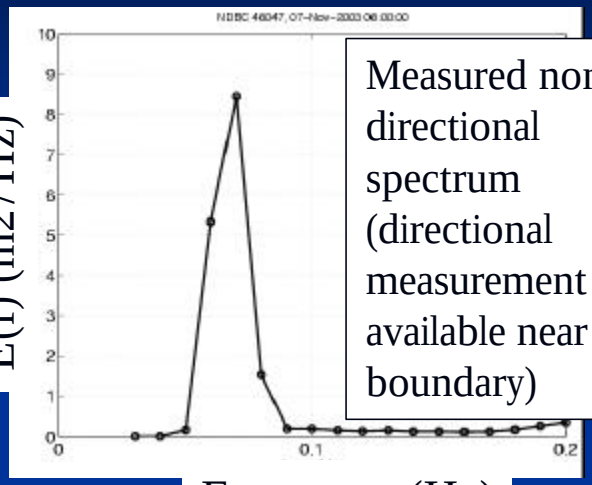
Example:

Torrey Pines "Inner buoy"



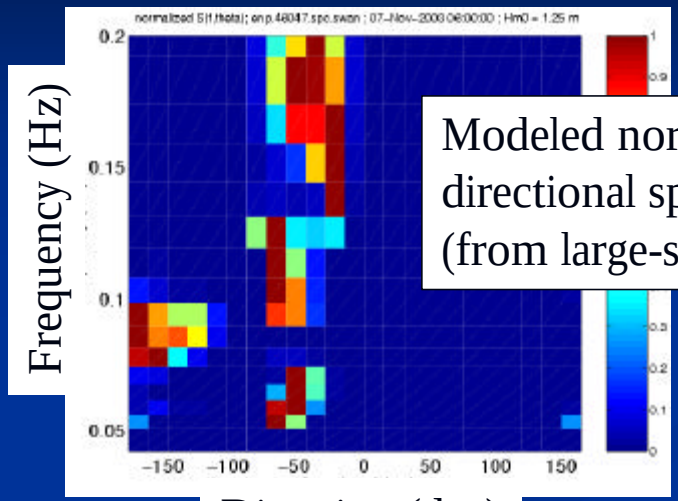
http://www7320.nrlssc.navy.mil/NCEX/NCEX_mod.htm

Strategy: Blend model and buoy spectra to get best possible boundary forcing at southern boundary



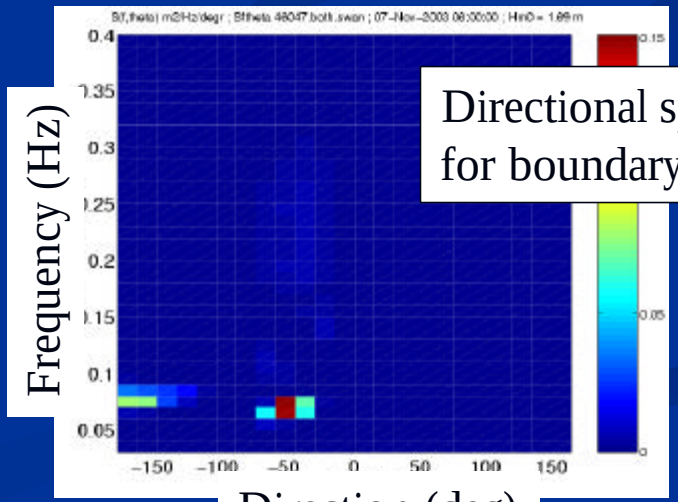
Measured non-directional spectrum (directional measurement not available near this boundary)

+



Modeled normalized directional spectrum (from large-scale model)

=



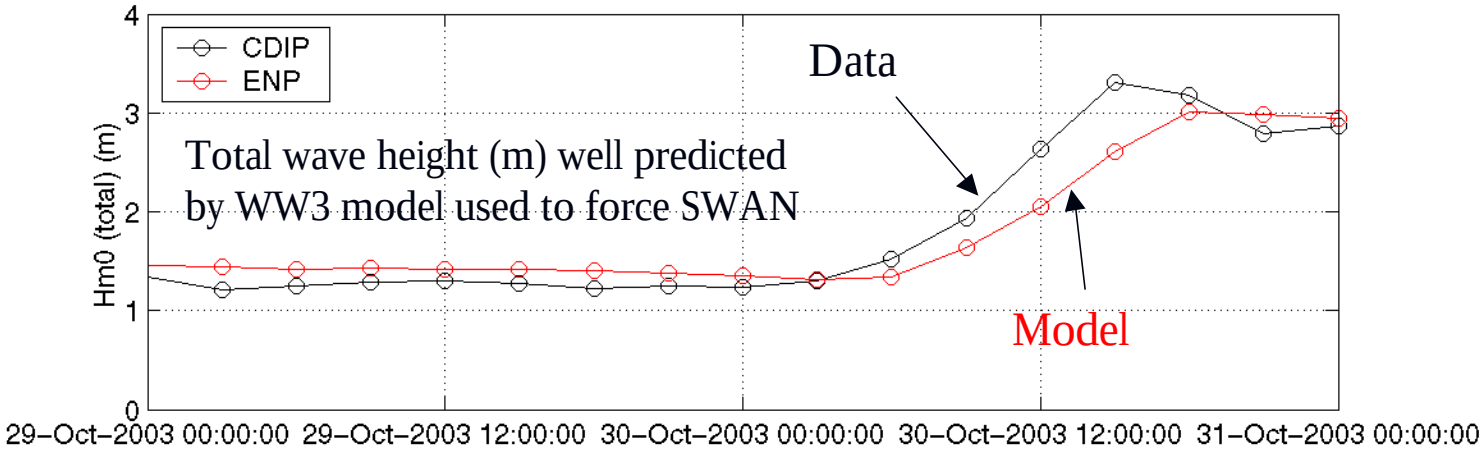
Directional spectrum for boundary forcing

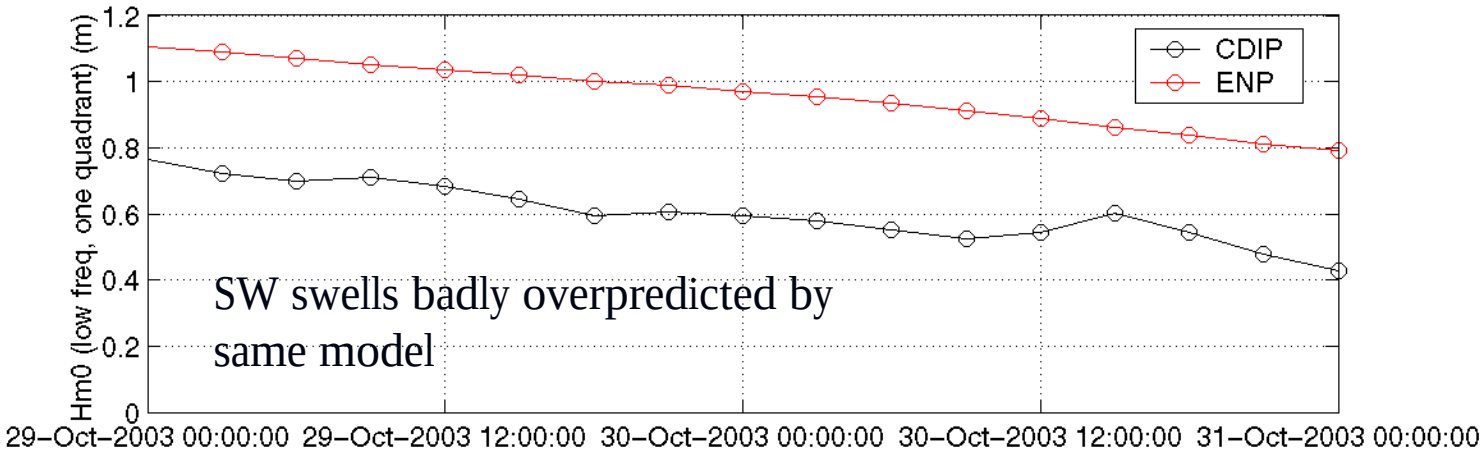
Blending forcing

Strategy: Blend model and buoy spectra to get best possible boundary forcing at southern boundary:
(Why it does not work.)

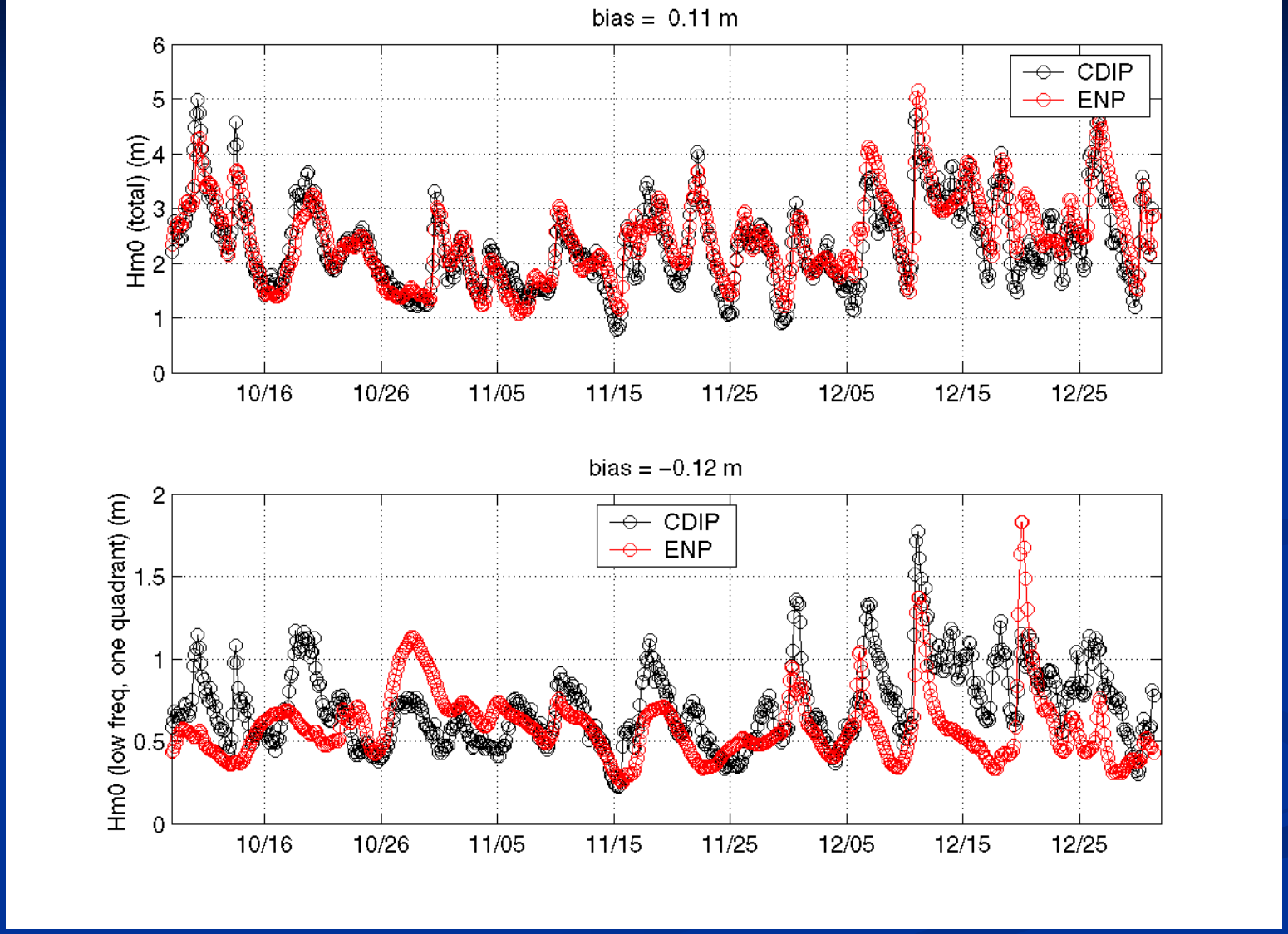
Scenario:

- Buoy measures strong swell at 0.06 Hz (almost all from northwest, but buoy does not know this)
- WW3 model has this strong swell in the wrong frequency bin, so WW3 E(0.06Hz) is weak (one weak swell component from NW and one weak swell from SW). Normalized spectrum at 0.06 Hz show two equal components.
- Combining spectra, we get a medium swell from NW and medium swell from SW
- Swell from NW is irrelevant to NCEX area (it is blocked)
- Swell from SW is too high in boundary forcing and is overpredicted by SWAN at NCEX area.

