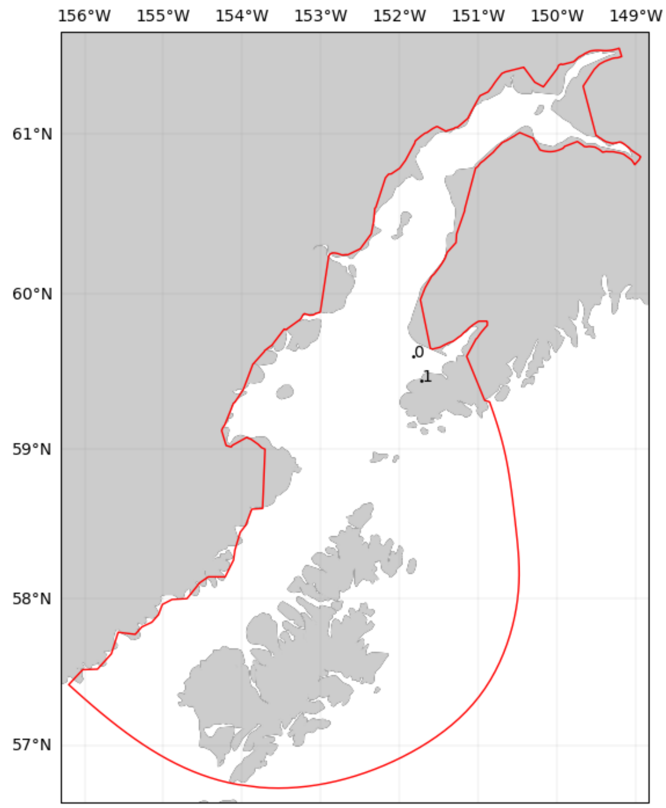
OCS Study
BOEM 2023-012

Improvements to the Oil Spill Risk Analysis (OSRA) Input Data - Verification and Validation



U.S. Department of the Interior

Bureau of Ocean Energy Management

Alaska OCS Region, Anchorage, AK

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Improvements to the Oil Spill Risk Analysis (OSRA) Input Data - Verification and Validation

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DISCLAIMER

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ABOUT THE COVER

A map produced by the ocean-model-skill-assessor (OSMA) package which compares model output with observation data. The red line outlines the approximate domain of the numerical model, and the black dots indicate the observation locations, each with a numeric marker for matching to the model-data time series comparison. Cover graphic credit: Kristen Thyng.

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List of Abbreviations and Acronyms

AOOS	Alaska Ocean Observing System
API	Application Programming Interface
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
CF	Climate and Forecast metadata convention
CIOFS	Cook Inlet Operational Forecast System
ERDDAP	Environmental Research Division Data Access Program
GCM	general circulation models
GEO	Global Earth Observation
HYCOM	Hybrid Coordinate Ocean Model
IOOC	Interagency Ocean Observation Committee
IOOS	U.S. Integrated Ocean Observing System
MOM6	Modular Ocean Model
NEPA	National Environmental Policy Act
netCDF	network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NODC	National Ocean Data Center
NSF	National Science Foundation
OBIS	Ocean Biodiversity Information System
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act (1953)
OMSA	ocean model skill assessor
OSRA	Oil Spill Risk Analysis
POM	Princeton Ocean Model
ROMS	Regional Ocean Modeling System
TBOFS	Tampa Bay Operational Forecast System
URL	Uniform Resource Locator

1 Introduction

The Outer Continental Shelf Lands Act (1953), as amended (OCSLA), established a policy for the management of energy resources on the Outer Continental Shelf (OCS) and for the protection of the marine and coastal environments. The Bureau of Ocean Energy Management (BOEM) is the administrative agency mandated by OCSLA to identify, monitor, and assess impacts of OCS activities on the human, marine, and coastal environments.

