Comparison of Receptor-Oriented Dispersion Calculations Based on ECMWF Data and Nested MM5 Simulations for the Schauinsland Monitoring Station

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1 Motivation

The German Federal Office for Radiation Protection (Bundesamt für Strahlenschutz) maintains monitoring sites for airborne radioactivity measurements. For our work, we are focusing on the mountain station Schauinsland (1200 m) and the station Freiburg im Breisgau (270 m), located in the Rhine Valley (Fig. 1 (left)). Schauinsland is also the only station located in Central Europe among the 80 radionuclide monitoring stations being built up for the operational monitoring of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) by its Provisional Technical Secretariate (PTS) in Vienna. In addition, the Federal Office of Environment (Umweltbundesamt) carries out monitoring of background atmospheric conditions at Schauinsland.

Observations in the past have shown that Schauinsland and Freiburg may sample different air masses depending on the meteorological situation. For the investigation of atmospheric trace substances, receptor-oriented dispersion models with meteorological input data from ECMWF analyses are presently used by the PTS. It is obvious that on this base the differences in the airmass origin are probably not captured. The work presented here was thus guided by the following questions:

- Can the origin of air masses at the two stations be simulated better based on a high-resolution, nested meteorological model than a based on a global model?
- For which weather patterns are differences significant? Could such patterns be diagnosed from available data?
- Is it possible to obtain an improved consideration of orographic effects with simplified methods such as using an elevated receptor position for the mountain station?

These questions have been answered by simulating several episodes with FLEXPART, based on ECMWF fields and MM5 calculations.

