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Coastal "El Niño" and its impacts on the Peruvian marine ecosystem

Peru

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COASTAL "EL NIÑO" AND ITS IMPACTS ON THE PERUVIAN MARINE ECOSYSTEM

by

Gutiérrez, Dimitri; Cahuín, Sandra; Román Gersson; Bouchon, Marilú

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This report contains information on the fishery in Peruvian jurisdictional waters that, we reiterate, the delegation of Peru, in use of its discretionary powers, voluntarily provides for the purpose of information and support to the scientific research work within the Scientific Committee of the SPRFMO. In doing so, while referring to Article 5 of the Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean and reiterating that Peru has not given the express consent contemplated in Article 20 (4) (a) (iii) of the Convention, Peru reaffirms that the decisions and conservation and management measures adopted by the SPRFMO Commission are not applicable within Peruvian jurisdictional waters.

2023

Coastal "El Niño" and its impacts on the Peruvian marine ecosystem

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Introduction

The Pacific Ocean off Peru is characterized by its high biological variability and productivity which affects all trophic levels of the marine ecosystem (Espino and Yamashiro, 2012; Espino, 2014). This high biological productivity is mainly due to the specific physical and chemical conditions of this area, in particular for the presence of coastal upwelling, oceanic dynamics (Zuta and Guillén 1970; Chávez, 1989; Graco et al., 2007; Bakun and Weeks 2008). El Niño event is an element that generates strong changes in the oceanographic and climate conditions on Peruvian waters. The planktonic productivity is altered, causing antagonistic reactions in fishery species, due to the modification of their distribution patterns, alteration of some physiological processes, such as growth and reproduction, which have repercussions on the development of fisheries and other socioeconomic aspects of Peru (Rojas de Mendiola et al., 1985).

In this sense, this document describes the oceanographic conditions, focusing mainly on the El Niño event, and its effects on commercially important fishery resources in Peru.

1. **Evolution of El Niño in the South Eastern Tropical Pacific and perspectives until the austral summer 2024**

Current conditions in the Tropical Pacific exhibit the development of El Niño. By the first week of September 2023, sea surface temperature anomalies (SSTA) in the far South Eastern Tropical Pacific (SETP) range from +1 °C to +4 °C on average, with the peak values off Northern Peru and Ecuador (Niño 1+2 region), and the lower ones off Southern Peru and Northern Chile. A 'warm tongue' of anomalies extends westwards in the Equatorial band, reaching average values between +1 and +2 °C in the Central Equatorial Pacific (Niño 3.4 region) (Figure 1).

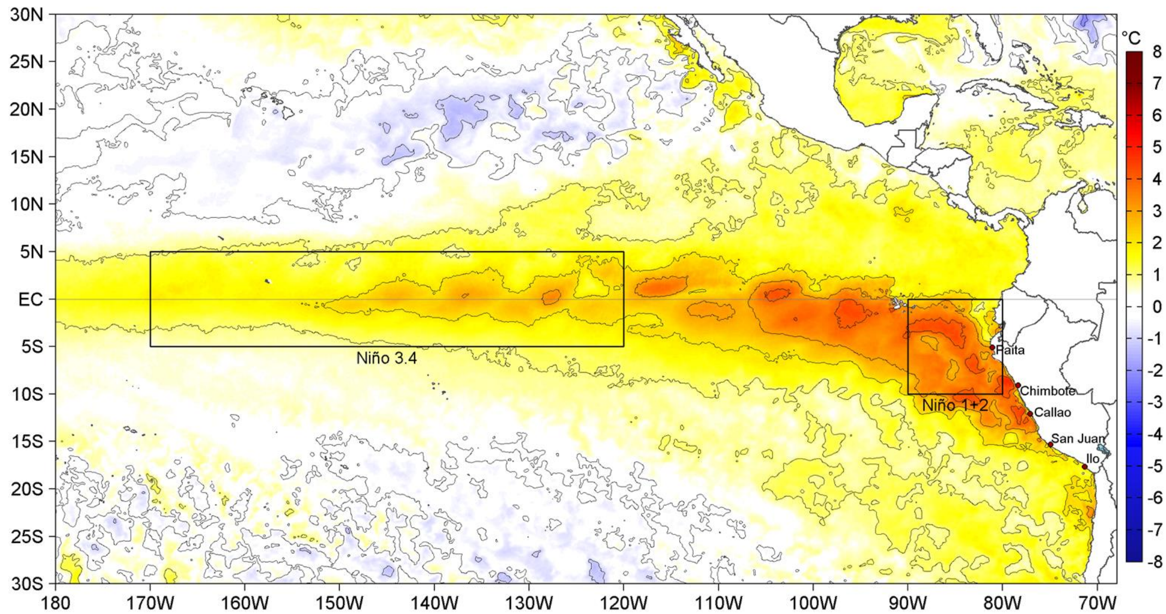

Figure 1. Sea Surface temperature anomaly for the week from September 03 to September 09, 2023.Data source: OSTIA-UKMO-L4-GLOB-v2.0 (UK Met Office, 2012; Donlon et al, 2012); https://podaac.jpl.nasa.gov/dataset/OSTIA-UKMO-L4-GLOB-v2.0. Reference period: 1991 – 2020.

1.1 *Evolution of the sea surface temperature anomalies*

The development of anomalous warm conditions was rapid in the Niño 1+2 region and along the Northern Peruvian coastal band. Previously, according to the Oceanic Niño Index (Bamston et al., 1997; L'Hereux, 2014), since late 2020 until January 2023, La Niña conditions prevailed in the central Equatorial Pacific. In the South Eastern Equatorial Pacific (or Niño 1+2 region) neutral to La Niña conditions alternated in the same period. According to the 'Coastal' El Niño index (the 3-month running mean of monthly Sea Surface Temperature anomaly- SSTA in the Niño 1+2 region) and its thresholds (ENFEN, 2012), there was a transition from La Niña conditions to neutral conditions in the Niño 1+2 region from November 2022 to January 2023. For the Peruvian Chicama coastal station (08° S), the transition from cold to neutral conditions, as based as on the 3-month running mean SSTA anomalies occurred earlier (July to September 2022), but the onset of the warm, coastal El Niño conditions was in February 2023, similar as in the Niño 1+2 region (Figure 2).

From February to April 2023, the Chicama SSTA index climbed from +1.6 °C to + 4.9 °C, while in the Niño 1+2 region the ICEN increased from +0.4 °C to + 2.2 °C. By May, the Peruvian Commission for the study of El Niño Phenomenon – ENFEN predicted the Coastal El Niño would continue until at least austral spring (ENFEN, 2023). In the same period, in the Central Pacific, ONI only increased from -0.2 °C to +0.1 °C (Figure 2). Later on, the extreme warming nearshore at Chicama stabilized and then slightly weakened to +4.1 °C in July, while ICEN continued to increase, reaching +2.94 °C, and ONI increased to +1.1 °C by the same month. These trends (downward nearshore and upward in the Niño regions) continued in August 2023, based on the monthly SSTA anomalies of Chicama (+3.8 °C, IMARPE), Niño 1+2 (3.3 °C) and Niño 3.4 (+1.3 °C) (ERSST v5, NOAA).

