Large Ensemble pCO2 Testbed from 3D climate models interpolated to 1x1 spatial grid over time period 1982-2017

Website: https://www.bco-dmo.org/dataset/840334
Data Type: model results
Version: 1
Version Date: 2021-02-09

Project
» Collaborative Research: Uncertainty in Predictions of 21st Century Ocean Biogeochemical Change (ESM Uncertainty)

Program
» Ocean Carbon and Biogeochemistry (OCB)

Contributors	Affiliation	Role
McKinley, Galen A.	Lamont-Doherty Earth Observatory (LDEO)	Principal Investigator
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Abstract
These Large Ensemble Testbed (LET) data come from 3D climate models. The intention of this dataset was to evaluate ocean pCO2 gap-filling techniques. See Gloege et al. (2021) for further details about the Earth System Models run for the Large Ensembles. For more information about the large ensembles see https://www.cesm.ucar.edu/projects/community-projects/MMLEA. The methodology was an earth system model (ESM) large ensemble initialized with small perturbations such that the climate state evolved along a different phase of internal variability in each ensemble member. 25 monthly averaged large ensemble members were interpolated to 1x1 spatial grid over time period 1982-2017. The intention of this dataset was to evaluate ocean pCO2 gap-filling techniques. Reducing uncertainty in the global carbon budget requires better quantification of ocean CO2 uptake and its temporal variability. Several methodologies for reconstructing air-sea CO2 exchange from sparse pCO2 observations indicate larger decadal variability than estimated using ocean models. We develop a new application of multiple Large Ensemble Earth system models to assess these reconstructions' ability to estimate spatiotemporal variability. With our Large Ensemble Testbed, pCO2 fields from 25 ensemble members each of four independent Earth system models are subsampled as the observations and the reconstruction is performed as it would be with real- world observations. The power of a testbed is that the perfect reconstruction is known for each of the 100 original model fields; thus, reconstruction skill can be comprehensively assessed. We find that a commonly used neural-network approach can skillfully reconstruct air-sea CO2 fluxes when and where it is trained with sufficient data. Flux bias is low for the global mean and Northern Hemisphere, but can be regionally high in the Southern Hemisphere. The phase and amplitude of the seasonal cycle are accurately reconstructed outside of the tropics, but longer-term variations are reconstructed with only moderate skill. For Southern Ocean decadal variability, insufficient sampling leads to a 39% [15%:58%, interquartile range] overestimation of amplitude, and phasing is only moderately correlated with known truth (r=0.54 [0.46:0.63]). Globally, the amplitude of decadal variability is overestimated by 21% [3%:34%]. Machine learning, when supplied with sufficient data, can skillfully reconstruct ocean properties. However, data sparsity remains a fundamental limitation to quantification of decadal variability in the ocean carbon sink.

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Coverage

Spatial Extent: **N**:90 **E**:180 **S**:-90 **W**:-180
Temporal Extent: 1982 - 2017

Methods & Sampling

In total, there are 100 unique ensemble members across four large ensembles (CanESM2, CESM-LENS, GFDL, MPI-GE). Testbed data can be downloaded from https://figshare.com/collections/Large_ensemble_pCO2_testbed/4568555.

The large ensemble testbed data are a collection of randomly selected ensemble members from 4 the following large ensemble projects:

- CanESM2 (http://data.ec.gc.ca/data/climate/scientificknowledge/the-eccc-climate-model-datasets-for-climate-science-and-impacts-research/the-canadian-earth-system-model-large-ensembles/)

- CESM-LENS (http://www.cesm.ucar.edu/projects/community-projects/LENS/)

- GFDL (http://poseidon.princeton.edu)

- MPI-GE (https://mpimet.mpg.de/en/grand-ensemble/)

Analysis scripts in python are provided to produce from these model output the figures of Gloege et al. (2021). See "Data Files" for access to the analysis scripts. The “Notebooks” directory includes notebooks to create each figure, and are labeled by figure. The “Scripts” and “Processing_scripts” directories include auxiliary scripts.

