Decomposition of the Multimodal Multidirectional M_2 Internal Tide Field

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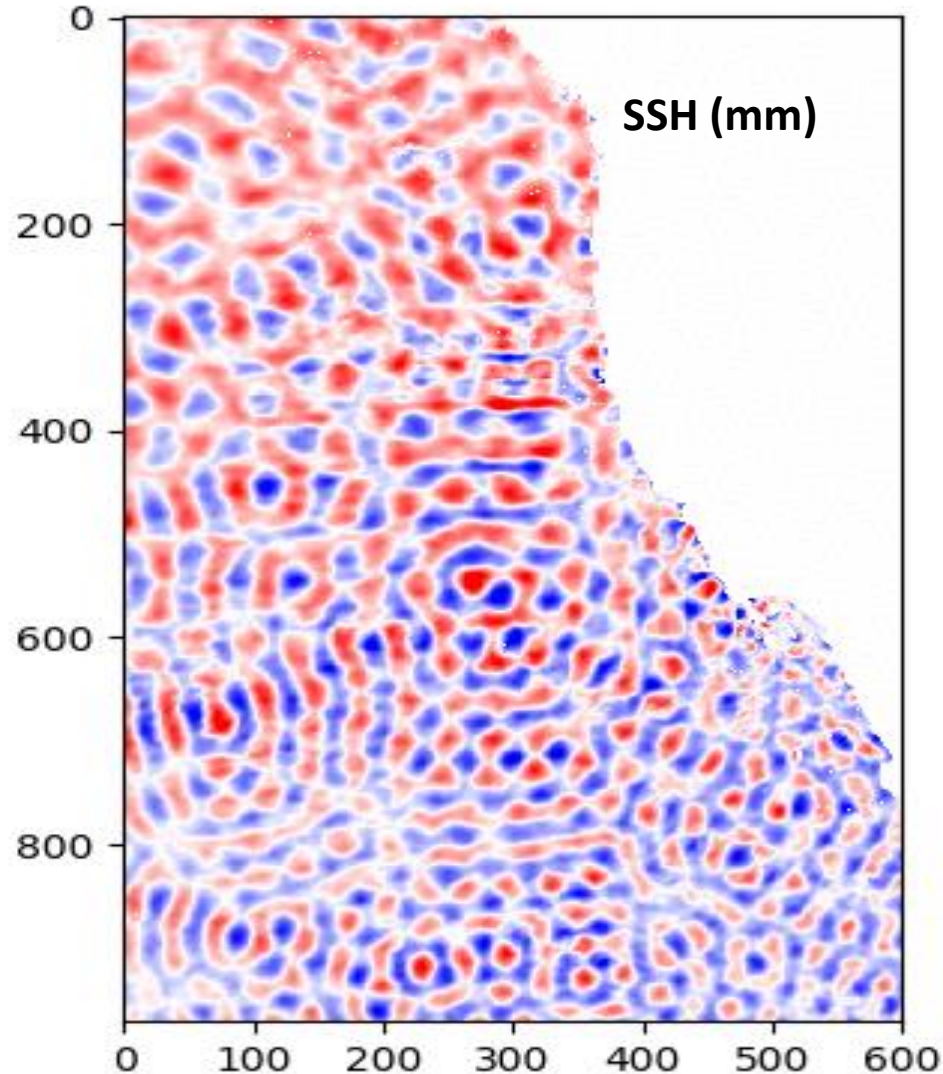
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Motivation

How to extract details of the internal tide field?

M$_2$ internal tide field simulated by MITgcm

- MITgcm run llc4320 with 1/48° grid, 90 levels
- Atmosphere forcing: ECMWF
- Barotropic tidal forcing
  8 short constituents + 8 long constituents

- Hourly output, Sep 2011 – Nov 2012 (14 months)
- Steric sea surface height (SSH)
- Point-wise harmonic analysis to get M$_2$

- Complex multi-wave interference
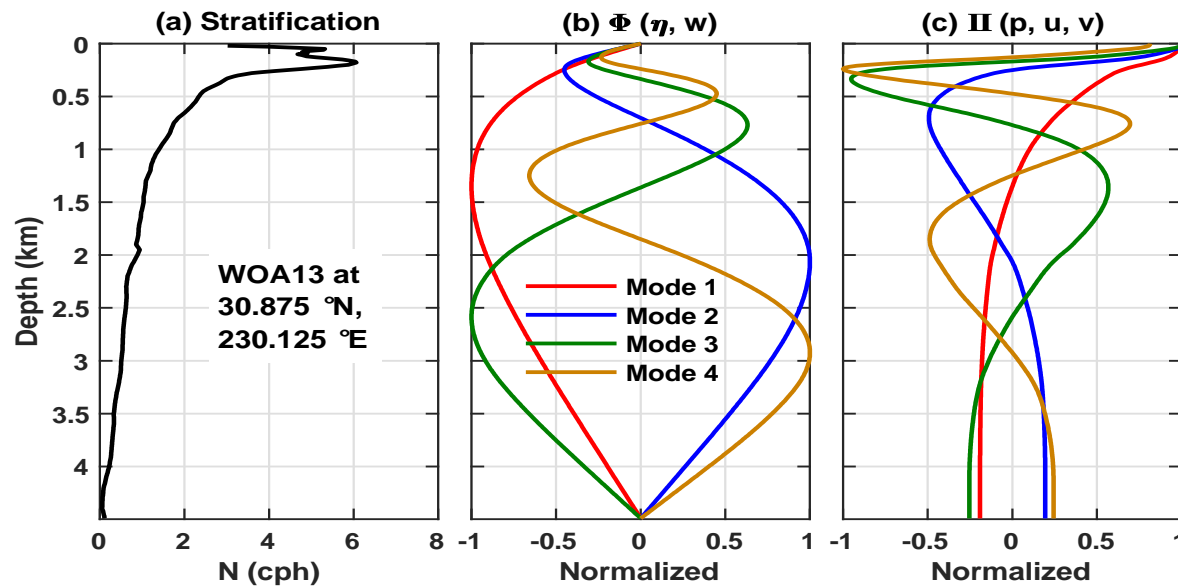
Multiple Generation Sites
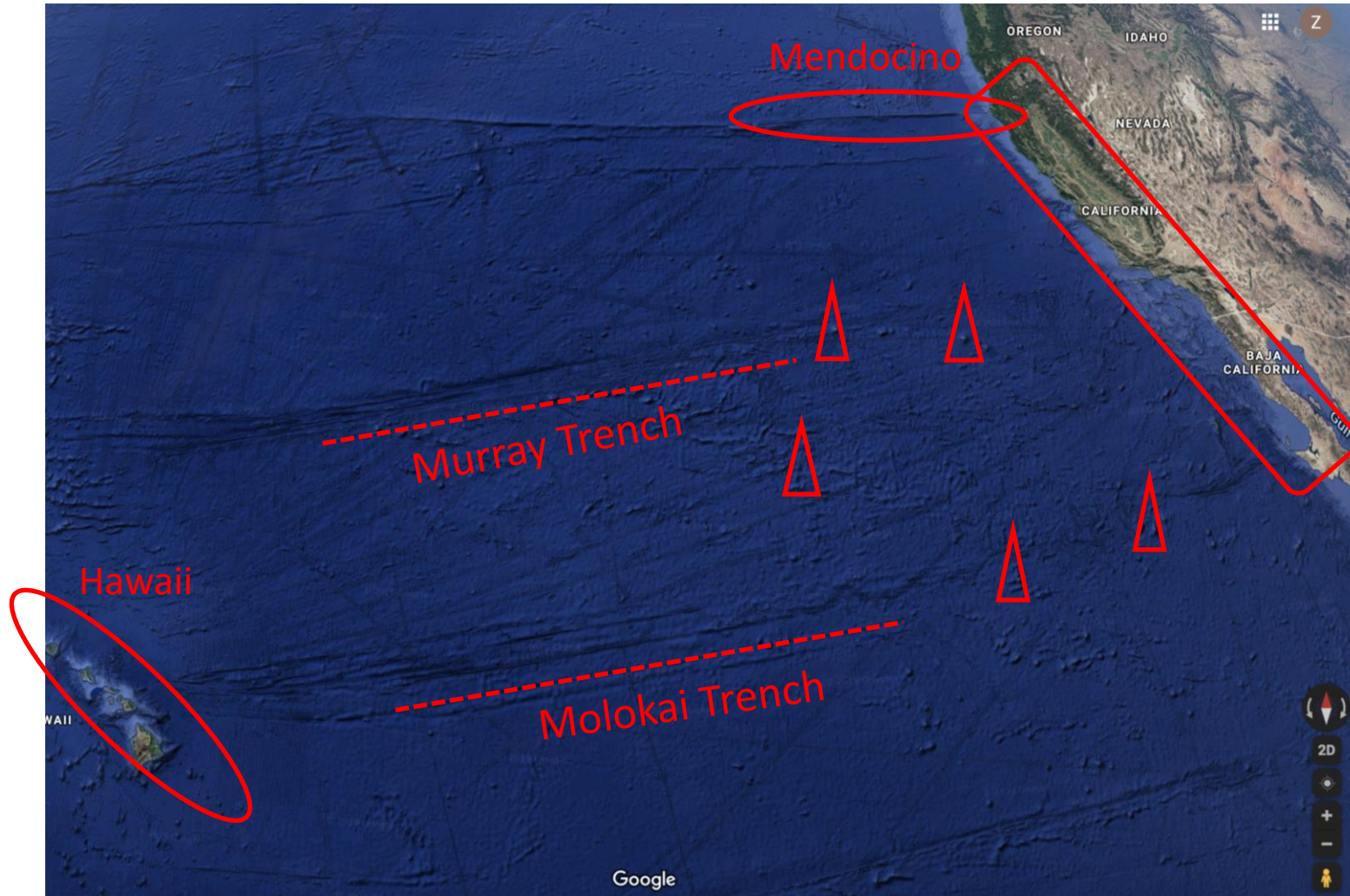
(google map)