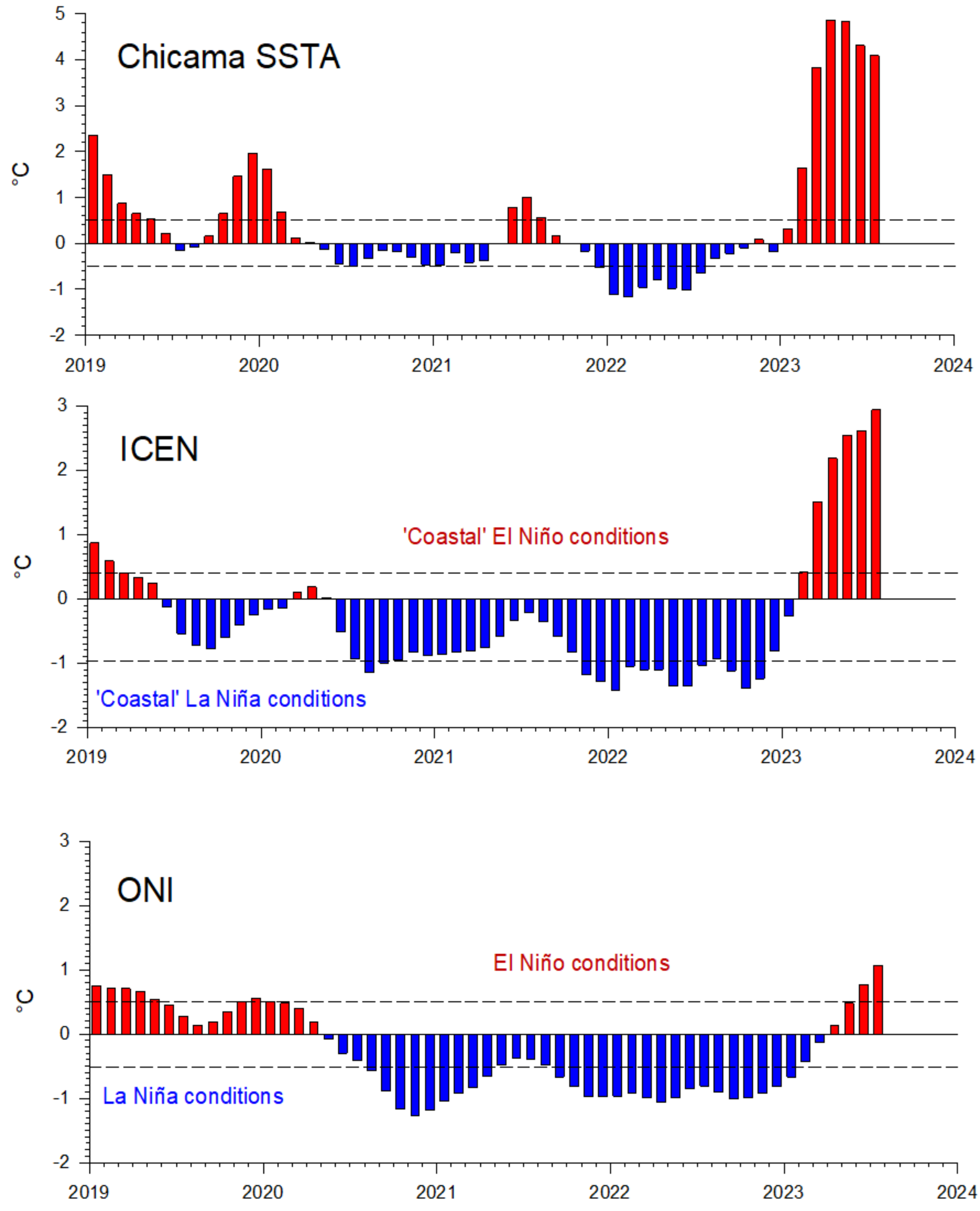

Figure 2. Time series of the Chicama SSTA (3-month running mean), ICEN (3-month running mean of the Niño 1+2 Region SSTA), and time-series of ONI (3-month running mean of SSTA in the Niño 3.4 region) since 2019. The dashed lines in the ICEN and ONI panel depict the thresholds for El Niño and La Niña conditions, as defined by Takahashi et al. (2014) and L´Heureux (2014), respectively. For the Chicama SSTA record dashed lines depict the +/-0.5 °C anomaly.

1.2. Dynamics of the coastal El Niño evolution

The driving factors of the coastal El Niño conditions were both remote and local. A downwelling Kelvin wave arrived to the far Eastern Equatorial Pacific in January 2023 that warmed the subsurface waters but had little impact on the negative thermal anomalies of the surface waters. Off Northern Peru, during February a rapid surface warming was observed in the top 25 m. On the second half of the month a new downwelling Kelvin wave arrived, deepening the thermocline from 20 to 50 m and amplifying the positive subsurface anomalies (> 250 m) (Figures 3, 4). However, the rapid surface warming was related to unusual changes in the atmospheric circulation. In fact, on average during February, the Southeast trades off Peru and the northerly Panama jet were weaker and stronger than normal (Figure 3), respectively, likely contributing to enhance the thermal stratification on one side, and/or to advect the warm Equatorial Surface Waters to Northern Peru, on the other. By the end of February and first two weeks of March, a divergent phase of the Madden-Julian Oscillation (MJO) (ENFEN, 2023a) arrived to the far Eastern Tropical Pacific, driving strong anomalies of the local and regional atmospheric circulation. West and Northwest wind anomalies were recorded in the region, further amplifying the warming intensity in the upper layer (< 50 m) off Northern Peru that reached anomalies up to +6 °C. Furthermore, a train of downwelling Kelvin waves arrived from March to May, deepening the anomalously warm temperatures down to 500 m of water depth (Figures 2, 4).