Each ensemble member was interpolated from its native grid to a 1x1 degree lat/lon grid. The variables are monthly over the 1982-2017 time frame and sampled as the SOCATv5 data product. Historical atmospheric CO2 is used up to 2005 with RCP8.5 after 2005.

Gap-filling techniques can be evaluated across 100 unique climate states.

The methodology is an earth system model (ESM) large ensemble. The ESM is initialized with small perturbations such that the climate state evolves along a different phase of internal variability in each ensemble member. The forcing scenario is historical through 2005, then RCP8.5 after.

For more methodology details refer to the following publications.

MPI ocean pCO2 testbed:
N. Maher, *et al.*, Th e Max Planck Institute Grand Ensemble-Enabling the Exploration of Climate System Variability. *Journal of Advances in Modeling Earth Systems* **11**, 2050–2069 (2019).

GFDL ocean pCO2 testbed:
K. B. Rodgers, J. Lin, T. L. Frölicher, Emergence of multiple ocean ecosystem drivers in a large ensemble suite with an Earth system model. *Biogeosciences* **12**, 3301–3320 (2015).

CESM ocean pCO2 testbed:
J. E. Kay, *et al.*, The Community Earth System Model (CESM) large ensemble project: A community resource for studying climate change in the presence of internal climate variability. *Bulletin of the American Meteorological Society* **96**, 1333–1349 (2015).

CanESM2 ocean pCO2 testbed:
J. C. Fyfe, et al., Large near-term projected snowpack loss over the western United States. Nature communications 8, 14996 (2017).

Data Processing Description

BCO-DMO Data Manager processing notes:
* GitHub repository https://github.com/lgloege/large_ensemble_testbed forked was forked to BCODMO organization https://github.com/BCODMO/large_ensemble_testbed. BCO-DMO forks github repositories submitted to us for curatorial purposes. The original github repository may continue to be updated, or may be taken down the future.
* We made a release of the repository that corresponds with this version of the dataset https://github.com/BCODMO/large_ensemble_testbed/releases.
* A copy of the release zip file was attached to this dataset and the zip file containing the release is archived and DOI'ed along with this dataset.

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Supplemental Files

File
Large Ensemble Testbed Analysis Scripts filename: large_ensemble_testbed-code_840334_v1.zip (ZIP Archive (ZIP), 12.47 MB) MD5:19c2a0ec26ea884b7915712c9943f8bd Analysis scripts in python to produce from Large Ensemble Testbed model output the figures in : Gloege, L., G.A. McKinley, P. Landschützer, A. Fay, T. Frölicher, J.C. Fyfe, T. Illyina, S.D. Jones, N.S. Lovenduski, C. Rödenbeck, K.B. Rodgers, S. Schlunegger and Y. Takano: Quantifying errors in observationally-based estimates of ocean carbon sink variability, in review 2020. https://doi.org/10.1002/essoar.10502036.2 The “Notebooks” directory includes notebooks to create each figure, and are labeled by figure. The “Scripts” and “Processing_scripts” directories include auxiliary scripts. The files in this .zip package were forked from original github repository https://github.com/lgloege/large_ensemble_testbed to BCO-DMO for archival purposes. Commit forked from https://github.com/lgloege/large_ensemble_testbed was d177ae3 by Lucas Gloege committed on Sep 2, 2020.

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Related Publications

Fyfe, J. C., Derksen, C., Mudryk, L., Flato, G. M., Santer, B. D., Swart, N. C., … Jiao, Y. (2017). Large near-term projected snowpack loss over the western United States. Nature Communications, 8(1). doi:10.1038/ncomms14996
Methods

Gloege, L. (2020). Large Ensemble Testbed (Commit d177ae3) [Computer software]. GitHub. https://github.com/lgloege/large_ensemble_testbed/tree/d177ae327da93ab0d2bb947bba57b196e2ba1ceb
Software

Gloege, L. (2020). Large ensemble pCO2 testbed. figshare. https://doi.org/10.6084/M9.FIGSHARE.C.4568555.V2 https://doi.org/10.6084/m9.figshare.c.4568555.v2
Different Version