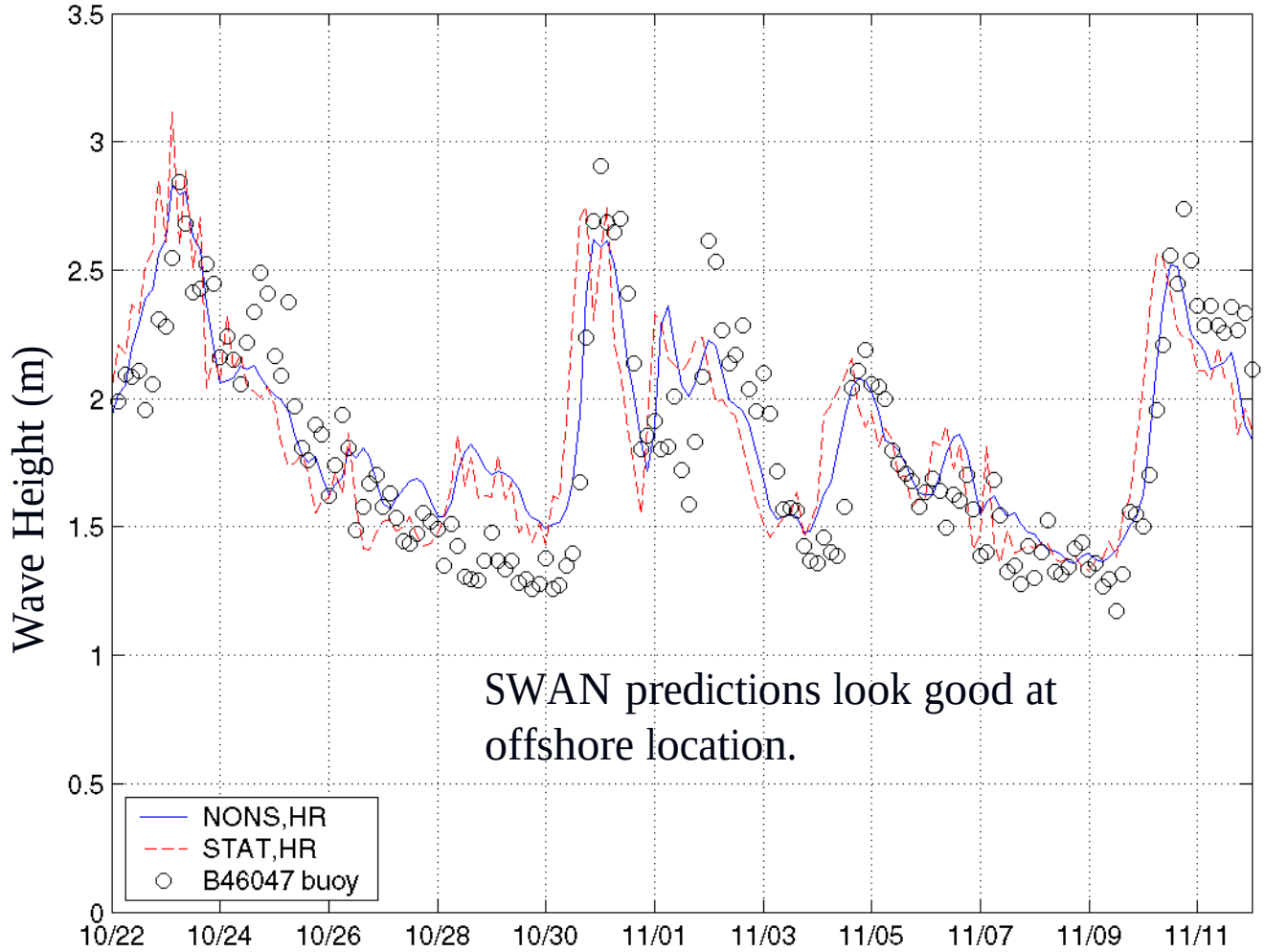




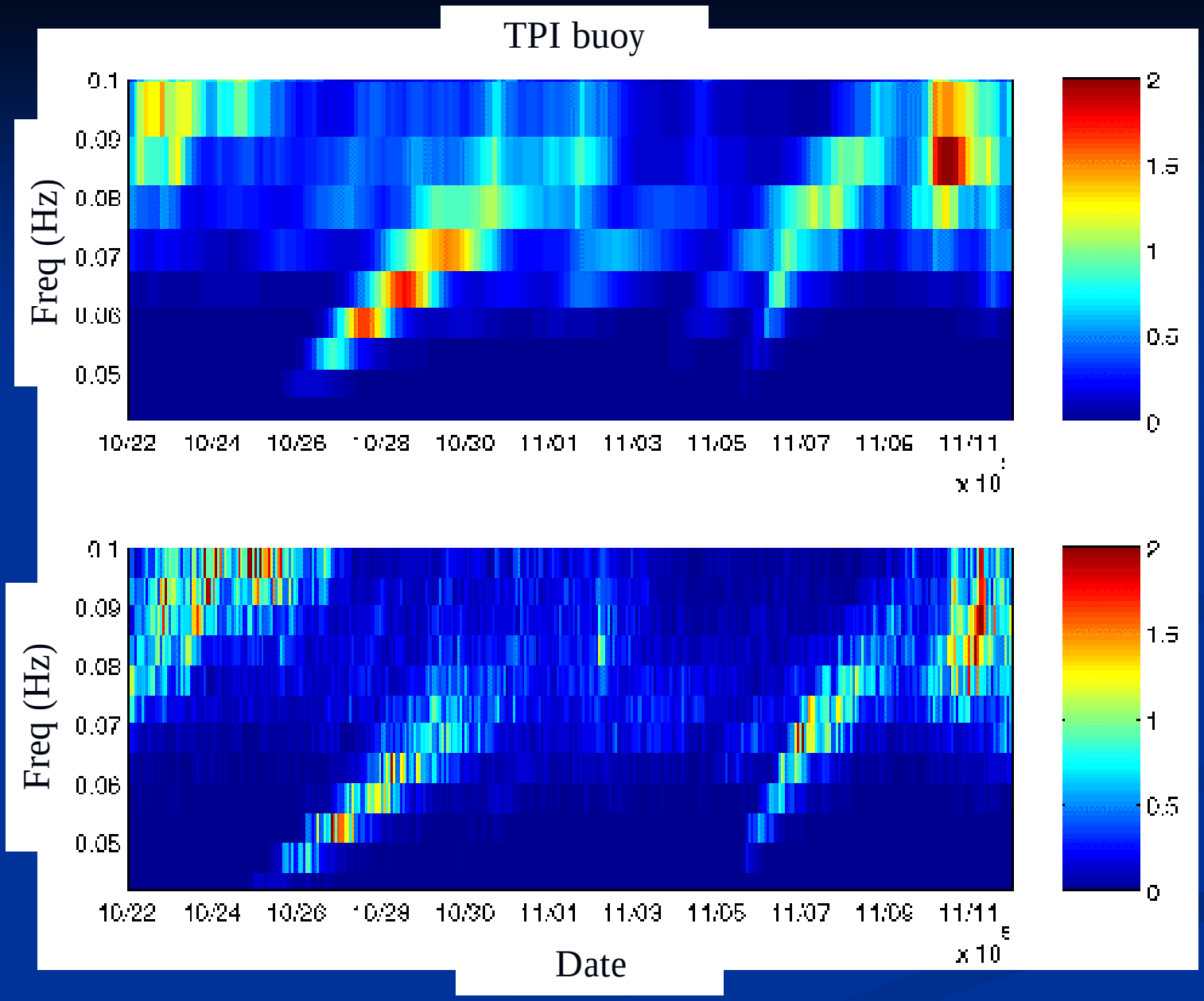
Oct 22 – Nov 8: study of swell forcing



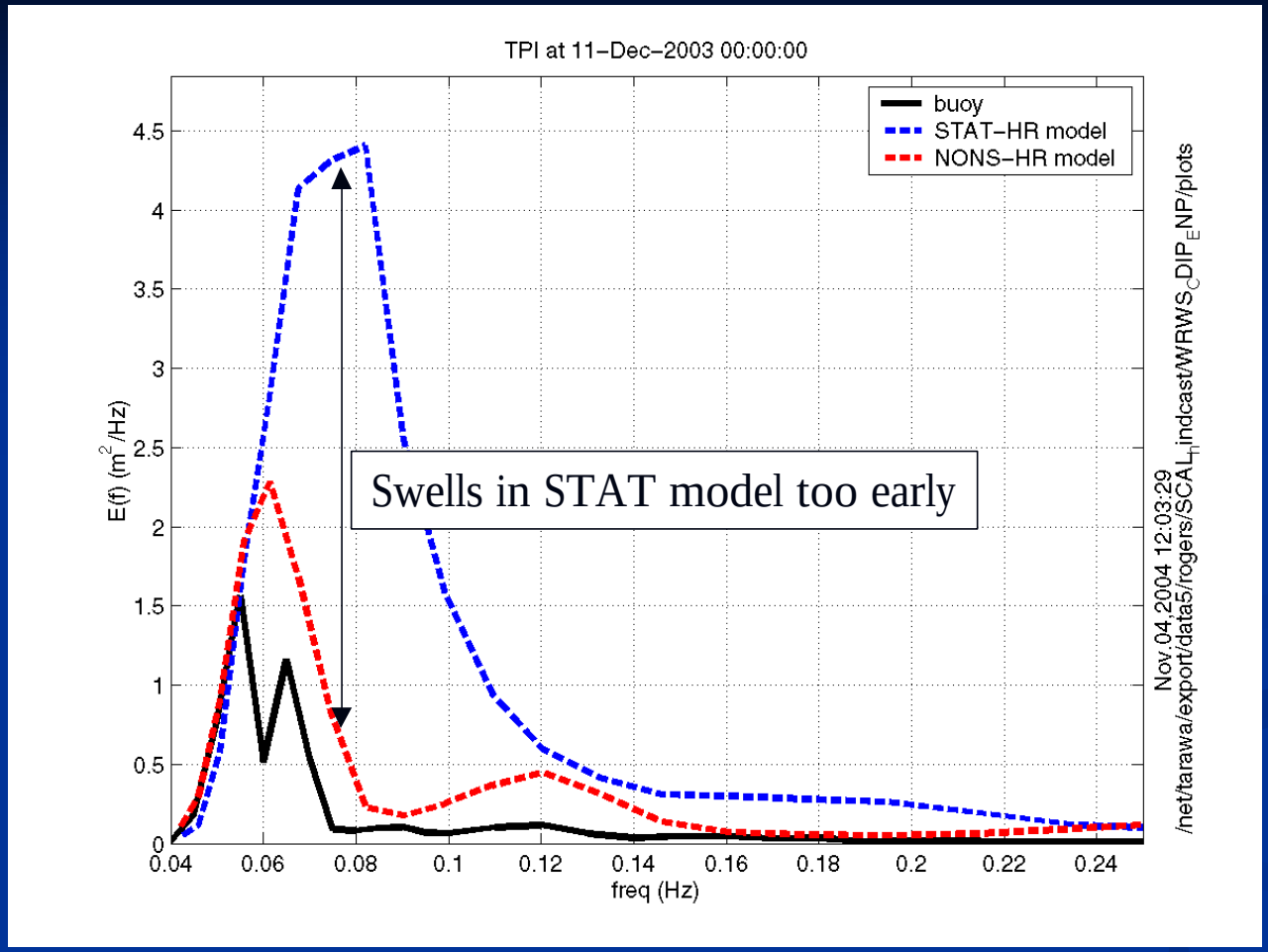
Oct 22 – Nov 8: study of swell forcing



Oct 22 – Nov 8: study of swell forcing



Oct 22 – Nov 8: study of swell forcing

