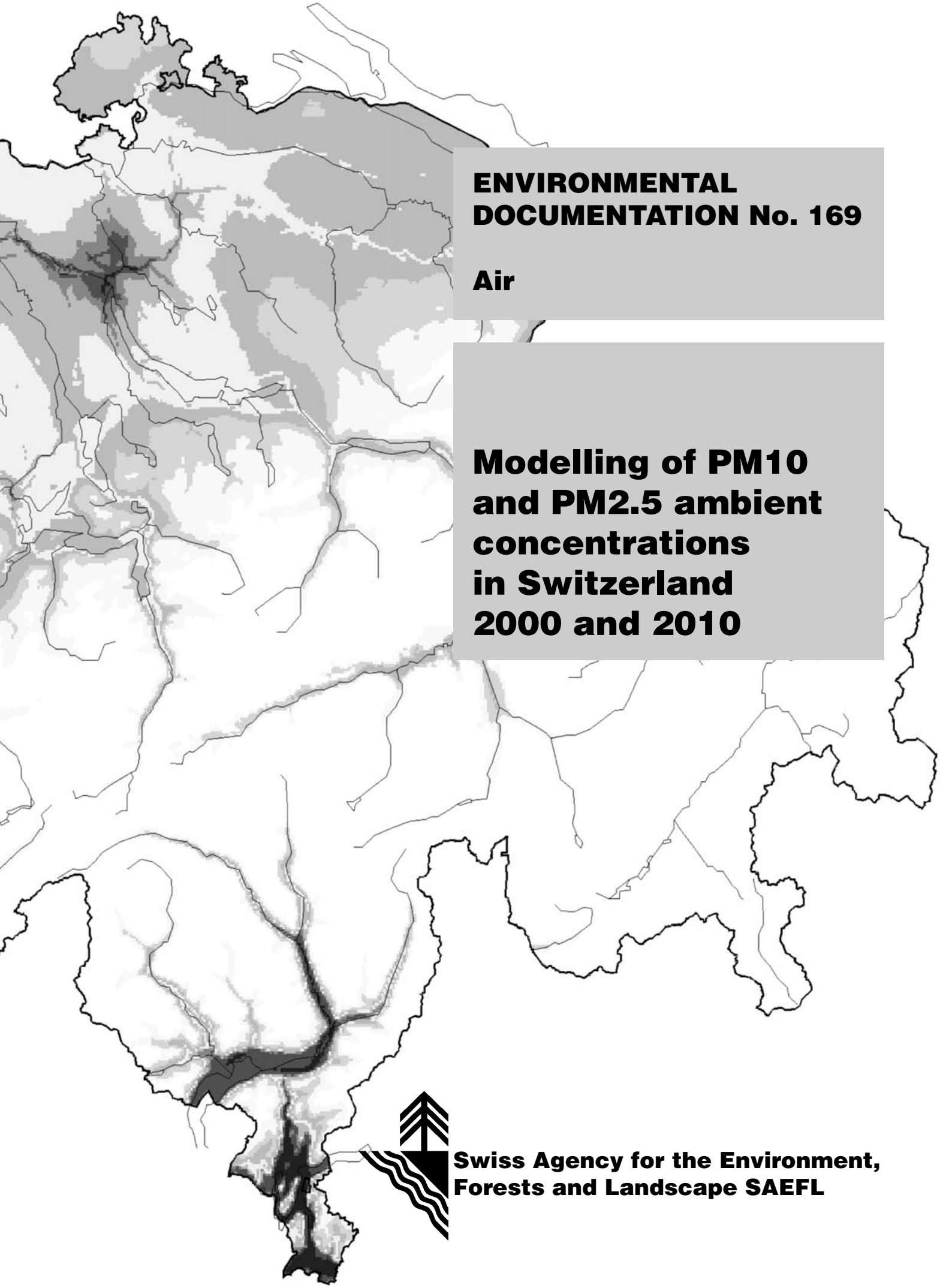

ENVIRONMENTAL DOCUMENTATION No. 169

Air

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Overview

Table of contents

Abstracts

Modelling of PM10 and PM2.5 ambient concentrations in Switzerland 2000 and 2010

This report presents dispersion modelling for PM10 and PM2.5 throughout Switzerland. Concentration maps for PM10 and PM2.5 and population exposure were computed for the year 2000, and for two scenarios in the year 2010.

First, emissions of primary particles were modelled. Separate emission inventories were drawn up for each source group (road transport, industry, households etc.) for the whole of Switzerland, at a spatial resolution of 200 m. Each PM10 emission inventory was split into a fine fraction (PM2.5) and a coarse fraction (PM10-PM2.5) using specific PM2.5/PM10 ratios. Dispersion was then modelled by applying transfer functions to the emission inventories. These functions were computed based on a Gaussian plume model, using hourly meteorological data for the year 1998. Different functions reflect source group characteristics (emission height, deposition velocity) and dispersion characteristics (e.g. in alpine valleys, the transfer functions are aligned with the direction of the prevailing wind).

Secondary particles like nitrate and sulphate aerosols were modelled by transforming the ambient concentrations of their gaseous precursors (NO_2, SO_2). Ammonium is calculated assuming complete neutralization of nitrate and sulphate ions. Secondary organic particulate matter was modelled using VOC emission inventories, yield factors and dispersion modelling. Finally, the imported background concentration was parameterized.

The main results are the annually averaged PM10 and PM2.5 concentration maps for the whole of Switzerland at 400 m grid resolution, with some areas of interest also shown at 200 m resolution. Exposure was also computed: in 2000, only 5.5% (2'300 km^2) of the land area of Switzerland had a mean PM10 concentration above the 20 $\mu g/m^3$ ambient air quality standard. However, 41.3% of the population (3.01 million people) live in this area. For the "business as usual" scenario, in 2010 these numbers drop to 2.0% (839 km^2) of the land area and 20.8% of the population (1.51 million people), because various measures such as the EURO-4 legislation on motor vehicles will lead to a reduction in PM10 emissions. For the "maximum feasible reduction" scenario, only 0.7% (273 km^2) of the land area and 4.9% of the population (0.36 million people) would be exposed to levels exceeding the standard. To validate the model, the predicted concentration levels for 2000 were compared with measurements.

Modellierung der PM10- und PM2.5-Immissionen in der Schweiz 2000 und 2010

Dieser Bericht dokumentiert Ergebnisse der Immissionsmodellierung von Feinpartikeln (PM10 und PM2.5) für die Schweiz. Die Berechnung der PM10- und PM2.5-Immissionen und die Bevölkerungsexpositionen erfolgte für das Jahr 2000 sowie in zwei Szenarien für 2010.

Zuerst wurden die Emissionen der Primärpartikel modelliert. Für alle Emittenten (Strassenverkehr, Industrie, Haushalte usw.) entstanden separate Kataster in 200 m-Auflösung. Alle PM10-Emissionskataster wurden aufgrund ihres spezifischen PM2.5-Anteils in eine feine (PM2.5) und eine grobe (PM10-PM2.5) Fraktion eingeteilt und anschliessend mit Transferfunktionen in Immissionen umgerechnet. Die Transferfunktionen wurden vorgängig mit einem Gaussmodell für die stündlichen meteorologischen Daten des Jahres 1998 bestimmt. Die Verwendung mehrerer Transferfunktionen ermöglichte es, die verschiedenen Eigenschaften der Emittentengruppen (Emissionshöhe, Depositionsgeschwindigkeit) und die Ausbreitungsbedingungen abzubilden (z.B. werden in Alpentälern die Transferfunktionen in Hauptwindrichtung ausgerichtet).

Berücksichtigung fanden auch die sekundären Partikel: Nitrat und Sulfat wurden mittels Transformationsvorschriften aus den Immissionskarten ihrer gasförmigen Vorläufer NO_2 und SO_2 bestimmt. Der Ammonium-Berechnung lag die vollständige Neutralisation von Nitrat und Sulfat zu Grunde. Die Modellierung der sekundären organischen Partikel erfolgte mittels Ausbreitungsrechnung und Umwandlungsraten aus VOC-Emissionskatastern. Schliesslich wurde die importierte Hintergrundkonzentration parametrisiert.

Hauptresultat sind PM10- und PM2.5-Immissionskarten (Jahresmittelwerte) für die Schweiz in 400 m-Auflösung; illustrative Ausschnitte liegen ausserdem in 200 m-Auflösung vor. Expositionskennziffern zeigen: Im Jahr 2000 waren zwar nur 5.5% (2'300 km^2) der schweizerischen Landesfläche mit einer Immission über dem Jahresmittelgrenzwert von 20 $\mu g/m^3$ der Luftreinhalteverordnung belastet. Allerdings leben in diesem Gebiet 41.3% der Bevölkerung (3.01 Millionen Einwohner). Im Szenario "business as usual" sinken diese Zahlen bis 2010 auf 2.0% (839 km^2) der Landesfläche und 20.8% der Bevölkerung (1.51 Mio. Einwohner), weil diverse Massnahmen die PM10-Emissionen reduzieren, z.B. die EURO-4-Abgasstufe für Strassenfahrzeuge. Im Szenario "maximum feasible reduction" sind nur noch 0.7% (273 km^2) der Fläche und 4.9% der Bevölkerung (0.36 Mio. Einwohner) übermässig belastet. Zur Validierung des Modells wurden die berechneten Immissionswerte für das Jahr 2000 mit den entsprechenden Messwerten verglichen.

Modélisation des immissions de PM10 et de PM2.5 en Suisse 2000 et 2010

Le présent rapport rend compte des résultats de la modélisation des immissions de PM10 et de PM2.5 sur le territoire suisse. Les immissions de PM10 et de PM2.5 ainsi que les expositions de la population sont calculées pour les années 2000 et 2010, selon deux scénarios.

On procède tout d'abord à la modélisation des émissions des particules primaires. Des cadastres avec une résolution spatiale de 200 m sont établis pour chaque source d'émissions (trafic routier, industrie, ménages, etc.). Chaque cadastre d'émissions de PM10 est subdivisé en une fraction fine (PM2.5) et une fraction grossière (PM10-PM2.5), selon la part proportionnelle spécifique de PM2.5. Au moyen de fonctions de transferts, préalablement déterminées grâce à un modèle de Gauss utilisant les données météorologiques horaires relatives de l'année 1998, ces fractions sont ensuite converties en immissions. Plusieurs fonctions de transfert sont utilisées pour représenter les diverses propriétés des types de sources (altitude des émissions; vitesse de dépôt) et les conditions de dispersion (p. ex. dans les vallées alpines, les fonctions de transfert sont alignées sur la direction des vents dominants).

Les particules secondaires, nitrate et sulfate, sont déterminées par conversion des valeurs d'immissions de leurs précurseurs gazeux (NO_2, SO_2), ammonium sous condition de la neutralisation de nitrate et sulfate. Les particules secondaires organiques sont modélisées au moyen de calculs de dispersion et de taux de conversion issus des cadastres d'émissions de COV. Finalement, on procède à la paramétrisation de la concentration de base importée.

Le résultat principal est constitué par les cartes d'immissions de PM10 et PM2.5 (moyennes annuelles) avec une résolution spatiale de 400 m (200 m pour certains extraits présentés à des fins d'illustration). Par ailleurs, il ressort des calculs d'exposition effectués qu'en l'an 2000 il n'y avait certes que 5,5% (2'300 km^2) du territoire suisse exposés à une immission supérieure à la valeur limite moyenne annuelle de 20 $\mu g/m^3$ fixée par l'ordonnance de la protection de l'air, mais pas moins de 41,3% de la population (3,01 millions d'habitants) vivant sur ce territoire. Pour le scénario "business as usual", ces valeurs tomberont d'ici 2010 à 2,0% (839 km^2) du territoire et 20,8% de la population (1,51 million d'habitants), parce que diverses mesures conduiront à la réduction des émissions de PM10, notamment la norme EURO 4 sur les gaz d'échappement des véhicules à moteur. Selon le scénario "maximum feasible reduction", il n'y aurait que 0,7% (273 km^2) du territoire et 4,9% de la population (0,36 million d'habitants) encore surexposés. A des fins de validation du modèle, les immissions se rapportant à l'année 2000 sont comparées à des résultats de mesure.

Modellazione delle immissioni di PM10 e PM2.5 in Svizzera 2000 e 2010

Il rapporto presenta i resultati dei modelli di dispersione atmosferica di PM10 e PM 2.5 sul territorio svizzero. Le concentrazioni di PM10 e PM2.5 e le esposizioni della popolazione sono state calcolate per l'anno 2000 e per due diversi scenari relativi al 2010.

Primo, dei modelli delle emissioni di particolato primario sono preparati. Per ogni tipo di fonte (traffico stradale, industria, economie domestiche ecc.) è stato creato un catasto delle emissioni di PM10, con una risoluzione spaziale di 200 m. In seguito, utilizzando i rapporti specifici tra PM10 e PM2.5, ciascun catasto delle emissioni è stato suddiviso in una proiezione relativa alla frazione fine (PM2.5) ed una relativa alla frazione grossolana (PM10-PM2.5). La dispersione atmosferica è stata calcolata servendosi dei funzioni di trasferimento previamente determinate in base ad un modello gaussiano con dati meteorologici orari relativi del anno 1998. Si tratta di funzioni di trasferimento diverse fra loro, le quali riflettono le caratteristiche delle varie tipologie di fonti e le differenti condizioni di dispersione (nelle valli alpine, ad esempio, le funzioni di trasferimento sono state orientate nella direzione del valle).

Anche il particolato secondario è stato preso in considerazione: nitrato e solfati sono stati modellati trasformando i valori relativi alle concentrazioni dei loro precursori gassosi NO_2 e SO_2. L'ammonio è stato calcolato alla condizione che il nitrato e il solfato siano neutralizzati completamente. I modelli di particolato organico secondario sono realizzati mediante un calcolo della dispersione e l'impiego di fattori di conversione basati sui catasti delle emissioni di COV. Si sono infine creati dei parametri relativi alla concentrazione di fondo importata.

Il risultato principale sono delle carte che mostrano la concentrazione media annua di PM10 e PM2.5 sul territorio svizzero con una risoluzione di 400 m (e di 200 m per alcuni esempi illustrativi). Dal calcolo dei valori di esposizione è inoltre emerso che, se è vero che nel 2000 solo il 5,5% della Svizzera (2'300 km^2) era esposto ad una concentrazione superiore al valore medio annuo di 20 $\mu g/m^3$ fissato dall'ordinanza contro l'inquinamento atmosferico, è altrettanto vero che in tale area viveva il 41,3% della popolazione (3,01 milioni di abitanti). Secondo lo scenario "business as usual", questa percentuale scenderà al 2,0% (839 km^2) entro il 2010 e sarà pertanto esposto solo il 20,8% della popolazione (1,51 milioni di abitanti). Secondo lo scenario "maximum feasible reduction", l'esposizione eccessiva interesserà invece nel 2010 solamente lo 0,7% della superficie svizzera (273 km^2) e il 4,9% della popolazione (0,36 milioni di abitanti). Ai fini della validazione del modello, le concentrazioni relative all'anno di riferimento 2000 sono state comparate con risultati di misurazioni.

Preface

In the past decade, emissions of fine particles (PM10) were reduced by about 25% in Switzerland, and ambient concentrations of PM10 have consequently decreased. However, the ambient air quality standards regarding PM10 are still exceeded in densely populated areas and along major highways. In a first report, published in 1999, the PM10 concentrations in Switzerland as well as the population exposure to PM10 were illustrated. Meanwhile, new vehicle emission standards came into force or will be introduced in future years according to the time schedule given by the European Union.

As a result of these new emission standards, the emissions of primary particles and the emissions of precursors for secondary particles are supposed to decrease in the next years. Hence, it is of great interest to model the particle concentrations for the next decade to see whether the measures introduced will be sufficient to reduce particle concentrations below air quality standards. Furthermore, PM2.5 is in discussion to become an air quality standard for particulate matter in the EU. Therefore, ambient PM2.5 concentrations are also calculated.

The results show that in 2000 41% of the population live in areas where the ambient air quality standard for the annual mean of PM10 concentration is exceeded. In 2010, this number drops to 21% of the population for the "business as usual" scenario and to 5% for the "maximum feasible reduction" scenario.

The report shows that in future years a significant improvement of the air quality with respect to PM10 and PM2.5 concentrations can be expected, provided that the feasible measures of emission reduction are taken and their implementation is enforced. Considerable efforts are still necessary to fasten the process of improvement and to guarantee that the air quality standards for PM10 are met for the whole of Switzerland.

Gerhard Leutert

Swiss Agency for the Environment, Forests and Landscape
Head of the Air Pollution Control Division

1. Introduction

1.1. PM10 ambient air quality standards in Switzerland

The Swiss Ordinance on Air Pollution Control (OAPC) of 16 December 1985, which entered into force on 1 March 1986, prescribes that the level and evolution of air pollution have to be monitored. To this end, surveys, measurements and dispersion calculations have to be carried out. The Swiss Agency for the Environment, Forests and Landscape (SAEFL) recommends accordingly suitable methods.

As of 1 March 1998, the formerly existing ambient air quality standard for total suspended particles (TSP, which is about PM50) was replaced by a new standard for particulate matter with an aerodynamic diameter below 10 µm (PM10). The permitted yearly average is 20 $\mu g/m^3$ for PM10. As short-term standard, the concentration averaged over 24 hours may exceed 50 $\mu g/m^3$ only once per year. At present there is no ambient air quality standard for PM2.5 in Switzerland.

1.2. Current PM10 and PM2.5 ambient air quality

Since the first half of the 1980ies, TSP measurements have been conducted at most of the air pollution monitoring stations of the national NABEL network under the responsibility of SAEFL. Since 1997, PM10 is measured at 13 NABEL monitoring stations; TSP measurements were stopped at the end of 1998. Parallel to PM10, measurements of PM2.5 are performed at some of these sites. For technical reasons, the measurements at the Jungfraujoch site at 3580 m a.s.l. still relate to TSP.

In the first half of the 1990ies, based on TSP measurements, a clear decrease of particle mass concentrations in ambient air can be identified. For PM10, in 1998 the yearly averaged PM10 concentration was clearly lower than in 1997 (first year with sufficient PM10 measurements) at all sites on the northern side of the Alps. This was attributed to meteorological effects (lower number of days with persistent daytime inversions). In 1999, PM10 measurements were at most sites again lower than in 1998, the decrease ranging from 10% to 30%, probably again partly influenced by meteorological conditions (warm winter) (SAEFL 2000a). In 2000, another decrease of 5% on average relative to 1999 was observed (SAEFL 2001c). This trend did not continue in 2001, where roughly the same PM10 concentrations as in 2000 have been observed (SAEFL 2002c). Newest results for 2002 even indicate that ambient concentrations show an increase of 5% on average, compared to 2001. This increase probably also can be

attributed to meteorological conditions. For the period 1998 to 2002, therefore, no clear tendency towards lower PM10 ambient air concentrations can be identified.

PM10 concentrations in Switzerland frequently exceed the ambient air quality standards (limit values) of the OAPC. In 2000, those air pollution monitoring sites situated in cities and urban agglomerations exhibited yearly averaged PM10 levels between 23 and 34 µg/m^3, well above the 20 µg/m^3 standard. At rural sites, concentrations between 18 and 26 µg/m^3 were recorded. Only those sites located at altitudes above 1000 m a.s.l. had PM10 concentrations of 10 to 11 µg/m^3, well below the ambient air quality standard. OAPC's ambient air quality standard of 50 µg/m^3 for the 24-hour averaged concentration was exceeded at most sites several times (OAPC permits only once per year). At urban monitoring stations, the limit value was exceeded on 12 to 61 days. The highest daily average was observed in Lugano (165 µg/m^3) (SAEFL 2001c), illustrating the fact that PM10 concentrations are generally higher south of the Alps than in the north.

The residence time of PM10 and PM2.5 particles in the atmosphere extends to several days. Therefore particles can be transported over long distances. Moreover, secondary particles are formed from their precursor gases. These facts lead to less pronounced differences between rural and urban sites than observed for gaseous pollutants like, e.g., NO_2. The contribution of foreign sources to ambient levels of PM10 amounts to roughly 10 µg/m^3. This underlines the importance of air pollutant abatement measures in other European countries, too (Geneva Convention on Long-Range Transboundary Air Pollution and corresponding protocols).

According to the Law on the Protection of the Environment (LPE) and the OAPC, therefore, the authorities must initiate further reduction strategies in order to lower the PM10 emissions. In the near future, the introduction of new legislation on motor vehicle emission levels (EURO-3 and EURO-4 exhaust standards), the new mileage-related heavy vehicle tax (MRHVT), and additional measures in the industrial, domestic and off-road sector will lead to a further reduction of PM10 and PM2.5 emissions. The present report accounts for these future developments in the forecasts of the PM10 and PM2.5 concentration for the year 2010, using two different scenarios. However, still further reduction measures, both domestic and abroad, will be necessary in order to fully comply with the OAPC ambient air quality standards.

1.3. Previous modelling studies

PM10 concentration levels for Switzerland for 1997 resulting from dispersion modelling were first published in SAEFL (1999a). The dispersion model used in that study had the same modelling approach as the NO_x model (SAEFL 1997), but was far more complex due to the complicated nature of particulate matter. The figures on road transport emissions used in SAEFL (1999a) were based on HBEFA 1.1 (SAEFL 1995a) for tailpipe emissions, and on estimated non-tailpipe PM10 emission factors.

1.4. Recent developments

Since the publication of SAEFL (1999a), the amount of research and publications on all aspects of particulate matter has been growing rapidly. The present report attempts to take account of this scientific progress. For example, the revised non-tailpipe emission factors for road transport based on SAEFL (2001a) were used. On the side of transport legislation and policy, several new developments have taken place:

- Introduction of legislation to further reduce the emissions from motor vehicles: EURO-3 (in force since 2001) and EURO-4 (in force in 2006) as well as the so-called 2nd phase of EURO-4 (from 2008 on). The new version 1.2 of the Handbook on Emission Factors for Road Transport (SAEFL 1999b) accounts for this new legislation.

- The bilateral treaty on road transport between Switzerland and the European Community (EC), the so-called Overland Transport Agreement (OTA), includes the increase of maximum allowable lorry weights from 28 tons (until 2000) to 34 tons (as from 2001) and finally to 40 tons (2006), as well as the introduction of the mileage-related heavy vehicle tax (MRHVT) for all heavy duty vehicles. Both OTA and MRHVT are in force since January 2001. The traffic activities have been revised accordingly, up to the year 2015 (GS UVEK 1999). Based on these new traffic activities, the estimates on emissions from road transport in Switzerland have been revised as well (SAEFL 2000b).

These new developments have major impacts on the emissions from road transport for the year 2010. Therefore the present study also forecasts PM concentrations for 2010, taking into account the new emission factors and traffic activities.

1.5. Model enhancements

In comparison to the modelling approach presented in SAEFL (1999a), several improvements of the dispersion model and the over-all emission modelling concept were performed. The

fundamentals of the modelling approach remain identical; they are summarized in Chapter 2. The dispersion modelling in the present report has the following advantages with respect to the SAEFL (1999a) approach:

- Instead of one set of transfer functions (which represent the impact of a source of unit emission strength to the neighbouring areas) throughout Switzerland, the country is divided into three regions with distinct micro-climatologic characteristics (alpine region, Swiss Plateau region, and the remaining part of Switzerland).
- The primary dispersion model used to calculate the transfer functions complies with the TA-Luft directive (BMJ 1987).
- The new transfer functions are the average of three (alpine region) to five (Plateau region) different transfer functions, each calculated using data from a meteorological surface station for a full year in hourly resolution.
- In the alpine region, covering the valley floor of all major alpine valleys in Switzerland, the main valley orientation was manually derived for all valley segments separately. For each grid cell of the valley floors, the corresponding alpine transfer function was rotated such that it corresponds to the main valley orientation. This improves the dispersion modelling in alpine valleys.
- The emission strengths of the emission inventories now vary with the season and the hour of the day (stationary sources) or with the day of the week and the hour of the day (transport sources).
- The parameterization of the regional PM10 (anthropogenic and biogenic) background concentration was updated.
- Emission modelling was also done for PM2.5 by applying PM2.5/PM10 ratios to the PM10 emission loads. For the dispersion modelling for PM2.5, separate sets of transfer functions based on a reduced particle deposition velocity were used.
- Most recent estimates on PM10 emissions from rail transport were integrated in the model.
- Emission inventories for those agglomerations in the neighbour countries (France, Germany, Italy and Austria) that are close to the Swiss border were added.
- Forecasts were also made for the year 2010 using two different scenarios.

2. Modelling approach

2.1. Concept

The concept basically remains the same as in the SAEFL (1999a) study:

- The PM10 or PM2.5 total mass is modelled, not the number of particles.
- Primary and secondary particles are modelled separately. Primary particles are assumed to be an inert trace quantity, but their dry deposition to the soil is accounted for (impaction on other surfaces and vegetation is neglected). Secondary particles are modelled using emission inventories of the gaseous precursors and yield factors (VOC/organic matter) or concentration maps (NO_2/ ammonium nitrate, SO_2/ ammonium sulphate) assuming complete neutralisation of nitrate and sulphate by ammonium.
- Emissions with distinct source characteristics are grouped into different inventories.
- All emissions and all dispersion computations take place on a rectangular grid with 200 m mesh size. For road transport emissions, emissions are computed for all major roads individually, and are then projected onto the grid. For all other source categories, first the total emission load is estimated, which is then spatially dis-aggregated by distributing it equally to all grid cells with a certain characteristic – for example, the land use category.
- For the dispersion modelling, transfer functions are used that represent the impact of a source of unit emission strength to the neighbouring areas (also called source-receptor modelling approach). Each emission inventory (transport, industry, etc.) is dispersed separately. Different transfer functions for different source heights (ground-level and elevated sources) are used. Also, different transfer functions result from the use of different deposition velocities for PM2.5 and PM10–PM2.5 (PM10–PM2.5 denotes particles in the size range 2.5 to 10 µm). The resulting concentrations are representative for the annual average.
- A chemical composition is attributed to each emission inventory. Since the dispersion modelling is performed for each inventory separately, the chemical composition of the total resulting PM concentration can be estimated.
- Both a short-range dispersion modelling (up to 6 km from the source, with a spatial resolution of 200 m) and a long-range modelling (up to 200 km from the source, with a spatial resolution of 2 km) are performed.
- Area statistics and the population exposure are determined using the concentration (annual average) per grid cell. For the population exposure, the living location of the population (population density) is used.

In several important parts, however, the dispersion model has been improved. These model enhancements are described in further detail in the following sections:

- Three regions with different micro-climatologic characteristics are distinguished (section 2.2.1);
- New sets of transfer functions for these three areas are used, based on hourly meteorological data of a full year (section 2.2.2);
- A Gaussian plume dispersion model using hourly meteorological data, using TA-Luft (BMJ 1987) stability classes, is used (section 2.2.3);
- The parameterization of the regional PM10 (anthropogenic and biogenic) background concentration has been updated (section 2.5);
- Particulate matter emissions from rail transport has been included as a new source category (section 4.2.1);
- Secondary PM from biogenic VOC has been included as a new source category explicitly (section 4.5.3);
- PM2.5 emissions are now modelled separately, using PM2.5/PM10 ratios for each emission inventory. The resulting PM2.5 emissions are dispersed with their own set of transfer functions. So each emission inventory is split up for PM2.5 and PM10–PM2.5 (particles in size range 2.5 to 10 μm), the sum of which is used for PM10.

2.2. Dispersion model for primary particles

2.2.1. General approach

The SAEFL (1999a) model predicted most annual averaged PM10 ambient concentrations well, but a general underestimation of PM10 levels in alpine valleys was observed. Several major European transit highways cross the Swiss Alps in the north–south direction, and cause high PM concentration levels in the ecologically sensitive areas of the Alps.

Therefore an enhanced model with a refined treatment of atmospheric pollutant dispersion in Alpine valleys was used for the present study. This new dispersion model is identical to the SAEFL (2003) model. Sets of transfer functions were computed for three different climatologic regions: Alpine valleys, Swiss Plateau, and the remaining part of Switzerland. They are based on hourly meteorological data from meteorological stations operated by the Swiss Meteorological Service.

The dispersion model uses wind speed and direction, temperature, mixing height, and TA-Luft stability classes (BMJ 1987) as main input variables. The transfer functions were derived

from a simple Gaussian plume dispersion model and reflect the annually averaged ground concentration impact of a point source with specific source characteristics onto each of the neighbouring grid cells.

2.2.2. Meteorological data

The total area of Switzerland was divided into three different regions (see Figure 21 on page 92 for a detailed map). 65% of the land cover of Switzerland belongs to the Alps. The main residential and commercial areas are located in the densely populated so-called Swiss Plateau (Mittelland), between the Jura and the Alpine mountain ridges.

In the alpine region, covering the valley floors of all major alpine valleys in Switzerland, the main valley orientation was manually derived for all valley segments separately. For each alpine grid cell, the corresponding alpine transfer function was rotated such that it corresponds to the main valley orientation (i.e., the direction of water flow). The remaining part of Switzerland (i.e., neither Plateau nor belonging to the floor of a major alpine valley) was treated as a separate climatologic region as well, where transfer functions based on isotropic (rotationally symmetric) wind directions (for further details see section 2.2.3) were used.

Hourly meteorological data (for each hour, the average over the first 10 minutes was used) for a range of surface stations for the year 1998 were used to compute the transfer functions:

- Five stations were used to represent the Swiss Plateau: Geneva (GVE), Payerne (PAY), Wynigen (WYN), Kloten (KLO), Güttingen (GUT). The average over these five yearly climatologies was computed and applied to the whole Swiss Plateau.
- For the remaining part of Switzerland, the same meteorological input as for the Swiss Plateau was used, but the wind direction was randomized. This yields a rotationally symmetric transfer function which does no more show the pronounced channelling in south-west to north-east direction that is characteristic for the Swiss Plateau region.
- The Alpine valleys were divided into 49 valley segments, as shown in Figure 1. These valley segments were split up into 3 different groups:
    - There is a meteorological station situated in 14 valley segments (in Figure 1; the locations of the meteorological stations are indicated with crosses);
    - Another 21 valley segments are closely related to one of those 14 which have a meteorological station (vertical line pattern in Figure 1, “indirect”);
    - For the remaining 14 valley segments, a generic meteorology has been used (horizontal line pattern in Figure 1).

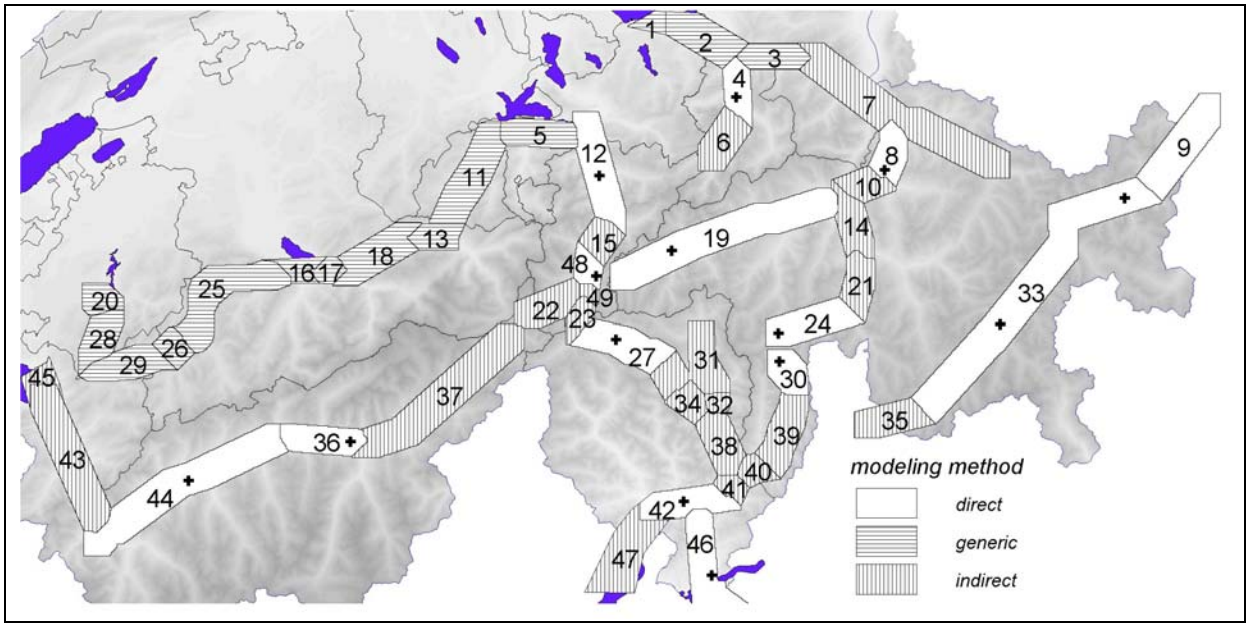

Figure 1: Valley segments. Sites of meteorological stations used are indicated with crosses.

All stations are operated by MeteoSwiss (the Swiss national meteorological service) on a regular basis. A wide range of parameters can be obtained with an hourly resolution. For this study, wind speed and direction were used. Additionally, based on hourly meteorological data, the TA-Luft stability class and the mixing height were computed by MeteoSwiss (1999) and were made available for the present study.

Table 1 lists the 49 valley segments by their ID number as depicted in Figure 1. For each segment, the name and the modelling method are given. "Direct" modelling is done by computing the transfer function using one year of meteorology for the meteorological station indicated, with "alpine" dispersion modelling as discussed below in section 2.2.3. "Indirect" modelling refers to valley segments that are neighbours to segments with "direct" modelling. The corresponding transfer functions were also used for these neighbouring segments, without any change. For 14 segments, which have only moderate alpine characteristics, a "generic" modelling approach was adopted: the average of the transfer functions using the meteorology from the stations Magadino (MAG), Sion (SIO) and Chur (CHU) was used (in order to obtain a general, alpine shape of the transfer function without local influences), but the dispersion modelling was done with "non-alpine" settings.

ID	name of valley segment	modeling method	met. station
5	Beckenried_1/1	generic	
35	Bergell_1/1_(SAM)	indirect	SAM
32	Blenio_1/1_(PIO)	indirect	PIO
13	Brünig-Spiez_1/4	generic	
18	Brünig-Spiez_2/4	generic	
17	Brünig-Spiez_3/4	generic	
16	Brünig-Spiez_4/4	generic	
33	**Engadin_1/2_SAM**	**direct**	**SAM**
9	**Engadin_2/2_SCU**	**direct**	**SCU**
6	Glarus_1/2_(GLA)	indirect	GLA
4	**Glarus_2/2_GLA**	**direct**	**GLA**
23	Gotthard_1/1_(GUE)	indirect	GUE
24	**Hinterrhein_1/3_HIR**	**direct**	**HIR**
21	Hinterrhein_2/3_(HIR)	indirect	HIR
14	Hinterrhein_3/3_(HIR)	indirect	HIR
7	Klosters-Linthebene_1/4_(CHU)	indirect	CHU
3	Klosters-Linthebene_2/4	generic	
2	Klosters-Linthebene_3/4	generic	
1	Klosters-Linthebene_4/4	generic	
27	**Leventina_1/7_PIO**	**direct**	**PIO**
31	Leventina_2/7_(PIO)	indirect	PIO
34	Leventina_3/7_(PIO)	indirect	PIO
38	Leventina_4/7_(MAG)	indirect	MAG
41	Leventina_5/7_(MAG)	indirect	MAG
42	**Leventina_6/7_MAG**	**direct**	**MAG**
47	Leventina_7/7_(MAG)	indirect	MAG
46	**Lugano_1/1_LUG**	**direct**	**LUG**
30	**Misox_1/3_SBE**	**direct**	**SBE**
39	Misox_2/3_(SBE)	indirect	SBE
40	Misox_3/3_(SBE)	indirect	SBE
19	**Oberrhein_1/3_DIS**	**direct**	**DIS**
10	Oberrhein_2/3_(CHU)	indirect	CHU
8	**Oberrhein_3/3_CHU**	**direct**	**CHU**
22	Realp_1/1_(GUE)	indirect	GUE
49	Reusstal_1/4_(GUE)	indirect	GUE
48	**Reusstal_2/4_Andermatt_GUE**	**direct**	**GUE**
15	Reusstal_3/4_Gurtnellen_(ALT)	indirect	ALT
12	**Reusstal_4/4_ALT**	**direct**	**ALT**
37	Rhone_1/5_Ulrichen_(VIS)	indirect	VIS
36	**Rhone_2/5_Visp_VIS**	**direct**	**VIS**
44	**Rhone_3/5_SIO**	**direct**	**SIO**
43	Rhone_4/5_Aigle_(SIO)	indirect	SIO
45	Rhone_5/5_(SIO)	indirect	SIO
26	Saanen-Gruyères_1/4	generic	
29	Saanen-Gruyères_2/4	generic	
28	Saanen-Gruyères_3/4	generic	
20	Saanen-Gruyères_4/4	generic	
11	Sarnen_1/1	generic	
25	Simmental_1/1	generic	

Full names of met. stations: Samedan (SAM), Piotta (PIO), Scuol (SCU), Glarus (GLA), Gütsch (GUE), Hinterrhein (HIR), Chur (CHU), Magadino (MAG), Lugano (LUG), San Bernadino (SBE), Disentis (DIS), Altdorf (ALT), Visp (VIS), Sion (SIO)

Table 1: Valley segments as displayed in Figure 1, modelling method applied and corresponding meteorological station.

The areas covering the alpine valleys have been derived manually. Their width is chosen such that they cover the valley floor and the slopes up to an height of 300 meter above the local valley floor level. For those areas on the valley slopes that are still part of the valley, but are located at altitudes higher than 300 meter above the local valley floor, the transfer functions for the "rest of Switzerland" are applied.

Figure 2 displays the distribution of wind directions for some of the meteorological stations. The wind channelling in the Swiss Plateau is clearly visible (left-hand panel). For the Alpine sites (right-hand panel), the wind direction is dominated by the local valley orientation. They therefore have been rotated such that they fit on top of each other, corresponding to a valley where water runs from north to south. For further details and statistics on the meteorological parameters, please refer to SAEFL (2003).

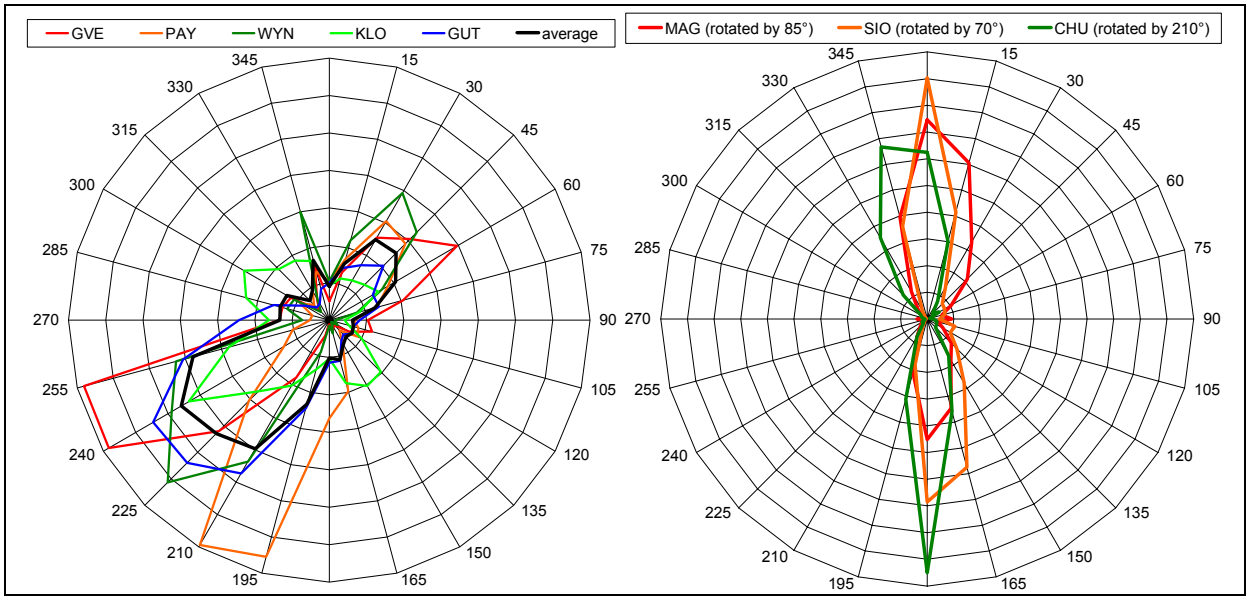

Figure 2: Distribution of wind direction (10-min. average, one measurement per hour) at five Swiss Plateau sites (left) and three Alpine sites (right). Data for 1998 (8760 hours). The wind direction of the Alpine sites has been rotated to correspond to a north-south valley orientation.

