Development of an Interactive Visualization and Training Toolkit for Climate Impacts on the Channel Islands National Marine Sanctuary

PROPOSERS

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CLIENT & FACULTY SUPPORT

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OBJECTIVE

The objective of this project is to develop an educational toolkit and interactive, Python-based Web application to visualize ecologically significant climate variables near the Channel Islands National Marine Sanctuary (CINMS). The Web application will be used by UCSB researchers to analyze 'large ensemble' sets of climate model output, and by CINMS staff to develop new indicators of shocks to marine ecosystems, which will inform management decisions. The educational toolkit, comprised of Jupyter notebooks, will be part of the ongoing development of the Climate DataLab training environment.

SIGNIFICANCE

California's coastal waters are home to some of the most productive and vibrant ecosystems in the country, which provide a variety of critical ecosystem services (Harvey et al. 1967). However, these sensitive ecosystems are highly susceptible to climate-driven 'shock' events, which are associated with extreme values of temperature, pH, or ocean nutrient levels. A particularly devastating example was seen in 2014-16, when extreme temperatures and changes in nutrient conditions off the California coast led to large-scale die-offs of marine organisms (Sanford et al. 2019). Climate change is expected to exacerbate the impacts of these events: warming will increase the intensity of marine heat waves, while ongoing ocean acidification will worsen the impacts of short-term pH changes (e.g. Cheung et al. 2020). Understanding the physical mechanisms driving impacts in the Channel Islands is critical to management and conservation.

Since extreme events are rare, "large ensemble" climate model projections are needed to get a good sense of their behavior. These are sets of simulations run with a given climate model, varying only the initial conditions in order to understand the range of possible extremes (Deser et al. 2020). Large ensembles are fairly new, and as of yet, underutilized for marine conservation – this will be the **first exploration of large ensembles applied to the Channel Islands**.

BACKGROUND

Marine sanctuaries along the US West Coast have long been involved with monitoring and evaluating ecological health. In recent years, the recognition of the importance of climate change

led to the adoption of a nationwide framework for climate adaptation (ONMS, 2019). The heart of these efforts is the Condition Report/Climate Vulnerability Analysis Framework, where Sanctuary staff synthesize ecological, social, and physical information to form 'indicators' summarizing the confidence level and direction of change in quantities relevant to ecosystem health. Some of these relate to water quality (e.g. health risks); others focus on habitat/species status; but all are likely to be affected by climate change. Despite its importance, there has been no quantitative incorporation of climate data into the indicator framework.

A new NOAA-funded collaboration between UCSB and CINMS is using information from large ensembles of climate model simulations to determine the range of possible future climate-driven 'shocks' to marine ecosystems. The goal of this collaboration is to support the CINMS staff in their development of new, quantitative climate-based indicators - this will involve bringing together place-based knowledge with ecological insights, as well as physical climate information. The proposed Web application will provide direct visualization of how climate trends and extremes are expressed as changes in ocean conditions near the Channel Islands, which will enable the range of potential impacts to be quantified for the first time.

EQUITY

The CINMS is a crucial marine conservation resource; it is also pursuing environmental justice-focused efforts, including the Chumash Ecosystem Services Assessment (ONMS, 2019). The tutorial products will also be used for training URM students at UCSB in climate modeling. However, the core objectives are not primarily focused on Environmental Justice and Equity.

DATA

All data to be used is publicly available and free to the community. Access will take place via the cloud-based Pangeo network, which has built-in compatibility with Python tools and enables easy computation. Initial data exploration will use the Community Earth System Model version 1 Large Ensemble (CESM1 LENS; Kay et al. 2015), one of the most reliable and widely used large ensembles that has already been ported to Pangeo. The CESM1 Data will be used to create mapping layers for ocean temperature, salinity, dissolved oxygen, nutrients, and pH. The project scope may also expand to other large ensembles submitted to the Coupled Model Intercomparison Project version 6 (CMIP6), subject to time constraints.

Resource	**Link**
CESM1 LENS	https://www.cesm.ucar.edu/community-projects/lens/data-sets
Pangeo	(https://pangeo.io/) (https://gallery.pangeo.io/).
CMIP	https://esgf-node.llnl.gov/search/cmip5/

COMPUTATIONAL TOOLS & NEEDS

Students will be expected to develop Jupyter notebooks using Taylor or VS Code to create well-commented, reproducible Python tutorials. These will be used as the backend code for a web application. It will be coded using a multitude of Python packages, including Pangeo and Dash. Some exploration of Python packages for interactive web applications will be required. Results will be maintained by the Stevenson group after the completion of the project. Both the tutorials and the dashboard will be incorporated into the forthcoming Climate DataLab website (climate-datalab.org), which will be released in Winter 2024 and provide long-term hosting.

