

Modelling the spreading of air pollution with weather models

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Abstract: Industrial emissions affect the air quality in Switzerland. There is an inhomogeneous distribution of emission sources causing the pollution. Emissions from Switzerland as well as different European regions may contribute to the pollution measured in Switzerland. Further, the highly variable meteorological transport of the air pollution determines the air quality. As a decision basis for the air pollution control politics, it is of fundamental importance to identify emission sources, and to model the air pollution transport mechanisms. To access the meteorological transport of emissions, we employ weather models such as the ECMWF model (European Center for Medium-Range Weather Forecast, Reading) and the Local Model of MeteoSchweiz. A number of methods and techniques have been developed for the localization and the quantification of the emission impact. In our studies, two approaches are employed. Firstly, trajectory statistics are used as a tool to localize and map source regions. Thus, receptor data are combined with airmass histories to perform source apportionment. In a second step, a Lagrangian Particle Dispersion Model (LPDM) is used for case studies to quantify emission sources.

Keywords: Air pollution; Emissions; Trajectories; LPDM; Modelling

1. INTRODUCTION

The boost in industry and transport since the last century has been accompanied with an increase in pollutants as sulphur dioxide (SO₂), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), dust and heavy metals (e.g., lead and cadmium). For monitoring the air quality and the effects of pollution control regulations, the National Air Pollution Monitoring Network (NABEL) is operated at the Swiss Federal Laboratories for Material Testing and Research (EMPA). To draw conclusions from the measurement series of air pollution, various tools of modelling are employed. The modelling aims to explain the data series with respect of origin and long-term change of pollution input, e.g., emissions. For this purpose, mountain stations proved to be especially valuable. Local pollution often can be excluded. Then these remote stations sample medium-range or long-range transported pollution. Occasionally, the free troposphere is sampled at the high alpine stations. Thus, the complex situation requires modelling at different scales.

Firstly, meteorological and chemical filter functions have been developed to distinguish between Northern Hemispheric background, local pollution (at the measurement site) and influence

from adjacent pollution hot spots (as e.g., the Po-valley).

Secondly, meteorological fields of the European Centre for Medium Range Weather Forecast (ECMWF) and of the Swiss Meteorological Office (MeteoSwiss) are used to calculate back trajectories. Thus, the geographical displacements of air parcels over time are described. In connection with the measured concentrations, trajectory statistics provide the potential source regions of the pollutants.

Thirdly, a Lagrange Particle Dispersion Model (LPDM) is used for case studies to estimate the dilution a polluted air parcel experiences during its transport to Switzerland.

2. AIR QUALITY MONITORING

The National Air Pollution Monitoring Network (NABEL) network is designed to monitor on the long term the air quality of Switzerland (including NO₂, NO, O₃, CO, VOC's). The sixteen measurement sites had been chosen such that some represent highly polluted locations, and others rather remote areas. The monitoring equipment is maintained and calibrated regularly, and checked versus inter-laboratory tests, parallel field measurements and are compliant with national and international standards [EMPA, 2000]. The

sampling time of most substances are between 10 minutes and daily values.

The long-time measurement series show for instance the success of air quality regulations as establishing the catalytic converter in cars (Figure 1). Still, the NO₂ concentrations are exceeding the air quality standard. To achieve further reduction, the areas of emission influencing the air quality most have to be determined. Whereas in large cities, the sources of relevant emission are near, the remote stations often measure pollution, which is transported across the borders of Switzerland.

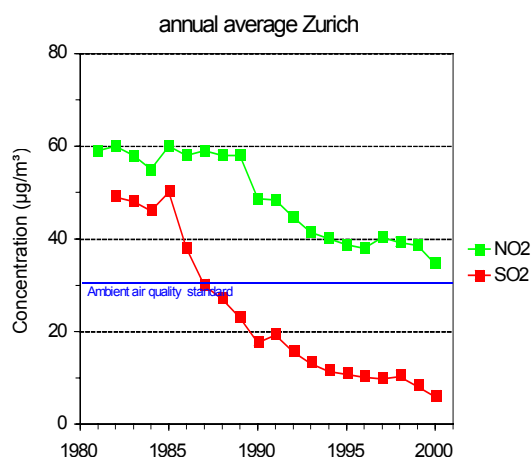


Figure 1. Air quality in Zurich compared with the national ambient air standard

3. MODELLING TOOLS

3.1 Filter flags

The importance of meteorological transport processes for the interpretation of measurement trace gas concentration has been subject of extensive research.