BOEM's Oil Spill Risk Analysis (OSRA; Ji et al. 2021; Li et al. 2021) is a key component in supporting National Environmental Policy Act (NEPA) analysis. Modeled oil spill trajectories are essential when identifying potential impacts to important sociocultural, biological, and ecological resources. When offering lease blocks for sale, it is vital that BOEM considers both the probability of an oil spill occurring and the chance a spill could contact these resources.

Generally, OSRA is frequently based on Lagrangian studies of trajectories (van Sebille et al. 2018) of point-based oil spills which are driven by the velocity fields from general circulation models (GCMs; Spaulding 2017). As such, the accuracy of oil spill forecasts is dependent on the ability of circulation models to accurately represent ocean conditions. Although skill assessment is typically applied in the course of model development and validation, it is not necessarily sufficiently comprehensive to describe how the model will represent conditions for specific applications such as OSRA. Furthermore, there are commonly multiple models available for a given region and time, and there rarely exists a common skill assessment to allow for a quantitative inter-model comparison of skill. Development of a common toolset to perform skill assessment on GCMs and to provide a simple means of performing inter-model comparison has the potential to substantially decrease the amount of human time required to perform this analysis, increase confidence in models, and greatly expand the application of models.

Data from ocean general circulation models (GCMs) are key inputs for accurately forecasting the chance of a spill contacting resources; thus, it is necessary to validate these data before using them in the OSRA model. As noted by Ji (2017), it is crucial in an ocean modeling study to demonstrate that the model used realistically represents the water system. Quantitative (or statistical) comparisons are used to measure how well the model results fit the observational data. Statistical analyses numerically quantify the state of the model calibration/verification (sometimes referred to as model skill assessment). Although several methods exist for analyzing and summarizing model performance, there is not a consensus in the modeling community about a standard set of measures for model performance evaluation. A number of statistical variables are useful in model-data comparison for model calibration, verification, and validation, including the following: (1) mean error, (2) mean absolute error, (3) root mean square error, (4) relative error, (5) relative root mean square error, and (6) model skill.

To meet these needs, Axiom Data Science, a Tetra Tech Company (henceforth "Axiom") developed a common toolkit to facilitate model skill assessment among multiple GCMs for BOEM's *Improvements to the Oil Spill Risk Analysis (OSRA) Input Data - Verification and Validation* study. The toolkit, referred to as the ocean model skill assessor (OMSA) package, fully runs the comparison between data and model to assess model skill. The package was developed to produce model skill assessment of GCMs using time series observations of physical fields including, but not limited to, sea surface elevation, temperature, salinity, and velocities. The variables listed are commonly used for physical oceanography and, specifically, oil spill applications, but any variable present in the model output or data files can be used in the assessment. The package also includes the ingestion and pre-processing of observation data, extraction of model data, calculation of statistical estimates of skill, and presentation of model skill results in figures and tables.

The OMSA toolkit and its associated products leverage Axiom's technical cyberinfrastructure, which was developed to meet the guidelines and specifications recommended by the National Oceanic and Atmospheric Administration (NOAA)-funded U.S. Integrated Ocean Observing System (IOOS) and endorsed by the federal Interagency Ocean Observation Committee (IOOC) and Global Earth Observation (GEO) Program. Axiom has developed a data system approach that is used to manage, serve, and process more than 600 terabytes of metocean data from regional and national sources, including data provided by BOEM, the Bureau of Safety and Environmental Enforcement (BSEE), the National Ocean Data Center (NODC), the National Science Foundation (NSF), Ocean Biodiversity Information System (OBIS-USA), as well as IOOS and its regional data assembly centers, including the Alaska Ocean Observing System (AOOS).

2 Objectives

The specific objectives of this study were as follows:

- Standardize and streamline verification of General Circulation Model (GCM) output fields.
- Provide methods for validation/ground-truthing of GCM results with real world data.
- Visualize GCM fields and reformat the data for use in OSRA.

