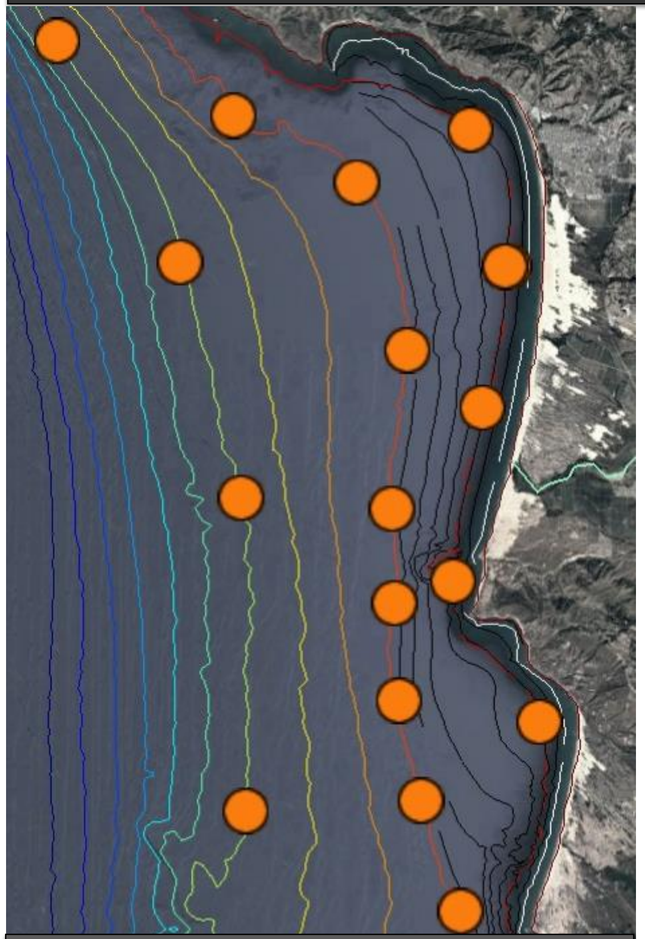
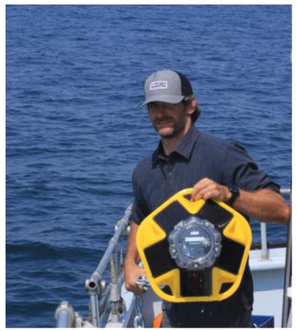
Real-Time Assimilation Using A Dense Array Of Directional Wave Observations

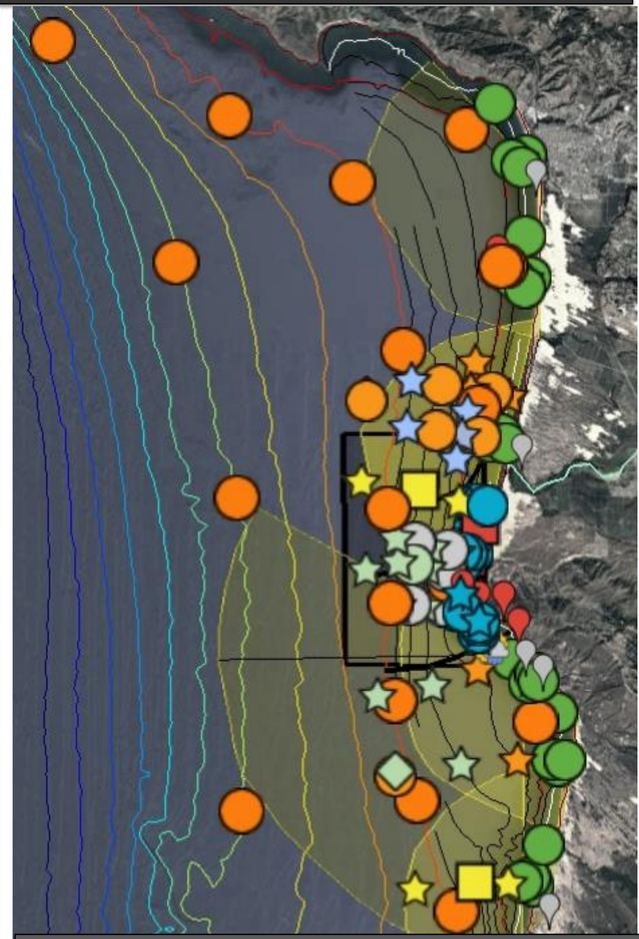
Pieter Smit, Tim Janssen, Cameron Dunning, Wheeler Gans

ONR Inner-Shelf DRI



Spotter Array





All Instruments

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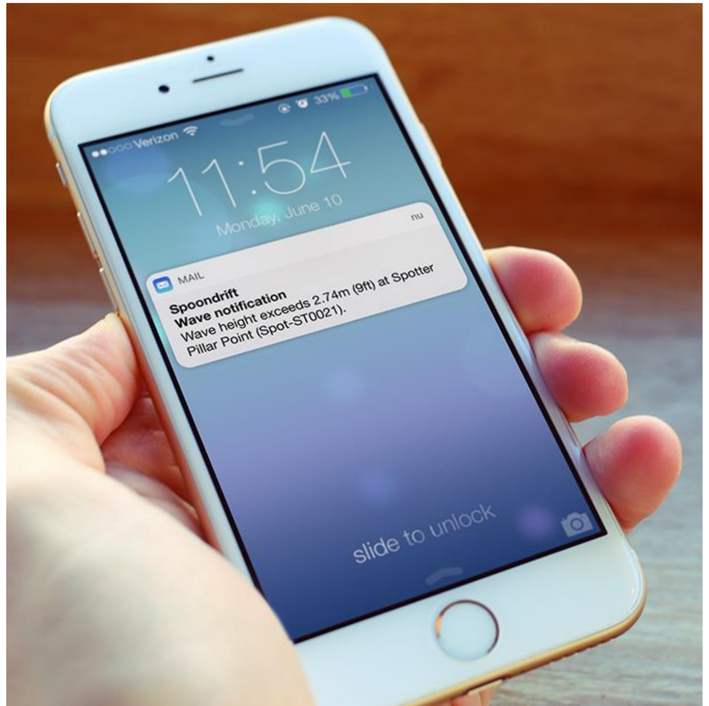
The Spotter device.

- Consists of sealed hull and removable electronics box
- Solar-powered
- Small and lightweight (12lbs)
- Cost-effective materials
- Free floating or moored
- Onboard data logging
- Onboard analysis for advanced wave statistics (directional moments, spectra etc).



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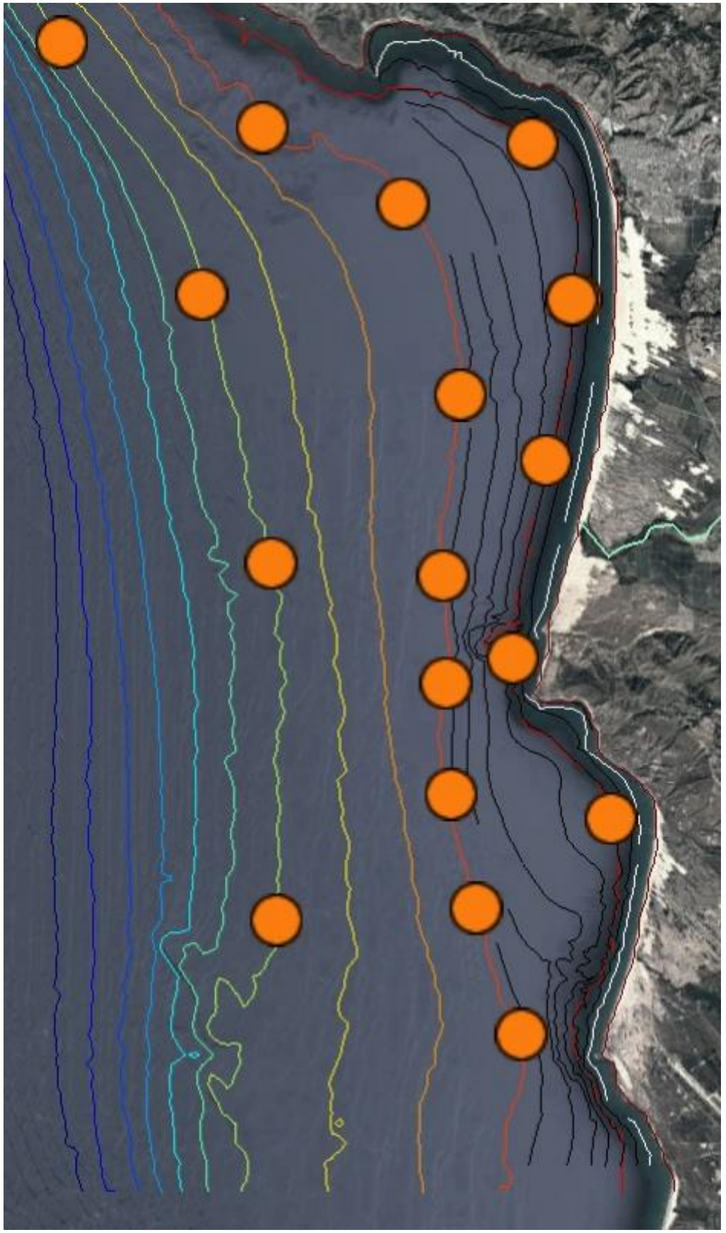
The Spotter dashboard.

