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Testing GISS-MM5 physics configurations for use in regional impacts studies

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Abstract The Mesoscale Modeling System Version 5 (MM5) was one-way nested to the Goddard Institute for Space Studies global climate model (GISS GCM), which provided the boundary conditions for present (1990s) and future (IPCC SRES A2 scenario, 2050s) five-summer "time-slice" simulations over the continental and eastern United States. Five configurations for planetary boundary layer, cumulus parameterization, and radiation scheme were tested, and one set was selected for use

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in the New York City Climate and Health Project—a multi-disciplinary study investigating the effects of climate change and land-use change on human health in the New York metropolitan region. Although hourly and daily data were used in the health project, in this paper we focus on long-term current and projected mean climate. The GISS-MM5 was very sensitive to the choice of cumulus parameterization and planetary boundary layer scheme, leading to significantly different temperature and precipitation outcomes for the 1990s. These differences can be linked to precipitation type (convective vs. non-convective), to their effect on solar radiation received at the ground, and ultimately to surface temperature. The projected changes in climate (2050s minus 1990s) were not as sensitive to choice of model physics combination. The range of the projected surface temperature changes at a given grid point among the model versions was much less than the mean change for all five model configurations, indicating relative consensus for simulating surface temperature changes among the different model projections. The MM5 versions, however, offer less consensus regarding 1990s to 2050s changes in precipitation amounts. All of the projected 2050s temperature changes were found to be significant at the 95th percent confidence interval, while the majority of the precipitation changes were not.

1 Introduction

Regional-scale mesocale climate models (RCMs) have been used to downscale global climate model (GCM) output for the purpose of simulating regional climate change (e.g, Dickinson et al. 1989; Bates et al. 1993; Giorgi et al. 1993a, b; Walsh and McGregor 1995; Bell et al. 2004; Han and Roads 2004; Leung et al. 2004; Liang et al. 2004; Lynn et al. 2004; Fu et al. 2005). These models can improve the representation of regional climate change for impact studies because they employ higher grid resolution than GCMs, have more realistic topography, better resolve convective-scale processes, and simulate air-sea contrasts and sea-breezes (Giorgi and Marinucci 1996; Colle et al. 2000; Mass et al. 2002; Leung and Qian 2003; Leung et al. 2003a, b, c).

In this study we use the Goddard Institute for Space Studies Global Climate Model (GISS GCM) (Hansen et al. 2002; Russell et al. 1995) to force the Mesocale Modeling System, Version 5 (MM5) (Dudhia 1993; Grell et al. 1994). The combined model is referred to as the GISS-MM5. The model system was used in an interdisciplinary study of climate change and land-use change effects on regional climate, air quality, and health in the New York metropolitan region, the New York Climate and Health Project (NYCHP) (Hogrefe et al. 2004; Knowlton et al. 2004; Bell et al. 2007).

As part of the development of the regional modeling system, we tested the MM5 with different physics components (plantary boundary-layer, cumulus, and radiation parameterizations) at two grid resolutions (108 and 36 km) to simulate current climate in the 1990s and projected climate change in the 2050s (as suggested by Cortinas and Stensrud (1995) and Rosenzweig and Solecki (2001)). The results of this study allowed us to identify the model configuration that performed the best in simulating the New York metropolitan region for the NYCHP study. Although hourly and daily data were used in the health project, in this paper we focus on the ability of the climate models to simulate long-term current and projected mean climate.

2 Description of GISS-MM5

2.1 GISS GCM

The GISS GCM, from which lateral boundary and initial conditions for the MM5 were taken, has been extensively used in climate-sensitivity studies. The version used here is a coupled atmosphere-ocean version with horizontal grid spacing of 4° by 5°, for nine vertical atmospheric layers and 13 vertical ocean layers with realistic bathymetry (Russell et al. 1995). Flux adjustments are not used in the GISS GCM, which has a sensitivity to doubled atmospheric CO_2 of 2.5–3.0°C. Results for the 1990s and the 2050s were taken from the GISS GCM model run with the IPCC SRES A2 greenhouse gas and sulfate emissions scenario (IPCC 2000). The A2 scenario is characterized by high CO_2 emissions (30 gt/year max), relatively weak environmental concerns, and large population increases (15 billion by 2100). It ranks as medium-to-high compared to other emission scenarios. The GISS GCM simulation uses observed greenhouse gas and sulphate emissions from 1850 to 1990, and the emissions projected by the A2 scenario thereafter.

2.2 MM5

The non-hydrostatic Mesoscale Modeling System, Generation 5, MM5 version 3.5 (Dudhia 1993; Grell et al. 1994) was chosen as the regional modeling component of the GISS regional modeling system. The MM5 was developed by Pennsylvania State University and the National Center for Atmospheric Research. The standard model includes predictions for three-dimensional wind components, temperature, mixing ratios for water vapor, and cloud water/ice and rain/snow (using bulk parameterizations).

The NOAH land-surface submodel developed by Chen and Dudhia (2001a, b) was used to calculate the lower boundary condition of the model with constant deep soil temperature. While a constant soil temperature would not be realistic in longterm simulations of climate change, the goal of our multiple 4-month simulations was to highlight differences among various model configurations.

Important physics components in the GISS-MM5 relevant to the sensitivity study described here are the (1) planetary boundary layer (PBL) scheme, (2) cumulus parameterization, and (3) radiation package. We focus on different model configurations of the following components: (1) the Medium Range Forecast Model (MRF) and Eta planetary boundary layer schemes; (2) the Betts–Miller and Grell cumulus parameterizations; and (3) the Community Climate Model (CCM2) and the Rapid Radiative Transfer Model (RRTM) radiation packages (Table 1). The two boundary layer schemes are widely used in mesoscale model studies; the cumulus parameterization schemes are also widely used and both are designed to work at the spatial scales of this study. The radiation packages are the two most sophisticated available in the MM5.

The MRF PBL is an efficient scheme based on the Troen-Mahrt representation of the counter-gradient term and K profile in the well-mixed PBL (Hong and Pan 1996). The MRF also includes vertical mixing in clouds, i.e., mixing along a wet adiabat. In comparison, the Eta PBL is based on the Mellor-Yamada scheme that predicts the

Table 1 Acronyms for the eight model configurations

List of acronyms	Boundary layer scheme	Cumulus parameterization	Radiation package
MIBR	MRF	Betts–Miller	RRTM
EBR	Eta	Betts–Miller	RRTM
MIGR	MRF	Grell	RRTM
MIGC	MRF	Grell	CCM2
EGC	Eta	Grell	CCM2

Boundary layer schemes: Medium Range Forecast Model (M, MRF) or Eta (E); inclusion of vertical mixing in clouds (I); cumulus parameterizations: Betts–Miller (B) or Grell (G); radiation packages: Community Climate Model version 2 (C, CCM2) or Rapid Radiation Transfer Model (R, RRTM)

turbulent kinetic energy (TKE). It uses the TKE to affect local mixing and does not include vertical mixing in clouds (Janjic 1990, 1994).

The Betts–Miller scheme is based on a relaxation adjustment to a reference post-convective thermodynamic profile over a given period (Betts 1986; Betts and Miller 1986; Janjic 1994). In comparison, Grell uses the quasi-equilibrium assumption of Arakawa and Schubert (Grell and Kuo 1991; Grell 1993). In this scheme, the rate of cloud stabilization associated with moist convection balances the large-scale destabilization rate.

The CCM2 radiation scheme accounts for multiple short-wave and spectral bands. It includes the effects of both resolved and unresolved clouds (based on a relative humidity-derived cloud fraction) (Hack et al. 1993). The RRTM contains both short-wave and long-wave radiation schemes (Mlawer et al. 1997), but does not include a relative humidity-derived cloud fraction.