Gloege, L., McKinley, G. A., Landschützer, P., Fay, A. R., Frölicher, T. L., Fyfe, J. C., … Takano, Y. (2021). Quantifying Errors in Observationally Based Estimates of Ocean Carbon Sink Variability. Global Biogeochemical Cycles, 35(4). doi:10.1029/2020gb006788 https://doi.org/10.1029/2020GB006788
Results

Kay, J. E., Deser, C., Phillips, A., Mai, A., Hannay, C., Strand, G., … Vertenstein, M. (2015). The Community Earth

System Model (CESM) Large Ensemble Project: A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability. Bulletin of the American Meteorological Society, 96(8), 1333–1349. doi:10.1175/bams-d-13-00255.1 https://doi.org/10.1175/BAMS-D-13-00255.1
Methods

Maher, N., Milinski, S., Suarez-Gutierrez, L., Botzet, M., Dobrynin, M., Kornblueh, L., … Marotzke, J. (2019). The Max Planck Institute Grand Ensemble: Enabling the Exploration of Climate System Variability. Journal of Advances in Modeling Earth Systems, 11(7), 2050–2069. doi:10.1029/2019ms001639 https://doi.org/10.1029/2019MS001639
Methods

McKinley, G. (2020). Upper Open Carbon Box Model, McKinley et al. 2020, AGU Advances. figshare. https://doi.org/10.6084/M9.FIGSHARE.11983947.V1 https://doi.org/10.6084/m9.figshare.11983947.v1
Different Version

McKinley, G. A., Fay, A. R., Eddebbar, Y. A., Gloege, L., & Lovenduski, N. S. (2020). External Forcing Explains Recent Decadal Variability of the Ocean Carbon Sink. AGU Advances, 1(2). doi:10.1029/2019av000149 https://doi.org/10.1029/2019AV000149
Results

Rodgers, K. B., Lin, J., & Frölicher, T. L. (2015). Emergence of multiple ocean ecosystem drivers in a large ensemble suite with an Earth system model. Biogeosciences, 12(11), 3301–3320. doi:10.5194/bg-12-3301-2015
Methods

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Related Datasets

HasPart

Gloege, L. (2019). *CESM ocean pCO2 testbed* [Data set]. figshare. https://doi.org/10.6084/M9.FIGSHARE.8798999.V1 https://doi.org/10.6084/m9.figshare.8798999.v1

Gloege, L. (2019). *CanESM2 ocean pCO2 testbed* [Data set]. figshare. https://doi.org/10.6084/M9.FIGSHARE.11477874.V1 https://doi.org/10.6084/m9.figshare.11477874.v1

Gloege, L. (2019). *GFDL ocean pCO2 testbed* [Data set]. figshare. https://doi.org/10.6084/M9.FIGSHARE.11477946.V1 https://doi.org/10.6084/m9.figshare.11477946.v1

Gloege, L. (2019). *MPI ocean pCO2 testbed* [Data set]. figshare. https://doi.org/10.6084/M9.FIGSHARE.11477949.V1 https://doi.org/10.6084/m9.figshare.11477949.v1

IsRelatedTo

CESM Large Ensemble Community Project (n.d.). Community Earth System Model - CESM®. CESM-LENS. http://www.cesm.ucar.edu/projects/community-projects/LENS.

Max Planck Institute for Meteorology (n.d.). Grand Ensemble, MPI-GE. https://mpimet.mpg.de/en/grand-ensemble/.

NOAA GFDL (n.d.). Poseidon GFDL_ESM2M. Princeton University. http://poseidon.princeton.edu/.

The Environment Canada Data Catalogue (n.d.). The Canadian Earth System Model Large Ensembles. CanESM2. http://data.ec.gc.ca/data/climate/scientificknowledge/the-eccc-climate-model-datasets-for-climate-science-and-impacts-research/the-canadian-earth-system-model-large-ensembles/.

