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Innovative Approaches and Applications to Foster Resilience in North Pacific Ecosystems

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Subseasonal Effects of Coastal Trapped Waves in the Northern Region of Peru

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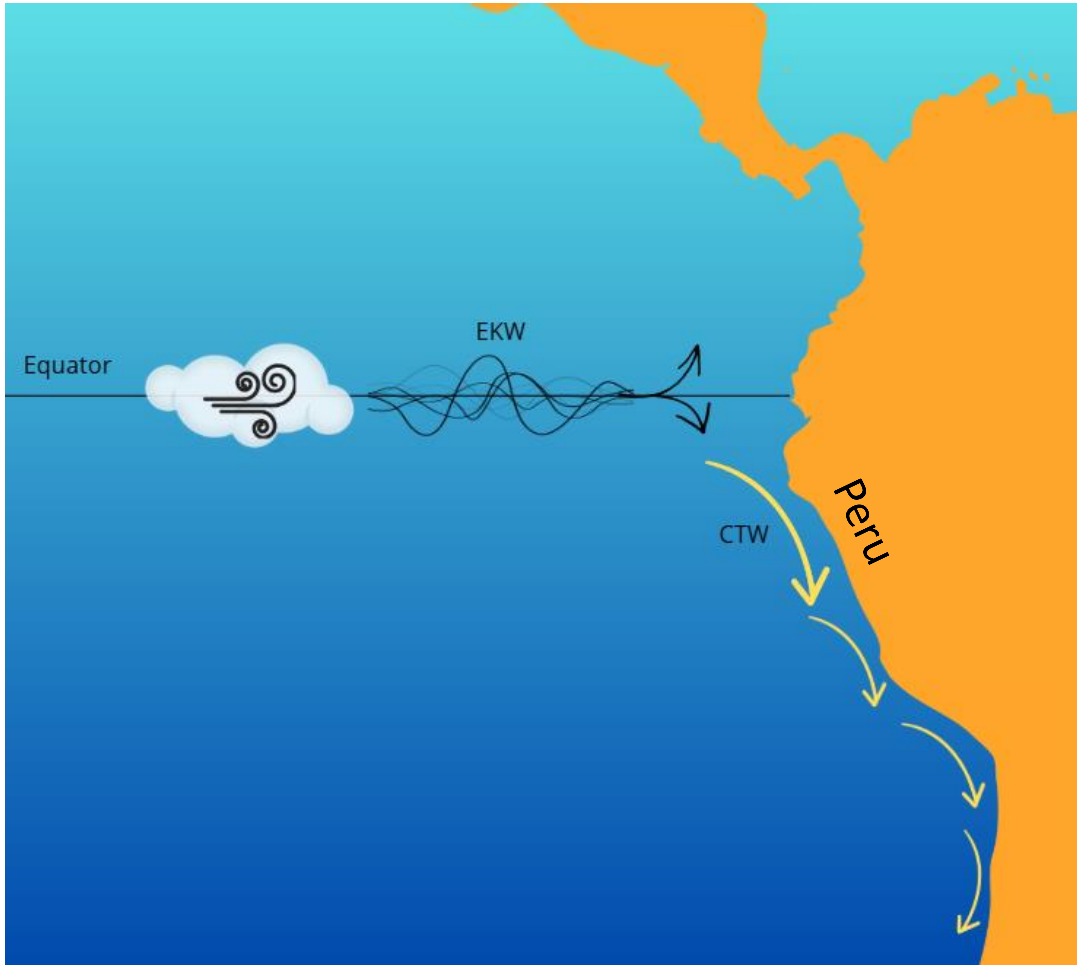
Introduction

❖ Coastal Trapped waves

Coastal trapped waves (CTWs) are wave phenomena in which energy is concentrated on the continental shelf and propagates poleward along the coast, influencing coastal dynamics.

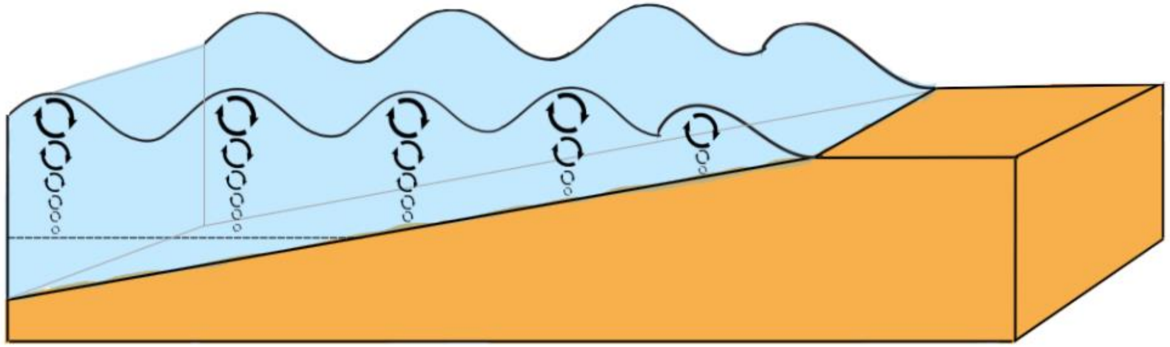


- Energy pathway:
Equatorial Kelvin waves (EKW) arrive from the central Pacific and reflect at the coast.

- Coastal conversion:
Upon impact, part of their energy is converted into Coastal Trapped Waves (CTWs)

- Coastal waveguide:
CTWs propagate parallel to the coastline, with maximum amplitude over the continental shelf.

