

Methods summary for

“Three decades of heat stress exposure in Caribbean coral reefs: a new regional delineation to enhance conservation”

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Abstract

This data package presents a three-decade (1985-2017) assessment of heat stress exposure in the wider Caribbean coral reefs at the ecoregional and local scales. This database is part of the doctoral thesis of A. Israel Muñiz Castillo carried out at CINVESTAV Unidad Mérida with a CONACyT doctoral grant #340074. The study presented in Muñiz-Castillo et al. (2019) related to this dataset aimed to: (a) Characterize the geographical extent and variability of heat stress in the Caribbean ecoregions, (b) classify the wider Caribbean into new heat-stress regions based on historical heat stress, and (c) assess the temporal variability of heat stress in the Caribbean and its relation to past ENSO events. The main heat stress indicator used was the Degree Heating Weeks (DHW) (Liu et al., 2014) calculated from daily Sea Surface Temperature "CoralTemp" data from CRW-NOAA available from 1985 to the present (<https://coralreefwatch.noaa.gov/product/5km/index.php>) and from the maximum monthly mean (MMM) version 3.1 at 5 km of the CRW-NOAA program (<https://coralreefwatch.noaa.gov/satellite/bleaching5km/index.php>). Different metrics were calculated based on daily DHW and are available in this dataset: a) the maximum value of DHW per pixel for the entire time series, b) the frequency of the annual maximum values of DHW ≥ 4 °C-weeks (a predictor of coral "bleaching risk") per pixel, c) the frequency of the annual maximum values of DHW ≥ 8 °C-weeks (a predictor of bleach-induced mortality or "mortality risk") per pixel, d) the year in which the maximum of DHW occurred, and e) the trend of the annual maximum values of DHW per pixel. Based on the spatiotemporal annual maximum DHW, a new regionalization of heat stress was performed by cluster analysis with the K-means algorithm through the unsupervised classification, this new regionalization delimits the Caribbean in 8 Heat Stress Regions (HSR). We summarized spatiotemporal daily data to describe the temporal patterns at an ecoregional scale (Spalding et al., 2007) by calculating the descriptive statistics of the regional DHW on a given day. This dataset represents a new baseline and regionalization of heat stress in the wider Caribbean coral reefs that will enhance conservation and planning efforts underway.

COMPONENT DATA SETS - METHODS:

Historical heat stress data source and calculation:

The spatiotemporal variation in daily Sea Surface Temperature (SST) from 1985 to 2017 was obtained from the NOAA's Coral Reef Watch Program "CoralTemp" dataset, the latest and most

complete global satellite-derived dataset at a resolution of 5 km (0.05°) available for 1985 to present (<https://coralreefwatch.noaa.gov/product/5km/index.php>). The Maximum Monthly Mean (MMM) was also obtained from the Coral Reef Watch Program version 3.1 dataset at 5 km (<https://coralreefwatch.noaa.gov/satellite/bleaching5km/index.php>), the MMM is a value of SST that represents the warmest monthly climatological mean from 1985 to 2012 for each location (Liu et al., 2014). We then calculated coral bleaching HotSpot (HS) and Degree Heating Weeks (DHW) metrics. HS represent daily positive anomalies above the MMM (Equation 1) (Liu et al., 2014). DHW quantify heat stress by summing HS above 1 °C over 84-days (12 weeks), divided by 7 to express values per week (Equation 2) (Liu et al., 2014), and calculated daily. Analyses were conducted in R version 3.4.1 (R Core Team, 2017) using the “raster” (Hijmans, 2017) and “sp” (Bivand, R.S., Pebesma, E.J., & Gomez-Rubio, 2013; Pebesma & Bivand, 2005) libraries.

$$HS = \begin{cases} SST_{daily} - MMM, & SST_{daily} > MMM \\ 0, & SST_{daily} \leq MMM. \end{cases} \quad (1)$$

$$DHW = \frac{1}{7} \sum_{i=1}^{j=84} (HS_i, \text{if } HS_i \geq 1^{\circ}\text{C}) \quad (2)$$

The daily DHW values were the main inputs for the data presented in this dataset, these daily DHW values are not included in this data package, but daily HS and DHW are available by the CRW-NOAA program (<https://coralreefwatch.noaa.gov/product/5km/index.php>).

1) Reef locations mask:

Heat stress on coral reefs was characterized by analyzing the pixels within 20 km of reef locations within the wider Caribbean (32.7°N-8.4°N, 59.2°-97.0°W). We used a buffer to include nearby adjacent areas with the presence of coral reefs and improving visualization and reef scale. Reef locations were obtained from the Global Distribution of Coral Reefs (UNEP-WCMC & Centre, 2010). This raster represents the mask of the coral reefs for the subsequent analysis presented in Muñiz-Castillo et al. (2019) and in this dataset.

Resultant data is given in file ‘Reef_locations_mask.nc ‘

2) The annual DHW maximum value from 1985 to 2017 for the Caribbean reefs:

The annual DHW maximum was the main indicator used to evaluate the exposure to heat stress and represents the maximum heat stress accumulated in the year (Muñiz-Castillo et al., 2019). This multi-layer raster was produced with functions conducted in R version 3.4.1 (R Core Team, 2017) using the “raster” (Hijmans, 2017) and “sp” (Bivand, R.S. et al., 2013; Pebesma & Bivand, 2005) libraries.

