Problems of Atmospheric Transport Simulation for Mountain Oicewbservatories

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Introduction

Even with present-day ECMWF resolution (ca. 0.125°), model topography and real topography differ significantly in mountain areas. This makes accurate atmospheric transport simulations difficult. Influencing factors are discussed and examples are shown in this poster.

Influencing factors and processes

- **Station location and topography:**
  - **Deviation of station height:**
    Mountain top stations will in general be significantly higher than the model ground.
  - **Displacement of crest line:**
    A station that is situated on a major crest, possibly a divide of large catchments, may lie within one of the adjacent catchments in the model topography. Similar deviations are possible with respect to other topographic features.
- **Meteorological processes** can be divided into
  - advective conditions and
  - weak-gradient conditions.

  For *advective conditions*, relevant processes are mainly flow-over versus flow-around topography, of which many variants exist in real complex topography. Correspondingly, the mountain top station may be exposed to more free-tropospheric air or to boundary-layer air. Possible issues:
  - Representation of dry stability as influence factor for wind patterns
  - Representation of resolved-scale moist stability, localised ascent regions as influence factor for wind patterns
  - Representation of cumulus convection
  - Mountain heights and aspect ratios in real and in model topography
  - Representation of gap flows and channeling in valleys

  Under *weak-gradient conditions*, relevant error sources are
  - Representation of dry stability as influence factor for vertical mixing
  - Representation of slope winds
  - Representation of valley winds
  - Representation of cumulus convection