- Mendocino Ridge
- Hawaiian Ridge
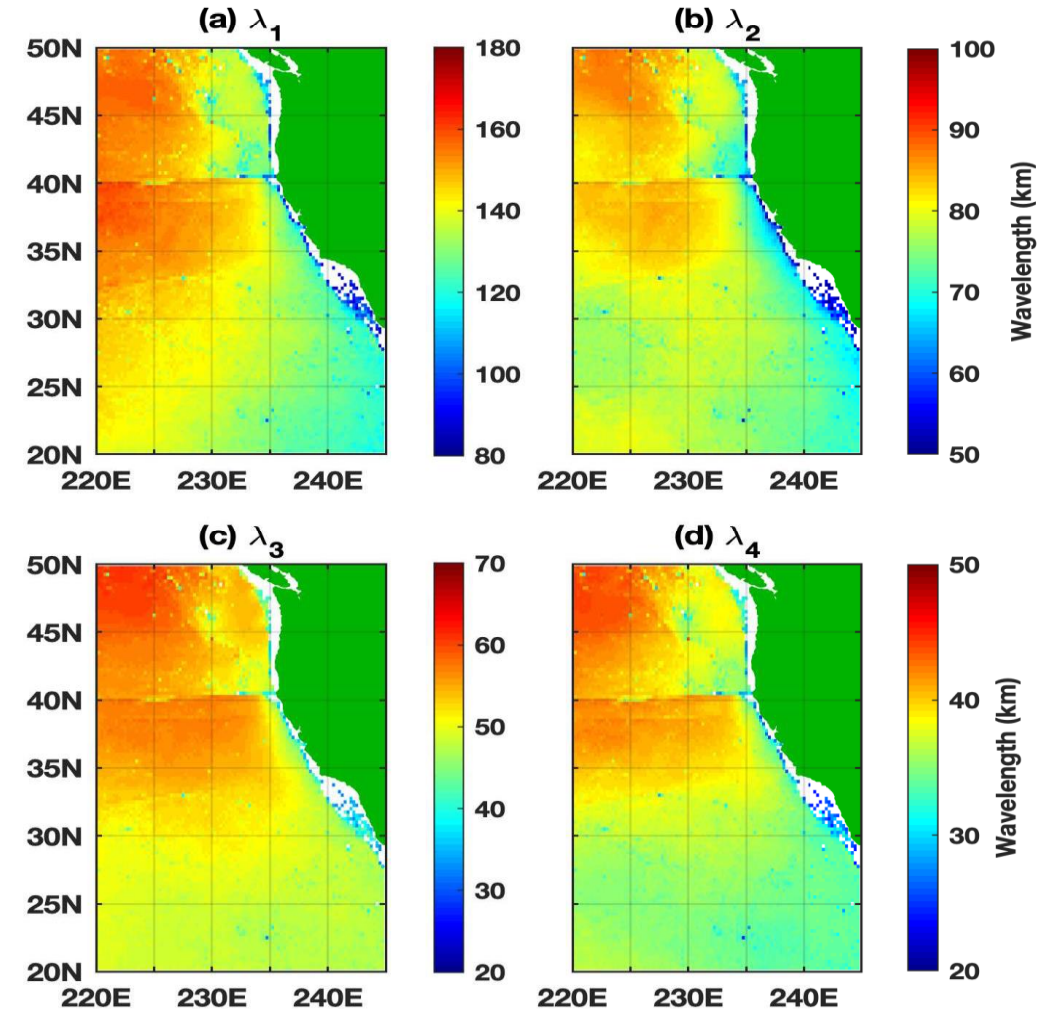- Trenches
- Numerous seamounts
- Continental slopes

Multiple Baroclinic Modes

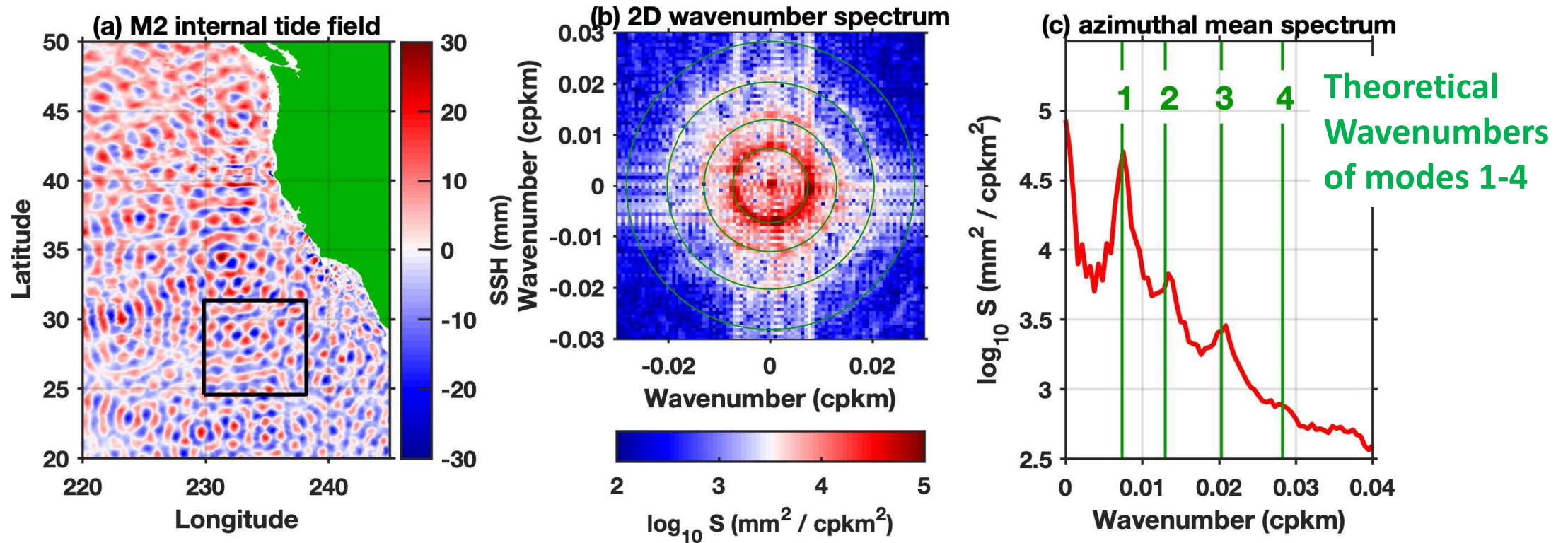Orthogonal equation: $\dfrac{d^2\Phi(z)}{dz^2} + \dfrac{N^2(z)}{c^2}\Phi(z) = 0,$

(a) Stratification — WOA13 at 30.875 °N, 230.125 °E

(b) Φ (η, w) — Mode 1, Mode 2, Mode 3, Mode 4

(c) Π (p, u, v)

➢ Different vertical structures (Φ_n, Π_n)
➢ Different speeds (c in the equation)

(a) λ_1 (b) λ_2
(c) λ_3 (d) λ_4

Different wavelengths (WOA2013)

Horizontal 2D Wavenumber Spectrum

(a) M2 internal tide field

(b) 2D wavenumber spectrum

(c) azimuthal mean spectrum

Theoretical Wavenumbers of modes 1-4

➢ Snapshot field; one 750 km by 750 km window
➢ Wavenumber spectrum of complex number (amplitude and phase)
➢ Baroclinic modes ("rings" and spectral peaks)

