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A method for estimating the effects of radiative transfer process on precipitation

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ABSTRACT

Radiative transfer process affects precipitation through complicated interactions and numerous processes between radiation, cloud microphysics, dynamical processes and precipitation processes. In this paper, a method is proposed to quantitatively estimate the effects of radiative transfer process on precipitation by defining equivalent radiative cooling/heating, which is combined by radiative cooling/heating and the vertical velocity variation ascribed to radiative transfer process. This algorithm is verified by modelling a long-period rainfall case in June 2002. The results show that radiative transfer process enhances diurnal precipitation variation by increasing the nocturnal rainfall and suppressing the daytime's as well as the total rainfall. The analysis of the domain-averaged and centres rainfall validates the applicability of the equivalent radiative mechanism, in which the vertical integrated saturation vapour depth temporal trend ascribed to the equivalent radiative cooling/heating is employed to estimate the effect of radiative transfer process on precipitation. The results show that the method is a good approach for quantitatively estimating the effects of radiative transfer process on precipitation.

1. Introduction

Observational and numerical studies (Gray and Jacobson, 1977; Randall et al., 1991; Tao et al., 1996; Sui et al., 1997, 1998; Takayabu, 2002, etc.) showed that precipitation has distinct diurnal variation, namely the strongest rain appears in the late night or early morning over ocean and maximum in late afternoon or evening over the continent and large island, while the weakest appears in the fore-and-aft noon. Studies suggested that the diurnal variation over seas is fully related to the diurnal cycle of radiative transfer process and major over continent. An early study by Kraus (1963) suggested that the development of clouds tends to be reduced by solar heating and enhanced by infrared cooling. In the review by Gray and Jacobson (1977) and Randall et al. (1991), a comparable complicated mechanism suggested that the low-level convergence and upper-level rising motion due to the vertical radiative heating gradient in cloud region and the different heating between cloudy and clear regions is enhanced during the night and suppressed during the daytime. Sui et al. (1997, 1998) concluded that the available precipitable water variation owing to the radiative cooling/heating cycle is the primary cause for the nocturnal rainfall maximum and daytime minimum.

It is still questionable to quantify the effects of radiative transfer process on precipitation due to the complicated interactions and numerous processes between radiation, cloud microphysics, dynamical processes and precipitation processes. In the past decades, many scientists investigated the mechanisms by which radiation affects precipitation. Three mechanisms for the interactions among radiation, cloud and precipitation based on modelling had been summarized by Fu et al. (1995) and Tao et al. (1996). These are: (1) large-scale longwave or IR cooling (Dudhia 1989); (2) cloud-top cooling and cloud-bottom heating (Stephens, 1978; Ackerman et al., 1988; Chen and Cotton, 1988); and (3) secondary circulation caused by horizontal differences in radiative heating between cloudy and clear regions (Gray and Jacobson, 1977). Fu et al. (1995) examined several cloud–radiation interactions and confirmed the destabilization of the tropical environment by IR cooling (mechanism 1). Radiative cooling/heating influences the microphysics in cloud, such as condensation and frozen etc; the modified cloud microphysical properties impacts radiative transfer processes, so the effect between cloud and radiation is interactive and called cloud–radiation interaction. Tao et al. (1996) performed a

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comprehensively cloud–radiation mechanism study in the tropics and mid-latitudes by using the Goddard Cumulus Ensemble model and they suggested that the precipitation is greatly enhanced (36% in tropics and 8% in mid-latitudes) by mechanism 1, slightly by mechanism 2 and is negligible by mechanism 3. The effect of radiation on convection is also obviously, as Xu et al. (1995) indicated, that the radiation–convection interaction significantly changes precipitation. Inhomogeneous radiative cooling/heating in vertical influences convection within cloud. At the same time, the radiative process might be modified by the changed cloud. Therefore, radiation and convection affect each other interactively. In general, precipitation can be mainly modified by both cloud–radiation interaction and radiation–convection interaction.

Radiative transfer process can affect precipitation through two ways in physics: modifying cloud microphysics and convection; and their effect is interactive. So the quantitatively estimation of radiation on precipitation is a challenge. Sui et al. (1998) built an algorithm to calculate resultant change of the available precipitable water caused by radiative cooling/heating cycle to investigate the cause of nocturnal rainfall maximum and the daily minimum. They found that temporal change of the vertical integrated saturation water vapour could be regarded as the theoretical limit of the effect of radiation on precipitation. This idea provides an insight to find an approach to estimate the precipitation variation due to the radiative transfer process.

In this paper, a continuous raining case was simulated to investigate the effect of radiative transfer process on the diurnal variation of rainfall and a new method for estimating the effects of radiative transfer process on precipitation is presented. Model results and discussion are described in Section 2. The new algorithm for estimating the impact of radiation on precipitation will be shown in Section 3 and followed by discussions in Section 4. In Section 5, the summary and conclusions are given.

