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

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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 model code is now sufficiently optimized for the Earth Simulator. Scale Selective Bias Correction method is developed to reduce the large-scale error in the regional downscaling analysis. Smaller downscaling studies over California at the same resolution are discussed to illustrate the quality of products that are being made on the Earth Simulator for the United States. The analyses of California show that hourly outputs of fine resolution enable detailed spatial and temporal studies. The downscaled fields will be verified against station observations as well as the North American Regional Reanalysis. 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 (3) and ECMWF ERA-40 (6). 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 (1 and 2) 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 (3) 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) and NEC Systems in Texas. The target domain is 1024 x 651 grid at 10 km resolution that covers the contiguous United States, Gulf of Mexico, Caribbean Sea, part of Atlantic Ocean and Pacific Ocean. By April 2005, optimization and vectorization of the code is complete. The 8-CPU simulation of the 1-hour model integration took 2800 seconds in the first practice run in December 2003. Now the 24-hour model integration on 1024 processors takes about 380 seconds. This includes post-processing, surface field routines, and all I/O, whereas the initial test did not include any of these. The parallelization ratio is more than 99.97 %. A variety of optimization techniques have been used to achieve this performance of the model. 1) Use of process splitting time scheme that allows longer time step for integration. 2) Use of FFT and other ASLES routines for Fourier and sine/cosine transforms. 3) Vectorization of key transform and spatial interpolation routines. 4) Parallelization of post-processing codes and application of parallel I/O. 5) Application of longer vector length for physics routines. 6) Inline expansion and other Fortran compilation optimizations. Figure 1 shows the precipitation output from our 24-hour integration test run. The fields are not quite settled after the short integration particularly at the western lateral boundaries but you can see many detailed features including a hurricane in the Gulf of Mexico. The product will be available for analyses not only over the mainland U.S. but also over the ocean for tropical cyclones studies.

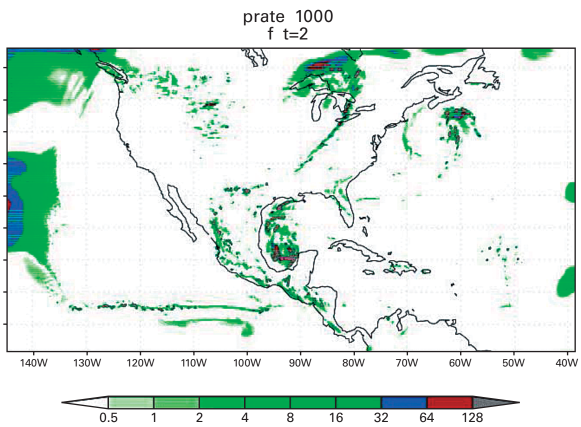

Fig. 1 10 km downscaled precipitation field over the United States after 24 hour integration.

3. Scale Selective Bias Correction method

Regional downscaling does not necessarily produce better fields than the coarse resolution fields that are used to force the regional model. One of the reasons for this shortcoming is the systematic large-scale error that develops within the regional domain. In order to reduce this large-scale error, a method called Scale Selective Bias Correction is developed. This method is a combination of multiple procedures to reduce the large-scale difference between global base field and the regional full field. The method consists of 1) damping the large-scale component of winds (horizontal scale of 1000 km or larger) towards base field, 2) setting the domain average temperature and humidity differences between base and regional field to zero, and 3) adjusting area-mean logarithm of surface pressure field to the corresponding logarithm of surface pressure difference between the base and regional domain by incorporating the difference in average surface elevations. The downscaling with this method was shown to have several advantages and its effect is larger when the regional domain is larger. In the large domain of the order of a few thousand kilometers, the SSBC improves the skill score and bias of precipitation (Table 1). Furthermore, the simulation becomes more insensitive to the selection of the domain size (not shown). The lateral boundary relaxation can be reduced significantly when combined with SSBC method.

4. 50-year 10-km downscaling over California

In parallel with 50-year 10-km downscaling over the US using Earth Simulator, downscaling over smaller region that covers state of California using cluster machines available at various computer centers in the US (SDSC, National Center for Supercomputing Applications, Texas Advanced Computing Center, and Pittsburgh Supercomputing Center) is in progress. Nearly 20 years of downscaling is complete so far. Several preliminary analyses of the 5-year climatology and diurnal variation in the simulation are performed. The horizontal resolution of the model is 10 km with the domain size of 128 x 199. It is expected that the product for

	Summer		Winter	
	Threat	Bias	Threat	Bias
Control	0.40	0.95	0.44	1.47
SSBC	0.42	0.97	0.46	1.14

Table 1 Precipitation threat scores and bias scores from downscaling over continental US using 60 km resolution RSM.

