50-year Regional Downscaling of NCEP/NCAR Reanalysis over the Contiguous United States Using the Regional Spectral Model

Group Representative
Masao Kanamitsu Scripps Institution of Oceanography

Authors
Hideki Kanamaru Scripps Institution of Oceanography
Yifeng Cui San Diego Supercomputer Center
Masao Kanamitsu Scripps Institution of Oceanography

Regional downscaling of the 50-year NCEP/NCAR Reanalysis is underway for the contiguous United States. The downscaling is being performed using a 10-km horizontal resolution Regional Spectral Model (RSM). The regional model produces fine scale detail in the regional domain during integration, forced with NCEP/NCAR Reanalysis, producing downscaled analysis. The RSM produces dynamically, thermo-dynamically, and hydrologically consistent fine scale fields of atmosphere and land surface. The long time series high-resolution meteorological fields can be used for a variety of studies such as climate change, urbanization, coastal ocean modeling, snow pack modeling, water management, and fire danger. The model code is currently being optimized for the Earth Simulator. The downscaled atmospheric parameters will be verified against station observations as well as the regional reanalysis (data assimilation) in progress at NCEP/NWS. The resultant datasets will be made available to the science community.

Keywords: Earth Simulator, regional climate model, Regional Spectral Model, high-performance computing, downscaling

1. Research Objectives

The identification of natural climate variability and detection of climate change at regional to continental scale within the historical meteorological observational records require understanding of complex interaction among atmospheric and surface parameters. The most advanced method to obtain dynamically, thermo-dynamically, and hydrologically consistent state of atmosphere, land, and ocean is the four-dimensional data assimilation. There are two available long historical atmospheric analyses using data assimilation technique: NCEP/NCAR Reanalysis [1] and ECMWF ERA-40 [2]. Although these datasets are widely used for climate studies, they are not best suited for regional climate studies for two main reasons. First, these reanalyses are archived at approximately 200 km horizontal resolution, which is too coarse for regional application. Secondly, inhomogeneous distribution of observations in time generates artificial trends in analyses. The current project aims to produce, refine, and analyze a high-resolution long-term historical analysis over the contiguous United States, using dynamical downscaling technique applied to the NCEP/NCAR Reanalysis. The method uses high-resolution (10 km horizontal) regional climate model forced by the large-scale analyses to generate high-resolution 'analysis'. The application of dynamical downscaling to data rich areas such as our target domain will minimize the artificial climate change caused by inhomogeneous observation coverage.

The Regional Spectral Model [3 and 4] is used as a dynamical downscaling tool. The model uses sine and cosine functions as base for mathematical expression of the difference between full regional field and the large-scale base field provided by large-scale global analyses. This method can be described as an optimum spatial perturbation filtering method that allows long stable integration without developing large deviation from the base filed. The RSM has been extensively used for operational short-range forecasting in various international meteorological centers.

The large-scale analysis field used as a base field will be taken from NCEP/NCAR and NCEP/DOE Reanalyses. The NCEP/NCAR reanalysis [1] spans the period of early 1950 to present, suitable for long-term downscaling but has problems with land surface analyses, while the NCEP/DOE Renalysis [5] spans the period 1979 to present and provides reasonable land surface analysis. The model used in these reanlyses is a version of the parent model of the RSM, which uses the same vertical and horizontal model structures as

well as many of the physical processes. This model consistency makes the downscaling of reanalyses more tractable.

2. Tuning of the Regional Spectral Model for the Earth Simulator

The Regional Spectral Model (RSM) was originally developed at NCEP and maintained by our research group at Scripps Institution of Oceanography (SIO). Parallelization of the code was complete in collaboration with San Diego Supercomputer Center (SDSC) and the MPI version of the code was tested on several platforms that include IBM-SP (Power 3 and 4) at SDSC, COMPAS Linux cluster at SIO, and SX-6 at Arctic Region Supercomputing Center (ARSC). Further optimization and vectorization of the code are being done on ARSC's SX-6. The preliminary target domain is set at 1024×651 grid at 10 km resolution to make full use of the high computing power of the Earth Simulator.

During December 2003, Kanamaru and Cui visited ESC for two weeks and made the first successful RSM run on the Earth Simulator with the target domain and resolution. The 8-CPU simulation of the 1-hour model integration took 2800 seconds but the scalability of the code is not fully tested yet. The model is still far from optimum, and more aggressive vectorization is in progress.

An improvement to the RSM has been explored to ensure the quality of downscaling. Spectral tendency damping technique [6] makes the downscaling output insensitive to the choice of the domain size and resolution by damping the amplitude of the tendency of the undesirable mode. Combined with a scheme to remove regional domain average bias of dependent variables, the method is shown to improve the downscaling significantly.

3. Future works

The model optimization will be finalized soon and we will start production runs. A few experiments are under consideration. The global warming signal is very likely contaminated by urbanization and the effect of irrigation on surface water budget. Dynamical downscaling will incorporate the effect of urbanization and irrigation through the change in land surface characteristics such as surface roughness, soil type and albedo.

The inaccuracies in the parameterization of physical processes in the model tend to make the model precipitation not as accurate as we expect. The use of observed precipitation, from rain gauges and satellites, will significantly improve the land hydrology as well as snow pack simulations, and subsequently improve the regional scale winds and temperature analyses.

The dynamical downscaling provides snow pack analysis from model precipitation, evaporation and snowmelt, and it can complement insufficient observation of snow pack. The simulation with a more realistic snow pack model will be compared with control runs and available observations to determine its capability and utility.

The RSM currently uses Oregon State University land surface model. Works are in progress to incorporate the latest land scheme from NCEP (NOAH model) and Variable Infiltration Canopy (VIC) model from Princeton University. It is expected that these models improve the land surface simulations.

In parallel with these experiments, the downscaled field of atmosphere and land will be verified against station observations as well as regional reanalysis in progress at NCEP/NWS. Three immediate applications of the downscaled output are planned within SIO: 1) streamflow simulation, 2) fire weather application, and 3) regional ocean coupling. The final products will be made available to wider science community.

References

[1] E. Kalnay et al., "The NCEP/NCAR 40-year reanalysis project," Bull. Amer. Meteor. Soc., 77, 437–471,1994.

[2] A. J. Simmons and J. K. Gibson, "The ERA-40 project plan," ERA-40 project report series No.1, ECMWF, 2000. (available at http://www.ecmwf.int/publications/)

[3] H.-M. Juang and M. Kanamistsu, "The NMC nested regional spectral model," Mon. Wea. Rev., 122, 3–26, 1994.

[4] H.-M. Juang, S. Y. Hong, and M. Kanamitsu, "The NCEP regional spectral model: an update," Bull. Amer. Meteor. Soc., 78, 2125–2143, 1997.

[5] M. Kanamitsu et al., "NCEP/DOE AMIP-II Reanalysis (R-2)," Bull. Amer. Meteor. Soc., 83, 1631–1643, 2002.

[6] H. Kanamaru and M. Kanamitsu, "Regional Downscaling of the 50-year NCEP/NCAR Reanalysis for the California Region," 28th annual climate diagnostics and prediction workshop, Reno, Nevada, USA, Oct. 2003.