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Evaluating the Stationarity Assumption in Statistically Downscaled Climate Projections: Is past performance an indicator of future results?

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GFDL-HiRAM-C360 model climate experiments used in this study

The high resolution general circulation model (GCM) used here as a data source is the GFDL-HiRAM-C360 model (hereafter "C360") which has ~25km horizontal grid spacing and 32 vertical levels. The model grid has the topology of a cube, covers the entire globe, and has 360x360 grid elements on each face of the cube. For this perfect model (PM) study, we present results focusing on a region centered on the contiguous forty-eight United States. Aspects of a lower resolution C180 (or ~50km) version of this model are described in Zhao et al. (2009) and Zhao and Held (2012). A Northern Hemisphere-only implementation of the C360 model is presented in Chen and Lin (2011).

The C360 model climate experiments were run as time-slice integrations (sometimes referred to as AMIP-style runs) following protocols established for phase five of the Climate Model Intercomparison Project (CMIP5) (Taylor et al. 2012). In time-slice experiments, time-varying sea surface temperatures (SSTs) and sea ice values are prescribed as lower boundary conditions, rather than having the GCM's prognostic atmosphere and land surface components coupled to fully dynamical ocean and sea ice model components. The PM framework described in this study can be applied equally well to experiments conducted using a fully coupled dynamical atmosphere-ocean global climate model (AOGCM) as to models run in the time-slice manner.

Output derived from a total of 120 years of C360 model integrations are used in the PM analyses of statistical downscaling performance. Figure S1 depicts the annual mean climatology of daily maximum near-surface air temperature (CMIP5 variable "tasmax") calculated from a two-member ensemble of C360 experiments run for the time period 1979-2008 (60 years total). Consistent with CMIP5 protocols, the SST and sea ice fields used as lower boundary conditions for the 1979-2008 "historical" time period were derived from observation-based datasets containing both seasonal and inter-annual variability. The two historical period ensemble members were initialized from different points in a well spun-up C360 control experiment representative of late 20th century conditions.

Additionally, output from two sets of C360 time-slice climate projection experiments covering the time period 2086-2095 are used in the PM analyses. Each set of late 21st century C360 experiments is comprised of three ensemble members (a total of 30 years in each set). The late 21st century C360 experiments' forcings differ from the historical experiments in two ways: (a) prescribed levels of atmospheric radiative forcing agents are based on the Representative Concentration Pathways 8.5 (RCP 8.5) scenario (Moss et al. 2010, Riahi et al. 2011) and (b) SST and sea ice lower boundary conditions incorporate projected late 21st century climate change anomalies simulated by a pair of previously completed, lower resolution AOGCM experiments run with the RCP 8.5 emissions scenario. One set of three late 21st century C360 time-slice experiments were generated using lower boundary conditions based on results of GFDL-ESM2M model projections (Dunne et al. 2012) and the other set used results of GFDL-CM3 climate model experiments (Donner et al. 2011, Griffies et al. 2011), hereafter ESM2M and CM3, respectively.

More specifically, for each AOGCM, SST and sea ice anomalies were calculated by subtracting values the model simulated for 1979-2008 from values simulated for 2086-2095. Lower boundary conditions for the C360 late 21st century period time-slice experiments were constructed by adding the AOGCM-projected SST and sea ice climate change anomalies to the same lower boundary conditions that had been prescribed for a ten year segment (1999-2008) of the C360 historical experiments. In effect, seasonally varying projected anomaly patterns were super-imposed on observation-based lower boundary conditions from the historical period that contain seasonal and inter-annual variability. The intent of this anomaly methodology is to address biases in the fully coupled AOGCMs' simulations of SST and sea ice, which can be considerable. It also has the effect of ignoring any climate change-induced variations in the interannual variability characteristics of SST and sea ice, as simulated by the AOGCMs.

Although the ESM2M and CM3 coupled model experiments are forced by the same RCP 8.5 emissions scenario, the CM3 model exhibits greater climate sensitivity (i.e., more global warming) than is simulated by the ESM2M model. This is reflected in the results of the high resolution C360 time-slice experiments for the 2086-2095 period. As depicted in Fig. S1, over the area of interest, annual mean daily maximum temperatures in the set of late 21st century C360 experiments forced with lower boundary conditions derived from the CM3 AOGCM (hereafter C360 ensemble "C") on average warm ~2C more than in the set of C360 experiments forced with ESM2M lower boundary conditions (hereafter C360 ensemble "E"). For reference, Forster et al. (2013) report the global transient climate response (TCR) metric for ESM2M as being 1.3C and for CM3 it is 2.0C – values that bracket the CMIP5 multi-model mean of 1.82C.

