Sensitivity of Regional Climate Simulation to Radiation Parameterization

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Purpose

This set of experiments has two primary purposes: 1) to examine the capability of the nonhydrostatic MM5 model in regional climate simulation and 2) to test the sensitivity of regional climate simulation to different radiation parameterizations.

The MM5 Regional Climate Model

The model features were a horizontal grid size of 162 km, 27 vertical levels, the Blackadar planetary boundary layer (PBL) scheme, Grell convective parameterization, a bulk microphysics scheme with ice (Dudhia 1989) on the resolved scale, and nonhydrostatic dynamics. Initial conditions and boundary conditions were from the NMC MRF global analysis. Sea-surface temperature was updated every 8.5 days.

Experiment Design

Two radiation schemes were compared in these tests (Table 1), CCM2 Radiation (Kiehl et al. 1987; Briegleb 1992) from the climate model and MM5 Radiation (Stephens 1978; Chen and Cotton 1988; Dudhia 1989) from the MM5 mesoscale model.

The study was based on two cases, each a month long, in the tropical west Pacific. These cases were 1) 15 December 1992 - 15 January 1993 (tropical ocean global atmosphere [TOGA]-coupled ocean atmosphere response experiment [COARE]) and 2) 1-30 June 1994 (East Asian Monsoon).

There were four month-long simulations and six nine-day test simulations to investigate the impact of various physics parameterizations within the radiative schemes:

- *Set I (month-long simulations)*
  A00: TOGA-COARE, MM5 radiation
  A0: TOGA-COARE, CCM2 radiation
  B00: June 1994, MM5 radiation
  B0: June 1994, CCM2 radiation

- *Set II (nine-day test simulations)*
  A1: as A00 but enhanced cloud and precip path in shortwave and longwave
  B1: as B00 but enhanced cloud and precip path in shortwave and longwave
  B2: as B00 but enhanced cloud and precip path in shortwave only
  B3: as B00 but enhanced cloud and precip path in longwave only
  B4: as B00 but enhanced cloud path only in shortwave and longwave
  B5: as B0, CCM2 radiation without convective cloud fraction

Table 1. Summary of radiative schemes in tests.

Radiation Schemes	MM5	CCM2
LW clear-air	Broadband H_2O emissivity, Overlap for CO_2	Broadband O_3, CO_2, Overlap for H_2O.
LW cloud	LWP from model cloud/precip fields. Cloud fraction 0 or 1.	Cloud fraction from RH. Prescribed LWP.
SW clear-air	Downward broadband integration. H_2O vapor absorption and scattering.	18 spectral intervals. O_3, CO_2, O_2, H_2O gas absorption. Multiple scattering.
SW cloud	Look-up tables for absorption and albedo based on model LWP and zenith angle.	4 spectral ranges. Cloud fraction from RH. Prescribed LWP.

Results: 30-Day Simulations

The results in Figure 1 show that the regional climate in the TOGA-COARE simulation is sensitive to the choice of radiative scheme, and in particular the strength of the mean westerly wind in the 500 km x 1000 km IFA region, which shows a westerly wind burst event, is affected.

Figures 2 and 3 for the June 1994 simulation show that the CCM2 scheme performs better than the MM5 scheme in producing rainfall along the Mei-Yu front and in the strength of the subtropical high.