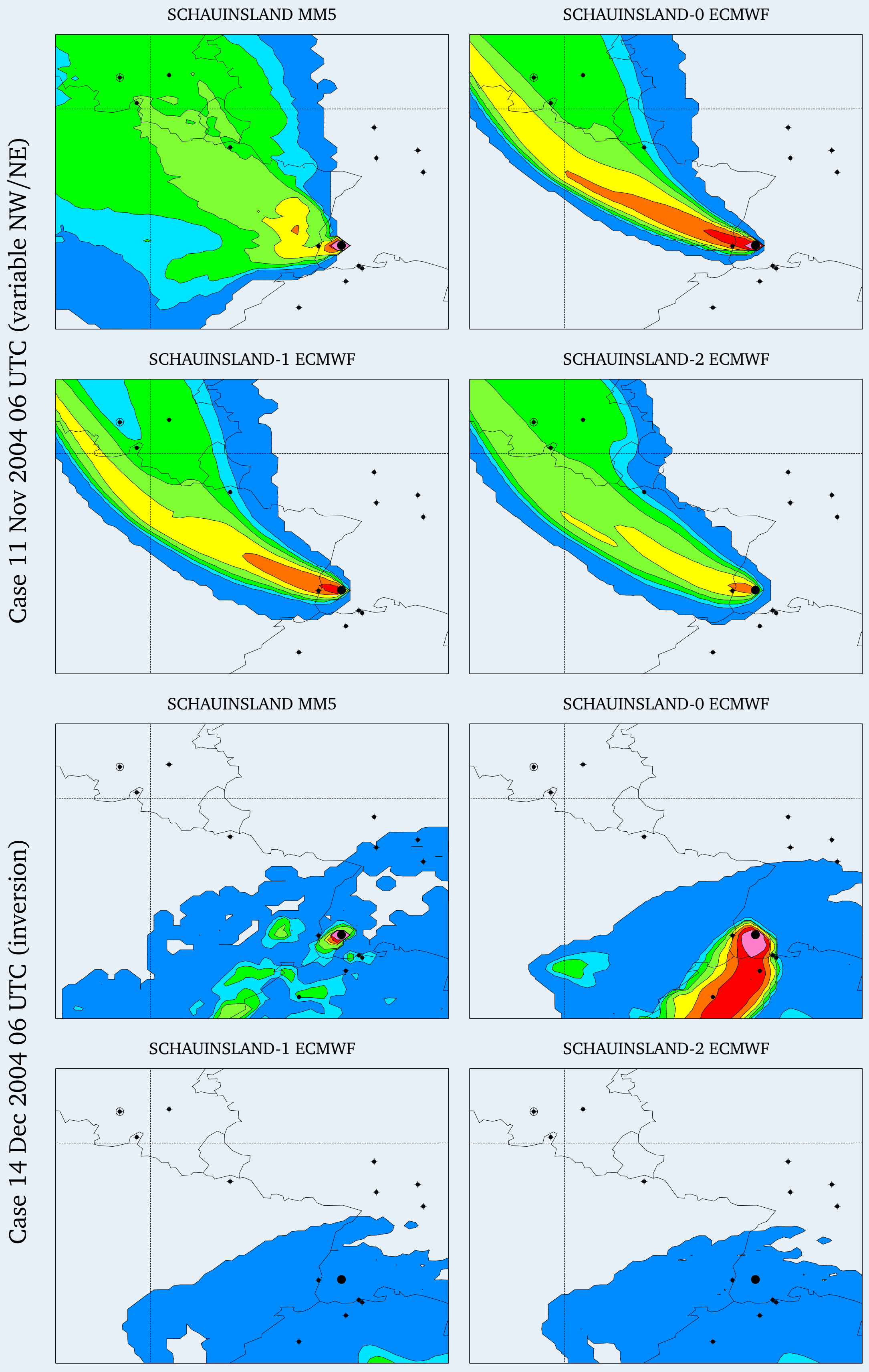
Examples from past studies

Schauinsland project

See Seibert P., Skmorowski P. (2007): Untersuchung der orographischen Besonderheiten der Probennahmestellen Schauinsland und Freiburg und deren Auswirkungen auf die Genauigkeit von adjungierten atmosphärischen Ausbreitungsrechnungen. Bundesamt f˝r Strahlenschutz, Salzgitter / Freiburg. Schriftenreihe Reaktorsicherheit und Strahlenschutz, BMU – 2008 – 713. `http://www.bmu.de/strahlenschutz/schriftenreihe_reaktorsicherheit_strahlenschutz/doc/4187`

- Backward simulations for the Schauinsland station with
  - FLEXPART and ECMWF 0.5°data,
  - FLEXPART-MM5 and MM5 data with 0.67 km resolution in innermost nest.
- Three different receptor heights for ECMWF-based simulations:
  - at ground level (SCHAUINSLAND-0)
  - in the middle between model ground and 1200 m (SCHAUINSLAND-1)
  - At the height of the station above sea level (1200 m, SCHAUINSLAND-2)

Following plots: source-receptor relationships in relative units, log scale.



SCHAUINSLAND MM5
SCHAUINSLAND-0 ECMWF
SCHAUINSLAND-1 ECMWF
SCHAUINSLAND-2 ECMWF

- First case (NW flow): significant difference between simulations. Not much topographic influence in ECMWF simulations.
- Second case (strong inversion): Only the MM5-based simulation gives a realistic example, with influence from the mountain top regions of Black forest, Vosges and Jura. In ECMWF-based simulations, SIL is either below the inversion and then wrongly inflenced by all the area to the south, or above the inversion and almost not seeing anything.

Acknowledgements:
We are thanking the data providers, IRE (Belgium) for the xenon emission data, Bundesamt für Strahlenschutz (Germany) and CTBTO (Vienna) for xenon measurements, Umweltbundesamt (Berlin) for meteorological data of the Schauinsland GAW station, and ZAMG (Vienna) for access to GTS and ECMWF meteorological data.

Global CFC inverse modelling

A global inverse modelling for HFC-134a was carried out, with atmospheric transport modelled by FLEXPART using ECMWF fields at 1° resolution and 60 levels. No special treatment was given to mountain stations.
The table shows the relative RMS error reduction achieved by the adjusting the emissions in the inversion, and the squared correlation coefficients with first guess emissions (R_a^2) and posterior emissions (R_b^2):

Station	*Error reduction*	R_a^2	R_b^2
Jungfraujoch, 3450 m	**4.6 %**	**0.08**	**0.11**
Monte Cimone, 2165 m	**9.6 %**	**0.30**	**0.39**
Barbados (Carribean)	12.5 %	0.68	0.74
Zeppelin (Spitsbergen)	17.1 %	0.93	0.95
Hateruma (Okinawa, JP)	23.9 %	0.78	0.85
Mace Head (Ireland)	39.8 %	0.75	0.86
Cape Grim (Tasmania)	41.9 %	0.89	0.92
Trinidad Head (N. California)	54.8 %	0.50	0.77

From:
Stohl, A., Seibert, P. et al. (2009): An analytical inversion method for determining regional and global emissions of greenhouse gases: Sensitivity studies and application to halocarbons `http://www.atmos-chem-phys.net/9/1597`

It is clear that the model performance is much worse for the two mountain stations, and that it can't be improved much by the inversion. Also, Jungfraujoch (higher station) has worse results than Monte Cimone. This shows that the practical value of trace substance monitoring at high mountain stations suffers from our lack of ability to model transport to such sites well.

