Visualizing Organismal Thermal Stress Over Time

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INTRODUCTION

Anthropogenic climate change is having a dramatic effect on earth's natural systems. To maintain functional ecosystems and preserve biodiversity in this changing world, the conservation community has come to rely on computational models to inform decision making. One particular class of model, known as a "biophysical model," uses mathematical representations of energy balance and organism-environment heat transfer to translate environmental conditions into organismal body temperatures.

From laboratory experiments with myriad ectothermic species (that is, organisms that rely on behavior and the environment for temperature regulation), we know that organisms are sensitive to certain body temperature thresholds ("biophysical thresholds") above or below which their performance (i.e. ability to eat, move, reproduce) is limited. When an organism's body temperature crosses one of these thresholds (i.e. goes below a lower threshold or above a high threshold), we consider the organism to be experiencing "thermal stress."

Conservation biologists, biological reserve planners, and policymakers have a mandate to protect species from human actions, and can use thermal stress to predict patterns of organism movement. Biophysical models are one of many tools that can be employed toward this task. Unfortunately, the outputs from these models are difficult for an untrained observer to assimilate into a planning process. Tools for visualizing the practical insights from these model outputs can fill this gap. Herein we develop a web-based visualization which attempts to demonstrate how levels of thermal stress are distributed both temporally and spatially for a theoretical ecothermic organism.

RELATED WORK

Ecological visualizations for the purpose of assisting decision making have heretofore mostly consisted of static geographic maps of predicted species range boundaries as determined by a class of models known as species distribution models [2]. To our knowledge, no attempts have been made to produce a public-facing visualization tool for the purpose of understanding trends in biophysical model output. The topic of biophysical modeling and its implications for predicting responses to changing climates has received treatment in the scientific literature [1, 3], but there is a lack of visualization tools for the purpose of understanding thermal stress across spatial and temporal dimensions in a public audience.

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METHODS

The methodology for this effort was divided into two parts: **1)** model output processing and **2)** web visualization design and development. The visualization was intended to address two primary goals: **1)** to allow a user to explore and draw conclusions about the spatial extent and the temporal trend of thermal stress over several decades of daily data and **2)** to distill these decades of daily model output data for a wide spatial extent into a concise interactive visualization. These goals introduced a central implementation challenge, namely the development of a new data pipeline for the conversion of many gigabytes of raw model output into a compressed package of visual elements for an interactive web visualization. We developed a set of software tools in Python which interpolate model output, apply a biophysical threshold to the interpolated model output to extract areas of thermal stress, and produce compressed model output imagery and spatial files for delivery to a web browser via Amazon Web Services' Simple Storage Service.

The actual data being displayed in the current iteration of the visualization represents model output derived from historical climatic data. For the purposes of illustration the biophysical threshold chosen is lower than is biologically-relevant to demonstrate visualization functionality.

The development of the actual interactive visualization was pursued using `D3.js` and `Mapbox.js`. Because a goal of the visualization was the exploration of decades of daily thermal stress information, the visualization was developed to allow for on-the-fly loading of pre-computed elements (such as the stressed area spatial extent and raw model output).

RESULTS

The visualization produced (**Figures 1, 2** and `https://cse512-18s.github.io/organismal-thermal-stress/`) delivers the ability to brush temporally across biophysical model output to examine the spatial extent of organismal thermal stress over time. Both the spatial extent (highlighted using spatial polygons over a geographic map) and the raw model output

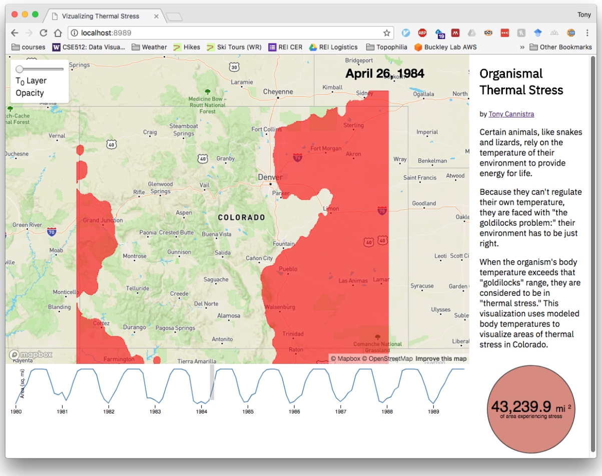

Figure 1. Organismal thermal stress visualization, showing April 26, 1984. Red polygons represent areas of thermal stress. Brushing over line chart of average weekly stressed area allows for exploration of stress over time (seasonal variation visible).

