Development of dynamical downscaling for climate decision aid applications

Kremena Darmenova, Glenn Higgins, Randall Alliss, Heather Kiley, Duane Apling
Atmospheric Sciences and Engineering Department
Northrop Grumman Information Systems

1. Introduction

Current General Circulation Models (GCMs) provide a valuable estimate of both natural and anthropogenic climate changes and variability on global scales. At the same time, future climate projections calculated with GCMs are not of sufficient spatial resolution to address regional needs. Responses to climate change and mitigation of negative impacts must be resolved at regional and local levels, therefore it is important to quantify the potential for climate change on regional scales (Bell et al. 2004). Because GCM coarse grids can significantly mischaracterize the topography, land use and land-water boundaries, any climate response driven by surface interactions (e.g. orographic and vegetation effects) may not be adequate and reliable (Salathe et al. 2008). This necessitates the use of methods for producing climate change scenarios that fully account for such effects. One such method is the dynamical downscaling, which uses a limited-area, regional climate model (RCM) driven by boundary conditions from a GCM to derive smaller-scale information.

The number of regional climate studies using dynamical downscaling to assess local responses to climate change has been steadily increasing over the last decade. A significant body of studies has focused on changes in hydrological regime and extreme event frequency over the Pacific Northwest (Salathe et al. 2008; Duliere et al. 2009; Jackson et al. 2010). Fewer studies have investigated regional climate change and climatological indices of extreme weather in the Mid-Atlantic States (Miguez-Macho et al. 2004; Darmenova et al. 2009; Higgins et al. 2010). This served as a motivation to perform ensemble runs over the Mid-Atlantic with the Weather Research and Forecasting (WRF) model initialized with the European Center Hamburg Model (ECHAM5), and the National Center for Environmental Prediction/National Center for Climate Research (NCEP/NCAR) reanalysis data. The goal of this study is to derive extreme event climatology and develop climate adaptation decision aids such as heating/cooling degree days, heat stress, frost days and length of growing season.

2. Modeling setup

For the present climate (1980-1989), WRF was forced with ECHAM5 20th century simulation and NCEP reanalysis data. For the 21th century climate, we used an ECHAM5 simulation with the Special Report on Emissions (SRES) A1B emissions scenario. WRF was run in nested mode (see Figure 1) at spatial resolution of 108 km, 36 km and 12 km and 28 vertical levels. The model output was saved on every hour. In this study the microphysics and convective parameterizations used were the WRF Single-moment 5-class (WSM5) scheme and the Kain-Fritsch scheme. The Land Surface Model (LSM) and Planetary Boundary Layer (PBL) scheme used were Noah LSM and YSU PBL. Shortwave and longwave radiation were computed with the CAM SW and LW scheme.

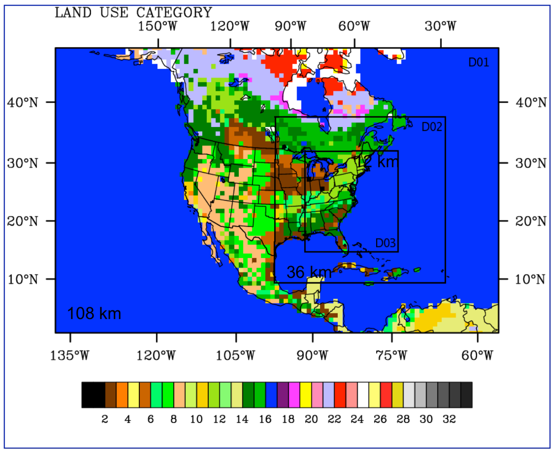

Figure 1. WRF domain setup

3. Model Validation

To assess the performance of the WRF model in reproducing regional climate we compared the WRF-NCEP and WRF-ECHAM5 January and July monthly mean temperatures averaged over the ten years of simulation with the University of Delaware global air temperature dataset (Figure 2). Overall, we found a good agreement between the model and observations: the topography temperature effects are well resolved (i.e. the Appalachian Mountains).

