TOWARDS UNDERSTANDING TSUNAMI RESONANCE AT BAY SCALES THROUGH STOCHASTIC SIMULATIONS

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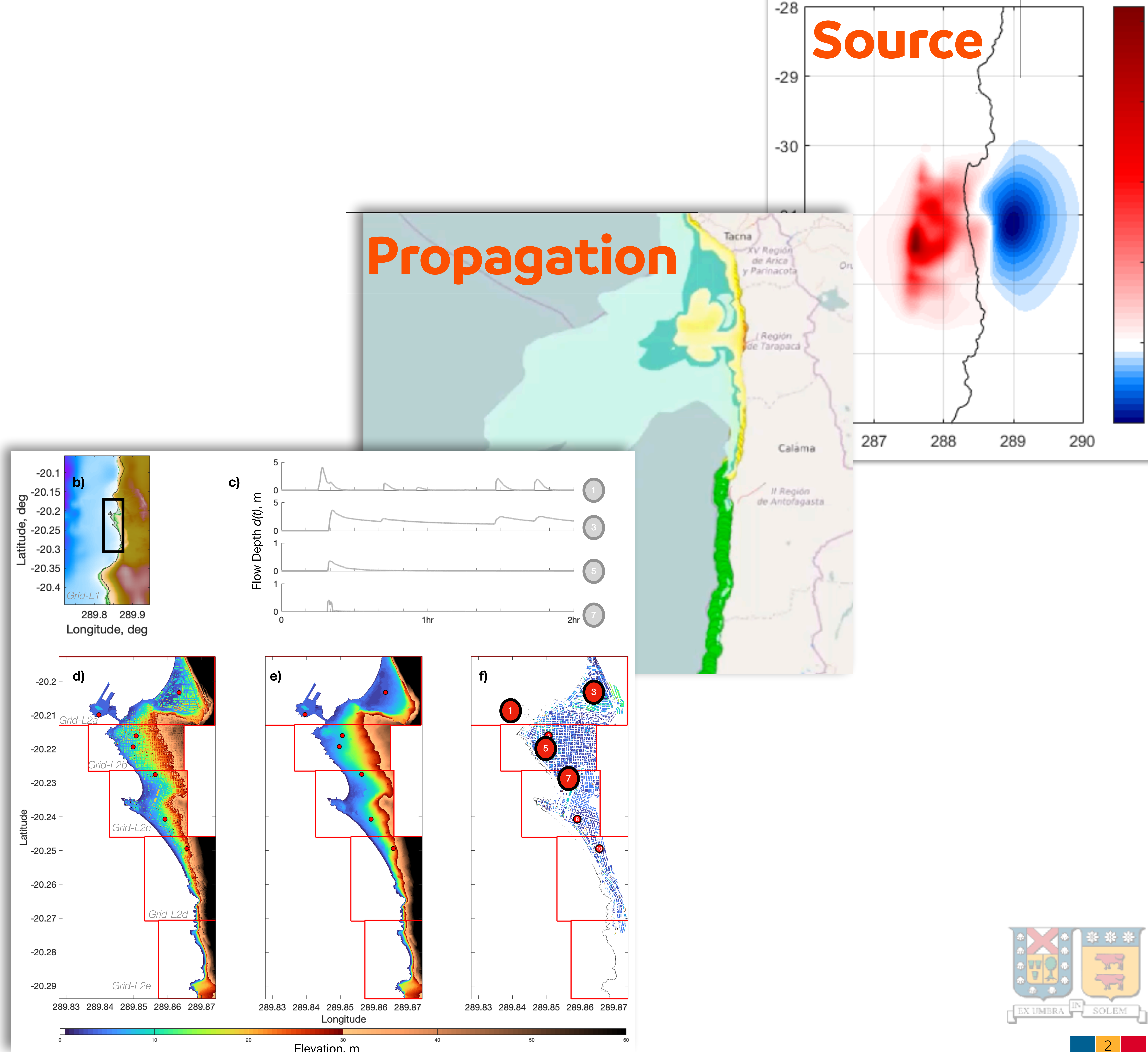
Background

- **Tsunami life in time**
- Generation
- Propagation + Transformation
- Inundation
- **What we see at the coast**



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Background

- Spectral response of a system can be due to the transformation of the source spectrum by several factors
  - e.g. Rabinovich, (2009)

- We would like to know if this is controlled by either ***W(f)*** or ***Z(f)***, or both.

- And **where/when** this dominance occurs.

Local response

$$S_t(f) = W(f) * Z(f) * O(f)$$

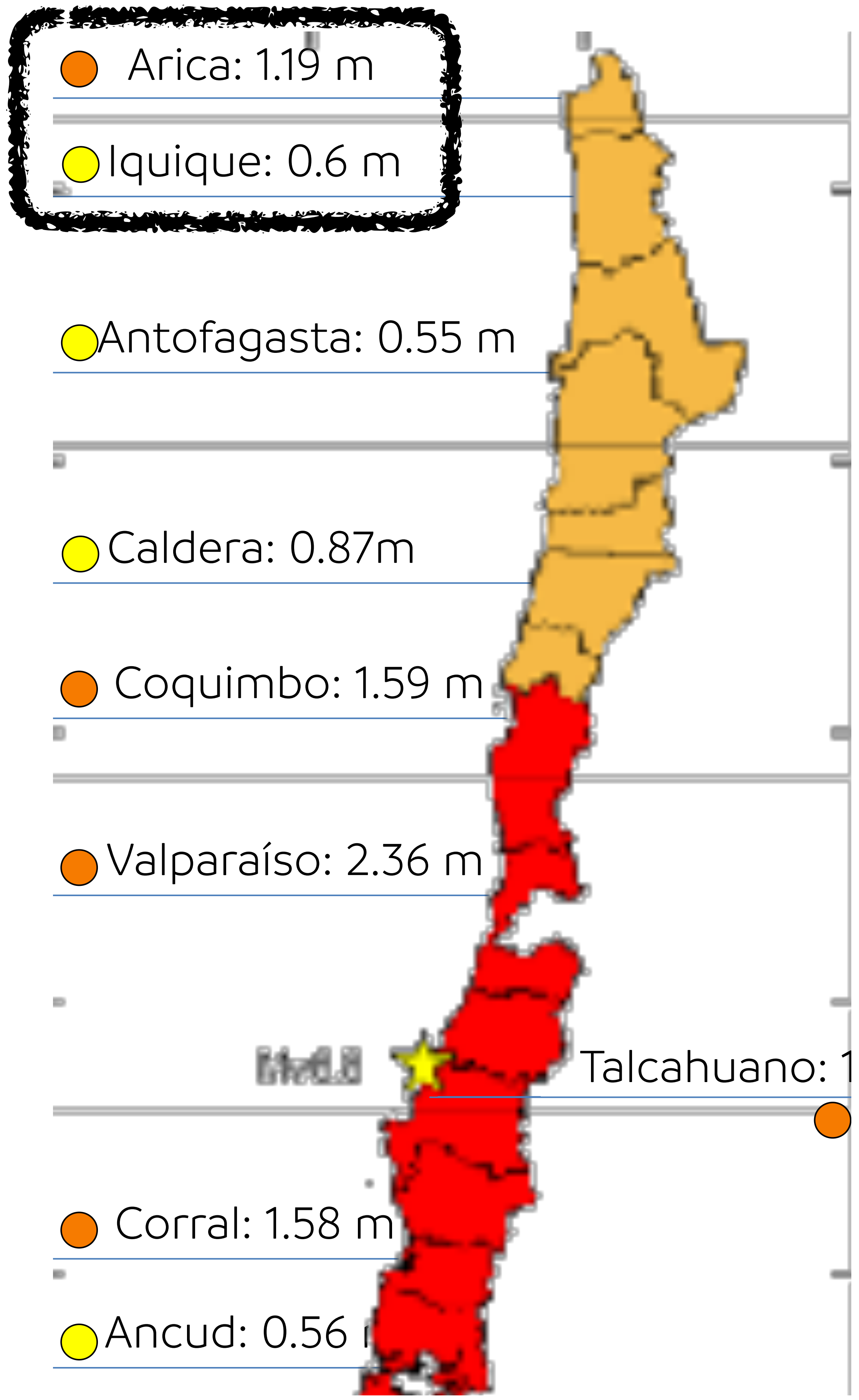
Total Bathymetry Modulation Function

Source spectrum

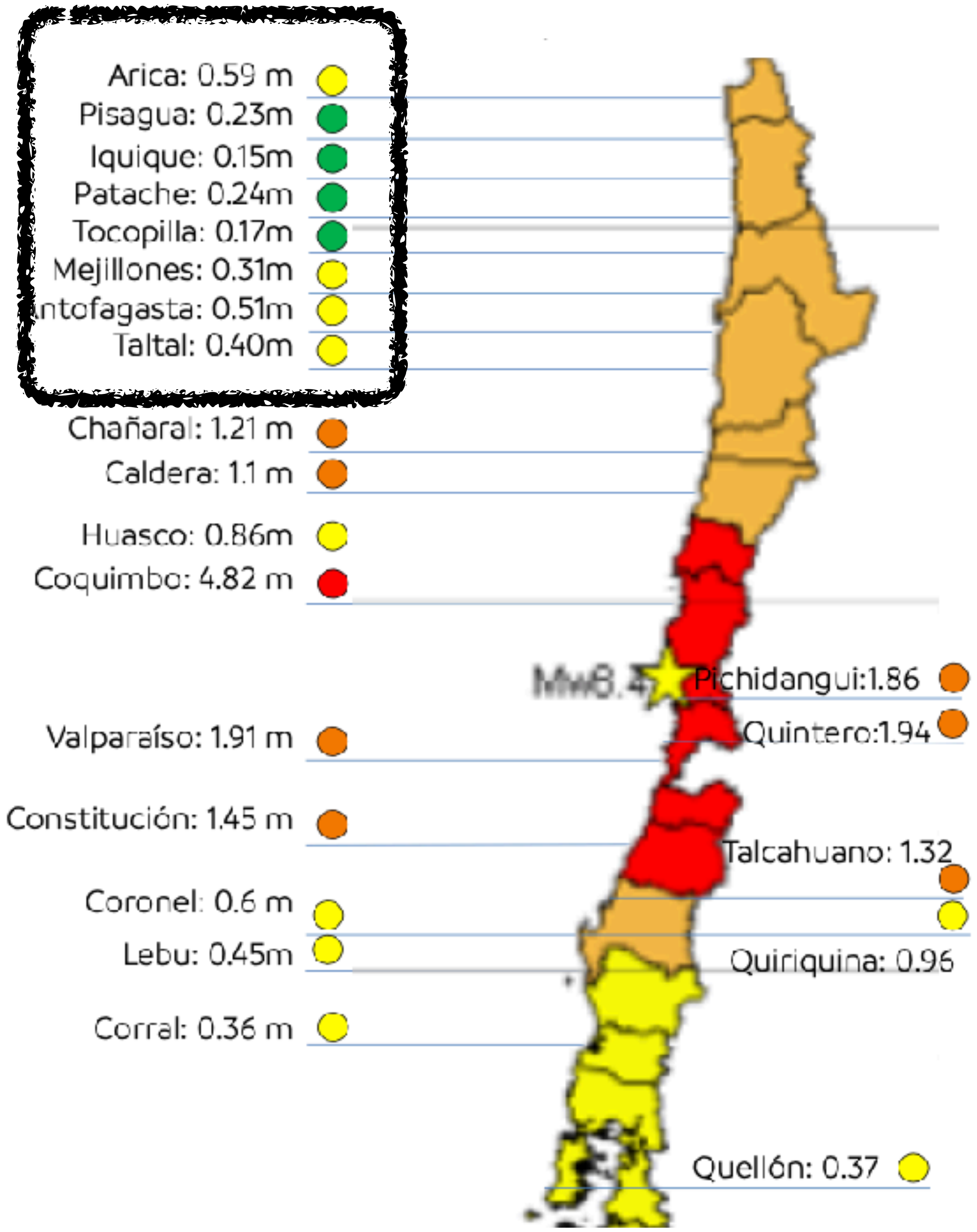
Other

Why the Interest?

- Cities like **Arica**, in northern Chile, consistently exhibit large tsunami amplitudes
- Clear difference with surrounding cities
- Complicates Emergency communication



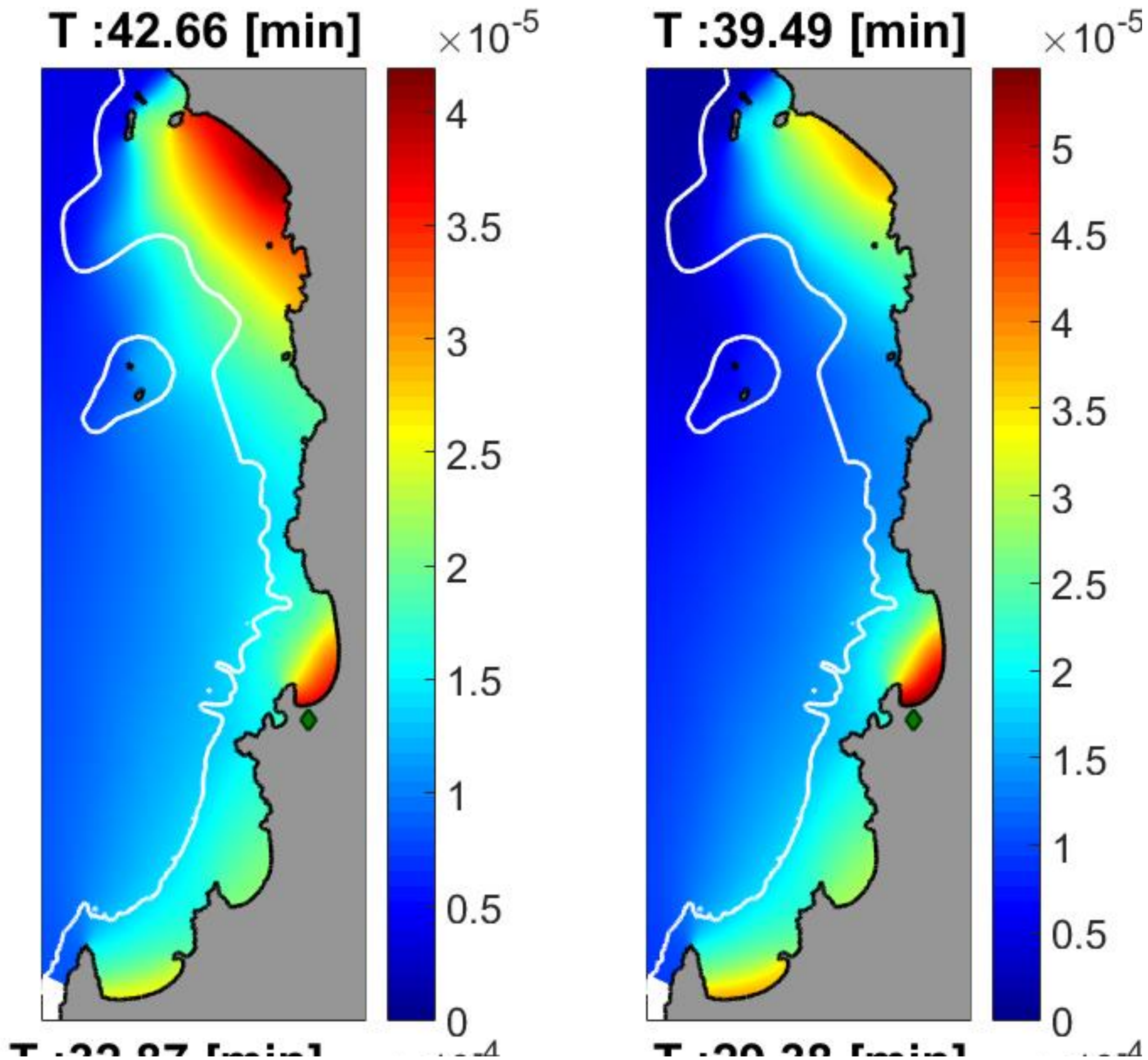
Maule
Mw 8.8



Illapell
Mw 8.3

Why the Interest?

Dominio Punta Choros – Tongoy



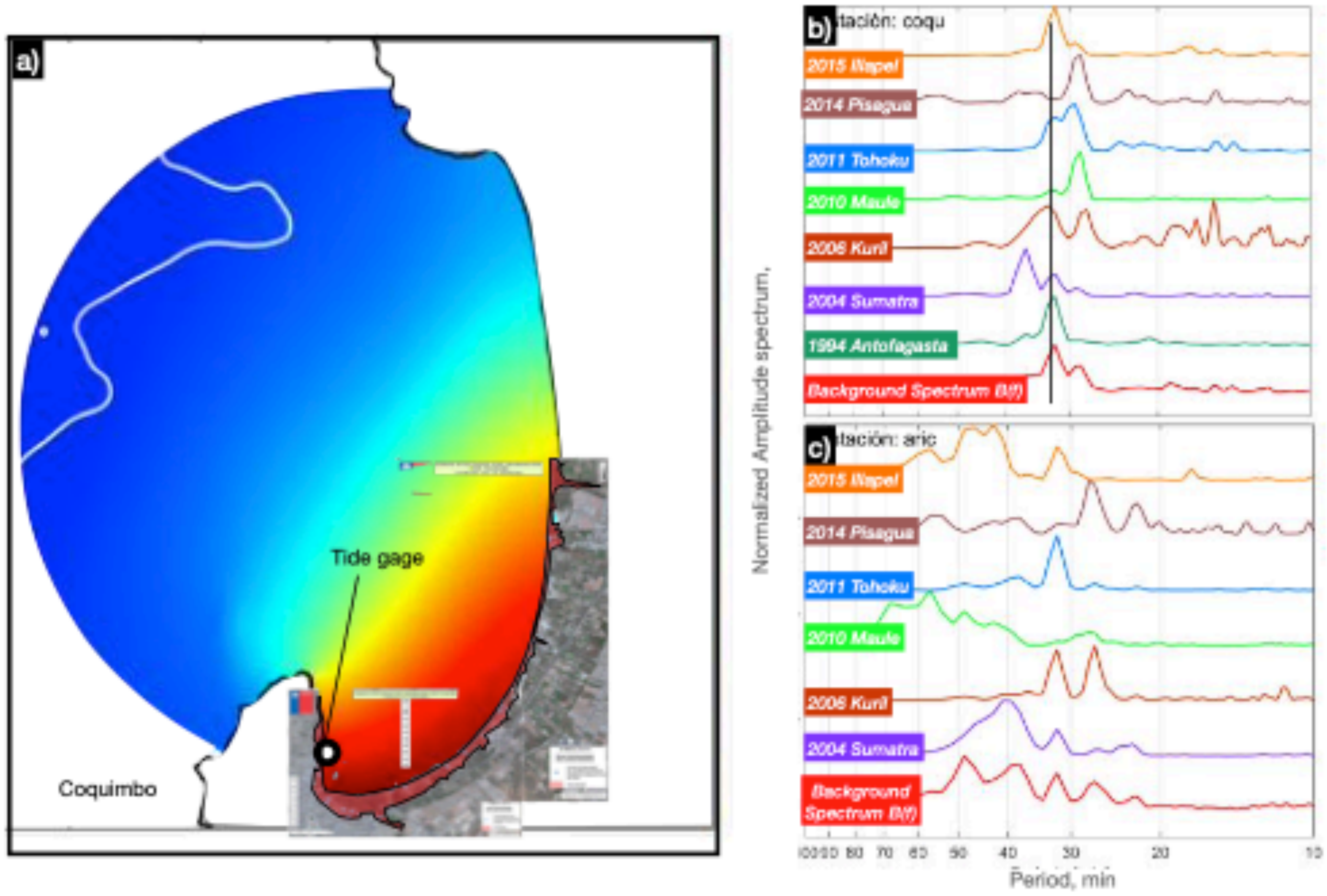


Figure 1: *a) Composite image of the first natural mode (T=32 min) of the bay of Coquimbo, as determined by the FOM (largest amplitude in red), overlaid two maps of the inundation of the tsunami that followed the Mw8.4 Illapel 2015 Earthquake, as published by SERNAGEOMIN. The highlighted area correlates well with published sources (Paulik et al., 2021, Aránguiz et al., 2016). b) Normalized amplitude spectrum for seven tsunamis recorded at the tide gage in this bay show a remarkable independency of source characteristics. Vertical line shows the T=32 min period displayed in a). c) Same as b), but Arica, in northern Chile. This bay shows a different response across different tsunamis. Unpublished preliminary results. In b) and c) individual spectra are offset vertically to facilitate discrimination among them.*