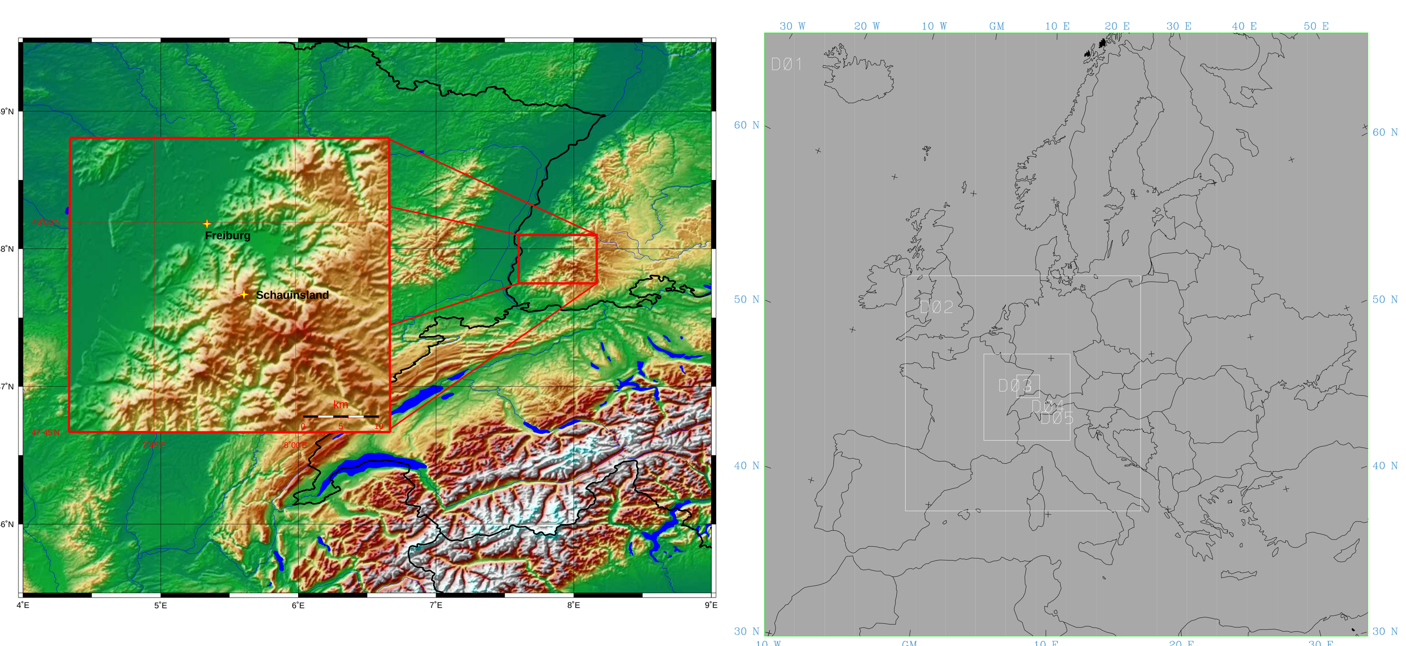


Figure 1: Area of interest (left) and MM5 model area setup with 4 nests (right).

2 Model description

2.1 MM5 meteorological model

The nohydrostatic meteorological model MM5 (Grell et al., 1994) is used in this study to generate high-resolution meteorolgical fields.

- initial and boundary condition: 1°×1° ECMWF data
- Mother and 4 nests (Fig. 1, right)
- horizontal resolution (D1–D5): 54, 18, 6, 2 and 0.67 km grid distance
- 2-way nesting
- NOAH land-surface scheme, Kain-Fritsch convection scheme for D1 and D2, Reisner 1 for precipitation, cloud-radiation scheme with shadowing effects, radiative upper boundary condition for dynamics
- Grid-nudging every 3 h with ECMWF data (1°×1° resolution) on the coarse domain

2.2 Lagrangian particle model FLEXPART

FLEXPART (Stohl et al., 2005) is a Lagrangian particle dispersion model (LPDM) initially developed at BOKU-Met, based to some extent on the older trajectory model FLEXTRA. It simulates the transport, turbulent diffusion, dry and wet deposition, convection and radioactive decay of air pollutants released from any kind of sources. There is a special option for backward calculations, giving a source-receptor relationship (sensitivity), which is closely related to residence times, instead of a concentration (see Seibert and Frank (2004) for details). It was used in the latest version 6.2.

For application with MM5, the old FLEXPART-MM5 version based on FLEXPART v3 was reprogrammed to reflect the latest developments. Two specific improvements have also been introduced:

- Replacing the constant map scale factor for the MM5 grid by exact an transformation in geographical grid
- Introducing an option of z-diffusion (horizontal diffusion cannot change the height of a particle above sea level, instead of acting on surfaces parallel to the topography). This feature is important for high-resolution simulations over mountain topography.

This new version will soon be made public, at the moment a beta version can be obtained from the author.

Setup used:

- backward mode
- temporal resolution of input meteorological fields 3 h (for ECMWF), 1 h (for MM5)
- temporal resolution of output: 3 h
- horizontal resolution of output: 0.5° and (nest over Central Europe) approx. 8 km
- vertical layer thickness for ouput: 150 m with ECMWF input, 25 with MM5 input
- number of particles per receptor day: 150,000 / 180,000

3 Selected episodes

A total of 10 (nomiminally 11) periods with duration from 5 to 10 days have been selected. On this poster, we show results of four periods to illustrate the main findings:

- Episode 3 from 3–11 Nov 2004 with strong northwesterly, later northeasterly flow
- Episode 8 from 31 Jan – 8 Feb 2004 with strong southwesterly flow
- Episode 5 from 19–24 June 2005 with anticyclonic summer conditions
- Episode 9 from 8–17 Dec 2004 with anticyclonic winter conditions (inversion)

