The First Semiannual Report of the Project Entitled "Physics-Based Ensemble Generation in the Global Forecast System (GFS)"

Prepared for:

Zoltan Toth
Environmental Modeling Center
NOAA/NWS/NCEP
5200 Auth Rd., Rm. 207
Camp Springs, MD 20746

Prepared by:

Jian-Wen Bao, Evelyn D. Grell, Georg A. Grell

NOAA/Earth System Research Laboratory

325 Broadway, Boulder, CO

(in cooperation with Dr. Jeff Whitaker at NOAA/ESRL)

Submitted on January 15, 2008

Table of Contents

1. EXECUTIVE SUMMARY ………………………………………………………………………. 1

2. INTRODUCTION ……………………………………………………………………....... 2

3. MODEL SETUP AND AN OVERVIEW OF THE G-D SCHEME ………………….......... 2

4. PRELIMINARY RESULTS …….….…..……………………………………..…………. 3

5. SUMMARY AND CONCLUSIONS ……………………….…………….………....... 12

6. REFERENCES ………………………………………………………….……….......... 13

1. EXECUTIVE SUMMARY

This report summarizes the progress in the first six months of a project sponsored by the USWRP THORPEX Program, in which the convective parameterization scheme developed by Grell and Devenyi (2002) is implemented and tested in the GFS model. The implementation of the G-D scheme will provide proxy realizations of global convective activities in addition to those simulated by the standard operational convective parameterization scheme. Experimental runs of the model with the scheme have been carried out for a 5-day forecast experiment. The preliminary results indicate that the G-D scheme can be adjusted to produce a similar precipitation distribution to that produced using the standard scheme in the GFS model. The spread of the simulated total precipitation rate associated with the various realizations of the G-D scheme tested thus far is encouraging. Further evaluation of the scheme is underway.

2. INTRODUCTION

A project sponsored by the USWRP THORPEX Program is being carried out at NOAA/ESRL/PSD, in which the convective parameterization scheme developed by Grell and Devenyi (2002, hereafter referred to as the G-D scheme) is implemented and tested in the GFS model to assess and represent uncertainties in the parameterization of subgrid convection. The working assumption of this project is that properly perturbing the convective parameterizations will improve the ensemble spread of the model forecast. The unique feature of the G-D scheme is that it uses an ensemble of closures to determine the rainfall rate and the vertical redistribution of heat and moisture at a given time and location. In this project, the G-D scheme is implemented in the GFS model in a way that allows for a series of permutations of various closure assumptions, control parameters and weights for the ensemble average in order to introduce additional spread in the solutions. This modification has been shown to lead to reasonable ensemble spread in regional model simulations/forecasts of precipitation (Bao et al. 2007). The goal of the first 6 months of the project is to demonstrate that the performance of the scheme is comparable to the standard SAS scheme in the GFS model, which is based on Arakawa and Schubert (1974) as simplified by Grell (1993) and modified by Pan and Wu (1994).

The rest of the report is organized as follows: section 3 describes the model setup for the implementation test, section 4 presents the preliminary results and section 5 concludes the report with a summary and discussion.

3. MODEL SETUP AND AN OVERVIEW OF THE G-D SCHEME

For the implementation and testing of the G-D scheme, the GFS model is run in the operational T126L64 setup for 120 hours, initialized at 1200UTC on 8 May 2007. The model code was adapted and maintained on the ESRL supercomputer (wJet) by Dr. Jeffrey Whitaker. For comparison purposes, a control run was performed using a typical GFS setup with the SAS convective parameterization and grid-scale condensation based on Zhao and Carr (1997)

The standard application of the G-D scheme uses an average of 144 ensemble members to represent realizable convection at a given time and location. There are five basic closure methods in the G-D scheme for calculating the cloud base mass flux, a critical closure parameter.

These five closure methods are summarized in Table 1, which shows that along with the added permutations to the closure methods, a total of 16 basic ensemble members can be generated. It is important to point out that in principle any one of these 16 members can be run individually, resulting in a possible solution of the model. It is also worth noting that this creation of ensemble members is not unique because there are other control parameters with uncertainties that can be permuted with each of the 16 basic members, each of which leads to a possible solution of the model.

In the implementation of the G-D scheme in the GFS model, three controlling parameters are allowed to permute with the 16 basic members when convection is occurring at a given time and location: (i) the strength of the downdraft, (ii) the depth of the capping inversion (two basic parameters of the cloud properties), and (iii) the upper bound of the capping inversion. Each of the three parameters is permitted three possible realizations respectively. Each of these realizations interacts with the 16 closure possibilities, giving a total of 432 (16×3×3×3) possible realizations of convection at a given time and location. Since the current application of the G-D scheme in the GFS model is to estimate the spread of possible individual solutions of the GFS model due to the uncertainties in the sub-grid convection physics, initial experiments were carried out to explore the use of one of the above controlling parameters for generating ensemble solutions of the GFS model.