3 Methods

3.1 Coupling

The one-way nesting of the MM5 model to the GISS GCM occurred at the model initialization and subsequently through the lateral boundaries. Six-hourly GISS GCM data were interpolated to the lateral boundaries of the high-resolution grid. A five-point linear time interpolation was used to make the lateral boundary data synchronous with the MM5 time steps. The sea-surface temperatures were obtained from the GISS GCM. The land surface model was initialized at the first time step with GISS GCM soil temperature and soil moisture, interpolated to the MM5 grid. The MM5 model used the same carbon dioxide (CO_2) gas concentrations as the GISS GCM.

3.2 Simulation experiments

The MM5 model was driven with NCEP reanalysis data for the summer of 1993 to test model performance and to evaluate consistency with the GISS GCM driven results. In these simulations the reanalysis data were used to initialize and to set the lateral boundary conditions for the MM5 model. While 1 year is not enough to fully evaluate the ability of the MM5 model driven by NCEP reanalysis data to replicate observed climate, the results are indicative of similar tendencies in both sets of runs.

The GISS-MM5 was run for five summers in the 1990s and the 2050s. (Time and resource limitations prohibited further simulations.) Simulations with the GISS-MM5 model were first run at 108 km grid resolution for a domain that covered the continental US (see Fig. 1a for model domain and grids). Thirty-five vertical layers were used, with finer grid resolution in the lower troposphere to allow the model to better simulate boundary-layer processes. The time step was 270 s, and each simulation was run from May 1st to Sept 1st, to allow spin-up before the start of the analysis on June 1st in each summer. Although allowing only 1 month for GISS-MM5 model spin-up time is less than ideal, the purpose of the work was to examine model differences rather than actual values. Although the simulated soil moisture and temperature evolve in response to radiation, wind, and precipitation forcing, soil temperature and moisture distribution from the GISS GCM used to initialize the model can leave a residual signal during the development of summertime meteorology (Dirmeyer 2002). All of the sets of runs were done using the same MM5 basic code, initial conditions, and climate forcings. Our goal was to highlight differences between the various model configurations given the limitations of the model version used.

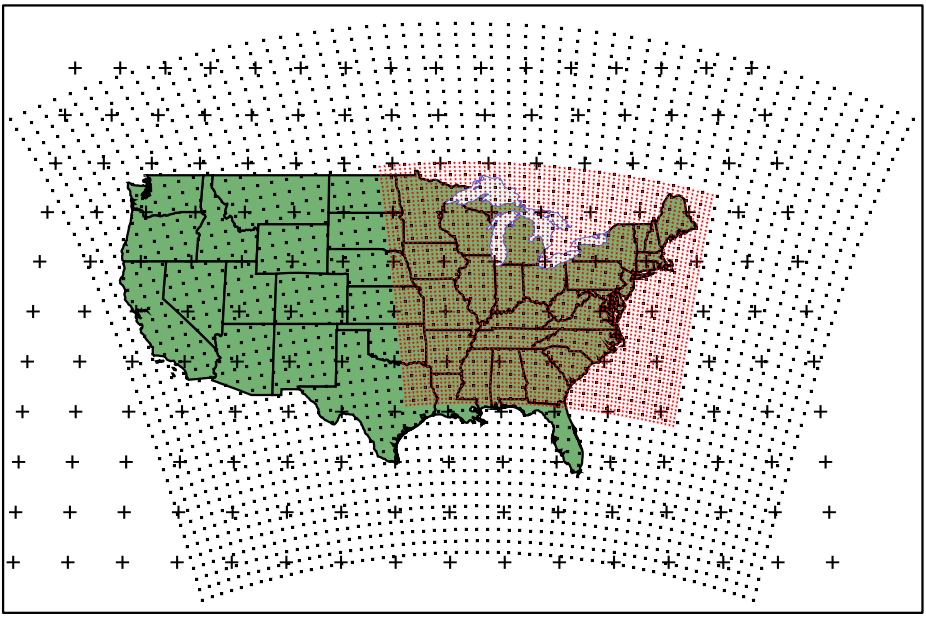
After testing the model configurations at the 108 km resolution, we selected the MIBR version (with the MRF boundary-layer scheme, the Betts–Miller cumulus parameterization, and the RRTM radiation package) to simulate the eastern United States for five summers in the 1990s and 2050s at 36 km resolution. The 36 km grid was a single nest with two-way interaction with the 108 km grid. For comparison, we tested the same configuration and resolution with the Grell cumulus parameterization scheme (MIGR). In these simulations the western edge of the nested domain responded directly to the incoming information from the coarse, upstream, 108 km MM5 domain, not the GISS boundary data. The GISS boundary data elicited a different response in the coarse domain that depended on the MM5 physics on the coarse grid, which manifests itself, in part, in the results we see on the nested domain.

3.3 Validation

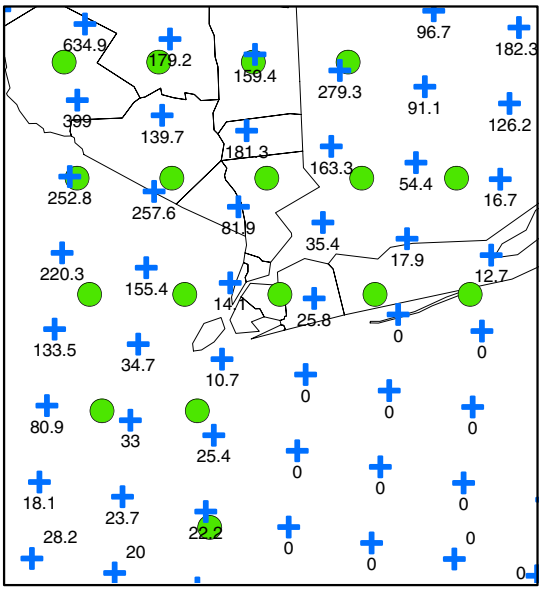
Here we analyze how well the GISS-MM5 model is able to reproduce the long-term summer 1990s climatic means. Results from the model configurations described in Table 1 were compared with observations and NCEP simulations. Model temperature and precipitation results from the 108 km (36 km grid results from MIBR and MIGR) were compared to the seasonally-averaged $0.5^\circ \times 0.5^\circ$ gridded observations of New et al. (2000) (hereafter New et al.) for the period 1990 to 1999 over the continental United States. Incident solar radiation at the surface simulated by GISS-MM5 was validated against corresponding data from the Langley Observatory (Darnell et al. 1996). The 'observed' solar radiation data are derived from a combination of satellite measurements and models.

We compared the 5 years of MM5 simulations to 10 years of observed and GISS GCM data centered on 1995 because we do not expect an exact year-to-year correspondence between modeled and observed years, and because the larger sample size depicts current climate more accurately. In order to see if 5 years were enough data from which to draw conclusions we ran one configuration, EBR, for 10 years over the entire 108 km domain. The mean domain-averaged 5- and 10-year temperatures were 20.96 and 21.09°C, respectively, while the precipitation means were

a GISS GCM, MM5 108 and 36 km Grids



b NYC Metropolitan Region Study Area



● = New et al. (2000) observed point

+ = 36 km MM5 gridbox mid-point

x.x = MM5 elevation (m)

◀ **Fig. 1** **a** Model grid resolutions: GISS GCM 4° × 5°; GISS-MM5 108 and 36 km. **b** MM5 36 km grid-box centers and associated elevations (m), and observed New et al. (2000) gridpoints in New York metropolitan region 36 km domain

259.8 and 265.1 mm, respectively. These values were not significantly different from one another. For the NCEP-driven MM5 simulations, we compared 1 year (1993) of simulated climate to those obtained from the GISS-MM5, GISS GCM, and New et al. observations for that same year.

We compared GISS-MM5 modelled mean summer 1993–1997 temperatures and precipitation for each model configuration to observed and GISS GCM 1990–1999 values. The modelled means were interpolated to the observed data-points using a simple two-dimensional interpolation method in which weights are assigned by the inverse of the distance from the model grid points to the observed New et al. gridpoints. An initial search radius was increased until at least three model data points were found. For the 36 km comparison, GISS GCM and GISS-MM5 108 km results were interpolated onto the 36 km grid.