4 Results of meteorological simulations

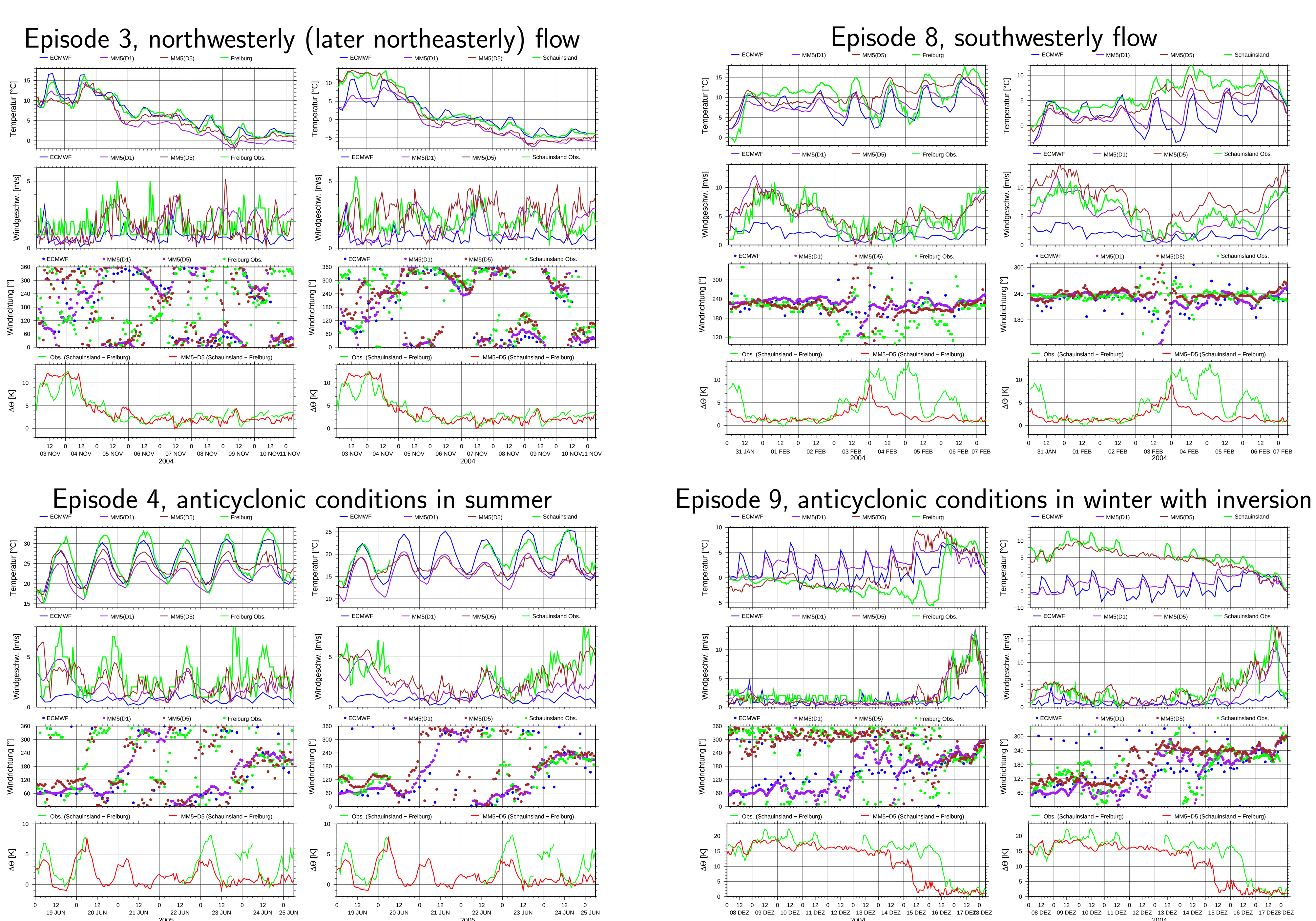
