Historical Sea Level Analysis of the Chilean Littoral

Florencia Garcia Garcia (1), Víctor Sanz Fernández * (2), Pedro Apablaza Bastías (2), Tomás Berger Muñoz(2), Carolina Calvete Maldonado (3), Julio Castro Barraza (4)

(1) Alumno pregrado de Oceanografía, Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso, Universidad 330, Curauma, Valparaíso, Chile.

(2) Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso, Universidad 330, Curauma, Valparaíso, Chile.

(3) Centro Nacional de Datos Hidrográficos y Oceanográficos de Chile (CENDHOC). Servicio Hidrográfico y Oceanográfico de la Armada de Chile (SHOA).

(4) División Dinámica Costera, Departamento de Oceanografía. Servicio Hidrográfico y Oceanográfico de la Armada de Chile (SHOA).

*Author corrresponding: victor.sanz@pucv.cl

INTRODUCTION

Mean sea level (MSL) has risen 20 cm since 1880, with projected increases between 30 and 122 cm by 2100 (UNDP,2020).In Chile about one million people live less than 10 meters above sea level, making the country highly vulnerable to these changes (Morales, Winckler & Herrera,2020).

Sea level rise causes coastal erosion, flooding and loss of territory affecting ecosystems and communities (Nicholls, 2002; Martinez et al., 2018).

This study examines the variability of the tide series allowing the detection of trends and anomalies, facilitating mitigation and adaptation strategies.

RESULTS

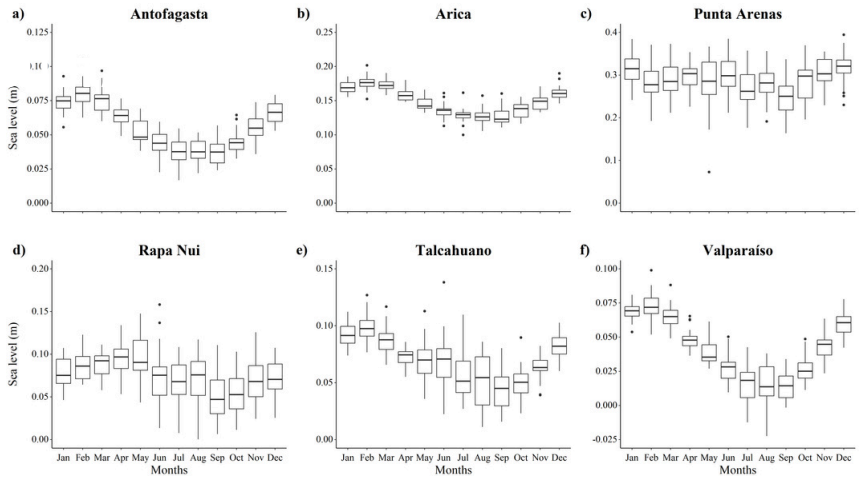

Figure 2. Seasonal variability of sea level by tide gauge stations (1999-2023). A cyclical pattern with fluctuations throughout the year is observed, showing changes in mean sea level in different months.

Table 1. Sea level characteristics by tide gauge stations, showing the presence and type of trend (linear or quadratic). Arrows indicate the main direction of the trend.

Variable	Trend
Antofagasta	Linear ↓
Valparaíso	quadratic ↗
Rapa Nui	Linear ↓
Talcahuano	Linear ↓
Punta Arenas	quadratic ↘
Arica	Linear ↑

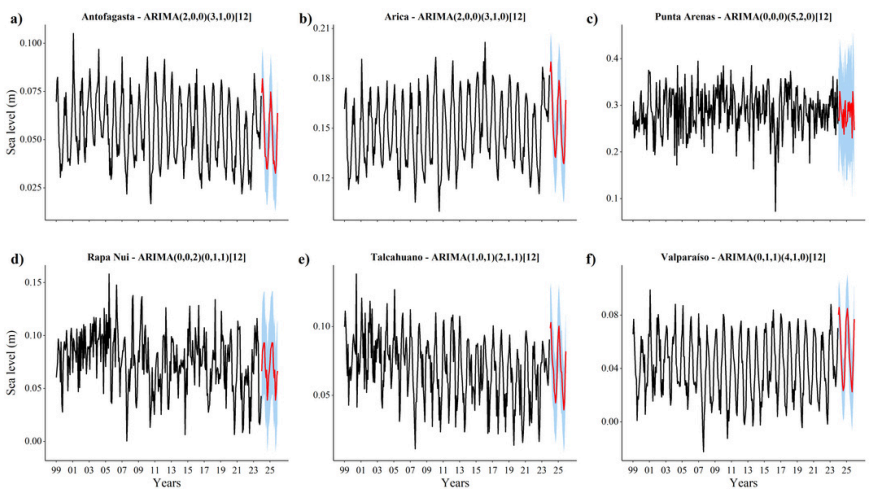

Figure 3. Future sea level projections by tide gauge stations. Observed data are represented in black while projections made by the ARIMA model in red associated with the uncertainty shaded in blue (95% confidence interval).

