How the cumulonimbus cloud affects redistribution of the SO_2 emitted from a thermal power station?

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Motivation

ÅChemical composition of the troposphere can be changed due to local convection.

ÅThe convective redistribution of SO_2 has a meaningful role in the local air quality and formation of the acid rains.

ÅIn the most types of the fossil fuels that are used in the thermal power stations (TPS), the sulphur is prevalent. A large amount of the sulphur dioxide in the atmosphere is a consequence.

ÅIn the air, cloud water and rainwater, the sulphuric acid and sulphates are produced due to the gaseous and aqueous chemical reactions. All this causes the environmental issues and posing the detrimental effects on the human health.

ÅThe question is: how the cumulonimbus cloud (Cb) affects the redistribution of SO_2 (that is released from the TPS) in the atmosphere?

Model description

ÅA 3D non-hydrostatic cloud-resolving atmospheric model ARPS (Xue et al. 2000; 2001) coupled with a chemistry module (Vujović and Vučković, 2012) is used in this research.

ÅSO_2 mixing ratio in *j* water category (water vapour, cloud water, rainwater, cloud ice, hail and snow) is calculating using equation:

$$\frac{\partial q_{i,j}}{\partial t} + \mathbf{V}\cdot\nabla q_{i,j} - FR_{i,j} = S_{i,j} + CH_{i,j} + LI_{i,j}$$

ÅThe equation includes advection, sedimentation, turbulence mixing, source or sink chemical transformation terms and the liquid-ice phase processes where the retention was included.

ÅThe model is one-moment. Linõs microphysics is used (Lin et al., 1983).

ÅPrognostic variables are mixing ratios of the chemical species: sulphyr dioxide, ozone, hydrogen peroxide, suphate, ammonium aerosol.

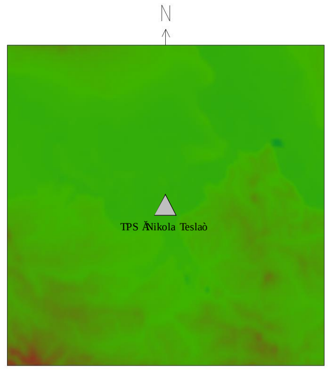

FIG. 1 The real topography is used in the model (the 30-s terrain elevation Shuttle Radar Topography Mission data, Far et al. (2007), were prepared for the area of the interest). The center of the model is 20° E, 45.5° N, and it is located in the power plant ÑNikola Teslaò.

Numerical experiments setup

TWO EXPERIMENTS ARE CONDUCTED:

1) T, experiment with bubble-shaped initial perturbation for potential temperature (the cloud is initialized by the warm bubble in ellipsoidal shape, with the maximum potential temperature perturbation of 2 K in the center of the bubble),
2) NT, experiment without initial perturbation for potential temperature.

ÅThe model domain is 112 ×112 km in horizontal and 16 km in vertical direction.

ÅThe real topography is prepared to use in the model (Fig. 1).

ÅThe model resolution is 500 m in the horizontal and 250 m in the vertical.

ÅThe big time step is 3 s for the integration of the dynamics, microphysics, and chemistry and the small one is 0.5 s for sound waves.

ÅChemical species exponentially decrease with the height and are initialized according to Taylor (1989), for the polluted atmosphere.

ÅThe concentration of S(IV) in cloud water and rainwater is calculated by detailed kinetic mass transfer (KMT) approach that does not assume gas-liquid equilibrium (Pandis and Seinfeld, 1989)

ÅRadiating (open) conditions are used for the lateral boundaries. Rigid wall boundary conditions are applied for the top and for the bottom of the domain.

ÅThe initial reference state is homogenous in the horizontal direction and initialized by a realistic summer sounding giving the values of temperature, humidity, pressure, wind velocity and direction (Fig. 2).

ÅTo simulate a plume from the TPS we used the real data for the release height, emission rate, gas exit temperature, gas exit velocity and inside diameter of the chimney of Obrenovac TPS.

What we done?

ÅInvestigate how the presence of a convective cloud, presented by a thermic, affect the redistribution of the SO_2 which is released from the thermal power plant.

ÅThe model simulations are state-of-the-art in including several aqueous phase chemical reactions, tracking of solute concentrations in different hydrometeors, realistic topography, and high spatial resolution.

ÅAs a result, the most detailed analysis of time-dependent partitioning of SO_2 among the gas phase, different hydrometeors, and precipitation is obtained.