Modelled and observed temperatures and precipitation were averaged over the entire domain for each summer. Statistical tests were then performed on these summer-time averages ($n = 1, 5,$ or 10 summers). Means, standard errors, and student t-tests for independent samples (unpaired) were performed to test for significance at the 95th percent confidence interval. In addition, a spatial test was performed by first obtaining the modeled summer means over the whole time series at each gridpoint ($n = 3062$) and then computing the RMSEs at each point. All of the above validations were then repeated over a much smaller region, the New York City metropolitan area (Fig. 1b), both with the 108 km configurations and the 36 km configurations for MIBR and MIGR.

4 Results

4.1 Current climate simulations

Figure 2 shows temperature and precipitation biases that were obtained by comparing simulations driven by NCEP reanalysis data for 1993 to New et al. observations from that same year. Because the NYCHP study focused on the effects of heat stress and air quality, good comparison to observed temperature was our main criterion for model selection. While the model configurations generally produced temperatures that were too cold, the NCEP-MIBR temperatures were closest to observations. Most of the simulations were dry compared to observations, except in the mid-US, where they were too wet.

Figure 3 shows that the physics configurations had similar effects in the GISS-MM5 compared to the NCEP simulation (with the caveat that the NCEP simulation was for only 1 year). Simulated temperature in the GISS-MIBR was closest to the New et al. observations just as in the NCEP-MIBR; MIBR was also the warmest and wettest configuration in both sets of simulations. However, each of the GISS-MM5 model configurations exhibits regional biases in surface temperatures and precipitation. For example, MIBR was too warm in the southern United States, while MIGR had a cool bias in areas outside of the southeast. MIGR (like MIBR) was too

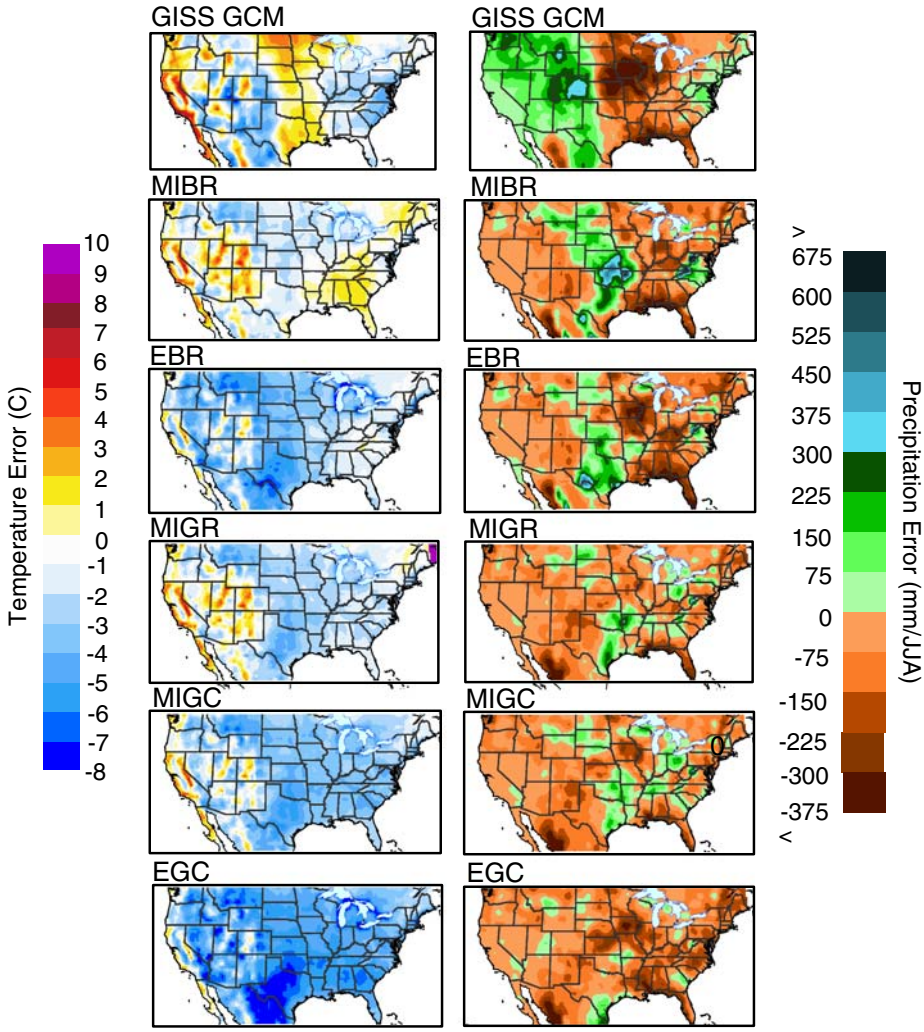


Fig. 2 Model minus observed errors in JJA 1993 2 m mean surface temperature (*left*) and precipitation (*right*) over the continental US GISS GCM (4° × 5°) and NCEP-MM5 (MIBR, EBR, MIGR, MIGC, EGC) (108 km) interpolated to New et al. (2000) observations (0.5° × 0.5°)

wet in the Plains States, while most of the GISS-MM5 simulations were too dry in the southeast. The GISS GCM was too cold in the eastern and western US and too warm in the middle of the country; the GISS-MM5 simulations did not follow that pattern.

All of the GISS-MM5 configurations and the GISS GCM itself were found to be significantly different from observations (Fig. 4). Most of the GISS-MM5 configurations produced mean temperatures that were significantly different from one another and most were different from the GISS GCM as well. The GISS-MM5 simulations that used the MRF boundary layer scheme and the Betts–Miller cumulus parameterization produced warmer mean temperatures than those with