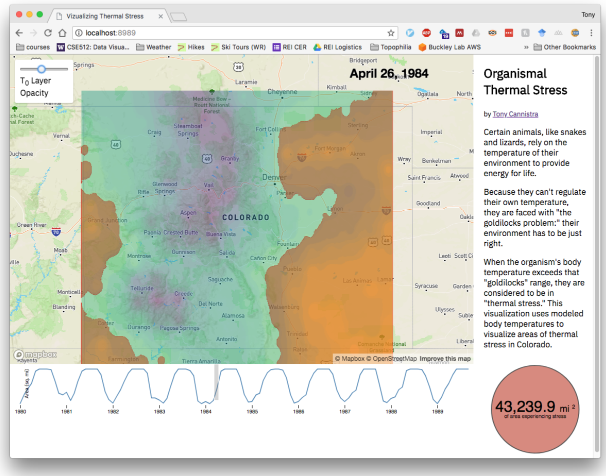

Figure 2. Organismal thermal stress visualization demonstrating ability to view raw model output(blue: cooler, yellow: warmer body temperature) using opacity slider (top left).

(available using a variable-opacity overlay) are viewable. In addition, the visualization offers the facility to evaluate change in spatial extent of thermal stress over the modeled timeframe. It is available as a responsive web-based visualization backed by pre-processed visual components.

Figure 1 demonstrates the visualization of a single day of model output, both spatially-aggregated using a biophysical threshold (left panel) and the raw model output (right panel). Dragging a slider (top left, Figure 2) allows for the selective view of model output. The bottom of the visualization demonstrates the trend in geographic landscape area containing stressful body temperatures over time, and a brush allows for the inspection of the spatial extent of thermal stress over time. Moving the brush updates the map.

This type of visualization allows for a quick understanding of whether there are any trends in the amount of thermal stress over time as well as the ability to qualitatively assess whether certain geographic regions contain stressful conditions frequently (or not). When coupled with model output generated from future climate projections this visualization can assist in the interpretation of these model projections and their relevance to the effect of climate change on organisms.

DISCUSSION

The primary contribution of this work has been the establishment of a visual framework for the presentation of a large quantity of biophysical model output. We have coupled a novel data pipeline with an aggregate data visualization to enhance the ability to view gigabytes of model output information over wide temporal and spatial domains. The objective value of this contribution is in the laying of groundwork for the development of further public-facing data products for the purpose of enabling decision making and conservation planning backed by rigorous science. In particular, the developing ability to view both spatial and temporal trends in organismal thermal stress will serve as a critical stepping-stone on the path to these policy-relevant model visualizations.

FUTURE WORK

The future of this project will be propelled by three primary thrusts: data, spatial comparison, and on-the-fly model parameterization. The current iteration of this visualization shows model output which is irrelevant for a conservation context as a result of its historical nature and short timeline—no appreciable similarities between the current data and future projections can reliably be drawn. Additionally, the biophysical threshold used in this demonstration is not backed by relevant biology, chosen only to eludicate functionality. A critical next step is to proceed with the generation of future organismal body temperature model output for future climate projections, parameterized to a focal species. Paired with actual species' thermal tolerances, we will create a visualization of thermal stress at greater temporal and spatial scale which is more easily operationalized in a conservation planning context.

A shortfall of our current visualization is the inability to visually compare thermally-stressed regions spatially. This makes it challenging to determine whether there are "thermal stress hotspots:" places where stress is occuring more often than the surroundings. Developing a visual encoding for "spatial continuity" as the user brushes across time will enhance their ability to discern areas of conservation relevance.

Finally, the "moonshot" goal of this project is to allow any conservation biologist to perform on-the-fly parameterization of the underlying biophysical model and resulting visualization. This will allow for the study of arbitrary species of interest without the specialized knowledge required to run the biophysical model and greatly enhances the general utility of this tool in the decisionmaking community. This goal offers engineering and implementation challenges at every part of the project, but also represents a considerable potential for gain in the usefulness of this tool.

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