"Atmospheric Transport Challenge"

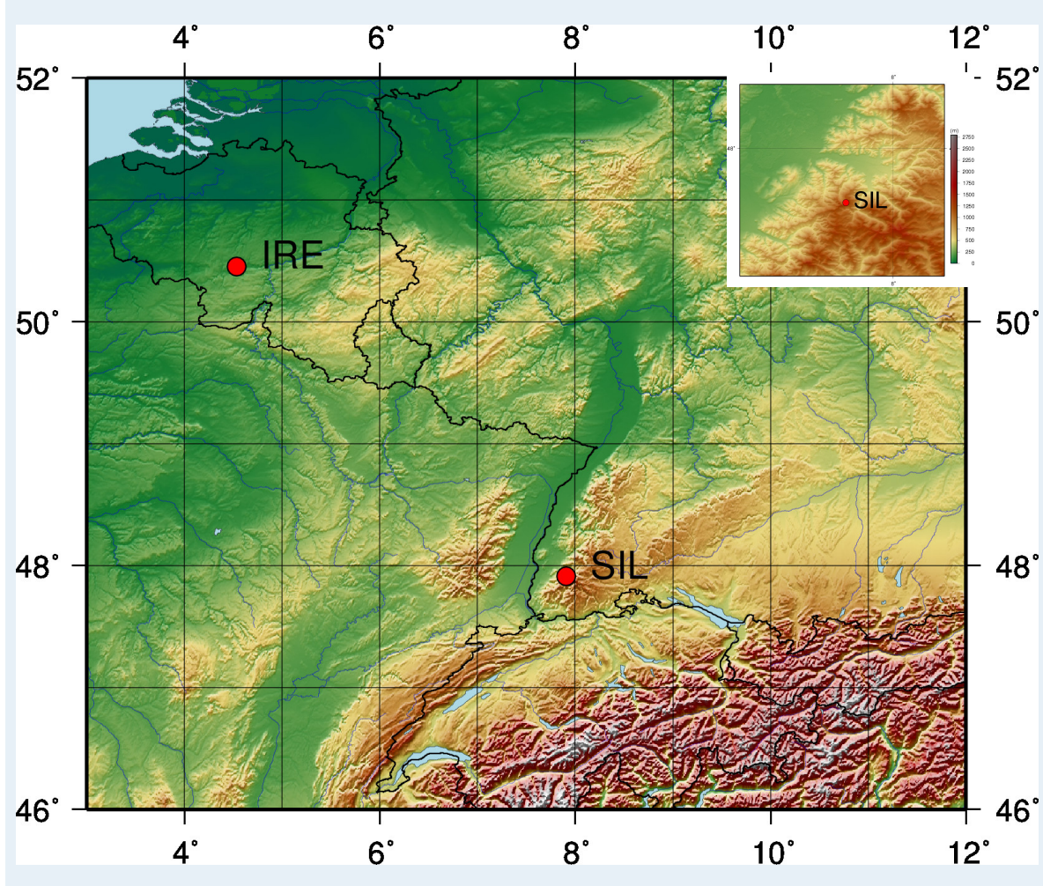
Background

- The Comprehensive-Nuclear-Test-Ban-Treaty Organisation (`www.ctbto.org`) builds and operates a global network for monitoring airborne radioactivity as a part of its mandate to verify the Treaty.
- Radioactive xenon (esp. ^{133}Xe) is to be measured at 40 stations around the globe, one of them being Schauinsland (henceforth **SIL**, CTBTO station code DEX33) at 1205 m asl just below the peak of Schauinsland mountain in the Black Forest, Germany.
- Production facilities for radiopharmaceuticals release significant amounts of radioxeon. Even though the emissions are well within the limits in terms of radiation protection, they are measured in the highly sensitive CTBTO network and are able to mask weaker traces from underground nuclear tests. One such facility which often influences the SIL station is the *Institut national des radioéléments (IRE)* in Fleurus, Belgium.
- The CTBTO science community conducted a numerical experiment, called *"ATM challenge"*, where Xe concentrations at SIL caused by IRE emissions were simulated based on detailed emission data provided by IRE, and measurements for comparison being available from CTBTO and German BfS.
- IMGW / BOKU participated in the ATM challenge with different simulations. The simulations and the insights they provide on atmospheric transport simulation in complex terrain are presented and discussed below.

