Combining SST data from buoys and climate models to predict climate thresholds for the past, present, and future of the Pacific Northwest

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Abstract:

Sea surface temperature (SST) of water is widely used to gauge the effects of climate change on the world's oceans. By focusing on the Pacific Northwest, I examined the ramifications of increased likelihood for extreme warm anomalies for a particular region as opposed to a global scale and see when this should be expected to happen. Data from observations, climate models and projections were used to create a picture of the region's SST history. The highest temperature reached in the historical data was averaged at 17.5^{o}C, so I used this historical maximum as a threshold marker for the observational and projection data. I concluded that the advent of climate change can be viewed through the combination of past, present, and future data as the climate threshold of 17.5^{o}C is passed more frequently as the CO^2 concentration increases in the atmosphere. As we move forward, anthropogenic sources will cause the global effects of climate change to only get worse.

Introduction:

This research aims to compare existing data sets from offshore NDBC (National Data Buoy Center) buoys to climate model simulations from 1850-2005 and model based projections extending up to the year 2100 to project future climate departure variations for the Pacific Northwest. This was partially inspired by the work of Mora et al. (2014), who used 39 Earth System Models developed for the Coupled Model Inter-comparison Project phase 5 (CMIP5) in order to quantify climate variability bounds. Climate departure constitutes a massive change in the overall state of climatic systems, shifting the balance of said system into a warmer or cooler state. One of the more straight-forward methods for quantifying climate departure is the measure of sea surface temperature (SST). Many different factors can be used to quantify climate change, but in order to focus on one aspect of climate variation SST will be the only factor considered.

Being able to accurately predict when detrimental effects from climate change will occur is becoming increasingly important to the health and safety of the world's oceans as well as for the people who depend on them. The economic impacts on commercial fishing have been well documented on inter-decadal timescales over the past 100 years, especially with large variations in salmon yield in the Pacific Northwest region (Mantua et al. 1997). Extreme warming events have been dubbed marine heat waves, and these have been shown to be prevalent in both large and small regions in both the Northern and Southern Hemispheres (Scannell et al. 2016).

Climate departure is defined by Mora et al. (2014) as the time period when temperature in a specific climate system exceeds the historical bounds of variation in that system. This is highly variable due to the nature of ecological systems differing greatly place to place, making it difficult to compare departure of one region to another. The warming of the seas is due to an increase in the concentration of heat energy in the atmosphere strongly correlated to rising concentrations of carbon dioxide (IPCC).

The work of Mora et al. (2014) used regional analysis in order to gauge effects of climate extremes on different ecosystems. This research will focus on a single regional area with one climate variable in order to minimize the number of factors that may cause variations in SST over time (e.g. comparing a northern climate to a southern climate). I will be examining how the SST responds to climate variability and change within the specified region to see if it is consistent across all data sources to form a complete picture. This research will look to the changes in SST over long time periods in order to assess the accuracy of models, projections, and data collection techniques.

Data and Methods:

I will be using a temperature threshold of 17.5^{o}C to function as an indicator when an abnormally high SST value is recorded. This temperature was chosen due to this value being averaged as the highest reading in the historical models for all three scenarios. In order to measure when the temperature threshold of 17.5^{o}C is reached the temperature readings off the Pacific Northwest coast must be quantified over time. Five NDBC buoys were chosen to show the general sea surface temperature (SST) trends in the region, with multiple locations used to minimize data biases (Table 1). The study area encapsulates waters off of both Washington and Oregon, with the majority being off the Washington coast (Fig. 1). Histograms were used in order to create graphics that can be used to visualize SST and be easily compared across all three data sources. It is important to note that there are data gaps in these time series due to the data being captured live. These histograms were then used to gauge the frequency of temperature increase or decrease with regard to the historical SSTs of the region.