3 Methods

An open-source software package (ocean model skill assessor) was developed on GitHub for analyzing and visualizing the comparisons of GCM output and datasets. The software system was based on the libraries and contributions to the Python and MetOcean (Meteorology and Oceanography) communities, as well as customized open-source contributions. This software system was built on commonly used Python libraries used in multi-discipline scientific communities, such as NumPy, SciPy, Matplotlib, pandas, xarray, netCDF-4, etc., and the custom packages include extract_model, cf-pandas, and intake-erddap. The package was developed to produce model skill assessment of GCMs using observations of physical fields including, but not limited to, sea surface elevation, temperature, salinity, and velocities. The package also includes the ingestion and pre-processing of observation data, extraction of model data, calculation of statistical estimates of skill, and presentation of model skill results in figures and tables.

The following sections describe the methods used in support of the study objectives.

3.1 Develop Standardized Procedures and Tools for Verification of GCM Results

A critical prerequisite for using a GCM is ensuring that the simulation results are within expected physical and domain-specific limits. This is typically assessed using variable specific summary statistics and a visual evaluation of predicted fields. The approach used for developing OMSA as a generalized tool for verifying GCM results included developing a common interface for calculating summary statistics and visualizations of fields from multiple model types including Regional Ocean Modeling System (ROMS), Hybrid Coordinate Ocean Model (HYCOM), Modular Ocean Model (MOM6), and Princeton Ocean Model (POM), though it is intended to be used with any model that outputs results in a Climate Forecast (CF)-compliant network Common Data Form (netCDF) file. OMSA was built in Python and utilized open-source packages including NumPy, SciPy, Matplotlib, pandas, xarray, netCDF-4, etc., as well as custom packages including extract_model, cf-pandas, and intake-erddap. Additionally, the package can be run using a command line interface on Linux, macOS, and Windows. Users have complete control over the specific model, variables, analyses, and visualization details using options provided throughout the package. Appendix A includes the user guide and technical documentation for the software packages, including OMSA, extract-model, cf-pandas, intake-axds, and intake-erddap. The documentation covers topics such as package installation, library configurations, package examples, Application Programming Interface (API) instructions, developer documentation, and the Python module index.

3.2 Develop Procedures and Tools for Validation of GCM results with Observations

OMSA performs the statistical analysis of the model results compared to observational data based on custom software developed by Axiom in combination with tools that already exist in community open-source software. With this package, users can input their own observational datasets or search for datasets. Using the intake-erddap package, the physical parameters to be compared to the model can be defined in the package vocabulary. Users also have the option to configure the analysis to be performed by specifying the areas of interest and temporal bounds. OMSA computes the statistical measures of model skill including descriptive statistics (max, min, mean and standard deviation), bias, correlation coefficient, index of agreement (Willmott 1981), mean square error, root mean square error, and the non-dimensional Murphy score to enable comparison between variables (Murphy 1988). Outputs from the statistical analysis are saved to the study directory in CSV format, as well as a time series plot of the model, observation, and the calculated statistics (Figure 1). An example of the statistical analytical outputs can be found in Appendix A in the ocean-model-skill-assessor user documentation under "CLI demo ocean-model-skill-assessor with known data files". Additionally, a map of the area around the model outlining the approximate domain of the numerical model, and the observation locations, each with a numeric marker for matching to the model-data time series comparison, is also produced (Figure 2).