In all the experimental runs shown in this report, an average is computed from an ensemble of 144 members to describe realizable convection at a given time and location. The total 144 members result from permuting the 16 basic ensemble members with 3 possible strengths of the downdraft and 3 possible depths of the capping inversion (i.e., 16×3×3 = 144). This allows 3 possible solutions of the GFS model corresponding to 3 possible values for the upper bound of the capping inversion. The next step of the project is to evaluate the effectiveness of other control parameters in generating a sufficient envelope of possible solutions in the GFS system.

4. PRELIMINARY RESULTS

In this report, the distribution of 3-h precipitation rates between 60°S and 60°N valid at 24 h (1 day) and 120 h (5 days) into the forecast are used to highlight the performance of the

Table 1: Closure options in the G-D scheme

Ensemble member	**Closure**	**Permutations**
1-3	Change of stability through effects other than convection (Grell, 1993)	+/- 10%
4-6	Vertical motion dependent (Frank and Cohen, 1987)	W(LCL), w(LFC), max(w(1:LFC))
7-9	Integrated vertical advection of moisture (Krishnamurti et al., 1983)	Vary moistening parameter (b=0, b=β, b=0.5*β), where β=precip. efficiency
10-12	Instability removal (Kain and Fritsch, 1992)	dt = 20,30,40 minutes
13-16	Change of stability (as in the original GFS scheme)	Adjusts to different climatological values of cloud work function

G-D scheme in the GFS model. Figures 1 and 2 are the 3-h average total and convective precipitation rates valid at 24 h into the forecast from the control forecast run and 3 ensemble forecast runs corresponding to 3 different realizations of the maximum depth of the capping inversion (i.e., capmax = 75, 125 and 175 mb). Figures 3 and 4 show the 3-h average total and convective precipitation rates at 120h. It is seen that the tropical precipitation (between 20°S and 20°N) is dominated by convective precipitation, while in higher latitudes, grid scale-precipitation is more prominent. The precipitation associated with extratropical cyclone systems has a noticeable contribution from sub-grid convection. Comparisons of these figures indicate that the capping inversion is indeed an effective parameter to generate ensemble solutions spread around the control solution.

This encouraging result can be further confirmed though Figs. 5-7 that depict time series of 3-h average total precipitation rate in the tropical and extratropical latitudinal strips for the 4 different runs discussed above (i.e., the control run with the standard operational convective scheme and the 3 runs with the G-D scheme in which capmax = 75, 125 and 175 mb). It is interesting to note that the differences made by the various schemes are the greatest during the first 12 h into the forecast, possibly related to the initial dynamical adjustment for the model to