WRF simulated temperatures were also compared with the GFDL and CRCM model simulations performed within the North American Regional Climate Change Assessment Program (NARCCAP). WRF-NCEP, GFDL and CRCM underpredict the mean annual temperatures compared to the Global Historical Climatology Network (GHCN) observational dataset. WRF-ECHAM5 is significantly warmer in the 2060-2069 period compared to the rest of the models (not shown).

4. Climate adaptation decision aid products

There is a fundamental and pressing need for a systematic approach to providing the latest results from climate change science research and analysis to community leaders and the populations that will be impacted by climate change. Our objective is to translate the climate information provided by the regional climate models into actionable information for policy and decision making by developing various climate adaptation decision aid products.

Heating degree days (HDD) and cooling degree days (CDD) are climatological metrics used to express the magnitude of the heating or cooling load in a given location. Degree days are quantitative indices designed to reflect the residential/commercial energy requirements for heating/cooling. These metrics are expressed in terms of a "base temperature" of 65 F. HDD/CDD are calculated by taking the daily average temperature; if it is colder/warmer than the "base temperature“, the difference is calculated. Figure 3 shows the Celsius-based cooling degree days for a base temperature of 18.3 C (65 F) calculated from the WRF-ECHAM5 simulated temperatures. Our analysis indicates significant increase of cooling degree days over the Southeastern US in the future (2060-2069). Calculated degree

