2.11 SIMULATING NORTH AMERICAN PRECIPITATION AND SOIL MOISTURE OF MAY AND JUNE 2003 WITH NASA/NCAR fvGCM WITH TWO CLOUD SCHEMES: CCM3 AND McRAS

David M. Mocko*, Y.C. Sud, and S.-J. Lin
NASA Goddard Space Flight Center, Greenbelt, Maryland

1. INTRODUCTION

Evaluating the influence of a new physics scheme on a model's performance can be a daunting task. Often, performance pluses and minuses lead to confusion, while decisions to include a new scheme, even with improved physics, get postponed in the hope of ameliorating the negative attributes. These delays hamper model development. The NASA/NCAR fvGCM (finite-volume general circulation model) uses hydrodynamics developed at NASA together with NCAR's CCM3 (Community Climate Model) physics. The McRAS (Microphysics of clouds with Relaxed Arakawa-Schubert) cloud scheme has shown several promising features in simulating rainfall climatology with the fvGCM in which the CCM3 cloud scheme and radiation packages were replaced with McRAS and Chou and Suarez radiation. Several options to test the effects of McRAS with new radiation in fvGCM were possible, and the one described in this paper was not only appealing, but also turned out to be useful and revealing.

This method involved a set of ensemble forecasts for the highly anomalous months of May and June 2003. During this period, the continental United States experienced persistent and anomalous circulation patterns and associated precipitation amounts. All-time high rainfall records were set in several eastern states on the basis of records dating back to 1895. The NASA/NCAR fvGCM is run daily on an experimental basis at NASA to make 10-day forecasts in real-time. This study compares those forecasts with a new set of forecasts made for May and June 2003 with McRAS and the updated radiation scheme in the fvGCM.

2. MODEL DESCRIPTION

The NASA/NCAR fvGCM uses a finite-volume dynamical core described in Lin and Rood (1996) and Lin (2004). The radiation and cloud schemes (along with the rest of the physics, including the Community Land Model) in fvGCM are from the NCAR CCM3 (Hurrell *et al.*, 1997). The fvGCM is used primarily for climate studies and reanalysis, but it is also used on an experimental basis at NASA for real-time short- to medium-range forecasting.

Cloud and radiation physics schemes developed and extensively tested at NASA have also been integrated into the fvGCM. The new cloud scheme, called McRAS (Sud and Walker, 1999), tracks the cloud amount via a prognostic method in which cloud microphysics is interactive within all cloud types. McRAS was built on the Relaxed Arakawa-Schubert method of Moorthi and Suarez (1992). Some aspects of McRAS have been shown to perform well in climate simulations using fvGCM (Sud and Walker, 2003). The radiation scheme of Chou and Suarez (1994) - with updates detailed in Chou *et al.* (1998) & Chou *et al.* (1999) - is coupled to McRAS and was carried over into the fvGCM. These two schemes replace the cloud and radiation schemes from CCM3 in a separate version of fvGCM.

3. EXPERIMENT DESIGN

Both versions of the GCM were run separately in the experiment described in this paper. The first version of fvGCM using the NCAR CCM3 physics will hereafter simply be referred to as fvGCM. The new version of fvGCM using the McRAS cloud scheme and Chou and Suarez radiation will be referred to as fvGMc. Both versions were run at a model grid spacing of 0.5 deg. lat. by 0.625 deg. long. with 32 Lagrangian vertical coordinate levels.

