

Global Dynamical Downscaling of Reanalysis with Bias Correction

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INTRODUCTION

Reanalysis is now an indispensable dataset for climate studies. It provides analysis of a variety of variables, which are internally consistent within the framework of the numerical model used in the data assimilation. However, its coarse spatial resolution has been problematic for various application studies. As pointed out by von Storch et al. (2000), dynamical downscaling with the spectral nudging technique is considered a “poor person’s data assimilation technique”, dynamical downscaling is an alternative to regional data assimilation. Therefore in this study, a global version of the dynamical downscaling is developed. The system uses global spectral model and spectral nudging, and produces finer resolution global datasets from 200 km resolution reanalysis. For this purpose, a modified version of the scale-selective bias correction (Kanamaru and Kanamitsu, 2007), is developed. The major objective of this paper is to demonstrate that a “global high-resolution” version of the NCEP global Reanalysis can be produced with relatively low computer cost.

METHOD

The scale-selective bias correction (SSBC) scheme for a regional spectral model (RSM) developed by Kanamaru and Kanamitsu (2007; KK07 hereafter) was modified for the global spectral model (GSM), and was used as a base for this study. The GSM is based on the medium range forecast (MRF) model developed at NCEP for making operational analysis and predictions (see Caplan et al, 1997), and was further improved at the Scripps Institution of Oceanography (SIO). The RSM used by KK07 was also developed at NCEP and improved later at SIO (Kanamitsu et al., 2005). The physical parameterizations used by GSM and RSM are identical and the two models share many other components. The SSBC developed for RSM required modification due to differences in the spectral basis functions used in GSM and RSM, as well as to the much wider area coverage that includes the tropics and extra-tropics.

Prior to the downscaling process, the driving reanalysis data were pre-processed; surface pressure was recalculated for higher resolution topography in the high-resolution global model with the hydrostatic relationship, and temperature, humidity, and wind fields were vertically interpolated to the new model sigma levels. This process is basically the same as that of the RSM-SSBC’s correction for surface pressure.

In the RSM, the sine and cosine series for both x- and y-directions are used as basis functions, and nudging is applied directly to the two dimensional sine and cosine amplitudes. In GSM, the basis function is a spherical harmonics, and the SSBC equivalent of RSM is to apply the nudging to the amplitude of total wavenumber. However, this implies that the nudging is uniformly applied in the zonal and meridional directions. In reality, it is desirable to nudge differently for the zonal and meridional directions, since the atmospheric long waves tend to have larger scale in east-west than in north-south. For this reason, SSBC for a specified zonal scale is applied at each Gaussian latitude. The equations for nudging using a fully implicit time scheme are written as follows:

$$f_{(\lambda, \phi)} = \sum_{m=-M}^{m=M} A_{(m, \phi)} e^{im\lambda}$$

$$A_{(m, \phi)} = \begin{cases} A_{f(m, \phi)} & (|m| > \frac{2\pi R_E \cos \phi}{L}) \\ \frac{1}{\alpha + 1} (A_{f(m, \phi)} + \alpha A_{a(m, \phi)}) & (|m| \leq \frac{2\pi R_E \cos \phi}{L}) \end{cases} \quad (1)$$

where f is a physical variable (full field), A is the Fourier coefficient, and the subscript f and a indicate forecast and analysis (driving data), respectively. λ , ϕ , R_E , m and M indicate longitude, latitude, radius of the earth, wavenumber, and the truncation wave number, respectively. α is a nudging coefficient, and L is a critical nudging scale where waves longer than L will be nudged.

The original SSBC nudged zonal and meridional wind components at all sigma levels towards coarse resolution reanalysis field by using a single weighting coefficient ($\alpha=0.9$). KK07 applied it only to waves whose physical wavelengths are 1000 km or longer. In GSM-SSBC, it was found that the nudging of temperature was necessary to improve simulation in the tropics. Furthermore, the removal of the correction and nudging to moisture was needed to avoid excessive precipitation.

With this modified version of SSBC, a global downscaling by T248 (about 50 km) resolution model was conducted (experiment named T248) for the year 2001. T62L28 6-hourly NCEP R2 was used for forcing. Considering the spin-up of land surface parameters, the model was run from 1998, but the results for 2001 are shown below.

