Coral Bleaching Event Prediction Model

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Abstract:

Mass Coral Bleaching Events have been a major issue that plague vary large, diverse, and important ecosystems found within the oceans. These events not only affect the coral but also have tremendous on-going detrimental effects that linger after the bleaching is over with. These events are being seen all over the world, and there seems to be a growing trend. In this study, the scientists will build an arc.py toolbox that'll utilize multidimensional data to generate a coral bleaching prediction model of the entire world. The data will be a netCDF file downloaded from the National Center for Atmospheric Research's (NCAR) Research Data Archive. The code used for the toolbox will be generated with Arc Pro. However, after being saved, the code will then be written using Notepad++ as it will allow for code editing within the Python 3 format. After the toolbox code is fully written, the data and toolbox will be added to the Arc Pro project and then utilized to generate the desired coral bleaching prediction model. Once the final multidimensional raster is completed, there will be an option to view it using a time loop to see the events that will take place in the future.

Introduction:

Coral bleaching has become a very important and detrimental issue to coral reefs across the globe. Coral bleaching events are caused by increasing ocean water temperature. The greatest contributor to this is climate change. Coral bleaching events are extremely noticeable as brightly vivid color coral will lose their unique and distinctive color patterns and look white. The discoloration is due to the warm water temperature causing the coral to expel the algae that lives inside of the coral tissue. It's worth noting that when a coral bleach itself, that the coral is not dead. The corals are under a lot of stress and this however will quickly cause the mortality rate to increase over the warming period of the ocean water. During 2005 the United States lost a server amount of its coral reefs due to a major bleaching event. This event was recorded to be a greater thermal stress inducing event, compared to the previous 20 years combined. This devastating coral bleaching event was concentrated around the Antilles of the coast of the Vergin Islands and Puerto Rico. This Coral bleaching event then stretched southward causing large sections, and many coral species to be lost. Both hard coral and soft coral are affected in these bleaching events. It's also worth noting that not all coral bleaching events are onset by the drastic warming of the surrounding ocean water, as cooling the water has the same effect as warming does. This was the case back in January of 2010 when the water temperature dropped low enough to induce a coral bleaching event in the Florida Keys. The drop in temperature was 12.06 degrees Fahrenheit below average temperatures of the ocean at that time of year. It's still unknown if cold-stress induced coral bleaching events have a similar effect on the coral as the warming bleaching events. A major area of interest is if both type of coral bleaching events cause coral to be susceptible to diseases in the same manor.

National Geographic says that the coral scientific name is Anthozoa, they are invertebrates, and are carnivores. National Geographic defines corals as individual polyps that live together to form massive communities called coral reefs. Coral polyps are soft-bodied creatures or organisms, that are related to creatures such as sea anemones, and even jellyfish. A polyp's life span is two to hundreds of years long. A polyp's size is anywhere between 0.25inches up to 12inches. Though generally they are roughly the size of a teacup. Each coral has a hard and protective based made of limestone Skellington. These bases are called calicles. A reef will form one a single coral attaches itself to a rock and begins to bud and divide into hundreds and thousands of clones. The polyp calicles will then connect to each other to create a single body structure, this in turn will cause the coral to act as a single organism, when in fact it's a community made up of hundreds if not thousands of organisms. A single colony can and will grow for over thousands of years. When colonies grow large enough to connect with other coral colonies, they will then form a coral reef. Some coral reefs have been growing for over 50million years. (National Geographic, 2018)

Weis, and colleges write that corals are responsible for the basic and fundamental structure of all coral reefs. However, due to current global environmental circumstances that corals are in massive decline. They claim that these disturbances are destroying a very crucial symbiotic relationship between the coral and their intercellular dinoflagellate partners. They go

on to say that it's imperative that there must be 100% understanding the simple and yet very complex relationship between both the coral and the zooxanthellae. Along with the cellular processes and exchanges between the two, that occur during the symbiosis relationship. This information will provide us with details on how the symbiotic relationship is affected by climate change, both mechanisms that are the key and minor driving forces. Along with corals' susceptibility to diseases. Another area that will provide a great amount of incite is the coevolution of the symbiotic relationship in the strange world of host-microbe interactions. They finish by say that both understanding coral biology and building coral bleaching event models are imperative to each other's understanding. It's crucial to have all the information at hand when looking at one or both sides of the equation. (Weis et al., 2008)