The daily simulation for each case was initialized at 12Z and integrated out to 10 days (240 hours). The initial states of the atmosphere and the land surface (including soil moisture) were taken from the real-time reanalysis of the experimental fvGCM 10-day forecasts at NASA. Daily gridded observations of precipitation over the U.S. were taken from the

---

Corresponding author address: David M. Mocko, NASA Goddard, Code 913, Greenbelt, MD 20771; e-mail: mocko@climate.gsfc.nasa.gov; *Additional affiliation:* SAIC/General Sciences Operation, Beltsville, MD

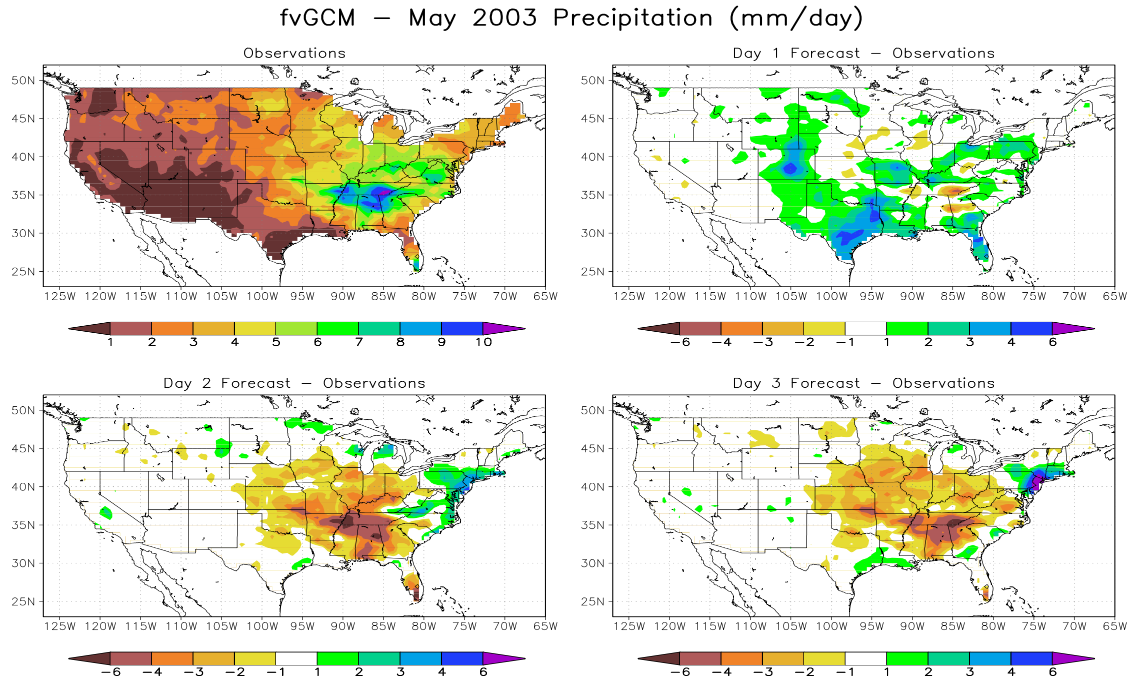

Figure 1: May 2003 precipitation (mm/day) of: top left) gridded observations taken from CPC; top right, bottom left, bottom right) Difference between the Day 1, 2, and 3, respectively, lead-time forecast of fvGCM and the observations.

