Effect of climate uncertainties on global and local sea-level rise projections

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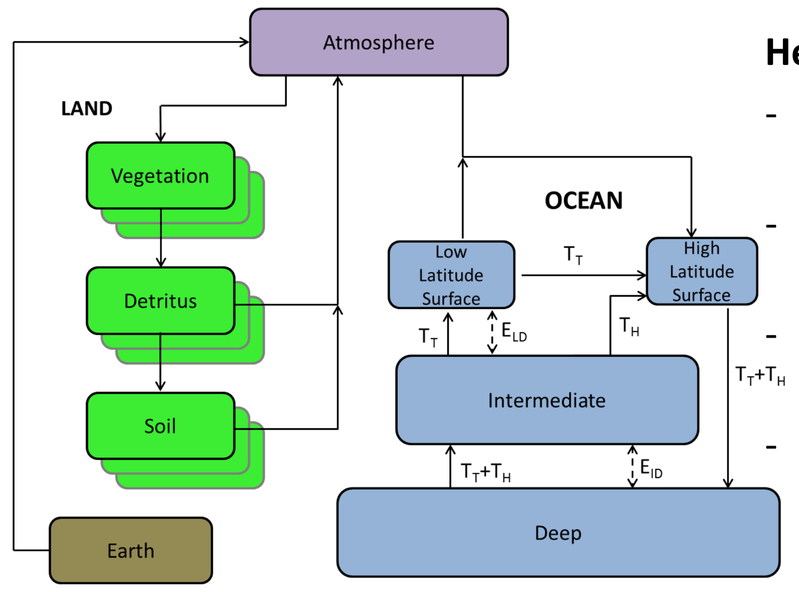
Work supported by the by Pacific Northwest 255 National Laboratory under contract DE-AC05-76RL01830

Abstract

Reduced complexity climate models are useful tools for quantifying decision-relevant uncertainties, given their flexibility, computational efficiency, and suitability for large-ensemble frameworks necessary for statistical estimation using resampling techniques (e.g. Markov chain Monte Carlo—MCMC). Here we document a new version of the simple, open-source, global climate model Hector, coupled with a one-dimensional diffusive heat and energy balance model (Diffusion Ocean Energy balance CLIMate model; DOECLIM) and a sea-level change module (Building blocks for Relevant Ice and Climate Knowledge; BRICK) that also represents contributions from thermal expansion, glaciers and ice caps, and polar ice sheets. We apply a Bayesian calibration approach to quantify model uncertainties surrounding 39 model parameters with prescribed radiative forcing, using observational information from global surface temperature, ocean heat uptake, and sea-level change. Results provide important constraints on probabilistic projections of global, regional, and local sea-level rise. Ongoing work includes combining probabilistic results with historical tide gauge records to analyze changes in flood risk at the local scale.

Hector-Brick Model

Hector is an open source simple global carbon-climate model that simulates global climate change given emissions and radiative forcings from greenhouse emission data and accounting for carbon cycling, radiative forcings from greenhouse gases, aerosols, and pollutants (Hartin et al., 2015).



Hector

- open-source (https://github.com/JGCRI/hector)
- Runs in under a second on a modern laptop
- Modular design (easily replaceable components)
- Climate component of GCAM (Global Change Assessment Model)

New sea-level rise component - BRICK

- New global sea-level rise (SLR) component using BRICK (Building blocks for Relevant Ice and Climate Knowledge; Wong et al., 2017), including SLR contributions from:
  - Thermal expansion (TE)
  - Antarctic Ice Sheet (AIS)
  - Greenland Ice Sheet (GIS)
  - Glaciers and small ice caps (GIC)

Calibration using Adaptive MCMC

We adapt a Bayesian calibration tool from BRICK to perform probabilistic assessment

- Include 39 parameters from sea-level and energy balance components
- Observational constraints include global surface temperature, ocean heat content, and sea-level rise
- Incorporates mechanistically-motivated prior ranges and employs Gelman-Rubin diagnostics to assess convergence.
- Initial Hector calibrations include 4 MCMC chains of 1 million runs

- Probabilistic version available at: https://github.com/bvegawe/hector/tree/dev_slr

Application 1: How does parametric uncertainty influence the tails of global sea-level rise?