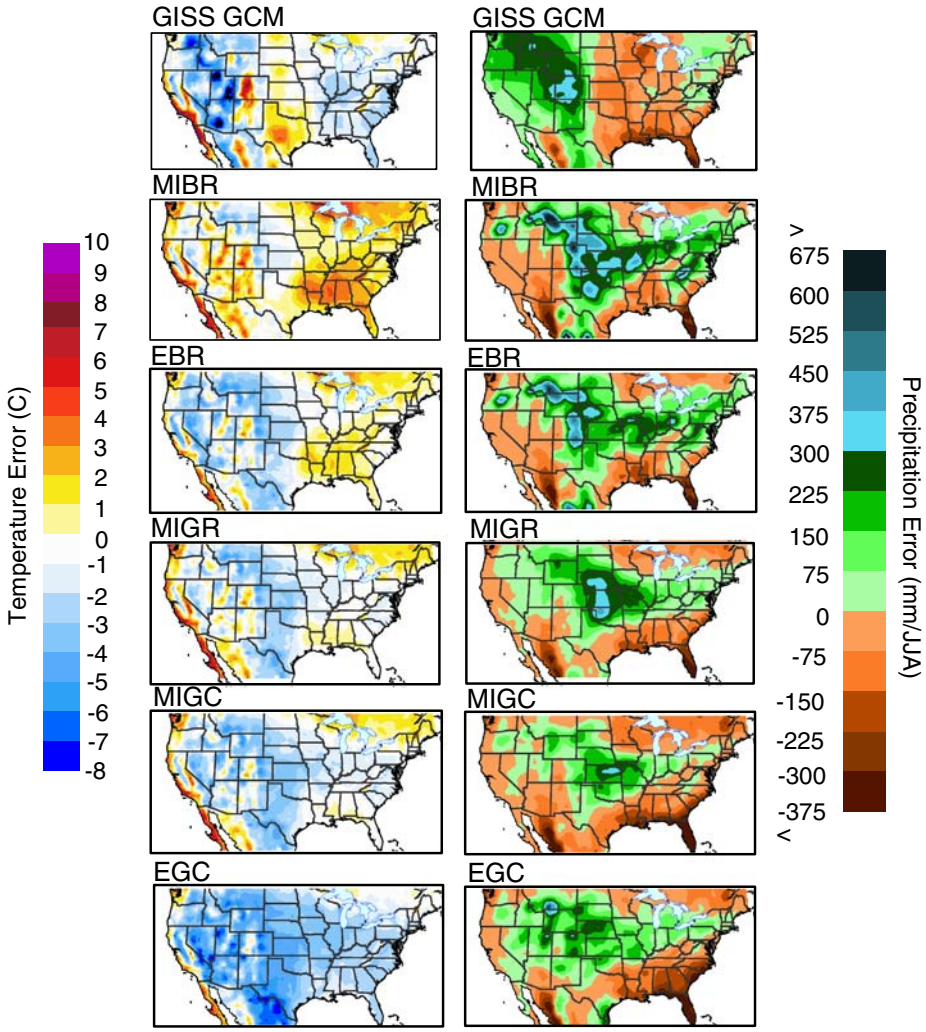


Fig. 3 Model minus observed errors in 1990s JJA 2 m mean surface temperature (*left*) and precipitation (*right*) over the continental US GISS GCM (4° × 5°) and GISS-MM5 (MIBR, EBR, MIGR, MIGC, EGC) (108 km) interpolated to New et al. (2000) observations (0.5° × 0.5°). GISS GCM and New et al., 10-year averages; GISS-MM5, 5-year averages

the ETA boundary layer scheme and the Grell cumulus parameterization scheme, respectively.

The GISS-MM5 model configurations also produced precipitation values that were significantly different from one another and different from the GISS GCM in most cases. The EGC GISS-MM5 configuration produced precipitation that was close to the observed value. With the exception of GISS-MIGC, the warmer scenarios were wetter and the drier scenarios were cooler. The MRF boundary layer scheme and the Betts–Miller cumulus parameterization tended to produce wetter simulations.

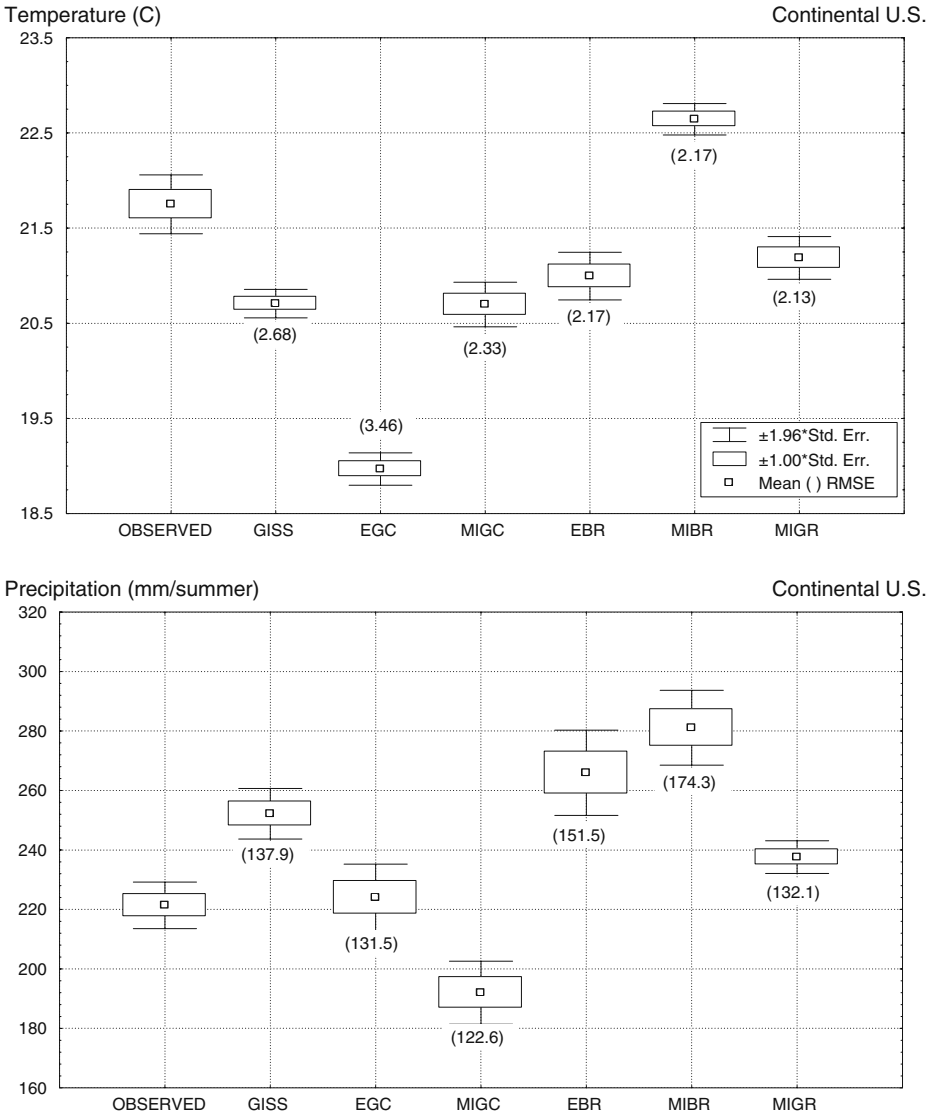


Fig. 4 Mean and standard errors (95th percent confidence interval) of simulated 1990s JJA 2 m mean surface temperature (C) (*top*) and precipitation (mm/summer) (*bottom*) over the continental US GISS GCM (4° × 5°) (10 years); GISS-MM5 (MIBR, EBR, MIGR, MIGC, EGC) (108 km) (5 years); Observations: New et al. (2000) (0.5° × 0.5°) (10 years). RMSEs were calculated at each point and then averaged over the study area

Figure 5 indicates which GISS-MM5 model physics combinations had the lowest average temperature and precipitation errors at each 0.5° × 0.5° grid point. The MIBR had the smallest temperature biases over most areas of the country outside of the southeast; in the southeast, EBR and MIGR performed best. MIGR and EGC generally did well in simulating precipitation. In summary, it appears that model