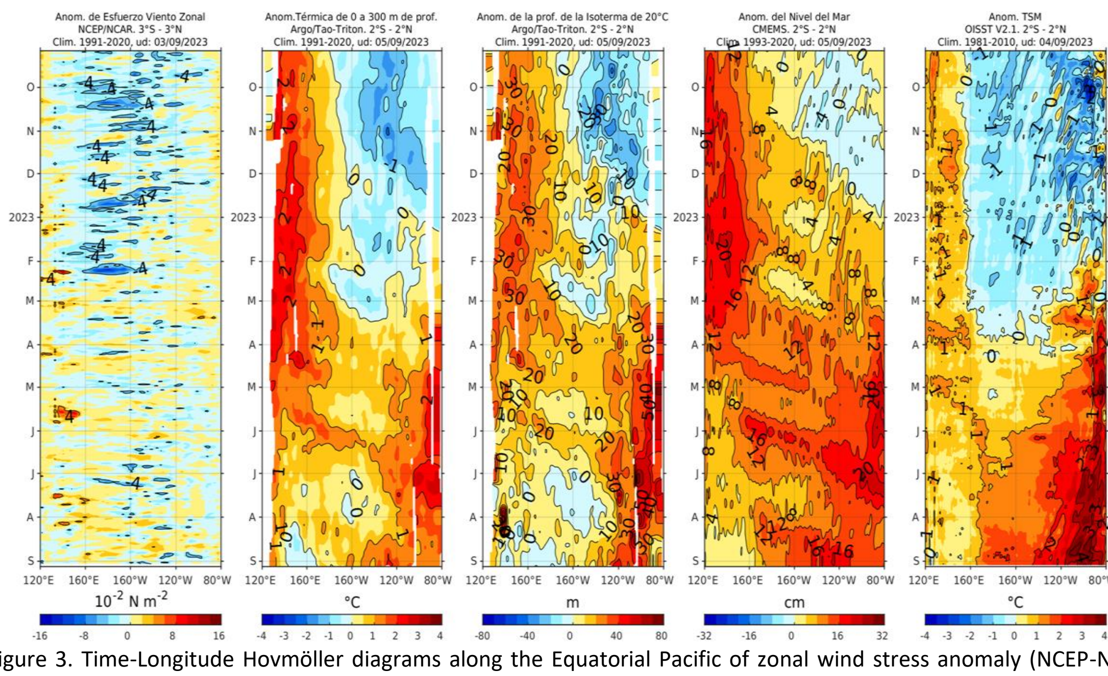

Figure 3. Time-Longitude Hovmöller diagrams along the Equatorial Pacific of zonal wind stress anomaly (NCEP-NCAR), integrated thermal anomaly (Argo+TAO-TRITON, 0 – 300 m), 20 °C isotherm depth anomaly (Argo+TAO-TRITON), sea level anomaly (CMEMS), and SST anomaly (OISST v2.1). The latitudinal range is 2° S – 2°N, with the exception of zonal wind stress (3° S – 3°N).

A tracking of the evolution of the SST warming in the SETP indicates that the warming behaves as a Marine Heat Wave (MHW; Hobday et al., 2016). It is remarkable that the MHW first developed in the oceanic region, and just by the end of February it expanded into the 150 nautical miles – band along the Peruvian coast, and particularly off its central and northern areas, in which the MHW attained its highest intensity by April 2023 (Figure 5). Oceanic warming was observed before the onset of the 2017 Coastal El Niño (Takahashi et al., 2018) as well, though in that event those warm waters followed anomalous weak Southeast trades that were detected since the 2016 austral spring (Echevin et al., 2018).

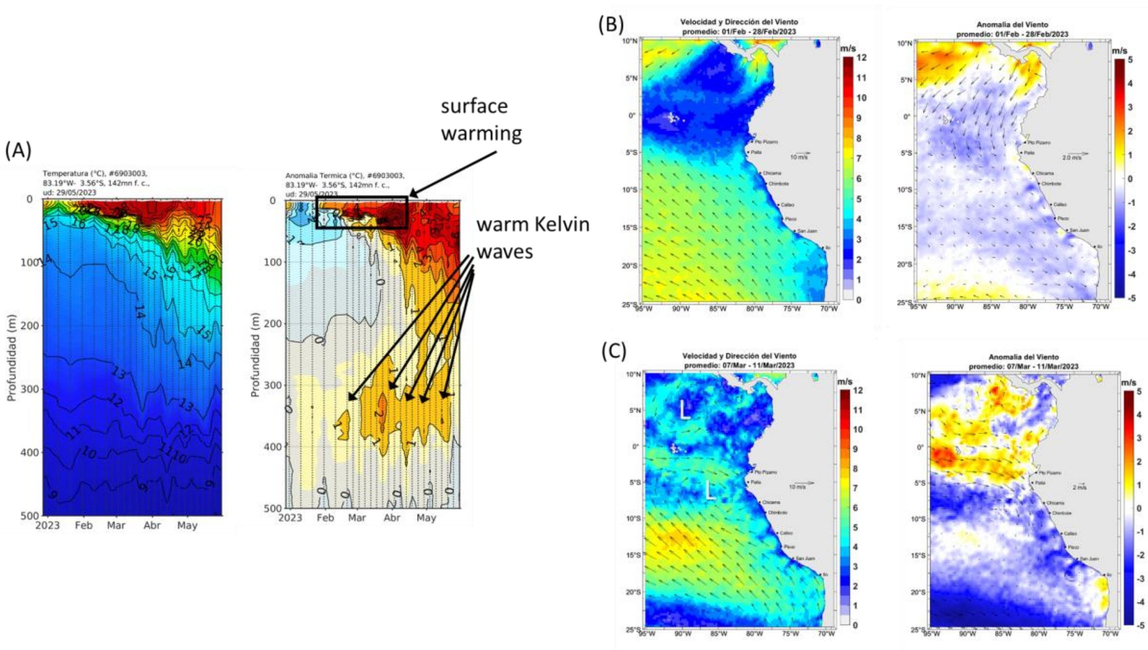

Figure 4. A) Time-depth Hövmoller diagram of the early evolution of the wáter column warming and signature of downwelling Kelvin waves off Northern Peru, as recorded by an Argo buoy located ca. 4° S, 140 nautical miles off the coast. B) Average wind field (intensity and direction) in the far Eastern Tropical Pacific and its anomalies (February 2023); C) Average wind field (intensity and direction) in the same region from March 07 to March 11, 2023. Low pressure, cyclonic cells (L), driving surface westerly winds are depicted.

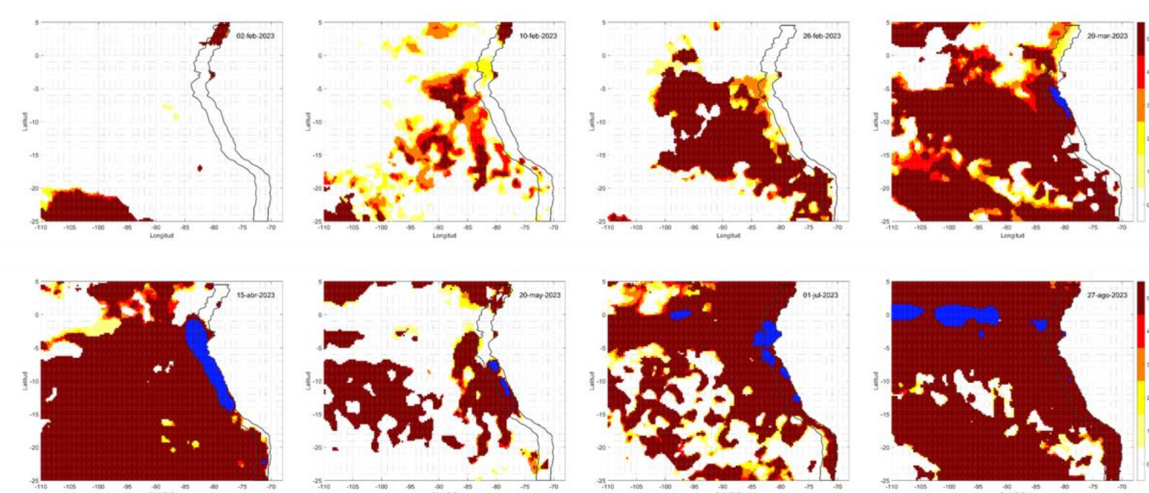

Figure 5. Evolution of the marine heat wave (MHW) in the South Eastern Tropical Pacific, associated with the development of El Niño conditions (February – August 2023). Color bar indicates the number of days in which the SST surpassed the 90th percentile of the historic records in a given day; when this occurs during at least 5 consecutive days (brown), a MHW is present (Hobday et al., 2016). Blue areas indicate the SST anomaly is more than +4 °C.

