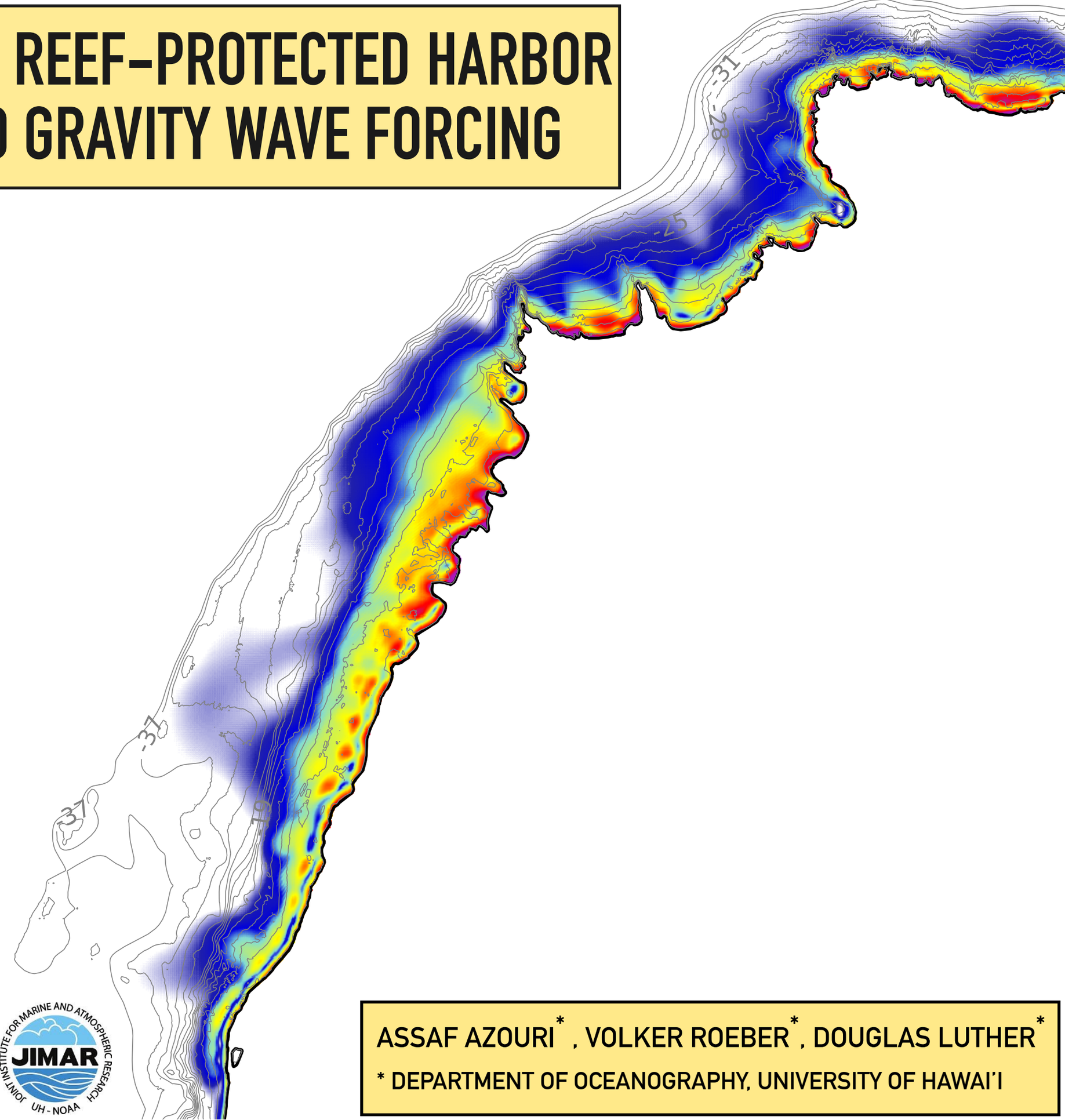
THE RESPONSE OF REEF-PROTECTED HARBOR ENVIRONMENTS TO GRAVITY WAVE FORCING



ASSAF AZOURI*, VOLKER ROEBER*, DOUGLAS LUTHER*

* DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY OF HAWAI'I

PacIOOS
Pacific Islands Ocean Observing System

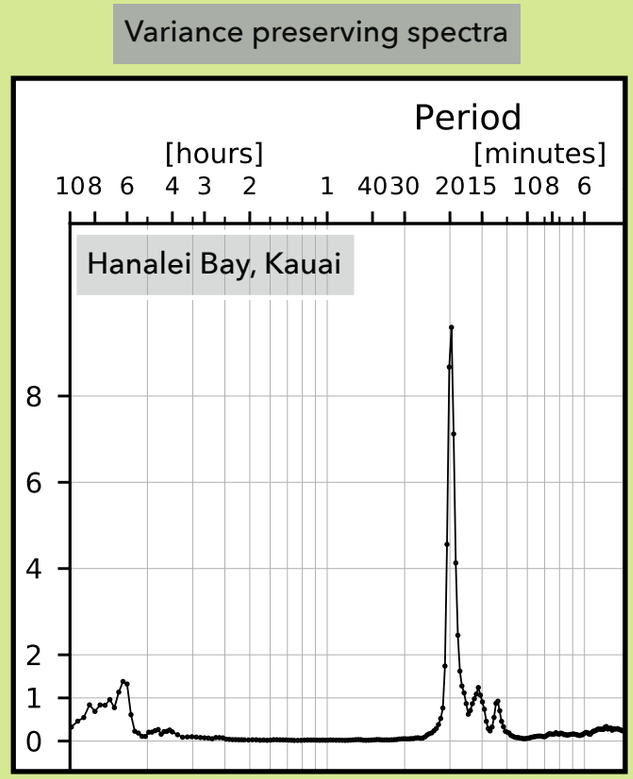
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

JIMAR
JOINT INSTITUTE FOR MARINE AND ATMOSPHERIC RESEARCH
UH - NOAA

MOTIVATION

- Wave-driven runup, inundation, erosion, and harbor surges, greatly depend on infragravity (IG) waves.

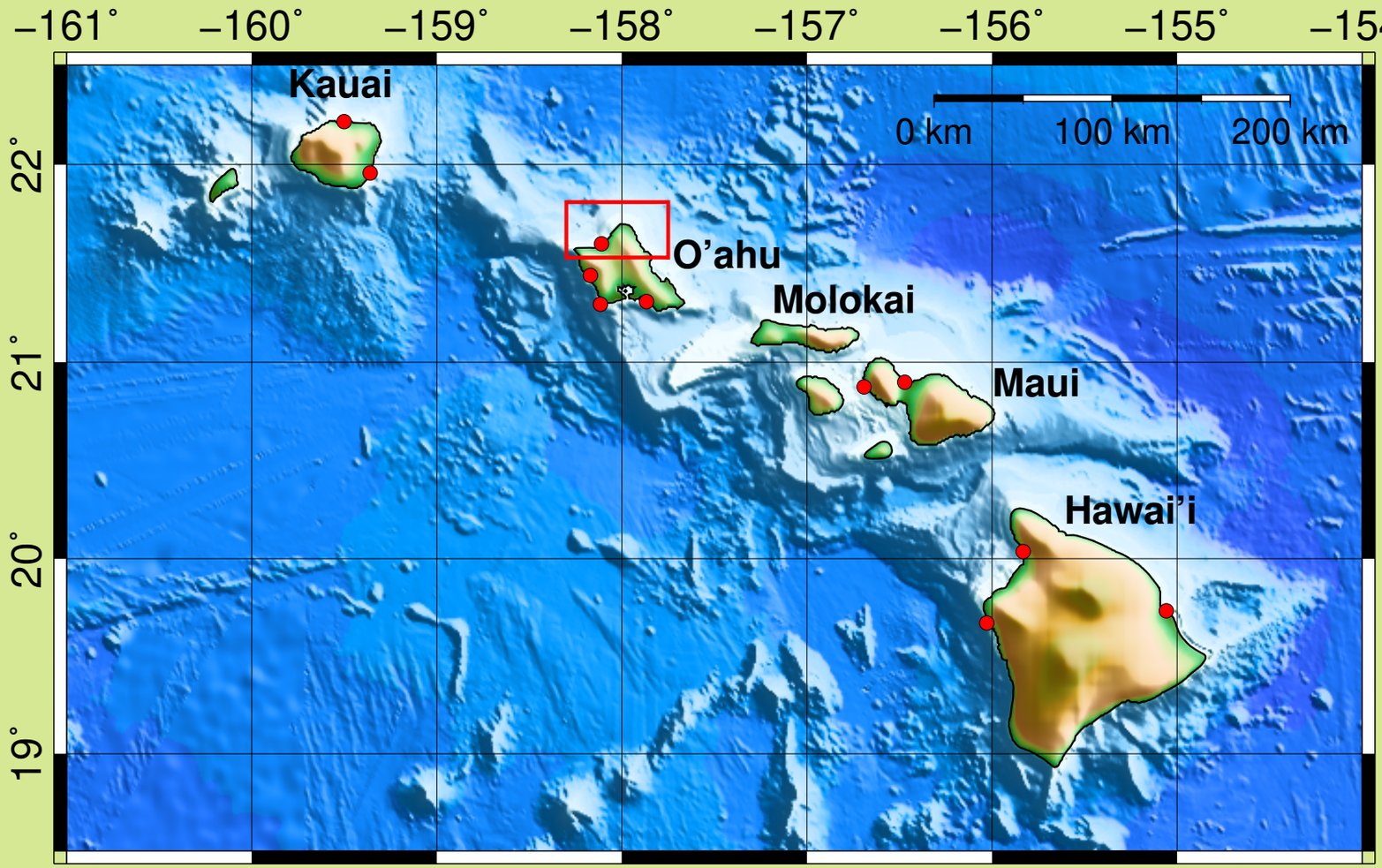
- The near-coast IG variability excited by tsunamis, sea/swell (SS) waves, etc., is often dominated by coastal & harbor resonances.



- Observations (SL):
  - Identify coastline & harbor response to weak/ strong forcing (primarily swell, but not only).
  - Is harbor dynamics affected by coastal dynamics?

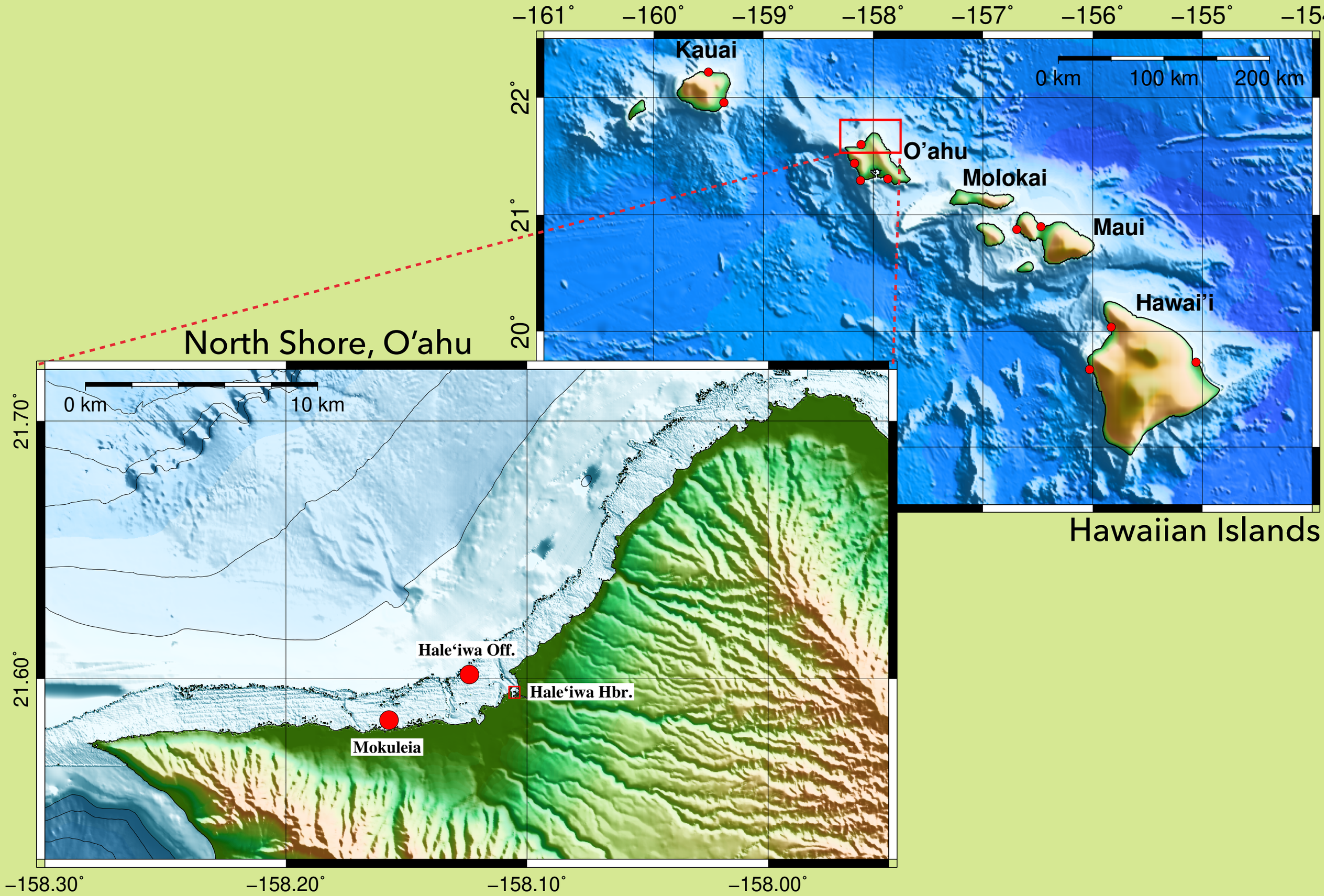
- Phase-Resolving Numerical Modeling:
  - Test ability of models to replicate the observed response under SS forcing.
  - Determine the spatial distribution of energy within the domain.

STUDY REGION: NORTH SHORE, O'AHU

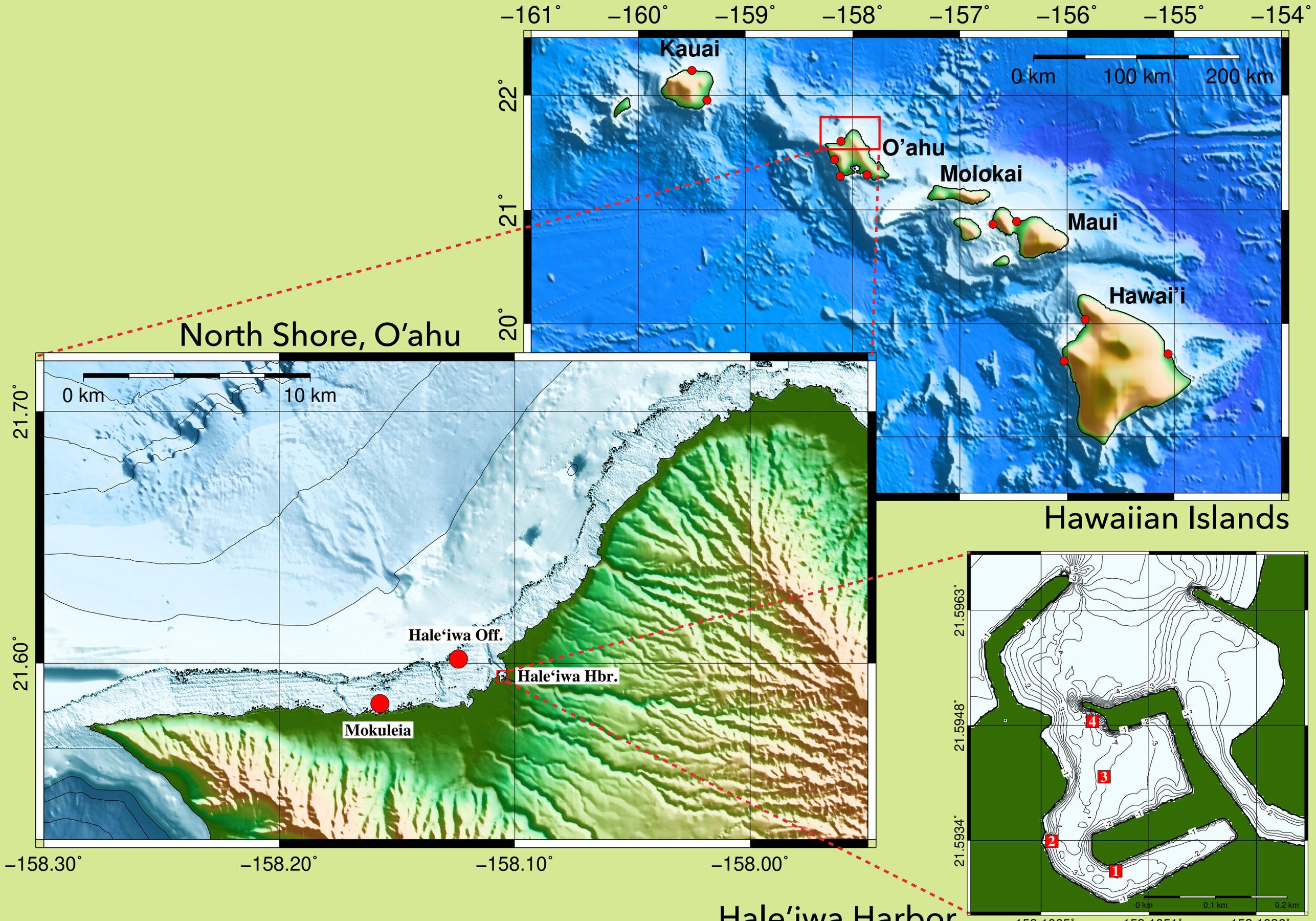


Hawaiian Islands

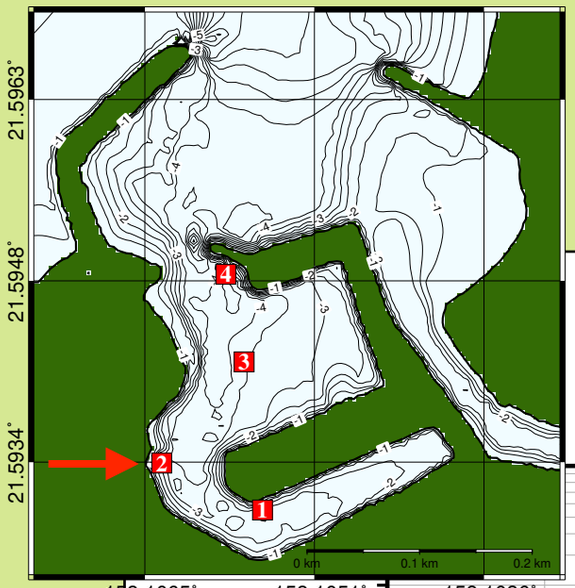
STUDY REGION: NORTH SHORE, O'AHU

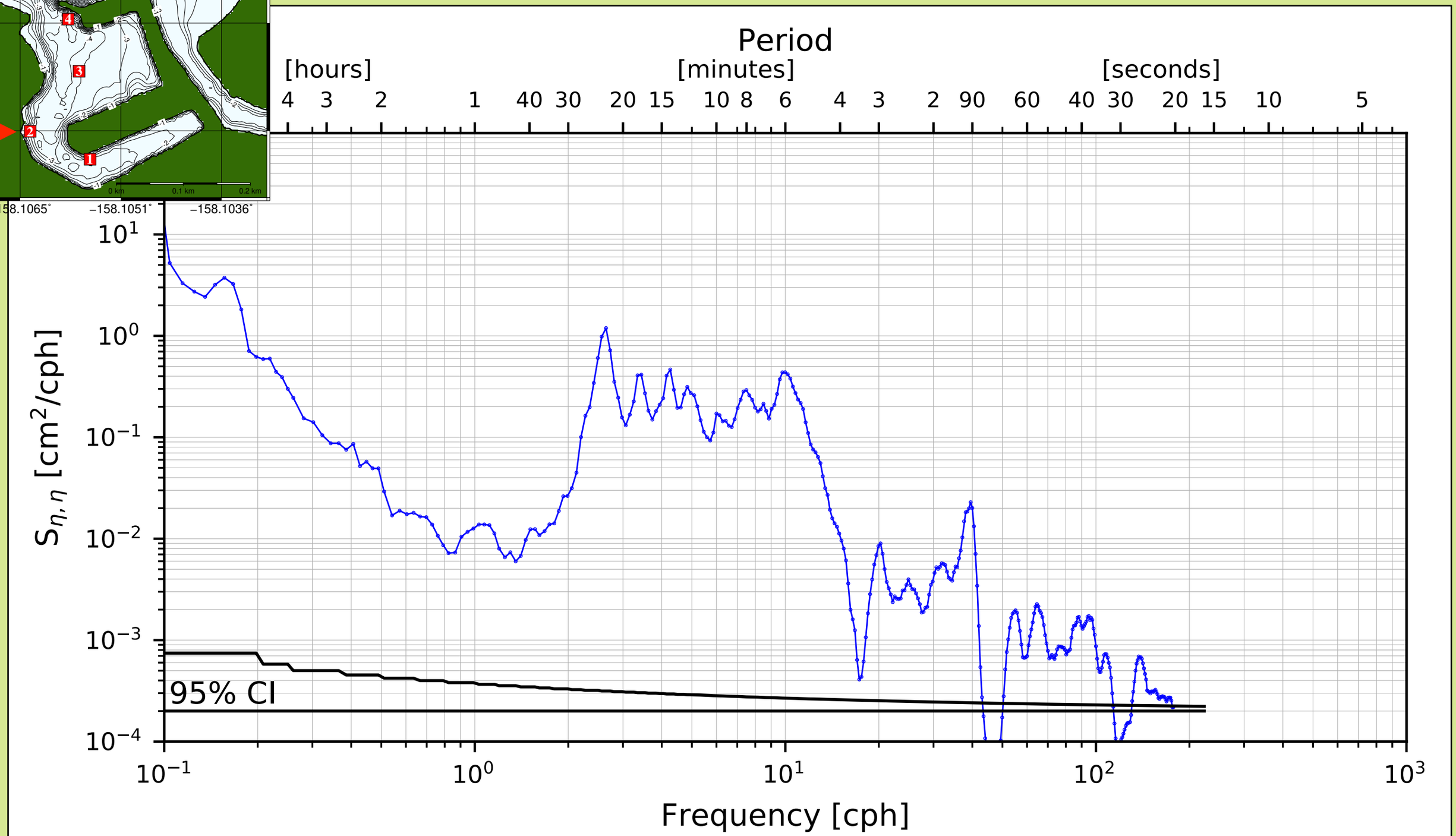


STUDY REGION: NORTH SHORE, O'AHU

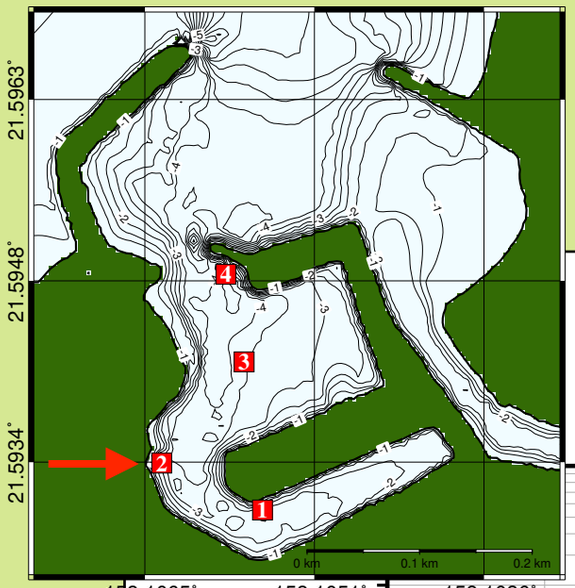


RESPONSE TO WEAK SS FORCING





RESPONSE TO WEAK SS FORCING



Period

[hours] [minutes] [seconds]

4 3 2 1 40 30 20 15 10 8 6 4 3 2 90 60 40 30 20 15 10 5

$S_{\eta,\eta}$ [cm^2/cph]

10^1 10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4}

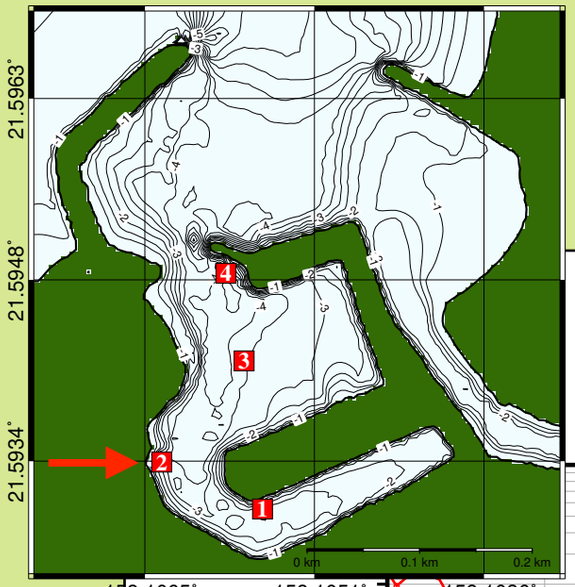
23 18 14 12.5 10 8 6 3 90 65 55

95% CI

10^{-1} 10^0 10^1 10^2 10^3

Frequency [cph]

RESPONSE TO WEAK VS. STRONG SS FORCING



Period

[hours] [minutes] [seconds]

4 3 2 1 40 30 20 15 10 8 6 4 3 2 90 60 40 30 20 15 10 5

$S_{\eta,\eta}$ [cm^2/cph]

10^1 10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4}

90 55 3 65

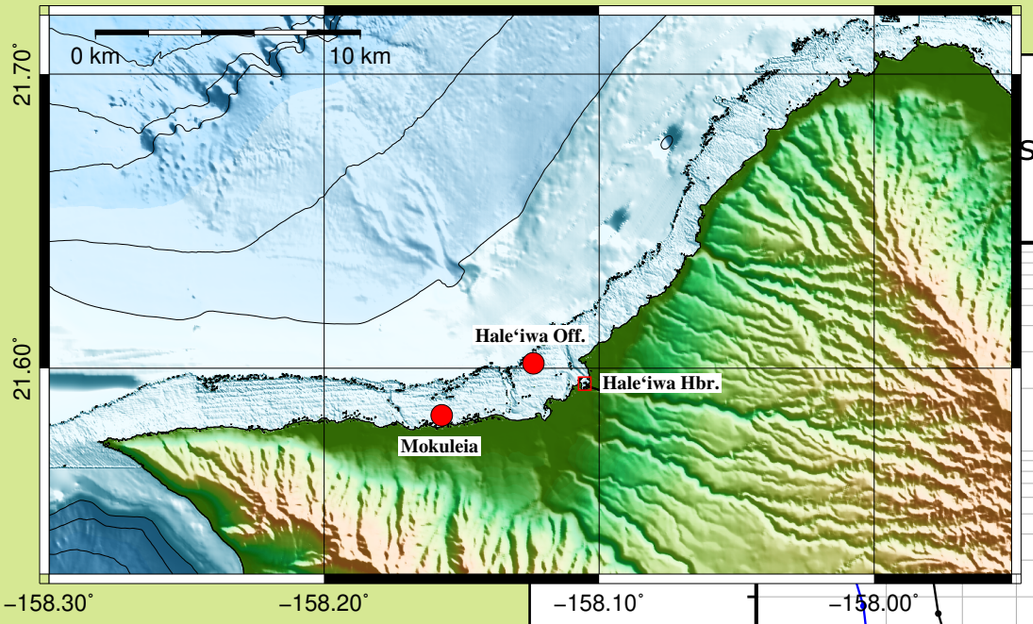
23 18 14 12.5 10 8 6

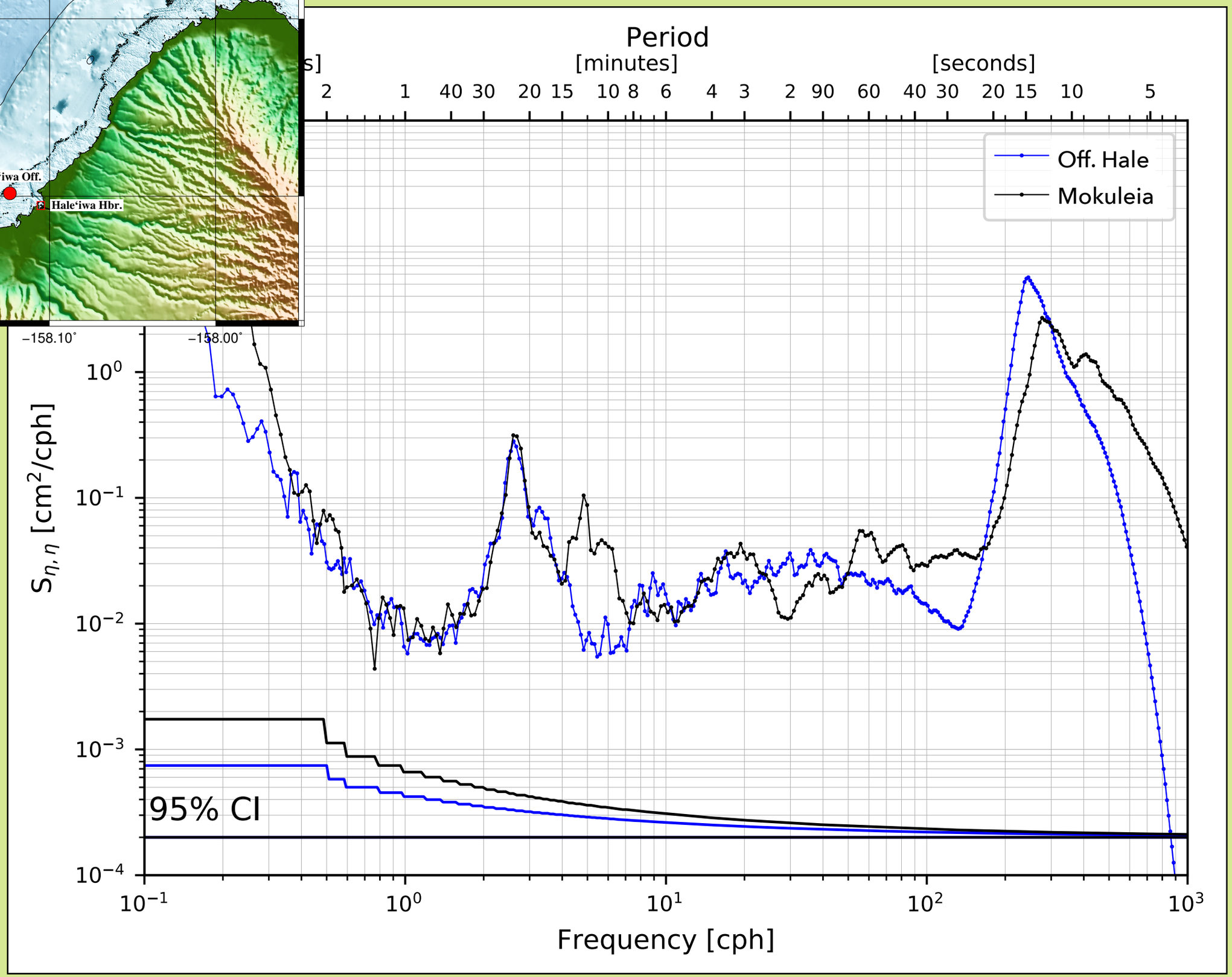
95% CI

10^{-1} 10^0 10^1 10^2 10^3

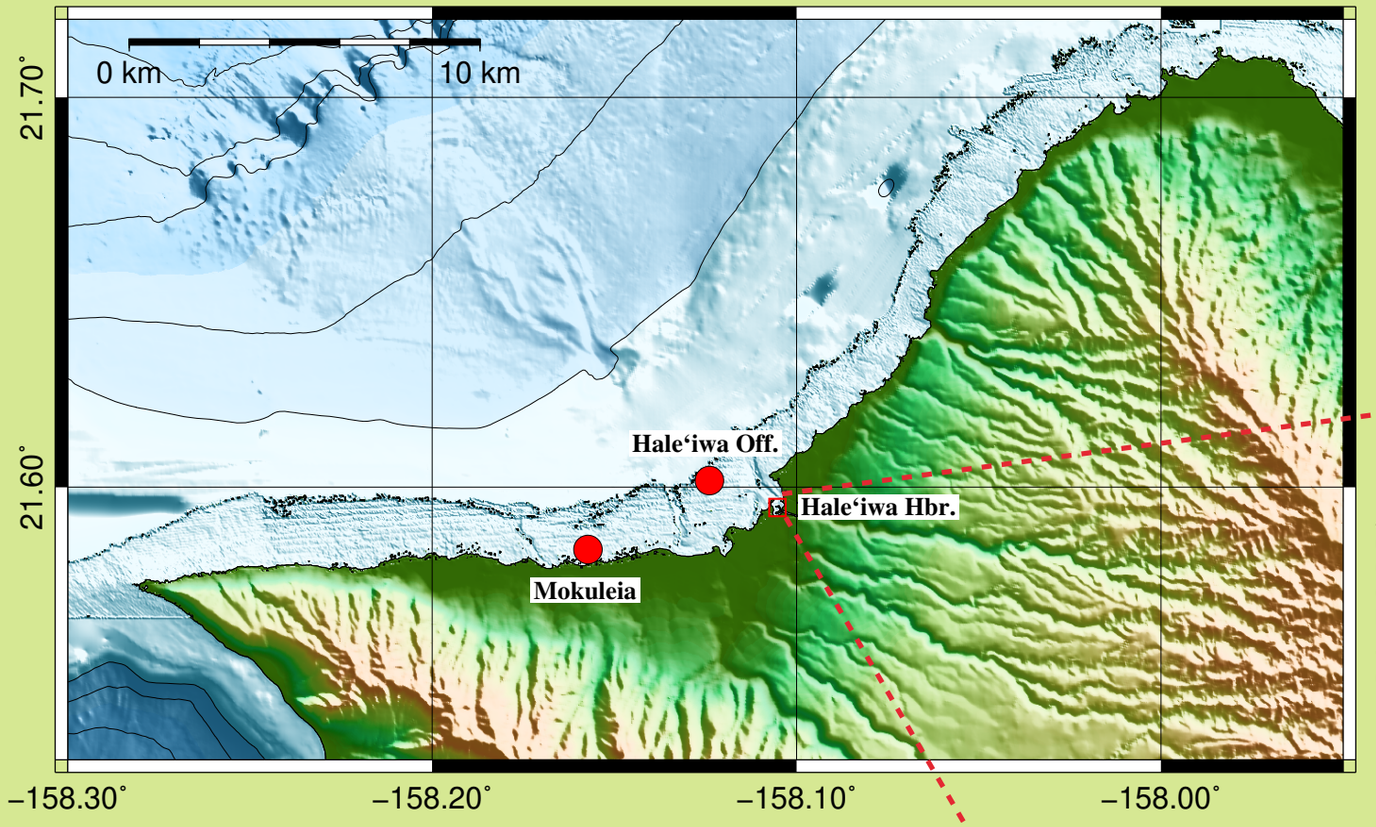
Frequency [cph]