RESULTS

(a) Global Temperature compared with CRU

Figure 1 shows the globally downscaled monthly mean temperature over land compared with the CRU (Climate Research Unit) dataset (version TS 2.1, Mitchell and Jones, 2005). From Figure 1d and 1e, it is found that the Arctic Islands, the extreme northern part of North America, and the eastern part of Siberia are slightly warmer in both R2 and the downscaled analysis. There are slightly cooler biases in Central Africa, the Sahel, and the Amazon Basin. However, there is an obvious improvement associated with the global downscaling due to more realistic surface topography, especially over mountain ranges. The clearest difference can be seen in the Tibetan Plateau and in the Andes, but there are also improvements over the Pacific Coastal Ranges, the Alps, the Ethiopian Plateau, the Mongolian Plateau, and many other locations. Although the other months' results are not shown, the advantage of the downscaling is similar throughout the year.

(b) Global Precipitation compared with GPCP

In Figure 2, the downscaled analysis and original reanalysis R2 (T62 resolution) monthly precipitation are compared with those of GPCP (Huffman et al., 2001), and T248 run without nudging (FCST) during July 2001. Spatial contrasts associated with topography and coastlines become more apparent in the downscaled analysis, for example, in the Himalaya and Sierra Madre Ranges, the Coast Ranges in British Columbia, and the western coastline of India. The global average of the correlations is significantly higher for the downscaled analysis throughout the year, indicating better representation of daily precipitation variations in the downscaled analysis.

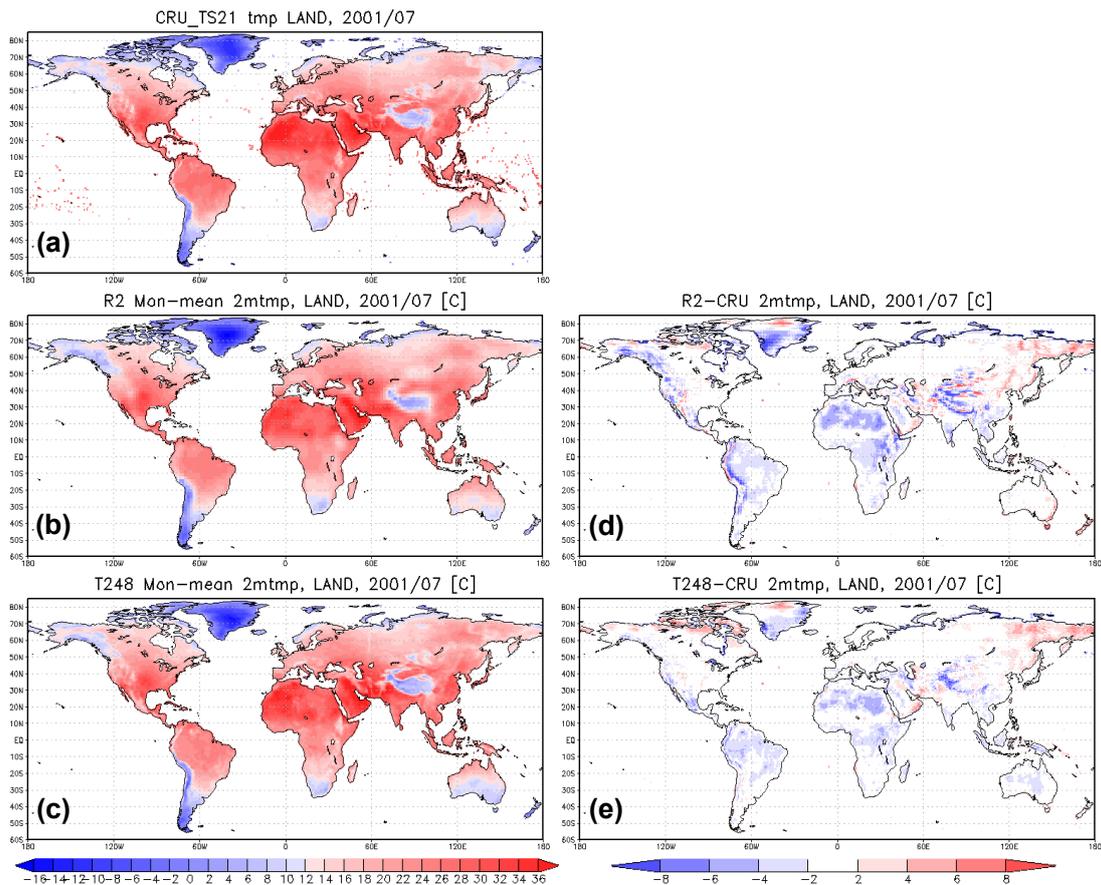


Figure 1: Global monthly mean air temperature at 2 meter surface over land in July 2001. (a) CRU observation, (b) Reanalysis 2, and (c) T248 simulation. Differences from CRU (a) of R2 and T248 are shown in (d) and (e), respectively. The differences are rendered in CRU's resolution (0.5 degree).