I also used model simulations showing modeled SST averages from 1850-2005. Three SST histograms were created for the historical models with the same process as used for the buoys for the different models (the three different models used had different initial conditions). The three conditions were chosen using different Community Earth System Model (CESM) configurations, each taking into consideration different biogeochemical cycles (Hurrell et al. 2013). I then used projection simulations showing probable climate outcomes for 2005-2100 using RCP values of 4.5 and 8.5. The Representative Concentration Pathway (RCP) is a numerical representation of the extent of greenhouse gas emissions in projection models moving into the future (Wayne 2013). By using the RCP values of 4.5 and 8.5, I was able to see both the most reasonable "best case scenario" at a value of 4.5 as well as the worst case scenario at a value of 8.5. Once again, I used the same method as used in both the models and NDBC buoy data in order to create histograms showing the frequency at which the threshold is reached over time.

In order to define extreme warm anomalies, I counted up the percentage of months where the monthly average reached or exceeded the 17.5^{o}C threshold created by the maximum values in the historical models. These percentages were then used to define the frequencies at which SST values were reached to quantify the predicted warming over time.

The shortest time frame for data availability was from the NDBC 46089 buoy, with only 11 years of available data with some gaps present (Table 1). The longest time period of available data was from the historical models, with all three having 155 years of available data with no data gaps (Table 1).

Results:

The results I collected were largely consistent between the three main data sources as a cohesive whole moving through time (the NDBC buoys, the historical models, and the RCP 4.5 and 8.5 projections). The frequencies for the NDBC buoys had the least common frequencies at 8.75^{o}C and the most common frequencies at 13.75^{o}C (Fig. 2). The most common frequencies for the historical models were all at the same temperature of 11.25^{o}C (Fig. 3). The projection model frequencies had the least common frequency at 12.50^{o}C and the most common frequency at 13.75^{o}C (Fig. 4).

The median value for the TOSr1 historical model was 12.81^{o}C, while the mean was calculated as 12.96^{o}C. The median value for the TOSr2 historical model was 12.89^{o}C, with the mean at 13.0^{o}C. The median value for the TOSr3 historical model was 12.64^{o}C, while the mean was 12.89^{o}C. For the RCP 4.5 projection, the median was 14.14^{o}C and the mean value was 14.33^{o}C. The RCP 8.5 projection had a median value of 14.87^{o}C and a mean value of 15.04^{o}C.

The highest percentage of months where the threshold value was reached was 23.04% for the RCP 8.5 projection, while the lowest percentage was 0.00% for the NDBC 46041 buoy (Table 2). The historical model excess percentages all fell within 0.53% to 1.07%, the NDBC buoy observational percentages fell within 0.00% to 11.25%, and the RCP projection percentages fell within 14.10% to 23.04% (Table 2).

Discussion and Conclusions:

The combination of the historical models, the data collected from NDBC buoys, and the RCP projections create a consistent picture that SST increases over time. The buoys show much more variability than the models due to them being collected locally, while the models are much smoother in the trends in data since they do not resolve eddies like what would actually occur in the ocean. This may lead to some bias in the trends for the models compared to the buoys due to their variations from the collected observational data. While the historical models rarely show any increase over the 17.5^{o}C threshold, the threshold is exceeded much more often as the time series moves forward (especially in the RCP 8.5 projection showing the worst case scenario for carbon emissions) (Table 2).

Due to the close proximity of the NDBC buoys to one another, the frequency of threshold exceedance falls within 2% of each other for the majority of the buoys with the exception of NDBC 46089 and NDBC 46002 (Table 2). While NDBC 46089 has the least amount of data available of the five chosen buoys, it is unclear why NDBC 46002 has such a drastic change in threshold exceedance over the other buoys. It is probable that this is due to NDBC 46002 being the furthest south of all five buoys, with it being located at 42.5890, -130.4740 (Table 1).