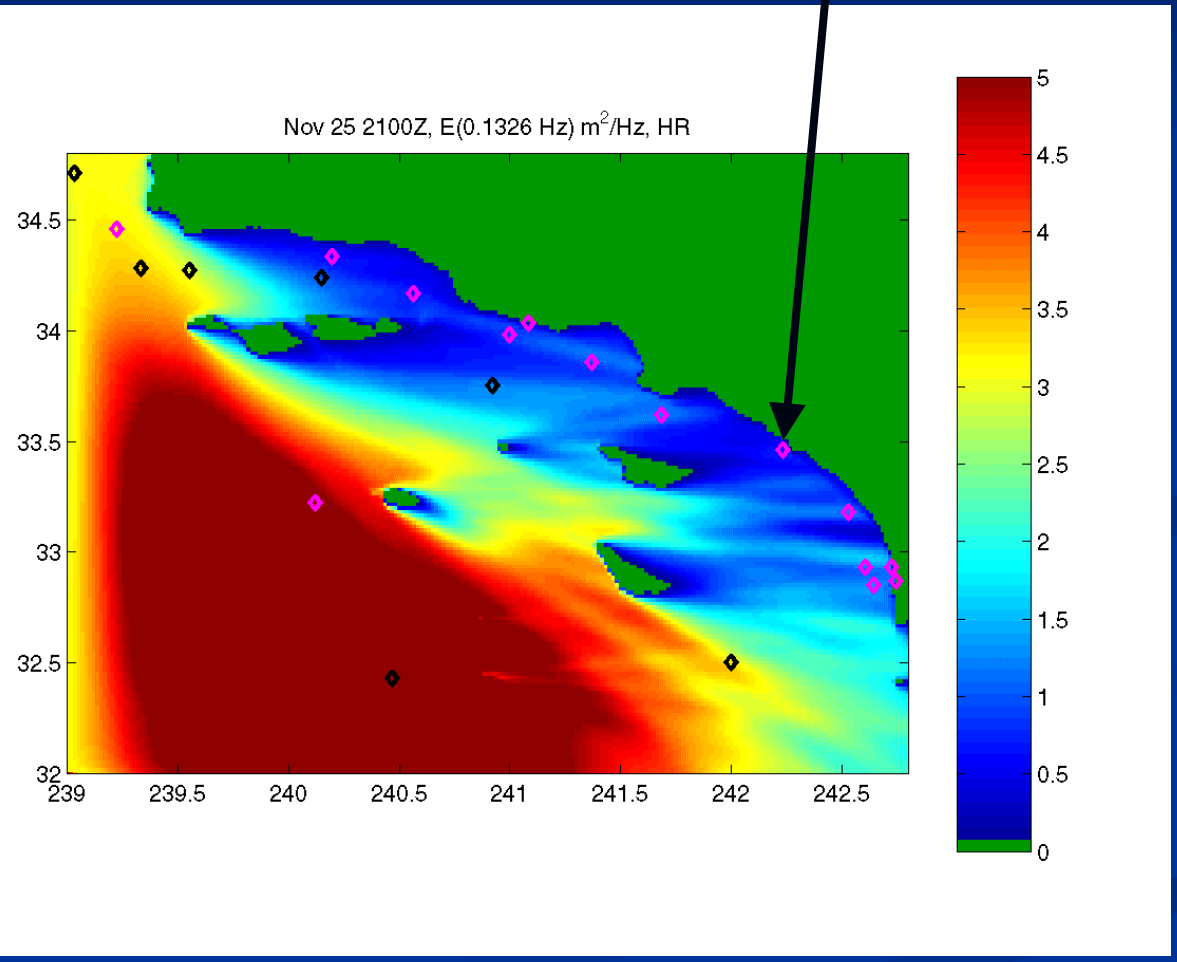


Omit this slide because wrong color scheme (STAT should be plotted red)

Dec 1-15 Case study: stationary assumption

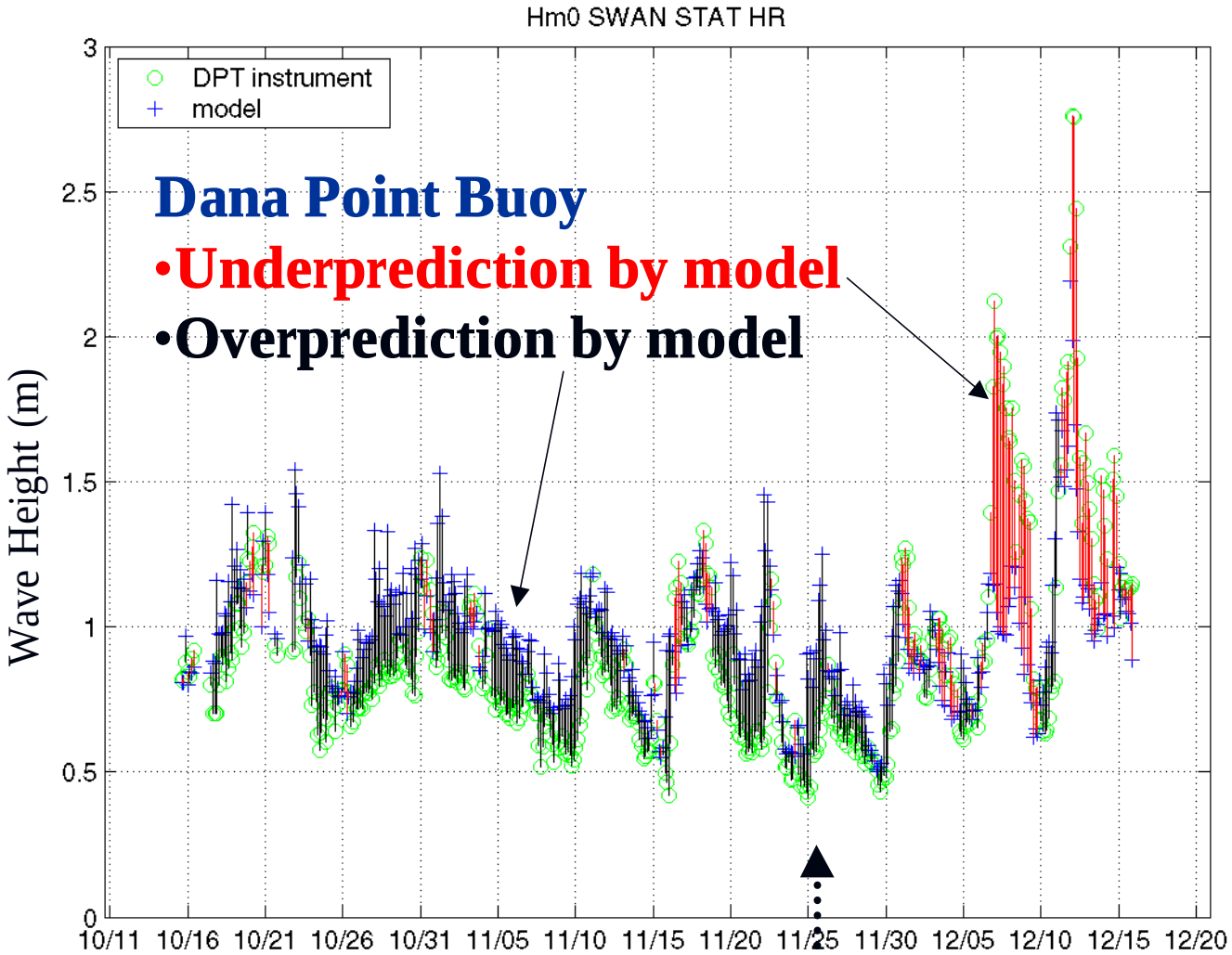
November 20-30 Case

Dana Point Buoy



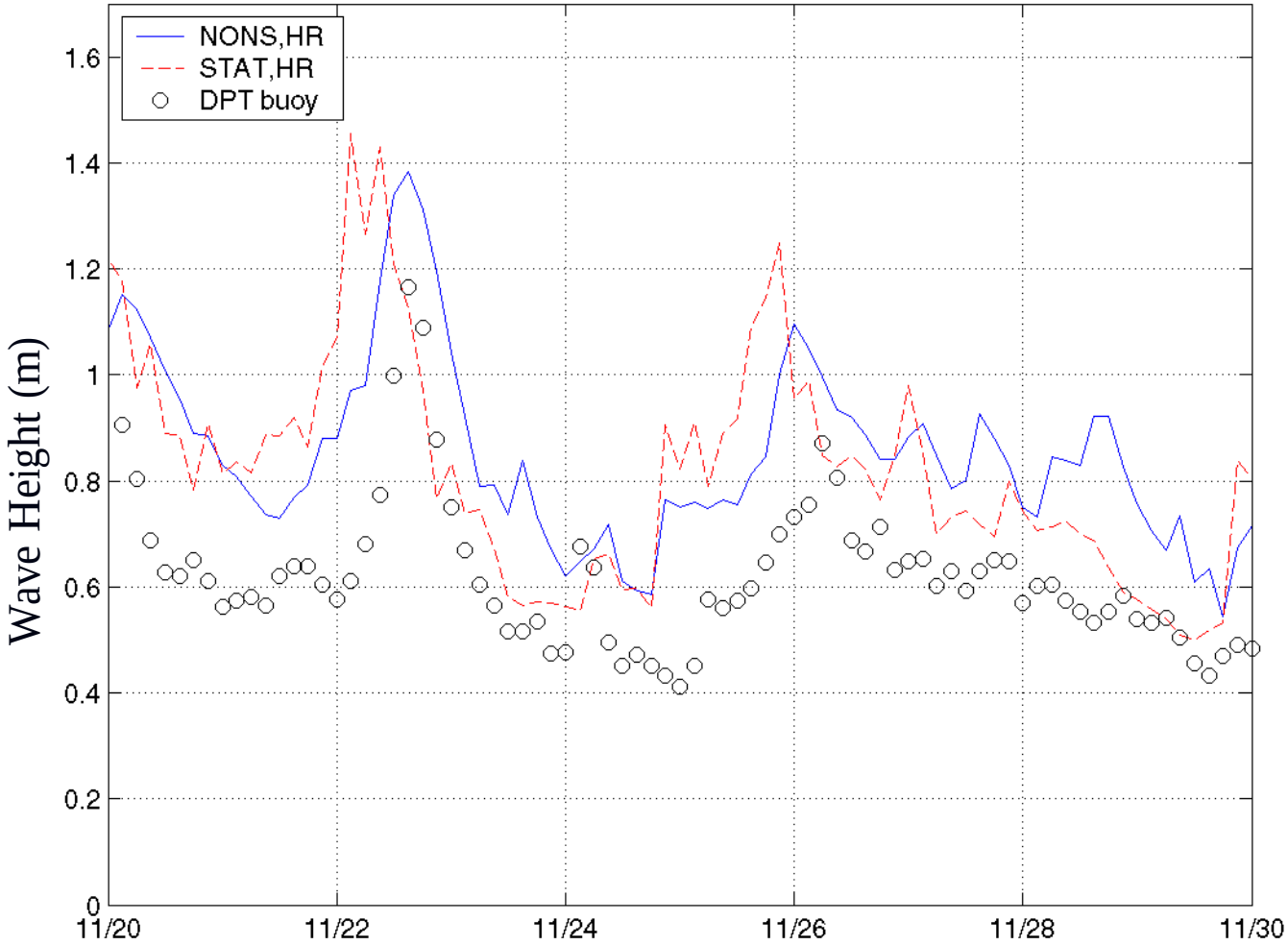
E(0.13Hz) shown (m^2/Hz) from stationary hindcast