- Realtime data access
- Globally connected
- User-friendly interface
- Data analysis tools
- Cloud-based data storage
- User profile and information
- Payment information

- Features include: geofencing, updates, notifications and alerts, historical data etc.



Science questions

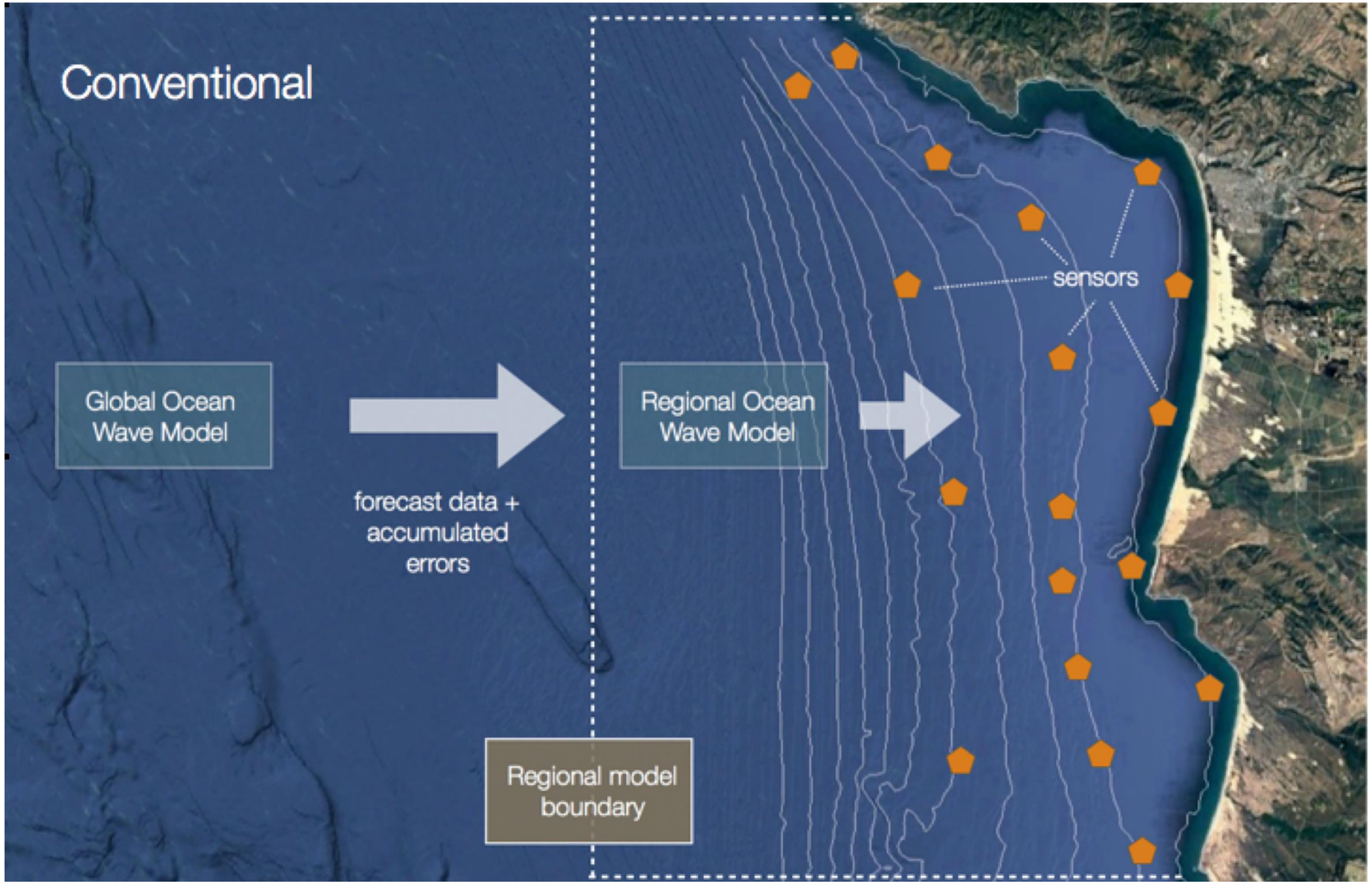
1. What do (semi-)Lagrangian instruments observe?

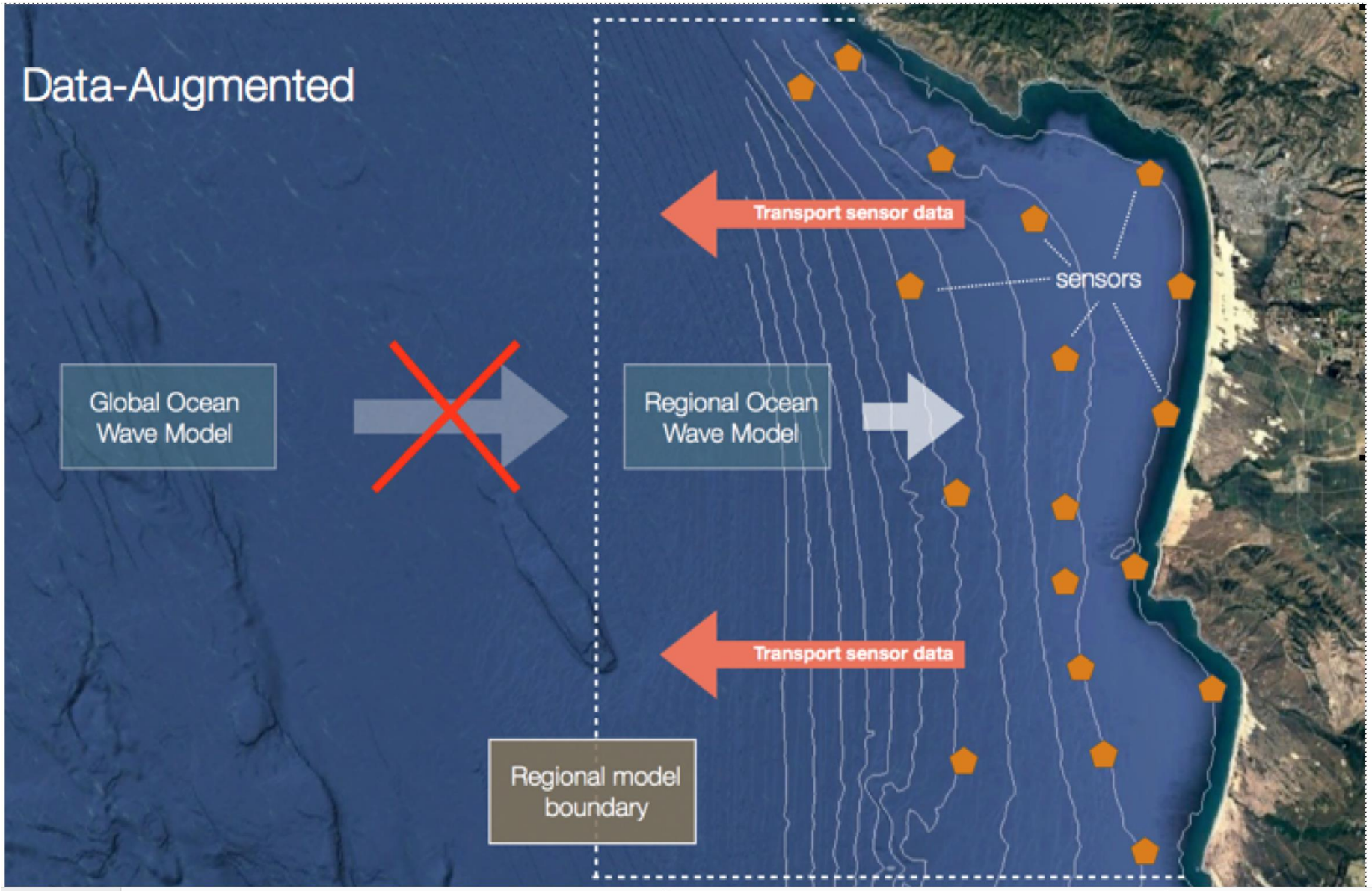
2. Infra gravity dynamics on the shelf

3. What can we do with data-abundance?

Real-time data driven nowcast

(this talk)


Conventional
Global Ocean Wave Model
forecast data + accumulated errors
Regional Ocean Wave Model
sensors
Regional model boundary


Data-Augmented
Transport sensor data
sensors
Global Ocean Wave Model
Regional Ocean Wave Model
Transport sensor data
Regional model boundary