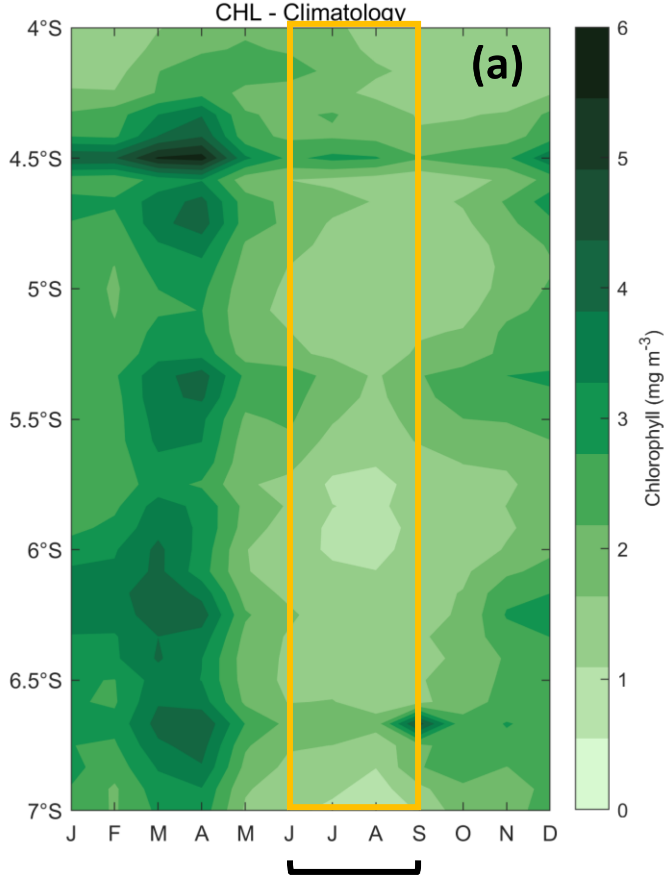
- Offshore decay:
Their amplitude decreases exponentially offshore.



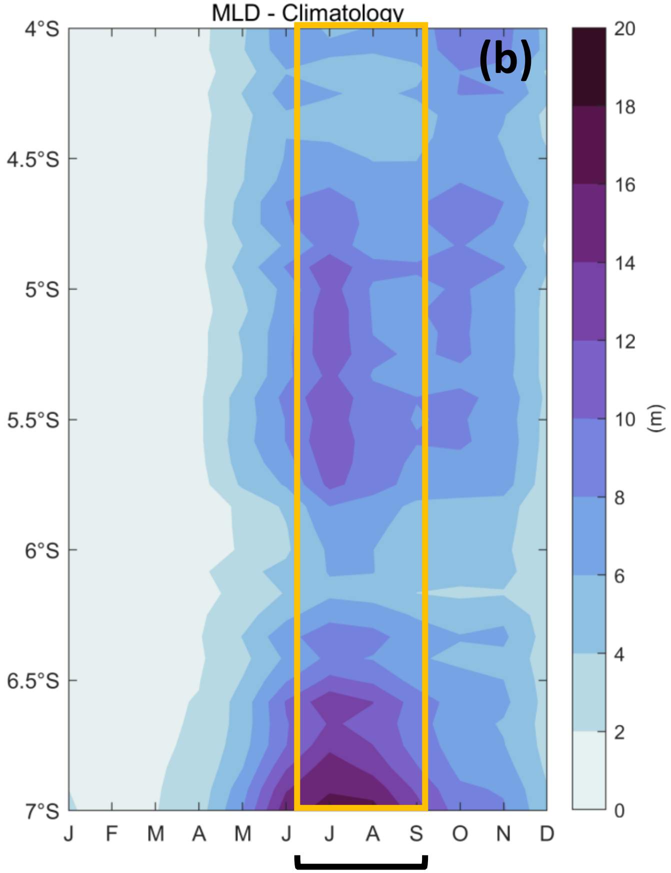
➤ Coastal trapped waves (CTW) are trapped to the continental shelf and slope, with velocities that exponentially decay with distance offshore.

Introduction

❖ Seasonal paradox

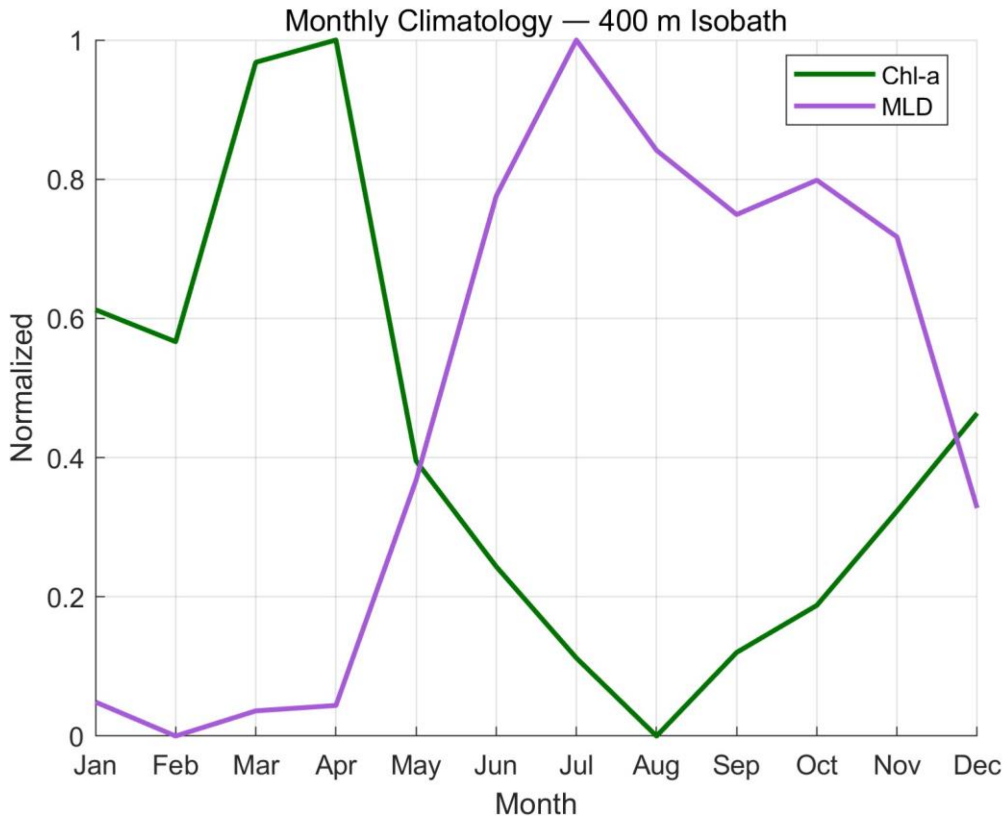


Austral winter



Austral winter

Hovmöller diagrams show (a) surface chlorophyll-a (mg m^{-3}) and (b) mixed-layer depth (m). Both fields are averaged along the 400-m isobath in the northern Peru sector.