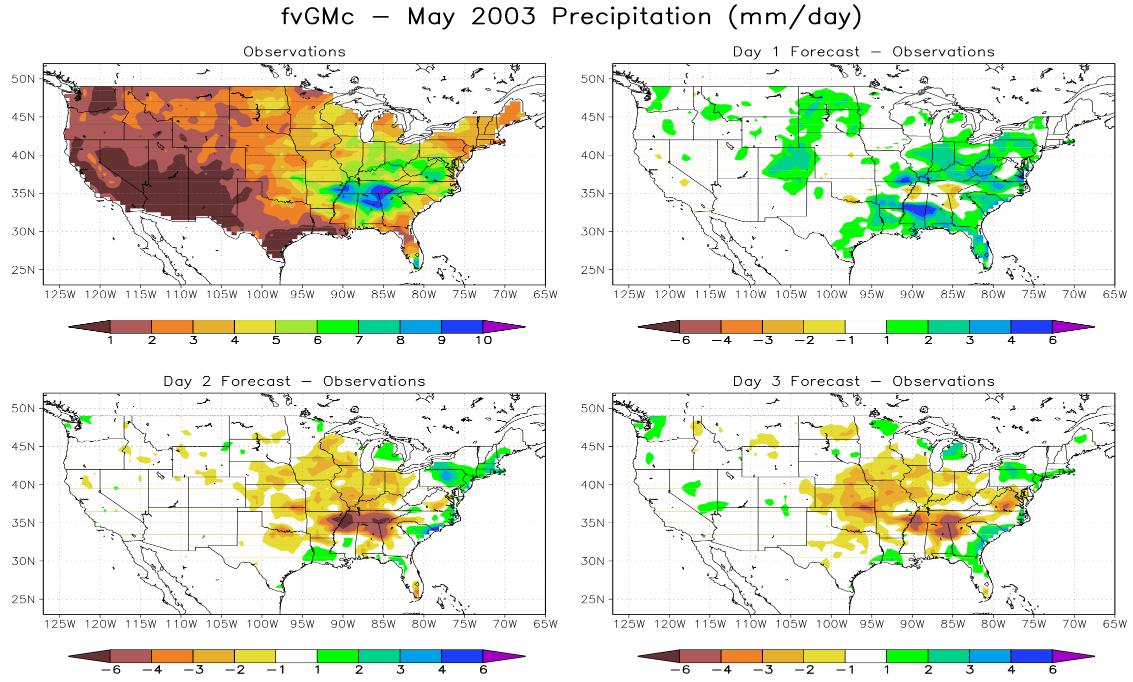

Figure 2: Same as Figure 1, only for fvGMc.

Climate Prediction Center (CPC) website. As these observations were from 12Z to 12Z, the model daily averages were also made for the same period. A mask was applied over the data to focus the analysis over only the continental United States.

Monthly time-lagged forecasts were produced with the data for each month by averaging the entire month using the first through ninth day of each forecast, respectively. This can be viewed as an ensemble of 31 (30) forecasts for May (June) with each average having one through nine day lead-time. Comparison of key fields with the observations will delineate the forecast skills of the two model versions.

4. RESULTS

Figure 1 shows the monthly precipitation for May 2003 from CPC in the upper left panel. Very high rain amounts were observed in the Southeast into the Mid-Atlantic. The upper right panel shows the difference between the average Day 1 lead-time forecast from the fvGCM and the observations. In the first day, the model tended to produce more rainfall than the observed, especially along the Gulf Coast and Front Range. The Day 2 lead-time forecast for May (lower left) shows that the model was too dry in the Southeast to Midwest, while too wet in the Mid-Atlantic to Northeast. For the Day 3 forecast (lower right), the fvGCM continued to under-predict the heavy precipitation in the Southeast and over-predict in a small area of the Mid-Atlantic.

Figure 2 shows the same plots, only for the fvGMc. The general trends in the precipitation errors remain the same as in Figure 1. However, the magnitudes of the errors appear to be less in the case with fvGMc than for fvGCM for May.

For Days 4 through 9 (not shown), the extent of the precipitation errors continues to be similar in both cases. Starting with Day 4, the under-prediction in the Southeast has slightly spread into the Mid-Atlantic, while by Day 7 the over-prediction in the Northeast has turned into a slight under-prediction. By Day 5 and beyond, small regions of over-prediction have appeared in the coastal areas of the Northwest and Gulf Coast. Similar results were found (not shown) for June 2003, with a Day 1 over-prediction of precipitation turning into, by Day 3 and beyond, an under-prediction of precipitation especially in the Southeast into the Mid-Atlantic. This type of analysis highlights model deficiencies more succinctly than a climate simulation.