Nov 20-30 Test Case: too much wind sea getting to nearshore areas



Study Nov. 25 2100Z in greater detail

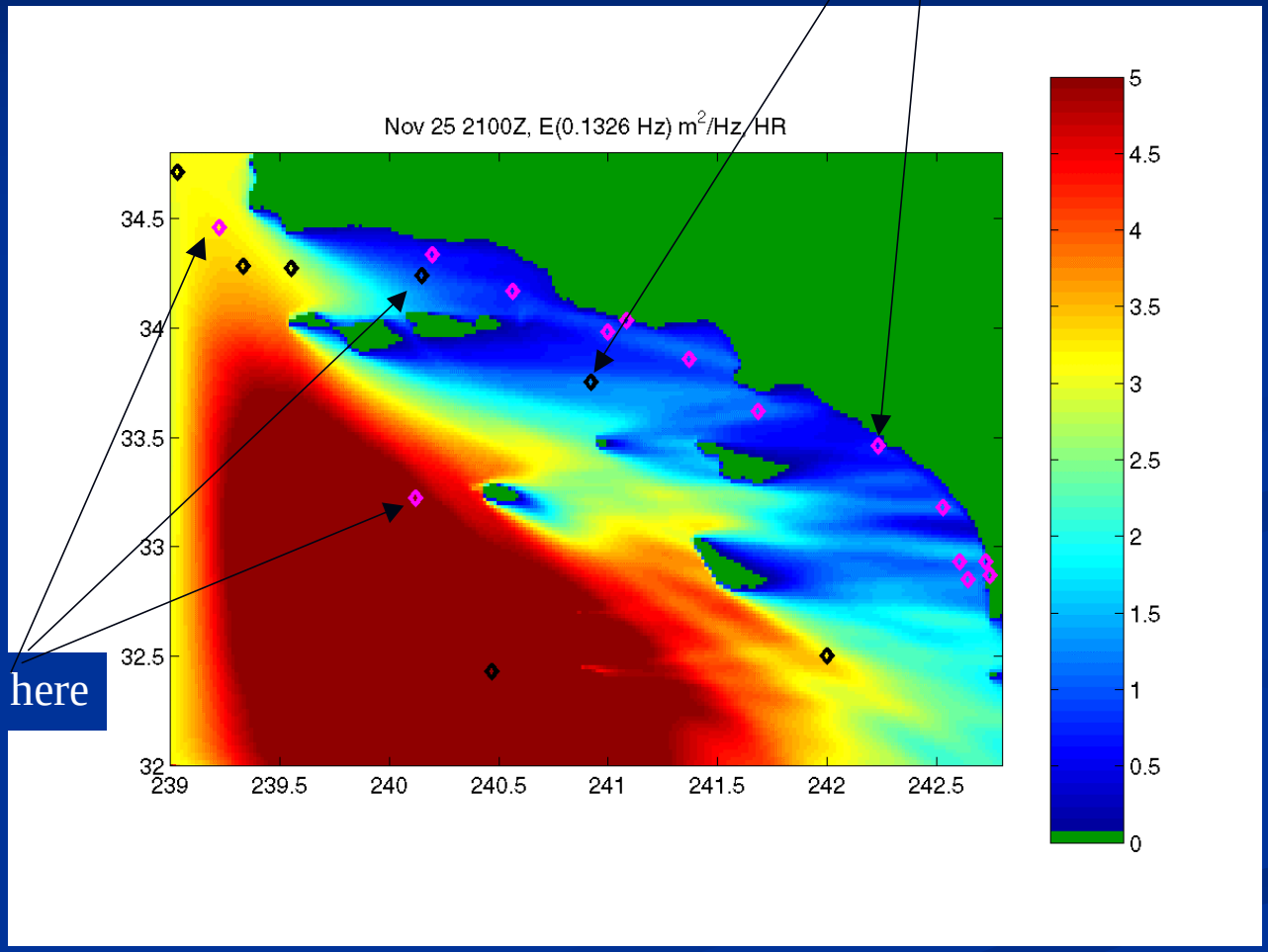
Nov 20-30 Test Case: too much wind sea getting to nearshore areas



Nov 20-30 Test Case: too much wind sea getting to nearshore areas

Positive bias with either mode of computation. Thus, we can use stationary model for diagnostics.

Overprediction here



Little or no bias here

E(0.13Hz) shown (m^2/Hz) from stationary hindcast

Nov 20-30 Test Case: too much wind sea getting to nearshore areas

Possible explanations for positive bias in Nov 20-30 case.

- Insufficient blocking by islands
  - Due to incorrect incident wave direction
  - Due to incorrect incident wave directional spreading
  - Due to inadequate resolution
- Not enough dissipation of short wave (0.13 Hz) energy

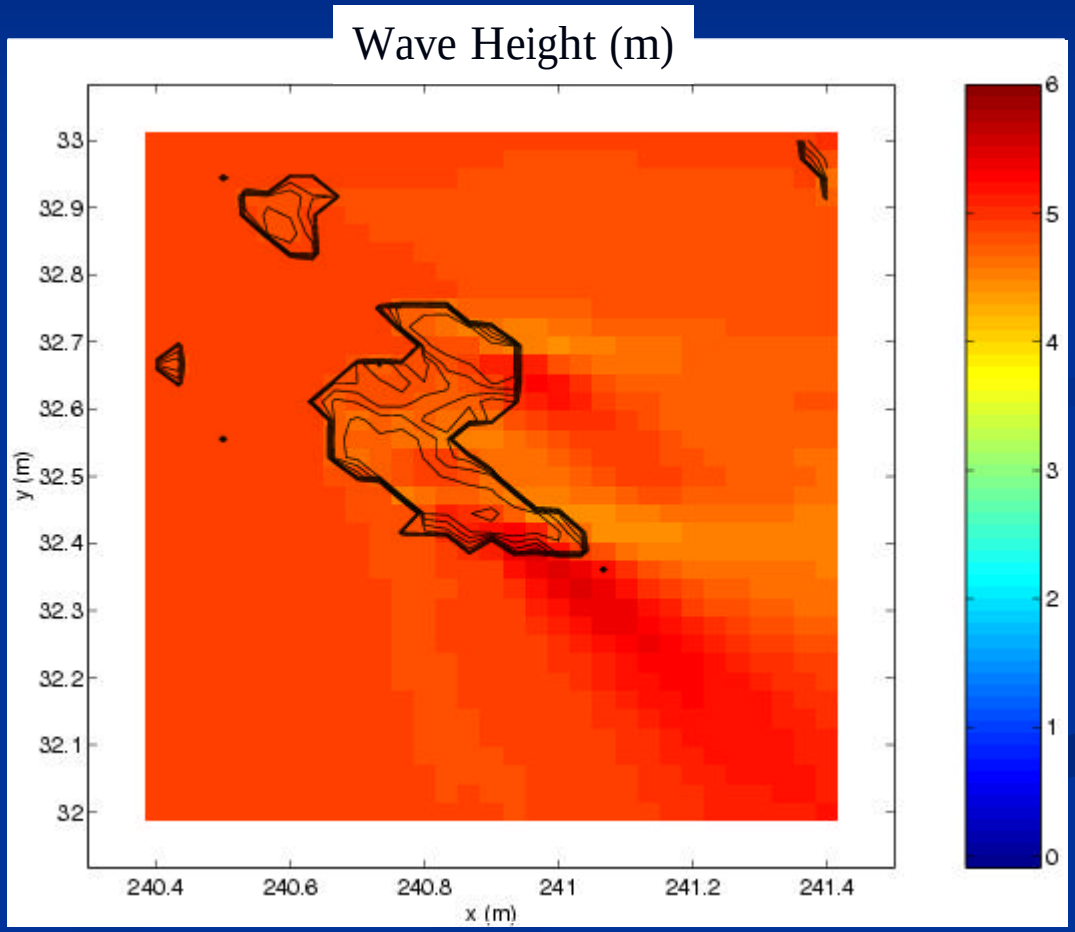
(Requires further study….)

End of slides for November 20-30 Case

Investigation of strange feature caused by refraction in SWAN

Numerics can be adjusted via a limiter on refraction: this limiter does not quite remove the artifact

- Limiter on refraction
  - CDLIM=1.5
- Resolution:
  - nx=31
  - ny=37
  - nq=36