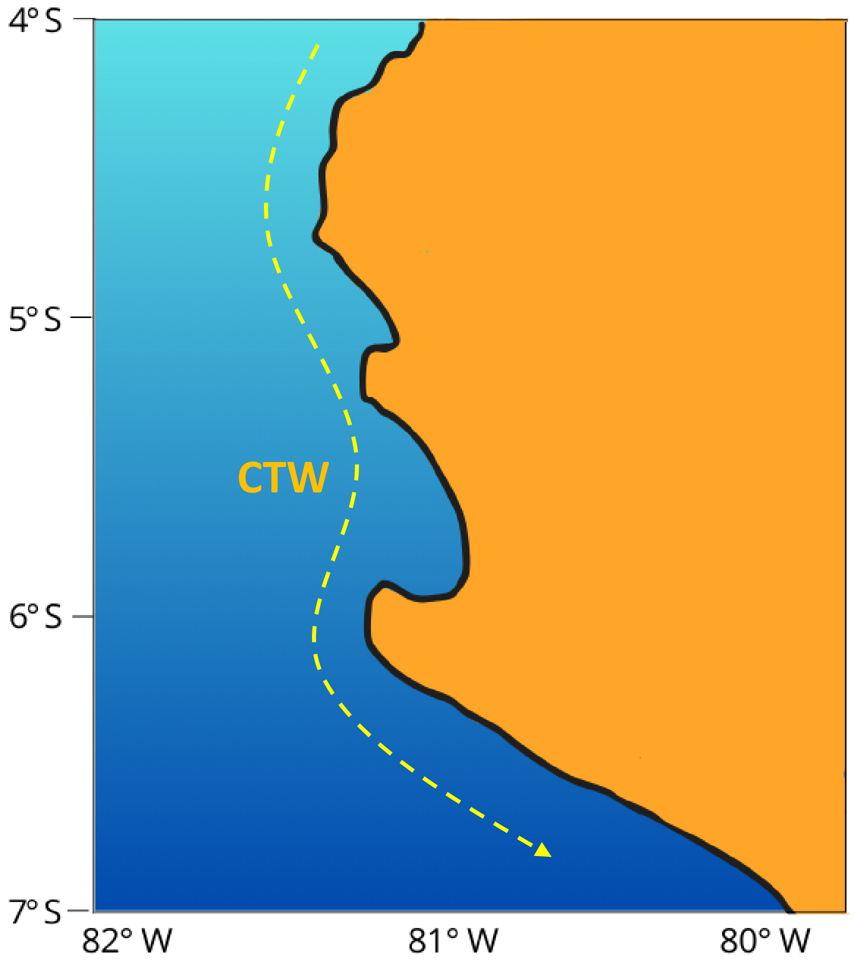


Seasonal paradox → Surface chlorophyll concentrations are lowest in the austral winter, when upwelling is at its peak. This contradicts the expectation that more intense upwelling should increase phytoplankton biomass.

Objetives

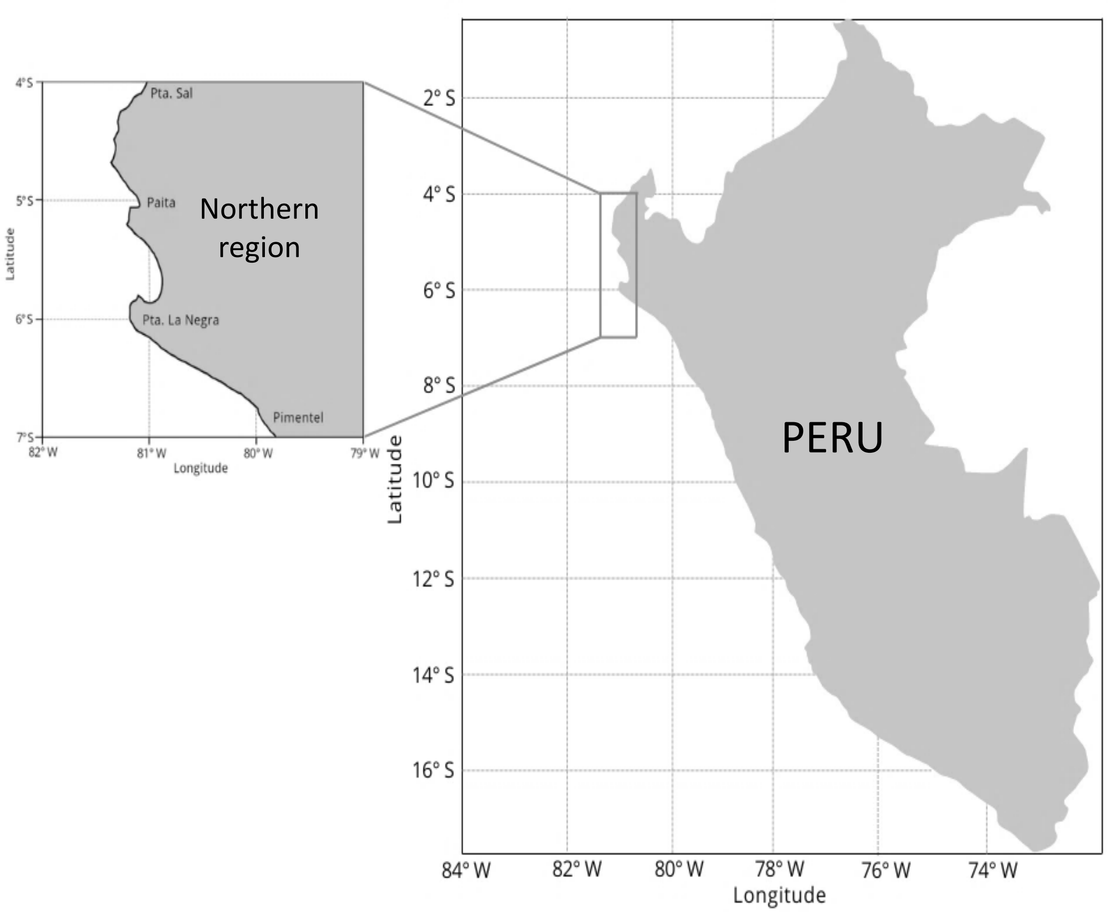
1. Characterize coastal trapped waves (CTWs) in the Peruvian region during 2015–2020, using Empirical Orthogonal Functions (EOF) and wavelet analysis.