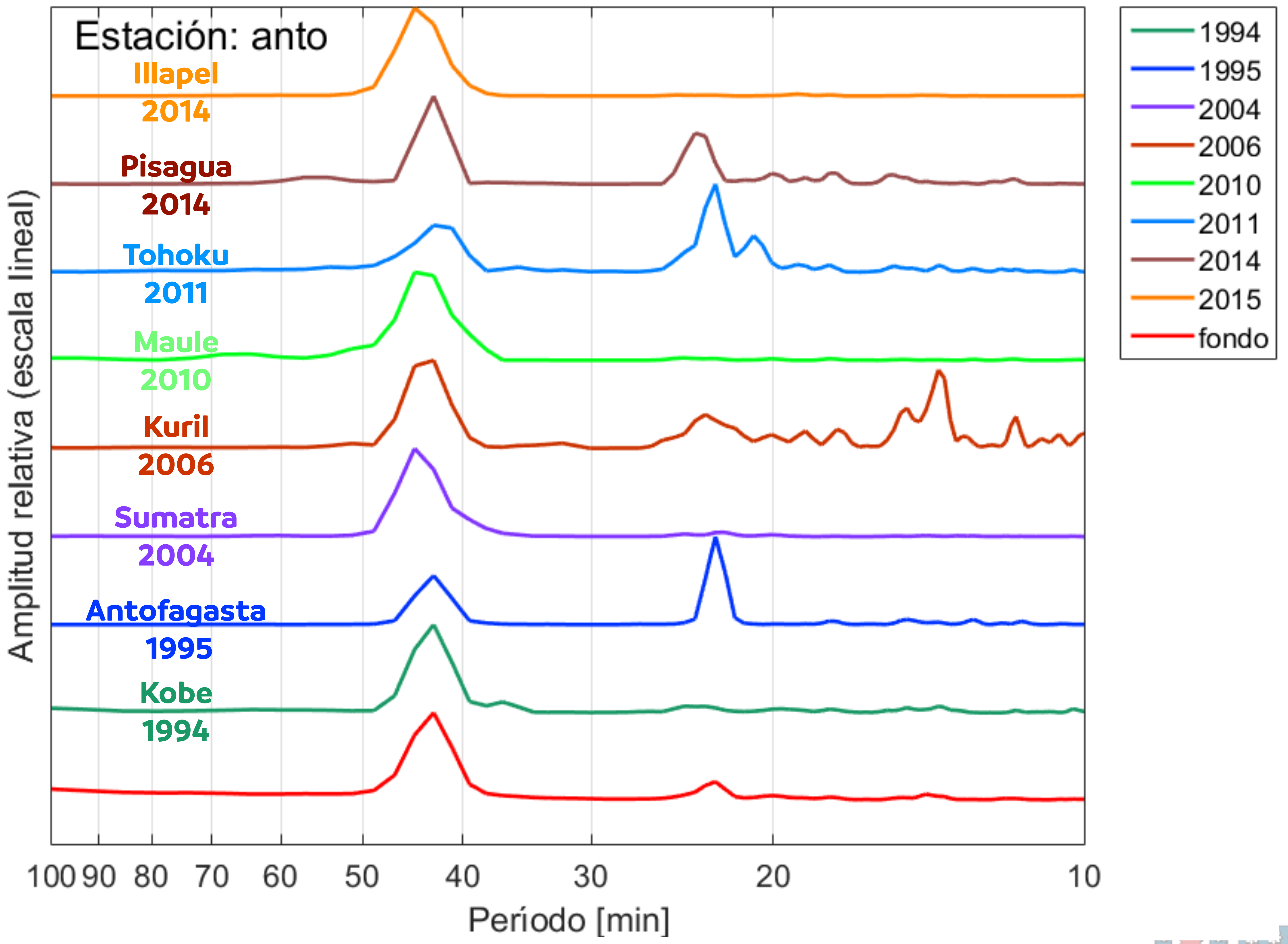
Why the Interest?

- And of course, **TIME**
- Resonance can drive **long tsunami durations**
- Resonance can drive **late tsunami arrivals of peak amplitudes**

STANDARD METHODS

Standard Methods: **Spectral response during past events**

- **Data Source:**
  - **Tide gage records**
- **Pros:**
  - **Actual** data from an event
- **Cons**
  - **Few** events
  - Very conditioned **by location** of tide gages



Tsunami records at ANTOFAGASTA (Northern Chile)

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Standard Methods: **Free Oscillation Modes**

- **Data Source:**
  - **Eigenvalue problem of the system**
  - **(just water)**
- **Pros:**
  - **Spatial Patterns** of amplification
- **Cons**
  - **Mixes** physical and numerical modes, hampering understanding
  - Very conditioned **by domain of simulation**

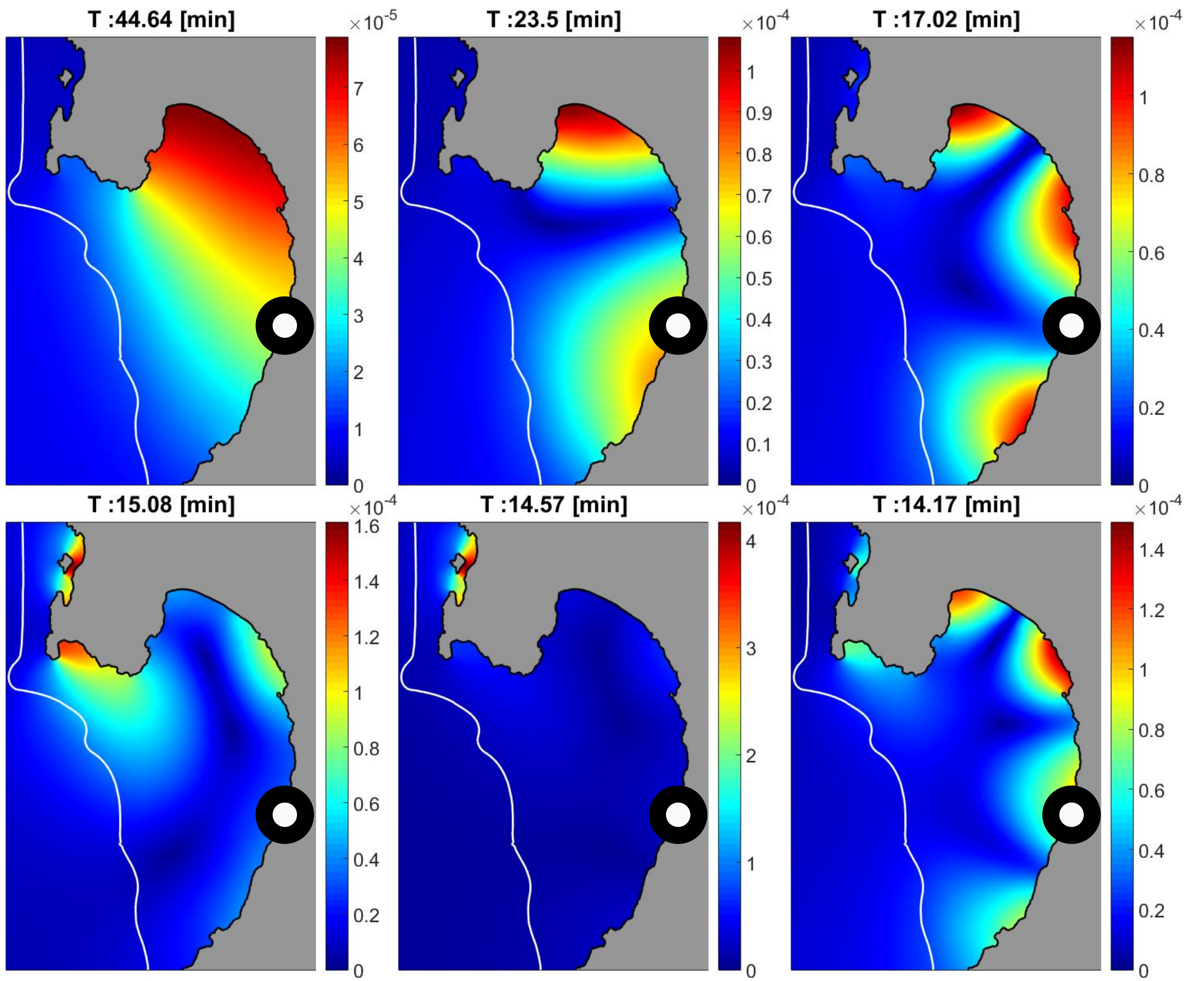

Figura 28.-Mapa de amplitud normalizada de los 6 primeros modos locales. El punto verde indica la ubicación aproximada del mareógrafo.

Free Oscillation Modes at ANTOFAGASTA (Northern Chile)

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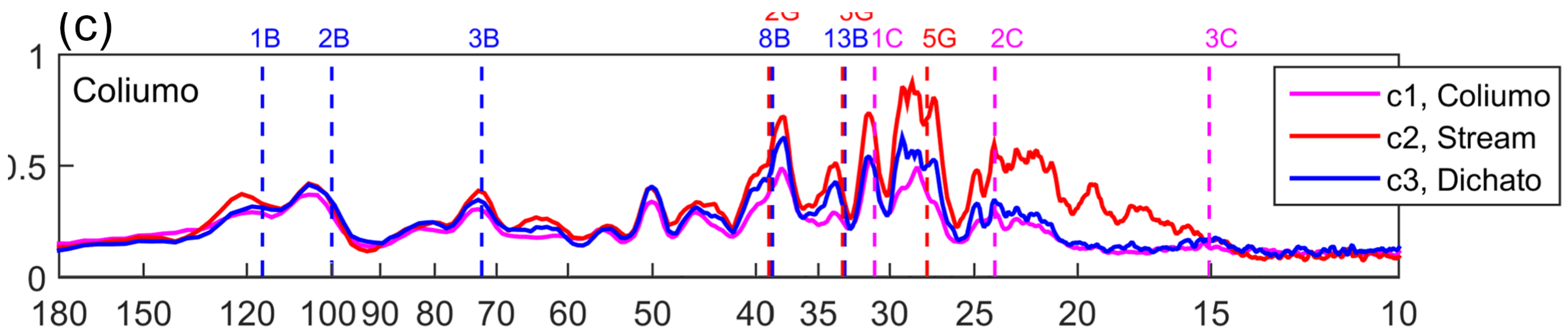
Aranguiz et al, 2019

- Coliumo bay showed the combined role of shelf and bay effects



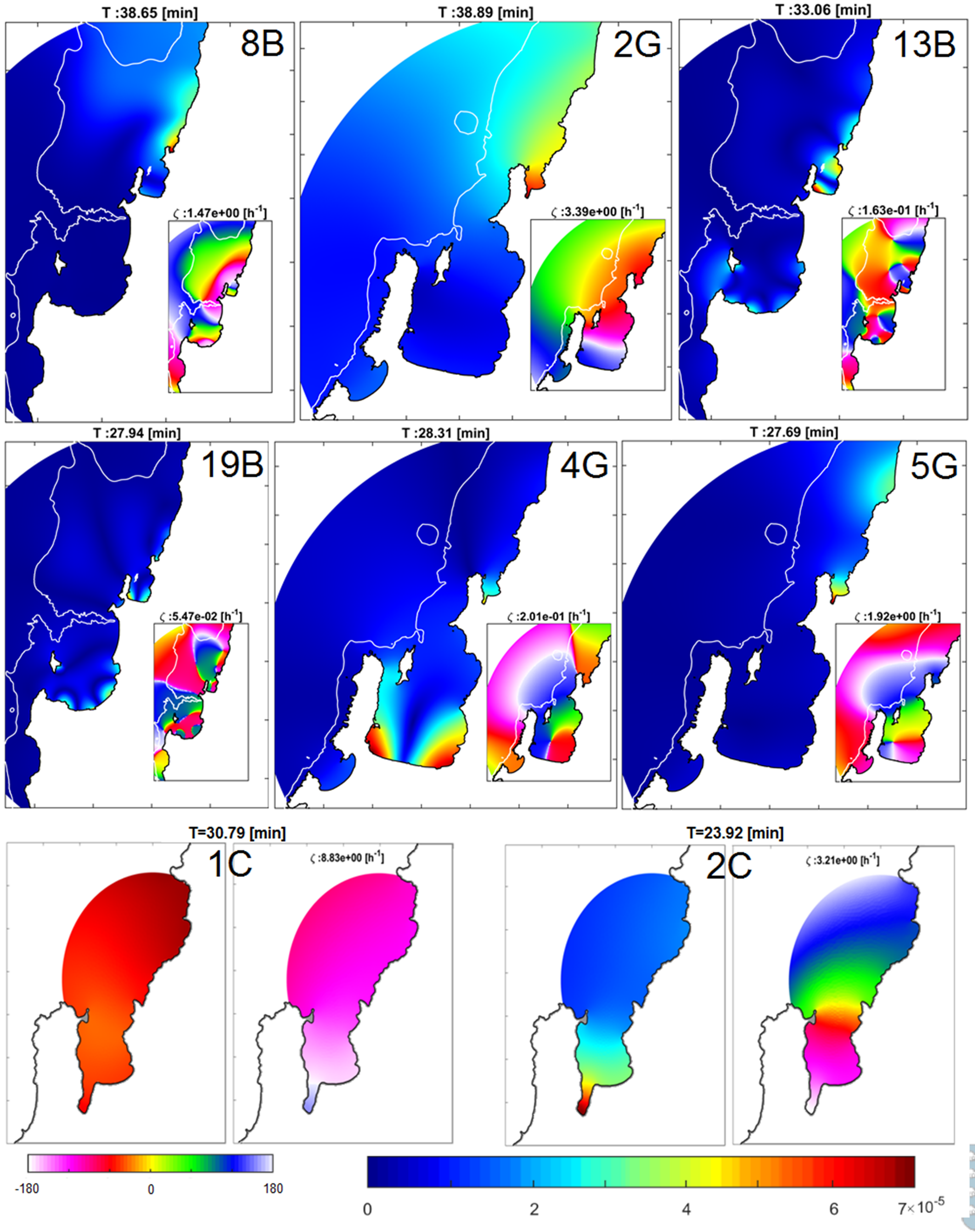


Figure 8. Representative eigenmodes for Coliumo Bay. The inset in each eigenmode amplitude map represents the phases. The white line in Domain B indicates the 200-m contour depth, while in Domain G, it indicates the 50-m contour depth.

Approach

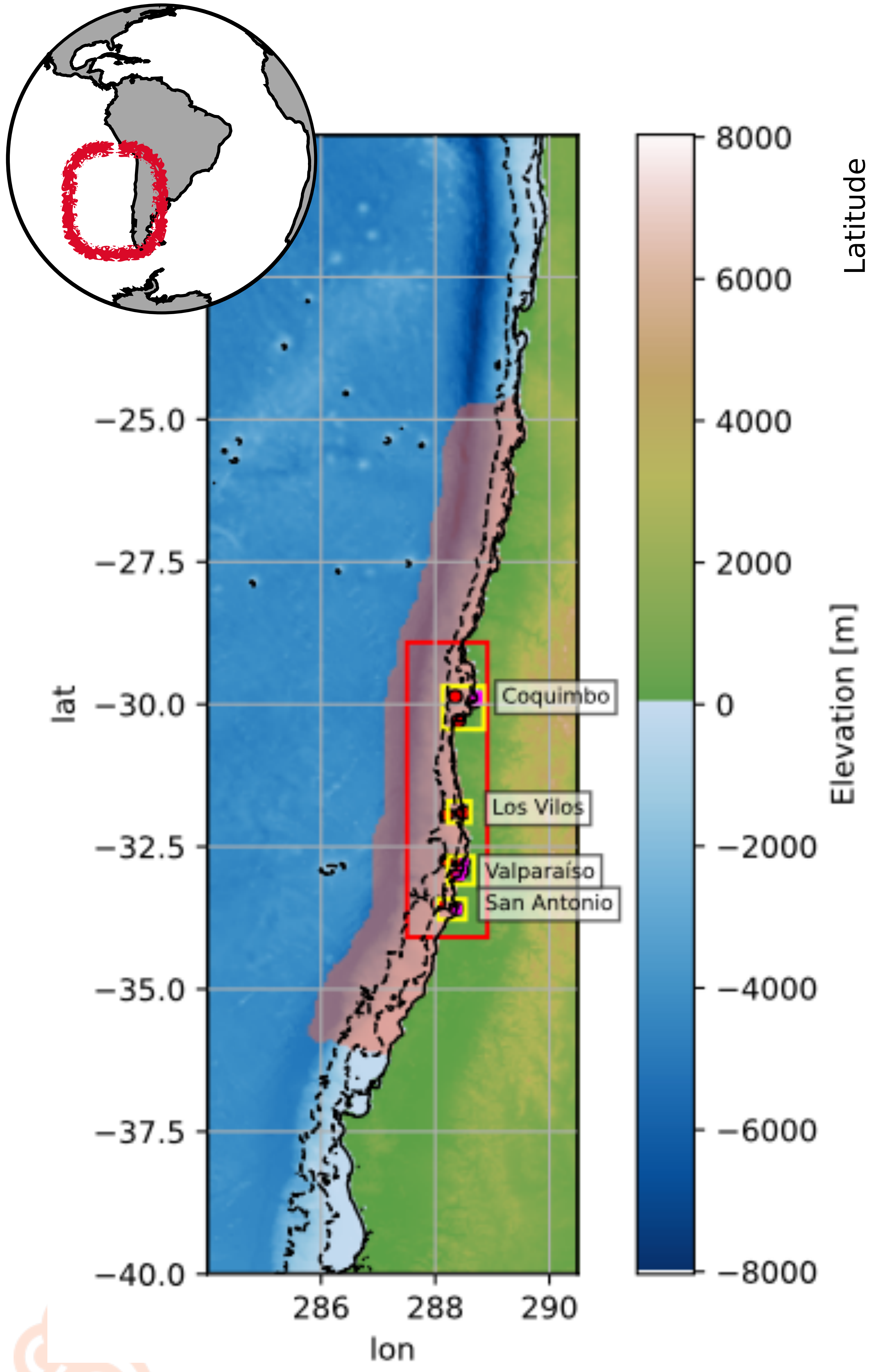
- These methods point in the right direction, but we need more data, especially at bays where no records exist

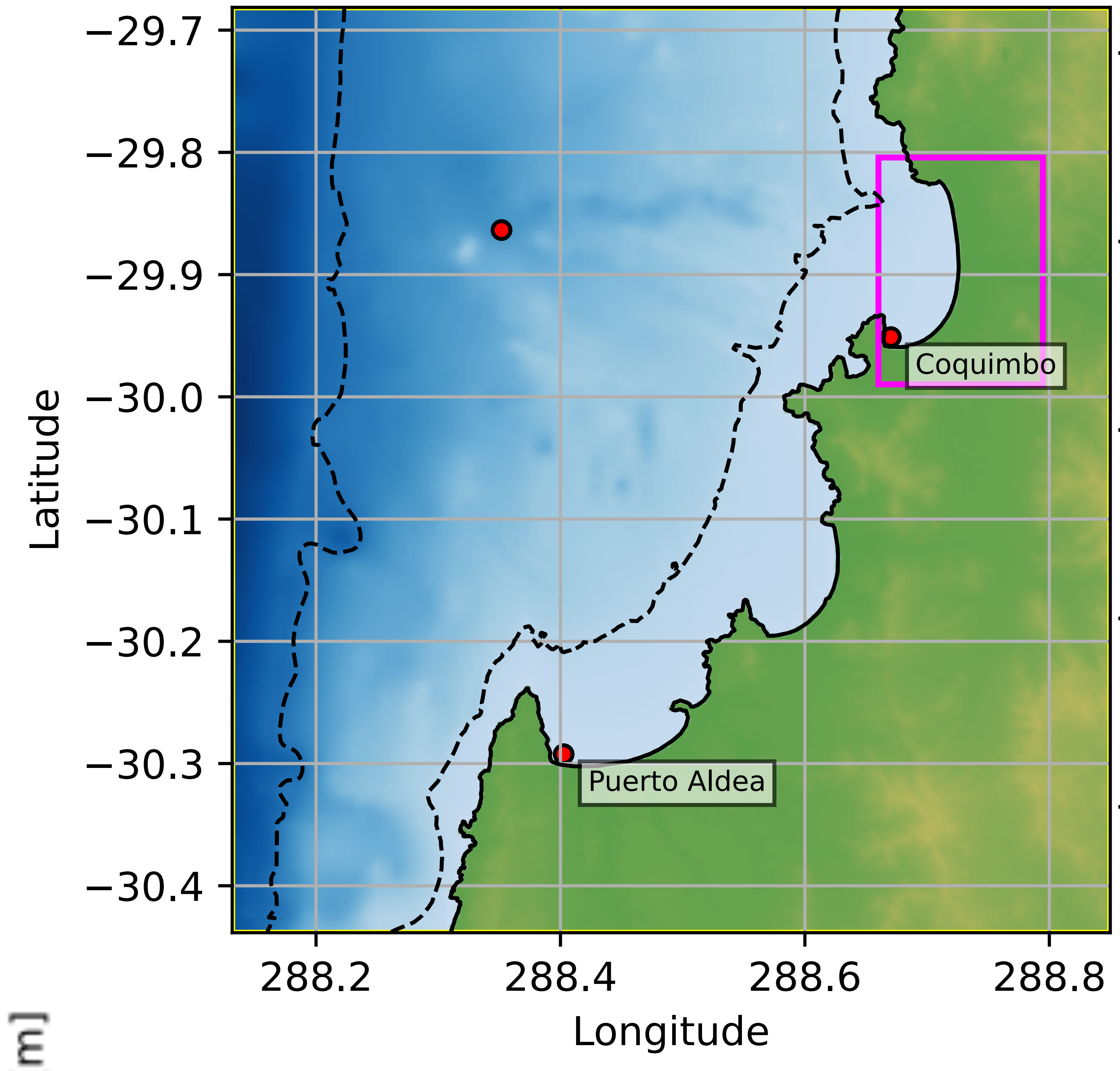
- Combine these two methods with a computationally intensive, modeling of stochastic scenarios

