Problems of Atmospheric Transport Simulation for Mountain Observatories

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Introduction

Using a global 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 paper.

Influencing factors and processes

- Variations in wind 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 wave-crest 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 recent advection as influence factor for wet patterns
- Representation of cumulus convection
- Mountain height and aspect ratio in real and model topography
- Representation of pop 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


Our calculations

Backdored calculations with the Schauinsland station with FLEXPART and ECMWF 0.125°, FLEXPART-MM5 and MNS data with 0.67 km resolution in innermost nest.

- Three different receptor heights for FLEXPART-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.

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 spatial treatment was given in mountain situations.

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 ($r_1^2$) and posterior emissions ($r_2^2$).

<table>
<thead>
<tr>
<th>pleasures</th>
<th>Error reduction</th>
<th>$r_1^2$</th>
<th>$r_2^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xe-133</td>
<td>4.5%</td>
<td>0.98</td>
<td>0.91</td>
</tr>
<tr>
<td>Chlorine</td>
<td>11.0%</td>
<td>0.96</td>
<td>0.95</td>
</tr>
</tbody>
</table>

In reality, some of the plume may have been entrained into the side valley leading up to Sin and Feldberg, although this cannot be resolved in the model. At the end of the valley, moist-advection could have occurred (observations show 100% moisture at Sil and stable stratification between Freiburg and Sil with respect to $b$). The plume does not hit Sil.

The model very nicely respects topographical influences on the flow and concentration pattern: outflow from the Rhine valley through the Porte de la Bourgogne (Burgundische Porte), some transport along the Sure Meuhlen and vice versa, and 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. The peak and the observed peak are clearly separate events.

Our calculations

- Backdored calculations with FLEXPART, using various receptor heights:
  - for non-topographical impact: ECMWF operational analysis (6 hourly forecasts, $t < 1$ h) or forecasts $t > 1$ h and ECMWF analysis (6 hourly forecasts, $t > 1$ h), impact 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.
  - A surface release [0-120 m asl] (model grid $b$)
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Discussion

The transport pattern for the 28 Nov peak is very complex. The model combines the transport to a shallow layer which entrains the Rhine valley. Eventual large-scale winds lead to the plume moving mainly located in the western part of the valley. Thus, 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, although this cannot be resolved in the model. At the end of the valley, moist-advection could have occurred (observations show 100% moisture at Sil and stable stratification between Freiburg and Sil with respect to $b$). The plume does not hit Sil.

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- The delta between model and real topography is remarkable, especially with respect to the vertical profile (we don’t have an explicit vertical profile for the backdored simulation). 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 topographic contours, as well as in less complex terrain.

Conclusions

- Atmospheric transport models cannot simulate transport to mountain observatories as well as in less complex terrain.
- The complex transport in mountainous terrain such as the Black Forest region and the largest version of ECMWF with approx. 10 km horizontal grid spacing and explicit vertical resolution.
- The potential influence of factors which escape simulation are numerous.
- Definities may not only be found in the driving meteorological data but also in the numerical solutions of Lagrangian particle dispersion models (Eulerian models as well, of course).
- Representing a monitoring station sited on a mountain by a receptor at model ground is problematic, since the station is situated somewhere between the surface and the real height above sea level may be lost.
- 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 and similar global simulations.