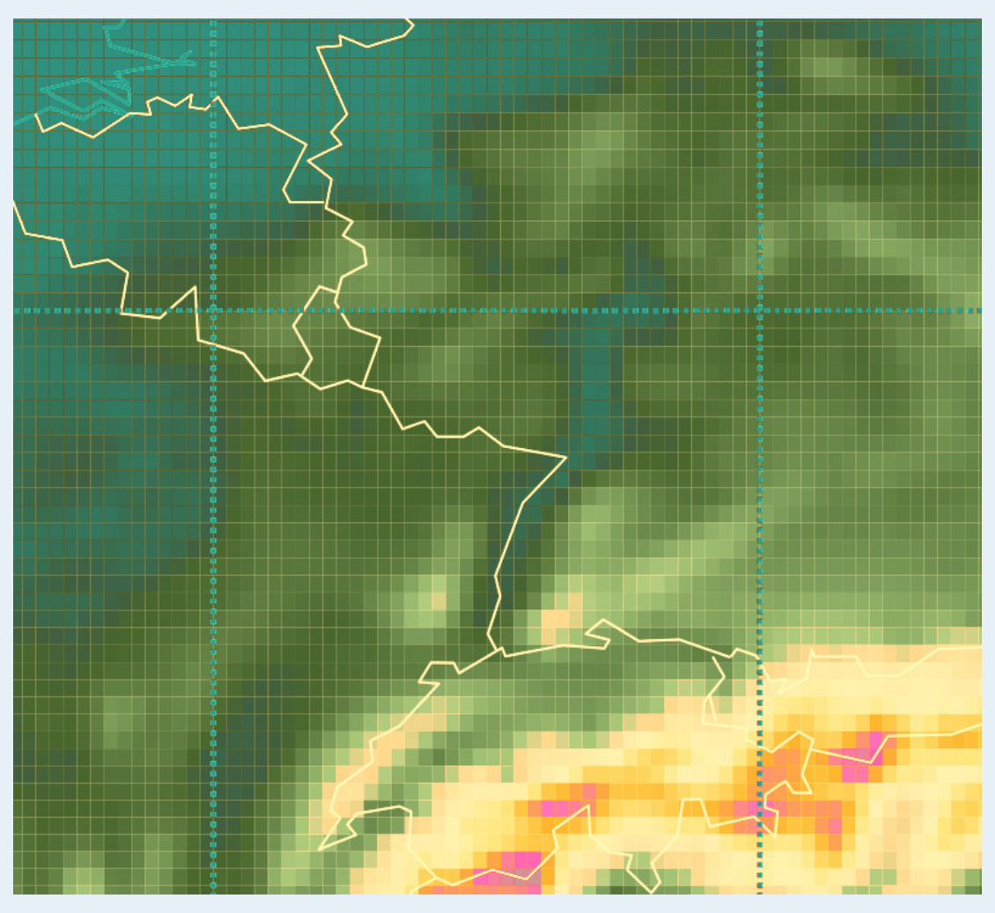
Our calculations

- Backward calculations with FLEXPART, using various receptor heights
  - using different meteorological input: ECMWF operational analysis (6 hrly) + forecasts (+1 … +5 h) at 0.125°; the same with 0.2° and +3 h forecast (and fields from ZAMG, not shown)
  - using different receptor heights where particles are released at Schauinsland: at 1200–1210 m asl; in a 10 m interval determined by the level where observed potential temperature is found in the ECMWF profile, but with 1200 m asl as upper bound; and a surface release (0–100 m agl[model].
  - 7 d back, 4E6 particles per calculation, one calculation per 24-h measurement interval, source resolution 5 km / 1 h.
  - Concentrations are obtained by multiplying source-receptor relationships from the FLEXPART output with Fleurus emissions aggregated to 1 h resolution, slightly smoothed.
- Forward calculations with FLEXPART
  - finest ECMWF resolution as above
  - tracking particles for 4 d
  - only for period 20 Nov 06 UTC – 4 Dec 06 UTC
  - source with 15 min resolution, number of particles <2.3E6
  - receptor: 1 h resolution, 20 vertical layers from 0–2000 m agl[model], 15 km grid (around SIL, 5 km)