2. Evaluate the surface chlorophyll-a response to the passage of CTWs, considering seasonal variability and the amplifying effect of the seasonal paradox.



Data and Methodology

❖ Area of study



❖ Data processing

- GLORYS12 Reanalysis
- Period: 2015–2020
- Variables: Sea Surface height (**SSH**), Mixed layer Depth (**MLD**), Chlorophyll-a (**CHL**)
- Spatial resolution: 0.083° , 0.083° , ~0.036°
- Spatial domain: 4° S–7° S; 79,5° W–82° W

Filtering (Band-pass Butterworth): Isolate **subseasonal variability** linked to **coastal trapped waves (CTWs)** and remove slower (seasonal) and faster noise.

- Daily anomalies
- Along the **400-m isobath**, 4°S to 7.0°S (N→S).
- Period band: **7–50 days**

➤ The use of sea Surface high (SSH) time series on isobaths to analyze the propagation characteristics of CTWs has been widely applied in academic research (Gelderloos et al., 2021; Poli et al., 2022, Hu, et al., 2024; Passaro, 2025)

Data and Methodology

❖ Empirical Orthogonal Functions (EOF)

❖ Wavelet analysis method

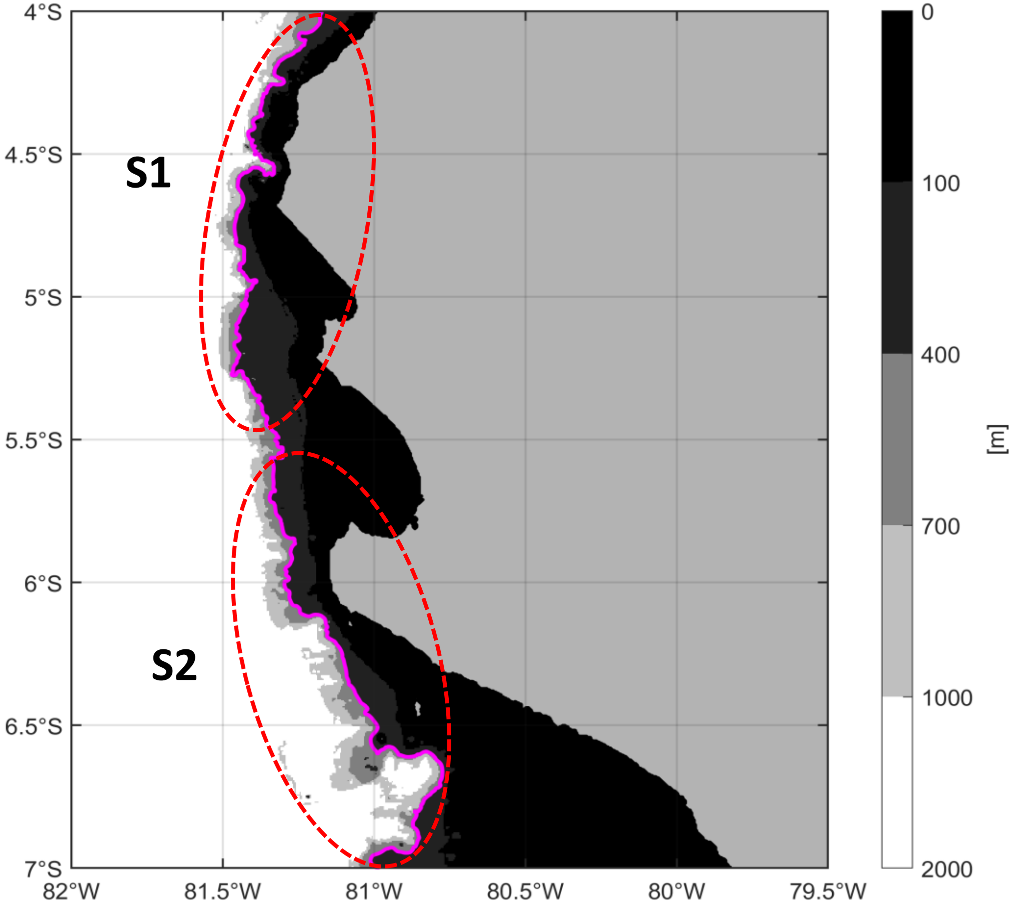
Torrence & Compo (1998)

The continuous wavelet transform will be used to decompose the time series into the time-frequency space in order to identify the dominant modes of CTWs variability.

- **Wavelet coherence**
- **Relative Phase**

Preprocess:

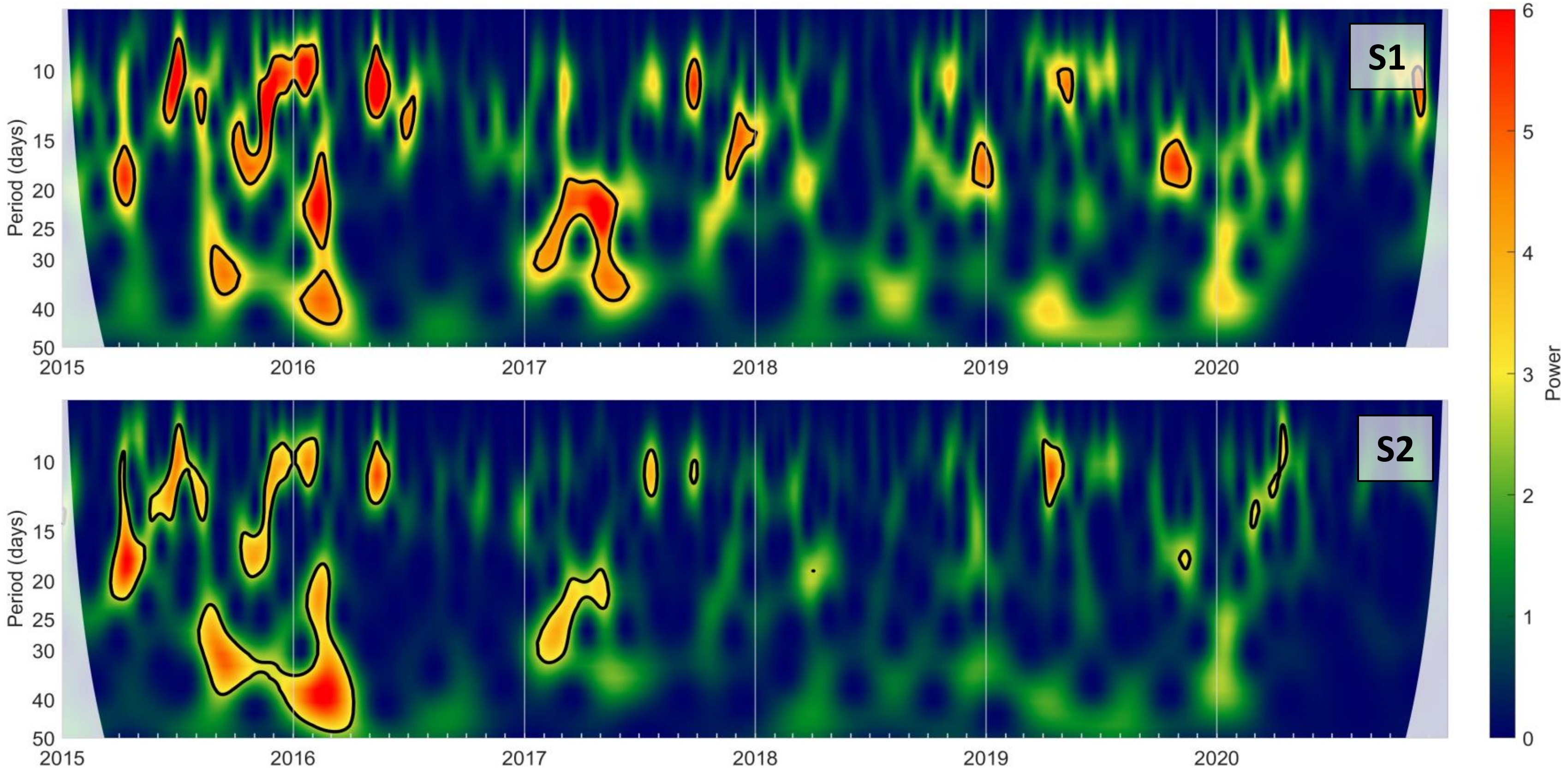
- SSH and Chl - daily filtered anomalies.
- 400-m isobath
- 4°S to 7°S
- 2015–2020



Bathymetry of the Northern Peru continental shelf. The 400 m isobath is highlighted (magenta), indicating the approximate position of the shelf break.

Results: Characteristics of Coastal Trapped Waves Based on Reanalysis Data

Wavelet Power Spectrum – PC1: SSH (2015-2020)



Wavelet power spectrum of PC1 of SSH data (with bandpass filtering) to S1 and S2. The black lines indicating the 95% confidence level and white shallow indicating the boundary below which the results are dubious.

Warm colors (red–orange) enclosed by the black contour (95% confidence level) represent statistically significant CTW signals.

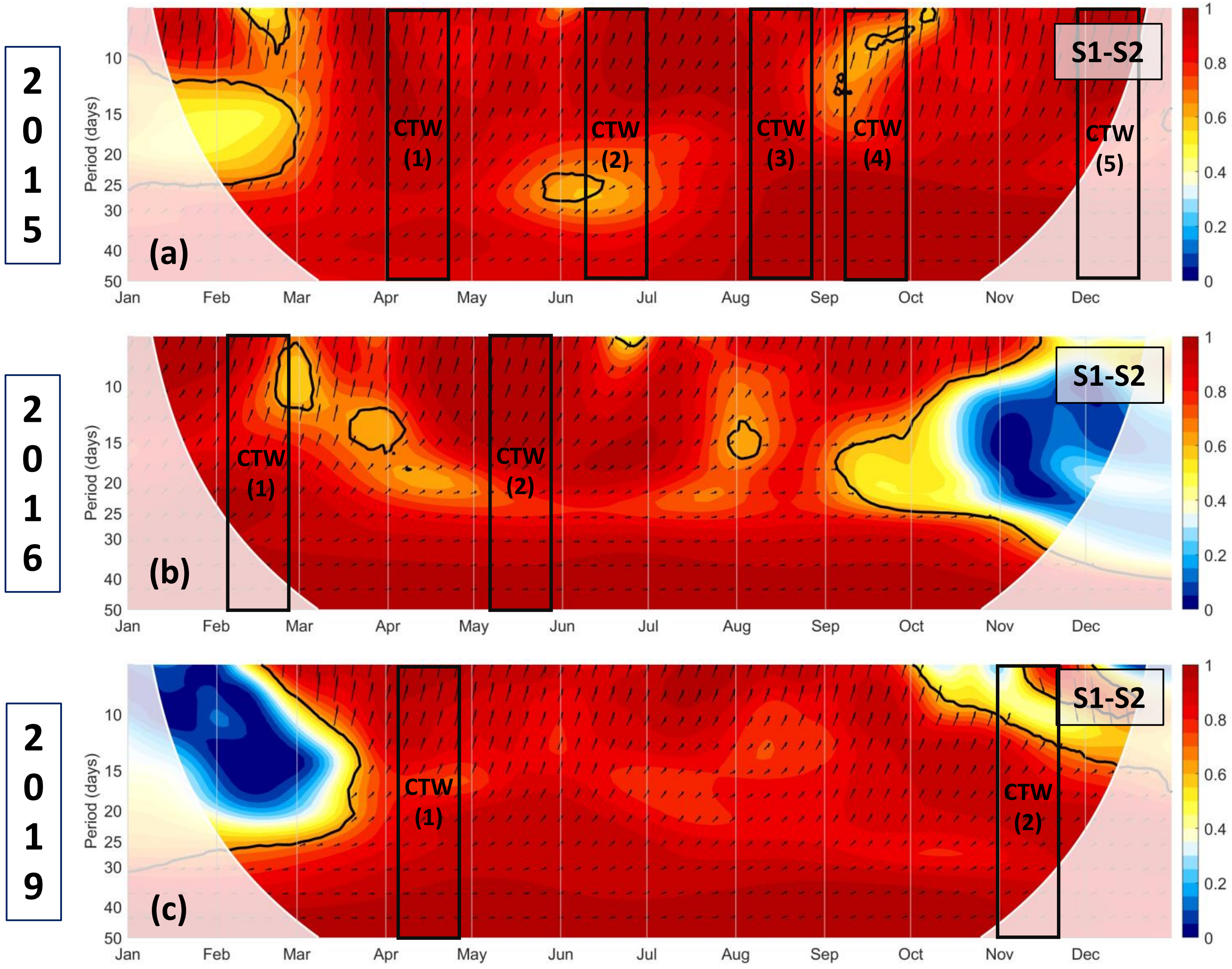
Downwelling CTWs detected between 2015 and 2020:

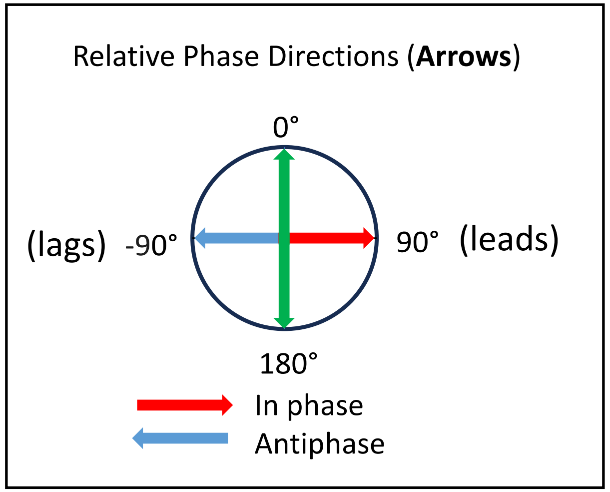
2015 (**5 waves**): Apr, Jun, Ago, Sep and Nov.
2016 (**2 waves**): Feb and May
2017 (**1 wave**): Mar
2019 (**2 waves**): Apr and Nov

- A significant portion of the energy is concentrated in the frequency band between 7 and 50 days. Within this band, the most dominant spectral peaks appear at around 10, 20, and 35 days.

Results: Characteristics of Coastal Trapped Waves Based on Reanalysis Data

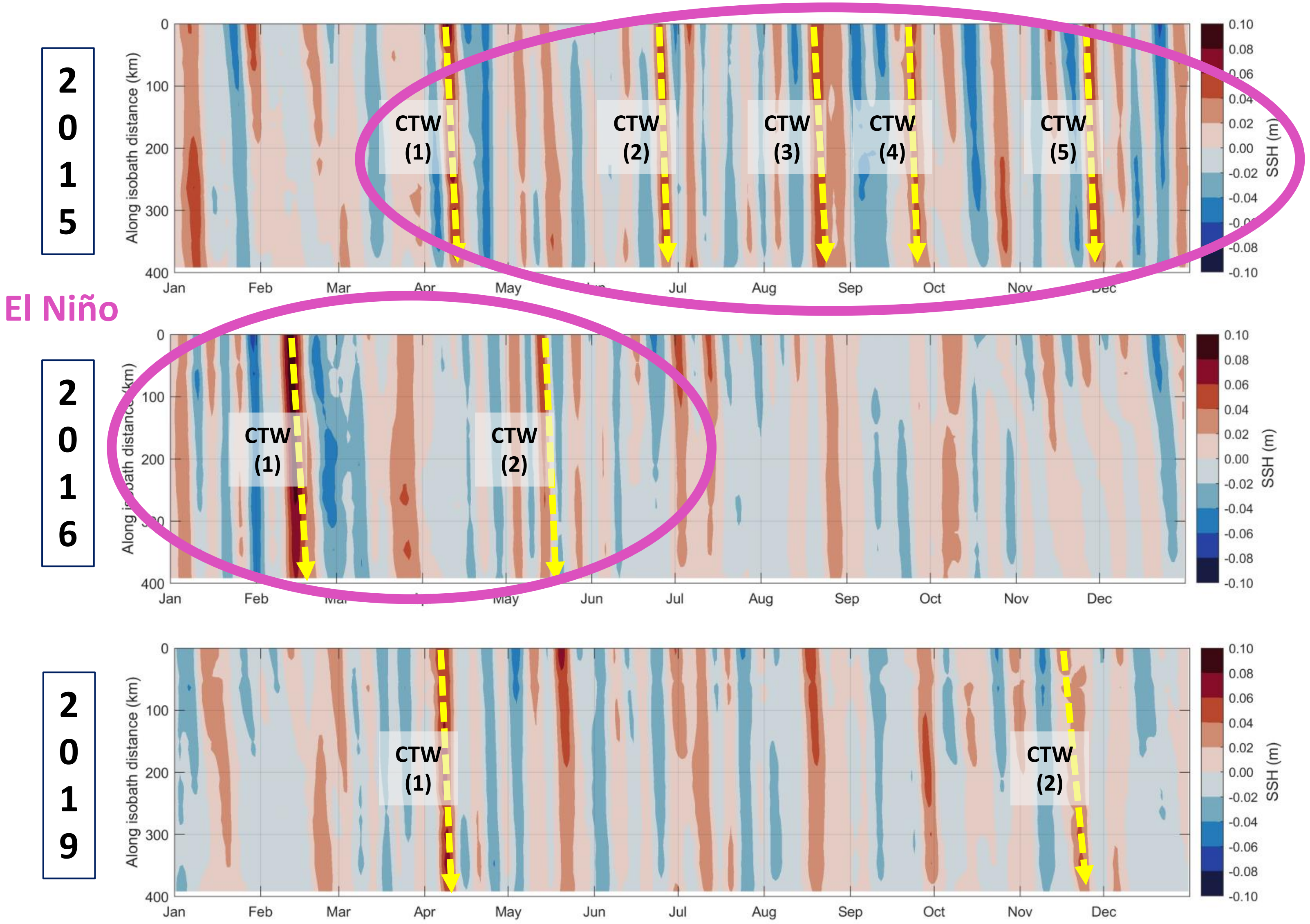
Wavelet Coherence / Phase - PC1 Signal SSH





(a–c) Wavelet coherence between the PC1 of band-pass (7–50 d) SSH for the northern (S1) and southern (S2) sections along the 400-m isobath in 2015, 2016, and 2019. Red: high coherence (0–1); blue: low. Black contours mark the 95% confidence level; cones of influence are shown. Arrows indicate relative phase: ↑ S1 leads S2, ↓ S2 leads S1 (positive phase = S1 → S2, north-to-south propagation).