Brown writes that though it's been over 10 years since the massive coral bleaching was first described. He claims that the most causes have been attributed to ocean temperatures climbing to intolerable conditions for coral. However, that other causes that can be contributor factors are high solar irradiance and dieses to some extents. Brown goes on to say that it's imperative for us to reevaluate all the data and knowledge that we have on the physical and biological factors that are involved with the bleaching events, zooxanthellae mechanisms, pigment loss, along with the ecological consequences on the coral communities. In his research he looks at recent data to see if the claims, that recent and steadily climbing background sea temperatures are to blame for repeating coral bleaching events, holds any water. In his research he also looks at the cellular mechanisms that cause the zooxanthellae to be degenerated and then algae being ejected from the host cells. He also goes on to examine the photo-protective defenses within the zooxanthellae to help mitigate the bleaching response wish is probably due to both elevated water temperatures and increase solar radiance. Lastly Brown goes on to state that corals' ability to adapt to recurring bleaching events is unknown. However, that both the phenotypic responses of both the coral and zooxanthellae may be significant. (Brown, 1997)

Bahr, and colleges say that both Ocean warming and acidification effect coral reefs with negative implications. Their study tries to evaluate the causes of all the negative responses observed in the Hawaiian corals to different climate change scenarios. Theis study will include the following areas of interest: Net Calcification, dark respiration, and gross photosynthesis. All three were measured in three different species across the different ranges of temperature and acidification regimes. One observation was that Calcification rates were displayed as a curvilinear response due to temperature. The peak calcification rates were observed at twenty-six degrees Celsius. The different coral responses to ocean acidification was a lot more dependent per species and there for highly variable. (Bahr et al., 2018)

Magel and colleges did a study looking at how the effects of climate change and heat stress events have on the reef life. This study is worth noting as it looks at the reef fish communities and how they deal with the increased stress on the reef. They write that yes, climate change effects corals, but that even less is known about its effect on the coral reef fish population. They found that during a marine heatwave that biomass and abundance dropped. They say this is because the reef fish, unlike coral, can swim to cooler water. Another

remarkable thing they found that is reef fish communities bounced right back after the area cooled down. Unlike reefs that have human disturbances. (Magel et al., 2020)

Khan and colleges are working on a way to increase prediction model outputs. They claim that one way to accomplish this will be to combine forecasts from multiple models. The way that this has been being implemented is by using the same time constraints from each model and disregarding all the extra data. The study aims to try this approach by combining multi-model sea surface temperature models. However, each data set they use will start and end on different dates. Thus, they will get rid of all data that is outside the shared time zone. (Khan et al., 2018)

Rolfer and colleges are currently working on looking at the combination of both the warming of the ocean and the decreasing of the ocean's pH caused by ocean acidification. They claim that both effects are being caused by rising CO2 emissions in the atmosphere. These scientists say this the combination will cause a large amount of stress on both the corals and macroalgae that cause a great abundance on organisms on the reef and reef health overall. (Rolfer et al., 2020)

Peng and colleges claim that long-term ocean warming trends will have other major implications opposed to aspects of the ocean environment outside of coral bleaching events. They claim that one of these major impacts is that with increased ocean water temperatures, there is a reduced lipid and FA content in phytoplankton. However, at the end of their study they did manage to see a recovering curve to extended exposure to the long-term warming. They are hopeful that the phytoplankton will be able to adapt and overcome the new introduced stress factor of the increased heat. (Peng et al., 2020)