2. Modelling results and discussions

2.1. Data and simulation

There is a period of extended rain, cloudiness, and high humidity that affects Yangtze-Huaihe river drainage area of Central East China during June and July. While the precipitation is sometimes heavy, the rain during this rainy season is more typically a light, persistent drizzle. The case selected here is from the middle to the end of June 2002. The FNL version of NCEP reanalysis data was used to supply the initial condition as well as the lateral boundary layer condition. The resolution is 1×1 degree horizontally, 6 hr interval temporally and 26 layers (1000, 975, 950, 925, 900, 850, 800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 250, 200, 150, 100, 70, 50, 30, 20 and 10 hPa) in the vertical.

The PSU/NCAR (Pennsylvania State University/National Center for Atmospheric Research) non-hydrostatic Mesoscale Model (MM5 version 3) (see Dudhia et al., 2005) is employed for the simulation in this paper. MM5 is extensively used for mesoscale weather process simulation and has great advantage over cloud models in the aspect of dynamic fields and physical parametrization. While being used in this paper, MM5V3 was developed by coupling new explicit moisture scheme (Lou et al., 2003) and radiative scheme (Zhou et al., 2005). Using this model Zhou et al. (2005) studied the effects of radiative transfer process and its uncertainty on precipitation.

The simulation is from June 18th 00:00 UTC (Universal Time Coordinated, about 08:00 locally) to 27th 00:00, 2002 with time step length 60-sencond for dynamics and 20-minute for radiation. The domain is centred at (33°N, 112°E), 23 sigma layers vertically, 100 grids in both latitude and longitude and the grid size is 30 km. The domain is mainly over continent and covers some ocean area. The 24 category USGS (the United States Geological Survey) data is used for landform, vegetation type, vegetation fraction, etc. concerning terrain. The physical schemes are selected as following: CAMS (Lou et al., 2003) explicit moisture scheme, Betts/Miller (Betts and Miller, 1986a, b) cumulus scheme, MRF planetary boundary layer scheme (Hong and Pan, 1996, vertical mixing moist adiabatic in clouds) and multilayer soil temperature model, in which a slab scheme is used to calculate the surface temperature tendency according to the residual of the surface energy budget (Blackadar 1978). Relaxation/inflow-outflow lateral boundary conditions, upper radiative boundary condition and other MM5 recommended options are employed.

For this study, two different radiative condition option experiments are carried out. One is 'radiation' run, in which all radiative transfer processes are calculated, including radiative cooling/heating rate, longwave and shortwave radiant flux to the surface. The other one is 'no radiation' simulation. In this simulation, the radiative cooling/heating rate is removed, but the longwave and shortwave radiant flux to the surface is kept for the surface energy budget. The 'no radiation' run was designed to provide the environmental or background fields for the 'radiation' run.

2.2. Results of radiation and precipitation

For precipitation, the model supplies two types: convective and non-convective. In this case, convective precipitation takes the relative important role. The integrated rainfall of the nine simulated days, the ratios of convective precipitation to the total of 'no radiation' and 'radiation' run are comparative, 77.5% and 69.9%, respectively. The ration agrees with that in mid-latitude by Tao et al. (1996).

To estimate the effect of radiation on precipitation, the applicability of the simulated precipitation needs to be investigated and the sum of convective and non-convective precipitation is used. The observational results depict three stronger rainfall days during this duration, whose 24 hr precipitation is shown in Fig. 1. In major, simulation has a similar precipitation pattern to