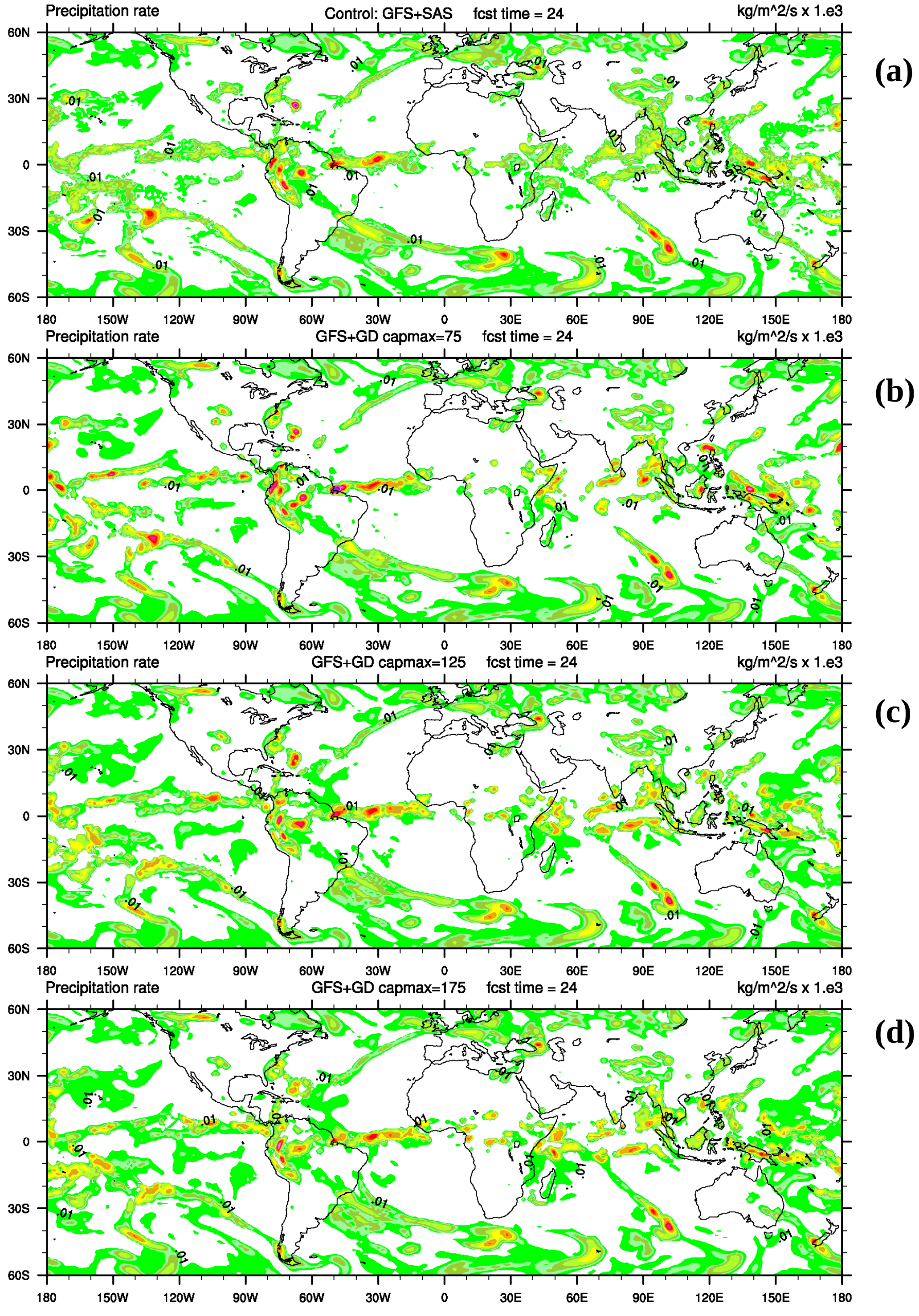

Figure 1: Distributions of 3-h average total precipitation rate (equivalent to mm/s) valid at 24 h into the forecast from the 4 forecast runs. (a) is for the control run, and (b)-(d) are for the runs with capmax = 75, 125 and 175 mb, respectively.

