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Pulsations of the Azores anticyclone at intra-seasonal scale : how oceanic waves and coastal wind anomalies combine constructively to force the variability of the north-eastern boundary upwelling system in winter-spring

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1. Abstract

The Azores anticyclone shows a strong intra-seasonal variability that, transmitted to the whole North Atlantic by the Trade Wind, generates a multi-factor variability of the Canary Islands eastern edge upwelling system. In this work, we study the cold season (March to May), using satellite observations and numerical simulation, and how the variability of the wind at the equator, the Kelvin and coastal waves, and the local wind along the North West African coast combine to force the variability of the upwelling. Composite analyses show how, in 80% of the cases, the pulsations of the 40 days high excite equatorial waves that arrive in the Senegalese upwelling 15 days later, precisely at the time of the phase change of coastal wind anomalies. These waves trapped at the coast, from upwelling or downwelling, thus reinforce the local wind anomaly. The intra-seasonal variability of the SST is thus the result of a double local and remote effect, whose respective contributions we quantify.

2. Data and Methods

Data:

Satellite:

SLA OSTM/JASON-2 and SST OISST NOAA for a period of 1993-2018 with a spatial resolution of 0.25° and daily temporal resolution.

Reanalysis:

SLP ERA 5 and Wind ERA 5 for a period of 1993-2018 with a spatial resolution of 0.25° and daily temporal resolution.

Methodology:

- Implementation of tracks and Study Zone
- Application of an intra-seasonal tape filter: retain periods between 20 and 90 days
- Composite waves: average of a large number of events impacting the Senegalese upwelling.
- Coefficients that vary between 0.1 and 0.5 °C/cm in the S-M upwelling system.
- Strong regression coefficients => strong link between SST & SLA about 0.5 °C/cm

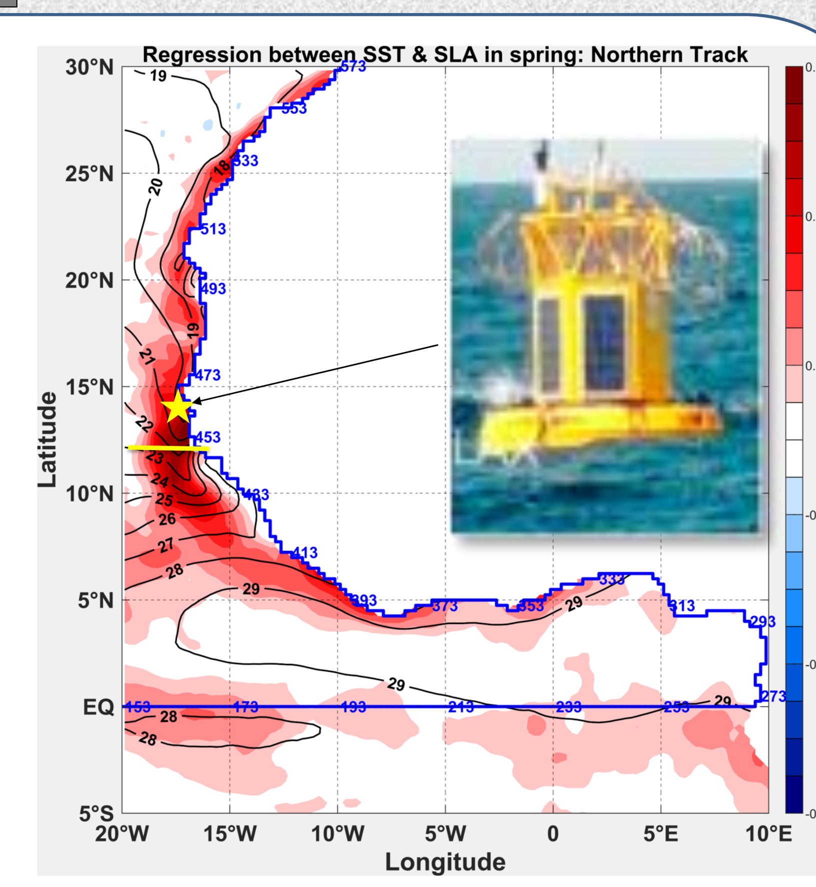


Figure 1 : March-April-May regression map of the SST on the SLA for the period 1993-2018 and represents our study area. The blue line materializes the path followed by the Kelvin waves along the equator and the northern West African coast. The black contours, represent the climatology of the SST. The yellow image is the MELAX buoy represented by the yellow star. The line yellow represents the latitude 12°N.