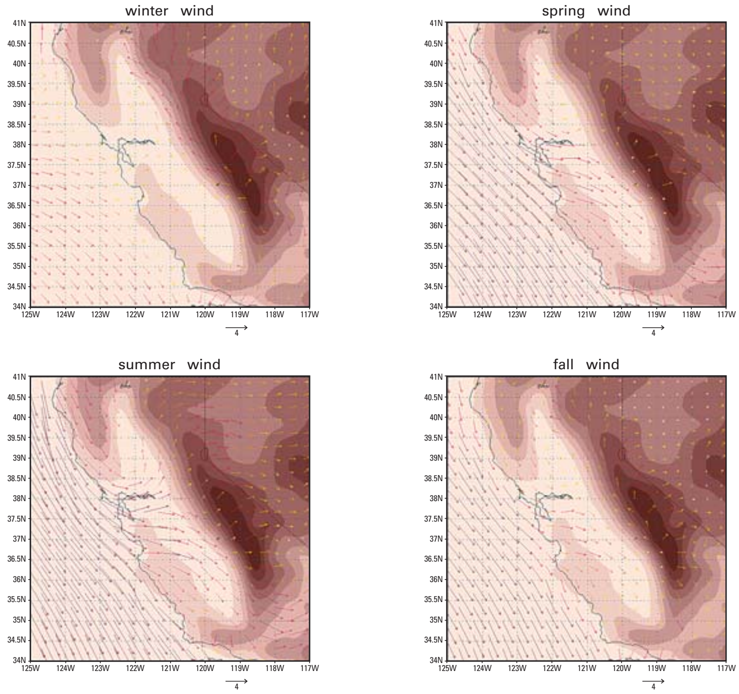

Fig. 2 Seasonal climatology of 10 meter wind obtained from 5.5 years of downscaling simulations.

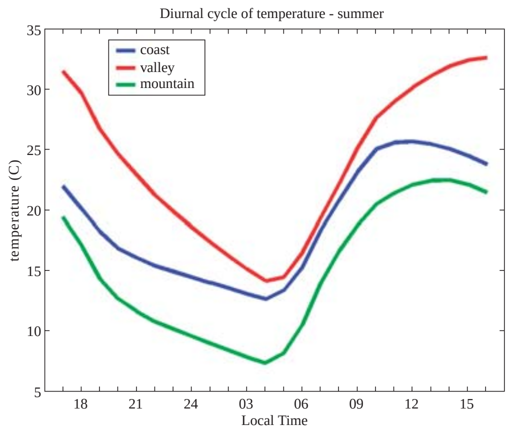

Fig. 3 Climatological diurnal variation of near surface temperature during summer obtained from 5.5 years of downscaling simulations. Three plots are for coast, valley, and mountain regions of California.

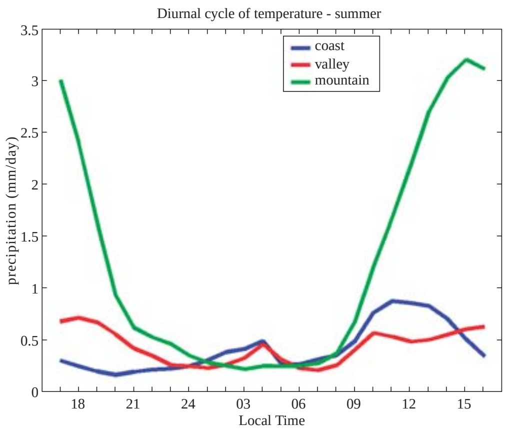

Fig. 4 Climatological diurnal variation of precipitation during summer obtained from 5.5 years of downscaling simulations. Three plots are for coast, valley, and mountain regions of California.

the United States from the Earth Simulator runs will have comparable quality as the California runs reported here.