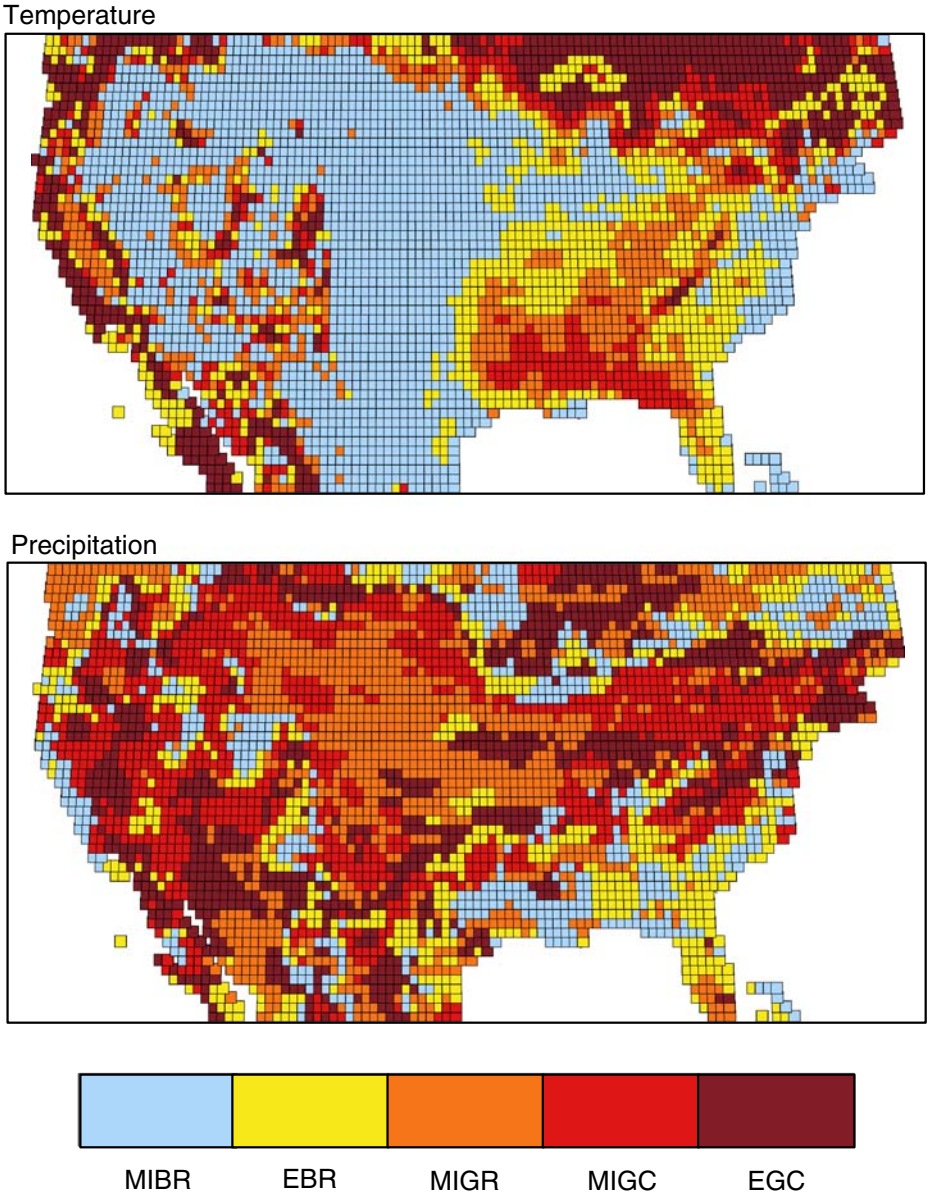


Fig. 5 GISS-MM5 physics combination with lowest average JJA 2 m surface temperature (*top*) and precipitation (*bottom*) error at each 0.5° × 0.5° grid-point over the continental US (MIBR, EBR, MIGR, MIGC, EGC) 1990s (108 km) (5 years). Observations: New et al. (2000) (0.5° × 0.5°) (10 years)

configurations with the Betts–Miller cumulus parameterization (especially those with the MRF boundary-layer scheme) produced more realistic surface temperatures than those that used Grell. On the other hand, model configurations that used Grell produced more realistic precipitation.

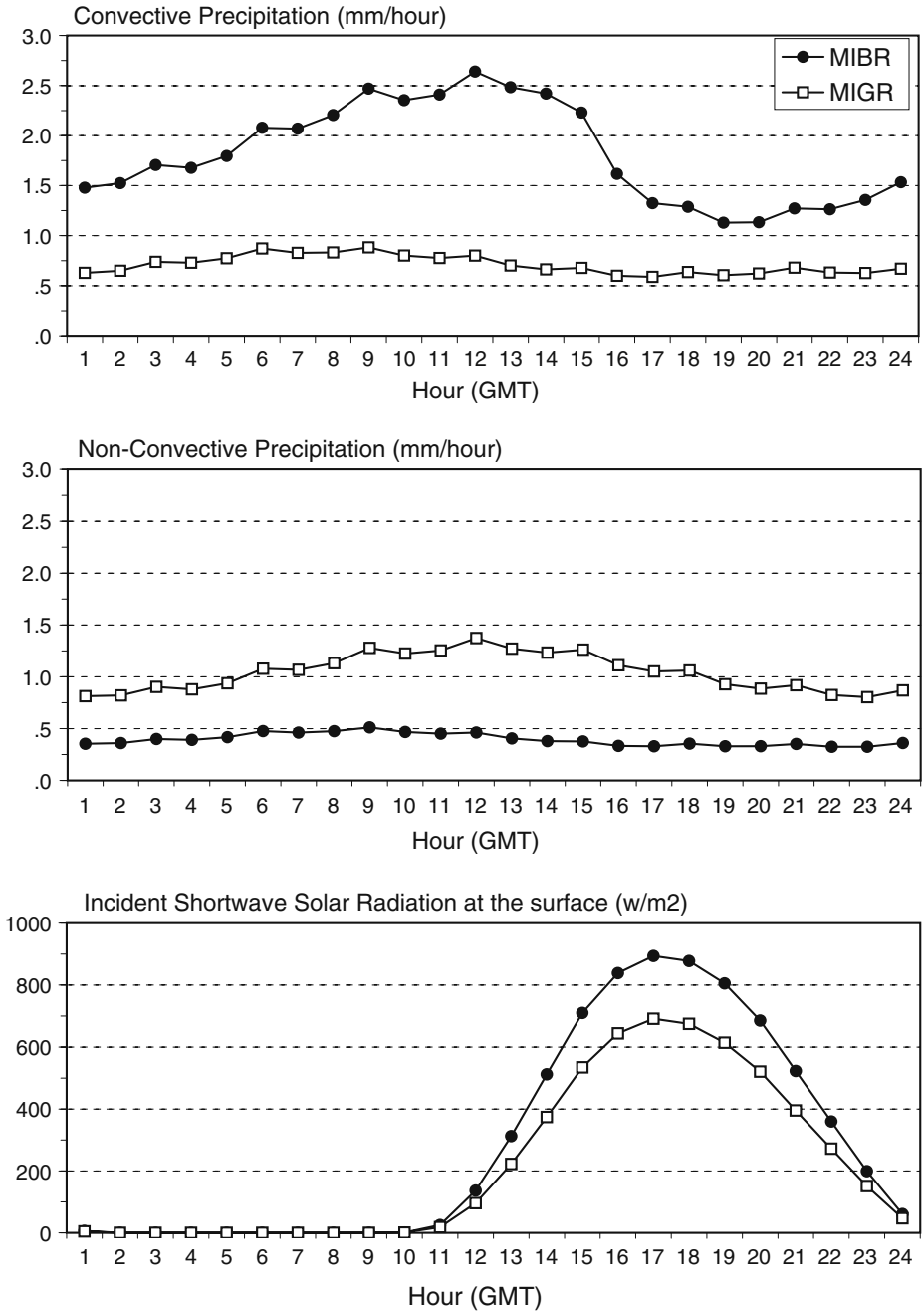


Fig. 6 Simulated hourly NCEP-MM5 (MIBR and MIGR) 1993 JJA convective precipitation (*top*); non-convective precipitation (*middle*); and incident solar radiation at the surface (*bottom*) over the continental US