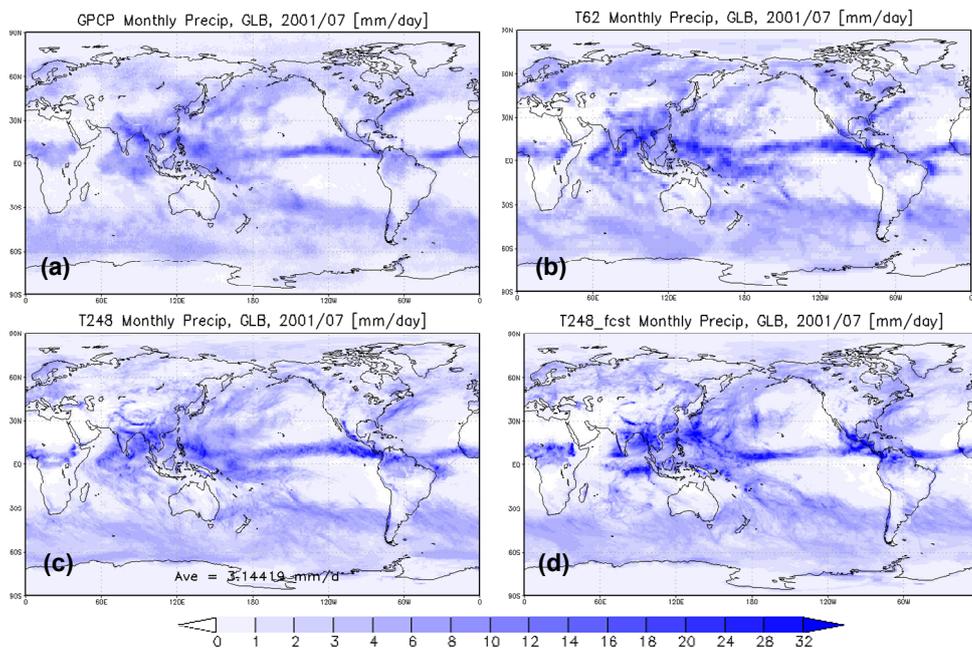


Figure 2: Global distribution of monthly precipitation in July 2001. (a) GPCP, (b) R2, (c) T248 nudged simulation results, and (d) T248 forecast simulation results are shown.

(c) Validation over Japan with AMeDAS

Next, we compared our results with more than 1000 Automated Meteorological Data Acquisition System (AMeDAS), in-situ meso-scale surface observatories covering all of Japan, for wind speed, humidity, temperature, and precipitation. The average AMeDAS station location interval is about 20 km, and most of the observations are hourly. The averages of correlation coefficient of the four surface variables between the downscaled analysis and AMeDAS in January and July 2001 showed clearly a large improvement in January precipitation, and a somewhat smaller improvement in the temperature fields for both months. By averaging the coefficients over the region for all months, the wind speed, temperature, and precipitation of the downscaled analysis became closer to the AMeDAS observations than those of Reanalysis. Only the humidity fields stayed similar or became worse than R2, because humidity was not nudged and corrected in T248. Because the analysis of surface moisture plays an important role at the regional scales, improving the moisture field would make the whole simulation better.

In Figure 3, the temporal variations of the variables (a) wind speed, (b) temperature, (c) humidity, and (d) precipitation for the first 10 days in July 2001 at a single grid point at 140.0E and 36.0N (near Tsukuba, Japan) are shown. We see that the improvement of the correlation coefficient was from better reproduction of diurnal variations of wind speed and temperature. The diurnal cycle of absolute humidity is weak, but other fluctuations were better reproduced in the T248 downscaling. In precipitation, the downscaled analysis captured a rain event on 6 July, 2001, which was very sharp and short according to the observation, whereas R2 did not have any precipitation in that period.

(d) Synoptic/Sub-synoptic Scale Weather Patterns

Some typical intense synoptic- and subsynoptic-scale atmospheric phenomena are selected and the downscaled analysis is compared with the corresponding coarse resolution Reanalysis; a Santa Ana wind event in Southern California, a Mistral in West Europe, and the katabatic wind in Antarctica. Figure 4 shows daily snapshots of temperature anomaly (deviation from monthly mean), wind, and surface elevation of those events for R2 and the downscaled analysis, and captured more vivid temperature contrasts and more detailed wind patterns associated with the complex topography, whereas winds in R2 were more uniform.