The prescription of observation-based SSTs and sea ice values in time-slice experiments provides a constraint that prevents the atmospheric model component from being influenced by unrealistic lower boundary conditions – a condition that can arise in some fully coupled dynamical AOGCM simulations that exhibit pronounced climate drift (Stouffer and Dixon 1998; Gupta et al. 2013). However, while prescribing realistic lower boundary conditions mitigates against one source of GCM biases, the prescription alters or eliminates some feedback mechanisms, thereby suppressing potential sources of temporal variability and non-stationarity in the coupled climate system.

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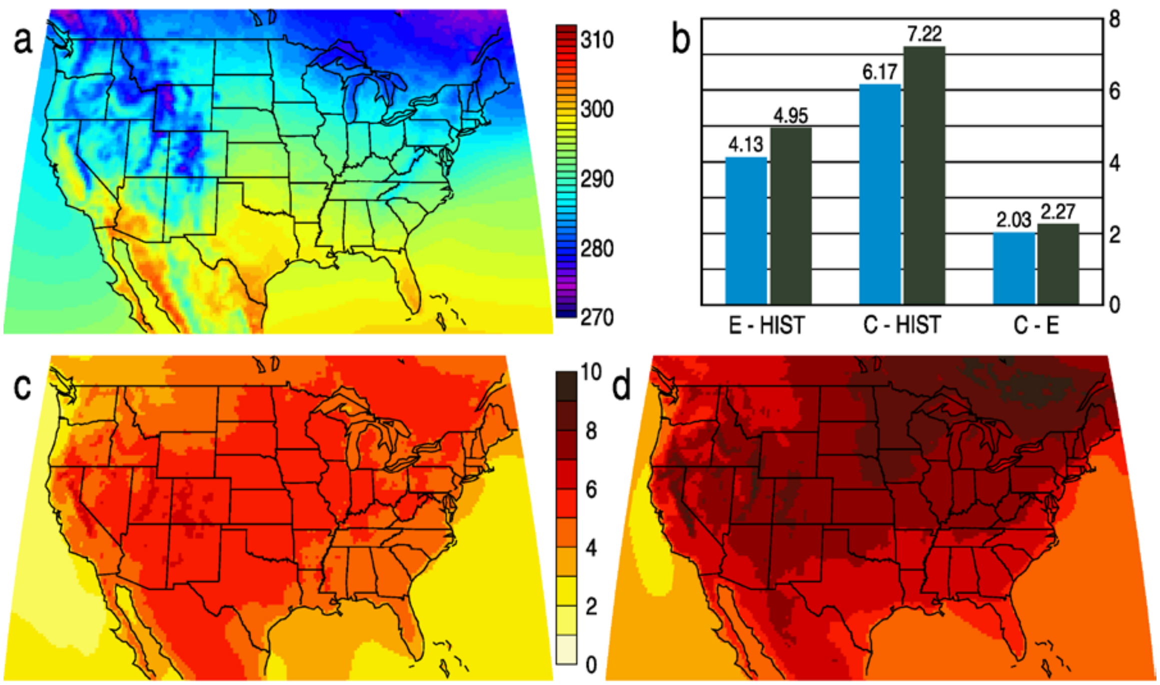

Fig. S1 Measures of annual mean daily maximum surface air temperatures (tasmax, [K]) simulated in ensembles of GFDL-HiRAM-C360 time-slice experiments.
(a) Annual mean tasmax climatology of the two-member historical time-slice ensemble (1979-2008).
(b) Differences between area-averaged annual mean tasmax simulated in C360 time-slice ensembles. Differences calculated over land and ocean points are shown as blue bars and differences averaged over land points shown as dark green bars. Left: E ensemble minus historical ensemble. Center: C ensemble minus historical ensemble. Right: C ensemble minus E ensemble.
(c) Annual mean tasmax warming pattern of the E ensemble (2086-2095) relative to the historical ensemble.
(d) Same as (c) but for the C ensemble.