Influences of Regional Climate Change on Air Quality across the Continental U.S. Projected from Downscaling IPCC AR5 Simulations

C. Nolte[1], T. Otte[1], R. Pinder[1], J. Bowden[2], J. Herwehe[1], G. Faluvegi[3], and D. Shindell[3]

[1]U.S. Environmental Protection Agency, Research Triangle Park, NC 27711 USA
[2]Institute for the Environment, University of North Carolina, Chapel Hill, NC 27599 USA
[3]NASA Goddard Institute for Space Studies, New York NY 10025 USA

Abstract Projecting climate change scenarios to local scales is important for understanding, mitigating, and adapting to the effects of climate change on society and the environment. Many of the global climate models (GCMs) that are participating in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) do not fully resolve regional-scale processes and therefore cannot capture regional-scale changes in temperatures and precipitation. We use a regional climate model (RCM) to dynamically downscale the GCM's large-scale signal to investigate the changes in regional and local extremes of temperature and precipitation that may result from a changing climate. In this paper, we show preliminary results from downscaling the NASA/GISS ModelE IPCC AR5 Representative Concentration Pathway (RCP) 6.0 scenario. We use the Weather Research and Forecasting (WRF) model as the RCM to downscale decadal time slices (1995-2005 and 2025-2035) and illustrate potential changes in regional climate for the continental U.S. that are projected by ModelE and WRF under RCP6.0. The regional climate change scenario is further processed using the Community Multiscale Air Quality modeling system to explore influences of regional climate change on air quality.

Keywords: Regional climate modeling, climate change, air quality

Introduction

Global climate models (GCMs) and, more recently, global earth system models are used to simulate the past and future evolution of the Earth's climate. Because these models are run for centuries and cover the entire globe, computational resource considerations limit them to using relatively coarse spatial resolution (e.g., 1° latitude × 1° longitude). Climate change impacts, however, are experienced at much finer spatial scales. Regional climate models (RCMs) provide one way to bridge the gap between coarse future climate scenarios provided by a GCM and the regional/local scales needed for climate change impact assessments. Previously, Nolte et al. [2007, 2008] used the Goddard Institute for Space Studies (GISS) II' global climate model as input to the mesoscale meteorological model MM5 and the Community Multiscale Air Quality (CMAQ) Model to examine climate change impacts on regional scale air quality over the continental United States circa 2050. Surface ozone levels were predicted to increase by 2-5 ppb over much of the eastern U.S. However, the interpretation of these results was hampered by biases in the meteorological simulation of current climate.

Development of Downscaling Methodology

Recognizing the limitations in simulating air quality imposed by errors in downscaling, recent work has focused on development and testing of a regional climate downscaling methodology [Bowden et al. 2012a, 2012b; Otte et al. 2012]. The Weather Research and Forecasting (WRF) model was used to downscale the 2.5° × 2.5° Atmospheric Model Intercomparison Project (AMIP-II) Reanalysis data [Kanamitsu et al. 2002] (hereafter, R-2), which emulates the spatial and temporal resolution of fields provided by a GCM. The R-2 data are the best available representation at coarse spatial scales of the meteorology that occurred, and thus can be regarded as "perfect boundary conditions." During the course of a continuous simulation of the 20-year period 1988-2007, no observational data exogenous to R-2 were assimilated in order to maintain consistency with the scale of data available from a GCM. However, unlike the situation when downscaling a GCM future climate scenario, the downscaled R-2 simulation can be evaluated against finer-scale observations or analyses, such as the 32-km North American Regional Reanalysis (NARR) [Mesinger et al. 2006].

The results showed that when forcing WRF only via the lateral boundaries of a large continental modeling domain, substantial biases can exist over large regions [Bowden et al. 2012a]. These biases can be significantly reduced by using the large-scale driving fields to constrain or "nudge" the RCM solution. Nudging not only improves the simulation of mean quantities, but also improves the accuracy of simulated extreme temperature and precipitation events [Otte et al. 2012] and the large-scale atmospheric circulation [Bowden et al. 2012b].

Modeling Application

The downscaling techniques that were tested and evaluated using the historical data sets were applied to simulations from the NASA GISS ModelE [Schmidt et al. 2006]. Two 11-year time slices were simulated, one a control run representing current climate around 2000 (nominally 1995-2005) and one following RCP6.0 around 2030 (i.e., 2025-2035). As shown in Fig. 1, WRF projects no temperature change for most of the western U.S. and a warming of up to 2 K in the central U.S.

during July, and a much broader warming exceeding 3 K for most of the domain during January.