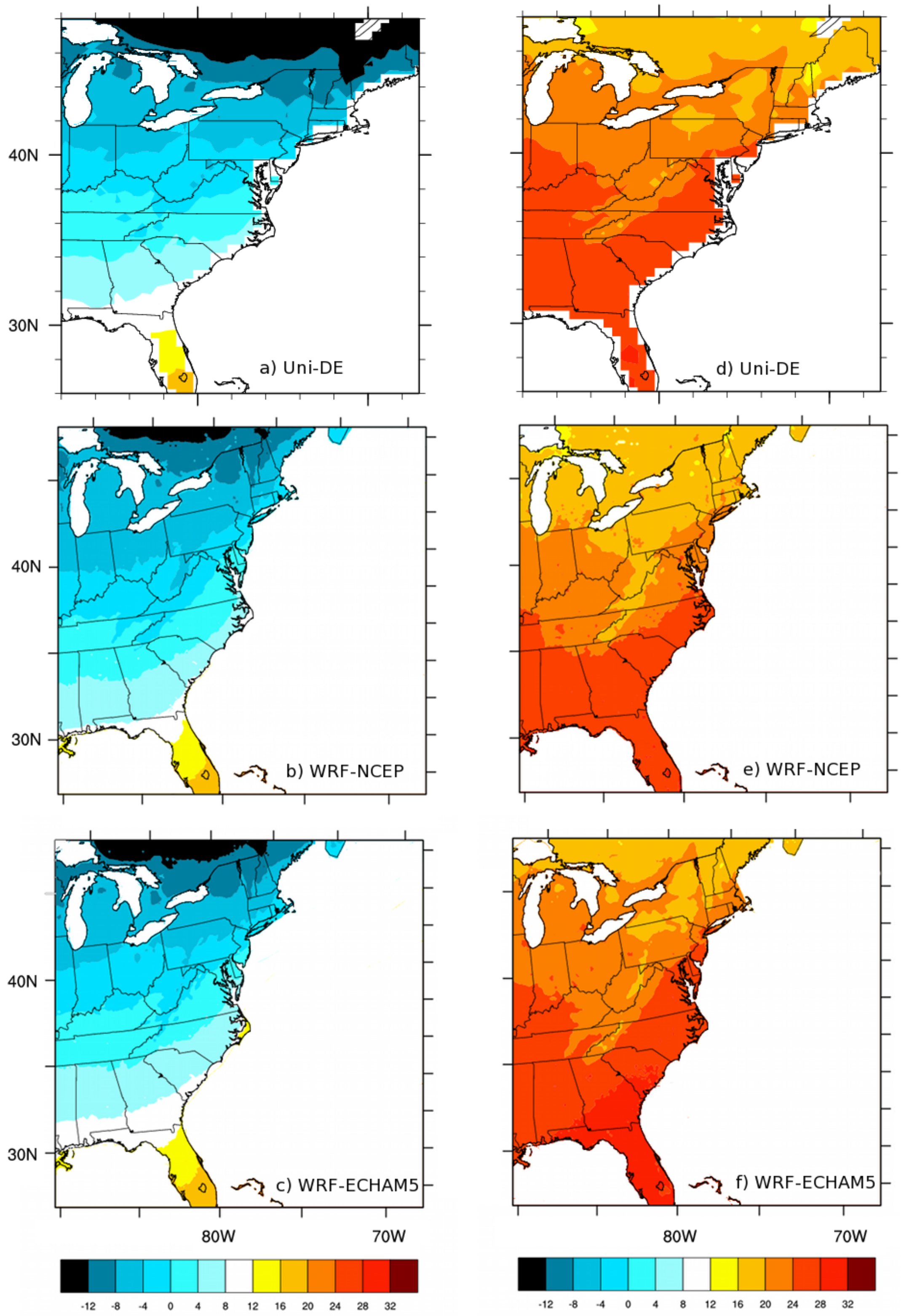

Figure 2. January (left column) and July (right column) monthly mean temperatures (deg C) averaged over the ten years of simulation calculated with the University of Delaware (Uni-DE) dataset, WRF-ECHAM5 and WRF-NCEP.

days can be used for estimating the heating/cooling energy consumption which is an important metric in urban planning and development.

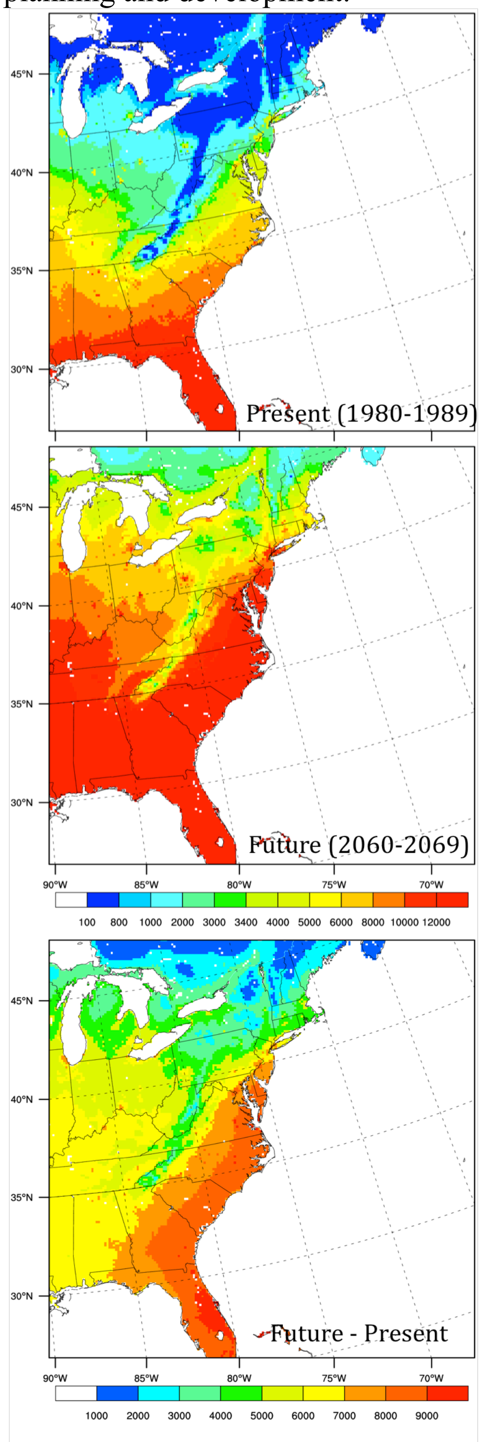

Figure 3. Celsius based cooling degree days for a base temperature of 18.3 C

When both temperature and humidity are high, humans can experience considerable heat stress. The combined effects of temperature can be assessed by calculation of an "apparent temperature". The apparent temperature is calculated as:

$$T_a\,(°C) = -1.3 + 0.92T + 2.2e,$$

where T is ambient air temperature (°C) and e is water vapor pressure (kPa).

Extreme heat is a significant source of avoidable mortality for outdoor workers, elderly and respiratory impaired populations. Heat stress higher than 42°C (105°F) is related to sunstroke, heat cramps or heat exhaustion, and heat stroke is possible with prolonged exposure and/or physical activity. Figure 4 shows that the number of days with apparent temperature exceeding 42°C is increasing significantly in the future. An interesting observation is that in the future the coastal waters (Gulf coast and the East coast) also experience days with heat stress exceeding 105°F.

5. Testing WRF performance in long term simulations

While the WRF model has been primarily developed for short-term weather prediction (7-10 days), it has been successfully used in long term regional climate studies (Salathe et al. 2008). A number of new features have been added since Version 2 that allow realistic representation of the climate system in long-term simulations, e.g. diurnal variations of the skin SST, deep soil temperature and SST updates. The WRF namelist files also provide options for bucket reset value for rainfall and radiation fluxes.

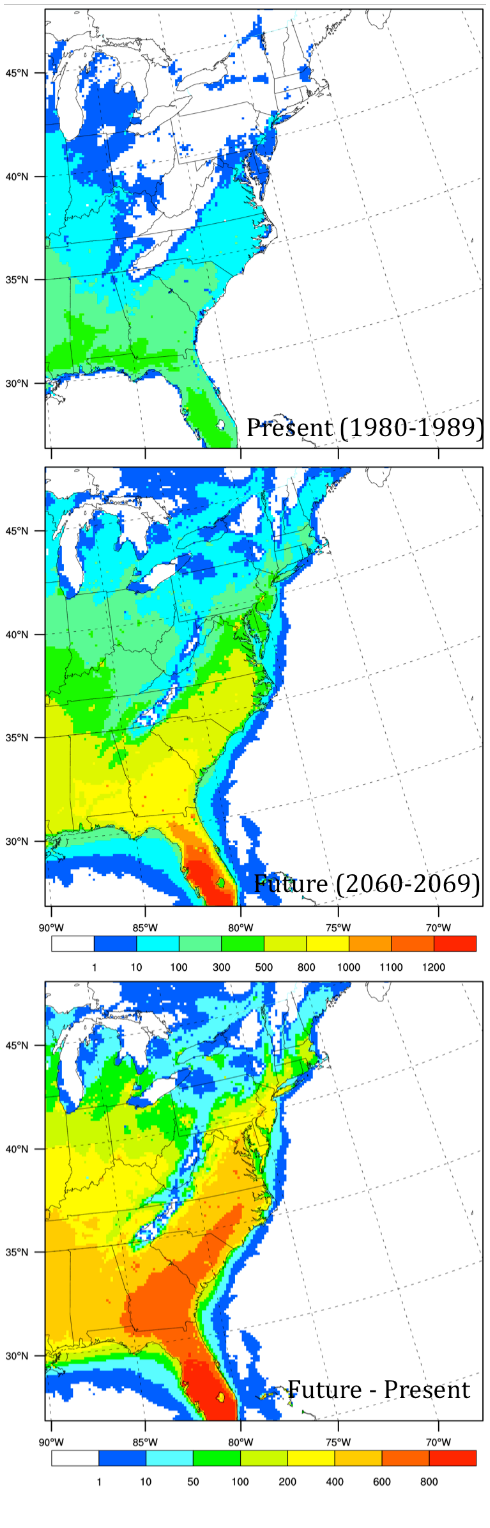

Figure 4. Number of days with apparent temperature exceeding 42°C (105°F)