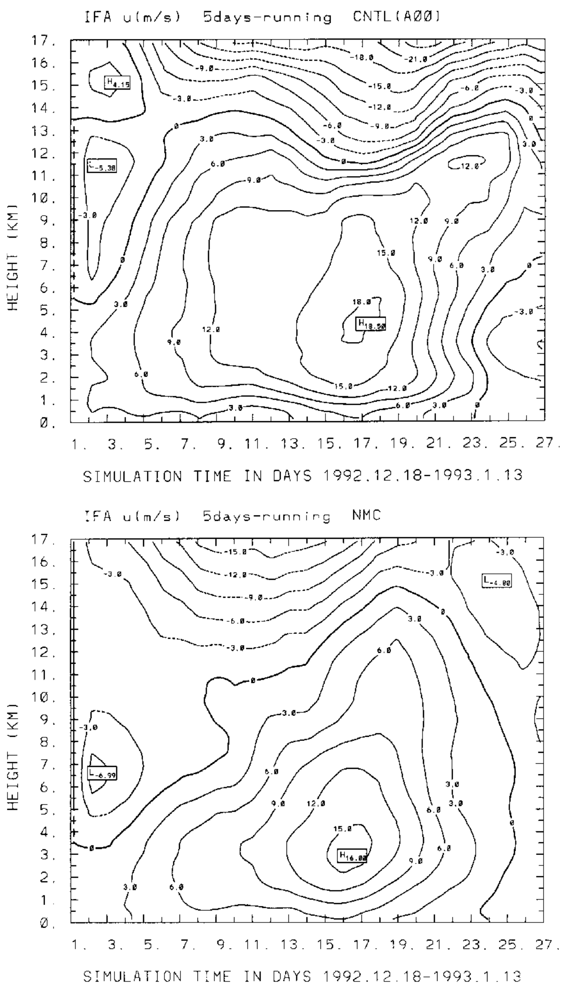

Figure 1. Time-height plot of mean wind speed in IFA region in a) simulation A00 with MM5 radiation and b) NMC analysis with MM5 radiation.

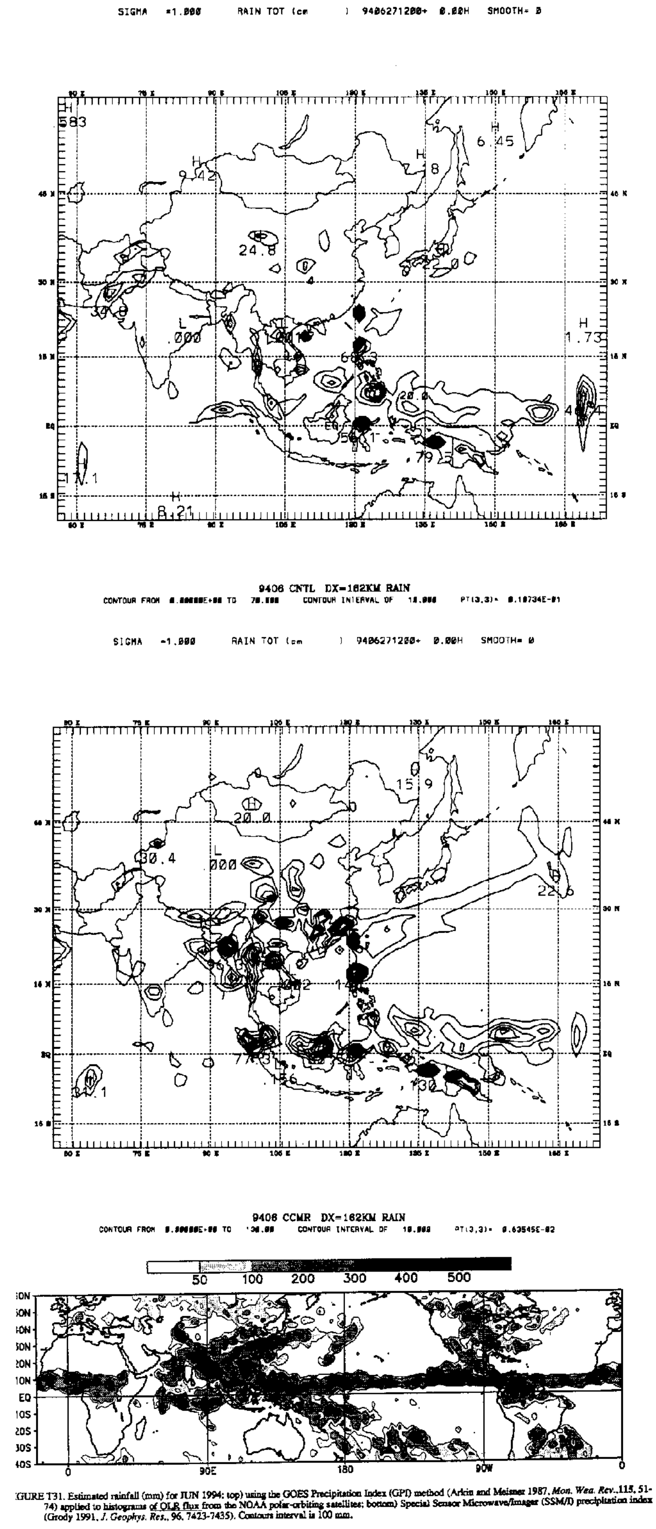

Figure 2. 30-day mean rainfall in a) simulation B00 with MM5 radiation, and b) simulation B00 with CCM2 radiation; c) SSM/I derived precipitation for June 1994.