Wave field inversion

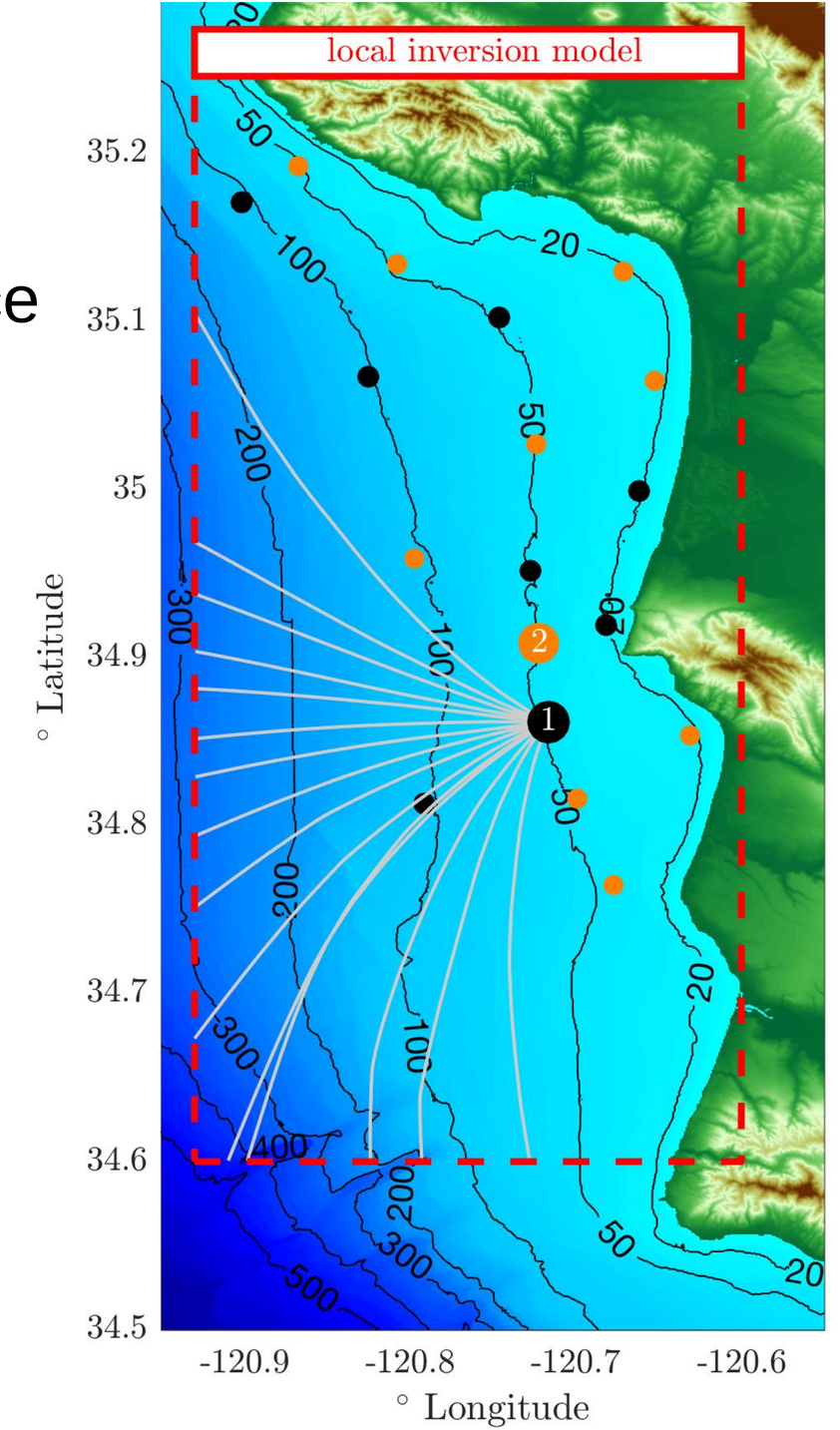
1. Assume physics in area described by Energy balance

$$\cancel{\frac{\partial E}{\partial t}} + \frac{\partial c_x E}{\partial x} + \frac{\partial c_y E}{\partial y} + \frac{\partial c_\theta E}{\partial \theta} = \cancel{\Delta S}$$

2. Conditions completely determined by boundary condition

3. Boundary condition that best reproduces buoy observations?

$$E_b(\theta, f) = ?$$



Determine best fit boundary?

(Crosby et al, 2017)

boundary spectrum

$$\frac{d}{ds}\left(cc_g E\right) \approx 0 \quad \Rightarrow \quad E(\theta, f) = JE(\theta_b, x_b, f)$$

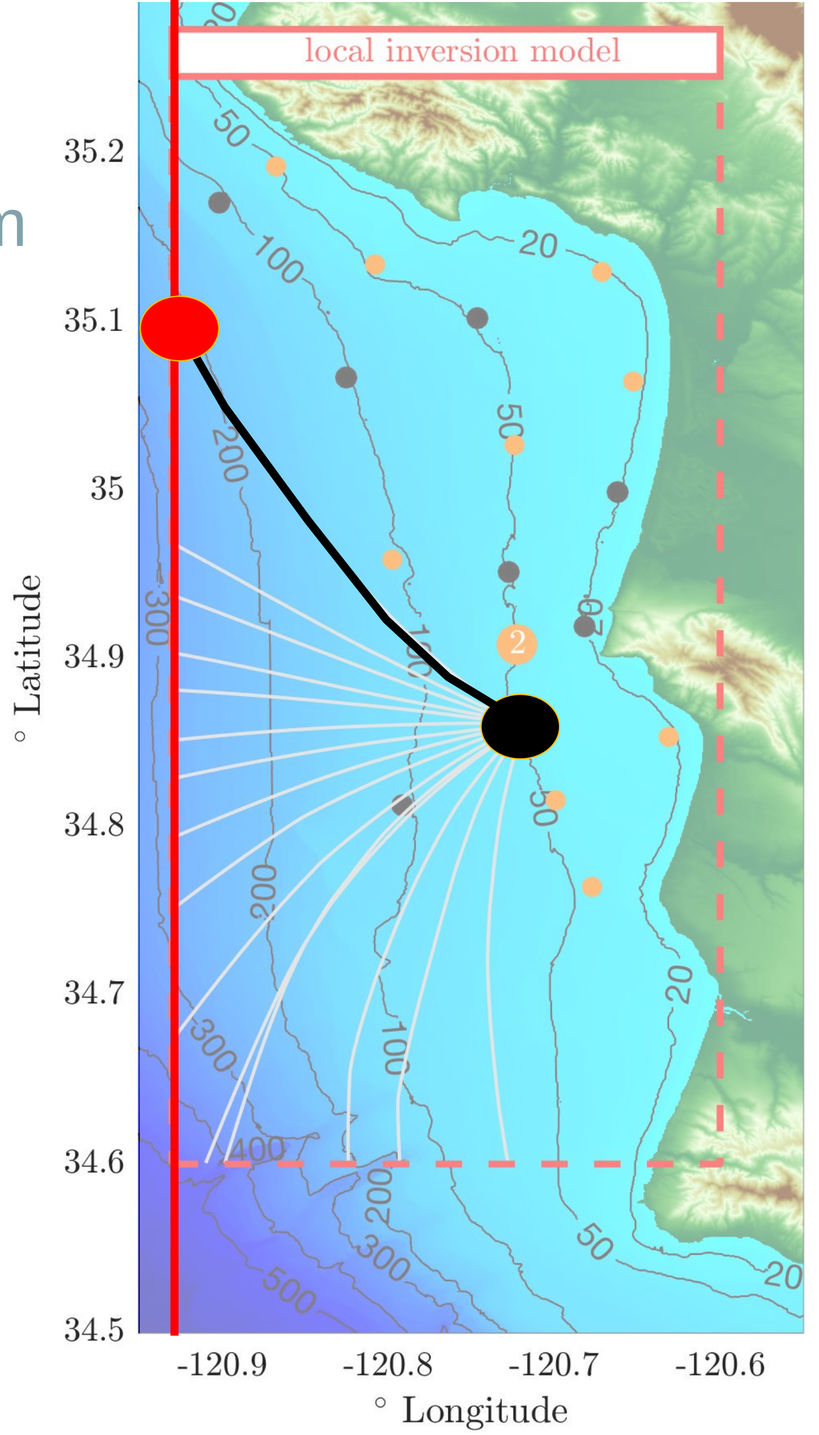
Boundary spectrum constant along incident boundary

$$E(\theta_b, x_b, f) = E(\theta_b, f)$$

Relate spectrum at buoy *to* boundary

$$E_i(f, \theta) = R_i \left\{ E_b \right\}$$

Refraction operator



Determine best fit boundary?