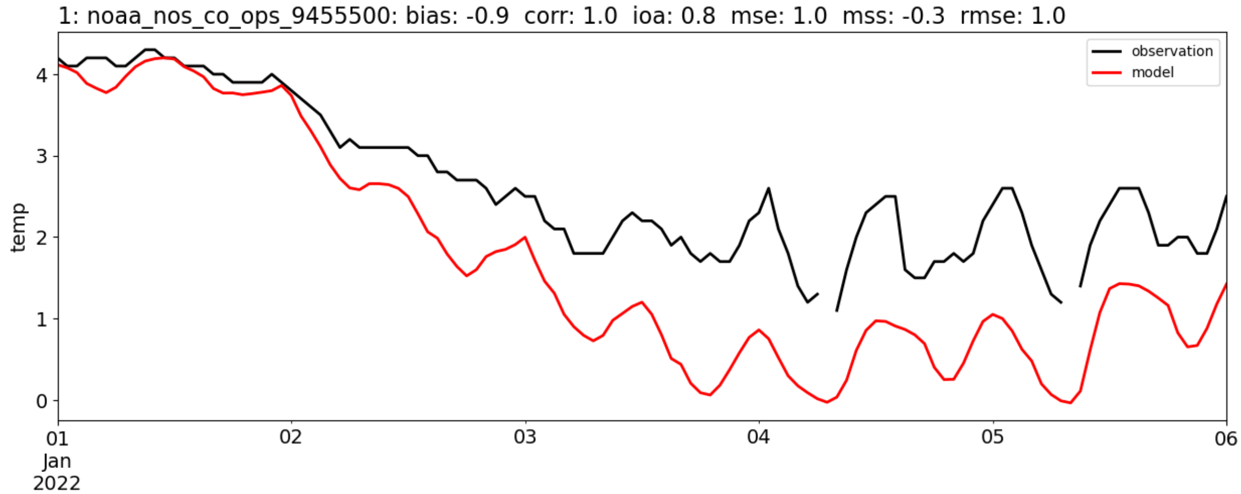

Figure 1. Time series comparison chart

A time series chart produced by the ocean-model-skill-assessor (OSMA) package. The black line shows the observation values and the red line is the comparable values from the model. A subset of the statistical measures of model skill are captured in the title bar; the full set of statistical measures are in the saved CSV file. An example of the statistical analytical outputs can be found in Appendix A in the ocean-model-skill-assessor user documentation under "CLI demo ocean-model-skill-assessor with known data files". In the above figure, water temperature is compared from the Cook Inlet Operational Forecast System (CIOFS) model (red) and at station "noaa_nos_co_ops_9455500" (black). The comparison time range is January 1, 2022, through January 5, 2022. The lines are reasonably similar, as captured by the statistical values in the title.