Hussain and college say that the 2014-2017 mass bleaching event has gone down as the third largest global bleaching event that had been recorded by the time this study was wrote. This study is mainly looking at the bleaching events that took place during the 2015 and 2016 years. As this will help give in-sight into how the environment changes, adapts, and taking record of the dire consequences during these heighten stress levels on the coral reefs. (Hussain et al., 2020)

Kwiatkowski and colleges looked at ocean warming trends, acidification, deoxygenation, upper-ocean nutrient, and primary production declining trends predictions by using the CMIP6 model. They find that with both the current data that they inputted into the CMIP6 model and used parameters that they though best would represent future restrictions on the ever-changing environment. They found that all the detrimental effects will be increased as these trends will continue and cause more damage than good. (Kwiatkowski et al,. 2020)

Project Objective:

The Objective of this project is to create a Coral bleaching event prediction model. This project will be completed, by using the ESRI software: Arc Pro. Along with data that obtained from the National Center for Atmospheric Research's (NCAR) Research Data Archive. Once the data set is downloaded and brought into Arc Pro, the data will be processed using geoprocessing

tools. Further analysis can then be ran, to determine, which areas will be at a greater risk due to warming water anomaly events causing coral beaching.

Materials and Methods:

The data used for this project will be a netCDF file downloaded from the National Center for Atmospheric Research's (NCAR) Research Data Archive. The file will be included in a Climate System Reanalysis Forecast (CSRF) product. This data set is set up to have data recording of 35 years of sea surface temperature data recorded monthly. The data set also has a spatial resolution of 0.5 degrees. The National Center for Atmospheric Research's (NCAR) Research Data Archive data portal URL is https://rda.ucar.edu/.

The software that will be used is the ESRI's Arc Pro. As this will allow for all the geoprocessing tools to be utilized without having to further download other extensions. The toolbox batch file will be generated using the arc.py window in Arc Pro, then saved to a project folder. However, the Batch file for the coral bleaching event prediction model will then be written using the Notepad ++ text editor using the Python language feature with the default python settings.

First go to the National Center for Atmospheric Research's (NCAR) Research Data Archive data portal and download the data. The data package can be found at https://rda.ucar.edu/. Once data has been downloaded from NCAR's Research Data Archive data portal, the next thing will be to do is open ESRI's Arc Pro. After Arc Pro opens choose start new project and name it Coral Bleaching Prediction Model. Next, right click the toolbox in the catalog and choose New Python Toolbox. Navigate to the project folder for the coral bleaching prediction model and save the python toolbox there. Next close the pop-up window that generates the python toolbox code and minimize Arc Pro. Next will be to program the following parameters.

Trend parameter:

Input Multidimensional Raster = input dataset raster

Output Multidimensional Raster = Generated Trend Raster

Dimension = StdTime

Variables = cfsrsst

Trend Line Type = Harmonic

Frequency / Polynomial Order = 1

Ignore No Data = box is checked

Predict parameter:

Input Multidimensional Raster = Generated Trend Raster

Output Multidimensional Raster = Generated Prediction Raster

Variables = cfsrsst

Dimension Definition = By Interval

Start = 2011-01-01T00:00:00

End = 2022-01-01T00:00:00

Value Interval = 1

Unit = Weeks

Anomaly parameter:

Input Multidimensional Raster = Generated Prediction Raster

Output Multidimensional Raster = Generated Anomaly Raster

Variables = cfsrsst

Anomaly Calculation Method = Difference From Mean

Mean Calculation Interval = Recurring Weekly

Ignore No Data = box is checked

Find Argument Statistics parameter:

Input Multidimensional Raster = Generated Prediction Raster

Dimension = StdTime

Variables = cfsrsst_diff_anomaly

Output Raster = Argument Statistics Raster

Statistics Type = Duration

Dimension Definition = Interval Keyword

Keyword Interval = Yearly

Minimum Value = 0.1

Maximum Value = 5

Ignore No Data = box is checked

The code after completition will look like the following:

```
# -*- coding: utf-8 -*-
import arcpy
```

```
class Toolbox(object):
    def __init__(self):
        """Define the toolbox (the name of the toolbox is the name of the
        .pyt file)."""
        self.label = "Coral Bleaching Event Prediction Toolbox"
        self.alias = ""
        # List of tool classes associated with this toolbox
        self.tools = [CoralBleachingEventPredictionTool]

class CoralBleachingEventPredictionTool(object):
    def __init__(self):
        """Define the tool (tool name is the name of the class)."""
        self.label = "Coral Bleaching Event Prediction Tool"
        self.description = ""
        self.canRunInBackground = False

    def getParameterInfo(self):
        """Define parameter definitions"""
        #Input Multidimensional Raster
        imdr = arcpy.Parameter(
            name="imdr",
            displayName="Input Multidimensional Raster",
            direction="Input",
            datatype="GPRasterLayer",
            parameterType="Required")

        #Generate Trend Raster Output
        gtro = arcpy.Parameter(
```

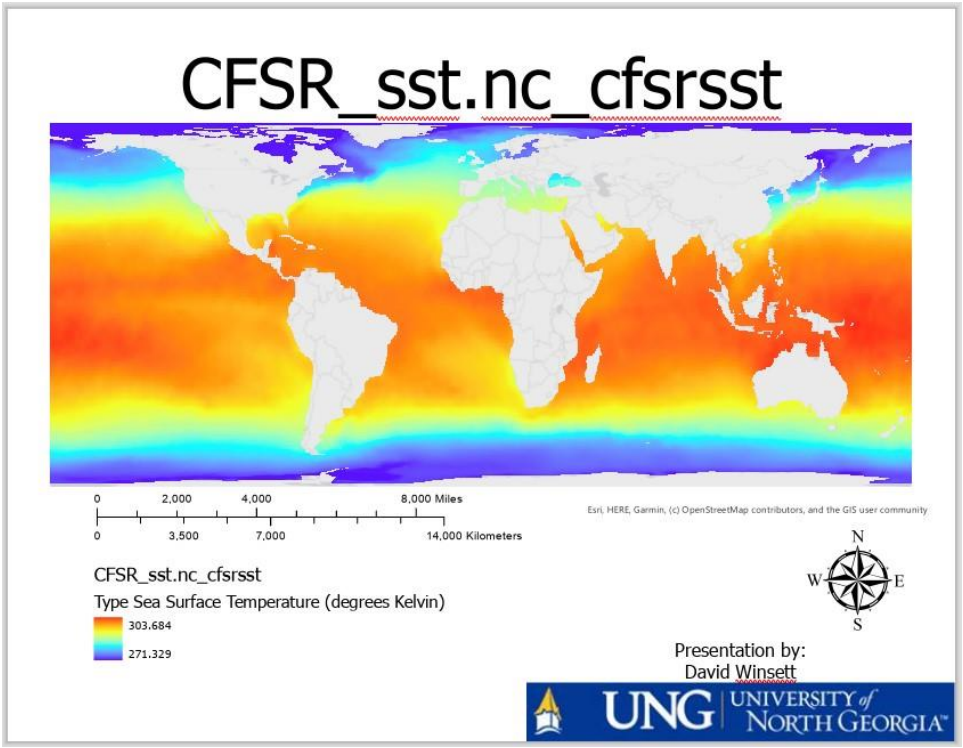
```
    name="gtr",
    displayName="Generate Trend Raster Output",
    direction="Output",
    datatype="DERasterDataset",
    parameterType="Required")

#Predic Using Trend Raster Output
putro = arcpy.Parameter(
    name="putr",
    displayName="Predic Using Trend Raster Output",
    direction="Output",
    datatype="DERasterDataset",
    parameterType="Required")

#Generate Multidimensional Anomaly Output
gmao = arcpy.Parameter(
    name="gma",
    displayName="Generate Multidimensional Anomaly Output",
    direction="Output",
    datatype="DERasterDataset",
    parameterType="Required")

#Find Argument Statistics Output
faso = arcpy.Parameter(
    name="fas",
    displayName="Find Argument Statistics Output",
    direction="Output",
    datatype="DERasterDataset",
```

```
        parameterType="Required")

    params = [imdr, gtro, putro, gmao, faso]
    return params

def isLicensed(self):
    """Set whether tool is licensed to execute."""
    return True

def updateParameters(self, parameters):
    """Modify the values and properties of parameters before internal
    validation is performed.  This method is called whenever a parameter
    has been changed."""
    return

def updateMessages(self, parameters):
    """Modify the messages created by internal validation for each tool
    parameter.  This method is called after internal validation."""
    return

def execute(self, parameters, messages):
    """The source code of the tool."""
    imdr = parameters[0].ValueAsText
    gtro = parameters[1].ValueAsText
    putro = parameters[2].ValueAsText
    gmao = parameters[3].ValueAsText
    faso = parameters[4].ValueAsText
```

```
    out_gtro = arcpy.ia.GenerateTrendRaster(imdr, "StdTime", "cfsrsst", "HARMONIC", 1,
"DATA", 1, "YEARS", "RMSE", "NO_R2", "NO_SLOPEPVALUE")

    out_gtro.save(gtro)

    out_putro = arcpy.ia.PredictUsingTrendRaster(gtro, "cfsrsst", "BY_INTERVAL", None,
"2011-01-01T00:00:00", "2022-01-01T00:00:00", 1, "WEEKS")

    out_putro.save(putro)

    out_gmao = arcpy.ia.GenerateMultidimensionalAnomaly(putro, "cfsrsst",
"DIFFERENCE_FROM_MEAN", "RECURRING_WEEKLY", "DATA", None)

    out_gmao.save(gmao)

    out_faso = arcpy.ia.FindArgumentStatistics(gmao, "DURATION", 0.1, 5, None, "DATA")

    out_faso.save(faso)

    return
```

