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MimiBRICK.jl: A Julia package for the BRICK model for sea-level change in the Mimi integrated modeling framework

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Software

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Statement of need

Assessing strategies to manage climate risks requires sound projections of future climate. For coastal risks, this includes projections of future sea levels. Major contributors to sea-level change include glaciers and ice caps, thermal expansion, land water storage, and the Greenland and Antarctic ice sheets. Characterizing coastal hazards and managing the associated risks requires resolving the tails of distributions. While many practitioners can obtain sea-level scenarios from synthesis reports, including the Intergovernmental Panel on Climate Change (IPCC, (Fox-Kemper et al., 2021)), improving our understanding of the importance and impacts of the many inherent uncertainties often requires fast and efficient models to explore these uncertainties. Semi-empirical models for sea-level rise offer a computationally efficient method for studying uncertainties in future coastal hazards and fusing observational data with models (R. Kopp et al., 2017; Mengel et al., 2016; Nauels et al., 2017; Wong et al., 2017). These models can also be flexible and modular, which enables their use in integrated frameworks for assessing climate damages and examining the efficacy of climate risk management policies. Interfaces such as the Framework for Assessing Changes To Sea-level (`FACTS`, (Garner & Kopp, 2022)) enable users to access these models and facilitate experimentation and intercomparisons. `FACTS`, coded primarily in Python, advances the older `LocalizeSL` MATLAB modules (R. E. Kopp et al., 2014). `FACTS` offers users a set of modules through which various forcing scenarios and modeling workflows can be combined to interrogate uncertainties in sea-level projections, particularly in structural uncertainties. `FACTS` is open source and freely available, and is a suitable source for local sea-level projections for many users.

`MimiBRICK.jl` is a Julia (Bezanson et al., 2017) implementation of the Building Blocks for Relevant Ice and Climate Knowledge (BRICK) semi-empirical model for sea-level change (Wong et al., 2017) in the Mimi integrated modeling framework (https://www.mimiframework.org/). The Mimi modeling framework is a coding platform that facilitates coupling models and running coupled modeling experiments. Mimi is explicitly employed in more than 10 peer-reviewed studies, as of this writing, with more presently in review. `MimiBRICK.jl` is flexible, efficient, and modular, to facilitate incorporating BRICK into coupled models and integrated assessments of climate impacts in a modular fashion to provide global average as well as local sea-level projections (National Academies of Sciences & Medicine, 2017). This focus on tight model coupling (Srikrishnan et al., 2022) and integrated modeling is a distinction between `FACTS` and

`MimiBRICK.jl` and the broader Mimi modeling framework.

This implementation includes examples for using observational data to calibrate the model, as well as various configurations in which `MimiBRICK` is coupled to other climate model components. For users who do not wish to re-run computationally intensive model calibration algorithms, this implementation also includes scripts for using existing calibration output for standard future climate change scenarios, and examples downscaling these global projections for assessments of local impacts.

Summary

BRICK is a semi-empirical model for global and local mean sea-level change (Wong et al., 2017). The core model includes component sub-models for the major contributors to global mean sea-level change - glaciers and ice caps, thermal expansion, land water storage, and the Greenland and Antarctic ice sheets. The resulting global mean sea levels can be downscaled via a data set that represents the "fingerprint" of each sea-level component on local mean sea level (Slangen et al., 2014). In this way, BRICK provides information about local sea-level changes, including characterizations of key uncertainties. BRICK is flexible and efficient enough to resolve high-risk upper tails of probability distributions. BRICK has been used in a number of recent assessments, including for examining the impacts of sea-level rise as a constraint on estimates of climate sensitivity (Vega-Westhoff et al., 2018), estimates of deep uncertainty in coastal flood risk (Ruckert et al., 2019), and most recently was noted in comparisons of sea-level projections in the Sixth Assessment Report of the IPCC (Fox-Kemper et al., 2021).

