Occurrence of Marine Heatwaves along the Northeastern Brazilian coast during 2002 - 2020

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Abstract. *Marine Heatwaves (MHWs) are defined as high-impact events in which the Sea Surface Temperature (SST) stays anomalously high during at least five consecutive days. This events are directly related to mass mortality of organisms, loss of benthic habitat and changes on the biological, economic and political structure. Here we proposed to identify the occurrence of MHWs along the Northeastern Brazilian coast, during 2002-2020. We used MODIS-Aqua/L3SMI products for retrieving the SST, then applied spatial reductions to obtain the temporal series for three major polygons created along the coastline. Time series analysis was carried in order to remove seasonality effects and to identify consecutive extreme events above 98th percentile. The obtained results indicated the presence of eight MHWs between the years 2009, 2010, 2019 and 2020. Ultimately, all these occurrences were classified as strong, severe or extreme events.*

Resumo. *As Ondas de Calor Marinhas (OCMs) são definidas como eventos de alto impacto no qual a Temperatura da Superfície do Mar (TSM) permanece anomalamente alta durante pelo menos cinco dias consecutivos. Esses eventos estão diretamente relacionados à mortalidade em massa desses organismos, perda de habitats bentônicos e mudanças nas estruturas biológica, econômica e política. O presente trabalho apresenta a identificação da ocorrência de OCMs ao longo da costa nordestina do Brasil durante os anos de 2002-2020. Foram extraídas as TSM dos produtos do sensor MODIS-Aqua/L3SMI, aplicando uma redução espacial para obter as séries temporais dos três principais polígonos criados ao longo da costa. As séries temporais foram analisadas para remover os efeitos da sazonalidade e para identificar eventos extremos acima do percentil 98. Os resultados obtidos indicaram a presença de 8 OCMs nos anos de 2009, 2010, 2019 e 2020. Por fim, todas as ocorrências foram classificadas como eventos fortes, severos ou extremos.*

1. Introduction

Extreme weather events of prolonged warming have intensified their effects over the years as a consequence of climate change, causing significant impact on the environment and species in general [Hobday et al. 2018]. Recent studies have reported anomalous seawater warming occurrences known as Marine Heatwaves (MHWs). This phenomenon is categorized by abnormal Sea Surface Temperature (SST) conditions above the historical threshold for at least five consecutive days, being associated with various impacts in marine ecosystems such as increase in coral bleaching patterns [Hughes et al. 2018], mass mortality of organisms and loss of benthic habitat [Oliver et al. 2017].

The MHWs are caused by a range of ocean-atmosphere processes with different spatial and temporal scales observed all around the world [Smale et al. 2019]. One of the first events documented in literature was in the northern Mediterranean Sea [Garrabou et al. 2009], associated with the strong warm conditions over Europe in 2003. Although ocean warming has not been uniform across the planet, there is a tendency for the global average temperature to rise [Collins and Sutherland 2019]. Anomalous SST records already were observed across many parts of the ocean, including the North and South Atlantic Ocean; the western Indian Ocean; and areas of northern, central and southwestern Pacific Ocean [Lindsey and Dahlman 2020]. Recently, MHWs were also spotted along the South Atlantic Ocean and present a threat to our marine biodiversity [Gouvêa et al. 2017, Rodrigues et al. 2019, Duarte et al. 2020]. Here we proposed to identify the occurrence of MHWs along the northeastern Brazilian coast during 2002 - 2020, categorizing their spatial distribution and classifying their intensity.

2. Materials and methods

The study area included the entire length of the northeastern Brazilian coast, which was partitioned into three major regions: (I) North polygon, (II) Central polygon and (III) South polygon (Figure 1). This procedure was performed in order to optimize the detection of MHWs, considering the large spatial extent of the study area and greater processing capability required at pixel level. Daily SST data were obtained from L3 4km MODIS-Aqua product, with a spatial resolution of 4 km and a revisit time of 1-2 days. SST was extracted during 2002 to 2020 considering the spatial average for each delimited polygon. A quick validation procedure was performed in order to verify MODIS/Aqua SST accuracy in relation to in situ observations. Thus, the Root Mean Squared Error (RMSE), Coefficient of determination (R) and Bias were estimated comparing the satellite data and in situ records from PNBOIA buoys.