UCAR (2021). Multi-Model Large Ensemble Archive, https://www.cesm.ucar.edu/projects/community-projects/MMLEA/. Accessed May 7th, 2021.

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Parameters

Parameters for this dataset have not yet been identified

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Project Information

Collaborative Research: Uncertainty in Predictions of 21st Century Ocean Biogeochemical Change (ESM Uncertainty)

NSF Award Abstract:
The biogeochemistry of the oceans is undergoing large-scale changes due to anthropogenic climate change. Recent research suggests these changes are occurring significantly on regional scales, but due to model uncertainties, it is difficult to constrain the difference between anthropogenic and natural influences. In studying climate change and its effect on ocean biogeochemistry in the future, it is crucial to be able to distinguish between these influences; therefore, it is critical to identify and quantify the uncertainty in Earth System Models (ESMs). The researchers will use output from Community Earth System Model (CESM) and models participating in the Fifth Coupled Model Intercomparison Project (CMIP5) to isolate prediction uncertainty due to 1) internal variability, 2) model structure, and 3) emission scenario. This research will bridge an existing gap between Earth System Models and observational studies to assess how climate change will influence ocean biogeochemistry. Additionally, this project will support an early-career scientist and a graduate student, and the researchers are dedicated to mentoring undergraduate students through various programs at Colorado University - Boulder, National Center for Atmospheric Research, and the University of Wisconsin.

Earth System Model (ESM) simulations used to predict future changes in ocean biogeochemistry attributed to either natural or anthropogenic influences suffer from uncertainties, particularly on regional scales. This is problematic because, as the ocean continues to undergo large-scale change under the current climate, it is crucial to have an accurate predictor of the future and to be able to delineate between natural and anthropogenic forcing. This research aims to quantify the uncertainty on three levels: uncertainty due to internal variability, model structure, and emission scenario. Using output from the Community Earth System Model (CESM) and models in the Fifth Coupled Model Intercomparison Project (CMIP5), this study will evaluate the degree to which uncertainty has changed with newer models. Additionally, observations from global databased, satellites, and time-series sites will be used to compare models and assess the varying levels of skill in predicting the biogeochemistry of a region. The researchers also plan to break down the various components of the driving mechanisms behind prediction uncertainty, so that future models can begin to take these factors into account.

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Program Information

Ocean Carbon and Biogeochemistry (OCB)

Website: http://us-ocb.org/

Coverage: Global

The Ocean Carbon and Biogeochemistry (OCB) program focuses on the ocean's role as a component of the global Earth system, bringing together research in geochemistry, ocean physics, and ecology that inform on and advance our understanding of ocean biogeochemistry. The overall program goals are to promote, plan, and coordinate collaborative, multidisciplinary research opportunities within the U.S. research community and with international partners. Important OCB-related activities currently include: the Ocean Carbon and Climate Change (OCCC) and the North American Carbon Program (NACP); U.S. contributions to IMBER, SOLAS, CARBOOCEAN; and numerous U.S. single-investigator and medium-size research projects funded by U.S. federal agencies including NASA, NOAA, and NSF.

The scientific mission of OCB is to study the evolving role of the ocean in the global carbon cycle, in the face of environmental variability and change through studies of marine biogeochemical cycles and associated

ecosystems.

The overarching OCB science themes include improved understanding and prediction of: 1) oceanic uptake and release of atmospheric CO2 and other greenhouse gases and 2) environmental sensitivities of biogeochemical cycles, marine ecosystems, and interactions between the two.

The OCB Research Priorities (updated January 2012) include: ocean acidification; terrestrial/coastal carbon fluxes and exchanges; climate sensitivities of and change in ecosystem structure and associated impacts on biogeochemical cycles; mesopelagic ecological and biogeochemical interactions; benthic-pelagic feedbacks on biogeochemical cycles; ocean carbon uptake and storage; and expanding low-oxygen conditions in the coastal and open oceans.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1558225
NSF Division of Ocean Sciences (NSF OCE)	OCE-1558258
NSF Division of Ocean Sciences (NSF OCE)	OCE-1818501

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