An online coupled Lagrangian particle dispersion model for COSMO

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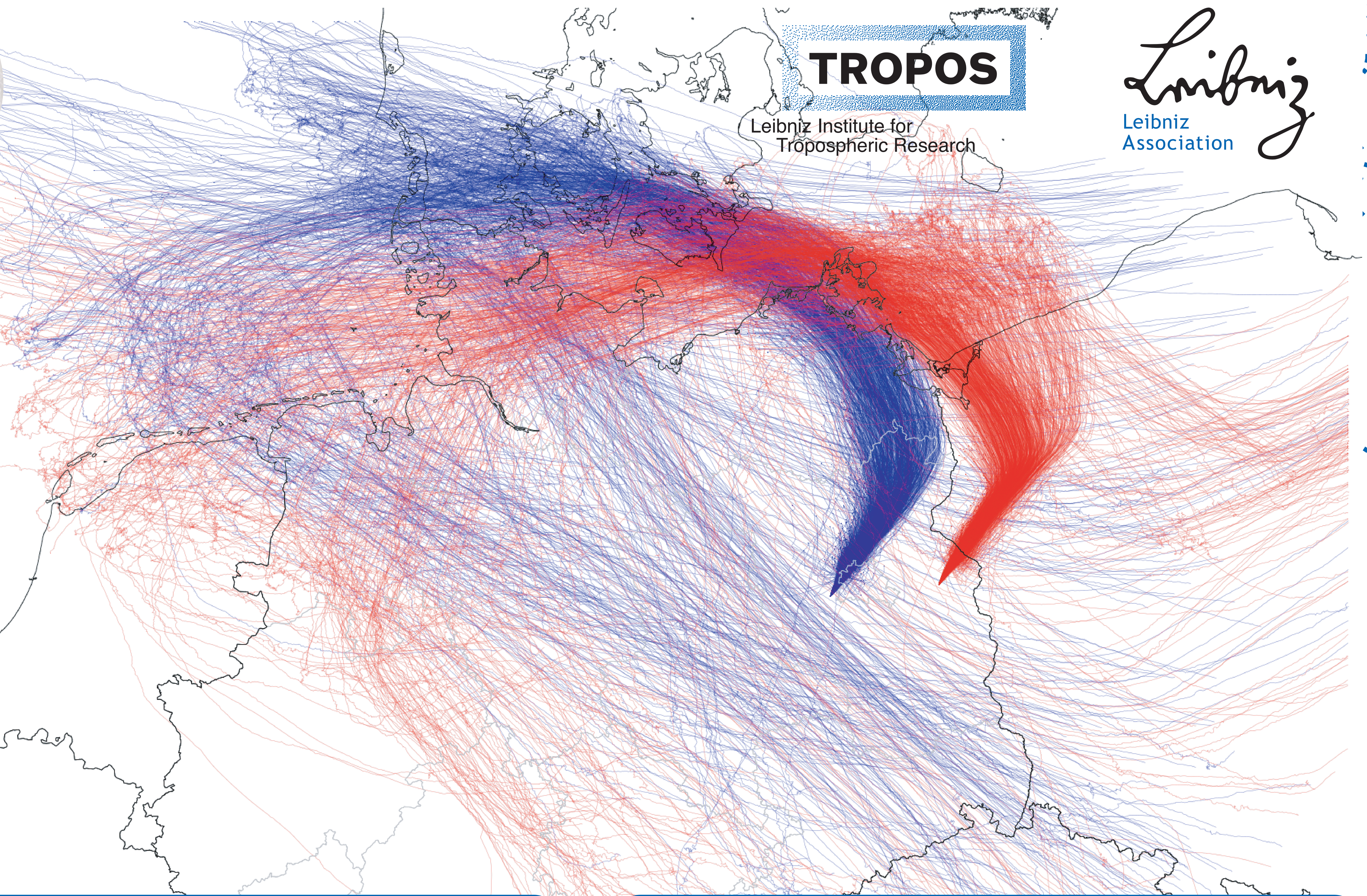

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Introduction

Trajectories are a common method to investigate the pathway of an air parcel through the atmosphere. Unfortunately, a single trajectory is not able to represent the air flow inside the atmospheric boundary layer correctly because of the strong disturbance by turbulences. The Lagrangian particle dispersion model (LPDM) uses a stochastic approach to calculate the turbulent displacement of the trajectory. Thousands of these trajectories combined yield to the dispersion of air parcels inside the boundary layer.

Based on the COSMO trajectory module[1] we develop the LPDM LaPaSi (Lagrangian Particle Simulation) which calculates the trajectories of weightless particles that are not able to leave the boundary layer.