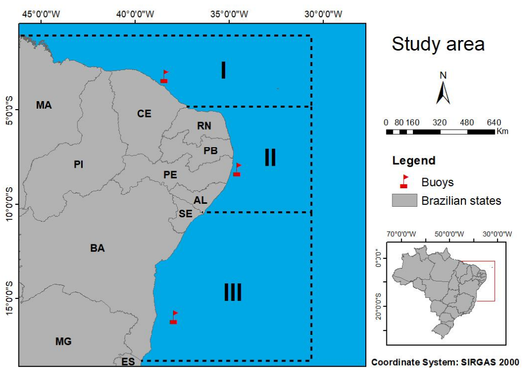

Figure 1. Northeastern Brazilian coast with emphasis on the three delimited polygons (I - North, II - Central and III - South) and geographic location of PNBOIA buoys.

SST time-series was decomposed in order to obtain its trend, seasonal and residual components. We then performed a normalization procedure by subtracting the seasonal component from the original series, removing the influence of periodical variations in order to identify truly anomalous events [Laufkötter et al. 2020]. The thresholds defining MHWs categories are based on the percentiles of the historical distribution of SST values in a region (e.g. 90th, 95th, 98th) [Hobday et al. 2018]. Here we defined the 98th percentile as the threshold in order to spot only the most intense MHWs. The percentile value was used as inferior limit for identifying anomalies with minimum duration of 5 consecutive days. In addition, intervals between continuous events of two or less days were considered as part of the same MHW [Hobday et al. 2016].

For the MHWs classification we followed the method proposed by [Hobday et al. 2018], which takes in consideration three parameters: (i) 90th Percentile threshold; (ii) MHW maximum intensity (I_{max}); (iii) Difference from the climatological mean (ΔT). The difference multiples between I_{max} and ΔT portray the categories of MHWs: Category I (Moderate) = 1x ΔT; Category II (Strong) = 2x ΔT; Category III (Severe) = 3x ΔT; Category IV (Extreme) = 4x ΔT. Since the identification of the MHWs was made on the basis of the 98th percentile, the difference between the 98th and 90th threshold temperatures was added in the pixel values above 98th percentile as a normalization procedure.

3. Results and Discussion

Satellite-derived SST presented a good correlation and accuracy in comparison to in situ observations (Figure 2a). The SST validation provide ground-truth of satellite data via comparisons with in situ temperature measurements in the study area [Proctor 2019]. Therefore eight MHWs (A-H) were identified during 2002 - 2020 (Figure 2b). The minimum duration observed was around 6-days (MHW H) and the maximum around 19-days (MHW E). The maximum intensities detected ranged from 1.19°C to 2.17°C. Most of the MHWs were identified in austral autumn and summer, with the exception of MHW A in late spring. It was possible to observe a higher frequency and intensity of recent MHWs in comparison to 2009 and 2010 events (see Table 1). This finding corroborates with IPCC statements that claim the increase in likelihood occurrence of MHWs in recent years[Collins and Sutherland 2019], which must be related to human-induced global warming [Laufkötter et al. 2020].

In terms of the marine heatwaves spatial distribution, Figure 3 shows the averaged SST image for each MHW period and its classification according to Hobday categorization scheme [Hobday et al. 2018]. All pixel anomaly values over 98th percentile were classified as *Strong* or above, indicating that this percentile threshold is useful for spotting only the most intense MHWs. The events that occurred in 2009 and 2010 were predominantly classified as *Strong* with *Severe* excursions, and only concentrated in one portion of the study area (South for MHW A; North for MHWs B and C). Whereas 2019 events were more diffuse and with less *Severe* pixel appearances, indicating wider but more bland MHWs. Lastly, the 2020 occurrences were heavily concentrated in the north and central portion of the study area, with *Strong*, *Severe* and *Extreme* excursions. This corroborates with the already discussed IPCC statements about the increase of extreme anomalous events occurrences. Specially, the MHWs F, G and E shows a degree of intensity that can be related to the coral bleaching phenomenon [Duarte et al. 2020].