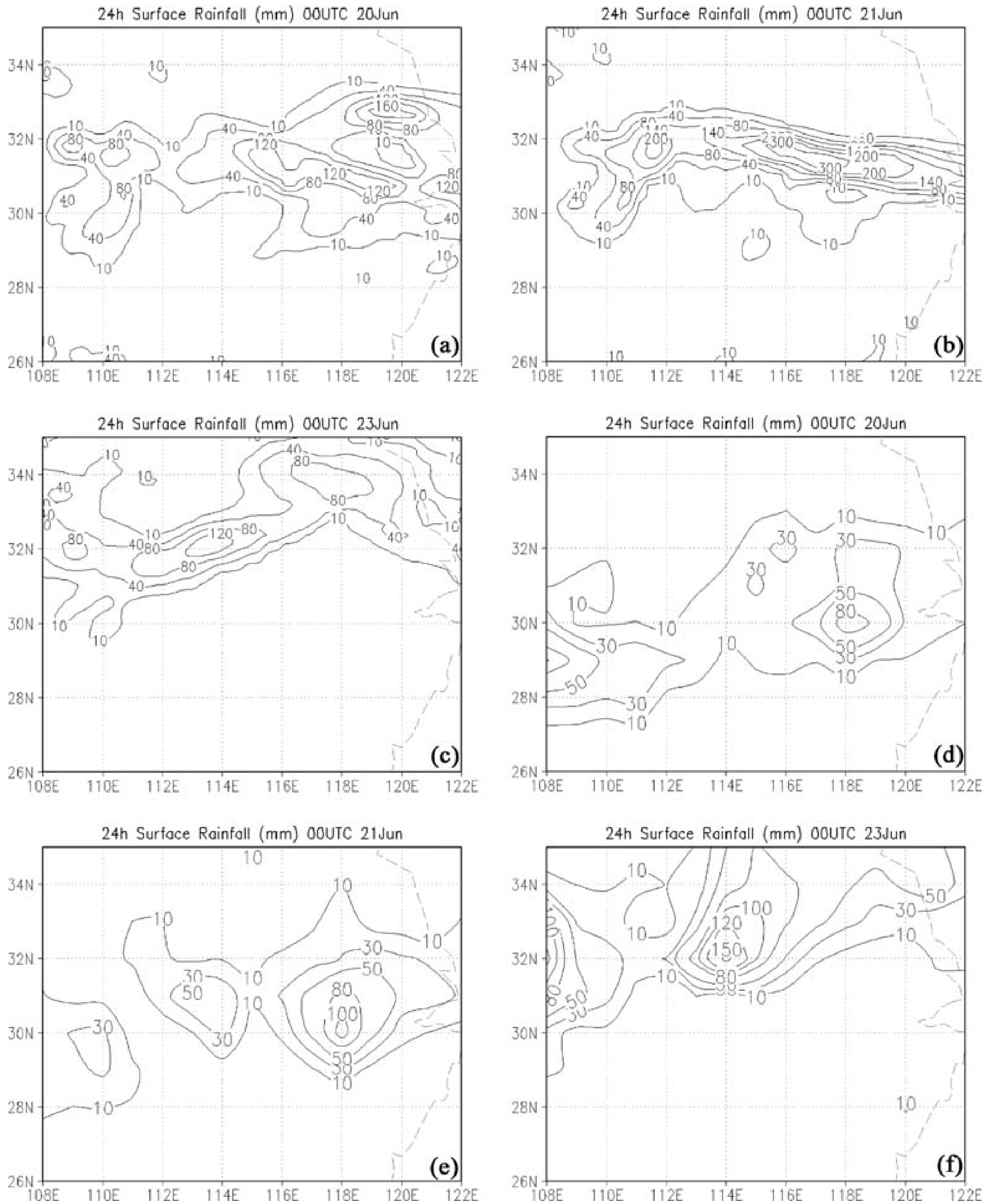

Fig. 1. The 24 hr precipitation (mm) at 00:00 UTC on June 20, 21 and 23 of simulation (a–c) and observation (d–f), respectively.