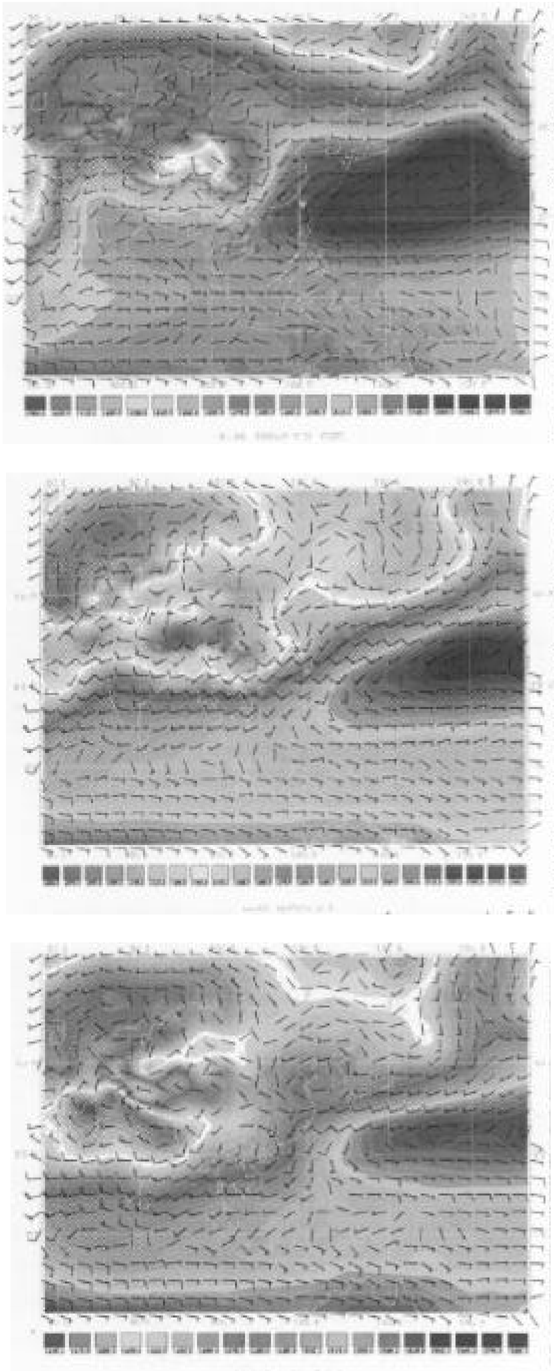

Figure 3. 30-day mean geopotential height at 850 hPa in a) simulation B00 with MM5 radiative scheme, b) simulation B0 with CCM2 radiative scheme, and c) simulation B00 with NMC analysis and MM5 radiative scheme.

This general improvement in behavior with the CCM2 scheme is expected since it is designed for long-term coarse grid scale models, whereas the MM5 radiative scheme is designed for resolved cloud-radiative interactions, and is not normally run at such low resolution. The model microphysics likewise is meant for use on scales at which cloud variations are resolved.

However, it has been found that small modifications to the MM5 radiative scheme give highly improved results and these tests are presented in the next section.

Sensitivity Tests

TOGA-COARE Case

Figure 1 shows that MM5 overpredicts the westerly wind speed in the first 9 days of the simulation. The simulation with the CCM2 scheme (A0) produced results much more similar to the NMC analysis (not shown).