Results: Characteristics of Coastal Trapped Waves Based on Reanalysis Data



Hovmöller diagram of band-pass-filtered sea surface height (SSH) anomalies along the 400-m isobath, based on GLORYS12 reanalysis data.

Propagation Speed

	Wavelet	Speed	R^2	
2015	CTW 1	1.27 m/s	0.92	Apr
2015	CTW 2	1.80 m/s	0.85	Jun
2015	CTW 3	2.40 m/s	0.74	Aug
2015	CTW 4	1.58 m/s	0.70	Sep
2015	CTW 5	1.53 m/s	0.88	Nov
2016	CTW 1	1.83 m/s	0.69	Feb
2016	CTW 2	2.40 m/s	0.69	May
2019	CTW 1	2.04 m/s	0.76	Apr
2019	CTW 2	0.46 m/s	0.68	Nov

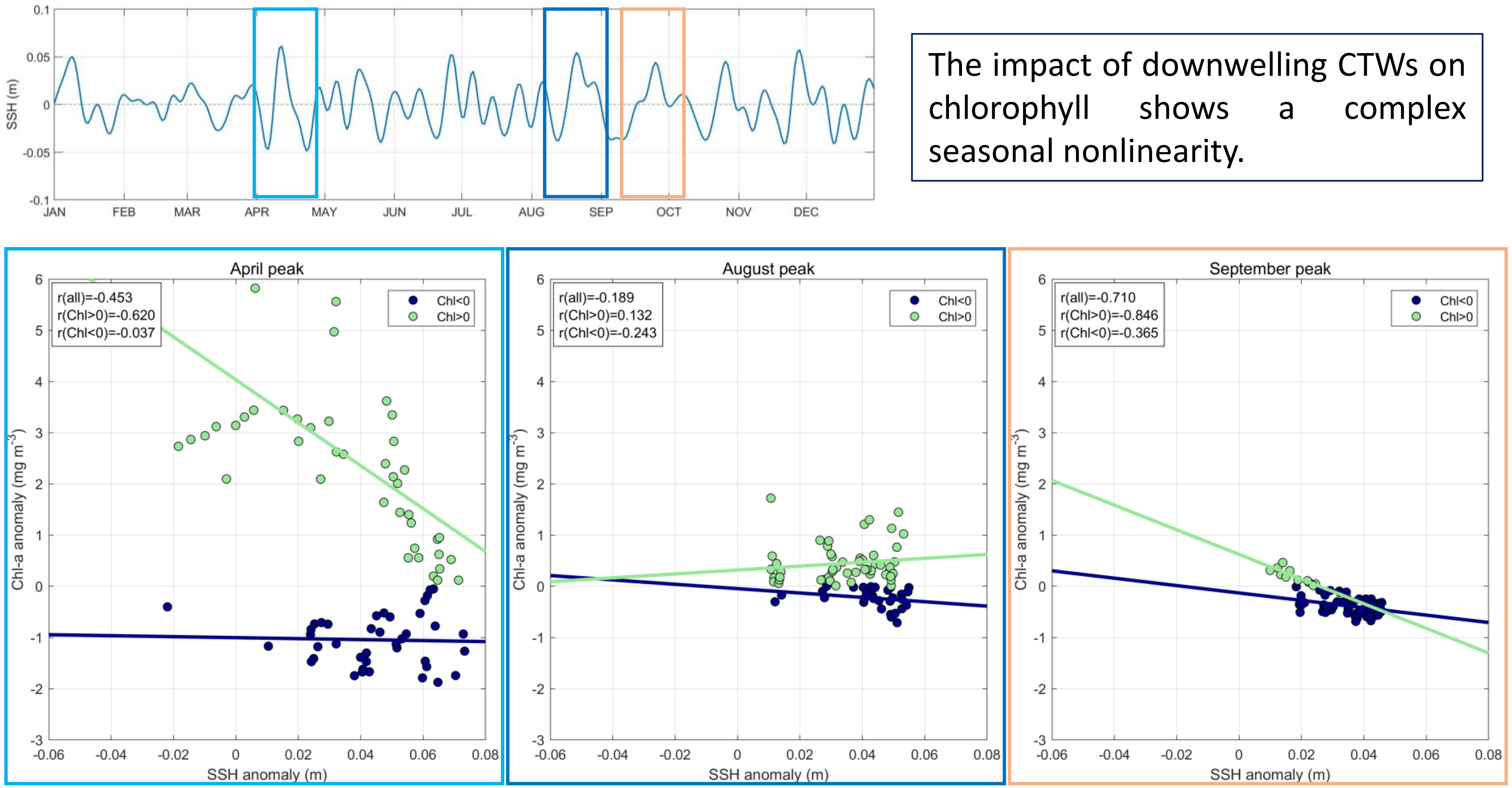
Phase-lag vs. along-coast distance (linear regression) on band-pass (7–50 d) SSH gives c ≈ 0.46–2.40 m/s across 4–7°S.

- Echevin et al., 2014: 2.48 ± 0.40 m/s.
- Arellano et al., 2022: ~1.9 m/s
- Pietri et al., 2014: 1.2 ± 0.4 m/s
- Camayo & Campos, 2006: 1.85–3.94 m/s.
- Pizarro et al., 2001: 0.5–2.9 m/s.

Results: Effect of Coastal Trapped Waves on Chl-a

CTW Impact on Chlorophyll: Seasons under the Seasonal Paradox/El Niño (2015)

- **Latitudes: 6-7°S**



The impact of downwelling CTWs on chlorophyll shows a complex seasonal nonlinearity.

April (Autumn, MLD shallow):
System decoupled, local forcing dominates.

