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Sensitivity of the Indian summer monsoon rainfall and its interannual variation to model time step

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ABSTRACT

The sensitivity of the Indian summer monsoon rainfall (ISMR) and its interannual variation (IAV) to model time step is investigated using NCAR-Community Atmosphere Model version 3 (CAM3). A set of multiyear numerical experiments is performed using the atmospheric model inter-comparison project (AMIP) protocol with observed sea surface temperature (SST). The default value of time step for 64×128 horizontal resolution with semi-Lagrangian dynamical core is 60 min. The model overestimates the mean and underestimates the standard deviation. The mean and standard deviation of ISMR systematically decrease with decrease of time step size. With respect to observations, the mean becomes more reasonable but standard deviation becomes less reasonable. There is a decrease in precipitation over the Saudi Arabia, Maritime Continent, and northwestern Arabian Sea with decrease in time step, while over the Eastern Indian Ocean, Eastern Arabian Sea, and Eastern Bay of Bengal there is an increase in precipitation. The pattern correlation of precipitation with observation systematically increases with decrease of time step. In regard to the IAV of ISMR, simulation with 20 min time step outperforms the other time steps i.e. 60, 40, 30, and 05 min. When it is decreased to 20 min, the model bias in precipitation climatology is reduced and the low-level westerly jet over the Indian peninsular becomes more realistic. There is an overall improvement in the climatology of rainfall and winds in the vicinity of Indian summer monsoon region with 20 min time step.

1. Introduction

The vegetation, economy, and society across the Indian sub-continent are all critically influenced by the evolution and variability of the Indian summer monsoon (June–September). Therefore it is important to simulate and understand this phenomenon satisfactorily. The low-frequency component of the Indian monsoon variability is primarily influenced by the boundary conditions such as sea surface temperature (SST), soil moisture, and Eurasian snow cover (Hahn and Shukla, 1976; Shukla and Mintz, 1982; Rasmusson and Carpenter, 1983; Lau, 1985; Latif et al., 1990; Webster and Yang, 1992; Goswami, 1994). Charney and Shukla (1981) pointed out that the seasonal mean circulation in the tropics may be potentially predictable as the low frequency component is primarily forced by the slowly varying boundary conditions. This hinted that long-range dynamic prediction of Indian summer monsoon one or two seasons in advance might be possible. In the last decade, many studies have tried to simulate the interannual variation (IAV) of the Indian summer monsoon (Palmer et al., 1992; Zwiers, 1993; Chen and Yen, 1994; Sperber and Palmer, 1996; Goswami, 1998). The basic features of monsoon circulation have been reproduced reasonably, however the monsoon rainfall and its variability have not been satisfactorily simulated (Zhou and Li, 2002; Kang et al., 2002). Modeling studies have showed that the IAV of Indian monsoon is sensitive to model components, spatial resolutions, and initial conditions (Giorgi and Mearns, 1991; Sperber et al., 1994; Sperber and Palmer,

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1996; Palmer and Anderson, 1994; Brankovic and Palmer, 1994). However its sensitivity to temporal resolution (time step size) is unknown so far.

The dynamical core governs the time step size based on the Courant–Friedrichs–Lewy (CFL) criterion (Courant et al., 1967) for numerical integrations. The longer the time step size the lesser is the computational cost for simulation. The general rule of CFL criterion is numerical domain of dependence must include the analytical domain of dependence to assure that the numerical scheme can access the information required to form the solution. In the past decades, several dynamical cores have been developed to increase the computational efficiency of models. This is achieved by lengthening the maximum permissible time step size. The modeling community prefers to use computationally more efficient numerical schemes with longer time step for their simulations.

In a previous study (Mishra et al., 2008), we showed the effects of time step on model simulation in an aqua-planet configuration. The total rainfall in the inter tropical convergence zone (ITCZ) increases steadily when the model time step is decreased. When time step decreases there is an increase in surface wind speed, this leads to higher surface evaporation over the entire tropics. The higher surface evaporation leads to higher water vapor content, which leads to higher rainfall. It was shown that the impact is robust across various boundary conditions and horizontal resolutions and is independent of the dynamical core.