Test A1 (Figure 4), where both shortwave and longwave cloud absorption in the MM5 scheme are enhanced, was

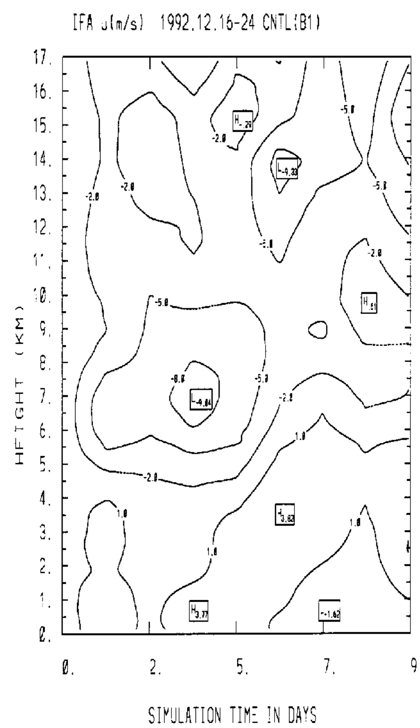

Figure 4. Time-height plot of mean wind speed in IFA region in test case.

also capable of producing the easterlies seen in the first nine days around 7 km, and appeared to perform equally with the CCM2 scheme.

June 1994 Case

Figure 5 shows the geopotential height bias as a function of height and time for the MM5 scheme, CCM2 radiation, and Test B3 for the June 1994 case. This test shows a marked improvement in the MM5 scheme when longwave cloud absorption is enhanced over its default values. However, for reasons that are not yet clear, the test that produced the best temperature bias (Figure 6) was Test B2 which was enhancement of solar absorption by clouds.(a)

Implications

These results are still being investigated in order to find the best way to improve the MM5 scheme for regional climate simulations. It appears that the default scheme has cloud effects on both shortwave and longwave that are too weak. This is possibly due to the uniform-cloud assumption which becomes unrealistic for 162-km grid size. While enhancement of the absorption coefficient seems to work, it is clear that allowing for cloud fractions is a more satisfactory solution. This would require assumptions about grid resolution.

Conclusions

We have made the following conclusions based on this study:

- MM5 is capable of simulating month-long climate.
- The regional climate simulation is very sensitive to different radiation parameterization.
- Cloud optical depth parameterization needs refinement in the MM5 radiation parameterization for it to be used at coarse grid resolution.