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At each site 5 observables

In terms of local directional spectrum

In terms of boundary spectrum

Substitute

$$E_i(f,\theta) = R_i\left\{E_b\right\}$$

directional moments

$E_i(f)$

$a_{1,i}(f)$

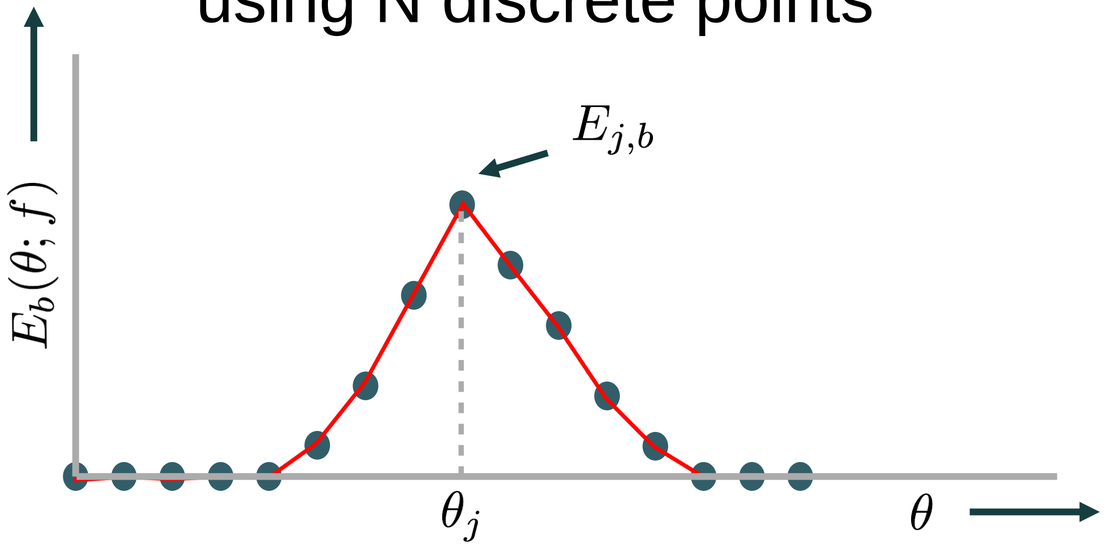
$b_{1,i}(f)$

$a_{2,i}(f)$

$b_{2,i}(f)$

Determine best fit boundary?

Describe boundary directional spectrum
using N discrete points



Observed spectrum expressed as linear sum

$$E_i(f) = \int R\left\{E_b(f,\theta)\right\} \mathrm{d}\theta \approx \sum_j A_{i,j} E_{j,b}$$

(similar for moments)

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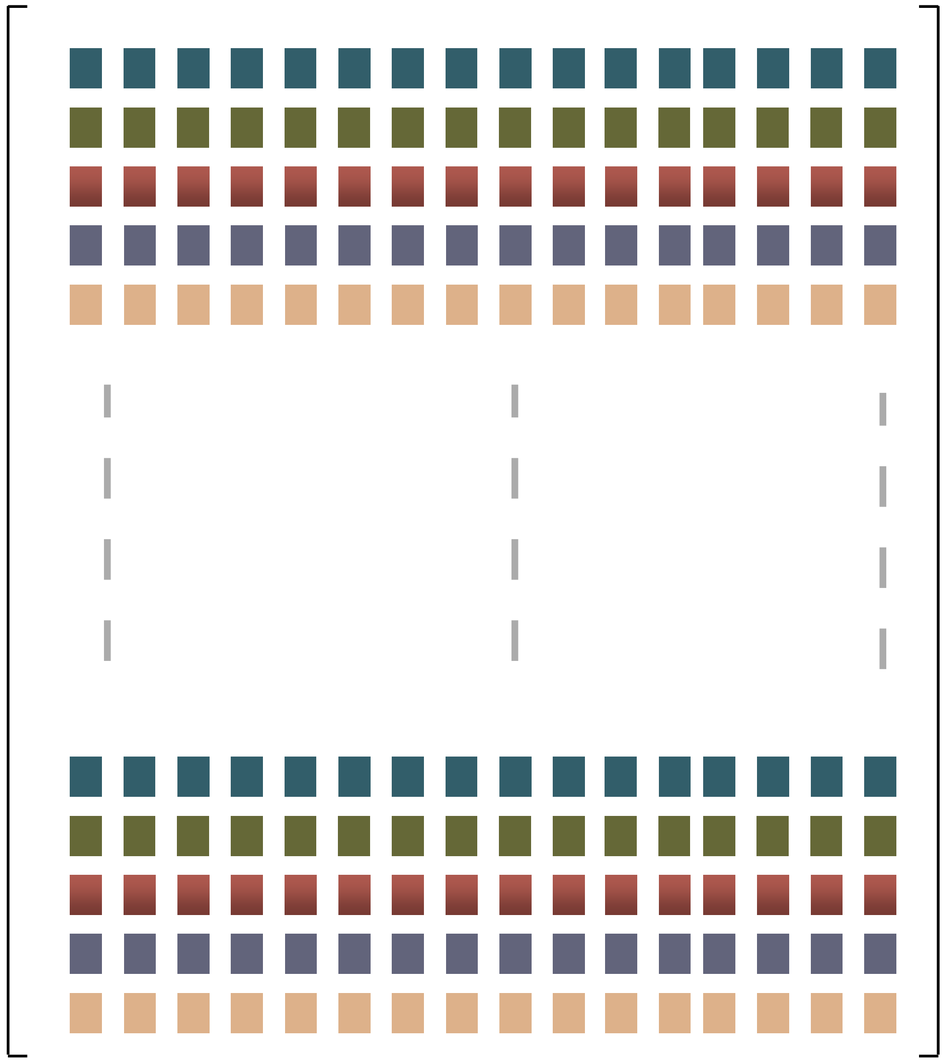
5 equations with N unknowns per buoy

buoy 1

buoy M



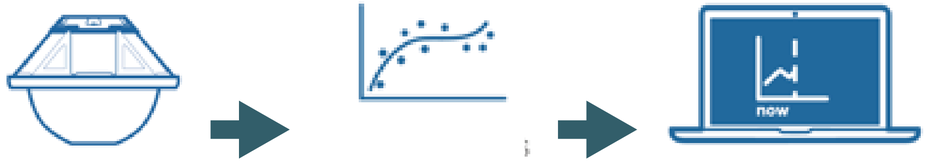
$$\begin{bmatrix} E_{1,b} \\ E_{2,b} \\ \\ \\ \\ E_{15,b} \\ E_{16,b} \end{bmatrix} = \begin{bmatrix} E(f) \\ a_{1,i}(f) \\ b_{1,i}(f) \\ a_{2,i}(f) \\ b_{2,i}(f) \\ \\ \\ \\ E(f) \\ a_{1,i}(f) \\ b_{1,i}(f) \\ a_{2,i}(f) \\ b_{2,i}(f) \end{bmatrix}$$

boundary spectrum

observations

M buoy's gives 5M observations, and 5M equations with N unknowns

Real-time system during deployment.



