Improving smoke injection height modeling for climate simulations

Biomass burning is one of the most important sources of trace gases and aerosols in the atmosphere. The wildfire smoke injection height is an important parameter to describe wildfire plume as it can influence the lifetime and transmission distance of fire emissions, consequently influence its environmental impact. (Val Martin M et al., 2018). The aerosols fire emitted can not only absorb and scatter solar radiation but also influence the formation of clouds as CCN. Therefore, it is significant to concentrate on the simulation of fire emissions and their impact.

In many global climate models, smoke injection height is prescribed. For illustration, the distribution of plume heights in Aerosol Inter Comparison project (AeroCom) is given regionally and empirically. (F.Dentener et al., 2006). But there is a strong dependence between plume height and factors like meteorological conditions and intensity of wildfire. Pyrocumulonimbus (pyroCb) , which is a intense convection caused by wildfires, can upraise plenty of smoke into tropopause in about one hour. (Rosenfeld et al., 2007; Rodriguez et al., 2020). These extreme plumes can hardly described in empirical models.

In this case, Briggs et al. (1984) considered plumes had circular cross-section and gave a plume height model, but in fact plumes cross-section can be various and many variables in his model would be defined and achieved difficultly. Freitas et al. (2007) came up with his model by combining 1-D plume rising model with 3-D atmosphere diffusion model. But when calculating each plume height it has to solve a group of differential equations which would result in a huge amount of computation. Sofiev et al. (2012) gave a plume height model as formula (1) including boundary layer height, fire radiative power (FRP) and Brunt-Väisälä frequency and compared this model with others. Plume height can be calculated more accurate and fast using Sofiev’s model, but many high plume are underestimated obviously.

In this study, we improve Sofiev’s model according to the existing limitations and our new model will be more suitable for climate simulation. Firstly, Sofiev’s model is examined in a wider scope of time and space. We use plume height achieved by Multi-angle Imaging Spectro Radiometer (MISR) as observation data, including fire events in 2008-2011 and 2017-2018 which is much more than cases used by Sofiev et al. The calculated value within the margin of MISR bias, called “good”, is in a percentage of 62.52%, which is lower than the percentage in his research. Secondly, RMSE is used as a new objective function to achieve parameters the model needed instead of the number of “not good”. After applying new parameters to Sofiev’s model, RMSE decreases more than 30 m, while good percentage becomes 68.42% and the absolute value of mean bias decreases over 60 m. To improve the underestimation of high plumes, black carbon emission and convection available potential energy (CAPE) are introduced in the model, as formula (2). RMSE decreases further and underestimation is improved.

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