Topography

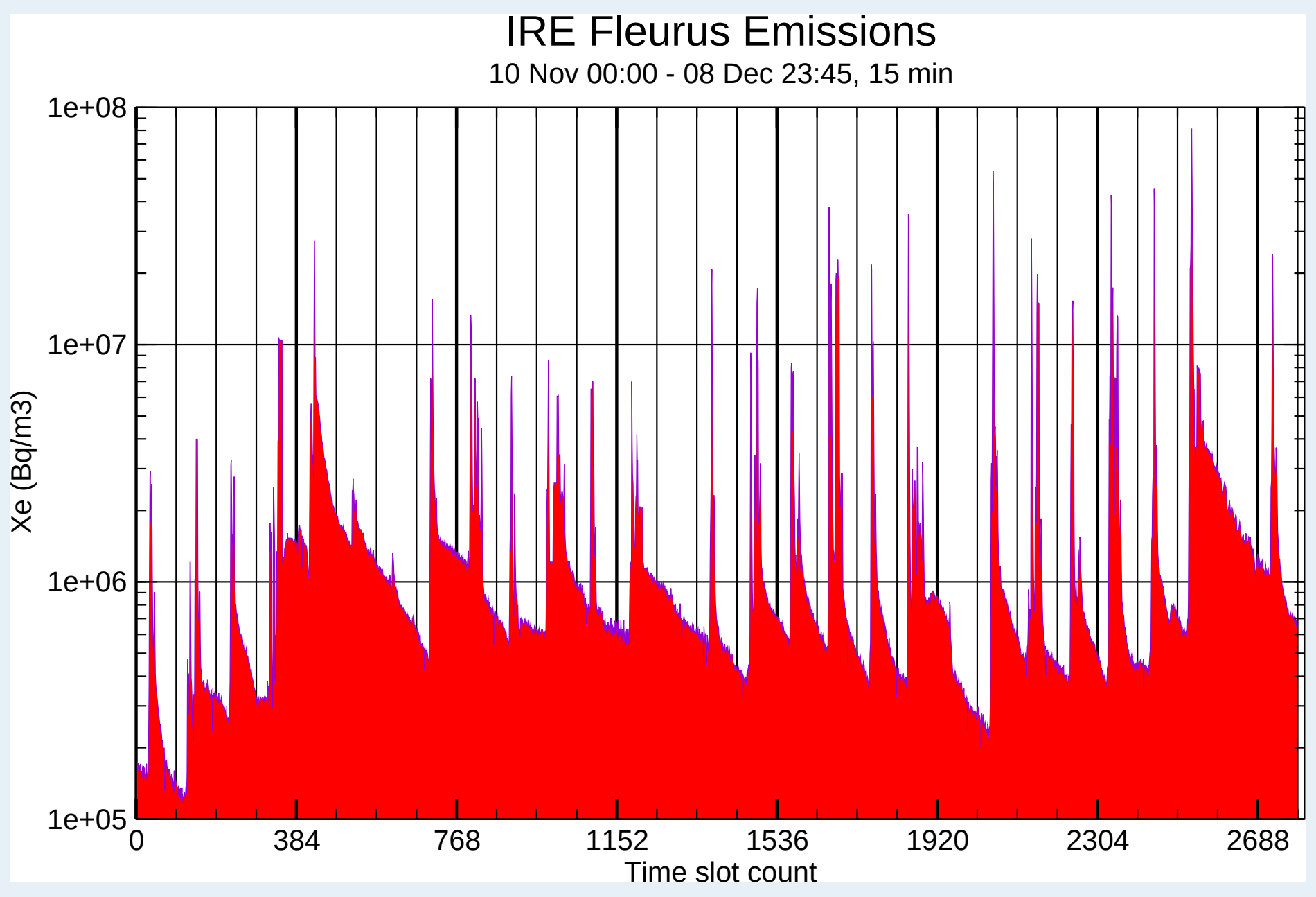


High-resolution topography with zoom to Schauinsland region.



