ANALYSIS OF HISTORICAL EXTREME COASTAL WATER LEVEL, AND CONTRIBUTORS ALONG SOUTH AMERICAN PACIFIC COAST

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INTRODUCTION

Coastal behavior in South American Pacific coasts (SAPC) is subjected to oceanographic and tectonics conditions and those triggered by anthropogenic and climate change. Extreme Coastal Water Level (ECWL) is considered an important variable for coastal communities, infrastructure design, ports, and harbor operations (IPCC AR-6) due to the integration in a determinist approach of Relative Sea Level Change (RSLC), Astronomical Tides (AT), Storm Surge (SS), and Waves Run-up (Rup2%). Vertical Land Motions produced (VLM) by tectonics along the SAPC are generated because the Nazca plate subducts beneath the South American plate and can generate secular uplift/subsidence of about 1 to 10 mm/yr (Ruegg et al., 2009) that are comparable with sea level rise rates or even larger. This study aims to understand the historical behavior and trends of the ECWL along the SAPC and their individual contributors, and how they interact with the VLMs produced by tectonics (Figure 1).

DATA-SETS

Data used in this study combines both measurements and numerical modeling. OSU-TPXO model was used to obtain the AT, sea level anomalies (SLA), and absolute dynamic topography (ADT) from Copernicus satellite data. Climatological indexes (CI) (SOI, PDO, SAM, etc.) were selected from NOAA. JRA-55 reanalysis was used to obtain SS and waves hindcast for the 1959-2019 and 1979-2019 periods respectively. Foreshore slope values obtained from the CoastSat website were used to obtain Rup2%. Tide gauge (TG) and wave buoy measurements along the Chilean coast were obtained from the Hydrographic and Oceanographic Service from Chile (SHOA in their Spanish abbreviation). CMIP-6 Data was used to obtain regional projections of SLR and VLM.

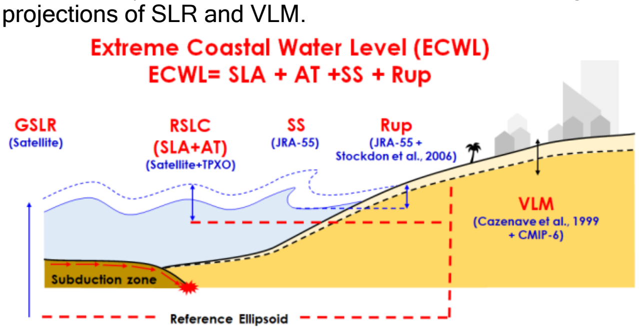

Figure 1: ECWL determination, data source (in blue) to obtain its contributors, and their interaction with VLM.

METHODOLOGY

ECWL along the SAPC were obtained following the expression in Figure 1 for the 1993-2019 period. Analysis of the hourly individual components was conducted to understand their variability, contributions, and trends through different time periods. AT was obtained every 0.5° from 0° to -60°. Comparison between wave hindcast data and buoy measurements located among the -18° to -45°was conducted, and once validated was used to obtain Rup2% with Stockdon et al., (2006). Multivariable regression between CI and SLA to understand the total and individual contribution in the anomalies was conducted. VLMs were obtained in TG stations distributed in the SAPC by merging ADT and TG measurements (Cazenave et al., 1999) for the 1993-2019 period. Once obtained, they were compared with ECWL trends in the same positions.

RESULTS

Wave analysis, essential for the Rup obtention, showed an increasing pattern from north to south. Extreme waves along the south part of SAPC can reach values over 10 m height, while in the equatorial zone maximum wave height only reaches 2 m. Trends reveal minor increases in significant wave height and mean period, but for the 1979 -2019 period, a major change in the mean wave direction was found reaching 0.1° per year, which means 4° along the complete analyzed period. Comparison between wave hindcast and buoys conducted had correlation values between 0.70 to 0.93 for the Hs and 0.60 to 0.90 for the Tm.

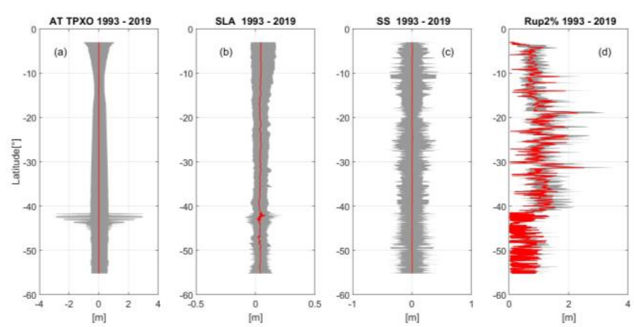

Figure 2: ECWL Individual components variability for the 1993-2019 period. Red Line shows the median value, and the grey area represents 5% and 95% tiles of the data.

Individual components variability for the 1993-2019 period along the SAPC (Figure 2) has different patterns from north to south. When 5% and 95% tiles are analyzed, SS reaches values between 0.2 to 0.3 m, with maximum values in latitudes near the Equator and in the extreme south. AT reveals almost a constant value along the SAPC except near the equator between 0° to -15° and between -40° to -45° where the coastal configuration changes, forming fjords, and canals that increase the tidal ranges. SLA range varies from 0.30 to -0.20 m, with a median value of 0.10 m. Multivariable regression analysis reveals SOI and PDO contributions between 85% to 35% and 55% to 30% from central America to the extreme south respectively, and SAM with slightly 20% in the southern zone. Rup2% median values fluctuate between 0.5 to 3.0 m, reaching heights between -20° to -40° while in the SAPC extremes, can reach 1.0 m height.