Observe

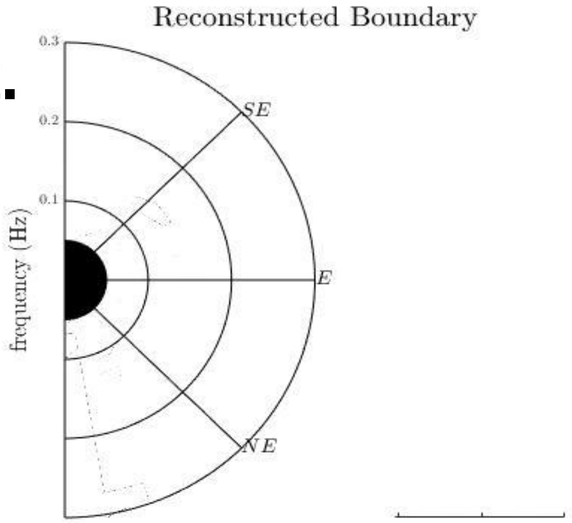
Inverse and forward model

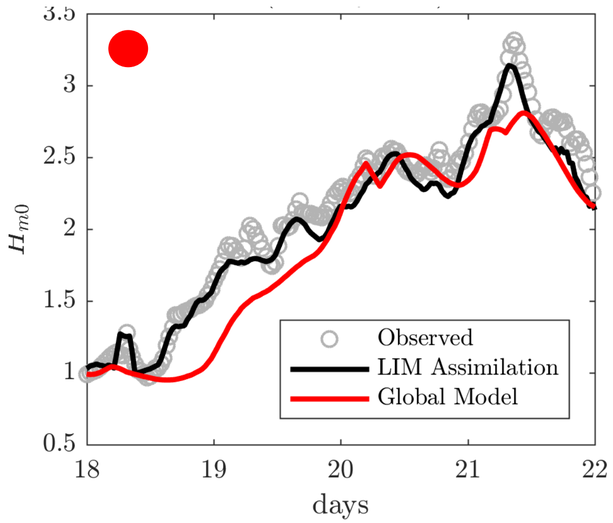
Dashboard

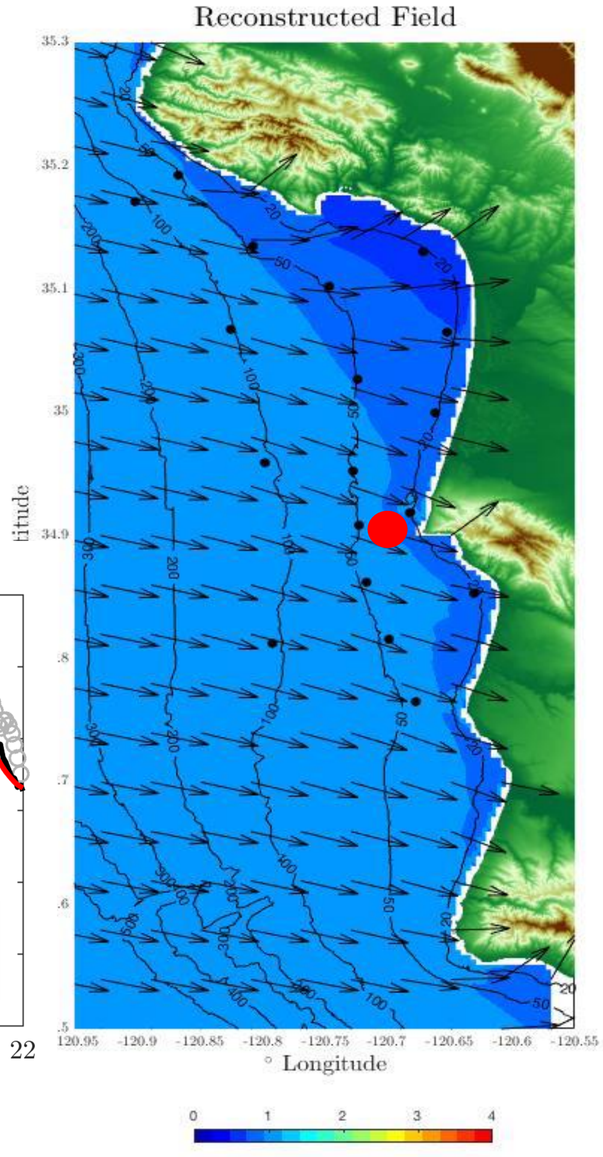
1. Observations communicated hourly

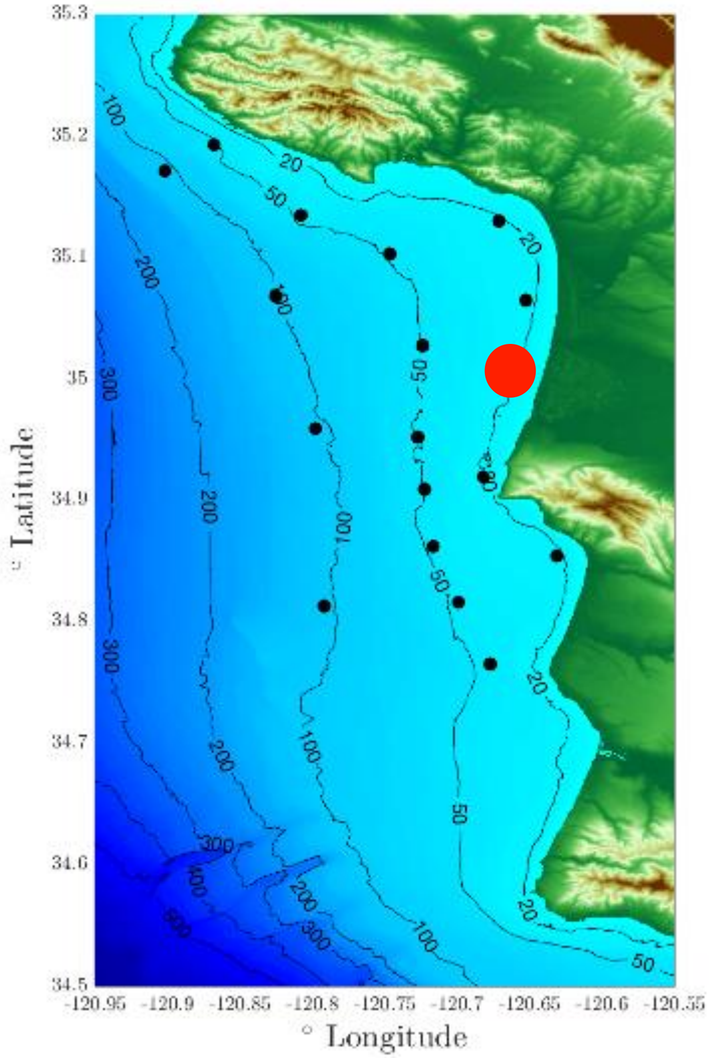
2. Inversion and forward SWAN model (wave heights throughout the domain)