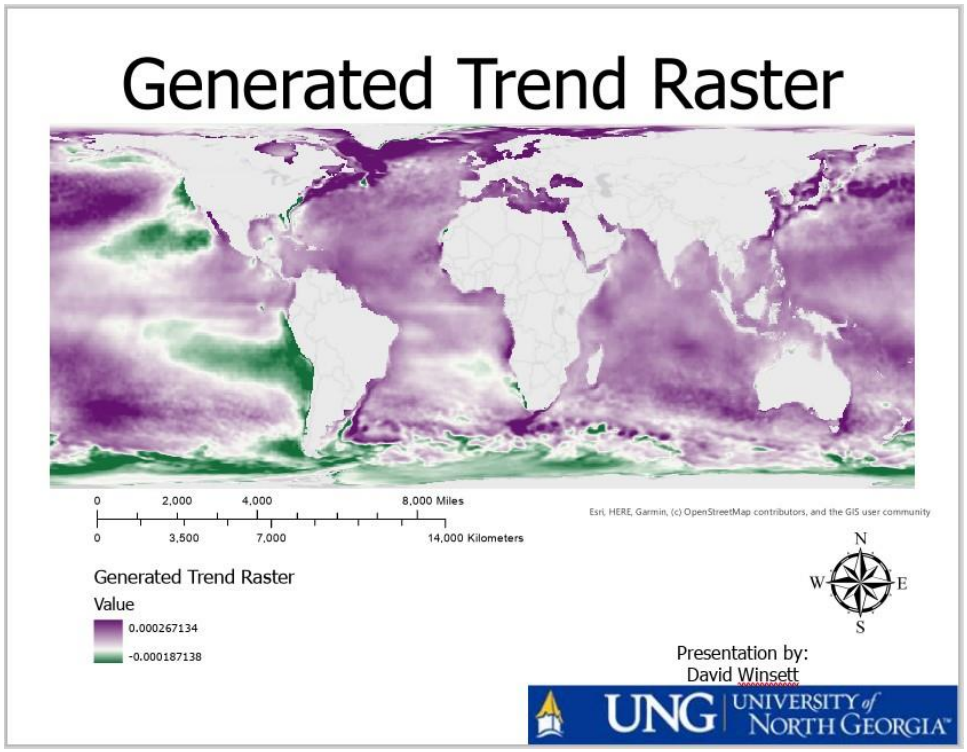
Once the python toolbox is created. Then reopen the Coral Bleaching Prediction Model project, add the Coral Bleaching Prediction Model toolbox and double click the newly created tool. Then add a map to the template and input the data obtained from the National Center for Atmospheric Research's (NCAR) Research Data Archive data portal. By clicking Add Data and choosing the Multidimensional Data Raster Set. Click the check box and then ok to have the data added to the map. Now click background map and choose the grey map choice. Next select the newly created layer for the tool's input. Next name each given output using a .crf at the end, as the files will contain multiple bands, thus the .tif won't be sufficient. The product will then be the Find Argument Statistics Raster.