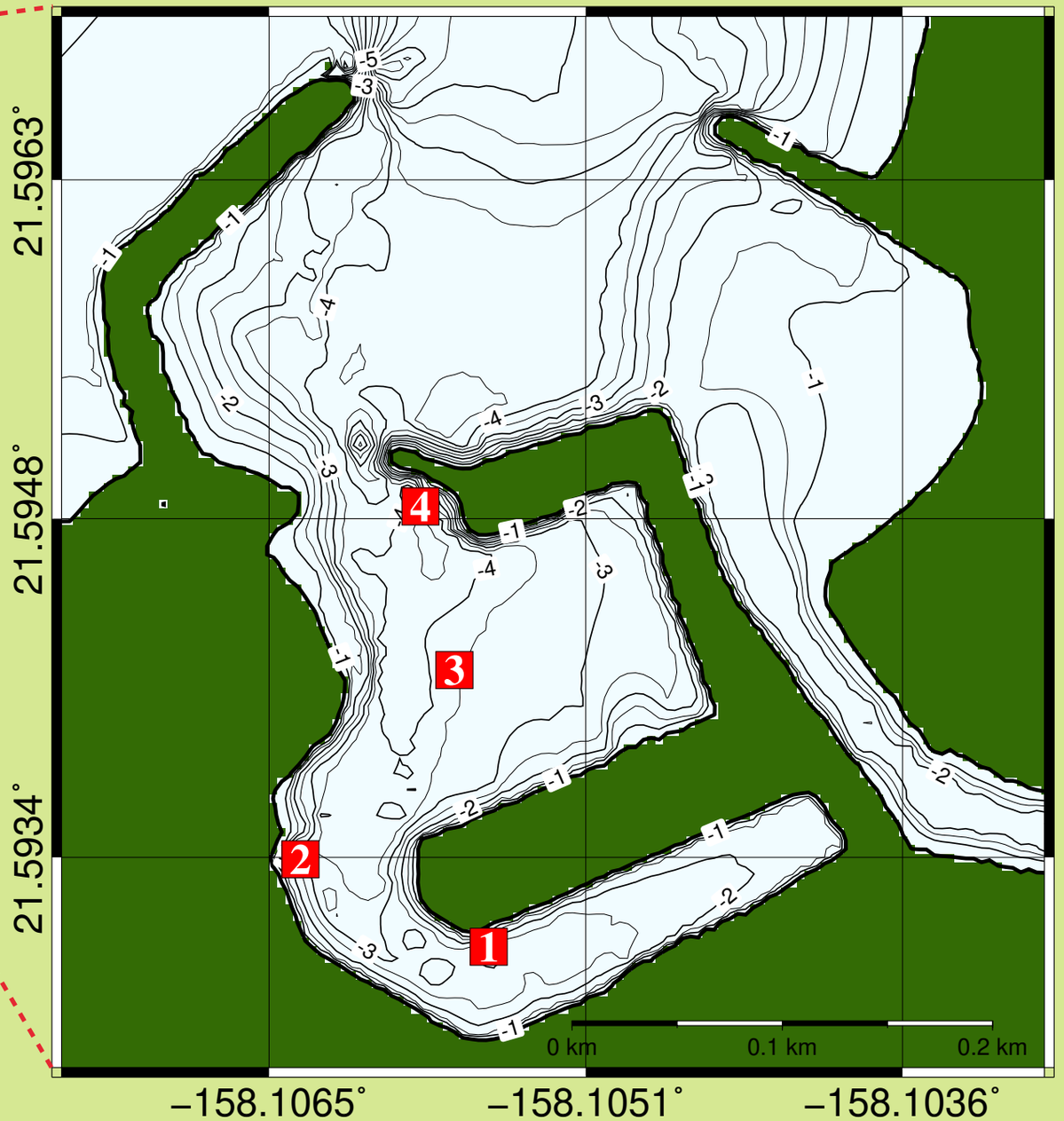
SPATIAL DEPENDENCE OF COASTAL RESPONSE



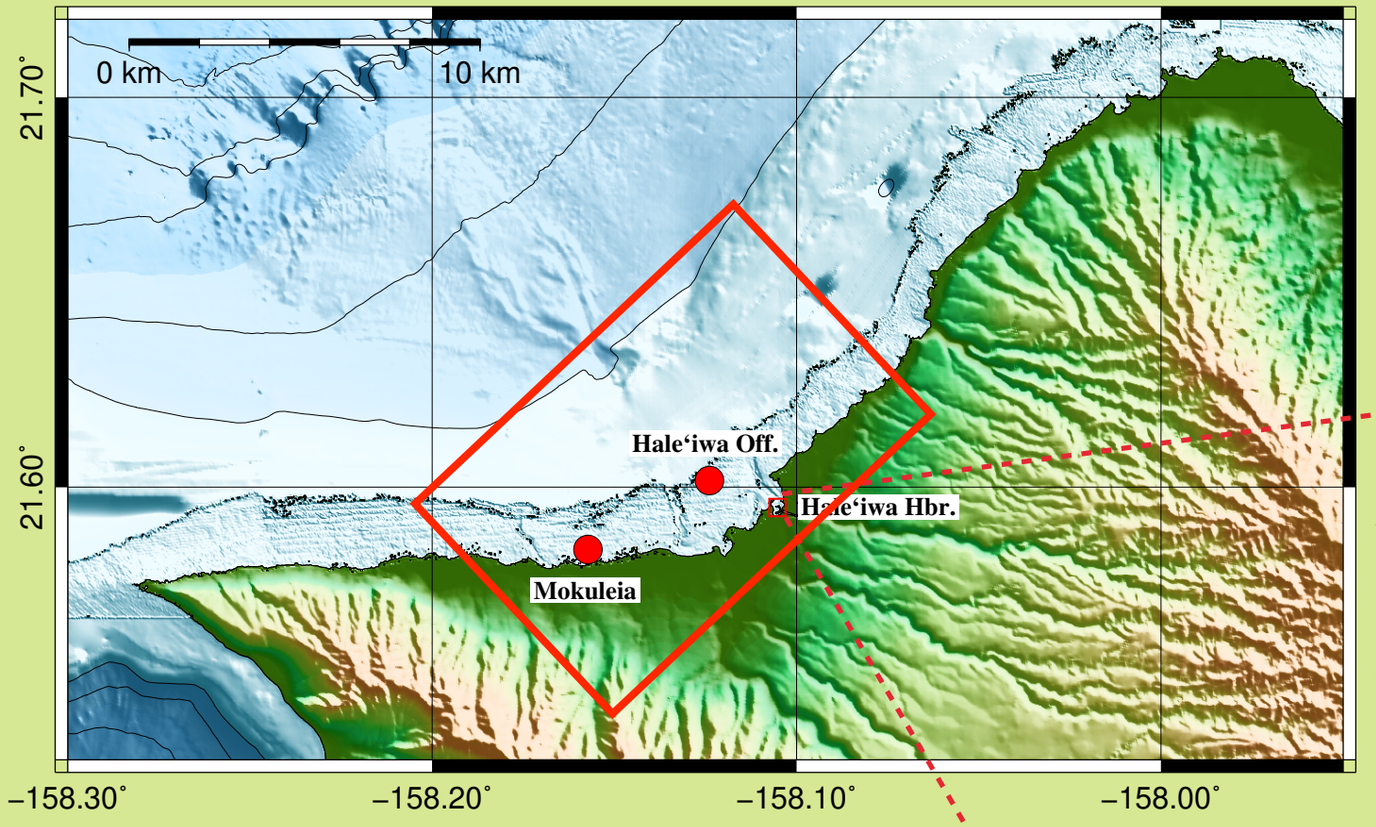


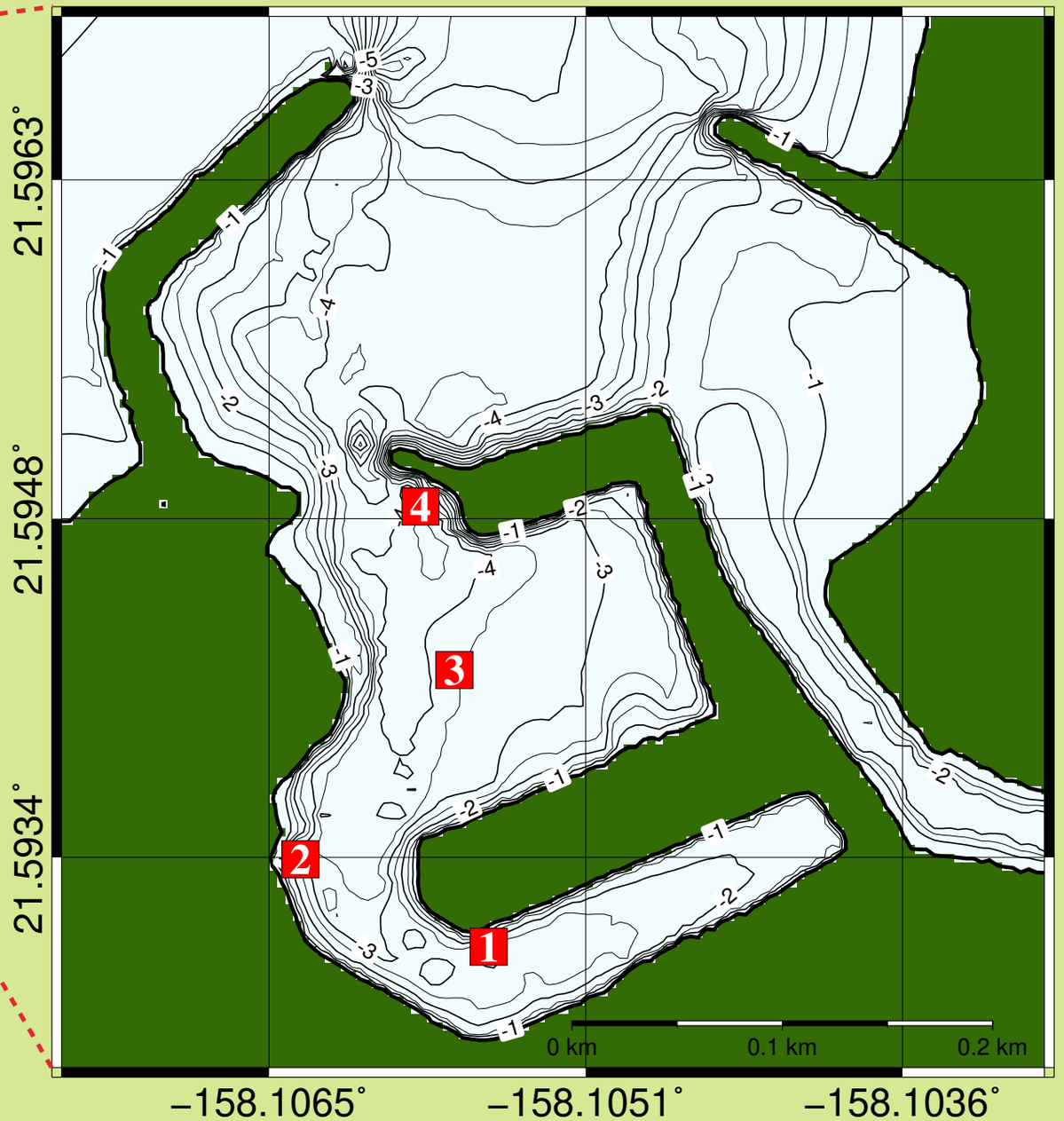
AUTOSPECTRA: HARBOR SITES 1–4





AUTOSPECTRA: HARBOR SITES 1–4





AUTOSPECTRA: BOSZ [BZ], FUNWAVE [FW], XBEACH [XB], OBS

AUTOSPECTRA: BOSZ [BZ], FUNWAVE [FW], XBEACH [XB], OBS

Roeber and Cheung [2012]

Shi et al. [2012]

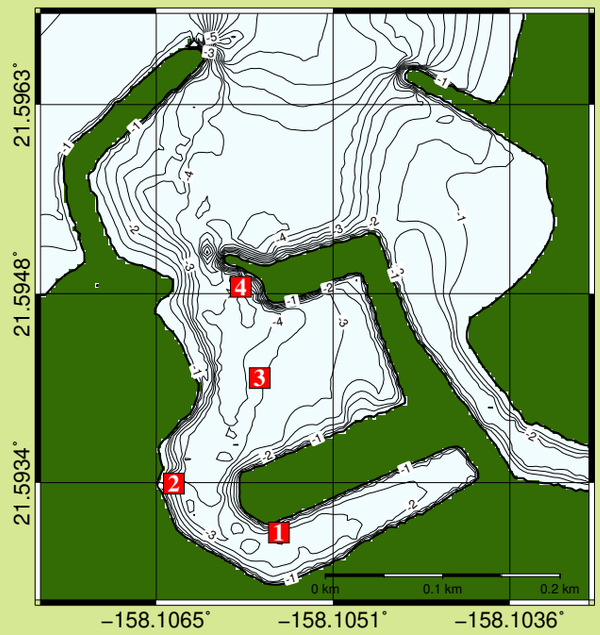
Roelvink et al. [2009]

- Phase-resolving numerical models.
- Account for nonlinear and weakly dispersive waves.
- Suitable for nearshore wave processes, including wave breaking.

AUTOSPECTRA: BOSZ [BZ], FUNWAVE [FW], XBEACH [XB], OBS

Strong SS:

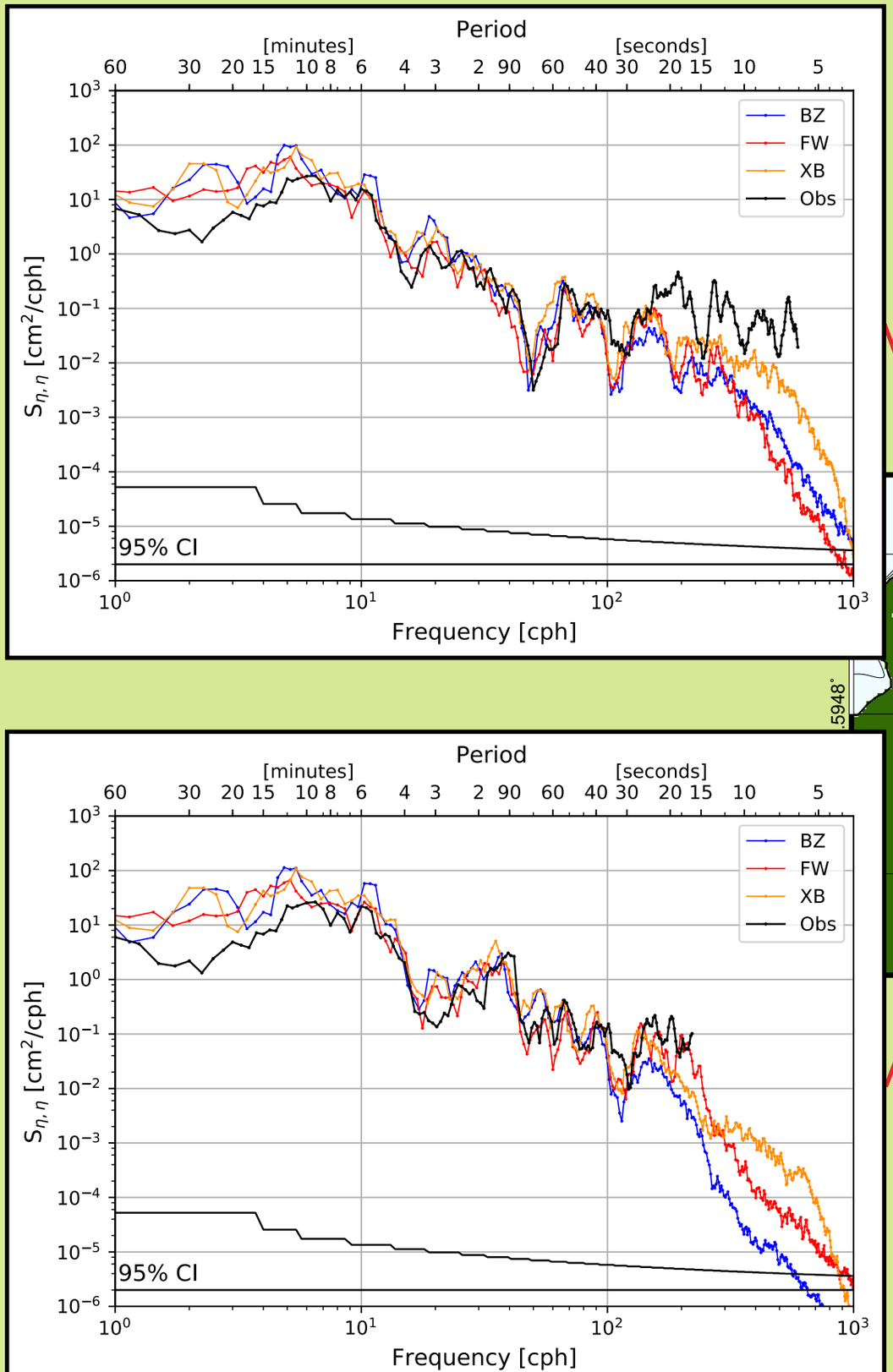
- H_s = 7.4 m
- T_p = 15.4 s
- θ_p = 315°



- Δx, Δy = 7 m
- 2.5M cells

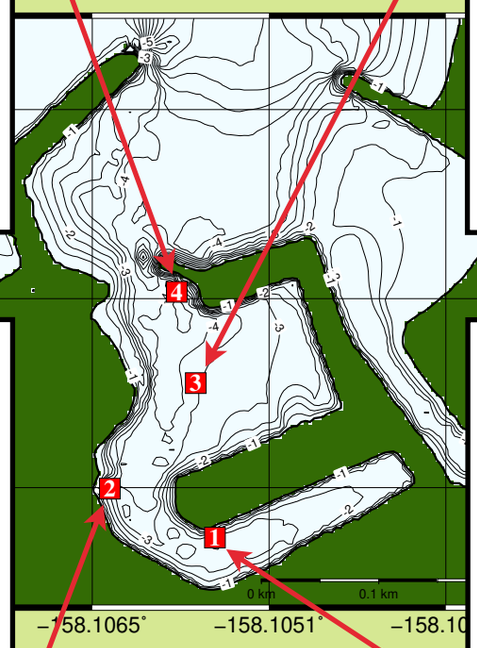
RESULTS: MODEL-DATA COMPARISONS IN HALE'IWA HARBOR

AUTOSPECTRA: BOSZ [BZ], FUNWAVE [FW], XBEACH [XB], OBS

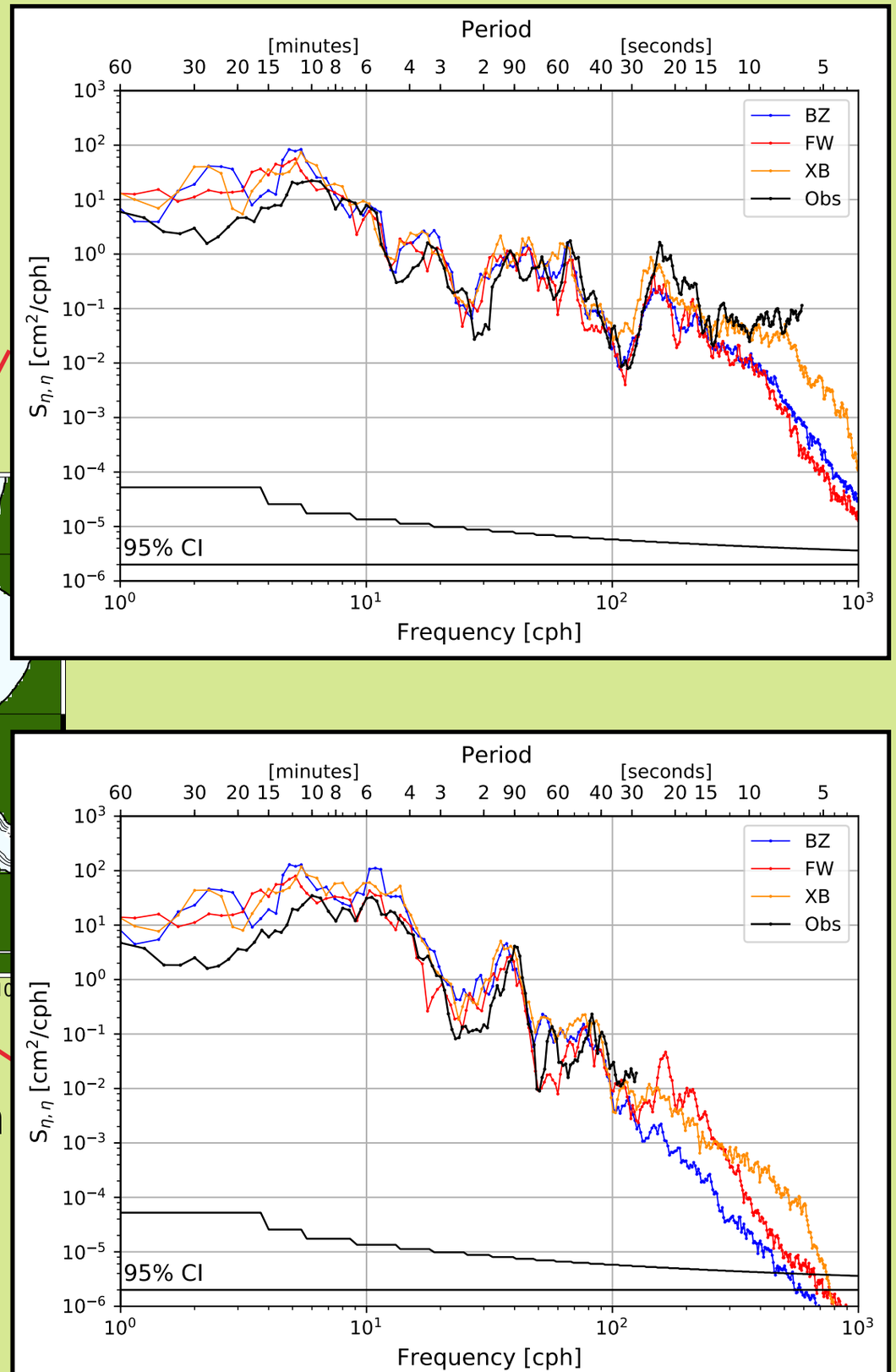


Strong SS:

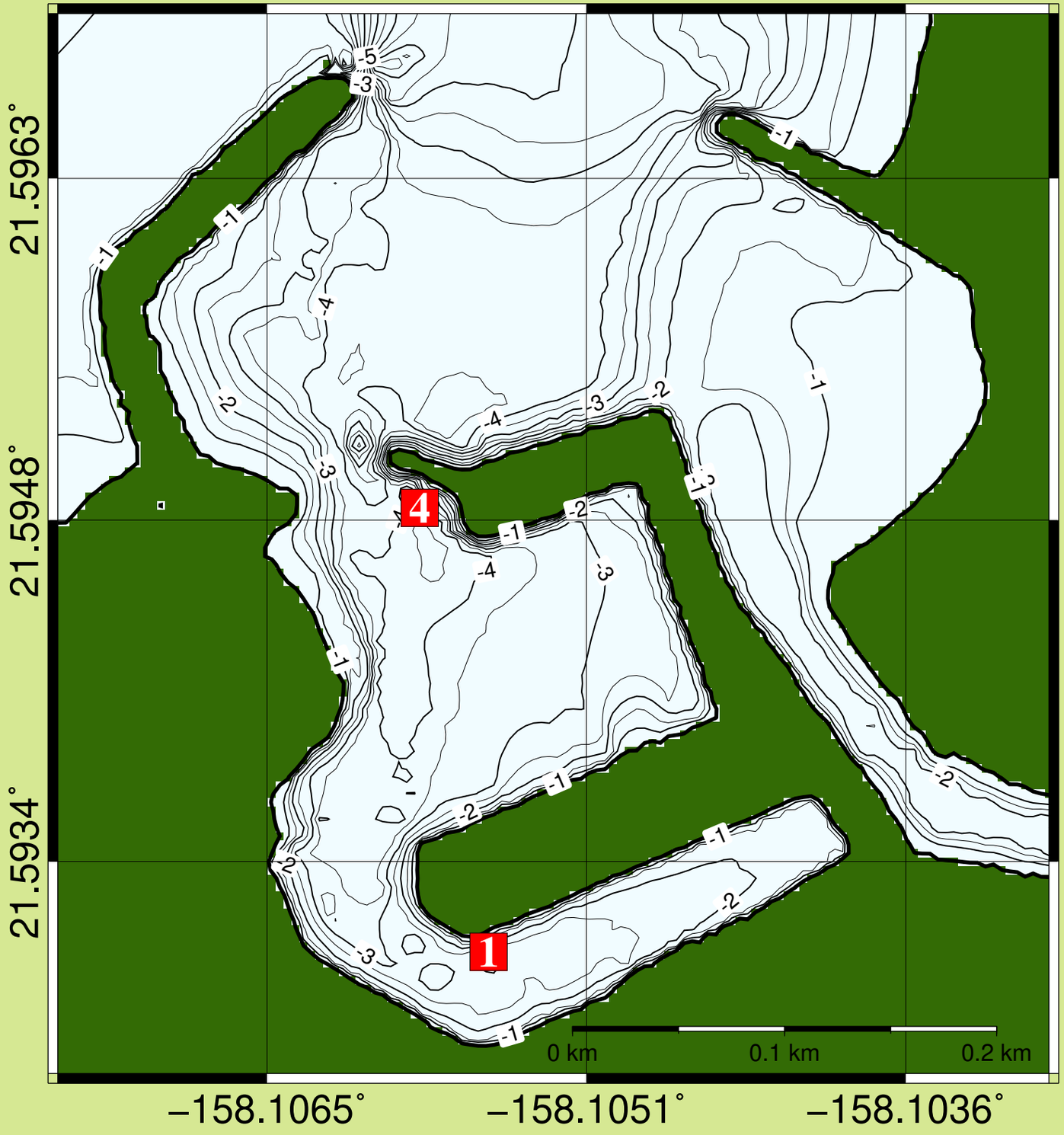
- H_s = 7.4 m
- T_p = 15.4 s
- θ_p = 315°



