Bringing Marine Heatwaves to Life with Animation

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ABSTRACT

Large-scale marine heatwaves can be extremely damaging for both ecosystem functioning and fishery productivity. Modern high spatial and temporal resolution datasets now make it possible to investigate regions of persistent and extreme anomalies in sea surface temperature (SST). Using the 2013-2015 Pacific marine heatwave as an example, we develop an animated visualization to show the growth, movement, and decay of extreme ocean temperatures associated with this event. A classification algorithm extracts marine heatwave event information from daily sea surface temperature observations and computes event summary metrics (intensity, duration and frequency) over a 37-year period. Marine heatwave SST anomalies are then mapped and animated using Matplotlib and rendered as an interactive JavaScript widget. Using animation to track marine heatwaves helps tell an interesting story about these events that could be used to communicate their dynamics.

Author Keywords

Animation; Visualization; Extremes; Geospatial; Interaction.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

INTRODUCTION

Marine heatwaves are extreme and prolonged warming events in sea surface temperature (SST) that have been observed around the world [1,2]. The effects from these events cascade through complex physical, ecological, and societal systems that can lead to increased economic tensions between nations [3]. Traditional event-based research often portrays marine heatwaves (MHWs) as static composites of abnormal temperatures over some period of time. The problem with this view is that it does not convey the complex growth, evolution, nor decay of MHWs in space and time. This motivates the development of MHW visualizations to better understand their evolution and movement through animation.

RELATED WORK

Marine heatwaves have occurred in different regions throughout the global ocean. Well-known events have been documented in the northern Mediterranean Sea in 2003 [4,5], along the coast of Western Australia in 2011 [6], in the northwest Atlantic in 2012 [7], in the northeast Pacific from 2013-2015 [8,9], and off southeastern Australia in 2015-2016 [10]. Anomalous weather patterns play a crucial role in controlling the extent and location of MHWs through local air-sea heat fluxes that generate and maintain anomalous temperature conditions [9]. Changes in advection by warm ocean surface currents forced by changes in regional, local or remote surface winds can also contribute to the generation of marine heatwaves.

The evolution, movement, and patterns of warming associated with these documented MHWs vary considerably in that no two MHWs are alike. Events forced by the atmosphere often develop instantaneously over a large area, like during 2012 in the northwest Atlantic and 2003 in the Mediterranean Sea. These types of MHWs tend to be related to concurrent atmospheric heatwaves or stalled weather systems [5,7]. Other marine heatwaves are the result of unusual intensification of warm water current, like during the 2011 MHW off Western Australia where warm equatorial waters were brought poleward by an accelerated ocean surface current [6]. The large variety of MHW events lends itself well to animation. In the remainder of this paper, we will focus on visualizing the evolution and movement of the 2013-2015 North Pacific MHW that had devasting impacts on U.S. West Coast ecosystems, fisheries and economy.

METHODS

Global daily sea surface temperatures are available from the Optimum Interpolation Sea Surface Temperature (OISST) dataset maintained by the National Oceanic and Atmospheric Administration. Global gridded fields have a 0.25º-latitude x 0.25º-longitude resolution and are available from 1981 through present. The OISST used in this analysis consists of satellite sea surface temperatures from Advanced Very High Resolution Radiometer and are combined with ship and buoy observations on a regular global grid. Interpolation is used to

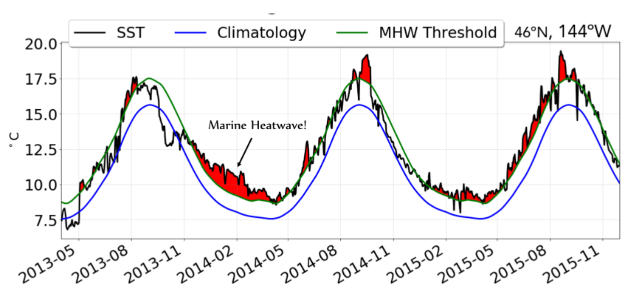

Figure 1: Defining Marine Heatwaves. A time series of sea surface temperatures at 45ºN, 144ºW (white dot Figure 2a) shows several marine heatwaves (red shading) above the 90th percentile threshold calculated from a 30-yr climatology.