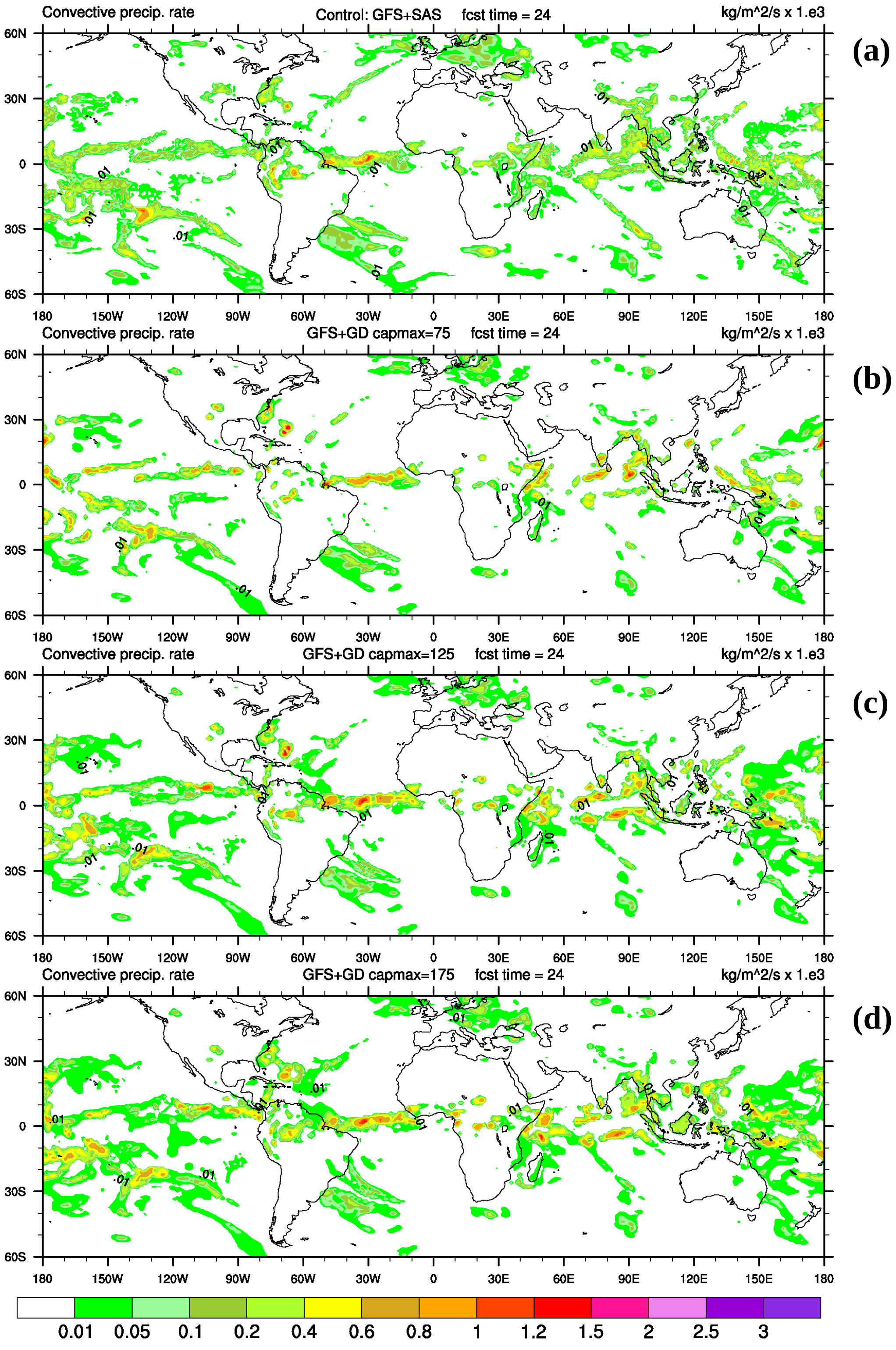

Figure 2: Same as Fig. 1, except for the convective precipitation rate.

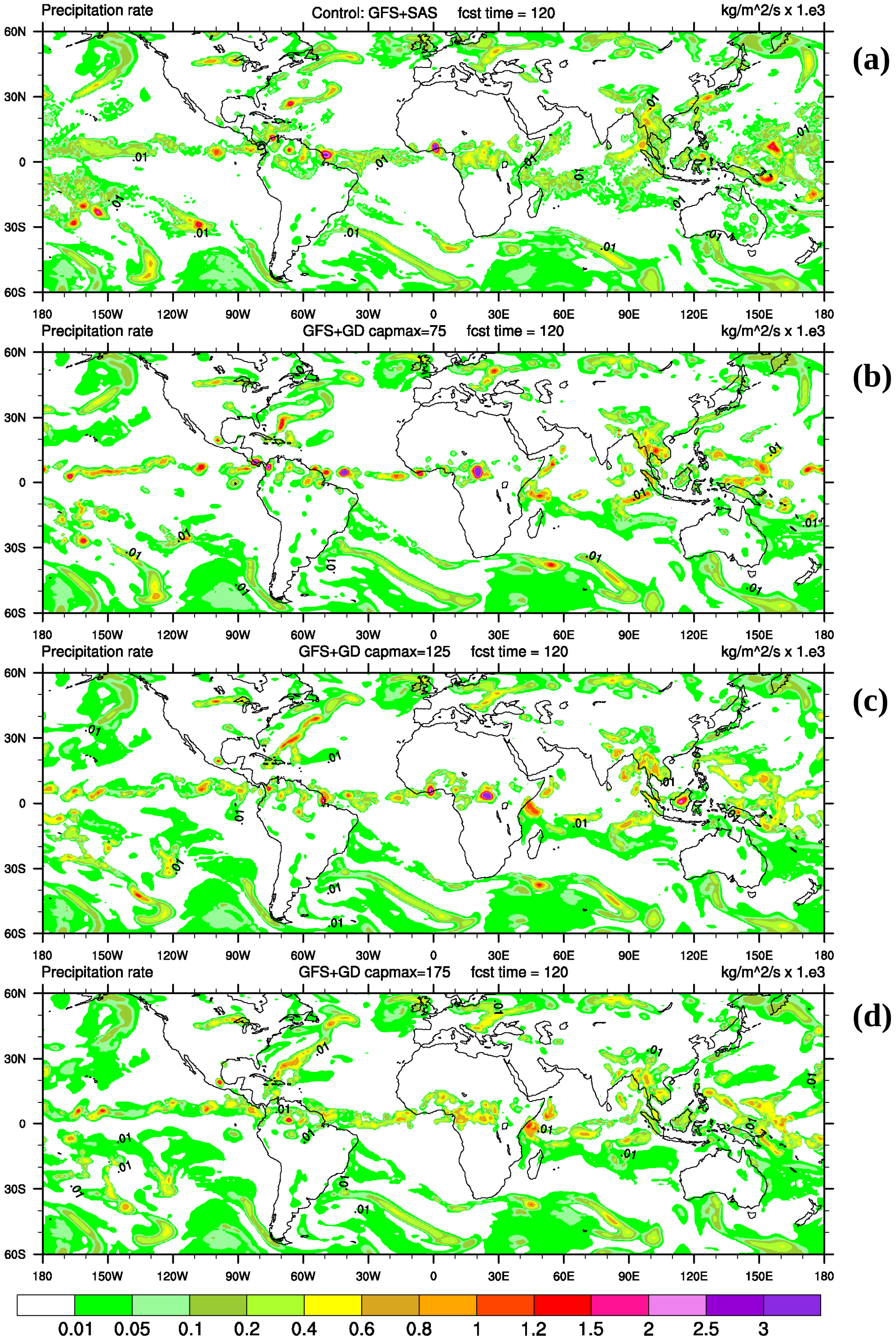

Figure 3: Distributions of 3-h average total precipitation rate (equivalent to mm/s) valid at 120 h into the forecast from the 4 forecast runs. (a) is for the control run, and (b)-(d) are for the runs with capmax = 75, 125 and 175 mb, respectively.