1.3. Water mass changes and other oceanographic manifestations off the Peruvian coast

During January, the 60 nm band along most of the Peruvian coast was occupied by upwelling waters with SSTs below 20 °C and negative SST anomalies of 1-2 °C; at 300 nm offshore SSTs varied from 23 to 25 °C on average. By February the 20 °C band has almost disappeared and in general SSTs increased in 2 to 3 °C. Warming continued until April in the Northern and Central areas, and maximal values over 28 °C were recorded, giving rise to SST anomalies up to +7 °C in the 60 nm band at 5-6 °S. Even though SSTs decreased afterwards following its annual cycle, SST anomalies over +4 °C were still recorded until mid-August in the 60 nm band, decreasing to +3 °C by the end of the month (Figure 6). Off Chicama, the anomalous subsurface warming over +1 °C rapidly expanded in March, and in April the layer with temperature anomalies of >+1 °C occupied the top 500 m; afterwards it shoaled to 150 m in May and June, deepened to 350 m in July, and shoaled again to 200 m by the end of August (Figure 7). Further south, off Callao (12 °S), this layer reached 150 m in July and August within 80 nm (SF 1).

Salinity variations indicated significant changes in the distribution of water masses (Zuta & Guillén; 1970; Fiedler & Talley, 2006) (Figure 8). An unusual southward intrusion of Equatorial Surface Waters (ESW; $34 < S < 34.8$) was detected from mid-February through May that reached the oceanic area (~200 nm) off Callao (12 °S, central Peru). Tropical Surface Waters (TSW; $S < 34$) also anomalously intruded southward in March and April, when they were detected at 5 -6 °S by Argo buoys (Figure 8). In June, a strong eastward projection of Subtropical Surface Waters (SSW; $S > 35,1$) was detected, occupying down to 150 m of the water column. The switch was more evident in the north, where mixing with ESW took place in the surface and SSW clearly occupied the subsurface layer. Pockets of ESW remained, mostly in the oceanic central zone, undergoing mixing with SSW in July and finally disappearing in August (Figures 8, 9).

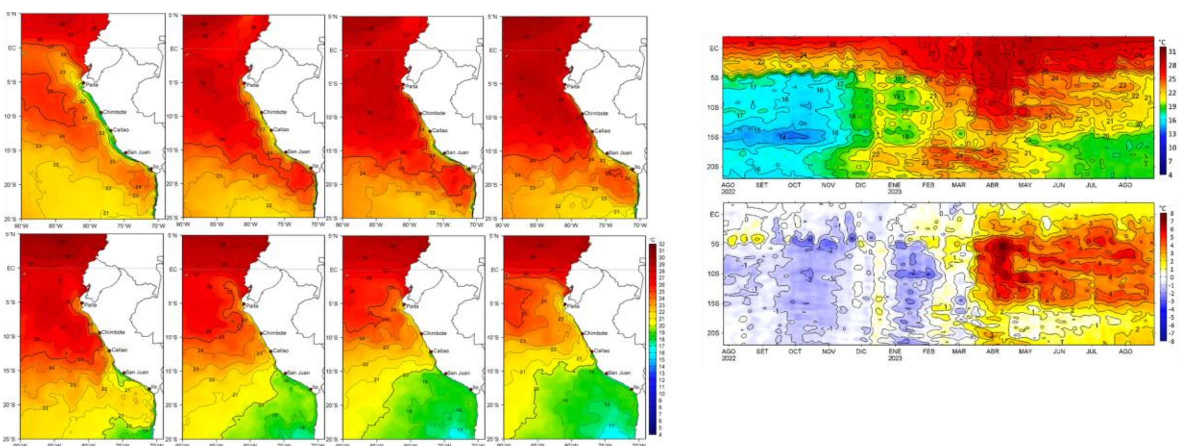

Figure 6. Sea Surface Temperature (SST; OSTIA-UKMO-L4-GLOB-v2.0) off Peru. Left. Monthly mean maps of distribution (January – August 2023). Right: Time-latitude Hovmöller diagrams of SST and SST anomaly in the 60 nm coastal band from Ecuador to Northern Chile (reference period of the climatology: 1991 – 2020).

Deepening of the oxygen minimum zone (OMZ, dissolved oxygen concentration < 0.5 mL L^{-1}) followed the changes of the thermal structure and water masses. Off Chicama, in mid-February, the OMZ upper boundary was located at 20 -30 m of water depth. It deepened to 150 m during March and reached 220 m in April. It shoaled to 170 m in May and June, and then deepened slightly down to about 200 m in July and August (Figure 7). Off Callao, OMZ deepening was recorded down to 100 m in July and August, coinciding with the intrusion of SSW (SF 1).

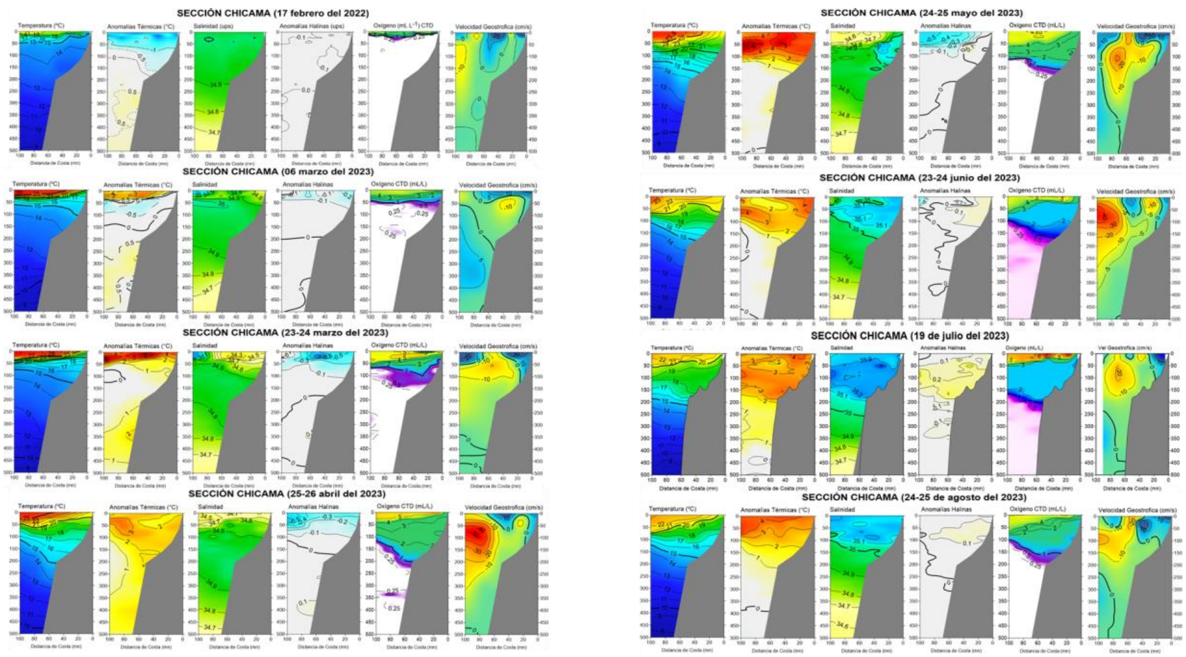

Figure 7. Oceanographic sections off Chicama (08° S) within 100 nautical miles, including temperature, temperature anomaly, salinity, salinity anomaly, dissolved oxygen and geostrophic flows. Base period for climatology: 1991 – 2020 (Domínguez et al., 2023).