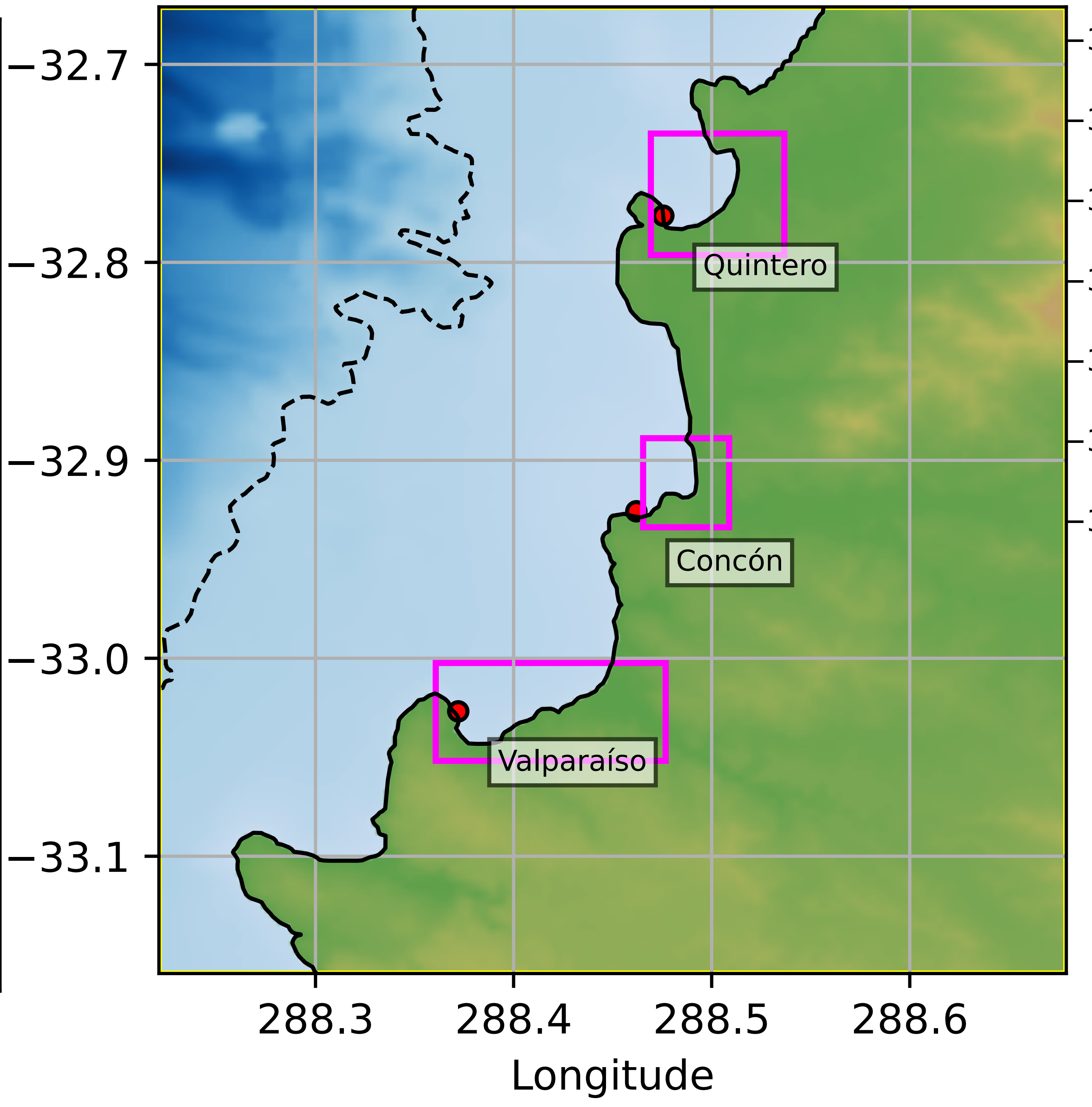
  - Stochastic modeling of tsunamis
  - Integrate results at tide gages
  - Estimate results of admittance function

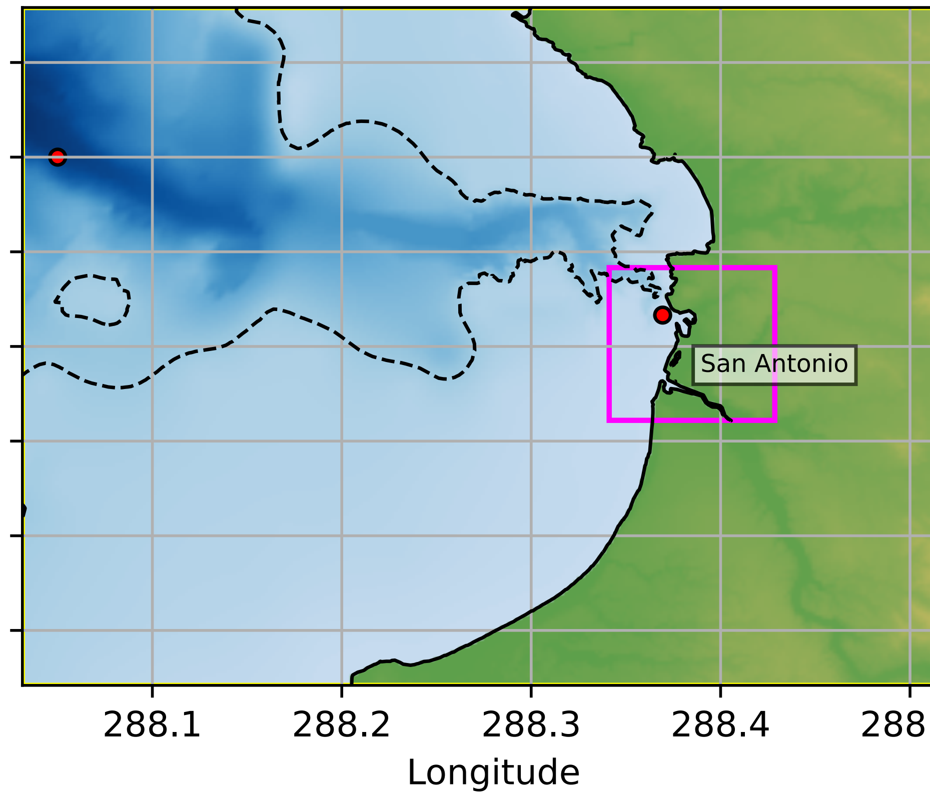
Can we classify bays in advance?

Domain of Interest









Coquimbo Bay System

- Shallow and wide bays
- Have shown characteristic response on past tsunamis

Valparaíso Bay System

- Deep yet wide bays
- Have shown mixed behavior

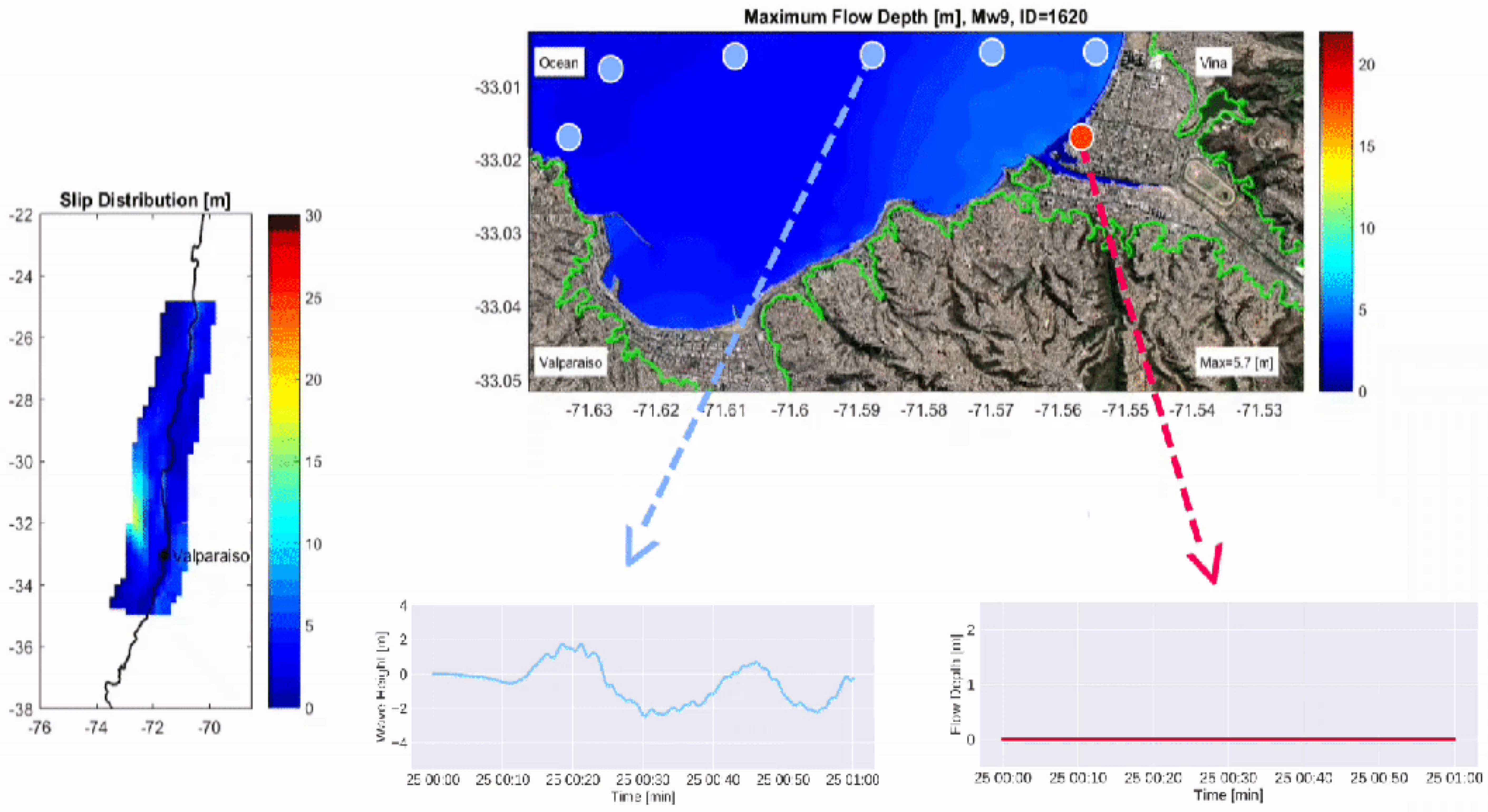
San Antonio Port

- At the mouth of a canyon

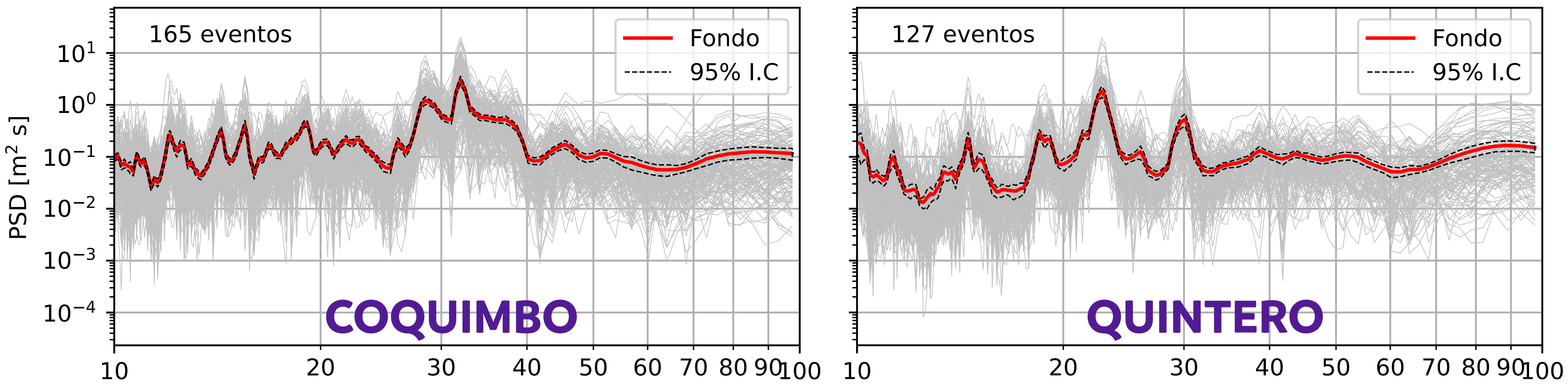
- All modeled using the same stochastic sources
- Propagation modeling using three nested levels with **Tsunami HySEA**

Early Results

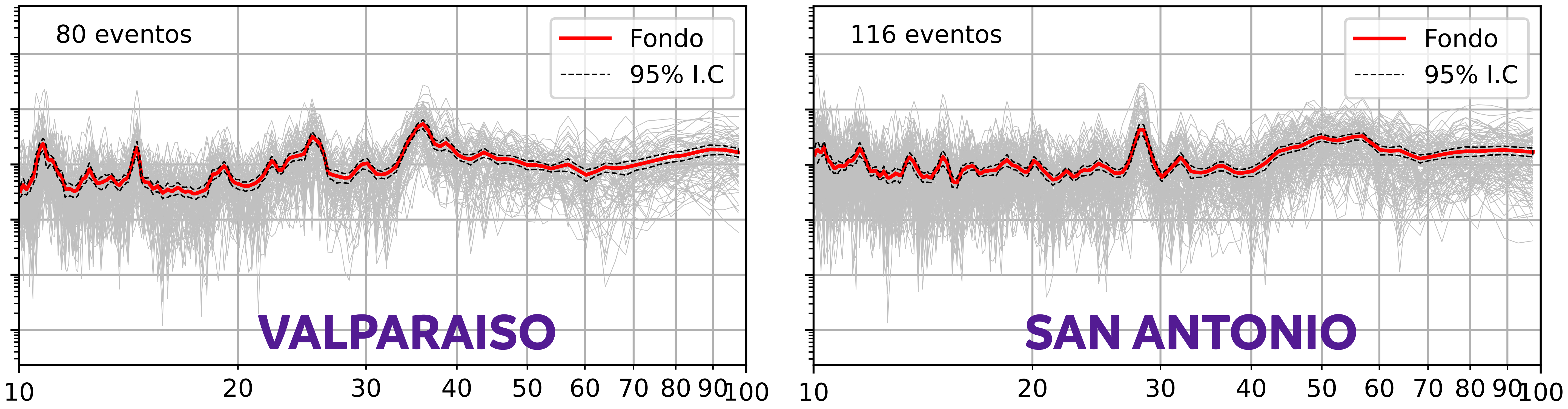
- Stochastic modeling of 350 sources in Central Chile, that affect bays that have shown evidence of
  - strong resonant behavior
  - coupled bay behavior
  - source dependency
- Collected time series of free surface data at
  - deep(er) water: Proxy for source spectrum
  - intermediate water: to determine shelf admittance
  - shallow water: bay admittance



Background Spectra



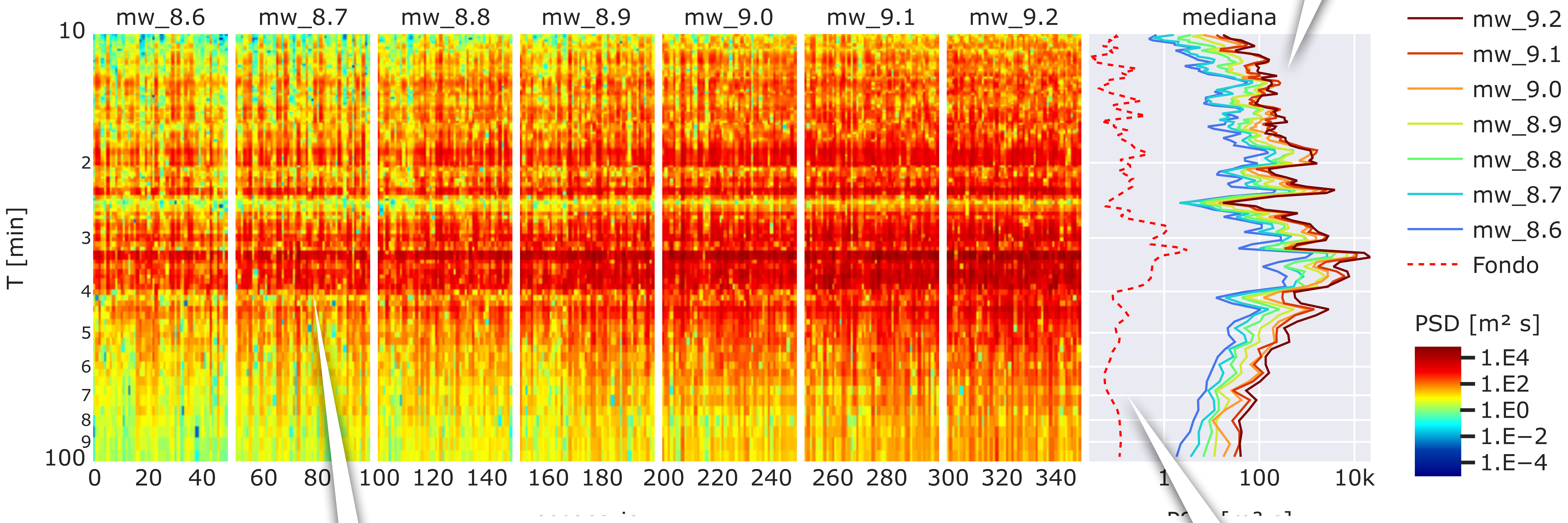
- These bays show strong amplification at periods in the range 20-40 min