.

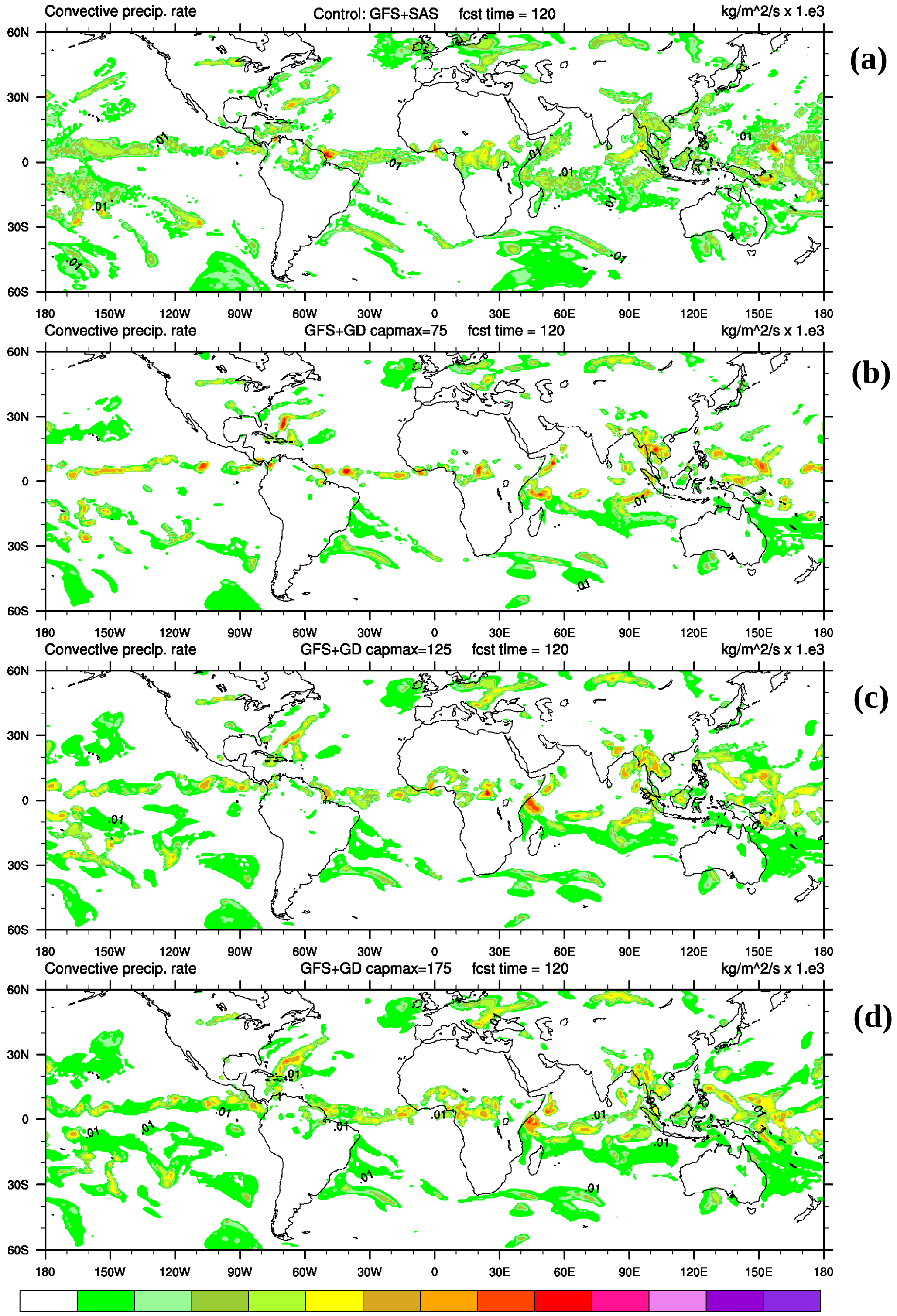

Figure 4: Same as Fig. 3, except for the convective precipitation rate.