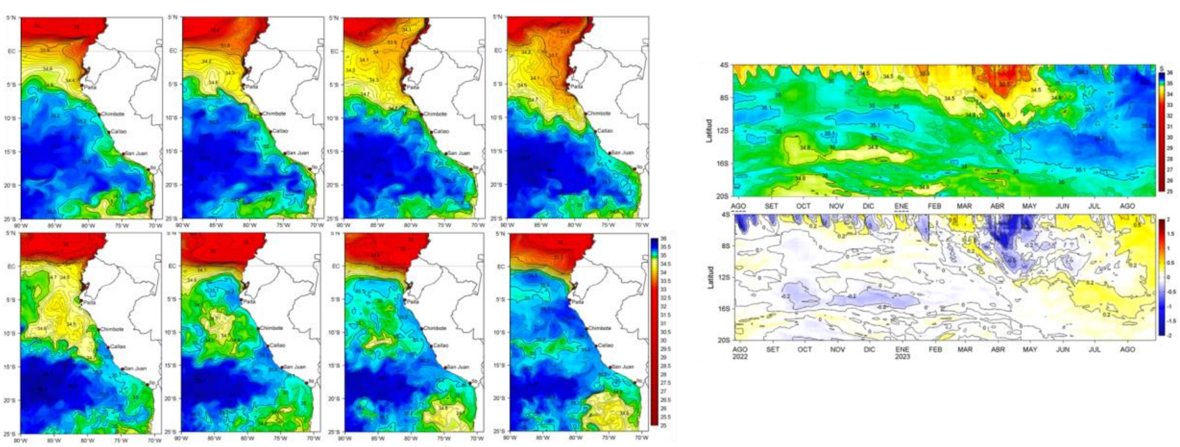

Figure 8. Sea Surface Salinity (SSS) from the MERCATOR model. Left. Monthly mean maps of distribution (January – August 2023). Right: Time-latitude Hovmöller diagrams of SSS and SSS anomaly in the 60 nm coastal band from Northern Peru to Northern Chile (reference period of the climatology: 1993 – 2015).

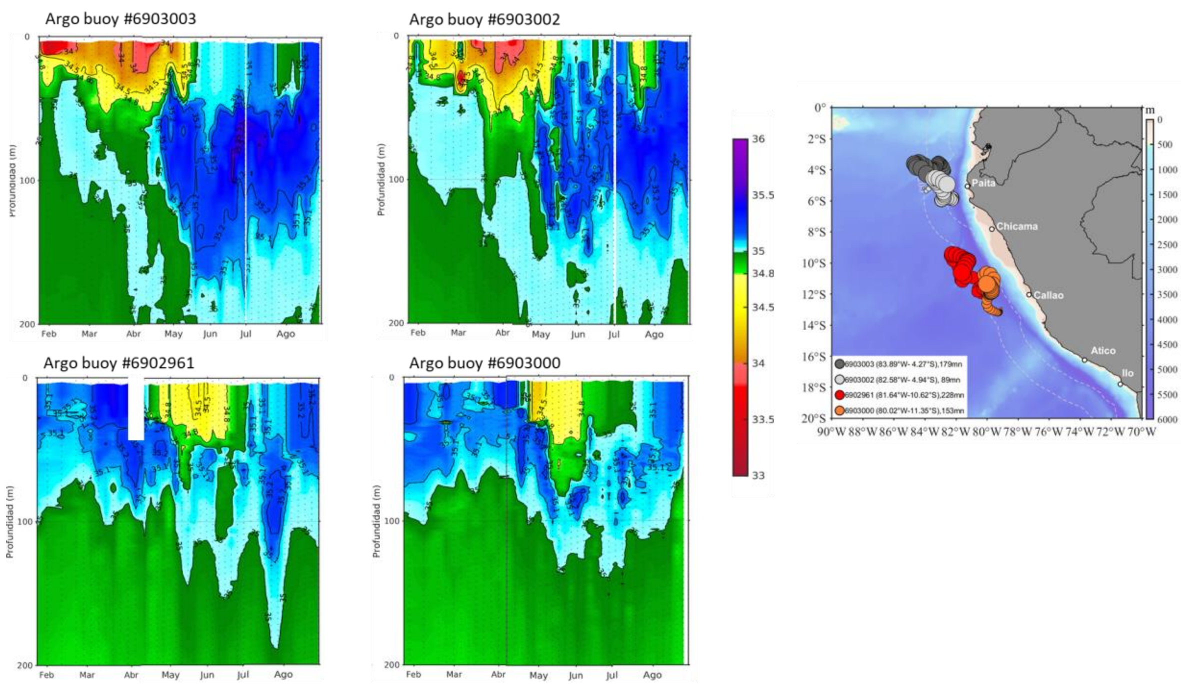

Figure 9. Time-depth Hovmöller diagrams of salinity changes offshore Northern and Central Peru, from January to August 2023, as recorded by Argo floats. Map shows the positions during the recorded period.

1.4 Comparison with past events

Off Northern Peru, warming evolution since the onset of the current event has been more intense and persistent than the first phase of the 2015-2016 El Niño (from April to September 2015; Figure 8). Peak temperature anomalies have been larger and the deepening of the 16 °C isotherm was more persistent throughout the current period. Another remarkable contrast of the current El Niño with the 2015-16 El Niño is the differential warming between the Niño 1+2 region relative to the one in the Niño 3.4 region (Figure 9). While the subsurface temperature anomalies (0- 70 m) in the Niño 1+2 region have been larger in 2023 (up to +4.6 °C) than in the 2015-2016 El Niño for the same period since onset, the anomalies in the Niño 3.4 region (0 – 300 m) were larger (up to +1.5 °C) in the 2015-2016 El Niño than during the current event (up to +0.8 °C; Figure 10). Moreover, while the onset of warm subsurface anomalies were earlier in the Niño 3.4 region in 2015, they were the opposite in the current event.

In fact, the delayed and weaker warming in the Central Pacific relative to the SETP during austral autumn, as in the current event, is a pattern of the Canonical El Niño (Rasmusson & Carpenter, 1982), while a stronger warming in the following austral spring-summer characterizes the Modoki El Niños (Takahashi et al., 2011; Takahashi, 2014a), as it occurred in the 2015-2016 El Niño.