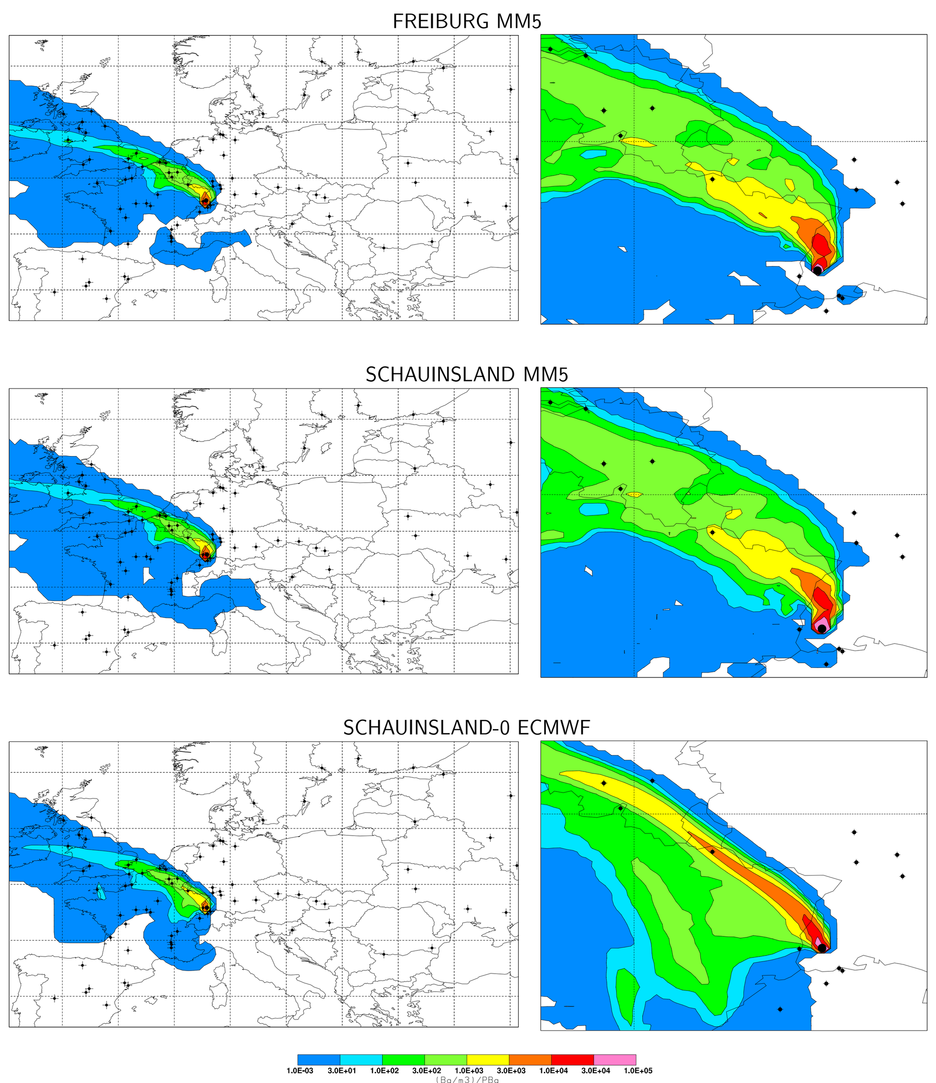


