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Far-Future Climate Projection of the Adriatic Marine Heatwaves: a kilometre-scale experiment under extreme warming

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The aim of this paper is to use a km-scale coupled atmosphere-ocean-wave-sediment model to study the evolution of the Marine Heat Waves (MHWs) in a far-future scenario in the Adriatic Sea. For this purpose, the author starts from a simulation of 31 years (1987-2017 also known as "historical") and projects it to the period 2070-2100 based on the RCP 8.5 simulation (known as RCP8.5). To obtain the temperature in the far-future scenario it is used the Pseudo Global Warming (PGW) approach. This method consists in to superimpose climatological differences between historical and future scenarios to obtain high resolution simulations. This method has some limitations that are well explained in the paper (non-linear climate change processes can not be taken into account).

The MHWs are calculated using the well-known Hobday method with the Schlegel R-package, selecting the MHWs covering more than 5% of the Adriatic Basin. The MHWs of each period (historical and RCP8.5) are computed based on the daily climatology and 90 percentile computed for each period.

General comments

The Mediterranean, and the Adriatic in particular, is severely affected by global warming. Over the last 40 years, its surface has warmed by more than 1.5ºC [1] and up to 2ºC in some regions of the Adriatic. The deep waters are also expected to warm to a greater or lesser extent. Then, even for shorter periods than 31 years, the trend in the temperature series cannot be neglected. And this fact introduces my main objection to the publication of this work as is. For time series with trend, the calculation of the extremes cannot be performed using the original time series. Such a calculation leads to an overestimation or underestimation of the extremes, depending on the characteristics of the trend and the position of the extremes in the time series. This is specially important if the value of extremes (their deviation from the mean or the median) are comparable to the accumulated trend in the series. The non-stationarity, including trends and seasonality, of time series can invalidate the assumptions of many extreme value models [2]

Let me illustrate with an example my concern about MHW detection in trending time series.

Let's consider a time series consisting of an oscillation, a linear trend and randomly distributed extreme values. An example of such a series is shown in Figure 1a. In this case the trend (3.33°C/decade) has been exaggerated to illustrate what happens when you study a time series with a trend. This time series consists of daily data over 30 years (30x365 values) and the values in the series are not intended to be realistic, but are chosen as an example. The daily climatology (Fig. 1b), composed of 365 values, has been calculated by averaging the 30 values of each day of the year. The 90th percentile is calculated for each day of the year using the 30 available values (Fig. 1c). Following a procedure similar to that proposed by Hobday, but assuming for simplicity that an MHW can have a duration of 1 day, we found the MHW and intensities shown in Fig. 1d.

The first thing we see is that as the temperature increases in the latter part of the time series, values are detected as MHW even though they are not extreme values. This results in a continuous MHW condition (see years 27-30), although it is clear that this situation cannot be qualified as MHW. The opposite happens in the early part of the time series: extreme values are not detected in the early years. This leads to the false conclusion that the extreme values (MHW) are increasing in time.