Step 1: Modal Decomposition by 2D Bandpass Filtering

(a) raw M2 internal tide
(b) 2D wavenumber spectrum
(c) 2D spatial filter
(d) mode 1
(e) mode 2
(f) mode 3
(g) low-pass
(h) high-pass
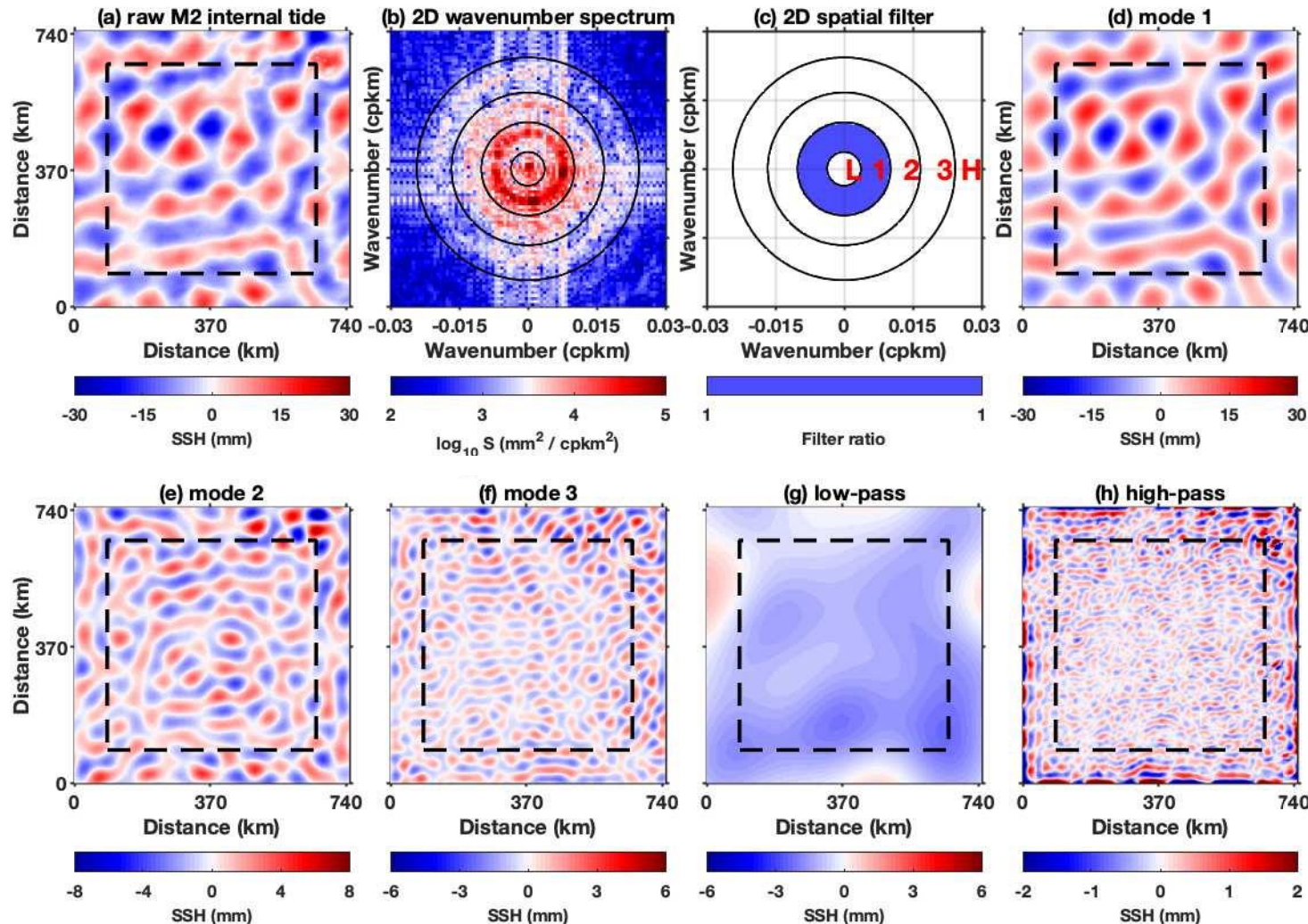
➤ Wavenumber spectrum (same)
➤ Bandpass filter (black circles)
➤ Cutoff wavenumbers: $(K_n+K_{n+1})/2$
➤ Inverse Fourier transform
➤ Boundary (artificial wiggles)

➤ 5 components
  • Mode-1
  • Mode-2
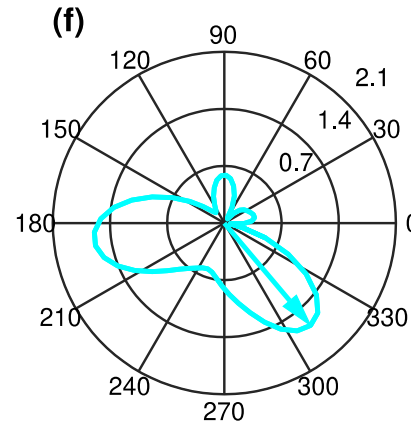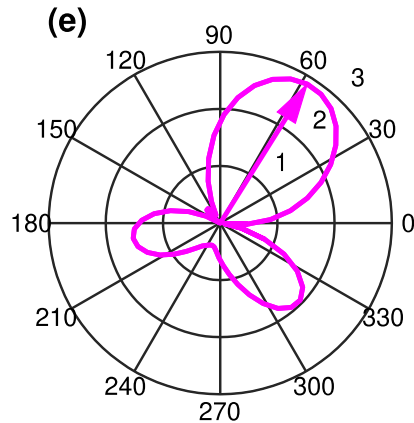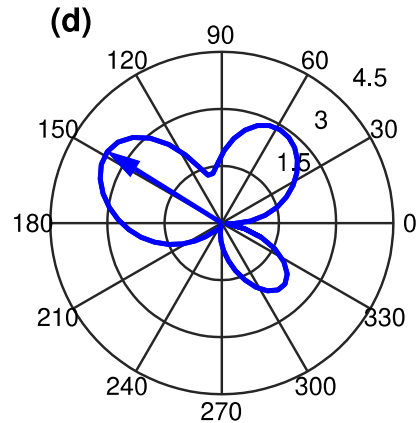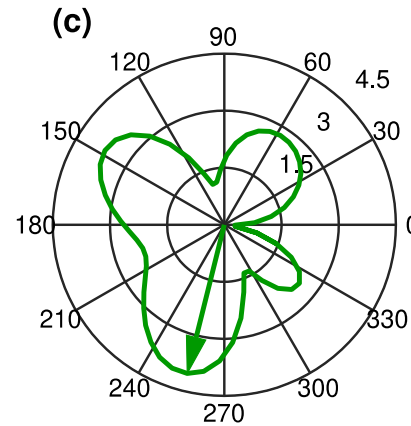 • Mode-3
  • Low-pass component
  • High-pass component