Figure 2: Comparison of observations, ECMWF analysis on 1°, MM5 domain 1 (54 km), and MM5 domain 5 (0.67 km) of temperature and wind in Freiburg (left column) and Schauinsland (right column). The last row gives the potential temperature difference as a stability index, it is repeated to provide the time scale for the right column, too.

The comparisons in Figure 2 largely speaks by themselves. In episode 8, MM5-D5 is overestimating the southwesterly wind at Schauinsland because of local sheltering of the station (at Feldberg [not shown] MM5 still underestimates!) In episode 9, only MM5-D5 can simulate the inversion, though it is dissolved too early. A new MM5 run with z-diffusion for temperature hopefully solves the problem. MM5 is generally too cold for daytime maxima under fair weather, the reason is unknown. In-valley (westerly, during daytime) and out-valley (easterly, nighttime) local winds are simulated well by MM5-D5 as seen in the first days of episode 5.

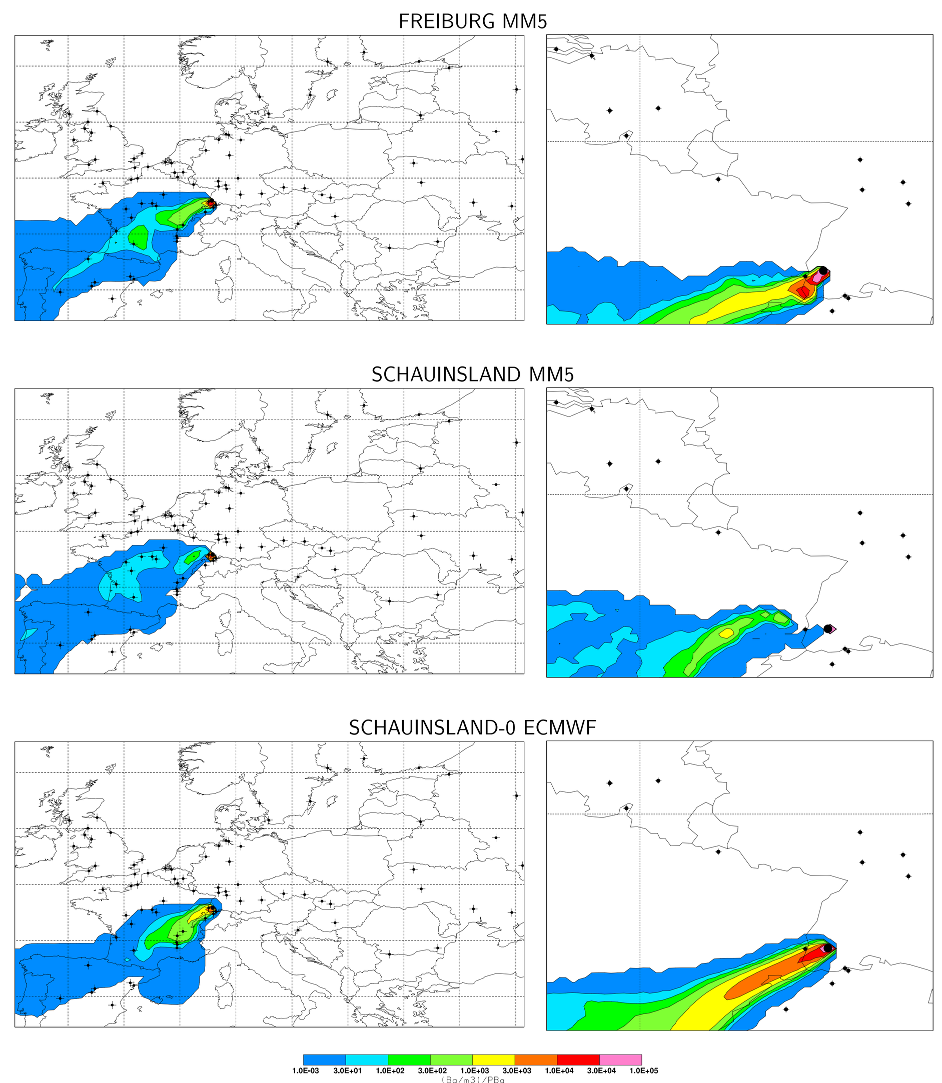
5 Results of dispersion simulations

20041106 06 (Episode 3)