- Δx, Δy = 7 m
- 2.5M cells

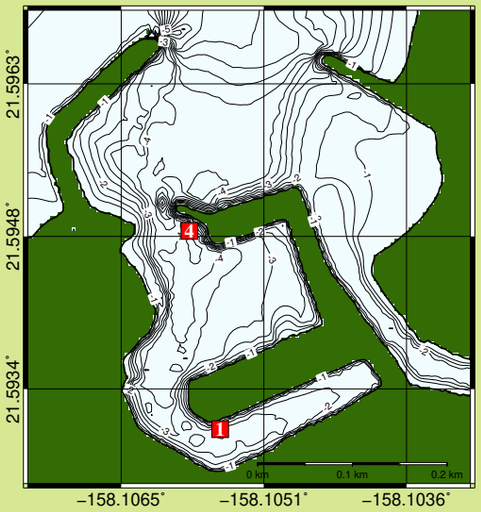


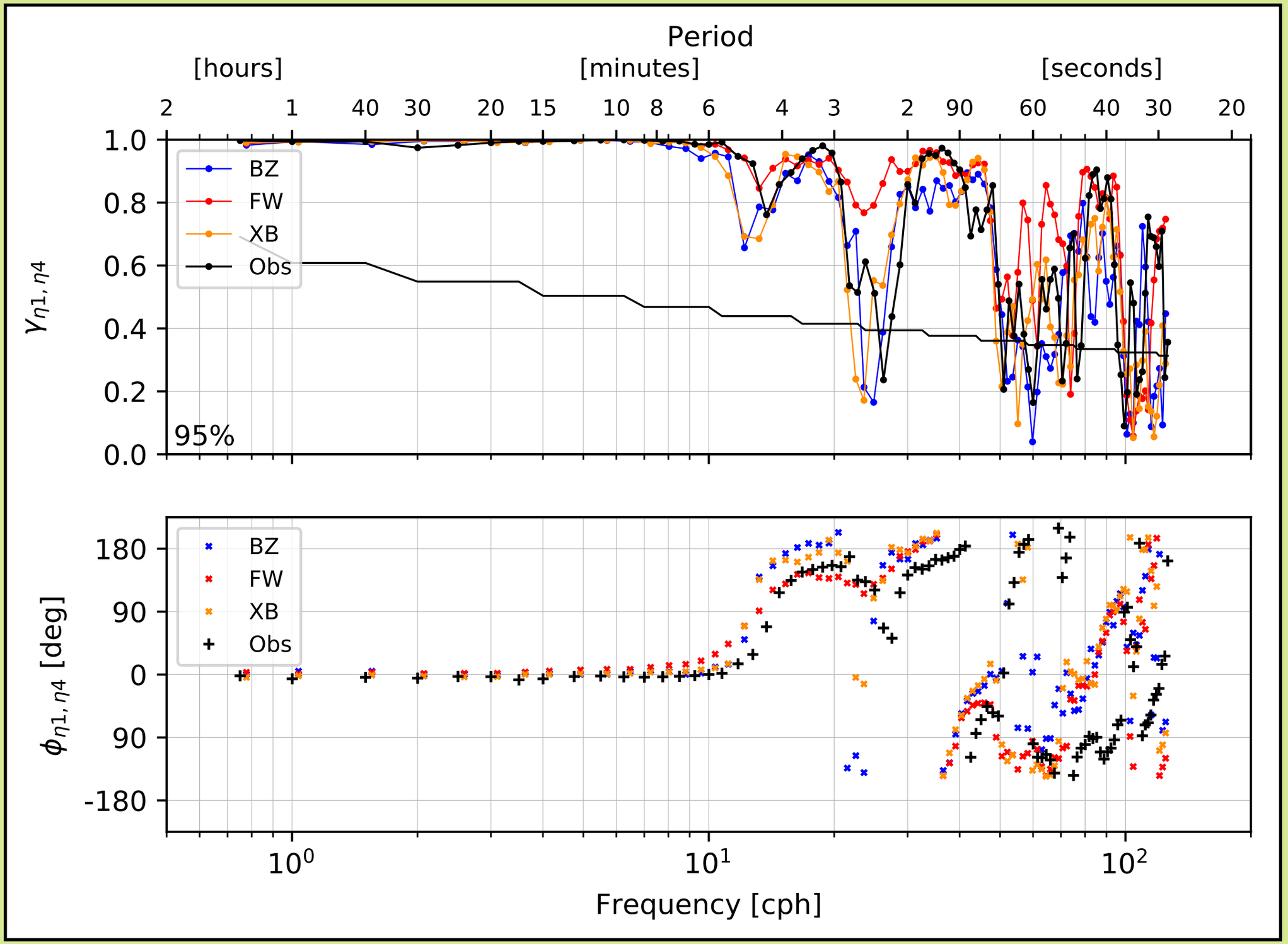
CROSS-SPECTRA: HARBOR SITES 1 VS. 4



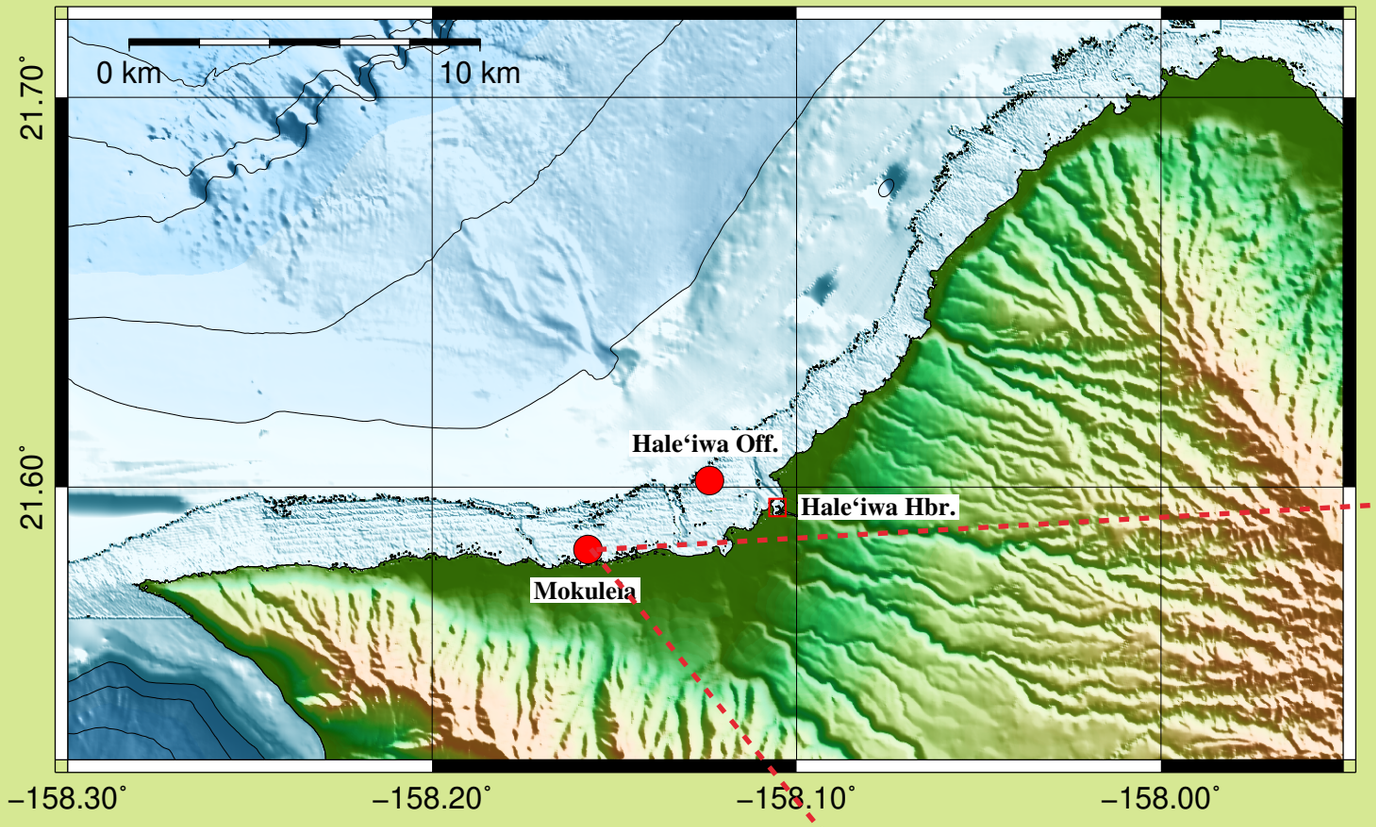
RESULTS: MODEL-DATA COMPARISONS IN HALE'IWA HARBOR

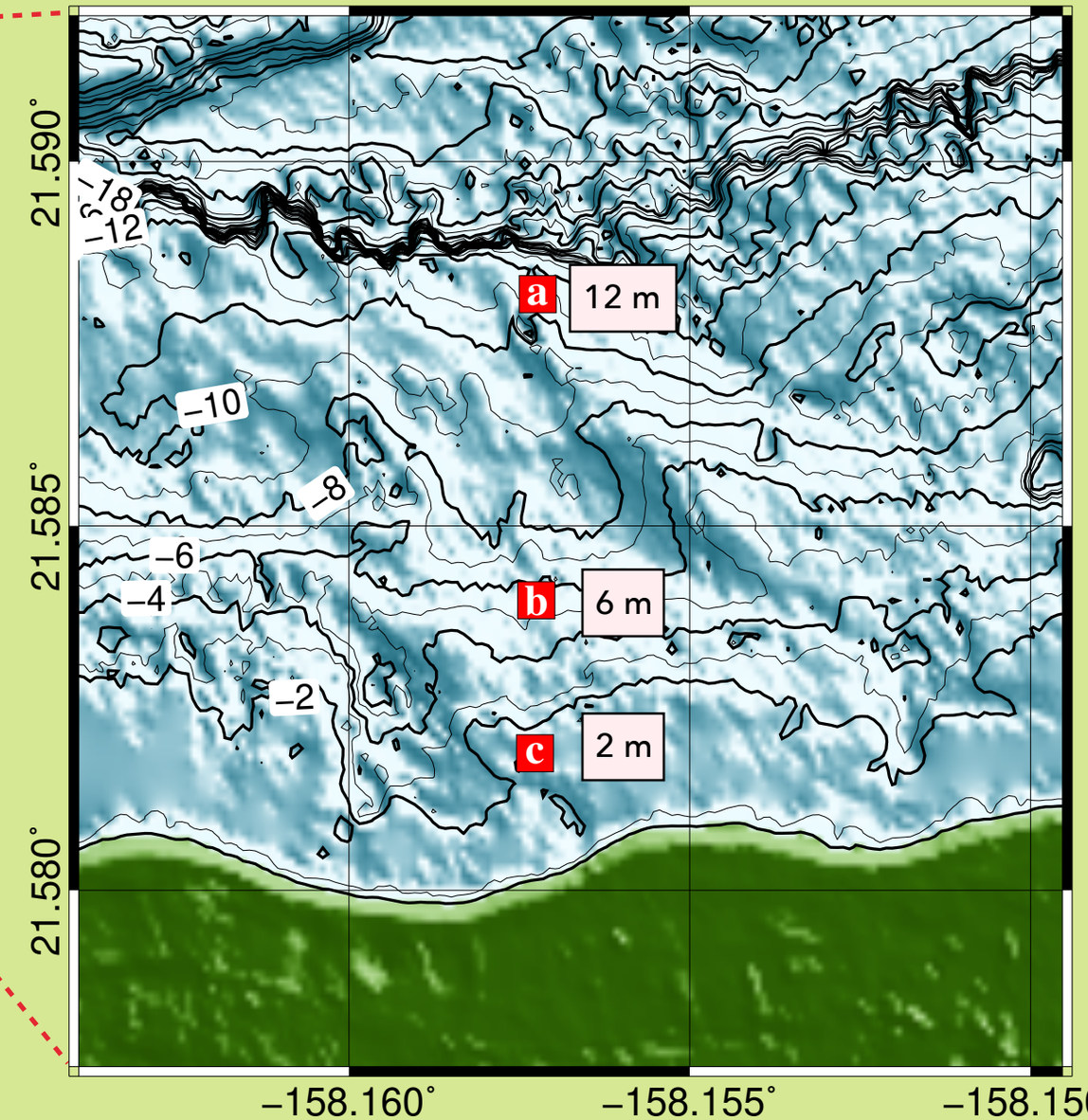
CROSS-SPECTRA: BOSZ [BZ], FUNWAVE [FW], XBEACH [XB], OBS





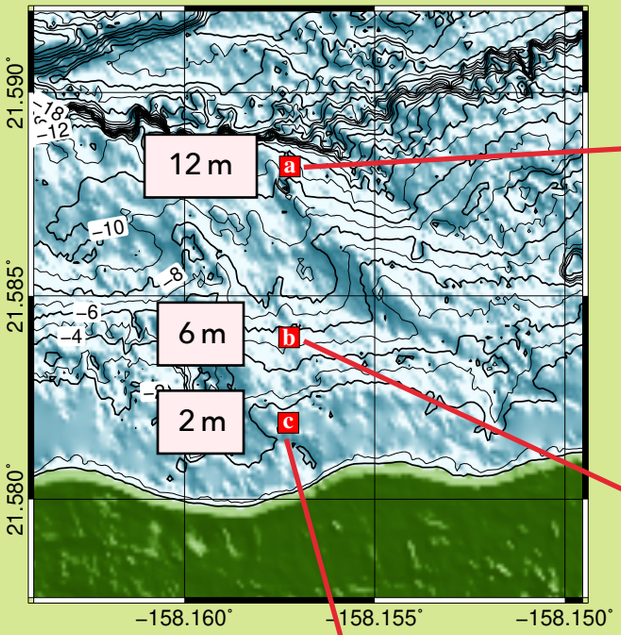
AUTOSPECTRA: COASTAL SITES A–C

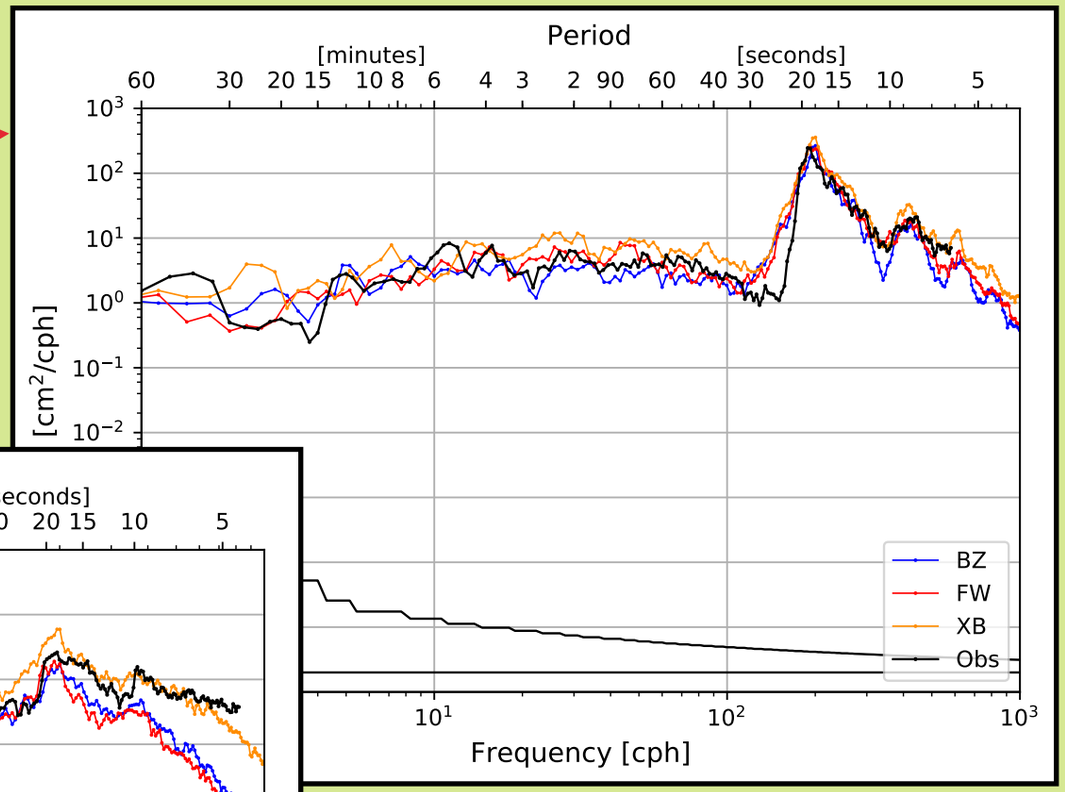


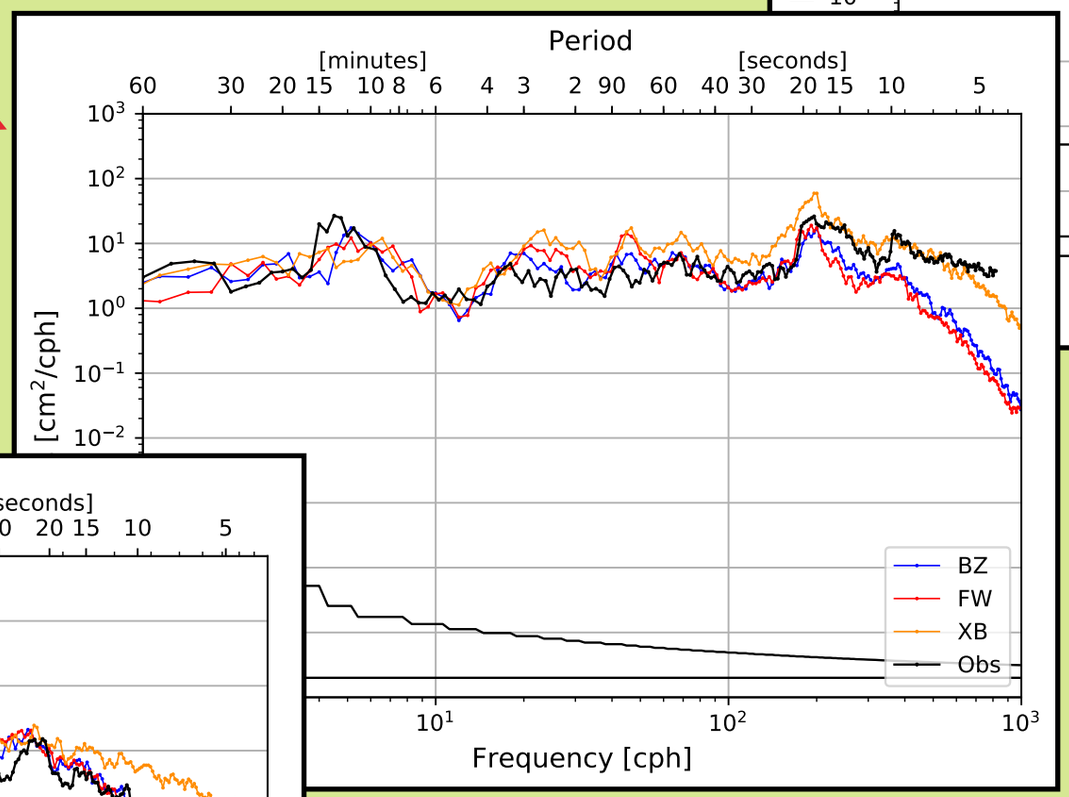


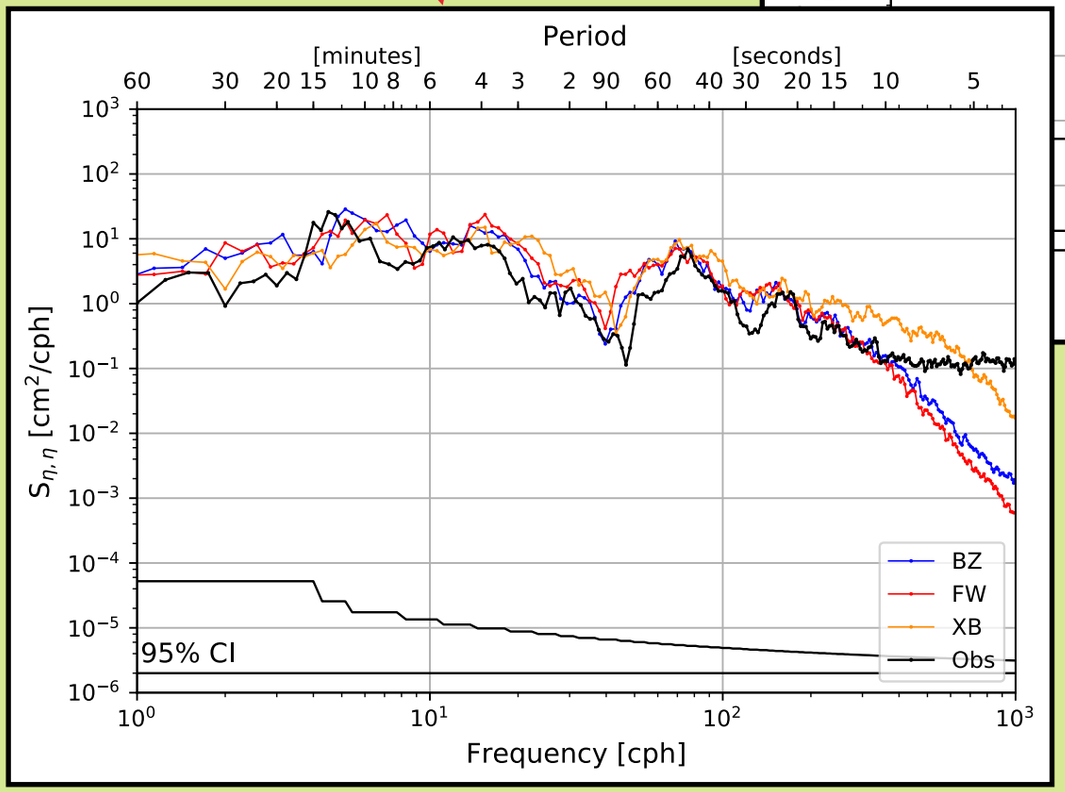
RESULTS: MODEL-DATA COMPARISONS OVER MOKULEIA REEF

AUTOSPECTRA: BOSZ [BZ], FUNWAVE [FW], XBEACH [XB], OBS

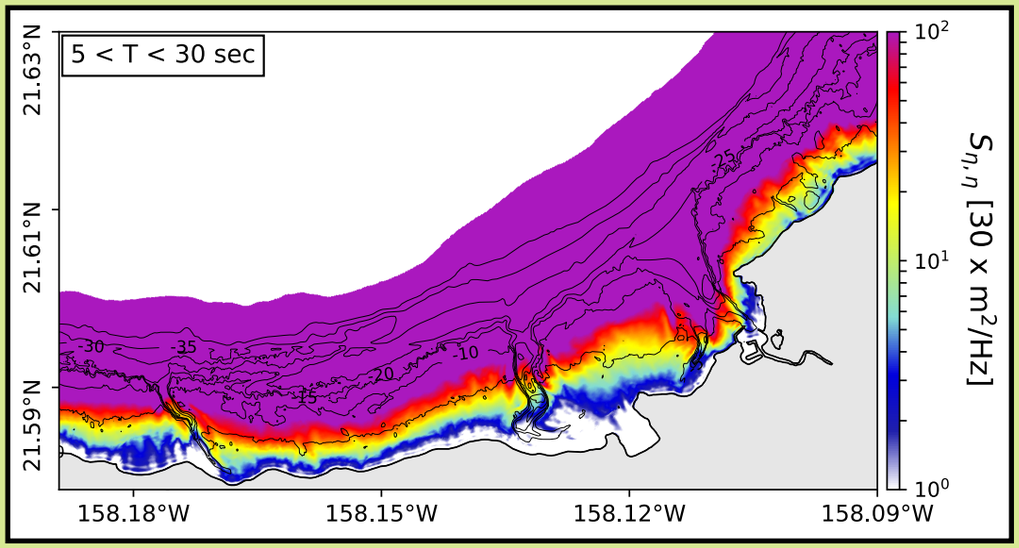




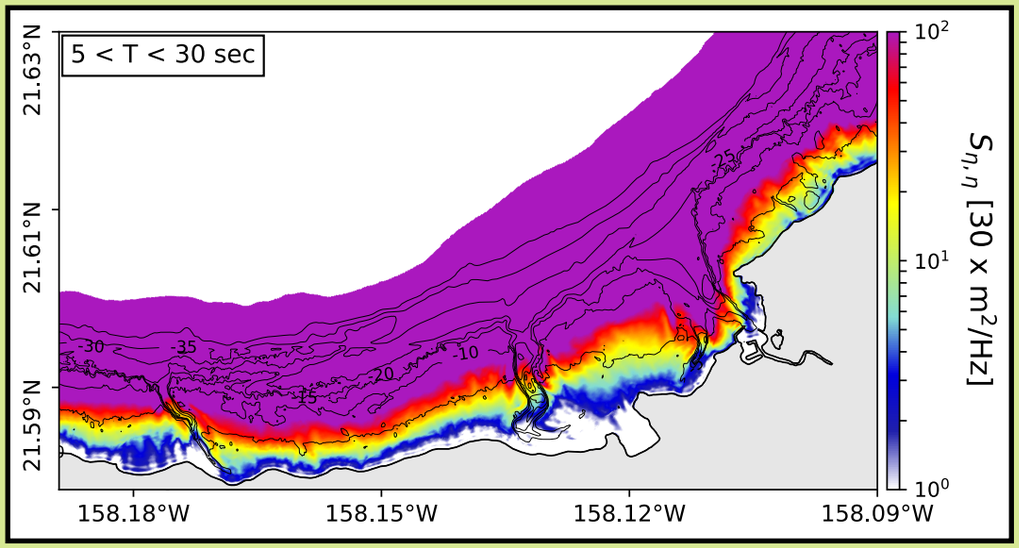


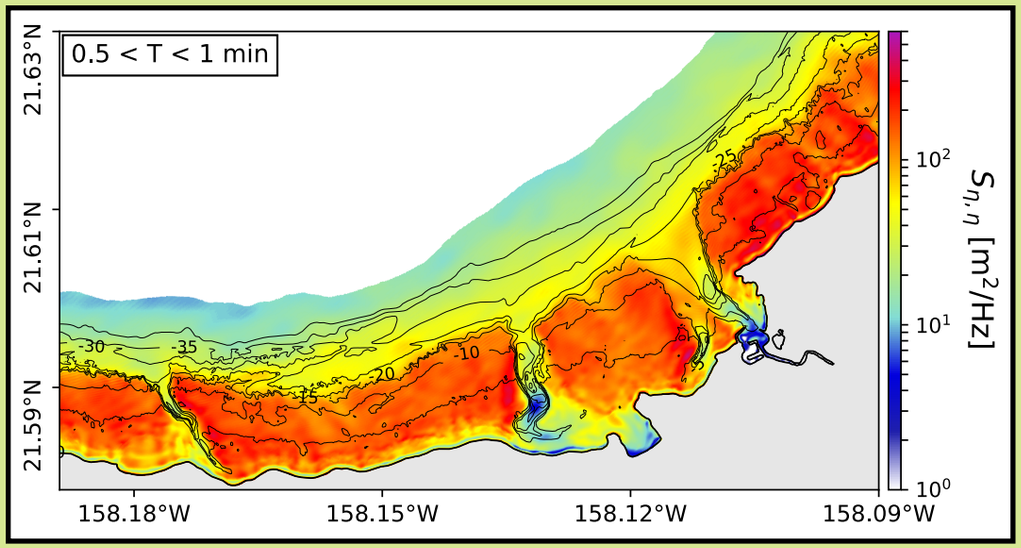


SPATIAL DISTRIBUTION OF IG WAVE FIELD: PSD

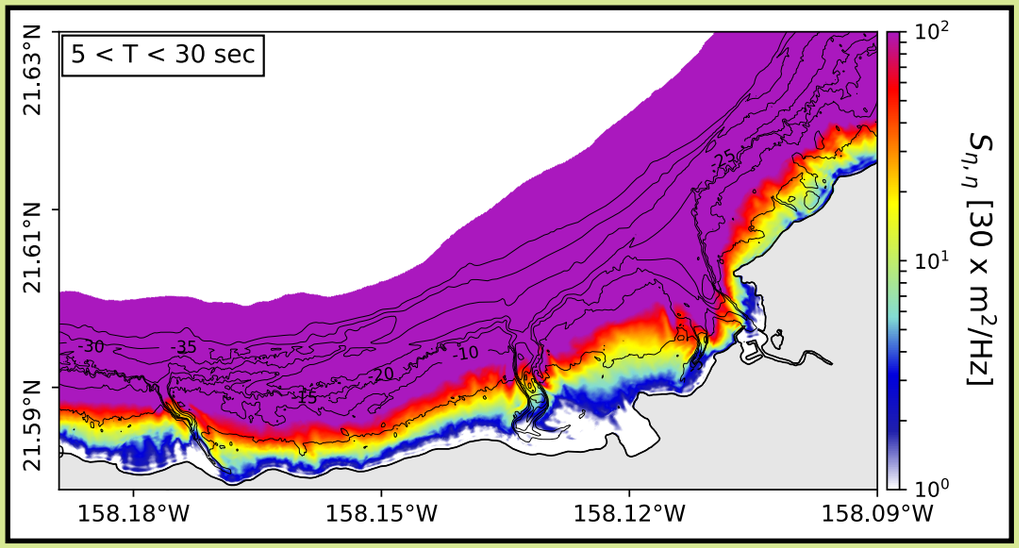


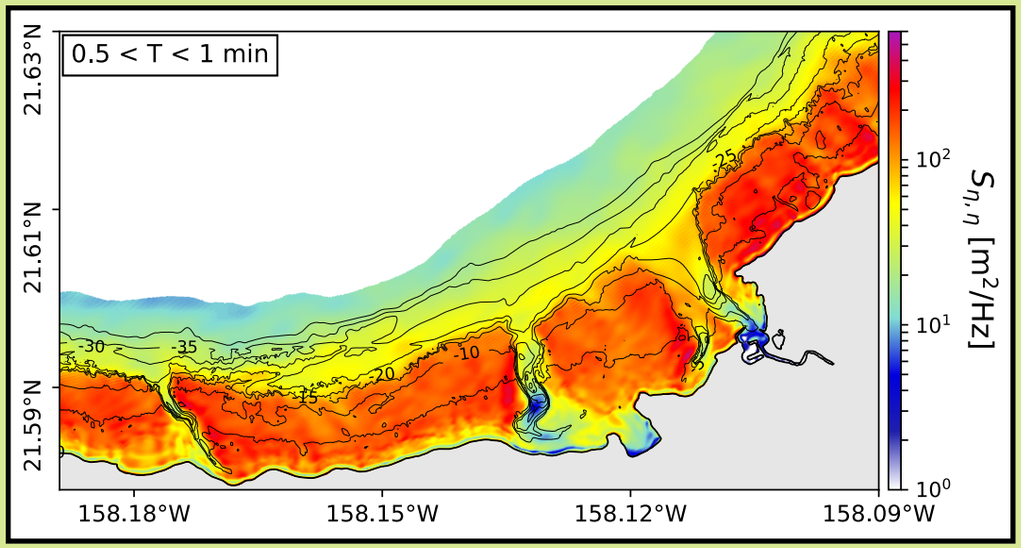
SPATIAL DISTRIBUTION OF IG WAVE FIELD: PSD

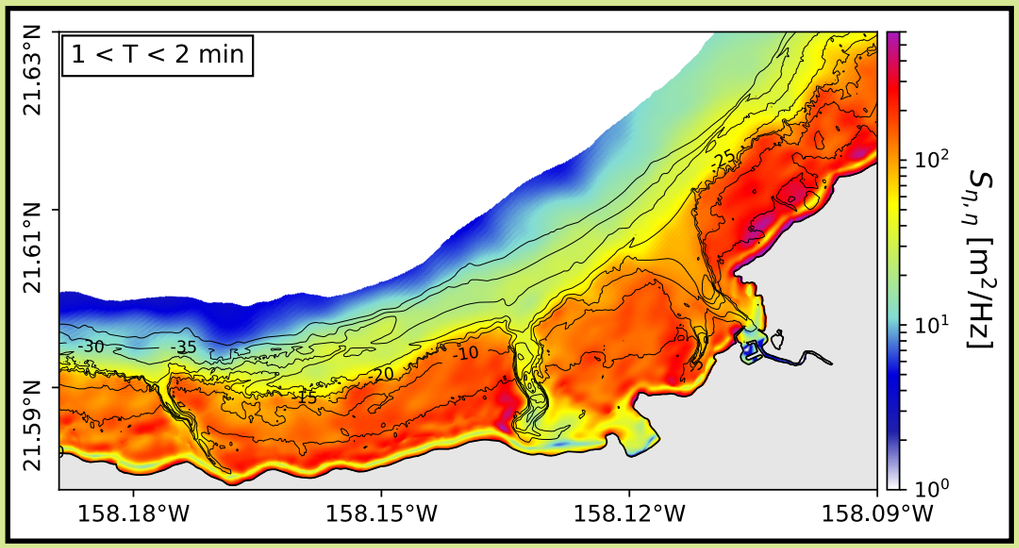




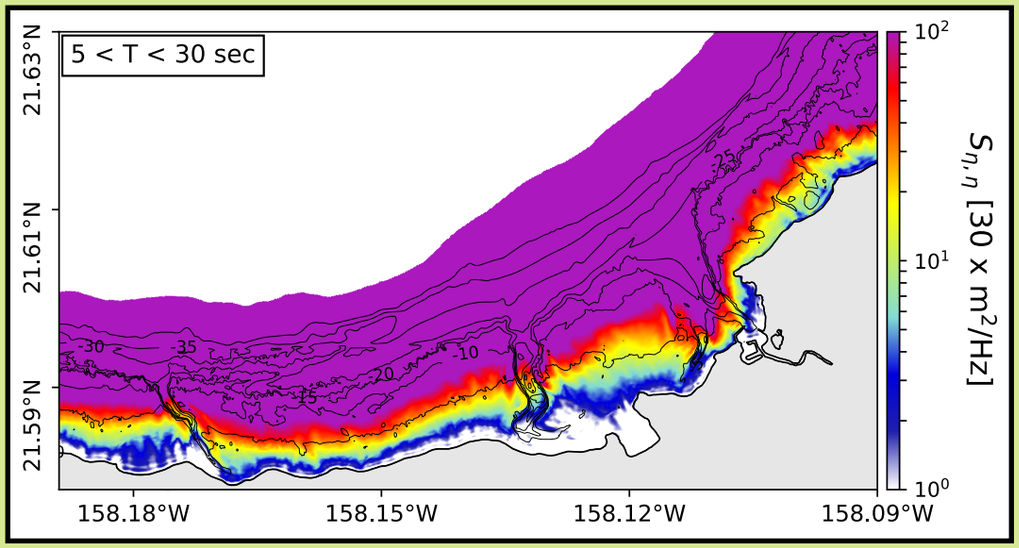
SPATIAL DISTRIBUTION OF IG WAVE FIELD: PSD