Decomposed Baroclinic Components

(a) raw M2 internal tide
(b) mode 1
(c) mode 2
(d) mode 3
(e) low-pass
(f) high-pass
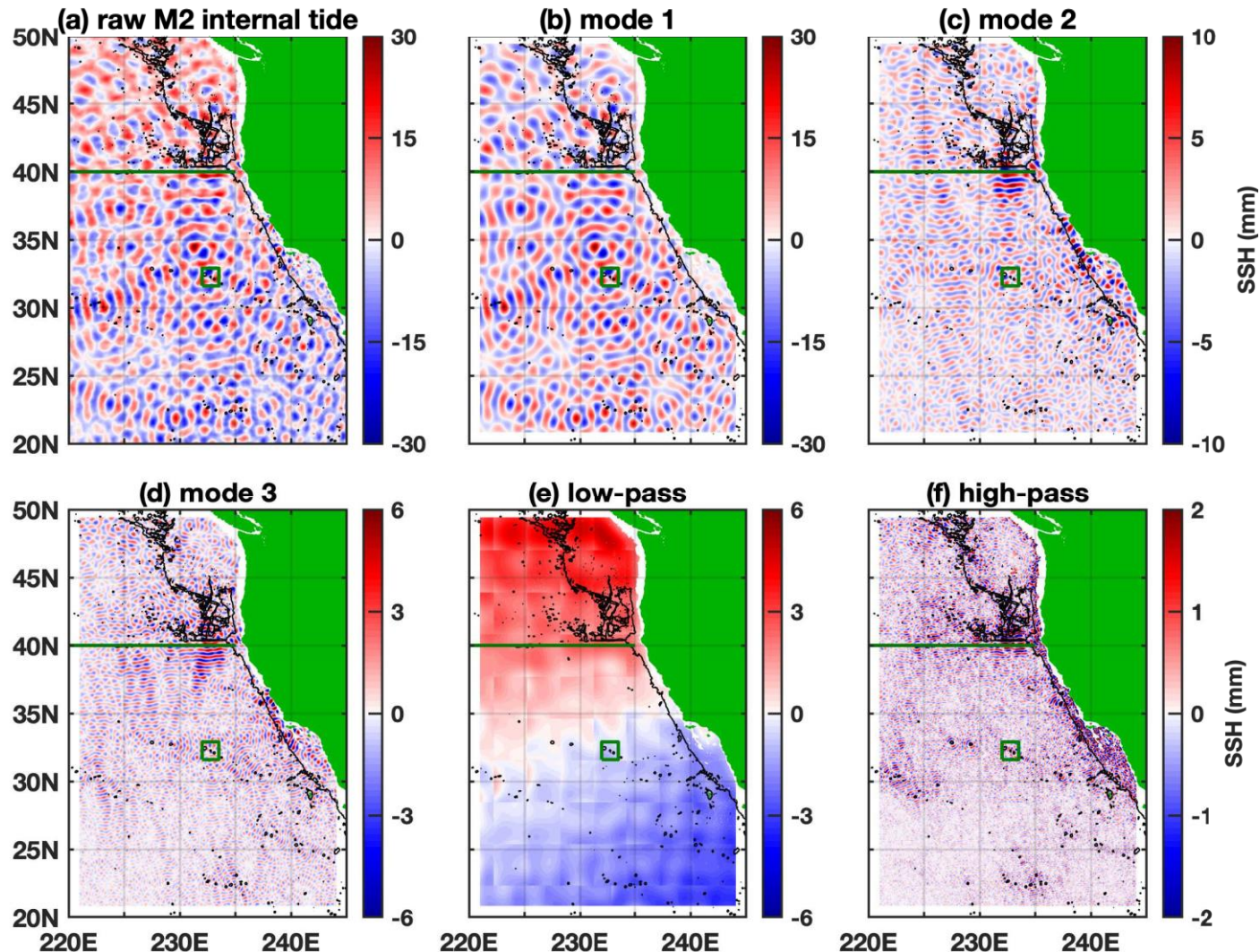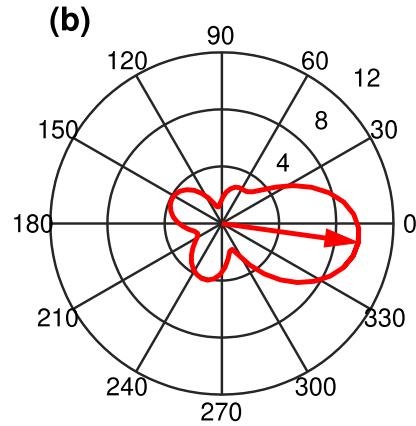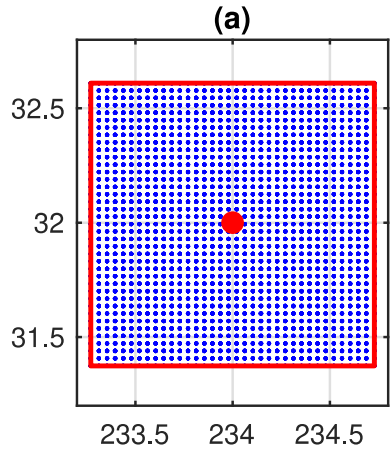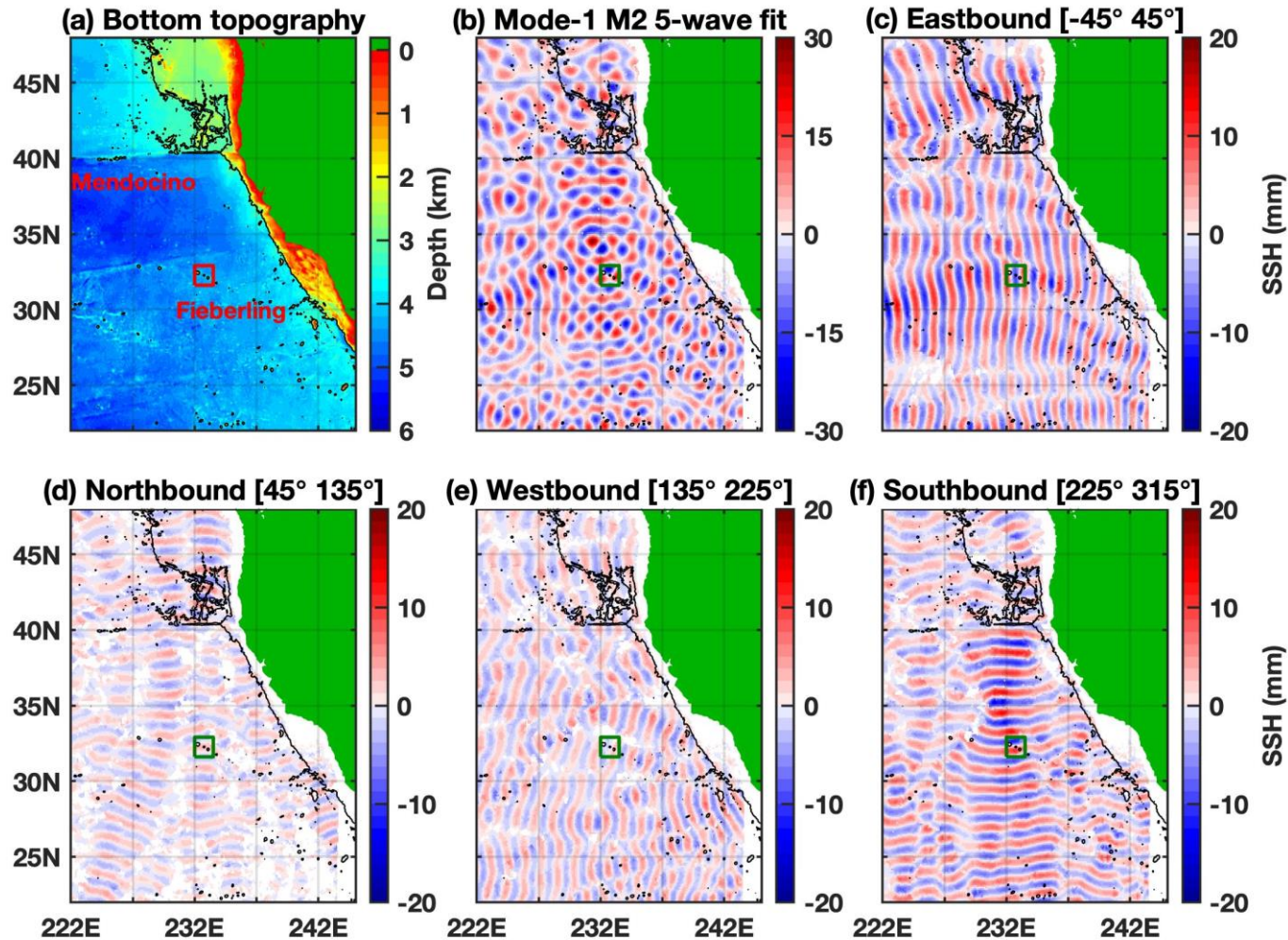
This is not good enough. More **details** please …

➢ Repeat in overlapping 750 km by 750 km windows

➢ The raw field is decomposed into 5 components

➢ New information
  • Mendocino (green line)
 • Fieberling (green box)

- ➢ An example for mode 1

- ➢ Fitting plane waves in windows of 150 km (one wavelength)