3. Results

3.1. Identification of intra-seasonal Kelvin waves in MAM along the North Track

Figure 2 shows the intra-seasonal sea level variability (SLA) for the March-April-May (MAM) period from 1993-2005 (left panel) and 2006-2018 (right panel) along the northern track. Indeed, to identify the intra-seasonal Kelvin wave propagations along the Equatorial Atlantic and the North West African coast over the period 1993-2018 during the spring season, we plotted the hovmûller diagram of the SLA intra-seasonal variability.

Many signals similar to the Kelvin wave propagation appear clearly from the equator, along the Gulf of Guinea and the northern West African coast. The hovmûllers diagrams for the filtered signal show downwelling and upwelling wave propagations observed all year round for all years for the period 1993-2018 with a period of about 2 months. The continuity of the equatorial Kelvin wave propagating eastward and the coastal propagation is sometimes broken due to the shape of the coast.

Indeed, 80 waves (downwelling + upwelling) have been identified in MAM for the period 1993-2018. The mean absolute value of the SLA signal amplitude is 0.5-3.7 cm at the equator and it is amplified to 3.7-5 cm at the coast.

The variance of the SLA (not shown) is about 2 cm at the equator and increases to 4 cm on the African coast on average, with higher variance at some points along the coastal path.

A visual estimate of the slopes for the continuous signals suggests a steady propagation speed of about 1.8 m/s and varies seasonally: Change in stratification or wind forcing. After the separation of the equatorial Kelvin wave at its arrival on the West African coast, the propagation of the wave towards the North Pole of part of its energy can be observed up to 30°N.