4.1 5-year climatology

The precipitation climatology of the RSM downscaling runs (not shown) shows a clear maximum over the Sierra Nevada and a secondary peak along the coast in the winter precipitation. In summer, the peak that was stationed over the Sierras during winter is shifted to the east and the maxima along the coast disappear. During winter, the two-meter temperature climatology (not shown) appears cold over and east of the Sierras while more uniform in the Central Valley to the coast. During summer, temperature is highest over the Central Valley and southeast (Death Valley area). Interestingly there are peaks of high temperature to the north and to the south with slight minimum in between over the Central Valley. The 10-meter wind climatology (Figure 2) shows a clear low level jet along the Sierras in winter. During the summer, northerly wind over the ocean penetrates into the Central Valley through the Bay Area.

4.2 Diurnal Variability

The diurnal variability of temperature, wind and precipitation over coast, valley and mountain regions are examined. Here, we show only the results for temperature and precipitation during summer in Figs 3 and 4. The temperature shows gradual cooling from midnight to morning with a much faster warming in the morning. The peak cold hour is

4 am (local time) over all the regions. The hour of maximum temperature is different for different regions, ranging from 10 am over the coast, 12 pm over the mountains and 4 pm over the valley. The summer precipitation climatology is explained well by the diurnal signal, which has a marked variation over the Sierra Nevada Mountains, peaking at 3 pm local time. Over coast and valley regions, diurnal variations are much smaller, but still quite evident. Curiously, there seem to be double peaks in the precipitation at the coast at 4 am and 12pm. Over the valley, there are triple peaks at 4am, 10am and 6pm.

4.3 Soil moisture

Figure 5 shows variation of soil moisture in the middle of the central valley (38°N, 121°W). Large annual variation as well as relatively small interannual variation is clear. The initial soil moisture spin-up seems to be minimal at least at this location.

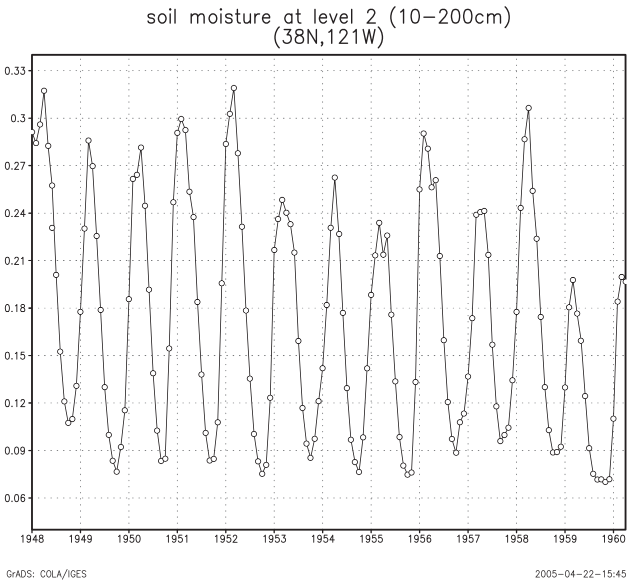

Fig. 5 Variation of deep soil moisture from 1948-1960 at a point in Central Valley from downscaling over California region.

5. Future works

In parallel with the production runs, the downscaled field of atmosphere and land will be verified against station observations as well as North American Regional Reanalysis 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.

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アメリカ合衆国上での50年分のNCEP/NCAR 再解析のRegional Spectral Modelによるダウンスケーリング

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アメリカ合衆国全体を対象にした、NCEP/NCAR再解析の50年分のダウンスケーリングを行なった。ダウンスケーリングには10 kmの解像度のRegional Spectral Model（RSM）を用いる。NCEP/NCAR再解析を境界条件として、領域モデルを走らせることによって、再解析では再現できなかった高解像度の解析が領域内で計算できる。現在、地球シミュレータ上でのモデルのコードの最適化を終え、プロダクションを開始した。大きなスケールのエラーを領域内で減らすために、Scale Selective Bias Correction法を開発した。本稿では、同じ10 kmの解像度で行なったカリフォルニアを対象領域としたダウンスケーリングを例に、プロダクトの品質について説明する。アメリカ合衆国全体のダウンスケーリングも、カリフォルニアと同様の質のダウンスケーリング解析が得られると期待される。プロダクトは空間分解能が高いばかりでなく、1時間ごとに出力されているので高い空間分解能をもっている．そのため、このデータセットは、今まで困難であった研究が可能にするものである。出力は観測値やNorth American Regional Reanalysisと比較検証を行ない、いずれは一般のユーザーにも配布する予定である。

キーワード：地球シミュレータ，領域気候モデル，Regional Spectral Model，ハイパフォーマンスコンピューティング，ダウンスケーリング