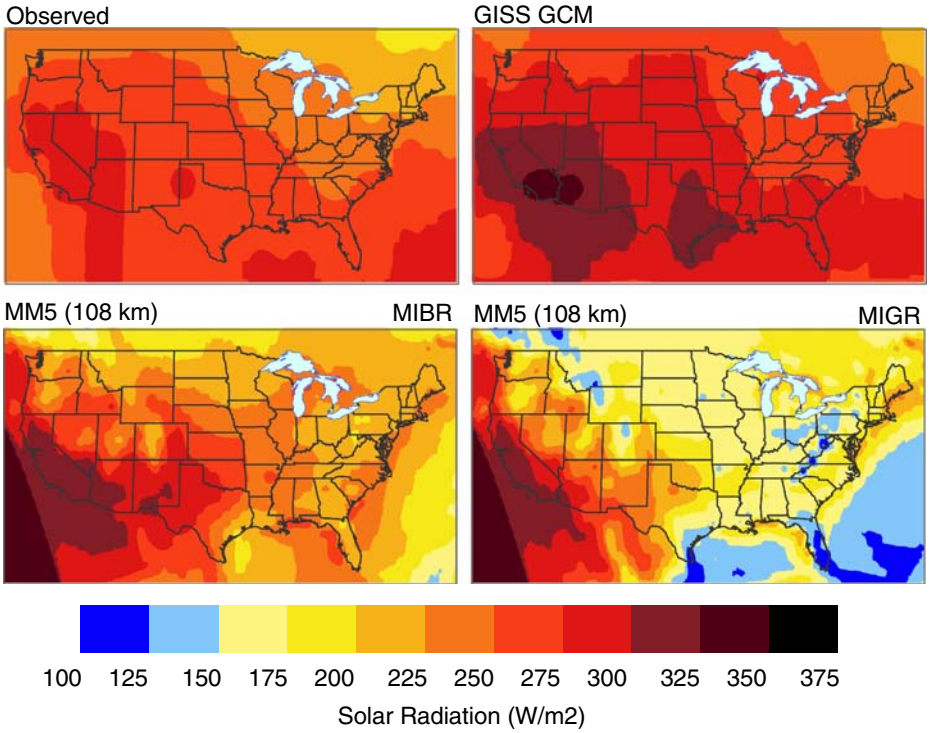


Fig. 7 Simulated and observed 1990s JJA mean incident solar radiation at the surface over the continental US GISS GCM (4° × 5°) (10 years); GISS-MM5 (MIBR and MIGR) (108 km) (5 years); observations (10 years) derived from satellite data and models (Darnell et al. 1996)

Figure 6 shows the hourly-averaged summer convective precipitation, non-convective precipitation, and the incident solar radiation at the surface for NCEP-MIBR and NCEP-MIGR for the summer of 1993, averaged over the continental US. These figures show that the Betts–Miller cumulus parameterization scheme produced a higher percentage of convective precipitation than did the Grell cumulus parameterization scheme. Lynn et al. (2004) showed that the Grell scheme produces too frequent and too light precipitation, contributing to a radiation deficit. On the other hand, the Betts–Miller scheme produces less frequent but more intense convective precipitation, which can lead to a large positive bias in precipitation amounts without large effects on surface temperatures. This behavior is related to differing assumptions related to each configuration, as described in greater detail in Lynn et al. (2004). Figure 7 shows the simulated incident shortwave radiation from the GISS GCM, MIBR and MIGR; observations are shown for comparison. Although both MIBR and MIGR had negative solar radiation biases, MIBR was closer to the observations, while MIGR was extremely low. The simulated radiation from MIGR was, relatively speaking, lower than that of MIBR, which led to a cool bias when it was used with other combinations of model physics.

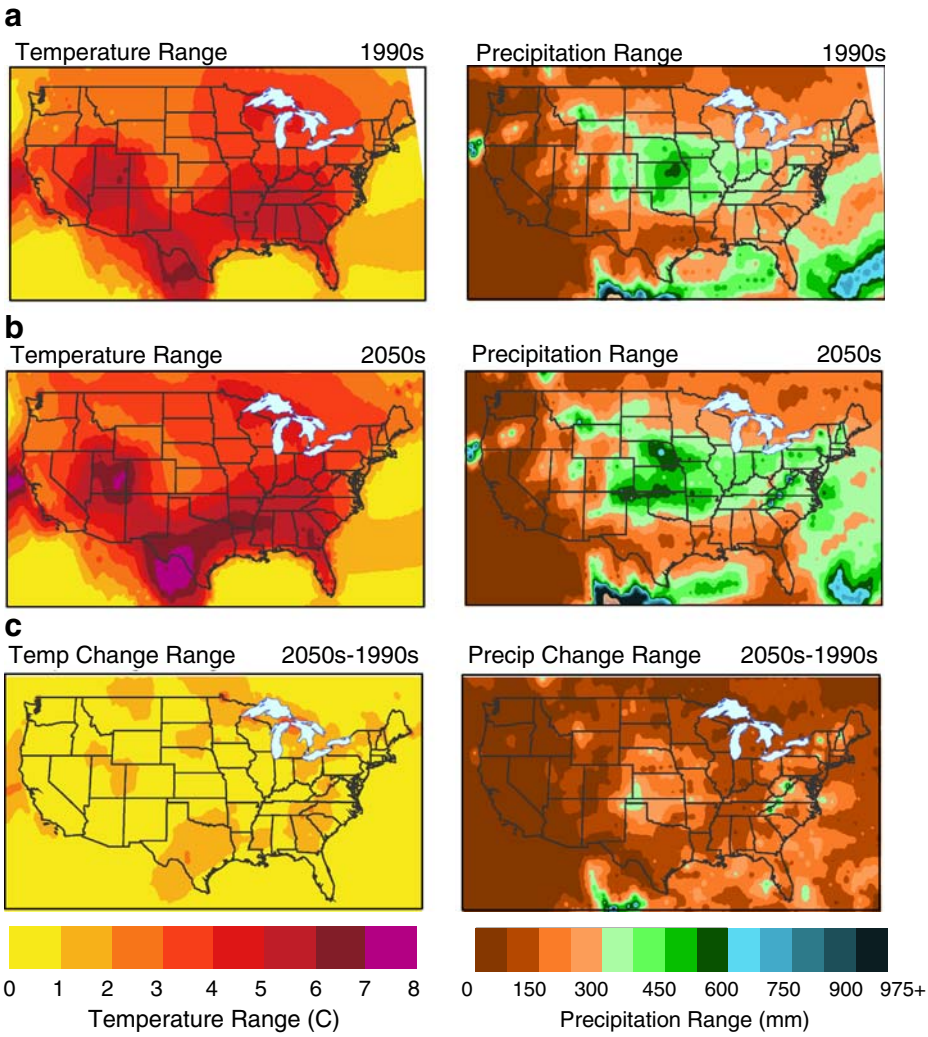


Fig. 8 **a** Range (hottest/wettest minus coldest/driest) of 1990s, JJA 2 m mean surface temperature and precipitation simulated by GISS-MM5 configurations at each (0.5° × 0.5°) gridpoint over the continental US (MIBR, EBR, MIGR, MIGC, EGC) (108 km) (5 years). **b** Same as Fig. 8a, except for the 2050s. **c** Same as Fig. 8a, except for the projected temperature and precipitation changes (2050s minus 1990s) at each gridpoint

4.2 Climate change simulations

Figure 8a shows the range at each gridpoint of the 1993–1997 summer-averaged GISS-MM5 configurations. This range is defined as the value of the simulation with the model configuration that produced the hottest five-summer mean average temperature/wettest (i.e., highest) precipitation minus the value of the simulation

