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Interaction of Atmospheric Aerosol and Temperature, Wind Fields

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The radiative effect of atmospheric aerosol is for the first time comprehensively discussed in an urban atmospheric boundary model. In the model design the author has tried to reasonably choose basic boundary equations, carefully design a calculation scheme of the atmosphere radiative effect, a parameterization scheme of the basic physical processes close to the ground and a numerical solution scheme. Finally a 1.5-level-closure-used 3-D non-stationary atmospheric boundary model, an atmospheric diffusion model and its corresponding radiation transmission model are established in this thesis. The test shows that the 16-hour to 39-hour integrated temperature and wind figures are in good conformity with the actually measured data. Therefore, the model is proved to be stable in this aspect.

To describe the interaction of aerosol and boundary layer, the author has synthetically considered the effect of the atmospheric aerosol on the boundary layer and the feedback of the boundary layer to the distribution of the aerosol. The modeling of the interaction of the aerosol and boundary layer reveals the specific problems of boundary layer and atmospheric diffusion in seriously polluted cities and thus it provides us with an opportunity to have better understanding of such problems. The study involves the following aspects.

(1) A synthetic boundary layer numerical model is for the first time put forward and successfully established in consideration of the radiative effect of atmospheric aerosol and the diffusion of the aerosol particle. The model includes three sub-models, which are a 3-D non-stationary atmospheric boundary layer model, an atmospheric diffusion model and its corresponding atmospheric radiation transmission model. In this model a 1.5-level-closure scheme is used.

The model has been validated with the atmosphere boundary layer and diffusion data. The result shows that during the integration period between 16 and 39 hours the simulated boundary temperature and wind do agree fairly well with the actually measured temperature, wind profile and surface wind field. Therefore it is of great stability.

The atmospheric diffusion model in this thesis is involved with the combination of an advection diffusion equation and the modified Gaussian point source equation, which is applicable to the time variation wind field. The combination of the two equations is proved more effective than the previous respective ones. The validation of the measured TSP concentration shows greater accuracy of the diffusion model.

Based on the frame of LOWTRAN 7, an atmospheric radiation transmission model is developed to suit the atmospheric realities in Lanzhou city. Firstly, on the basis of the studies and achievements in this field, the combined spectrum model of Junge spectrum and graded, 3-parameter spectrum is modified to be more in conformity with the reality and more convenient in use. Secondly, a scheme is designed to convert real time aerosol mass concentration into radiation parameter and then put it into the radiation transmission model. The validation of the radiation transmission model shows that the simulated short and long wave radiation flux matches the measured data very well. The computation can reach the precision of the computation result made by specific aerosol spectrum model, especially the error of long wave radiation flux is reduced from former 15% to below 10%.

Thus the time depended aerosol mass concentration can be converted into radiation flux and heating rate (cooling rate respectively) so as to realize the coupling of the atmospheric boundary layer model, diffusion model and atmospheric radiation transmission model.

(2) With the established boundary model in this thesis, we simulate the evolution characteristics of temperature field, wind field, vertical wind speed and turbulence kinetic energy of day time under heating condition of the aerosol radiative effect. The simulation can reproduce the development of mixed layer, variation of the wind field which is caused by the dynamic and theromodynamic effect, such as revolving fluid, upslope and downslope wind, convergence and divergence. The simulation result shows that the vertical air stream in the lower layer of the basin is weak in day time, but there appears a strong updraft in the middle and upper layer of the boundary layer, and w* can reaches 0.05~0.2m/s. The hills around the basin are mainly controlled by the updraft. The simulation of the boundary layer at night shows that there is a strong inversion layer below 25m level under the heating influence of the aerosol long wave and artificial source in the lower layer, and above this level there is a neutral or a very weak upper inversion layer extending to 200m level. At night, there is a weak updraft in the basin and a downdraft above the surrounding hills, w* is -0.005~-0.05m/s.

(3) The simulation can reveal the features of the vertical distribution and variation of TSP concentration. Under the joint influence of the emission source strength, source height and meteorology field, TSP concentration varies greatly according to height and time in daytime and its variation is 1.0mg/m3. The TSP transmission diffusion height can reach 600~800m in daytime. The simulated TSP concentration profiles on the representative spots demonstrate the highest concentration and the most extensive vertical diffusion range at noon. These results correspond with the former observation of the smog layer height and the turbidity.

(4) Through the simulation scheme, the influence of the aerosol radiative effect on boundary layer structure and the variation of TSP concentration are discussed in consideration of the change of the boundary layer. Moreover a further analysis of the influence of aerosol radiative effect after a period of one hour is made in the study.

The above results show an obvious heat increase in the boundary layer due to the short wave aerosol radiation effect. The increment of the temperature reaches more than 1 K in an hour. The maximum value of the temperature increase occurs near the mixed layer top level (500m). See Fig.1-a. Influenced by the temperature increase, the vertical wind field and horizontal wind field are adjusted correspondingly. The vertical ascending motion above 400m level is strengthened with its increment value 0.05m/s; the horizontal convergence in the lower layer is strengthened, the variation value of the wind speed is about 0.3m/s. See Fig.1-b. In this meteorology field, TSP concentration in the lower layer decreases. The decrease value is 0.2~0.4mg/m3. In some local convergence areas, the concentration increases with the increase value 0.2~0.4 mg/m3. TSP concentration increases by about 0.4 mg/m3 at 500m level.

At night, the long wave radiative effect of the aerosol gives rise to an increase in temperature of the atmosphere near the ground. The temperature can increase by 0.1~0.2K in an hour. The long wave radiative effect also tends to make the lower layer atmosphere cooler, the decrease value is about 0.1~0.2K/h; wind speed decreases by 0.1~0.2m/s below 100m level and increases slightly in the upper layer. See Fig.2. The convection is strengthened at the same time. Because of the variation of the meteorology field, TSP concentration decreases below the 100m level, and the decrease value is about 0.06 mg/m3. Close to the upper inversion layer top (about 400~500m), the concentration may increase slightly, and the increase value is about 0.001 mg/m3. Corresponding to the increased TSP concentration area in the lower layer is an area with a very weak vertical air stream. The downdraft therefore corresponds with an increase in ground concentration.

The approach of the thesis can be applied to the study of sand aerosol and it is believed to be helpful for the improvement of the aerosol radiative parameterization in climate model.

Meteorology (Poster)