Gulf of Mexico Spatial-Temporal Environmental Data

Holden Harris

SEDAR87-DW-09

14 September 2023

Please cite this document as:

Harris, Holden. 2023. Gulf of Mexico Spatial-Temporal Environmental Data. SEDAR87-DW-09. SEDAR, North Charleston, SC. 8 pp.

Gulf of Mexico Spatial-Temporal Environmental Data

Holden Earl Harris*[1,2]

*holden.harris@noaa.gov

1. Southeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration
2. Cooperative Institute of Marine and Atmospheric Sciences, Rosenstiel School of Marine Atmospheric and Earth Science, University of Miami

Summary

Gulf of Mexico spatial-temporal environmental data was acquired and processed from:

1. MODIS satellite imagery from 1993-2022 for chlorophyll-a, normalized carbon fluorescence, particulate organic carbon, and particulate inorganic carbon, and
2. HYCOM ocean model outputs from 2003-2022 for ocean temperature (surface, bottom, and average) and salinity (surface, bottom, and average).

These data are in gridded maps (8-second grid cells with an area of 14 km^2) with monthly time steps, and these resolutions could be adapted as needed for the stock assessment. The data processing and outputs are publicly available in a GitHub repository and described below.

Introduction

An ecosystem-based modeling framework can help an assessment incorporate the temporal variability and spatial heterogeneity of real environmental conditions, allowing for a more accurate representation of ecosystem processes and responses to changing environmental conditions. For example, we can model downstream impacts in the marine ecosystem from climatic changes in temperature patterns, precipitation, and circulation patterns through their biological impacts on primary and secondary production, species distribution, behavior, and ecological interactions. Collectively, these can provide insight into understanding and predicting the responses of the marine ecosystem to future environmental changes and support effective decision-making to promote climate-resilient fisheries. Collectively, including spatial-temporal environmental (STE) data enables us to understand and predict the interactions between species and a dynamic environment.

This STE data was collected and processed for the purpose of incorporating environmental drivers into a U.S. Gulf of Mexico Ecosystem Model (USGWEM) developed with Ecopath with Ecosim and Ecospace (EwE). Recent research with the USGWEM included parameterizing the Ecopath diet matrix (Sagarese et al. 2016), building its food web (Sagarese, Lauretta & Walter, 2017), and its recent application to examine ecological reference points for Gulf Menhaden as a forage fish and commercial fishery (NOAA technical memorandum; Berenshtein et al. 2023). To develop STE data for Ecospace, monthly maps were derived from historical satellite imagery and ocean model hindcast projections. These were linked in the USGWEM by developing environmental response functions from parameters queried from the Aquamaps database. The effects of linking these STE drivers into the model were examined for biomass distribution projections from the USGWEM Ecospace and by comparing biomasses and catch timeseries to observed timeseries and Ecosim projections. The integration of hindcasted and forecasted STE data and projections into decision support models can ultimately help better understand climate and fisheries interactions and test ecosystem responses to simulated management actions.

About the Data

We process STE data made available from remote satellite imaging and earth system modeling from the following data sources:

- NASA's MODIS (Moderate Resolution Imaging Spectroradiometer; modis.gsfc.nasa.gov) is a satellite-based sensor that provides high-resolution oceanographic imaging, including measurements of ocean color, primary production indices, and other environmental variables over large spatial scales. MODIS satellites image the entire Earth's surface every 1 to 2 days. MODIS imagery is available from 2003-2022.

- HYCOM (Hybrid Coordinate Ocean Model; hycom.org) is a numerical ocean model that integrates satellite observations, in situ measurements, and oceanographic data to simulate and forecast ocean currents, temperature, salinity, and other oceanographic variables with high spatial and temporal resolution. HYCOM model outputs are available from 1993-2022.

This data from MODIS and HYCOM are non-confidential and openly available. The data processing and outputs are publicly available at github.com/SEFSC/IEA-GWEM-DataSynth/Ecospace-environmental-drivers. More specific links from this repository are given below.