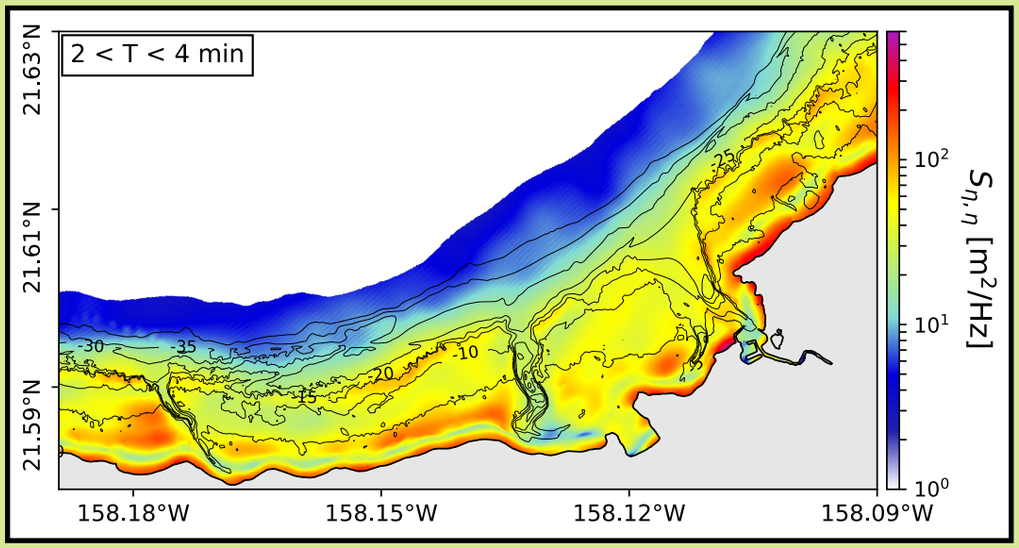


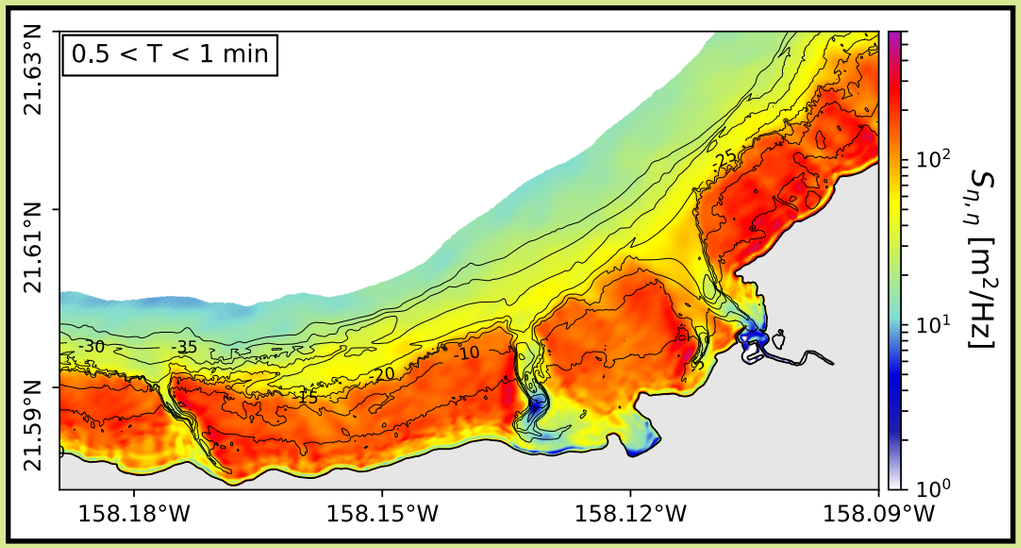


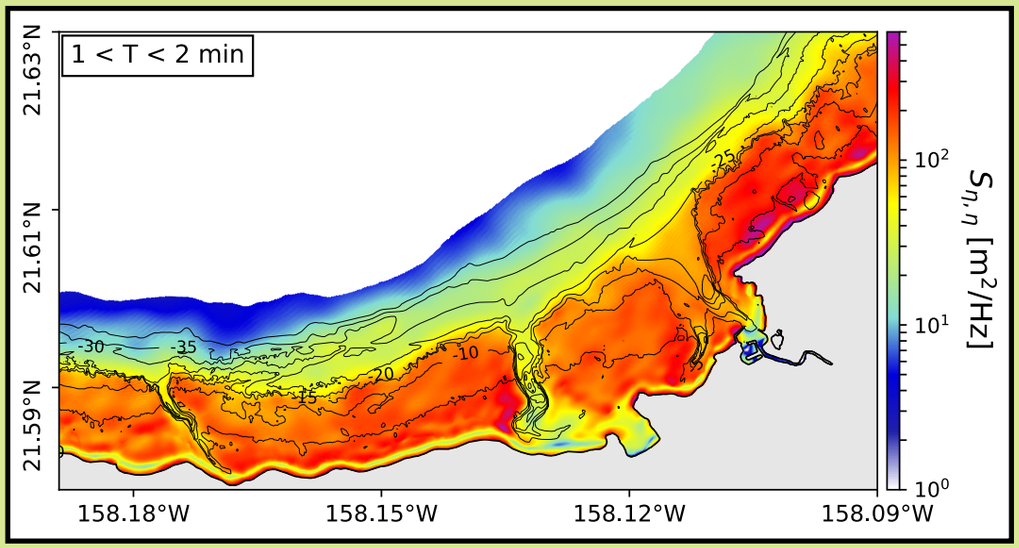


SPATIAL DISTRIBUTION OF IG WAVE FIELD: PSD

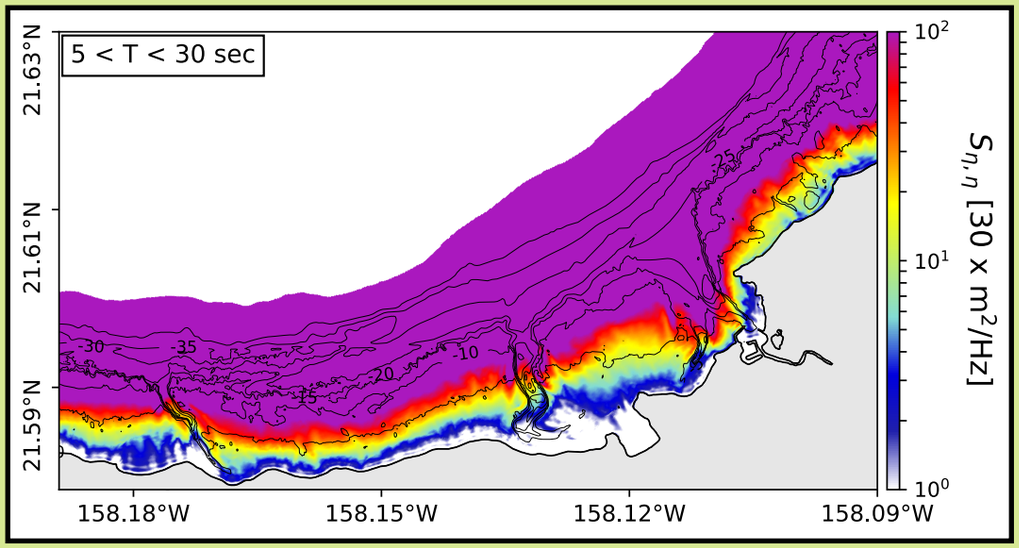


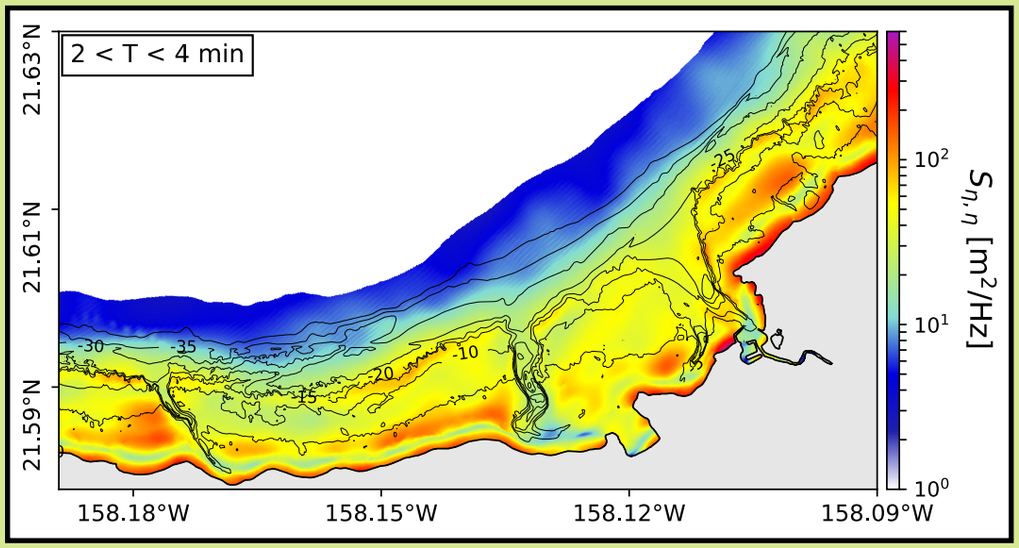


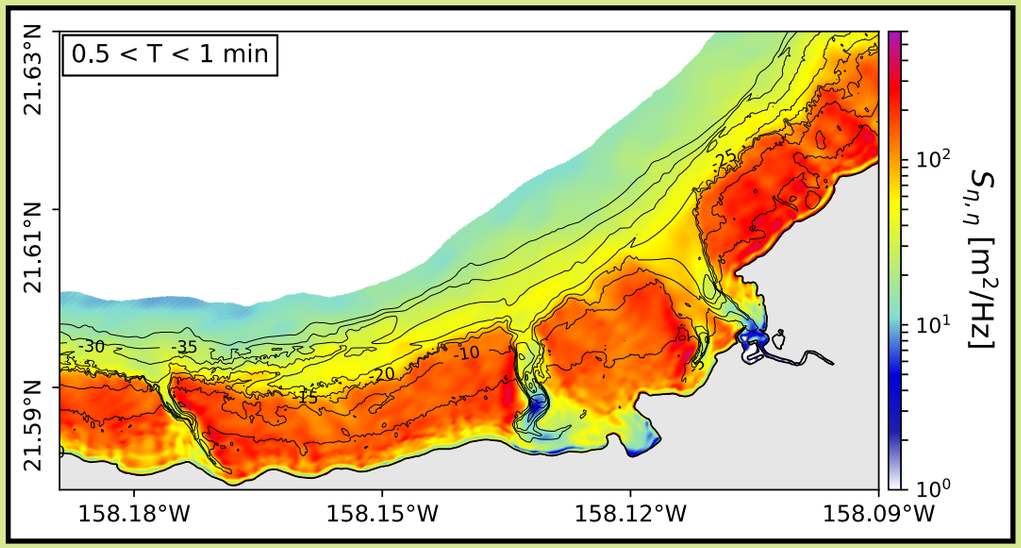


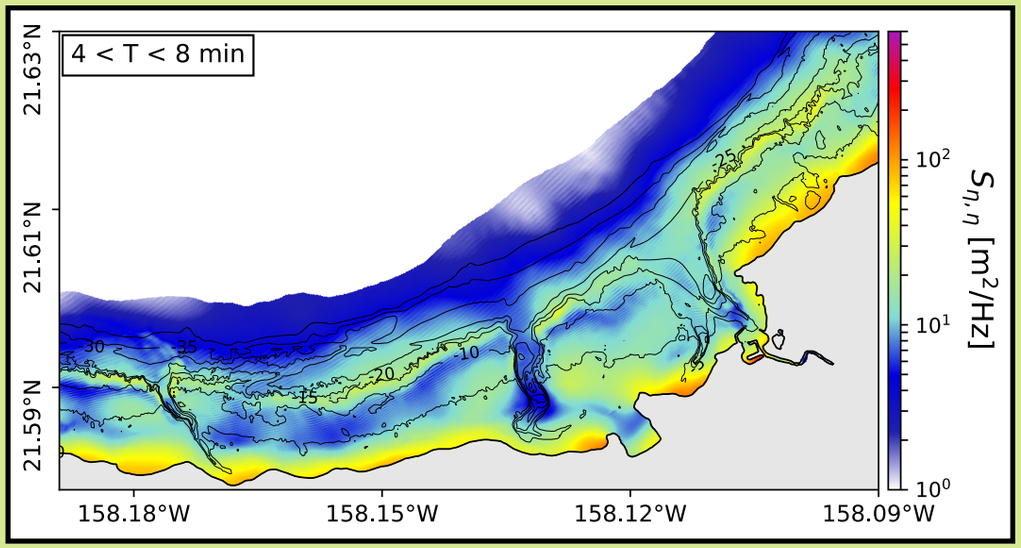


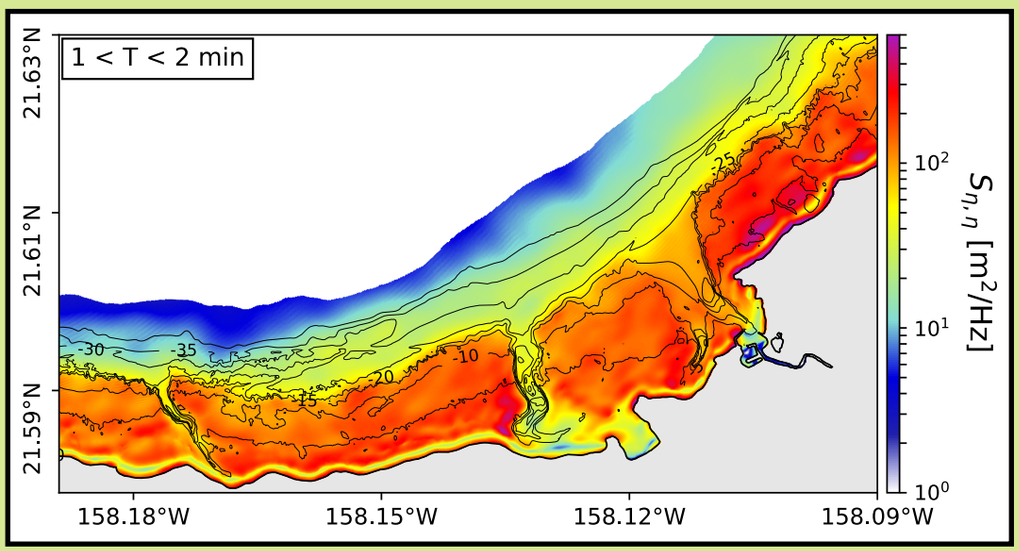
SPATIAL DISTRIBUTION OF IG WAVE FIELD: PSD



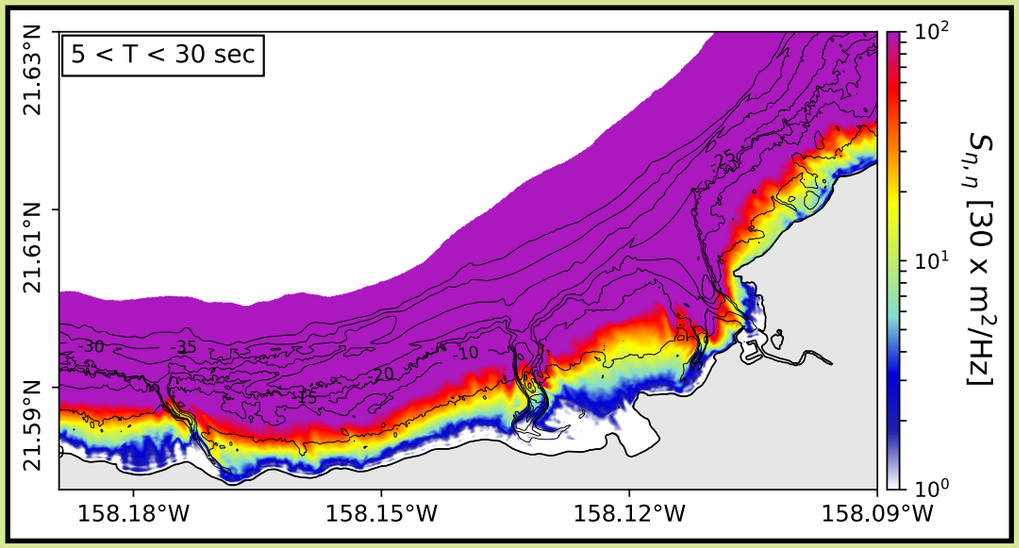


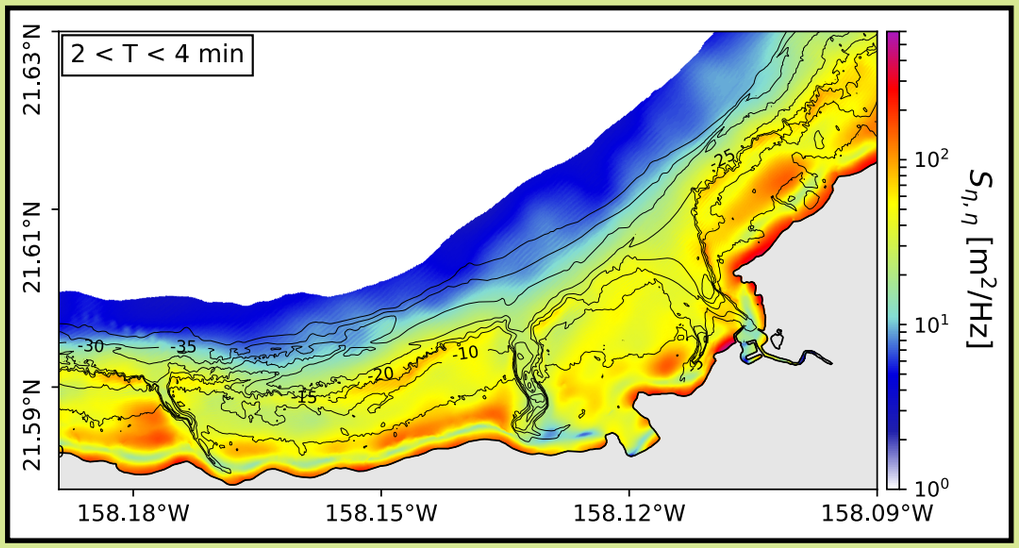


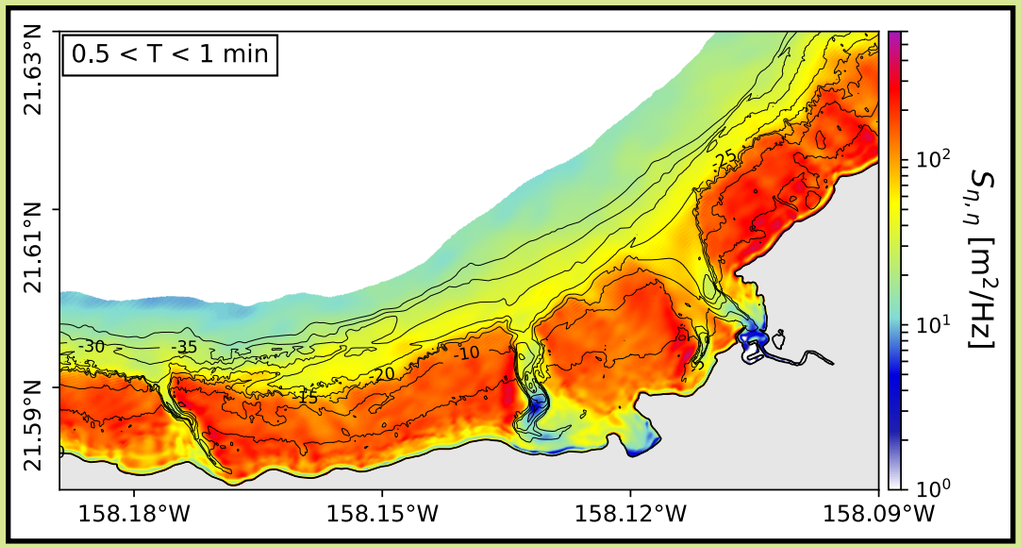


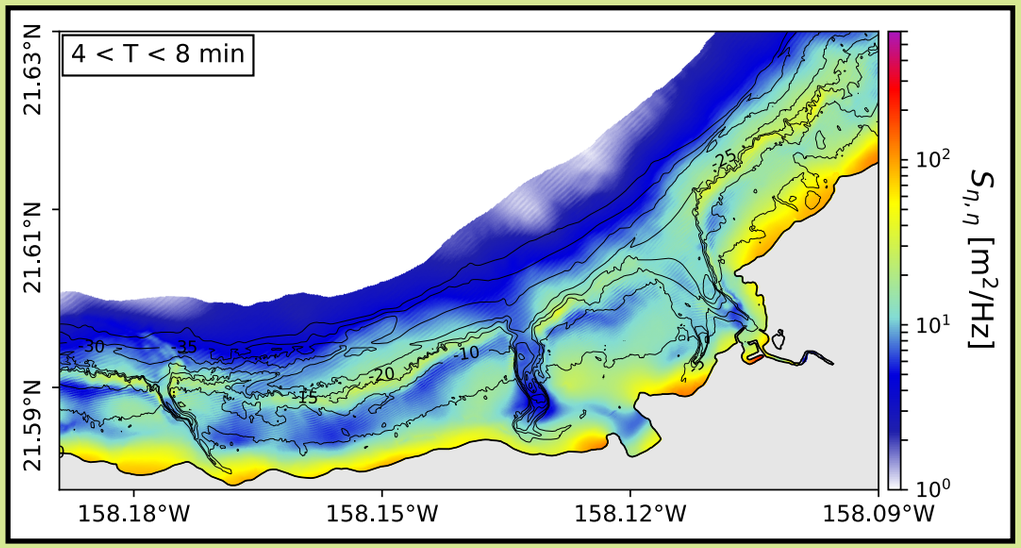


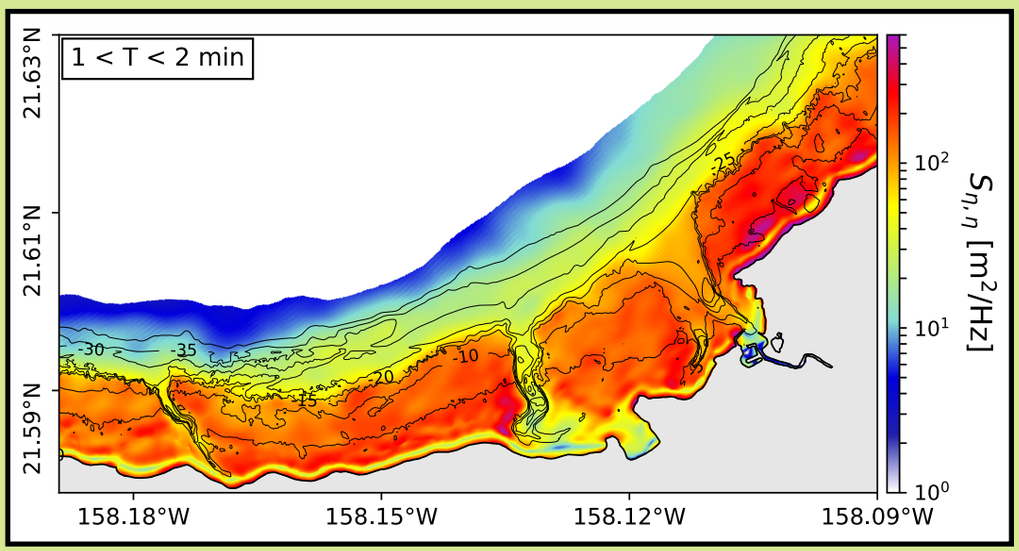
SPATIAL DISTRIBUTION OF IG WAVE FIELD: PSD

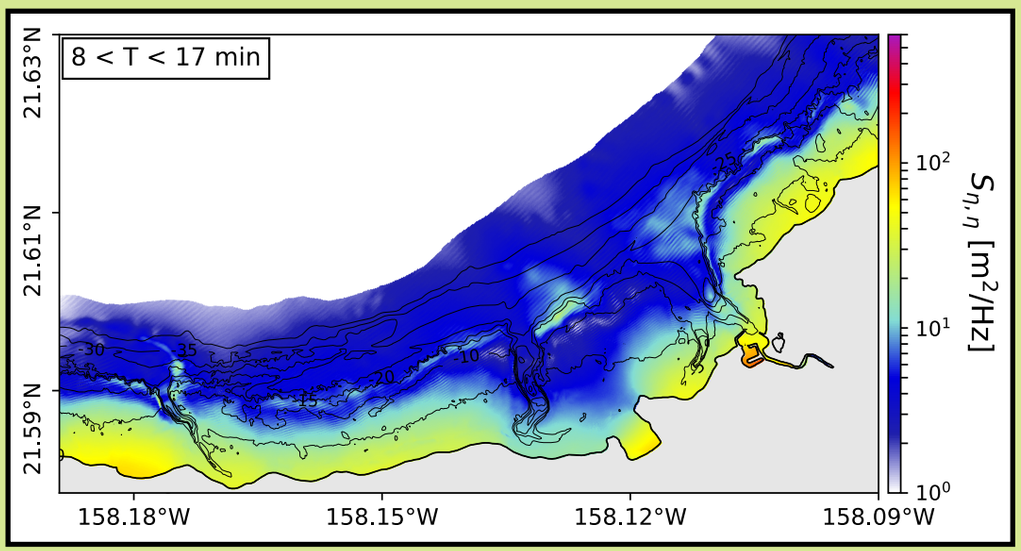




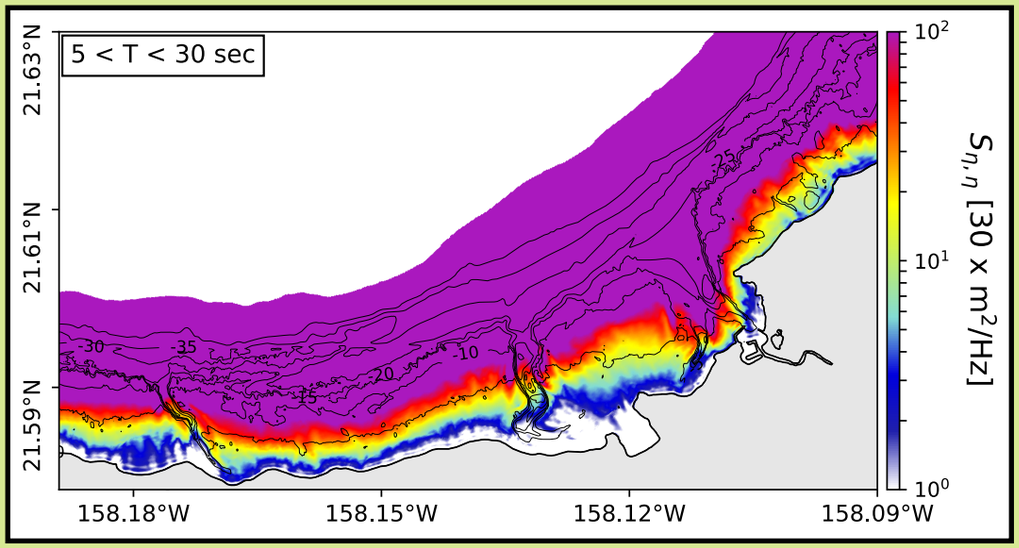


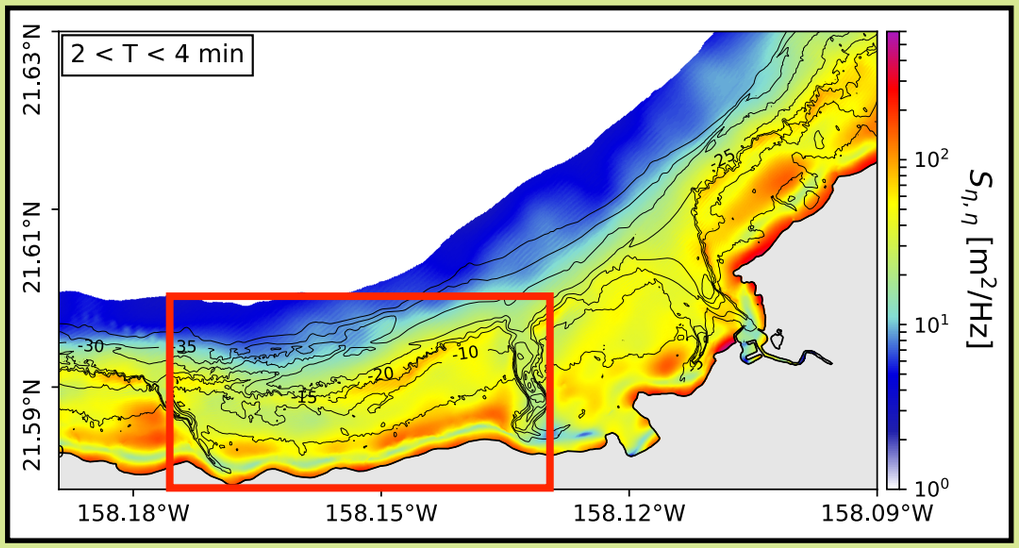


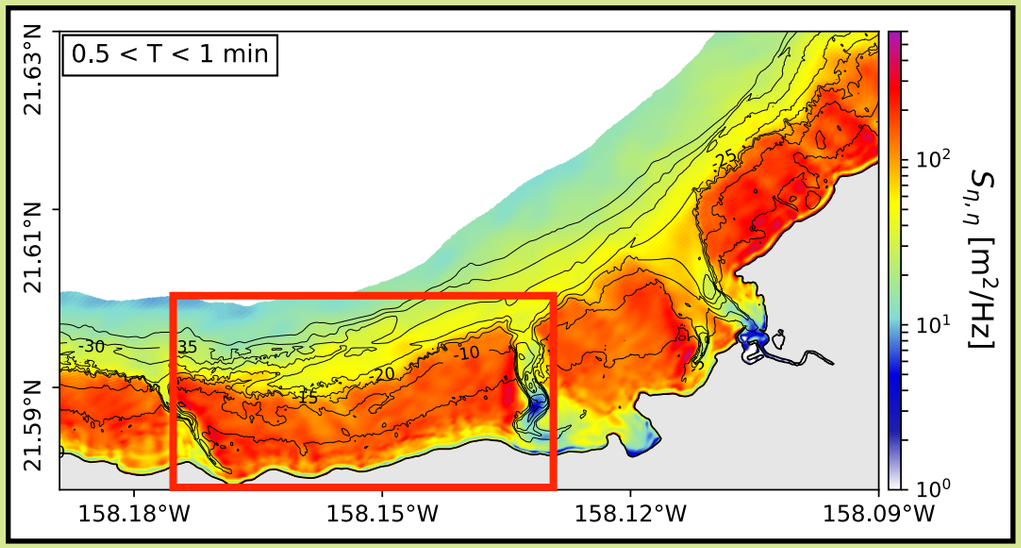


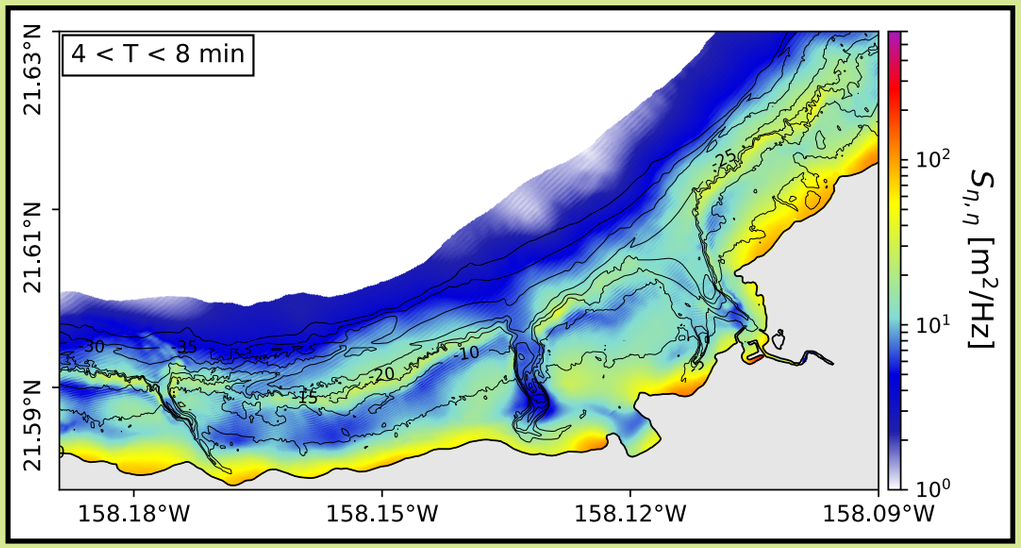


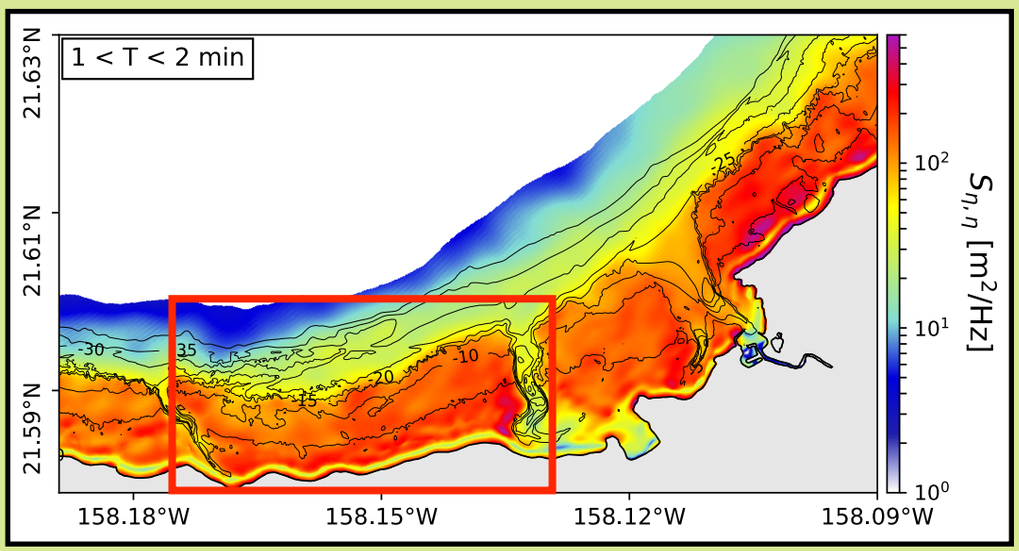
SPATIAL DISTRIBUTION OF IG WAVE FIELD: PSD