The anomaly correlation for the continental United States, which was computed to quantify the results from the two cases, was calculated in the following manner. The anomaly in the observations (observed 2003 values minus observed climatology from GPCP) was multiplied by the anomaly of the model (simulated 2003 values minus simulated model climatology) for each grid point and summed up over all land points of the U.S. The sum was divided by the standard deviation (σ) of the observation (O) anomaly times the standard deviation of the simulated model (M) anomaly. This results in a single anomaly correlation (AC_ψ) value for each day lead-time forecast:

$$AC_\psi = \frac{\Sigma_{i,j}\left[\left(\psi_{O_{i,j}} - \overline{\psi_{O_{i,j}}}\right)\left(\psi_{M_{i,j}} - \overline{\psi_{M_{i,j}}}\right)\right]}{\sigma_O \sigma_M}$$

where the overbar represents the climatology (long-term mean) of a field ψ, and i, j is for each land point in the continental United States.

The anomaly correlation has been used in a number of model evaluations (e.g., Hollingsworth *et al.*, 1980; Kalnay *et al.*, 1990). The AC does a good job in measuring the linear association between two fields (Stensrud and Wandishin, 2000), while ignoring biases and errors in scale (Murphy and Epstein, 1989). Hollingsworth *et al.* (1980) suggested that for "useful" medium-range forecasts an AC value of 0.6 should be used as a lower limit, although that is a tough standard for rainfall.

Figure 3 shows the AC of precipitation for May and June 2003, for both models and for the first 9 days of lead-time. In both months, the AC in the fvGMc case is higher than for the fvGCM case for the first 5 days of the forecast, indicating a better

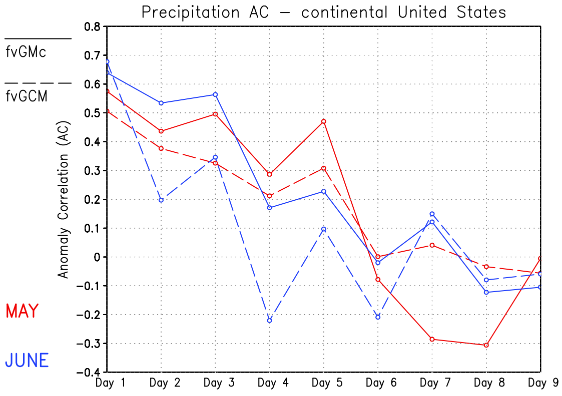

Figure 3: Anomaly correlation of precipitation over the continental United States for May (red) and June (blue) 2003 for both cases, fvGCM (dashed line) and fvGMc (solid line).

relative quality of the fvGMc precipitation forecast. By Day 6 and beyond, the AC of precipitation for both cases is well below 0.1.

The sea-level pressure and 500 hPa and 300 hPa heights were also examined. For these variables, the "observed" values used for 2003 correspond to Day 1 states of the real-time fvGCM reanalysis and for the climatology correspond to the GEOS-1 15-year reanalysis. Figure 4 shows the anomaly correlation of the sea-level pressure (SLP) over the U.S. In May, the fvGMc case has a higher AC than the fvGCM case for all 9 days of lead-time, although by Day 6, the AC drops for both cases. In June, however, the fvGCM case has a higher AC than the fvGMc case for the first 6 days of the forecast.

Figure 5 shows the anomaly correlation of the 500 hPa heights over the U.S. In both months, the fvGCM case has a higher AC than the fvGMc case for all days of lead-time. In particular, the May AC for 500 hPa heights in fvGMc is rather low even at Day 1. Similar biases dominated the outcome for 300 hPa heights (not shown).

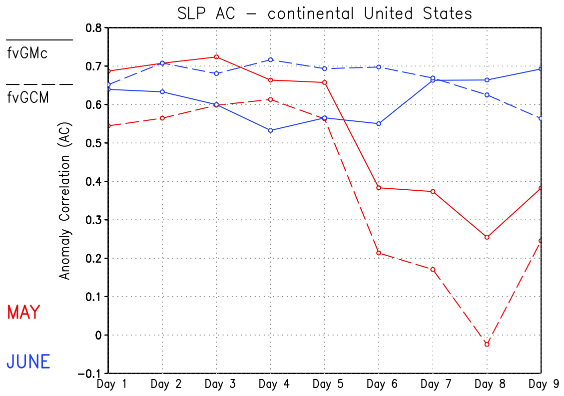

Figure 4: Same as Figure 3, only for SLP.