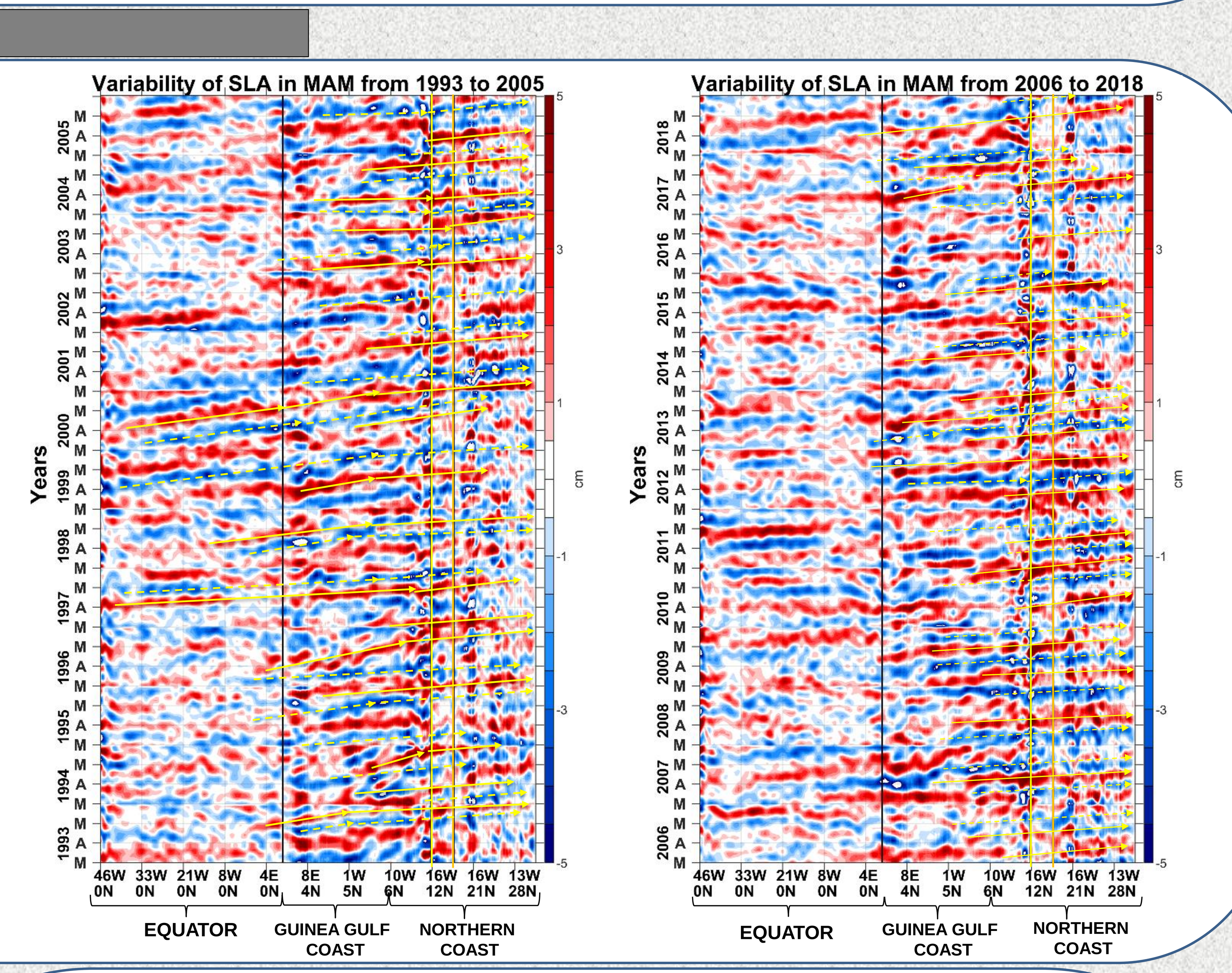
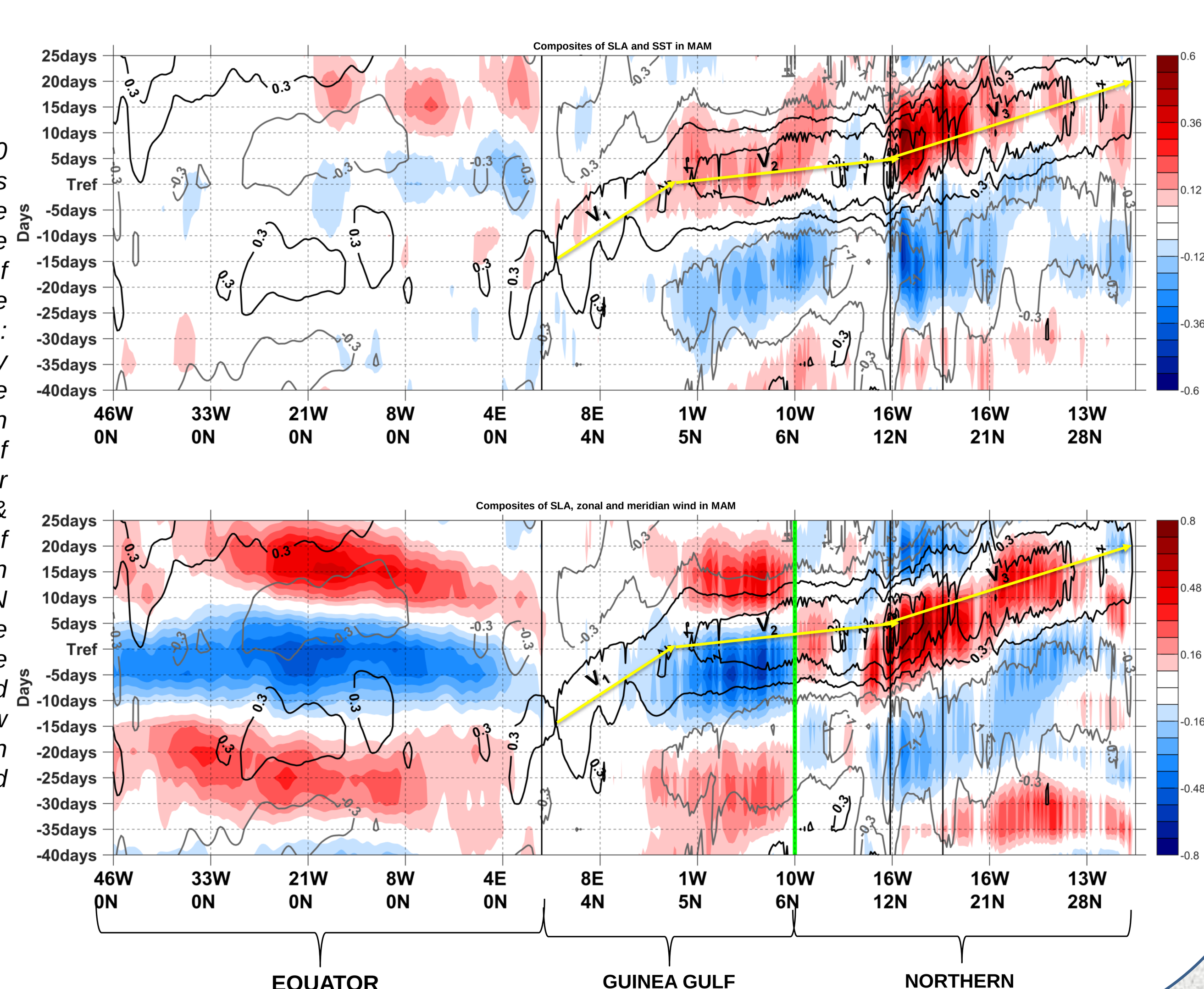