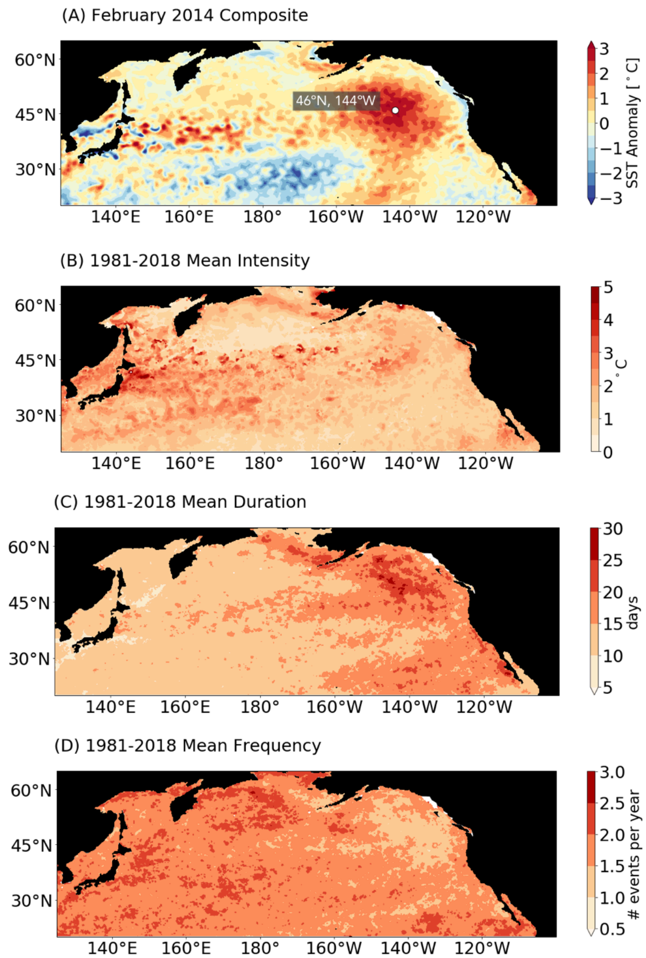

Figure 2: Marine Heatwave Snap-shots. These still frames provide a sense of limitation when trying to understand event dynamics.

fill in spatial gaps and the methodology in [11] describes the procedure for bias adjustment across different data collection platforms and sensor suites. We downloaded this dataset using netCDF Operators and Wget from the command-line. Marine heatwaves are defined relative to their temperature intensity using a 90th percentile threshold calculated over on a 30-year climatology (1988-2017). An event is considered a marine heatwave when at least 5 continuous days are above this threshold with no more than a 2-day gap in between [2]. For each ocean grid point, a time series of MHW intensities and durations are computed using this method and averaged across the 37-year record (Figure 2b,c,d). Duration is calculated by determining the start and end dates for each event. By definition, MHWs must last at least 5 days. Intensity represents the temperature anomaly above the 30-year climatology and frequency is determined by the number of discrete events per year.

All SST anomalies that exceeded the 90th percentile are saved as a separate data file and used in the final animation. This data is projected on a map with a Plate Carrée projection of equal rectangles. This projection was chosen over Mercator as it distorts polar regions to a lesser extent. Land areas are masked and shaded black to enhance color contrast with ocean data values. The values of SST anomaly are hue encoded with a sequential monotonically increasing colormap (*gist_heat*). Frames are animated from February 2013 to December 2015 using Matplotlib and rendered as an interactive JavaScript widget directly inside a Jupyter Notebook using iPython's HTML display method (Figure 3). This widget plays in-line with an HTML5 slider element that advances frames forwards and backwards. The animation is saved as an HTML file and hosted on a GitHub website (https://cse512-18s.github.io/marine-heatwave/images/mhw.html). The slider can be dragged with a mouse or clicked forward and backwards. There is the option of speeding up or slowing down the animation by clicking on + or – buttons respectively (Figure 3).

RESULTS

Using animation to track the Pacific marine heatwave helps to tell an interesting story about this event. Anomalies >2ºC were confined offshore early in the year, then spread to the U.S. West Coast by late spring where the intensity was initially less severe. Anomalies were likely brought to the coast by seasonal spring storms and cooled via coastal upwelling. By late summer, the pattern becomes canonical extending westward and reaching further north and south with the most extreme temperatures occurring near the Bering Sea and surrounding Baja California. During the winter of 2014/15 a strong El Niño developed in the tropical Pacific. El Niño influence SST patterns in the North Pacific with warming in the east and cooling in the west and central part of the gyre. The El Niño likely caused the MHW pattern to appear more canonical in early 2015. These sequences of events can be effectively communicated using the animation of MHW SST anomalies to tell a story. The animation was demonstrated to researchers at the University of Washington who had a clearer understanding of what marine heatwaves "look" like after interacting with the widget.

DISCUSSION

The marine heatwave animation allows users to see how these events evolve over time. It provides the audience with a perception that these events interact energetically with background ocean circulation and weather patterns, which play important roles in shaping MHW patterns over time. This type of visualization tool, paired with data analysis, could be used for outreach demonstrations to communicate a sequence of events leading up to an impact caused by a MHW. For example, an unprecedented harmful algal bloom occurred off the U.S. West Coast during summer 2015, causing prolonged closures of lucrative shellfisheries, and was attributed to the warming caused by the Pacific MHW [12]. Animation of the MHW during this period shows the progression of extreme temperature conditions propagating down the coast, which led to this toxic algae outbreak.

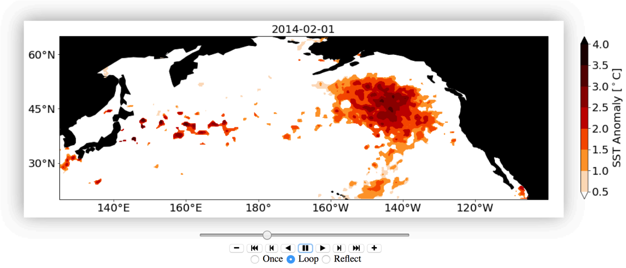

Figure 3: Interactive animation of the Pacific marine heatwave during February 2014. The slider bar controls the speed and direction of animation.

FUTURE WORK

Going forward, we would like to incorporate a size encoding using a clustering approach to create continuous contours of SST anomaly area. This would simplify the design and draw attention to areal extent. We also plan to implement detection-based multiple object tracking to distinguish several marine heatwaves from one another based on distance separation and study human perception of trajectory animation.

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