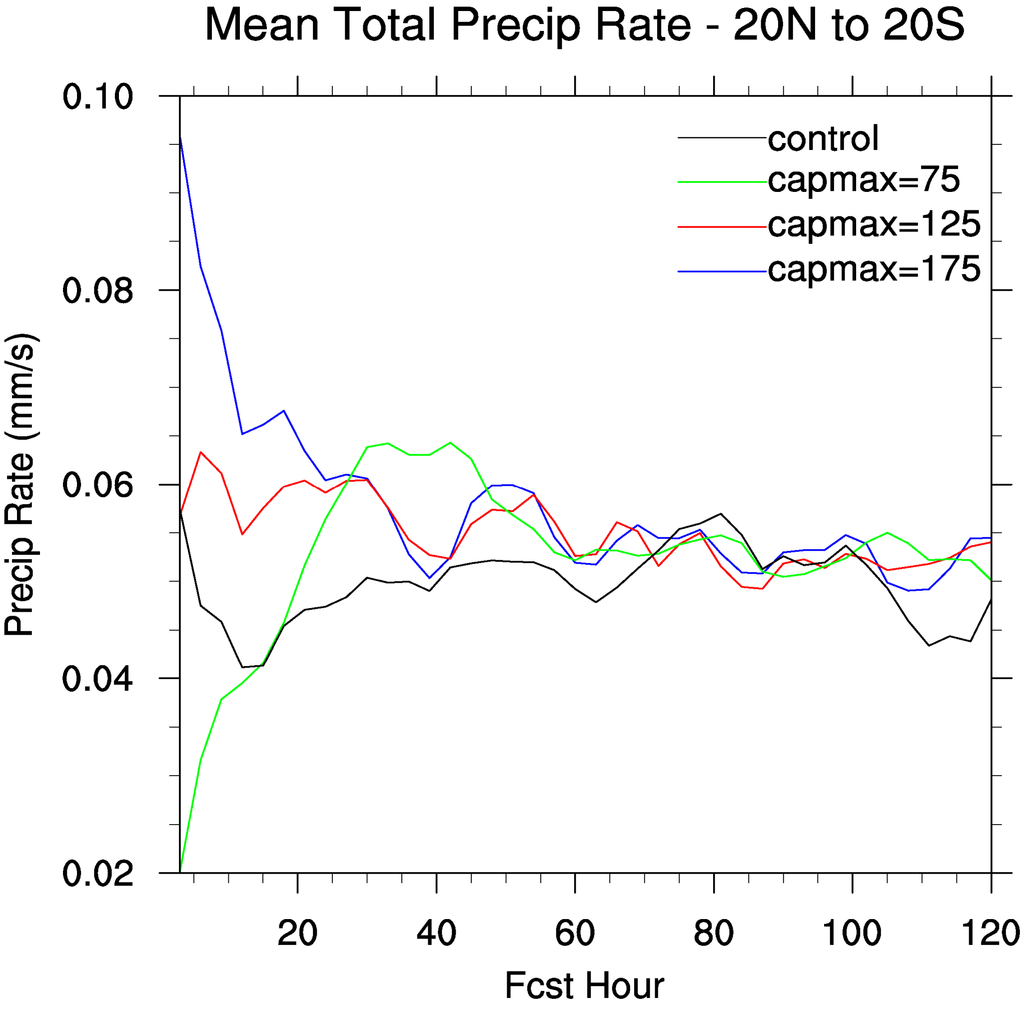

Figure 5: Time series of 3h average total precipitation rate in the latitudinal strip between 20°S and 20°N for the 4 different runs discussed in the report. The black curve, labeled "control", is for the standard GFS convective parameterization scheme. The blue, red and green curves are gfs runs using the Grell-Devenyi (2002) ensemble convective parameterization with a particular cloud property control (capmax) varied. Each of the colored curves represents a mean of a 144-member ensemble within the framework of the convective parameterization.