Vega Westhoff, B., Sriver, R. L., Hartin, C. A., Wong, T. E., and Keller, K. (In Review), Impacts of observational constraints related to sea-level rise estimates of climate sensitivity, Earth's Future

Objective

Apply new Hector-Brick model to analyze parametric uncertainties surrounding extreme global sea-level rise projections

Approach

- Performed a Bayesian model calibration (adaptive MCMC) to estimate 39 model parameters with prescribed RCP8.5 radiative forcing
- Analyzed probabilistic projections of global sea-level rise for different combinations of observational constraints from the atmosphere, ocean, and land ice

Impact

- Different combinations of observational constraints can yield similar temperature but drastically different SLR projections, particularly for extreme scenarios.
- **Next Steps: Analyze effects of different forcing scenarios from CMIP5 and CMIP6 on extreme SLR.**

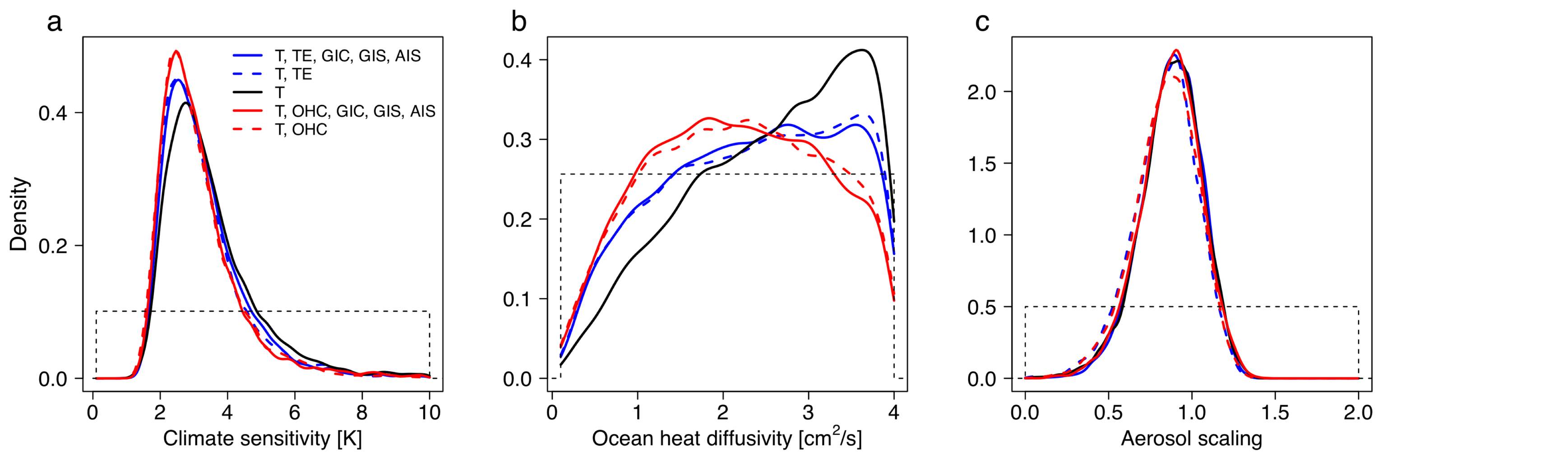


Figure 2. Posterior distributions (sample size n=10,000) of the climate model parameters: equilibrium climate sensitivity (a), vertical ocean heat diffusivity (b), and aerosol scaling (c). Curves represent calibrations with different combinations of observational constraints from the atmosphere (T), ocean (OHC), and sea-level data (TE, GIC, GIS, AIS).