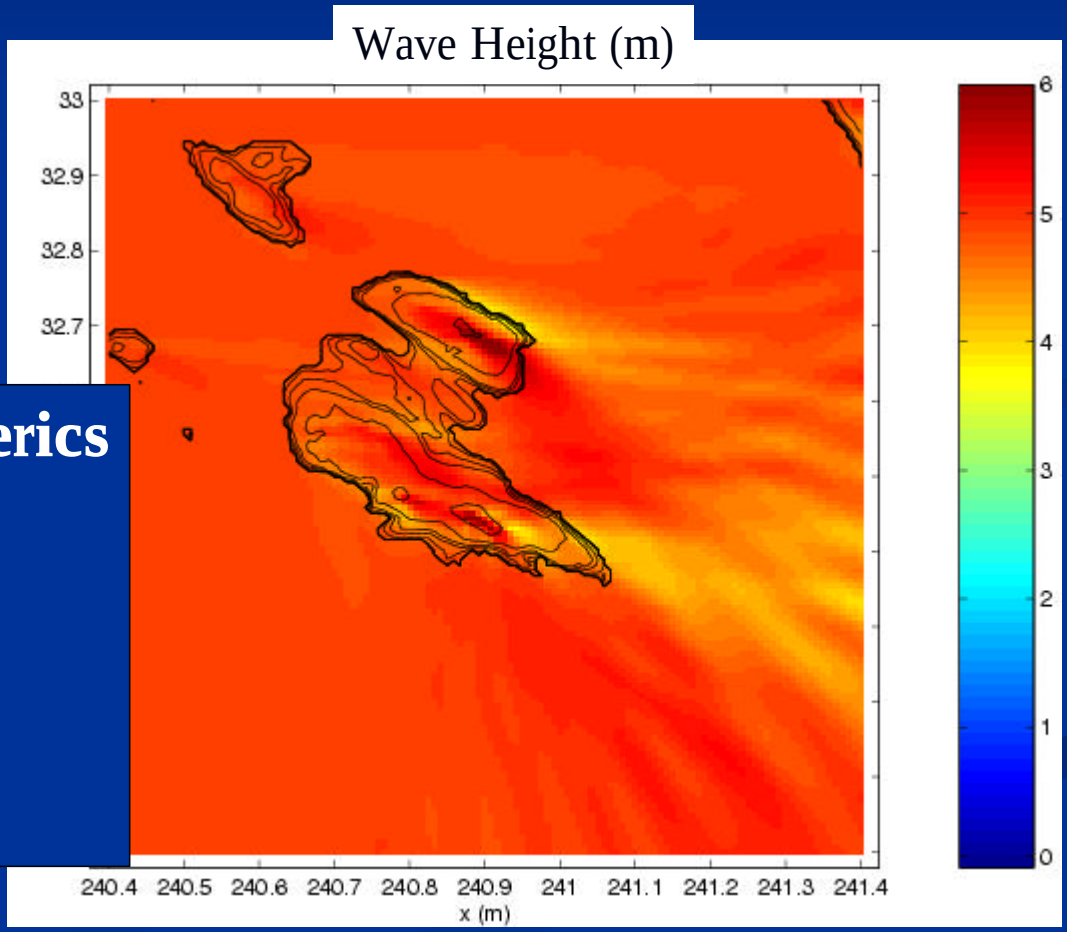


Refraction in SWAN

Investigation of strange feature caused by refraction in SWAN

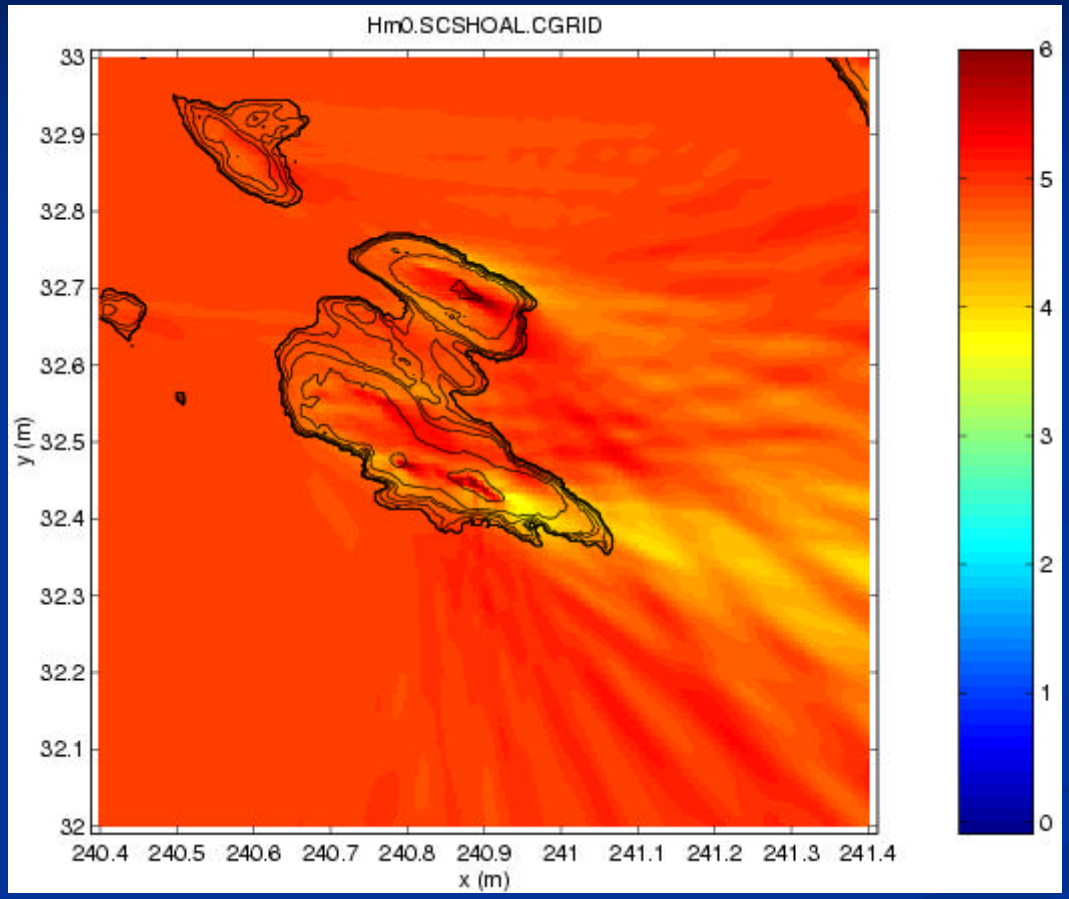
Can correct using high geographic resolution, but garden sprinkler effect becomes apparent.

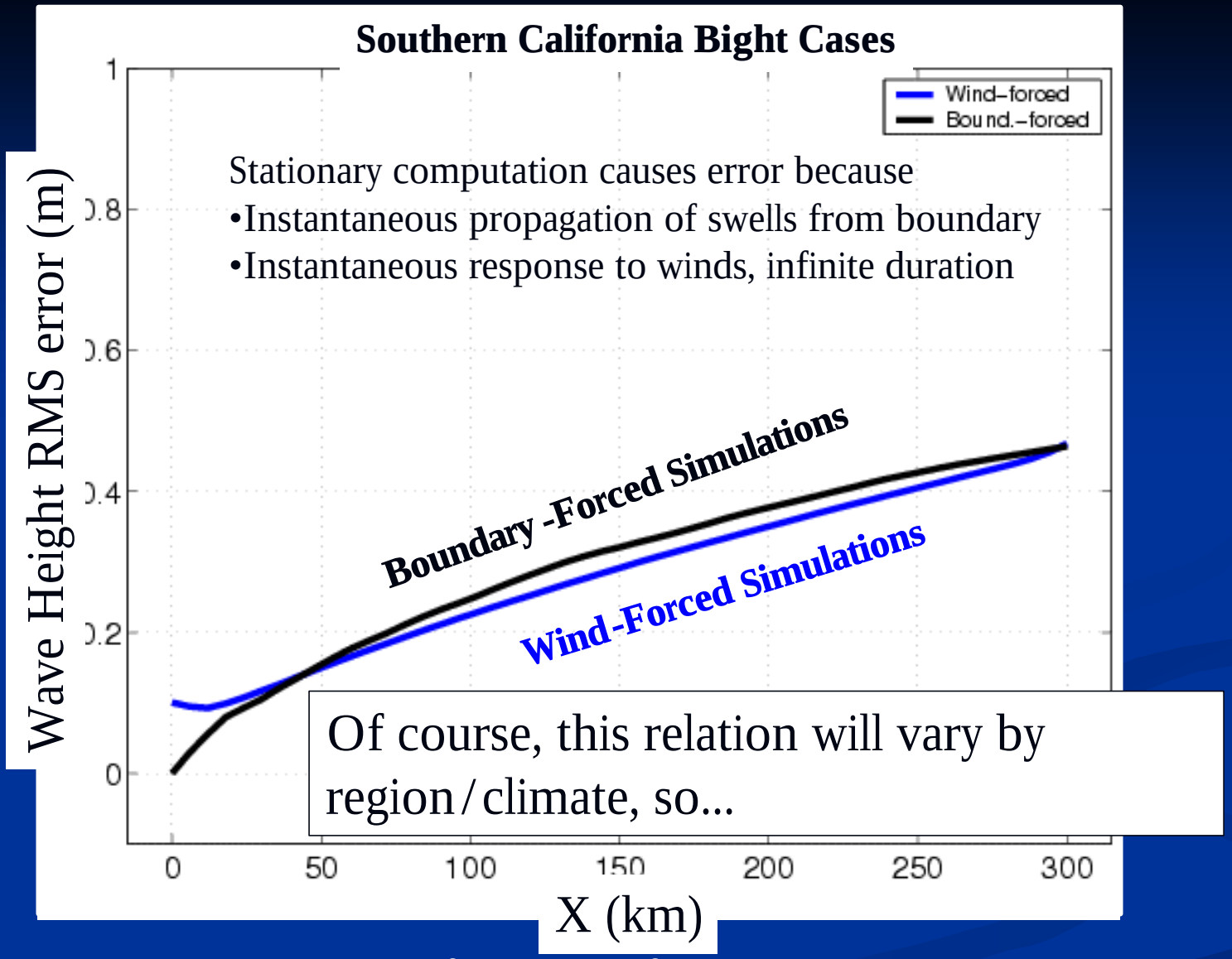
- Default settings for numerics
- Refraction back on
- Resolution:
  - nx=121
  - ny=145
  - nq=36



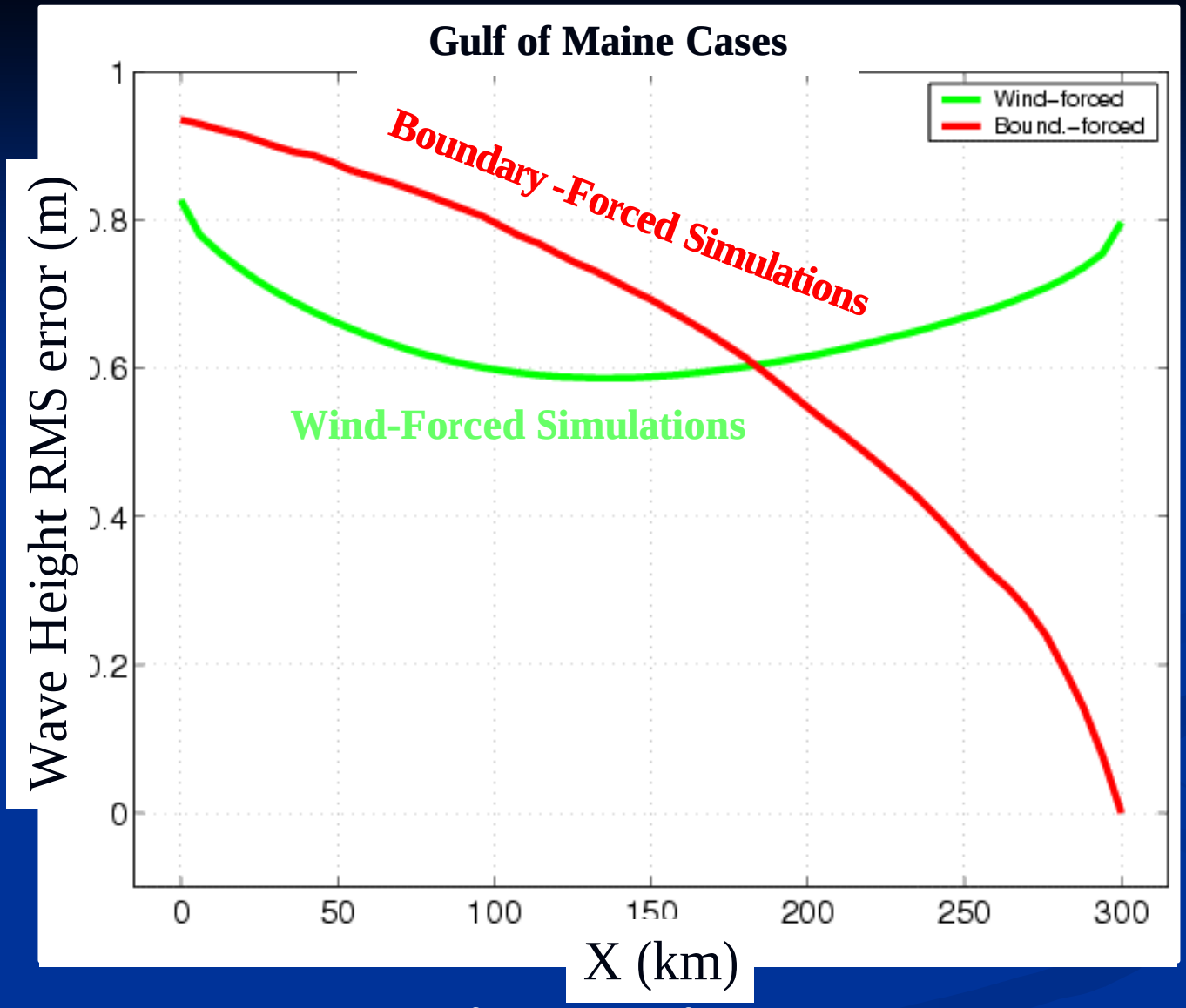
Refraction in SWAN

240x288x36 case (not included above)