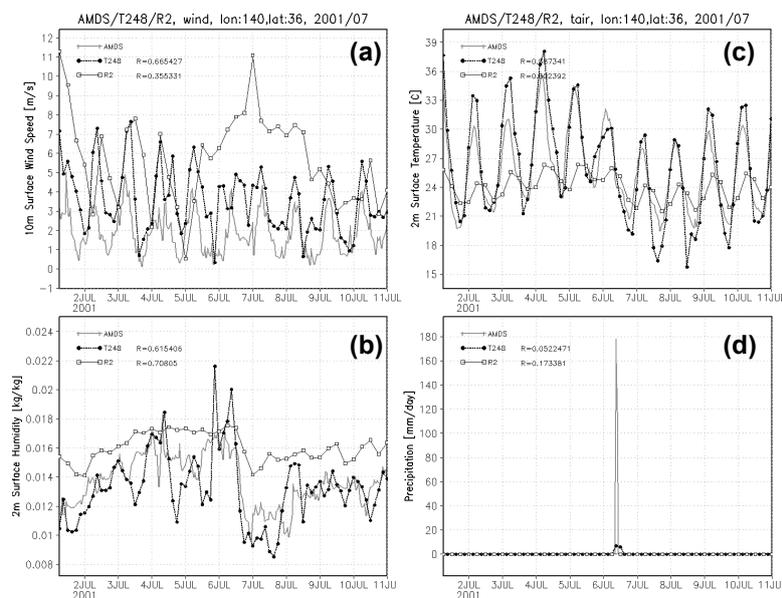


Figure 3: Temporal variations of Reanalysis 2 (thin solid line with open square), T248 (black thick line with closed circle), and AMeDAS observation (gray thick line) are compared for (a) surface wind speed, (b) surface temperature, (c) surface humidity, and (d) precipitation.