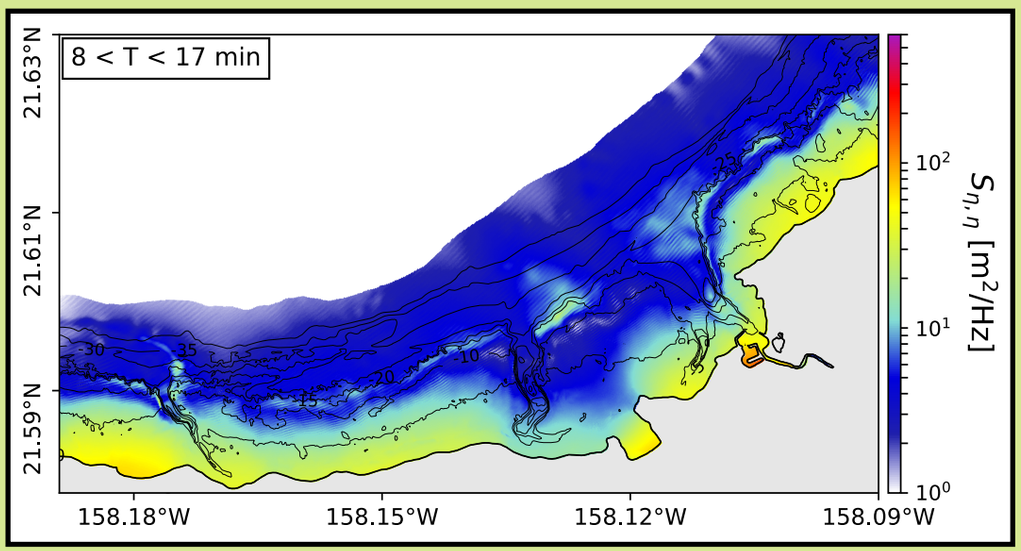






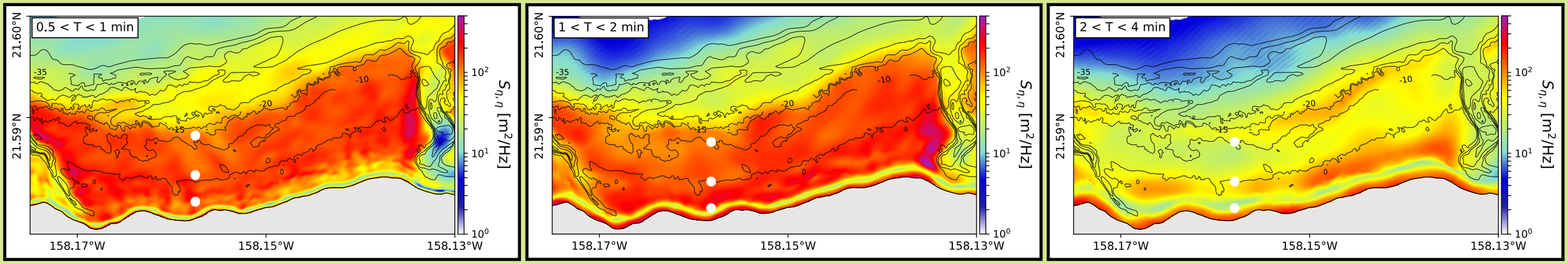






X-SHORE STANDING IG WAVES

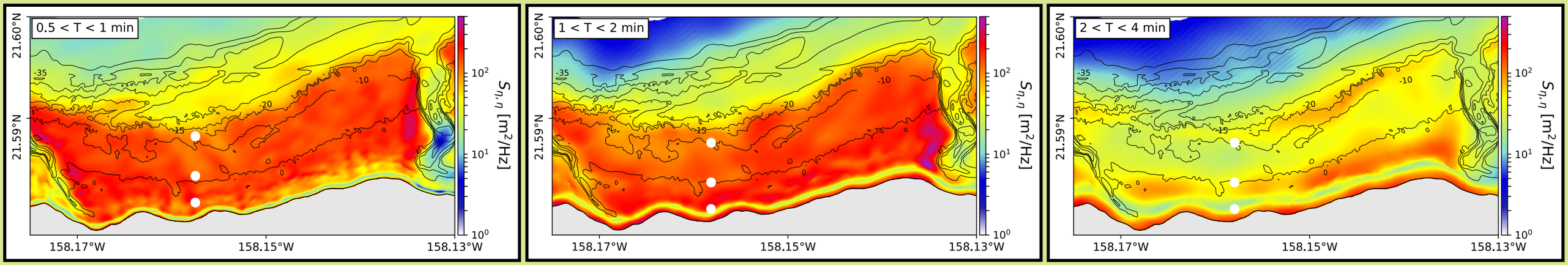
PSD



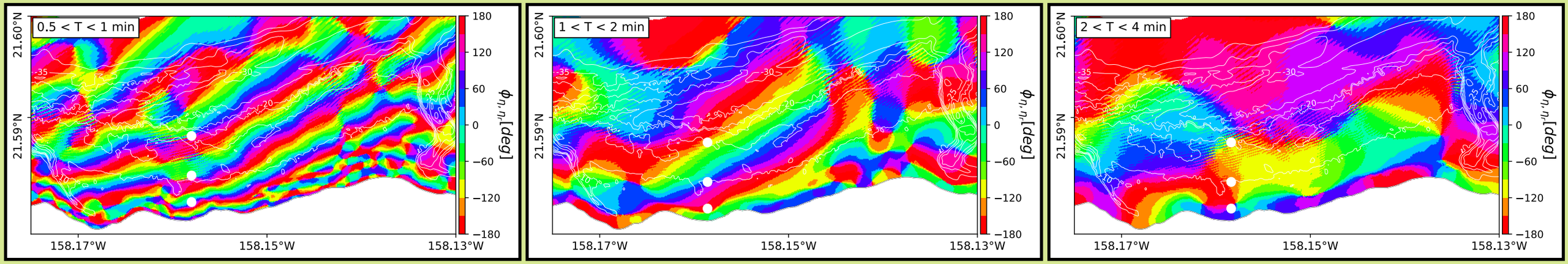
RESULTS: MODEL SPECTRAL MAPS [BOSZ]: NORTH SHORE, O'AHU

X-SHORE STANDING IG WAVES

PSD



Coherence Phase

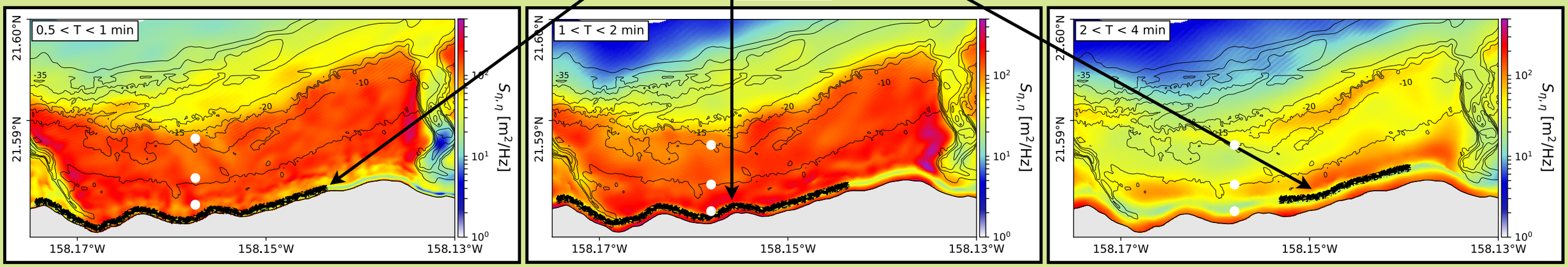


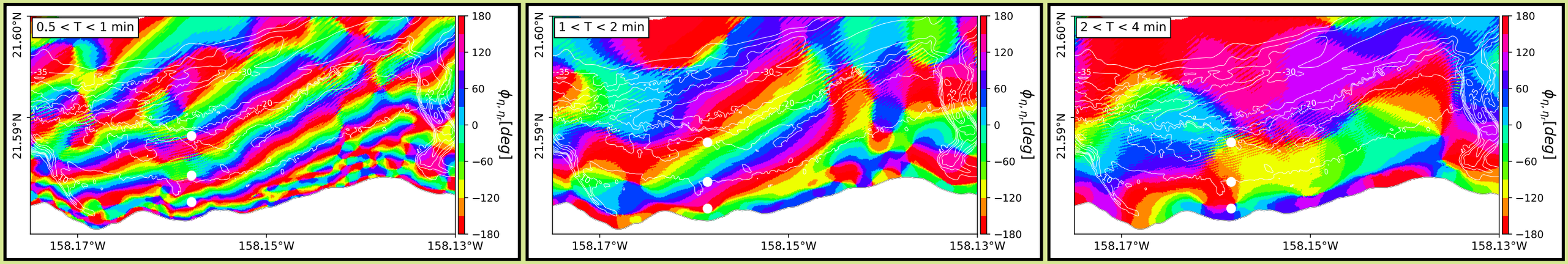
RESULTS: MODEL SPECTRAL MAPS [BOSZ]: NORTH SHORE, O'AHU

X-SHORE STANDING IG WAVES

Energy minima

PSD





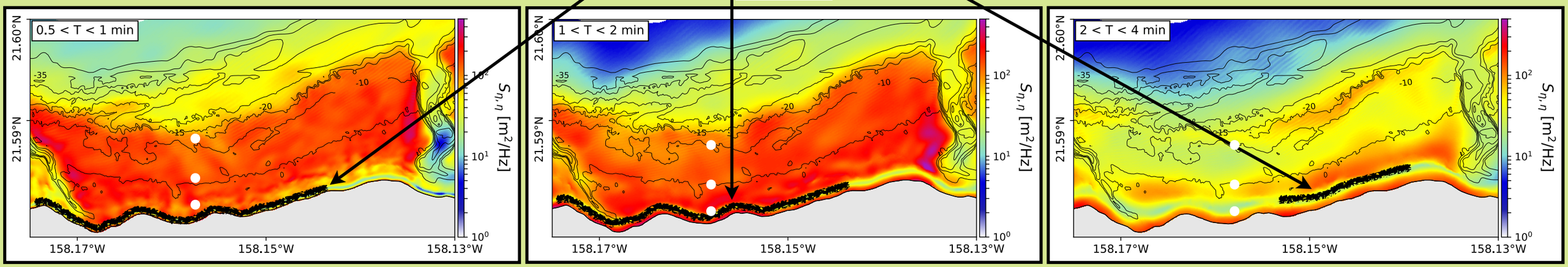
Coherence Phase

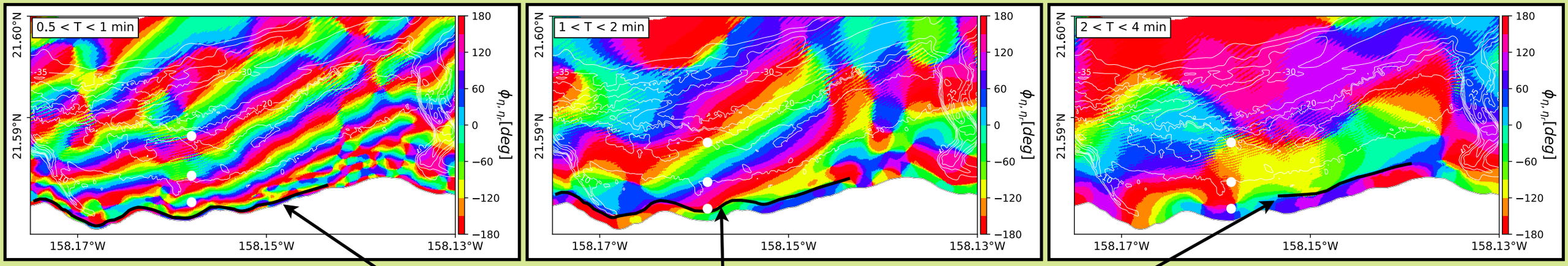
RESULTS: MODEL SPECTRAL MAPS [BOSZ]: NORTH SHORE, O'AHU

X-SHORE STANDING IG WAVES

Energy minima

PSD

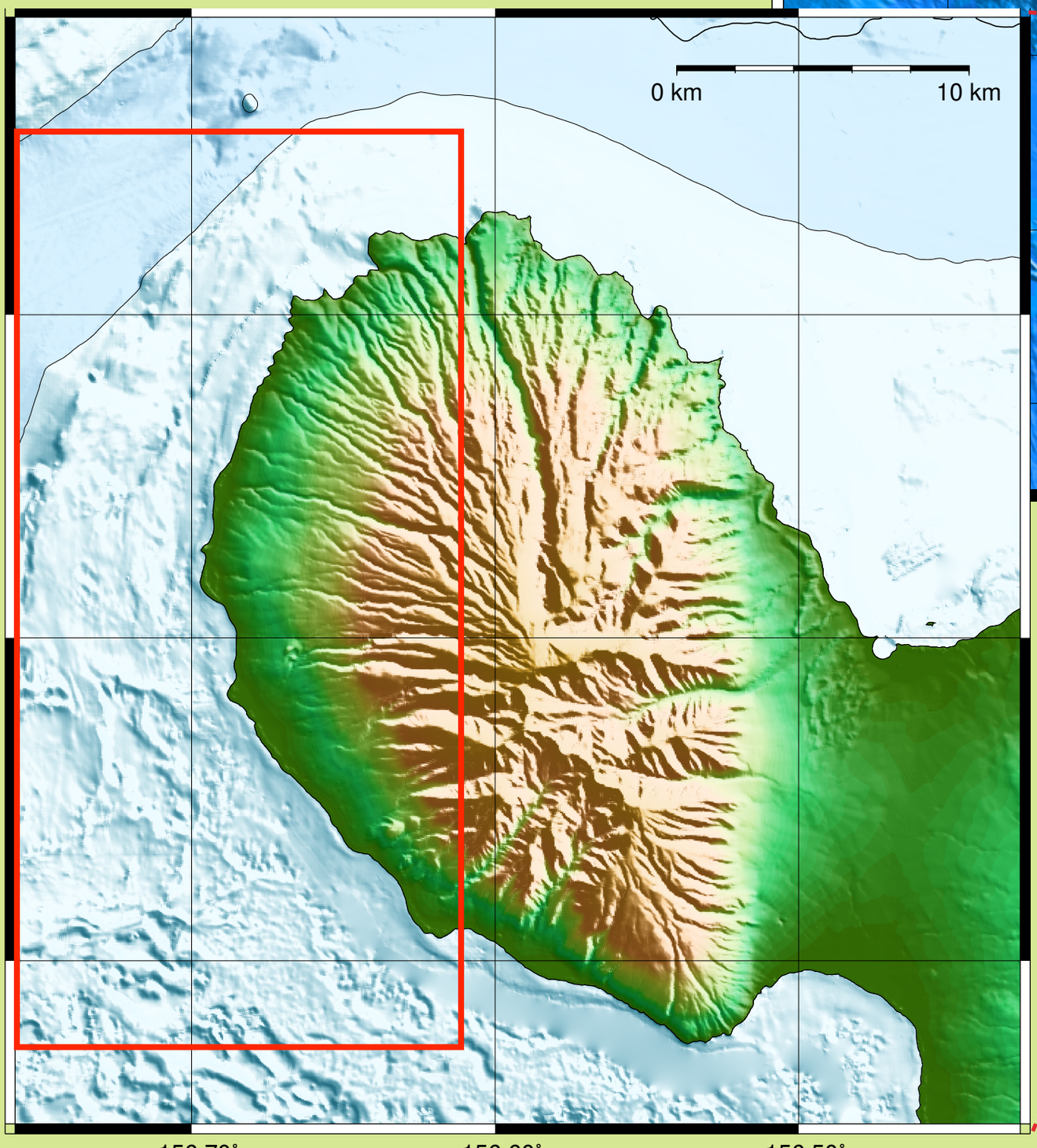


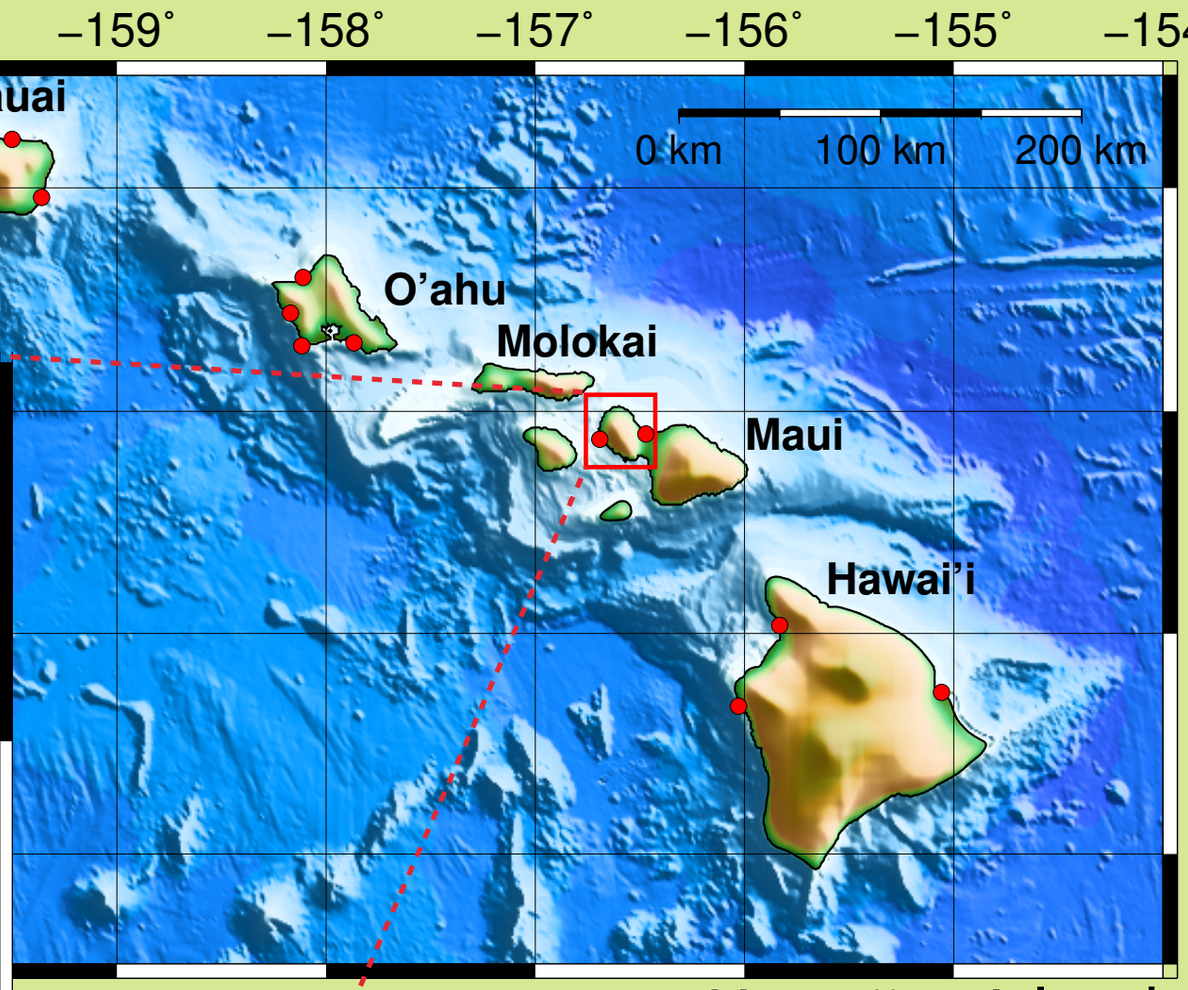


Coherence Phase

Nodal lines

COMPUTATIONAL DOMAIN: WEST MAUI

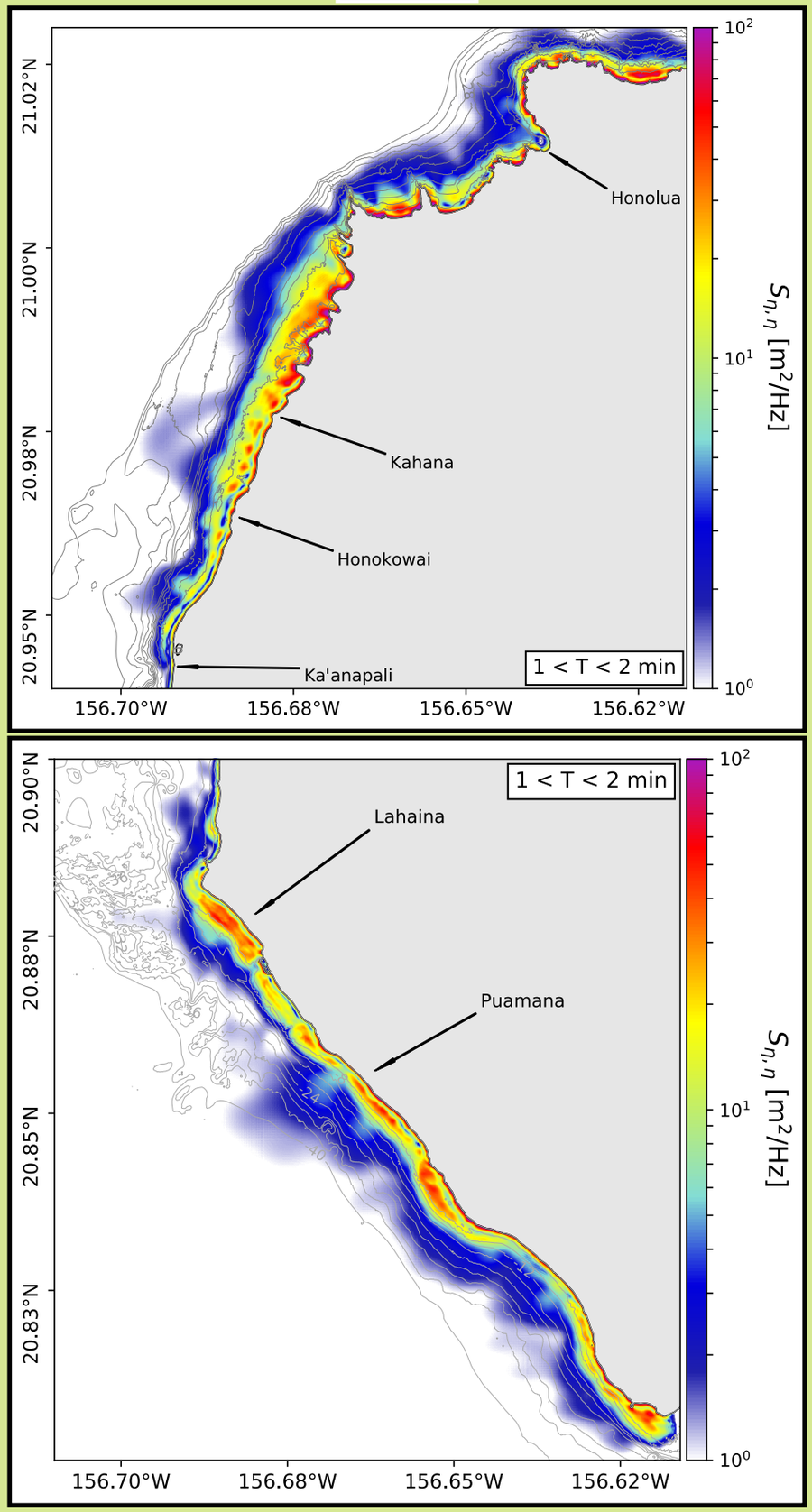




Hawaiian Islands

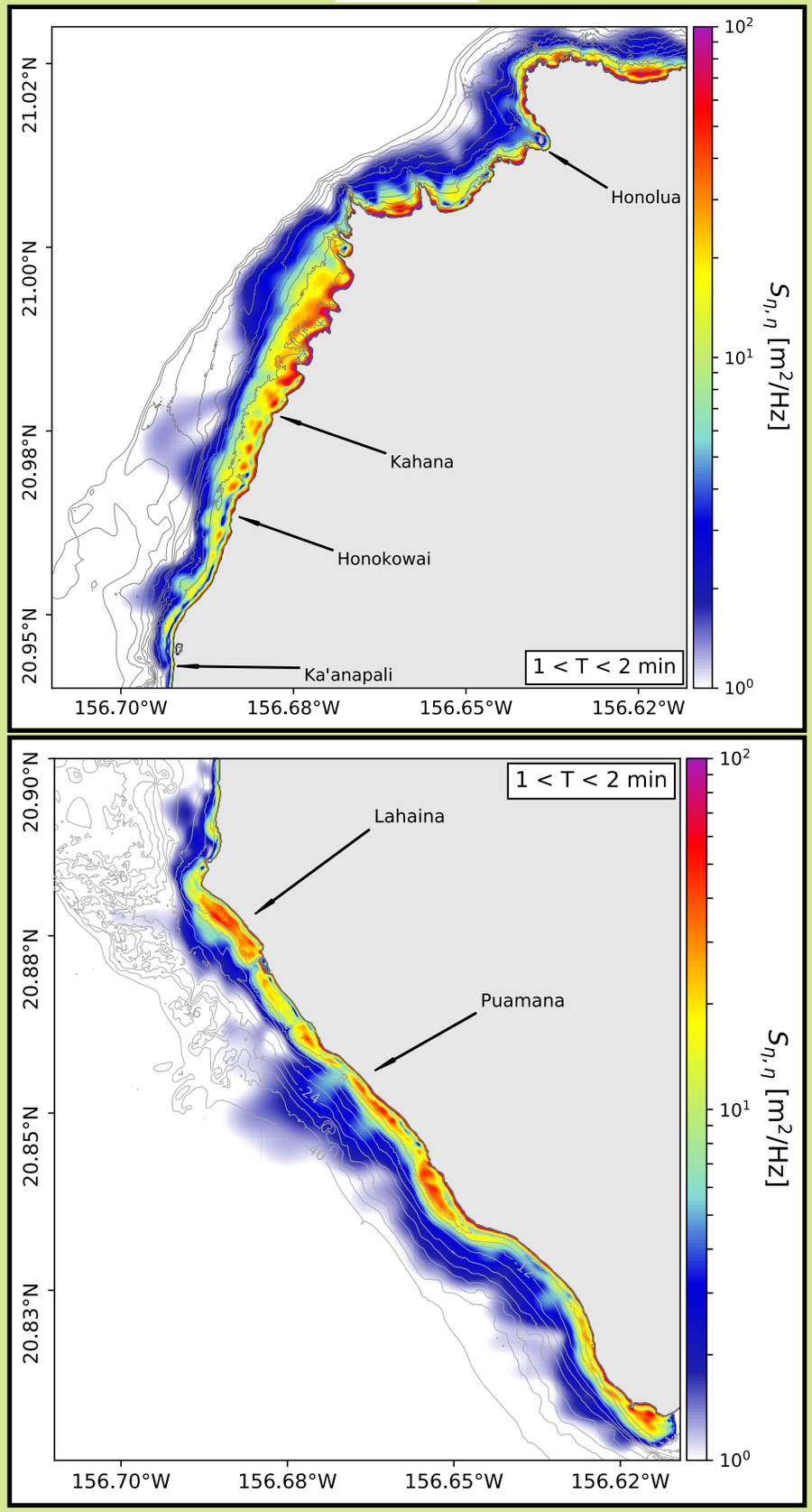
RESULTS: MODEL SPECTRAL MAPS [BOSZ]: WEST MAUI