ECWL variability reveals a different behavior along the SAPC. While in the 0° to -20° Latitudes, the median value goes from 0.5 to ± 0.3 m, while between -20° to -40° these values increase to reach 1.5 m median values but with maximums above 2.5 m and a minimum of 0.3 m. If the 5% and 95% tiles are analyzed, the variability fluctuations can reach values oscillating between 0.2 to 3.5 m as is shown in Figure 3, panel (a). A superior 5% events average contribution was obtained (Figure 3 panel (b)), revealing that the main contributor of the ECWL along the SAPC is associated with the Rup2%, oscillating between 60% to 70%, and reaching a maximum contribution of 80% in some parts. The second contributor to the events is the AT, with 15% to 25%. An inverse proportion of their contributions can be found near the Equator and below -40° where AT contribution becomes larger than the one obtained from the Rup2%.

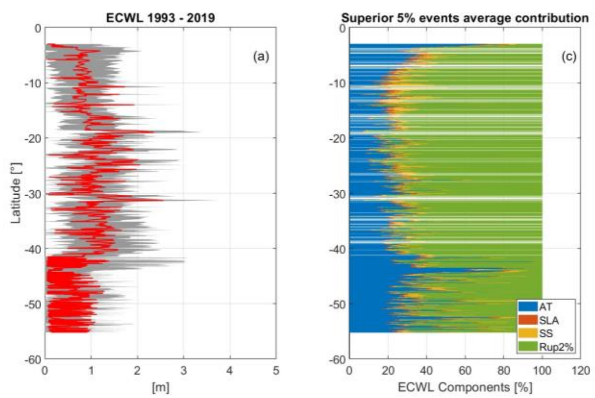

Figure 3: ECWL obtained along SAPC are shown in panel (a), where the red line represents the median value, and the grey area refers to the 5% and 95% tiles. Panel (b) presents the superior 5% events average percentage contribution at each location of the SAPC.

ECWL trends (Figure 4), reveal similar increasing values to the ones associated with SLR, but their spatial behavior responds to the Rup2% distribution. Between -20° to -40° a decrease in the trend values occurs, contrasting with the increasing pattern shown along latitudes from 0 to -20 and -40° to -55°. One of the phenomena that can be influencing these changes is the South Pacific high, located among the mentioned coordinates, but also its south shifting, which directly affects the Hs and Tm behavior. SS and Rup trends tend to maintain a similar magnitude as the one shown in their long period, meaning that the most influential contribution in the trends is coming from the SLR.

Secular uplift/subsidence due to tectonics effects in some stations are changing faster than the ones obtained for the ECWLs in the same period. A second analysis was comparing VLMs obtained from CMIP-6 data from 2005 to 2019 along the SAPC. Some of the stations analyzed had a good agreement with the values projected by CMIP-6 but others showed larger tendencies, maybe referring to recent uplift/subsidence generated from large earthquakes.

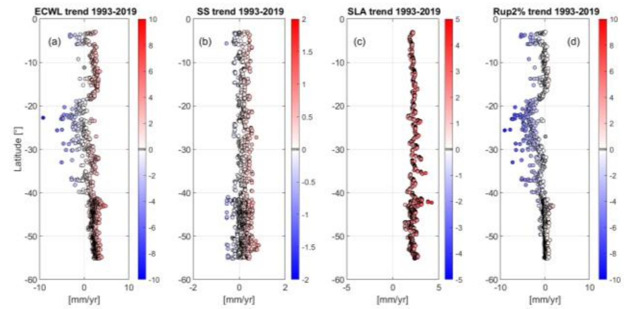

Figure 4: Panel (a) shows the ECWL Trends obtained for the analyzed period along the SAPC. Panels (b),(c), and (d), trends obtained for each contributor SS, SLA, and Rup2% respectively.

CONCLUSIONS

ECWL trends are strongly affected by the tendencies of SLA, reaching a median value of 2.26 mm/yr, but their shape distributions respond to the wave mean period influence. Wave Run-up is mostly the main contributor along the SAPC oscillating between 60% to 70%, followed by the AT contribution. Between -40° to -45° due to the canal and fjords configuration, AT takes place as the main contributor.

Changes in the wave climate will also significantly affect the ECWL projections, along this area, due to the strong contribution reflected in the Rup2%. Between -20° to -40° negative trends are presented for the Tm and Rup, differing from the behavior in the remaining locations. These changes can be associated with the migration toward southern areas of the South Pacific High and influence the SAM, needing to comprehend the possible changes that will be generated in future projections.

VLM rates can play a fundamental role when their occurrences are compared with SLR rates. In this analysis VLMs produced by tectonic strain accumulation possess trends larger than the ones obtained for the ECWL in the TG stations analyzed. Is necessary also to consider uplift/subsidence produced by earthquake occurrence, which can be in larger orders than the ones obtained in this study.

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