This project set out to find when climate departure will be felt by the Pacific Northwest in the near future. By using a variety of data sources drawing from existing SST data and sophisticated projection programs, I was able to extract a clear picture of climate change through time. Moving forward through time produces more counts of threshold exceedance (Table 2). This is consistent with the work by Mora et al. (2013), where SST was found to increase by upwards of 5^{o}C on a global scale by the year 2100. The earliest data sets used in this project were from 1850, and these models had the lowest average percentages of threshold exceedance of the three data sources (Table 2).

In order to improve the structure of this research project in future work, more coastal buoys should be used to broaden the coverage of data to be compared to historical and future projection analyses. It is difficult to create an analysis of trends when the maximum amount of existing data extends only to around four decades. Even in the five NDBC buoys used for this project where the space between each was negligible when compared to a global scale, there were measured incredible differences in measured SST (Fig. 2).

There exists a trend in SST in both the observational data and the models. It is confirmed that most of this warming trend is due to anthropogenic sources, although there is much variability and the most impactful changes in SST are the extremes. A recent example of this is the warm blob off the northwest coast of the United States. Nicknamed “the blob”, this massive section of anomalously warm SST was first detected in 2013 and is bounded by 0°N-50°N, and 150°W-135°W (Bond et al. 2015). It is thought to be caused by disruptions in the biogeochemical that promotes homeostasis in the world’s oceans, but ongoing work is still in progress to find more about this potentially threatening marine heat wave (Bond et al. 2015). Marine heat waves are a trade-off between size, intensity, and duration that is modulated by the variability in different regions affecting the frequency of these events (Scannell et al. 2016). If the warm blob is any indicator, it is very likely that there will be more events like this as regions around the world are affected in different ways by mass SST changes. This is just one example of the types of anomalies that exist outside the expected trends of temperature variability that can make it difficult to accurately predict future warming.

From the historical models I saw the lowest count of threshold excess, the observational data has an increased count of threshold excess, and the projections have the greatest counts of threshold excess of the three sources (Table 2). With this taken into account, this research project was successful in supporting that the SST of the Pacific Northwest coast is increasing due to climate change.

Tables and Figures:

Table 1. Data locations and sources

Source	**Dates Available**	**Latitude/Longitude**
NDBC 46005	1976-2015	45.9580, -131.0000
NDBC 46089	2004-2015	45.9080, 45.9080
NDBC 46002	1975-2015	42.5890, -130.4740
NDBC 46050	1991-2015	44.6410, -124.5000
NDBC 46041	1987-2015	46.3530, -124.7310
Historical TOSr1	1850-2005	42-48, -124- -131
Historical TOSr2	1850-2005	42-48, -124- -131
Historical TOSr3	1850-2005	42-48, -124- -131
RCP 4.5 Projection	2005-2100	42-48, -124- -131
RCP 8.5 Projection	2005-2100	42-48, -124- -131

Table 2. Percentages of months over the defined threshold

Source	Percent of Monthly Averages Over 17.5^{o}C
NDBC 46005	2.04%
NDBC 46089	8.82%
NDBC 46002	11.25%
NDBC 46050	0.82%
NDBC 46041	0.00%
Historical TOSr1	0.53%
Historical TOSr2	1.06%
Historical TOSr3	0.81%
RCP 4.5 Projection	14.10%
RCP 8.5 Projection	23.04%