PSD

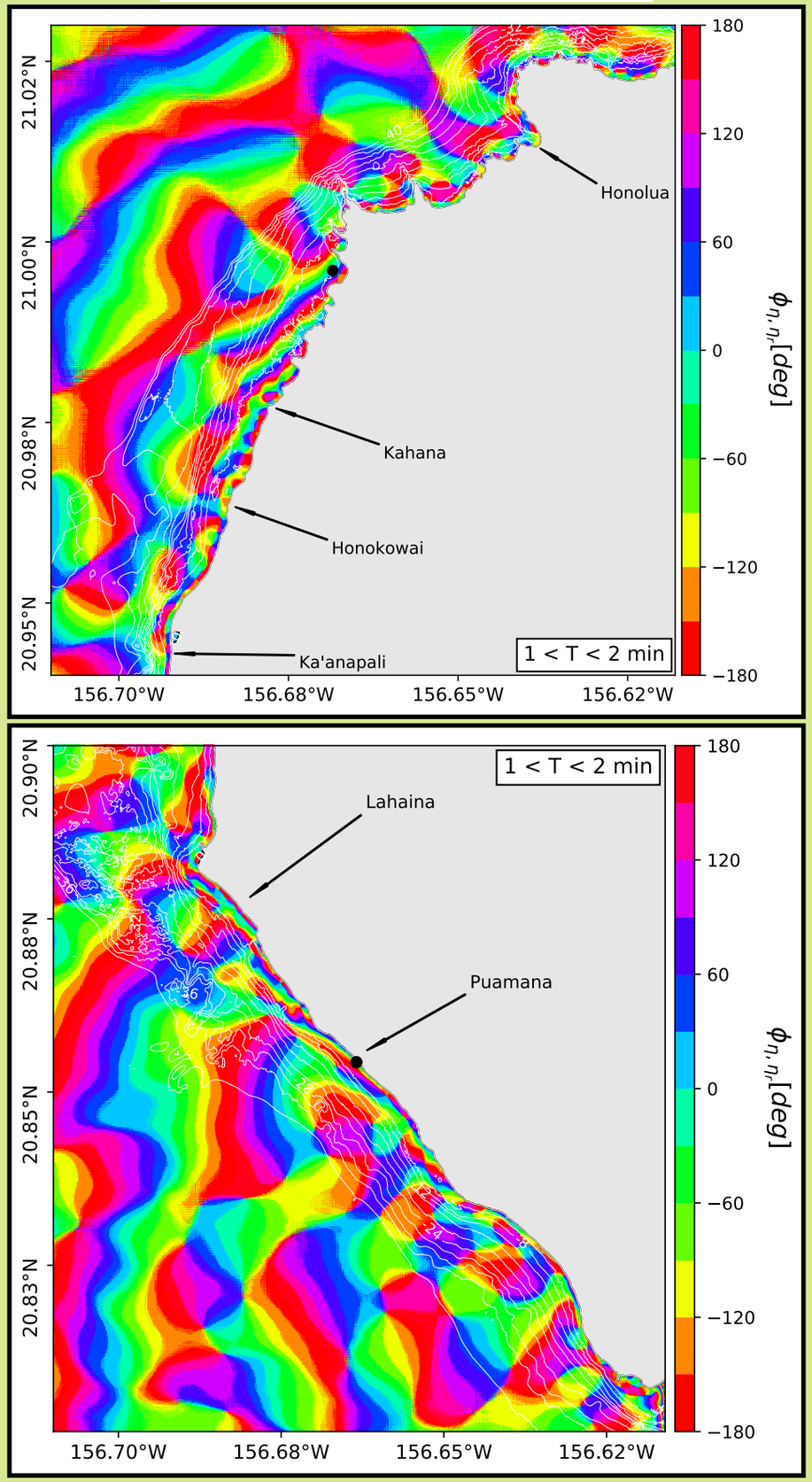


RESULTS: MODEL SPECTRAL MAPS [BOSZ]: WEST MAUI

PSD

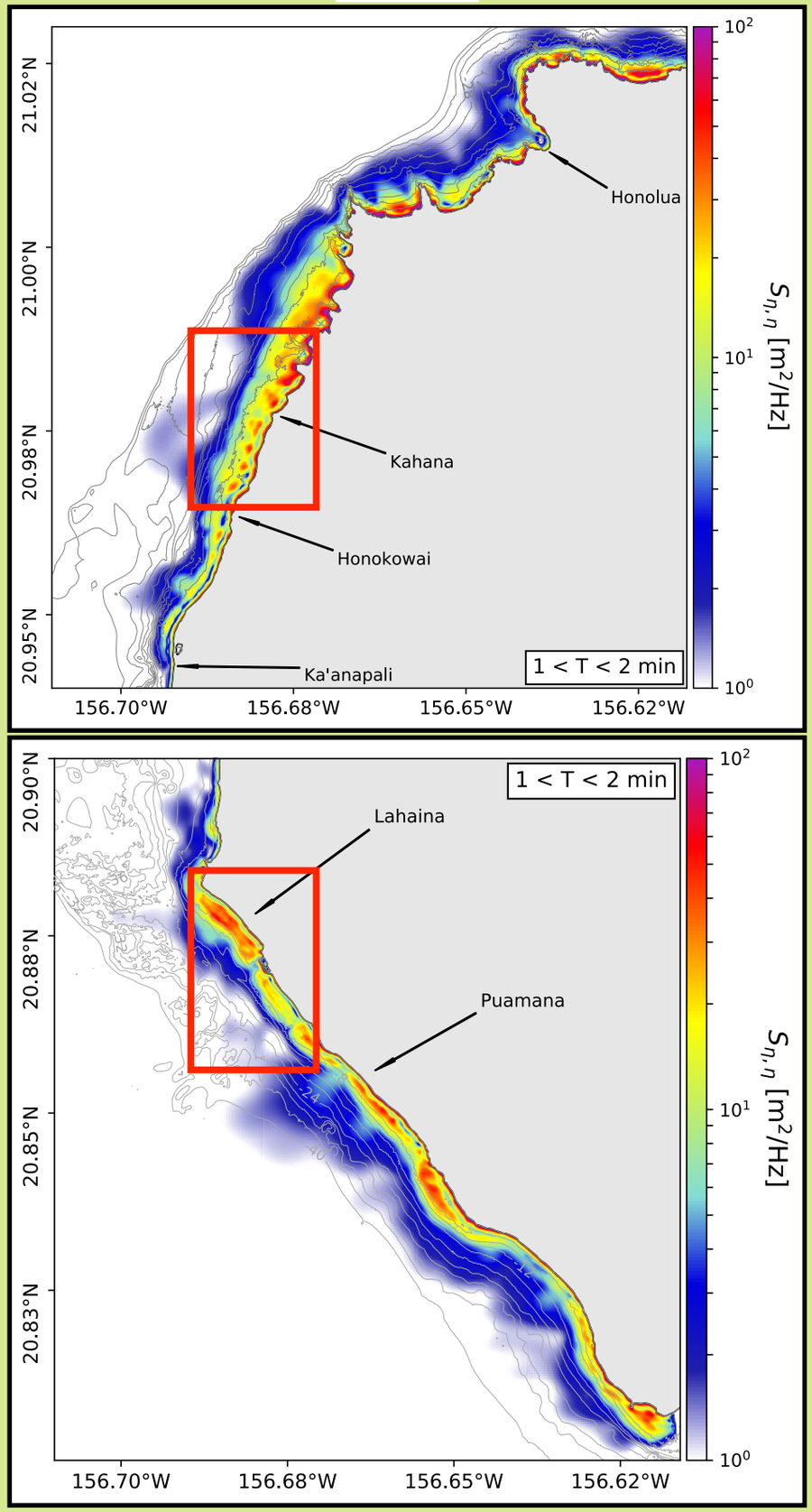


Coherence Phase

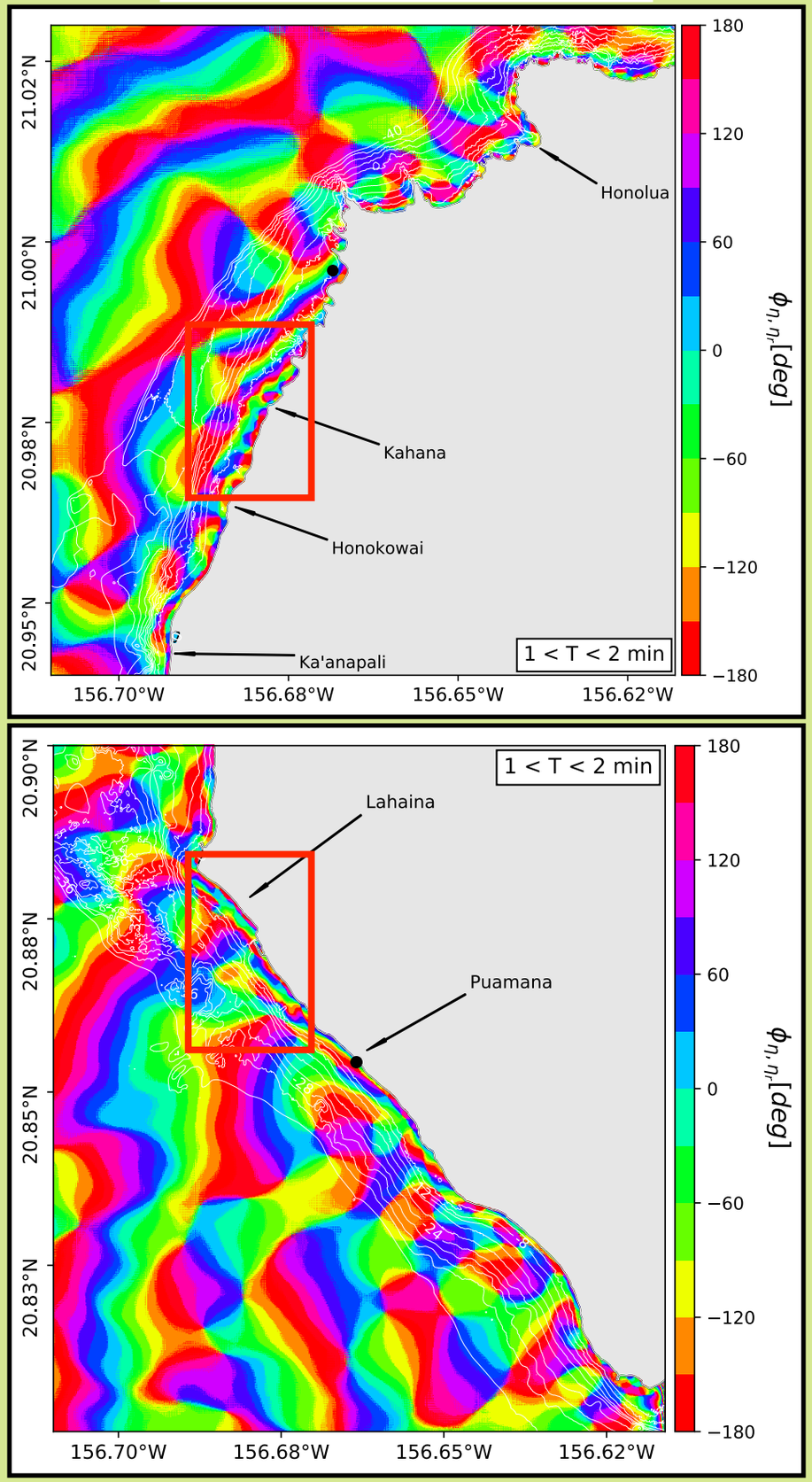


RESULTS: MODEL SPECTRAL MAPS [BOSZ]: WEST MAUI

PSD

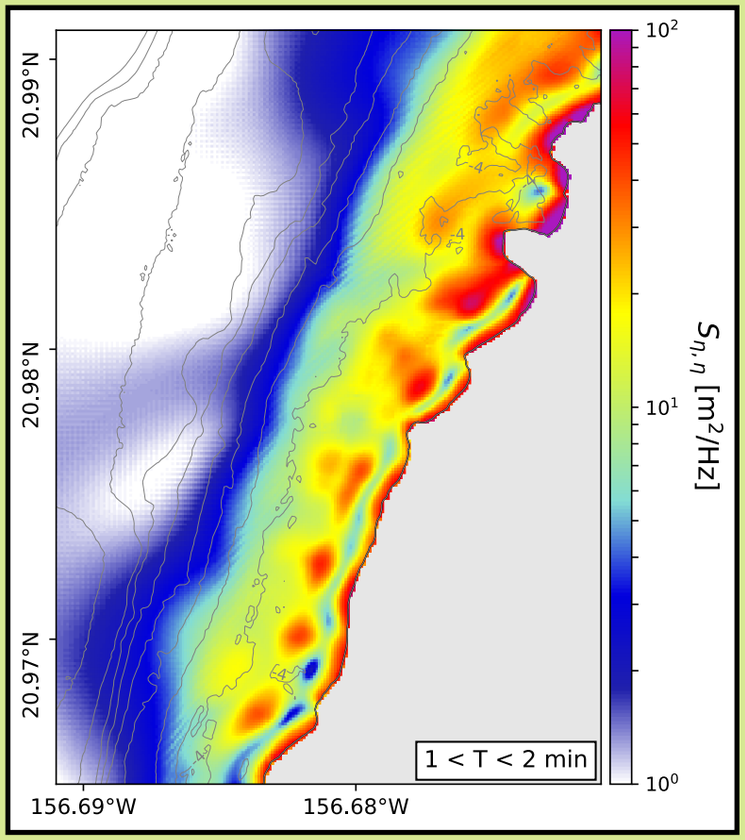


Coherence Phase

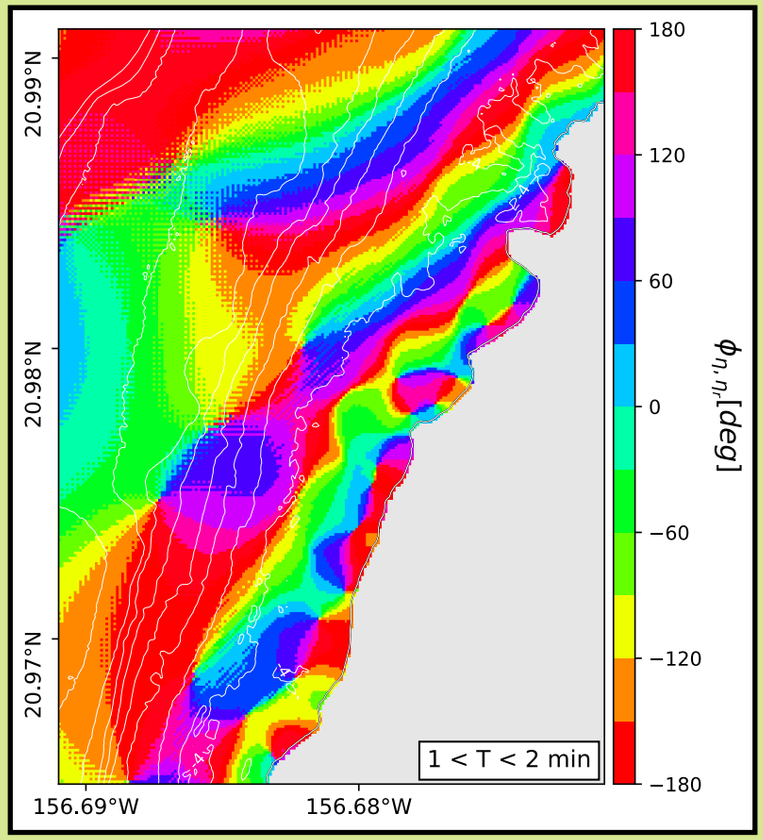


RESULTS: MODEL SPECTRAL MAPS [BOSZ]: WEST MAUI

PSD

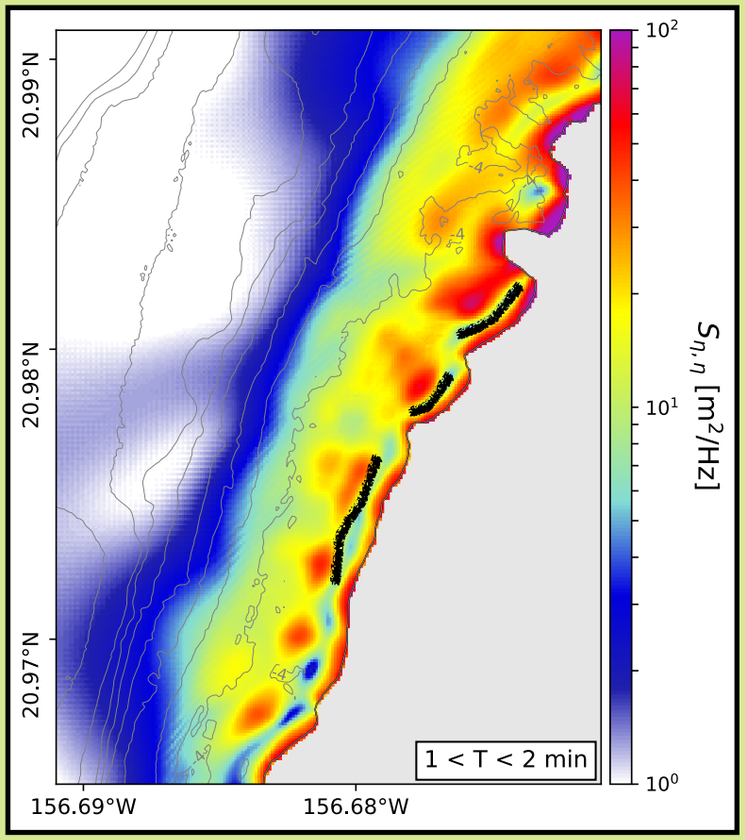


Coherence Phase

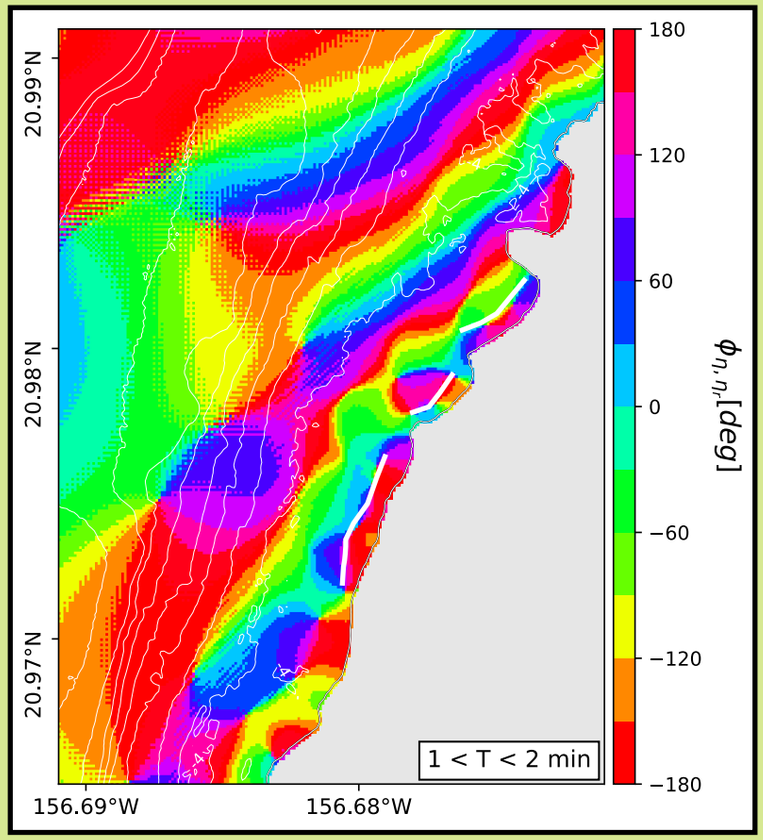


RESULTS: MODEL SPECTRAL MAPS [BOSZ]: WEST MAUI

PSD

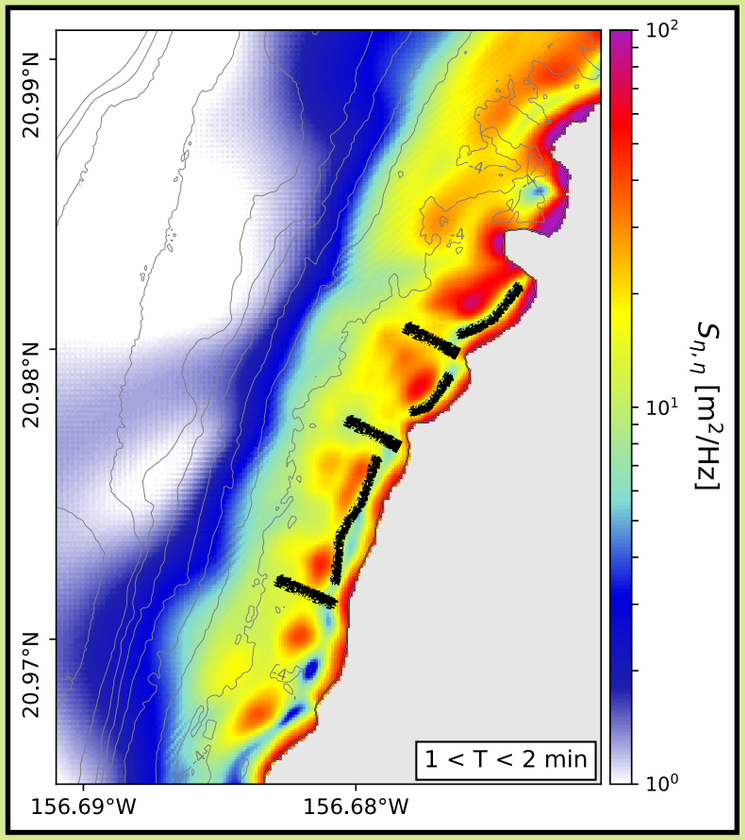


Coherence Phase

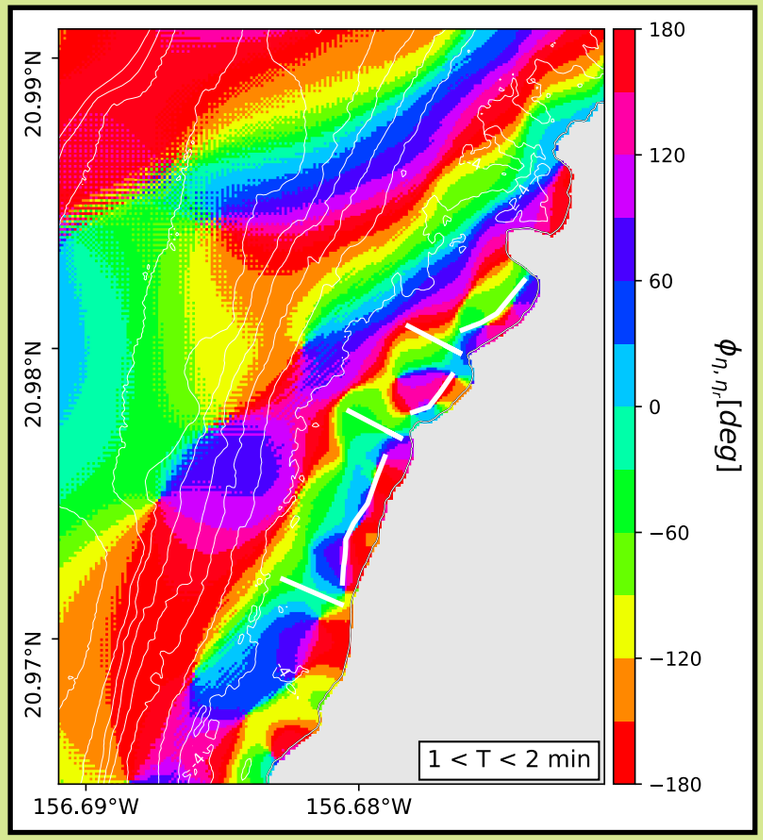


RESULTS: MODEL SPECTRAL MAPS [BOSZ]: WEST MAUI

PSD

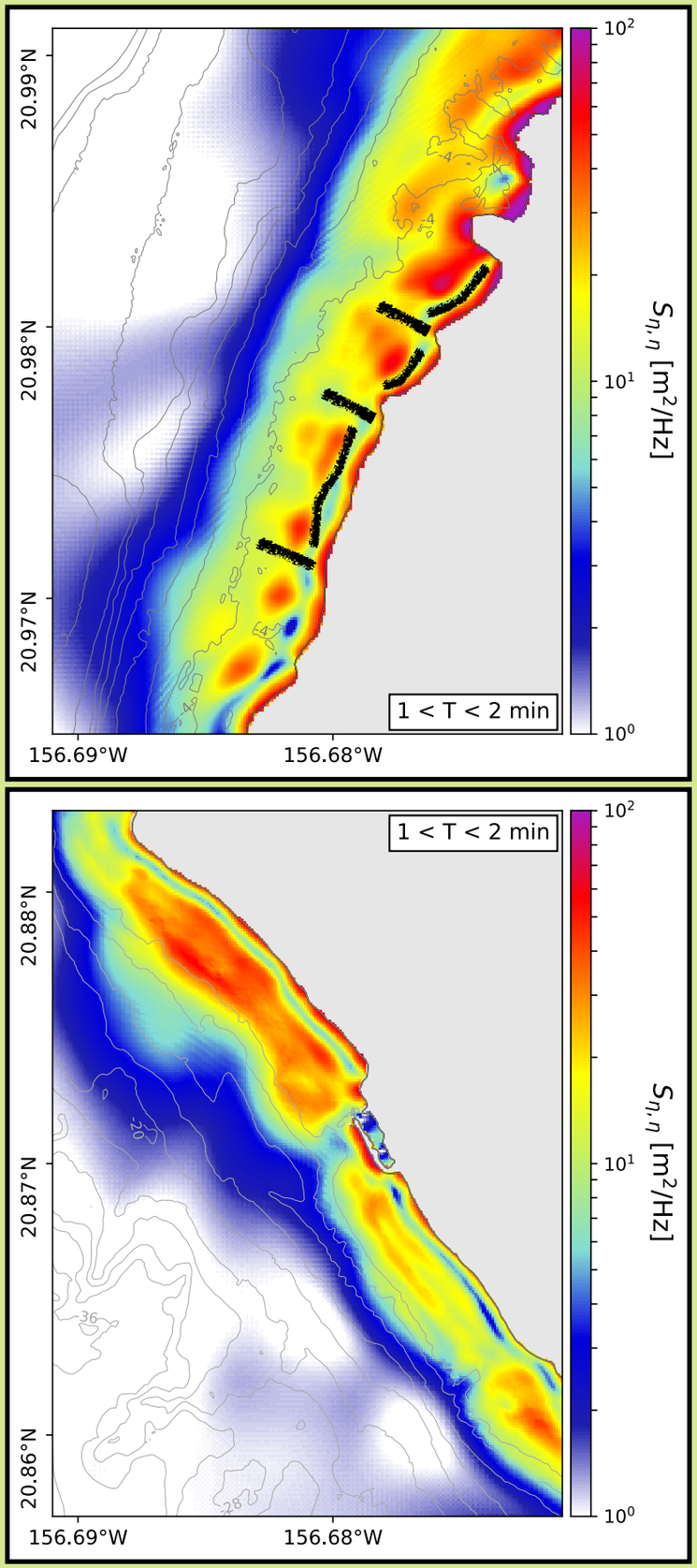


Coherence Phase

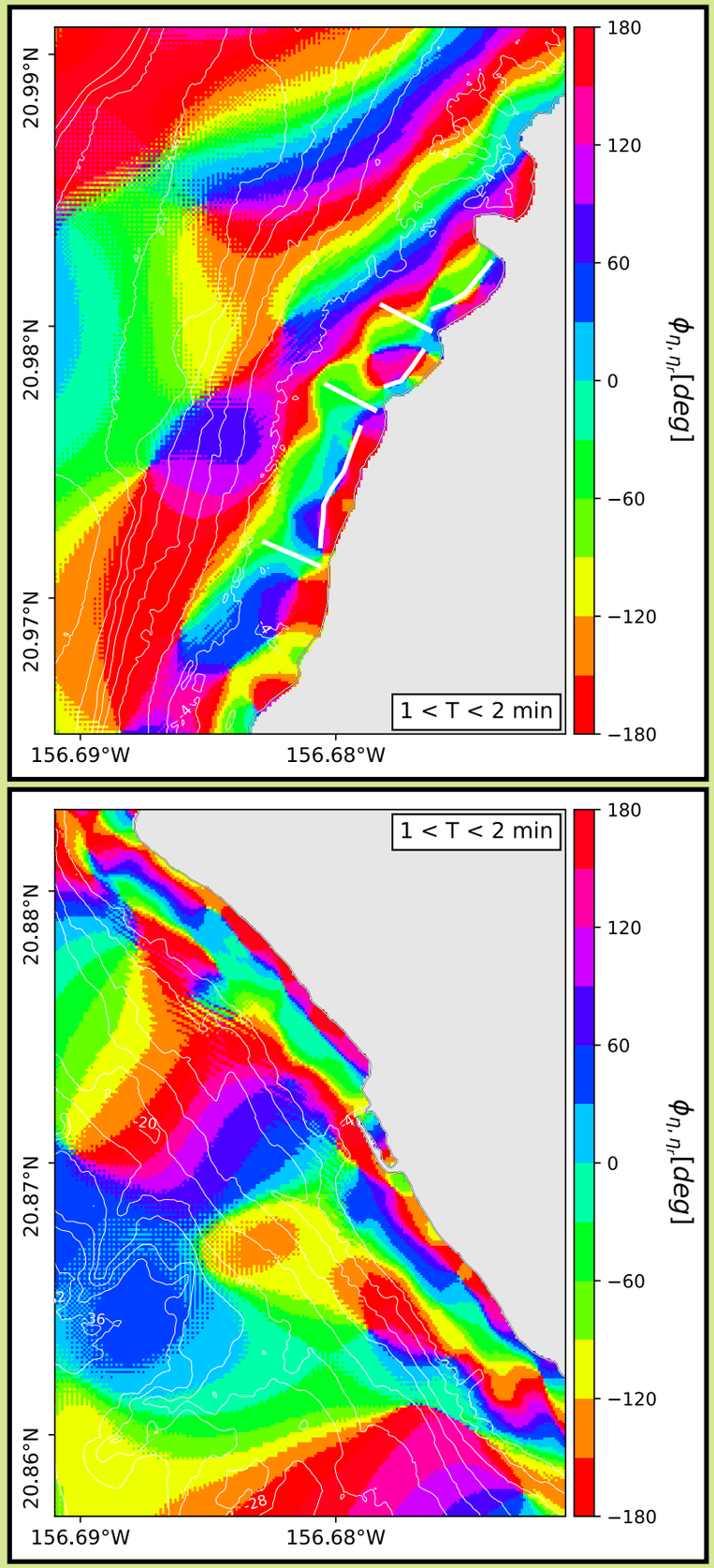


RESULTS: MODEL SPECTRAL MAPS [BOSZ]: WEST MAUI

PSD

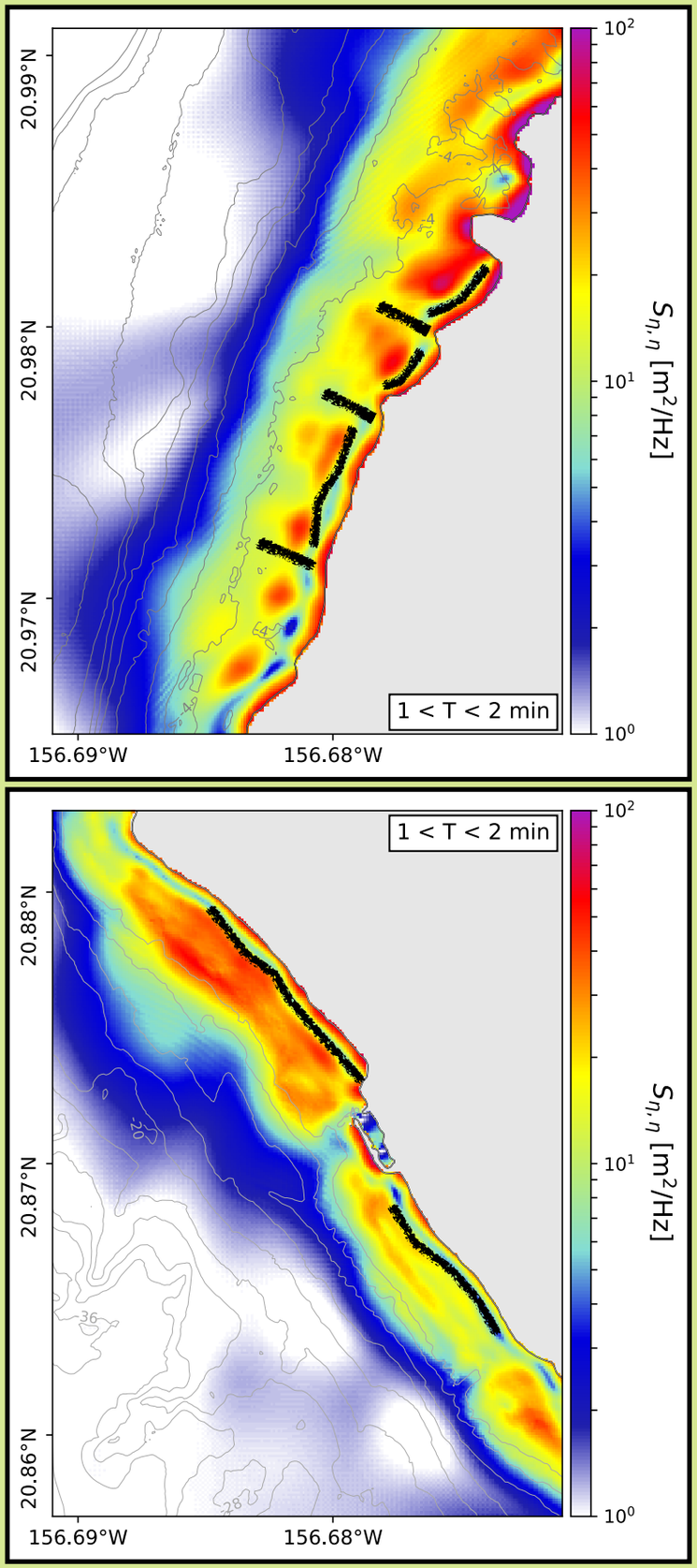


Coherence Phase

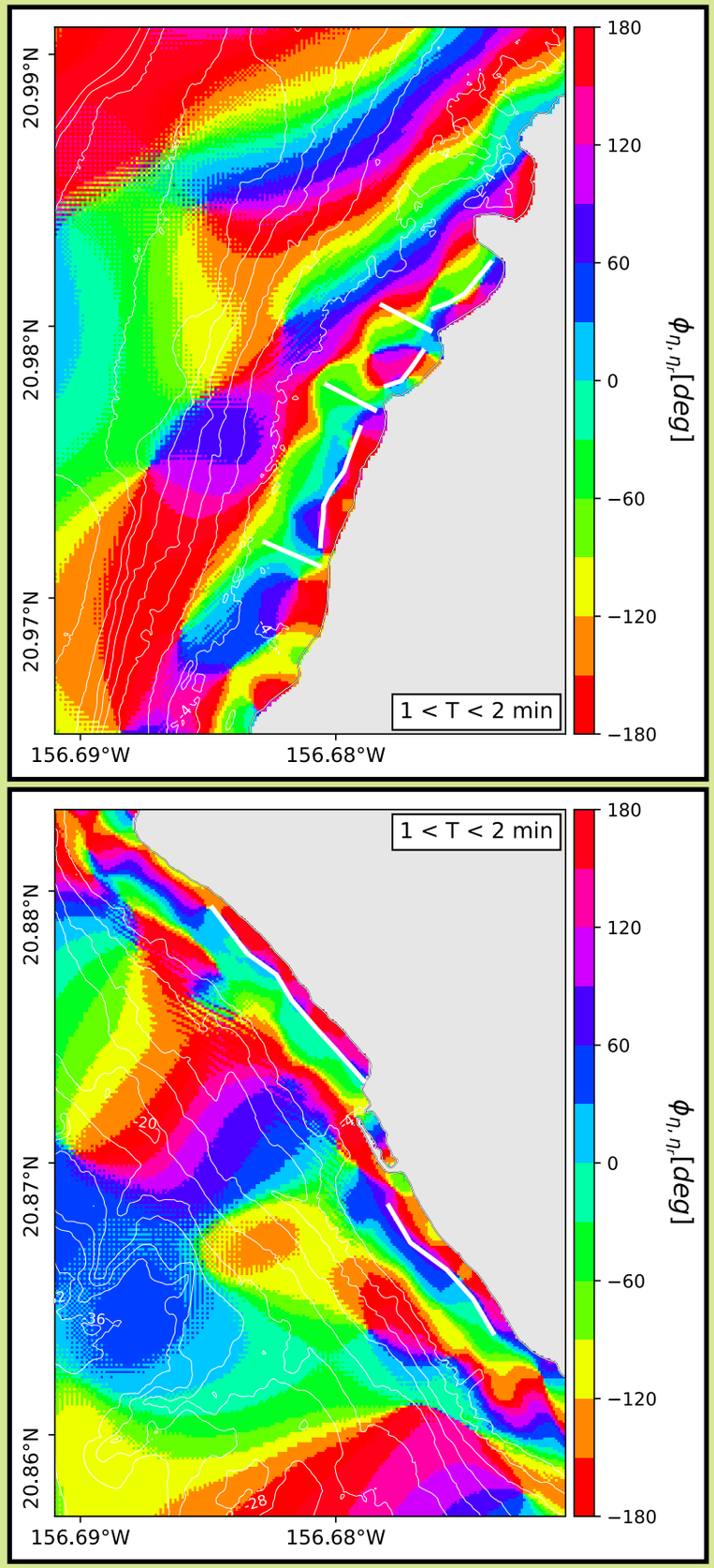


RESULTS: MODEL SPECTRAL MAPS [BOSZ]: WEST MAUI

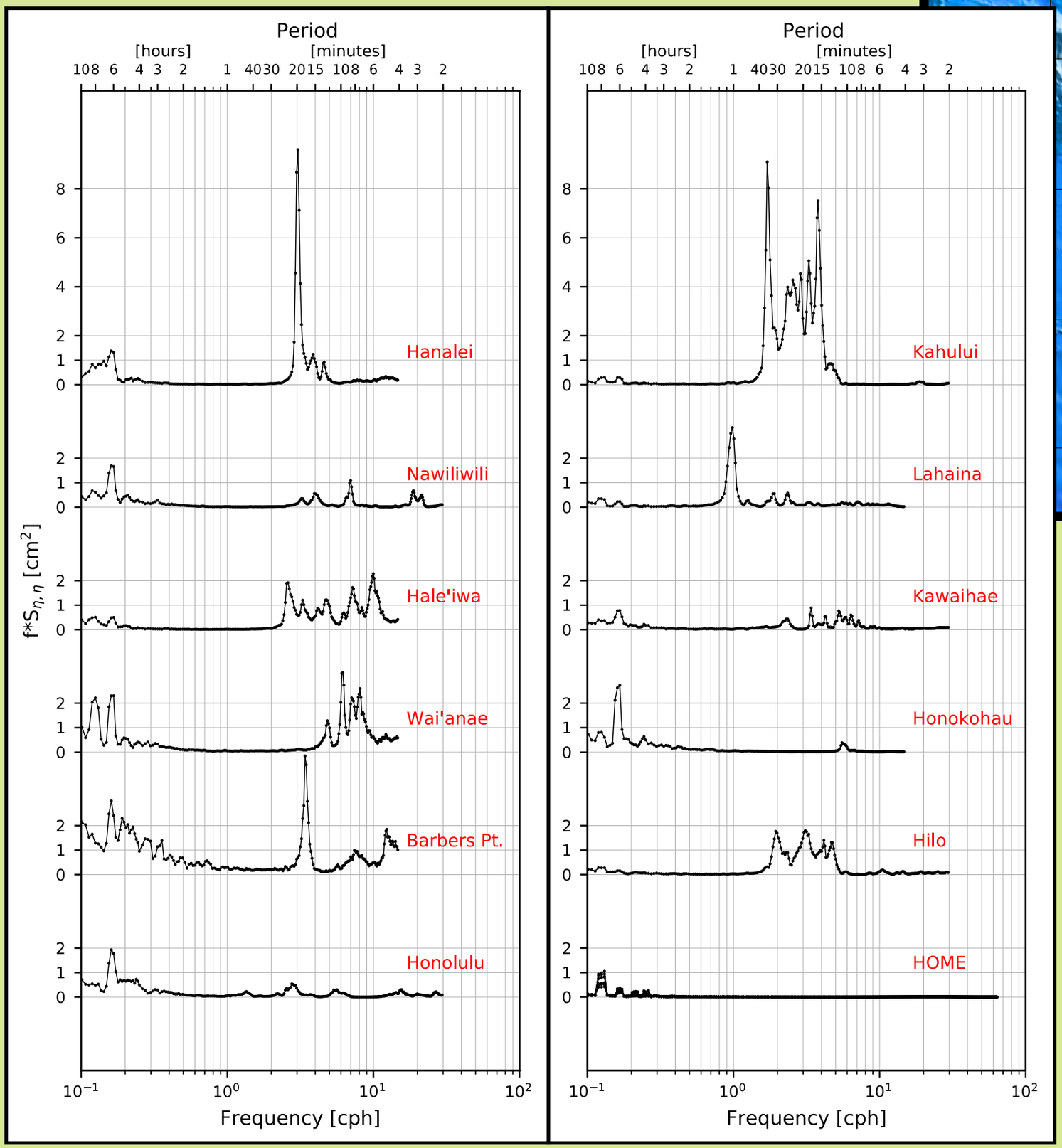
PSD

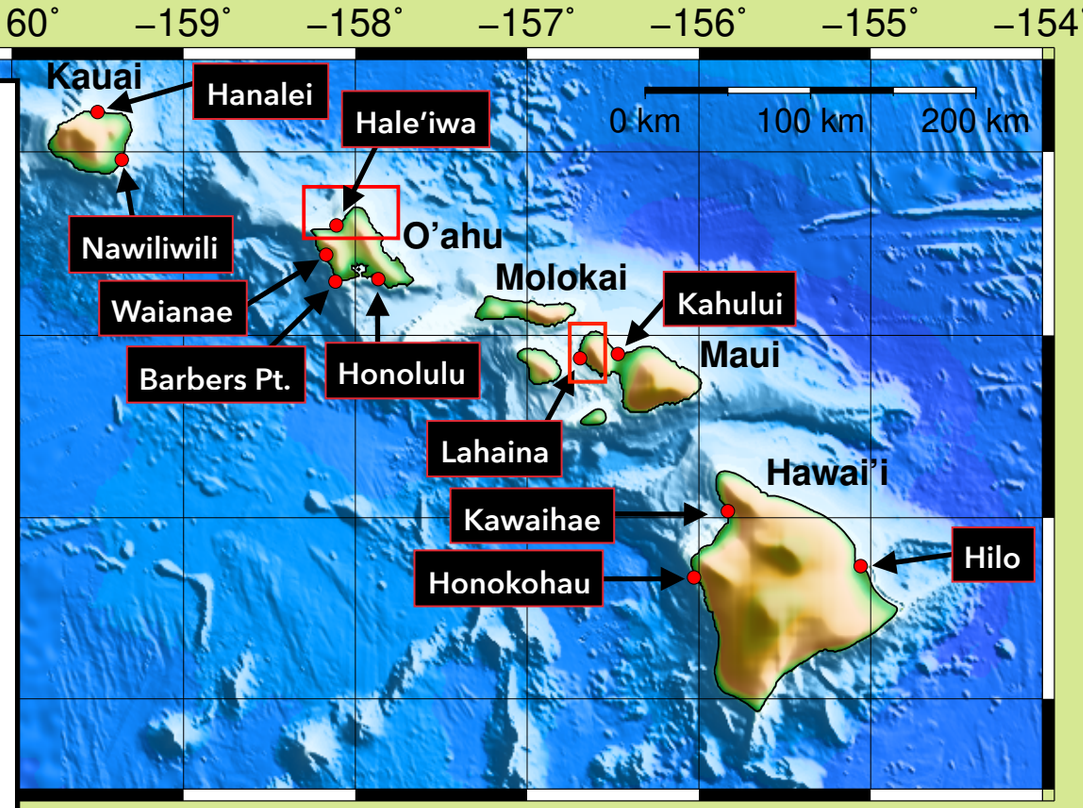


Coherence Phase

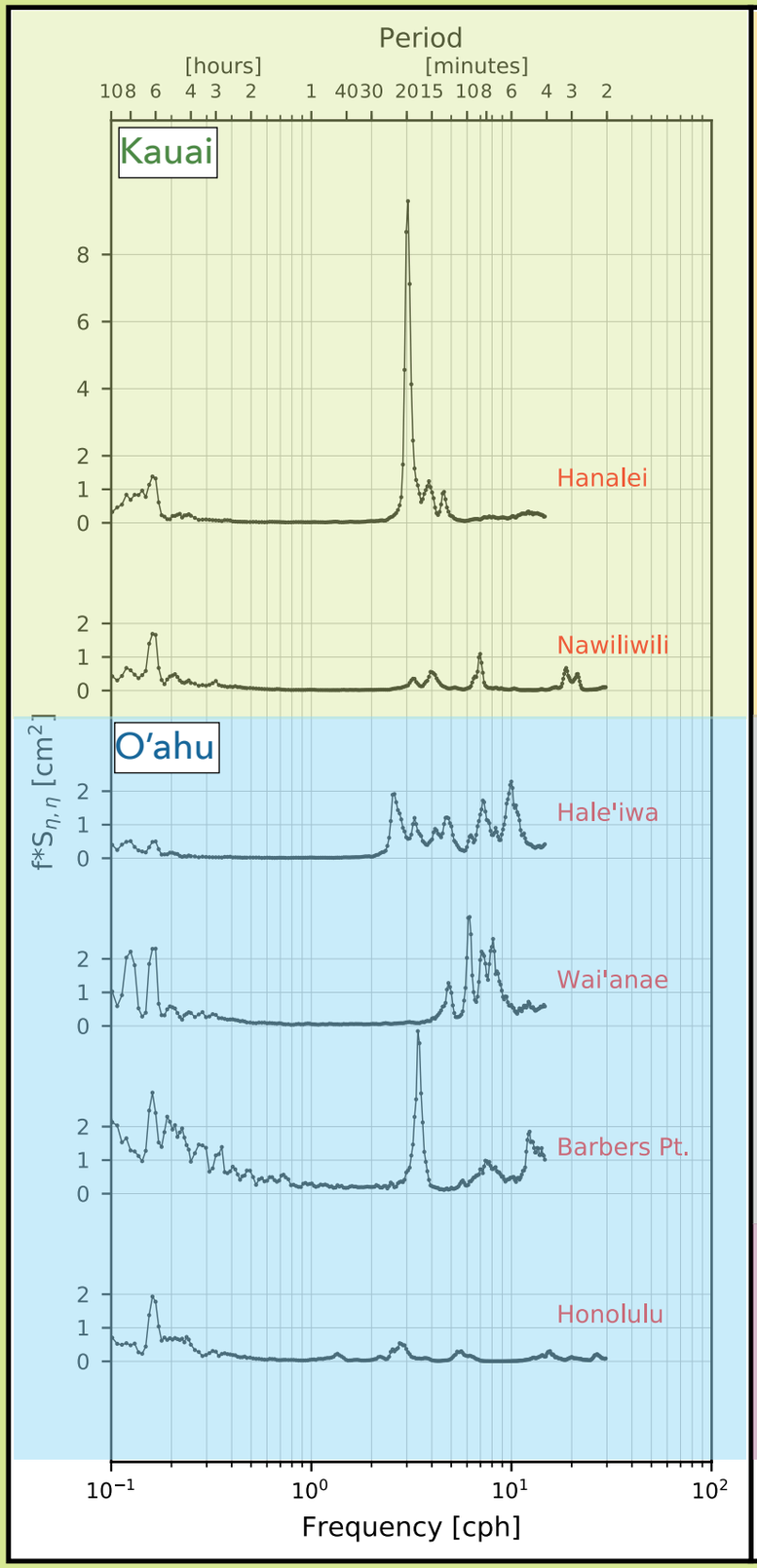


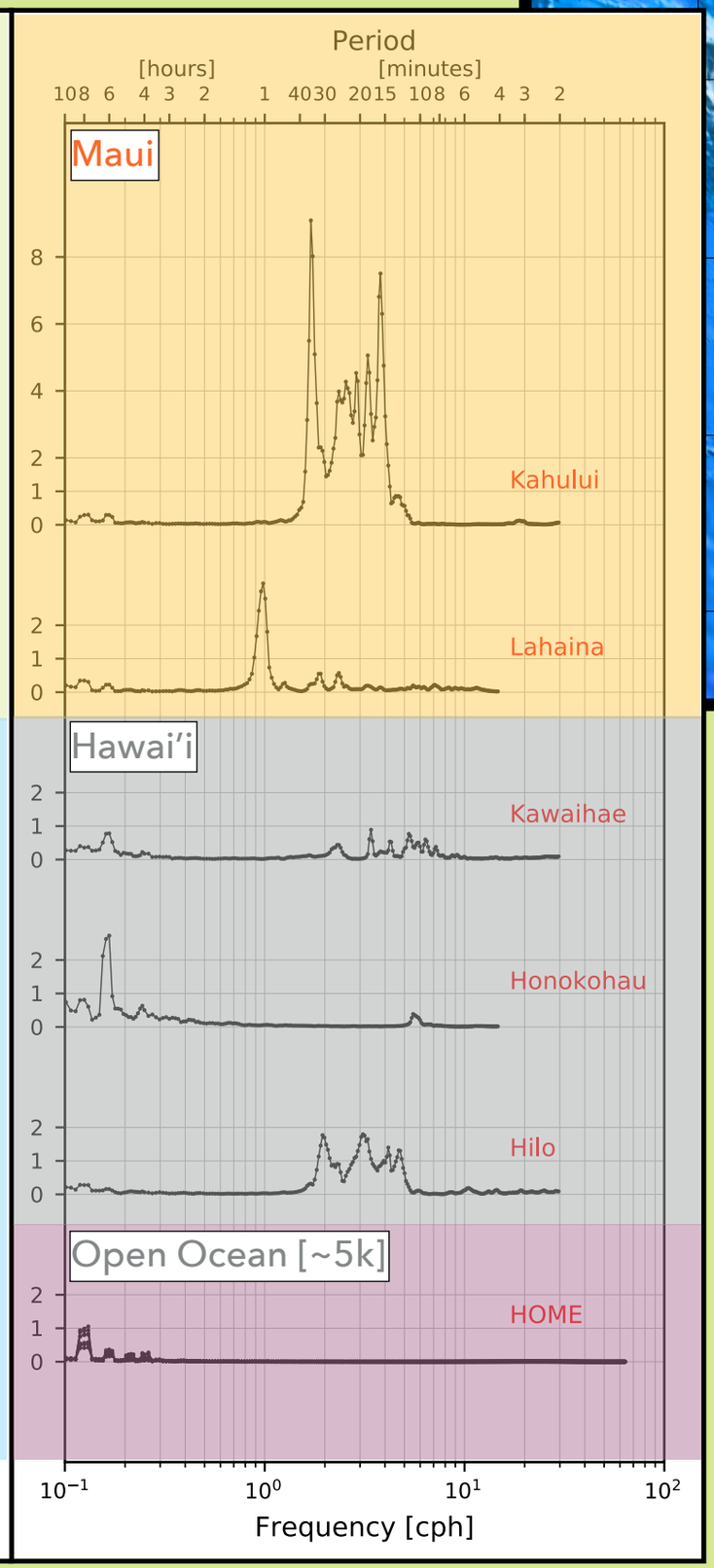
MODES ACROSS THE HAWAIIAN ISLANDS

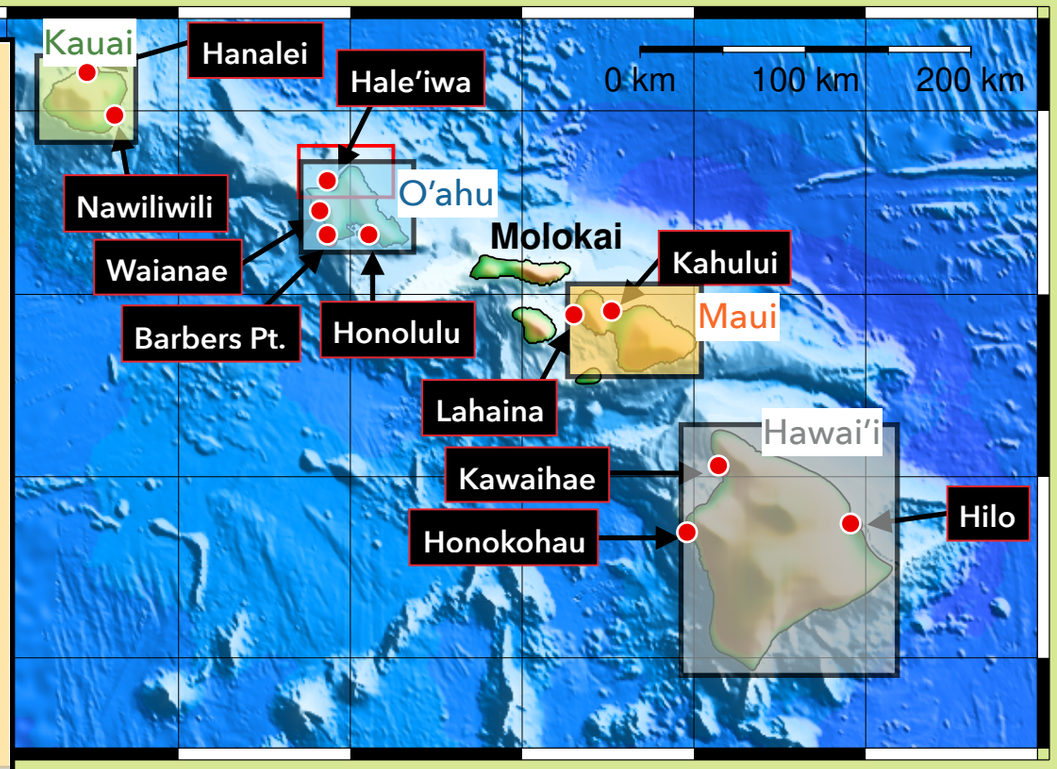




MODES ACROSS THE HAWAIIAN ISLANDS







CONCLUSIONS

Observations:

- A suite of harbor/coastal modes excited under weak forcing.
- Modal response no longer dominant under strong SS forcing.