Our filter approach used is based on chemical observations at the regional GAW station Jungfraujoch. This high alpine station is situated in the Swiss Alps (46°33'N, 07°59'E) at 3580m asl. Continuous air pollution measurements at the Jungfraujoch were started in 1973. Distant pollution reaches the station by advection. Upward transport from the boundary layer is caused by thermal heating, inducing up-valley and up-slope winds during the day, leading to diurnal variations of trace gas concentrations (see e.g., Lugauer [1998]). Thermally induced transport depends strongly on the season.

In addition, synoptic lifting [Bethan, 1998], especially caused by cold front passages, and foehn events [Seibert, 1998] transports polluted air to the height of Jungfraujoch.

The filters (defined after Forrer et. a., 2000) flag such influences and are appropriate to investigate long-term change (Figure 2)

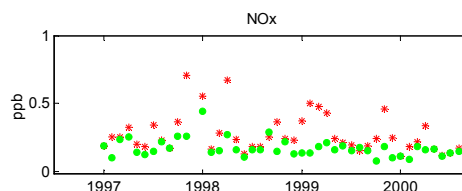


Figure 2. Monthly means of all (*) and filtered (·) NO_x Data. The filtered data exclude influences from the regional boundary layer.

3.2 Trajectory statistics

Backward trajectories with a length of 48 hours and resolved in 15 minute time steps were calculated twice a day (arrival time at the Jungfraujoch 00 and 12 UTC) and since July 2001 four times a day (00, 06, 12 and 18 UTC). They are provided by the Swiss Weather Service *MeteoSwiss*, calculated with the 3 dimensional TRAJEC model from *DWD* (German Weather Service). Wind fields are provided from the Swiss Model (with a horizontal resolution of 14 km) and since June 2001 from the better resolved Local Mode (with a horizontal resolution of 7 km). The trajectories arrive 100 m above model surface. To accommodate for complex flow regimes leading to simultaneously measured contributions from different source regions, we take into consideration not only the trajectory arriving at the accurate site location, but also four being displaced by $\pm 0.09^\circ$ in latitude and $\pm 0.06^\circ$ in longitude, respectively (Figure 3 and 4).

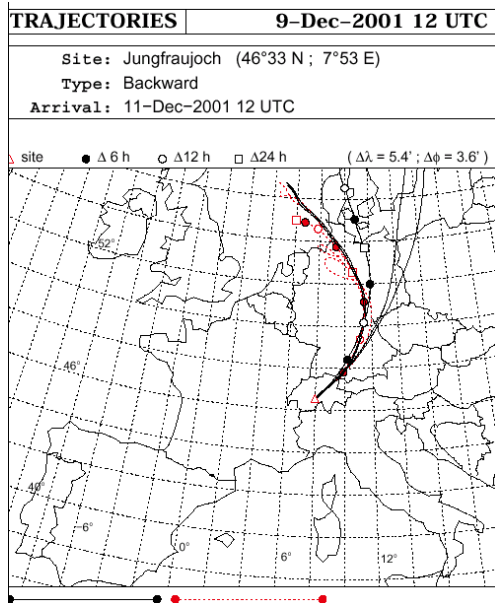


Figure 3. Example of the trajectories provided by MeteoSwiss

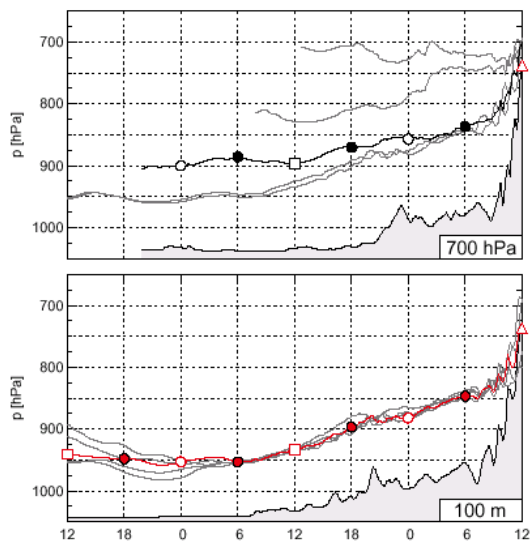


Figure 4. Pressure of the trajectories from Fig.3. The grey area marks the pressure on the model's ground level

Concerning the climatology of trajectories, the Jungfraujoch samples whole of Europe. There are often episodes, where air ascended to the Jungfraujoch, as well as episodes with descending trajectories, providing samplings of a large range of the troposphere.