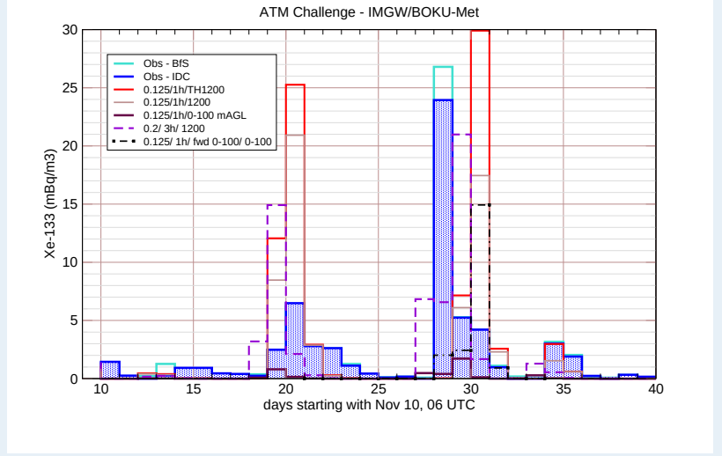
ECMWF model topography (0.125°)

IRE Xe-133 emission data

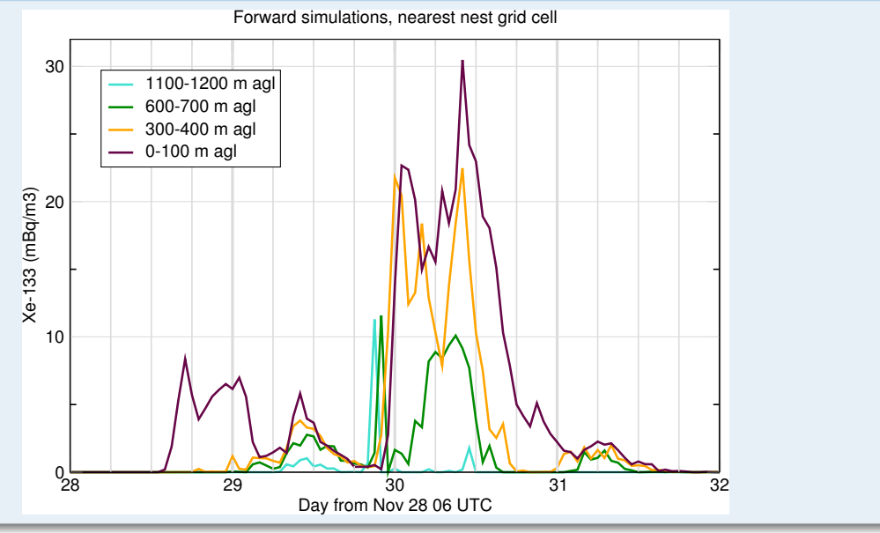


- Location see map above
- Temporal resolution is 15 min
- Main grid has 1 d spacing
- Emissions typically are composed of a continuous background release and a large peak on each work day, but there is some day-to-day variability

Simulated and observed Xe time series



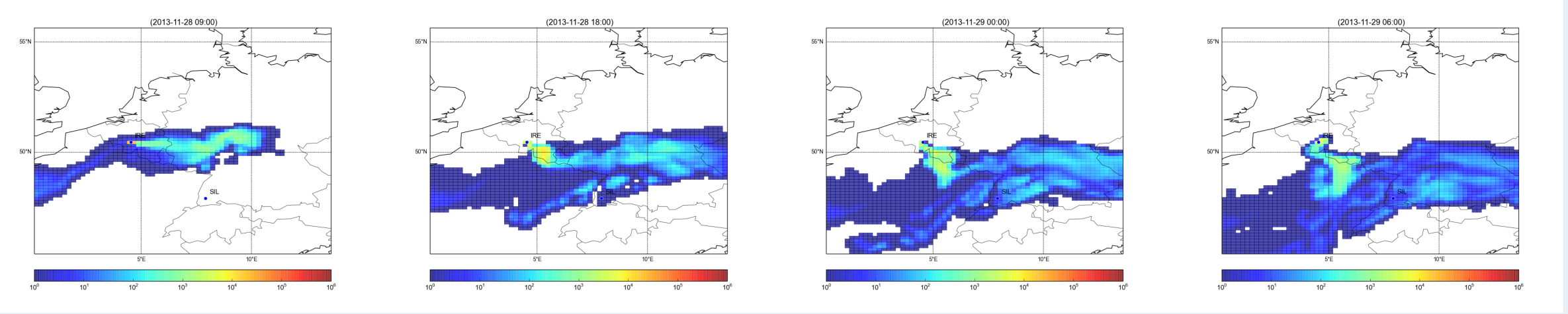
High-resolution Xe time series from forward simulation