Phase-Resolving Numerical Modeling:

- Spectral levels and content agree well with harbor and reef observations.
- Complex spatial IG distribution revealed.
  - X-shore standing wave patterns that scale as a function of IG frequency → edge/leaky waves.

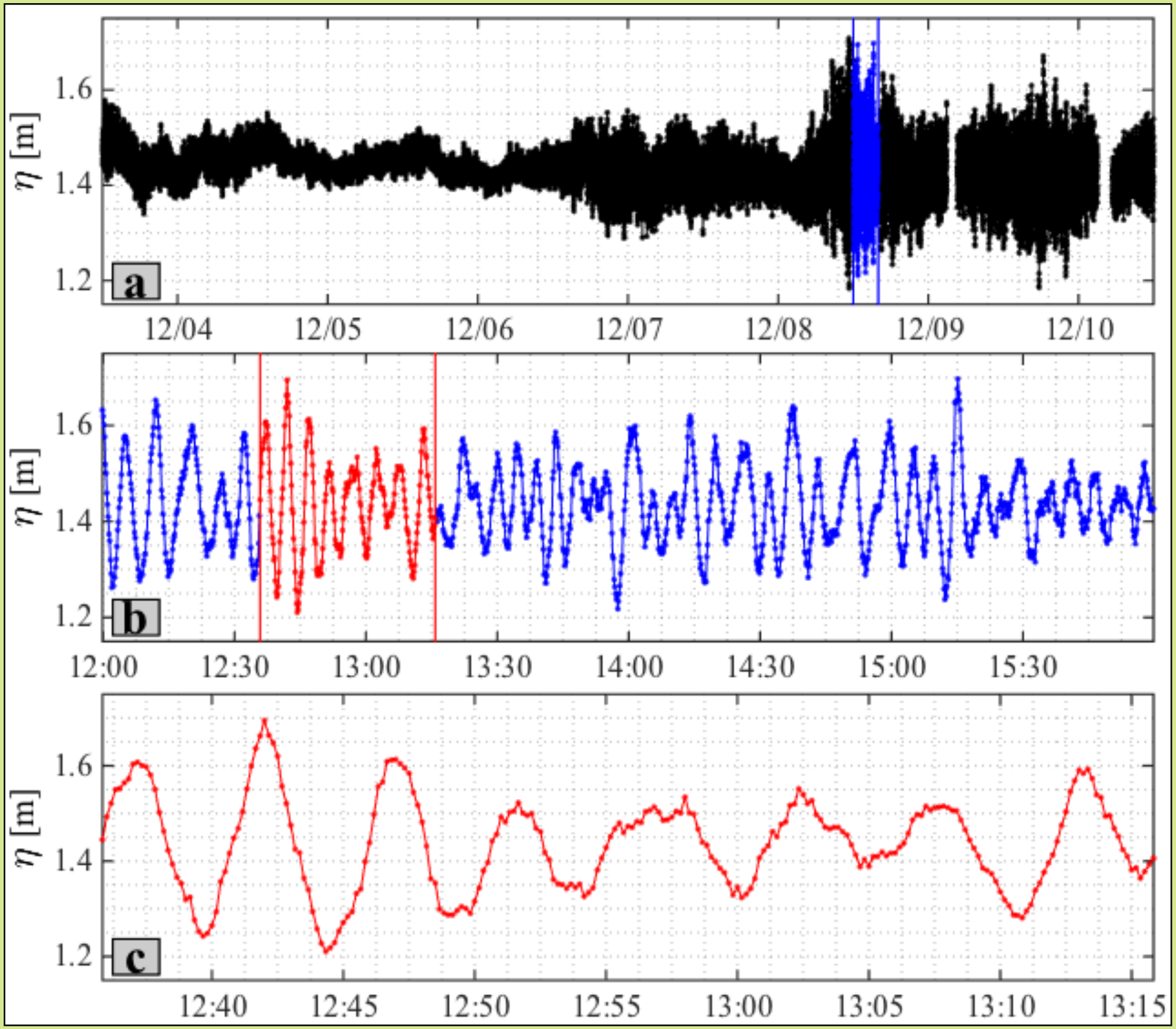
→ Understanding the dynamics of harbor oscillations requires understanding of the dynamics at the coast.

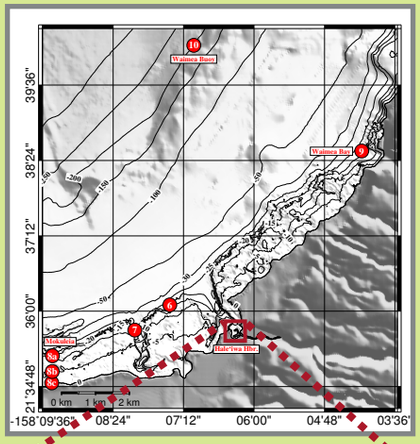
THANK YOU!

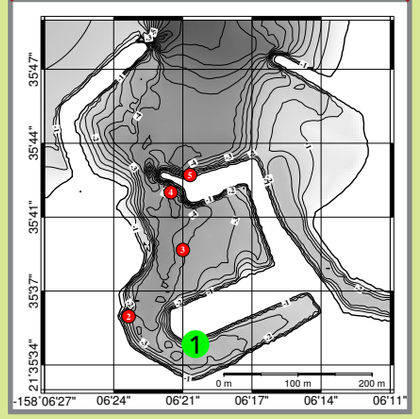
Contact: assaf@hawaii.edu

ADDITIONAL RESULTS

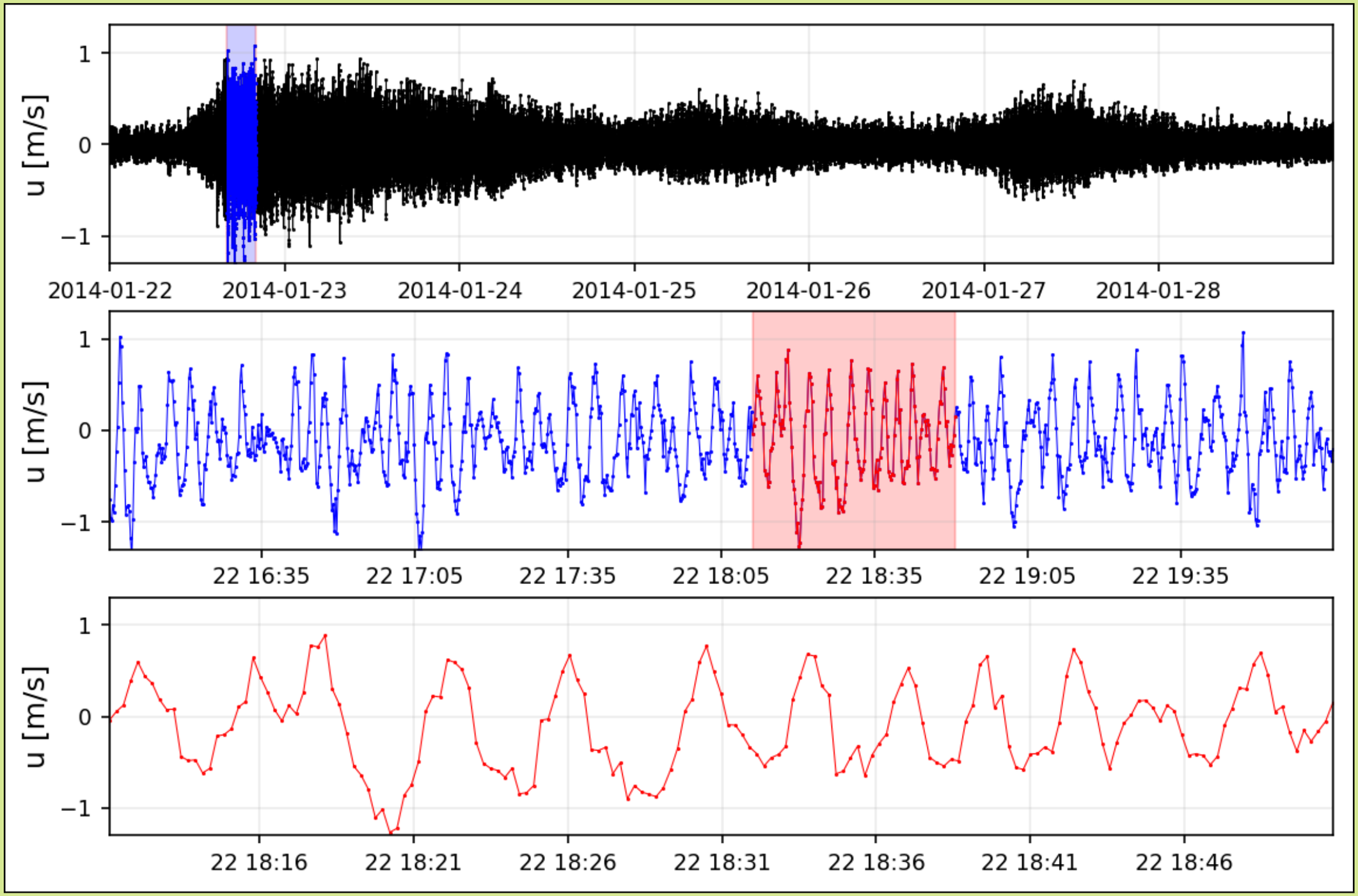
VARIABILITY IN HALE'IWA HARBOR: VELOCITY TIME SERIES

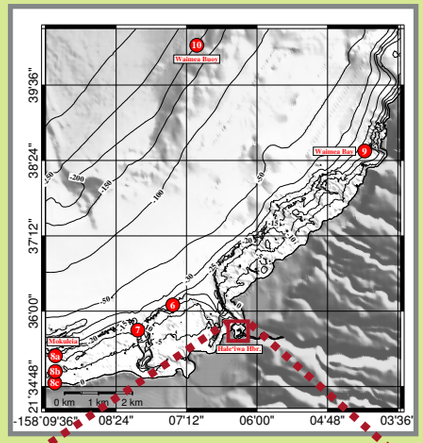


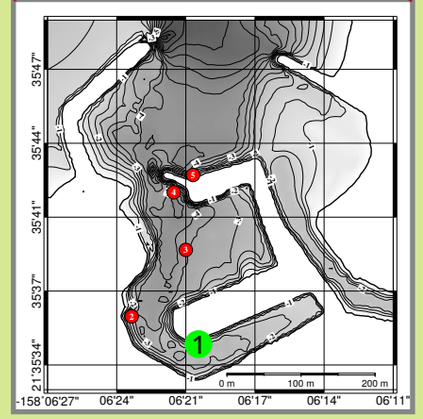




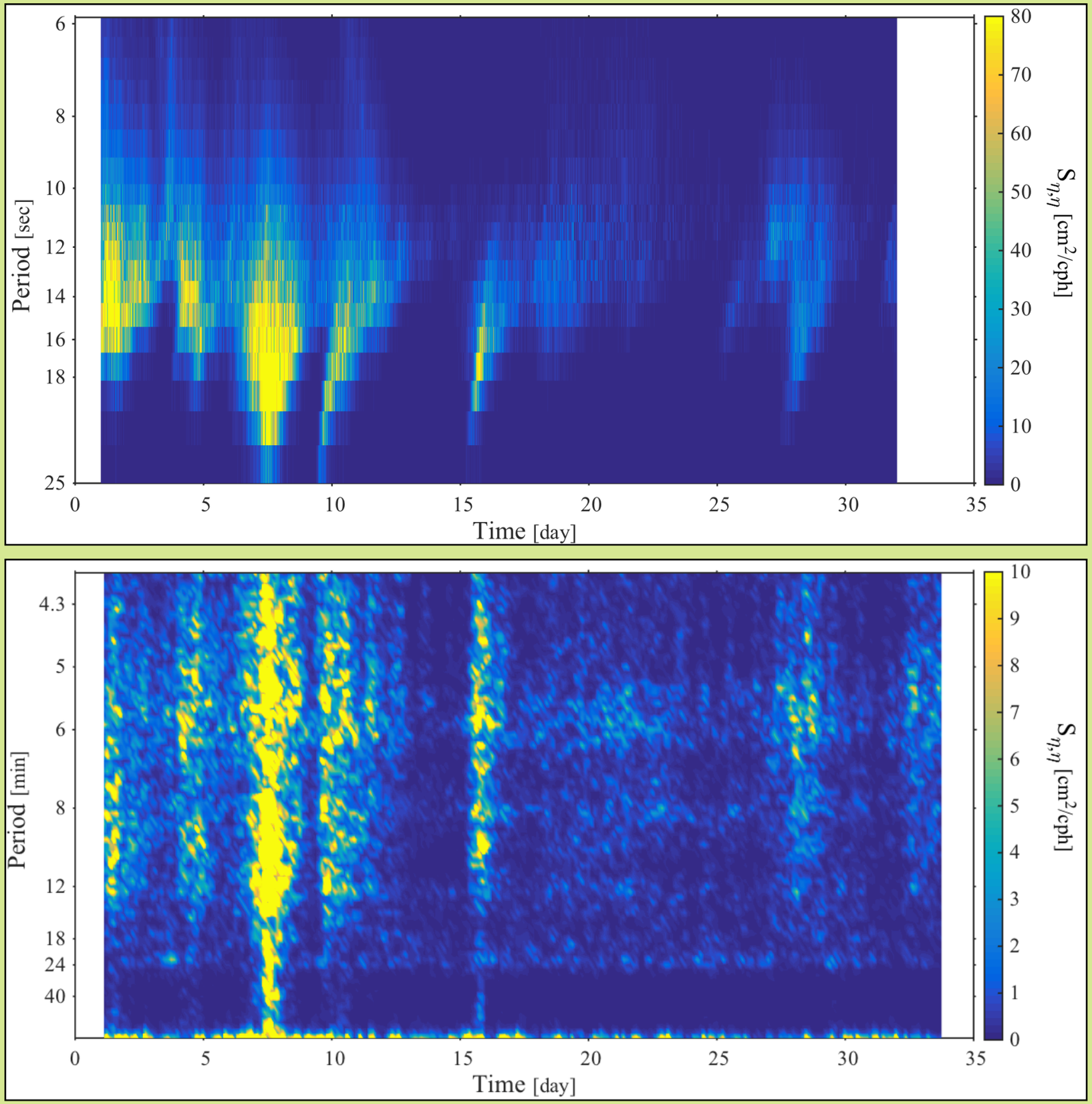
VARIABILITY IN HALE'IWA HARBOR: PRESSURE TIME SERIES



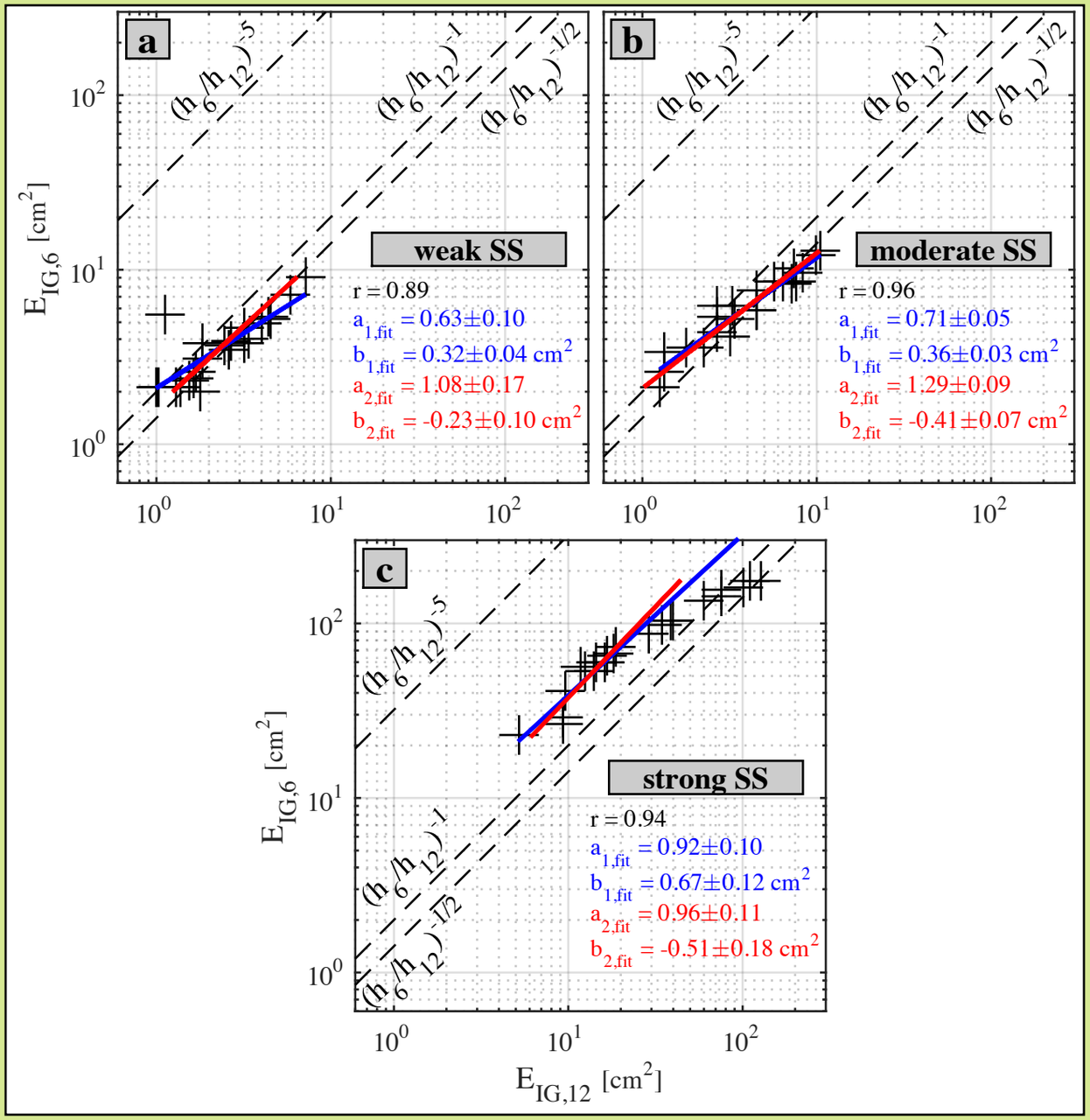




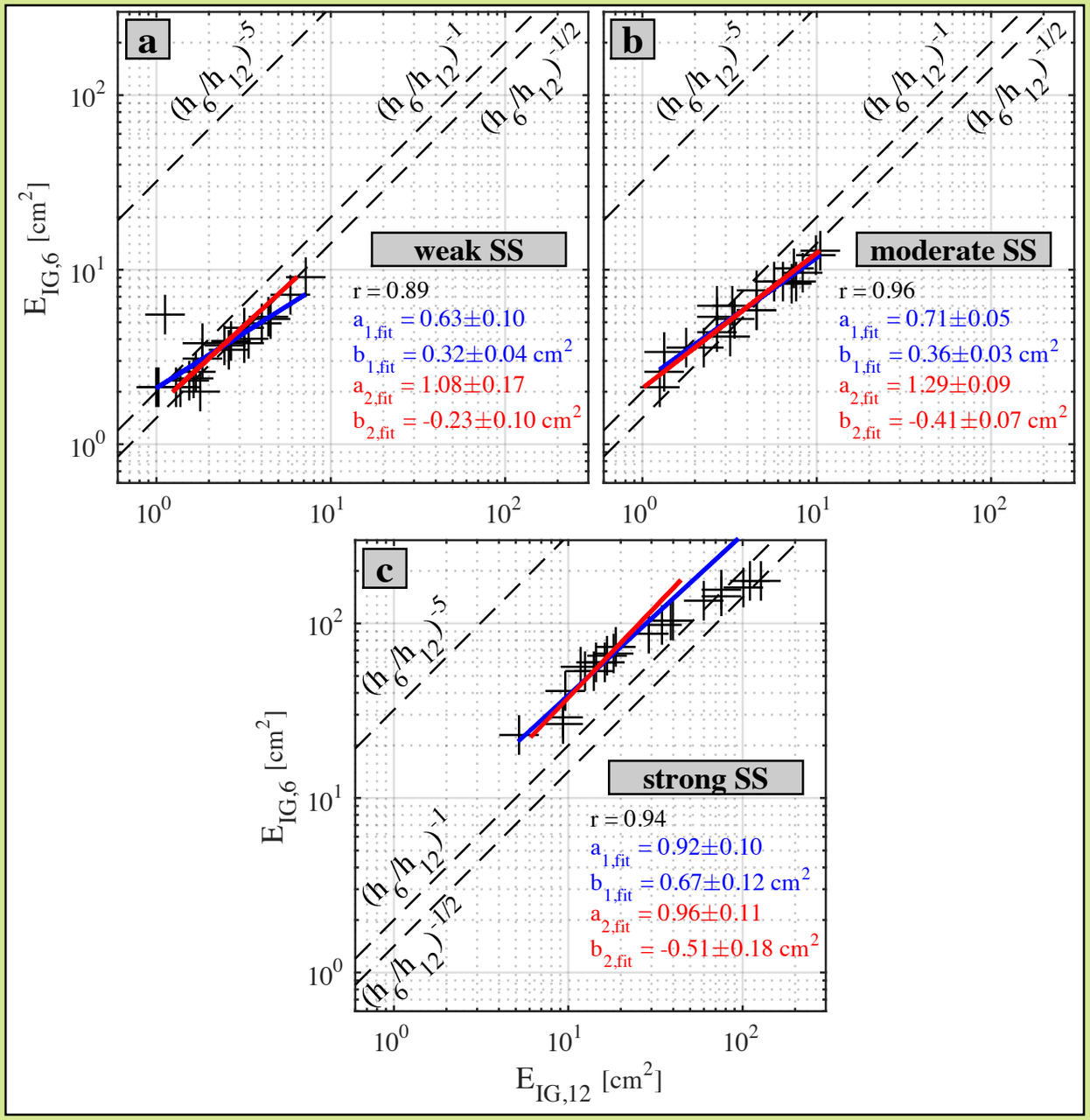
HARBOR IG RESPONSE TO SEA/SWELL FORCING

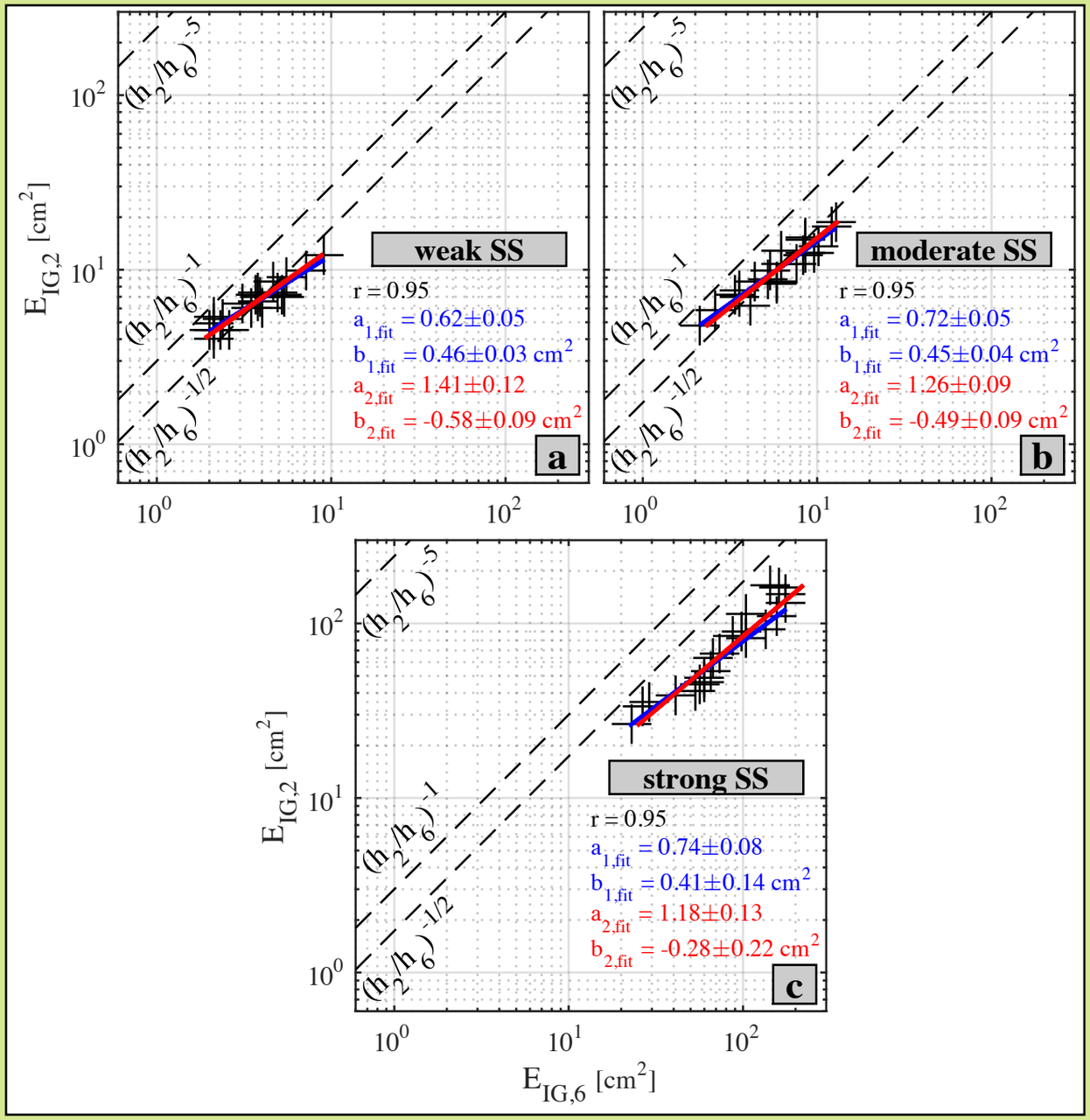


IG WAVE FIELD ON REEF: FREE LEAKY/EDGE VS. BOUND

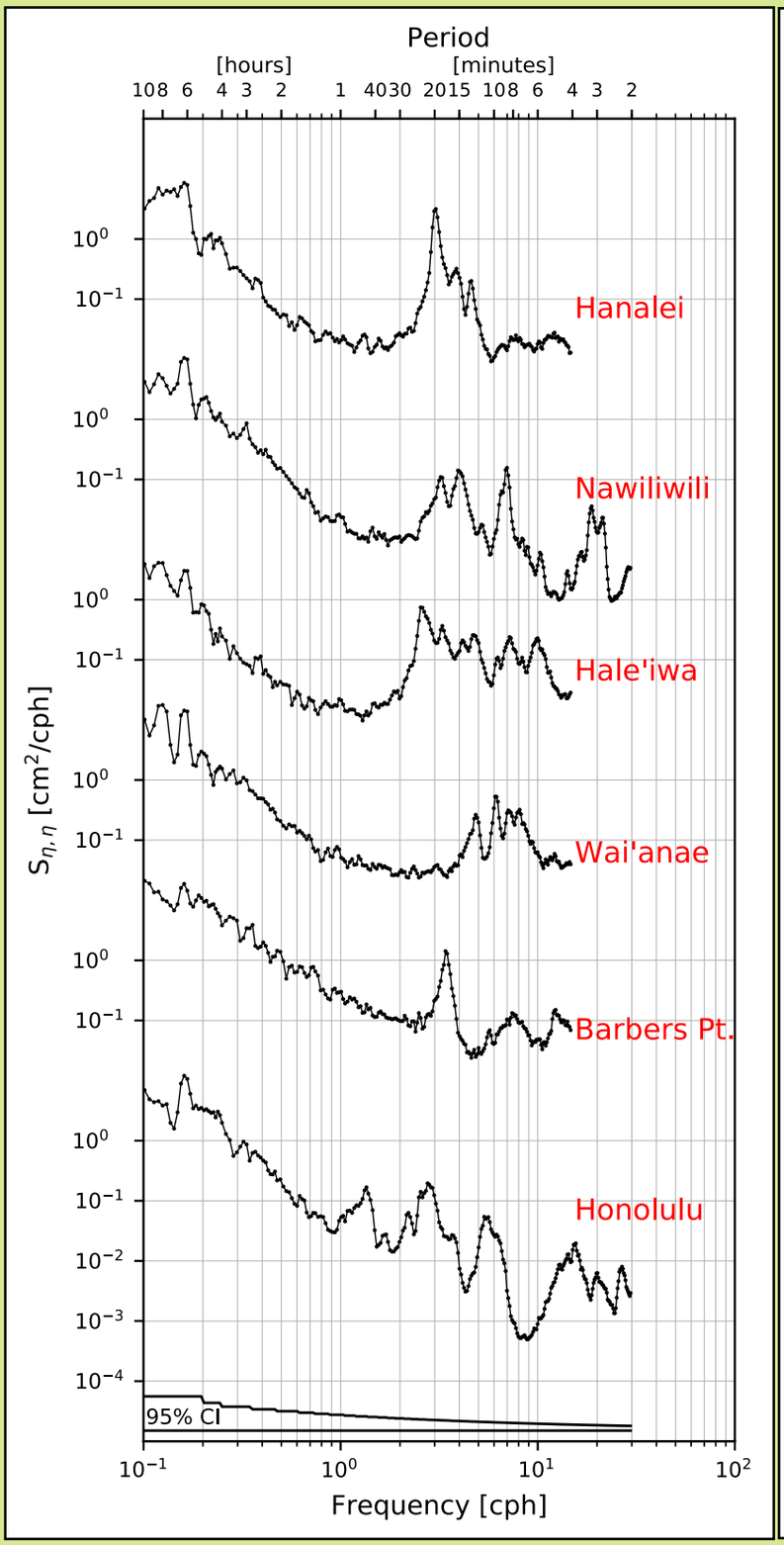


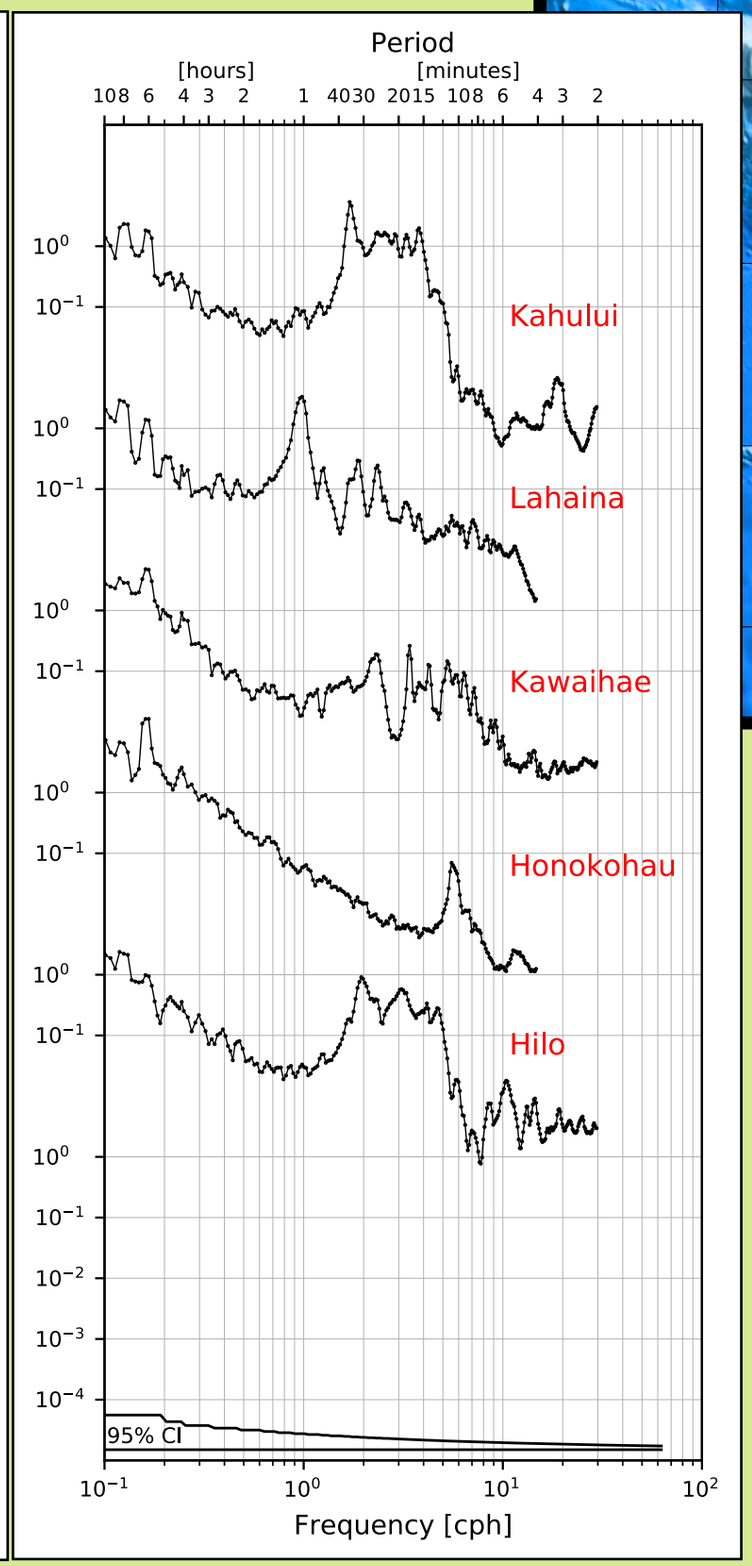
IG WAVE FIELD ON REEF: FREE LEAKY/EDGE VS. BOUND