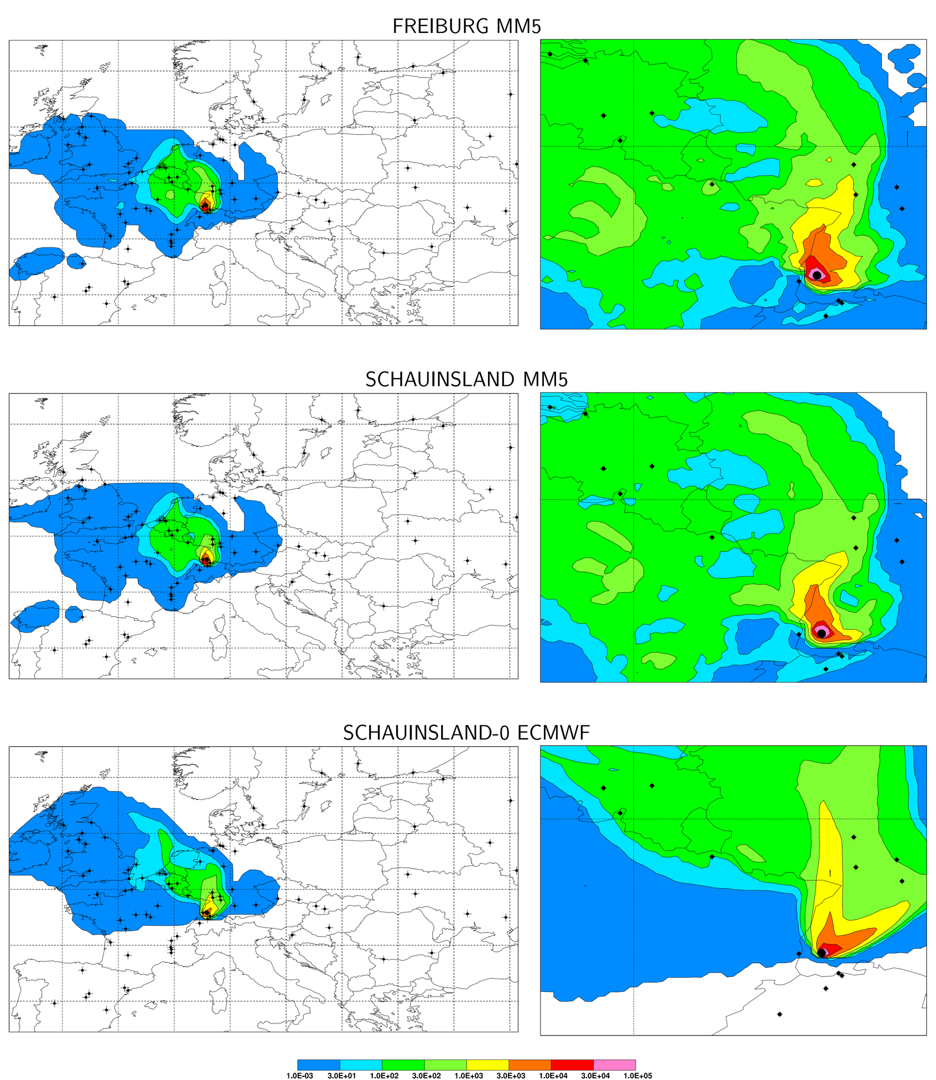
Northwesterly flow situation. All simulations are relatively similar. The isotope factory at Fleurus (Belgium) is a good candidate for the observed xenon peak on this day, though there are a number of nuclear power plants (NPPs) that could also be responsible. MM5-based simulations show more structures, and do not show the extension of the influence region towards central France.

20040203 06 (Episode 8)