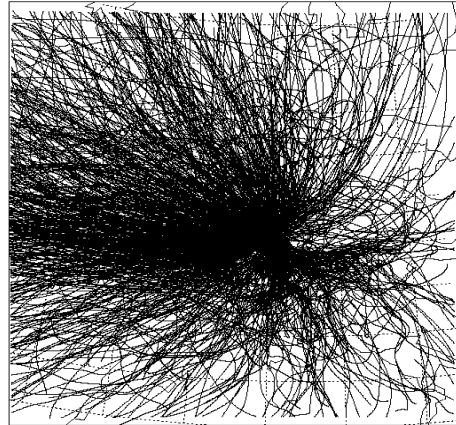


Figure 5. Trajectories of the years 2000 and 2001. They cover the model domain, a sparse coverage is only obtained in the east.

A grid is superimposed to the model domain. Then, a logarithmic mean concentration for each grid cell is calculated after an approach of Seibert et al. [1994], considering Stohl [1998]. Because the data are approximate log-normal distributed, we take normally distributed logarithmic values also required for standard statistics. To consider possible errors in the trajectories and insignificant variations in the calculated concentration field, a 9-point filter smoothing is applied. The result (Figure 6) shows which overpassed grid cells are on average associated with high concentrations at the Jungfraujoch site, thus the potential source regions of pollution measured at Jungfraujoch (Figure 6).

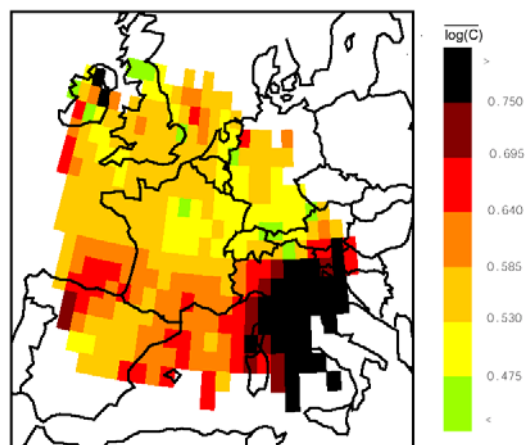


Figure 6. Potential source regions of F141 causing higher concentrations at Jungfraujoch

For instance, at Jungfraujoch the concentration of the halogenated greenhouse gas F141b is monitored. Applying the trajectory statistics explained above yields large potential source regions at the Po-valley and northern Italy. Note that source over sea are due to the restricted resolution of the method. An inherent limitation of the model is given by meteorologically conditioned correlations.

3.3 Applying the Lagrange Particle Dispersion Model

The Lagrange Particle Dispersion Model (LPDM) we are applying had been developed at the German weather service (Glaab [1986] and Fay [1993]) for the purpose of modelling radioactive emergency. Based on the wind fields of a numerical weather prediction model (in our case the Local Model of MeteoSwiss), a hypothetical emission is diluted and advected according to the modelled turbulence and air flow. A large number of particles (in our case 100 000) is released, mixed stochastically into the ambient air and traced by individual trajectories. Thus it is a Lagrange simulation. The number of particles in a grid cell is a measure for the dilution the hypothetical emission experienced.

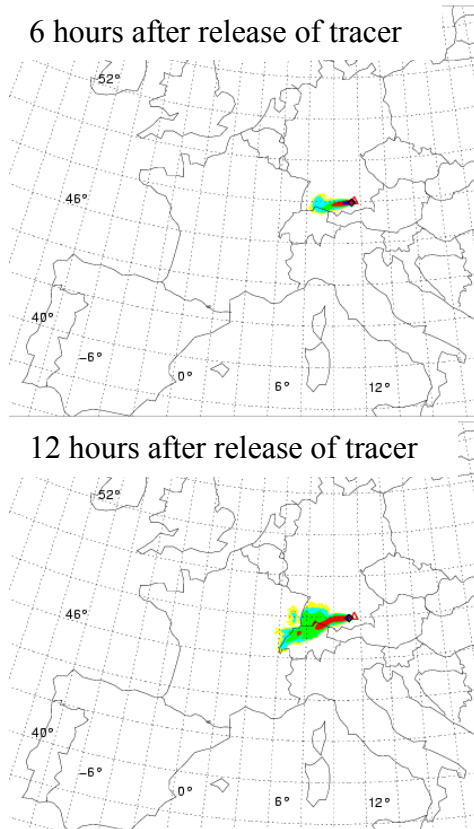


Figure 7 Case study for a pollution plume originating in Munich, compare Fig. 8.

