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Evaluation of stratospheric temperature simulation results by the global GRAPES model

Liu Ningwei[1], Wang Yangfeng[1], Ma Xiaogang[2], Zhang Yunhai[1]

[1]Institute of Atmospheric Environment, China Meteorological Administration, Shenyang, China
[2]Fuxin Meteorological Bureau, Fuxin, China

Abstract. Global final analysis (FNL) products and the general circulation spectral model (ECHAM) were used to evaluate the simulation of stratospheric temperature by the global assimilation and prediction system (GRAPES). Through a series of comparisons, it was shown that the temperature variations at 50 hPa simulated by GRAPES were significantly elevated in the southern hemisphere, whereas simulations by ECHAM and FNL varied little over time. The regional warming predicted by GRAPES seemed to be too distinct and uncontrolled to be reasonable. The temperature difference between GRAPES and FNL (GRAPES minus FNL) was small at the start time on the global scale. Over time, the positive values became larger in more locations, especially in parts of the southern hemisphere, where the warming predicted by GRAPES was dominant, with a maximal value larger than 24 K.To determine the reasons for the stratospheric warming, we considered the model initial conditions and ozone data to be possible factors; however, a comparison and sensitivity test indicated that the errors produced by GRAPES were not significantly related to either factor. Further research focusing on the impact of factors such as vapor, heating rate, and the temperature tendency on GRAPES simulations will be conducted.

1. Introduction

The global assimilation and prediction system (GRAPES) is a multi-scale general model independently developed by Chinese scientists [1]. The core technology of the system is a three-dimensional variational data assimilation [8, 13, 15, 18], semi-implicit and semi-Lagrange difference scheme, a compressible non-static equilibrium dynamical framework [11], an optimized physical process parameterization scheme that can freely combine data [14], and a standardized, modular, parallel data assimilation and numerical model program [12]. The quasi-operational running of GRAPES since March 2009 has enabled it to play an important role in China's numerical weather prediction business. However, the predictive ability of GRAPES ranks behind those of international advanced models in several respects, such as in medium-term circulation situations, low-level wind in East Asia, and high-level circulation [1].

Stratospheric temperature plays a significant role in the vertical temperature structure and radiation balance of the atmosphere through the exchange of quality, energy, and momentum between the troposphere and stratosphere. Because stratospheric temperature can effectively reflect the interaction of radiation, chemistry, and dynamic processes, trends in its variation have become an essential feature of the Intergovernmental Panel on Climate Change (IPCC) assessment reports in recent years. The Stratosphere Process and Its Effect on Climate (SPARC) project in the WCRP World Climate Research Programme (WCRP) has established a special team to evaluate the trend in stratosphere temperature variation. The variation in stratospheric temperature is a critical factor in global climate change.

As a powerful tool for recognizing the causes and rules of atmosphere motion and climate change, reanalysis datasets have always been used in atmospheric diagnostic analysis and research [3, 4]. Moreover, they are usually used as the initial and driving field for running weather forecasts in climate models. Among the many reanalysis datasets, the National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR) dataset has the widest application. Reanalysis datasets can generally be classified into four categories, A, B, C, and D. Among these, dataset A, which is mainly based on observations, is the most plausible and includes parameters such as geopotential height, temperature, and wind field [16].

To verify the stratospheric temperature simulation by GRAPES, this study compared the simulation results with a reanalysis dataset and analyzed the possible reasons for simulation errors. Through this study, an objective and reasonable evaluation of the stratospheric temperature simulation by GRAPES was obtained, with the aim of improving its predictive ability.

2. Model description and setup

In this study, GRAPES was used with a horizontal resolution of 1 × 1º in latitude and longitude, and with 29 vertical levels up to 10 hPa in the lower stratosphere. The initial conditions of GRAPES were taken from the NCEP/NCAR dataset products with horizontal, vertical, and temporal resolutions of 1 × 1º, 26 levels, and 6 hours, respectively, together with a 600-second time step. The model output frequency was also 6 hours.

In the evaluation, the horizontal and vertical resolutions of the global final analysis (FNL) products used to compare the model results were 2.5 × 2.5º and 17 levels, respectively.