- ➢ One wave from the largest lobe

- ➢ <u>Remove the wave and repeat for the next wave</u>

- ➢ 5 waves are determined, which are ranked by amplitude

- ➢ Sum of these 5 waves -> solution

Mode-1 Components in 4 Directional Ranges

(a) Bottom topography
(b) Mode-1 M2 5-wave fit
(c) Eastbound [-45° 45°]
(d) Northbound [45° 135°]
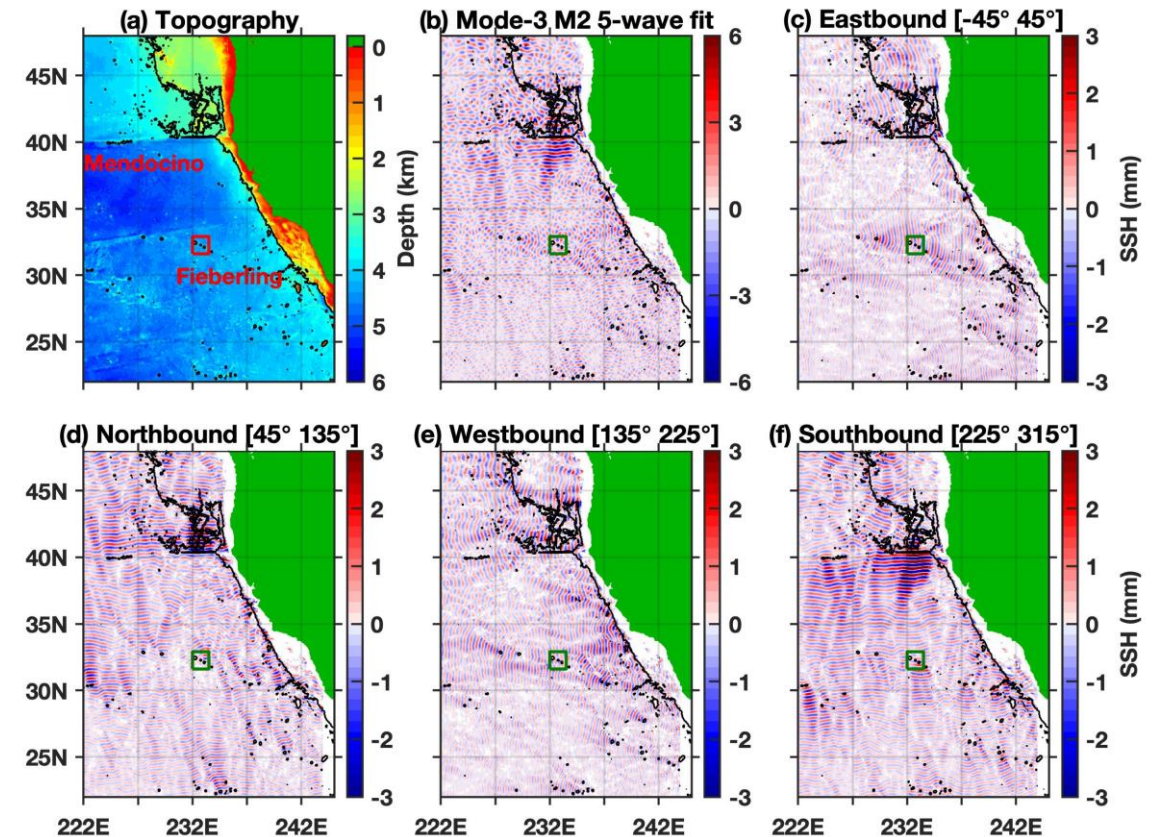(e) Westbound [135° 225°]
(f) Southbound [225° 315°]

➢ Five waves at each grid point

➢ Show these waves in 4 directional ranges (90° angle each)

➢ New information
  - Eastbound: Hawaiian Ridge
  - Southbound: Mendocino Ridge
  - Westbound: continental slope
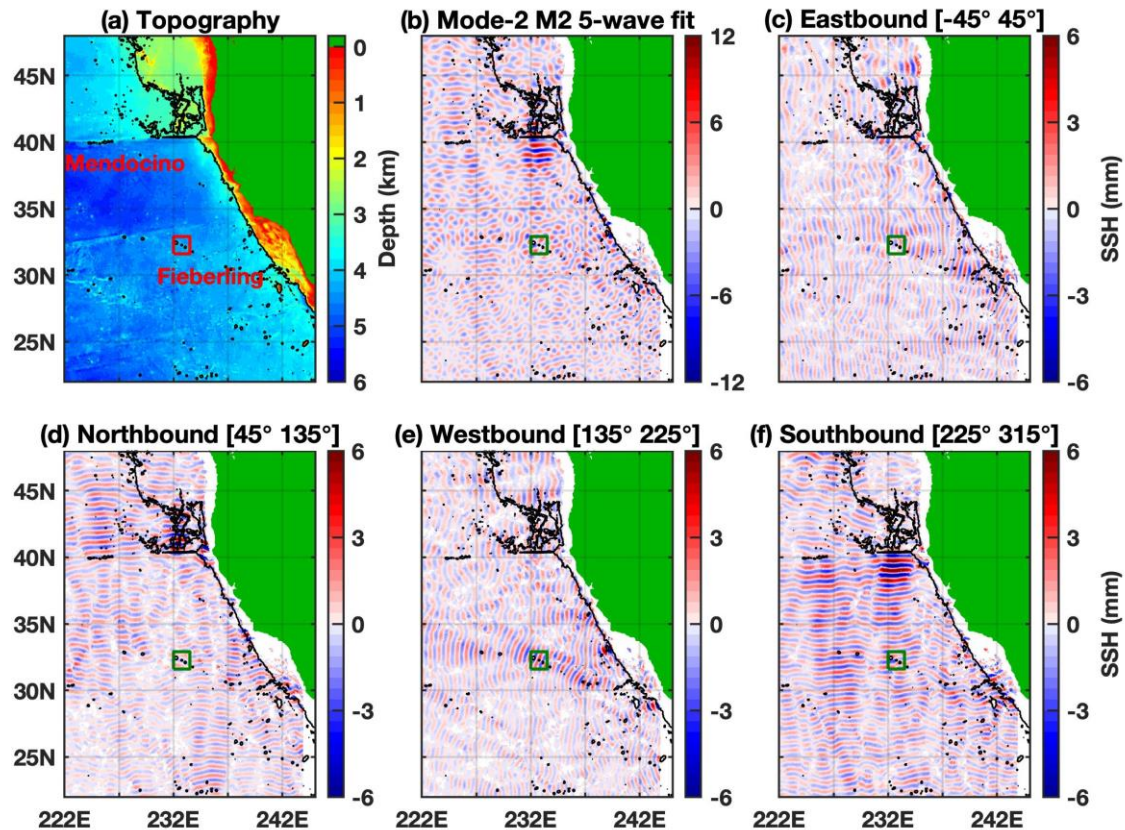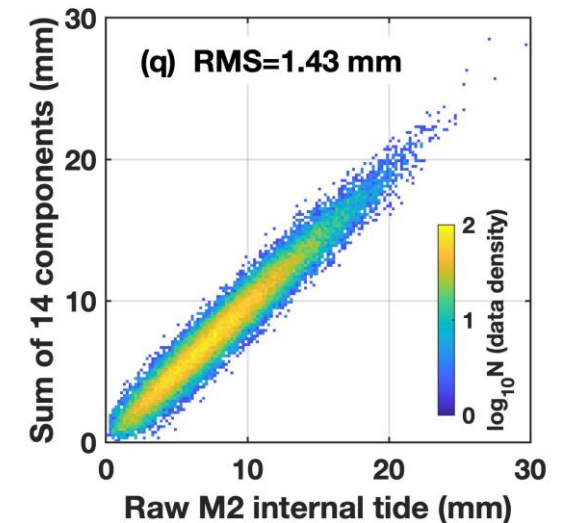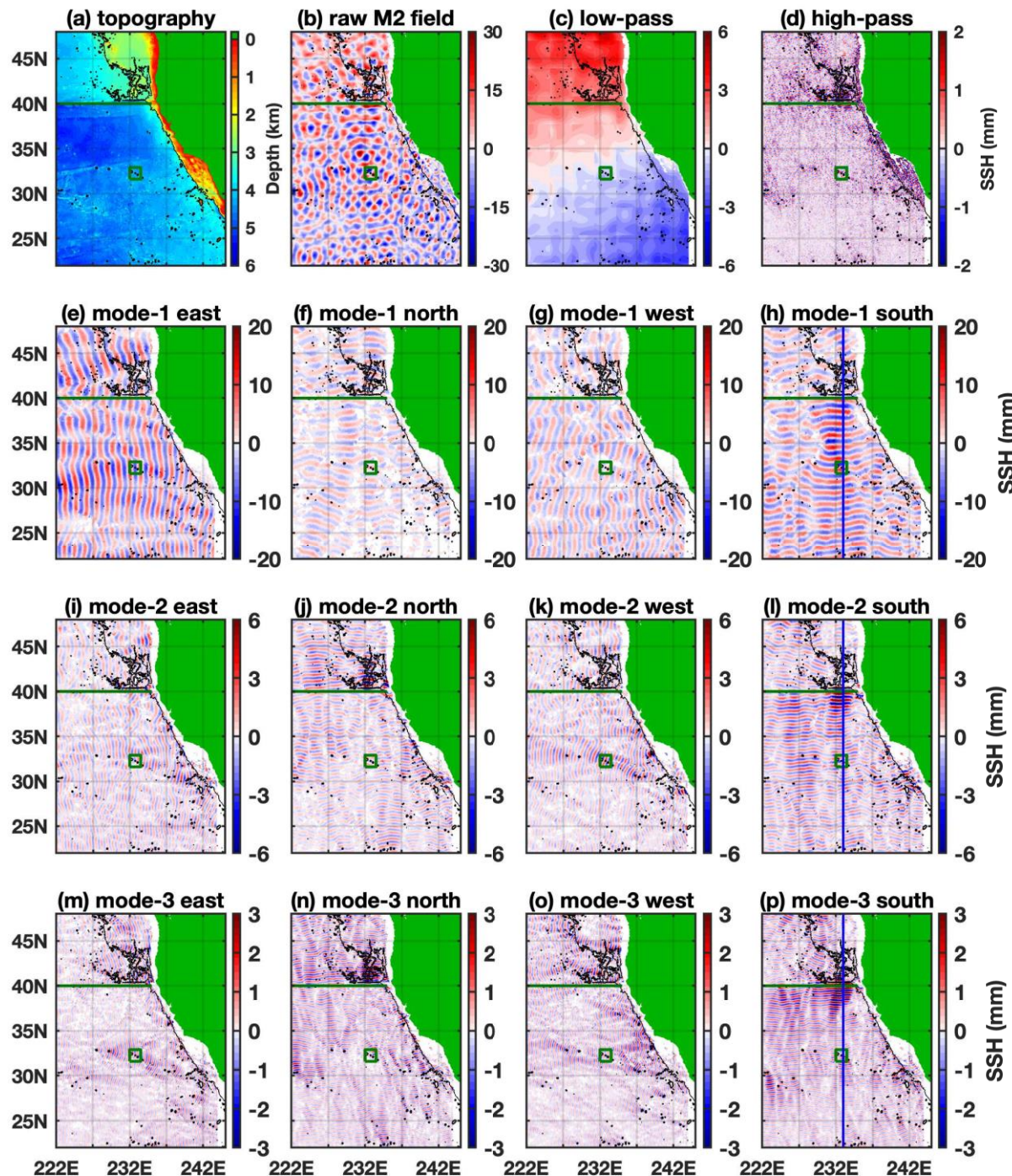
Mode 2