2.2.3. Calculation of transfer functions

A Gaussian plume model was used to produce the transfer functions, which give the annually averaged concentration impact per grid cell for a source of unit strength located in the centre of the grid. The dispersion model uses the stability class definitions from the German regulatory model TA-Luft (BMJ 1987). It assumes homogeneity and stationarity throughout the modelling domain. Only meteorology for the source location itself is used. A total of six mirror sources are placed beneath the ground and above of the mixing height to include the effect of the inversion height and to preserve mass conservation.

For the long-range dispersion modelling, it is assumed that the pollutants become vertically well-mixed, and remain well-mixed, as soon as the vertical standard deviation reaches a certain threshold percentage of the actual mixing depth. The deposition integral is evaluated using a Runge-Kutta approximation. Since the transfer functions extend to 200 km downwind from the source, and this corresponds to a long residence time in the atmosphere, for the deposition integral solving, TA-Luft stability class III_2 is used instead of classes IV and V, and stability class II is used instead of I. This is done because over long travel distances, due to the diurnal variation and changing meteorological conditions, the stability class prevailing at the hour of release is not representative for the whole travel path.

The transfer functions for the remaining part of Switzerland (i.e., neither alpine region nor Swiss Plateau region) were computed using the Swiss Plateau meteorological data, but instead of the observed wind direction, arbitrary wind directions from a random number generator were used. As a result, the transfer function for this remaining part of Switzerland is fully rotationally symmetric with respect to the centre of the transfer function (i.e., the source location); it does not show any influence of a predominant wind direction. These transfer functions were therefore used as "neutral" estimate for all those regions where the predominant wind direction is neither similar to the Swiss Plateau conditions, nor is it ruled by the complex terrain (valley floors of the Alps). Examples of Swiss regions where these "neutral" transfer functions are used are the Basle region (upper Rhine valley), and all mountainous areas which are not in the floor of a valley. It should be noted, however, that in the Alps, almost all emissions occur on the valley floors, and not on the mountain tops.

The main parameters determining the shape of the transfer functions are as follows:

1. Climatologic region (Swiss Plateau, Alpine valleys, rest of Switzerland);

2. Time series of emission strength (see section 2.4 for more details):
   i) time series for mobile sources (transport); or
   ii) time series for stationary sources.

3. Source characteristics: emission height, source type (line, area or point source), buoyancy or momentum induced plume rise.

4. Deposition velocity (see section 2.2.4 for more details):
   i) for particle size fraction up to PM2.5; or
   ii) for particles with diameter between 2.5 and 10 μm (denoted as PM10–PM2.5).

5. Horizontal extent:
   i) horizontal extent of 3 km around the source in the centre grid cell, cell width 200 m; or
   ii) horizontal extent of 200 km around the source, cell width 2 km (i.e. 400 km × 400 km).

6. Type of modelling (“alpine” or “non-alpine”):
   For “alpine” modelling, lower values for the minimum wind speed (0.5 instead of 0.8 m/s), and for the minimum mixing height (20 instead of 100 m) are used. In addition, the “alpine” dispersion modelling employs a special stability class computation scheme, and a special mixing height/inversion height computation scheme.

The cell-averaged concentration impact is estimated by computing the concentration at 25 points uniformly distributed among each grid cell. Line sources are represented by 10 point sources on a line, area sources by 16 point sources uniformly distributed among the grid cell of the source location. Transport sources are represented by a line source in Alpine valleys, but by areas sources otherwise, since in general no distinct road orientation can be identified for the 200 m × 200 m grid cells.

For all sources, it is assumed that no buoyancy or momentum induced plume rise occurs, i.e. the release height equals the effective emission height. For the dispersion coefficients, only the rural scheme of the TA-Luft directive has been used; no urban coefficients have been applied. This has been done to reflect the fact that most PM10 remain in the atmosphere during a long travel period and hence will be mostly in rural surroundings.

The link between the individual emission inventories and the corresponding transfer functions is listed in section 2.7. To illustrate the resulting transfer functions, Figure 3 shows a transfer function for Plateau (left panel) and Alpine meteorology (right panel), but with otherwise identical source characteristics. The transfer functions correspond to a source emitting 1 ton per year of PM10. Time series are used to reflect the daily and seasonal cycle of the emission strength.

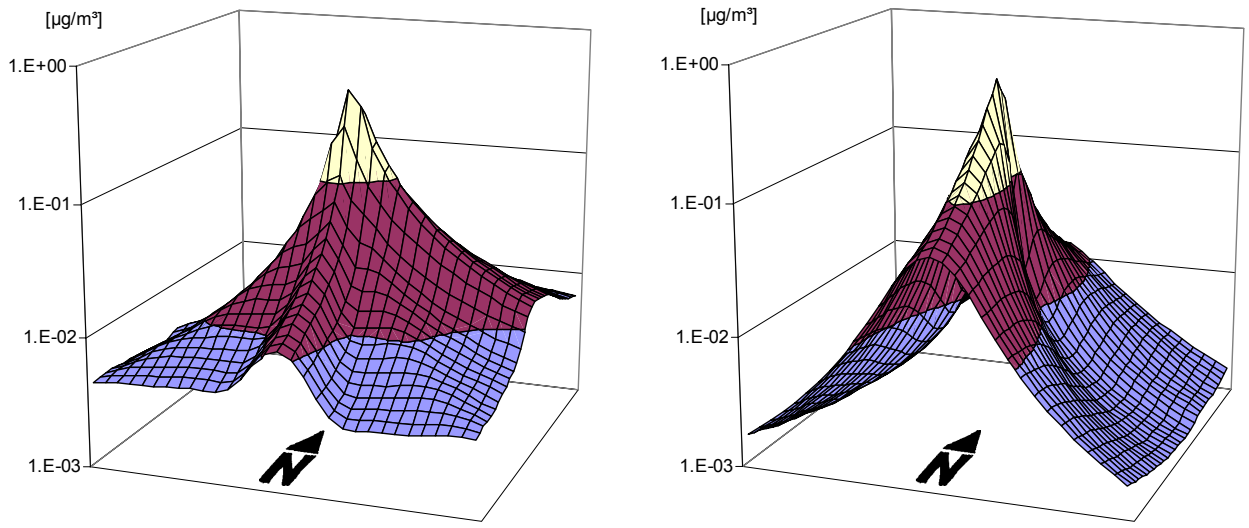

Figure 3: Short-range transfer functions with Plateau (left) and Alpine "generic" (right) meteorology for a source located in the centre, 20 m above ground (emission: 1 t/a), for PM10–PM2.5 (particulate matter in the size range 2.5 to 10 µm). Horizontal axes extend over a square of 6 km by 6 km, each cell is 200 m × 200 m. Vertical axis in µg/m³. Alpine function is for a valley with north-south orientation (water runs from north to south).

The Alpine transfer function is different from the Plateau function mainly because of the more pronounced channelling of the wind directions. The more pronounced channelling of the wind leads, because of superposition, to higher concentrations in the vicinity of line sources, since the major roads have the same orientation as the valley floor.

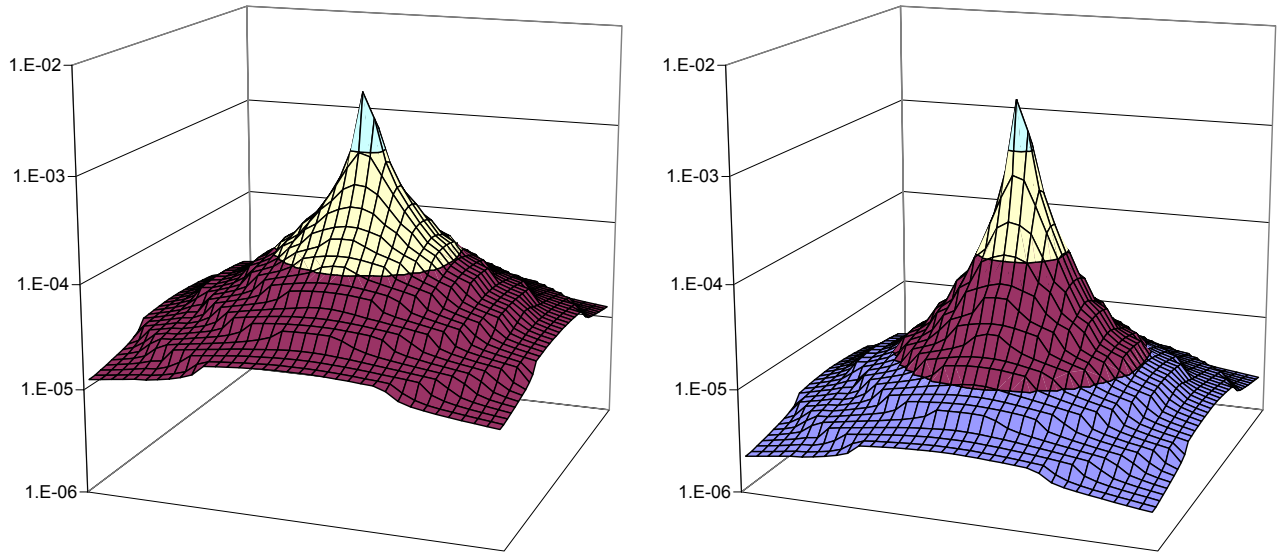

Figure 4: Long-range transfer functions with rotationally symmetric meteorology (used for the "rest of Switzerland" region) for a source located in the centre, 20 m above ground (emission: 1 t/a), for PM2.5 (left) and PM10–PM2.5 (particulate matter in the size range of 2.5 to 10 µm) (right). Horizontal axes extend over a square of 402 km by 402 km, each cell is 2 km × 2 km. Vertical axis in µg/m³.

2.2.4. Deposition velocities for PM10 and PM2.5

To account for the deposition of particulate matter while travelling through the atmosphere, a deposition velocity is introduced in the dispersion model used to compute the transfer functions. For very small particles with a diameter smaller than 0.1 µm, the Brownian diffusion is the main acting force. If the diameter is larger than 1 µm, gravitation becomes dominant. Particulate matter with diameters in between has the lowest deposition velocity and therefore may be transported over very long distances (Figure 5).

Since two groups of particulate matter are modelled, PM2.5 and PM10–PM2.5, deposition velocities are needed for an emission-weighted (by mass) sample of PM2.5 particles, and for an equivalent sample of particles in the PM2.5 to PM10 size range. Table 2 shows the details of this computation and the resulting deposition velocities used within the model. These

deposition velocities are used for all emission inventories regardless of the specific size distribution of their particulate matter emissions.

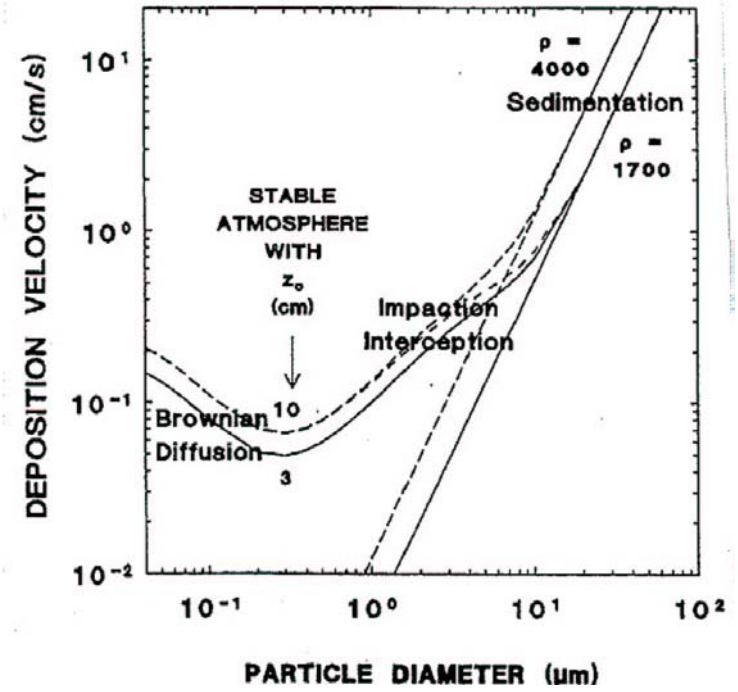

Figure 5: Illustration of the deposition velocity as a function of particle aerodynamic diameter. The minimal deposition velocity for particles between 0.1 and 1 µm enables the long-range transport of these pollutants (source: Ruijgrok et al. 1995, their figure 5).

particles size range			approx.	depos.
low	high	average	share	velocity
[µm]	[µm]	[µm]	[%]	[cm/s]
0.06	0.125	0.0925	3.2%	0.10
0.125	0.25	0.1875	8.1%	0.06
0.25	0.5	0.375	20.6%	0.06
0.5	1	0.75	29.4%	0.08
1	2.5	1.75	15.5%	0.18
Deposition velocity for PM2.5			76.8%	0.09
		rounded value used in dispersion model		**0.10**
2.5	4	3.25	7.6%	0.30
4	8	6	9.8%	0.50
8	16	12	5.7%	0.99
Deposition velocity for PM10-PM2.5			23.1%	0.56
		rounded value used in dispersion model		**0.50**

Table 2: Computation of the deposition velocity for PM2.5 and PM10–PM2.5 (particles in size range 2.5 to 10 µm).

2.3. Modelling approach for secondary particles

So-called secondary particles may form under normal atmospheric conditions out of gaseous precursors. These secondary particles further coagulate with other particles, or water condenses onto them. The most important gaseous precursors are nitrogen dioxide (NO_2), ammonia (NH_3), sulphur dioxide (SO_2), and VOC's (see Appendix A3). The higher the ambient concentration of the gaseous precursor, the higher the resulting yield of secondary particulate matter. They typically reach an aerodynamic diameter between 0.1 µm and 1 µm. The PM2.5/PM10 ratios have been estimated being 0.7 (nitrate), 0.9 (sulphate), and 1.0 (ammonium). These estimates are based on the median of the ratios of the daily averaged concentrations of the aerosol components (PM2.5 and PM10), as measured in the NFP41 project (Gälli 2002). They apply for particles from Swiss precursors. For imported secondary particles, a different PM2.5/PM10 ratio was adopted (see section 2.5.1).

In the present study, maps with annually averaged ambient concentration levels of the gaseous precursors for the whole of Switzerland were used (see section 4.5.1). Because the transformation from the gaseous to the particulate phase is a process that may take several hours after emission of the gaseous precursor, a spatial average is computed first. For each grid cell, the arithmetic average of all grid cells within a radius of 11 km is computed. Then, a transformation function is applied that parameterizes the formation of ammonium sulphate, $(NH_4)_2 SO_4$, and ammonium nitrate, NH_4NO_3, in terms of the ambient concentration of the precursors (EU DGXI 1997). These transformation functions assume that sufficient ammonia is present to neutralise all nitrate and sulphate:

$$NO_3^- + NH_4^+ \rightarrow NH_4NO_3 \text{ and } SO_4^{2-} + 2NH_4^+ \rightarrow (NH_4)_2 SO_4$$

The question is whether the concentration level of aerosol NO_3^- responds to changes in NH_3 or NO_x emissions. The approach of Blanchard *et al.* (2000) indicates that for conditions prevailing in Switzerland, most of the time aerosol NO_3^- formation will not be limited by the availability of NH_3. This justifies the assumption of complete neutralisation. Expressed in µg/m^3 units, the corresponding transformation formula reads as follows:

$$[NH_4^+] = 0.2909 * [NO_3^-] + 0.3756 * [SO_4^{2-}]$$

where square brackets indicate the concentration in µg/m^3.

2.4. Time series of emission strength

The transfer functions (see chapter 2.2) used to disperse the emission loads are based on the impact of a source with emission strength of 1 ton per year and are computed for a whole year on an hourly basis. Therefore time series are needed for all source categories, so that hourly emission behaviour can be associated with the annual emission load. Two different time series of emission strength are used: for ground-level sources, the emission strength depends on the hour of the day; for elevated sources, it depends on the season and the hour of the day.

The time series for elevated sources (used for emissions from industrial and commercial activities, households, and air transport) is the emission-weighted average of three different time series: first, a time series representing the average "human activity"; second, a time series for emissions from residential heating; third, a constant time series for those emissions that do not vary during the day (depicted in Figure 6). These time series are weighted according to their share in the total PM10 emission as estimated at the beginning of the work, in the year 1999. The respective weights are 74.7%, 12.1%, and 13.2%, and do not correspond exactly to the final emission balance as reported in section 4.

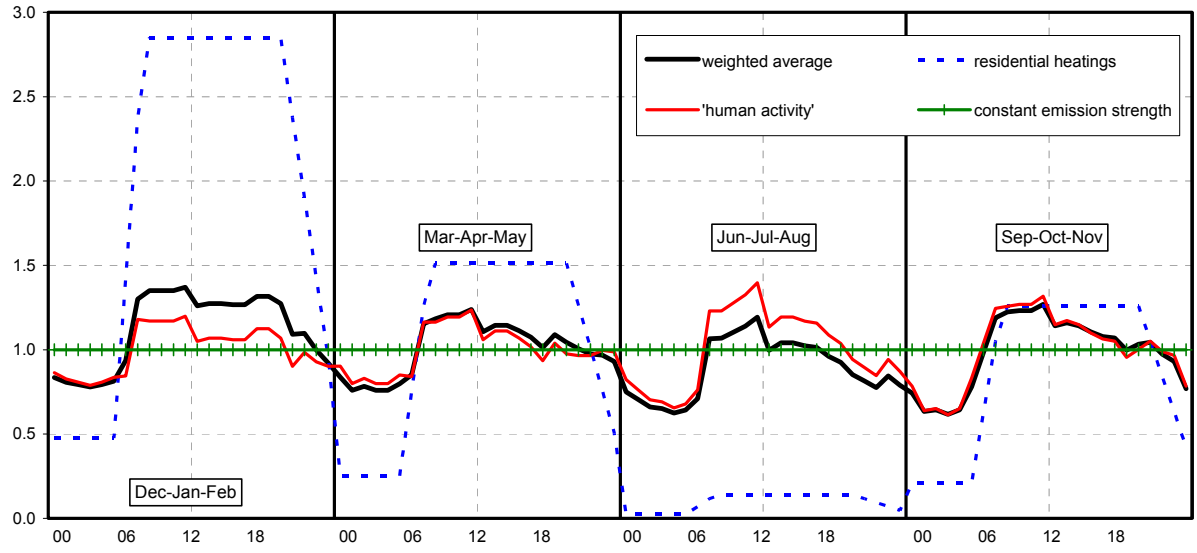

Figure 6: Emission strength time series for elevated sources (24-hour average equals unity for each season).

The "human activity" pattern (Figure 6) is based on average Swiss electrical consumption, because electricity usage is assumed to be related to general human activity patterns that will cause PM emissions (for more details, see SAEFL 2003). The seasonal dependence of the resi-

dential heating emissions is equal to the number of "heating degree days" (German: Heizgradtage) (average for Basle, Berne, Lucerne, St. Gall and Zurich). For the hourly behaviour of heating emissions, a manual estimate has been used.

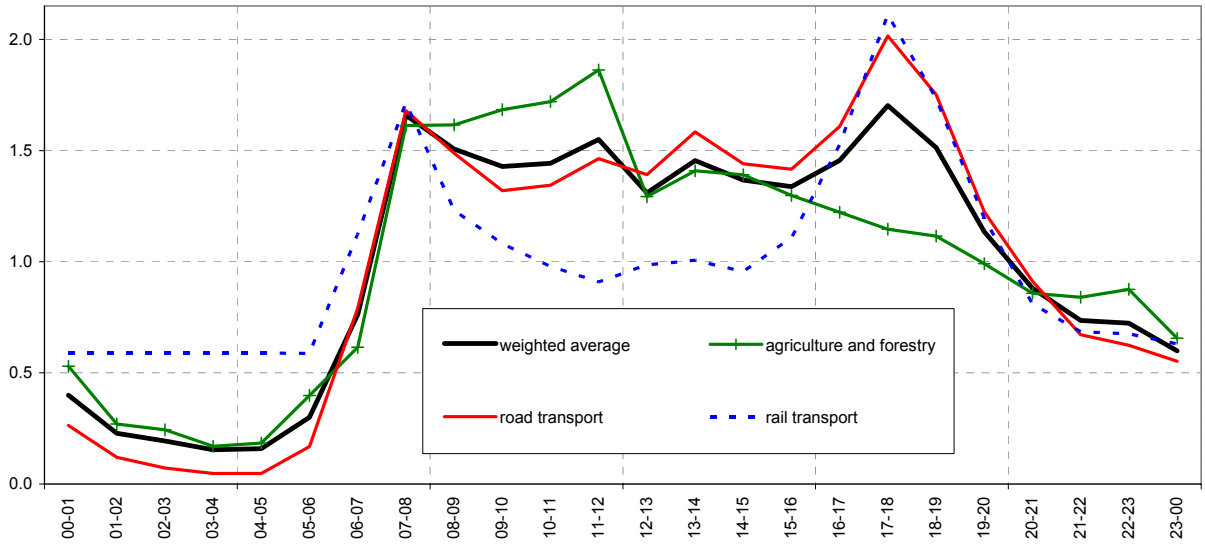

Figure 7: Emission strength time series for ground-level sources (24-hour average equals unity).

The time series for ground-level (i.e., road, rail, water transport, agriculture, forestry) sources is the weighted sum of time series for road transport, rail transport and agriculture plus forestry, as shown in Figure 7. Road transport emissions are strictly proportional to the average hourly Swiss DTV (sum of passenger cars, light and heavy duty vehicles), i.e. the fact that lorries have PM10 emission factors higher than those of passenger cars is ignored for this purpose. The rail transport time series is based on data that has been made available to this project by SBB (2000). It reflects total train kilometres (passenger, cargo and service trains) per hour (Figure 8). The time series for agriculture and forestry is equal to the hourly "human activity" (see above), where the average over the four seasons has been used.

As for the elevated sources, these time series are weighted using their estimated shares in total emission, which slightly differ from the final figures as reported in 4. The weights are 51.6%, 11.2% and 37.2% for road transport, rail transport, and agriculture plus forestry, respectively.

The same time series are used for PM10–PM2.5 (particles in size range 2.5 to 10 µm) and for PM2.5 despite the fact that the PM2.5/PM10 ratio is not equal for road transport compared to various other emission sources.

Figure 8: Emission strength time series for different train types (24-hour average equals unity).

2.5. Background concentration

2.5.1. Concept and vertical profiles

A regional background concentration was added to all computed primary and secondary PM concentration levels originating from the Swiss emission inventories. This background concentration accounts for various source categories: imported primary particles, imported secondary particles, as well as biogenic particles from sources in Switzerland for which no emission inventory was used. The same parameterized background concentration function was used throughout Switzerland, with the exception of the southern parts of Switzerland. These regions (Ticino, Misox and Bergell) are close to the heavily polluted Milan area in Northern Italy.

The background concentration depends on the altitude (in contrast to the dispersion modelling of the emission inventories, which is not depending on the height a.s.l.). This dependence was derived from measurements of sulphate (SO_4^{2-}) at three background monitoring stations at different elevations (see Figure 9). Since the emissions of SO_2 in Switzerland are very low since the mid 1990ies, the dominant part of sulphate stems from abroad. Therefore, the vertical sulphate profile is approximately equal to the true profile of the regional background.

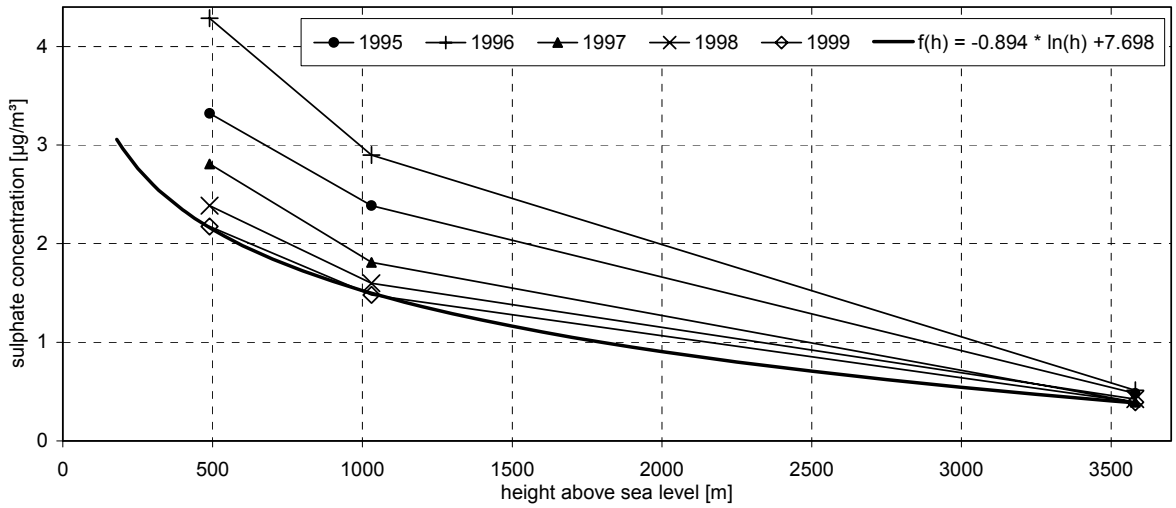

Figure 9: Annual mean sulphate concentration at Payerne (490 m a.s.l.), Rigi (1030 m a.s.l.) and Jungfraujoch (3580 m a.s.l.) stations for 1995 to 1999. The functional form of the regression curve (solid black line) is used for the height dependence of the background concentration parameterization.

The physical reason for the dependence of the background concentration on the height a.s.l. is the frequent occurrence of long-lasting temperature inversions in regions at lower altitudes. This leads to a trapping of pollutants, including those transported over long distances.

By definition, a background concentration should not show small-scale effects; but since the altitude is an important parameter for the background function, using the altitude without previous smoothing procedure would indeed produce a pattern with small-scale variations. Therefore, a smoothed altitude rather than the altitude of the grid cell itself is used. For the Central Plateau, the smoothed altitude is computed as the average altitude over a circle with an area of approx. 25 square kilometres (with the grid cell in question in the centre). For the rest of Switzerland, a circle with an area of 1 km^2 is used.

The PM2.5/PM10 ratio of imported (primary and secondary) particles is unknown; however, since these particles are transported over a very large distance, it is assumed that 90% of PM10 actually are PM2.5. This ratio is used for all primary and secondary imported particles.

2.5.2. Background concentration of primary particles

The background concentration of primary particles accounts for

- Sahara desert sand events;
- Emissions from sources that are not explicitly covered by the emission inventories;

- Biogenic (pollen) material from Swiss sources;
- Mineral dust (for example, volcanic dust, soil particles) and sea salt aerosols;
- Other primary particulate matter from abroad, mainly anthropogenic.

The background function does not need to account for long-range effects of Swiss emissions, since dispersion modelling is performed up to 200 km down-wind from the source (in contrast to the NO_x dispersion model of SAEFL [2003]).

Irregularly, dust from a Sahara dust storm is transported through the troposphere to Switzerland and is deposited during a precipitation event. This occurs mostly in winter; in some years, it does not occur at any relevant scale, in other years, a massive event dominates the PM10 measurements on short term. On average over many years, this impact, expressed as annually averaged concentration, is estimated to be near to 1 $\mu g/m^3$.

Among the sources whose primary PM10 emissions are not explicitly covered in any emission inventory and thus implicitly are accounted for by the background concentration are:

- road transport in ventilated tunnels (section 4.1);
- air transport at heights 200 m above ground and higher (section 4.2.2);
- water transport (section 4.2.3).

The total effect of these non-covered emissions is estimated to be minor; together with the Sahara dust impact (near to 1 $\mu g/m^3$), a total concentration of 1.0 $\mu g/m^3$ has been chosen to cover them. The effect of the other sources of background primary particles (biogenic, volcanic, sea salt) is supposed to be negligible for Switzerland.

The sum of primary (anthropogenic) particles that originate from abroad (international background) is estimated to be 3 $\mu g/m^3$ (SAEFL 1999a). Hence the total background of primary particles is estimated to be 4 $\mu g/m^3$. This additional concentration is valid for 440 m a.s.l. (440 m is the arithmetic mean of the altitudes of the following monitoring stations: Basel, 320 m; Zurich, 410 m; Payerne, 490 m; Berne, 540 m). In the previous model version (SAEFL 2000a), also 4 $\mu g/m^3$ was assumed, but for 490 m a.s.l., corresponding to 4.15 $\mu g/m^3$ for the new reference height of 440 m.

The water content of particles is not accounted for. See section 2.6 for details.

2.5.3. Imported secondary particles

Background concentration levels of nitrate, sulphate and ammonium were derived from the difference between measurements (where no distinction between foreign and inland contri-

butions is possible) and model results based on the Swiss emissions (of the gaseous precursors) only. Concentration measurements at the NABEL sites in Basel, Berne, Payerne and Zurich were used for this calibration. The Chaumont results are not used; they are listed here merely because they played an important role in SAEFL (1999a). Table 4 lists the modelled and measured concentrations. Since the EMEP measurement method (which is used at the Payerne site only) tends to systematically overestimate ammonium and nitrate levels, compared to the NFP41 method adopted at the other four sites, the 1999 annual averages at Payerne were reduced by 30% (Paul Filliger, personal communication).

Model result [µg/m³] (2000 emissions)		**sulphate**	**nitrate**	**ammonium**	**primary PM10**
		(from Swiss precursors only)			*(Swiss)*
BAS (Basel)		0.19	1.98	0.65	10.3
BER (Berne)		0.14	1.66	0.54	12.0
CHA (Chaumont)		0.14	1.34	0.44	5.6
ZUE (Zurich)		0.19	2.00	0.65	5.2
PAY (Payerne)		0.12	1.48	0.48	11.5
Measurements (1999)	**total PM10**	**sulphate**	**nitrate**	**ammonium**	**primary PM10**
		(from Swiss + foreign sources)			*(Swiss+foreign)*
BAS (in %)	100%	16%	13%	8%	63%
BER (in %)	100%	8%	8%	3%	81%
CHA (in %)	100%	20%	7%	8%	65%
ZUE (in %)	100%	15%	14%	8%	63%
PAY (in %)	100%	16%	8%	7%	69%
BAS (in [µg/m³])	23.1	3.69	3.00	1.85	14.5
BER (in [µg/m³])	37.9	3.03	3.03	1.14	30.7
CHA (in [µg/m³])	12.1	2.41	0.84	0.96	7.8
ZUE (in [µg/m³])	25.3	3.79	3.54	2.02	15.9
PAY (in [µg/m³])	20.6	3.29	2.77*	1.58*	14.2

* Original measurement result has been reduced by -30% to correct for systematic overestimation.

Table 3: Measurements of secondary particles, and modelled results when only using Swiss precursor emissions.

Table 4 lists the computed difference between measurement and Swiss emissions-only model result from Table 3. The average of these differences is interpreted as the background concentration originating from foreign emissions of precursors (in fact, these differences are the sum of two effects: foreign emissions and any model errors). For primary PM10, this approach cannot be adopted, since local effects dominate the differences between measurement and Swiss emission-only model results. For example, the monitoring site in Bern is situated in a street canyon and close to a major construction site that has emitted a lot of particles in

that specific street canyon during the last years. So it is expected and desirable that our model under predicts the measurements at the Bern site. A manual estimate of 4 µg/m^3 has been adopted for the imported primary PM10 (see previous section 2.5.2).

Estimated contribution from abroad		**sulphate**	**nitrate** *(*)*	**ammonium**	**primary PM10** *(*)*
BAS	320 m a.s.l.	3.50	1.02	1.20	4.3
BER	540 m a.s.l.	2.89	1.37	0.60	18.7
CHA	1140 m a.s.l.	2.27	-0.49	0.52	2.3
ZUE	410 m a.s.l.	3.60	1.54	1.37	10.8
PAY	490 m a.s.l.	3.17	1.29	1.11	2.7
Average without CHA	**440 m a.s.l.**	**3.29**	**1.30**	**1.07**	**4.0****

* Difference between measurement and modeled result for Swiss emissions only.
** Manual estimate (see previous section on primary particulate background).

Table 4: Modelling of background concentration of secondary particles.

The average background concentration is assumed to hold true for an altitude of 440 m a.s.l., which is the average of the altitudes of the underlying data. We then apply the vertical height profile from section 2.5.1. Figure 10 shows the modelled (due to Swiss precursor emissions) concentration plus the background concentration (depending on the altitude of the respective monitoring site) and the measured concentration. Note that the mean difference (for BAS, ZUE, PAY and BER sites) between measured and modelled concentration levels is zero by definition for nitrate, sulphate and ammonium. Measurements of CHA site have not been used for calibration.

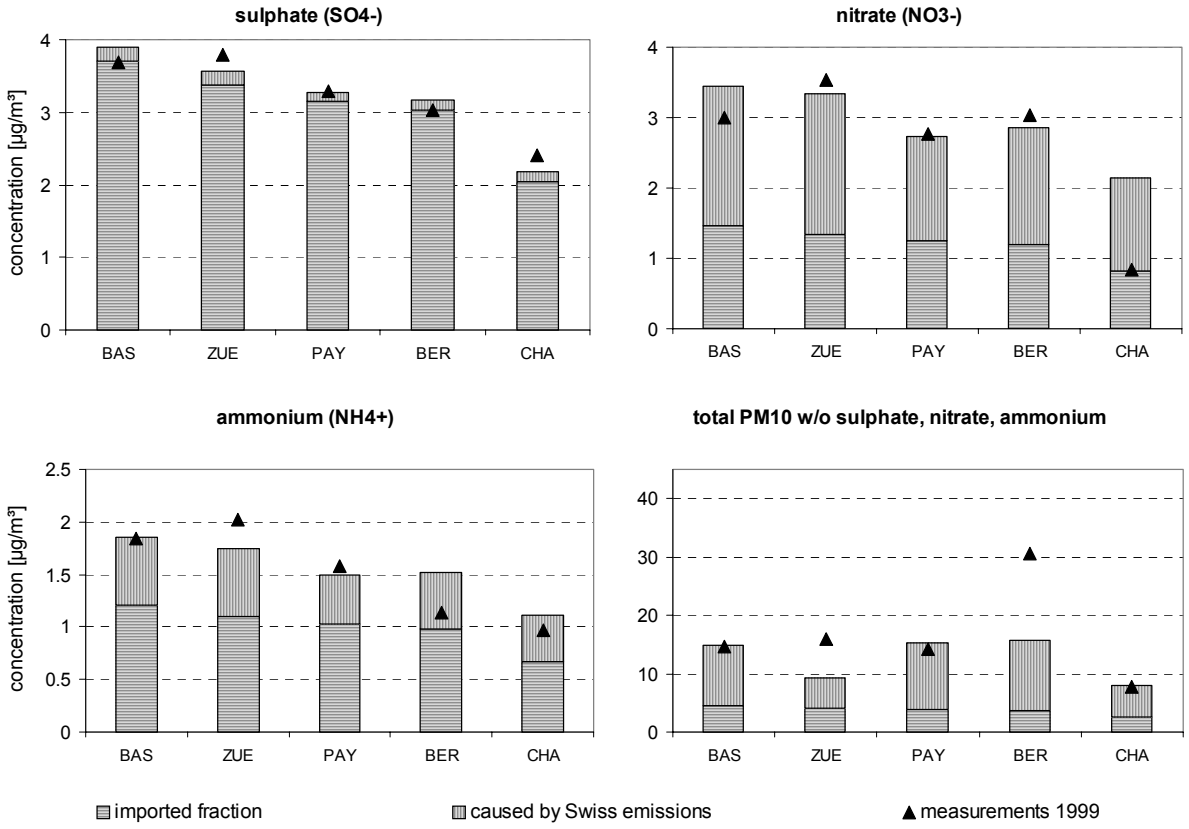

Figure 10: Validation of parameterized background concentration for secondary particles and total PM10 without the sum of sulphate, nitrate and ammonium.

2.5.4. Additional background concentration in Southern Switzerland

The mountainous area south of the Alps, which consists of the Canton of Ticino and the Misox and Bergell valleys which are a part of the Canton of Graubünden, are not heavy industrialized, but they experience the effect of a notable amount of imported air pollutants from Northern Italy, with the city of Milan as the main centre. As a result, this area belongs to the most polluted ones of Switzerland. The Sottoceneri region is most affected. To account for this, additional contributions were added to the background parameterization.

Two additional contributions were being used: for Southern Switzerland (Canton Ticino, and the Misox and Bergell valleys of the Canton of Graubünden), an additional background of 9.5 µg/m^3 PM10 for an altitude of 200 m a.s.l. was adopted. In addition, for the Sottoceneri region, a surplus concentration of 4.4 µg/m^3 PM10 is added. The latter does not depend on altitude. With this approach, the Ticino sites do not show any systematic underestimation

anymore. This is in contrast to the former SAEFL (1999a) study, where an additional contribution of 7.5 µg/m^3 at 200 m a.s.l. was used, resulting in an average model under-prediction at the monitoring sites located in Ticino (Lugano, Magadino, Bodio, Chiasso, Locarno) of roughly 4 µg/m^3 PM10. The PM2.5/PM10 ratio is assumed to be 0.526, i.e. identical to the ratio for emissions from foreign areas that are close to the Swiss border.

2.5.5. Total background concentration

Computing the sum of the primary and secondary (nitrate, sulphate and ammonium) background concentrations and the additional background for Southern Switzerland, the regional background, C_{reg}, for the year 2000 at a given height z in meters above sea level is:

$$C_{reg}(z) = C^0_{reg}\frac{a+\ln z}{a+\ln z_0} + \delta_1\left(C^0_{Ticino}\frac{\ln(z/1200)}{\ln(z_{Ticino}/1200)}\right) + \delta_2 C_{Sottoceneri}$$

where C^0_{reg} = 9.2882, $a = -8.6146$, $z_0 = 440$ m, $z_{Ticino} = 200$ m, δ_1 is unity for Southern Switzerland (Ticino incl. Sottoceneri, as well as Misox and Bergell) at altitudes lower than 1200 m a.s.l. and zero otherwise, C^0_{Ticino} = 9.5, δ_2 is unity for the Sottoceneri region and zero otherwise, and $C_{Sottoceneri} = 4.4$. It should be noted that z is smoothed, see section 2.7 for details.

Figure 11 depicts the vertical profiles of the total background concentration as well as of the individual components (primary and secondary particles), both for the southern part of Switzerland (Ticino) and for the remaining part of Switzerland.