The current El Niño can be compared with the six events since the 1950s in which strong El Niño conditions were recorded in the Niño 1+2 region, according to ICEN thresholds (ENFEN, 2012): 1957-1958, 1972-1973, 1982-1983, 1991-1992, 1997-1998 and 2015-2016 (Figure 11). All of these events had their onset in austral autumn, ending by austral autumn to austral winter of the second year.

The Multivariate ENSO Index (MEI) (Wolter & Timlin, 2011; Zhang et al., 2019) is still in the neutral range by June-July 2023, even though it has exhibited an upward trend for the past 14 months. In contrast, all the above mentioned six events showed higher MEI values by July-August and were above the threshold to El Niño conditions by May-June. Furthermore, the MEI values in 2022 were more negative than any of the past six events the year before the onset, indicating stronger La Niña conditions. As well, the Equatorial Southern Oscillation Index (Lindsey, 2009; https://www.cpc.ncep.noaa.gov/data/indices/reqsoi.for) exhibited stronger La Niña conditions in 2022 than in the year before El Niño in any of the other events, though its last value is only less negative than 1997 JJA and 2015 JJA. A regional atmospheric index, the South Pacific High Intensity Index (Quispe-Ccallauri et al., 2017), also showed stronger La Niña- favorable conditions in 2022, but it rapidly diminished by 2022 austral spring to neutral conditions in which it stayed until 2023 austral autumn. Finally, it dropped abruptly to more negative values, and its last magnitude is smaller than JJA 1982, JJA 1997 and JJA 2015.

The evolution of ONI resembles the one of MEI; very negative values in 2022, and the 2023 JJA ONI is only higher than the ones in 1982 and 1991. In contrast, even though ICEN was also very negative during most of 2022, it started to rise by the end of the year reaching record values throughout the austral autumn; by 2023 JJA ICEN is only lower than the one in 1997 JJA. The Chicama SSTA index showed negative to neutral values in 2022, similar to the average conditions in the year before the onset of coastal El Niño in the other cases. Its evolution resembled ICEN, as compared with previous events. Remarkably, in four of the six El Niños (1957-1958, 1972-1973, 1997-1998 and 2015-2016), both in ICEN and in the Chicama SSTA index, the first warming peak was recorded in austral autumn to winter and a secondary warming peak was detected by the end of the year or in summer the following year. However, while the secondary ICEN peak was lower or similar as the first peak, the second Chicama SST index peak was more intense or as intense as the first peak. The second SSTA index peak was also higher than the first one in the 1982-1983 El Niño, which had its onset just in austral winter.

Taken together, the past records suggest that when strong coastal El Niño conditions occurs, coupled to the development of warm ENSO events, it is likely that a secondary warming anomaly takes place in the Niño 1+2 region but particularly nearshore off Peru by late austral spring or austral summer, which could have strong impacts in marine productivity and habitat suitability for upwelling flora and fauna.

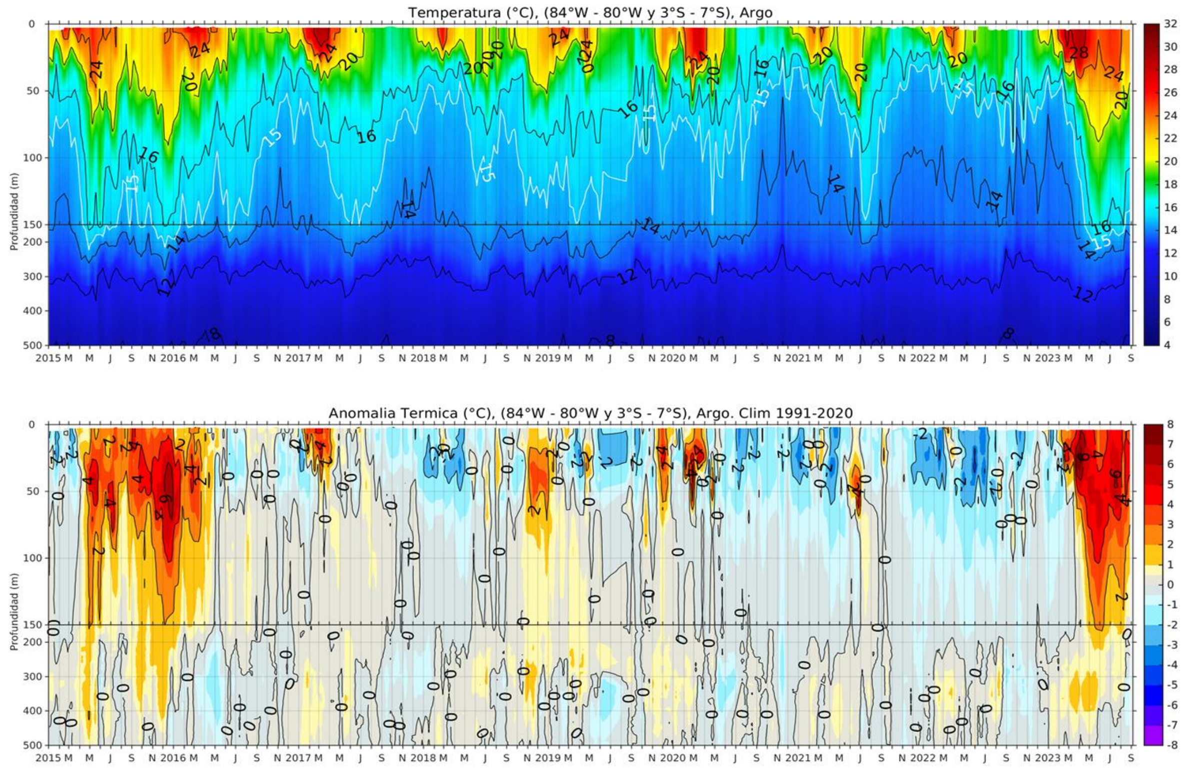

Figure 10. Time-depth Hovmöller diagrams of temperature and temperature anomaly in the upper 500 m since 2015, as recorded by Argo floats off Northern Peru (84° W – 80° W, 3° S – 7°S).