In this study, the FNL results and the 5th generation European Centre Hamburg general circulation spectral model (GCM), ECHAM (version 5.3.02) (Giorgetta et al., 2006; Jungclaus et al., 2006; Lauer et al., 2007; Lohmann et al., 2007; Hui et al., 2014), were used to evaluate the temperature simulation results produced by GRAPES. ECHAM was used at T106L90 resolution, corresponding to a horizontal resolution of 1.125 × 1.125º for the quadratic Gaussian grid, and with 90 vertical levels up to 0.01 hPa in the top stratosphere. The vertical resolution near the tropopause was about 500 m. The model time step and output frequency were 360 seconds and 6 hours, respectively. All the reference simulations were performed for the period 00:00 am, 1 January to 00:00 am, 6 January 2010.

3. Results

3.1 Temperature comparisons for models and FNL

In Figure. 1, the temperature results for GRAPES, ECHAM, and FNL at 50 hPa for every 6 hours are shown. Over the 120-hour simulation period, the temperature variations of ECHAM and FNL varied little over time, especially in the southern hemisphere, whereas the variation results produced by GRAPES were significantly elevated in the southern hemisphere. The temperatures simulated by GRAPES were increased by at least 6K below a latitude of 60°S (i.e., mostly located in the Antarctic continent), with little variation in the northern hemisphere. This regional warming seemed to be too significant and uncontrolled to be reasonable.