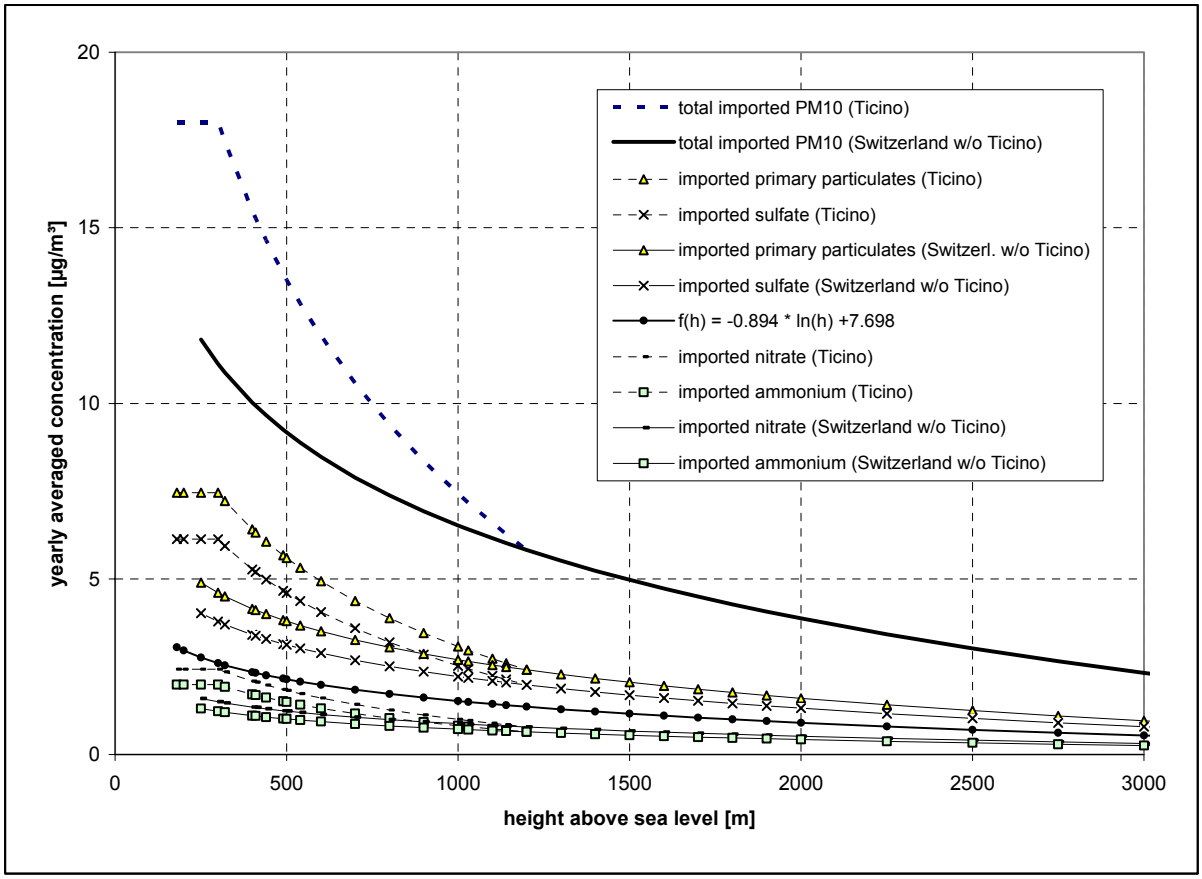

Figure 11: Background concentration function for Switzerland and the southern part of Switzerland (Ticino).

2.6. Water content of particles

Water molecules regularly condense onto the surface of particulate matter, thus increasing its mass. Since the regulatory ambient air quality standards currently target the total mass of particulate matter, and not the number of particles or any other characteristic such as certain chemical species, this water content of particles is also part of PM2.5 and PM10 and has to be modelled. Correct measurements of PM should also measure the mass of the water which condenses onto the solid particles; however, some devices (like TEOM) lose some or all of the water (and ammonium nitrate as well), and for this reason their results should be adjusted. Even with the reference method (CEN 1999) the water content is not authentically detectable if the filter weighing procedure takes place days or weeks after the filter exposition.

It is a current debate in science what the "average" water content of particulate matter might be. Most estimates range between 5% and 15% of total PM10 mass. But the uncertainties are

too large still. Therefore, the present study does not take into account the water content of particles. All concentration levels, mass figures and emission loads in this report refer to PM2.5 or PM10 mass *without* water.

2.7. Model implementation

The dispersion model that convolutes the grid cells of each emission inventory with the corresponding transfer function, and then computes the resulting total concentration level per grid cell, is fully implemented using the ArcInfo GIS (geographical information system). This section provides an overview which transfer function is used per emission inventory, and illustrates which intermediary steps have to be computed in the ArcInfo-based dispersion model to finally obtain the total PM2.5 or PM10 concentration levels.

For the short-range transfer functions,

- An emission height of 2 m is used for all ground-level sources (road and rail transport, agriculture and forestry);
- 20 m is used as averaged emission height for all elevated sources (air transport, industry/commerce, and residential emissions), and for secondary particles.

For the long-range transfer functions,

- no Alpine meteorology has been used, since the influence of any Alpine valley will not extend to 200 km down-wind of the source; instead, transfer functions with the so-called symmetric meteorology are used for the long-range impact of alpine emission sources;
- only one emission height of 10 m is used, since the influence of the emission height on the resulting concentration levels is negligible for long-range transfer functions.

As a result, 12 short-range transfer functions and only four long-range transfer functions are needed; they are listed in Table 5.

The background concentration of imported primary and secondary particles is not dispersed with a transfer function. Since it is expressed as a function of altitude, and it is not desirable that the background concentration reflects the small-scale changes in altitude, the following approach has been adopted: for each grid cell, the terrain height is averaged over a circle with a total area of 5 km^2. The background concentration (section 2.5) is then computed using this smoothed terrain height. This results in a smoothed background concentration map that reflects fewer small-scale fluctuations. In the southern part of Switzerland, with its steep valley slopes, a circle with an area of 1 km^2 instead of 5 km^2 is used.

	short-range (6.2 km x 6.2 km: 31 x 31 cells, cell width 200 m)		
1	emission height 2 m	PM2.5	Plateau meteorology
2			Symmetric meteorology
3			Alpine meteorology
4		PM10-PM2.5	Plateau meteorology
5			Symmetric meteorology
6			Alpine meteorology
7	emission height 20 m	PM2.5	Plateau meteorology
8			Symmetric meteorology
9			Alpine meteorology
10		PM10-PM2.5	Plateau meteorology
11			Symmetric meteorology
12			Alpine meteorology
	long-range (402 km x 402 km: 201 x 201 cells, cell width 2 km)		
13	emission height 10 m	PM2.5	Plateau meteorology
14			Symmetric meteorology
15		PM10-PM2.5	Plateau meteorology
16			Symmetric meteorology

Table 5: List of transfer functions.

The intermediary steps and the over-all structure of the dispersion model are illustrated in Figure 12 and Figure 13, respectively: For the example of emissions from road passenger transport, it is shown in detail how the maps with PM2.5 and PM10–PM2.5 concentration levels (due the emission inventory) are derived. Figure 13 then shows how this procedure, applied to all emission inventories, sums up to maps of total PM2.5 and PM10–PM2.5 concentration levels. The PM10 map is then computed as the sum of the PM2.5 and the PM10–PM2.5 maps.

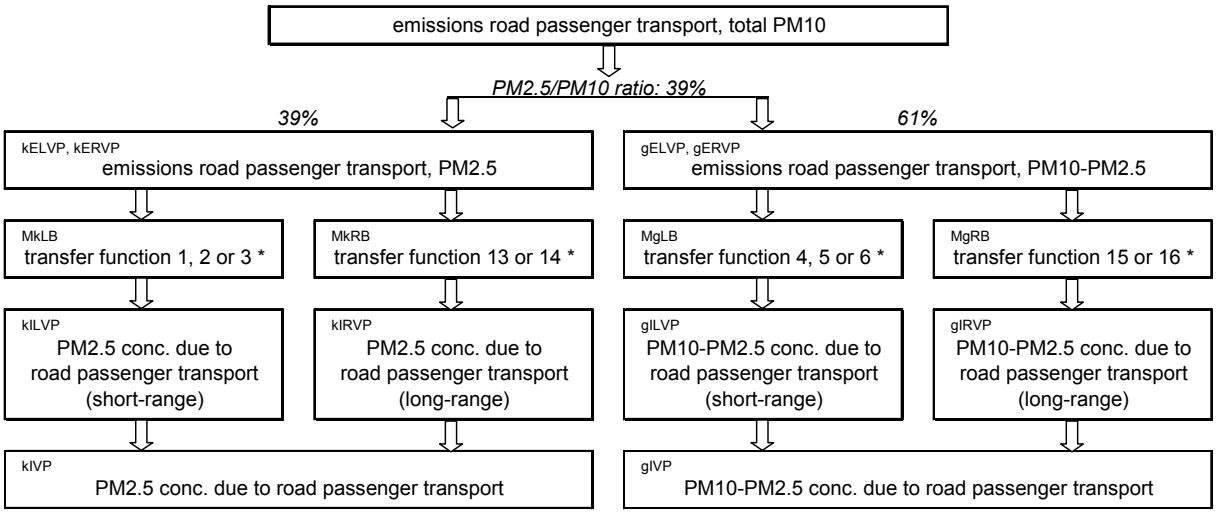

Figure 12: Flow chart to illustrate the PM dispersion model (implemented in ArcInfo), using the "emissions from road passenger transport" emission inventories as example.
**) exact transfer function used depends on climate zone to which the source belongs.*

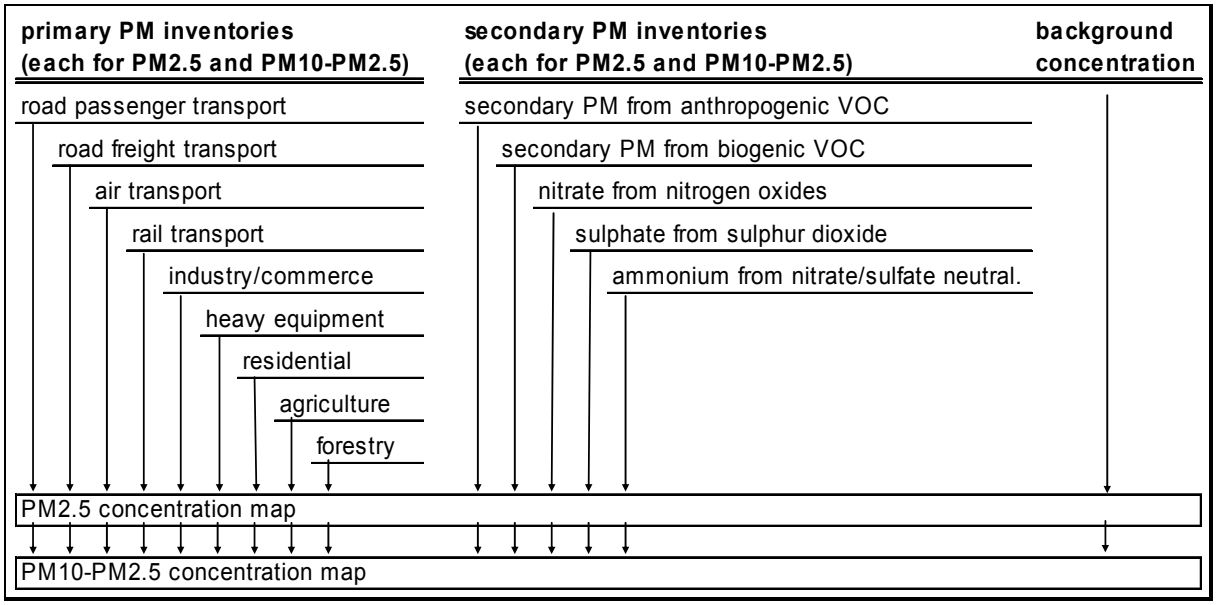

Figure 13: Illustration of the dispersion model structure implemented in ArcInfo.

3. Scenarios for 2010

3.1. "Business as usual" scenario

The "Business as usual" (BAU) scenario is identical to the so-called "trend" scenario in SAEFL (2001a). It reflects the temporal evolution of PM emissions assuming that from 2000 on, no new measures to reduce PM emissions are undertaken anymore. This basically means that the total emission load shows only a slight decrease until 2010. The detailed emission loads are listed in chapter 4. For individual source groups, the most important assumptions are as follows (for more details please refer to SAEFL 2001a):

- Road transport: Due to the already decided new limit values for road vehicles (EURO-3 and EURO-4), a sharp decrease of the PM from tailpipe emissions, which are partly carcinogenic, will take place from 1860 t/a (1995) to 850 t/a (2010). The non-tailpipe PM emissions will increase, as the amount of vehicle kilometres travelled will increase.

- Emissions from air transport will increase due to the increased amount of transport and because no new legislation exists that limits for PM emissions from aircrafts are yet decided.

- Emissions from industry and commerce and from agriculture and forestry basically remain unchanged or reflect the change in the underlying activity numbers. It should be noted that any effects of the recently decided regulation of emissions at construction sites (German: Baustellenrichtlinie) are not taken into account.

- Regarding emissions from installations for heating purposes and warm-water treatment, it is assumed that the Swiss law on CO_2 reductions together with already implemented measures to reduce energy consumption will lead to an increase in the use of wood as a fuel. This will increase the PM load, leading to a total increase of residential emissions of about 7% by 2010.

- Forecasts of the emissions of gaseous precursors of secondary particles are taken from SAEFL (1995a) and SAEFL (1995b) for Swiss sources and from the Göteborg protocol (IIASA 2000) for emissions from abroad. It should be noted that any effects from the recently decided regulation on VOC emissions (German: VOC-Lenkungsabgabe) are not taken into account.

3.2. "Maximum feasible reduction" scenario

The "Maximum feasible reduction" (MFR) scenario is identical to the so-called "M" scenario in SAEFL (2001a). It reflects the temporal evolution of PM emissions assuming that a wide range of additional measures will be implemented in the coming years to further reduce the PM emissions. This leads to a pronounced decrease until 2010. The detailed emission loads are listed in chapter 4. For individual source groups, the most important assumptions are as follows (for more details please refer to SAEFL 2001a):

- The largest reduction in PM10 emissions can be achieved for emissions from heavy equipment (2900 t PM10 /a, a relative decrease of 45%) by making the using of diesel particle traps compulsory for all heavy equipment and other mobile machinery for industrial/commercial purposes.
- PM10 emissions from road transport could be lowered by an additional 2250 t/a (taking into account that due to the forthcoming EURO-3 and EURO-4 legislation, the emissions from road transport will show a clear decrease even under the BAU scenario).
- PM10 emissions from wood furnaces could be reduced by approximately 900 t/a (which is about 50% of the total emission load from the source category).
- A reduction of up to 2100 t PM10/a could possibly be achieved for agricultural emissions.
- Emission reductions of the Swiss precursor gases (NO2, SO2, NH3, OM) could be possible (for details, refer to section 4.5.1).
- For the emissions of gaseous precursors from abroad, 2/3 of the emission reductions as laid down in the Göteborg protocol (IIASA 2000) is assumed. This is in line with SAEFL (2001a) assumptions.

3.3. Background concentration in 2010

For each of the scenarios for 2010, a specific background concentration function is derived that replaces the 2000 function (section 2.5.5). On the side of the primary particles background (totalling 4 µg/m³ in 1990), the anthropogenic part (3 µg/m³ in 2000) is reduced according to the reduction of the national PM10 emission load in the neighbouring countries. The biogenic and natural primary particles background (pollen and mineral dust including

Sahara dust events) is kept at the same level as in 2000 (1 µg/m³). Estimations of the BAU and MFR PM10 emission loads for Italy, Austria, Germany and France were taken from the "2010 trend" and "2010 MFR" scenarios of IIASA (2000), respectively (Table 6).

The additional background concentration for Southern Switzerland (9.5 µg/m³ at 200 m a.s.l. in 2000) is reduced by the same amount as the reduction of the primary particles. Because the PM10 emissions figures for Italy from IIASA (2000) are counterintuitive (2010 BAU emission load much higher than 1990 emissions), again the sum of the emissions for all four neighbouring countries was used rather than the Italian emission loads alone. This yields an additional background concentration in Southern Switzerland in 2010 of 8.6 µg/m³ or 6.92 µg/m³ for the BAU and MFR scenarios, respectively (see Table 6 for details). For the constant surplus concentration of 4.4 µg/m³ in the year 2000 for the Sottoceneri region, the same reduction factors were used (yielding 3.99 and 3.20 µg/m³, respectively).

	1990	2010 BAU	2010 MFR
PM10 emissions France [1000 t/a]	715	765	694
PM10 emissions Germany [1000 t/a]	851	438	256
PM10 emissions Austria [1000 t/a]	212	234	223
PM10 emissions Italy [1000 t/a]	227	379	287
Total [1000 t/a]	2005	1816	1460
Decrease 1990 > 2010		-9.4%	-27.2%
Decrease 2000 > 2010 (50% of above)		-4.7%	-13.6%
Primary particles, anthropogenic	3.00	2.86	2.59
Primary particles, biogenic+natural	1.00	1.00	1.00
Total primary particles background*	4.00	3.86	3.59
Additional background Ticino at 200m	8.90	8.06	6.48

* at an altitude of 440m a.s.l.

Table 6: Estimation of primary particles background concentration for the two 2010 scenarios, based on PM10 emission loads for neighbouring countries from IIASA (2000).

The background concentration of secondary particles was estimated using the emission load reductions from the Göteborg protocol. It is assumed that 66.7% and 100% of all reductions laid down in the Göteborg protocol will be realized for the 2010 BAU and 2010 MFR scenario, respectively. It was then assumed that the background concentration of nitrate, sulphate and ammonium will decrease by the same amount as the NO_x, SO_2 and NH_3 emissions of the neighbouring countries (see Table 7 for details).

	NOx		SO2		NH3	
	2000	Göteborg	2000	Göteborg	2000	Göteborg
Emissions France [1000 t/a]	1432	858	659	400	788	780
Emissions Germany [1000 t/a]	1637	1081	831	550	624	550
Emissions Austria [1000 t/a]	184	103	41	39	68	66
Emissions Italy [1000 t/a]	1485	1000	923	500	448	419
Total [1000 t/a]	4738	3042	2454	1489	1928	1815
Decrease 2000 > 2010		**-36%**		**-39%**		**-6%**
2010 BAU scenario: **66.67%** of projected Göteborg emission reductions						
2010 MFR scenario: **100.00%** of projected Göteborg emission reductions						
		nitrate		**sulphate**		**ammonium**
Background concentration 2000 [µg/m³]		1.304		3.290		1.068
Background concentration 2010 BAU		0.993		2.427		1.027
Background concentration 2010 MFR		0.837		1.996		1.006

Table 7: Estimation of secondary particles background concentration for the two 2010 scenarios, based on NO_x, SO_2 and NH_3 emission loads for neighbouring countries according to the Göteborg reduction scenarios (source: IIASA 2000).

For 2010 the regional background function, C_{reg}, has the same functional form (see section 2.5.5), but the values of some constants are different: C^0_{reg} is 7.9741 for the BAU and 7.1213 for the MFR scenario, C^0_{Ticino} is 8.06 for the BAU and 6.48 for the MFR scenario, and $C_{Sottoceneri}$ is 3.99 and 3.20, respectively.

4. Emission loads, spatial dis-aggregation, and size distributions

4.1. Emissions from road transport

Regarding road transport in Switzerland, several important developments have taken place or have been initiated recently. The bilateral treaty on road transport between Switzerland and the European Community (EC), the so-called Overland Transport Agreement (OTA), includes the increase of maximum allowable lorry weights from 28 tons (until 2000) to 34 tons (as from 2001) and finally to 40 tons (2006), as well as the introduction of the mileage-related heavy vehicle tax (MRHVT) for all heavy duty vehicles. Both OTA and MRHVT are in force since January 2001. These developments mainly concern heavy-duty vehicles (HDV). Their effects on road transport are taken into account by the corresponding future scenario of SAEFL (2000b).

For the needs of the present study, there is not a single road traffic model available that covers both HDV traffic loads and the other vehicle categories on the Swiss road network. Therefore, the relevant data had to be collected from various sources:

- The road network for passenger cars (PC), light-duty (commercial) vehicles (LDV), motor cycles (MC) and buses (both public transport buses and coaches) used is identical to that from SAEFL (1999a), including the relative distribution of traffic loads on it.
- For HDV, new traffic model results exist which have both an updated road network and a new relative distribution of traffic loads. For the present study, these results have been made available by the Traffic Coordination section of the Federal Office for Spatial Development (FOSD), who in turn used preliminary results from the transboundary freight transport (for transit and import/export transport) and the freight transport surveys of 1998 (for estimates on the national traffic) for the years 1998 and 2015.

It proved difficult to merge the traffic data that are available for the different road networks. It was therefore decided to compute the road transport emissions on the two networks separately. Major differences between the two networks are seen for the year 2010. The newer (HDV) network assumes a higher degree of completion of the planned national highway network. As a consequence, on these links only emissions from HDV transport are available.

The overall sum of the traffic data inputs does not exactly match the overall values as indicated by SAEFL (2000b). Scaling factors have been applied such that the overall traffic activity (vehicle kilometres travelled) corresponds to SAEFL (2000b). For passenger transport, the

loads on links and zones were scaled; for HDV traffic, only the zone traffic (roughly 11% of national freight traffic was attributed to zone traffic) was scaled, whereas the link loads were not altered. For import/export (i.e., international freight transport having either their origin or their destination within Switzerland) and for transiting freight traffic, it was assumed that no zone traffic occurs, and therefore a scaling factor was attributed to the link loads.

For the HDV, the road network and traffic loads were only available for the years 1998 and 2015. For the year 2000, a uniform re-scaling factor was applied to the 1998 data; for 2010, the 2015 traffic volume data was used as the basis of the emission modelling.

For important roads, and especially for all major transit highways, the effective link length has been manually derived from maps. For roads with low traffic, this effective length equals the geometric length of the straight line between the start and end node of the link.

The emission modelling was done in exact analogy to SAEFL (2000b), where more details can be found. Both tailpipe and non-tailpipe PM10 emission are taken into account. For the non-tailpipe emission factors used in this study, please refer to Appendix A2. The tailpipe emission factors are those from SAEFL (1999b) and SAEFL (2001a) and take into account the EURO-3 and EURO-4 legislation, as well as the so-called "2nd phase of EURO-4" for HDV from 2008 on. The PM2.5/PM10 ratio for tailpipe PM10 is assumed to be 100%, i.e., all PM actually is PM2.5 (Janssen *et al.* 1999, Kerminen *et al.* 1997, Kleeman *et al.* 1999).

The tailpipe emission factors reflect the lowered emission standards that will be introduced until 2010 and will reduced tailpipe PM10 emissions from 1859 t/a (2000) to 854 t/a (2010 BAU) or even down to 555 t/a (2010 MFR). Using scaling factors, it has been assured that the present modelling, which uses detailed road networks, yields exactly the same over-all emissions as the SAEFL (2000b) report, which only used aggregated traffic statistics. The resulting emissions from road transport are listed in Table 8 for 2000 and both 2010 scenarios.

Vehicle category	Tailpipe emissions	Tyre abrasion	Brake abrasion	Clutch abrasion	Road abr.+ resuspension	Total PM10 [t/a]
Year 2000						
PC (gasoline)	228	592	80	0	1'331	2'231
PC (diesel)	296	48	7	0	109	460
LDV (gasoline)	10	50	10	0	60	129
LDV (diesel)	205	31	6	0	37	278
HDV (diesel)	924	509	9	0	1'149	2'591
Coaches (diesel)	41	24	0	0	55	121
Urban buses (diesel)	107	40	1	0	90	238
MC (2- and 4-stroke)	26	10	1	0	22	59
Mopeds (2-stroke)	20	1	0	0	3	24
Total goods transport	1'139	589	25	0	1'245	2'998
Total passenger transport	720	715	89	0	1'609	3'133
Year 2010, "business as usual" scenario						
PC (gasoline)	247	642	87	0	1'443	2'419
PC (diesel)	155	62	8	0	138	363
LDV (gasoline)	14	67	13	0	81	175
LDV (diesel)	67	42	8	0	51	168
HDV (diesel)	273	583	10	0	1'314	2'180
Coaches (diesel)	18	34	1	0	76	128
Urban buses (diesel)	34	41	1	0	92	167
MC (2- and 4-stroke)	29	11	1	0	24	65
Mopeds (2-stroke)	18	1	0	0	2	21
Total goods transport	354	692	32	0	1'445	2'523
Total passenger transport	500	789	98	0	1'775	3'163
Year 2010, "maximum feasible reduction" scenario						
PC (gasoline)	135	472	64	0	929	1'601
PC (diesel)	121	45	6	0	89	262
LDV (gasoline)	6	51	10	0	54	121
LDV (diesel)	45	32	6	0	34	116
HDV (diesel)	182	443	8	0	874	1'506
Coaches (diesel)	14	25	0	0	49	88
Urban buses (diesel)	27	30	1	0	59	116
MC (2- and 4-stroke)	16	8	1	0	15	40
Mopeds (2-stroke)	10	1	0	0	1	12
Total goods transport	233	526	24	0	961	1'744
Total passenger transport	322	581	72	0	1'143	2'119

Table 8: PM10 emissions from road transport in Switzerland for 2000 and two 2010 scenarios.

Emissions from the major road tunnels are included in Table 8, but were removed from the emission inventory by deleting the appropriate amount from the link emission. This procedure was performed for the Gotthard, Seelisberg, Gubrist and Belchen tunnel, and (for 2010) for the newly constructed Uetlibergtunnel. The emission load thus deleted is ignored, i.e. the dispersion of the emissions from the entrances and ventilation stacks of such road tunnels is not modelled. This means that the effect of these emissions from road tunnels becomes part of the background concentration parameterization (section 2.5).

The spatial localization of emissions from road transport was performed differently for the link and zone emissions. The link emissions are known for each link of the road network individually and were localized accordingly. The emissions from all major road links that are curved were manually localized at the true road positions, which were manually derived from maps. The zone emissions were modelled for each traffic zone, not per road link. Traffic zones often are equal to a single community, or cover the area of several remote communities. The cold start emissions were attributed to the area of each community proportional to the population density.

4.2. Emissions from other transport modes

4.2.1. Emissions from rail transport

In Switzerland, almost the entire rail network is electrified; only very few trains coming from other countries are diesel powered. The only significant use of diesel fuel to power train operations is for diesel locomotives which operate on shunting yards and to deliver freight cars to individual customers, track tractors for track maintenance, and carriages for special operations.

PM10 emissions from rail transport have been addressed very recently. Whereas tail-pipe PM10 emissions from diesel locomotives were well-known since several years (SAEFL 1996b, 2000b), the emissions from brake pad, track and wheel abrasion for rail carriages and locomotives had not been quantified so far. A first estimate was based on statistics of the Swiss Federal Railways on the number of brake pads, wheels, and tracks purchased, their average weight loss over lifetime, and assumptions on which fraction of the total weight loss falls into the PM10 range.

This first assumption resulted in a total PM10 load from rail transport of approximately 3000 t/a (SAEFL 2001a), but contained large uncertainties. Compared to road transport emissions, this figure seemed to be rather high. As a consequence, a new research program has been launched, where, in a first part, PM10 concentration levels were measured in the vicinity of railways. The results show that particulate matter concentration levels are indeed increased in the vicinity of railway tracks, but that a large amount of the particles have diameters much larger than 10 µm. In a second part, brake emissions were measured in a railway test facility showing, in accordance with the concentration measurements, that a significant part of the brake particles had diameters larger than 10 µm. The third part of the research program contained sensitivity analyses using the enhanced modelling methods and comparisons with the

measurements. As well, the analyses gave strong evidence that the total PM10 load of 3000 t/a is largely overestimating the real emissions.

The results of the measurements and of the sensitivity analyses are documented and are available in SAEFL (2002a). Based on this study, a revised PM10 emission load from rail transport of roughly 1000 t/a is considered to be the most reasonable estimate. This is 36% of the figure given in SAEFL 2001a. For the present study, this new emission load of 1000 t/a has been used.

To derive a PM2.5/PM10 ratio, this total emission load was split into six parts according to their different origins: abrasion of brakes, tracks, wheels and overhead contact lines; exhaust emissions, and resuspension. Results are shown in Table 9. As for road transport, exhaust particles have an estimated PM2.5/PM10 ratio of 100%. Lacking any results from literature, the PM2.5/PM10 ratio for track and wheel abrasion was estimated to be 10% for this study, whereas for brake and contact line abrasion, 20% was assumed. In analogy to resuspended particles from road transport, the PM2.5 fraction of resuspended particulate matter was set at 25%. This yields an average PM2.5/PM10 ratio of 20%. For a proper spatial disaggregation, it also proved necessary to further split the emissions from each of the six emission sources into a passenger and freight transportation part. This was done on a different basis for each of them, as indicated in Table 9.

For the spatial disaggregation, the railway network consisting of nearly 2500 links was used. For each of these links, the amount of axle kilometres per year is known, separately for passenger and for freight transport. The total of the passenger emissions, 421 t/a, was spatially distributed along the links in proportion to the axle kilometres of passenger transport. The same procedure was performed for emissions from freight transport.

		PM10 emission from rail transport 2000		
Emission source	basis of split passenger/freight	passenger [t/a]	freight [t/a]	total [t/a]
brake abrasion	brake systems	84	329	413
track abraison	performance (axle-km/a)	170	103	273
wheel abraison	performance (axle-km/a)	77	47	124
contact line abrasion	performance (axle-km/a)	11	7	18
exhaust (diesel engines only)	freight transport only	0	45	45
resuspension	performance (axle-km/a)	79	48	127
total		421	579	1000

Table 9: PM10 emissions from rail transport (source: SAEFL 2001a, 2002a, 2002b).

For the two scenarios of the year 2010, the emission totals as indicated in SAEFL (2001a) were reduced by the same factor as for the emissions of the year 2000 (0.36). Thus, in the "business as usual" scenario, the emissions slightly increase from 1000 t/a to 1050 t/a, whereas they decrease to 910 t/a for the "maximum feasible reduction" scenario. For 2010, both the split of passenger and freight transport is kept constant (passenger 42%, freight 58%) and the split into the emission source categories, as shown in Table 9, are kept constant.

4.2.2. Emissions from air transport

For PM emissions from air transport, only the emissions occurring near the ground (to a height of approximately 200 m above ground level) are taken into account in the dispersion model. All emissions occurring above this height contribute to the background concentration and are included in the corresponding function (section 2.5). Only the two major commercial airports situated on Swiss territory, Geneva and Zurich airports, are taken into account; the Basle airport is actually located in France. The smaller airfields of Berne, Sion, Samedan, Lugano, etc., are neglected because no data is available.

The PM10 emission load from the Zurich airport for 2000 is estimated at 155 t/a (Canton of Zurich 2001). This figure represents approximately the system boundary of 200 m above ground level. The emissions for the 2010 scenarios are based on the SAEFL (2001a) emissions for air transport. These include emissions above 200 m, and even the emissions of transit flights crossing the Swiss airspace. Therefore their relative increase in emissions is applied to the load of 155 t/a for 2000.

For Geneva airport, all emissions are assumed being proportional to those from Zurich airport, weighted by the number of aircraft movements (sum of take-offs and landings). This means that we assume the same growth in air transport as for Zurich airport. For 2000, Geneva had 159'300 movements, and Zurich Kloten reported 306'200. Emissions from road transport to and from the airport were taken into account in the road transport inventory (section 4.1). The resulting figures are listed in Table 10.

	movements/a 2000	PM10 emissions [t/a] 2000 PM10/a	2010 BAU	2010 MFR
Emissions from air transport incl. transit flights		765	908	873
		100%	119%	114%
Zurich airport	306'200	155	184	177
Geneva airport	159'300	81	96	92
Sum of Zurich + Geneva airports	465'500	236	280	269
Not covered by air transport emission grid		*529*	*629*	*604*

Table 10: Assumed PM10 emissions of the two major Swiss airports for 2000 and 2010.

From the total PM10 emissions of aircrafts, 15.4% originate from combustion, having a PM2.5/PM10 ratio of 100%; 62.1% of PM10 emissions are from run field surface abrasion (ratio: 25%), 22.5% from tire abrasion (ratio: 10%). This leads to a total PM2.5/PM10 ratio for aircraft emissions of 34.5%.

The emissions from air transport were spatially disaggregated as follows: for Zurich airport, 85% of the total emission load have been uniformly distributed to those grid cells actually representing the airport area itself, and the remaining 15% have been uniformly distributed to grid cells which are outside of this airport area, but still inside the system boundary of the Canton of Zurich (2001) report; for Geneva airport, the total emission load has been distributed uniformly to those grid cells which cover the airport area, which was manually derived from maps.

4.2.3. Emissions from water transport

Emissions from water transport were ignored in the present study, because no data is available. Their emission load is thought to be small compared to other sources (in SAEFL 2001a, the total PM10 emissions from modes of transports other than rail, air or road are estimated at 118 t/a for 2000). This means that the corresponding emission loads enter the background function (section 2.5).

4.3. Emissions from industry, commerce, households, agriculture and forestry

4.3.1. Emissions from construction, including heavy equipment

Emissions from construction includes building construction, especially emissions from wood handling, and road construction, including heavy (mobile) equipment (like loaders, compac-

tors, forwarders, front shovels, knuckle-boom loaders, paving equipment, scrapers, etc.). All other industrial mobile machines are accounted for in the industrial/commercial emission load (see below). Total PM10 emissions for 2000 are 4578 t/a (SAEFL 2001a). The PM2.5/PM10 ratio was estimated for the various source categories separately: PM10 emissions from construction sites are 1500 t/a; their ratio is estimated to be 15% (figure of Countess 1999 for construction and demolition). Emissions from wood handling are 1565 t PM10/a; their ratio is estimated at 57% (Pregger and Obermeier 1999). Tailpipe emissions from heavy equipment are 1215 t/a with a ratio of 100% as for tailpipe emissions from road vehicles. Six other emission categories account for the missing 6.5% of emissions (298 t/a) and have an estimated ratio of 76%. The overall PM2.5/PM10 ratio for the entire emission inventory is 55.8%. For the spatial disaggregation, these emissions were equally distributed to grid cells with land use classes 16 and 17 (residential areas) and 18 to 20 (industrial/commercial areas) and to those grid cells covered by the road link network as described in Section 4.1.

4.3.2. Emissions from agriculture and forestry

Two different emission inventories were used for agricultural and for forestry emissions. The total emission load from agriculture and forestry is the sum of PM10 emissions (in 2000) from:

- Animal production (1705 t/a); the PM2.5/PM10 ratio is estimated at 30%, since no literature value could be found;
- Hew production (139 t/a), thereof 61% PM2.5 (from Pregger and Obermeier 1999);
- Open fire waste burning (1512 t/a: agriculture 378 t/a, forestry 1134 t/a); PM2.5 ratio of 93% for unplanned fires (Countess 1999);
- Mobile machinery and equipment (3222 t/a: agriculture 3041 t/a, forestry 181 t/a): The following PM2.5/PM10 ratios have been used. 1.00 for exhaust emissions (1131 t/a), 0.10 for tyre abraison (45 t/a), 0.30 for brake abrasion (24 t/a), 0.25 for road abrasion and resuspension (2020 t/a). The numbers in parentheses refer to the PM10 emissions (SAEFL 2001a).

The total PM10 emission load of 6578 t/a (in 2000) splits into 5263 t/a for agriculture and 1315 t/a for forestry (SAEFL 2001a). The overall PM2.5/PM10 ratios are 47.6% and 87.2%, respectively.

For the spatial disaggregation, all agricultural emissions have been uniformly distributed to all areas with a BFS (1992) land use category belonging to agricultural production (classes 5

to 8). For emissions from forestry, the emissions have been uniformly attributed to all areas with a BFS (1992) value for forests (class 1) that are situated at altitude lower than 1200 m a.s.l.

4.3.3. Residential emissions

PM10 emissions from households were taken from SAEFL (2001a). They include emissions from heating and warm-water facilities (752 t/a; the PM2.5/PM10 ratio is set at 100% like for other PM10 from internal combustion processes), emissions from mobile machinery and equipment (gardening and do-it-yourself tools, total 123 t/a; PM2.5/PM10 ratio: 100%), emissions from (illegal) open fire burning of waste (245 t/a; ratio of 93% for unplanned fires from Countess 1999) and emissions from fireworks (130 t/a; PM2.5/PM10 ratio estimated at 50% due to a lack of figures from literature). Hence the total load of residential PM10 emissions is 1251 t/a, with an averaged PM2.5/PM10 ratio of 93%.

All residential emissions (both from stationary sources and from mobile equipment) are spatially dis-aggregated proportionally to the population density.

4.3.4. Emissions from industry and commerce

The emissions from stationary industrial and commercial sources were taken from SAEFL (2001a). These emissions also include emissions from very tall stacks (like cement and concrete factories), in contrast to the SAEFL (2003) study, where their NO_x emission load has been ignored (i.e., was part of the background function).

This inventory includes PM10 emissions from

- industrial heating devices (551 t/a); PM2.5/PM10 ratio of 86% based on a weighted average of P2.5/PM10 ratios from Pregger and Obermeier (1999) for coal (58%), wood (89%) and mineral oil (97%) burning.
- Commercial heating devices (369 t/a) with a weighted PM2.5/PM10 ratio of 90% (due to a higher share of wood burning).
- Quarrying, cement and concrete production (total 1249 t/a). The main loads come from cement ovens (600 t/a; PM2.5/PM10 ratio of 83% from Pregger and Obermaier 1999), other emissions from cement production (160 t/a; the assumed PM2.5/PM10 ratio of 64% is based on various figures of Pregger and Obermeier [1999] for different types of cement ovens), gravel industries (242 t/a; ratio of 31% based on the corresponding figure from Pregger and Obermeier 1999), glass production (62 t/a; the estimated

PM2.5/PM10 of 75% is the average of two ratios from Pregger and Obermaier 1999). The overall average PM2.5/PM10 ratio is 60%.

- Mineral oil industry (mainly the two Swiss refineries) with PM10 emissions of 43 t/a, of which an estimated 90% are in the PM2.5 fraction (Countess 1999).
- Metal industry (total PM10 load 860 t/a). The main loads come from melting pots (604 t/a); their PM2.5/PM10 ratio is assumed at 70% (Pregger and Obermaier 1999). This factor has also been applied for the remaining emissions from metal industries (256 t/a).
- Food industry causes 314 t/a of PM10 emissions, of which 173 t/a are from mills (PM2.5/PM10 ratio of 27%, using figures from Pregger and Obermeier 1999 for the loading of floor), 104 t/a from the production of sugar, oil and fat (ratio of 50% due to a lack of figures from the literature). The remaining 37 t/a from the production of coffee and smoked meat are assumed having a PM2.5/PM10 ratio of 100%.
- Waste disposal causes 409 t/a of PM10, of which 323 t/a originate from waste incineration (with a PM2.5/PM10 ratio of 70%, an average of figures from Pregger and Obermeier 1999 for waste incineration), 86 t/a from waste dumps (with a PM2.5 share estimated at 50% due to a lack of literature values). The overall PM2.5/PM10 ratio is 65%.
- Industrial machines cause 186 t/a of PM10, 100% of which is in the PM2.5 fraction.
- Remaining small emission loads come from health care facilities (29 t/a), "other" sources (50 t/a) and energy production (105 t/a)

The industrial and commercial emissions (both stationary sources and from mobile machinery) were uniformly distributed to all grid cells with a BFS (1992) land use class 16 or 17 (residential areas) and 18 to 20 (industrial/commercial areas).

