

Numerical Simulations of the Effect of Black Carbon Aerosol on Regional Climate in China

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Abstract—Black carbon (BC) aerosol, as an important component of the atmospheric aerosols, has attracted much attention recently, due to its ability to absorbing solar radiation and the possible effect on climate. In this study, the Regional Climate Model version 3 (RegCM3) is used to investigate the temporal and spatial distribution of BC aerosol in East Asia and the possible effect on regional climate in China. The influence of BC aerosol on the atmospheric radiation transfer, air temperature, and rainfall are analyzed. It is revealed that three main heavy loading regions of BC exist in China, that is, Northern China, Southern China, and the Mid-lower reaches of the Yangtze River, and that the BC loading follows a clear seasonal cycle. The simulation results show that BC aerosol induces a positive radiative forcing at the top of the atmosphere, and a negative radiative forcing at the surface in this region. It is also found that the response of the climate system in summer to the radiative forcing due to BC aerosol is a decrease in the air temperature in the mid-lower reaches of the Yangtze River and Huanghe area, and an increase in the air temperature in some regions in northern China. Meanwhile, the total rainfall in Southeast China is increased, but it is decreased in some regions in northern China.

Keywords—black carbon aerosol; radiative effect; climate response; RegCM3

I. INTRODUCTION

In recent decades, China has been suffering an severity of increased rainfall in the south and drought in the north, and recent global climate model simulations have shown that

Black Carbon (BC) aerosols may contribute to this[1]. The importance of BC aerosol has attracted much more attention not only in scientific communities, but also in governmental agencies. BC aerosol in the atmosphere originating from the incomplete combustion of carbon fuel, could change the solar radiation transfer via strongly absorbing shortwave solar radiation[2].

In recent years, it have been demonstrated that BC aerosols impose positive direct radiative forcing on the atmosphere and increase the net radiation received by the atmosphere and the surface. Some studies indicate that BC aerosols contribute to the regional heating rate, indeed can counteract the cooling effect of sulfate aerosols[3]. Schult et al.[4] estimated that the globally averaged radiative forcing just due to external mixture of sulfate aerosols and BC aerosols to be $-0.2\text{W}/\text{m}^2$, but in some regions, the presence of BC aerosols may cause a conversion from the negative radiative forcing to positive. Haywood et al.[5] obtained a direct radiative forcing due to BC aerosols of $1.1\text{--}1.9\text{W}/\text{m}^2$ from their simulations using the R30 Geophysical Fluid Dynamics Laboratory (GFDL) general circulation model. Zhang et al.[6] investigated the radiation forcing of BC aerosols and the different effects impacting on the radiation forcing when the mixing ways of the were different sulfate aerosols and BC aerosols. Zhang et al.[3] obtained the radiative forcing of the soot aerosols to be $0.22\text{W}/\text{m}^2$, from their simulation using radiation transport model.

Results of the global model simulations indicate that China is one of the regions with maximum optical depth of BC

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aerosols, and the radiative forcing of BC aerosols over China can be larger than the global average[7][8][9]. Due to the coarse resolution, however, the detailed characteristics of the distribution of the radiative forcing of BC aerosols and the associated regional climate response can not be obtained from global models[10]. In this paper, the Regional Climate version 3 (RegCM3) is used to simulate the distributions of BC aerosols and their radiative effect over the China in 2000. The influences of BC aerosols in the atmospheric radiation transfer and on the air temperature and rainfall are analyzed.

II. MODEL AND DATASET

A. Model Description

RegCM3 uses the radiation scheme of the NCAR CCM3 (Community Climate Model 3). The soil-vegetation-atmosphere interaction processes are parameterized using the Biosphere-Atmosphere Transfer Scheme (BATS). Two ocean flux parameterizations can be used in RegCM3. One of them is BATS, implemented by Giorgi et al.[11][12], and the other is the one developed by Zeng[13][14]. The convective precipitation parameterizations used in this paper is the Grell scheme. The large-scale precipitation scheme used in RegCM3 is Subgrid Explicit Moisture Scheme (SUBEX) used to handle non-convective clouds and precipitation resolved by the model.