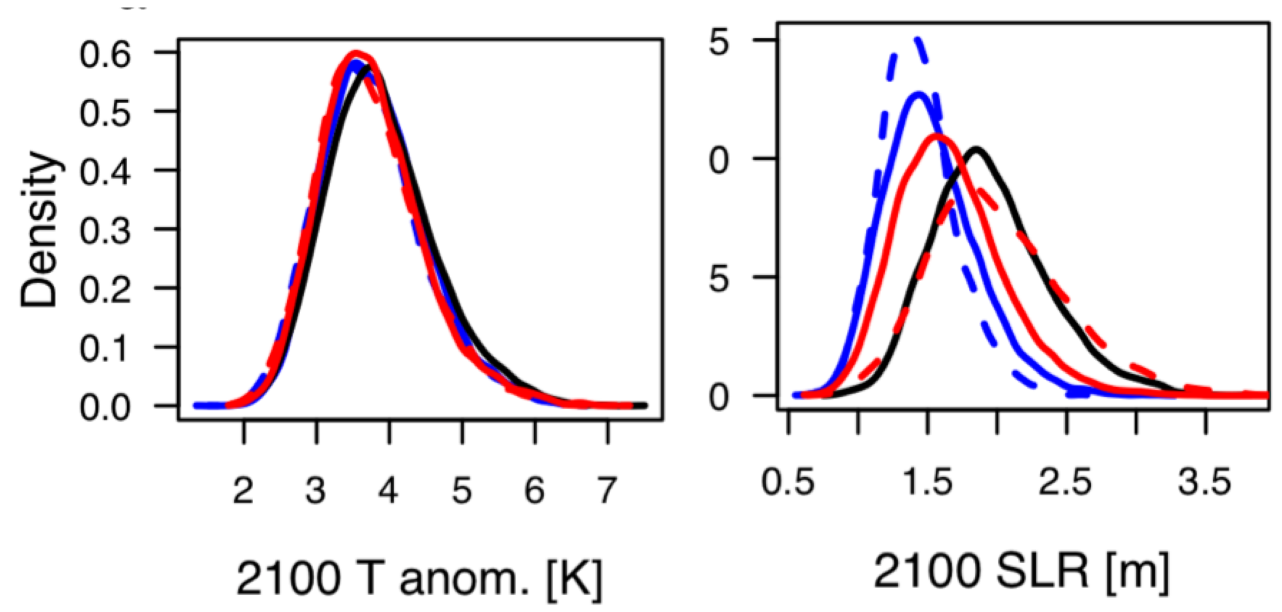


Figure 3: 2100 projections of global surface temperature (Left) and global sea-level rise (Right), based on Bayesian Hector calibrations using different combinations of observations constraints as in Figure 2

Application 2: How does parametric uncertainty influence local SLR projections?

Vega Westhoff, B., Sriver, R. L., Hartin, C. A., Wong, T. E., and Keller, K. (In Preparation), What is the role of climate sensitivity in extreme sea-level rise scenarios?, Geophysical Research Letters

Objective

Apply new Hector-Brick to analyze scenarios leading to extreme sea-level rise at the local scale, using Norfolk VA as a proof of concept