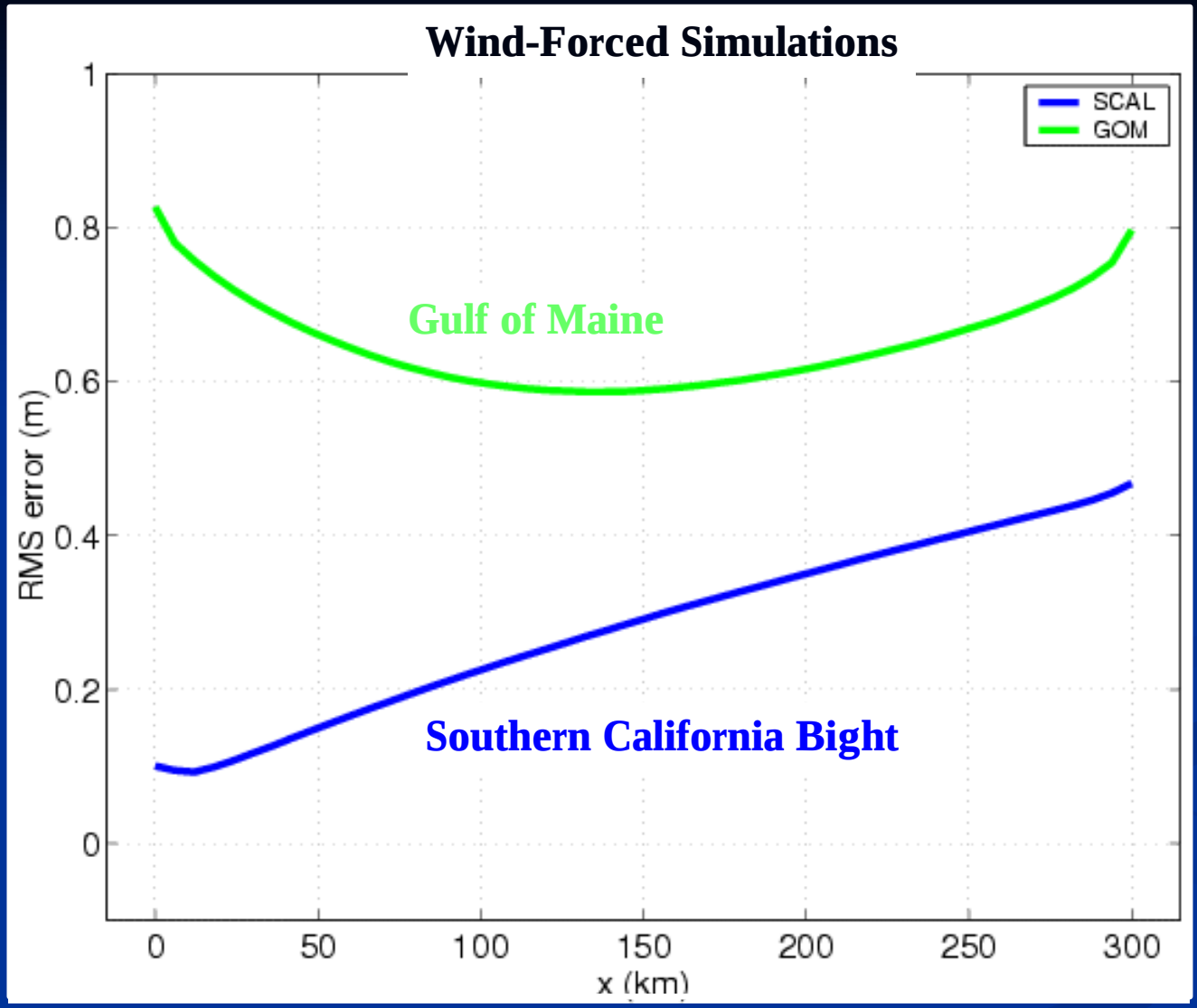




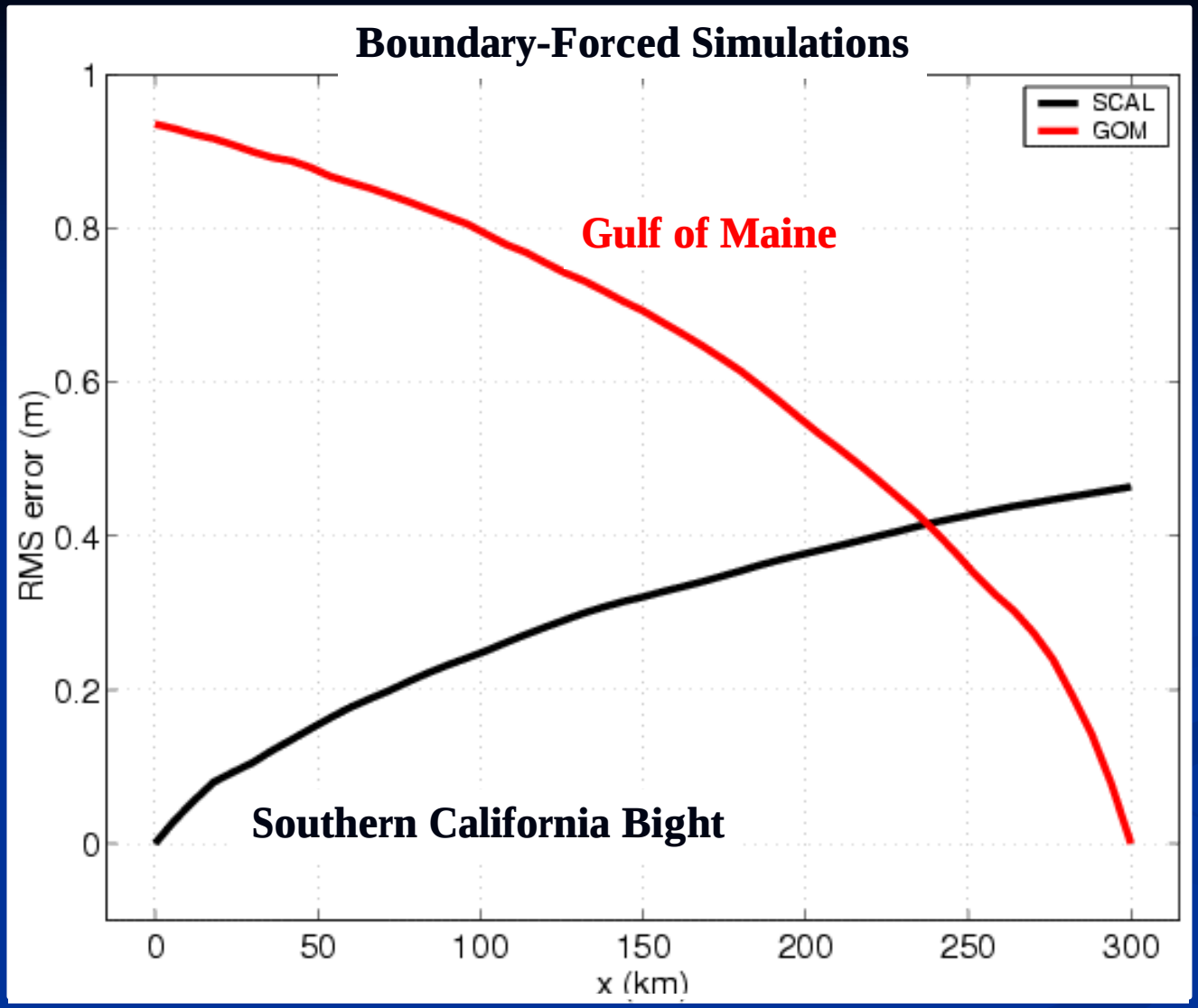
Wave height RMS error computations for the wind-forced idealized simulation with stationary computations (simulation with nonstationary computations are taken as ground truth). Cases with forcing corresponding to the Southern California Bight are shown.



Wave height RMS error computations for the wind-forced idealized simulation with stationary computations (simulation with nonstationary computations are taken as ground truth). Cases with forcing corresponding to the Gulf of Maine are shown.



Wave height RMS error computations for the wind-forced idealized simulation with stationary computations (simulation with nonstationary computations are taken as ground truth). Cases with wind forcing are shown.



Wave height RMS error computations for the boundary-forced idealized simulation with stationary computations (simulation with nonstationary computations are taken as ground truth). Cases with boundary forcing are shown.

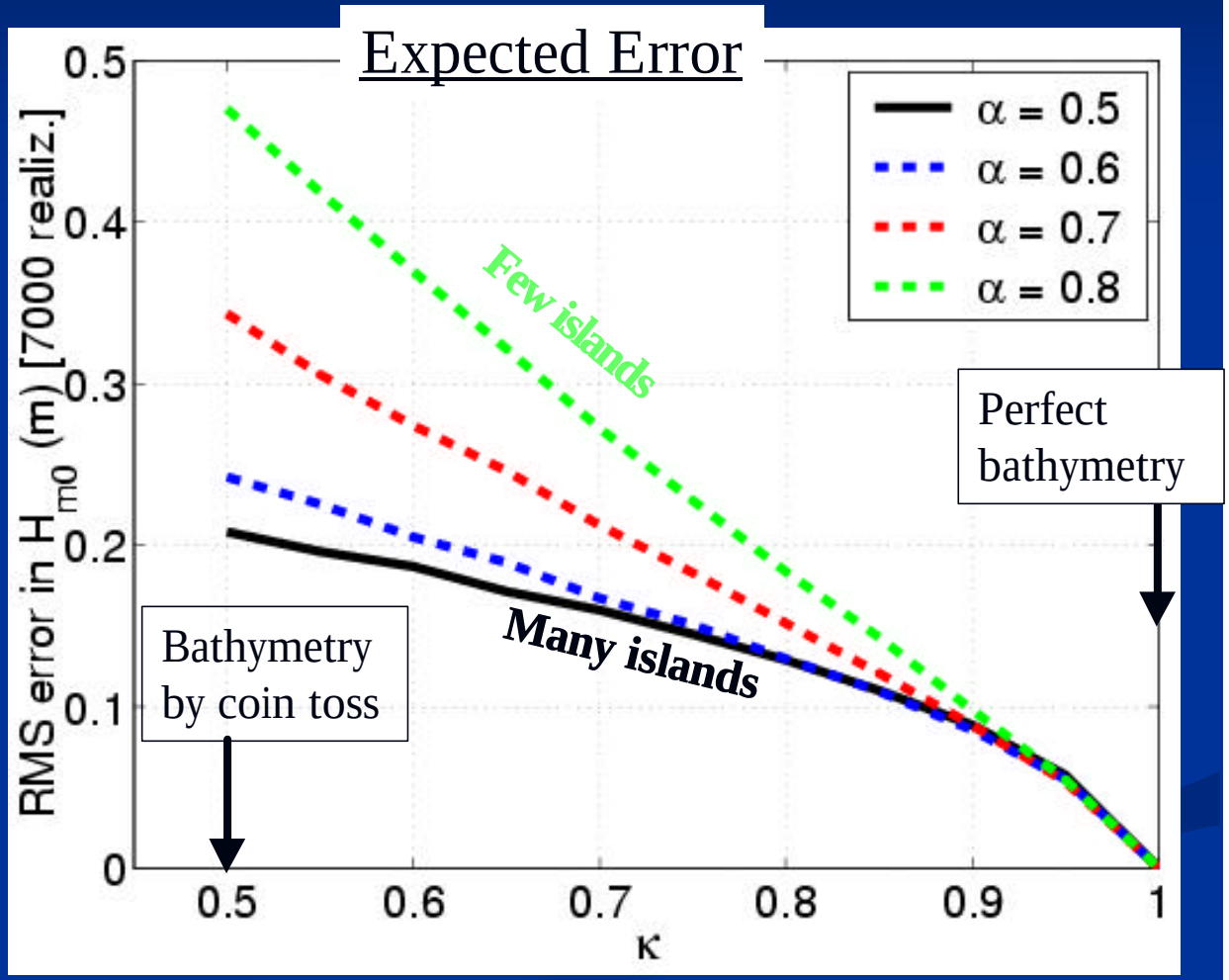
Representing the blocking of wave energy by islands, etc.: The impact of geographic resolution

