Dynamical Downscaling of NASA/GISS ModelE: Continuous, Multi-year WRF Simulations

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Background and Motivation

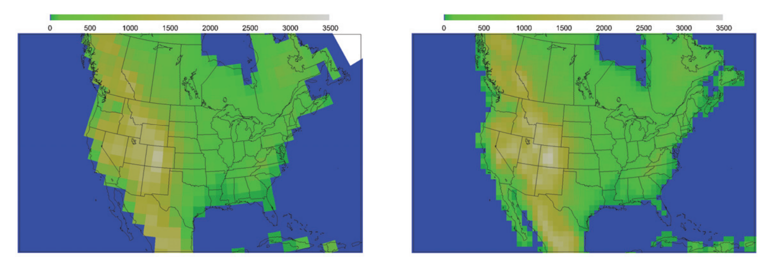
The WRF model is being used at the U.S. EPA for dynamical downscaling of the NASA/GISS ModelE global climate model (GCM) fields to assess regional impacts of climate change in the United States. WRF will be used to downscale decadal time slices of ModelE for recent past, current, and future climate as the simulations being conducted for the IPCC Fifth Assessment Report (AR5) become available. The dynamically downscaled climate fields from WRF ultimately will be used by the EPA to predict the regional impacts of climate change on water quality and availability, agriculture, ecosystems, human health, air quality resulting from emissions control strategies, and energy demand. In addition to changes in local temperature and precipitation distributions, one goal of this research is understanding changes in frequency and severity of extreme events, such as heat waves, droughts, flooding, and stagnation episodes.

This research focuses on the sensitivity to interior nudging in WRF. The use of interior nudging for downscaled regional climate model (RCM) simulations has been somewhat controversial over the past several years but has been recently attracting attention. Several recent studies that have used reanalysis (i.e., verifiable) fields as a proxy for GCM input have shown that interior nudging can be beneficial toward achieving the desired downscaled fields. For regional climate modeling, it is not simply a question of whether or not to use nudging to constrain WRF, it is a question of *how* to apply nudging. In this study, the method of nudging and the choices made with respect to how nudging is used in WRF are critical toward achieving a balanced RCM solution.

Modeling Configurations

Several WRF simulations have been run to demonstrate some sensitivities toward various methods of nudging. Simulations here are 108-km six-year simulations with one month of spin up. The simulations benefitted from two years of spin up in ModelE, and they nominally represent current climate (labeled 2002-2007).

ModelE is one of the three U.S. GCMs that will be participating in IPCC AR5. It is a coupled atmosphere-ocean model with 2.0° x 2.5° resolution and 40 hybrid σ-p layers up to 0.1 hPa. Because there are no observations, ModelE also serves as the source of verification and validation of the WRF simulations.



Topography from ModelE, cropped to WRF 108-km domain and Lambert conformal projection (left), and from WRF 108-km domain (right).

WRFv3.2 is used as the RCM. The advection time step is set to 7.5 min. There are 34 layers, and the model top is 50 hPa. The simulations are continuous (i.e., not reinitialized at any point in the runs). The model physics options are:

- WSM6 single-moment microphysics
- CAM longwave and shortwave radiation
- NOAH land-surface model
- Yonsei University planetary boundary layer scheme
- Grell 3D ensemble cumulus parameterization scheme

Simulations are performed with spectral nudging and with analysis nudging. In both techniques, nudging is restricted to fields above the PBL.

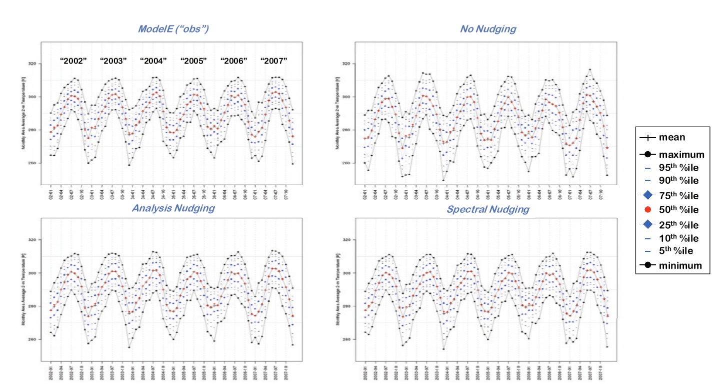
In the standard analysis nudging ("AN Reg"), the nudging coefficients are: $G_{UV} = 3 \times 10^{-4}$ s^{-1}, $G_T = 3 \times 10^{-4}$ s^{-1}, and $G_Q = 1 \times 10^{-5}$ s^{-1}. In the low analysis nudging ("AN Low"), $G_{UV} = 4.5 \times 10^{-5}$ s^{-1}, $G_T = 4.5 \times 10^{-5}$ s^{-1}, and $G_Q = 5.5 \times 10^{-6}$ s^{-1}. Additional analysis nudging simulations are performed where the nudging coefficients are varied and/or the nudging is further restricted below a specified prognostic layer.

In the standard spectral nudging ("SN Reg"), the coefficients G_{UV}, G_T and G_Φ are set to the default values of 3×10^{-4} s^{-1}, Xwav = 3, and Ywav = 3. In the low spectral nudging ("SN Low"), the nudging coefficients are set to 4.5×10^{-5} s^{-1}. Other simulations are performed where the wave numbers in the X and Y dimensions are varied.

Preliminary Findings

Seventeen 73-month simulations (six years plus a one-month spin-up) have been performed. Shown here are comparisons of monthly area-averages of 2-m temperature and precipitation in six regions (*below right*) of the contiguous United States.