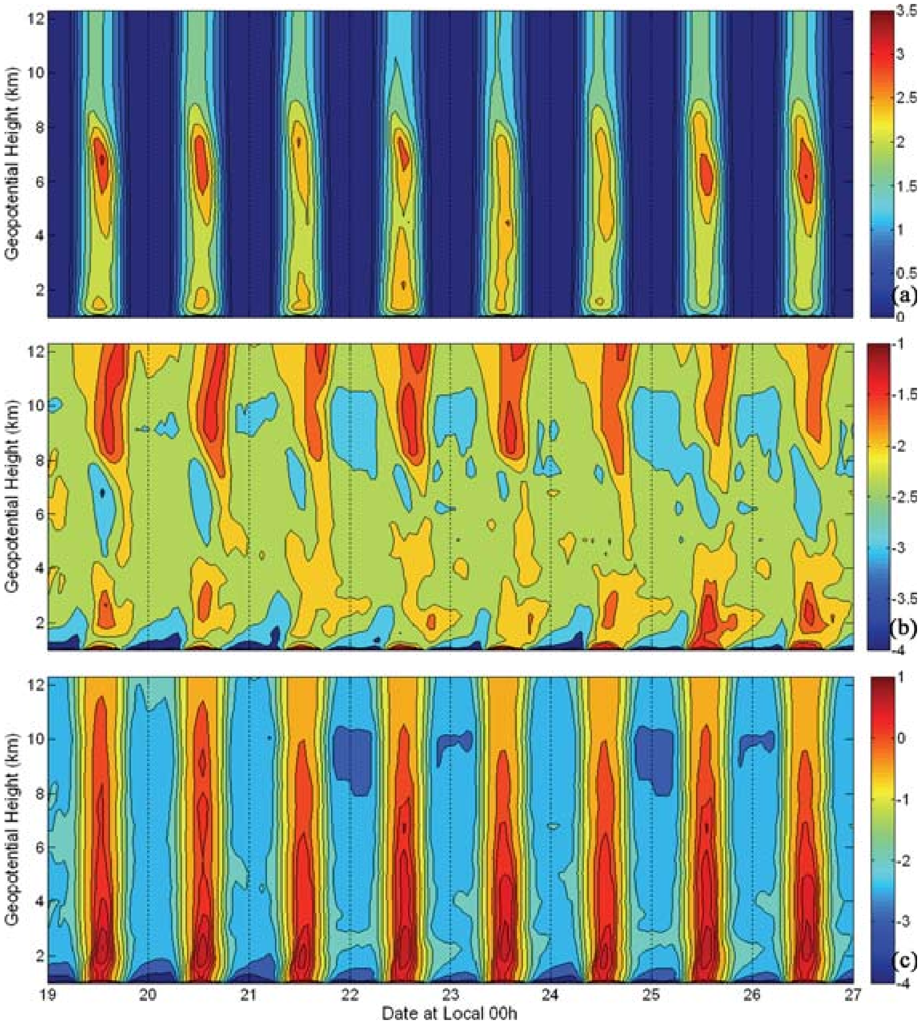

Fig. 2. Domain-averaged (a) solar heating, (b) IR cooling and (c) total radiative cooling/heating in units K d^{-1}.

that of observation but with stronger rainfall. In observation, the precipitation structure is east-west for all 3 d. There is one obvious centre for each day, they are nearby (30°N, 118°E) on 20th and 21st and (24°N, 114°E) on 23rd and the amount is 80, 100 and 150 mm, respectively. Model simulates the main precipitation structure and these centres, but some difference in exact values and positions. The structures in the 3 d are all east-west. The simulated centre of 20th and 21st is stronger than that of observation and northward displaced and slightly weaker on 23rd. Generally, the result of simulation is comparative to the observation and suitable for further work.

Figure 2 shows the domain-averaged radiative cooling/heating rate of solar, IR and total, respectively. Because of the same grid distance in MM5, the domain-averaged value is calculated as $\overline{x} = \frac{1}{ix \times jx} \sum_{i=1}^{ix} \sum_{j=1}^{jx} x_{i,j}$, where $x_{i,j}$ is the value at grid (i, j), ix and jx are the total grid number at x and y direction, respectively. It can be seen clearly that the solar heating maximum (~3 K d^{-1}) presents fore-and-aft noon in 6–8 km geopotential height (Fig. 2a). These heights locate in the upper layers of mean clouds. This result is in good agreement with the former researches that solar radiation heats the upper layers of clouds, e.g. Stephens (1978), Randall et al. (1991) and Sui et al. (1998). One can also find the relative high heating rate near the surface, which is caused by the higher temperature owing to the downward solar radiant flux. The IR cooling (Fig. 2b) results show that (1) the IR cooling rate is about -2 K d^{-1}, which is comparable with that of Dudhia (1989) and Sui et al. (1998) etc; (2) the obvious surface cooling effect during night-time and heating effect during the daytime in the atmosphere near surface, which is caused by the lower/higher surface temperature; (3) cooling effect in the upper layers of clouds, which is called as cloud-top IR cooling and (4) relative heating in the atmosphere over clouds fore-and-aft noon. The combination of solar and IR, total radiative cooling/heating (Fig. 2c), depicts

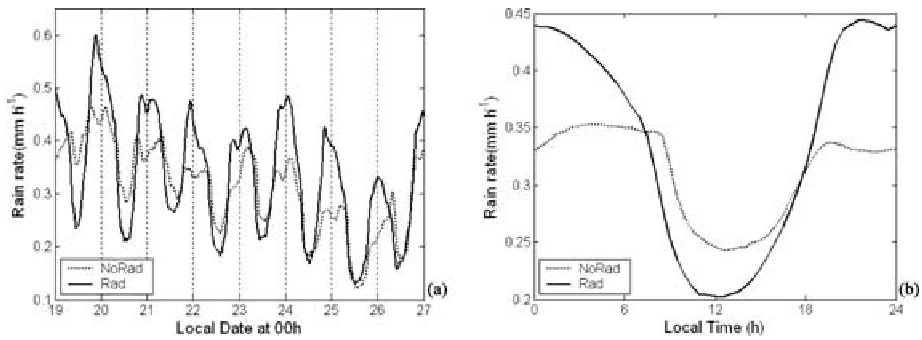

Fig. 3. Rain rate of radiation run (solid line) and no radiation run (dotted line) of (a) domain averaged and (b) temporal averaged of (a). Units: mm h^{-1}.

the primary radiative regime that radiative heating during the day and cooling during nighttime and the very obvious diurnal variation/cycle.

Previous studies (Gray and Jacobson, 1977; Tao et al., 1996; Sui et al., 1998, etc.) suggested that the rainfall is enhanced at night and reduced in the day owing to radiative transfer process. Both two runs depict the primary characters (Fig. 3a). The 'no radiation' run shows that the rain rate has a clear diurnal cycle: the domain mean rain rate during each daytime is much less than that at night and their abnormal is over 0.1 mm h^{-1}. Further and more important, the rain rate difference between in the day and at night of 'radiation' run is distinctly larger than that of 'no radiation' run. This result can be found in each daily cycle. Therefore, radiative transfer process enhances the diurnal precipitation variation.