- These bays show some structure, but relatively weak

Results: Spectrograms at the tide gage: COQUIMBO

Median of the spectrograms

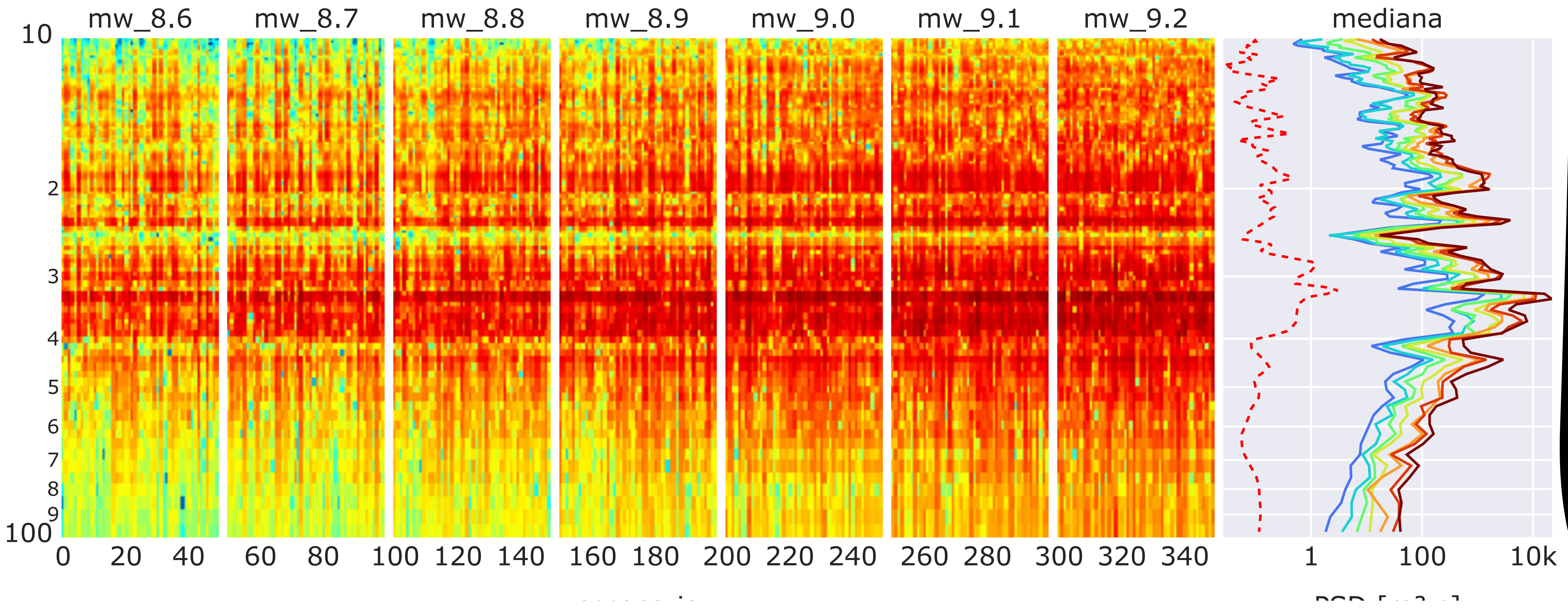


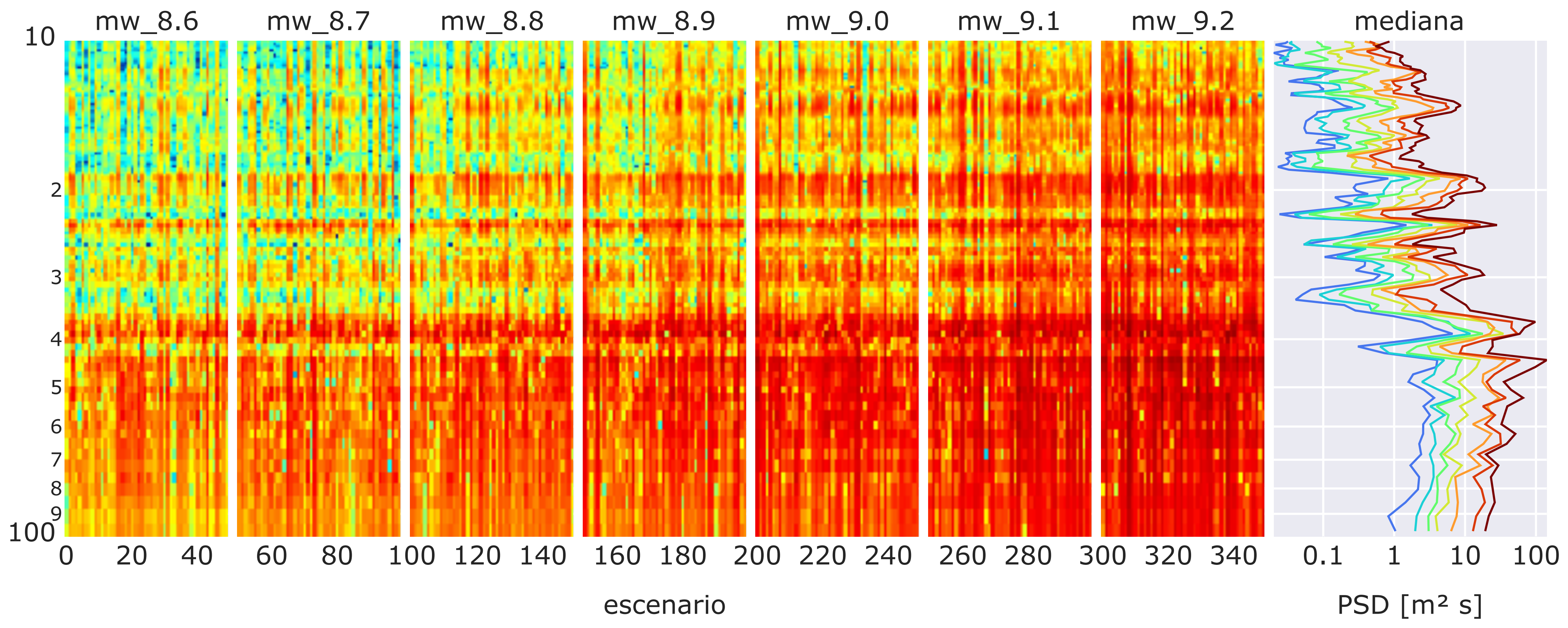
Background spectra for reference

50 scenarios for each magnitude bin.

Results: Admittance: COQUIMBO

SPECTRA AT the COAST $S_t(f)$



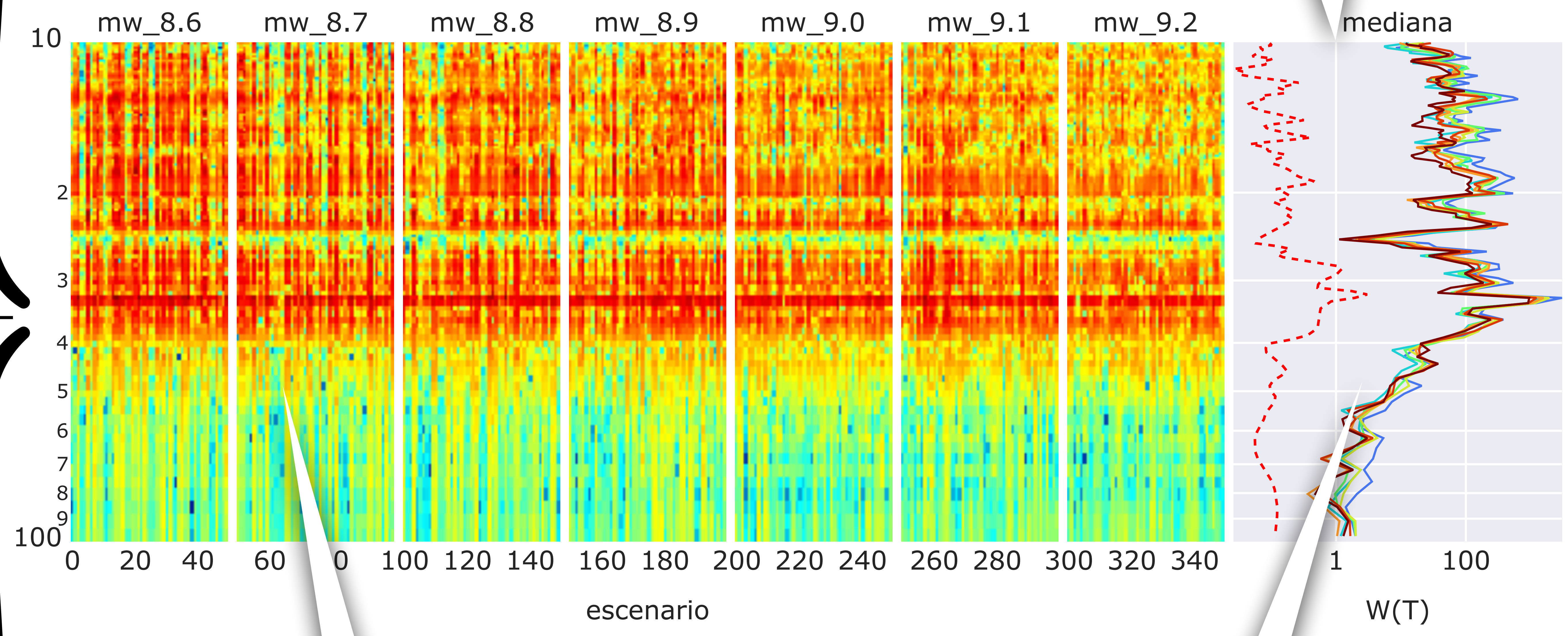


SPECTRA OFFSHORE $Z(f)$

$W(f)$

Admittance

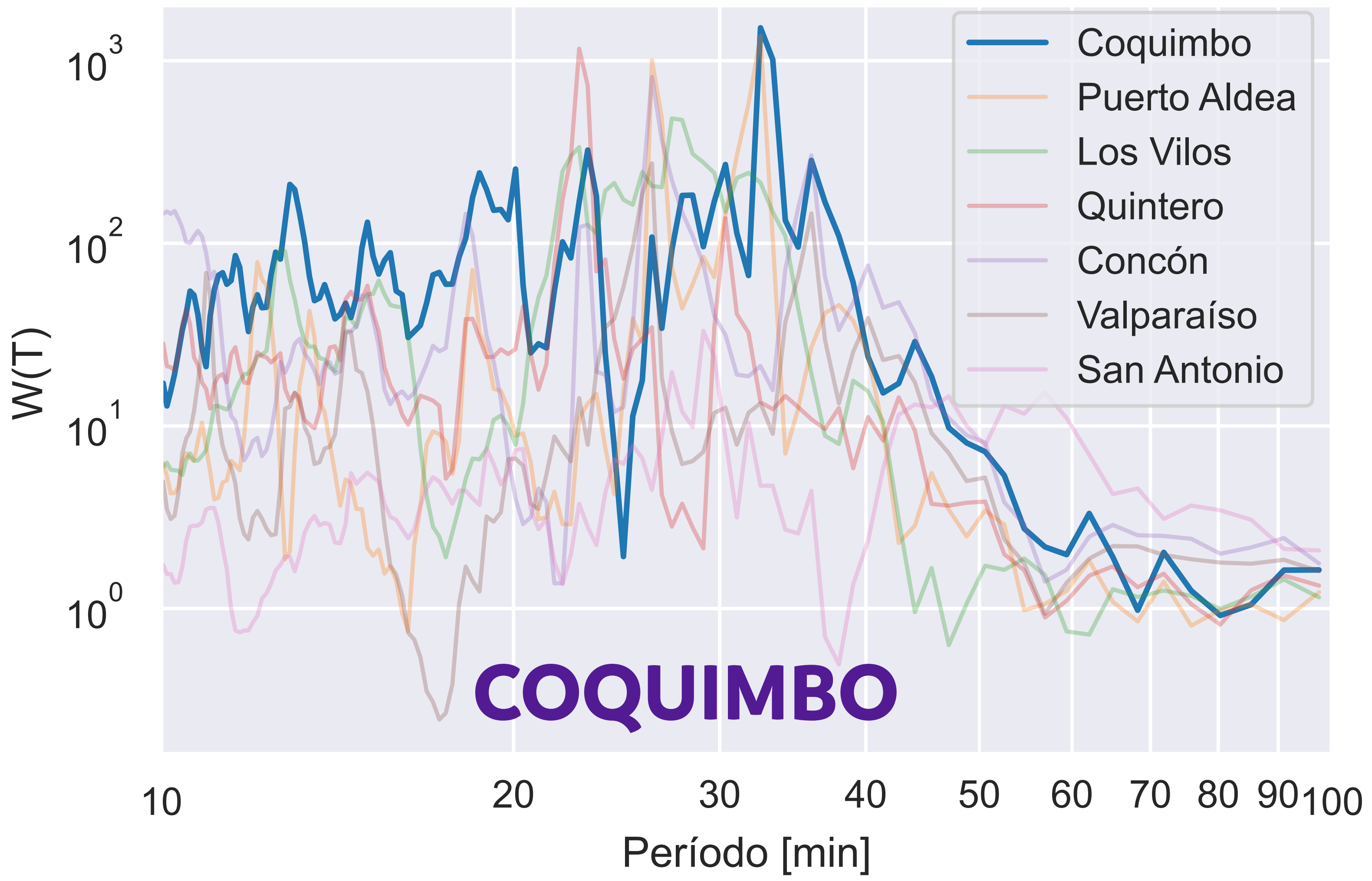
Some magnitude dependency for short periods