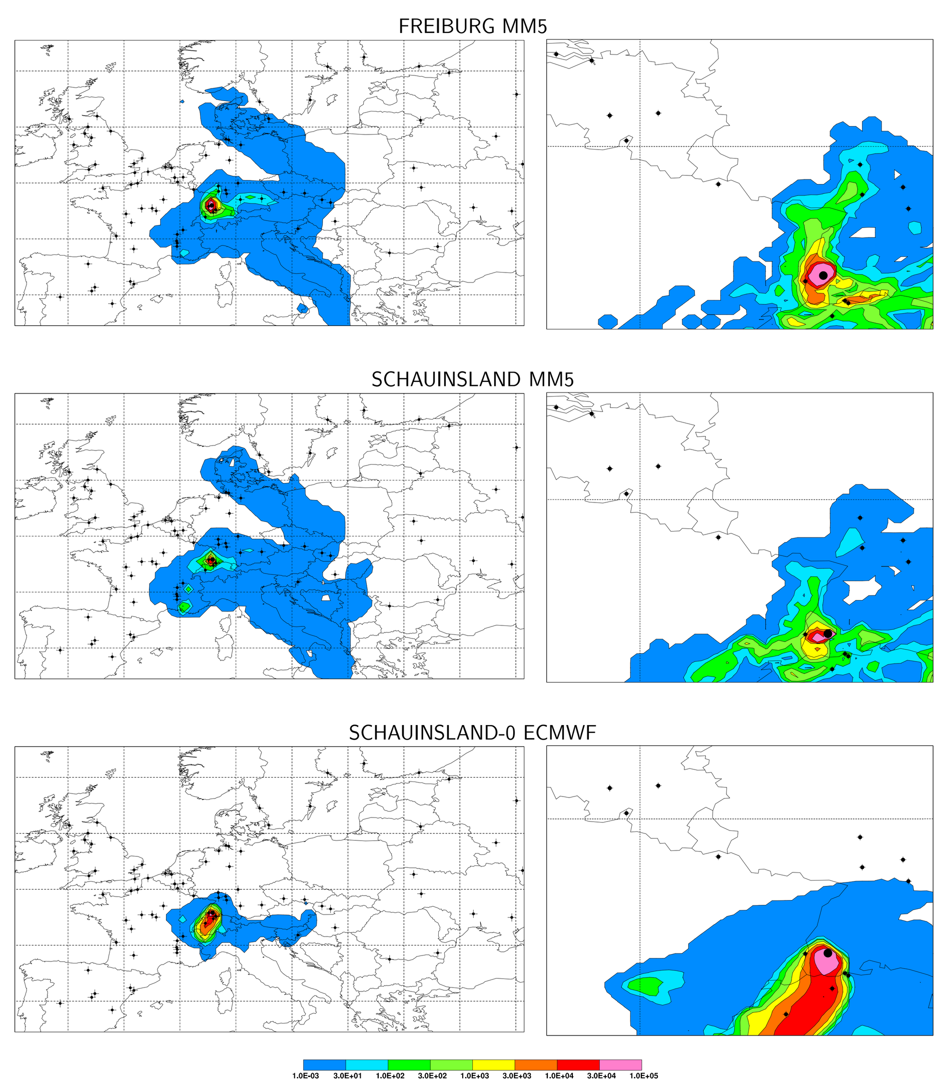
Southwesterly flow situation. MM5-based simulation shows a pronounced weakening of the s–r relationship for Schauinsland mountain as compared to Freiburg because of the high wind velocities on the mountains. The flow channeling in the gap between the Vosges and Jura mountains is nicely visible.

20050623 06 (Episode 5)



Anticyclonic situation in summer. Corresponding to the lower wind velocities and more inhomogeneous flow patterns, a large area is identified as field of regard, with the strongest influence near the receptors. The MM5 simulations concentrate the influence along the Rhine valley. This holds also for Schauinsland as convection and slope winds bring the air from the Rhine Valley up to the peaks. Only the MM5 simulations show a very weak contribution along the Rhone valley, which in many simulations manifests as a flow guide for air later reaching southern Germany or Austria.

20041214 06 (Episode 9)



Anticyclonic situation in winter, strong inversion between Schauinsland and Freiburg. ECMWF-based simulations show an unrealistic advection of the air directly over the Alps. MM5-based modelling shows that for Freiburg the main influence regions are the low-lying areas north of the Alps, especially Rhine Valley, Swiss Midlands, Lake of Constance and southeastern France. On Schauinsland, the influence area goes directly southwards over the crests of the Black Forest, the influence of the lower areas is weaker. Again, the Rhone valley turns out as a weak pathway with possible influence of areas south of the Alps. These air masses rather flow around the Alps, not over the Alps as shown by ECMWF-based simulations.

Figure 3. Source-receptor relationships for 24-hour recptor days ending at the given date. The rows are simulations with MM5-FLEXPART for Freiburg and Schauinsland, and ECMWF-FLEXPART for Schauinsland (receptor height 5 m agl). The zoom shows a part of the nested output domain. Crosses indicate nuclear facilities, the isotope factory at Fleurus in Belgium is marked additionally.