The time-averaged results are more helpful for the analysis of diurnal variation. Fig. 3b shows the domain and daily mean value obtained from the 8 d simulations, namely this result is mean of eight values at the same time from which shown in Fig. 3a. It indicates more obvious daily cycle. For 'no radiation' run, the rain rate has a very large daily variation (~0.1 mm h^{-1}) because of the strong change of solar radiative flux absorbed by surface while a slight change (<0.02 mm h^{-1}) during the nighttime for the relative stable IR radiative flux. Comparing to the mean rain rate, 0.31 mm h^{-1}, the maximum 0.35 at about 03:00 is about 13% larger and the minimum 0.24 at 12:00 is 22% less. The rain rate of the 'radiation' run has a more obvious diurnal variation with a range of 0.20–0.44 mm h^{-1}. The minimum is also at 12:00 while the maximum is at 21:00 and 22:00 earlier than that of 'no radiation'. The mean value is 0.34 mm h^{-1} and about 8.6% larger. This enhancement amplitude agrees with that of Dudhia (1989), Miller and Frank (1993) and Tao et al. (1996), etc. The variation during the night is more obvious, especially after 02:00. The difference of 'radiation' from 'no radiation' is −0.06–0.11 mm h^{-1} (Fig. 4 solid line), about −21–35% to the mean 'no radiation' rain rate. In general, radiative transfer process enhances the diurnal precipitation variation by enhancing the nocturnal rainfall and reducing that of daytime and increases the total precipitation.

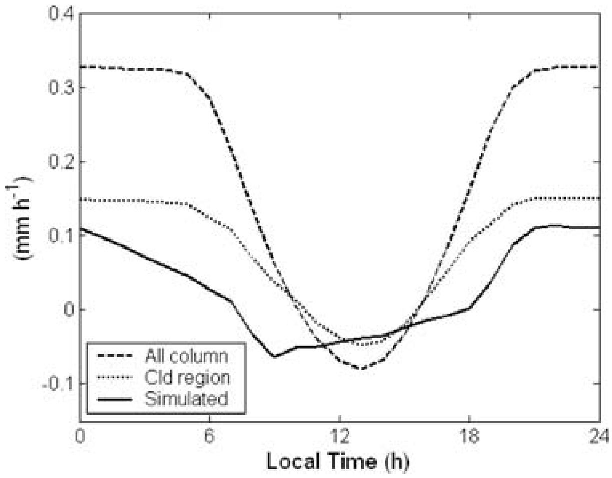

Fig. 4. Simulated rain rate difference (solid) and EP_R of the whole simulated atmospheric column (dashed) and in cloud region (dotted). Units: mm h^{-1}.

3. A method for estimating the impacts of radiation on precipitation

The saturation vapour depth (*SVD*) in a given atmospheric layer is defined by following equation similar with that of Sui et al. (1998):

$$SVD = \frac{\varepsilon}{\rho_w R} \int_{z1}^{z2} \frac{e_s}{T} dz, \quad (1)$$

where ρ_w, e_s, T, $z1$ and $z2$ are water density (1.0×10^3 kg m^{-3}), saturation vapour pressure, temperature, lower height and higher height of the layer, respectively. ε, 0.622, is ratio of molecular weight of water to dry air. Tetens formula (Murray, 1967)

$$e_s = e_{s0} \exp(a(T - 273.16)/(T - b)), \quad (2)$$

is employed, where $e_{s0} = 6.017$ hPa is the saturation vapour pressure while $T = T_0 = 273.16$ K; a and b are constant parameters, 17.27 and 35.86 on water surface, 21.86 and 7.66 on ice surface ($T < 273.16$ K), respectively. Further one can get the sensitivity of e_s to T that

$$\partial e_s/\partial T = e_s{}^* a(273.16 - b)/(T - b)^2. \quad (3)$$

So the temporal trend of *SVD* is

$$\frac{\partial SVD}{\partial t} = \frac{\varepsilon}{\rho_w R}\int_{z1}^{z2}\left\{\frac{e_s}{T^2}\left[\frac{aT(T_0 - b)}{(T-b)^2} - 1\right]\frac{\partial T}{\partial t}\right\}dz. \quad (4)$$

One can find in (4) that the temporal change of *SVD* is determined by T and its temporal trend $\partial T/\partial t$. Here a parameter, $X = \frac{e_s}{T^2}[\frac{aT(T_0-b)}{(T-b)^2} - 1]$, is defined to represent the contribution of T to $\partial SVD/\partial t$. Thus

$$\frac{\partial SVD}{\partial t} = \frac{\varepsilon}{\rho_w R}\int_{z1}^{z2} X\frac{\partial T}{\partial t}dz. \quad (5)$$

Now $\partial SVD/\partial t$ is divided into two individual parts: X is diagnostic and irrespective to time while $\partial T/\partial t$ is time correlative. Because the difference of parameters on water surface from ice surface, the sensitivity of X to T is different on the two kind of surface. But their difference is very slight (<0.02 Pa K^{-2} at about $T = 273$ K, Fig. 5), and furthermore it is the vertical integration instead of X itself is focused here. For a vertically symmetrical $\partial T/\partial t$ profile and the US standard atmospheric temperature, the difference of $\partial SVD/\partial t$ between water and ice surface is less than 1%. Therefore, this difference can be ignored if the layer is not very shallow, as a and b on the water surface are employed in this paper.

