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Does air-sea coupling influence model projections of the effects of the Paris Agreement?

Nicholas Klingaman (1,2), Emma Suckling (1,2), Rowan Sutton (1,2), Buwen Dong (1,2)

(1) National Centre for Atmospheric Science-Climate, Reading, UK (nicholas.klingaman@ncas.ac.uk), (2) Department of Meteorology, University of Reading, Reading, UK

The 2015 Paris Agreement includes the long-term goal to hold global-mean temperature to "well below 2°C above pre-industrial levels", with the further stated aim of limiting the global-mean warming to 1.5°C, in the belief that this would "significantly reduce the risks and impacts of climate change". However, it is not clear which risks and impacts would be avoided, or reduced, by achieving a 1.5°C warming instead of a 2.0°C warming.

Initial efforts to quantify changes in risk have focused on analysis of existing CMIP5 simulations at levels of global-mean warming close to 1.5°C or 2.0°C, by taking averages over ≈20 year periods. This framework suffers from several drawbacks, however, including the effect of model internal multi-decadal variability, the influence of coupled-model systematic errors on regional circulation patterns, and the presence of a warming trend across the averaging period (i.e., the model is not in steady state). To address these issues, the "Half a degree Additional warming, Prognosis and Projected Impacts" (HAPPI) project is performing large ensembles of atmosphere-only experiments with prescribed sea-surface temperatures (SSTs) for present-day and 1.5°C and 2.0°C scenarios. While these experiments reduce the complications from a limited dataset and coupled-model systematic errors, the use of atmosphere-only models neglects feedbacks between the atmosphere and ocean, which may have substantial effects on the representation of local and regional extremes, and hence on the response of these extremes to global-mean warming.

We introduce a set of atmosphere–ocean coupled simulations that incorporate much of the HAPPI experiment design, yet retain a representation of air–sea feedbacks. We use the Met Office Unified Model Global Ocean Mixed Layer (MetUM-GOML) model, which comprises the MetUM atmospheric model coupled to many columns of the one-dimensional K Profile Parameterization mixed-layer ocean. Critically, the MetUM-GOML ocean mean state can be controlled by prescribed, seasonally varying corrections to temperature and salinity, which substantially reduce SST biases without damping variability. This allows the present-day MetUM-GOML experiment to have a ocean mean state very close to the observed climatology (global RMSE ≈ 0.25°C). We perform three 150-year experiments with MetUM-GOML for (a) present-day (1976–2005 climatology) and for future scenarios with global-mean temperatures (b) 1.5°C and (c) 2.0°C above pre-industrial levels. For (b) and (c), we achieve these warming levels by increasing the CO_2 concentrations in MetUM-GOML, as well as by adjusting the prescribed sea ice using change factors derived from a transient simulation with the fully coupled Met Office model.

We analyse projected global and regional changes in temperature, precipitation and atmospheric circulation in our MetUM-GOML simulations, focusing on seasonal means, multi-annual persistence of seasonal extremes (e.g., the probability of consecutive wet summers) and intra-seasonal extremes (e.g., heatwaves, droughts, floods). To identify the influence of air–sea coupling on these projections, we compare the MetUM-GOML simulations to 150-year atmosphere-only simulations with prescribed daily SSTs from the corresponding MetUM-GOML runs. This comparison demonstrates whether atmosphere–ocean feedbacks influence the projections of changes hydro-meteorological extremes in a warmer world, as well as whether these feedbacks affect the assessment of the impacts avoided by limiting global-mean temperature change to 1.5°C. Our results will inform the choice of model framework for, and hence the experiment design of, further efforts to characterise the response to a fixed global-mean temperature increase, as well as future climate-change attribution experiments.