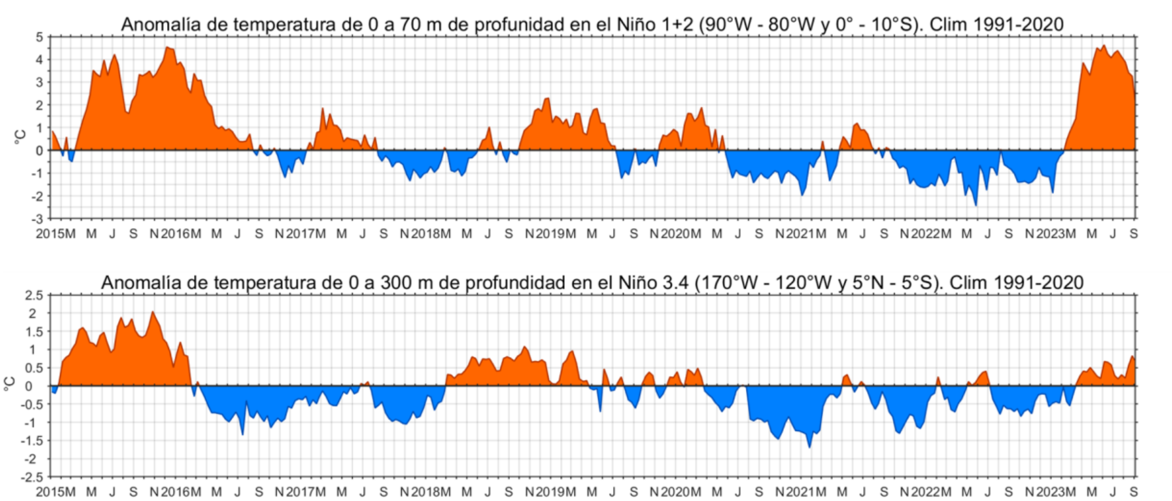

Figure 11. Comparison of the time series of the temperature anomaly in the upper 70 m of the Niño 1+2 región and in the upper 300 m of the El Niño 3-4 región since 2015, as recorded by Argo floats.

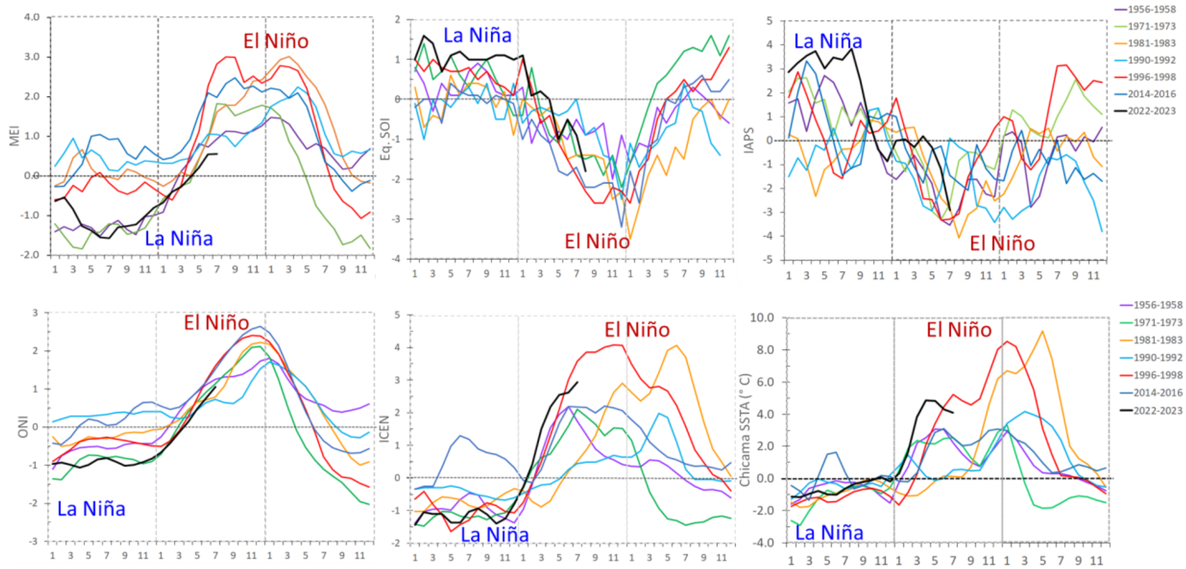

Figure 12. Comparison of the evolution of selected strong el Niños in the South Eastern tropical Pacific (year 0, year 1 and year 2). Top: atmospheric índices (Multivariate ENSO Index - MEI; Equatorial Southern Oscillation Index – Eq. SOI; South Pacific High Intensity Index – IAPS). Bottom: SST anomaly índices (Oceanic Niño Index – ONI; 'Coastal' El Niño Index – ICEN; Chicama SSTA (3-month running mean). ONI and ICEN are based on ERSST v5 1991-2020 climatology, while a long-term climatology (1925 – 2022) is used for Chicama SSTA (source: IMARPE). MEI values after 2018 were estimated from the regression between MEI (Wolter & Timlin, 2011) and MEI v2 (Zhang et al., 2019) in the overlap period 1979 – 2018.

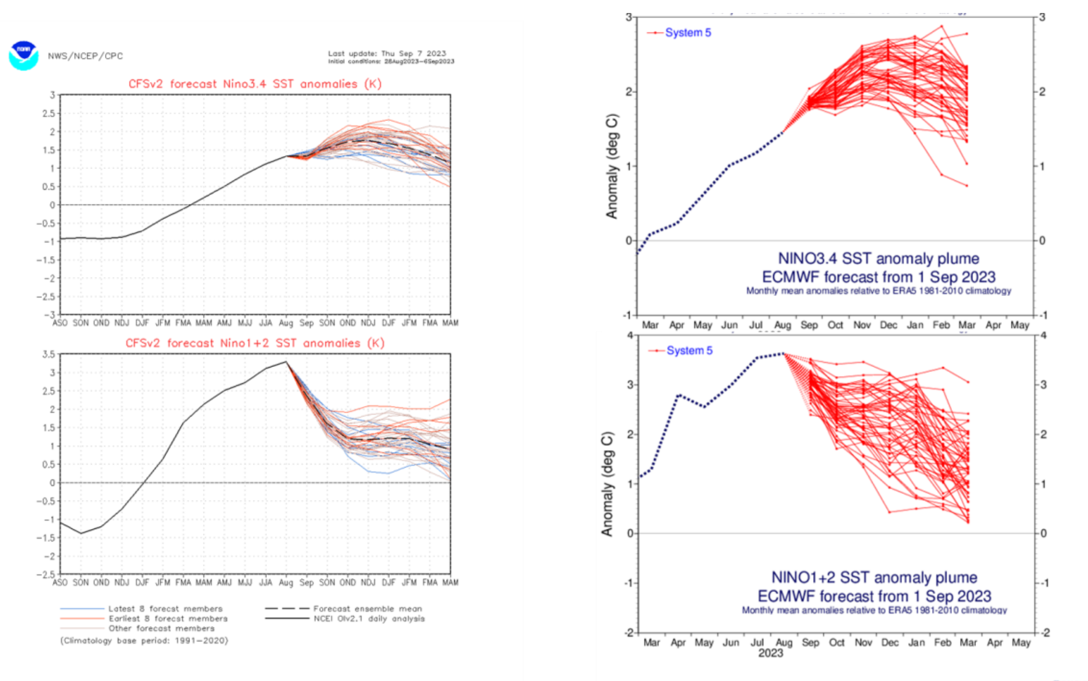

Figure 13. Plumes of SSTA forecasts for the Niño 3.4 region and the Niño 1+2 region by the NCEP Climate Forecast System Version 2 model (CFS v2) with initial conditions from August 28 – September 6, 2023 (left), and by the European Centre for Medium-Range Weather Forecasts (ECMWF) model, with initial conditions from September 1, 2023. CFS v2 forecast extends up to MAM 2024; ECMWF forecast extends up to March 2024.