Integration

Mean wind trajectory

- The mean wind part ($\overline{\boldsymbol{x}}$) of the particle motion is calculated with an iterative scheme, adapted from the COSMO trajectory module[1]

$$\overline{\boldsymbol{x}}_{t+1} = \boldsymbol{x}_t + \frac{\boldsymbol{u}_t(\boldsymbol{x}_t) + \boldsymbol{u}_{t+1}(\overline{\boldsymbol{x}}_{t+1})}{2}\, dt$$

Turbulent disturbance

- The standard deviation of the turbulence ($\boldsymbol{\sigma}$) can be described as the turbulent kinetic energy ($\overline{e}$) with a directional weighting ($\boldsymbol{m}$, Tab. 1)
- The correlation ($\boldsymbol{R}$) between the actual and the previous turbulence depends on the model time step and the characteristic time scale τ_L
- τ_L is the ratio of the diffusion coefficient ($\boldsymbol{K}_m$) to the variance of the turbulence

$$\boldsymbol{\sigma} = \sqrt{2\boldsymbol{m}\overline{e}} \qquad \boldsymbol{R} = \exp\left(-\frac{dt}{\tau_L}\right) \qquad \tau_L = \frac{\boldsymbol{K}_m}{\boldsymbol{\sigma}^2}$$

	stable	neutral	unstable
m_u	0.54	0.54	0.40
m_v	0.37	0.30	0.30
m_w	0.09	0.16	0.30

Tab. 1: Weighting factors[2]

- The first part of the turbulent wind velocity ($\boldsymbol{u}'_t$) describes the conservation of momentum
- The second part is a random displacement with the magnitude of $\boldsymbol{\sigma}$
- $d\xi$ is a normal distributed random number

$$\boldsymbol{u}'_t = \boldsymbol{R}\,\boldsymbol{u}'_{t-1} + \boldsymbol{\sigma}\,\sqrt{1-\boldsymbol{R}^2}\,d\xi$$

- The turbulent part ($\boldsymbol{x}'$) of the particle motion is calculated with an Euler forward step

$$\boldsymbol{x}'_{t+1} = \boldsymbol{u}'_t(\boldsymbol{x}_t)\,dt$$

Possibilities

- Simulation of transport processes inside the atmospheric boundary layer
- Stochastic reproduction of particles dispersion
- Accuracy calculation due to the online coupling
- Stable processing of 10^6 trajectories
- NetCDF output of the trajectories and the trajectory density
- Dry deposition – in test mode

Performance

- In the parallel program, a MPI process can only calculate trajectories in its own physical subdomain
- Worst case: if all particles are located in one subdomain all the work is done by one process

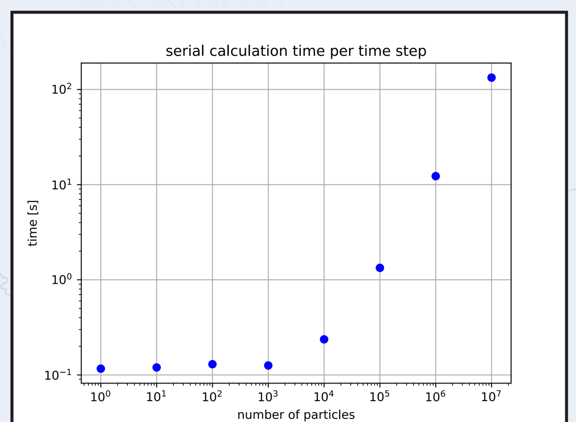

Fig. 1: Calculation time for a single time step

- Communication between the processes is only necessary if a particle leaves its subdomain[1]

Case study

Leaking pressure gas tank in Vřesová 10 November 2010

- Emission of pollutants in the morning until 01.30 pm in Vřesová (Czech Republic); in the afternoon, complaints about unpleasant odors in several towns in the Erzgebirge.
- This case was simulated with 1000 m spatial resolution of the COSMO-model; LaPaSi emitted between 09.00 am to 01.30 pm 36000 particle per hour.
- Air masses from Vřesová reach the target regions on two differed pathways (Fig. 2).
- The highest particle concentration was calculated in a height of 200 m above the target region (Fig. 3), however the surface level is influenced as well.
- The animation shows that the air accumulates in front of the mountains; early and late emitted particles overlap and reach the targets at the same time.
- Based on this study, a link between the gas leak and the odor is plausible.