The data outputs from MODIS and HYCOM are gridded monthly STE data maps. The high-resolution, downloaded files are NetCDF, which are as large as 250 GB. The processed data outputs are down-scaled, lower-resolution raster bricks and monthly ASCII files developed in R with the 'raster' and 'terra' packages. These are smaller (<1GB) and easier to manipulate.

The final 'processed-low resolution' outputs have been made to match the spatial extent of the U.S. Gulf of Mexico (long/lat bounding box = -98, -80.5, 24, 31) with 8-second grid cells that each have an area of 14 km2 (Fig. 1). This extent and resolution can be adapted to match the needs of the stock assessment scientists (e.g., higher resolution or a numeric timeseries for a specified area). Currently, the temporal resolution for the data is by month. Some data can be further resolved (e.g., daily) if needed. The MODIS data is available from 2003–2022, and the HYCOM data is available from 1993–2022.

Spatial-Temporal Environmental Variables

Spatially-explicit monthly data from MODIS are available for the following environmental variables:

1. *Chlorophyll-A (Chl-A)* Concentration. Euphotic-depth integrated Chl-A is a proxy for primary productivity and serves as an indicator of phytoplankton biomass. Monthly Chl-A concentration data provides information about the availability of nutrients and drives primary production.

    a. Processing Chl-A to estimate euphotic depth-integrated Chl-A is calculated based on equations from Morel and Berthon (1989), Morel and Marithorena (2001), and Lee (2007).
    b. The following PDF links in the above repository show the monthly plots for high-resolution and processed low-resolution map outputs (e.g., **Fig. 2**).

2. *Particulate organic carbon* (POC). This quantifies the amount of carbon held in tiny organic particles suspended in the water column, representing a fraction of the marine organic matter. The following PDF shows the processed low-resolution plots for this data.

3. *Normalized carbon fluorescence* (CFL). This data represents the relative fluorescence from organic carbon compounds when excited by light, which indicates the presence and health of phytoplankton in water bodies. The following PDF shows the processed low-resolution plots for this data.

Spatially-explicit monthly data from HYCOM are available for the following environmental variables:

1. *Seawater temperature* (surface, bottom, and average). Temperature influences the distribution and behavior of species and the rates of biological processes. The following PDFs show the monthly PDF plots for this data:
    a. Surface seawater temperature (high-resolution and processed low-resolution, e.g., Fig. 3)
    b. Bottom seawater temperature (high-resolution and processed low-resolution)
    c. Averaged seawater temperature (high-resolution and processed low-resolution)

2. *Seawater salinity* (surface, bottom, and average). Salinity changes can drive the spatial distribution of species based on their physiological responses, particularly for coastal and estuarine species or species that spend at least part of their ontogeny in inshore/coastal environments. The following PDFs show the monthly PDF plots for this data:
    d. Surface salinity (high-resolution and processed low-resolution)
    e. Bottom salinity (high-resolution and processed low-resolution)
    f. Averaged salinity (high-resolution and processed low-resolution)

Considerations and Limitations for MODIS and HYCOM data

MODIS offers relatively high temporal resolution, capturing the Earth's entire surface every 1 to 2 days. However, its spatial resolution might not always be sufficient to identify small-scale phenomena like algal blooms and red tides. One of the significant challenges with MODIS data, especially those related to ocean color, is the necessity for atmospheric correction. This correction can introduce errors in regions like the Gulf of Mexico, with various riverine inputs and fluctuating water types. Furthermore, in areas with intense phytoplankton concentrations, MODIS sensors can become saturated, leading to underestimations of chlorophyll-a concentrations. Sun glint, which is the reflectance from the sun, can also influence the quality of MODIS imagery. While the Gulf of Mexico isn't directly equatorial, sun glint can have an impact during specific times of the year. Lastly, as an optical sensor, MODIS's observations can be obscured by cloud cover, resulting in potential data gaps due to persistent cloud coverage.