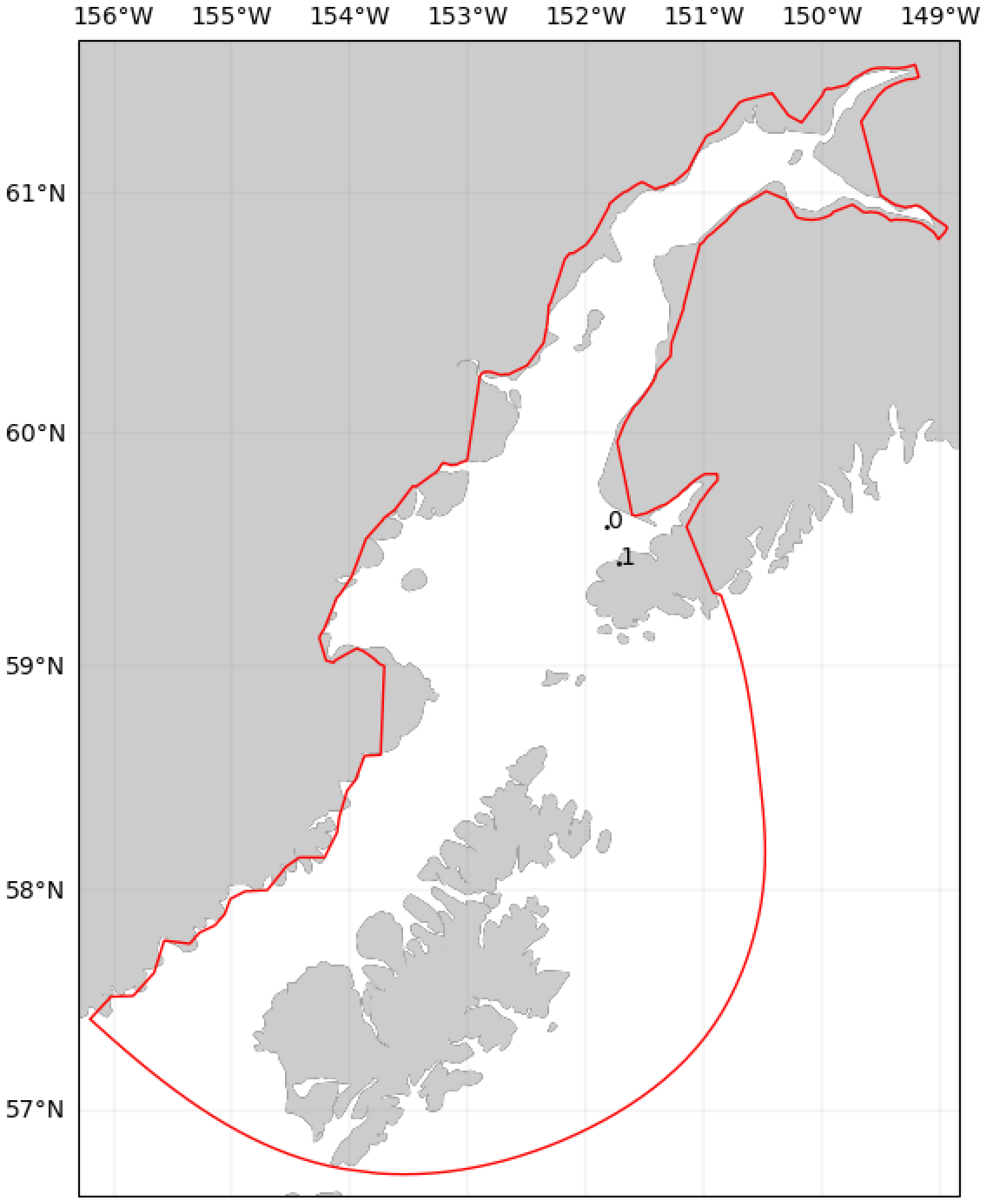

Figure 2. Map of the approximate domain of the model

A map produced by the ocean-model-skill-assessor (OSMA) package, which compares model output with observation data. The red line outlines the approximate domain of the numerical model, and the black dots indicate the observation locations, each with a numeric marker for matching to the model-data time series comparison. In this example for lower Cook Inlet, Alaska, water temperature is compared between the Cook Inlet Operational Forecast System (CIOFS) model and 2 *in-situ* observation stations (AOOS Lower Cook Inlet CDIP 204 buoy, and

NOAA Center for Operational Oceanographic Products and Services (CO-OPS) Seldovia, AK (OVIA2) station).

The skill assessment process with OMSA begins with the user specifying the model, variable, and time periods. The package can use data input by the user or can utilize the QA/QC'd time series observations from Axiom's Environmental Research Division Data Access Program (ERDDAP) server as a built-in feature to search for data stations in a spatial box and time rang; a user can use intake-erddap to set up a catalog of datasets. OMSA then prepares the model output for skill assessment using the extract_model package, which aligns it to match the timing and location of the data. Skill metrics are then computed between the observed and modeled time series, with outputs saved as CSV files and time series figures, along with a map showing the model domain and data locations. All outputs from the processing, including skill metrics, catalog of observations, catalog of model output, and plots are saved in a user-configurable location in formats adhering to community conventions and standards.