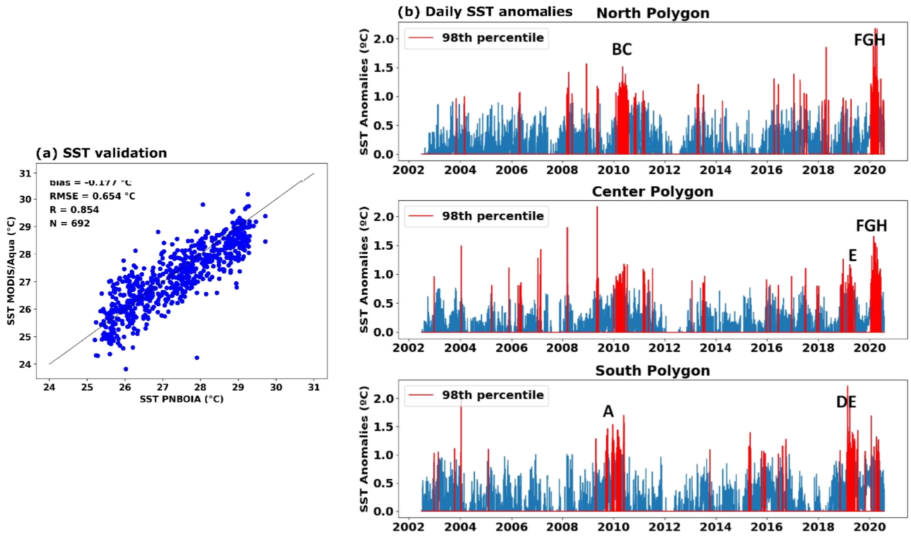

Figure 2. (a) SST validation considering in situ observations from PNBOIA buoys and statistical indices: bias, RMSE and R. N = Number of compared points. (b) Daily SST positive anomalies during 2002 - 2020. Values above 98th percentile are shown in red, with emphasis on MHWs occurrences (A, B, C, D, E, F, G and H).

Table 1. Identified MHWs with the total duration of the event, maximum intensity (I_{max}), difference between the 90th threshold from the climatological mean (ΔT) and occurrence season.

MHW	Duration	I_{max}	ΔT	Season
A	12 days	1.53	0.586	Spring/Summer
B	13 days	1.51	0.513	Autumn
C	7 days	1.23	0.513	Autumn
D	7 days	1.19	0.586	Summer
E	19 days	1.39	0.586	Autumn
F	9 days	1.88	0.494	Summer
G	15 days	2.17	0.494	Summer/Autumn
H	6 days	2.16	0.494	Autumn

The MHWs spatial distribuition shows an important limitation of our proposed method. MHWs A and D - which were only identified in the South polygon time-series (Figure 2b) - can also be observed as slightly present in the North and Central polygons when analyzing the image products. Large-scale marine heatwaves studies often work with finer grids than the proposed here [Laufkötter et al. 2020]. Working around the three major polygons discussed may have lead to an underesimation of MHWs detection at some degree. It is also important to note that although validation procedures for satellite-derived SST adequately represents in situ observations for the study area (Figure 2a), the presence of a negative bias of order 0.18°C may influence this understimation. Nevertheless, the method proved to be efficient in identifying the more wider and intense MHWs excursions for each region.

Ultimately, the particular causes for this marine heatwaves occurrences still needs to be studied. The occurrence of MHWs in Southwestern Atlantic may be associated with anomalous wind conditions, as the formation of anticyclonic patterns already identified as causing MHWs during the summer [Rodrigues et al. 2019]. Another paradigm is associated with the record-warming years of 2015-2016, recording one of the strongest El Niño events. However, marine heatwaves were not identified in these respective years at the study region. This indicates that they may be more associated with large-scale modes of climate variability, as well as by small-scale atmospheric and oceanic forcing, such as ocean mesoscale eddies or local atmospheric weather [Collins and Sutherland 2019].