4.4. Total primary PM10 emission load

The sum of all primary particle emissions from road and air transport, industry, commerce, agriculture, forestry and households is presented in Table 11. Those PM10 emissions that are listed in SAEFL (2001a) but that are not covered with a separate emission inventory in the present study are also listed. Not covered directly are emissions from water transport and from air transport above 200 m above ground level. These emissions are indirectly covered by means of the PM10 background concentration function (section 2.5).

Source category	PM10 emissions 2000	(%)	2010 BAU	(%)	2010 MFR	(%)
Emissions covered by emissions inventories						
Road transport	6'131	26%	5'686	26%	3'862	27%
Rail transport	1'000	4%	1'050	5%	910	6%
Air transport	236	1%	280	1%	269	2%
Industrial + commercial, incl. energy production	4'165	17%	3'220	15%	1'801	13%
Construction incl. heavy equipment	4'578	19%	3'804	17%	2'039	14%
Residential	1'251	5%	1'353	6%	705	5%
Agricultural	5'263	22%	5'334	24%	3'637	26%
Forestry	1'315	5%	1'332	6%	909	6%
Total	23'939	100%	22'058	100%	14'133	100%
Not covered by emissions inventories						
Air transport >200m above ground	529		629		604	
Other means of transport (water transport, etc.)	118		104		74	
Total covered by background function	647		733		678	
Rail emissions outside PM10 range	1'816		1'895		1'653	
Total PM10 emissions after SAEFL (2001a)	26'402		24'686		16'464	

Table 11: Primary PM10 emissions for 2000 and both 2010 scenarios.

4.5. Secondary particles from gaseous precursors

4.5.1. Nitrate and sulphate

The Swiss amount of nitrate and sulphate aerosols is derived from maps with annually averaged ambient concentration levels of the respective gaseous precursors throughout Switzerland. These ambient concentration maps of the precursors have a spatial resolution of 200 m (NH_3, NO_2) or 500 m (SO_2); a spatial average is computed first (see section 2.3) over all grid cells within a radius of 11 km (approximately 400 km^2). Then transformation functions are applied that parameterize the formation of ammonium sulphate, $(NH_4)_2 SO_4$, and ammonium nitrate, $NH_4 NO_3$, from the ambient concentrations of the precursors.

- For NO_2, the maps for 2000 and 2010 from SAEFL (1997) are used. The 2010 map from this source is assumed to be representative for the 2010 BAU scenario of the present study. For the MFR scenario, concentration levels of the 2010 map have been reduced by a constant factor of 0.843 (reduction of 15.7%). This is in line with the relative difference in NO_x emissions for the neighbouring countries between the BAU and MFR scenarios (see Table 7). Then, the nitrate concentration is computed as 0.29 * exp(0.63 * ln([NO_2]), where [NO_2] denotes the NO_2 concentration in µg/m^3 (EU DGXI 1997).
- For SO_2, the SO_2 map for the year 1995 (see SAEFL 1999a for details) has been extrapolated by multiplying with a constant factor (for the year 2000: 0.84; for both 2010

scenarios: 0.79). Then, the sulphate concentration is computed as $0.073 * \exp(0.57 * \ln([SO_2]))$, where $[SO_2]$ denotes the SO_2 concentration in $\mu g/m^3$ (EU DGXI 1997).

4.5.2. Aerosols from anthropogenic VOC

Secondary particles can not only be formed from inorganic gaseous precursors like NO_2, SO_2 and NH_3, but also from volatile organic compounds (VOC). Secondary particles from VOC either form through photochemical oxidation of the VOC followed by coagulation of the oxidized compounds (nucleation), or because the oxidized compounds associate with already existing particle of other origin.

Smog chamber experiments allow establishing a relationship between the VOC emissions and the secondary particulate matter originating there from. In these experiments performed with high VOC concentrations but with otherwise approximated atmospheric conditions, the mass increase of aerosols and the corresponding mass decrease of gaseous VOC are monitored. The resulting Fractional Aerosol Yield Coefficients (FAC) give the percentage of VOC mass that will convert to secondary particulate matter. These FAC are indicative only, as the formation of aerosols depends on the exact VOC concentration levels and on the presence of other aerosols that facilitate coagulation. At present it is not sure whether FAC figures from smog chambers also hold for real-world conditions with much lower VOC concentrations.

The rule-of-thumb is that VOC compounds with not more than 6 carbon atoms normally are not capable of aerosol formation, because they are too volatile (too high vapour pressure). But many VOC with more than 6 carbon atoms will also not yield aerosols. With the TRACT emission inventory (BBW 1995), a detailed (spatial resolution 200 m) VOC inventory for weekday and weekend conditions in summer is available for the whole of Switzerland. In this TRACT inventory, the VOC are grouped in 32 classes after Middleton *et al.* (1990).

For the present study, a representative average FAC has been derived for each of the 32 TRACT sub-inventories, each of which normally holds various chemically different VOC species. More details can be found in Appendix A2, where the assumptions made are listed. The TRACT inventory does not account for all VOC emissions; therefore the total VOC emission load for the year 2000 after SAEFL (1995b) has been used (NMVOC: total emissions 172'000 t/a, of which road transport 29'500 t/a). For the spatial distribution, the TRACT inventory is used; the FAC used is from Table 21. This results in a virtual emission inventory of secondary particulate matter from anthropogenic VOC precursors, with a total load of 2132

t/a, 1.24% of the total VOC emissions. The PM2.5/PM10 ratio of the secondary aerosols from VOC is assumed to be 90%, the same as for sulphate.

For the dispersion modelling, the secondary particles at first are dispersed in the same way as the primary particles, with a short-range spatial resolution of 200 m (up to 6 km from the source) and with a 2 km resolution up to 200 km away from the source. The emission height used is 12 m, as for residential and commercial emissions. Then, in contrast to primary particles, the resulting concentration from secondary PM is averaged over the area covered by a circle with a radius of 12 km around the source. This accounts for the transition time from gaseous precursor to secondary particulate matter.

4.5.3. Aerosols from biogenic VOC

Recent investigations show that apart from VOC emissions of anthropogenic origin, also the biosphere emits large amounts of VOC capable of transformation into secondary particles. Therefore, the present report introduces secondary aerosols from VOC of biogenic origin as a new emission source not accounted for yet in the SAEFL (1999a) study.

From the various VOC species, especially monoterpenes seem to be capable to yield secondary particulate matter (Griffin *et al.* 1999). Monoterpenes are cyclic C10 species emitted mainly during warm summer days by coniferous trees, but are reportedly also emitted by beech and birch trees. Other emitters are grass, rape, rye and grapes. While first estimates of the total biogenic emission load in Switzerland ranged at 82'650 t/a (Andreani-Aksoyoglu and Keller 1995), the more recent figure adopted for the present study is 34'310 t/a (Spirig and Neftel 2001). Table 12 lists the estimated emission of the different monoterpene species, and the annually averaged FAC (6.2%), resulting in 2127 t/a of secondary particles originating from biogenic VOC emissions.

The spatial dis-aggregation of these 2127 t/a is done using the terpene emission inventory which was one of the results of the Pollumet project (SAEFL 1996a). The way of dispersion modelling and the PM2.5/PM10 ratio are identical to those for the secondary particles from anthropogenic VOC.

Monoterpene[1,2]	aerosol yields[4] OH reaction	O3 reaction	FAC at 305 K[2]	Swiss emissions [t/a][2,3]
α-pinene	0.6%	6.7%	1.6%	13'724
β-pinene	2.0%	3.0%	2.2%	5'147
Sabinen	4.7%	2.0%	4.2%	5'147
Eimonen	1.3%	17.60%	4.1%	3'431
Δ^3-Caren	0.4%	6.6%	1.5%	3'431
not specified[5]	1.6%	6.5%	2.4%	3'431
Total	1.6%	6.5%	2.4%	34'310
FAC, averaged over 12 monthly temperatures			6.2%	
Secondary particles from monoterpene emissions [t/a]				**2'127**

[1] From all biogenic VOC, only monoterpenes are considered to contribute to aerosol formation.
[2] Spirig and Neftel (2001); [3] Andreani-Aksoyoglu and Keller (1995); [4] Griffin et al. (1999)
[5] 10% of monoterpenes are of unknown composition; they have been attributed the mean FAC.

Table 12: Biogenic monoterpene emissions for the year 2000 for 31 VOC classes, their estimated FAC, and the resulting amount of secondary particulate matter.

4.6. Summary

Table 13 presents the total primary PM10 emissions for Switzerland for the years 2000 to 2010, together with the amount of PM10 that is estimated to be in the PM2.5 range, and the resulting computed PM2.5 emission load, as used in this study. The spatially disaggregated PM10 emissions per grid cell are shown in Appendix A7 for the year 2000: Sum of all emissions in Figure 22; individual categories of the emission inventory in Figure 23 to Figure 27 and for both scenarios in the year 2010 in Figure 28.

Source category	PM2.5/PM10 ratio (2000)	year 2000 PM2.5	year 2000 PM10	year 2010, BAU PM2.5	year 2010, BAU PM10	year 2010, MFR PM2.5	year 2010, MFR PM10
Road passenger transport	39%	1'220	3'133	1'232	3'163	825	2'119
Road goods transport	51%	1'517	2'998	1'276	2'523	882	1'744
Air transport	35%	81	236	97	280	93	269
Rail transport	15%	151	1'000	158	1'050	137	910
Industry/commerce	72%	2'996	4'165	2'316	3'220	1'296	1'801
Heavy equipment	56%	2'553	4'578	2'121	3'804	1'137	2'039
Residential	93%	1'164	1'251	1'258	1'353	656	705
Agriculture	48%	2'503	5'263	2'537	5'334	1'730	3'637
Forestry	87%	1'147	1'315	1'162	1'332	793	909
Total	56%	13'332	23'939	12'158	22'058	7'549	14'133

Table 13: Summary of primary PM2.5 and PM10 emissions for Switzerland for 2000 and two 2010 scenarios, as used in this study.

5. Model results

5.1. PM10 and PM2.5 concentration maps

The main results of the present report are the annually averaged PM10 and PM2.5 concentration maps for the whole of Switzerland for the year 2000, and for two emission scenarios in the year 2010. Numerous maps are presented at the end of this report in Appendix A8.

5.2. Illustrative examples

In order to illustrate the PM10 ambient air quality levels at a higher spatial resolution, this section displays results for typical areas at a resolution of 200 m (Appendix A9). Of course, point measurements will always show a larger amount of variation and can reach levels that are above the spatially averaged model results of the present study (this is discussed in greater detail in Section 6.1). The city of Geneva has been chosen as an example for an urban agglomeration; the juncture of the two most important Swiss highways near Härkingen serves as an example for the PM10 concentration levels in the vicinity of major highways. Finally, the region where the city of Altdorf is situated illustrates the results of the PM10 dispersion modelling in Alpine valleys; the A 2 highway, the major north-south transit highway crossing the Swiss Alps, passes by Altdorf. One of the main railway connections from north to south, the Gotthard route, also passes near Altdorf.

As can be seen at the 200 m × 200 m resolution, in the city centre of Geneva (Figure 43, page 116) several areas have concentrations above 25 µg/m^3; these areas vanish in the coarse resolution of 400 m × 400 m. Differences in induced PM10 concentrations between road and rail transport are also visible: the A 1 highway (heading from the north-east to Geneva) is associated with much higher PM10 concentrations compared to the very busy railway connection from Lausanne to Geneva.

The highest PM10 levels of these illustrative examples are predicted for the Härkingen area (Figure 44, page 117); in 200 m × 200 m resolution, several grid cells have concentration levels above 27.5 µg/m^3. All grid cells close to the highway are above 22.5 µg/m^3. At the NABEL station Härkingen, an annual mean of 26.2 µg/m^3 was measured in the year 2000. Also visible are the railway tracks of the Bern to Olten route, which are among the busiest (with respect to passenger transport) railway tracks of the whole country. Still, PM10 concentrations near the tracks are clearly lower than near the highways.

In the Alpine valley near Altdorf (Figure 45, p.120), the general concentration level of PM10 is between 15 and 17.5 µg/m^3; but the higher resolution reveals that areas close to the highway can actually exhibit concentration levels in the 17.5 to 20 µg/m^3 range. South of Altdorf, the tracks of the main alpine rail transit route (Gotthard route) are visible – used by most cargo trains. Because the brake systems of cargo cars cause higher PM emissions, PM10 concentrations near the rail track are comparable to the PM10 concentrations near the A 2 highway.

5.3. Area statistics and population exposure 2000 to 2010

The percentages of the land and water surface of Switzerland exceeding the PM10 ambient air quality standard (20 µg/m^3) are computed using the (area averaged) concentration level for each grid cell with a grid spacing of 200 m. Population data (census of the year 2000; total population of Switzerland was 7.288 million persons) is available on a 100 m × 100 m basis; hence 4 hectares belong to each grid cell. The resulting cumulative density function is displayed in Figure 14.

It should be noted that transfer functions yielding area-averaged (for grid cells of 200 m × 200 m) concentration values are used. These area-averages systematically underestimate the true extent of exposure to local ambient PM concentration peaks (e.g. in street canyons), since local effects are ignored.

The 2000 census data have been used for the 2010 population exposure. Population growth and urban sprawl is not accounted for. Population groups are listed by exposure level with 2 to 5 µg/m^3 steps in Table 14. In 2000, 5.5% (2'300 km^2) of the total surface of Switzerland exhibit a mean PM10 concentration above the 20 µg/m^3 ambient air quality standard. In this area, 41.3% of the population (3.01 million persons) have their domicile. In 2010 for the "business as usual" scenario, these numbers drop to 2.0% (839 km^2) of the surface and 20.8% (1.51 million persons) of the population. For the "maximum feasible reduction" scenario, the corresponding number are 0.7% (273 km^2) of the surface and 4.9% (0.36 million persons) of the population.

The results from the present study (Figure 14) are also compared to those of the preceding study (SAEFL 1999a), shown in Figure 15. For the year 2000, the new version of the modelled population exposure is slightly lower (i.e., a lower percentage of the population has their domicile in areas where the ambient PM10 concentration is above the 20 µg/m^3 threshold) as compared to the results from the previous study for 1997 (for SAEFL 1999a, the 1990 census

data [BFS 1994] has been used). This result reflects two effects: (i) the new estimate of the emission loads is lower (e.g., non-tailpipe emissions from road transport); (ii) the reduction of emissions from 1997 to 2000. The various model enhancements do not seem to have lead to a systematic change in the predicted particle mass concentrations.

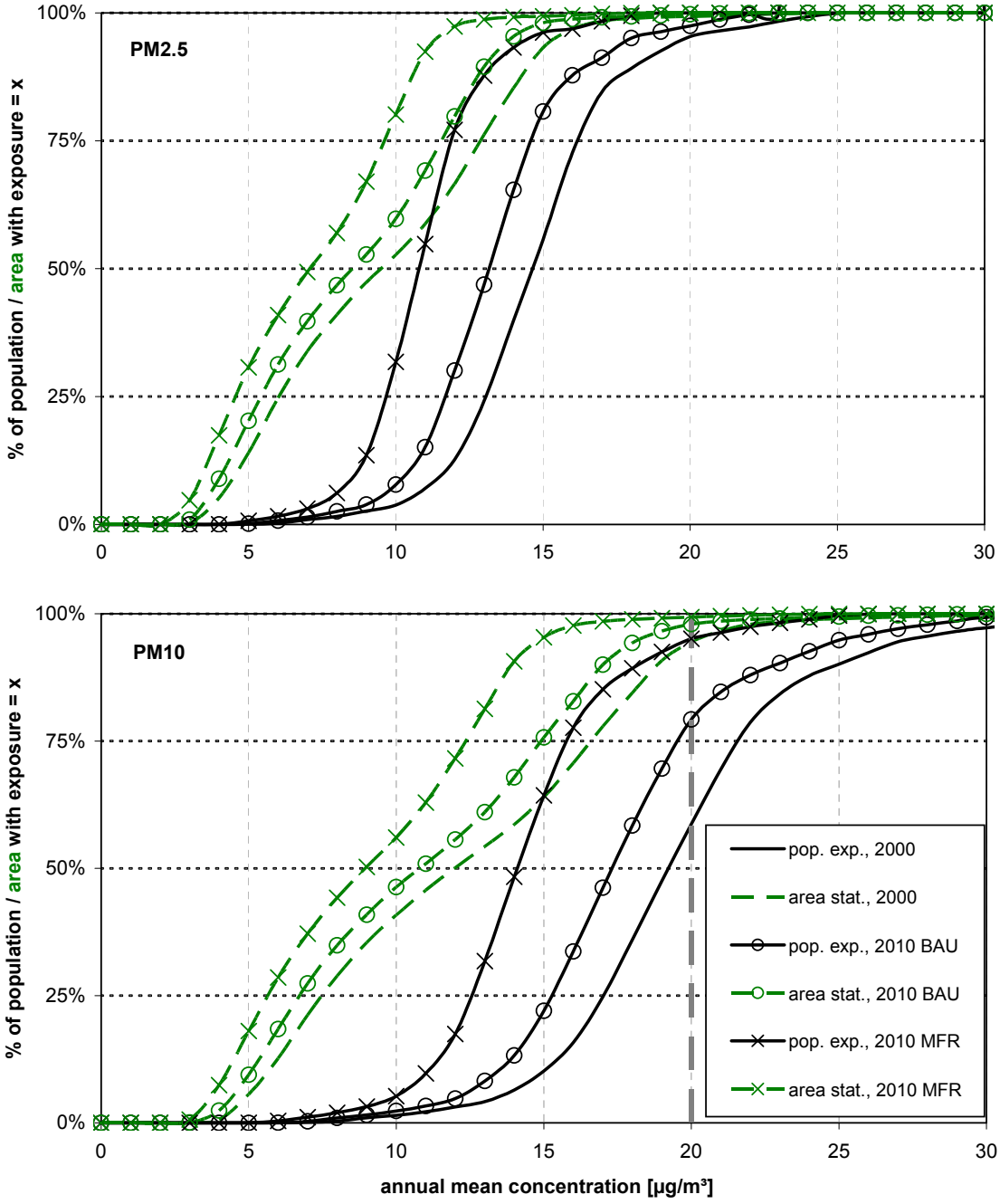

Figure 14: Cumulative area statistics (percentage of all 200 m × 200 m grid cells; concentration is the average over the cell surface) and cumulative population exposure (domicile) to an-

nually averaged ambient PM2.5 (top) and PM10 (bottom) concentration level. The vertical broken line) indicates the Swiss PM10 ambient air quality standard of 20 µg/m³.

exposure in µg/m³	PM10 2000		PM10 2010 BAU		PM10 2010 MFR		PM2.5 2000	PM2.5 2010 BAU	PM2.5 2010 MFR
0 <= 5	0.0%		0.0%		0.0%		0.0%	0.1%	0.7%
5 <= 10	1.5%		2.3%		5.2%		3.8%	7.6%	31.1%
10 <= 12	1.6%		2.5%		12.2%		8.9%	22.3%	45.3%
12 <= 14	3.4%	58.7%	8.4%	79.2%	30.9%	95.1%	27.2%	35.3%	16.1%
14 <= 16	9.3%		20.4%		29.3%		32.8%	22.4%	3.7%
16 <= 18	20.2%		24.7%		11.6%		16.5%	7.3%	2.6%
18 <= 20	22.7%		20.8%		5.8%		6.2%	2.4%	0.5%
20 <= 22	20.0%		8.7%		2.4%		1.9%	2.2%	0.0%
22 <= 24	9.1%		4.7%		1.5%		2.0%	0.4%	0.0%
24 <= 26	4.5%		3.3%		1.0%		0.7%	0.0%	0.0%
26 <= 28	3.3%	41.3%	1.9%	20.8%	0.1%	4.9%	0.0%	0.0%	0.0%
28 <= 30	1.7%		1.4%		0.0%		0.0%	0.0%	0.0%
30 <= 35	2.7%		0.7%		0.0%		0.0%	0.0%	0.0%
	100.0%		100.0%		100.0%		100.0%	100.0%	100.0%

Table 14: Population exposure to PM10 and PM2.5 in Switzerland in 2000 and in 2010 for the "business as usual" (BAU) and the "maximum feasible reduction" (MFR) scenarios. All percentages relate to the 2000 population and their 2000 domicile. The Swiss ambient air quality standard for PM10 is 20 µg/m³.

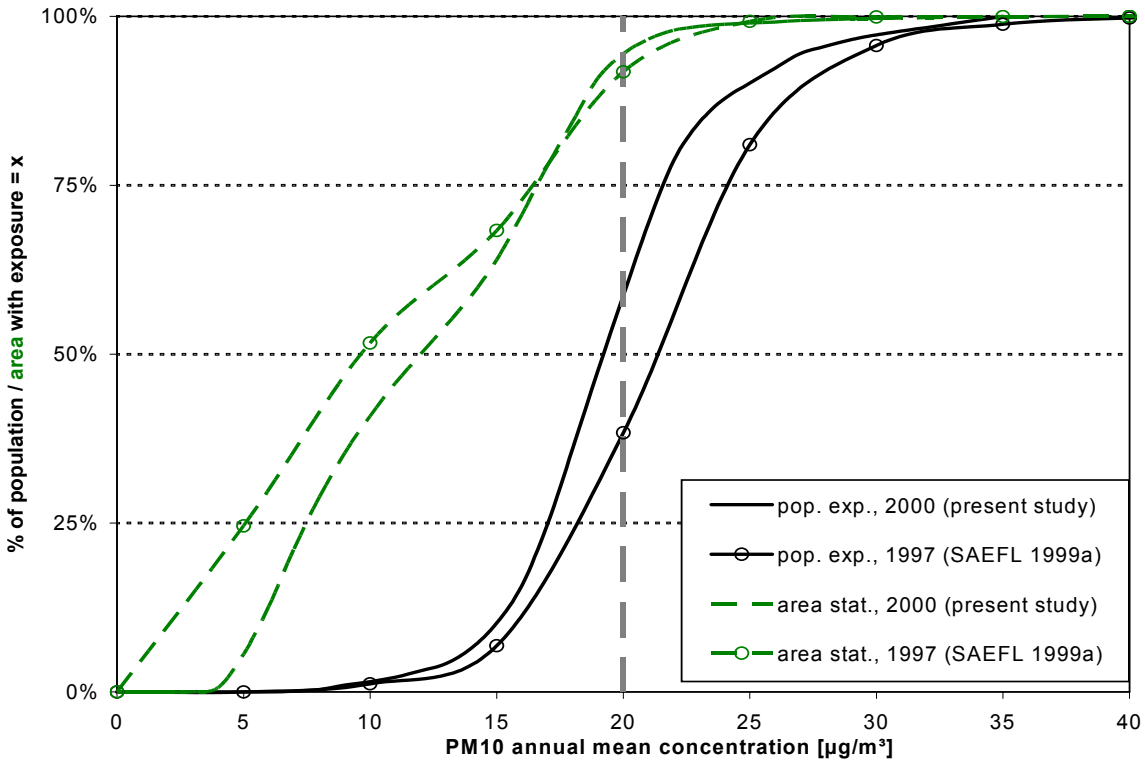

Figure 15: Comparison of area statistics and population exposure for 2000 (present study) with the corresponding results for 1997 from SAEFL (1999a).

5.4. Average population exposure

The average population exposure, based on the 2000 census, has been computed for total PM10 and for the source groups listed in Table 15. For this purpose, the background concentration parameterization had to be split into secondary and primary particles. The latter was further broken down into anthropogenic and non-anthropogenic contributions for the year 2000. The non-anthropogenic part of the primary background was then assumed to remain identical for the year 2010 as well. For further details see Table 15.

Source group		PM10 concentration maps
Anthropogenic, Swiss	primary PM10	primary particles from road/rail/air transport; residences; industry/commerce; heavy equipment; agriculture; forestry
	secondary PM10	nitrate; ammonium; sulphate; aerosols from anthropogenic VOC
Anthropogenic, foreign	primary PM10	2000: 75% of primary background 2010 BAU/MFR: primary background minus 1.01 µg/m³
	secondary PM10	secondary background concentration
Biogenic and geogenic	primary PM10	2000: 25% of primary background = 1.01 µg/m³ 2010 BAU/MFR: 1.01 µg/m³
	secondary PM10	aerosols from biogenic VOC

Table 15: Attribution of PM10 concentration maps to source groups for computation of the average PM10 population exposure.

		average PM10 population exposure [µg/m³]					
Scenario	Source group	primary	(%)	secondary	(%)	total	(%)
2000	Anthropogenic, Swiss	6.57	*33.6%*	2.88	*14.7%*	9.45	*48.3%*
	Anthropogenic, foreign	3.14	*16.0%*	5.54	*28.3%*	8.68	*44.4%*
	Biogenic and geogenic	1.05	*5.3%*	0.39	*2.0%*	1.44	*7.4%*
	Total	10.75	*54.9%*	8.81	*45.1%*	19.56	*100.0%*
2010 BAU	Anthropogenic, Swiss	6.09	*34.5%*	2.80	*15.8%*	8.89	*50.3%*
	Anthropogenic, foreign	2.56	*14.5%*	4.78	*27.1%*	7.34	*41.6%*
	Biogenic and geogenic	1.05	*5.9%*	0.39	*2.2%*	1.44	*8.1%*
	Total	9.70	*54.9%*	7.98	*45.1%*	17.68	*100.0%*
2010 MFR	Anthropogenic, Swiss	3.89	*27.1%*	2.63	*18.3%*	6.52	*45.4%*
	Anthropogenic, foreign	2.16	*15.0%*	4.25	*29.6%*	6.40	*44.6%*
	Biogenic and geogenic	1.05	*7.3%*	0.39	*2.7%*	1.44	*10.0%*
	Total	7.10	*49.4%*	7.26	*50.6%*	14.36	*100.0%*

Table 16: Average PM10 population exposure (based on data from the census for the year 2000), split up by source group.

The resulting average PM10 population exposure figures are listed in Table 16. The average exposure to total PM10 drops from 19.56 µg/m^3 in the year 2000 to 17.68 µg/m^3 and 14.36 µg/m^3 in the year 2010 for the BAU and MFR scenarios, respectively. Anthropogenic primary and secondary particles originating from Swiss emissions are responsible for roughly 50% of the total population exposure. For the average exposure to PM2.5, the respective figures are 14.76 µg/m^3 (2000), 13.29 µg/m^3 (2010 BAU) and 10.89 µg/m^3 (2010 MFR), which is roughly 75% of the PM10 exposure.

5.5. Health effects

In an earlier study, the population exposure 1997, as calculated in SAEFL (1999a), was used to determine the health costs due to air pollution. France, Austria and Switzerland presented their results on the World Health Organization Ministerial Conference on Environment and Health in London, June 1999 (ETEC 1999). In a trilateral research team, a methodological frame to model the population exposure, the health effects attributable to air pollution, and their monetary valuation were developed and applied to the three countries.

For the population exposure in Switzerland, now calculated for 2000, the same methods can be applied to compare the new results with those of 1997. In Table 17, a short summary is given. Main input for the determination of the health effects is the population-weighted mean PM10 concentration, which is given in the second column.

Scenario	concentration µg/m³	Long-term mortality 1'000 cases/a	Morbidity Mio. cases/a
1997	21.40	3.3	2.9
2000	19.56	2.9	2.5

Table 17: Health impacts in Switzerland induced by air pollution: Additional cases for long-term mortality and morbidity.

For 1997, 3314 cases of premature death among the adults over age 30 and almost 3 million of cases of morbidity were calculated. In the morbidity, several health outcomes were included: Respiratory and cardiovascular hospital admissions, chronic bronchitis with adults and bronchitis in children, the number of days with restrained activity, and asthma attacks.

With the PM10 concentration 2000, a lower population-weighted mean PM10 concentration of 19.56 µg/m^3 results, decreasing the number of cases by approximately 12.6%. As already noted in Section 5.2, the decrease in total PM emission load from 1997 to 2000 reflects two effects: (i) the new estimate of the emission loads is lower (e.g., non-tailpipe emissions from road transport); (ii) a true reduction of emissions from 1997 to 2000 occurred as well.

Care is needed while interpreting these figures. They do not imply that the annual mortality and morbidity 1997 and 2000 indeed developed in the simple manner suggested by the figures in Table 17. These figures are truly valid only for a stationary PM10 concentration pattern. If two identical populations were exposed to two spatially different PM10 concentration patterns, each of them stationary, impacts on health effects as given in Table 17 could be observed. In reality, PM10 concentration never is constant but varies over time. Ideally, the

health effects should be modelled dynamically, but this is much more complicated and has not been done so far. It is to be expected that the use of a dynamical model would decelerate the reductions in health impacts (and related costs) as shown in Table 17.

An ongoing study of the Federal Office for Spatial Development re-evaluates the health effects attributable to PM10 exposure and their monetary valuation. That study will allow an updated monetary valuation of health effects caused by particulate matter load.

6. Model validation

6.1. Comparison of PM10 model results with measurements

In this section, the predicted annually averaged PM10 concentrations (on the 200 m × 200 m grid) for 2000 are compared to measurements performed throughout Switzerland. Measurement data have kindly been made available by federal and local air quality authorities. At 37 sites high-volume samplers (HVS) are used, or methods that have been shown to be equivalent to HVS measurements; 7 stations use tapered element oscillation (TEOM) devices. (See Appendix A1 on page 79 for a complete list of the monitoring stations.) TEOM measurements have to be transformed in order to correspond with the reference gravimetric method (European Norm 12341). For the transformation, all measurements have been multiplied with a correction factor of 1.27 (valid for all TEOM devices except those with Nafion dryer; . for further details, see SAEFL 2001b). After correction, the group of TEOM measurements shows the same model performance as the HVS group, therefore the corrected TEOM measurements have been pooled with the HVS for subsequent analysis.

For further analyses in this section, the 44 monitors are further classified into 4 groups: monitors located in Ticino in Southern Switzerland (5 monitors), located in street canyons (2), monitors located in areas where the set of alpine transfer functions has been used (9), and the remaining monitors (28). Figure 16 depicts the scatter plot of predicted vs. observed PM10 concentrations for all 44 air quality monitoring sites. The dotted lines show the area where predictions lie within a factor of 1.33 of the measurements. 84% of all values are within this range.

Parameter	all data points	other	Ticino	street canyons	alpine
Number of data points	44	28	5	2	9
Average of measurements	22.59	20.75	30.40	34.00	21.44
Average of model predictions	21.38	20.72	30.31	27.85	17.03
Correlation coefficient (r^2)	0.74	0.66	0.46	---	0.69
Pearson coefficient	0.55	0.43	0.21	---	0.47
% of pred. within a factor of 1.33 of meas.	84%	96%	100%	50%	44%

Table 18: Statistical measures (---: not computed because n = 2).

Table 18 lists statistical measures per group and for all data points together. When comparing model and measurement results, one should be aware that measurements are representa-

tive for a given location (point measurement). The model result however is spatially averaged over a 200 m × 200 m grid cell. The main group of 28 monitors that do not belong to any special group (denoted "other" in Table 18) has on average a slight underestimation by the model of –0.15% only. For the 5 monitor stations located in Ticino, the model on average shows a perfect match. This is due to the additional regional background concentration function for the Southern part of Switzerland, which has been adjusted to the measurements.

For the two monitoring sites that are located in street canyons (NABEL site at Berne, and Zurich Schimmelstrasse), an under-prediction of –18% occurs. This should be expected, since the model approach used cannot account for small-scale influences (emission and dispersion modelling is done on grids with a spacing of 200 m). Valley sites (excluding those from Ticino) are underestimated by –20.6% on average, despite the special alpine dispersion modelling applied in this study.

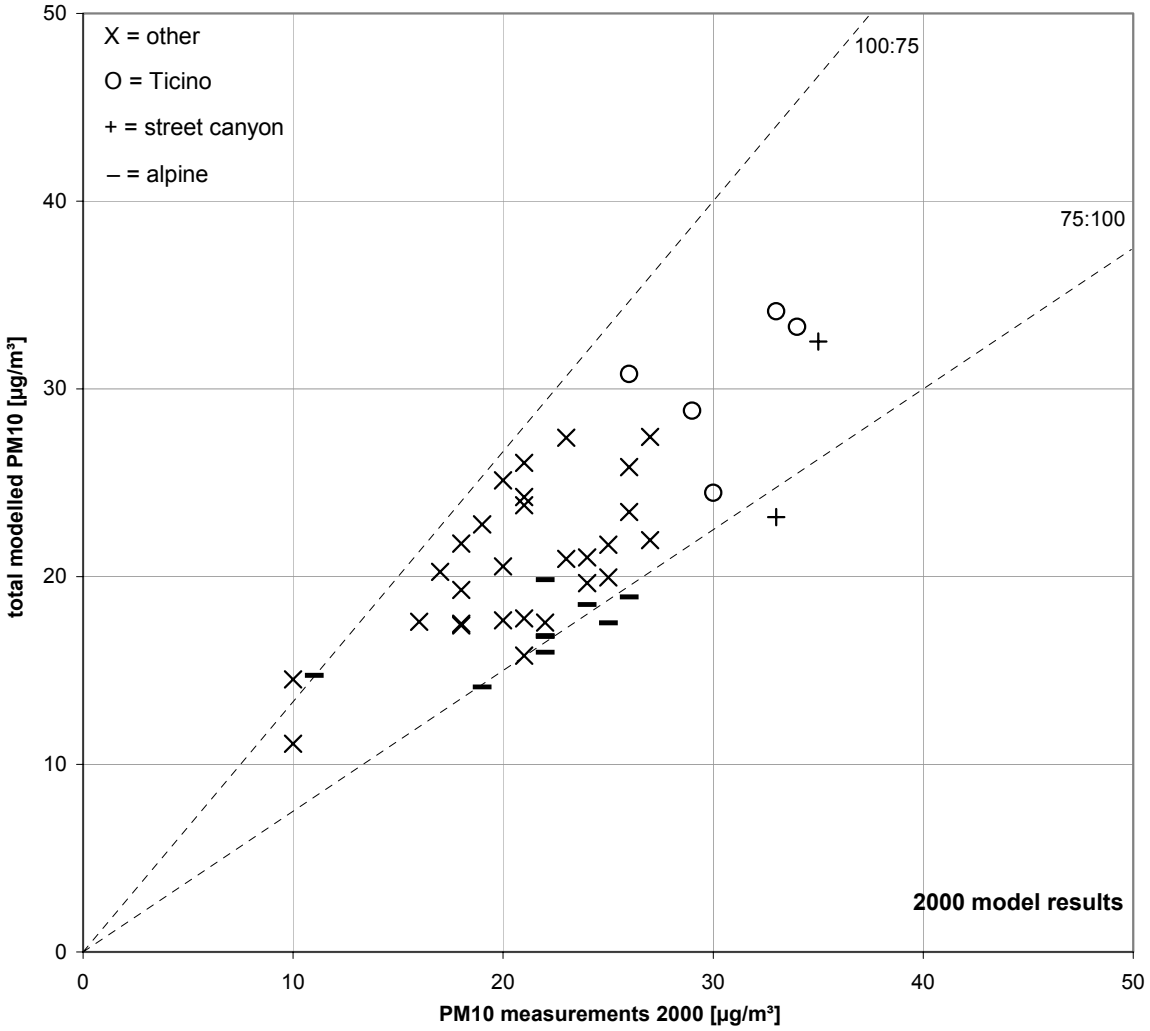

Figure 16: Scatter plot of observed and modelled PM10 annual average concentration. Total 44 data points. For further explanations see text.

6.2. Residual analyses

The differences between the predicted and measured values, i.e. the model errors (residuals), are depicted as a function of other modelled components in order to analyze any systematic model errors. Figure 17 shows the residuals as a function of the PM10 concentration originating from road transport emissions.

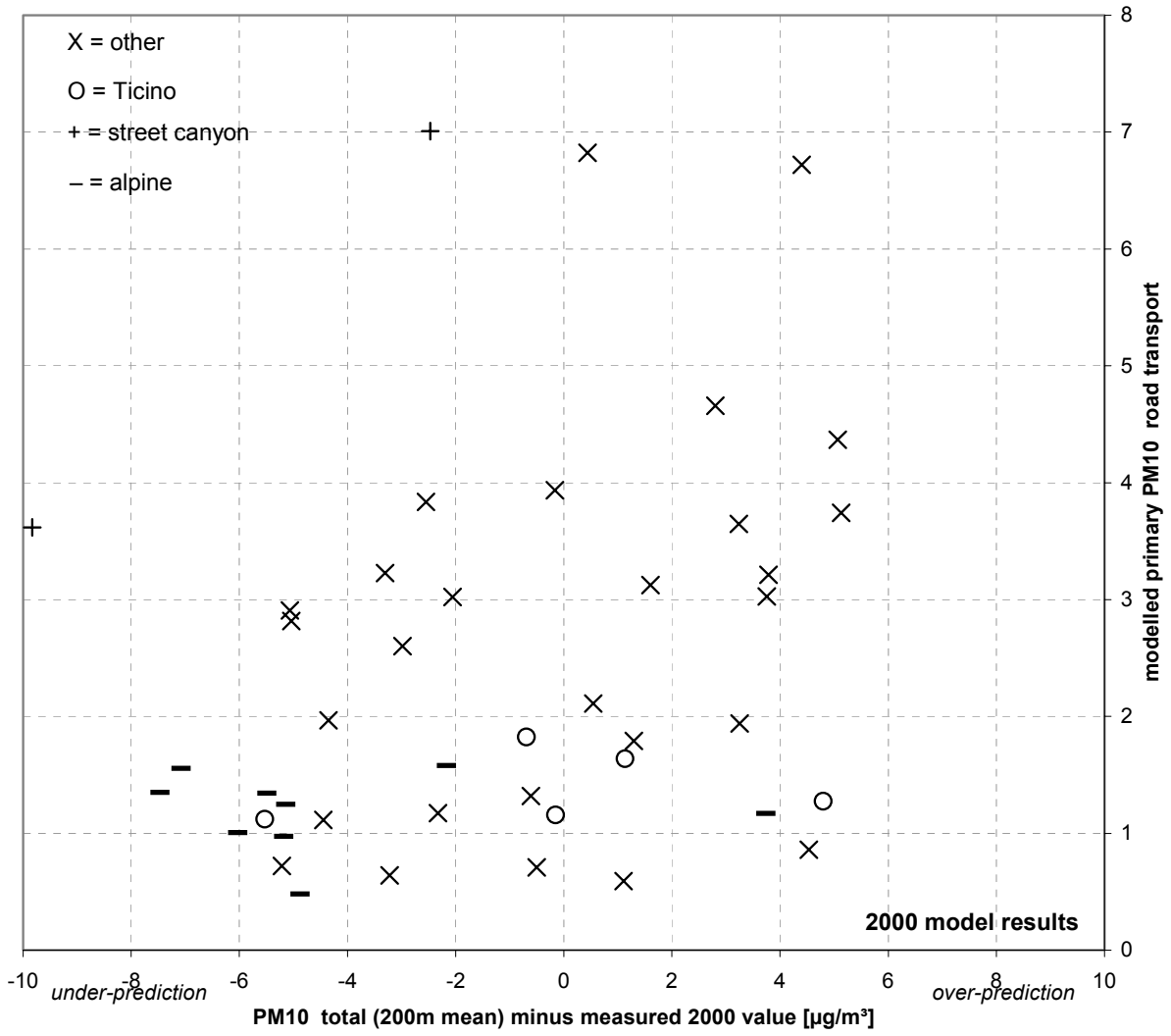

Figure 17: Model prediction error as a function of the primary PM10 concentration originating from road transport emissions.