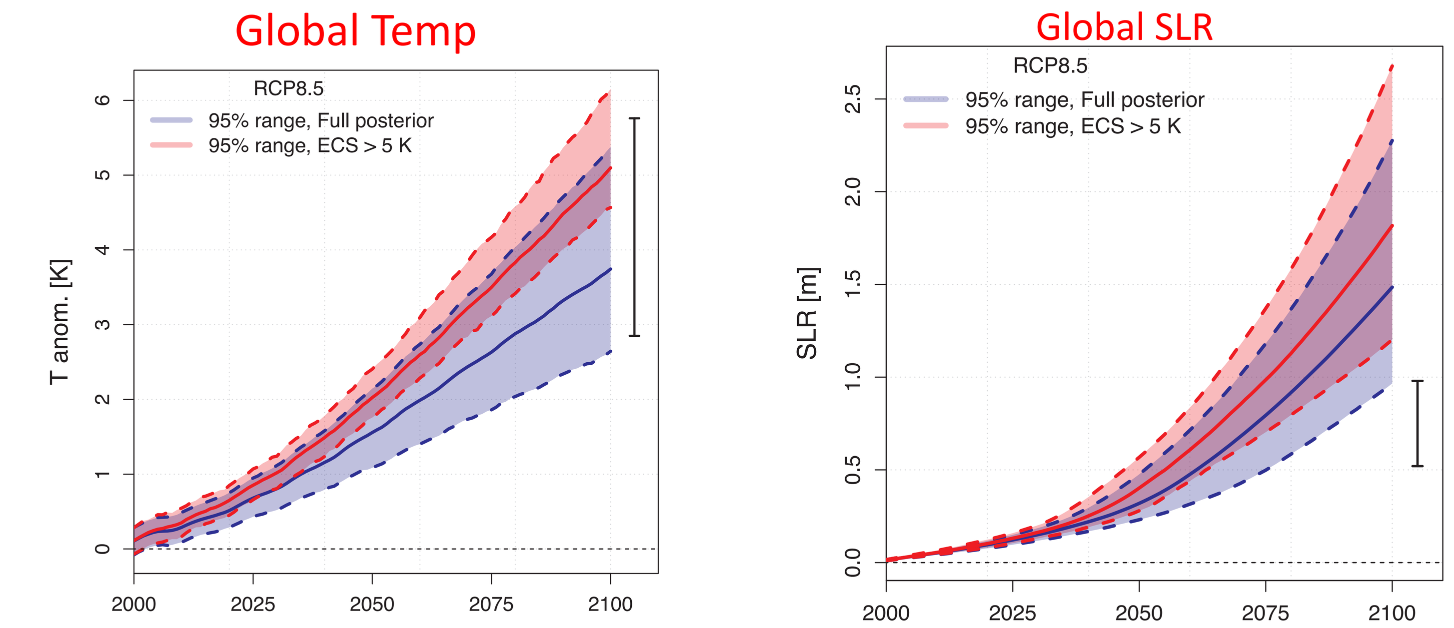
Approach

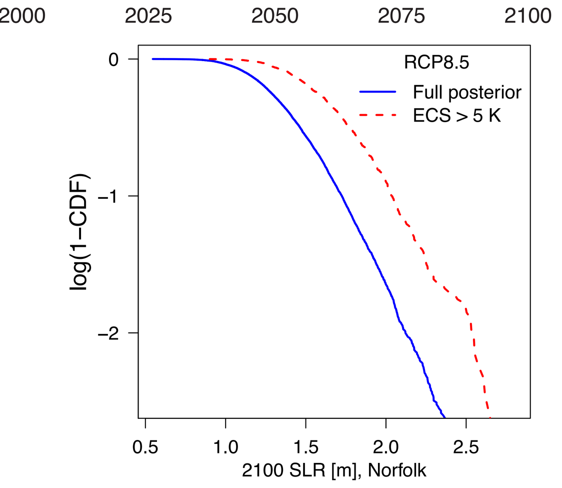
- Combine Hector-Brick ensemble results with regional fingerprinting (Slangen et al., 2014) to analyze relationships between climate sensitivity (CS) above and below 5 C, and local SLR projections

Impact

- CS has a major effect on global temp, but not on global SLR
- Technique can connect global uncertainties with local-scale impacts

- **Next steps: Combine results with local sea-level observations to investigate effects on flood risks**





Global temperature (**upper left**) and sea-level rise (**upper right**) projections from new Hector-Brick calibration. Red shading denotes ensemble members with climate sensitivity > 5 K. Vertical bars represent the IPCC range in 5th Assessment Report. Survival function (1-CDF) of local 2100 sea-level rise for Norfolk VA (**lower**). Red curve denotes ensemble members with climate sensitivity > 5K.

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Vega Westhoff, B., Sriver, R. L., Hartin, C. A., Wong, T. E., and Keller, K. (In Preparation), What is the role of climate sensitivity in extreme sea-level rise scenarios?, Geophysical Research Letters

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