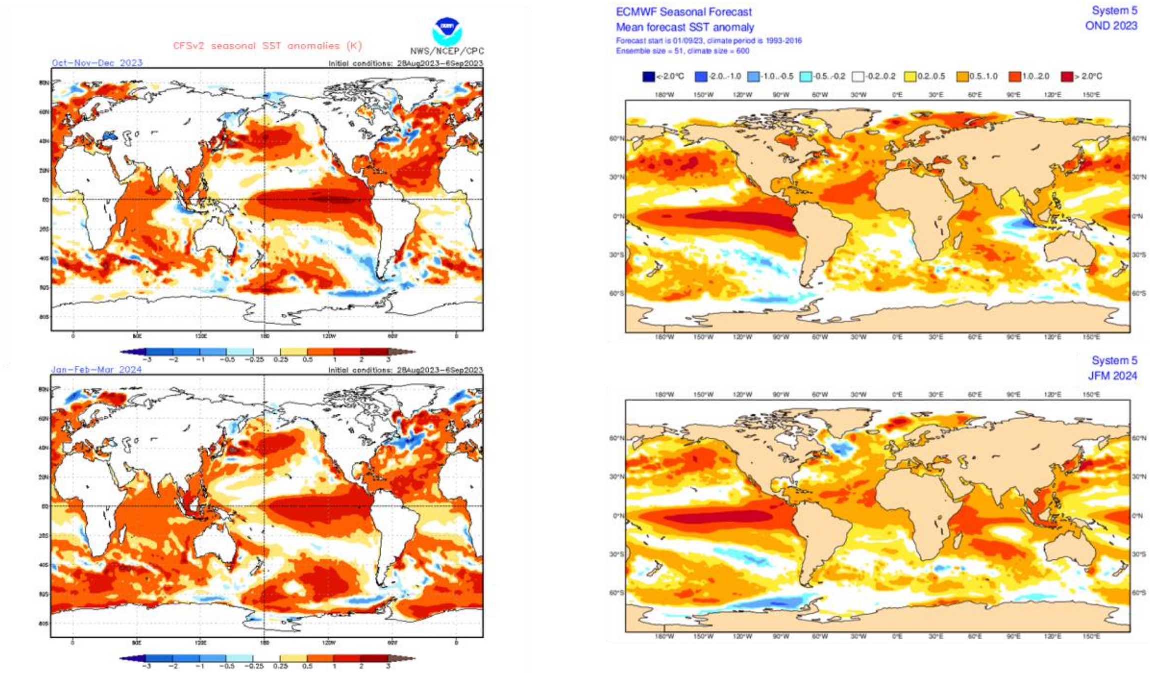

Figure 14. Global seasonal forecast maps of SSTA for OND 2023 and JFM 2024. Left: forecasts from the NCEP Climate Forecast System Version 2 model (CFS v2) with initial conditions from August 28 – September 6, 2023; right: forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF) model, with initial conditions from September 1, 2023.

1.5 Perspectives for the austral summer 2024

Forecasts of international agencies have been just issued based on climate models with initial conditions in early September (Figure 12). Both the NCEP Climate Forecast System Version 2 model (CFS v2) and the European Centre for Medium-Range Weather Forecasts (ECMWF) model predict El Niño will attain its peak intensity in the Central Pacific (Niño 3.4) by the end of the year (+1.5 °C and ≥+2 °C, respectively). They also predict El Niño will lose strength in the Niño 1+2 region and ETSP in the following months. The CFS v2 model predicts the end of El Niño by autumn 2024. CFS v2 and ECMWF differ on the relative intensity of anomalies in the Niño 1+2 region relative to the Niño 3.4 region, particularly for OND, because ECMWF predicts, on average, anomalies of +2 °C for the Niño 1+2 region and Northern to Central Peru, while CFS v2 predicts average anomalies between +1 °C and +2 °C in the same areas. By summer 2024, in the Niño 1+2 region and off Northern to Central Peru, CFS v2 predicts anomalies between +0.5 °C to +2 °C, while ECMWF, between +1 °C and +2 °C. In any case, forecasts are consistent with a Canonical El Niño evolution for the following months. However, local and regional ocean-atmosphere dynamics off Ecuador and Northern Peru that can lead to a secondary warming peak and/or more MHWs are probably not foreseen by the international models. Thus the international forecasts should be taken with caution. Intensified monitoring and regional simulations are urgently needed in order to improve the accuracy of El Niño forecasts in the region.

2. El Niño effects on fishery commercial species and the fisheries management in Perú

As mentioned, El Niño generates strong changes in the oceanographic and climate conditions on Peruvian waters. The planktonic productivity is altered, causing antagonistic reactions in fishery species due to the modification of their distribution patterns. Also, alteration of some physiological processes occurs, such as growth and reproduction, which have repercussions on the development of fisheries and other socioeconomic aspects of the country (Rojas de Mendiola et al., 1985).

This type of event generates stress in some pelagic fish populations such as the Peruvian anchovy (*Engraulis ringens*), with high aggregation areas towards the coast, and deepens and migrates southwards (Ñiquen & Bouchon, 2004; Ñiquen et al., 1999; Zuzunaga, 1985). During coastal El Niño 2023 between April and May 2023, the anchovy retreated towards the coast within 10 nautical miles and deepened up to 190 m, causing mortality due to lack of food for its predators such as guano birds, sea lions and other mammals. Another important species like the Peruvian hake *Merluccius gayi peruanus*, deepens and disperses during these events, expanding its distribution area due to the increase in bottom oxygen concentrations (Arntz & Valdivia, 1985). During 2023, Peruvian hake landings decreased due to its southward migration, reducing its availability. Likewise, jumbo flying squid landings are negatively affected related to the intensity and durability of these events.

The presence of oceanic waters on the coast was reflected in the increased availability of tropical species such as tuna *Thunnus* sp., frigate tuna *Auxis* sp., skipjack tuna *Katsuwonus pelamis*, pacific sierra *Scomberomorus* sp. and billfishes. Within this particular scenario, where the coastal El Niño and canonical El Niño events converge, characterized by the presence of SSW and ESW within the Peruvian jurisdictional waters, the availability of tranzonal resources such as Jack Mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*) is favored within 200 nm.

In this context of oceanographic and biological-fishery changes, the management of fishing activities in Peru becomes a complex task. IMARPE bases its recommendations for sustainable fisheries management on scientific information obtained through its continuous national research programs on Peruvian waters. In that sense, IMARPE noted the importance of having management strategies (Espino and Yamashiro 1996) using an "adaptive management" (Defeo, 2015; Bahri, et al., 2021), which incorporates some elements of the ecosystem approach, allowing stability in the development of the fishery and ensuring the sustainability of fishery resources over time and influencing their impact in the short-term as well as in the long-term (Bouchon 2018). Therefore, IMARPE provides recommendations to the Ministry of Production (PRODUCE), to make fundamental decisions for the management, protection and sustainability of resources, and to mitigate the effects that these events could cause in the production chain, including fishermen and workers linked to the activities of Indirect and Direct Human Consumption, which represent the direct and indirect work of more than one million people.

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