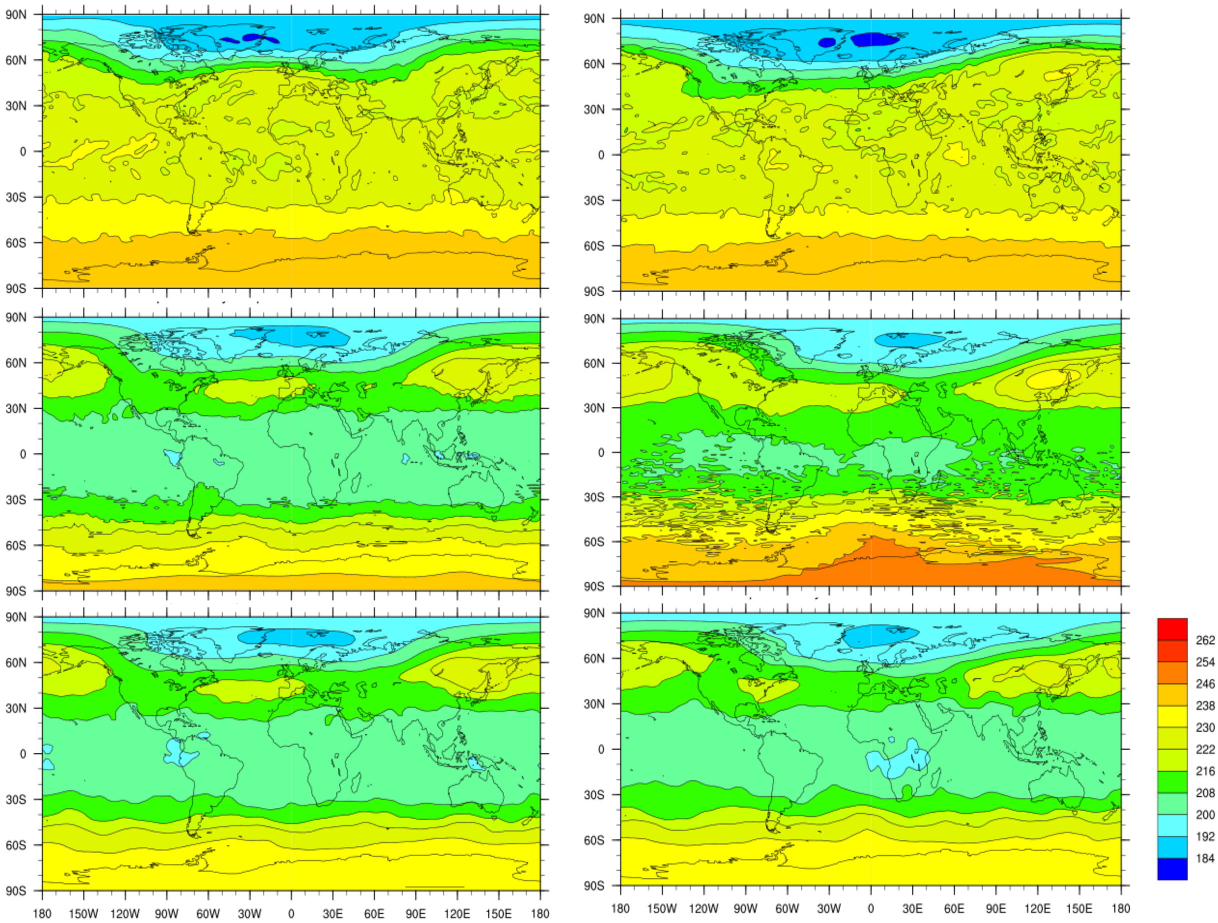

Fig.1. The temperature results (in K) for GRAPES, ECHAM and FNL at 50hPa for every 6 hours.

GRAPES projected higher values than FNL did, and the difference became larger as the simulation time increased, becoming more than 10 K in the Antarctic continent during the final 2 days. Figure 2 shows the temperature differences between the end and start times of the 5-day simulation at 50 hPa projected by GRAPES and the differences between those and the corresponding times in FNL. The warming projected by GRAPES was most prominent around Cloth Weft Island (i.e., 60°S latitude, 0° longitude), with a maximum of more than 20 K. There was a cooling center 50 km to the east, where the warming was less than 10 K. However, the warming pattern in the Antarctic continent during the 5-day simulation remained fairly stable, with a value between 5 and 15 K. In contrast to GRAPES, the temperature variation projected by FNL during the simulation was very small, except for a warming area with a value of more than 10 K in northern Canada.

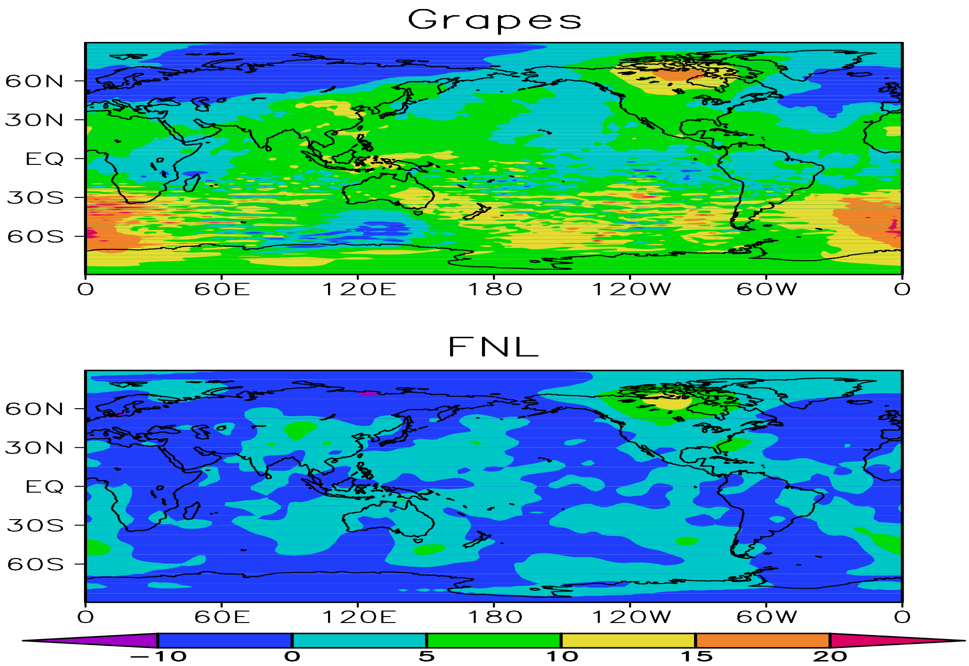

Fig.2 The temperature differences between the end and start times of the 5-day simulation at 50 hPa projected by GRAPES (the upper)and the differences between those and the corresponding times in FNL (the lower).

3.2 Temperature differences projected by GRAPES and FNL

As mentioned above, the temperature differences projected by GRAPES and FNL were relatively large, and therefore we analyzed the exact difference between them further. The temperature differences could only be compared after the horizontal resolutions of GRAPES and FNL (1 and 2.5°, respectively) were made uniform. So we interpolated the temperature results of GRAPES from 1 to 2.5° using a bilinear interpolation.