Figure 1 displays the Initial Multidimensional Data Raster



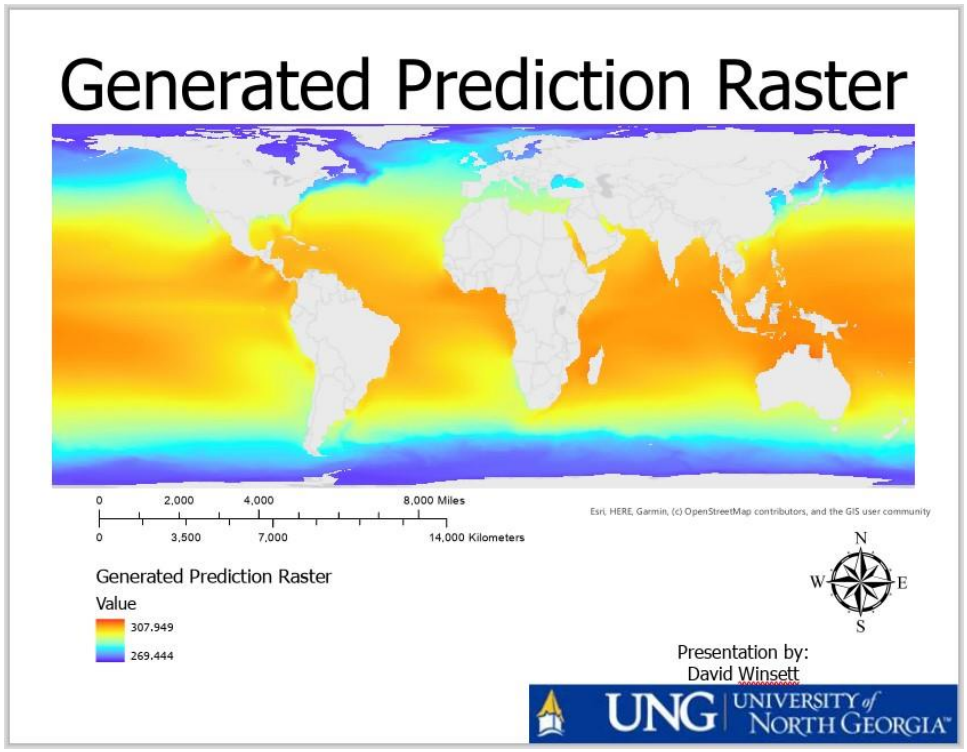
[Figure 1]