METHODOLOGY

Study area

The data used in this analysis were obtained from 6 sea level stations along the Chilean coastline (Figure 1) of the Chilean Navy Hydrographic and Oceanographic Service (SHOA) tide gauge network.

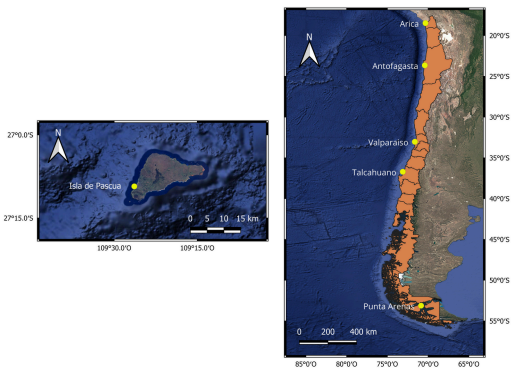

Figure 1. Locations of SHOA tide gauge stations. From North to South: Arica, Antofagasta, Rapa Nui (Easter Island), Valparaiso, Talcahuano and Punta Arenas.

Missing data processing

Missing data from the sea level time series were processed according to the methodology of Emery & Thompson (2001). Two methodologies were used to handle gaps in the data: for gaps smaller than 6 hours, linear interpolation was used, while for gaps larger than 6 hours, harmonic analysis was used.

Sea level correction

The effect of the inverted barometer was corrected using sea level atmospheric pressure (SLP) data from the ERA5 reanalysis product, distributed by Climate Data Store, Copernicus (Hersbach et al., 2023). The methodology described by Vinogradova et al.(2015) was applied using the expression:

$$NM = NM - \frac{(SLP - P_{ref})}{(\rho_{air} * g)}$$

Analysis techniques

The analysis of sea level time series was carried out in the Rstudio environment, where trends and seasonal characteristics were addressed through an exploratory analysis with linear and nonlinear approaches.

To model and project sea levels, ARIMA models were applied following the Box-Jenkins methodology (Box & Jenkins,1976) with the R forecast package (Hyndman & Khadakar,2018). Validation of the results was performed using error indices (RMSE, MAE, AICc) and fit metrics (R^2, PI) to ensure the model with the best forward projection.

CONCLUSION

1. **Sea level seasonality:** Clear inter-monthly variability, possibly attributable to seasonal cycles of temperature, precipitation, atmospheric pressure and wind, reflecting upwelling patterns and local weather and climate conditions.
2. **Trends**: Presence of cyclical level changes, compatible with effects of climate change, weather events, decadal oscillations and seismic activity.
3. **ARIMA models and projection**: Short-term future trends with high variability indicating continuous increases or decreases, showing the need to develop adaptation and mitigation strategies for the Chilean coastline and the approval of the new Coastal Law.

REFERENCES

Box, G. E., Jenkins, G. M., Reinsel, G. C., & Ljung, G. M. (2015). Time series analysis: forecasting and control. John Wiley & Sons.

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., ... & Thépaut, J. N. (2023). ERA5 hourly data on single levels from 1940 to present, Copernicus Climate Change Service (C3S) Climate Data Store (CDS)[data set].

Hyndman, R. J., & Khandakar, Y. (2008). Automatic time series forecasting: the forecast package for R. Journal of statistical software, 27, 1-22.

Martínez, C., Contreras-López, M., Winckler, P., Hidalgo, H., Godoy, E., & Agredano, R. (2018). Coastal erosion in central Chile: A new hazard?. Ocean & coastal management, 156, 141-155.

Morales, E., P. Winckler & M. Herrera (2020). Costas de Chile. Medio Natural, Cambio Climático, Ingeniería Oceánica, Gestión Costera. Servicio Hidrográfico y Oceanográfico de la Armada de Chile. Valparaíso: 182 pp.

Nicholls, R. J. (2002). Analysis of global impacts of sea-level rise: a case study of flooding. Physics and Chemistry of the Earth, Parts A/B/C, 27(32-34), 1455-1466.

Vinogradova, N. T., Ponte, R. M., Quinn, K. J., Tamisiea, M. E., Campin, J. M., & Davis, J. L. (2015). Dynamic adjustment of the ocean circulation to self-attraction and loading effects. Journal of Physical Oceanography, 45(3), 678-689.

ACKNOWLEDGMENTS

This research has been possible thanks to the project **"Historical Analysis of Sea Level and Atmospheric Pressure of the Chilean Littoral (MAR-CHILE) (VCM 0724)"** funded by the Dirección General de Vinculación con el Medio (PUCV) together with the Escuela de Ciencias del Mar (PUCV), in collaboration with the Servicio Hidrográfico y Oceanográfico de la Armada de Chile (SHOA).

MAR-CHILE
Análisis Histórico del Nivel del Mar y la Presión Atmosférica del Litoral Chileno