The estimated precipitation (*EP*) due to $\partial T/\partial t$ of a given layer produced can be expressed by

$$EP(t) = -\frac{\partial SVD}{\partial t} = -\frac{\varepsilon}{\rho_w R}\int_{z1}^{z2} X\frac{\partial T}{\partial t}dz \quad (6)$$

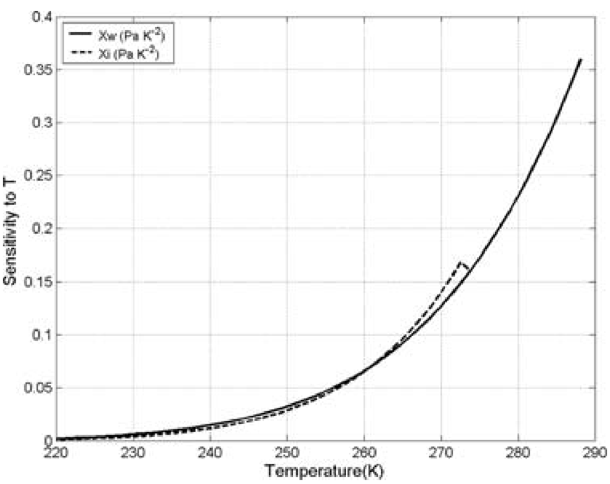

Fig. 5. Sensitivity of X to T. The solid line is on water surface (Xw) and dashed on ice surface (Xi).

Using radiative cooling/heating rate $(\partial T/\partial t)_{rad}$ replaces $\partial T/\partial t$, the *EP* ascribed to the radiative transfer process (EP_R) is

$$EP_R(t) = -\frac{\varepsilon}{\rho_w R}\int_{z1}^{z2} X\left(\frac{\partial T}{\partial t}\right)_{rad} dz \quad (7)$$

By employing (7), the EP_R of the whole atmospheric column is calculated same as that by Sui et al. (1998) ($z1 = 0$ and $z2$ is the model top height, Fig. 4 dashed line). Here the rain rate difference of 'radiation' run from 'no radiation' run is employed as the effect of radiative transfer process on precipitation. It is found that the temporal trend of EP_R agrees with the simulated results (solid line), but they are much different on quantity. So the EP_R of the whole column can be only regarded as the theoretical limit of the radiative effect on precipitation. One important fact, which is ignored in the former calculation, is that the clouds do not exist in the whole column. There is no cloud in some layers and so the temperature change in those layers cannot influence the rainfall. Thus the calculation in the whole column overestimates the contribution of radiative transfer process on rainfall. The over-calculated part should be removed. So the EP_R in the cloud region is calculated (dotted line in Fig. 4). Cloud region is defined as the layers in which the amount of all cloud water substances (water cloud droplet, ice crystal, snow and graupel) is larger than 1.0×10^{-5} kg kg^{-1}. The value in cloud region is much improved quantitatively. But the accuracy is not as good as the expected and this algorithm needs to be developed and ameliorated.

The interaction between radiation and convection suggested in several former studies that the radiative transfer process has effect on precipitation by modifying vertical velocity, for example, the updraft benefits rainfall (e.g. Xu et al., 1995). So the potential impact on adiabatic cooling/heating, which is due to the change of vertical velocity (δw) by the radiative cooling/heating, ought to be contained in the estimation of radiative effect on precipitation. Consequently, the equivalent radiative cooling/heating rate is defined to represent the combination of direct radiative cooling/heating rate and the indirect adiabatic cooling/heating as

$$\left(\frac{\partial T}{\partial t}\right)_{equ} = \left(\frac{dT}{dt}\right)_{rad} = \left(\frac{\partial T}{\partial t}\right)_{rad} + \left(\frac{\partial T}{\partial z}\right)_{wa}\delta w, \quad (8)$$

where $(\frac{\partial T}{\partial z})_{wa}$ is the wet adiabatic temperature lapse rate and so $(\frac{\partial T}{\partial z})_{wa}\delta w$ is the additional adiabatic cooling/heating rate due to radiative modified convection change. So the *EP* change ascribed to equivalent radiation (EP_{ER}) is founded as

$$EP_{ER}(t) = -\frac{\varepsilon}{\rho_w R}\int_{z1}^{z2} X\left(\frac{\partial T}{\partial t}\right)_{equ} dz = EP_R(t) + EP_W(t), \quad (9)$$

where $EP_W(t) = -\frac{\varepsilon}{\rho_w R}\int_{z1}^{z2} X(\frac{\partial T}{\partial z})_{wa}\delta w dz$. Formula (9) links radiation produced precipitation change with the direct effect of radiative transfer process on temperature and its indirect effect on convection. So the equivalent radiative cooling/heating rate expresses the additional thermal sources due to radiation, which