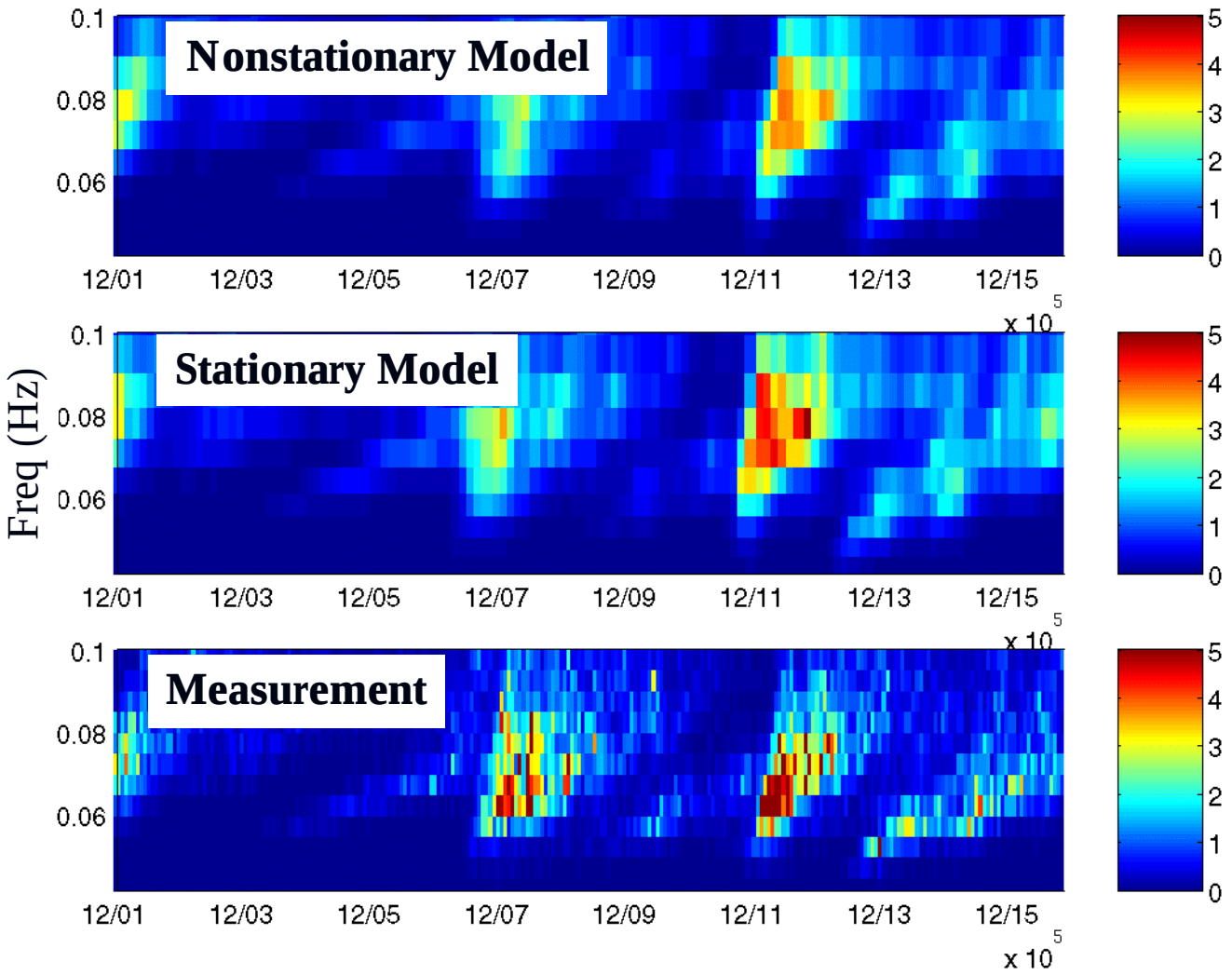
We can simplify problem such that for a given route of wave energy traveling through a region with islands/shoals, there are 4 possible scenarios:

	Energy is blocked in real world	Energy is not blocked in real world
Energy is blocked in wave model	Model is correct	Model is wrong
Energy is not blocked in wave model	Model is wrong	Model is correct

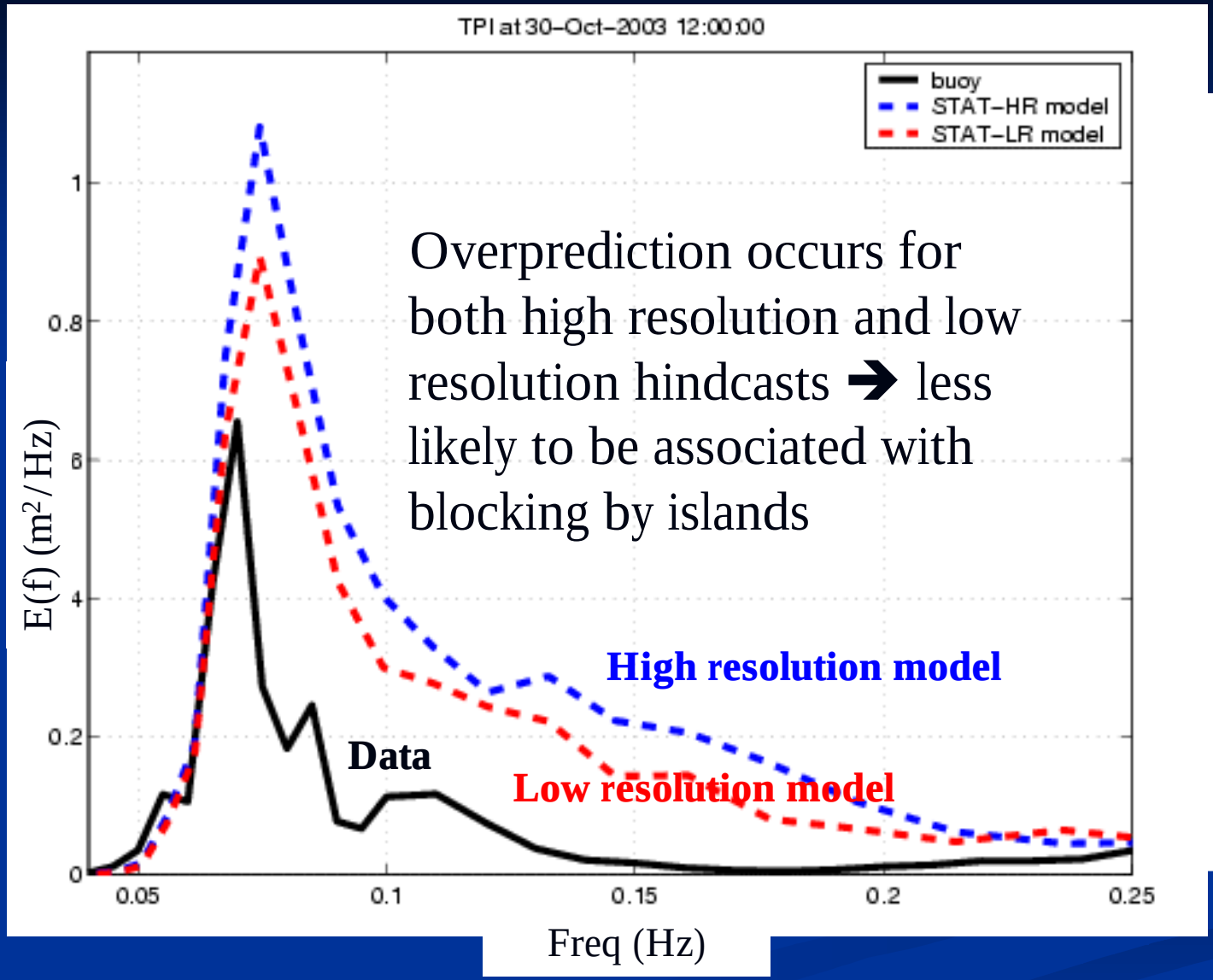
Representing the blocking of wave energy by islands, etc.: The impact of geographic resolution

- For a single geographic location, "route" is defined by direction of approach
- Problem is then simply a function of
  - permeability α
  - and accuracy κ, the probability that a given "route" is correctly represented
- 7000 realizations with spectra from CDIP buoy 071
- Random number generator to determine which of 4 scenarios occurs