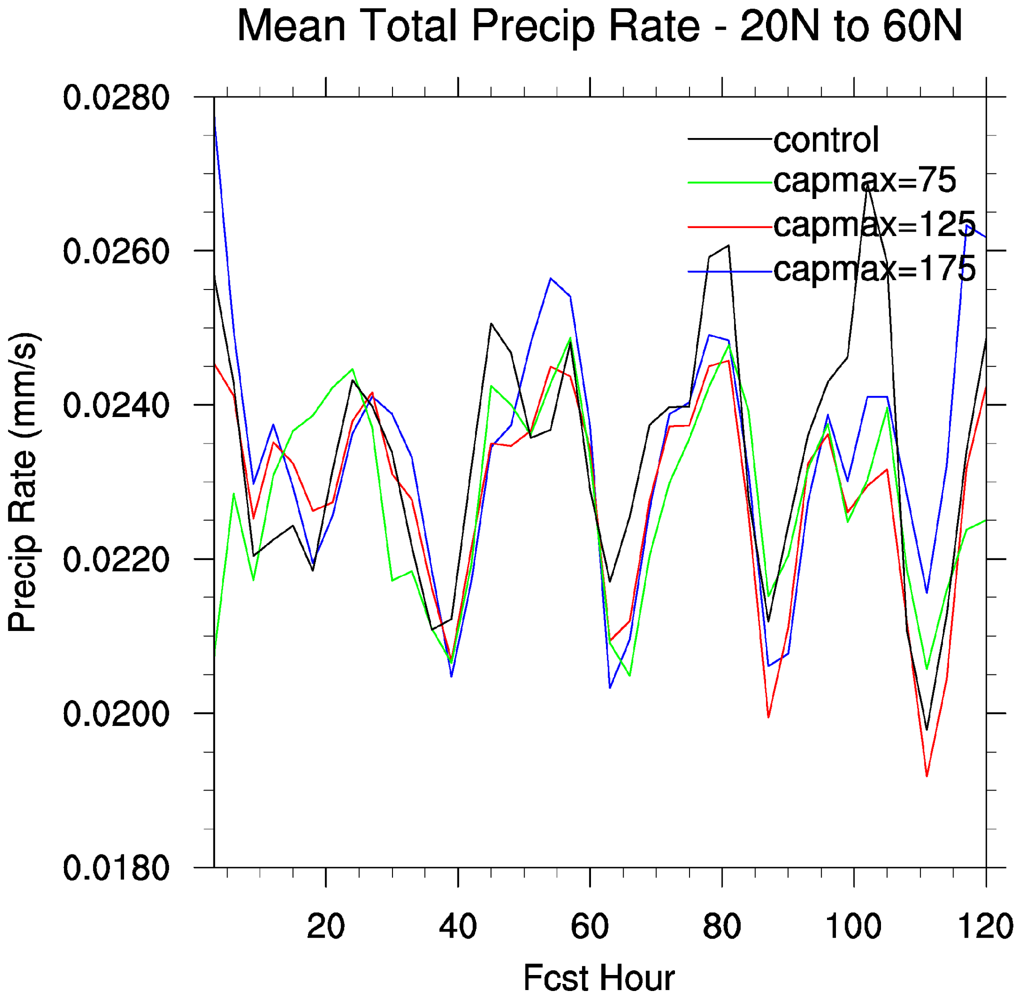

Figure 6: The same as Fig. 5, except for the latitudinal strip between 20°N and 60°N.