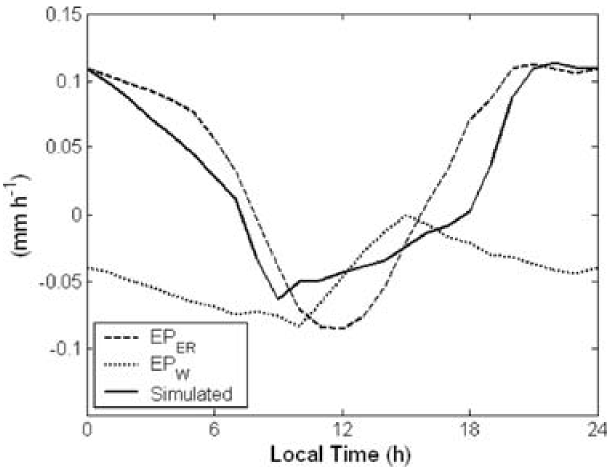

Fig. 6. Rain rate difference of simulated (solid), EP_W (dotted) and EP_{ER} (dashed) in units mm h^{-1}.

cause the additional condensation and precipitation in the cloud parcel.

Figure 6 depicts EP_W (dotted), EP_{ER} (dashed) and the simulated rain rate difference. The calculation shows that EP_W provides a contribution of about -0.1–0 mm h^{-1} in domain-averaged results. The combination of EP_R and EP_W, EP_{ER} is in very good agreement with the simulated rain rate difference in both trend and quantity. So the precipitation change calculated from equivalent radiative cooling/heating rate is a good approach to estimate the effect of radiative transfer process on precipitation. As a result, the increase (decrease) of precipitation is related to less (more) *SVD* due to the equivalent radiative cooling/heating (called as equivalent radiation mechanism after).

4. Discussions on equivalent radiation mechanism

In Fig. 6, the application of equivalent radiation mechanism is carried out for the domain-averaged results. In this section we investigate the situation at some given locations. Three of the precipitation centres, C1 (31–32°N, 116.5–117.5°E), C2 (31–32°N, 115–116.5°E) and C3 (31–32°N, 110–112°E), are selected. The results show that the estimated values of radiative effect on precipitation are in good agreement with those of simulated (see Fig. 7). Their temporal trends are fully accordant: the same increase and decay time for each pulse, such as P1, P2, P3 and P4 marked in the figure. Although there are some differences in quantity, the amounts are comparable. The comparison made at these centres also suggests the good applicability of equivalent radiation mechanism.

It is noticed that the effect of radiative transfer process on precipitation was ~0.1 mm h^{-1} for the domain averaged while ~10 mm h^{-1} for the centres. This difference was mainly due to the different orders of the related variables of the domain

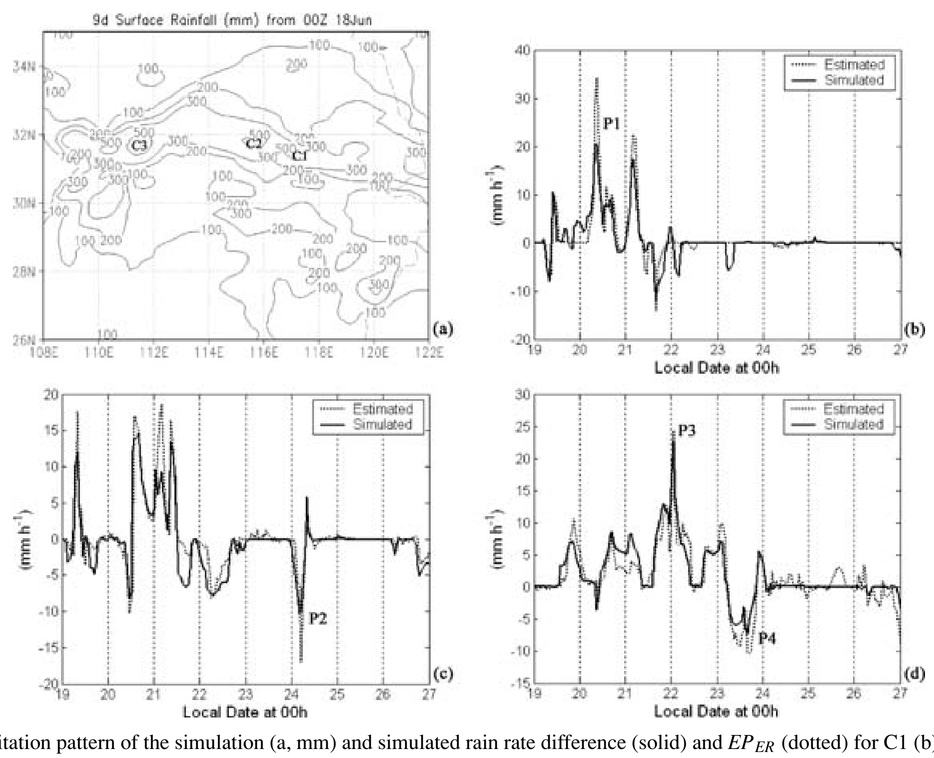

Fig. 7. The precipitation pattern of the simulation (a, mm) and simulated rain rate difference (solid) and EP_{ER} (dotted) for C1 (b), C2 (c) and C3 (d) in units mm h^{-1}, respectively.