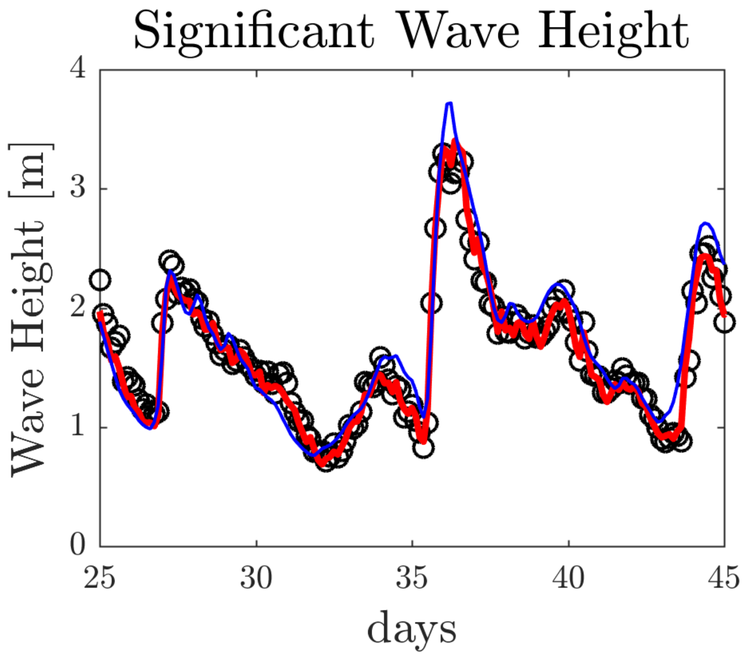
3. Display at backend



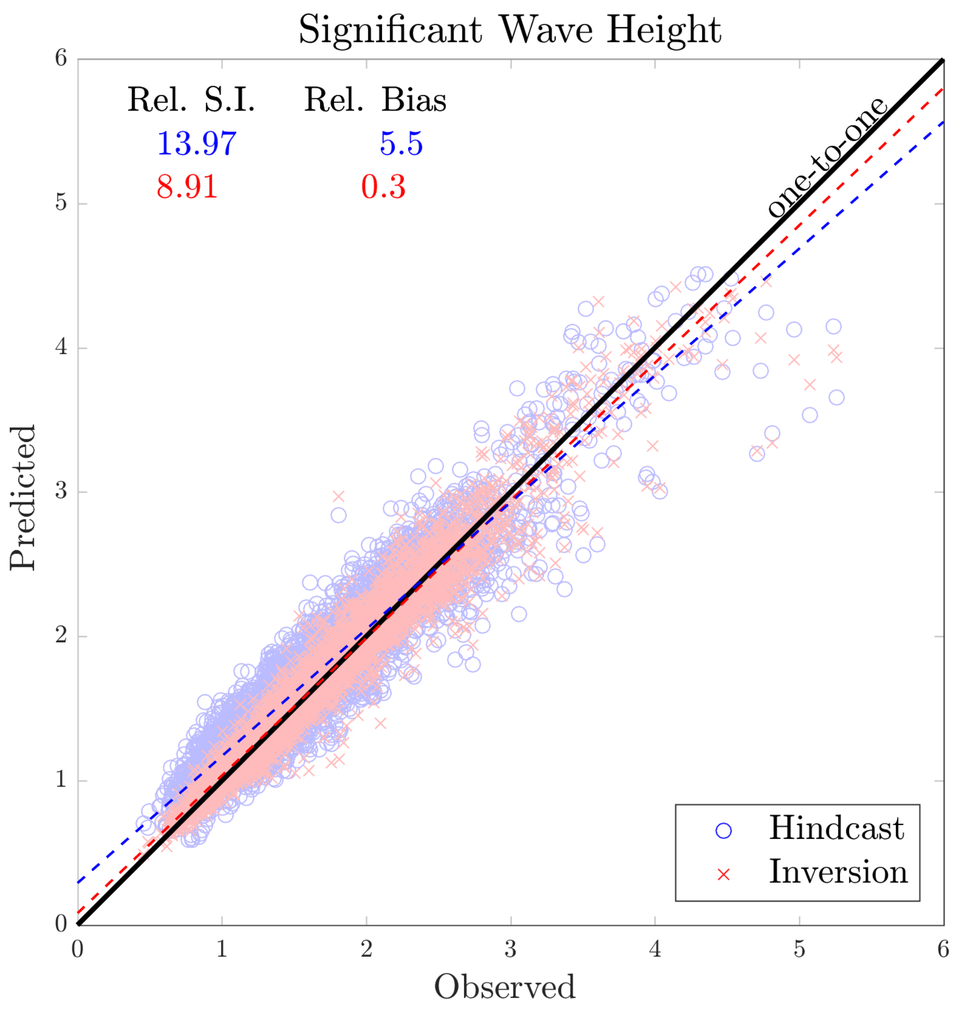


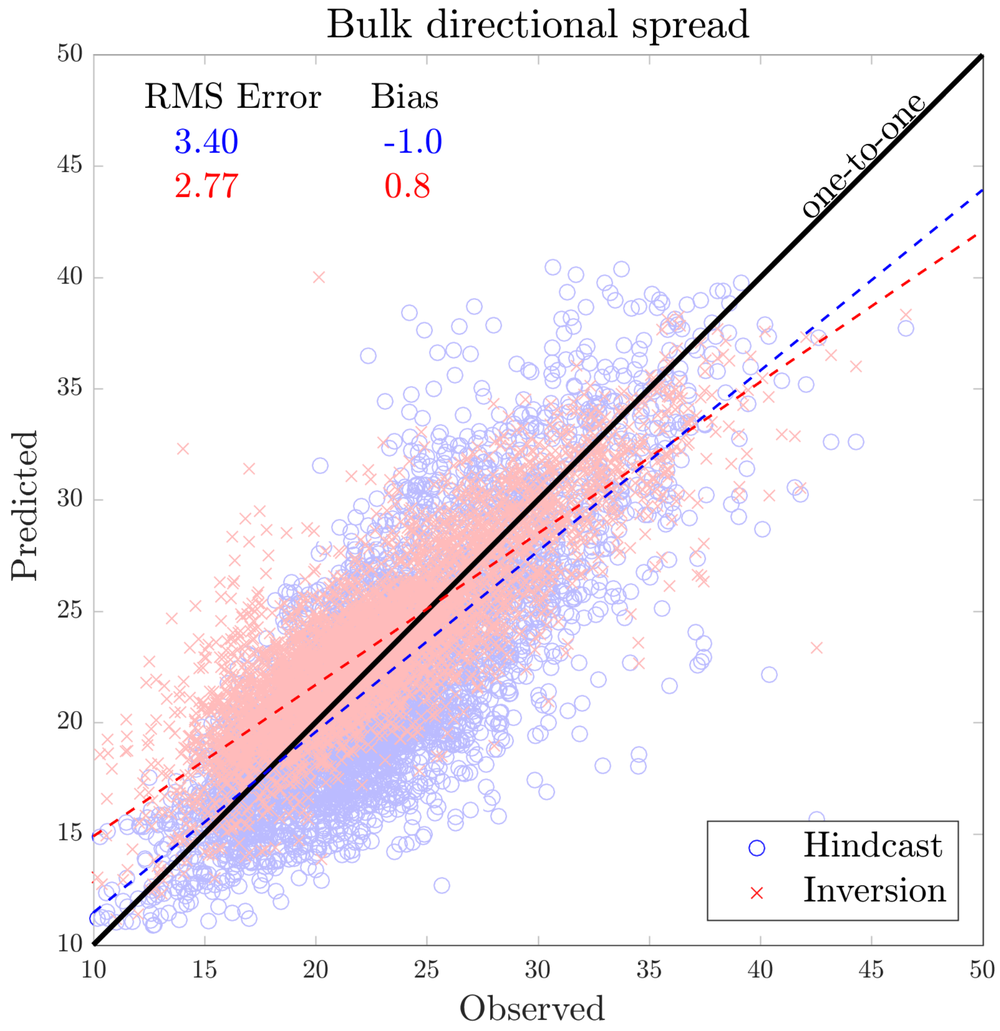






observed — Hindcast — Inversion


Significant Wave Height
Rel. S.I.
Rel. Bias
13.97
5.5
8.91
0.3
one-to-one
Hindcast
Inversion
Predicted
Observed
0
1
2
3
4
5
6


Bulk directional spread
RMS Error
Bias
3.40
-1.0
2.77
0.8
one-to-one
Hindcast
Inversion
Predicted
Observed
10
15
20
25
30
35
40
45
50

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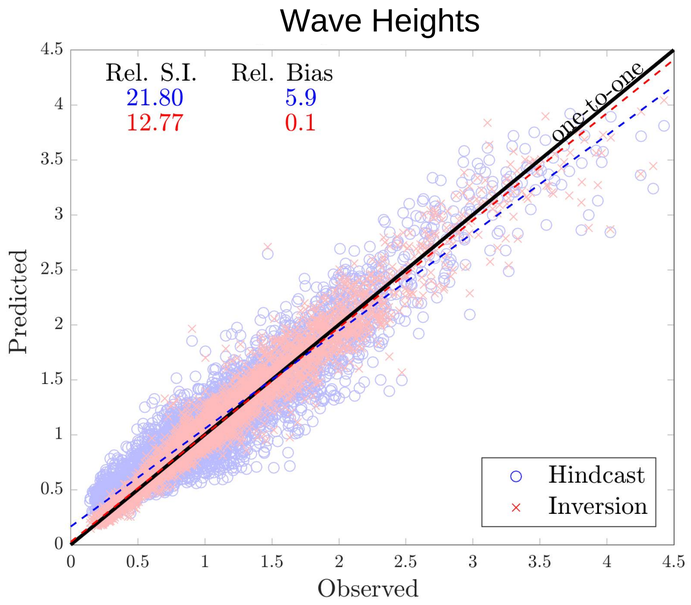
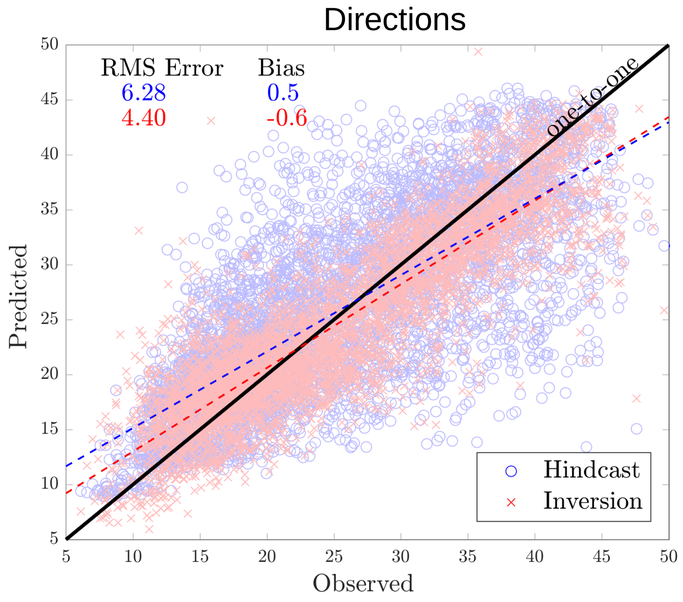
0-0.1Hz