HYCOM, as a numerical model, operates based on a set of assumptions. While it integrates data from satellite observations and in-situ measurements, its outputs are shaped by these assumptions along with model parameters and boundary conditions that might not perfectly align with real-world scenarios. Although HYCOM boasts high spatial and temporal resolutions, the model might not capture short-term and rapid environmental changes. Modeling in dynamic areas like the Gulf of Mexico, especially concerning salinity, is challenging. With major freshwater inputs, such as from the Mississippi River, accurately representing freshwater plumes with nutrients and sediments can be intricate. Lastly, there's a risk of a drift between HYCOM's output and the actual observations over extended periods, especially if not updated with recent observational data.

It should be considered that the intense human activity in the Gulf of Mexico—including shipping, oil and gas exploration, and fishing—can influence the region's environmental conditions in ways that may not be completely represented in satellite or modeled datasets. Noteworthy events, like the Deepwater Horizon oil spill, have profoundly impacted the Gulf's ecosystems, and the realized impacts of such incidents may not be entirely encapsulated in these datasets. Lastly, marine and coastal areas with high river outflows, particularly near the Mississippi River, can have extremely high turbidity and hypoxia, challenging both satellite data and modeling efforts.

Data Processing

Data processing was originally performed to develop STE for ecosystem modeling performed to develop the USGWEM Ecospace Model. The “data currency” for spatial input data in Ecospace are ASCII files, which all need consistent extent and resolution. The code to process the data is provided in the repository above and described with this ReadMe**.** Broadly, this queries the NOAA ERDDAP server for daily MODIS imagery (code) and directly queries HYCOM data outputs from (code). The next coding blocks process the NetCDF into STE outputs compatible with EwE. This includes cropping to match extent, resampling to match distribution, smoothing, and masking to prevent data loss near coastlines, and creating monthly average maps for years of missing data (for example, before the data products are available. These ultimately produce monthly ASCII files that are connected in Ecospace.

Querying and processing the STE data involves the following steps:

1. Set and loop over each environmental variable for download
2. Pulling daily imagery and aggregating into monthly raster stack
3. Setting up input and output directories
4. Crop and resample to match the base map (8s resolution)
5. Smoothing near-coastal data lost from downscaling by iteratively filling in missing values from averaging neighboring cells.
6. Making monthly averages for Ecospace years before data collection begins
7. Making monthly ASCII maps for Ecospace
8. Making global average ASCII to initiate Ecospace
9. Making PDF maps with the ‘pdf_map’ function for visualization

References

Berenshtein, I., Sagarese, S.R., Lauretta, M.V., Nuttall, M.A. and Chagaris, D.D., 2021. Technical documentation of a US Gulf of Mexico Ecopath with Ecosim model. NOAA technical memorandum NMFS-SEFSC; 751. https://doi.org/10.25923/zj8t-e656

Berenshtein, I., Sagarese, S.R., Lauretta, M.V., Schueller, A.M. and Chagaris, D.D., 2023. Identifying trade-offs and reference points in support of ecosystem approaches to managing Gulf of Mexico menhaden. Frontiers in Marine Science, 9, p.935324.

Lee, Z. P., et al. (2007). Euphotic zone depth: its derivation and implication to ocean-color remote sensing. Journal of Geophysical Research, 112(C3).

Morel, A., and Berthon, J. F. (1989). Surface pigments, algal biomass profiles, and potential production of the euphotic layer: relationships reinvestigated in review of remote-sensing applications. Limnology and Oceanography, 34(8), 1545-1562.

Morel, A., and Maritorena, S. (2001). Bio-optical properties of oceanic waters: A reappraisal. Journal of Geophysical Research: Oceans, 106(C4), 7163-7180.

Sagarese, S.R., Nuttall, M.A., Geers, T.M., Lauretta, M.V., Walter III, J.F. and Serafy, J.E., 2016. Quantifying the trophic importance of Gulf menhaden within the northern Gulf of Mexico ecosystem. Marine and Coastal Fisheries, 8(1), pp.23-45.

Sagarese, S.R., Lauretta, M.V. and Walter III, J.F., 2017. Progress towards a next-generation fisheries ecosystem model for the northern Gulf of Mexico. Ecological Modelling, 345, pp.75-98.