Mode 3

14 Components

> 2-step decomposition technique
>   • **2D bandpass filtering**
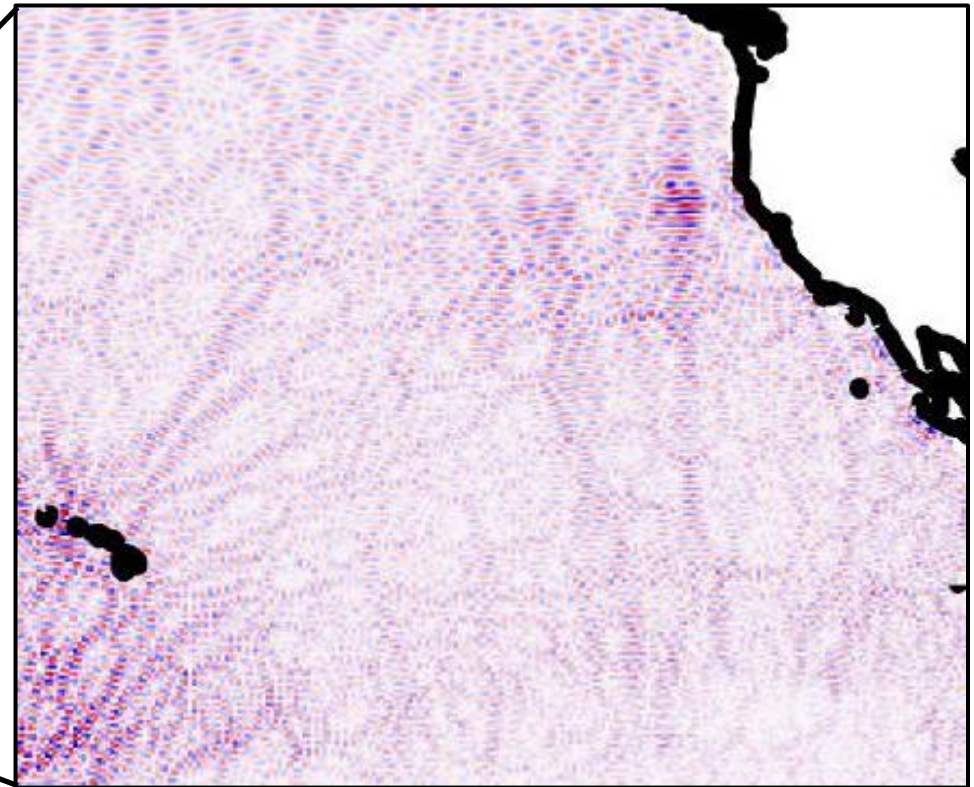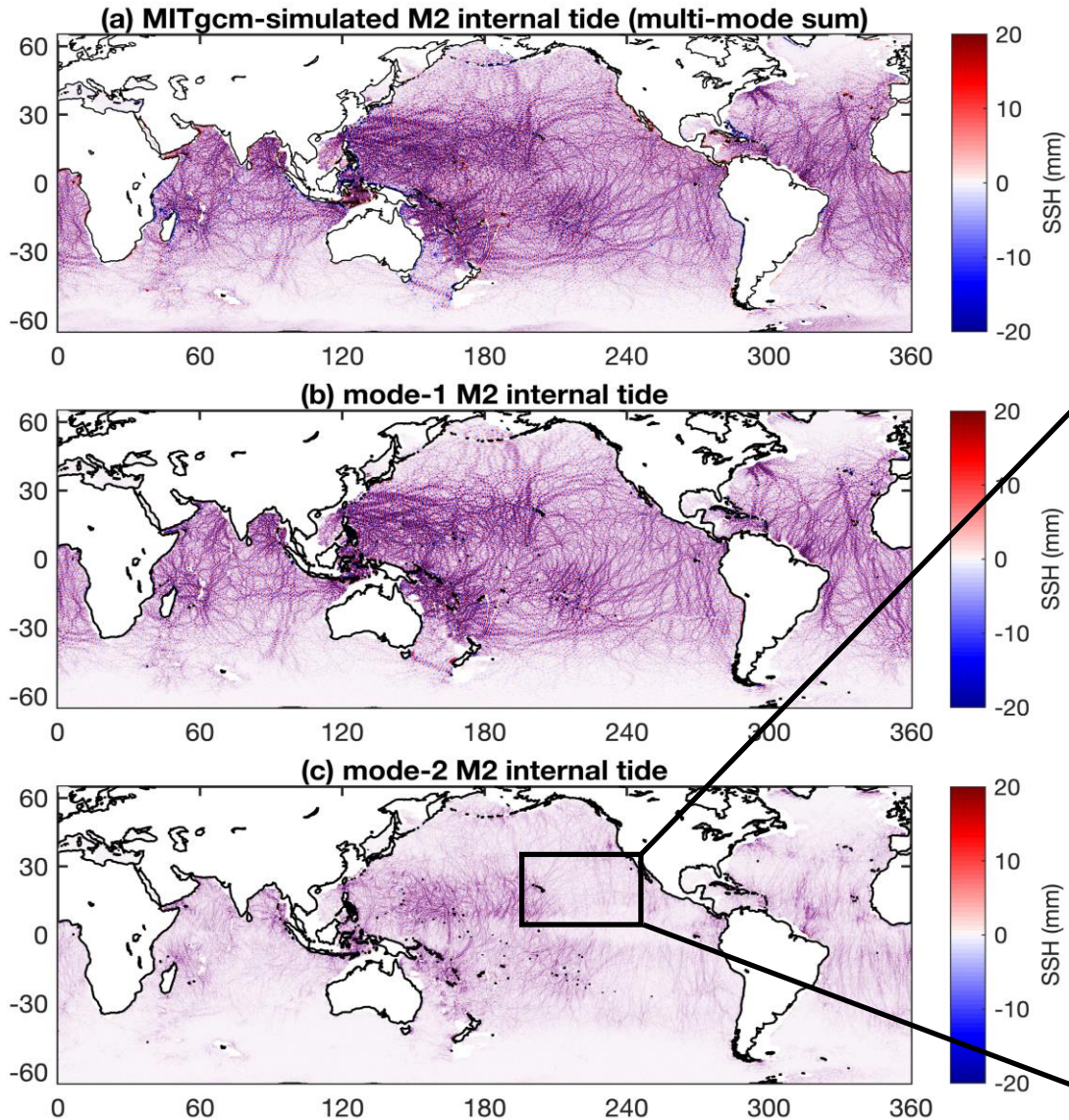>   • **2D plane wave analysis**