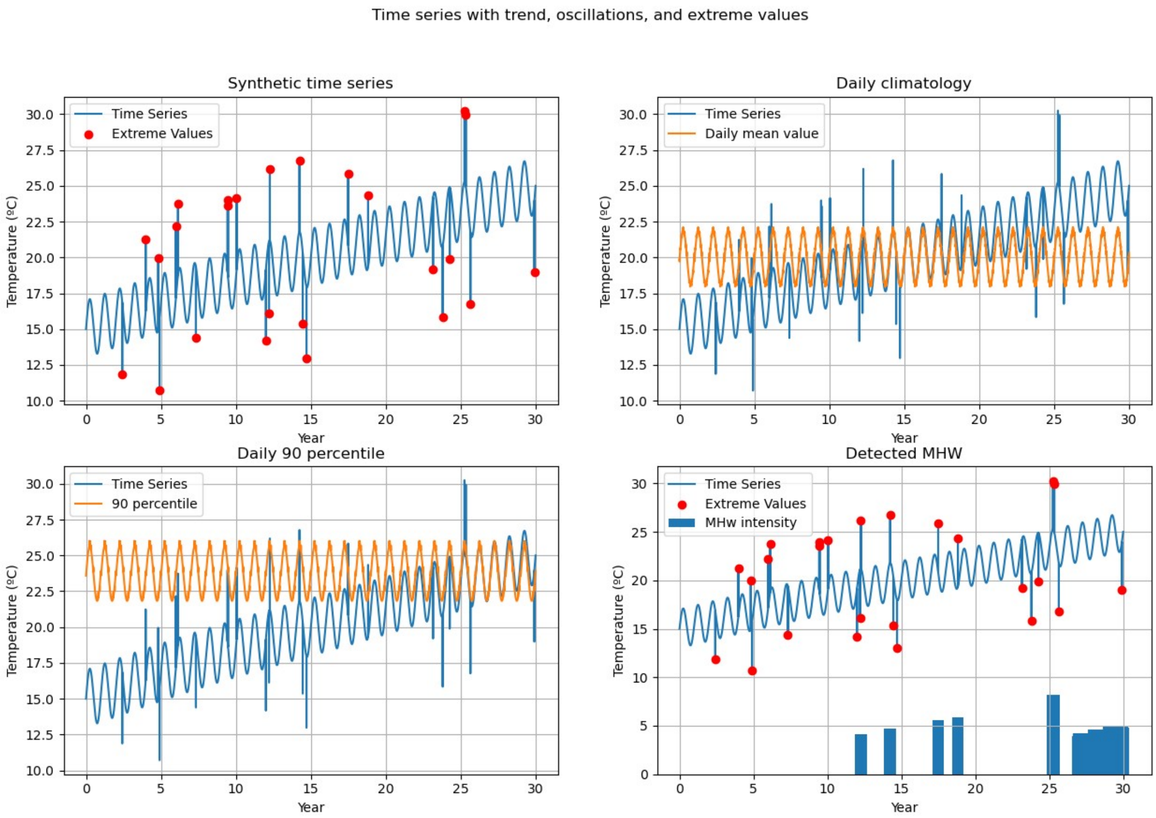

Figure 1.- Simplified experiment. Left top (a): 30 years temporal series simulating oscillatory behavior with linear trend and randomly distributed extreme values. Right top (b): The corresponding daily climatology. Bottom left (c): The daily 90th percentile. Bottom right (d): MHW detected (values above the 90th percentile)

However, if we detrend the original time series shown in Figure 1a (see Figure 2a) and apply the Hobday method to this detrended time series, the correct hot extremes are detected (Figure 2d). The Python code to reproduce the above figures is attached to this review as a separate file (test.py)

The detrending method [2] is not the only option to study the extremes, but it is probably is the most suitable to be used with the Hobday procedure. Other approaches to the study of extreme values in statistics [3] for non-stationary time series can be performed by quantile regression [4,5], or Generalized Pareto Distributions (GPD) [6]

I know that studies of MHW are usually carried out using non-detrended time series, but as I mentioned above, detrending is necessary at least when the extreme values are of the order of the total accumulated trend in the time series. This is a major shortcoming in the study of, at least, Mediterranean Sea MHWs, where it has been shown that the trend is not negligible over periods of 30 years. This aspect has recently been discussed by Amaya et al

[7], who agree that the use of a fixed baseline to detect MHW tells us little about the patterns of future extremes.

In the light of all this evidence, I think that in order to study the phenomenon occurring in some years of the time series (such as the influence of the EMT in the MHW intensity), it is necessary to use the detrended time series (historical and RCP 8.5). This is not difficult as the Schlegel R package can be fed with the detrended time series instead of the original time series.

The MHW community is making efforts to establish a common definition of MHW, mainly based on the baseline used. The recent work by Smith et al [8] is a first step in this direction, defining different baselines (i.e. different MHW detection methods) according to the aim of the study (ecological risk of MHW, effect of variability changes...). In particular the fixed baseline (the one used by the author in the work under revision) is the recommended for intercomparisons between periods (the case under study in this case) but not for variability changes derived from dicharges of rivers (Po) or temporal intrusion of deep waters (EMT).