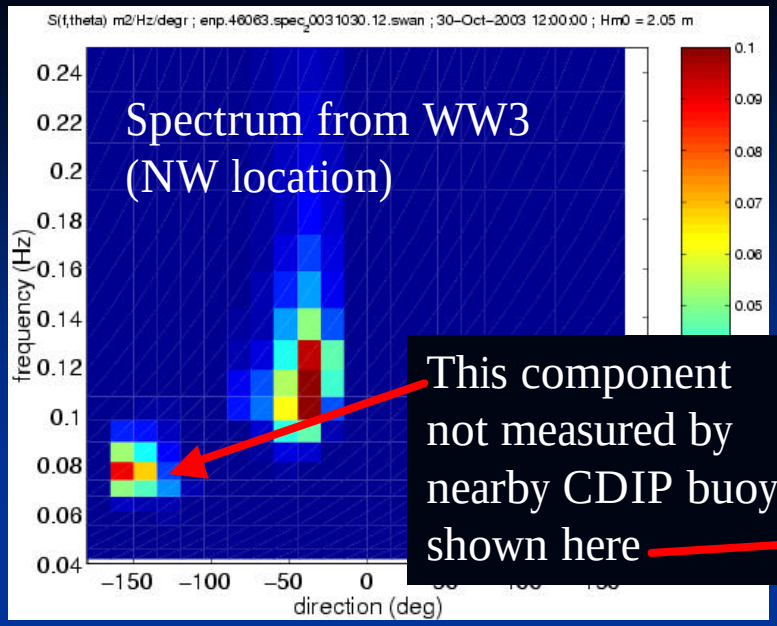


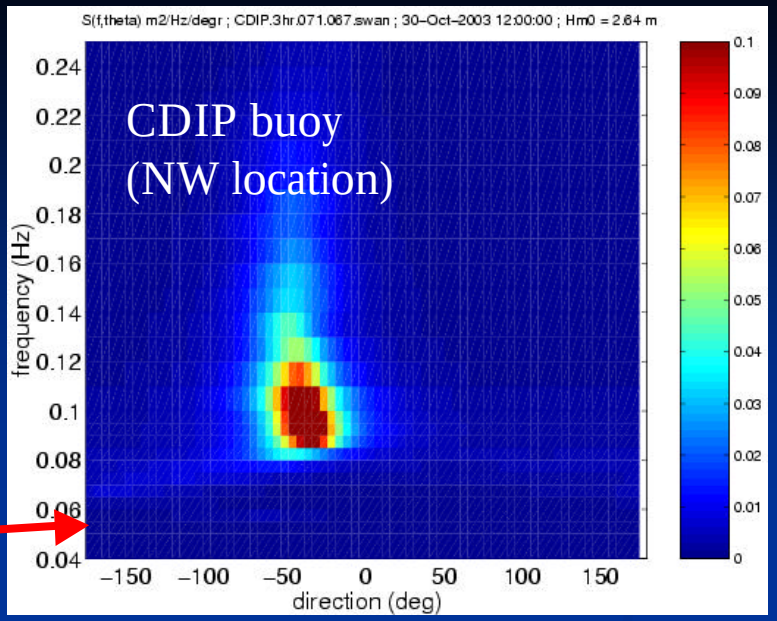


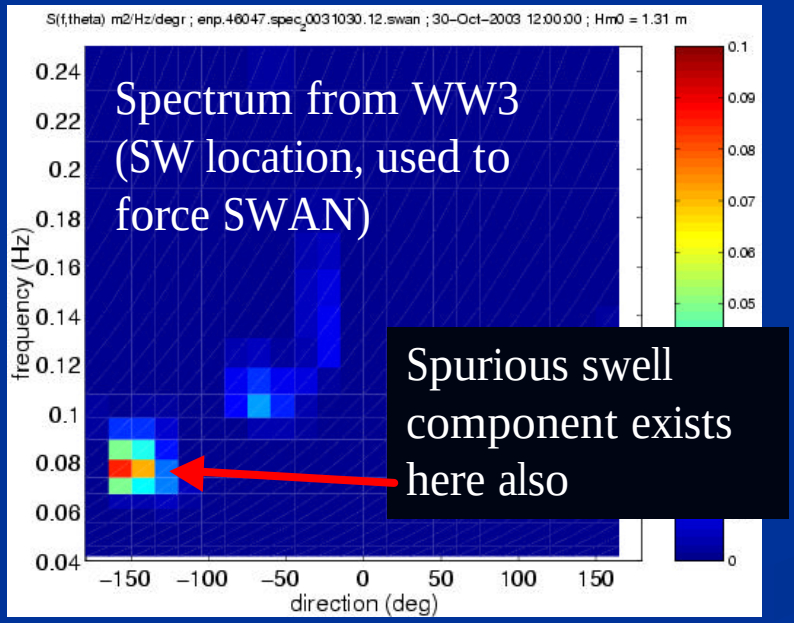
Dec 1-15 Case study: stationary assumption



Oct 22 – Nov 8: study of swell forcing



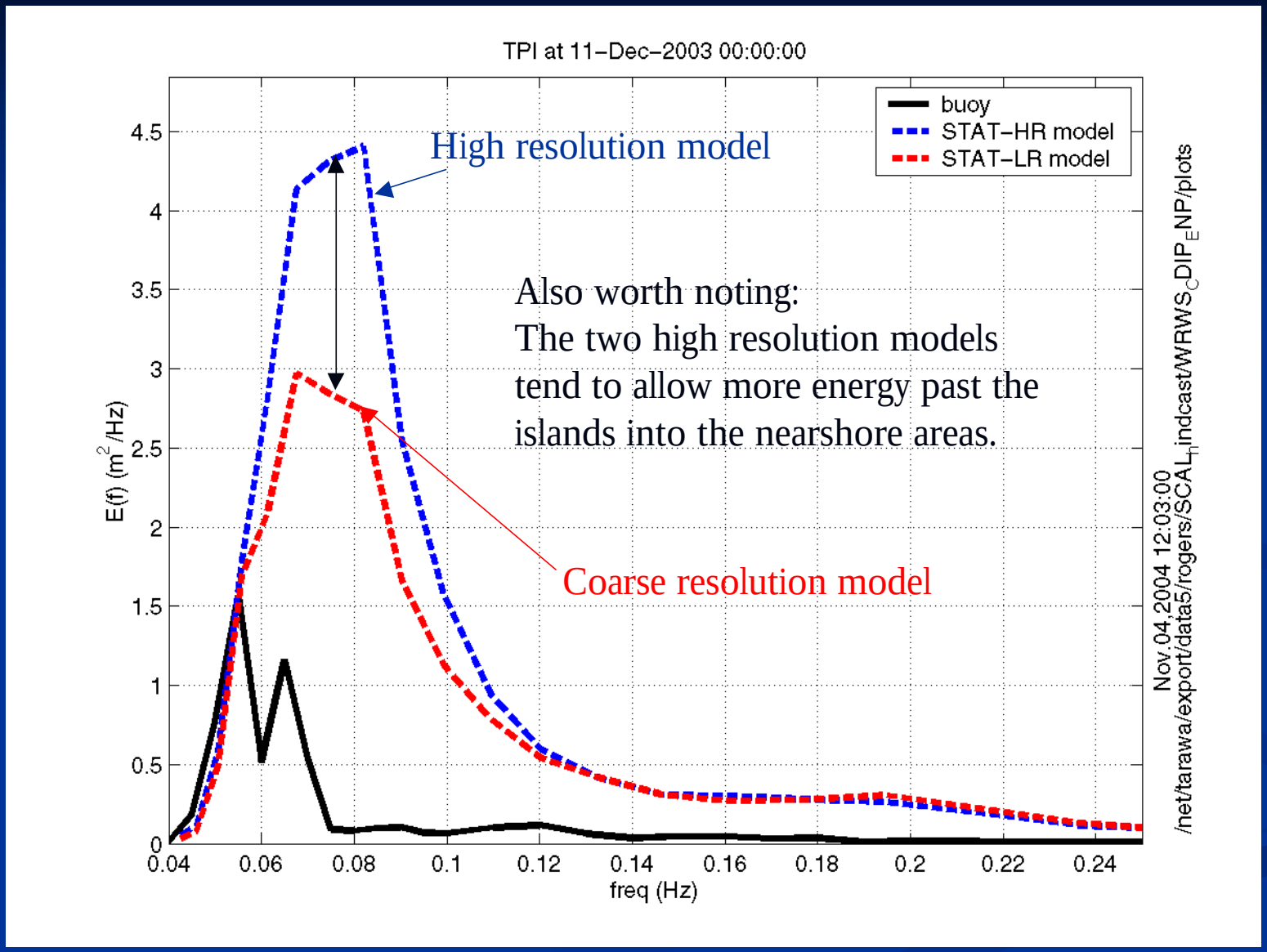




Spurious swell from southwest exists in the boundary forcing from WW3 ENP model

Oct 22 – Nov 8: study of swell forcing

Example result at a nearshore location

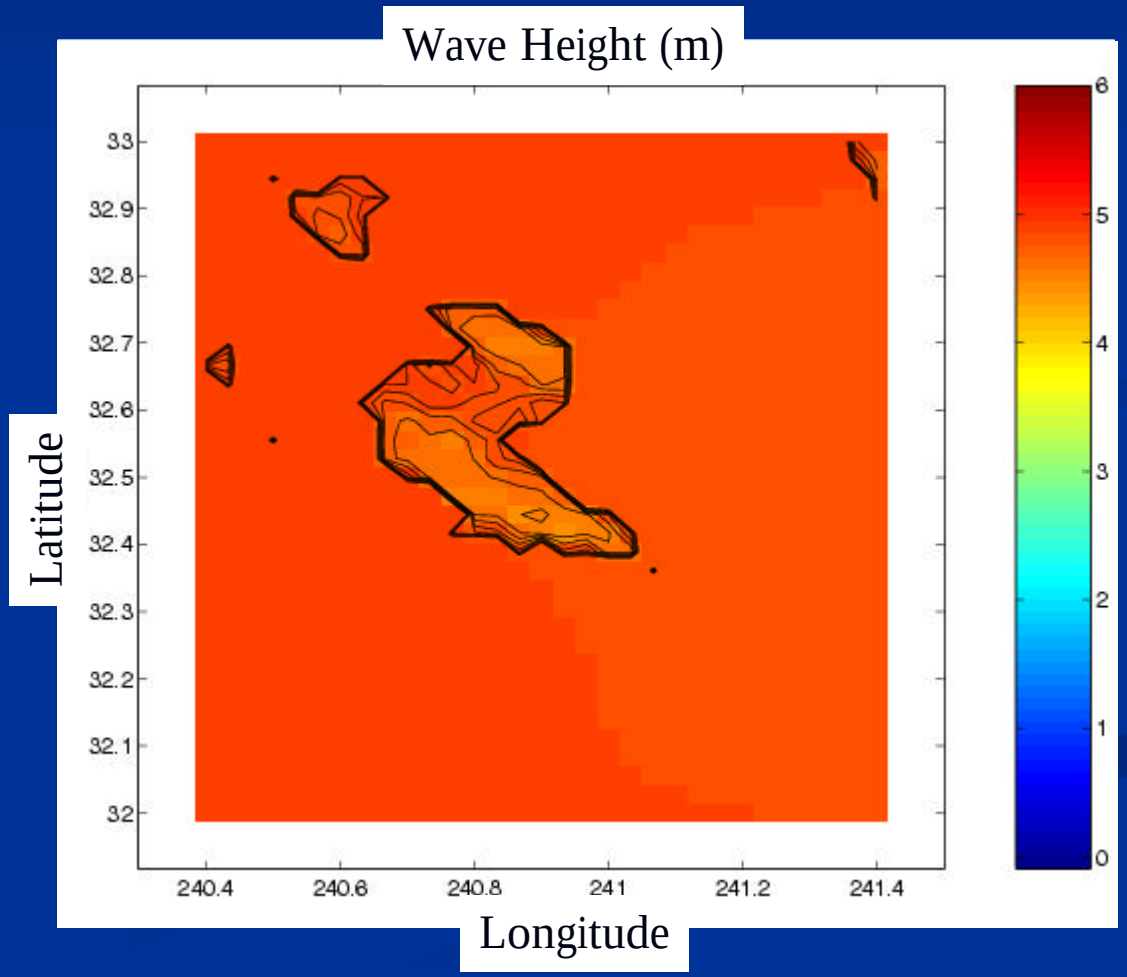


Dec 1-15 Case study: impact of resolution

Investigation of strange feature

...It is apparently caused by refraction:

- **Refraction disabled**
- **Resolution:**
  - **nx=31**
  - **ny=37**
  - **nq=36**



Investigation of strange feature caused by refraction in SWAN

Correct garden sprinkler effect using high directional resolution: this simulation can then be used as a “ground truth” case for adjusting numerics

Longitude

Investigation of strange feature caused by refraction in SWAN

…