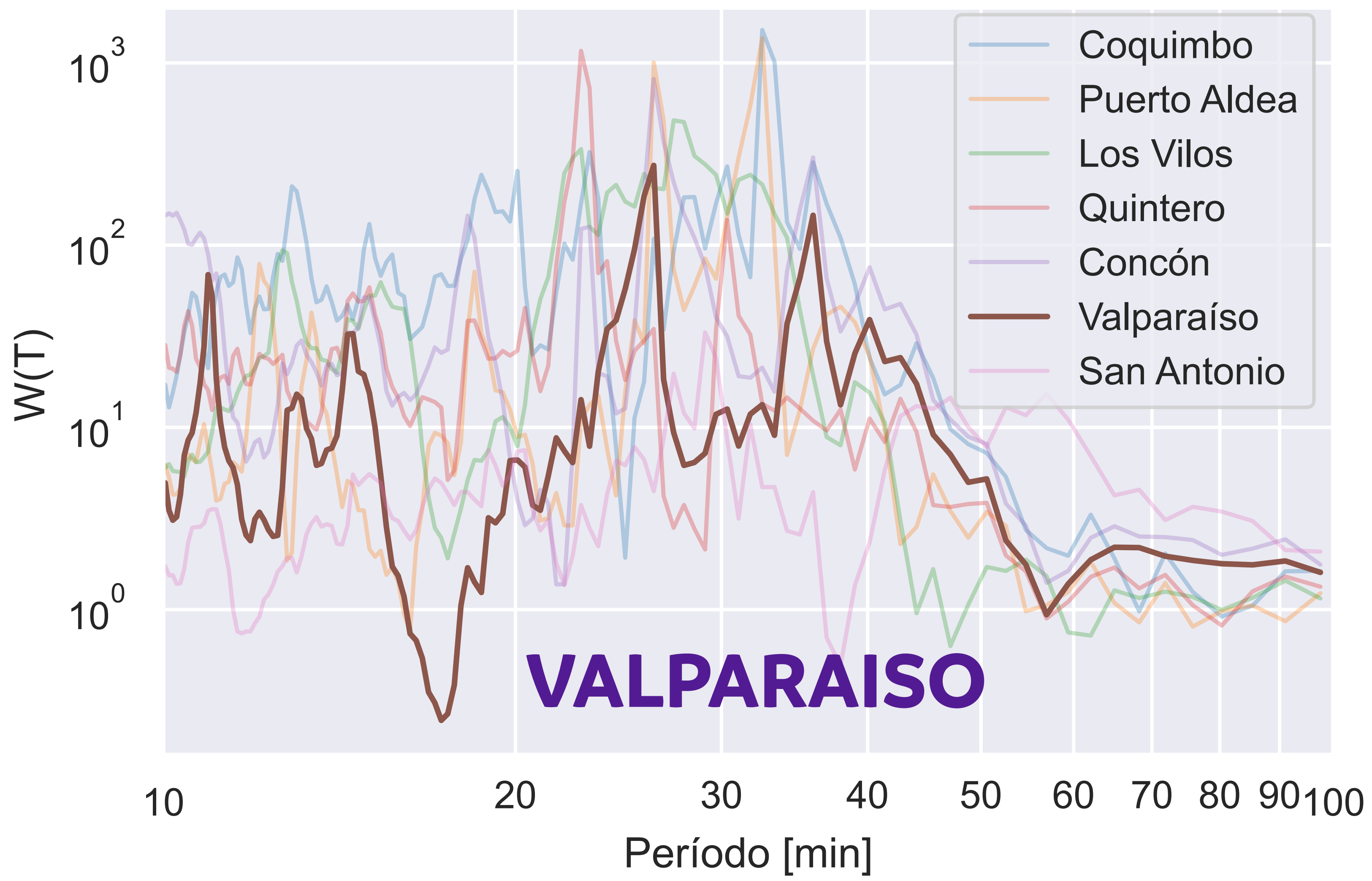


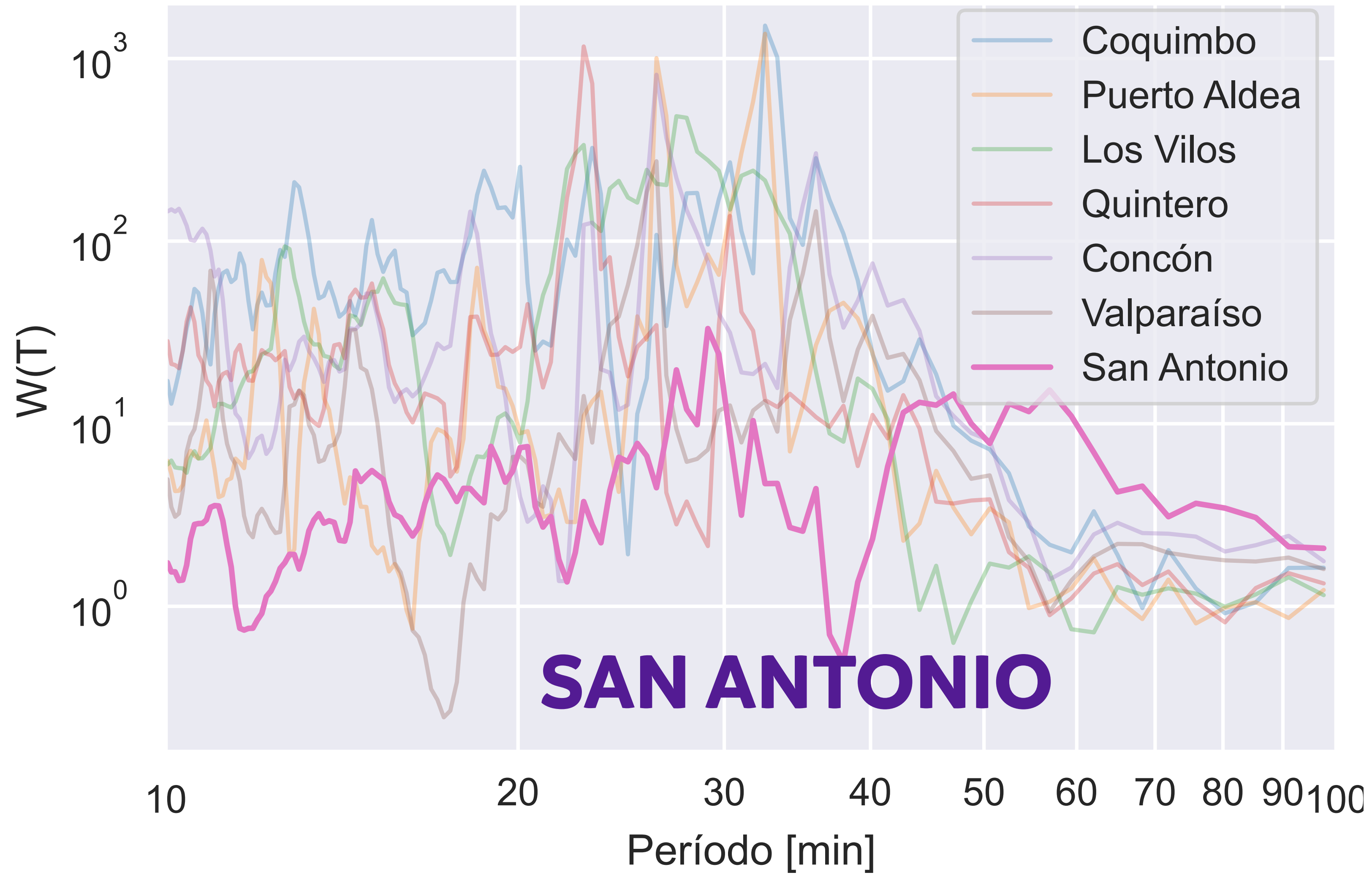
Remarkably similar across simulations

No significant magnitude dependency for long periods

Results: Median Admittance across Bays





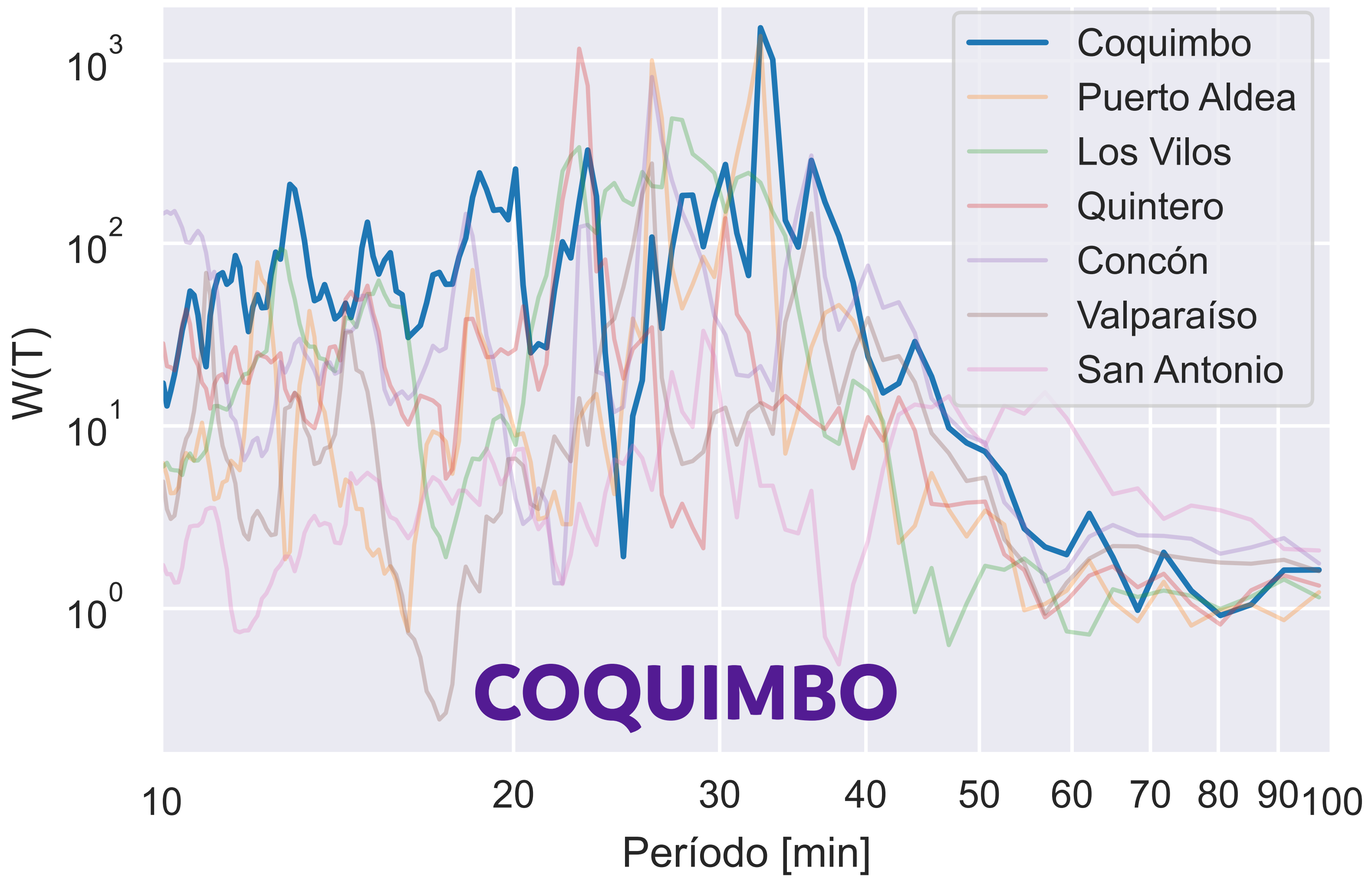


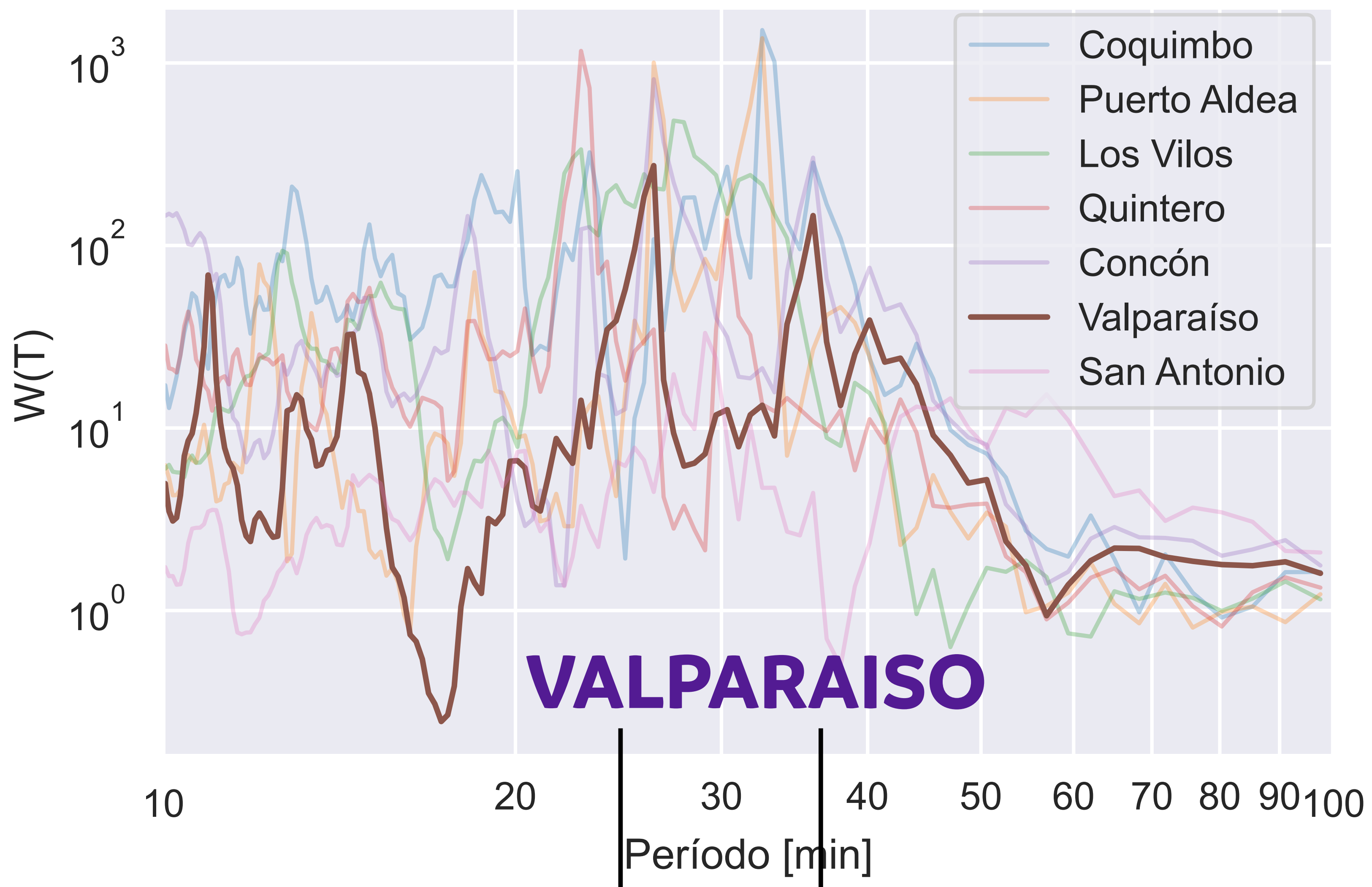
- Very strong amplification at periods in the range 32 min regardless of source characteristics
- **Response is colored by the bay**

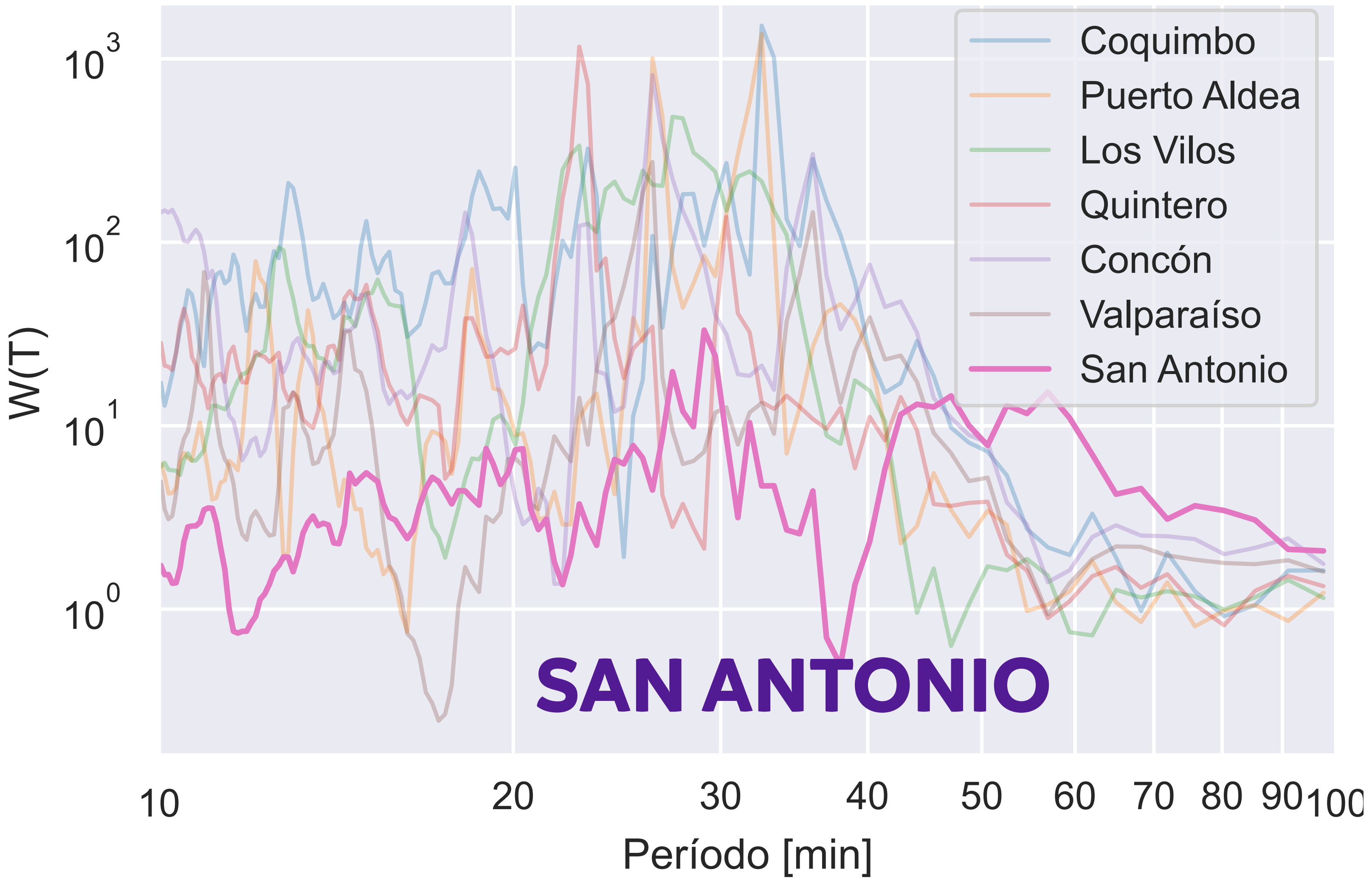
- Mild amplification at 26 min and 37 min.
- Less amplification than surrounding bays!!

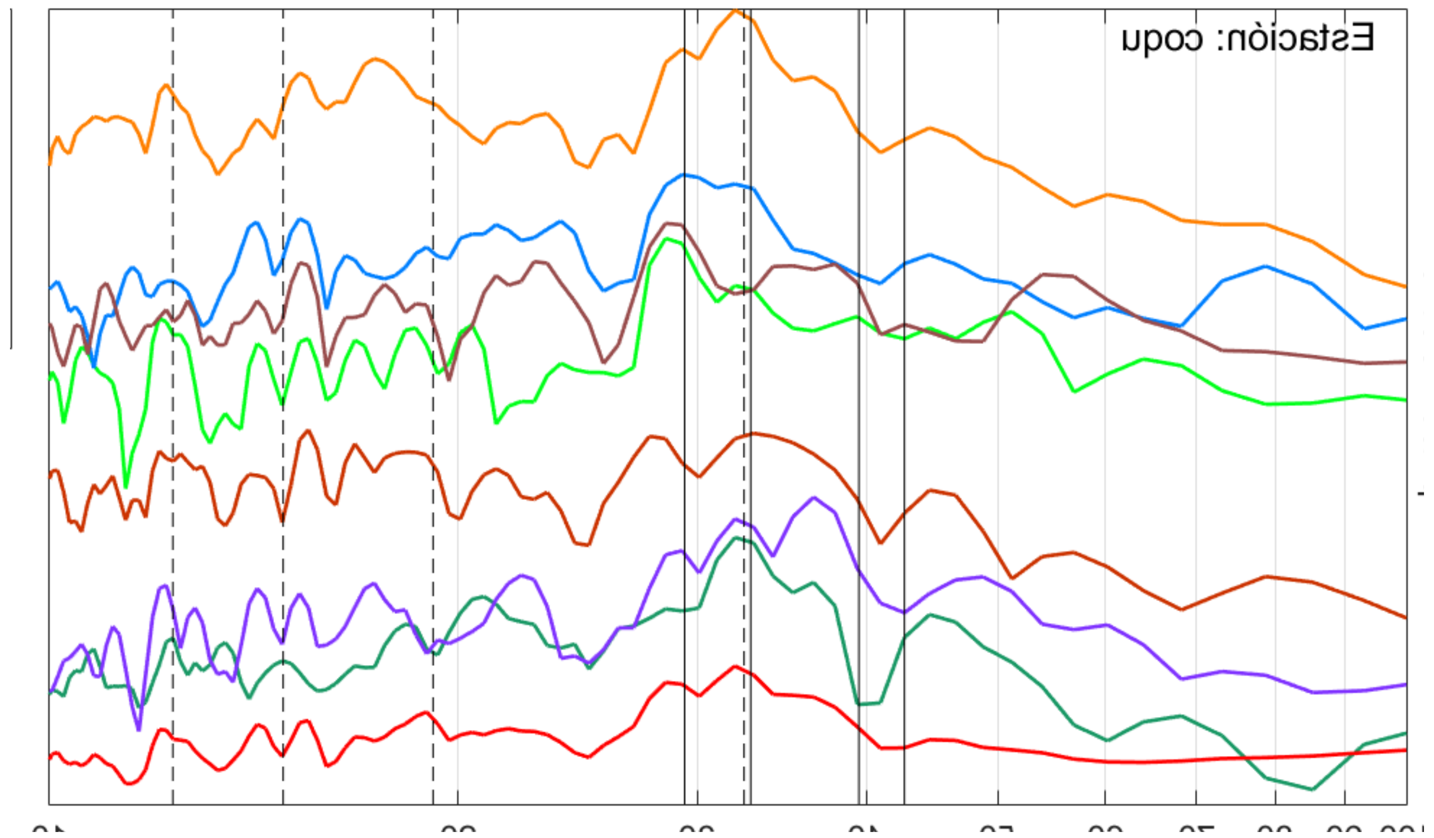
- Weak amplification throughout
- **Response depends on source characteristics**

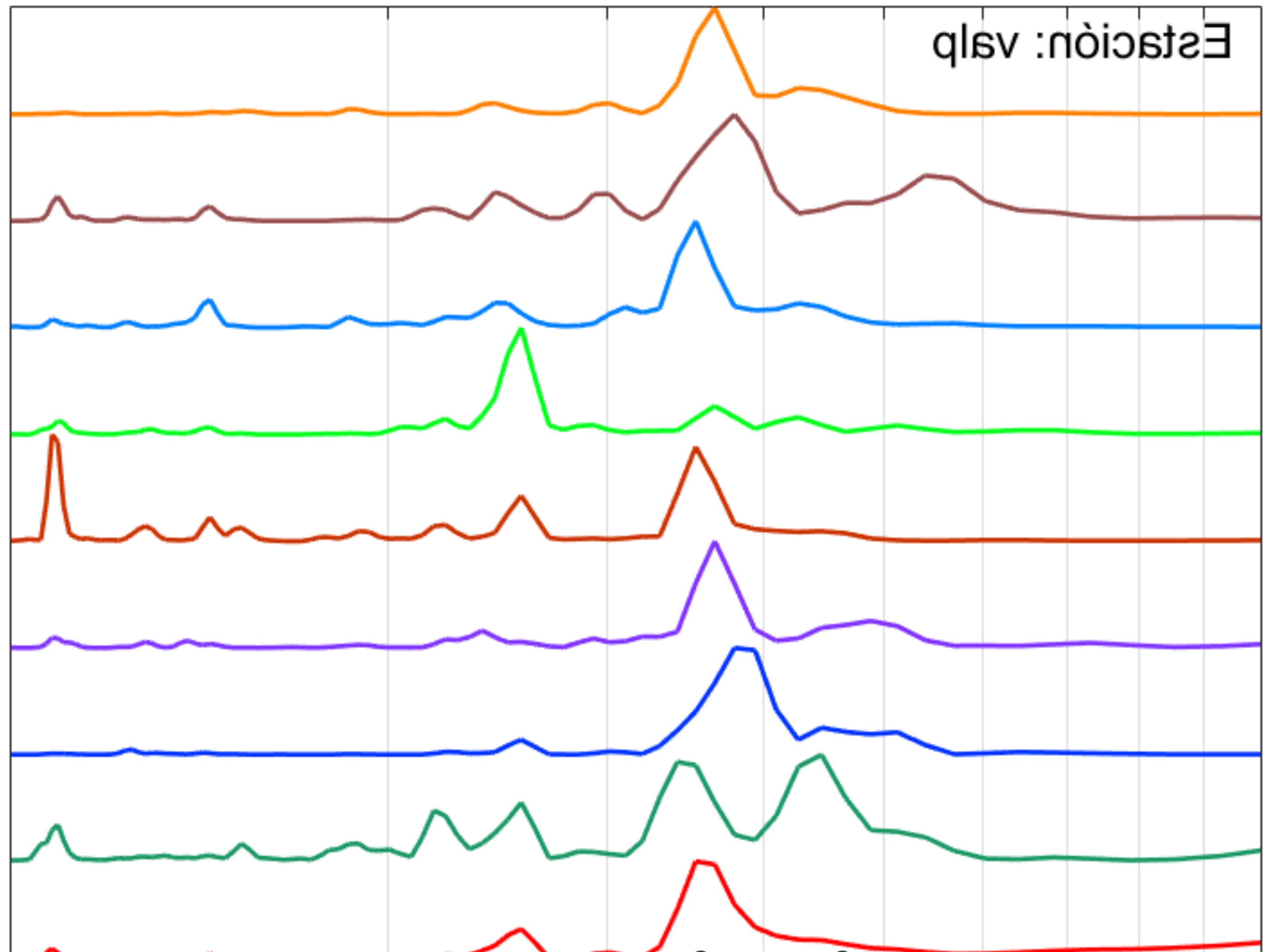
Results: Comparison with Historical Records