In Figure 17, the two monitoring sites in street canyons clearly show an underestimation. This has to be expected since the model cannot simulate small-scale effects like the accumulation of pollutants in a street canyon. Other sites showing pronounced differences between model result and measurement mainly are situated in alpine regions. These differences are likely not caused primarily by road transport emissions. Overall, this comparison shows that the PM10 emissions from road transport (that have been substantially lowered in comparison to the previous SAEFL 1999a study) do not cause a systematic model bias (neither a clear over- nor a clear under-prediction).

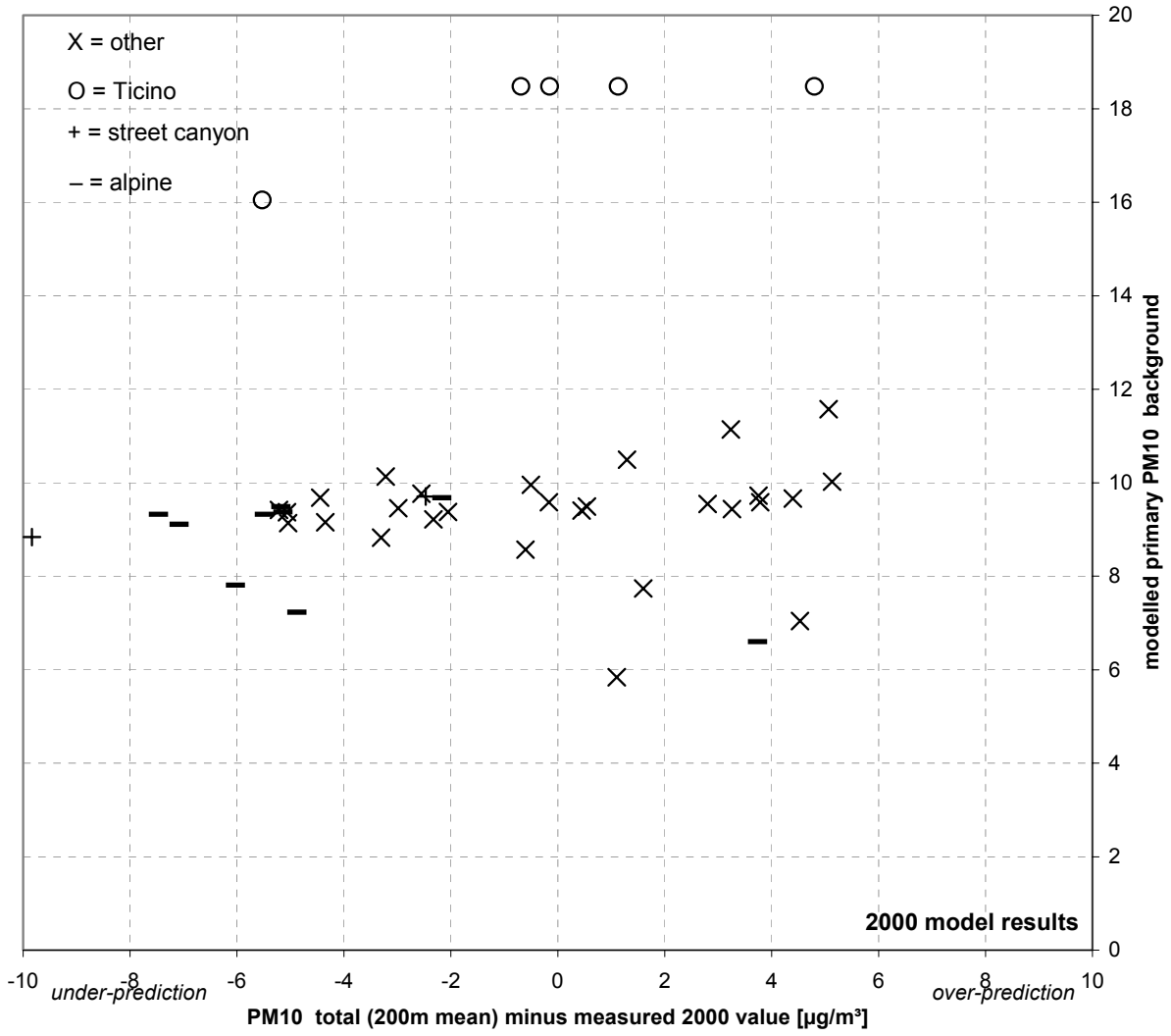

Figure 18: Model prediction error as a function of the modelled PM10 background concentration.

Figure 18 depicts the residuals against the PM10 background concentration. The sites in alpine valleys clearly show a systematic under-prediction. All Ticino sites are also in areas where alpine transfer functions have been applied, but they differ from the other alpine sites in that an additional background concentration accounting for the close neighbourhood of the heavily polluted Milan area is used, thus eliminating the systematic under prediction observed for the other alpine sites. It might be suspected that part of the model under-prediction at alpine sites occur for the same reason as the under-prediction at the Ticino sites. So it appears that the additional Ticino background concentration in fact partly compensates the model under-prediction common to all alpine sites.

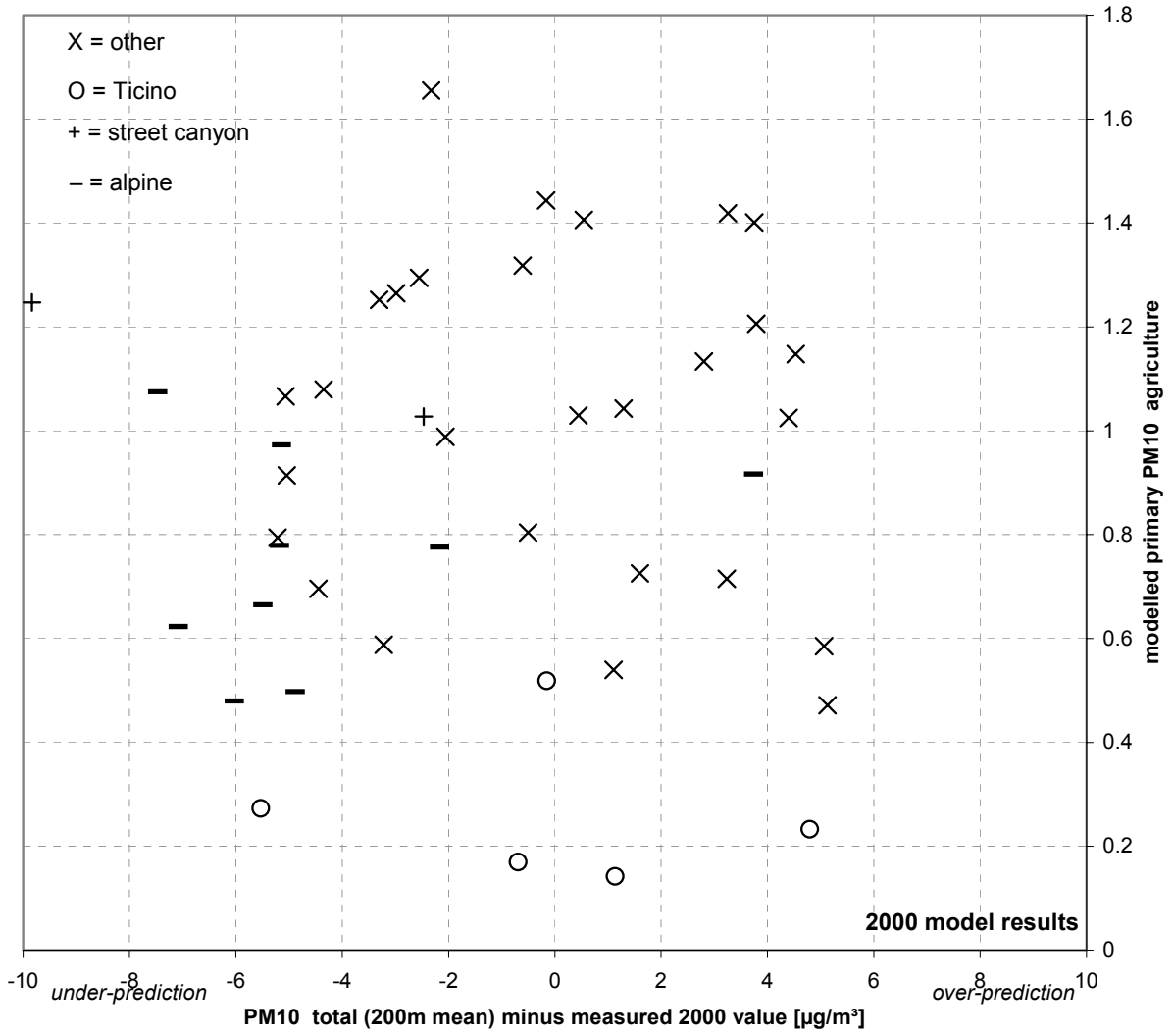

Figure 19: Model prediction error as a function of the primary PM10 concentration due to agricultural emissions.

Figure 19 depicts the model prediction error in relationship to the PM10 concentration due to agricultural emissions. The monitoring sites have been classified as either "urban", "suburban" or "rural". The PM10 emission loads from agriculture are uncertain. If a higher contribution from agricultural emissions would correlate with a systematic model underestimation of the air quality at rural stations, this would suggest that agricultural emissions be underrepresented in the emission inventories. No systematic effects are present.

6.3. Comparison of PM2.5 model results with measurements

Figure 20 shows a scatter plot of measured vs. modelled PM2.5 concentrations. Yearly averages have been measured at six locations in Switzerland for the year 2000. Table 19 lists the corresponding statistics.

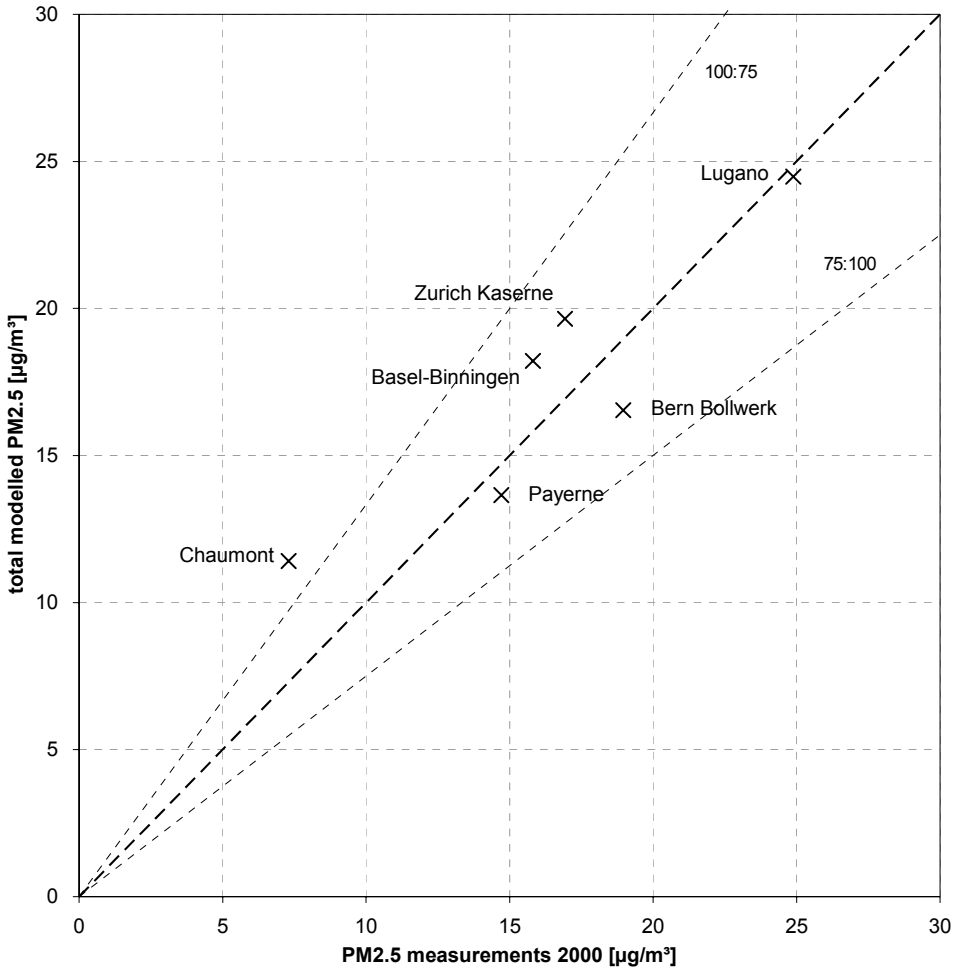

Figure 20: Scatter plot of observed and modelled PM2.5 annual average concentration.

Parameters	all data points
Number of data points	6
Average of measurements	16.43
Average of model predictions	17.33
Correlation coefficient r^2	0.90
Pearson coefficient	0.81
% of pred. within a factor of 1.33 of meas.	83%

Table 19: Statistical measures for PM2.5 model performance.

7. Conclusions and future steps

This report presents annual average PM10 and PM2.5 concentration levels for the whole of Switzerland for 2000 and for two different scenarios for the year 2010. All major source categories were modelled and are represented with emission inventories with a spatial resolution of 200 m x 200 m. The total PM10 emission load in Switzerland for the year 2000 is 23'939 t/a, which is 30% lower than the emissions in the first PM10 modelling study (SAEFL 1999a) for the year 1997 (33'000 t/a). This 30% decrease is partly due to the fact that lower emission factors for non-tailpipe PM10 emissions from road transport have been used, and is partly due to true decreases in the emission load between 1997 and 2000. Results show that in 2000, large areas of Switzerland exhibit PM10 concentrations that are above the ambient air quality standard of 20 $\mu g/m^3$ for the annual mean.

In the year 2000, 41.3% of the Swiss population have their home location in areas with a PM10 concentration exceeding the annual average ambient air quality standard of 20 $\mu g/m^3$. With the "business as usual" scenario, this percentage will decrease, but in 2010 still about 20.8% of the population will live in areas with a too high PM10 concentration level. With the "maximum feasible reduction" scenario, this number would drop to 4.9%.

On the side of the emission modelling, the most important steps in the near future are to further investigate the emissions from rail transport (PM10 measurements near railway track sites are currently being performed by EMPA and PSI, under a contract to SAEFL), and the non-tailpipe emission factors of road transport (road-side measurements for different types of roads are currently being made by EMPA and PSI under a contract to ASTRA). Some PM2.5/PM10 ratios have potential for improvement as well. Finally, much research is currently carried out on the chemical composition of particulate matter. This will enable to further improve the chemical composition of the PM emissions per source category.

Concerning the dispersion modelling, a further fine-tuning of the background concentration parameterization is needed, especially in alpine regions. For a next generation of the dispersion model, it might prove desirable to take wet deposition of the particles into account and to introduce a dependence on the altitude above sea level for all long-range transfer functions.

Appendix

A1. List of air quality monitoring stations

		coordinates		height	year 2000 conc. [µg/m³]			site characteristics		
ID	Name of station	X	Y	a.s.l.	measu-rement	model result	diff.	environ-ment	device type	category
1	Basel-Binningen NABEL	610'885	265'600	320	21	24.2	+3.2	suburban	HiVol	other
2	Bern NABEL	600'135	200'000	540	33	23.2	-9.8	urban	HiVol	street canyon
3	Chaumont NABEL	565'110	211'075	1140	10	14.5	+4.5	rural	HiVol	other
5	Duebendorf NABEL	688'650	250'850	430	21	23.8	+2.8	suburban	HiVol	other
6	Haerkingen NABEL	628'875	240'185	430	26	25.8	-0.2	suburban	HiVol	other
9	Lausanne NABEL	538'675	152'600	530	25	20.0	-5.0	urban	HiVol	other
10	Lugano NABEL	717'750	96'640	280	34	33.3	-0.7	urban	HiVol	Ticino
11	Magadino NABEL	715'500	113'200	200	29	28.8	-0.2	suburban	HiVol	Ticino
12	Payerne NABEL	562'310	184'775	490	20	17.7	-2.3	rural	HiVol	other
13	Rigi NABEL	677'875	213'460	1030	11	14.7	+3.7	rural	HiVol	alpine
14	Sion NABEL	592'550	118'725	480	24	18.5	-5.5	rural	HiVol	alpine
15	Taenikon NABEL	710'500	259'795	540	18	17.4	-0.6	rural	HiVol	other
16	Zuerich NABEL	682'425	247'850	410	23	27.4	+4.4	urban	HiVol	other
103	Suhr Distelmatte AG	647'225	246'400	405	18	21.8	+3.8	suburban	TEOM (corr.)	other
104	Sisseln, Areal Roche	640'725	266'250	405	18	19.3	+1.3	suburban	HiVol	other
105	Suhr, Zentrum	648'490	246'985	403	26	23.5	-2.5	urban	HiVol	other
401	Bern Zentrum BE	600'823	199'792	533	25	21.7	-3.3	urban	HiVol	other
602	Basel St.Johannplatz BS	610'750	268'350	260	21	26.1	+5.1	urban	HiVol	other
801	Anieres GE	506'750	126'550	390	21	17.8	-3.2	rural	HiVol equiv.	other
804	Ste. Clotilde GE	498'950	117'350	375	20	25.1	+5.1	urban	HiVol equiv.	other
808	Passeiry GE	489'280	113'360	426	18	17.5	-0.5	rural	HiVol equiv.	other
1217	Luzern Museggstrasse SG	666'190	211'975	460	23	20.9	-2.1	urban	TEOM (corr.)	other
1401	Stans, Engelbergstrasse, N	670'850	201'025	438	25	17.5	-7.5	suburban	HiVol equiv.	alpine
1604	St. Gallen Volksbad SG	746'950	255'000	660	16	17.6	+1.6	urban	TEOM (corr.)	other
1605	Grabs, Markplatz SG	752'150	227'830	475	21	15.8	-5.2	suburban	HiVol	other
1807	Biberist Ost	609'850	225'130	450	20	20.5	+0.5	suburban	HiVol equiv.	other
1808	Biberist West	609'160	224'750	450	17	20.3	+3.3	suburban	HiVol equiv.	other
1809	Solothurn Werkhofstrasse S	607'330	228'800	450	24	21.0	-3.0	urban	HiVol equiv.	other
1902	Schwyz SZ	691'920	208'030	470	22	16.9	-5.1	suburban	TEOM (corr.)	alpine
2101	Bodio TI	713'450	137'300	320	30	24.5	-5.5	suburban	HiVol	Ticino
2103	Chiasso TI	723'450	77'450	230	33	34.1	+1.1	urban	HiVol equiv.	Ticino
2104	Locarno TI	704'625	113'800	200	26	30.8	+4.8	urban	HiVol	Ticino
2204	Altdorf Gartenmatt UR	690'175	193'550	438	22	19.8	-2.2	suburban	TEOM (corr.)	alpine
2402	Brigerbad VS	636'900	127'500	650	22	16.0	-6.0	rural	HiVol	alpine
2403	Eggerberg VS	634'040	128'490	840	19	14.1	-4.9	rural	HiVol	alpine
2405	Les Giettes VS	563'300	119'340	1140	10	11.1	+1.1	rural	HiVol	other
2406	Massongex VS	564'920	121'280	400	22	17.6	-4.4	suburban	HiVol	other
2407	Saxon VS	577'540	109'780	460	22	16.8	-5.2	rural	HiVol	alpine
2408	Sion VS	593'600	120'000	505	26	18.9	-7.1	urban	HiVol	alpine
2503	Zug Postplatz ZG	681'625	224'625	420	24	19.6	-4.4	urban	TEOM (corr.)	other
2603	Wallisellen Dietlikerstrasse	688'070	252'880	470	19	22.8	+3.8	suburban	HiVol	other
2604	Winterthur Obertor ZH	697'475	261'825	448	27	21.9	-5.1	urban	TEOM (corr.)	other
2606	Stampfenbachstrasse	683'140	249'040	445	27	27.4	+0.4	urban	HiVol	other
2609	Schimmelstr. Bhf. Wiedikor	681'950	247'250	413	35	32.5	-2.5	urban	HiVol	street canyon
average					22.59	21.38	-1.21			

Table 20: List of air quality monitoring stations with PM10 measurements in Switzerland for the year 2000.

A2. PM emissions from road transport

The non-tailpipe emission factors for passenger cars (PC), light-duty (commercial) vehicles (LDV), heavy-duty vehicles (lorries, coaches and urban buses; HDV), motor cycles (MC), and for coaches and urban public transport buses, have been computed as follows (for more details, please refer to SAEFL [2001a]):

- Measurements of total PM10 and NO_x with a time resolution of 30 minutes are available for both an urban road-side and a nearby urban background station (Hüglin 2000). The differences in both NO_x and PM10 between the two sites can be attributed to the local traffic at the road-side site. The traffic density data measured at the road-side site together with the known NO_x emission factors allow estimating the dilution factors of the transport emissions. With this information, total PM10 emission factors (tailpipe and non-tailpipe) can be computed for light-duty (average for PC, LDV and MC) and heavy-duty vehicles separately.

- From these total PM10 emission factors, the tailpipe emission factors after SAEFL (2000b) are subtracted and give the total sum of non-tailpipe emissions. Since results from only one measurement site are available, these numbers are applied to the whole of Switzerland, both to urban and rural areas as well as to highways. Currently on-going research will probably allow for a more refined approach in the near future.

- For tire abrasion, the emission factor for PC is estimated at 13.2 mg PM10/km; for LDV and HDV, the corresponding factors are 24.65 and 199.6 mg/km, respectively. The PM2.5/PM10 ratio for PM10 emissions from tire abrasion is very uncertain. Figures between 50% (TNO 1993) and 0% (Rauterberg-Wulff 1998) are reported. For the present report, this ratio is estimated being 10%.

- For PM10 originating from the abrasion of brake pads, results from a field study of the Swiss army have been used. 1.79 mg/km for PC, 4.86 mg/km for LDV, 3.47 mg/km for HDV. The PM2.5/PM10 ratio is estimated at 30%, the lower of two available numbers (Rauterberg-Wulff 1998: 30%; U.K. Airborne Particles Expert Group 1998: 40%).

- In contrast to SAEFL (1999a), the emission factors for PM10 from clutch abrasion have been set to zero for the present study, because it is believed that all particulate matter is effectively contained within the clutch.

- Finally, the emission factor for the sum of road surface abrasion and resuspension of dust on the road surface is defined in the study as the remaining fraction of the non-tailpipe emission factor that is left over after subtracting the emission factors for tire and brake pad abrasion. 29.7 mg/km for PC/LDV, 450 mg/km for HDV and buses. These emissions factors are substantially lower than those used in the previous study (SAEFL 1999a). The PM2.5/PM10 ratio is assumed being 25%, which is on the lower end of estimates from literature: 50% (TNO 1993), 44% (Wang *et al.* 1999), 25% (Countess 1999). EPA's revised AP-42 emission factor also is 25%.

- The emission factors for tire and brake pad abrasion and for road abrasion/resuspension for motor cycles and for mopeds are assumed being one-half and one-fourth of corresponding PC/LDV emission factor, respectively.

Using scaling factors, it has been assured that the present modelling, which uses detailed road networks, yields exactly the same over-all results (both in vehicle kilometres travelled and in total emissions), as the SAEFL (2000b) report, which only used aggregated traffic statistics.

For the 2010 scenarios, identical emission factor for the non-tailpipe emission factors have been assumed.

A3. Secondary PM from anthropogenic VOC

#	VOC class	NMVOC emission total [t/a]	NMVOC emission road tr. [t/a]	average C atoms [C]	FAC [%]	PM10 from VOC total [t/a]	PM10 from VOC road tr. [t/a]
2	Ethane	356	258	2.0	0.00 [1,3]	0	0
3	Propane	92	71	3.0	0.00 [1,3]	0	0
4	Alkanes 0.25<r<0.50	2'021	1'754	4.0	0.38 [2]	8	7
5	Alkanes 0.50<r<1.00	11'804	5'636	5.5	0.75 [2]	89	42
6	Alkanes 1.00<r<2.00	25'840	3'477	7.7	1.50 [2]	388	52
7	Alkanes r>2.00	8'842	2'645	12.4	5.00 [2]	442	132
8	Alkanes/Aromatic Mix	1'903	0	10.0	2.39 [4]	45	0
9	Ethene	3'292	2'147	2.0	0.00 [1,3]	0	0
10	Propene	1'178	810	3.0	0.00 [5]	0	0
11	Alkenes (primary)	862	639	4.7	2.82 [6]	24	18
12	Alkenes (internal)	540	481	4.9	2.82 [7]	15	14
13	Alkenes (mix)	2'936	979	5.9	2.82 [4]	83	28
14	Benzene, Halobenzene	1'310	973	6.0	0.94 [8]	12	9
15	Aromatics (r<2.00)	9'243	2'305	7.3	2.16 [9]	200	50
16	Aromatics (r>2.00)	18'605	4'328	8.9	3.84 [10]	715	166
17	Phenols and Cresols	0	0	6.6	5.00 [11,12]	0	0
18	Styrenes	59	47	7.0	0.00 [11]	0	0
19	Formaldehyde	1'126	593	1.0	0.00 [5]	0	0
20	Higher Aldehydes	783	334	2.4	0.00 [5]	0	0
21	Acetone	2'653	123	3.0	0.00 [1,3]	0	0
22	Higher Ketones	5'425	0	4.8	0.80 [3,13]	43	0
23	Organic Acids	158	59	2.3	0.00 [1]	0	0
24	Acetylene	1'620	1'226	2.0	0.00 [1,3]	0	0
25	Haloalkenes	6'188	0	2.0	0.00 [1]	0	0
26	Unreactive	10'125	0	1.5	0.00 [14]	0	0
27	Others r<0.25	13'384	0	1.9	0.00 [5,15]	0	0
28	Others 0.25<r<0.50	11'027	0	2.1	0.00 [17]	0	0
29	Others 0.50<r<1.00	18'862	53	3.4	0.00 [3, 16]	0	0
30	Others r>1.00	6'379	35	2.9	0.00 [3,18]	0	0
31	Unidentified	3'180	387		1.24 [19]	39	5
32	Unassigned	2'205	140		1.24 [19]	27	2
Total		172'000	29'500		1.24	2'131	524

[1] FAC=0 because [C]<=6; [2] "k-r" equation; [3] Grosjean 1989, table 7; [4] averaged by weight; [5] Grosjean 1989, table 6;
[6] assuming 50% with [C]>7, of which 70% alkenes [SCAQMD mix], 30% cyclic olefins [SCAQMD mix];
[7] as class 11; [8] assuming 30% benzene [FAC=0], 30% ethylbenzene, 40% 1,x,y-trimethylbenzene (Grosjean 1989);
[9] assuming 80% toluene, 20% o/m/p-ethyltoluene (Grosjean 1989); [10] assuming 97% xylene, 3% 1,x-diethylbenzene;
[11] Grosjean 1989, table 9; [12] assuming 100% phenols; [13] assuming ketone mix; [14] FAC=0 because not reactive;
[15] assuming 51% methyle/ethyle acetate, 40% methanol; [16] ass. 60% isopropyle alcohol, 25% propyle/higher acetates;
[17] assuming 85% ethanol; [18] glycoles etc.; [19] mean FAC of classes 2 to 30 weighted by share in Swiss emissions.

Table 21: Anthropogenic non-methane VOC (NMVOC) emissions for the year 2000 for 31 VOC classes, together with their estimated Fractional Aerosol yield Coefficient (FAC), and the resulting amount of secondary particulate matter.

Table 21 shows the estimated average FAC per VOC class. For most of these classes, the exact chemical mix is not known and had to be estimated. For the classes 11 to 16 (alkenes and aromatics), and for classes 27 to 30 ("other" VOC), this was done using the mix of VOC species of the southern Californian SCAQMD inventory (Middleton *et al.* 1990).

For VOC compounds with not more than 6 C atoms (on average, using the average number of C atoms of the SCAQDM inventory), the FAC has been set to zero. However, as most VOC classes consist of various compounds, it might occur that a class with an average number of C atoms below 6 still is attributed a non-zero FAC, because some compounds in that class actually are above the limit of 6 C atoms and are capable of aerosol formation.

For alkenes (classes 4 to 8) a relationship had to be established between the reactivity number *k* of Grosjean and Seinfeld (1989) and the reactivity number *r* of Middleton *et al.* (1990). Using this "*k*-*r*" equation, and average *r* values attributed to each alkenes class, the FAC was derived based on the parameterized *k* value. Class number 17 has a high FAC of 5%, but no emission load attributed to it in the TRACT inventory. The average FAC (weighted by emissions) of the classes 2 to 30 has been attributed to the classes 31 and 32 so that they do not affect the mean.

A4. Abbreviations

a.s.l.	above sea level
BAU	Business as usual scenario for 2010
DTV	Daily Traffic Volume (number of vehicles per day, averaged over 1 year)
EC	elemental carbon; major compound of particles originating from the combustion of fossil fuels.
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe
FAC	fractional aerosol coefficient; indicates which percentage of a gaseous VOC component will be transformed into secondary particulate matter.
FOSD	Federal Office for Spatial Development (German: Bundesamt für Raumentwicklung, ARE)
GIS	Geographical Information System
HDV	Heavy-Duty Vehicles
LDV	Light-Duty (commercial) Vehicle
LPE	Law on the Protection of the Environment (German: Umweltschutzgesetz, USG)
MC	Motorcycle
MFR	Maximum feasible reduction scenario for 2010
MRHVT	Mileage-Related Heavy Vehicle Tax (German: Leistungsabhängige Schwerverkehrs-Abgabe, LSVA)
NABEL	Swiss National Air Pollution Monitoring Network (German: Nationales Beobachtungsnetz für Luftfremdstoffe, NABEL)
NH_3	Ammonia
NH_4^+	Ammonium
NH_4NO_3	Ammonium nitrate
$(NH_4)_2SO_4$	Ammonium sulfate
NO_2	Nitrogen dioxide
NO_3^-	Nitrate
NO_x	Nitrogen oxide (sum of nitrogen monoxide, NO, and nitrogen dioxide, NO_2)
OAPC	Swiss Ordinance on Air Pollution Control (German: LRV, Luftreinhalte-Verordnung des Bundesrates vom 16. Dezember 1985, Stand am 31. März 1998, SR814.318.142.1)
OC	Organic carbon; usually only the carbon part is given in mass or concentration figures

OM	organic material; like OC, but including the other atoms linked with the carbon (hydrogen, oxygen, etc.). Mass or concentration figures concerning OM usually cover the total mass including those other atoms, not only the organic carbon part. All OM figures in the present report have been derived from the original measurements of the OC content by multiplying with 1.4: OM ≈ 1.4 * OC
OTA	Overland Transport Agreement (German: Landverkehrsabkommen)
PC	Passenger car
PM	Particulate Matter
PM10	PM with an aerodynamic diameter less than 10 µm
PM2.5	PM with an aerodynamic diameter less than 2.5 µm
PM10-PM2.5	PM with an aerodynamic diameter between 2.5 µm and 10 µm
SAEFL	Swiss Agency for the Environment, Forests and Landscape (German: Bundesamt für Umwelt, Wald und Landschaft, BUWAL)

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A6. Climatologic regions in Switzerland

Figure 21 shows where the different transfer functions apply. For details see section 2.2.

Figure 21 (next page): Climatologic regions in Switzerland. Different sets of transfer functions apply for the Swiss Plateau region and for the remaining part of Switzerland. In Alpine valleys, the Alpine transfer functions are rotated corresponding to the valley orientation. The valleys have been grouped in 24 classes of 15 degrees each. For this figure, these 24 classes have been aggregated to 8 classes of 45 degrees each.

A7. Maps with PM10 emissions

The figures on the following pages depict the annual emission load of PM10 (in t/a) averaged per grid cell of 2000 m x 2000 m:

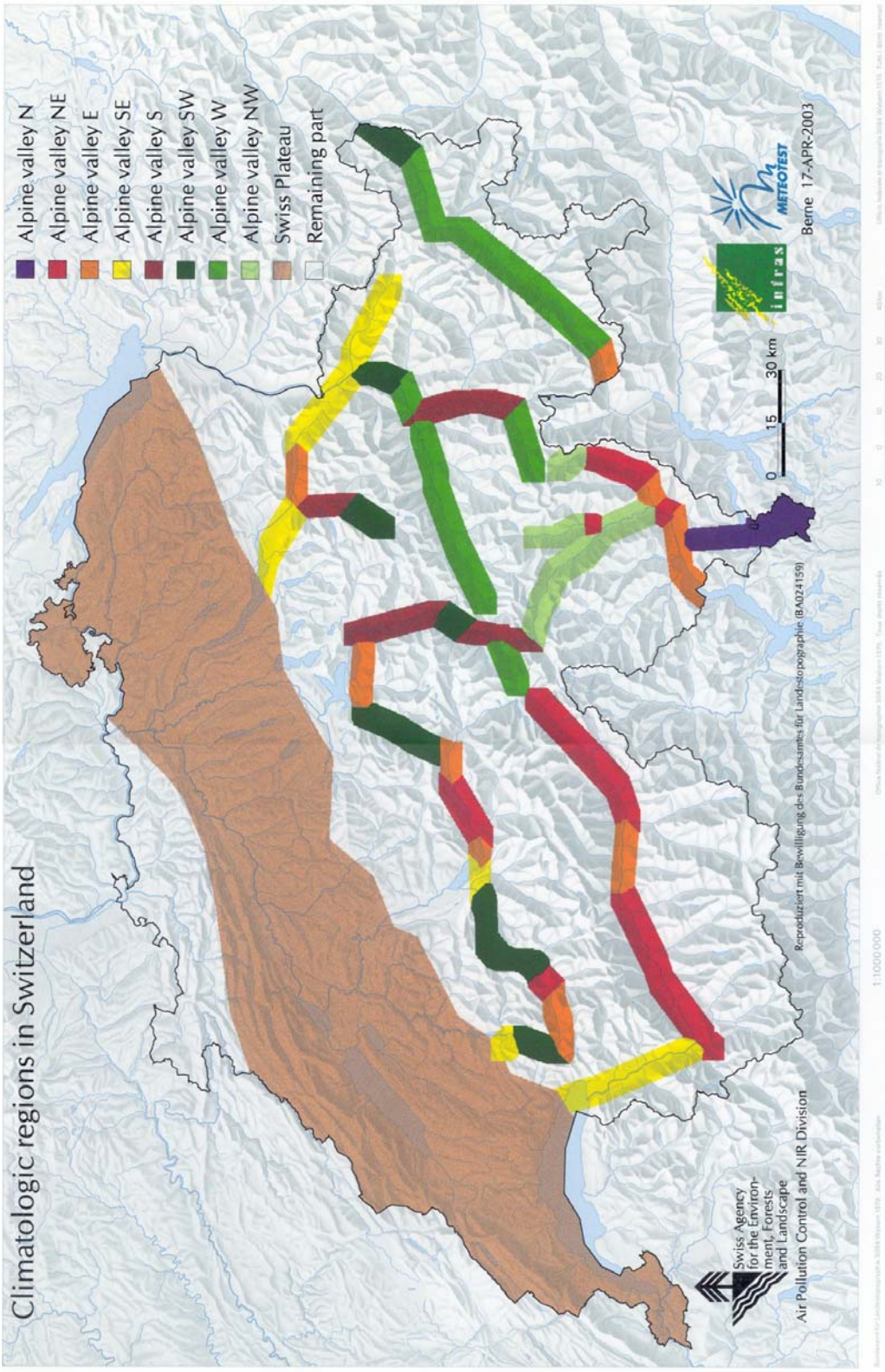

Climatologic regions in Switzerland
Alpine valley N
Alpine valley NE
Alpine valley E
Alpine valley SE
Alpine valley S
Alpine valley SW
Alpine valley W
Alpine valley NW
Swiss Plateau
Remaining part
0 15 30 km
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Berne 17-APR-2003
METEOTEST
infras

Figure 21

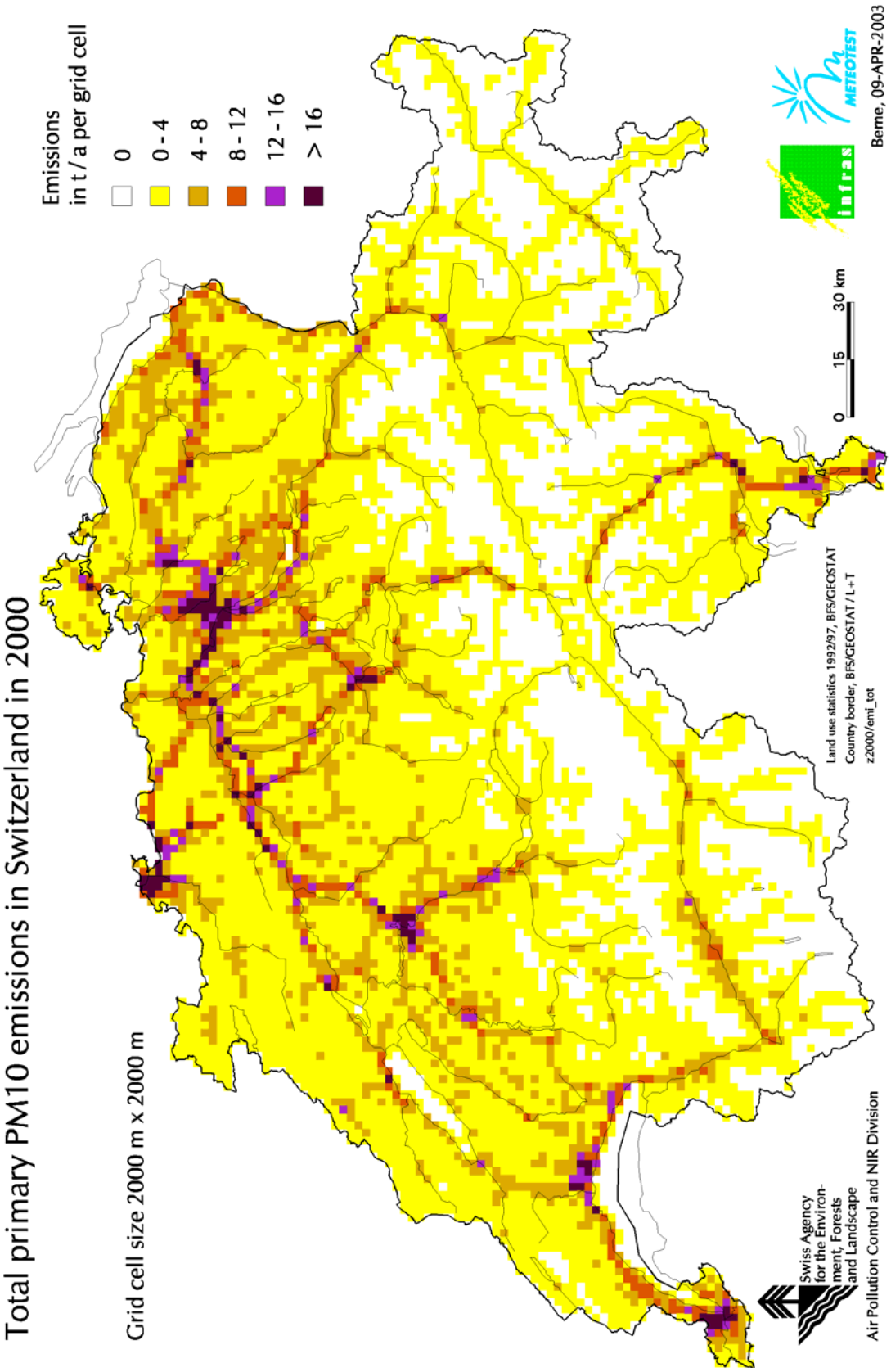
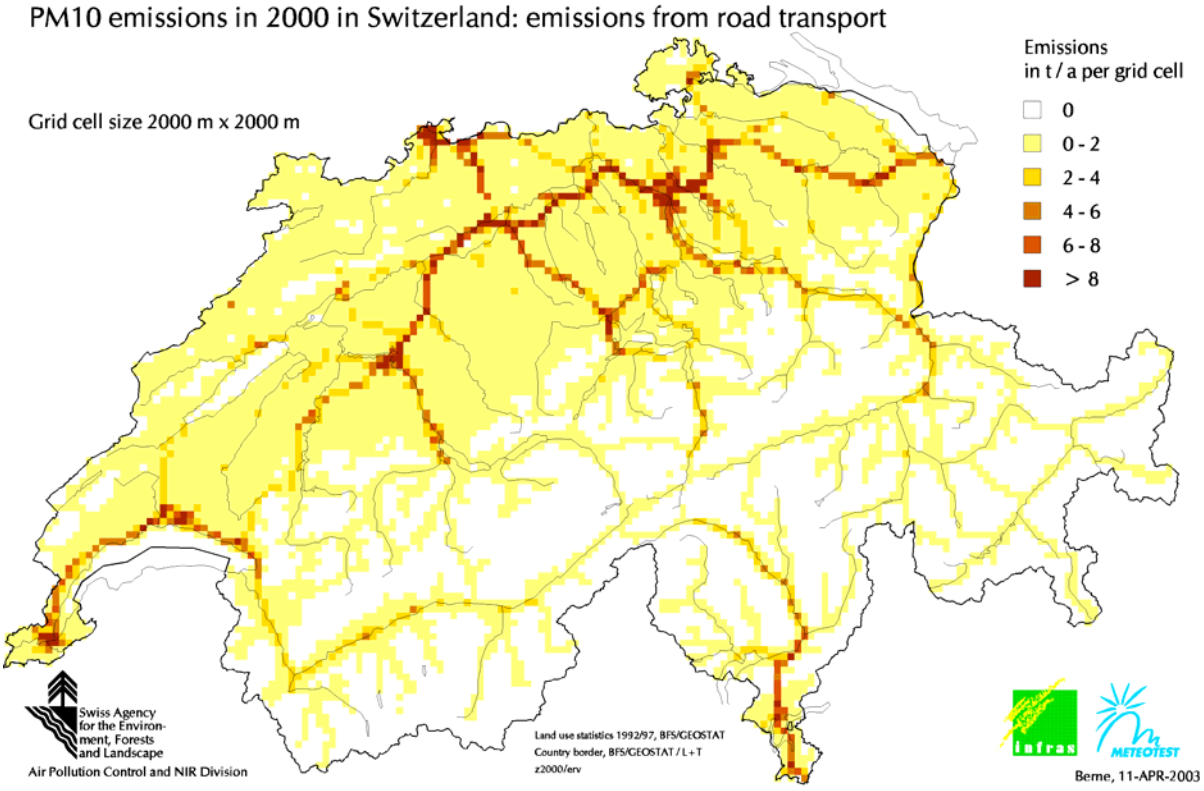