Figure 3 shows the temperature differences at 50 hPa at different times as projected by GRAPES and FNL (GRAPES minus FNL). At the start time, the temperature difference was small, with values of no more than plus or minus 2 K on the global scale. Over time, the temperature difference became positive in more locations, indicating significant warming projected by GRAPES. The warming projected by GRAPES was dominant in the southern hemisphere, with a maximal temperature difference of more than 24 K at 30–60°S, 30–60°E at 00UTC on 4 and 5 January 2010. The area with positive values continued to increase, resulting in a rise of more than 12 K across the whole Antarctic continent on 6 January 2010.

3.3 Possible reasons for the higher temperature projected by GRAPES

Numerical weather prediction is a kind of typical initial value problem, meaning that the prediction results of models are directly affected by the ability of the initial conditions to properly reflect the virtual atmospheric motion and to match and coordinate well with the models [10, 17]. Tiny differences in the initial conditions might lead to distinctly different model forecasts. Because the initial conditions used in ECHAM and GRAPES were data in spectral and grid point space, respectively, there is little comparability between them. Therefore, we converted the spectral data (i.e., T106L90) to grid point space, and then interpolated them to the same resolutions as the initial condition of GRAPES (i.e., 1 × 1º in the horizontal direction and 26 levels in the vertical direction) to enable comparison.

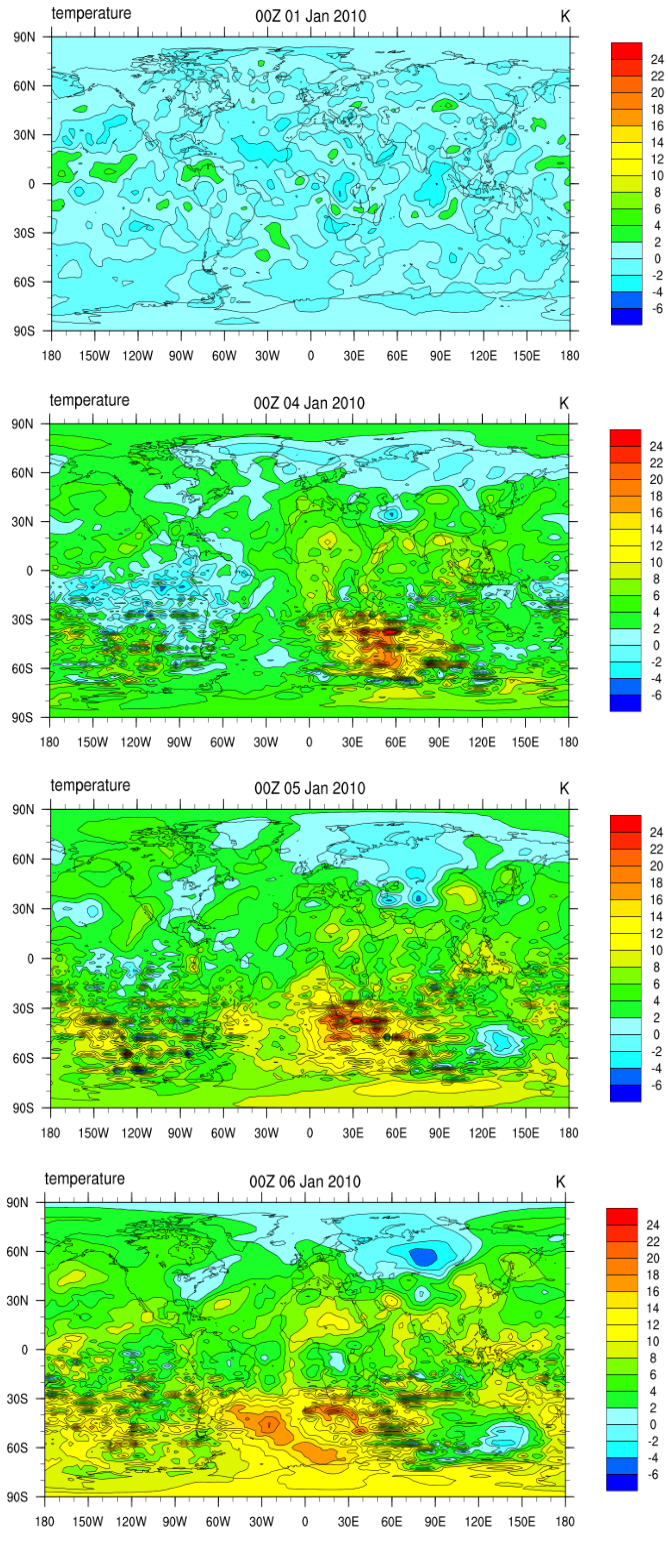

Fig.3. The temperature differences at 50 hPa at different times as projected by GRAPES and FNL