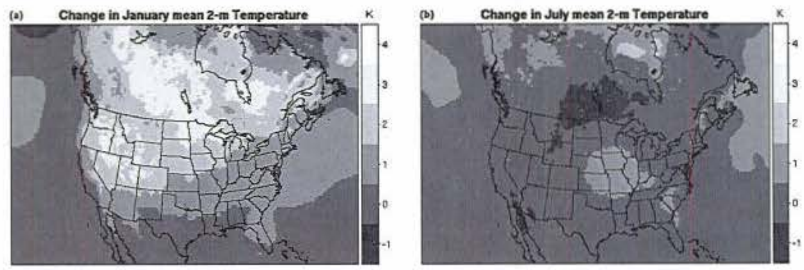

Fig. 1.Change in monthly mean 2-m temperatures downscaled from ModelE by WRF for (a) January and (b) July.

To examine the implications of this climate scenario for future air quality, the downscaled meteorology was used to drive the CMAQ chemical transport model. Two one-year simulations were conducted using meteorology downscaled from the current decade GCM simulation (i.e., 1995) and downscaled from the RCP6.0 simulation (i.e., 2025). For both simulations, anthropogenic emissions were based on the U.S. EPA National Emission Inventory for 2005, while biogenic emissions were computed online.

The number of days simulated as exceeding the U.S. 8-h average surface ozone concentration standard of 75 ppb was computed for both annual runs. It was found that, for these two years, the future meteorology leads to a substantial increase in the number of ozone exceedances. However, the location and magnitude of the change in ozone levels varies widely over the course of the year, with strong increases in June and July partially offset by decreases in August. These differences, though plausible, are not statistically significant, as more years of model simulations are needed to distinguish the climate change signal from the noise of interannual variability. Both simulations will be extended to encompass the entire 11-year period, and the analysis will be repeated to discern the impact of the change in ozone and particulate matter air quality attributable to regional climate change.

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References

Bowden JH, Otte TL, Nolte CG, Otte MJ (2012a), Examining interior grid nudging techniques using two-way nesting in the WRF model for regional climate modeling, *J. Clim.*, 25, 2805-2823.

Bowden JH, Nolte CG, Otte TL (2012b), Simulating the impact of the large-scale circulation on the regional 2-m temperature and precipitation climatology, *Clim. Dyn.*, in press.

Kanamitsu M, Ebisuzaki W, Woolen J, Yang S-K, Hnilo JJ, Fiorino M, Potter GI (2002), NCEP-DOE AMIP-II Reanalysis (R-2), *Bull. Amer. Meteor. Soc.*, 83, 1631-1643.

Mesinger F et al. (2006), North American regional reanalysis, *Bull. Amer. Meteor. Soc.*, 87, 343.

Nolte C, Gilliland A, Hogrefe C, Linking global and regional models to simulate U.S. air quality in the year 2050 (2007). In Borrego C and Miranda AI (eds) *Air Pollution Modeling and its Application XIX*, Elsevier, 633-647.

Nolte CG, Gilliland AB, Hogrefe C, Mickley LJ (2008), Linking global to regional models to assess future climate impacts on surface ozone levels in the United States, *J. Geophys. Res.*, 113, D14307.

Otte TL, Nolte CG, Otte MJ, Bowden JH (2012), Does nudging squelch the extremes in regional climate modeling? *J. Clim.*, in press, doi:10.1175/JCLI-D-12-000048.1.

Schmidt GA et al. (2006) Present day atmospheric simulations using GISS ModelE: Comparison to in-situ, satellite and reanalysis data, *J. Clim.*, 19, 153-192.

Discussion

P. Makar:

The model results show effects due to nesting/downscaling very well. What would be the impact of running an RCM globally? That is, the computers we use should have reached the state where this is possible. Would you expect similar effects with a global RCM?

C. Nolte:

It is difficult to differentiate effects due to discontinuities at the lateral boundaries from errors in the RCM physics formulations. Though a global version of WRF has been developed, to my knowledge it has not been used for long-term simulations, which could help determine whether WRF is in radiative balance. We are experimenting with using WRF on a hemispheric domain, which may reduce the influence of lateral boundary conditions. It might also be interesting to conduct a global-to-regional "Big Brother Experiment" using the WRF model.