Resultant data is given in file ‘Annual_maximum_DHW_value_from_1985_to_2017.nc ‘

3) The maximum DHW value from 1985 to 2017 for the Caribbean reefs:

The maximum DHW value for the entire time series from 1985 to 2017 for the Caribbean reefs was obtained (Muñiz-Castillo et al., 2019). This raster shows the greatest magnitude of exposure to heat stress presented in the entire time series, it was obtained from simple functions performed in R version 3.4.1 (R Core Team, 2017) using the “raster” (Hijmans, 2017) and “sp” (Bivand, R.S. et al., 2013; Pebesma & Bivand, 2005) libraries.

Resultant data is given in file ‘Maximum_DHW_value_per_pixel_from_1987_to_2017.nc’

4) Frequency of annual maximum DHW values ≥ 4 °C-weeks (“bleaching risk”):

The frequency of annual maximum DHW values ≥ 4 °C-weeks (a predictor of coral “bleaching risk”) per pixel based on the annual DHW maxima was calculated (Muñiz-Castillo et al., 2019). This indicator represents the frequency at which annual maxima have exceeded the recognized threshold at which coral bleaching can occur (Beyer et al., 2018; Eakin et al., 2010; Heron, Maynard, van Hooidonk, & Eakin, 2016). The resulting raster presenting the frequency of events was obtained from simple functions performed in R version 3.4.1 (R Core Team, 2017) using the “raster” (Hijmans, 2017) and “sp” (Bivand, R.S. et al., 2013; Pebesma & Bivand, 2005) libraries.

Resultant data is given in file ‘Frequency_of_annual_maximum_DHW_values_ ≥ 4 °C-weeks.nc’

5) Frequency of annual maximum DHW values ≥ 8 °C-weeks (“mortality risk”):

The frequency of annual maximum DHW values ≥ 8 °C-weeks (a predictor of bleaching-induced mortality or “mortality risk”) per pixel based on the annual DHW maxima was calculated (Muñiz-Castillo et al., 2019). This indicator represents the frequency at which annual maxima have exceeded the recognized threshold at which mass coral mortality due to bleaching may occur (Beyer et al., 2018; Eakin et al., 2010; Heron et al., 2016). The resulting raster presenting the frequency of events was obtained from simple functions performed in R version 3.4.1 (R Core Team, 2017) using the “raster” (Hijmans, 2017) and “sp” (Bivand, R.S. et al., 2013; Pebesma & Bivand, 2005) libraries.

Resultant data is given in file ‘Frequency_of_annual_maximum_DHW_values_ ≥ 8 °C-weeks.nc’

6) The trend of the annual maximum values of DHW:

The trend of annual maximum DHW was calculated with a Generalized Least Squares model (GLS) (Muñiz-Castillo et al., 2019), introducing to the regression a structure of temporal autocorrelation (AR1, which represents the covariance of order 1 considering the temporal similarity between the nearest years; Weatherhead et al., 1998). Because we calculated the trend from annual values, the GLS model did not consider seasonality. Once the slope of the regression was obtained, we calculated the significance of the slope at a 95% confidence, considering as a null hypothesis that the tendency was equal to zero. In all pixels in which the slope was not significant, the value of

zero was set to represent a null slope. The analyses were performed from the functions available in the “nlme” library (Pinheiro J, Bates D, DebRoy S, 2017) of program R (R Core Team, 2017).

Resultant data is given in file ‘Trend_of_annual_maximum_DHW.nc’

7) The year in which the maximum DHW occurred:

The year in which the maximum DHW was recorded in each pixel was calculated (Muñiz-Castillo et al., 2019). The resulting raster presenting the year with the maximum DHW in the entire time series and was obtained from simple functions performed in R version 3.4.1 (R Core Team, 2017) using the “raster” (Hijmans, 2017) and “sp” (Bivand, R.S. et al., 2013; Pebesma & Bivand, 2005) libraries.

Resultant data is given in file ‘Year_in_which_the_maximum_DHW_occurred.nc’

8) Heat-stress Regions (HSR):

The regionalization of heat stress was performed by a clustering analysis with the K-means algorithm through the unsupervised classification function present in the “RStoolbox” library (Leutner, Horning, Schwalb-Willmann, & Hijmans, 2018). The maximum annual DHWs during the years 1985-2017 were used as input to the clustering procedure. To identify the optimal number of groups, we used the graphic elbow criterion. This evaluation illustrated a curve of the remaining variation from the addition of each given number of groups, revealing a relationship of the variance among added groups and the total variance. The spatiotemporal variation of heat stress (cluster analysis using K-means and eight optimal regions obtained using elbow criteria) yielded eight spatially distinct heat-stress regions (HSR) characterized by different time patterns of exposure levels (Muñiz-Castillo et al., 2019).

Resultant data is given in file ‘Heat-Stress_Regions.nc’

9) Daily ecoregional statistics of DHW:

Based on the spatiotemporal information of the daily DHW in the mask of coral reefs, time series that present the main descriptive statistical indicators at the ecoregion scale (Spalding et al., 2007) on a given day was made. For this purpose, the statistical descriptors were obtained summarizing the information of all the pixels of each ecoregion in each of the days considered (Muñiz-Castillo et al., 2019). The number of pixels considered within each ecoregion for the calculation of the statistical indicators varied considerably:

BHM = Bahamian (7,653 pixels); EC = Eastern Caribbean (2,021 pixels); FL = Floridian (832 pixels); GA = Greater Antilles (7,003 pixels); SC = Southern Caribbean (1,622 pixels); SGoM = Southern Gulf of Mexico (1,281 pixels); SWC = Southwestern Caribbean (3,326 pixels); WC = Western Caribbean (1,861 pixels); and wider Caribbean (25,591 pixels).

Resultant data is given in file ‘Median_of_the_regional_DHW_values_on_a_given_day.csv’

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