Total primary PM10 emissions in Switzerland in 2000
Grid cell size 2000 m x 2000 m
Emissions in t / a per grid cell
0
0 - 4
4 - 8
8 - 12
12 - 16
> 16
0 15 30 km
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/emi_tot
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
infras
METEOTEST
Berne, 09-APR-2003

Figure 22


PM10 emissions in 2000 in Switzerland: emissions from road transport
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/erv
infras
METEOTEST
Berne, 11-APR-2003

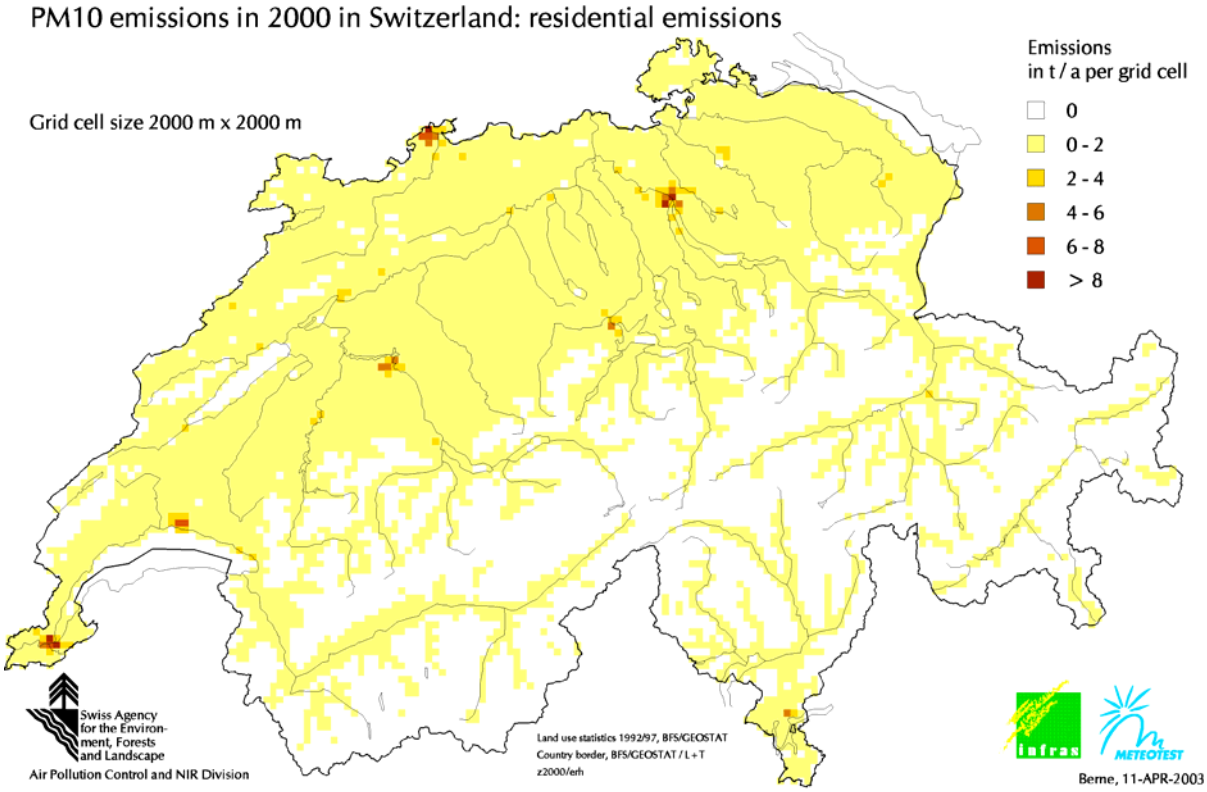
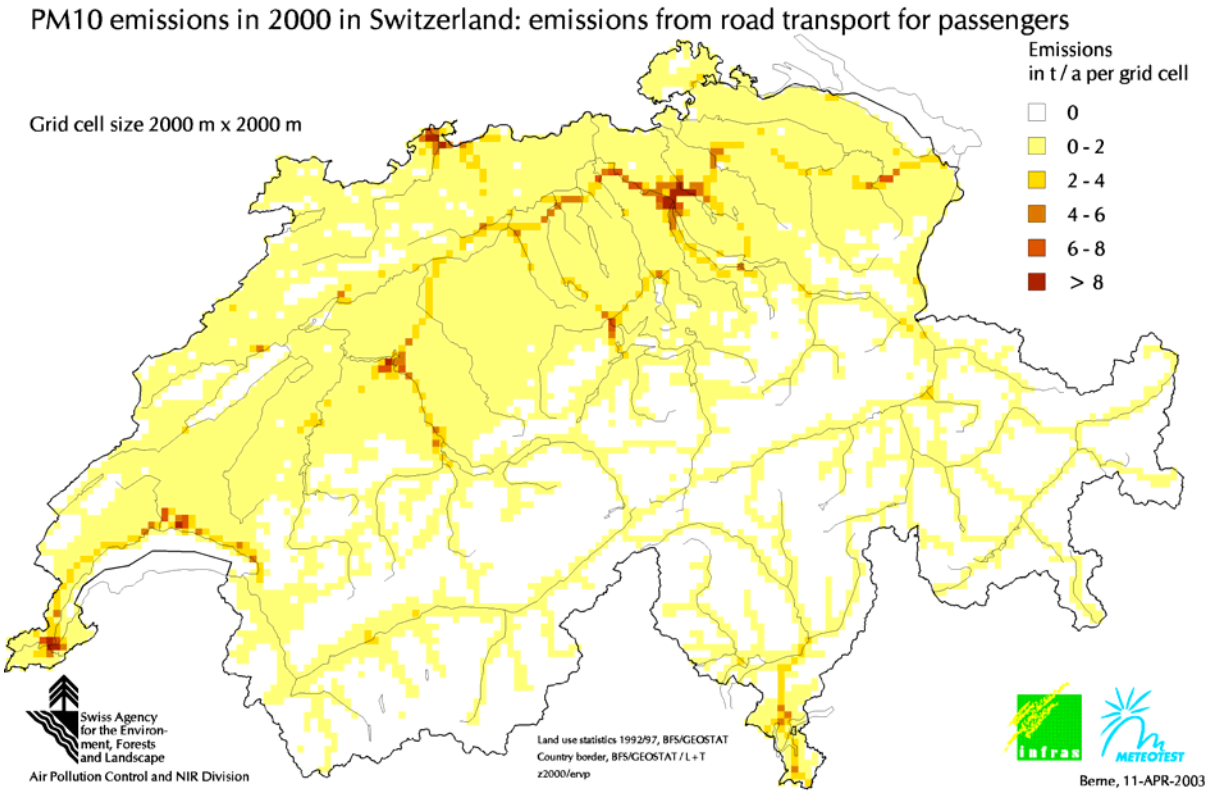

PM10 emissions in 2000 in Switzerland: residential emissions
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/erh
infras
METEOTEST
Berne, 11-APR-2003

Figure 23


PM10 emissions in 2000 in Switzerland: emissions from road transport for passengers
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ervp
infras
METEOTEST
Berne, 11-APR-2003

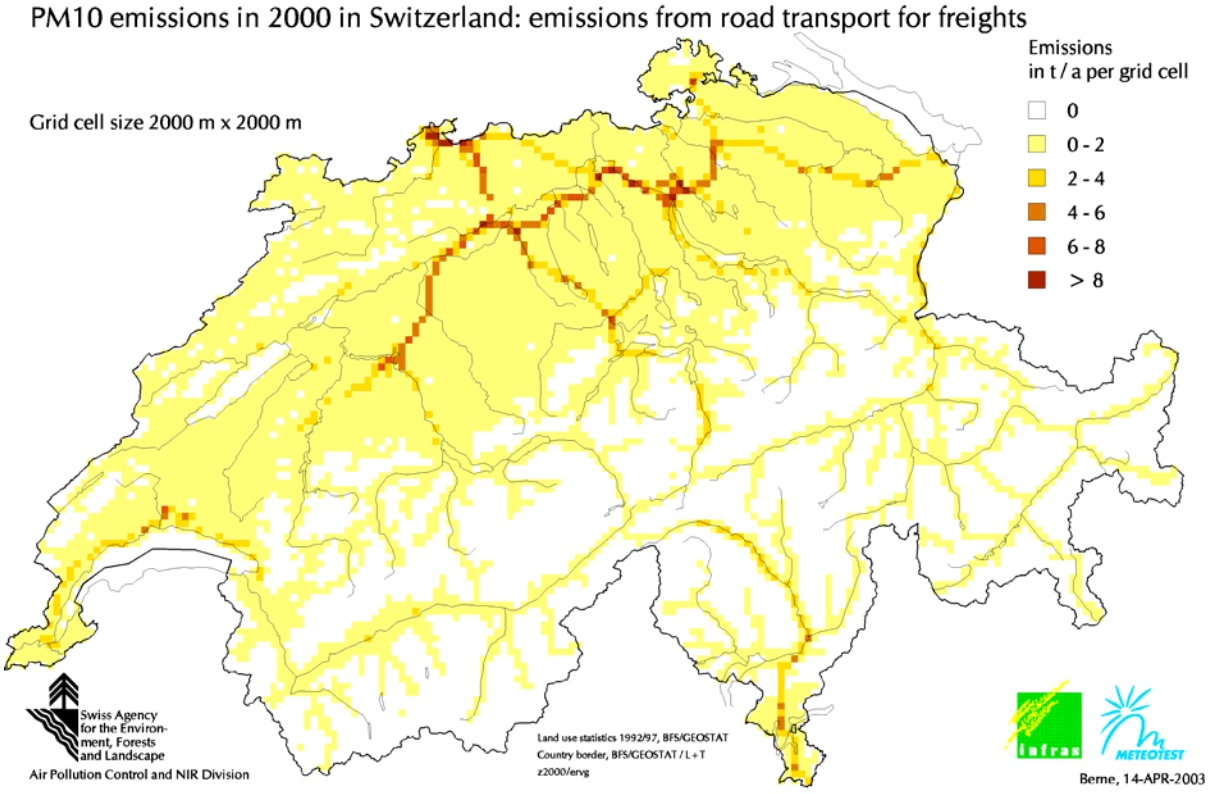
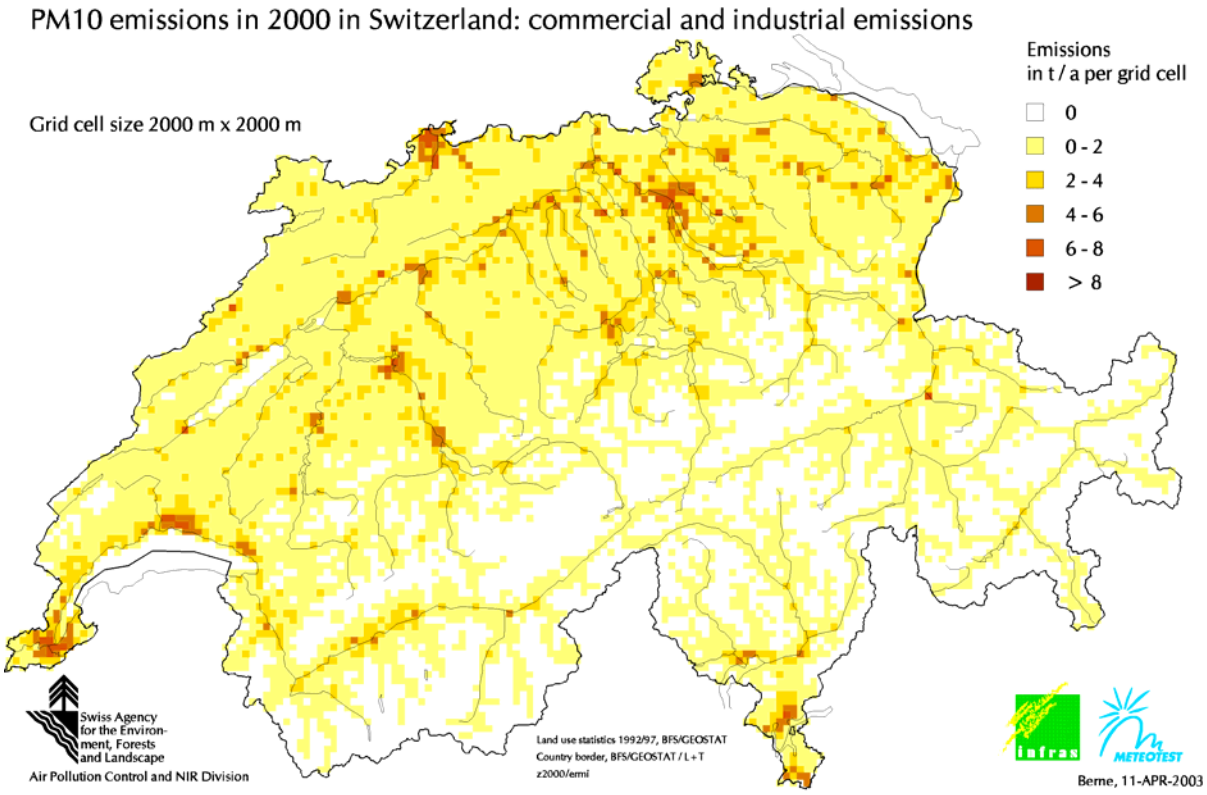

PM10 emissions in 2000 in Switzerland: emissions from road transport for freights
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ervg
infras
METEOTEST
Berne, 14-APR-2003

Figure 24


PM10 emissions in 2000 in Switzerland: commercial and industrial emissions
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ermi
infras
METEOTEST
Berne, 11-APR-2003

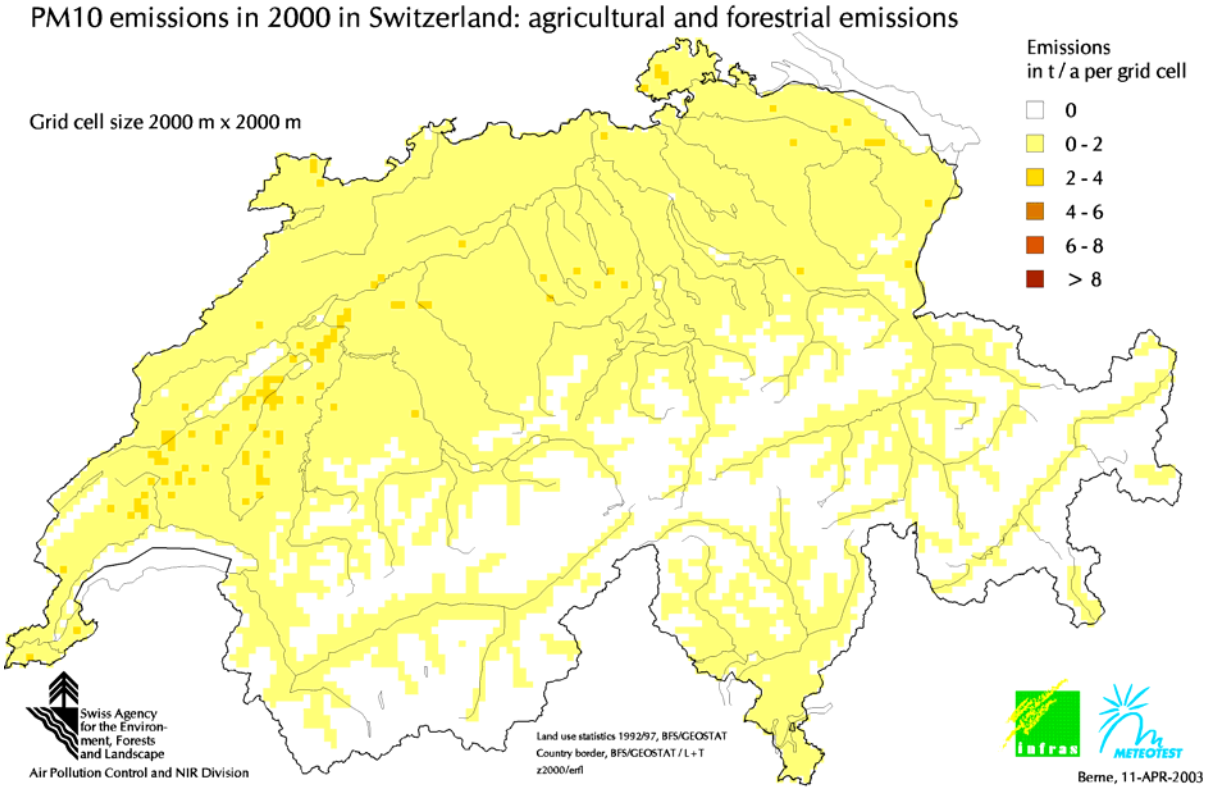
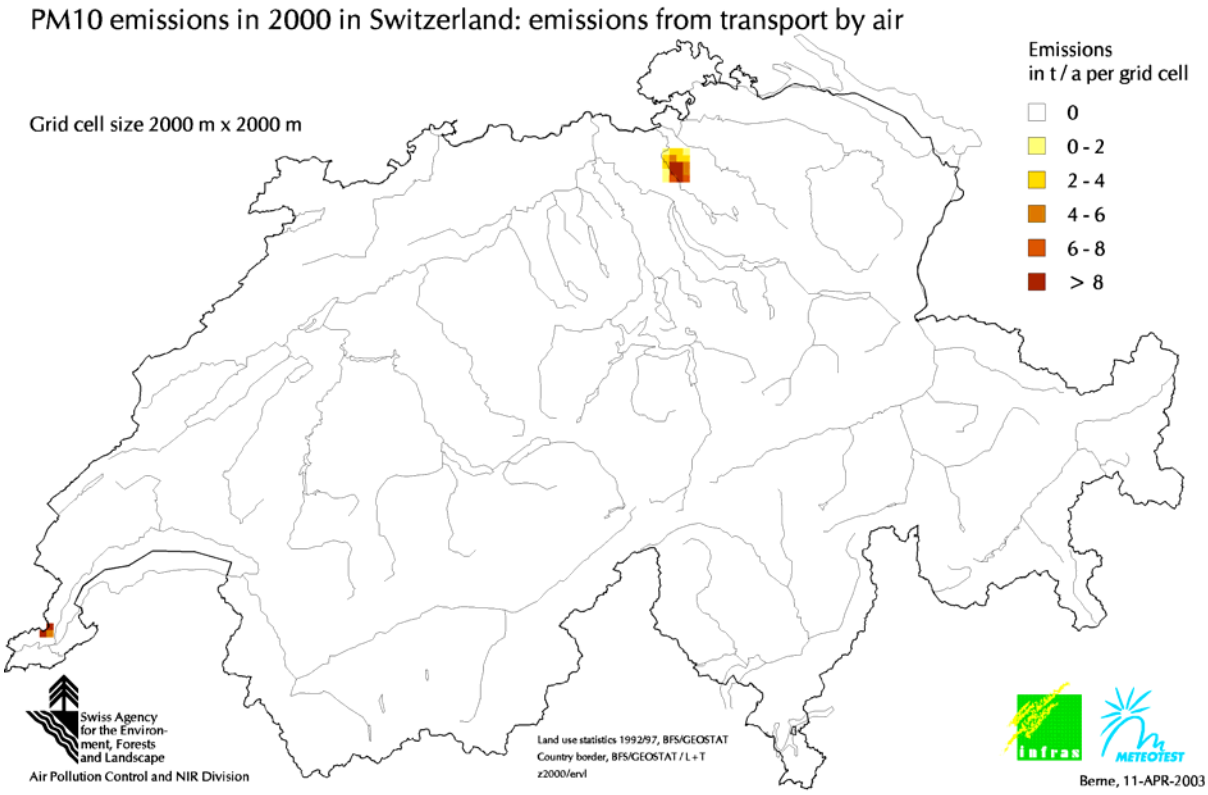

PM10 emissions in 2000 in Switzerland: agricultural and forestrial emissions
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/erfl
infras
METEOTEST
Berne, 11-APR-2003

Figure 25


PM10 emissions in 2000 in Switzerland: emissions from transport by air
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ervl
infras
METEOTEST
Berne, 11-APR-2003

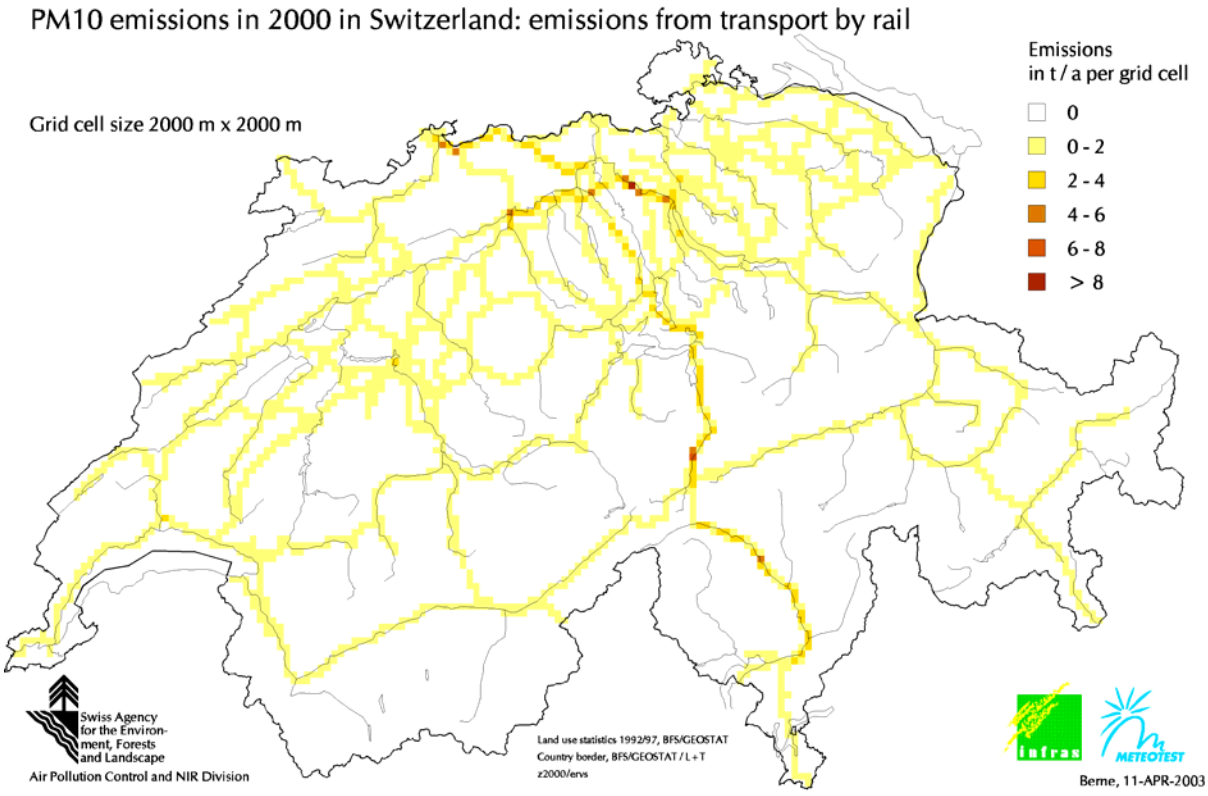
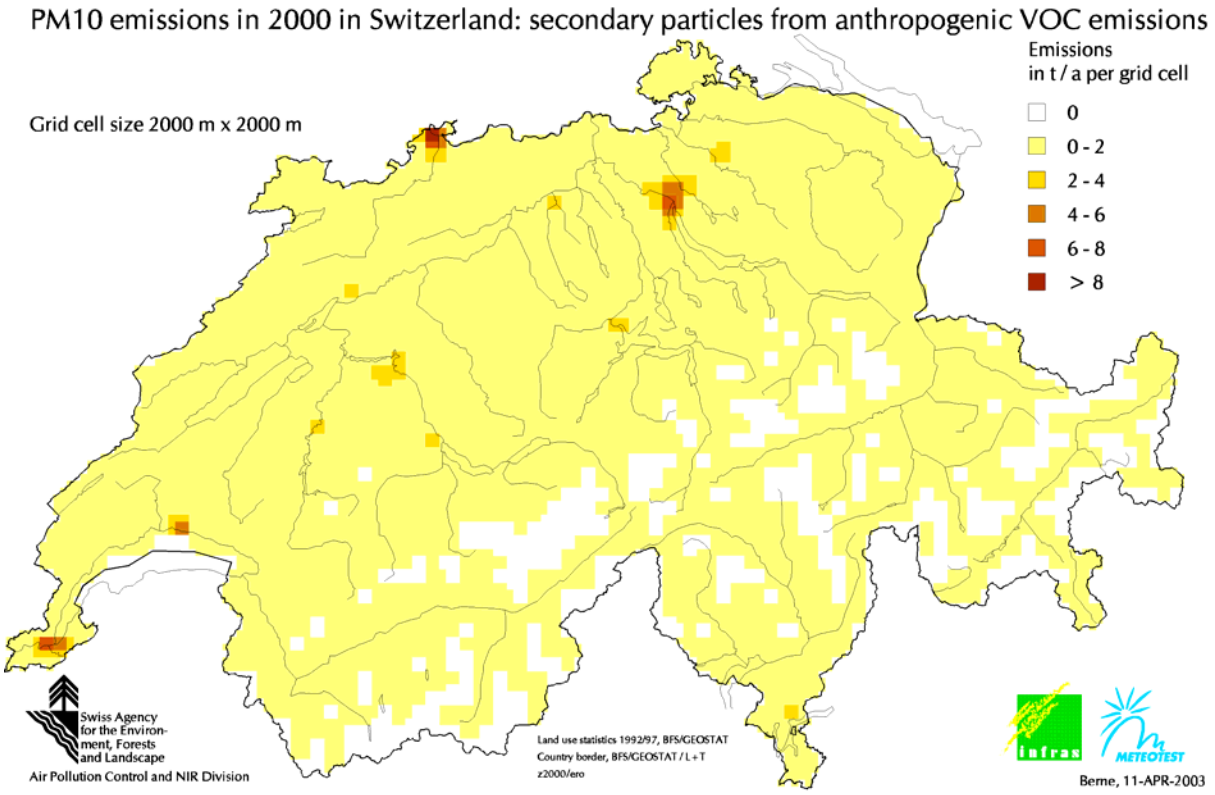

PM10 emissions in 2000 in Switzerland: emissions from transport by rail
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ervs
infras
METEOTEST
Berne, 11-APR-2003

Figure 26


PM10 emissions in 2000 in Switzerland: secondary particles from anthropogenic VOC emissions
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ero
infras
METEOTEST
Berne, 11-APR-2003

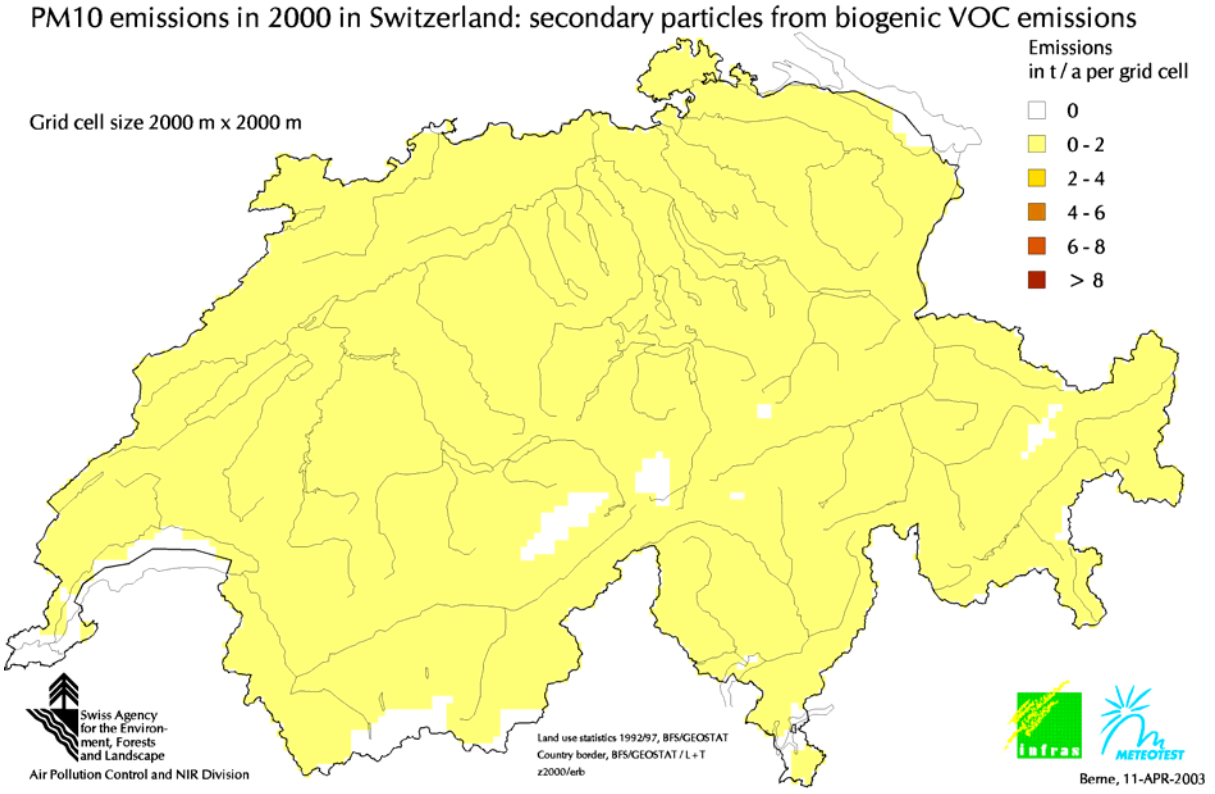

PM10 emissions in 2000 in Switzerland: secondary particles from biogenic VOC emissions
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 2
2 - 4
4 - 6
6 - 8
> 8
Swiss Agency
for the Environ-
ment, Forests
and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/erb
infras
METEOTEST
Berne, 11-APR-2003

Figure 27

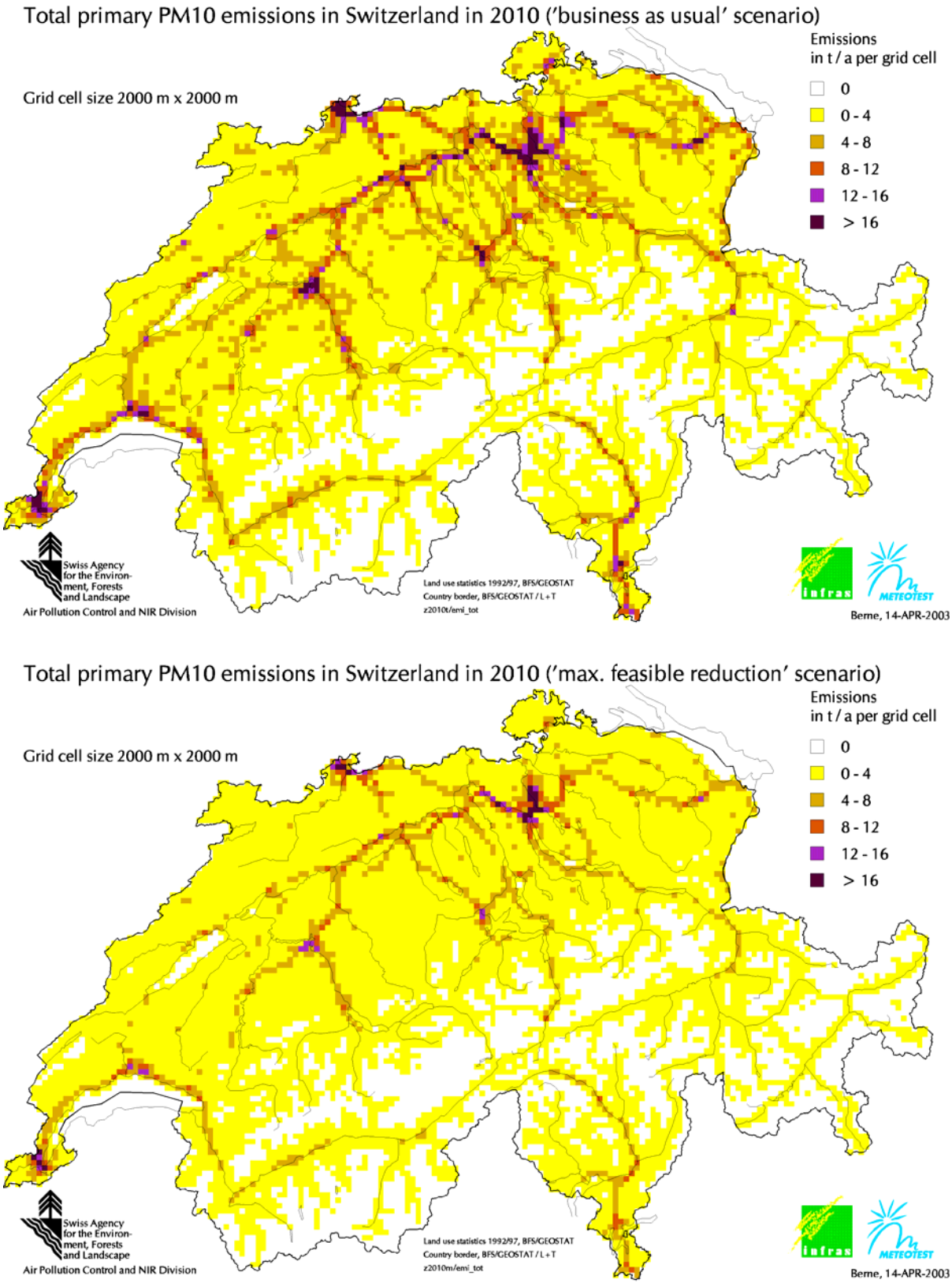

Total primary PM10 emissions in Switzerland in 2010 ('business as usual' scenario)
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 4
4 - 8
8 - 12
12 - 16
> 16
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2010t/emi_tot
infras
METEOTEST
Berne, 14-APR-2003
Total primary PM10 emissions in Switzerland in 2010 ('max. feasible reduction' scenario)
Grid cell size 2000 m x 2000 m
Emissions
in t / a per grid cell
0
0 - 4
4 - 8
8 - 12
12 - 16
> 16
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2010m/emi_tot
infras
METEOTEST
Berne, 14-APR-2003

Figure 28

A8. Maps with PM10 and PM2.5 concentrations

The figures on the following pages depict the resulting annual mean concentration level (in $\mu g/m^3$) averaged per grid cell of 400 m x 400 m:

Figure 29: PM10 annual mean concentration (all sources) in Switzerland in 2000.

Figure 30: PM10 annual mean concentration (all sources) in Switzerland in 2010 ("business as usual" scenario).

Figure 31: PM10 annual mean concentration (all sources) in Switzerland in 2010 ("maximum feasible reduction" scenario).

Figure 32: PM2.5 annual mean concentration (all sources) in Switzerland in 2000.

Figure 33: PM2.5 annual mean concentration (all sources) in Switzerland in 2010 ("business as usual" scenario).

Figure 34: PM2.5 annual mean concentration (all sources) in Switzerland in 2010 ("maximum feasible reduction" scenario).

Figure 35: PM2.5 concentration expressed as percentage of PM10 concentration in 2000 in Switzerland.

Figure 36: PM10 annual mean concentration in 2000 in Switzerland, due to road transport (top) and residential (bottom) emissions (without secondary particles). Grid cell size 400 m × 400 m, concentrations in $\mu g/m^3$ averaged per grid cell.

Figure 37: PM10 annual mean concentration in 2000 in Switzerland, due to commercial + industrial (top) and agricultural + forestry (bottom) emissions (without secondary particles). Grid cell size 400 m × 400 m, concentrations in $\mu g/m^3$ averaged per grid cell.

Figure 38: PM10 concentration in Switzerland in 2000, due to emissions from road transport for passengers (top) and freight (bottom).

Figure 39: PM10 concentration in Switzerland in 2000, due to emissions from transport by air (top) and rail (bottom).