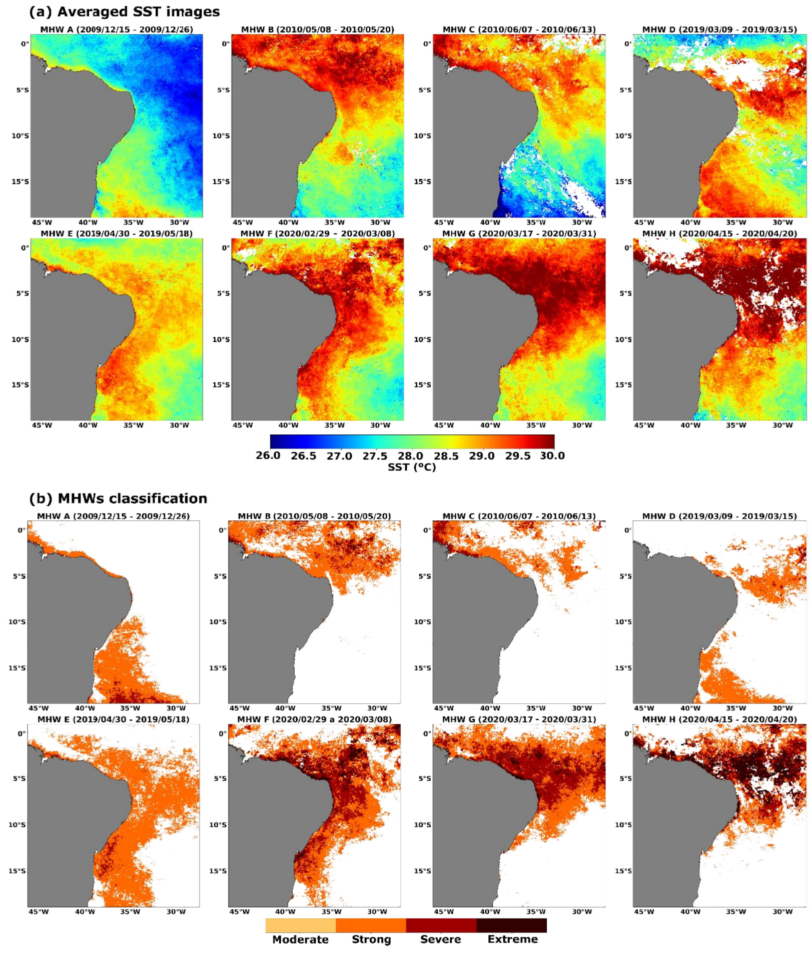

Figure 3. (a) Averaged SST images for each MHW period and (b) MHWs spatial distribution classified according to Hobday et al. (2018) categorization scheme.

4. Conclusions

As the worsening of climate change progresses it is expected that the frequency and intensity of marine heatwaves will increase over the coming years. Therefore, studies related to the identification and categorization of MHWs becomes more relevant in order to make its methodology even more consistent. In this article we performed a case study applying some of the recent techniques discussed for MHWs topic, through an image-processing approach for classifying its categories. In total, eight marine heatwaves were identified along northeastern Brazilian coast with the 98th threshold during 2002-2018. Since the forecast is for a growing rise in ocean temperatures, it is also expected that the thresholds that define MHWs may vary within time. Our results confirm that the 98th percentile is a safe limit for detecting intense marine heatwaves at the moment. All events occurred during Summer or Autumn season, giving these periods a special attention in terms of mitigating MHWs impacts. The spatial distribution of the occurrences also highlighted the northern and central regions as the most likely to face extreme MHWs conditions. Ultimately, the causes for this events at northeastern Brazil are inconclusive. Further studies will be conducted to understand what type of climatic and oceanographic variables are associated with the occurrence of this marine heatwaves.

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