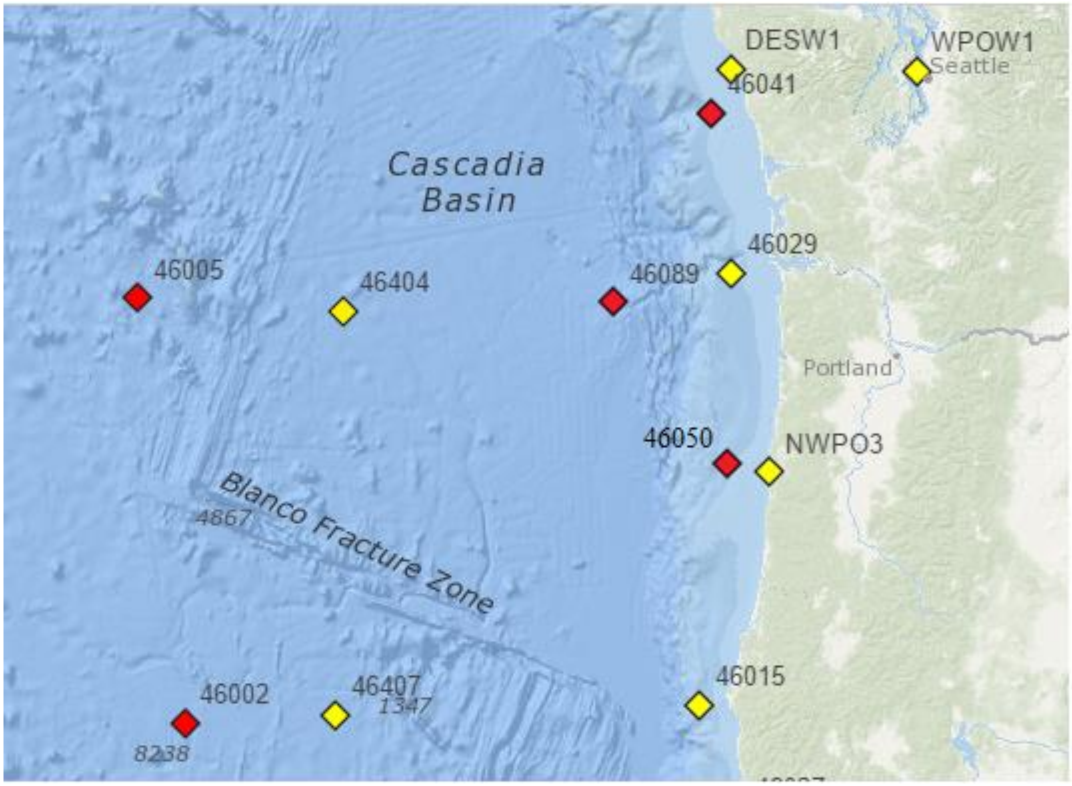

Figure 1. Study area off the coast of Washington and Oregon (NDBC). Buoys used are marked in red

