Geophysical Research Abstracts
Vol. 21, EGU2019-915, 2019
EGU General Assembly 2019

Chaotic features in the dispersion and deposition of aerosol particles: escape rate and lifetime

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In three-dimensional flows, as it is the case in the atmosphere, the advection of particles (emanated e.g., from volcanic eruptions or other pollutant events) exhibits chaotic behavior. Nearby particles diverge within short time, their motion is irregular, and traces out complex but regular (fractal) structures. Due to vertical flows in the atmosphere and due to gravitational force, aerosol particles carry out this complicated, chaotic motion and move downwards on average. Analogously to dynamical systems with transient chaos, we consider the particles that reach the surface to be "escaped" from the atmosphere. The number $n(t)$ of particles not yet deposited from the atmosphere after time t does not change for a while but after a time t_0 $n(t)$ starts to decay rapidly, exponentially: $n(t) \sim \exp(-\kappa(t - t_0))$ if $t > t_0$. Here κ is called the escape rate, $\kappa^{-1} = \tau$ is considered the average lifetime of the particles. We show that for particles initially uniformly distributed on a pressure level all over the globe κ has an approximately exponential dependence on the particle size, and, as well as, it fluctuates slightly also in time for particles initiated at different time instants in a year. We also demonstrate that the geographical distribution of the individual lifetime of the particles shows a filamentary, fractal geometry, typical for chaos, i.e., the strength of the deposition may be quite different at very nearby geographic locations (e.g., 10 days to 100 days for particles of 5 μm diameter). The structure of the map of individual lifetimes becomes finer with decreasing particle size. The longest lifetimes can be observed near the thermal equator; therefore, also the unstable manifold (of a hypothesized chaotic saddle) lies mainly in this region and wanders with it along the year. We shows that the typical structure of the individual lifetimes is somewhat smoothed out but does not change remarkably when turbulent diffusivity with values characteristic in the atmosphere is taken into account. The trajectories of aerosol particles are obtained from the Real Particle Lagrangian Trajectory (RePLaT) atmospheric dispersion model [1] by solving Newton's equation and taking into account turbulent diffusion as an additional stochastic term.

[1] Haszpra, T., Horányi, A. (2014): Some aspects of the impact of meteorological forecast uncertainties on environmental dispersion prediction. Időjárás, 118 (4), 335–347.