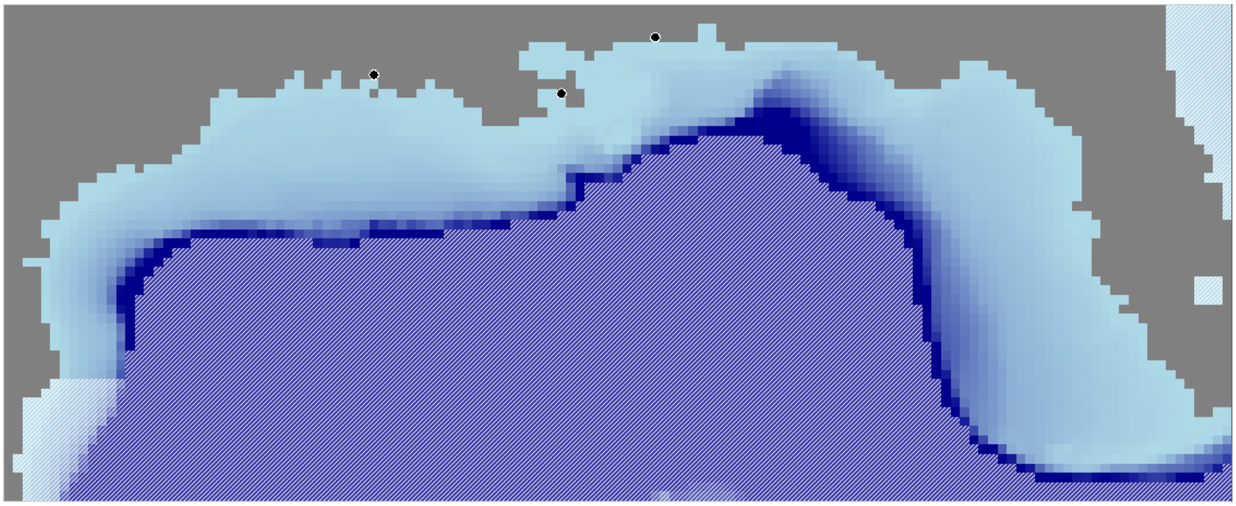

Figure 1. Gridded depth map used as ‘base map’ for the U. S. Gulf of Mexico Ecopath with Ecosim and Ecospace model. The processed low-resolution STE data outputs (PDF files) all match the spatial extent (long/lat bounding box = -98, -80.5, 24, 31) and resolution (8-second / 14 km2) of this base map.