The model updates the state variables, as shown in Eq. (1), where, n stands for the time instant.

$$(state)^{n+1} = (state)^{n} + (tendency)^{n} time\ step\ size \tag{1}$$

According to the current computational flow, the state variables are updated after computation of each parameterization scheme, and then the updated variables are used for the computation of tendencies in the next parameterization scheme. We showed that the impact of time step originated from the deep convection scheme, which subsequently affected the model solution through non-linear interactions. The root cause and pathway of the impact was explained in Mishra et al. (2008).

This infers that time step is an influential parameter of the model. As mentioned in the beginning, simulation of IAV of the Indian summer monsoon rainfall (ISMR) is important and understanding of its sensitivity to various model components is desirable. Since the sensitivity of the IAV of ISMR to model time step is not yet known, herein the issue has been investigated. For this, a realistic model configuration is used with the actual land–ocean distribution, actual topography, observed sea surface temperature with seasonal cycle and fully interactive physics. The Community Atmosphere Model version 3 (CAM3) is used for the study. CAM3 is a widely used model and simulates various aspects of climate reasonably well (Collins et al., 2006; Hurrell et al., 2006; Hack et al., 2006; Meehl et al., 2006; Rasch et al., 2006). The model and numerical experiment is described in the next section. Section 3 discusses the results and the conclusion follows in Section 4.

2. Model and experiments

We performed a set of simulations using NCAR CAM3. It is a three dimensional global atmospheric model developed by NCAR in collaboration with the atmospheric modeling community. CAM3 has been designed to produce simulations with reasonable accuracy for various dynamical cores and horizontal resolutions. For this study, semi-Lagrangian dynamical (SLD) core was used at 128 × 64 horizontal resolution with 26 vertical levels. The SLD core is a two-time-level, spectral transform applied at T63 truncation on a 128 × 64 linear Gaussian grid with maximum permissible time step size of 60 min. The model uses the hybrid vertical coordinate, which is terrain following at earth's surface, but reduces to pressure coordinate at higher levels near the tropopause. The physical parameterization package consists of moist precipitation processes, clouds and radiation processes, surface processes, and turbulent mixing processes. The moist precipitation processes consist of deep convective, shallow convective and stratiform components. All parameterizations except the radiation parameterization are called during every time step. The frequency of calling the radiation parameterization is one hour and is independent of the time step size used in the dynamical core. For a detailed description of CAM3 refer to Collins et al. (2004).

To identify the impact of time step on the simulation of the IAV of ISMR, two multi-year (1979 to 1995) numerical experiments were performed using the atmospheric model inter-comparison project (AMIP) protocol with observed SST. One simulation was conducted with a time step size of 60 min (SLD60) while the other was conducted with a time step size of 20 min (SLD20). The maximum permissible time step of SLD for the above-mentioned spectral resolution is 60 min. On the other hand, due to the computational cost, we could not use a time step size below 20 min for such long integrations. However, in order to verify the consistency of the effects of time step, we carried out a set of additional simulations with 40, 30, and 05 min time step, with 10 years long each. The model parameters (except the time step) and physics package were same for all the simulations. The initial condition used was generated for 01 January 1979. The model computed and predicted the soil moisture and snow cover.

To understand the underlying mechanism of the impact, similar to the simulations explained above, two more sets of integrations were performed; one set with climatological SST as boundary condition and another with a specified soil moisture condition. In the climatological runs, the cyclic climatological SST (50-year HadISST) was prescribed, which repeats every year. However, snow cover and soil moisture were computed and predicted by the model. The specified moisture runs were similar to the observed SST runs, except with saturated soil moisture everywhere. Supplementary information about the numerical experiments is mentioned in the corresponding places of the following discussion.

3. Results

3.1. Interannual variation of ISMR

Here we discuss the impact of model time step on the Interannual Variation (IAV) of Indian Summer Monsoon Rainfall (ISMR). Time mean (JJAS), area averaged rainfall