Figure 2: Hovmûller plot of SLA intra-seasonal variability (cm) along the northern path. We concatenated only the months of March, April and May on our time series. The first black line on both panels represents the separation between the equator and the coast. The second yellow line represents 12°N (our recovery benchmark for all waves arriving at this position). The third orange line represents 16 °N. The yellow arrows represent the propagation speed of downwelling and upwelling Kelvin waves.

3.2. Hovmûller of the spring downwelling and upwelling composite

Figure 3 shows that the mean downwelling wave of MAM seems to be generated off the Gulf of Guinea (GG) by a zonal west wind anomaly (west to east) in this area creating a southward Ekman transport and inducing a heating of the ocean surface in the GG. The MAM wave propagates initially at a propagation speed of 1 m/s along the coast of the Gulf of Guinea corresponding to a sea level rise of 2 cm inducing a warming of 0.1 °C, and then at a speed of 5, 5 m/s along the coasts of Liberia, Sierra Leone and Guinea-Bissau and in a third time at a speed of 2.8 m/s along the Senegalese-Mauritanian coast for an amplitude of 2.5 cm accompanied by a warming of 0.6 °C. This change in slope may be the result of a change in stratification or by local wind forcing changing the propagation speed. The Senegal-Mauritania front is affected by a positive temperature anomaly of the order of 0.6 °C appearing 5 days after the passage of the wave in the upwelling system and is accompanied by a constructive anomaly of the meridional wind contributing to the attenuation of the effect of the upwelling.

Figure 3: Composite of 80 (downwelling+upwelling) waves along the northern track for the months March-April-May, time steps are 5 days and the Tref corresponds to the arrival of the wave in the 12 and 16°N area. a): the composite of the SLA anomaly in black contour (cm) and the composite of the SST anomaly in color (°C). b): the composite of the zonal wind anomaly in color (plotted between 46°W-0°N & 10°W-6°N) and the composite of the meridional wind anomaly in color (plotted between 10°W-6°N & 13°W-30°N). The green line represents the boundary of the zonal coast (Equator + GG) and the meridional coast. The yellow arrows represent the propagation speed of downwelling and upwelling Kelvin waves.



3.3. Effect of the Azores Anticyclone pulses on the trapped coastal waves arriving in the Canary Islands upwelling in spring at intraseasonal frequencies

Figure 4 shows the map of the composite of the SLA, the SST anomaly and the meridional wind anomaly spatially lagged at one month and ten days (at -25 days) before and +15 days (at +20 days) after the passage of the intra-seasonal Kelvin wave in the Senegalese upwelling system. forcing of the wave at the equator by the zonal wind anomaly with 5 days of offset between the peak of the zonal wind anomaly and the wave. Positive anomalies of the SLP correspond to an anticyclonic circulation => abnormally warm air mass. The Azores anticyclone pulses throughout the basin to the equator with a period of 45 days. It generates an equatorial and then coastal Kelvin wave which reinforces the effect of the local wind.