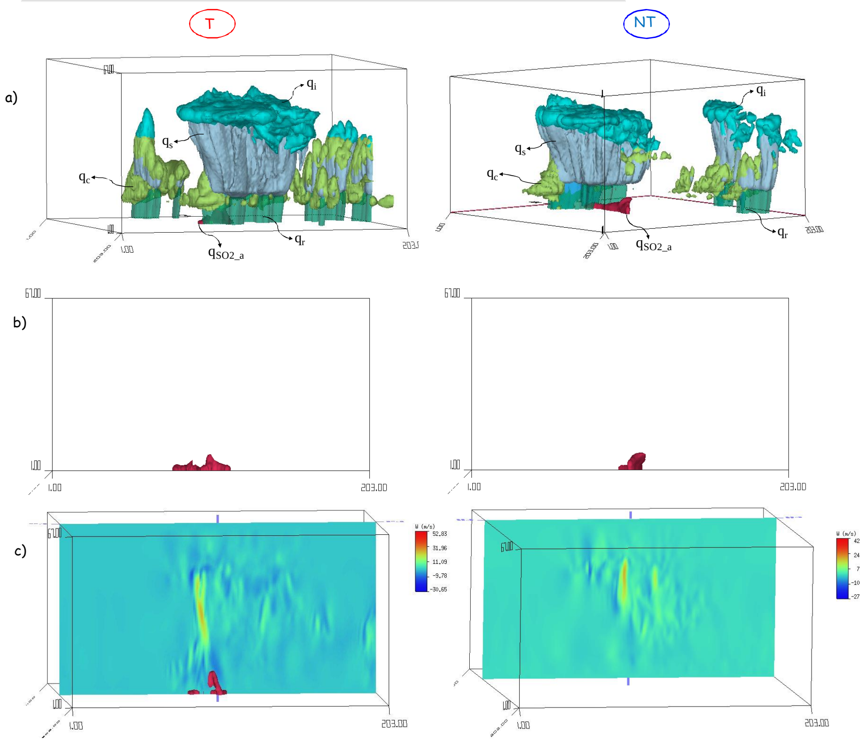

FIG. 3 a) The cloud (mixing ratios of cloud ice q_i, snow q_s, cloud water q_c, rainwater q_r and hail q_h in mg kg^{-1}) and mixing ratio of SO_2 in the air (red color), εg kg^{-1}; b) Mixing ratio of SO_2 in the air, q_{SO2_a} (εg kg^{-1}); c) vertical velocity, w (m s^{-1}). Left panels are for experiment with the bubble perturbation (T), and right ones for experiment without it (NT).

Discussion

ÅThe experiment with initial perturbation of potential temperature (T) gives more intense cloud then experiment without this perturbation (NT), Fig. 3a.
ÅDue to the strong wind shear at height, the SO_2 in the air released by the TPS does not penetrate higher levels, but spreads horizontally instead (Fig. 3).
ÅWhen cumulonimbus cloud passing by over the TPS, due to strong vertical currents, it sucs the plume of SO_2 into the cloud, and the plume reaches the higher altitude in the case of T in comparison with case without bubble initiation (Fig. 3c).
ÅThere is more mass of SO_2 in the air in the case when there is not bubble initiation (Fig. 4). That means that a substantial fraction of SO_2 entrained in the convective cloud is redistributed to the different water categories and eventually scavenged by aqueous reaction with H_2O_2 and O_3 (that is included in this chemistry module). The similar was concluded by Mari et al. (2000), who used a one dimensional convective plume model.
ÅThe difference of masses of SO_2 in the case of T and in the case of NT in different water categories is given in Fig. 5. All this masses are greater in the case of T than in the case of NT until approxsimatelly 100 minutes of the integration (with the exception of the difference of mass of SO_2 in the snow, which is all the time positive). This is the time when the cloud in the experiment NT finally reaches the position of the TPS.
ÅScavenging of SO_2 increased in the case of presence of cumulonimbus cloud. Difference of accumulated SO_2 rainfall in the case of T and in the case of NT, in the whole domain, is shown at Fig. 6.

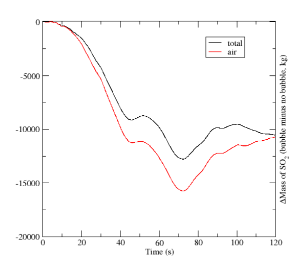

Fig. 4 The difference of masses of total SO_2 ($q_{tot} = q_a+q_c+q_r+q_i+q_h+q_s$) and SO_2 in the air in experiments T and NT (i.e. mass in T minus mass in NT).

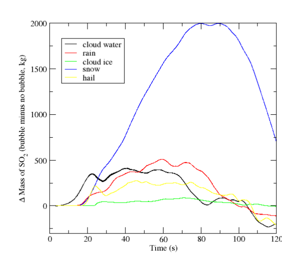

Fig. 5 The difference of masses of SO_2 in the case of T and in the case of NT in different water categories (i.e. mass in T minus mass in NT), kg.

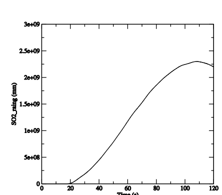

Fig. 6 Difference of accumulated SO_2 rainfall in the case of T and in the case of NT, in the whole domain.

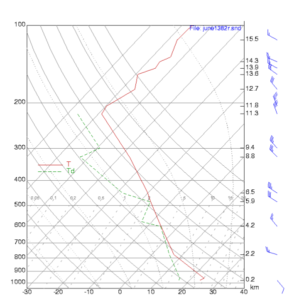

Fig. 2 The realistic summer sounding used to initialize the reference state.

Conclusion

ÅA chemistry module, coupled with a complex 3D cloud resolving numerical model has been developed and used to analyze the effects of mass transport in mixed-phase convective cloud on scavenging and vertical redistribution of SO_2 released from thermal power station in the troposphere.
ÅThe plume rise is closely related to the vertical air velocity into the cloud. Stronger updrafts give plume rise to higher elevations.
ÅWhen Cb with the strong updrafts passed over the TPS, SO_2 is transported to the higher altitudes.
ÅWhen the cloud is not developed, the higher mass of SO_2 remains into the air.
ÅConvective cloud increased the scavenging of the SO_2, as well as acidity of the rainwater.

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