Figure 4 shows the converted initial temperature of ECHAM, the initial temperature of GRAPES at 50 hPa and their difference. The patterns for the initial temperatures projected by ECHAM and GRAPES were so similar that their difference was close to zero, with the exception of values of -4 and 8 K in a few areas. This shows that the temperature difference, especially the warming projected by GRAPES, was related to the model itself rather than the initial conditions.

Although ozone is only a trace gas, it has a very important role in radiation and chemical processes in the stratosphere. On account of the strong absorption of solar ultraviolet radiation by stratospheric ozone, the variation of the ozone content has a large influence on stratospheric temperature [9]. Therefore, the reliability of the ozone data used in GRAPES may be the key factor that determines the accuracy of simulated stratospheric temperature. Given this, we replaced the ozone data used in GRAPES with those used in ECHAM, and then compared the new temperature results projected by GRAPES with the original results. The two sets of ozone data used in GRAPES and ECHAM are both climatic average values made through observations; however, their horizontal resolutions and vertical layers are totally different. Figure 5 shows the average ozone mixing ratio profiles from the data used in GRAPES and ECHAM, respectively. The peak difference between them exists at about 7 hPa in the upper stratosphere.

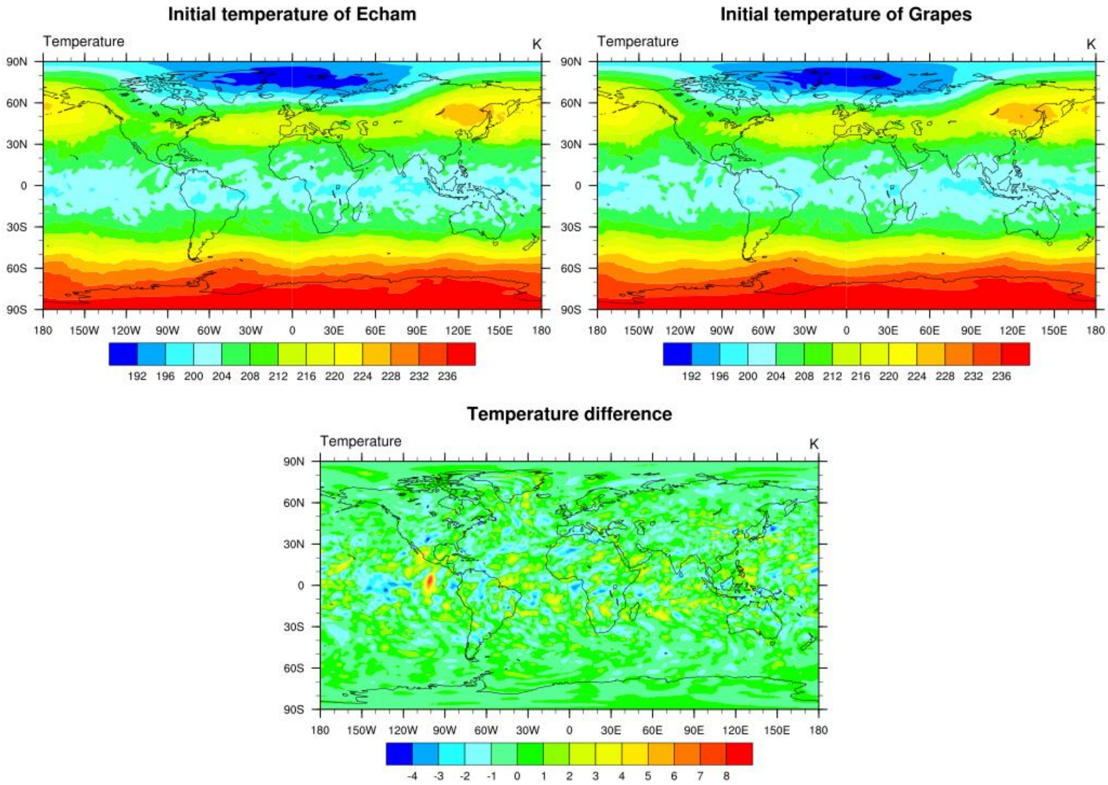

Fig.4. The converted initial temperature of ECHAM (the upper left), the initial temperature of GRAPES (the upper right) at 50 hPa and their difference (the lower).