By working with annual global mean temperatures and sea levels, BRICK is suitable for embedding within, and coupling to, other models for climate change and its impacts. `MimiBRICK.jl` is written in compliance with the Mimi integrated modeling framework to facilitate incorporating BRICK into larger-scale coupled modeling efforts. The `MimiBRICK.jl` repository includes three such examples: (i) standalone BRICK, which takes as input temperature and ocean heat uptake; (ii) BRICK coupled to a simple one-dimensional Diffusion-Ocean-Energy Climate model (DOECLIM), which takes as input radiative forcing scenarios such as the standard Representative Concentration Pathway (RCP) scenarios; and (iii) BRICK coupled to a Simple Nonlinear Earth System model (SNEASY), which takes as input radiative forcing and greenhouse gas emissions and concentration scenarios (such as the RCP scenarios).

The standalone BRICK model requires as input annual mean time series for global mean surface temperature and oceanic heat uptake. In the DOECLIM-BRICK and SNEASY-BRICK configurations, those temperatures and ocean heat uptake inputs are provided to BRICK through output from the DOECLIM and SNEASY models. In the examples provided in the `MimiBRICK.jl` repository, the temperature time series is from the maximum *a posteriori* simulation from the ensemble run using the SNEASY-BRICK configuration. In all Mimi modeling experiments, model output and parameter values can be explored using the Mimi `explore()` function (Figure 1). The `explore()` function allows users to easily view and zoom in on different features in the model simulation set-up or results. Coding BRICK in the Mimi style enables the user to more easily couple the BRICK model to the suite of other models already implemented in Mimi, and builds on the extensive documentation and community support online (https://www.mimiframework.org/Mimi.jl/stable/).

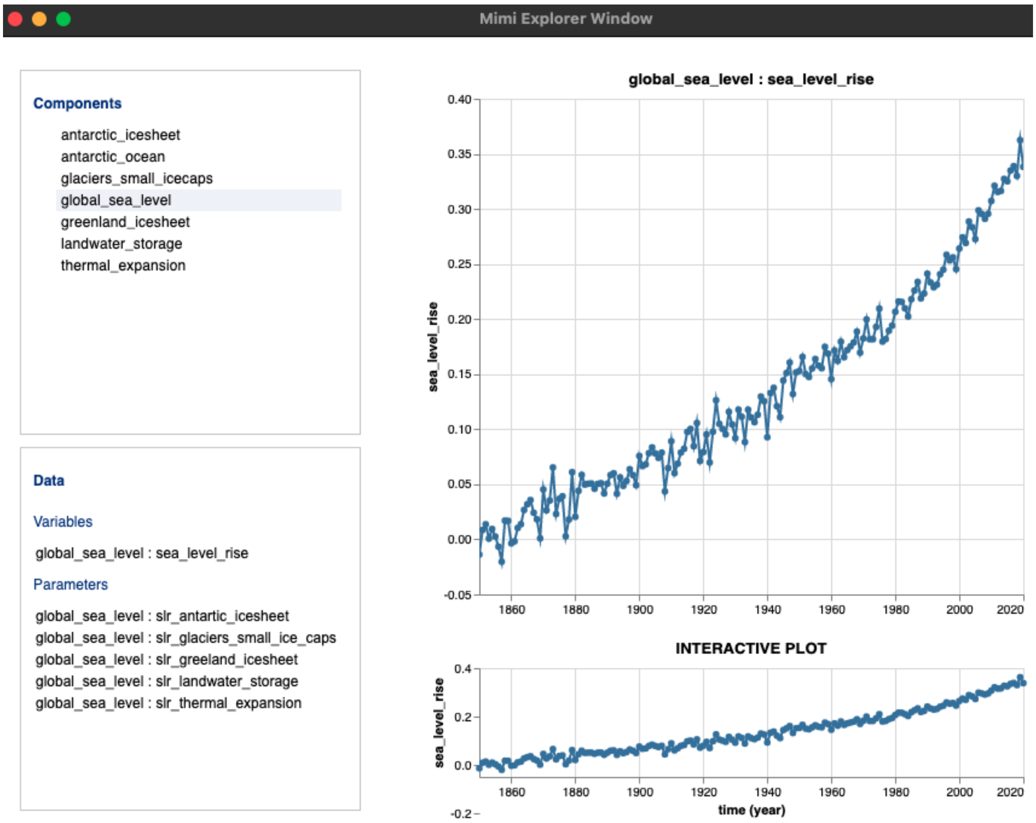

Figure 1: The Mimi `explore()` function allows users to interactively explore the coupled model output variables and parameters associated with each model component.

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