A9. Illustrative examples

The figures on the following pages depict the annual mean PM10 concentration level (in $\mu g/m^3$) averaged per grid cell of 200 m × 200 m:

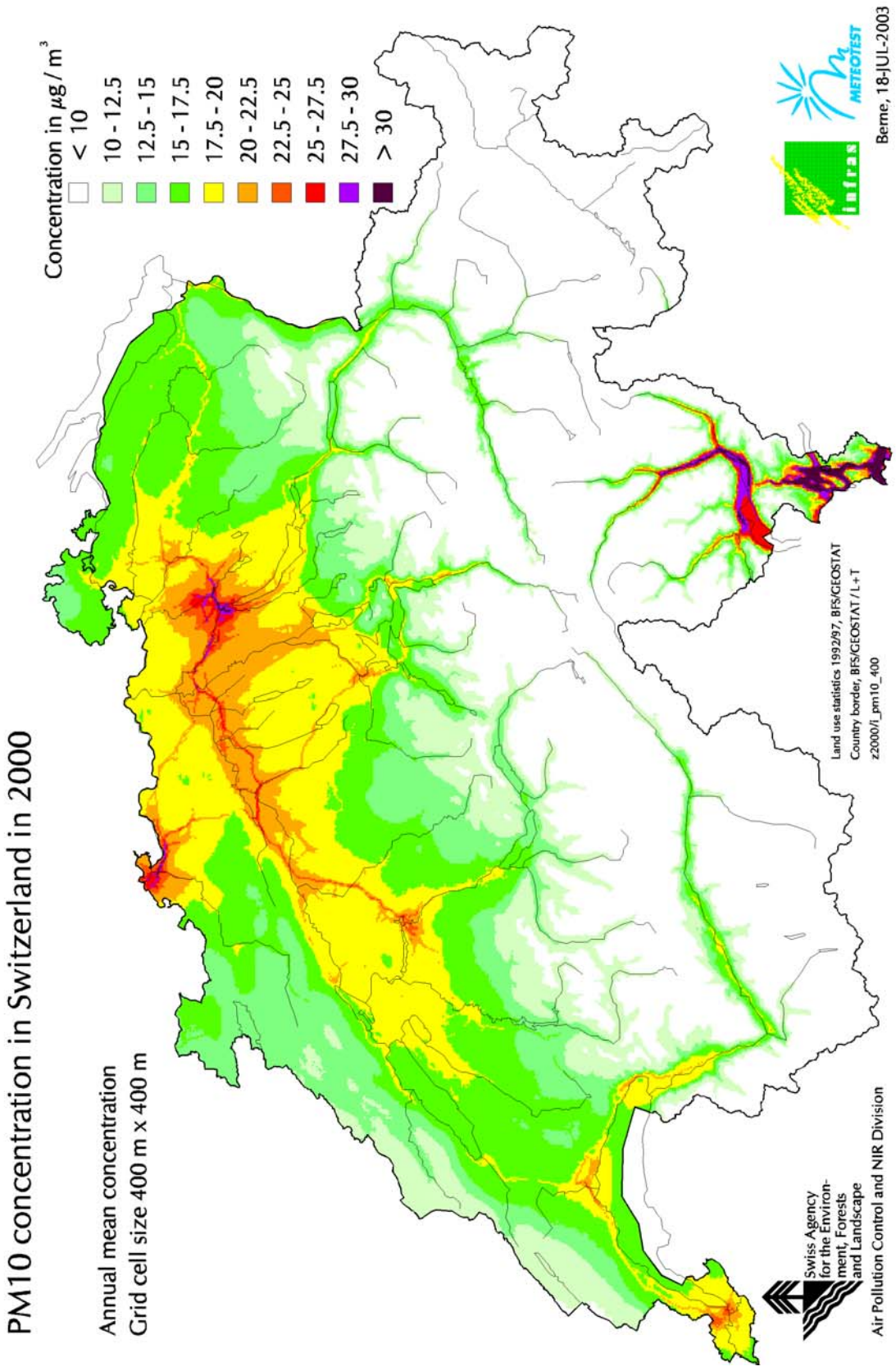

PM10 concentration in Switzerland in 2000
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
< 10
10 - 12.5
12.5 - 15
15 - 17.5
17.5 - 20
20 - 22.5
22.5 - 25
25 - 27.5
27.5 - 30
> 30
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/l_pm10_400
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
infras
METEOTEST
Berne, 18-JUL-2003

Figure 29

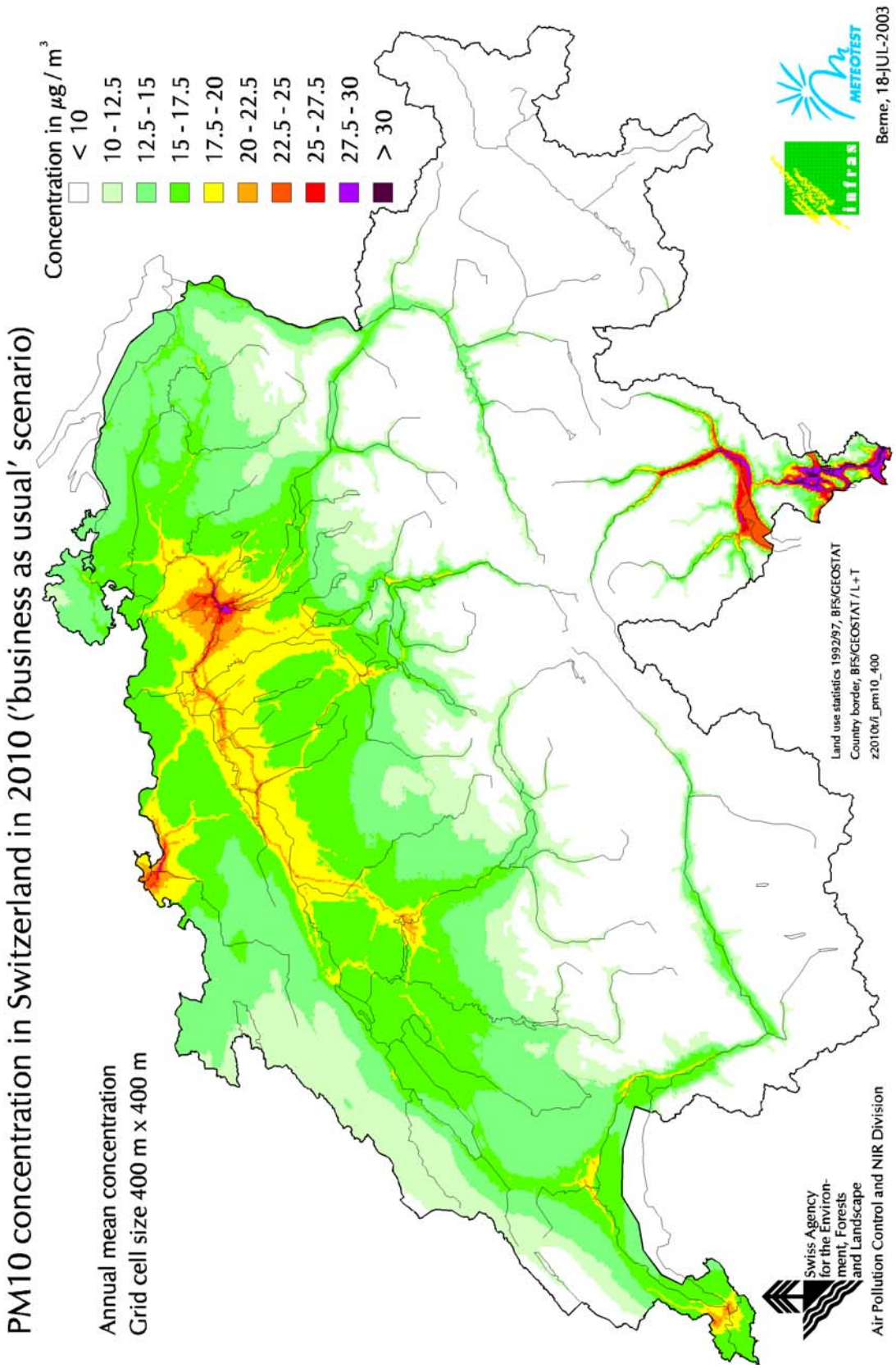

PM10 concentration in Switzerland in 2010 ('business as usual' scenario)
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
< 10
10 - 12.5
12.5 - 15
15 - 17.5
17.5 - 20
20 - 22.5
22.5 - 25
25 - 27.5
27.5 - 30
> 30
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2010t/i_pm10_400
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
infras
METEOTEST
Berne, 18-JUL-2003

Figure 30

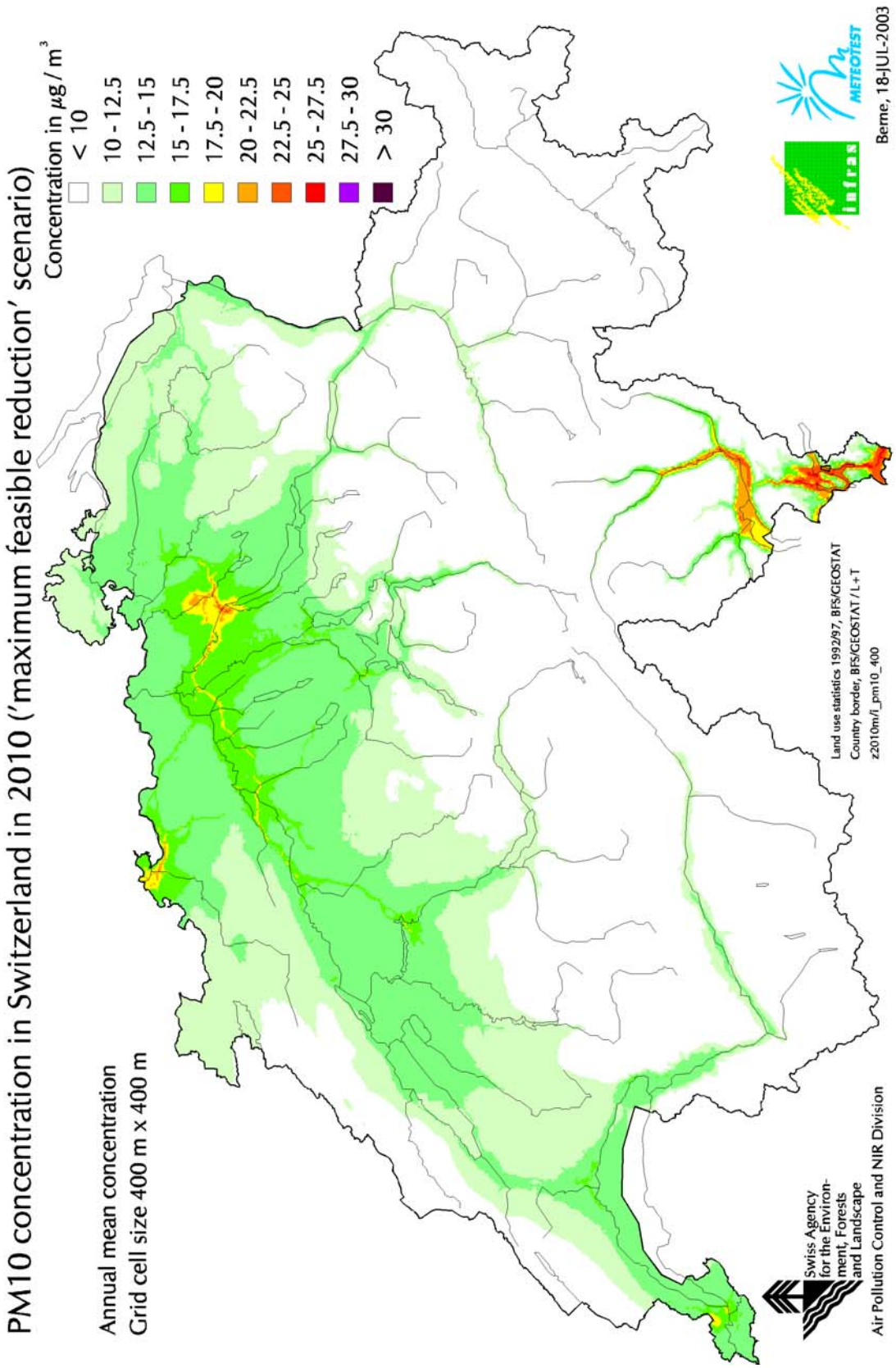

PM10 concentration in Switzerland in 2010 ('maximum feasible reduction' scenario)
Concentration in µg / m³
< 10
10 - 12.5
12.5 - 15
15 - 17.5
17.5 - 20
20 - 22.5
22.5 - 25
25 - 27.5
27.5 - 30
> 30
Annual mean concentration
Grid cell size 400 m x 400 m
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2010m/l_pm10_400
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
infras
METEOTEST
Berne, 18-JUL-2003

Figure 31

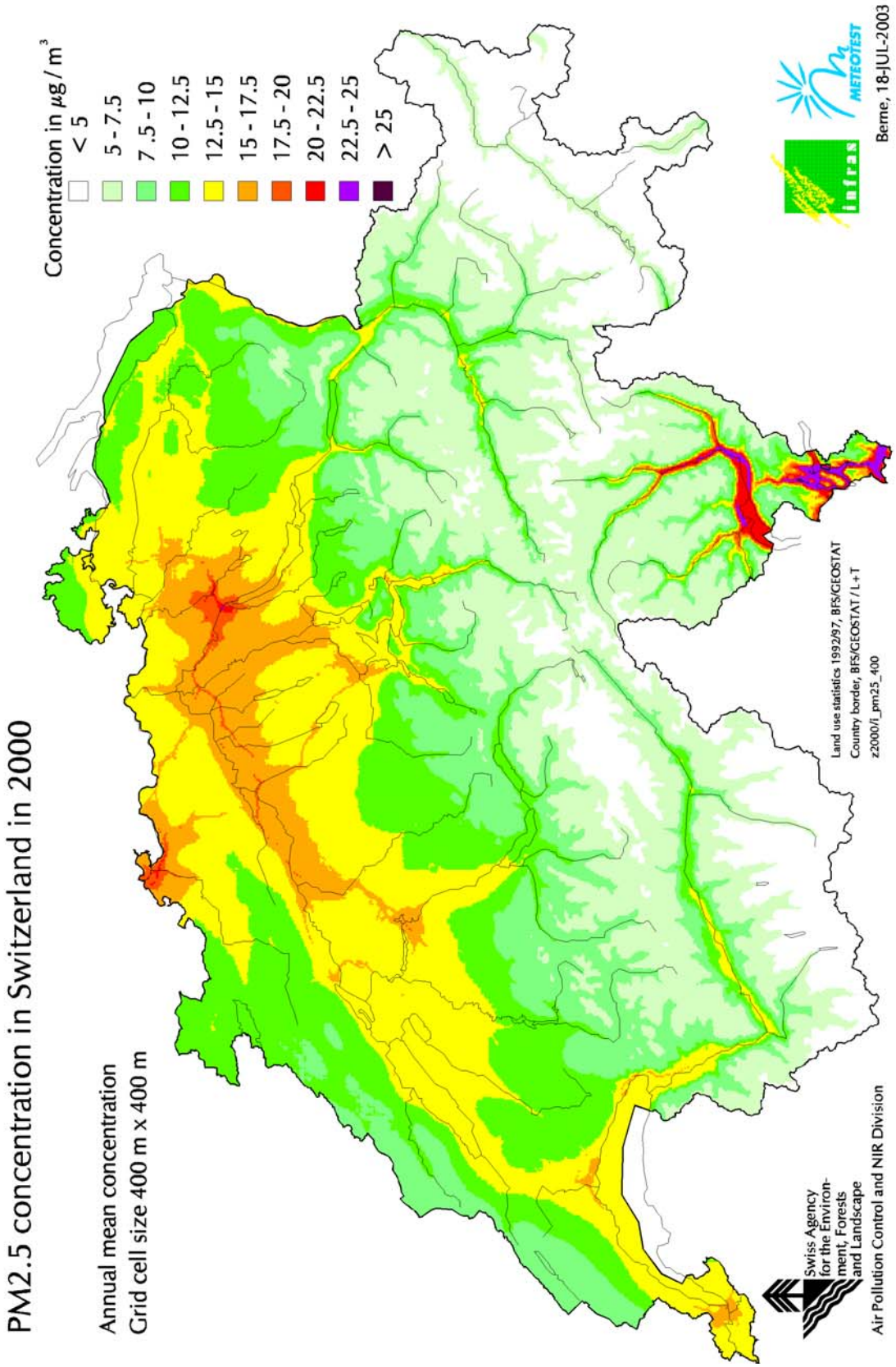

PM2.5 concentration in Switzerland in 2000
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
< 5
5 - 7.5
7.5 - 10
10 - 12.5
12.5 - 15
15 - 17.5
17.5 - 20
20 - 22.5
22.5 - 25
> 25
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/l_pm25_400
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
infras
METEOTEST
Berne, 18-JUL-2003

Figure 32

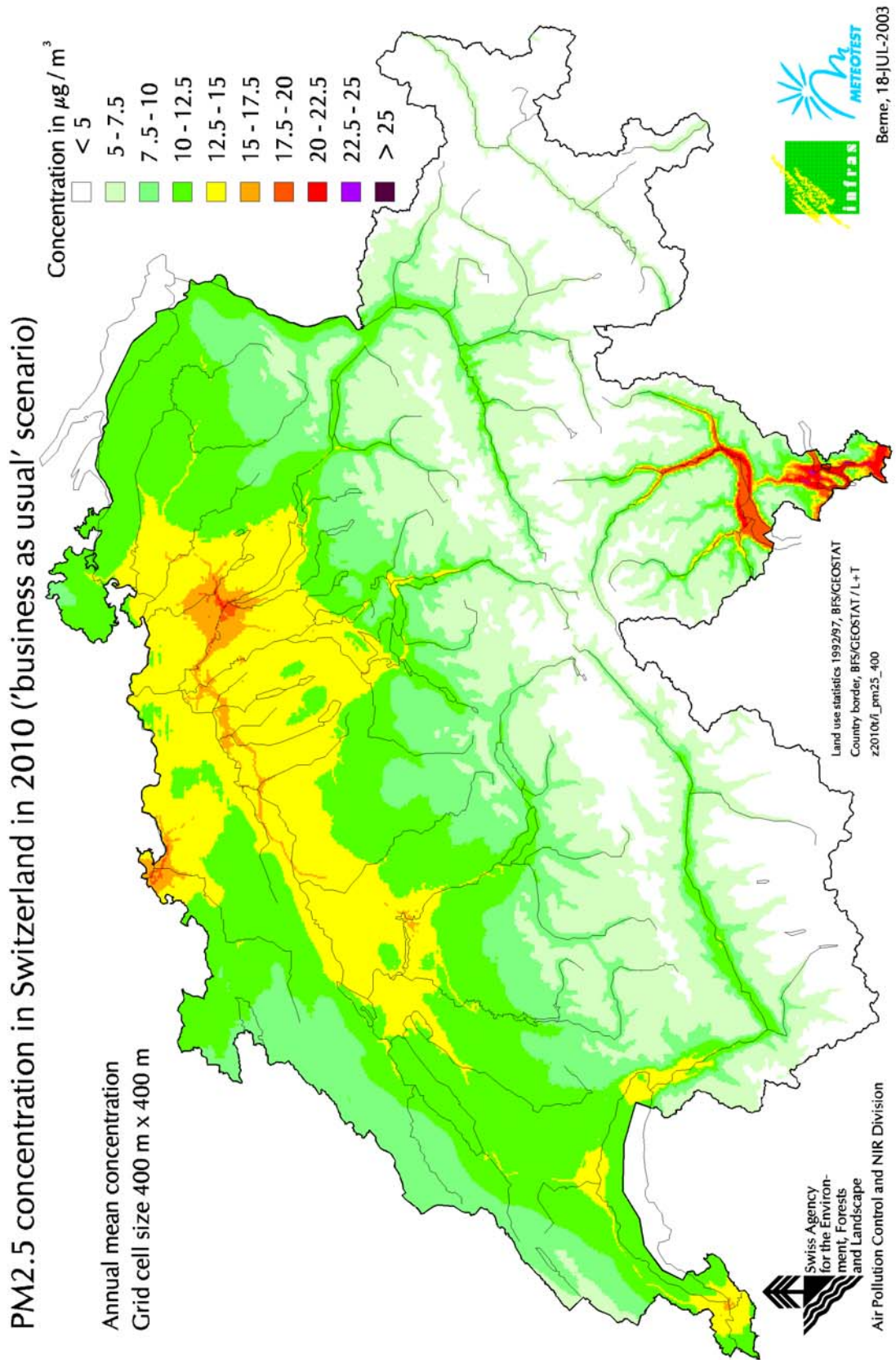

PM2.5 concentration in Switzerland in 2010 ('business as usual' scenario)
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
< 5
5 - 7.5
7.5 - 10
10 - 12.5
12.5 - 15
15 - 17.5
17.5 - 20
20 - 22.5
22.5 - 25
> 25
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2010f_pm25_400
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
infras
METEOTEST
Berne, 18-JUL-2003

Figure 33

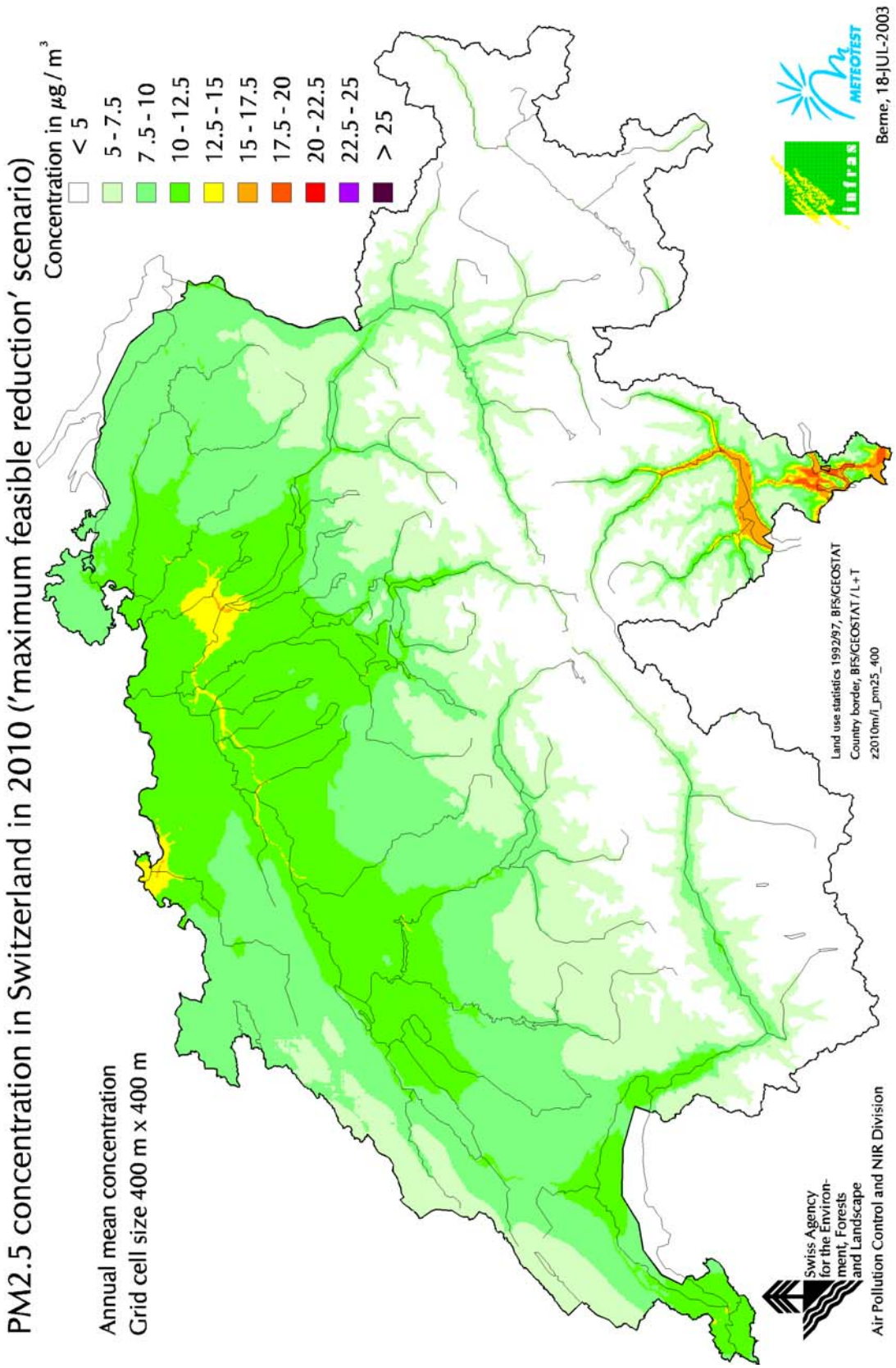

PM2.5 concentration in Switzerland in 2010 ('maximum feasible reduction' scenario)
Concentration in µg / m³
< 5
5 - 7.5
7.5 - 10
10 - 12.5
12.5 - 15
15 - 17.5
17.5 - 20
20 - 22.5
22.5 - 25
> 25
Annual mean concentration
Grid cell size 400 m x 400 m
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2010m/l_pm25_400
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
infras
METEOTEST
Berne, 18-JUL-2003

Figure 34

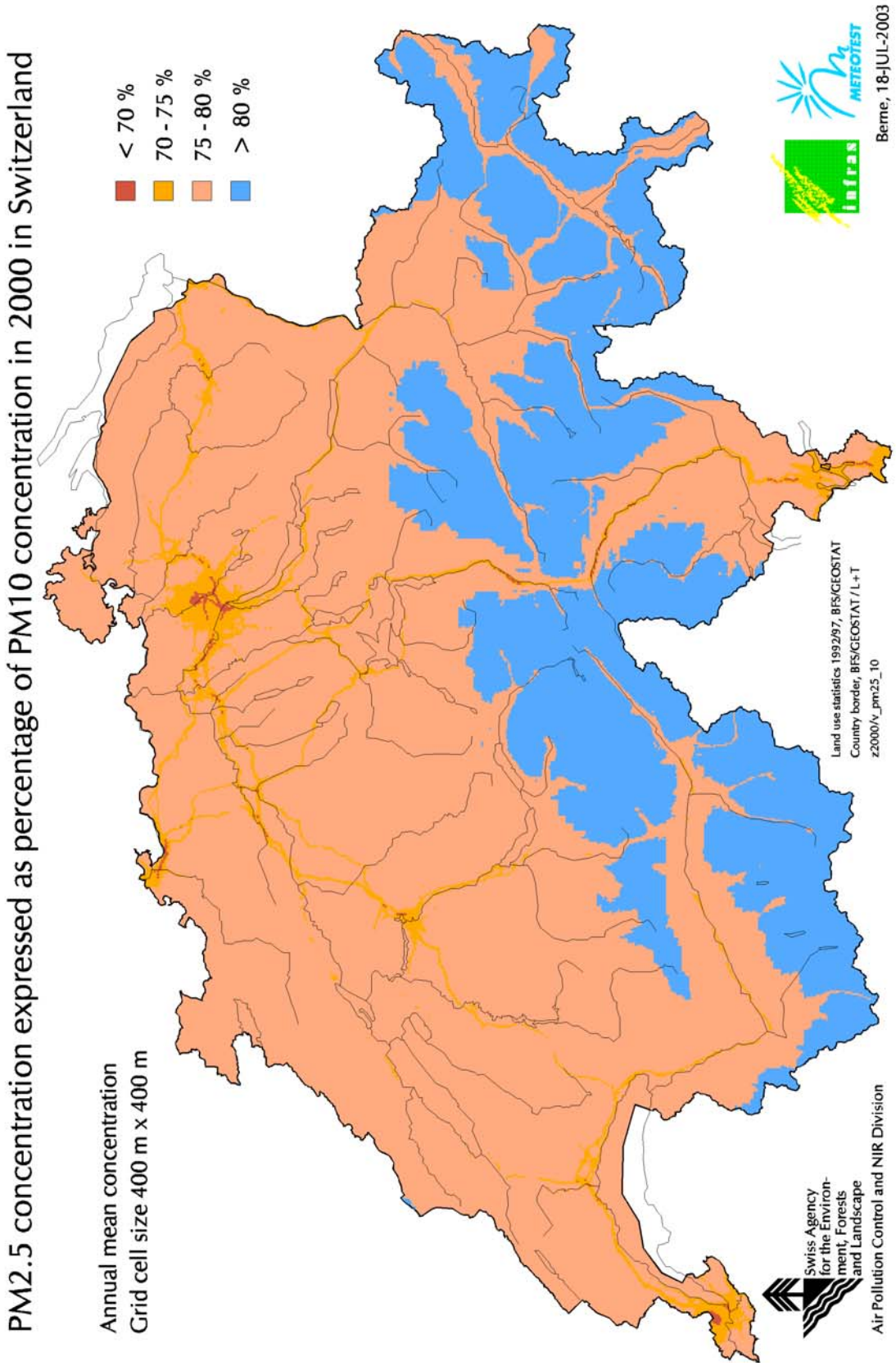
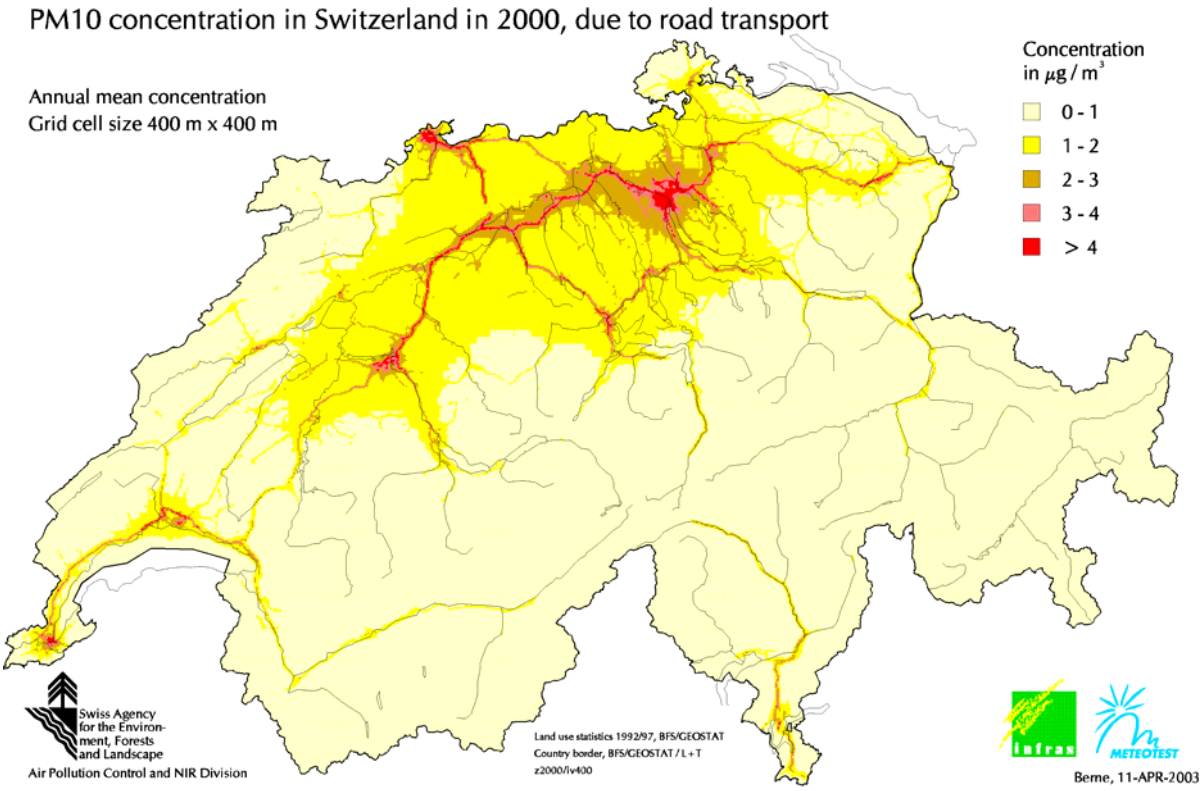

PM2.5 concentration expressed as percentage of PM10 concentration in 2000 in Switzerland
Annual mean concentration
Grid cell size 400 m x 400 m
< 70 %
70 - 75 %
75 - 80 %
> 80 %
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/v_pm25_10
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
infras
METEOTEST
Berne, 18-JUL-2003

Figure 35


PM10 concentration in Switzerland in 2000, due to road transport
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 1
1 - 2
2 - 3
3 - 4
> 4
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/iv400
infras
METEOTEST
Berne, 11-APR-2003

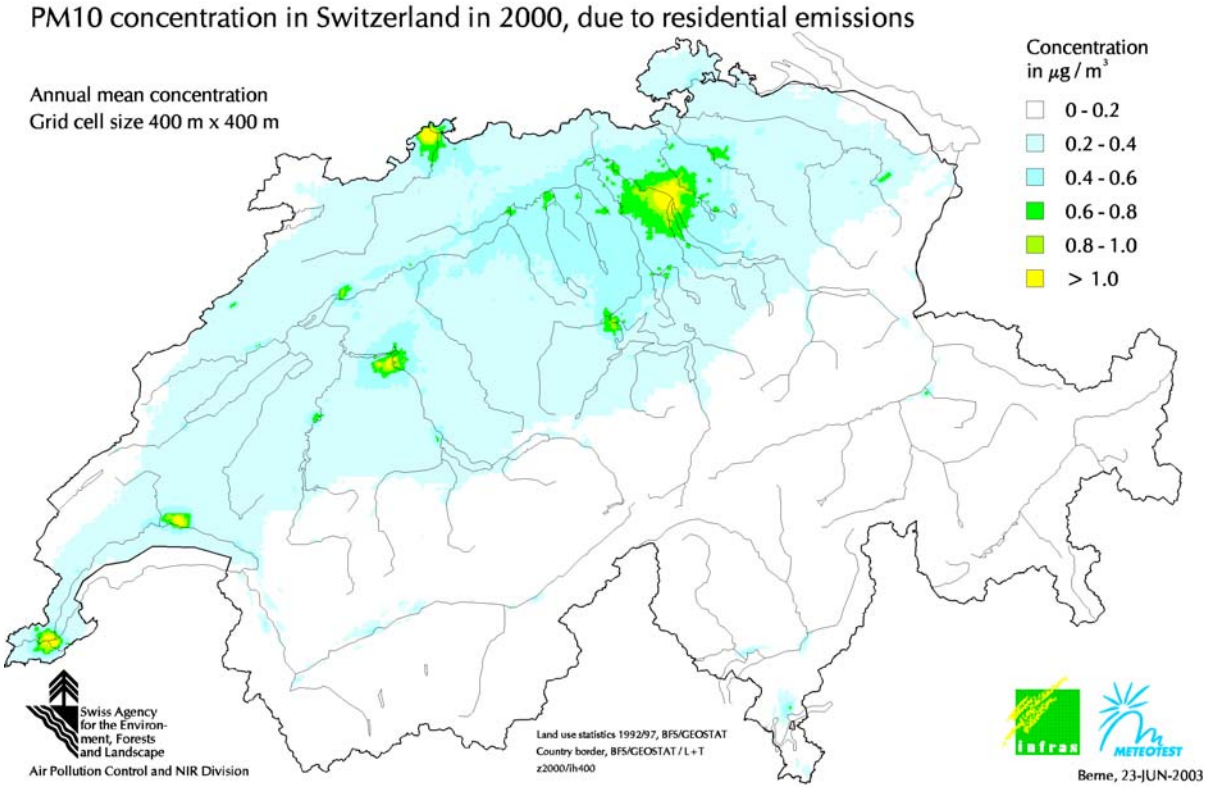
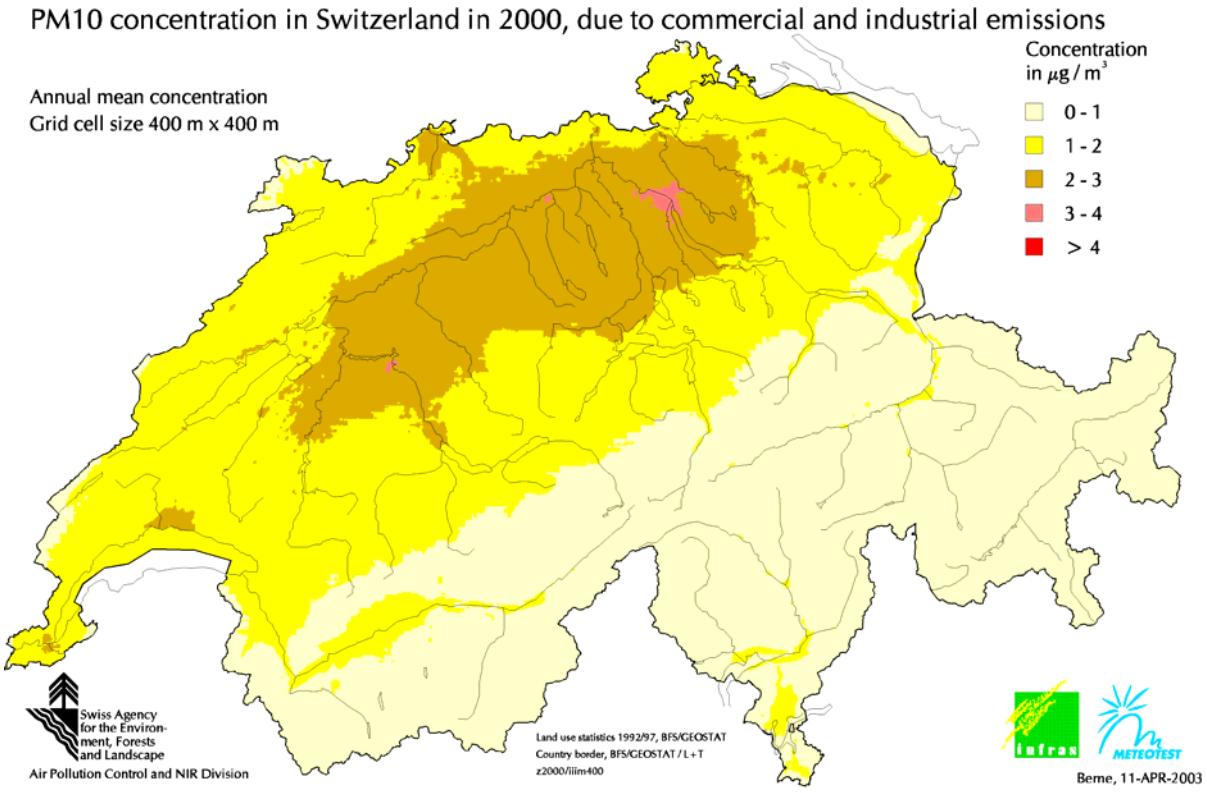

PM10 concentration in Switzerland in 2000, due to residential emissions
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
> 1.0
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ih400
infras
METEOTEST
Berne, 23-JUN-2003

Figure 36


PM10 concentration in Switzerland in 2000, due to commercial and industrial emissions
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 1
1 - 2
2 - 3
3 - 4
> 4
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/iiim400
Infras
METEOTEST
Berne, 11-APR-2003