POSSIBLE APPROACHES

The approaches proposed here are fairly standard, enabling the project to begin quickly. Tutorials using Jupyter notebooks are commonly used across data science, and we anticipate that this approach will be highly successful for Deliverable 1 (see below). We will create a Jupyter notebook-based coding framework to quickly display climate model data layers, covering both present-day and future projections. This code infrastructure will provide the back end for a Web application. Existing dashboard tools will be used to translate the resulting data layers into a Web application for Deliverable 2. One prospective tool is Dash (https://plotly.com/dash/), but other tools may also be explored. Mapping layers will include a range of variables, including ocean temperature, salinity, dissolved oxygen, nutrients, and pH, in coastal areas of California. The application will also allow for multivariable data visualization and computations of ecological threshold exceedances.

DELIVERABLES

1. **Standardized, reproducible Python tutorials** which can load in geospatial data from a variety of climate models covering CINMS waters. The results will be used by UCSB students/researchers, Sanctuary staff, and the wider climate research community, and this approach has the potential to be employed across other marine sanctuary areas.
2. **Interactive Web application** to visualize the results of this analysis. This will form the basis of a dashboard-based collaboration with CINMS staff, which will eventually inform new versions of climate vulnerability assessments for the Sanctuary networks.

AUDIENCE

The proposed deliverables will be useful to several different audiences (end users).

- *Researchers:* The Web visualization tool will facilitate UCSB/CINMS collaboration on indicator development, and UCSB researchers will use the Python code framework for further data analysis.
- *Students:* The tutorials will also be incorporated into education and training efforts across the Bren School.

BUDGET

Funding beyond what is provided by the Bren School should not be necessary, as all datasets are freely available. However, the Stevenson group can cover any incidental costs that arise.

Literature Cited

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To the MEDS Capstone Committee:

I am writing to express my willingness to support the proposal I recently submitted for a 2023-24 Bren School Masters of Environmental Data Science capstone project, entitled "Development of an Interactive Visualization and Training Toolkit for Climate Impacts on the Channel Islands National Marine Sanctuary". This project is focused on the analysis of geospatial datasets from publicly available cloud-based archives of climate model simulations, and using the results to develop 1) an interactive Web-based dashboard to display data layers corresponding to ecologically significant quantities over the Channel Islands coastal region, and 2) Python tutorials explaining the analysis process, which will be provided for research and training purposes. The details of how my group can support this project are provided below.

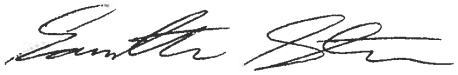
Data: All data used in the proposed project are freely available to the public. Datasets consist of output from 'large ensemble' simulations run with climate models, which contain spatially complete estimates of numerous (100+) individual variables. For these purposes, oceanic variables will be the focus, including quantities such as temperature, salinity, pH, dissolved oxygen, and other nutrients. The primary collection of simulation data to be used in this project was generated with a climate model called the Community Earth System Model version 1 (CESM1), simulations from which extend over the period 1920-2100. Due to the size of these datasets, they are hosted via Amazon Web Services and access is provided via a Python-based API, which is documented as part of the Pangeo community platform (https://pangeo.io/dev/index.html).

Although the data platform is publicly available and in theory should not present any issues for MEDS students to access, I am nonetheless prepared to provide logistical support for the capstone students in gaining familiarity with reading in information via Pangeo. I personally have over 15 years of experience working with climate model datasets, and both myself and students/postdocs in my group can provide examples of Python code as needed which can help MEDS students with any issues they may encounter.

Funding: I do not anticipate any needs for financial support for this project beyond what the Bren School has already committed to providing. All resources needed to complete the work should already be free and open-source, and therefore do not require additional financing. That said, if it becomes necessary for students to access a resource with an associated cost (for instance, proprietary dashboarding software, etc.), I am prepared to support this. The project is aligned with a recently funded grant to my group through the NOAA Climate Program Office, and the NOAA grant budget can cover moderate expenses (less than $500) as needed.

Please feel free to contact me if you have any further questions.

Sincerely,



Samantha Stevenson