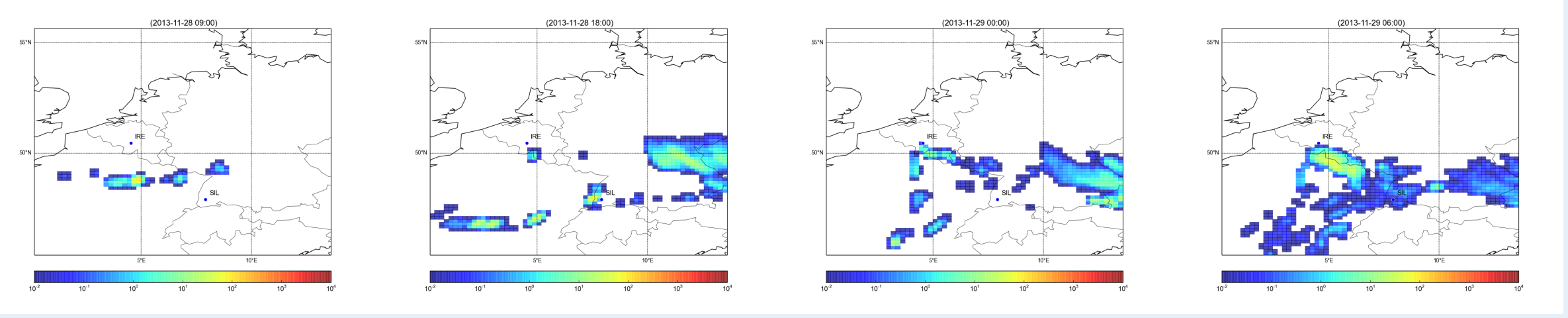
- Xe measurements have 24 h resolution (from 06 to 06 UTC), therefore simulations were also carried out for these intervals.
- Two major peaks were both observed and simulated in the 1-month period considered.
- The timing of the first peak is ok in most simulations, but the height is overestimated.
- The second peak has good agreement for its height in the "best" simulation (red curve), but it is found 2 d later than the observed one. This is surprising, and will be discussed below using a time series concentration maps
- A realistic peak height in backward simulations is obtained only if we release the numerical particles at about the real height of SIL and not for a release at the model surface.
- However, forward simulations sampled at ground level give heigher concentrations than corresponding backward simulations. At 1200 m asl, forward simulations yield very low concentrations (not shown). This will also be discussed below.
- Events of 28 Nov and 30 Nov clearly separated.
- 28 Nov event extremely shallow.