B. The Data Sets

The model domain is centered at (110°E, 37.5°N) with a 45km grid size and 130×106 grid points in the horizon. There are 18 vertical levels. The model top is at 100 hPa. The regional model is initialized at 00:00UTC, 5 days prior to the first day of January, April, July, and October 2000, to represent winter, spring, summer, and autumn, respectively. The NCEP reanalysis data are used to provide the initial and boundary conditions. The first 5days is the spin-up period, while the results of the last 30 or 31 days are analyzed. Sea surface temperature (SST) is obtained by interpolation of the Global Sea Surface Temperature (GISST) data. The topography and landuse data, derived from USGS and GLCC, respectively, with horizontal resolution of 10-min, are used to provide the terrain characteristics. Two radiation schemes are utilized in order to compute the direct radiative forcing of BC aerosols. The first scheme does not include BC aerosols, and

is included in the second scheme.

The BC aerosols emission datasets include fossil fuel combustion, biomass burning and anthropogenic emissions from the $1^{\circ} \times 1^{\circ}$ pollution emission inventory, in which anthropogenic emissions (Edgar) are annual mean values, and the biomass emissions are monthly mean values.

III. RESULTS

A. The Radiative Forcing of Black Carbon Aerosols

The radiative forcing at the top of the atmosphere (in W/m^2) (the figure is not given) is positive everywhere, which indicates the BC aerosols increased the radiation received by the earth-atmosphere system. In January and April, the forcing is mainly located in the Mid-Lower Reaches of the Yangtze River. In January the forcing values are 0.6-1.2 W/m^2 in the south of the Yangtze River, 0.1-0.5 W/m^2 in Northern China and the south part of Northeast China. In April, the radiative forcing in the south of the Yangtze River increases to above 0.9 W/m^2 , little increase in the north regions. In July, the radiative forcing decrease to 0.2-0.3 W/m^2 , meanwhile, the distribution of the radiative forcing reach to the north part of Northeast China, and there has a maximum value of 0.4 W/m^2 in Bohai Bay. This change is the result of the northward progression of strong southwesterly winds which advect BC aerosols to northern China, meanwhile, the sedimentation effect by rain water reduce substantially the radiative forcing in southern China. In October, the radiative forcing still extends northeastward, and the value is significantly higher than it is in July. The results obtained here are similar to the long term global climate model simulation[14].

The negative forcing on the surface (in W/m^2) suggests that BC aerosols reduce the shortwave radiant flux by increasing the reception by the atmosphere. The centers of the radiative forcing are located in the Mid-Lower Reaches of the Yangtze River. In January, the maximum (negative) value reaches to -2.6 W/m^2 , while the forcing is less than -0.4 W/m^2 in northern China. The distribution of the radiative in April is similar to that in January except for the northward extension. In July, the radiative forcing still extends northward, and the values decrease significantly. In October, there is a pronounced increase in radiative forcing compared to that in July, which is due to burning straws and stalks in countryside .

B. Temperature and Total Rainfall Response to Black Carbon Aerosols

Figure 1 depicts the vertical cross section of the temperature over 100°E and 120°E in July. The temperature decreases significantly below 700 hPa between the Mid-Lower Reaches of the Yangtze River and the Huanghe basin (32°N - 38°N), with a value of -1K near the surface. The decreased in the surface temperature results from the negative forcing on the surface by BC aerosols. On the contrary, the temperature of the atmosphere below 700 hPa between 39°N - 43°N and 48°N - 53°N increased on the different degree, with a maximum value of 0.6K. There is a especial phenomenon between 43°N - 47°N that the temperature below 950 hPa decreases but increases distinctly between 950 hPa and 400 hPa. This indicates that the distribution of BC aerosols is influenced by the vertical diffusion, which is not discussed here. This simulation demonstrates that BC aerosols do cause

some regions' temperature drops.

Figure 2 shows the total precipitation change in July. Obviously, the precipitation has a remarkable increase in Jiangsu province, Zhejiang province and Bohai regions, but a visible decrease in Shandong and Hebei province. The maximum value of decrease is -15cm in Hebei province. For some reason, there are some warps on the geographical position between the simulated results from RegCM3 and the observation dataset[15], but our results suggest that BC aerosols can affect the precipitation, engendering more precipitation in South China but less precipitation in North China. In the global climate model[1], the including of the absorbing aerosols causes a distinct impact on the precipitation in China, which is consistent with the observation data, approving the simulation here is feasible. That comes to light that the phenomenon of summer floods in south China and drought in north China is related to SST,