While testing the performance of WRF in long term simulations over the Mid-Atlantic states we noticed erroneous snow/ice cover fraction over the Great Lakes region and the Gulf of St. Lawrence (Nova Scotia) that persists even during the summer months. We reported the problem to the WRF development team who identified that the issue was related to inconsistency between the sst_update option and snow processes in the land-surface model. This issue was addressed in the WRF3.2 release.

Another problem that we found was related to the bottom soil temperature update code, which produced “division by zero” error for model time steps less than 30s. This was caused by a roundoff error in the calculation of the Julian day fraction. The problem was resolved after small modifications of the code and the method of calculating the day fraction.

6. Conclusions

We successfully developed a dynamical downscaling capability that enabled us to perform regional climate simulations with the WRF model initialized from the NCEP reanalysis data and the ECHAM5 A1B IPCC scenario. Our 10-year simulations were performed by varying CO_2 concentrations in WRF consistent with the A1B scenario and updating the sea surface and bottom soil temperatures. In addition we applied grid nudging to the coarser domain to prevent large discrepancies between the boundary conditions and the regional model.

We rigorously tested and validated the WRF model long term simulations and compared to the GHCN data, University of Delaware dataset and the NARCCAP

GFDL and CRCM models. WRF-NCEP and WRF-ECHAM5 mean monthly temperatures showed good agreement with the observational datasets for the 1980-1989 time period. WRF annual temperatures are somewhat higher than the GFDL and CRCM models for the future 2060-2069 period along the US East coast.

We derived various decision aid products based on the WRF output meteorological fields - heating/cooling degree days, heat stress index, frost days and length of growing season. Our results indicate significant increase in cooling degree days, heat stress index and length of growing season, and decrease in the heating degree days and frost days in the future as a result of warmer surface temperatures.

Our 10-year runs are the first step towards ensemble climate simulations performed with the WRF model that will enable us to bracket the uncertainties associated with the different climate projections.

7. References

Bell J.L, L.C. Sloan, M.A. Snyder, 2004, Regional changes in extreme climatic events: a future climate scenario, *J. Climate*, 17: 81-87.

Darmenova, K., G. Higgins, R. Alliss, H. Kiley, D. Apling, 2009, Development of dynamical downscaling for regional climate modeling and decision aid applications, AGU Fall Meeting, San Francisco, CA.

Dulière, V., Y. Zhang, E.P. Salathé, 2009, Changes in 20th century extreme temperature and precipitation over the western United States from regional climate model simulations and observations, *Submitted to Climatic Change*.

Higgins, G., D. Apling, R. Alliss, and H. Kiley, 2010, Regional climate modeling and decision aids, AMS conference, 22nd Conference on Climate Variability and Change, Atlanta, GA.

Jackson J.E., M. G. Yost, C. Karr, C. Fitzpatrick, B. K. Lamb, S. H. Chung, J. Chen, J. Avise, R. A. Rosenblatt and R. A. Fenske, 2010, Public health impacts of climate change in Washington State: projected mortality risks due to heat events and air pollution, *J. Climate*, DOI: 10.1007/s10584-010-9852-3.

Miguez-Macho, G., G. Stenchikov, and A. Robock, 2004, Downscaled regional climate simulations for the Mid-Atlantic States using RAMS, AMS conference, extended abstract.

Salathe, E.P, R. Steed, C. F. Mass, P.H. Zahn, 2008, A high-resolution climate model for the U.S. Pacific Northwest: mesoscale feedbacks and local responses to climate change, J. Climate, DOI:10.1175/2008JCLI20 90 .1