Figure 2 displays the Generated Trend Raster



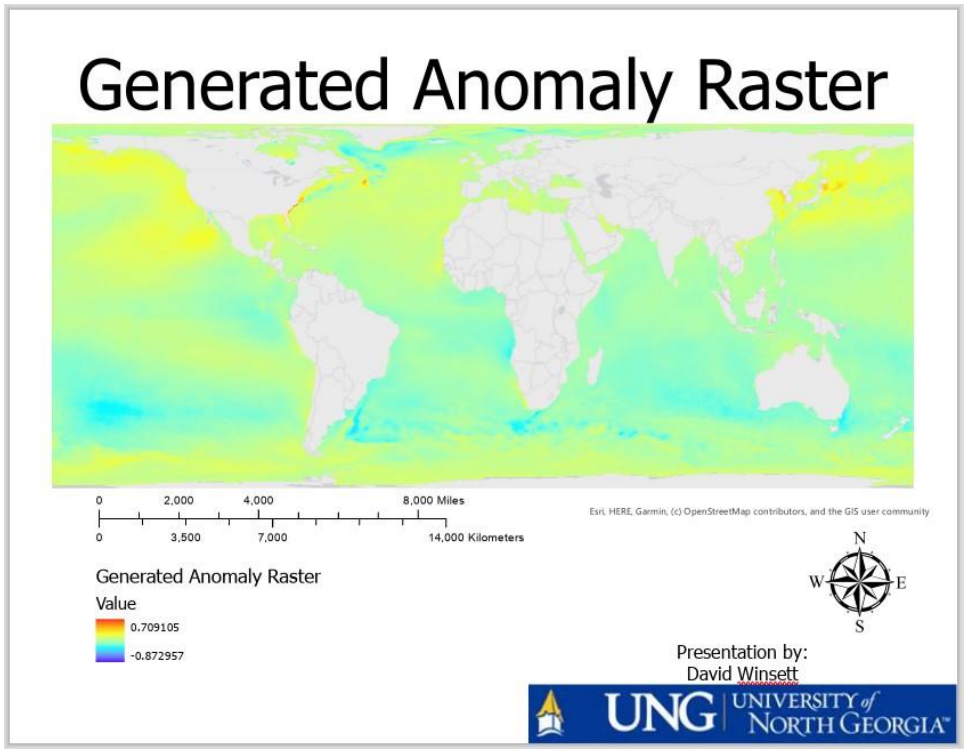
[Figure 2]

Figure 3 displays the Generated Prediction Raster



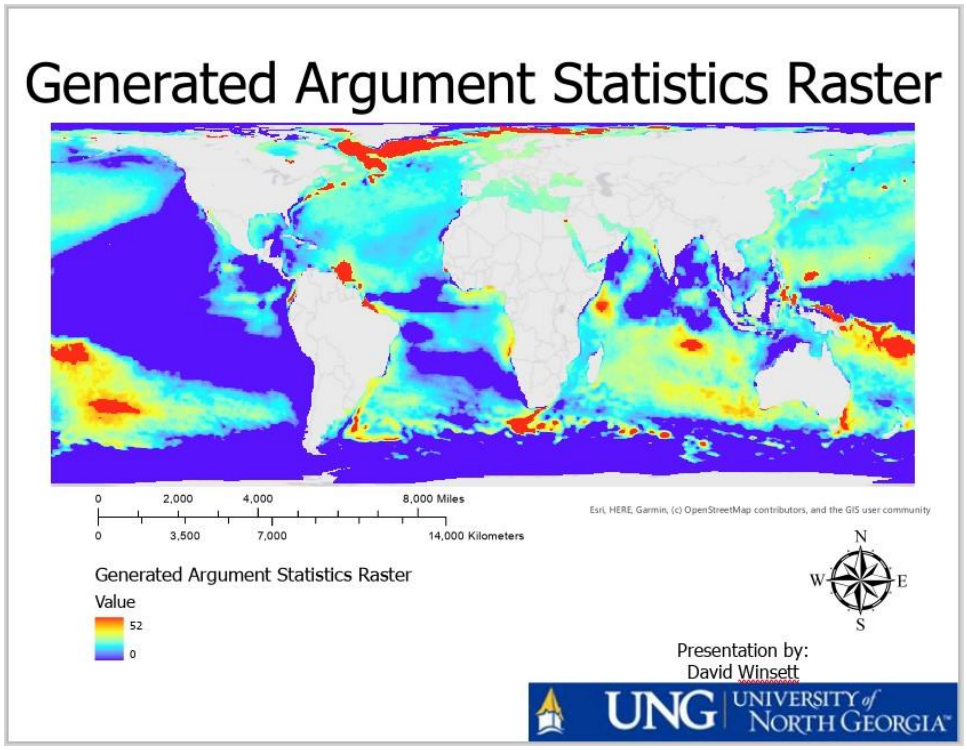
[Figure 3]