See an animation with 200 m spatial resolution

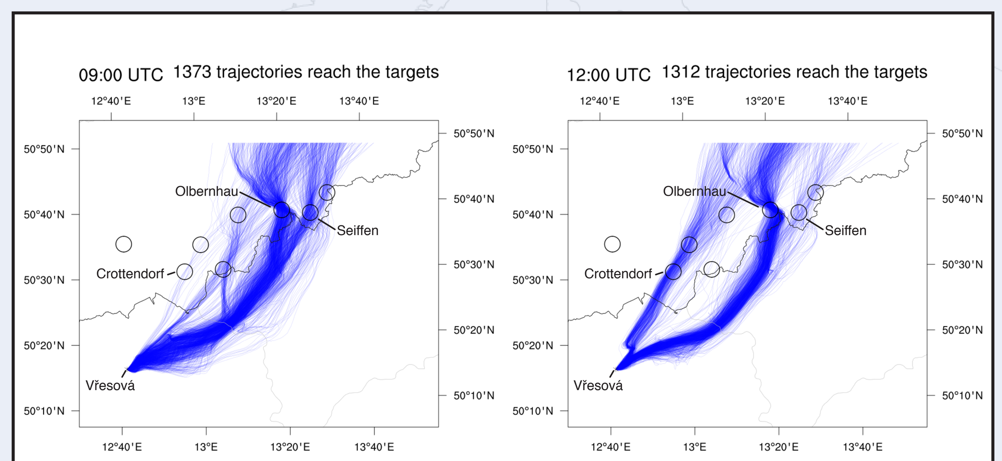

Fig. 2: Trajectories that reached the target regions above 100m altitude; emission between 09.00 am and 10.00 am (left) and 12.00 am and 01.00 pm (right)

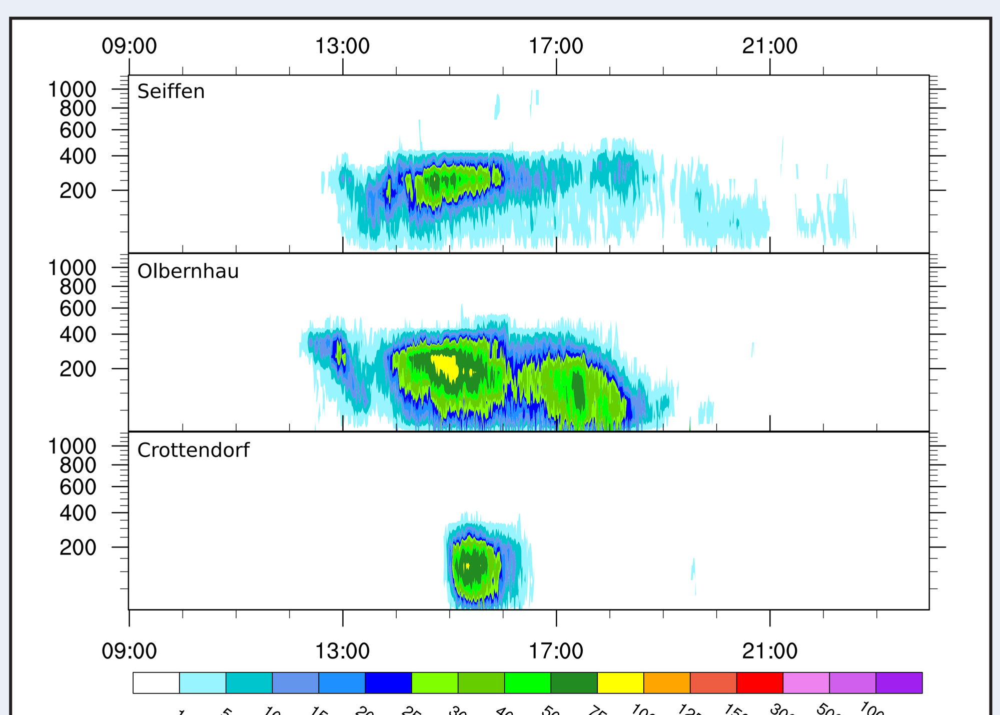

Fig. 3: Vertical trajectory density above the target regions

References

[1] **Miltenberger, A. K.**, Pfahl, S., and Wernli, H.: An online trajectory module (version 1.0) for the nonhydrostatic numerical weather prediction model COSMO, Geoscientific Model Development, DOI 10.5194/gmd-6-1989-2013, 2013.

[2] **Panitz, H.-J.**, Vogel, B., und Vogel, H.: The Lagrangian Particle Model Traveling Version 92/3, Tech. rep., Kernforschungszentrum Karlsruhe, 1994

Conclusions

We successfully implemented an LPDM for the COSMO-model. This allows accurate simulations of transport and dispersion processes inside the atmospheric boundary layer. First results show realistic trajectory pattern in a complex mountain region. Therefore, LaPaSi is an useful tool for many applications.

Outlook

- The model is used in the Leibniz project SOARiAL (Spread of antibiotic resistance in an agrarian landscape).
- The aim of SOARiAL is to simulate the dust borne transport of pathogenic bacteria.