> Give many details
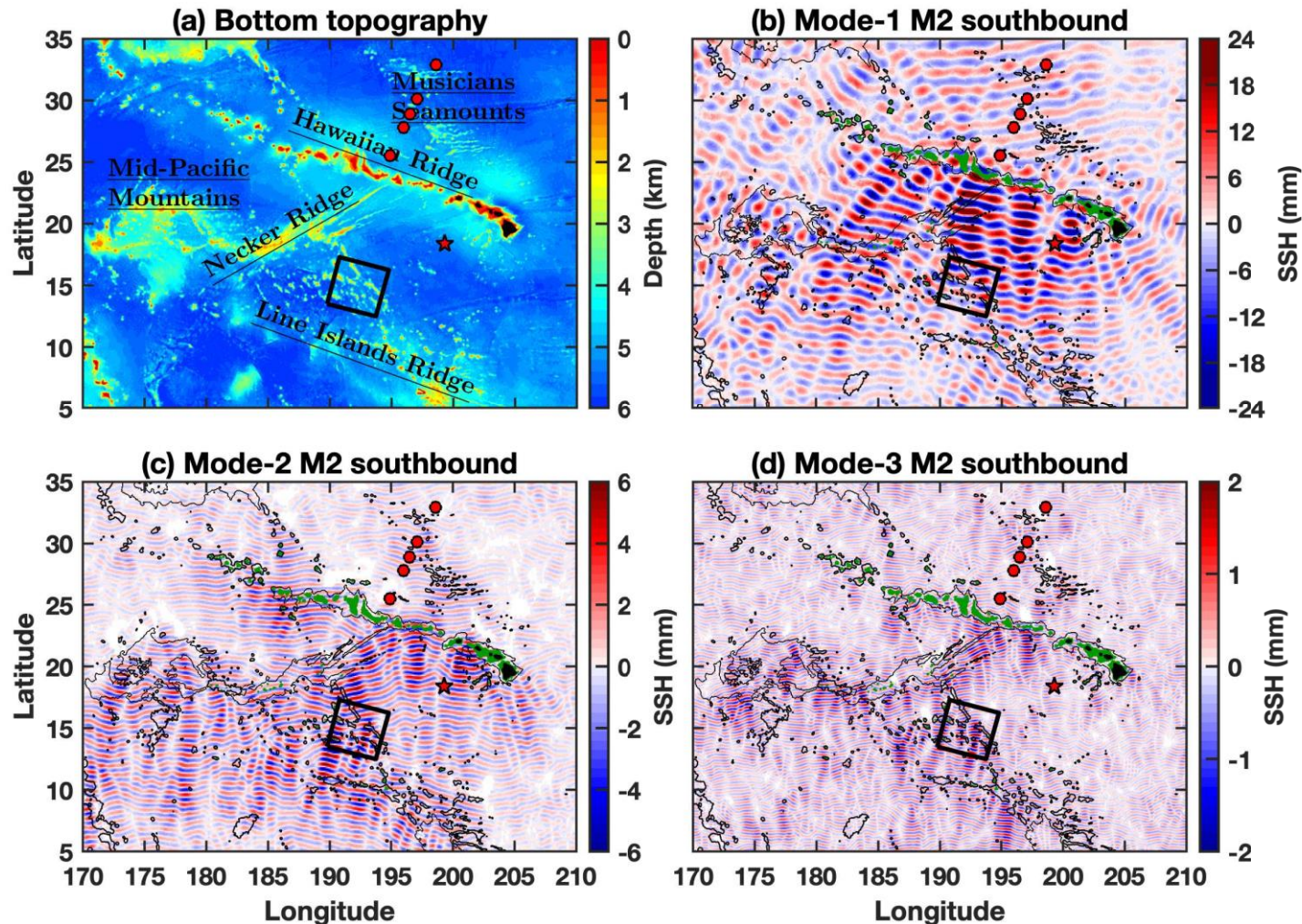>   • Internal tidal beams
>   • Generation
>   • Propagation

Application (1): the Global MITgcm Run

> - Global M_2 internal tide field
> - MITgcm run in $1/12^o$ (Data courtesy of Clement Ubelmann)
> - $1/48^o$ MITgcm data is underway

Application (2): Nadir-looking Altimeter Data

(a) Bottom topography
(b) Mode-1 M2 southbound
(c) Mode-2 M2 southbound
(d) Mode-3 M2 southbound

➢ Repeat-track data: TP, J1, J2, J3, GFO, E2, EN; 1992 –2017

➢ Similar method (due to <u>irregular</u> tracks and data points)
see Posters TID-007, TID-008

➢ Northbound not shown here

➢ Mode-1, -2, and -3
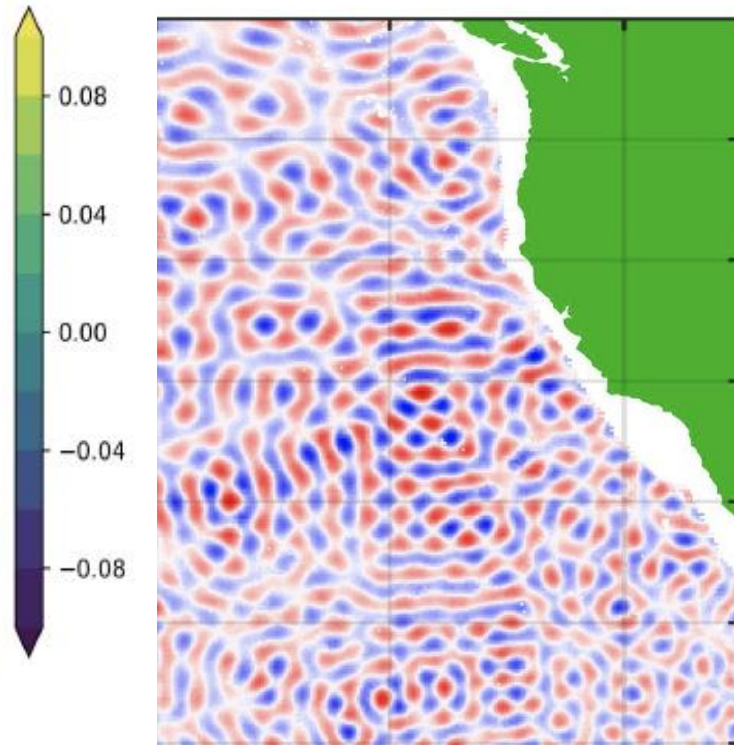 • generation sites
  • beams

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Application (3): Synthetic SWOT Data
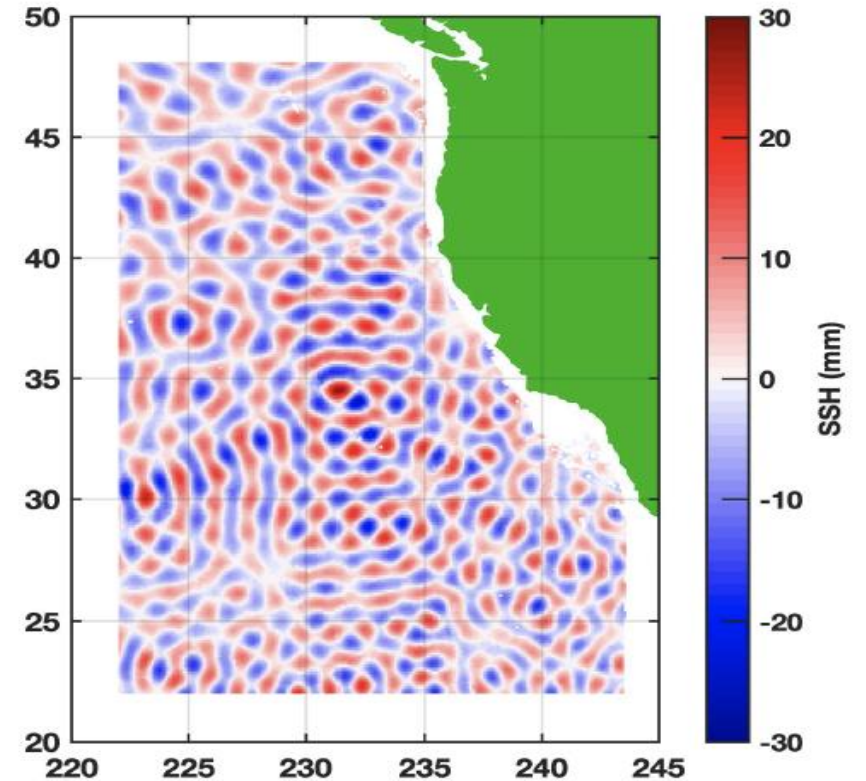
Synthetic SWOT data
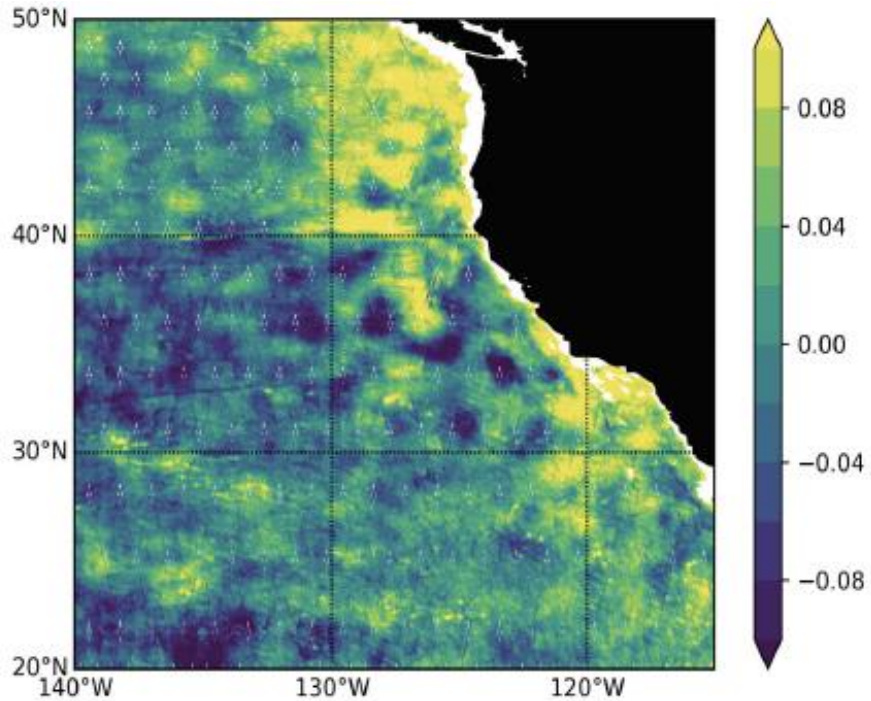
The MITgcm simulation is sampled by the SWOT simulator for 14-month. Shown is a 21-day SWOT field.