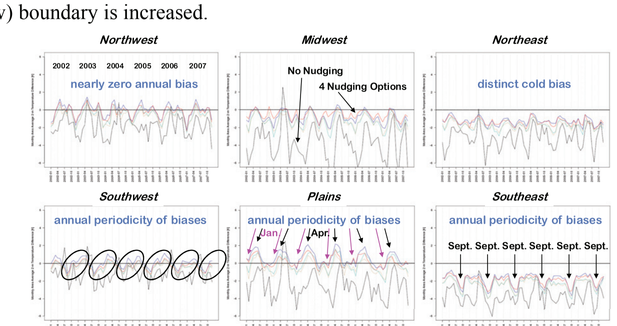
The distributions of monthly area-averaged 2-m temperature show that the multi-year downscaled simulations using WRF can capture interannual variability from ModelE, even when nudging is not used (*below*). For example, the minimum temperatures show that ModelE projected a cold winter in "2004", followed by warmer winters in "2005" and "2006", then a slight cooling in "2007". The WRF simulations were all able to capture the year-to-year trends from ModelE, regardless of whether or not nudging was used. Even some month-to-month variations in ModelE, such as the winter of "2007", are represented in the WRF simulations. It should be noted that the Plains region is sufficiently removed from the lateral boundaries, but the influence of ModelE through the lateral boundaries is strong enough to control the year-to-year fluctuations in this domain. The WRF simulation without nudging increased the overall range of 2-m temperatures (both high and low) compared to ModelE and the nudged cases. It is unclear, however, if the added range in 2-m temperature in the non-nudged simulation is unrealistic or if the nudged cases have inadvertently restricted the variability.



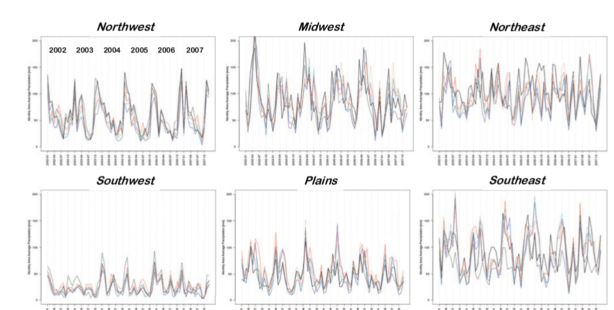
Monthly area-averaged 2-m temperature distribution from Plains region for ModelE, WRF with no interior nudging, WRF with analysis nudging, and WRF with spectral nudging.

Monthly area-averaged mean 2-m temperature difference and accumulated precipitation are computed for each region for the six-year period. The 2-m temperature differences (*below left*) show that the multi-year WRF runs using ModelE have persistent and systematic regional and seasonal differences, even when nudging is used. For example, the Northwest has a nearly zero annual bias in the nudged runs, but the Northeast (which is significantly removed from the primary inflow boundaries) has a distinct cold bias. In addition, there appears to be a periodicity to the differences that may change depending on the region. This periodicity of differences could be the result of inconsistencies in the ModelE and WRF physics packages or it could be due to errors in modeling physical processes for climate in WRF. This point needs to be further investigated with multi-year reanalysis runs.

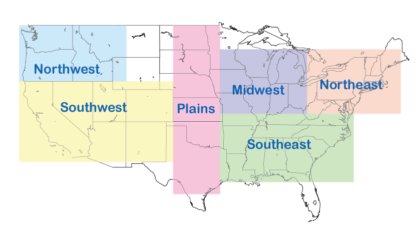
The area-averaged regional precipitation (*below right*) shows that WRF can generally capture the interannual and interseasonal trends projected by ModelE within each region. The relative precipitation totals in each region are also captured reasonably well (cf. Southwest vs. Midwest). However, there is more variability in the precipitation predictions in WRF as distance from the western (inflow) boundary is increased.



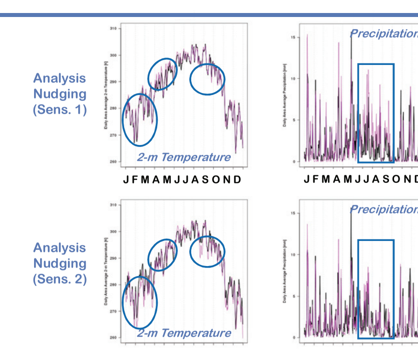
Monthly area-averaged 2-m temperature difference by region.



Monthly area-averaged accumulated precipitation by region.



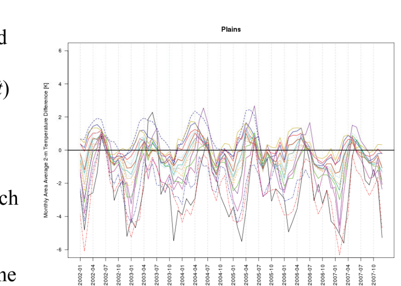
Six regions of the continental United States used for regional verification.



One-year area-averaged daily 2-m temperature and precipitation for two analysis nudging sensitivities for Plains region. ModelE is in black and WRF is in purple.

It's not just about whether or not nudging is used but *how* it is used. Examining daily area-averaged 2-m temperature and precipitation (*left*) shows that there can be large differences in the WRF simulation by making very subtle changes to the nudging strategy.

In addition, there is no "one size fits all" approach to using nudging in WRF for regional climate modeling (*right*). Some nudging strategies are clearly inferior, while others are comparable. The strategy for nudging may ultimately be dictated by the application and region(s) of interest.



Six-year area-averaged monthly 2-m temperature difference from 17 nudging sensitivities for Plains region.

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