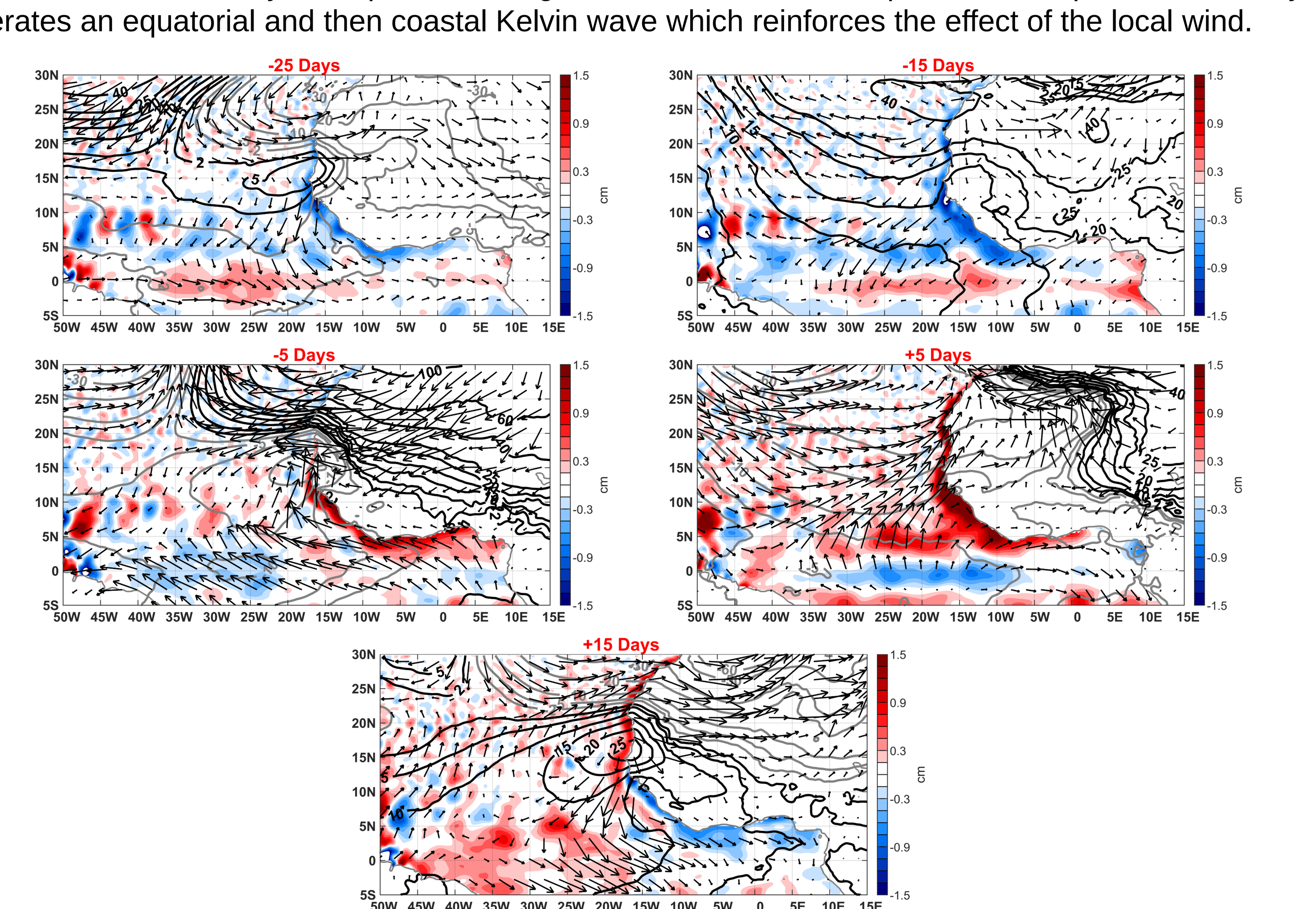


Figure 4 : Spatial map of the composite of sea level anomaly (SLA in color, in cm), surface pressure (SLP in black outline for positive values and gray for negative values, in Pa) and wind (black arrows, in m/s) along the northern track during the spring season.

4. Conclusion

This presentation focused on the intra-seasonal Kelvin waves and their impact on the SST in the Canary Islands upwelling system by performing a composite analysis in spring. This study is done with satellite observation data for Sea Level Anomaly (SLA), NOAA OISST, Sea Level Pressure (SLP), Zonal and Meridian Wind at 10m from ERA5 reanalysis for the period 1993-2018. To study the intra-seasonal coastal Kelvin waves, we filtered the data such as sea surface level, sea surface temperature and finally the zonal and meridional wind over the bandwidth in the period of 20-90 days. In addition, the regression map allowed us to quantify the relationship between SLA and SST during the spring season at wave passage in the upwelling systems and along the northern coast. Indeed, we note a very strong link between SST and SLA in the upwelling areas with regression coefficients between 0.1 and 0.5 °C/cm. However, in the spring composite analysis, our study shows that the SST follows the forcings (wave and wind) with a delay, physically it responds to them with an intensity of 0.5°C for an average wave of 2.5 cm. These waves appear to be generated by a zonal wind anomaly (positive for a downwelling wave and negative for an upwelling wave) persisting for 20 days.

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