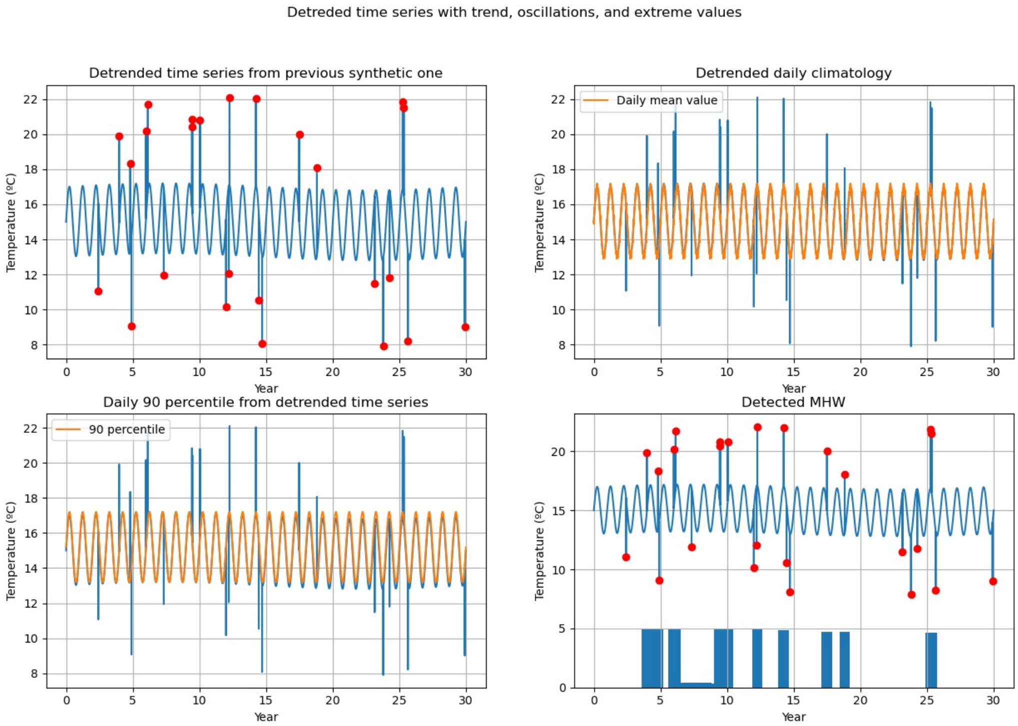

Figure 2.- Simplified experiment. Left top (a): The detrended temporal series corresponding to the 30 years temporal series shown in fig 1a. Right top (b): Its corresponding daily climatology. Bottom left (c): The daily 90th percentile. Bottom right (d): MHW detected (values above the 90th percentile)

Then, keeping the current baseline to perform the intercomparison between historical and RCP8.5 periods, and including the detrended baseline to study possible influence of Po outflow or EMT is, in my opinion, the correct approach to the study.

Specific comments

TThe influence of the Po outflow on the presence, intensity or extent of the MHW is a very interesting (and expected) result. If you finally agree to calculate the temperature trend for historical periods and RCP8.5, you may be able to relate the Po outflow and the Western Adriatic Current to a slower rate of warming. It could be an interesting new paper if you can relate Po outflow to lower warming rates as a function of depth using a km-scale experiment. This is something we can see intuitively using a global Mediterranean sea surface temperature product (see Figure 1 of the paper you referred to as Martinez et al 2023 in your manuscript). A large version of this figure can be found in

https://www.frontiersin.org/files/Articles/1193164/fmars-10-1193164-HTML/image_m/fmars-10-1193164-g001.jpg

Following our paper (Martinez et al 2023), note that you have identified the significant MHW of the second half of the period, but not the earlier ones, most likely due to the fixed baseline you have used.

Technical comments

I wish to clarify only two details:

- Figure 3e: The probability density functions are normalized to have unity area?. Same question for figures 5 and 6
- line 260: You mention a double peak in temperature in the Deep Adriatic subdomain. Are you referring to figure 5b?

References

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