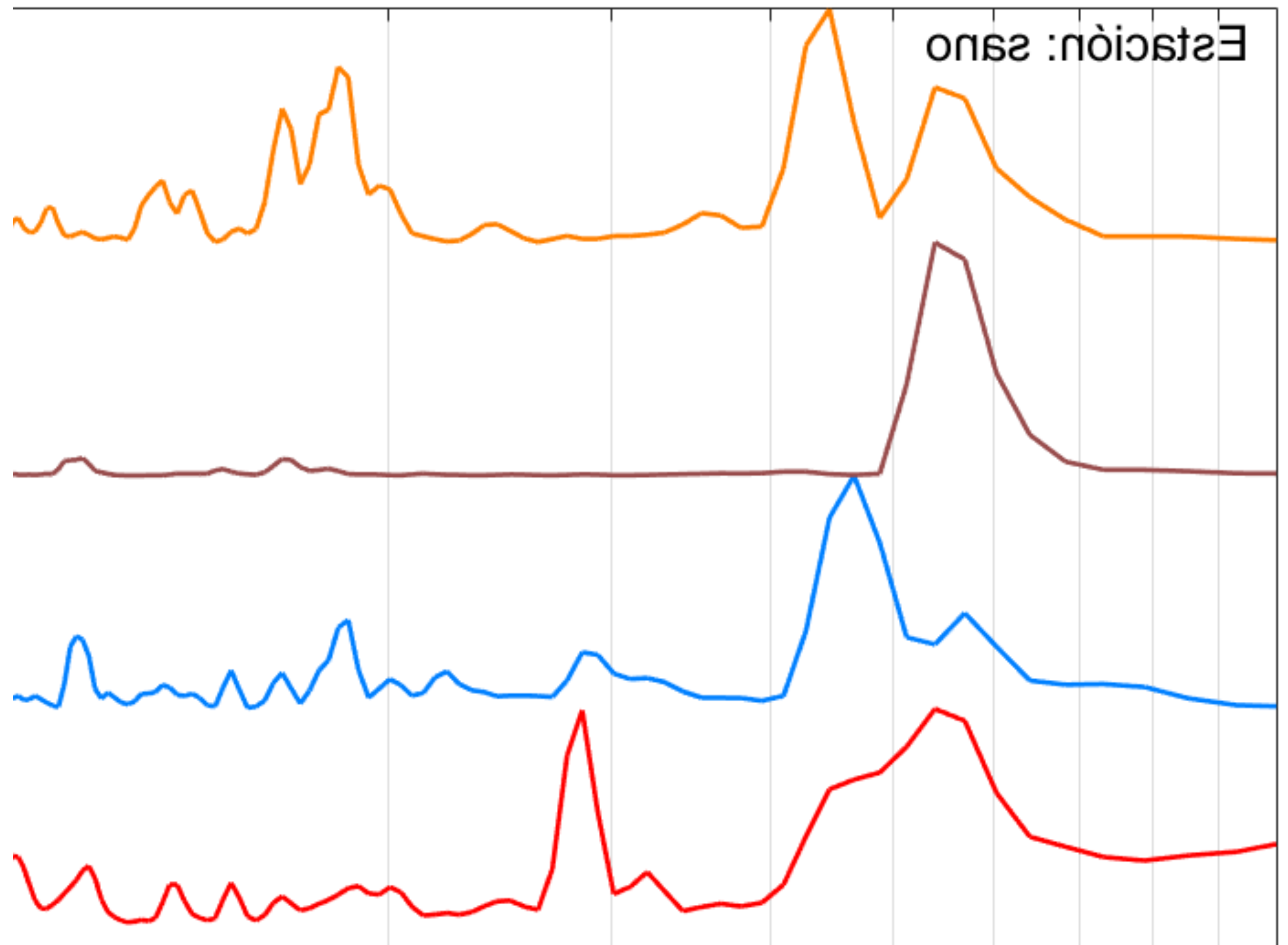






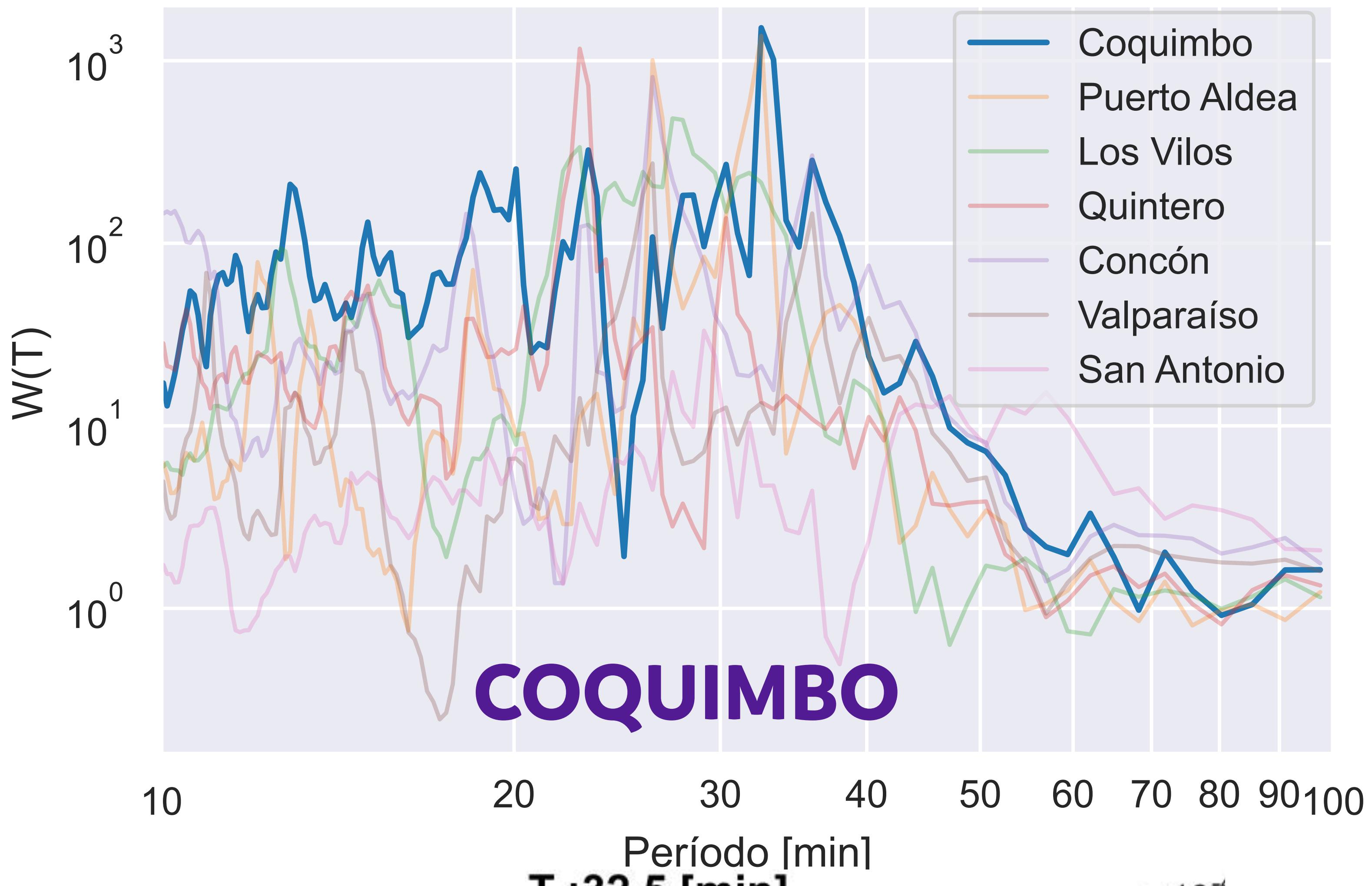


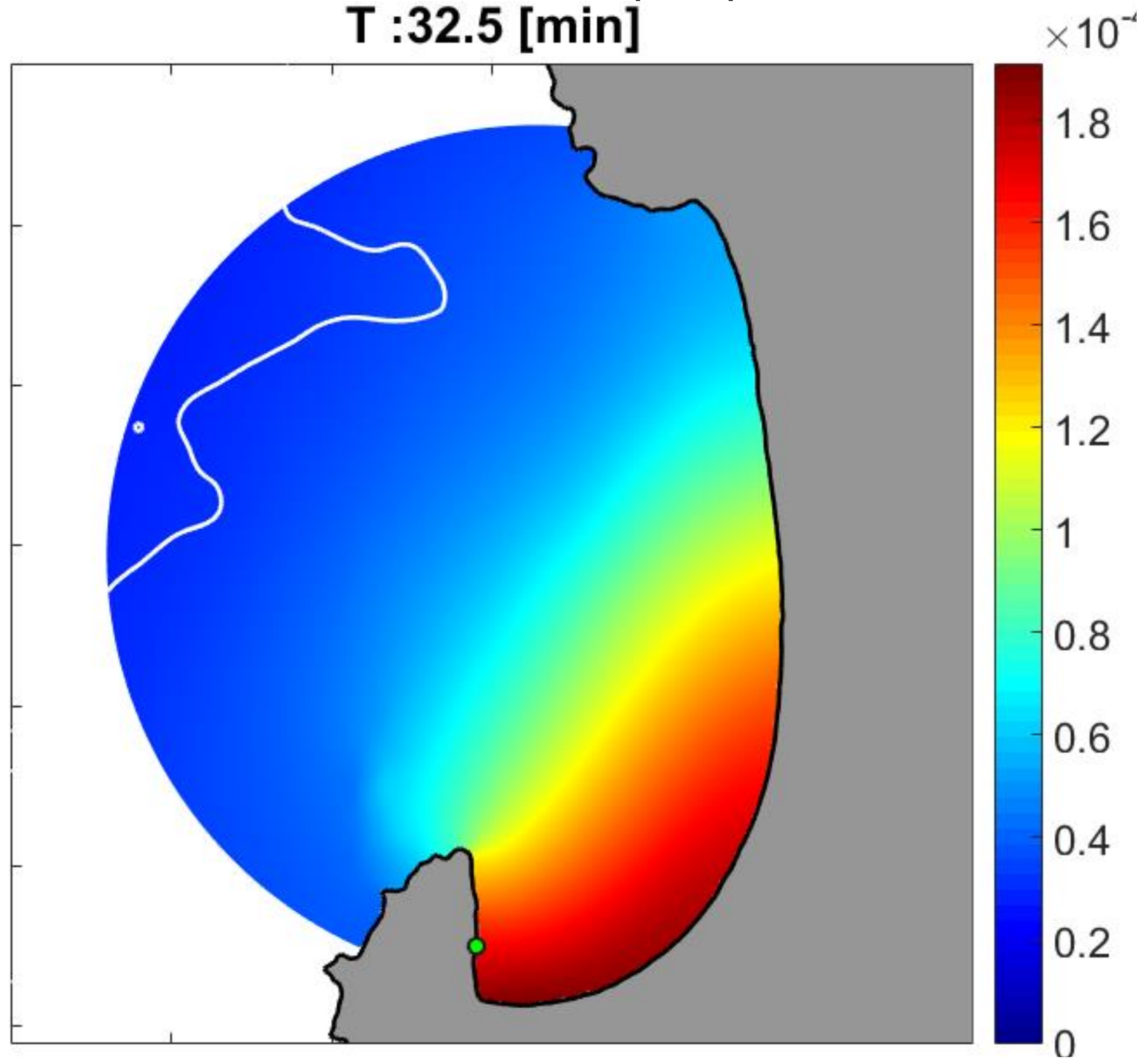


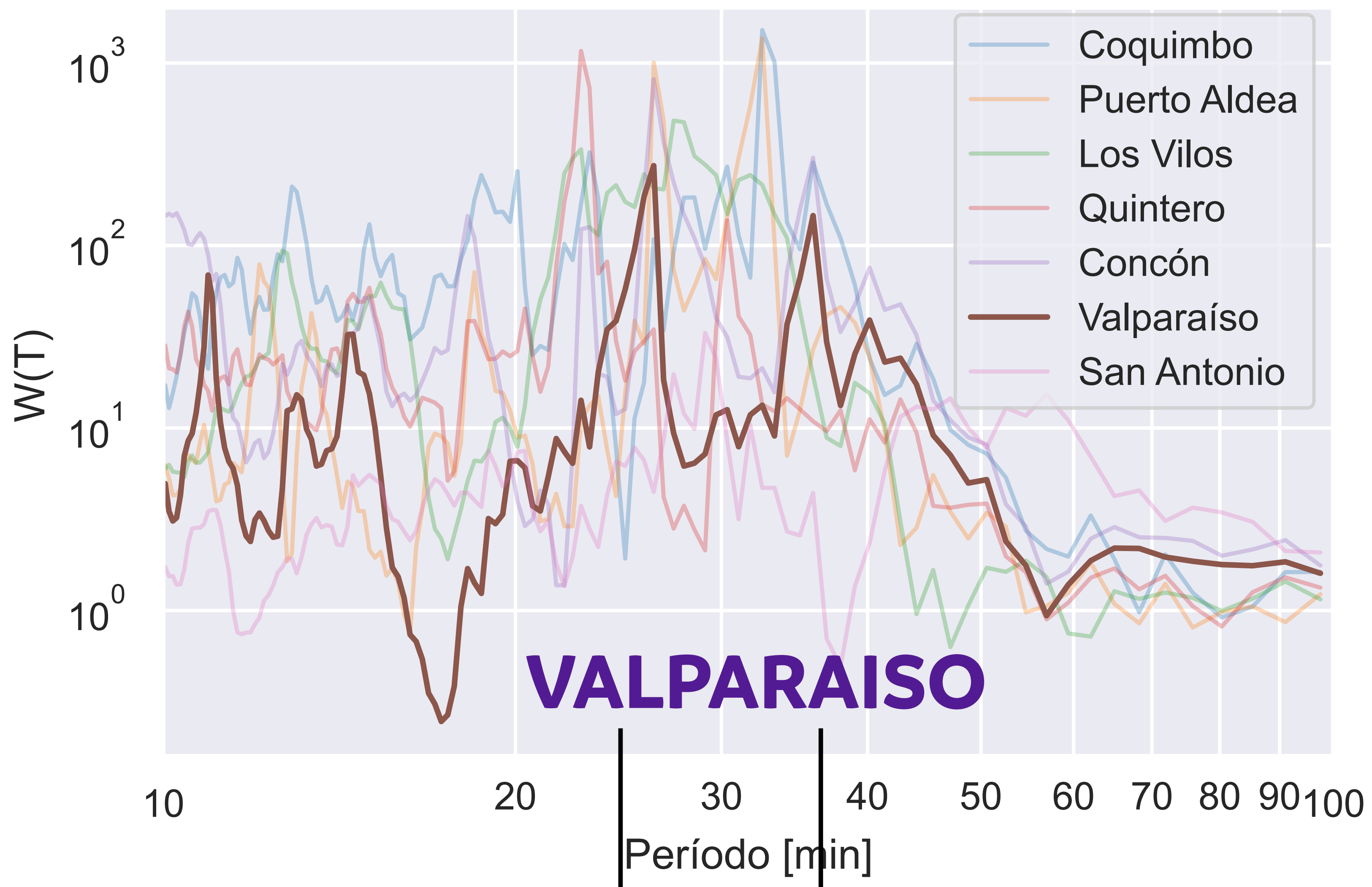


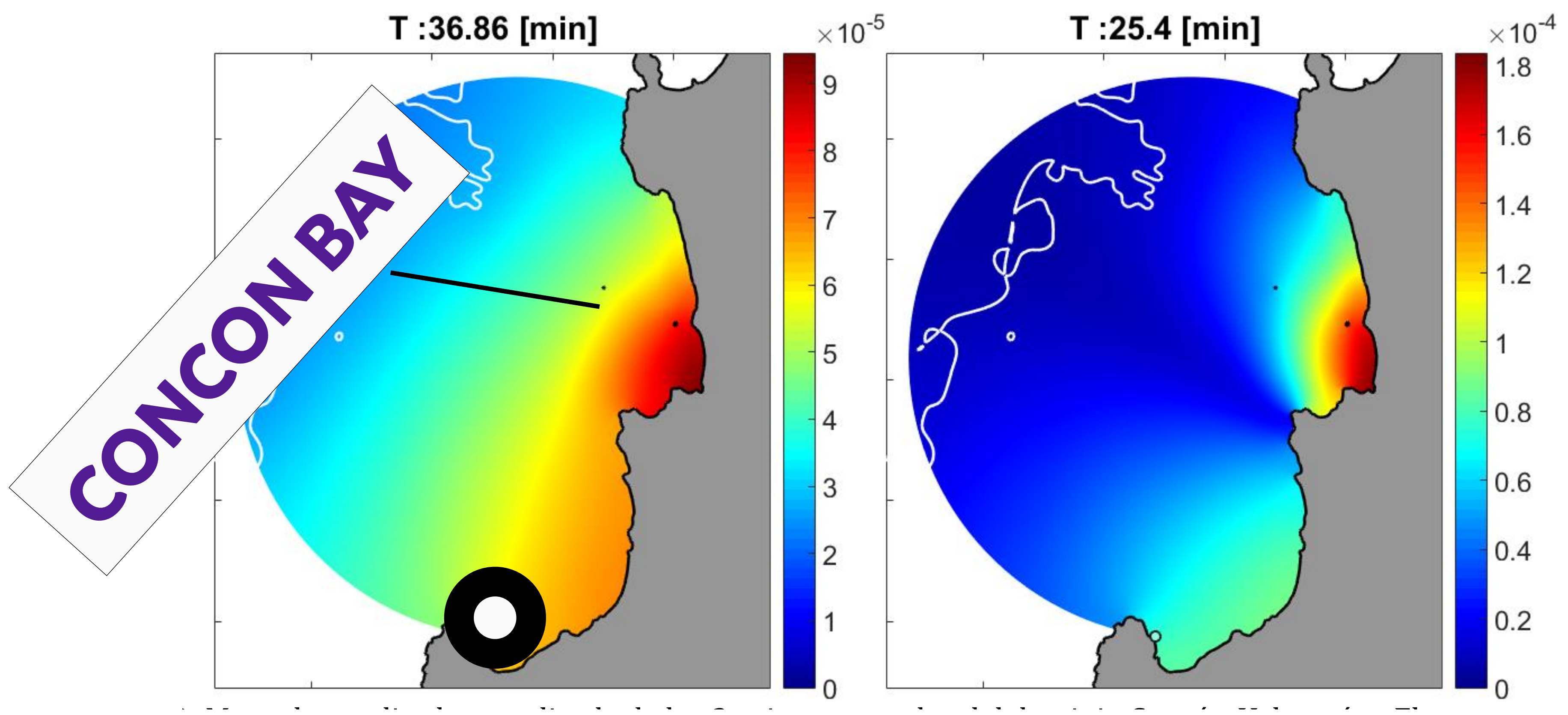
- Response is colored by the bay
- Some variations across events
- Significant variations across events