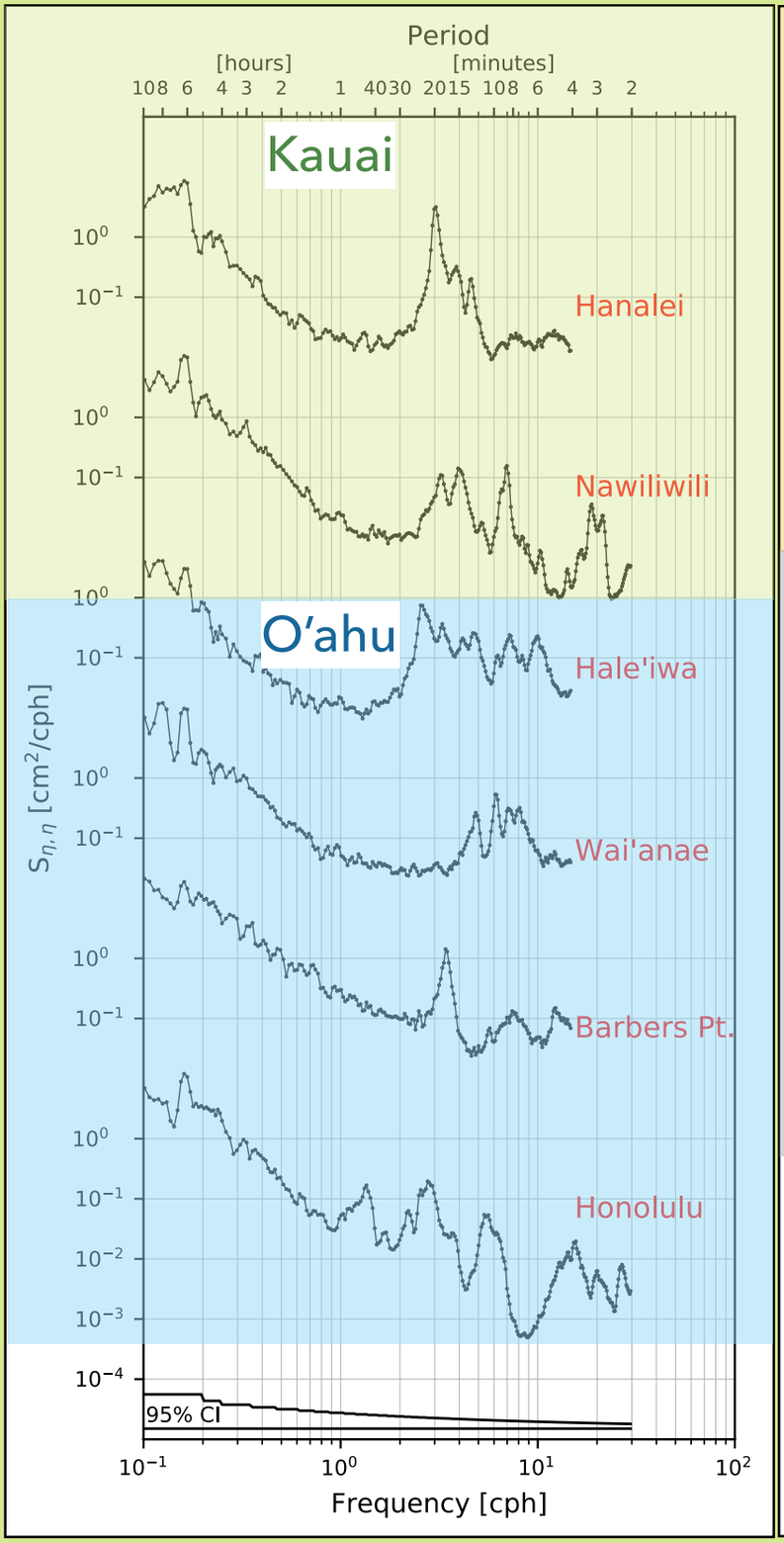


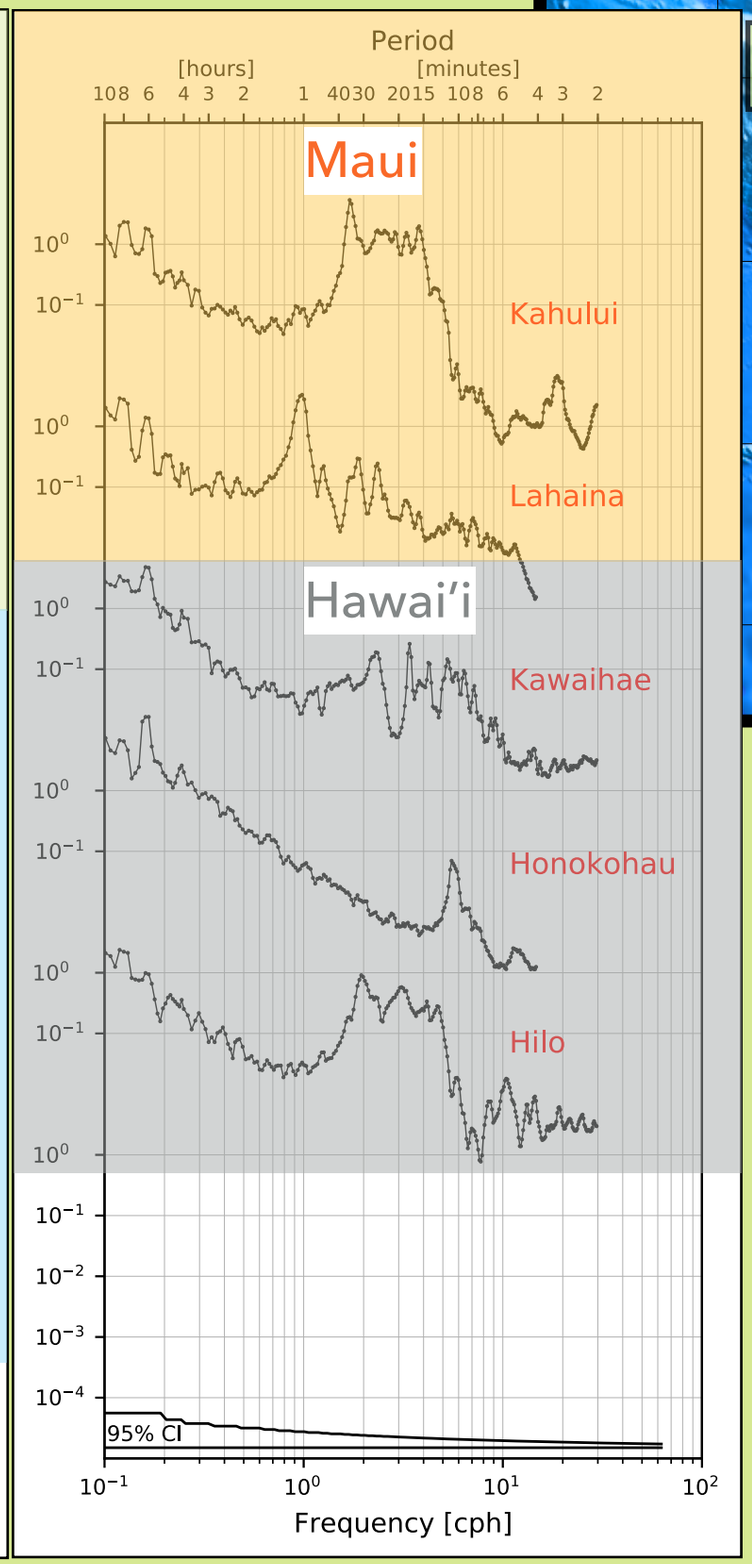
MODES ACROSS THE HAWAIIAN ISLANDS

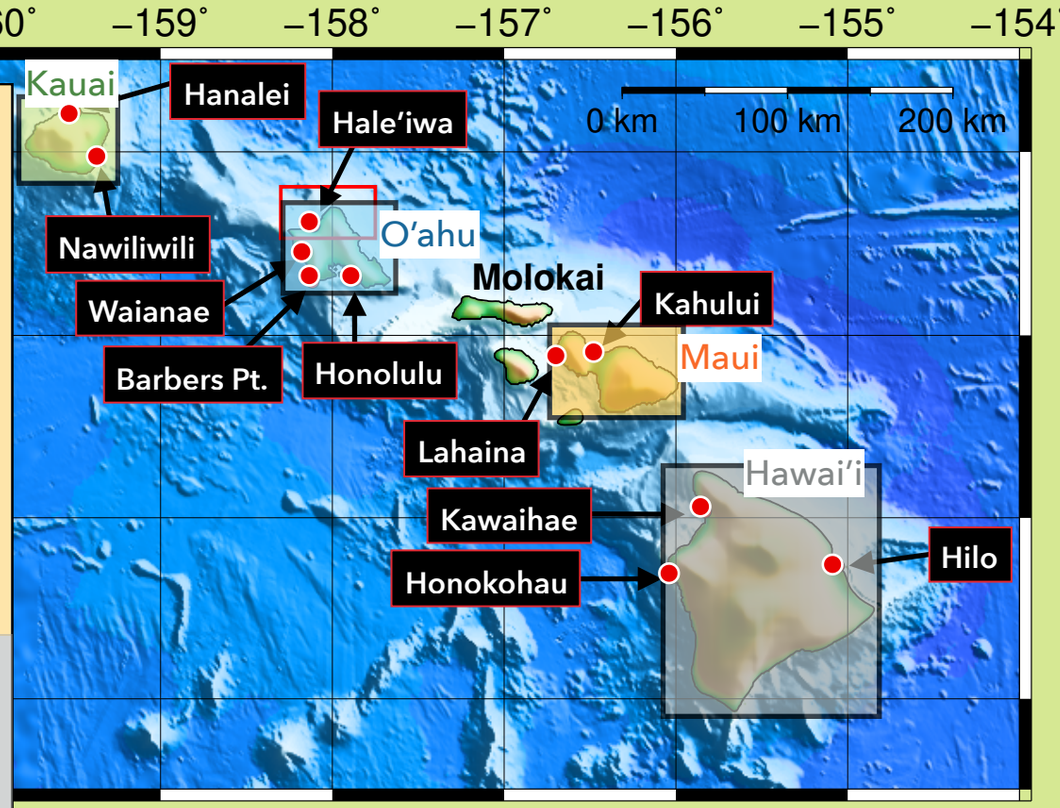




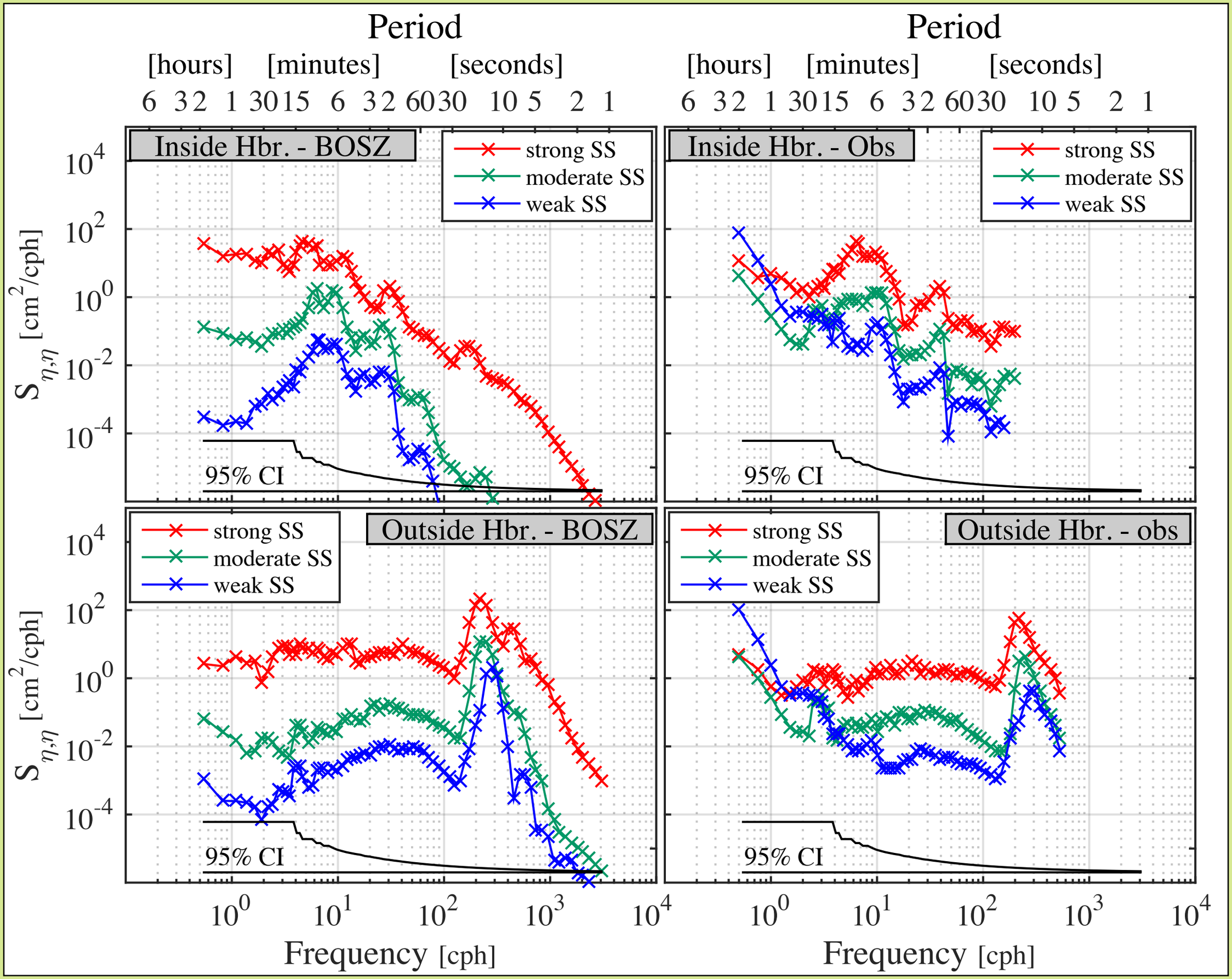
MODES ACROSS THE HAWAIIAN ISLANDS



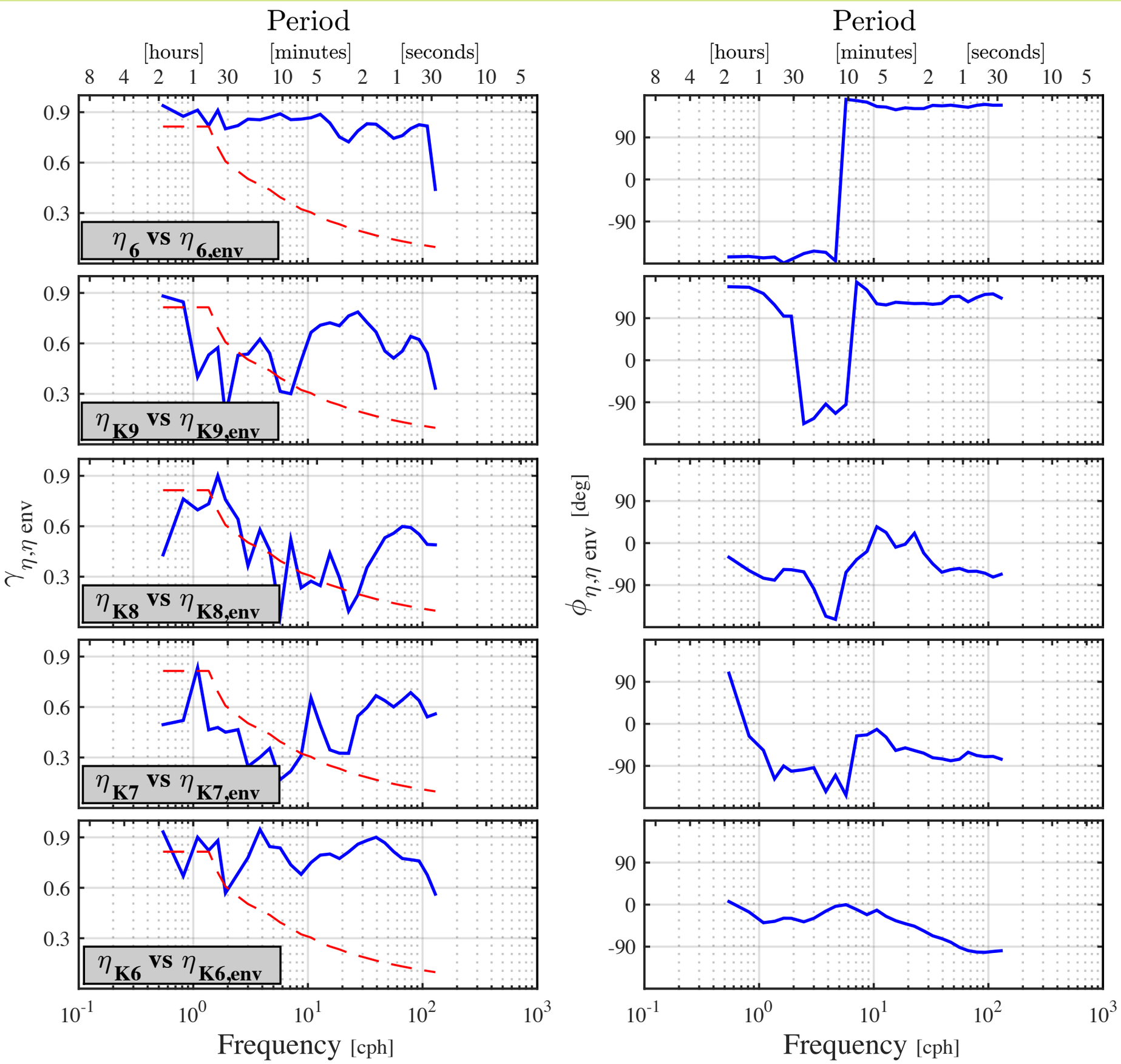


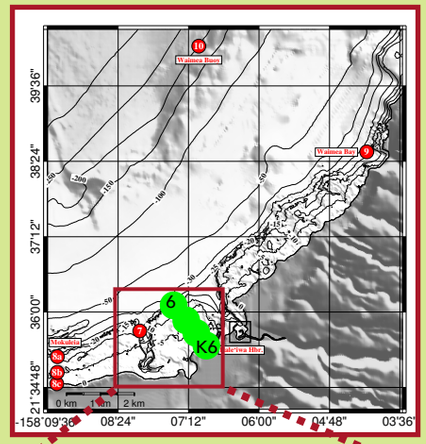


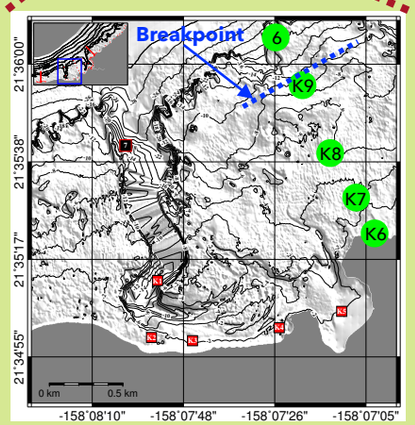
RESULTS: MODEL-DATA COMPARISONS: WEAK/MOD/STR SS FORCING



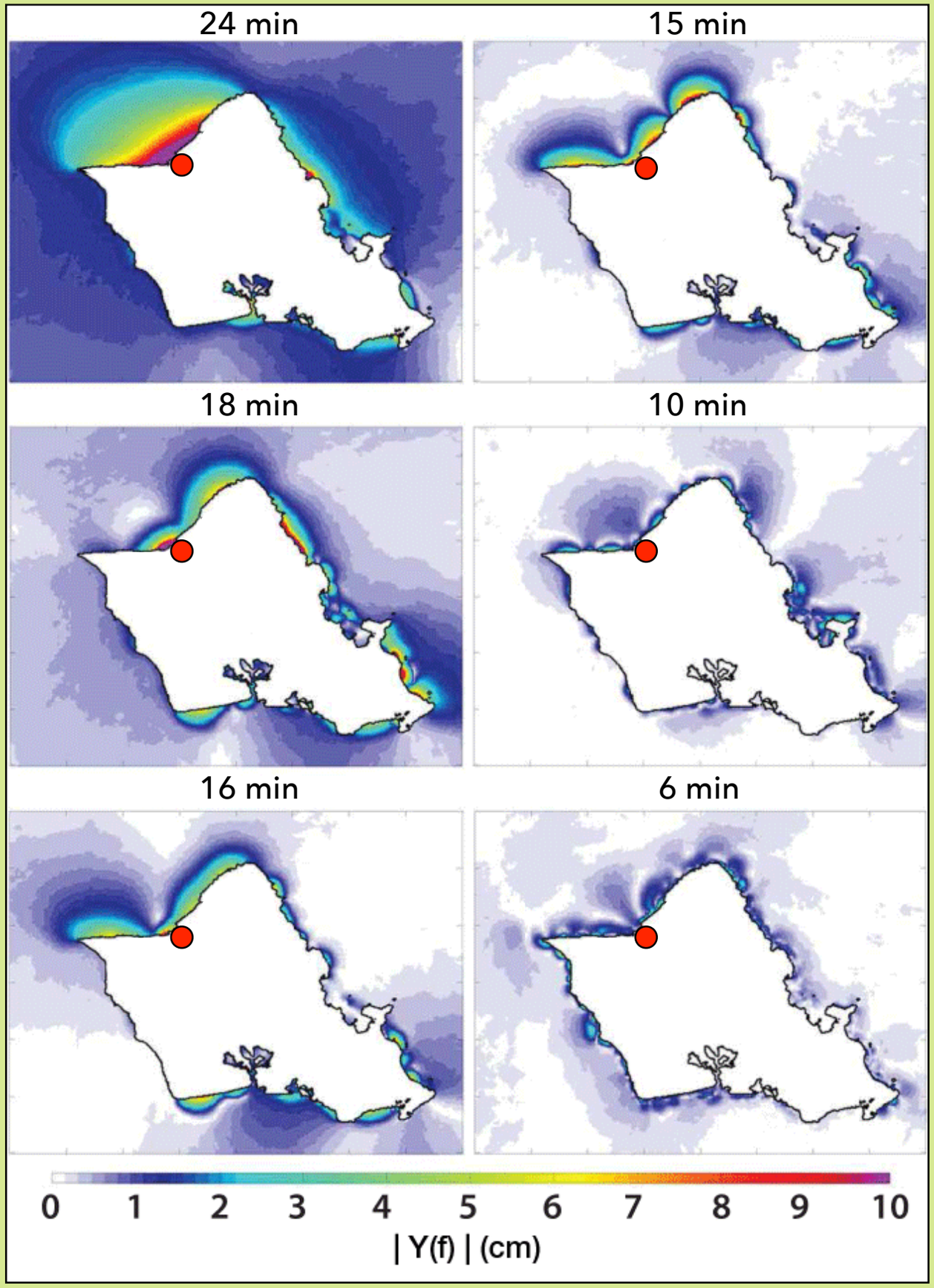
RESULTS: BOUND WAVE IMPACTS





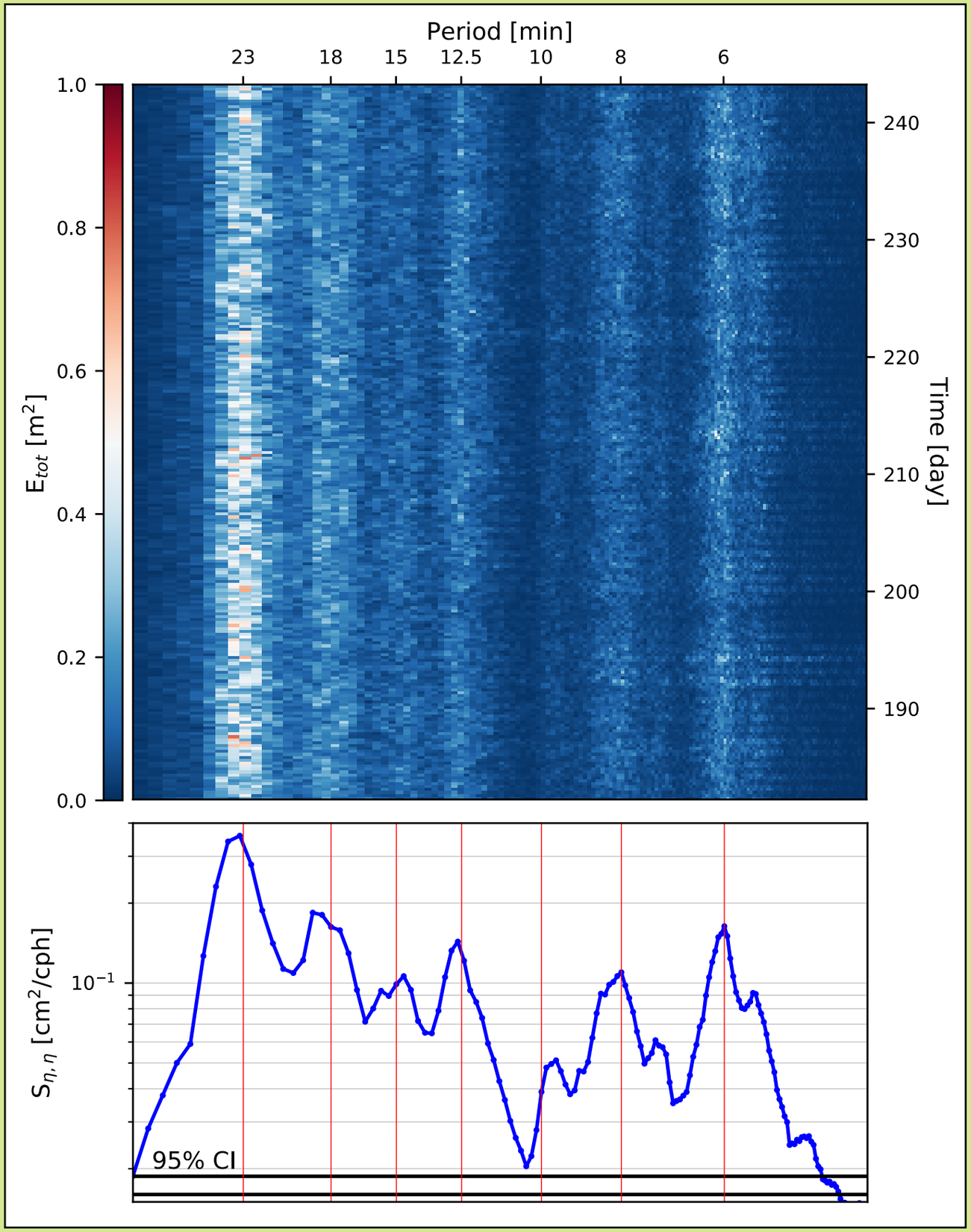


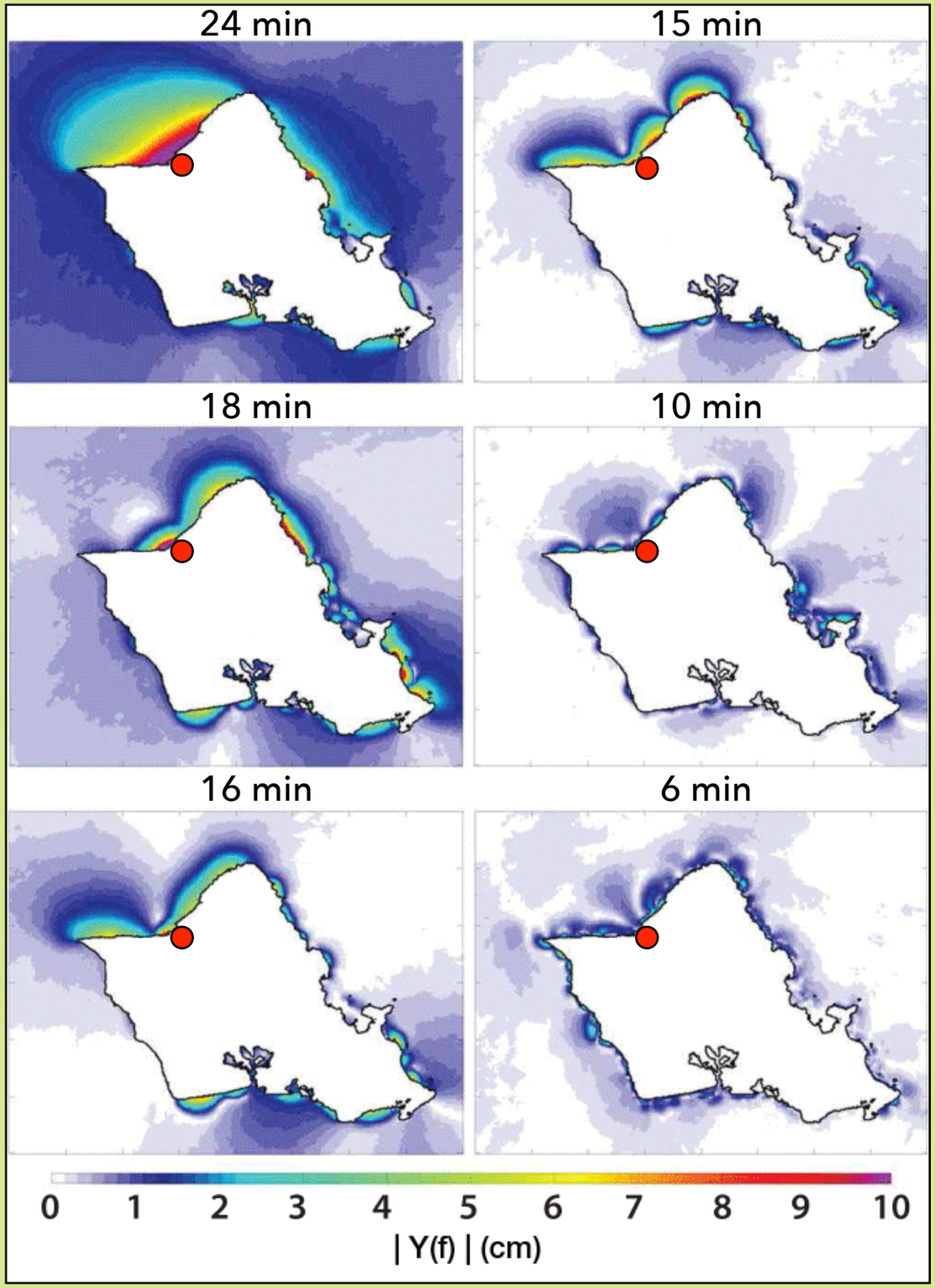
TSUNAMI MODELING: COASTAL MODES - O'AHU ISLAND



Munger & Cheung [2008], *GRL*

OBSERVED MODES: HALE'IWA HARBOR, O'AHU





Munger & Cheung [2008], *GRL*

MODELED MODES: HALE'IWA HARBOR, O'AHU