Table 1. The order of precipitation related variables for domain averaged and centres

	Domain averaged	Rainfall centres
$(\partial T/\partial z)_{rad}$ (K h^{-1})	$\sim 10^{-1}$	$\sim 10^{\circ}$
$(\partial T/\partial z)_{wa}\delta w$ (K h^{-1})	$\sim 10^{-2}$	10°–10^{1}
ERCH rate (K h^{-1})	$\sim 10^{-1}$	$\sim 10^{1}$
Rain rate difference (mm h^{-1})	$\sim 10^{-1}$	$\sim 10^{1}$
Major factor*	$(\partial T/\partial z)_{rad}$	$(\partial T/\partial z)_{wa}\delta w$

*The major factor that contributes to ERCH rate as well as the rain rate difference or *EP*.

averaged from the centres. Table 1 depicts the main characters of $(\frac{\partial T}{\partial t})_{rad}$, $(\frac{\partial T}{\partial z})_{wa}\delta w$, etc. It shows that the domain averaged $(\frac{\partial T}{\partial t})_{rad}$ is one order larger than $(\frac{\partial T}{\partial z})_{wa}\delta w$. While at the centres, the order of $(\frac{\partial T}{\partial z})_{wa}\delta w$ is one larger than that of $(\frac{\partial T}{\partial t})_{rad}$, and so $(\frac{\partial T}{\partial z})_{wa}\delta w$ contributes the major to equivalent radiative cooling/heating (ERCH) rate, which determines *EP*. Between at centres and the averaged, $(\frac{\partial T}{\partial t})_{rad}$ is one while $(\frac{\partial T}{\partial z})_{wa}\delta w$ is two or three larger in order, respectively. So the different variation at centres from the averaged produces the difference of effect of radiation on precipitation and the major factor. These differences also suggest that the estimation by radiative cooling/heating can be only used for the domain-averaged rainfall and the equivalent radiation mechanism extends the application for the centres.

Large-scale IR cooling and the cloud-top-cooling/cloud-bottom-heating mechanisms are the major causes effecting precipitation by radiation. Both them affect precipitation by two ways: one is modifying the cloud microphysics by changing temperature directly and the other one is influencing convection indirectly. Also, the convection can be modified by the horizontal inhomogeneous heating of radiation to some extend. The theoretical limit algorithm employed by Sui et al. (1998) can only calculate the direct effect and ignore the indirect effect and hereby it can only be employed for the domain-averaged estimation. The equivalent radiation mechanism algorithm developed in this paper improves the applicability for the indirect effect calculation. Since the equivalent radiative cooling/heating includes both the effect of radiative transfer process on direct temperature trend and indirectly convection, it generalizes the two former mechanisms and can be used for the domain-averaged and specific locations estimation. The analysis of the centres and the domain averaged verifies that the increase of precipitation is ascribed to the less *SVD* due to the equivalent radiative cooling/heating and the reduced rainfall owing to more.

5. Summary and conclusions

A long-term rainfall case in the mid- and end June 2002 is simulated to discuss the diurnal variation of precipitation over continent and an approach estimating the effect of radiative transfer process on precipitation is developed. A 'no radiation' run was designed to provide the background fields and a 'radiation' run to analyse the radiative effects.

Precipitation has an obvious diurnal variation and radiative cooling/heating greatly enhances it. The result that 'no radiation' indicates the basic diurnal precipitation variation suggests that the daily cycle and diurnal variation of the downward radiant fluxes to surface that produce this regime. Because the more radiant flux results in higher surface temperature and then more evaporation and provides more vapour fore-and-aft noon and in the afternoon. The existing of radiative cooling/heating distinctly enhances the diurnal variation by increasing the nocturnal precipitation and suppressing during the day. It also enhances the averaged rainfall.

The equivalent radiative cooling/heating mechanism is a good approach to estimate the effect of radiative transfer process on precipitation. Based on the relationship between *SVD* and precipitation, a method is built up to quantitatively calculate the effect of radiative transfer process on precipitation. The results show that the equivalent radiative cooling/heating can be employed to estimate that effect well. The equivalent radiative cooling/heating combines the effects of radiative transfer process both on temperature trend and convection, and can be used for the qualitatively analysis and the quantitatively estimation of the radiative effect on precipitation. Furthermore, this algorithm of equivalent radiation mechanism can be applied to estimate the effect of whether domain averaged or centres.

6. Acknowledgement

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