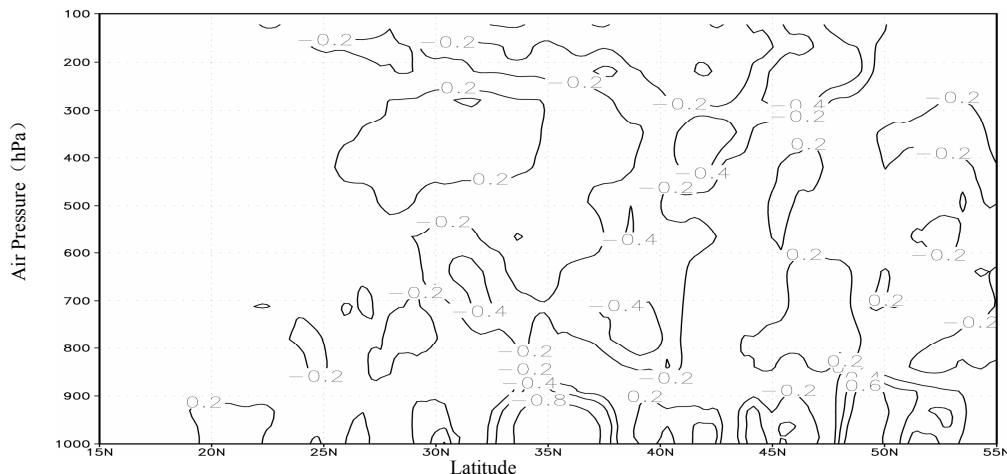


Fig 1 Vertical cross section of air temperature response over 100°E to 120°E in July (Units: K)

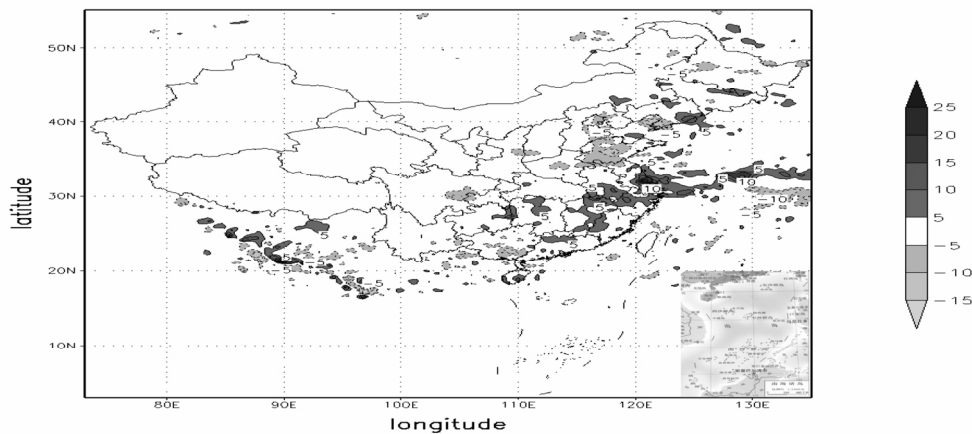


Fig 2 The total rainfall response to BC aerosols in July (Units: cm)

large-scale circulation, terrain change and aerosols radiation. This simulation indicates that the increase of BC aerosols can impact regional climate change.

IV. SUMMARY AND CONCLUSIONS

Using the RegCM3, we simulated the distribution of BC aerosols and their radiative effect over the China in 2000 and analyzed the influences of BC aerosols on the atmospheric radiation transfer and on the air temperature and rainfall. The main findings of the results are as follow:

The radiative forcing at the top of the atmosphere is positive, which indicates that BC aerosols are absorbing aerosols and could absorb solar radiation and cause a positive radiative forcing. The distribution of the main radiative forcing is similar to that of the column burden, and the maximum value occurs in the south part of the Yangtze River, with a prominent change following the season. The radiative forcing on the surface is negative because BC aerosols reduce reception of solar radiation by the surface. Meanwhile, it has a similar distribution to that at the top of the atmosphere. In July, there is a maximum value in Bohai Bay at that time, resulting from the southwest winds and much rain water in South China.

The response of the climate system in July to the radiative forcing due to BC aerosols is a decrease in the air temperature in some regions in southern China, and an increase in the air temperature in some regions in northern China. Meanwhile, the total rainfall in Jiangsu and Zhejiang is increased, but it decrease in some regions in northern China. BC aerosol is the important factor impacting the local climate change.

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