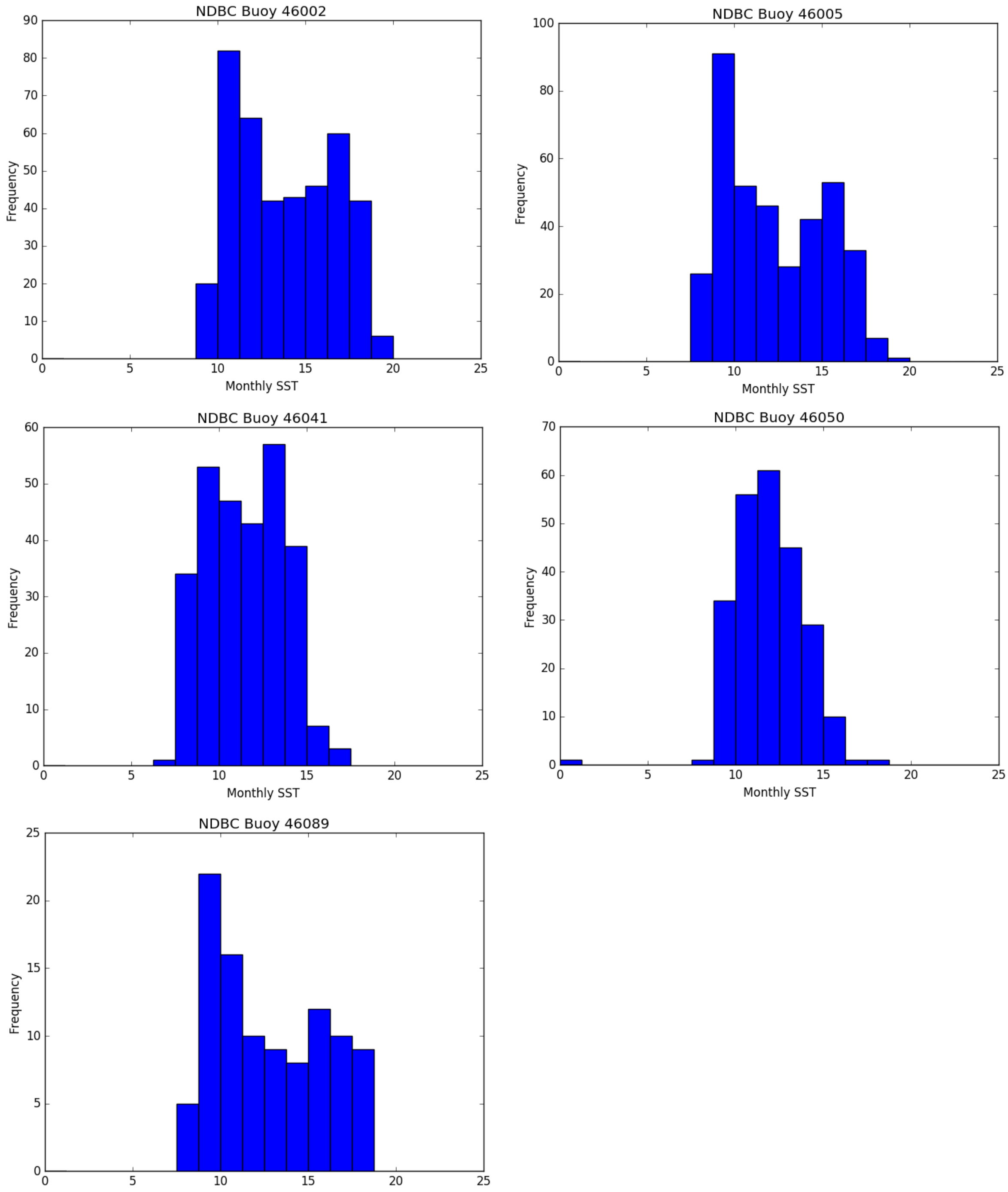

Figure 2. Monthly average SST frequencies for each NDBC buoy observational data set