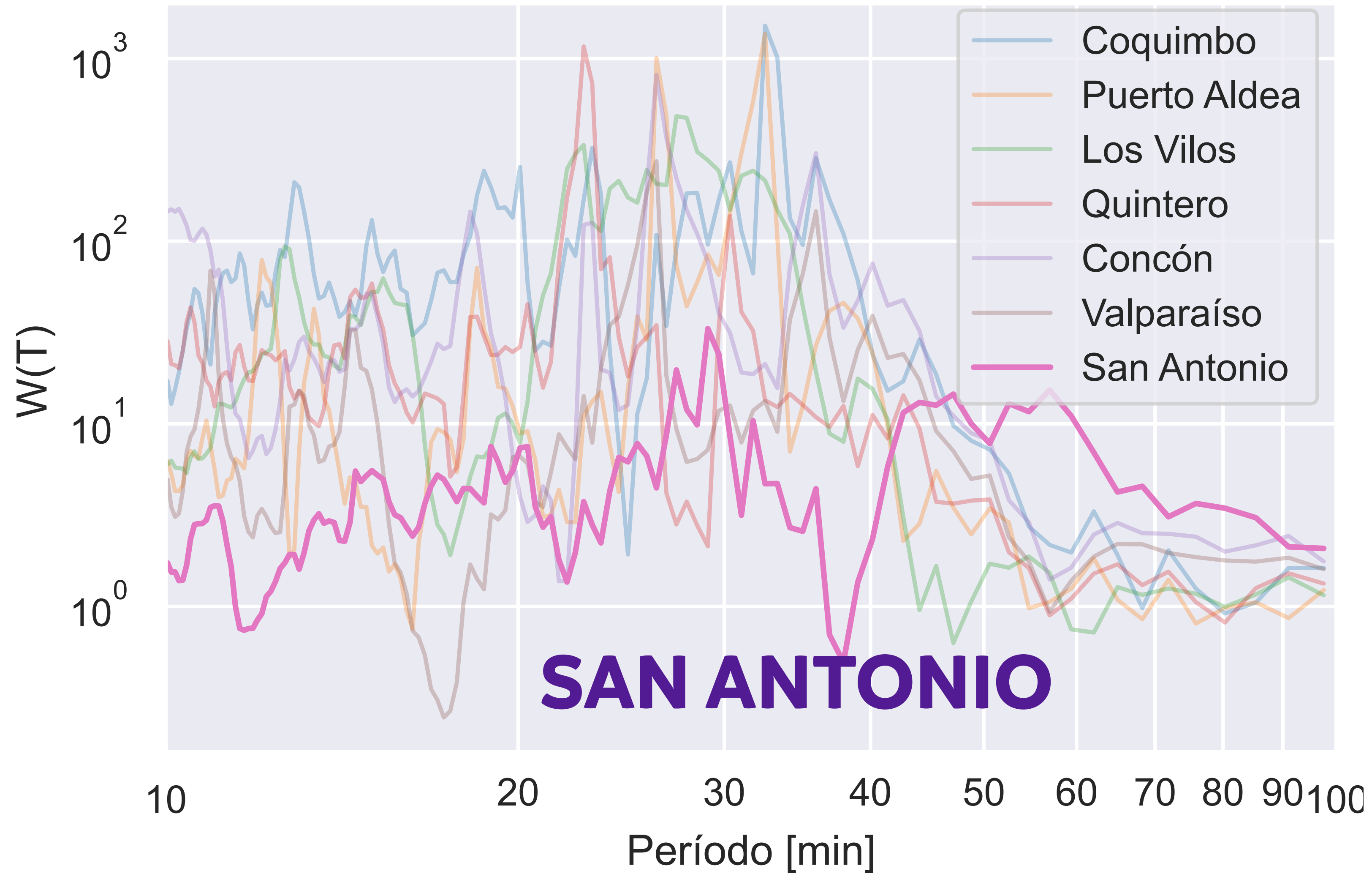
Results: Median Admittance across Bays

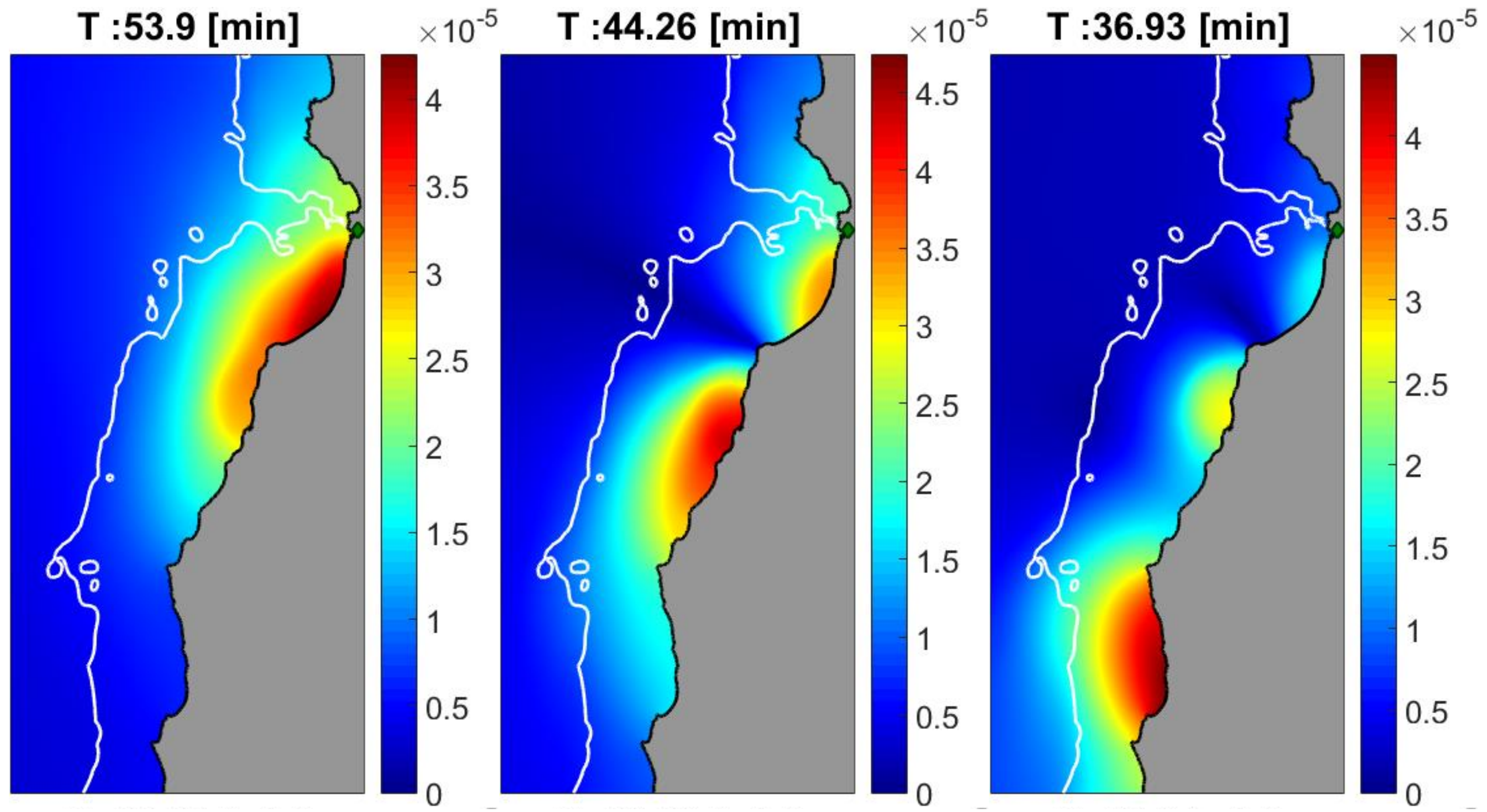












- **Strong first mode**
- **These are not Valparaíso modes, but of a system!**
- **These are shelf modes**

Northern Chile Examples

Northern Chile: **ARICA**

- “Strategically” placed
- Strongly influenced by southern Perú shelf but also by Northern Chile shelf
- **Event sensitive**
- Most modes **overlap** maximum amplitude region at Arica.

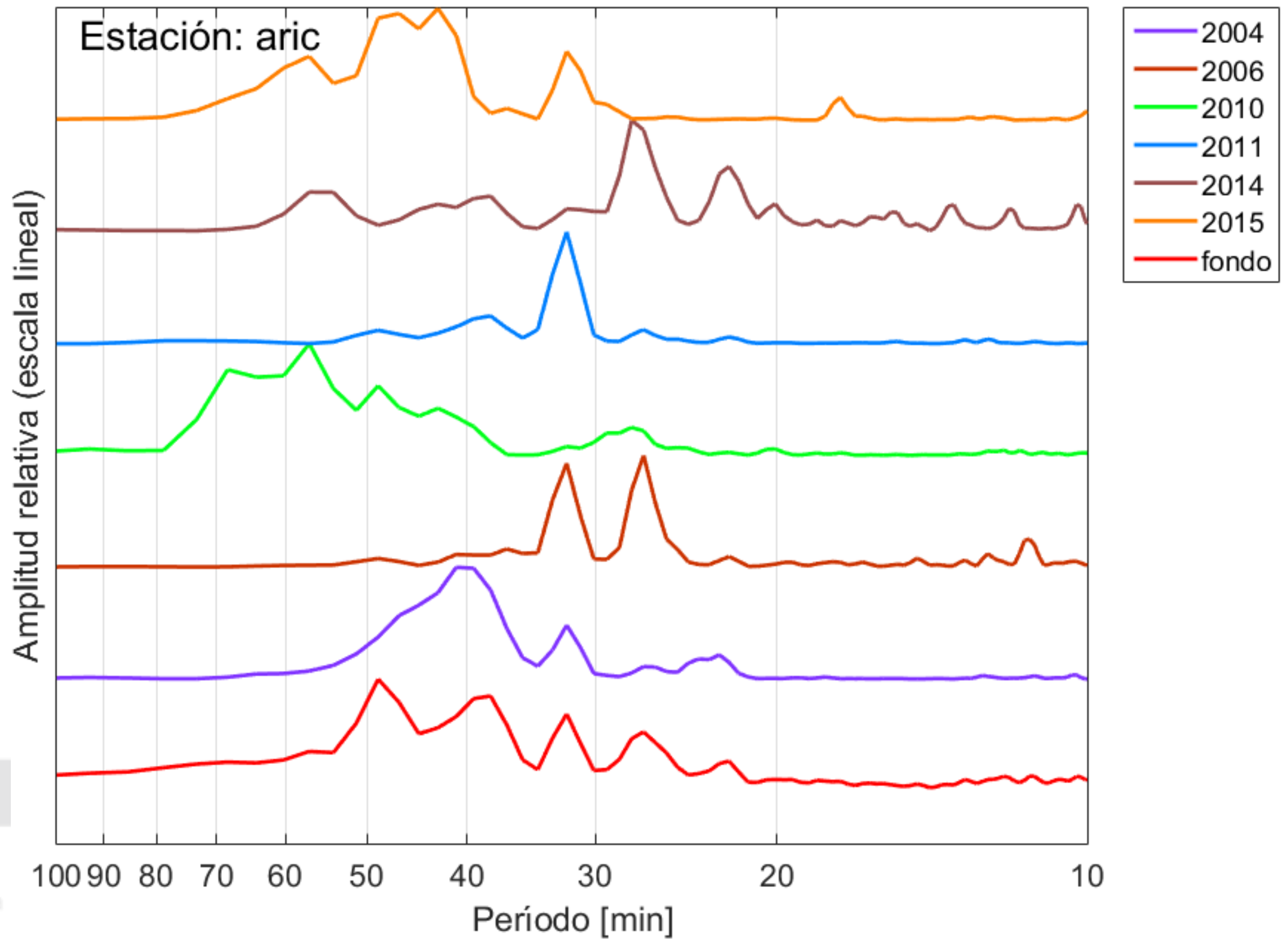
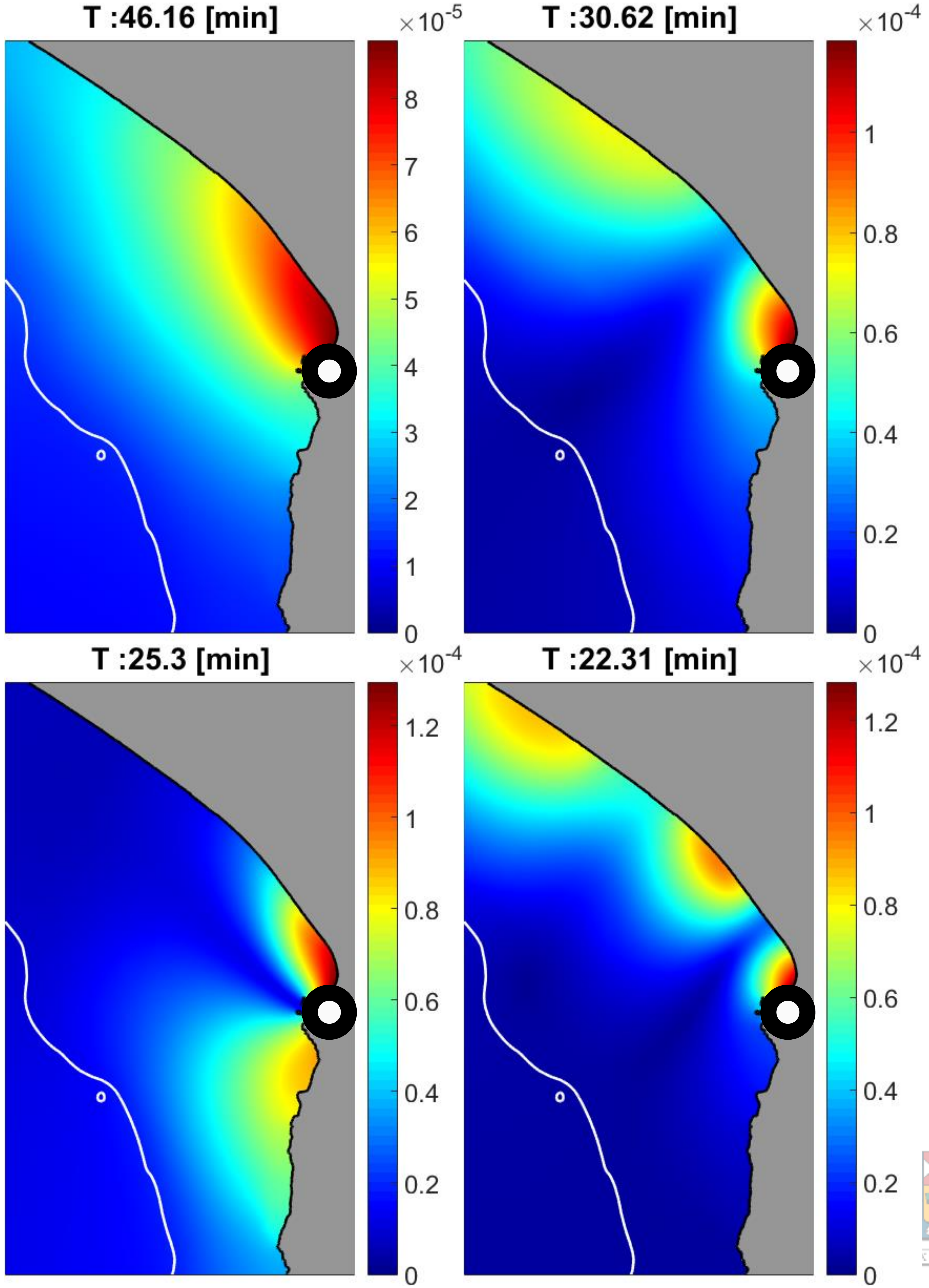


Figura 3.-Espectros normalizados para Arica.



Northern Chile: **Antofagasta**

- Even more “strategically” placed
- Strongly influenced by the bay
- **Event insensitive**
- Most modes **have nodes near Antofagasta**

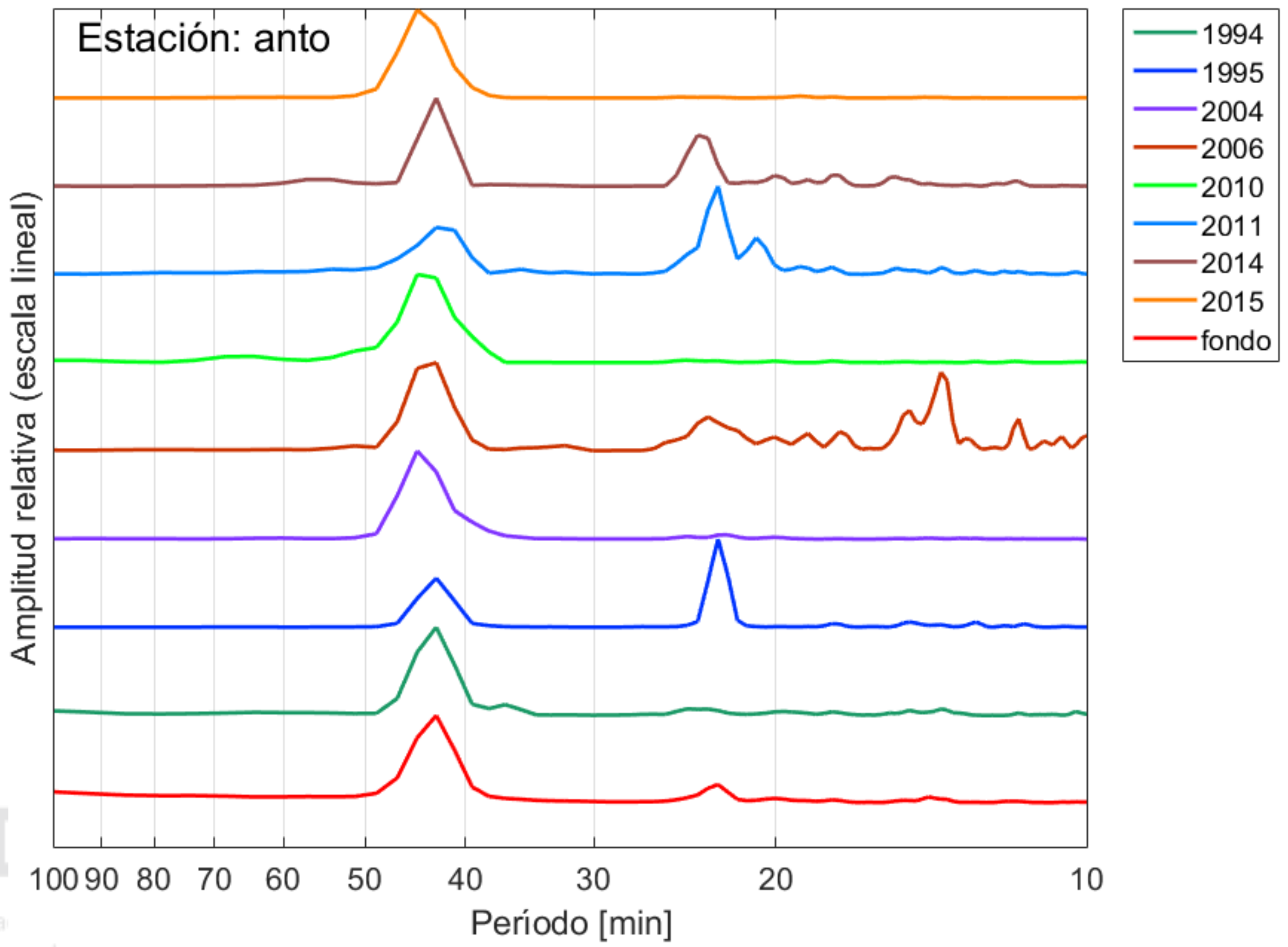


Figura 27.-Espectros normalizados para Antofagasta.

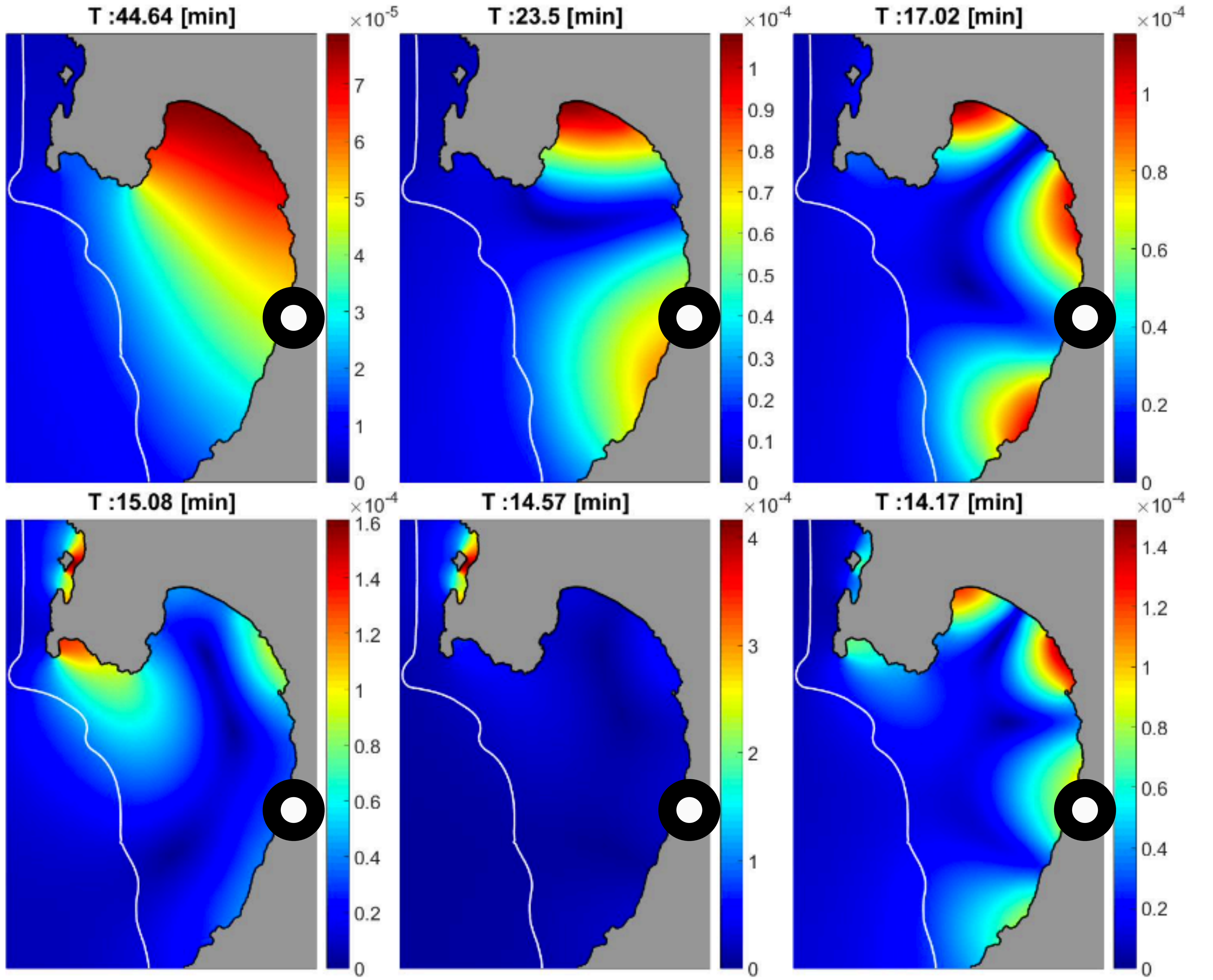
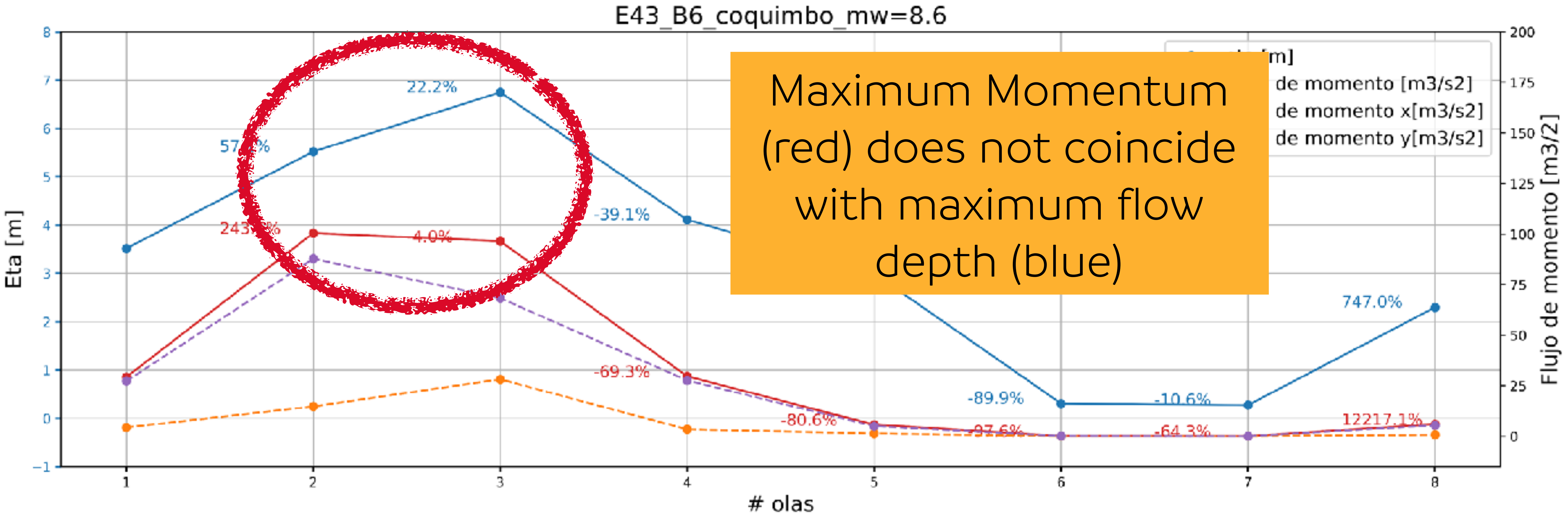
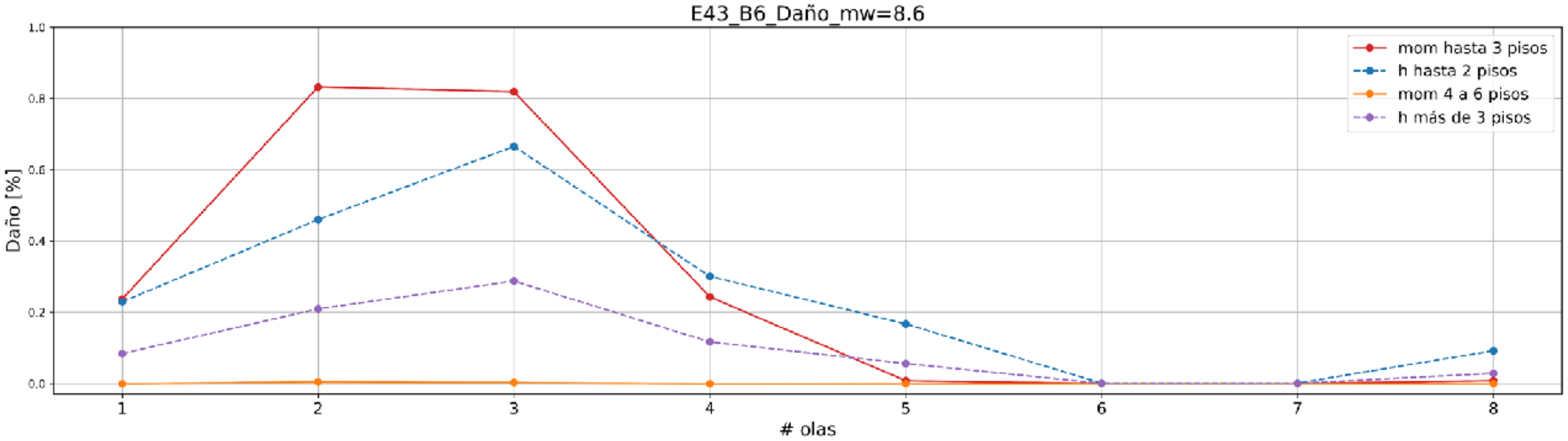