from synthetic SWOT data

Mode-1 M_2 internal tide obtained from synthetic SWOT data.

Ground truth (hourly output)

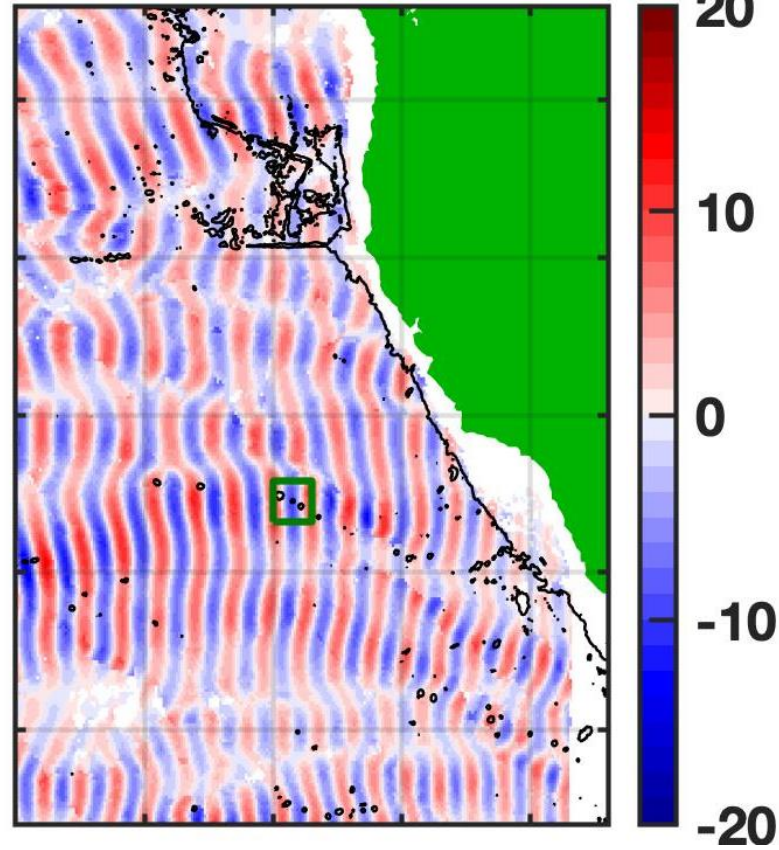**The SWOT-derived "model" explains 80% variance of the ground truth**

Can Internal tides Travel from Hawaii to California? Yes
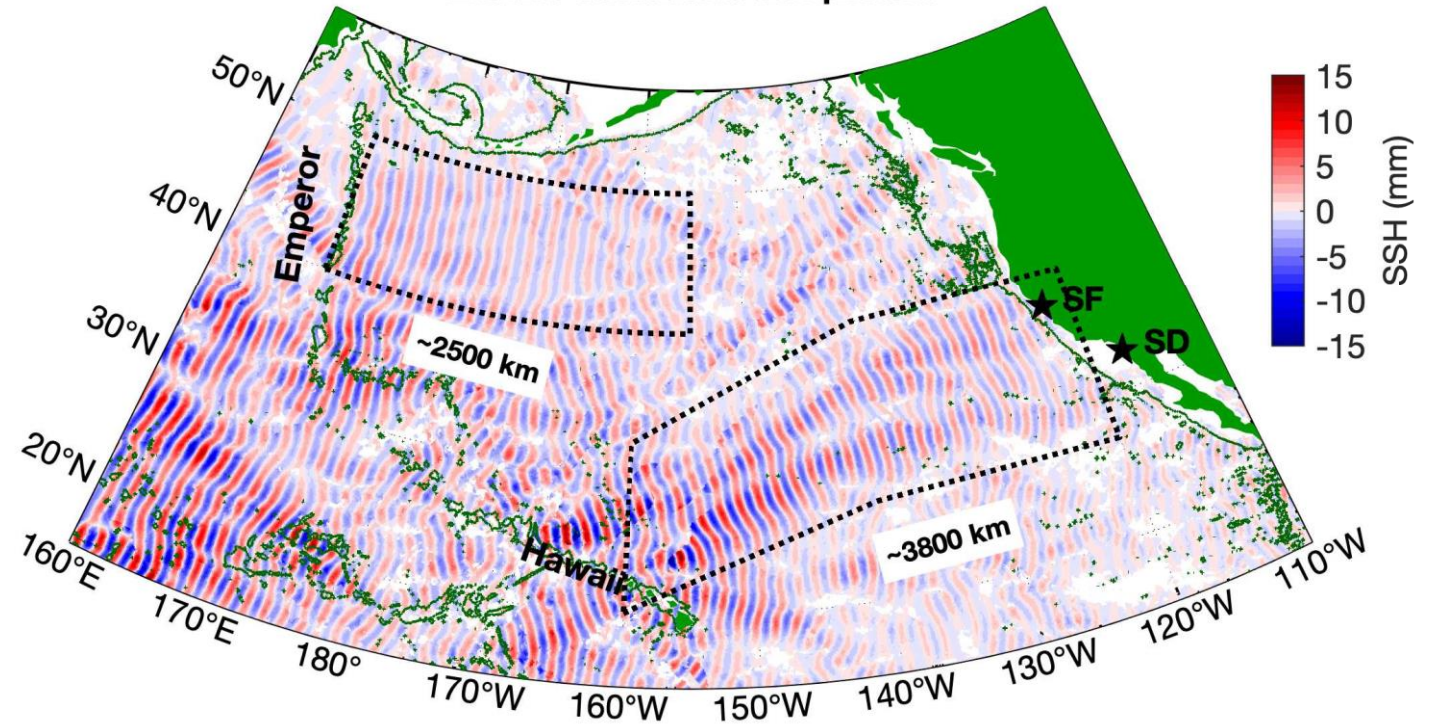

Travel time? 15 days

(c) Eastbound [-45° 45°]

Hawaii

MITgcm Mode-1 M$_2$

Zhao19 eastbound component

~2500 km

~3800 km

Hawaii

SF

SD

Emperor

SSH (mm)

Evidence from nadir-looking satellite data
(*Zhao 2019 JGR, under review*)

Summary

➤ The internal tide field is a superposition of multimodal multidirectional internal waves

➤ We develop a 2-step decomposition technique (**2D spatial filtering + 2D plane wave analysis**) to separately resolve multiple waves

➤ The decomposed results give a lot of details on internal tides

➤ This technique has been applied to
    1) other tidal constituents (O_1, K_1, S_2)
    2) regional MITgcm output
    3) global MITgcm output
    4) nadir-looking satellite altimeter data
    5) synthetic SWOT data

Question? See me at Posters TID-007, TID-008