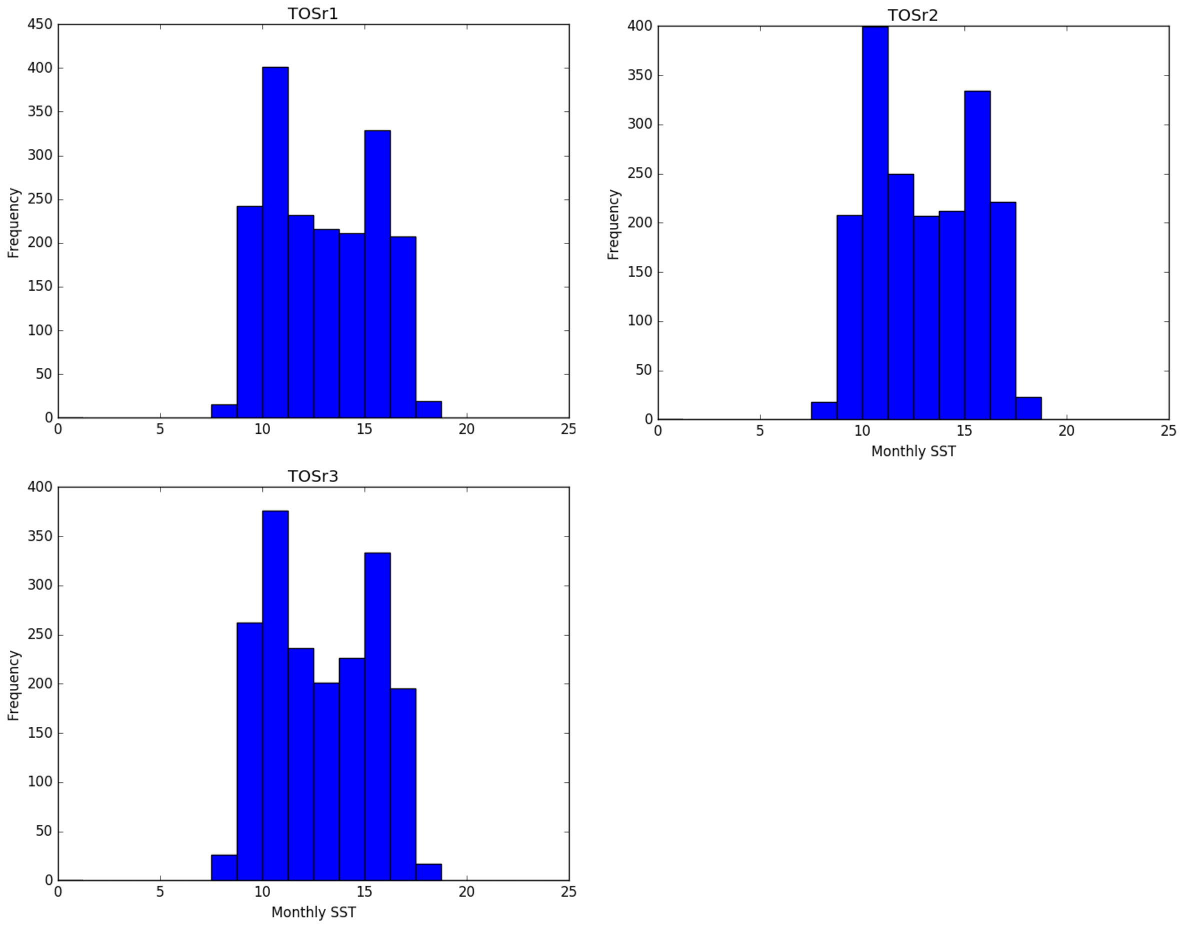

Figure 3. Average monthly SST values for historical model data sources

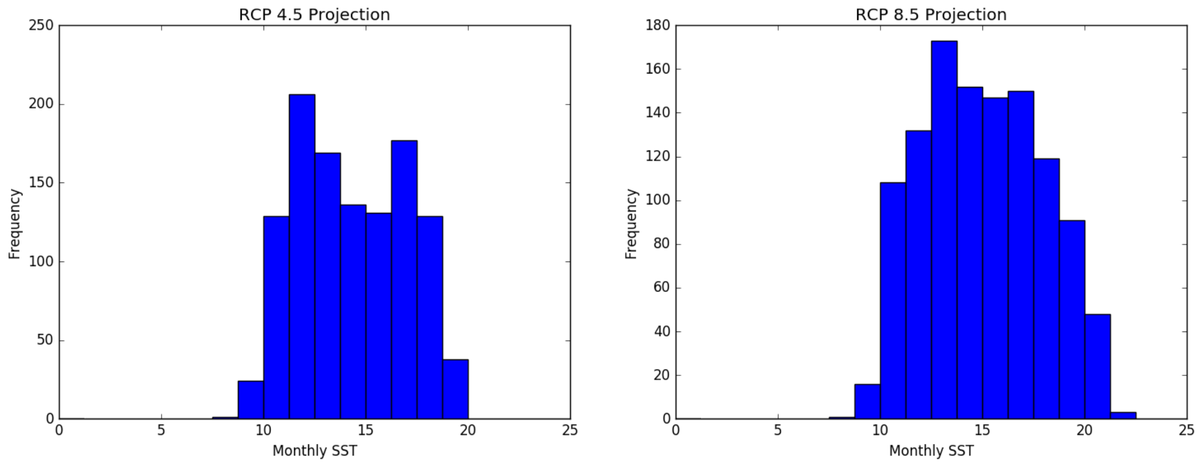

Figure 4. Monthly SST averages for RCP 4.5 and 8.5 projection data sources

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