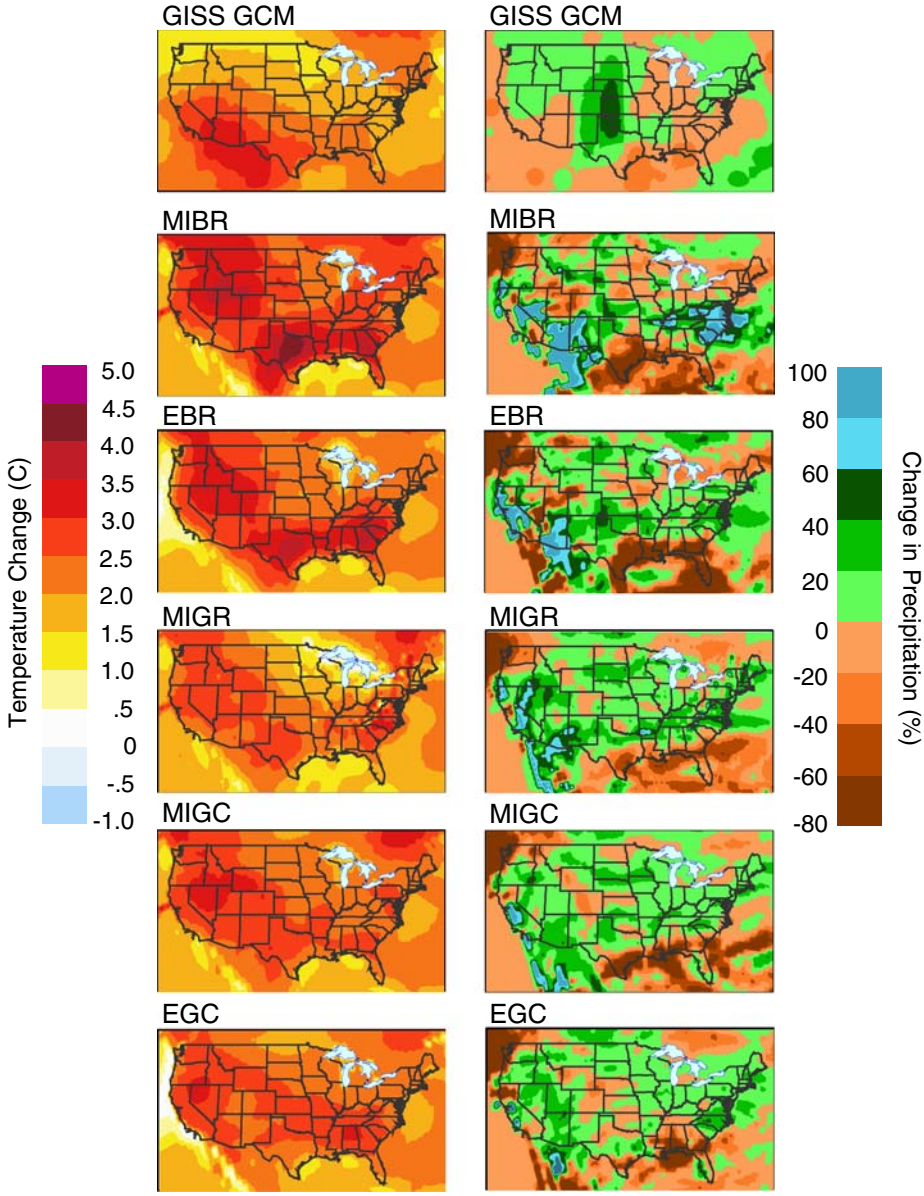


Fig. 9 Projected changes in 2050s JJA 2 m mean surface temperature (°C) (*left*) and precipitation (%) (*right*) over the continental US GISS GCM (4° × 5°) (10 years); GISS-MM5 (MIBR, EBR, MIGR, MIGC, EGC) (108 km) (5 years)

with the model configuration that produced the five-summer mean coldest average temperature/driest (i.e., lowest) precipitation. Figure 8b shows this same range for the 2050s. The patterns of the ranges across the model physics configurations are similar in the 1990s and 2050s with a slight amplification in the later decade.

Figure 8c shows the same range for the projected differences (2050s minus 1990s), i.e., the configuration with the highest temperature (precipitation) change minus the configuration with the lowest temperature (precipitation) change. This figure shows that the ranges of the projected differences across the model configurations are, for the most part, noticeably smaller than the ranges of the 1990s or 2050s themselves. Figure 9 shows the temperature and precipitation changes for the 2050s for the model configurations. For temperature, the warming projected by the GISS-MM5 simulations is slightly higher than the GISS GCM and is more variable spatially. The precipitation projections show increases on a national scale with a great deal of localized variability.

The mean simulated range of summer climate at each gridpoint for the 1990s for the five GISS-MM5 model configurations is about six times greater than the mean range of projected changes in 2050s temperature; the simulated 1990s precipitation range is about four times larger than the projected change in 2050s precipitation range. Thus the choice of model physics configuration produced a very large range of simulated current climate (1990s) temperature and precipitation. The projected climate changes (2050s minus 1990s) were more uniform, and less sensitive to model configuration. This is particularly true for temperature changes; precipitation changes tended to still have relatively large localized projected ranges at some locations.

At most locations across the US, the range (model configuration with the highest temperature change minus the model configuration with the lowest temperature change at each gridpoint) of the 2050s temperature changes (mean of 0.63°C) was much less than the mean change (mean of 2.46°C), suggesting a model-based consensus for the projected temperature change. The projected temperature changes were significantly greater than two standard deviations from the simulated 1990s temperatures at almost all locations (average $2 \times \mathrm{SD} = 0.43$°C). Precipitation changes, on the other hand, were more variable, but were generally less than two standard deviations ($2 \times \mathrm{SD} = 84$ mm) away from their 1990s mean values, indicating that most changes were not statistically significant.

4.3 Present and future regional climate

Here we focus on differences in long-term simulated current and projected climate change in summer using different model configurations. Hogrefe et al. (2004) analyzed the temperature data described here in greater detail since the New York metropolitan region air quality and health impact assessment used hourly and daily data from the MIBR simulations. For example, they constructed summertime cumulative distribution functions of daily maximum temperature over the entire 36 km grid for MIBR. They found that the GISS-MM5 lowest/highest yearly value of the 97.5th percentile of summertime daily maximum temperature was 35.2/37.2°C compared to 34.4/36.7°C for the observations. These differences were found to be not statistically significant.

Figure 10 shows the means, standard errors, and RMSEs of the model configurations for the New York metropolitan region. For this analysis there were a total of 17 New et al. observed gridpoints within our 31-county New York metropolitan region (see Fig. 1b). All of the GISS-MM5 configurations produced local temperatures that were significantly different from both the observations and the GISS GCM, with the

exception of MIBR, which was found to be significantly related to the observations. We selected MIBR and MIGR to downscale to 36 km because they performed the best for temperature. Of these two versions, MIBR was used to obtain simulated temperatures for the health impacts project.