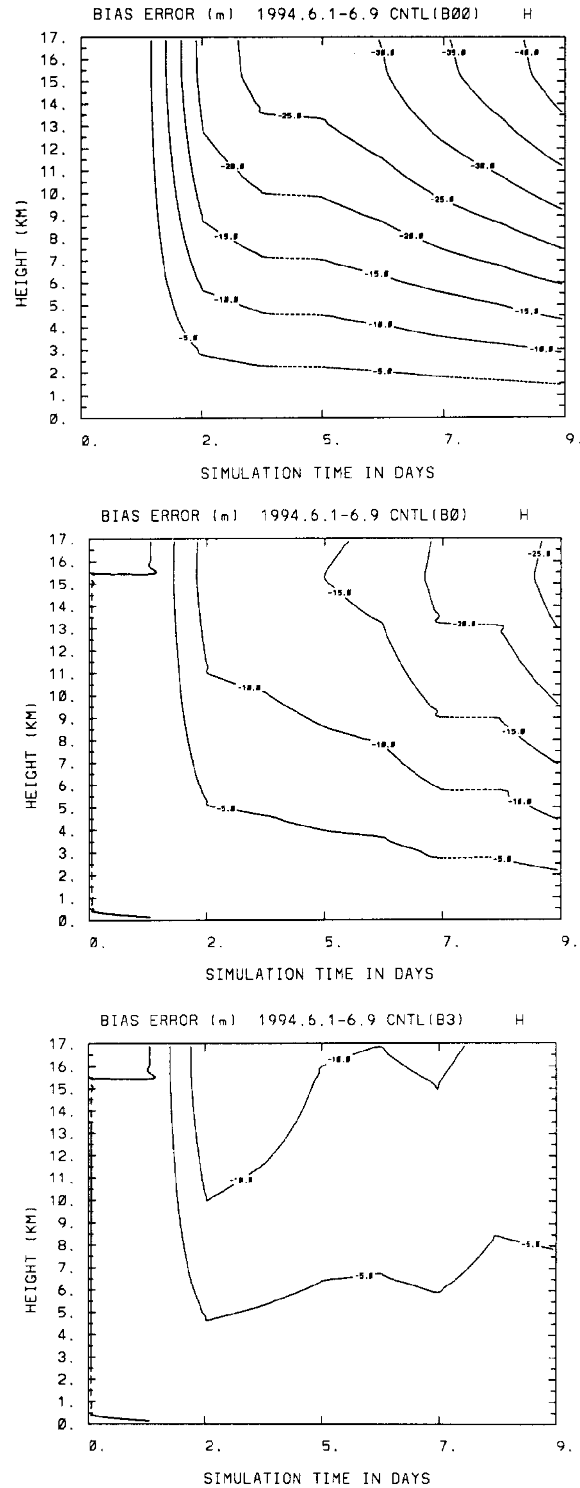

Figure 5. Time-height series of geopotential height bias in June 1994 for a) simulation B00 for MM5 radiative scheme, b) simulation B0 for CCM2 radiative scheme, and c) simulation B3 for MM5 radiative scheme.

(a) Note also that there is a persistent cold bias and also a moist bias (not shown) in the boundary layer. This points to a need for improved surface flux parameterization.

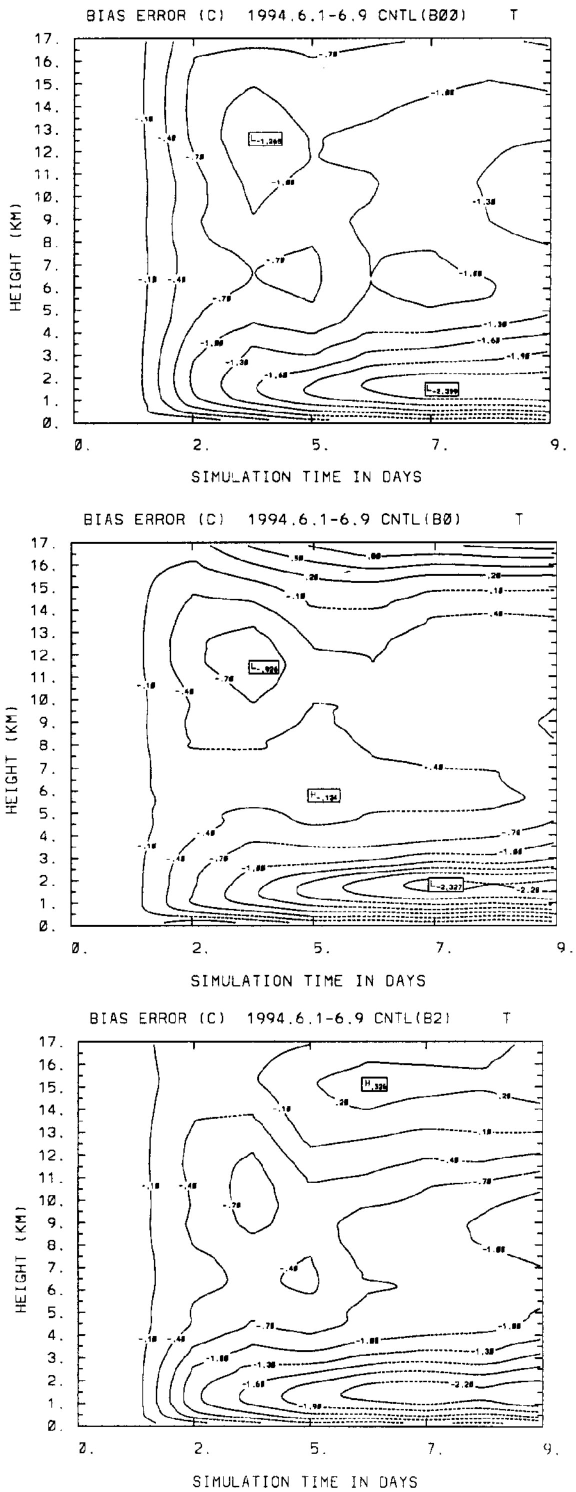

Figure 6. Time-height series of temperature bias in June 1994 simulation for a) simulation B00 for MM5 radiative scheme, b) simulation B0 for CCM2 radiative scheme, and c) simulation B2 for MM5 radiative scheme.

References

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