Table 1: Comparison of the s–receptor relationship (correlation oefficients) between Schauinsland (Freiburg) and Fleurus (Belgium) during the studied episode as calculated by different models.

R	FRB-0	SIM-0	SIL-0	SIL-1	SIL-2	HYSPLIT	CTBTO
FRB-0	1.000	0.983	0.613	0.662	0.559	0.243	0.803
SIM-0	—	1.000	0.567	0.625	0.518	0.277	0.791
SIL-0	—	—	1.000	0.980	0.907	0.615	0.763
SIL-1	—	—	—	1.000	0.944	0.527	0.783
SIL-2	—	—	—	—	1.000	0.502	0.792
HYSPL	—	—	—	—	—	1.000	0.610
CTBTO	—	—	—	—	—	—	1.000

Only those days when at least one model has non-zero values are considered (N=22 instead of 44). All values based on 1° s–r data. FRB-0 and SIM-0 refer to MM5-FLEXPART simulations for Freiburg and Schauinsland, SIL refers to ECMWF-FLEXPART simulations (-0 release at 5 m agl, -2 release at true height asl, -1 in-between), HYSPLIT is simple evaluation of HYSPLIT trajectory reseidence times, CTBTO is the ECMWF-FLEXPART simulation by CTBTO/PTS with release distributed 0-200 m agl.

Table 1 gives an overview of the similarity between different simulations for a specific potential source in the Northwest of our receptor. The MM5-based simulation do not differ very little for this situation between Freiburg and Schauinsland. Among the ECMWF-based simulations, the one with an intermediate release level is closest to the MM5-based run. The simple HYSPLIT trajectory evaluation compares worst. CTBTO's ECMWF-based runs have a relatively good correlation with the others, because they have a relatively broad influence region, probably as they release the computational particles initally over a 200-m layer.
However, correlation coefficients of quasi-log-normally distributed data a quite sensitive to the few highest values.

6 Conclusions and outlook

Conclusions:

- The MM5 model is does produce features such as the channelled flow in the Rhine Valley, realistic orographic thermal circulations and inversions under anticyclonic conditions in the cold season. Despite a cold bias for fair-weather daytime temperatures (whose reason could not be clarified) it creates mesoscale wind fields which are clearly better than ECMWF analyses. This was anticipated.
- The MM5 model showed that in southwesterly flow conditions a low-level jet passing through the gap between the Jura and Vosges mountains and impinging on the mountains of the southern Black Forest is being produced. Observations at Feldberg and Schauinsland confirm this result, while the feature is missing from ECMWF fields. This was unexpected.
- On a scale of several hundreds of kilometres, the rough shape of the influence areas (fields-of-regard in CTBTO terminology) produced on ECMWF and MM5 base is relatively similar, though there mayb be significant differences due to orography in detail, which can be important or not, depending on the circumstances.
- The least differences are found in fast northwesterly flows.
- Due to the mentioned jet, the source-receptor sensitivity for Schauinsland is strongly overestimated with ECMWF-based simulations of southwesterly flows.
- Under strong inversion conditions, ECMWF-based simulations deviate strongly from MM5-based simulations.
- Variation of the receptor height only marginally improves ECMWF-based simulations. A receptor height between the true height above sea level of the station and the model topography performs best.

CTBTO may wish to consider these results in the interpretation of their measurements, and for the siting of those stations not yet constructed.

Outlook

There are many ideas for deepening and continuing this work, e.g.:

- Study reasons for cold bias in MM5 simulations and other deficiencies and try to improve them
- Run FLEXPART-MM5 with a very high-resolution output grid (order of 1 km) to show impact of local circulations more clearly
- Full quantitative comparison of source-receptor fields from different simulations as a function of transport distance etc.
- Application of the toolbox created to other mountain observatories, especially those in high mountains (the next level of difficulty). Mountains are often preferred sites for background atmospheric monitoring, but from the point of view of the modeller these are less-than-ideal sites!

Acknowledgments

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