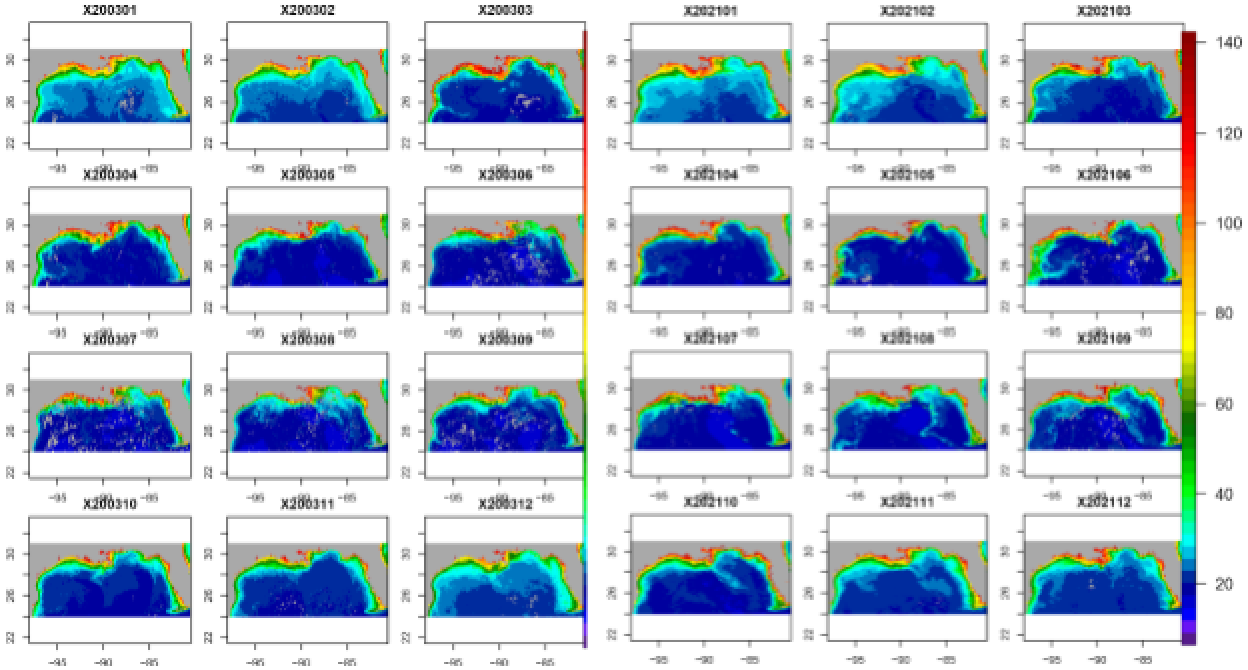

Figure 2. Example high-resolution plots of chlorophyll-A imagery for 1993 (left) and 2022 (right).

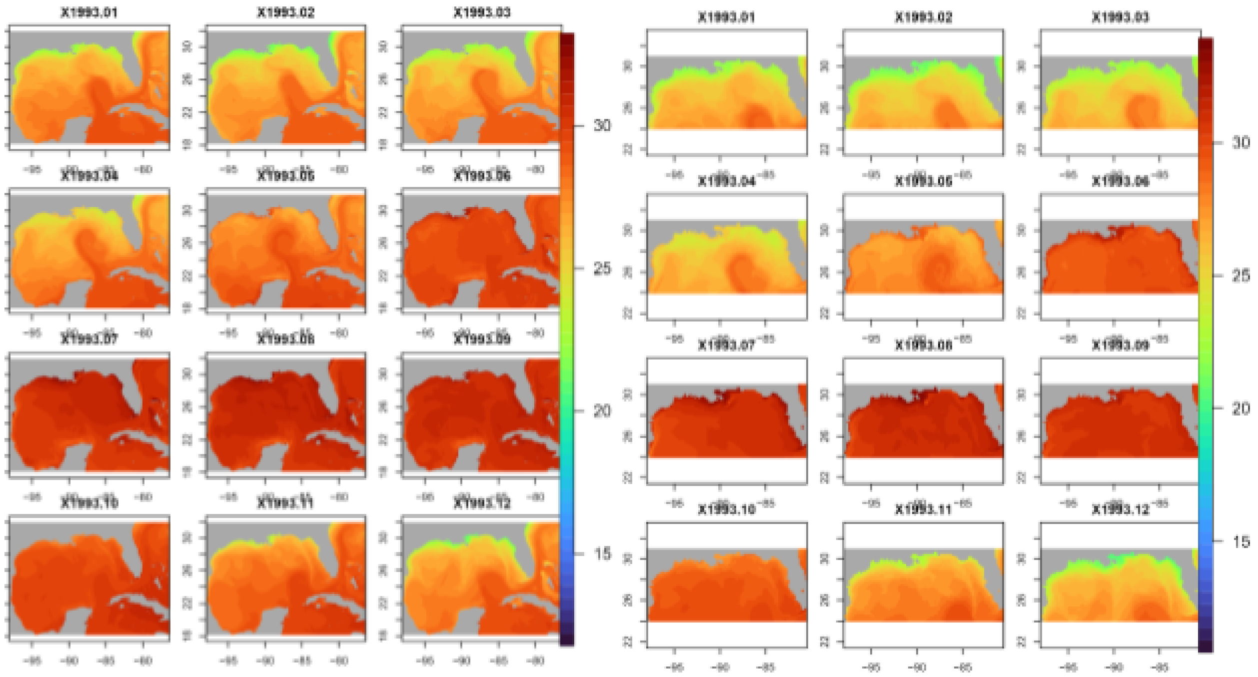

Figure 3. Example high-resolution (left) and processed low-resolution (right) monthly plots for surface seawater temperature in 1993.