Figure 5 shows the temperature differences at 50 hPa projected by GRAPES at various simulation times using both the original and the new ozone data (i.e., the data from ECHAM and the difference between them, respectively). The differences were always close to zero, except for few small regions where the values exceeded 10 K near the end of the simulation. Moreover, the regions with large differences were the same as those in Figure 3. The temperature differences at 50 hPa projected by GRAPES using the new ozone data and by FNL (GRAPES minus FNL) at the same time as in Fig. 5 are plotted in Fig. 5. In accordance with those shown in Fig. 3, the differences became more and more significant over time, and the large differences were distributed at 30–60°S latitude, 30–60°E longitude. The warming seemed more obvious than that shown in Fig. 3, meaning that the simulated stratospheric temperatures were higher when the ozone data from ECHAM were used; however, the

ECHAM results did not show a warming trend (Fig. 1). Therefore, under the initial conditions, the ozone data did not indicate a direct relationship with the warming projected by GRAPES.

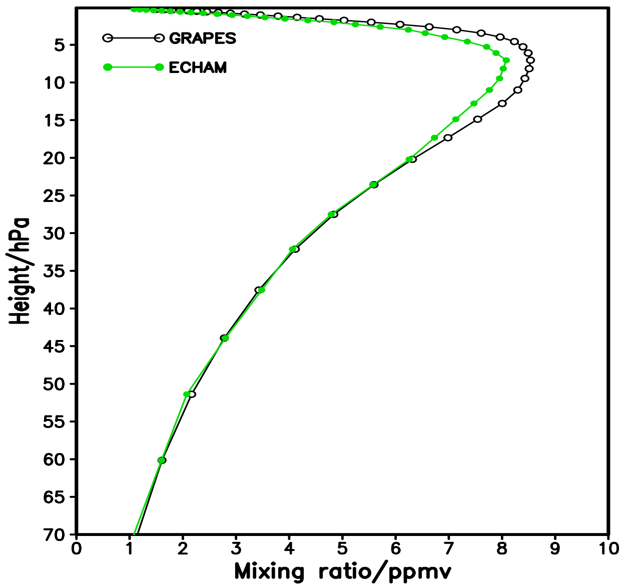

Fig.5. The average ozone mixing ratio profiles (in 10^{-6} mol mol^{-1}) from the data used in GRAPES and ECHAM, the resolution of which are 1×160×19 (horizontal grid points of longitude, latitude and vertical layers) and 72×64×59, respectively.

4. Conclusions

We compared the stratospheric temperature simulated by GRAPES and the results projected by FNL and ECHAM, and then analyzed the possible reasons for any simulation errors, so that an objective and reasonable evaluation could be made.

The temperature variations at 50 hPa projected by GRAPES were significantly elevated in the southern hemisphere, whereas those projected by ECHAM and FNL varied little over time. The regional warming projected by GRAPES seems too distinct and uncontrolled to be reasonable, although the warming pattern remained fairly stable with a value between 5 and 15 K relative to the start time.

The temperature difference projected by GRAPES and FNL was small at the start time on the global scale. Over time, the values become larger in more locations, indicating a significant warming projected by GRAPES. In the southern hemisphere, where the warming by GRAPES was dominant, the maximal temperature difference was larger than 24 K at 30–60°S latitude, 30–60°E longitude for the final two simulation days, and then increased to more than 12 K over the whole Antarctic continent.

We considered the model's initial conditions and ozone data to be the possible factors that resulted in the projected stratospheric warming; however, the errors produced by GRAPES did not seem to be related to either factor. Atmospheric vapor and heating rate may also be factors leading to stratospheric warming, but in this preliminary study, these factors could not be investigated due to a number of technical problems. In future studies, we will focus on the impact of vapor, heating rate, the temperature tendency, and other factors to further investigate the reasons for the simulated temperature errors produced by GRAPES.

Acknowledgments

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