3.3 Develop Tools to Reformat GCM Output for Use in OSRA

Many OSRA software packages are incompatible with curvilinear and unstructured meshes commonly used in coastal ocean modeling. One of the developed software packages, extract_model, provides a Python-based software package capable of regridding model output in curvilinear and unstructured meshes to a rectilinear format with user configurable projection and spatial resolution in a netCDF file capable of use with many common Lagrangian particle tracking software applications, such as PyGnome, OpenDrift, and OceanParcels. Regridding is the process of interpolating the model output from one grid – in this case the original numerical grid the model output was distributed on – to another that might be better suited for some analysis.

4 Results

The OMSA package (https://github.com/axiom-data-science/ocean-model-skill-assessor) fully runs the comparison between data and model to assess model skill. The package was designed to operate in a Microsoft Windows, Mac, or Linux environment, and to be used by scientists familiar with oceanographic data and analysis of GCM results. The model analysis can be run as a Python package or with a command-line interface. Installation requires use of Anaconda or Miniconda. A list of the study products and the web Uniform Resource Locators (URL) associated with the package is in Table 1.

There are 3 steps to follow for a set of model-data validation, which is for 1 variable:

- Make a catalog for your model output.
- Make a catalog for your data.
- Run the comparison.

These steps save files into a user application directory cache, along with the log. The package provides detailed examples for each of these steps using 3 different models: CIOFS, Tampa Bay Operational Forecast System (TBOFS), and Gulf of Mexico HYCOM.

In addition to a general vocabulary of key physical oceanographic terms, such as water temperature, salinity, sea surface height, velocity, wind speed and direction, and sea ice velocity and fractional area, users also have the capability to create custom vocabularies for different variables to be used with the OMSA package.

Robust documentation for OMSA users (available through read the docs: https://ocean-model-skill-assessor.readthedocs.io/en/latest/index.html) provides instructions and demonstrations of how-to make the model and data catalogs, run comparisons, create a vocabulary for physical variables, and plot results. User guides are available for running the package directly or using the command line interface. This documentation is available in PDF format in Appendix A. Installation instructions are also included in the package documentation.

Table 1. Table of study packages

The name of the study package and associated libraries, including the URL for web access, developed as part of this study.

Package Name	Package URL
ocean model skill assessor (OMSA) v0.6.1	https://github.com/axiom-data-science/ocean-model-skill-assessor
ocean model skill assessor user documentation	https://ocean-model-skill-assessor.readthedocs.io
extract-model v1.1.4	https://github.com/axiom-data-science/extract_model
extract-model user documentation	https://extract-model.readthedocs.io
cf-pandas v0.5.2	https://github.com/axiom-data-science/cf-pandas
cf-pandas user documentation	https://cf-pandas.readthedocs.io
intake-erddap v0.2.4	https://github.com/axiom-data-science/intake-erddap
intake-erddap user documentation	https://intake-erddap.readthedocs.io
intake-axds v0.1.2	https://github.com/axiom-data-science/intake-axds
intake-axds user documentation	https://intake-axds.readthedocs.io/

5 Conclusions

It is crucial in an ocean modeling study to demonstrate that the model used realistically represents the water system. The OMSA package generates statistical comparisons of how well the model results match the data and quantifies the state of the model calibration (i.e., model skill assessment). The package provided to BOEM has immediate applicability to assist BOEM scientists with validation of GCM results and comparisons to available observational data to supplement validation studies performed by the modelers. These results are important for informing potential impacts to sociocultural, biological, and ecological resources in lease block sale areas by validating the model output used for accurately forecasting the chance of a spill contacting these resources.

The OMSA package allows a user to set up an extensive model validation with 3 commands, including performing a database search, which is intended as an important time-saving step when running analyses. Still, further development will allow for yet more model assessment capabilities. In particular, next development steps should expand from fixed time series model-data comparisons to comparisons with other types of datasets, such as time series at other depths than surface, gliders, and 2D surface fields and other depth slices. These future advancements would expand the model validation utility of these tools while leveraging the same straight-forward package application developed under this effort.

6 References

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Appendix A: Product Documentation

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