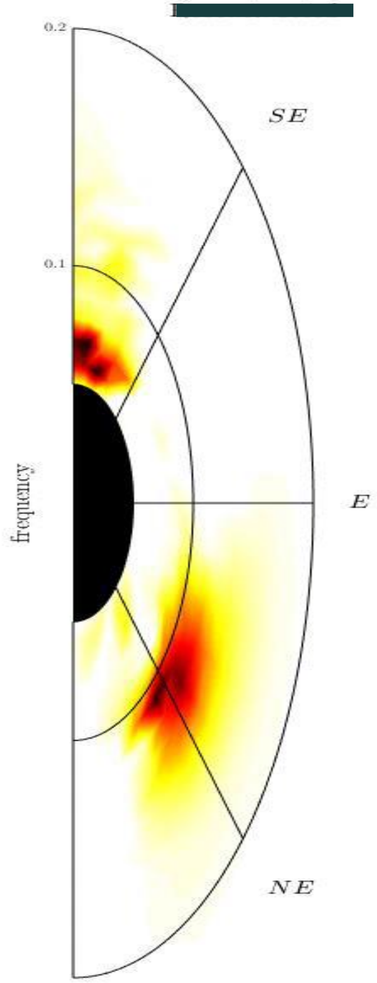


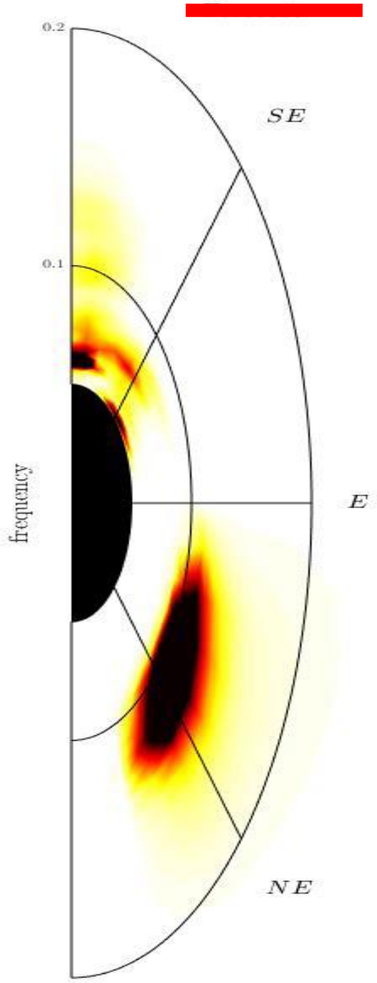


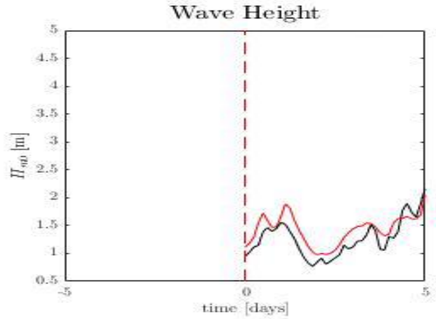
0.3-0.4Hz

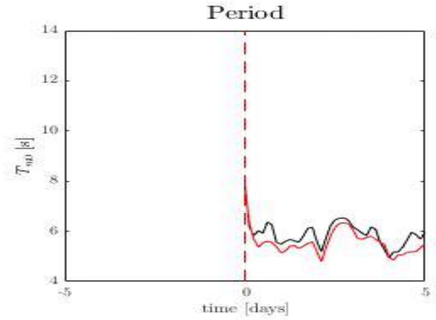
Inversion

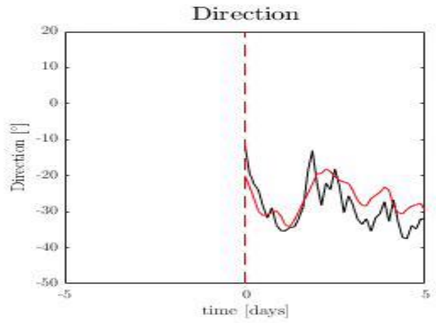
Hindcast



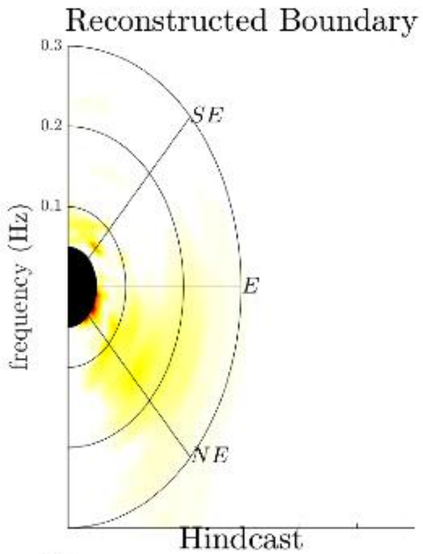


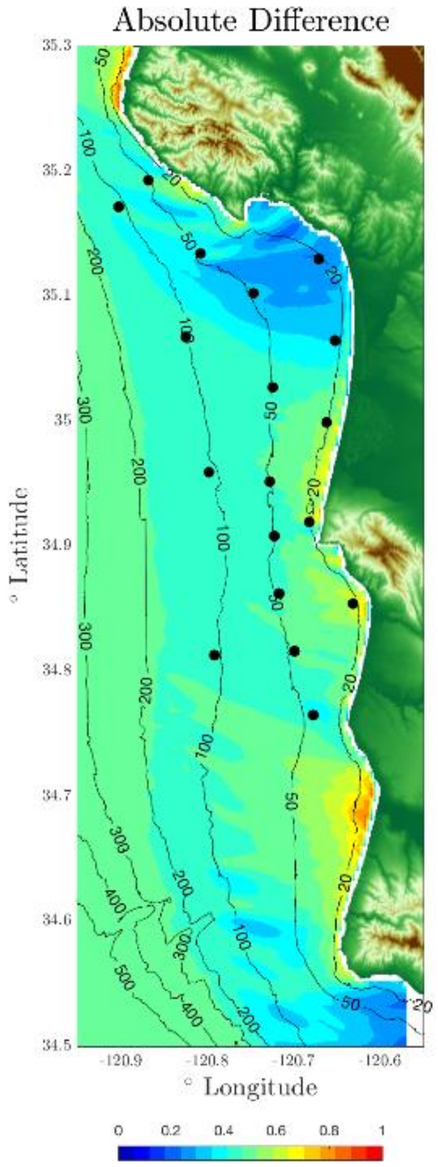


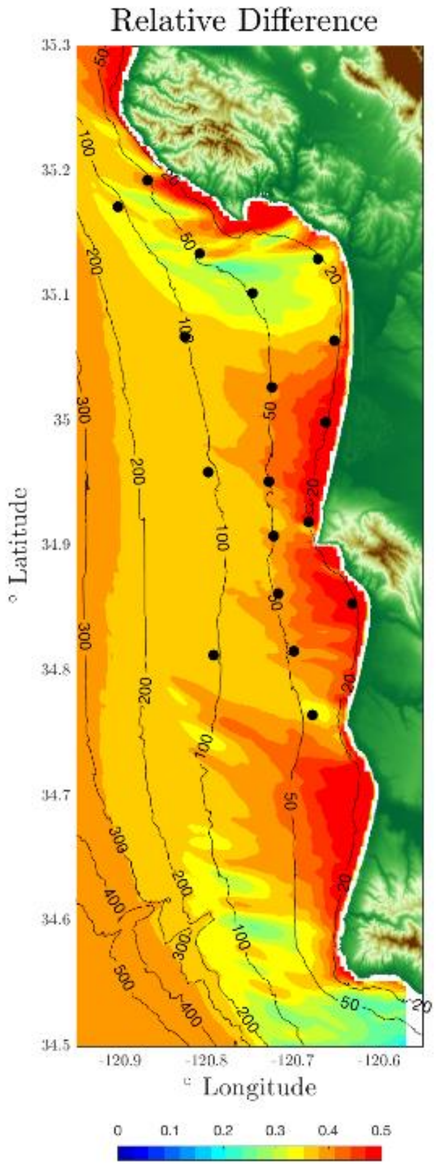




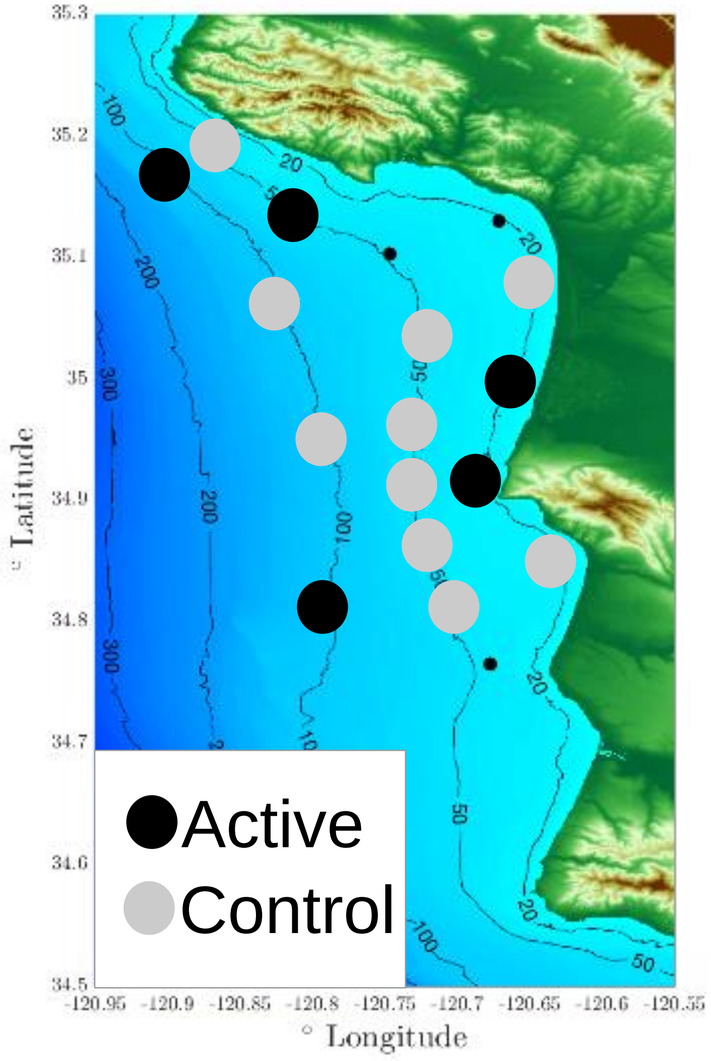
Significance?