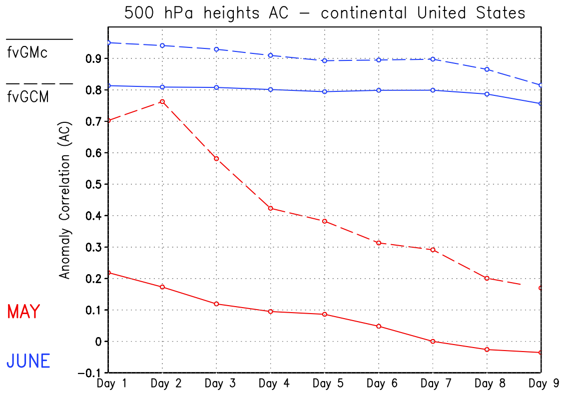

Figure 5: Same as Figure 3, only for 500 hPa heights.

To eliminate the influence of such biases in the height fields of fvGMc, the zonal average of the heights was subtracted instead of the model climatology. Figure 6 shows as an example that removing this bias makes the 500 hPa heights AC for both cases comparable, with the fvGMc being higher for the June simulation.

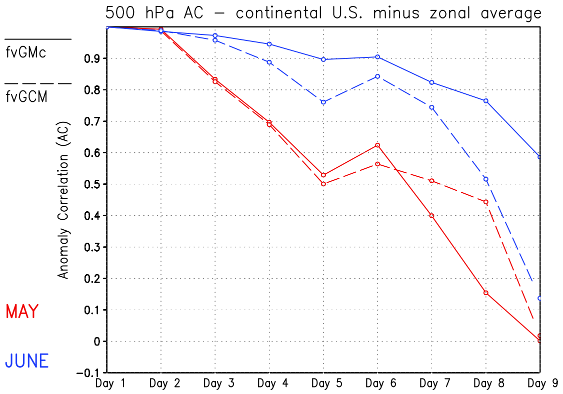

Figure 6: Same as Figure 5, only with the zonal average of the 500 hPa heights removed rather than the climatology in the calculation of the AC.

5. DISCUSSION

Two parallel sets of simulations of daily 10-day forecasts made with the fvGCM (with CCM3 physics) and the fvGMc (with McRAS and updated radiation) were made for May and June 2003. The addition of McRAS and the radiation package has improved the daily forecast of precipitation for these months over the United States. However, the medium-range precipitation forecast biases were similar for both cases, which may be related to initial condition biases or land hydrology, rather than deficiencies in the cloud schemes.

On the other hand, the fvGCM case produced higher anomaly correlations of upper-level heights than the fvGMc. This was related to cloud-radiative biases of the fvGMc, which produces biased warming in the upper-levels of the summer hemisphere. Most radiation schemes have such biases because of cloud-physics deficiencies; however, their optical properties are adjusted in a tuning mode to get the best possible radiative forcing of the column atmosphere. This exercise was not performed in the fvGMc case because its cloud-radiative forcing was based on a McFarquhar (2001) scheme based on zonal departures of an analysis of observations. Subtracting the zonal averages in fvGMc gave a similar performance of AC of upper-level heights as for fvGCM. It is evident that objective assessment of a new parameterization is better achieved in this evaluation instead of a comparison of straight climate simulations.

This work is a precursor to understanding the role of soil moisture in maintaining the circulation pattern and persistent rainfall anomalies of the spring of 2003. This work will enable us to choose an appropriate cloud scheme for assessing the role of initial soil moistures on the circulation patterns and rainfall amounts. Some key aspects of the influence of soil moisture and land-atmosphere interactions on the simulated climate of North America will be investigated.