Figura 28.-Mapa de amplitud normalizada de los 6 primeros modos locales. El punto verde indica la ubicación aproximada del mareógrafo.

Other Implications: **Hydrodynamics**





- **Different balance between kinetic and potential energy ?**

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Future Work

- **The approach has been useful to improve the understanding of the response of these bays**
- **Next aim: Characterize what triggers mixed bays**
  - Expand simulations using other correlation lengths to better understand role of source's frequency content
- Attempt to classify bays in terms of their response
- Provide guidelines for hazard monitoring during emergencies

Gracias
Danke schön
Merci
Thank you
Grazie
どうもありがとう
太感谢了

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That's not all, folks

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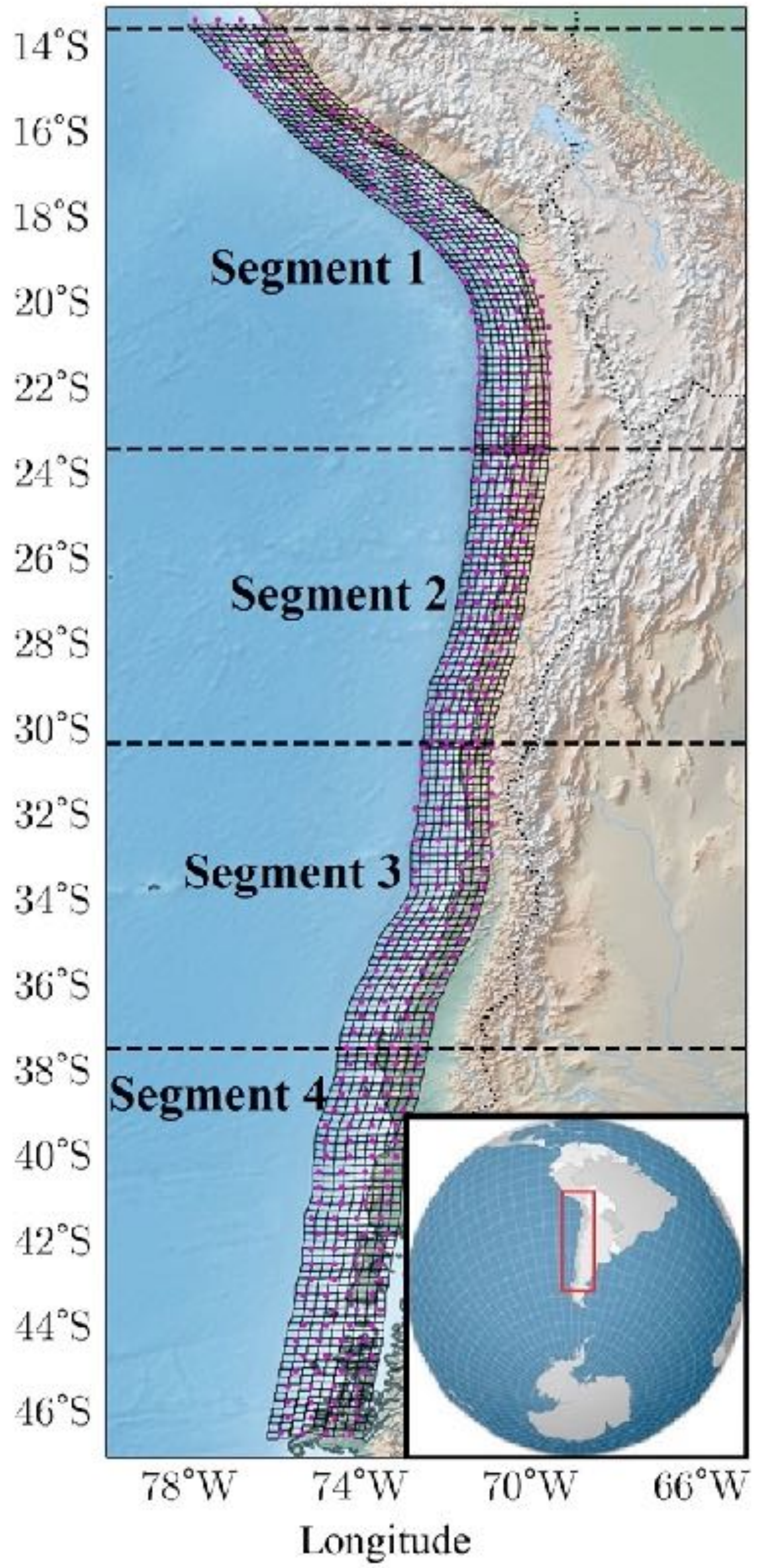
EX UMBRA IN SOLEM

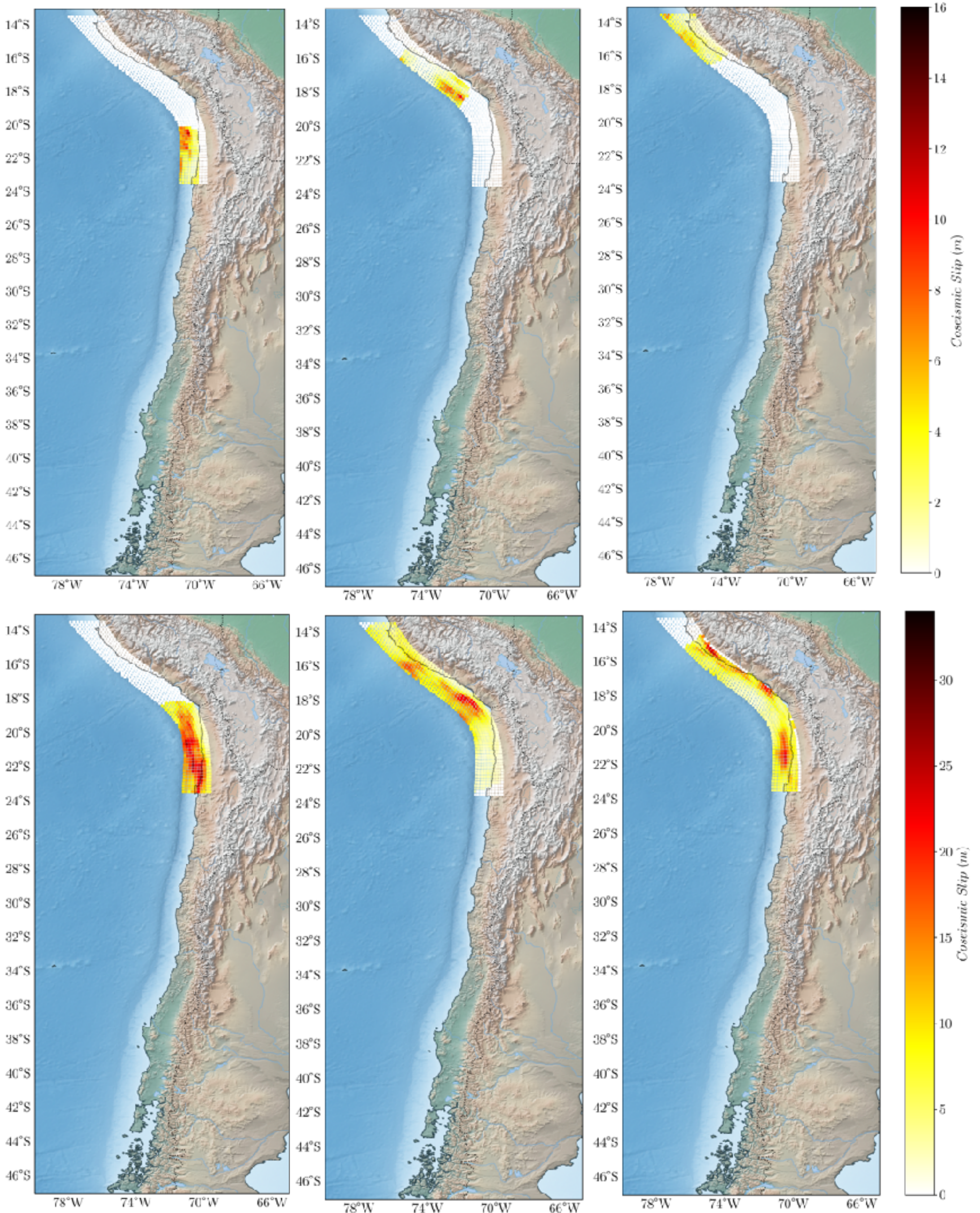
Probabilistic tsunami maps
FONDECYT 1210540 Project
R. Aránguiz



Stochastic Scenarios using K-L

Examples: Mw 8.4-8.6

Examples: Mw 9.0-9.2



Probabilistic tsunami maps
FONDECYT 1210540 Project
R. Aránguiz

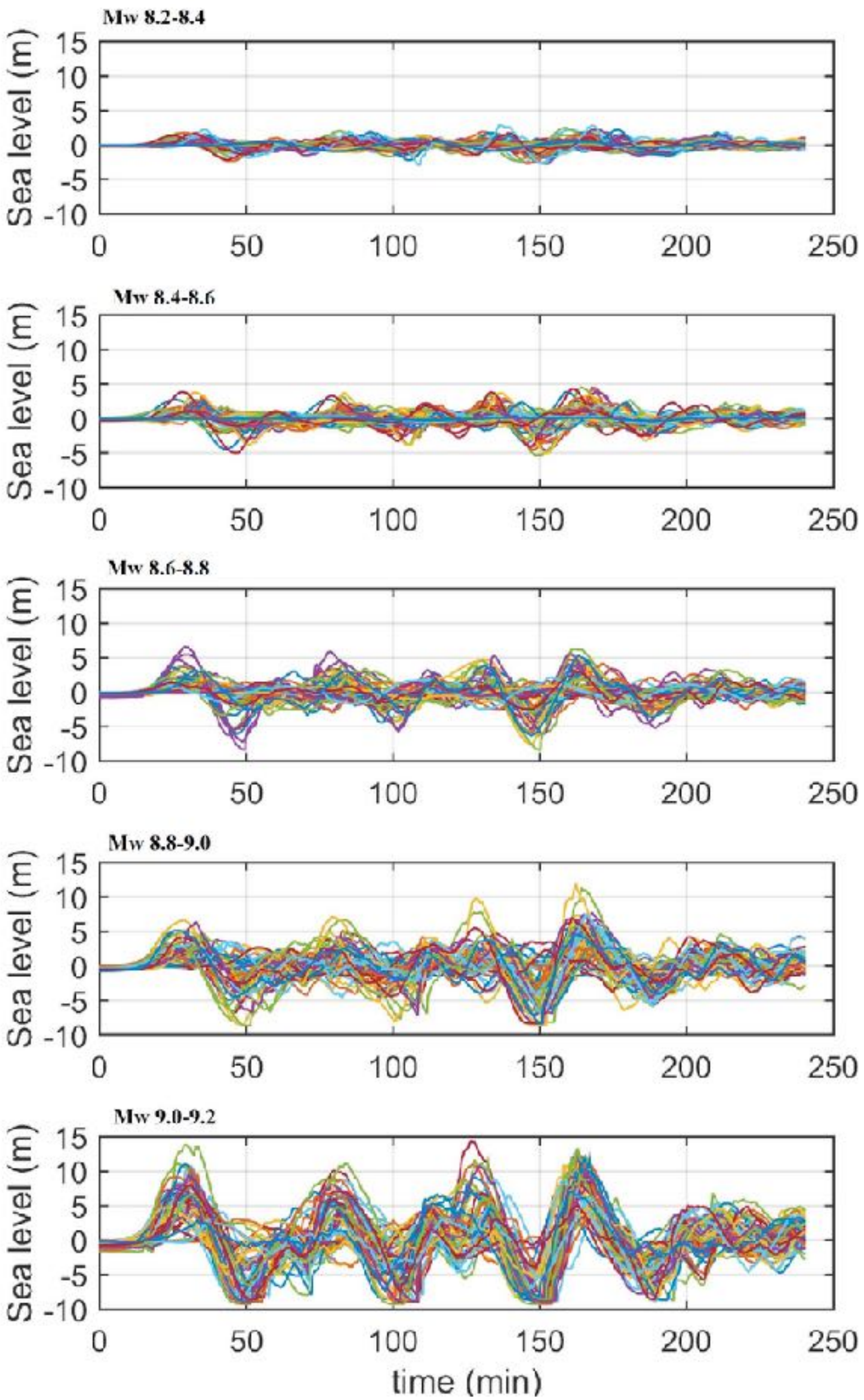
$$\lambda_m = \nu \frac{e^{-\beta(m-M_{min})} - e^{-\beta(M_{max}-M_{min})}}{1-e^{-\beta(M_{max}-M_{min})}}$$

$$M_{min} \leq m \leq M_{max}$$

$$T_R(h_c) = \frac{1}{\sum_j \sum_i \lambda^{Eq}_{M'_{wj},x_i} P_h(h>h_c|M'_{wj},x_i)}$$

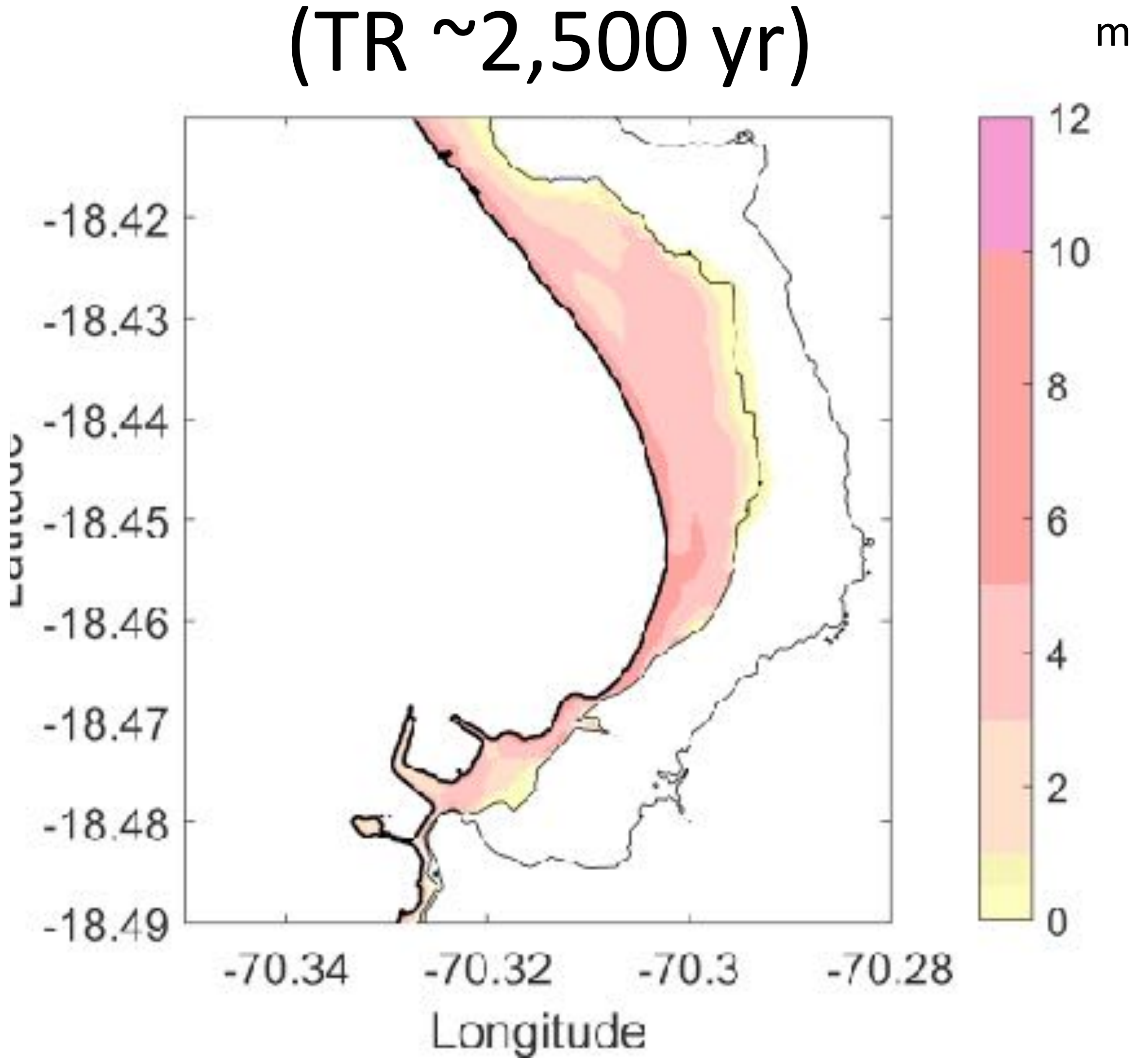
$$P = 1-(1-1/T_R)^L$$

300 scenarios in total



Probabilistic maps

P=2% in 50years
(TR ~2,500 yr)



P=0.5% in 50years
(TR~10,000yr)