Simulated concentration maps for the observed peak on 28 - 29 Nov

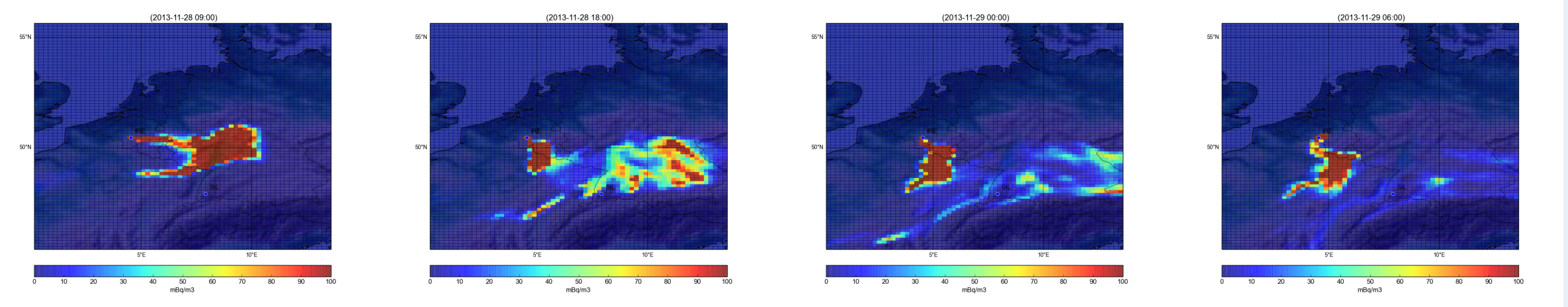
Surface concentrations, log scale



Concentrations in 500–600 m above ground level (of the model), log scale

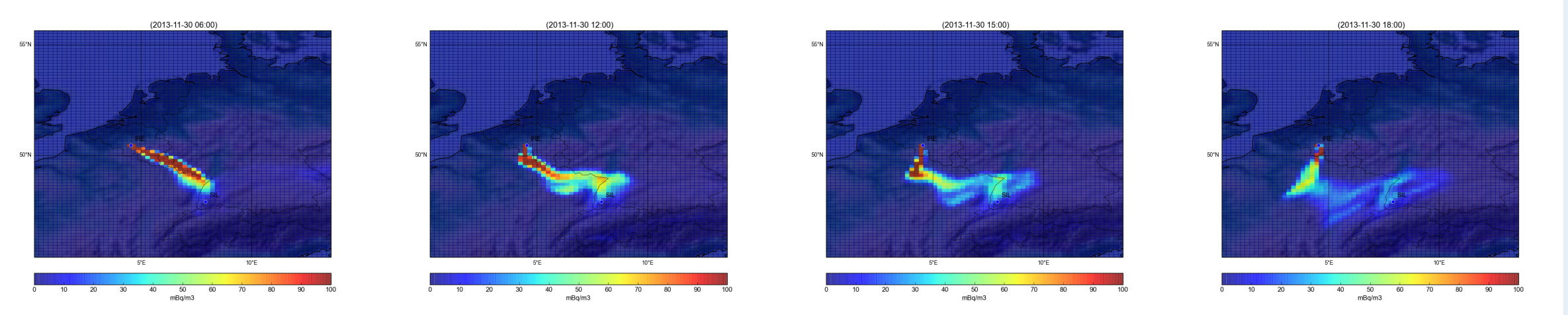


Vertically averaged concentrations between 0 and 1000 m above model ground level, linear scale with real topography in the background



Simulated concentration maps for the simulated peak 30 Nov - 01 Dec

Vertically averaged concentrations between 0 and 1000 m above model ground level, linear scale with real topography in the background. Note that frames are for 06/12/15/18 UTC.



Discussion

- The transport pattern for the 28 Nov peak is very complex. The model confines the xenon to a shallow layer which enters the Rhine valley. Easterly large-scale winds lead to the plume being mainly located in the western part of the valley. Thus, the the bulk of the plume does not hit SIL.
- In reality, some of the plume may have been entrained into the side valley leading up to SIL and Feldberg, but this cannot be resolved in the model. At the end of the valley, moist-adiabatic ascent could have occured (observations show 100% moisture at SIL and stable startification between Freiburg and SIL with respect to θ).
- The model very nicely resolves topographical influences on the flow and concentration pattern: outflow from the Rhine valley through the Porte de la Bourgoigne (Burgundische Pforte), some transport along the Swiss Midlands with bise, and flow splitting for the Alps as a whole.
- The peak simulated on 30 Nov is associated with more simple flow patterns, but topographical influences are still strong. It is not clear why observations don't show a strong peak on this day. This peak and the observed peak are clearly separate events.
- The difference between forward and backward simulations is remarkable, especially with respect to the vertical profile (we don't have an explicit vertical profile for the backward simulations, only two levels, but they show higher concentration at upper levels whereas the forward simulations show the opposite). This deserves more detailed investigation. Usually, such differences are a sign of numerical errors. With the strong horizontal gradients in the complex terrain, numerical errors related to horizontal diffusion along coordinate surfaces or other topography-related numerical effects could be the cause.
- Most other ATM challenge participants had too low peak values, and most of them used a receptor at or near model ground level. Even though we have seen that in this situation, the problem is clearly 3D and not just vertical, this is a hint that mountain station heights should be considered.
- ATM challenge participants who produced a peak on 28 Nov typically used coarse meteorological data and/or a course resolution of the source and/or receptor (e.g., 1°). Therefore, they were not plagued by details of topography. However, they have not much chance to get the details, including peak height, right.

Conclusions

- Atmospheric transport models cannot simulate transport to mountain observatories as well as in less complex terrain.
- This holds even for moderately complex terrain such as the Black Forest region and the lastet version of ECMWF with approx. 10 km horizontal grid spacing and excellent vertical resolution.
- The potential influence factors which escape simulation are numerous.
- Deficiencies may not only be found in the driving meteorological data but also in the numerics of Lagrangian particle dispersion models (and Eulerian models as well, of course).
- Representing a monitoring station sited on a mountain by a receptor at model ground is probably not the best choice. A height somewhere between the surface and the real height above sea level may be best.
- The problem does not only consist of finding the right receptor height, it is three-dimensional!
- This has significant impacts on studies relying on GAW stations situated on mountains for global simulations.