In Figure 7 and 8, an example is shown which demonstrate that a hypothetical emission in Munich will have reached the border of Switzerland after 6 hours. On this day, a special weather situation "Bise" occurred at Switzerland, causing an airflow from east into the Swiss Plateau (between Jury mountain and Alps).

As the simulation shows, the rather canalised air flow and stable meteorological situation allowed the pollution to reach the Swiss Plateau with a dilution of 100 only (compared to the maximum concentration near Munich, in the 7x7km model grid) after 12 hours. Again 12 hours later, the pollution would be diluted with again a factor 10-100.

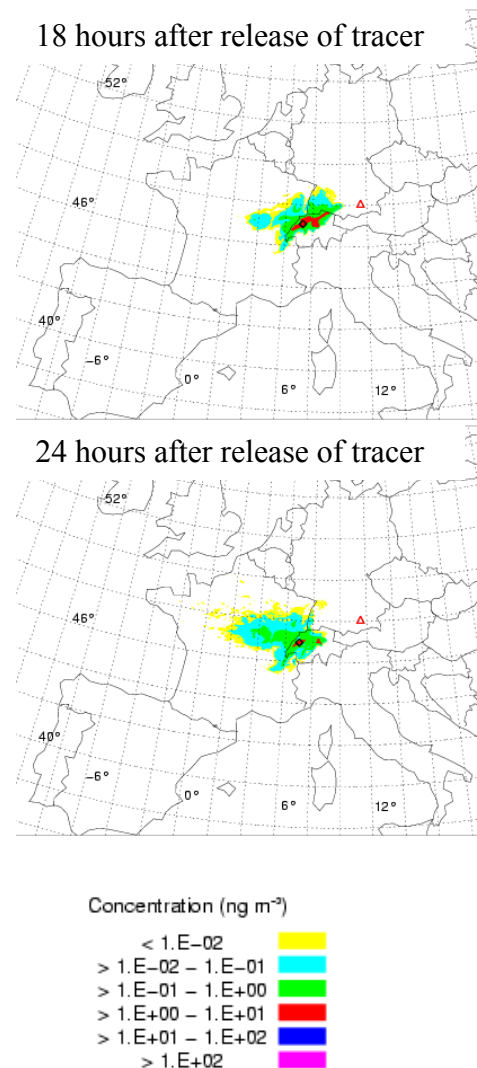


Figure 8 Concentration fields caused by a pollution plume originating in Munich, hypothetical emissions on 9.12. 2001, for 6 hours.

4. Strengths and Drawbacks of the different Modelling Tools

The different models proved useful for different applications:

Filter flags: useful to evaluate the potential of a measurement site to sample remote pollution. Filters are good for long-term trend evaluation.

Trajectories: to investigate the probable history of air masses for a certain case.

Trajectory statistics: to identify geographically the potential source regions

Lagrangische Particle dispersion model: Potential dilution of concentration fields, valuable for estimating export / import for certain cases.

According to the complexity of the model, following computer facilities are necessary:

Filter flags : little computing effort.

Trajectories: Rely on numerical weather models (e.g., need large wind fields)

Trajectory statistics: little computing effort, once trajectories provided

Lagrangische Particle dispersion model: large computer facilities (storage and CPU time) required.

5. CONCLUSIONS

Filters, Trajectory statistics and Lagrange Particle Dispersion Models (LPDM) are used to model the origin of air pollution. As the atmosphere is variable on different scales, the application requires different appropriate tools. In principle, one could try to solve all problems with extensive modelling by the LPDM, but this is limited by the capacity of wind field storage, (now) non-realistic extensive CPU time, and the problem of missing historical data.

Thus we use filters for trend analysis, trajectory statistics to find potential source regions, and the LPDM for case studies to investigate the air pollution in Switzerland.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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