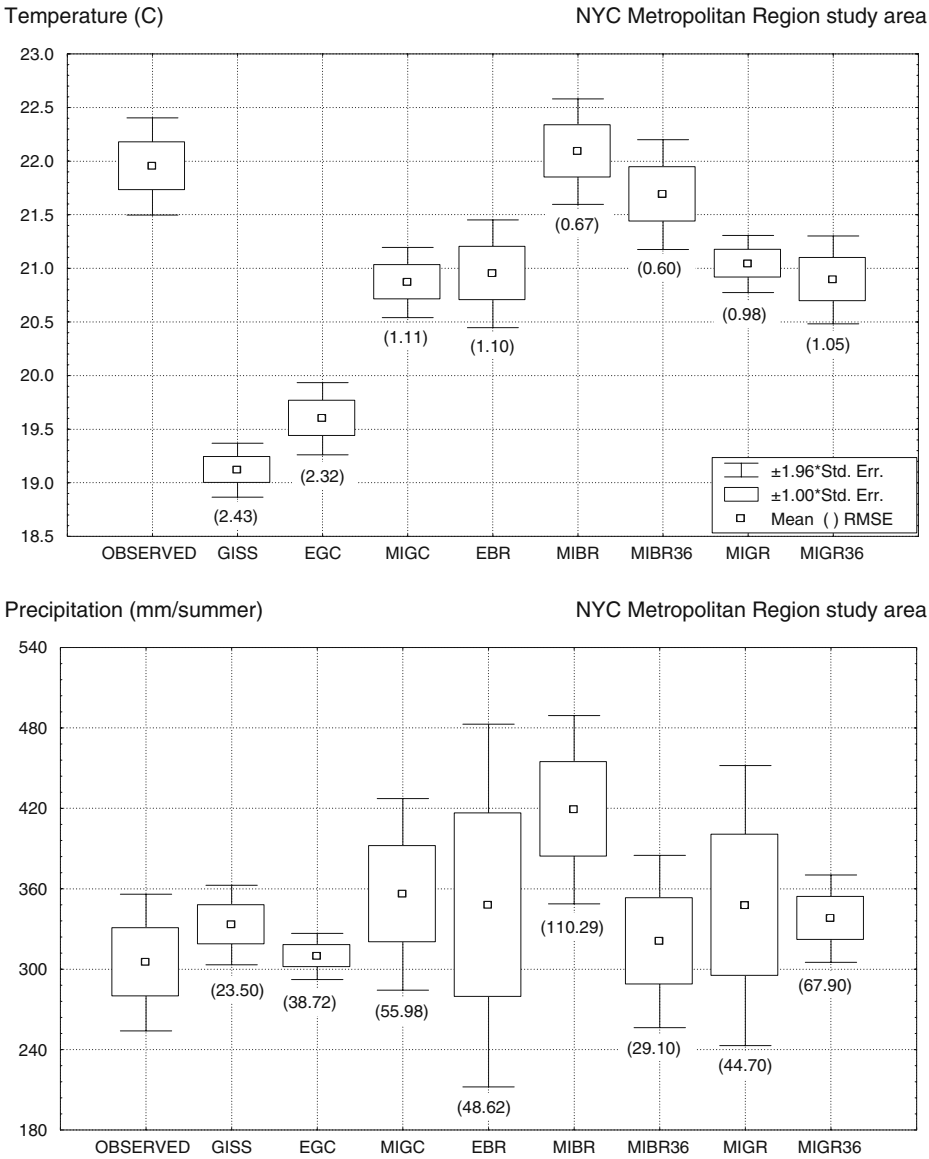


Fig. 10 Mean and standard errors (95th percent confidence interval) of simulated 1990s JJA 2 m mean surface temperature (°C) (*top*) and precipitation (mm/summer) (*bottom*) over the New York City metropolitan region. GISS GCM (4° × 5°) (10 years); GISS-MM5 (MIBR, EBR, MIGR, MIGC, EGC at 108 km) (MIBR and MIGR also at 36 km) (5 years); observations: New et al. (2000) (0.5° × 0.5°) (10 years). RMSEs were calculated at each point and then averaged over the study area

The GISS-MM5 MIBR improved the simulation of surface temperature and also better captured the spatial variability related to local topography, compared to the GISS GCM (Fig. 11). While the use of higher grid resolution (36 km) did not have a significant impact on the temperature skill, the local MIBR 36 km precipitation was significantly better than its 108 km counterpart. Thus, the main advantage of using the higher resolution is the ability to resolve finer-scale atmospheric features such as those related to the topography of the Appalachian Mountains and the proximity of the Atlantic Ocean. Such detail is also necessary to run simulations with air quality models and other regional impact models.

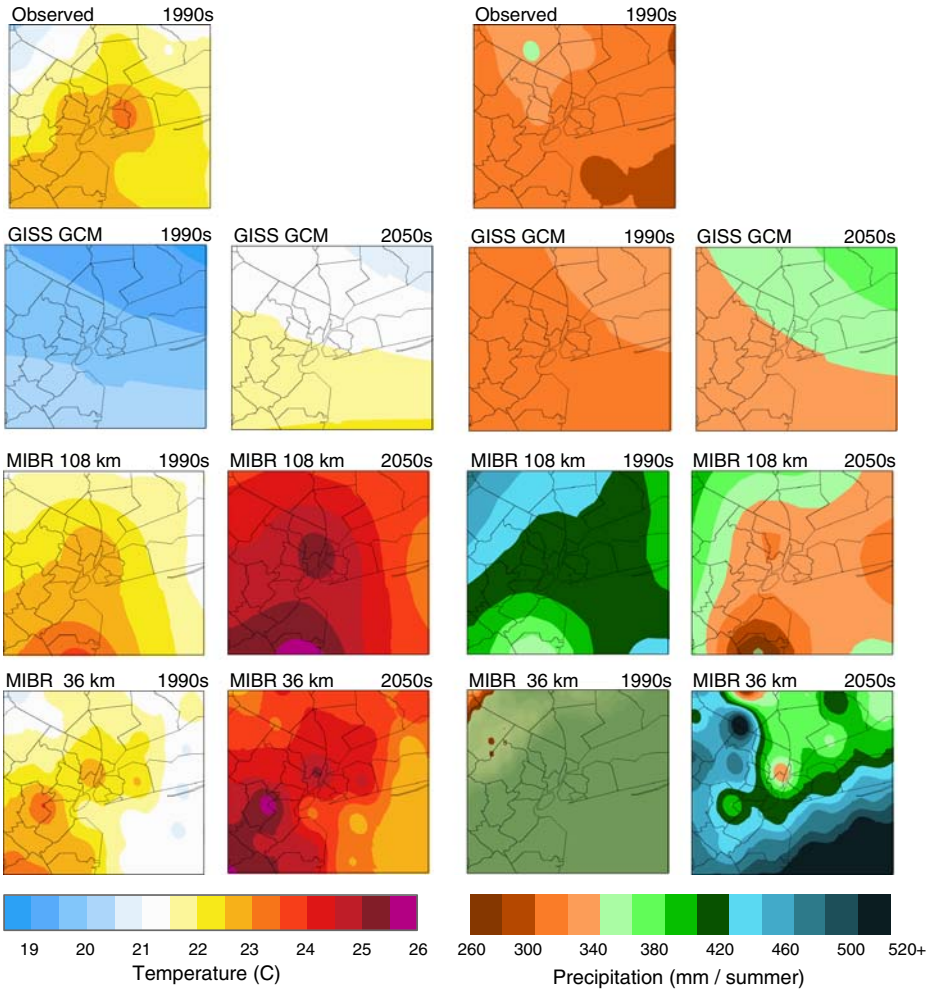


Fig. 11 Observed and simulated JJA 2 m mean surface temperature (°C) and precipitation (mm/summer) (1990s—*columns 1 and 3*; 2050s—*columns 2 and 4*) over the New York City metropolitan region. GISS GCM (4° × 5°) (10 years); GISS-MM5 (MIBR, MIGR) (108 km) (5 years); GISS-MM5 (MIBR, MIGR) (36 km) (5 years); observations: New et al. (2000) (0.5° × 0.5°) (10 years)

5 Discussion and conclusions

This study shows that the choice of model physics configuration is very important in selecting an RCM for use in regional climate impact studies. The combination of the MRF boundary layer scheme, the Betts–Miller cumulus scheme, and the RRTM radiation package gave the best modeled summer temperatures across the continental United States. Moreover, this model configuration gave the best simulated temperature results in the New York metropolitan area. Thus, it was selected for use in an integrated impact study of air quality and human health effects of climate change, the New York Climate and Health Project, where the absolute values of climate variables were needed as inputs for an air quality model. The projected climate changes (2050s minus 1990s) were more uniform. Making current and future simulations in which variables are later subtracted from one another lessens the importance of the model physics configuration.

Han and Roads (2004) compared the performance of the Parallel Climate Model (PCM) GCM with the Regional Spectral Model (RSM) driven by the PCM with grid resolutions of 50, 180 and 250 km. They found that during the summer, there were large differences in the precipitation produced by the PCM and the RCMs (and to a lesser extent the temperature), and they concluded that these differences were due to the differences in the convective parameterizations between the two models, not because of the model grid resolution. We confirm their findings and extend them to a comparison of model results obtained from the same model at the same grid-resolution, but with different model physics configurations.

Giorgi (2005) suggests that a prediction is deemed to be more reliable if different models agree on the magnitude and sign of the predicted changes. He suggested that PDFs should be constructed and used to make probabilistic climate change forecasts. Our five model configurations comprise a small, but meaningful sample to evaluate the reliability of an ensemble consisting of various MM5 model configurations. Here, the range of the projected surface temperature changes for the model versions at a given grid point was much less than the mean projected surface temperature change for all five model configurations, and all of the models show warming, indicating relative consensus among the different model projections. The MM5 versions, however, offer much less consensus regarding absolute changes in precipitation, although most models showed increases.

Our results further suggest that while the projected climate changes may be similar across the model configurations, the range of the values themselves may be quite large. Therefore, the choice of model physics configuration is especially important in selecting an RCM for use in regional climate impact studies that utilize their results directly in impact models. This should not be undertaken uncritically: higher-resolution, better-calibrated regional climate simulations are needed to properly address these issues.

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