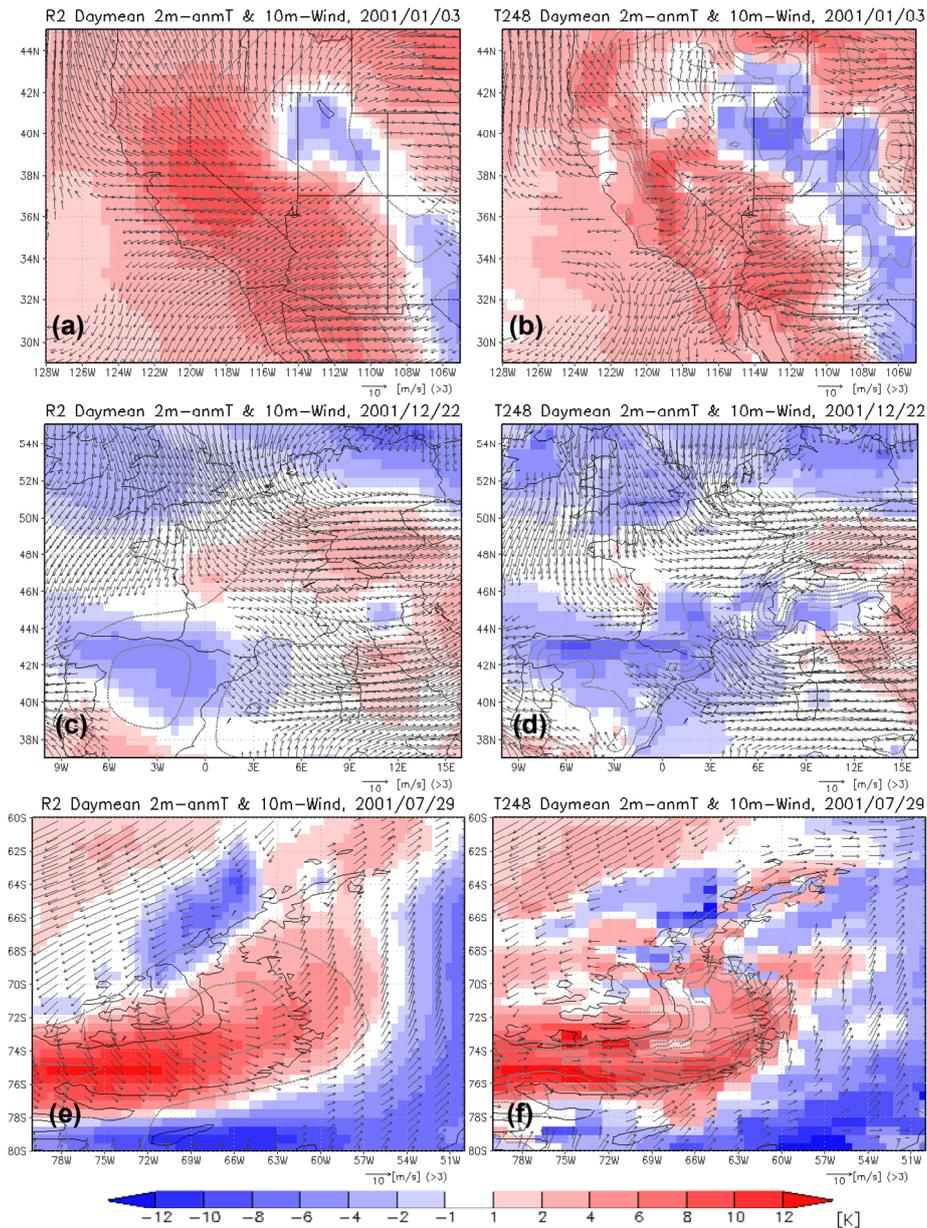


Figure 4 (topright): Daily averaged temperature anomalies (shades), winds (arrows), and topography (gray contour; 300 m interval and 0 m line are omitted). Left and right columns show Reanalysis 2 with linear interpolation to the same resolution with T248 and T248-nudged run, respectively. (a, b) Santa Ana wind in Southern California on 3 January 2001, (c, d) Mistral wind in West Europe on 22 December, 2001, and (e, f) katabatic winds in Antarctic Peninsula on 29 July 2001 are shown. Number of arrows is horizontally cropped to 1/4 in (f).

SUMMARY AND CONCLUSIONS

In this study, an attempt has been made to develop a global version of dynamical downscaling using the global spectral model (GSM) with a spectral nudging technique. A modified version of the scale-selective bias correction (SSBC) (Kanamaru and Kanamitsu, 2007) was applied. The global downscaling is free of the lateral boundary noise which contaminates regional downscaling, and is a way to produce computationally efficient high-resolution global reanalysis datasets from coarse resolution data assimilation analysis.

SSBC was modified for GSM in three different ways. First, the large-scale temperature of the scale greater than 2000 km was nudged at every Gaussian Latitude in addition to the zonal and meridional components of wind. This was necessary to reduce the large-scale temperature bias in the stratosphere in equatorial tropics. Second, the nudging of perturbation field was applied instead of the nudging of perturbation tendency. Large scale biases that can occur in the perturbation tendency nudging may not occur in the nudging of the perturbation itself. Third, humidity was not nudged or corrected. With this nudging scheme, large-scale features of the reanalysis were well maintained in the downscaling. The departures of geopotential height of downscaled analysis from reanalysis were in a range of 5 to 10 meters at all of the pressure levels.

Using a T248L28 (about 50 km resolution) global model, downscaling was performed for the entire year of 2001, using T62L28 NCEP/NCAR R2 as a large-scale forcing. Surface variables and precipitation were compared with R2 and available high-resolution observations. The global temperature fields compared with CRU temperature showed that the downscaled analysis better matched with observation due to the better topography. Monthly averaged precipitation, its seasonality and daily variation were compared with those of CRU and GPCP. The daily variability in the downscaled precipitation was better reproduced in the downscaled analysis than in the R2 throughout the year. Over Japan, the comparison with more than 1000 AMeDAS in-situ observations showed that the downscaled analysis fits better to observation than R2 for surface temperature, wind speed, and precipitation. The fit of humidity was not significantly improved. The improvement of diurnal variation of surface temperature was significant. In addition, three typical synoptic/sub-synoptic scale weather features were selected for comparison, namely the Santa Ana in Southern California, the Mistral in Southern France, and katabatic winds in Antarctica. The global downscale clearly showed realistic regional-scale features with respect to temperature and wind.

One of the purposes of this study is to determine whether this global downscaling can serve as a replacement of the global high-resolution reanalysis without performing an expensive high-resolution global data assimilation. From the present result, this seems to be the case at least for surface meteorological variables and precipitation. However, in order to confirm this, it is also necessary to investigate the fit of the downscaling to observations in the free atmosphere and to compare the results with the high-resolution data assimilation analysis. Since this would require a full objective analysis system capable of using high-density surface observation, it is beyond our capability at this time.

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