This methodology will continue to be used to evaluate future upgrades to McRAS and other model physics. This extended range weather-mode evaluation is vital for developing a climate model because clouds, which are central to climate change, are dependent on weather and its dynamics. Consequently, a better cloud simulation requires a more accurate background weather simulation as well as a better cloud model. Indeed, through interactive feedback, improved weather and precipitation forecasts are an expected outcome of an improved model physics (such as cloud physics) scheme.

Acknowledgments. The authors wish to thank T. Lee of NASA HQ for encouraging this research. G. K. Walker and B. Shen are thanked for their assistance with the fvGCM.

REFERENCES

Chou, M.-D., K.-T. Lee, S.-C. Tsay, and Q. Fu, 1999: Parameterization of cloud longwave scattering for use in atmospheric models. *J. Climate,* **12**(1), 159–169.

Chou, M.-D., and M. J. Suarez, 1994: An efficient thermal infrared radiation parameterization for use in general circulation models. 104606, NASA Technical Memorandum. Volume 3, 102 pp.

Chou, M.-D., M. J. Suarez, C.-H. Ho, M.-H. Yan, and K.-T. Lee, 1998: Parameterizations for cloud overlapping and shortwave single scattering properties for use in general circulation and cloud ensemble models. *J. Climate,* **11**(2), 202–214.

Hollingsworth, A., K. Arpe, M. Tiedtke, M. Capaldo, and H. Savijärvi, 1980: The performance of a medium-range forecast model in winter - Impact of physical parameterizations. *Mon. Wea. Rev.,* **108**(11), 1736–1773.

Hurrell, J. W., J. J. Hack, B. A. Boville, D. L. Williamson, and J. T. Kiehl, 1997: The dynamical simulation of the NCAR Community Climate Model version 3 (CCM3). *J. Climate,* **11**(6), 1207–1236.

Kalnay, E., M. Kanamitsu, and W. E. Baker, 1990: Global numerical weather prediction at the National Meteorological Center. *Bull. Amer. Meteor. Soc.,* **71**(10), 1410–1428.

Lin, S.-J., 2004: A vertically Lagrangian finite volume dynamical core for global models. *Mon. Wea. Rev.,*, in revisions.

Lin, S.-J., and R. B. Rood, 1996: Multidimensional flux-form semi-Lagrangian transport schemes. *Mon. Wea. Rev.,* **124**(9), 2046–2070.

McFarquhar, G. M., 2001: Comments on "Parametrization of effective sizes of cirrus-cloud particles and its verification against observations" by Zhian Sun and Lawrie Rikus (October B, 1999, 125, 3037–3055). *Quart. J. Roy. Meteor. Soc.,* **127**(571), 261–265. Part A.

Moorthi, S., and M. J. Suarez, 1992: Relaxed Arakawa-Schubert: A parameterization of moist convection for general circulation models. *Mon. Wea. Rev.,* **120**(6), 978–1002.

Murphy, A. H., and E. S. Epstein, 1989: Skill scores and correlation coefficients in model verification. *Mon. Wea. Rev.,* **117**(3), 572–581.

Stensrud, D. J., and M. S. Wandishin, 2000: The correspondence ratio in forecast evaluation. *Wea. Forecasting,* **15**(5), 593–602.

Sud, Y. C., and G. K. Walker, 1999: Microphysics of clouds with the Relaxed Arakawa-Schubert cumulus scheme (McRAS). Part I: Design and evaluation with GATE Phase III data. *J. Atmos. Sci.,* **56**(18), 3196–3220.

Sud, Y. C., and G. K. Walker, 2003: Influence of ice-phase physics of hydrometeors on moist-convection. *Geophys. Res. Let.,* **30**(14), 1758. doi:10.1029/2003GL017587.