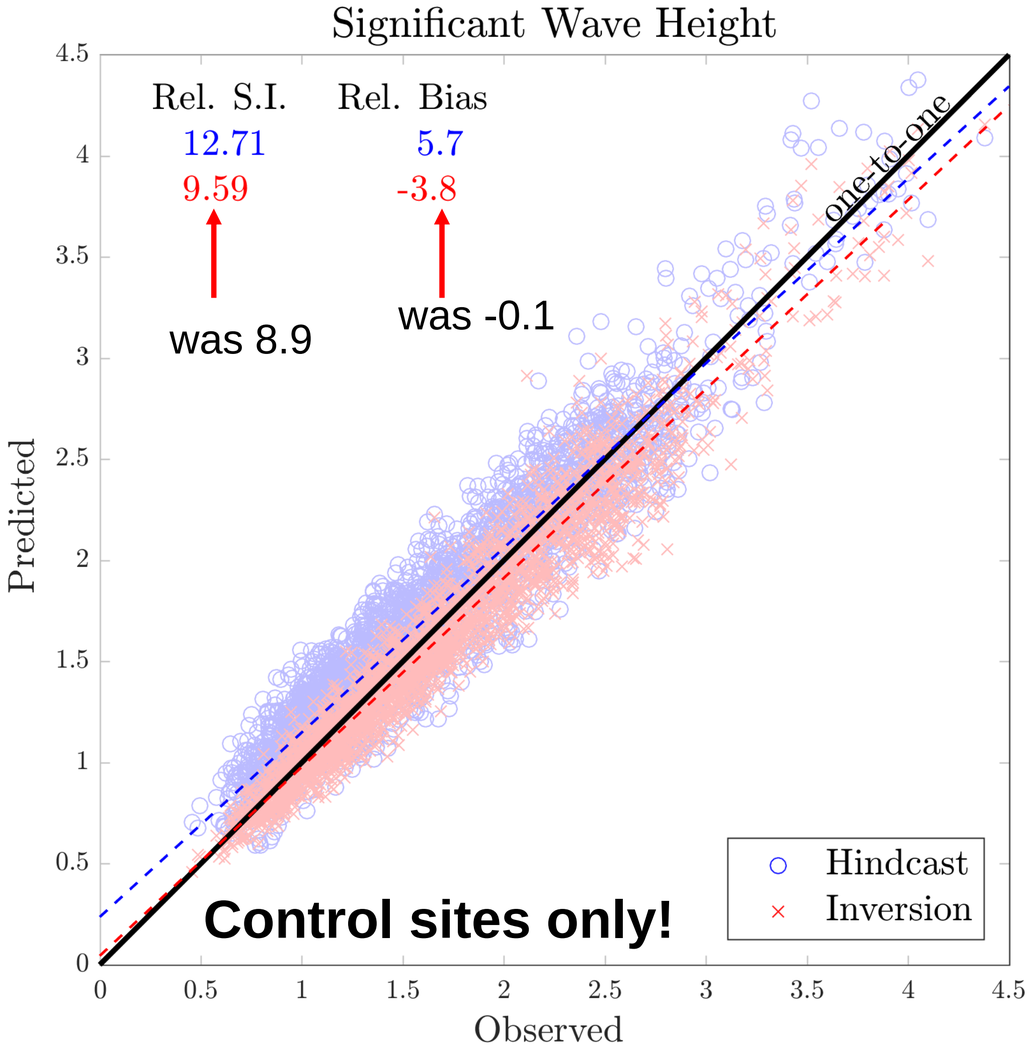






At sites included in optimization skill improves.. what about other sites?





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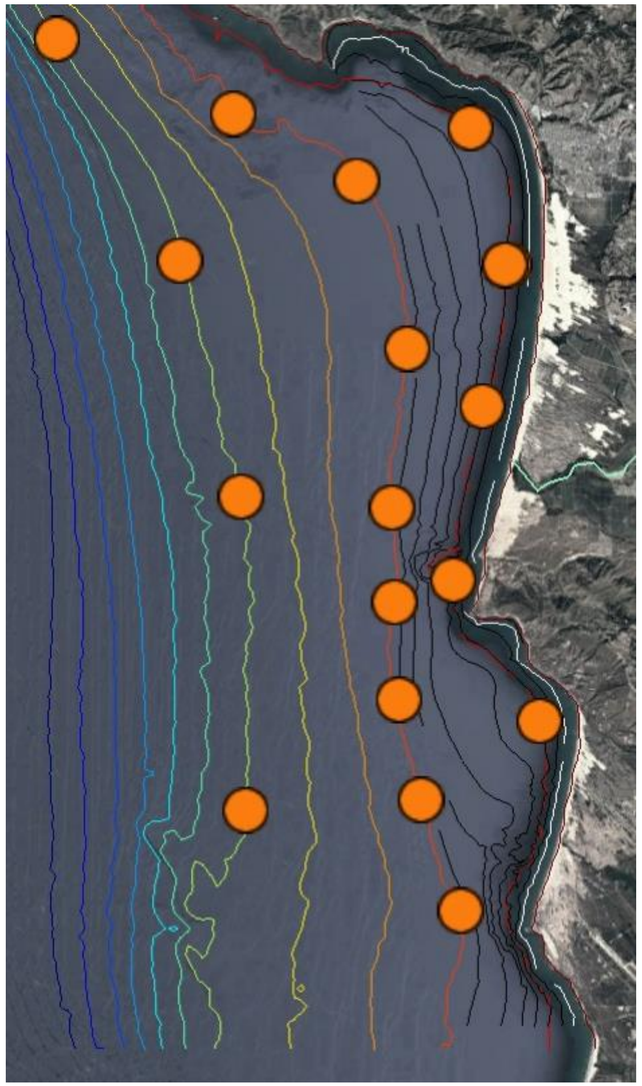
Open questions



1 Array size and geometry

Deep water buoys essentially observe the same directional moments (and noise)

(still usefull to suppress observational noise)

Each shallow site adds unique information on directionality.

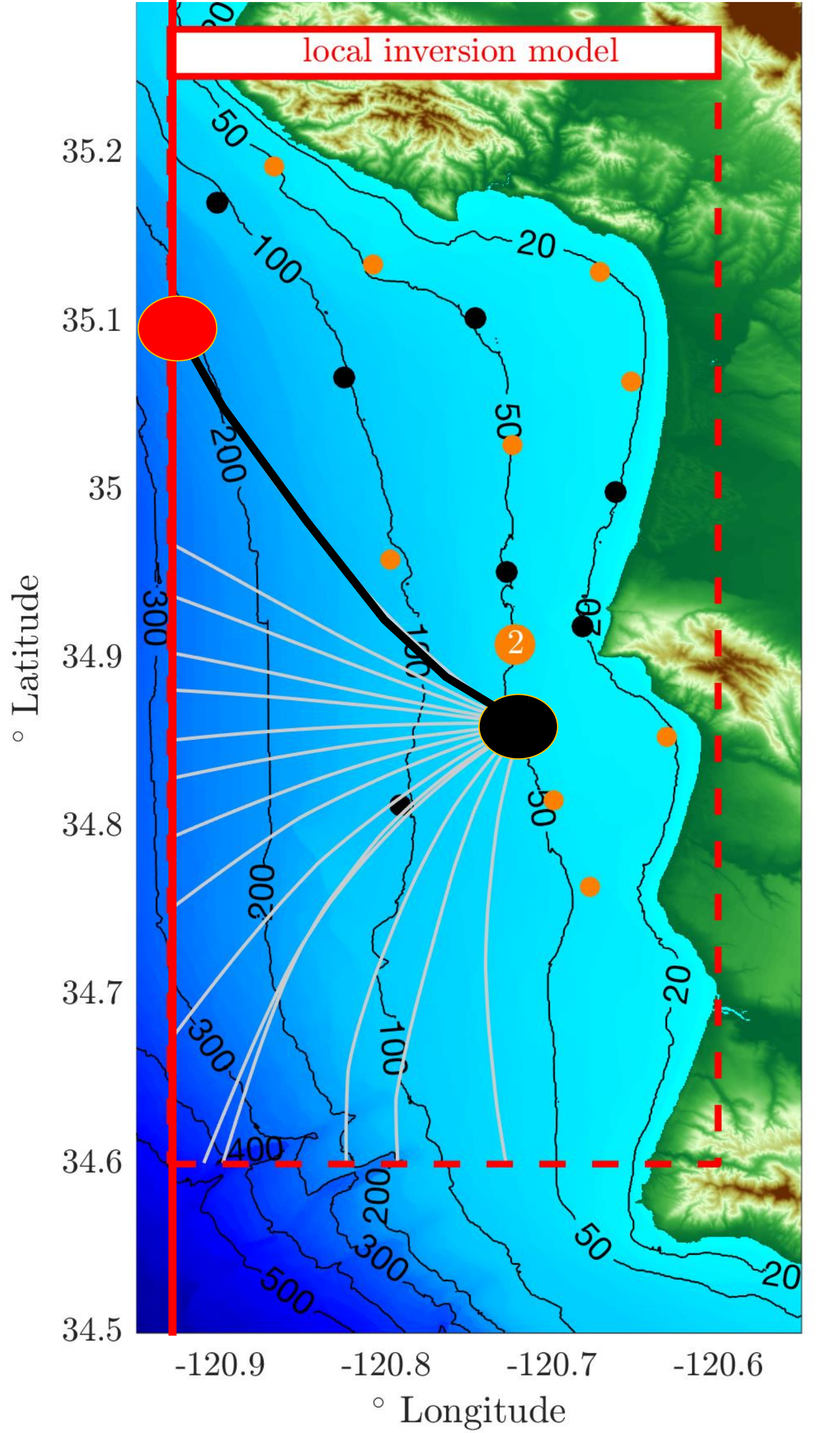
site specific deformation of ray geometry through refraction

Open questions

2 **Generation, dissipation, nonlinearity, stationarity,…..?**
I.e. source terms

$$\frac{d}{ds}\left(cc_g E\right) = \Delta S$$

$$E(\theta, f) = JE(\theta_b, x_b, f) + \int \Delta S \mathrm{d}s$$



Takeaway

1. Dense array of wave buoys can accurately reconstruct wave field in near real-time.

2. Low cost sensors open up new applications for data-integration to enhance modelling fidelity…

and pursue new science!

(manuscript in preperation)