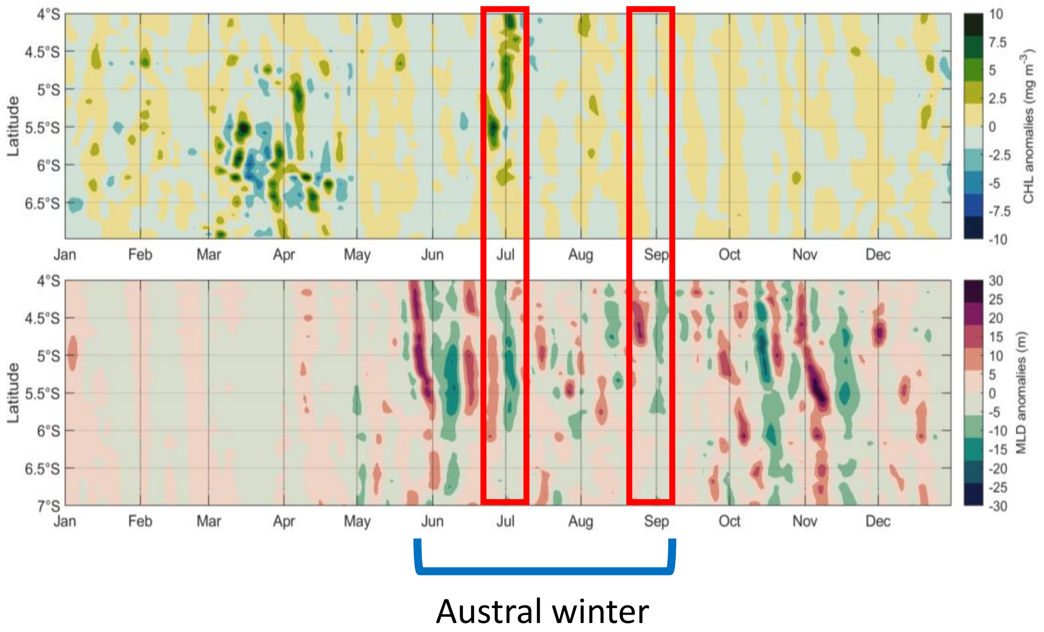
August (Winter, MLD deep):
Peak intensity of seasonal paradox.

September (Spring, MLD transitioning):
Shows clearest CTW signal.

The strongest SSH-Chl coupling occurs during seasonal transitions (September), not when the paradox is consolidated (August).

Results: Effect of Coastal Trapped Waves on Chl-a

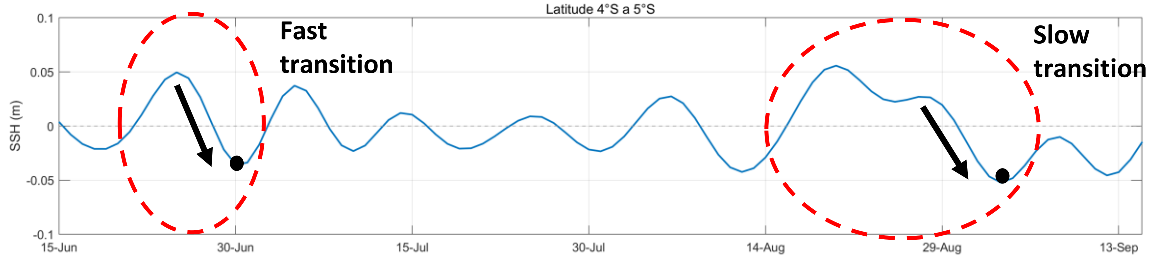
CTW Impact on Chlorophyll: Winter under the Seasonal Paradox/El Niño (2015)

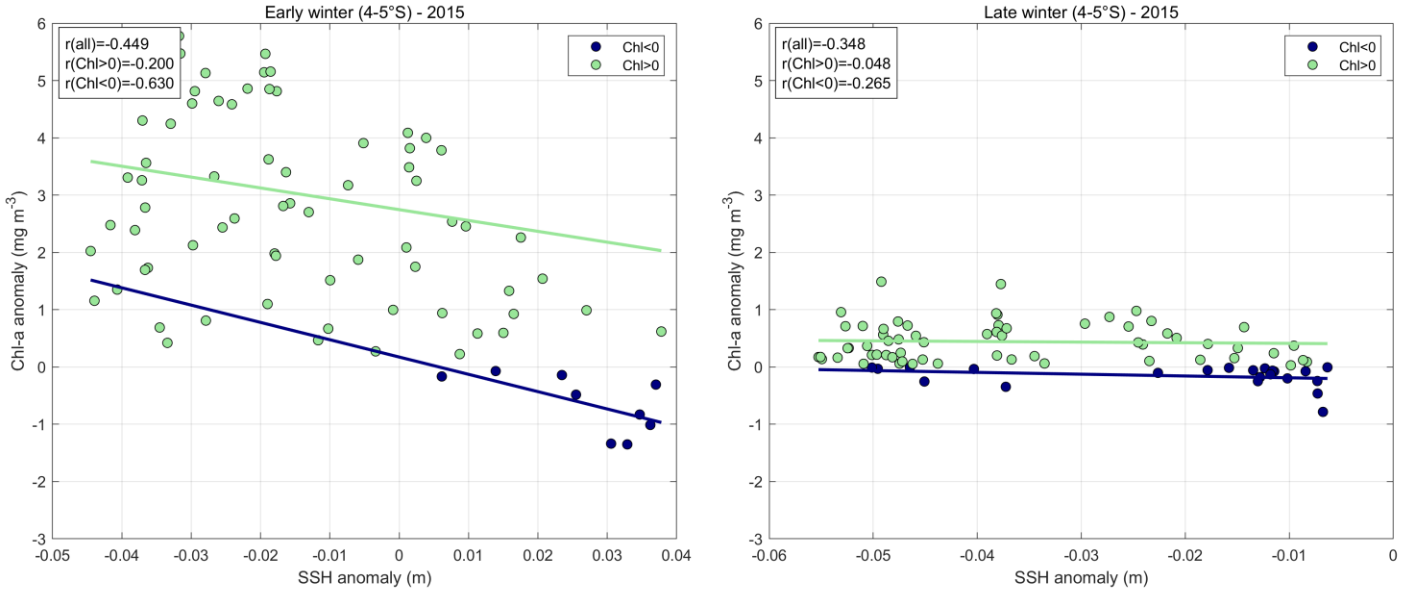


June event: Biological response
September event: No biological response

Mixed-layer dependence: The biological response depends on the mixed layer depth during short-lived negative SSH events.

- Region with positive biological response → 4–5°S





- **Early winter (June)**
- Strong negative correlation (r = −0.45)
- Positive Chl-a anomalies

- **Late winter (September)**
- Weaker correlation (r = −0.35)

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