Figure 4 displays the Generated Anomaly Raster



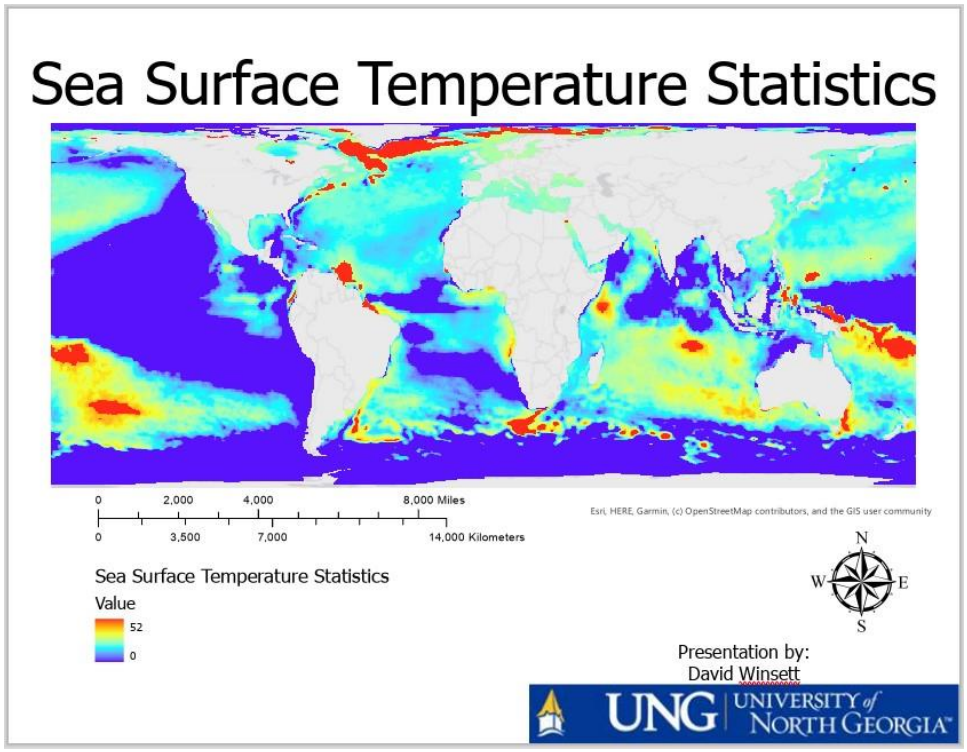
[Figure 4]

Figure 5 displays the Generated Argument Statistics Raster



[Figure 5]

Figure 6 displays the Final Product



[Figure 6]

Conclusion:

In conclusion, coral bleaching events have been a very significant issue when studying how climate change is affecting very complex and highly diverse ecosystems on earth. Mass bleaching events are caused by water temperatures being higher or lower than the normal trend ranges for an extended period of time. This is very noticeable as the bright coloration of the coral turns white as the coral ejects the algae out into the open sea. This in turn the makes the coral's mortality rate climb as it's then exposed to a lot of new threats that the algae help prevent. The human race has seen bleaching events time and time again since the 70's. However, nothing as extreme since the major warming of earth's climate. There are many case studies and efforts underway to help figure out a way to reduce the impact to the coral through these great times of stress. Along with newer and better models being produced to help better understand what's going to happen in certain areas of the ocean in the near to far future.

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