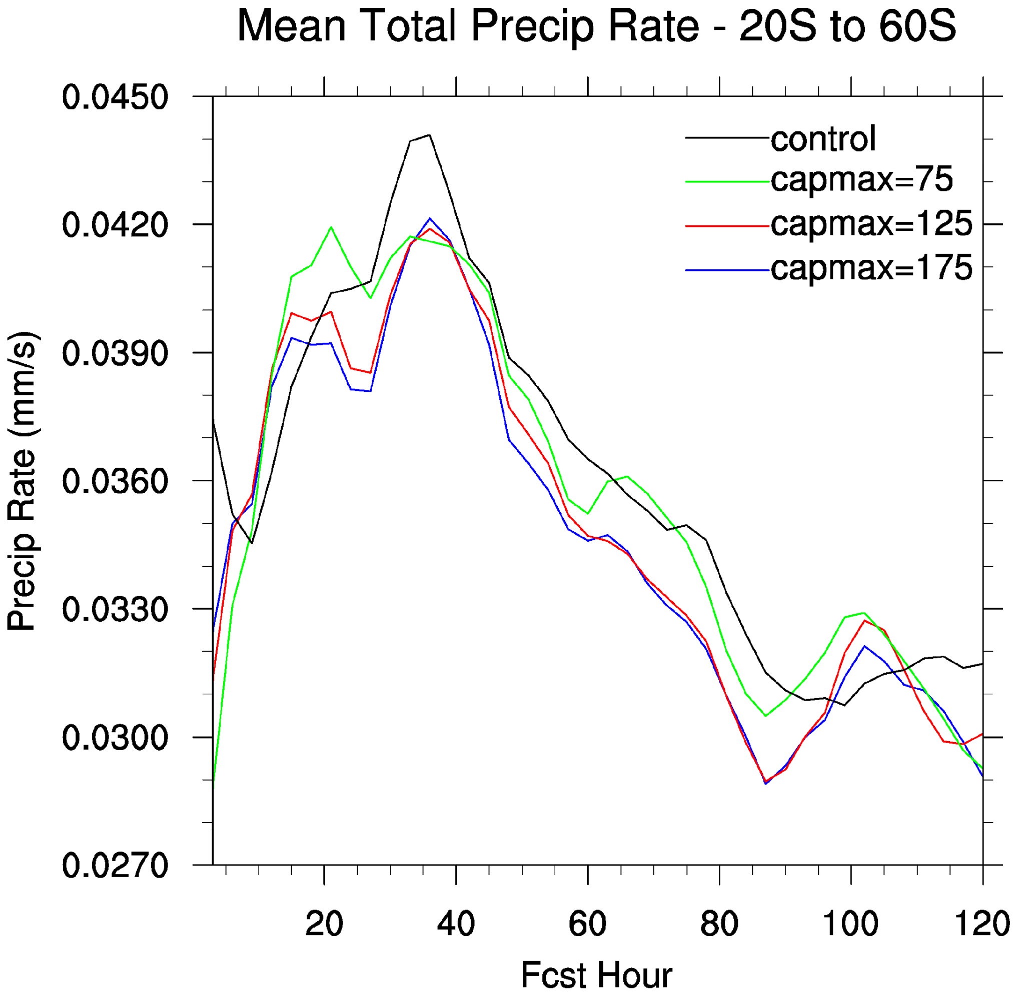

Figure 7: The same as Fig. 6, except for the latitudinal strip between 20°S and 60°S.

reach mass-wind consistency.

It should be pointed out that with capmax = 75mb, the model tends to produce less convective precipitation and more grid-scale precipitation, while the run with capmax = 175 has more convective precipitation and less grid-scale precipitation. It is worth noting that none of the 3 experimental solutions is identical to the control results. However, it is not the intention of this project to reproduce the precise precipitation pattern of the control run. Rather, the range of possible solutions, as demonstrated by varying one sensitive parameter, generally brackets the control results (Figs. 5-7), indicating similar performance in terms of precipitation. Evaluation of additional model parameters is underway.

5. SUMMARY AND CONCLUSIONS

This report presents the results from the first six months of our USWRP THORPEX project in which in which the G-D scheme is implemented and tested in the GFS model. The implementation of the G-D scheme will provide proxy realizations of global convective activities in addition to those simulated by the standard operational convective parameterization scheme. Experimental runs of the model with the scheme have been carried out for a 5-day forecast experiment, indicating that the G-D scheme can be adjusted to produce a similar precipitation distribution to that from using the standard scheme in the GFS model. The spread of the forecast total precipitation associated with the various realizations of sub-grid convection modeled by the G-D scheme is encouraging. The preliminary results suggest the following:

1. The GFS version of the G-D scheme is an effective alternative to representing the uncertainties in the physics of sub-grid convection parameterization.

2. The effect of the G-D scheme in the generation of the total precipitation rate is comparable on average to that with the standard operational convective parameterization scheme.

3. Adjusting the spread of the total precipitation using the metric of averaged precipitation rate can be straightforward.

While the results from the experimental runs are encouraging, further evaluation of the G-D scheme over a longer time period is required. Further comparisons with both standard GFS output and with observations will be made in cooperation with our colleagues at NCEP and ESRL. The remaining objective of the project is to systematically evaluate the effectiveness of using the G-FD scheme to generate ensemble solutions in the operational GFS-based ensemble prediction system.

6. REFERENCES

Arakawa, A., and W. H. Schubert, 1974: Interaction of a cumulus cloud ensemble with the large scale environment, Part I. *J. Atmos. Sci.*, 31, 674– 701, 1974.

Bao, J.-W., E. D. Grell, G. A. Grell and S. A. Michelson, 2007**:** Application of the Grell-Devenyi convective parameterization in ensemble QPFs. Preprints, *The 8th WRF Users' Workshop*, June 11 - 15, 2007, Boulder, Colorado.

Frank, W.M., and C. Cohen, 1987: Simulation of tropical convective systems. Part I: A cumulus parameterization. *J. Atmos. Sci*., **44**, 3787-3799.

Grell, G. A., and D. Devenyi, 2002: A generalized approach to parameterizing convection combining ensemble and data assimilation techniques. *Geophys. Res. Lett*., 29(14), Article 1693.

Grell, G., 1993: Prognostic evaluation of assumptions used by cumulus parameterizations. *Mon. Wea. Rev.*, **121**, 764– 787.

Kain, J. S., and J. M. Fritsch, 1992: The role of the convective “trigger function” in numerical forecasts of mesoscale convective systems. *Meteorol. Atmos. Phys*., **49**, 93-106.

Krishnamurti, T. N., S. Low-Nam, and R. J. Pasch, 1983: Cumulus parameterization and rainfall rates II. *Mon. Wea. Rev*., **111**, 815-828.

Pan, H.-L., and W.-S. Wu, 1994: Implementing a mass-flux convective parameterization package for the NMC Medium Range Forecast Model. Preprints, *The 10th Conf. on Numerical Weather Prediction,* Portland, OR, Amer. Meteor. Soc., 96–98.

Zhao, Q., and F. Carr, 1997: A prognostic cloud scheme for operational NWP models. *Mon. Wea. Rev*., **125**, 1931-1953.