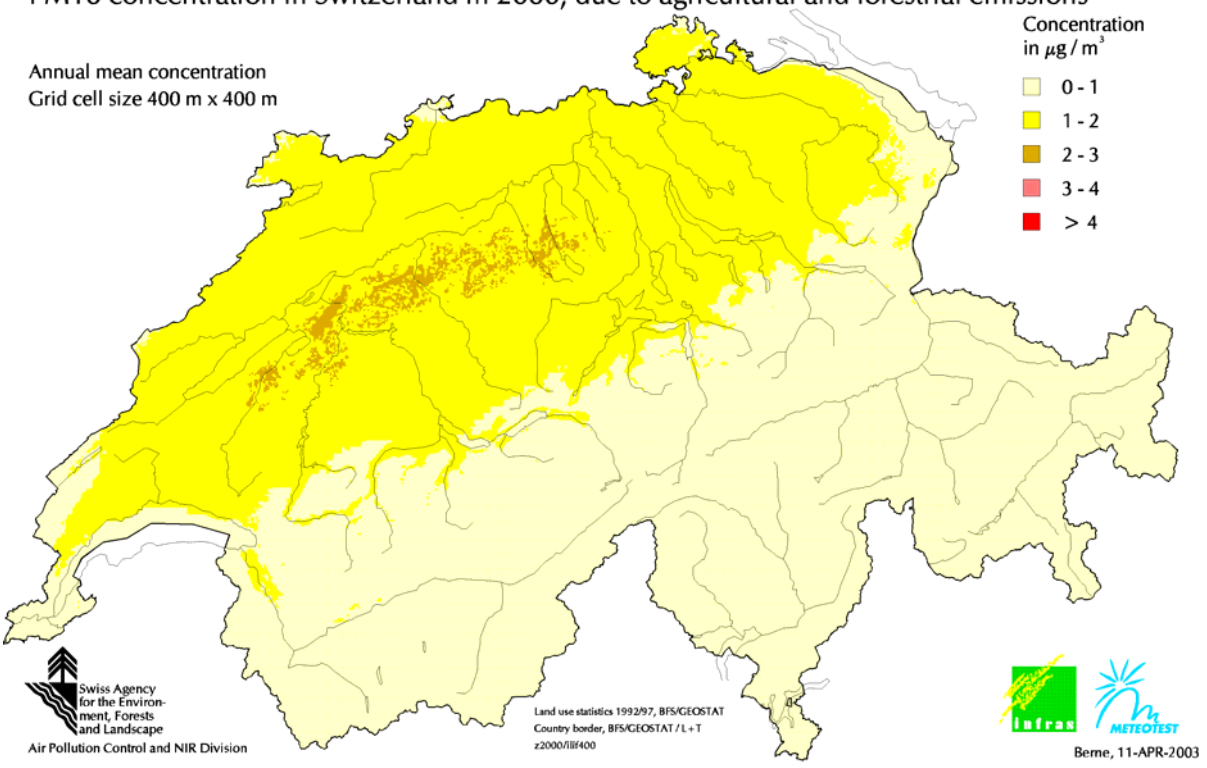
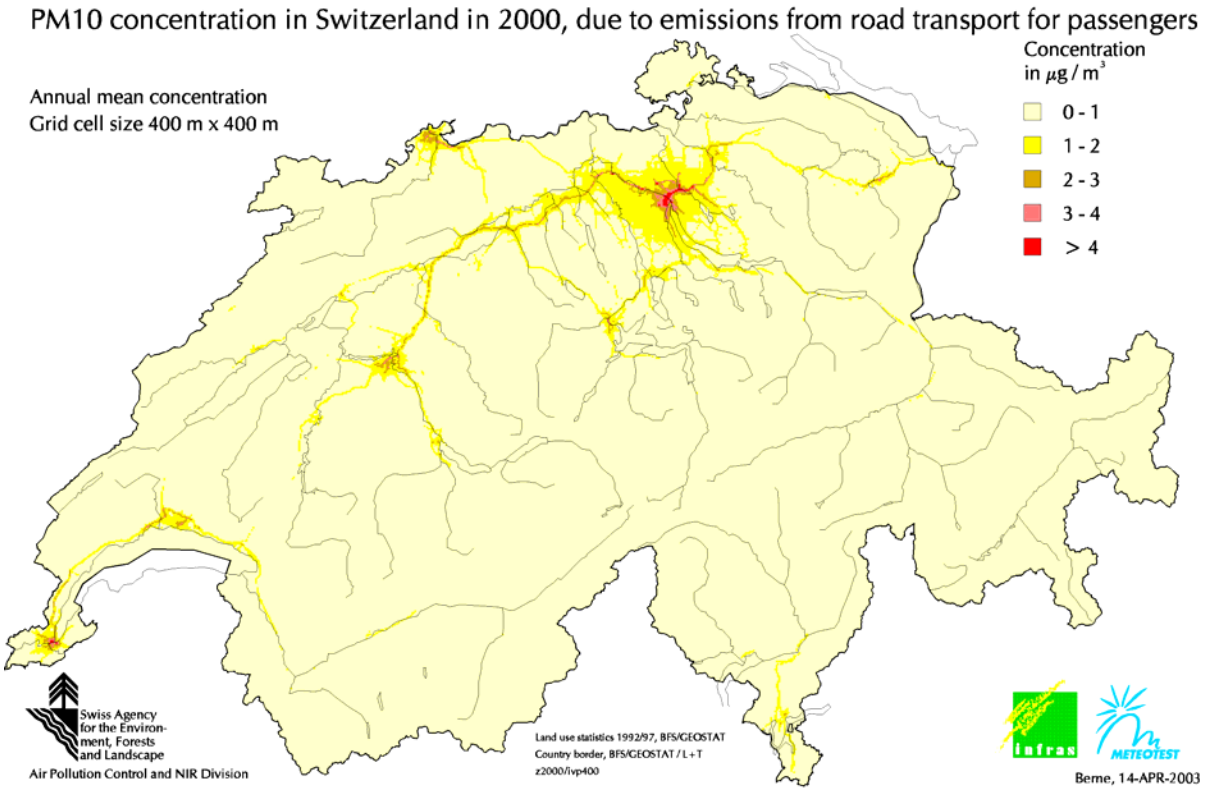

PM10 concentration in Switzerland in 2000, due to agricultural and forestrial emissions
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 1
1 - 2
2 - 3
3 - 4
> 4
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/iiif400
Infras
METEOTEST
Berne, 11-APR-2003

Figure 37


PM10 concentration in Switzerland in 2000, due to emissions from road transport for passengers
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 1
1 - 2
2 - 3
3 - 4
> 4
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ivp400
Infras
METEOTEST
Berne, 14-APR-2003

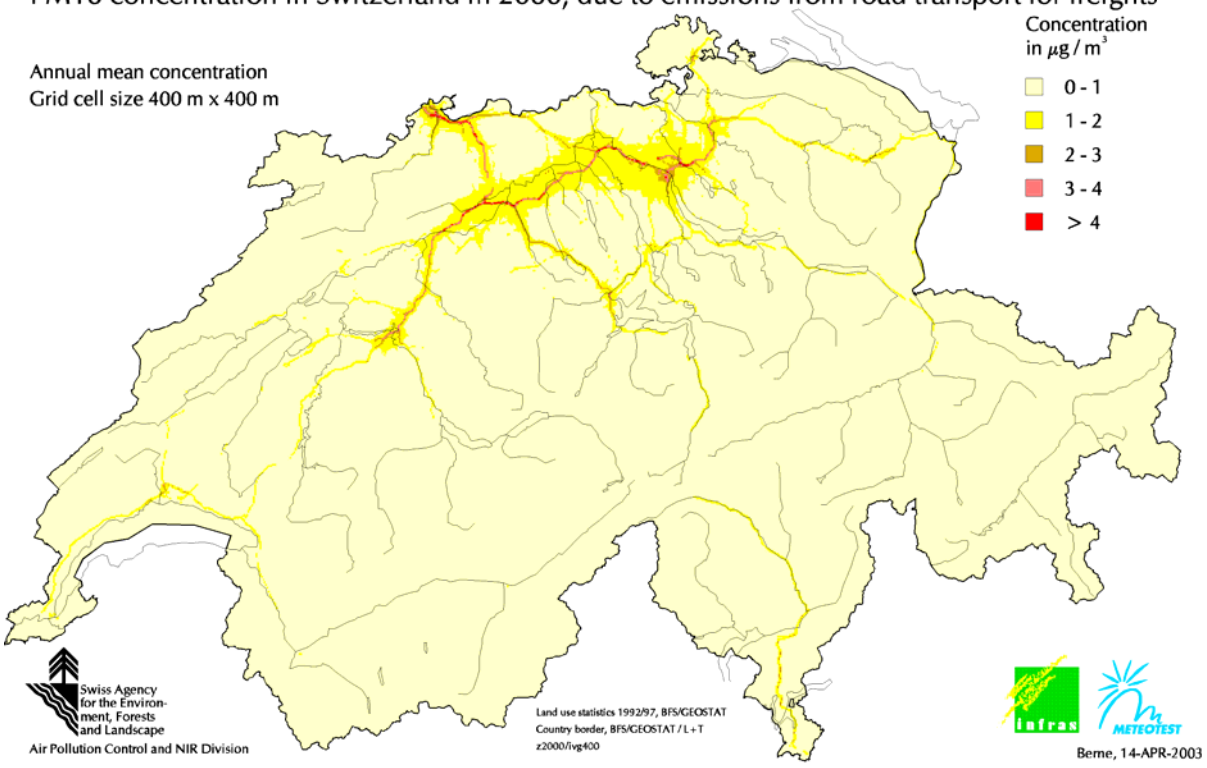
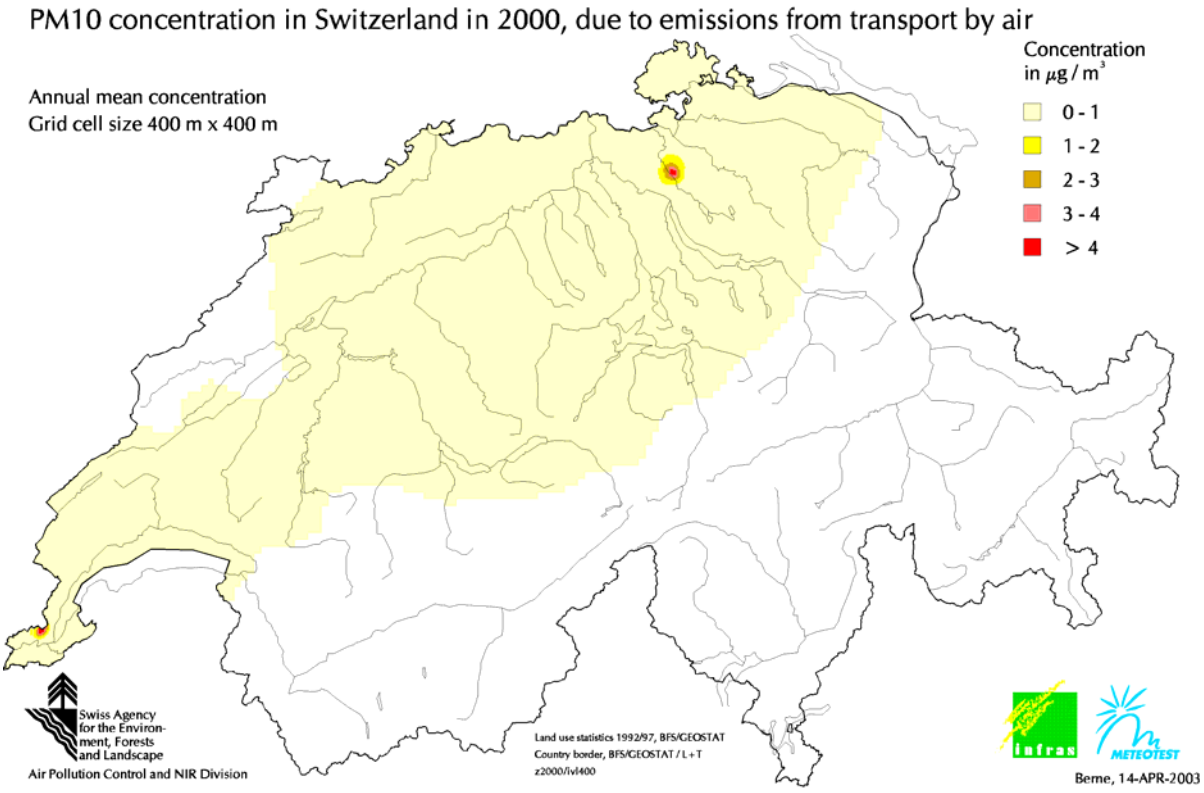

PM10 concentration in Switzerland in 2000, due to emissions from road transport for freights
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 1
1 - 2
2 - 3
3 - 4
> 4
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ivg400
Infras
METEOTEST
Berne, 14-APR-2003

Figure 38


PM10 concentration in Switzerland in 2000, due to emissions from transport by air
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 1
1 - 2
2 - 3
3 - 4
> 4
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ivl400
infras
METEOTEST
Berne, 14-APR-2003

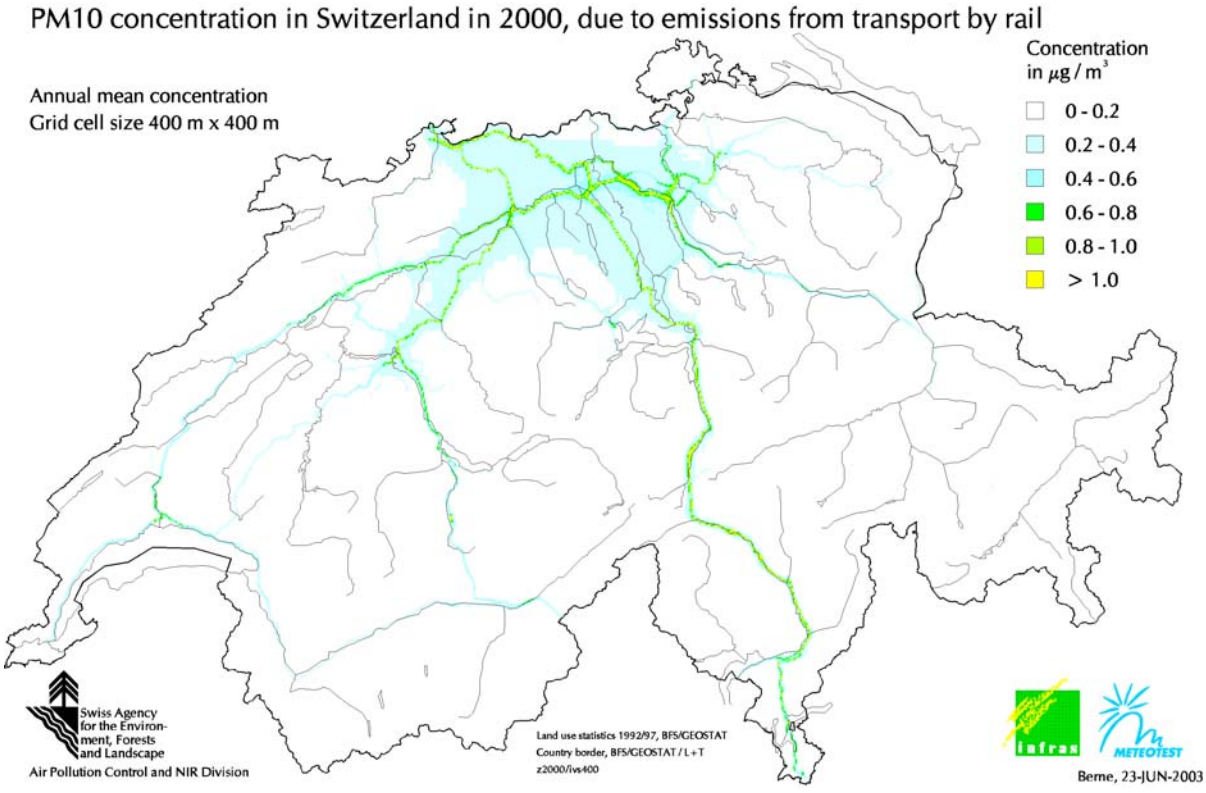
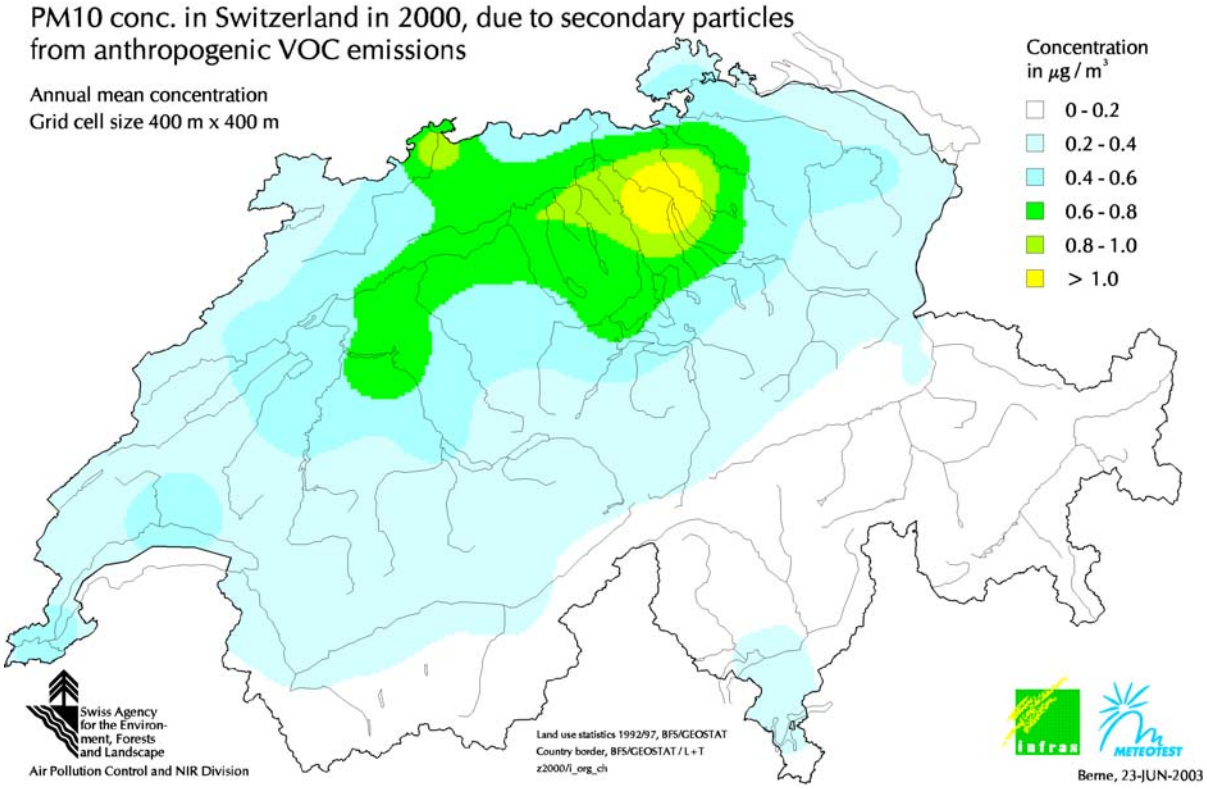

PM10 concentration in Switzerland in 2000, due to emissions from transport by rail
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
> 1.0
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/ivs400
infras
METEOTEST
Berne, 23-JUN-2003

Figure 39


PM10 conc. in Switzerland in 2000, due to secondary particles from anthropogenic VOC emissions
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
> 1.0
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/i_org_ch
infras
METEOTEST
Berne, 23-JUN-2003

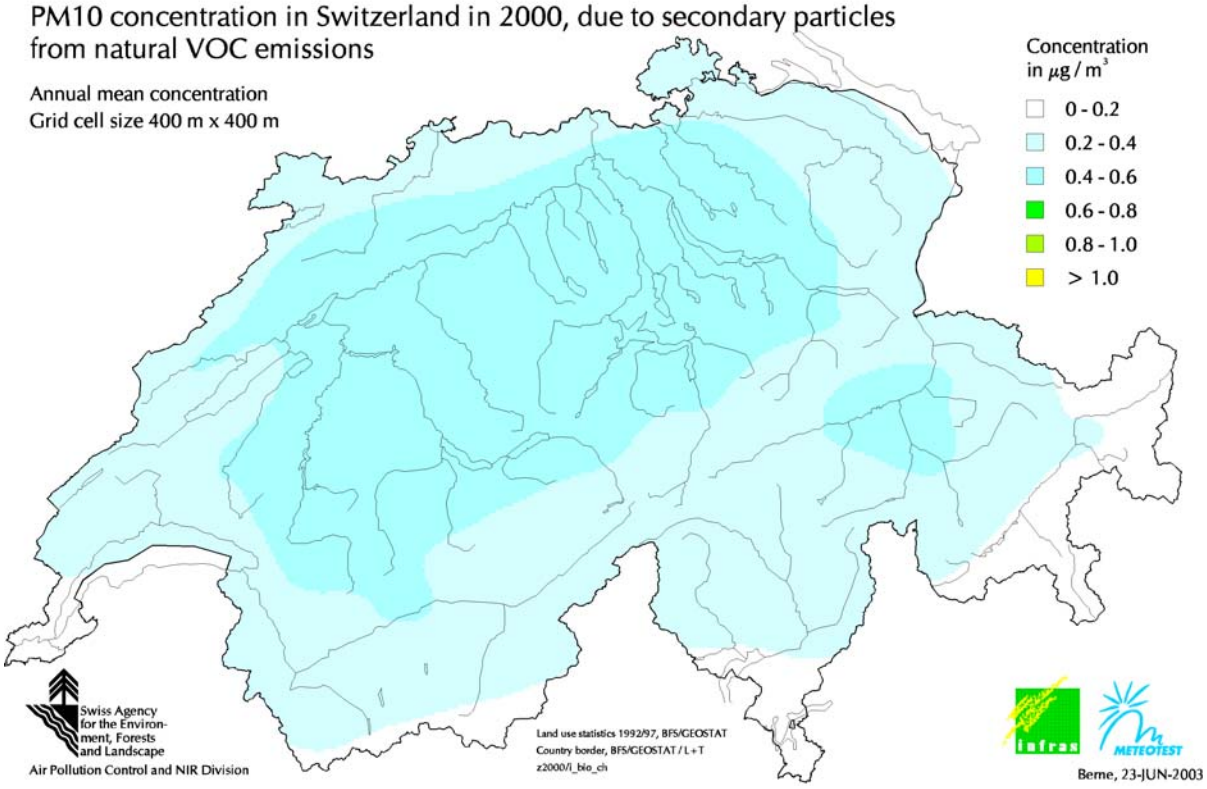
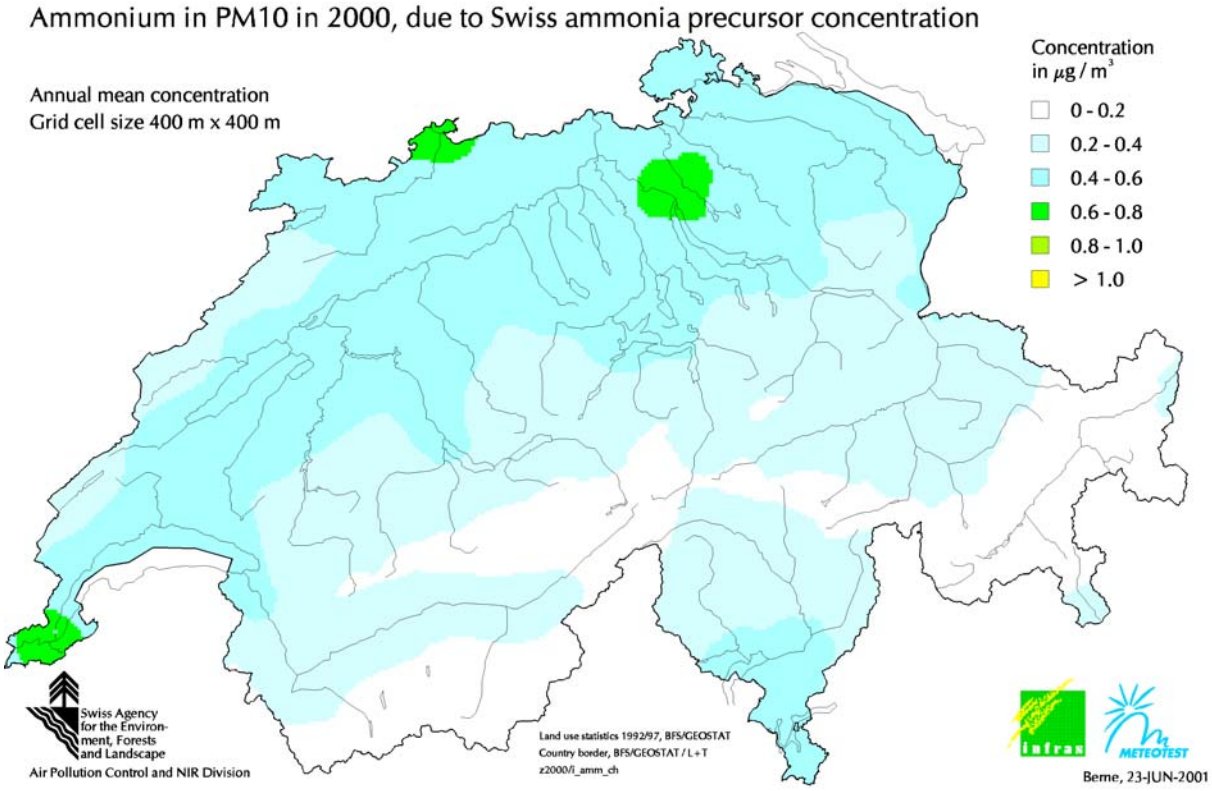

PM10 concentration in Switzerland in 2000, due to secondary particles from natural VOC emissions
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
> 1.0
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/i_bio_ch
infras
METEOTEST
Berne, 23-JUN-2003

Figure 40


Ammonium in PM10 in 2000, due to Swiss ammonia precursor concentration
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
> 1.0
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/i_amm_ch
infras
METEOTEST
Berne, 23-JUN-2001

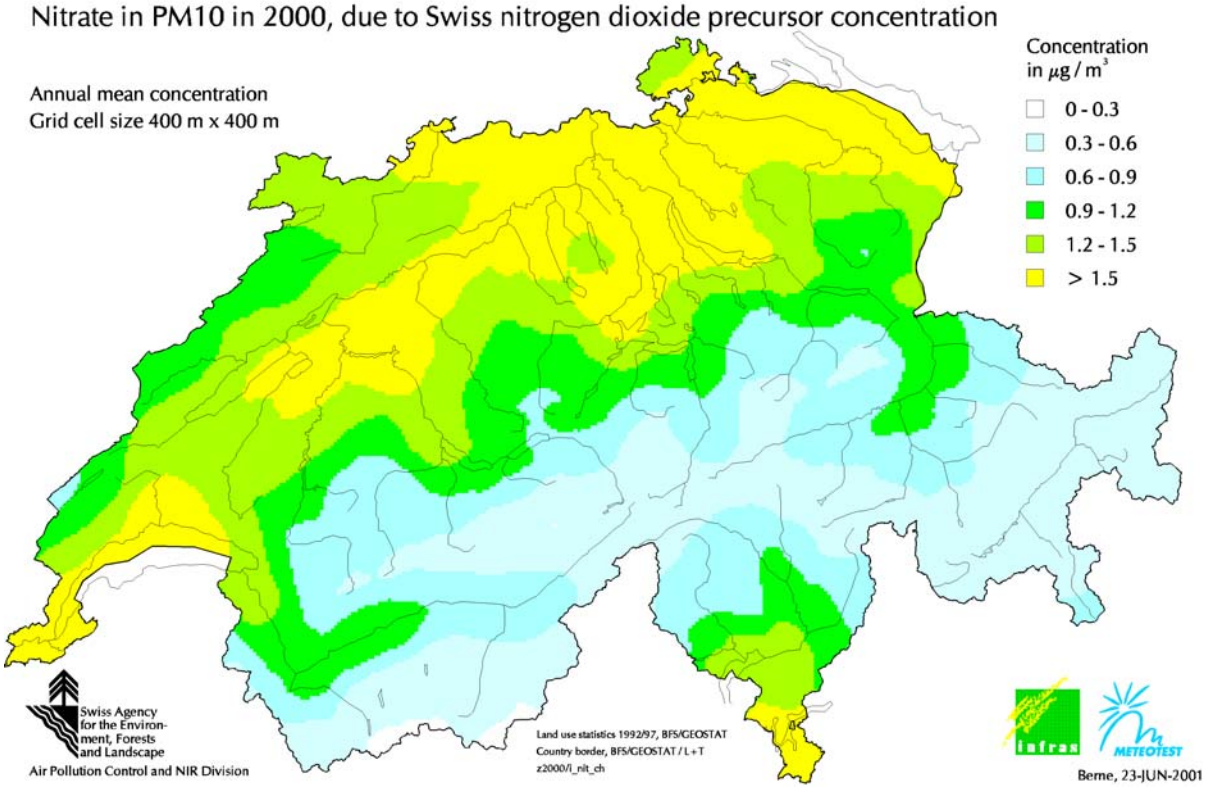
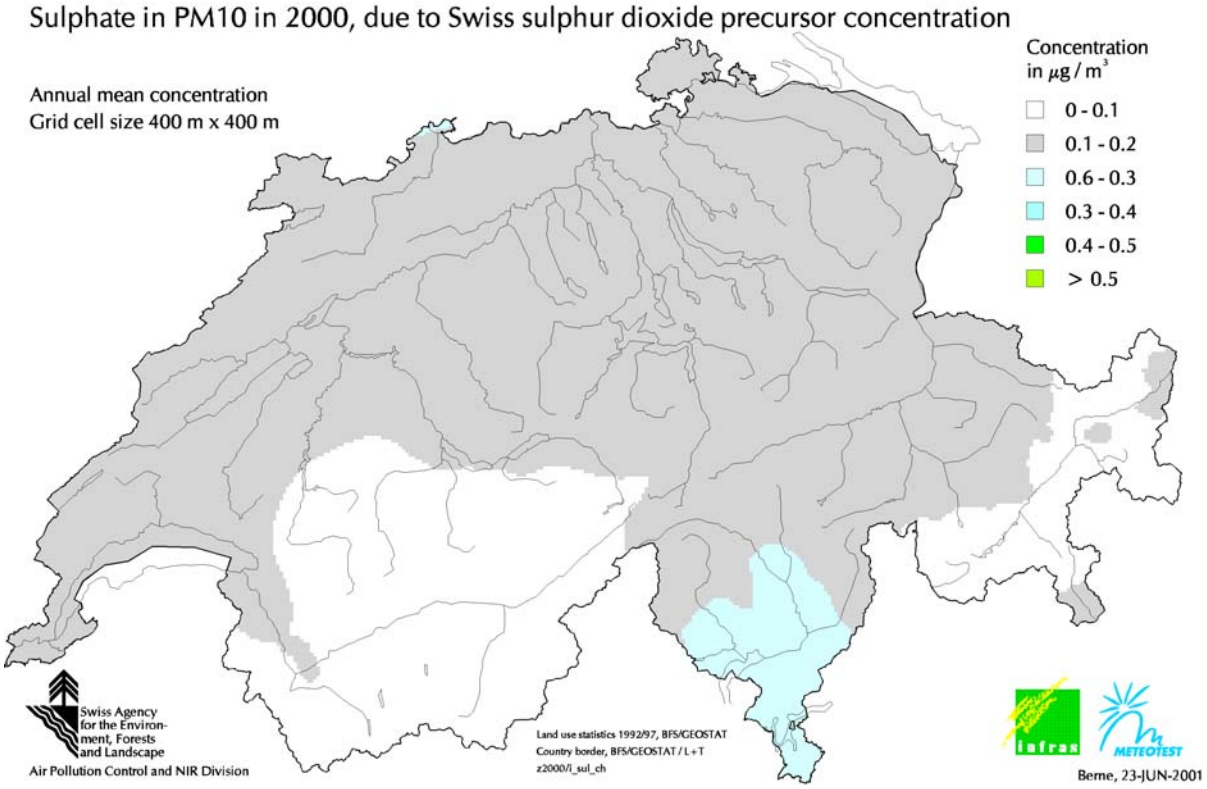

Nitrate in PM10 in 2000, due to Swiss nitrogen dioxide precursor concentration
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 0.3
0.3 - 0.6
0.6 - 0.9
0.9 - 1.2
1.2 - 1.5
> 1.5
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/i_nit_ch
infras
METEOTEST
Berne, 23-JUN-2001

Figure 41


Sulphate in PM10 in 2000, due to Swiss sulphur dioxide precursor concentration
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 0.1
0.1 - 0.2
0.6 - 0.3
0.3 - 0.4
0.4 - 0.5
> 0.5
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/l_sul_ch
infras
METEOTEST
Berne, 23-JUN-2001

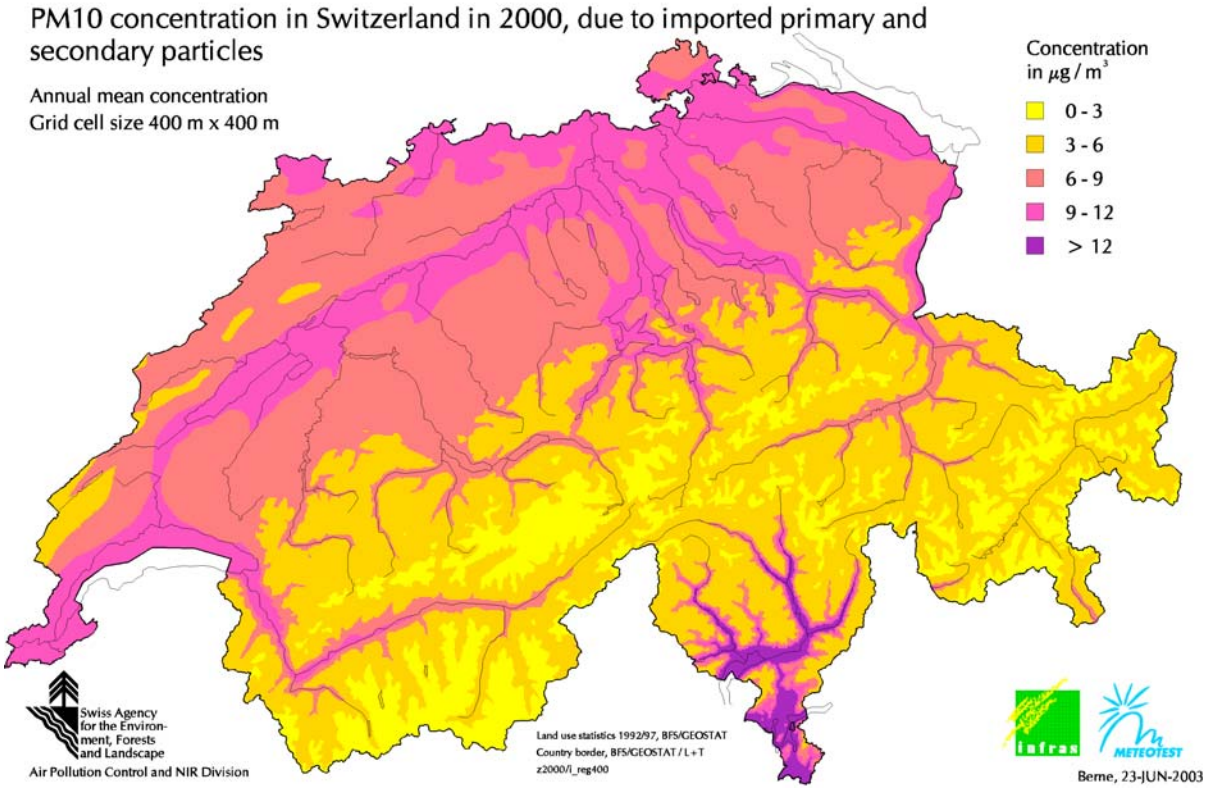

PM10 concentration in Switzerland in 2000, due to imported primary and secondary particles
Annual mean concentration
Grid cell size 400 m x 400 m
Concentration in µg / m³
0 - 3
3 - 6
6 - 9
9 - 12
> 12
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
Land use statistics 1992/97, BFS/GEOSTAT
Country border, BFS/GEOSTAT / L+T
z2000/l_reg400
infras
METEOTEST
Berne, 23-JUN-2003

Figure 42

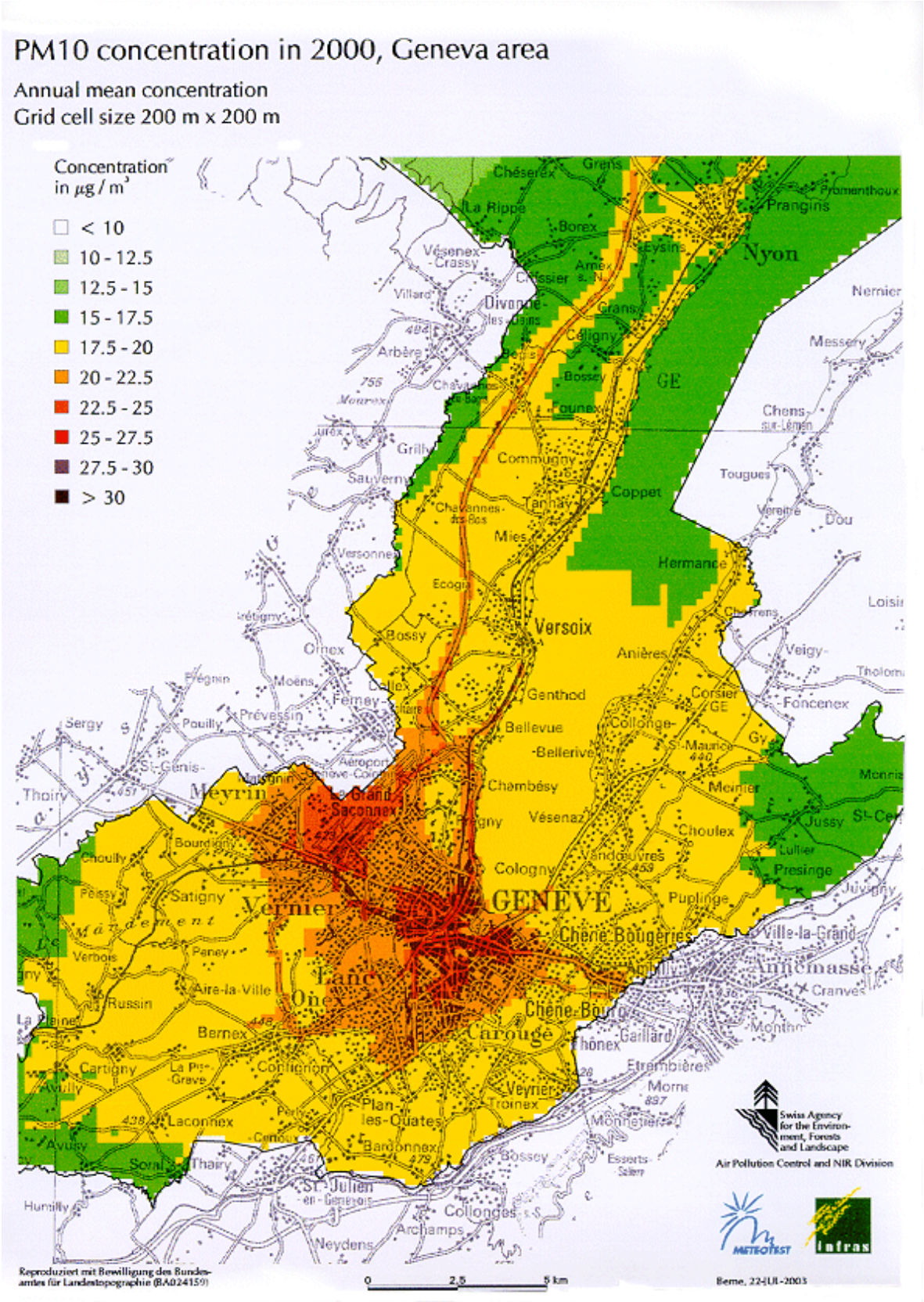

PM10 concentration in 2000, Geneva area
Annual mean concentration
Grid cell size 200 m x 200 m
Concentration in µg / m³
< 10
10 - 12.5
12.5 - 15
15 - 17.5
17.5 - 20
20 - 22.5
22.5 - 25
25 - 27.5
27.5 - 30
> 30
Versoix
GENEVE
Meyrin
Vernier
Lancy
Onex
Carouge
Thônex
Chêne-Bougeries
Chêne-Bourg
Cologny
Vésenaz
Bellevue
Genthod
Anières
Hermance
Coppet
Nyon
Prangins
Gland
Saconnex
Aéroport
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
METEOTEST
infras
Reproduziert mit Bewilligung des Bundesamtes für Landestopographie (BA024159)
0 2.5 5 km
Berne, 22-01-2003

Figure 43

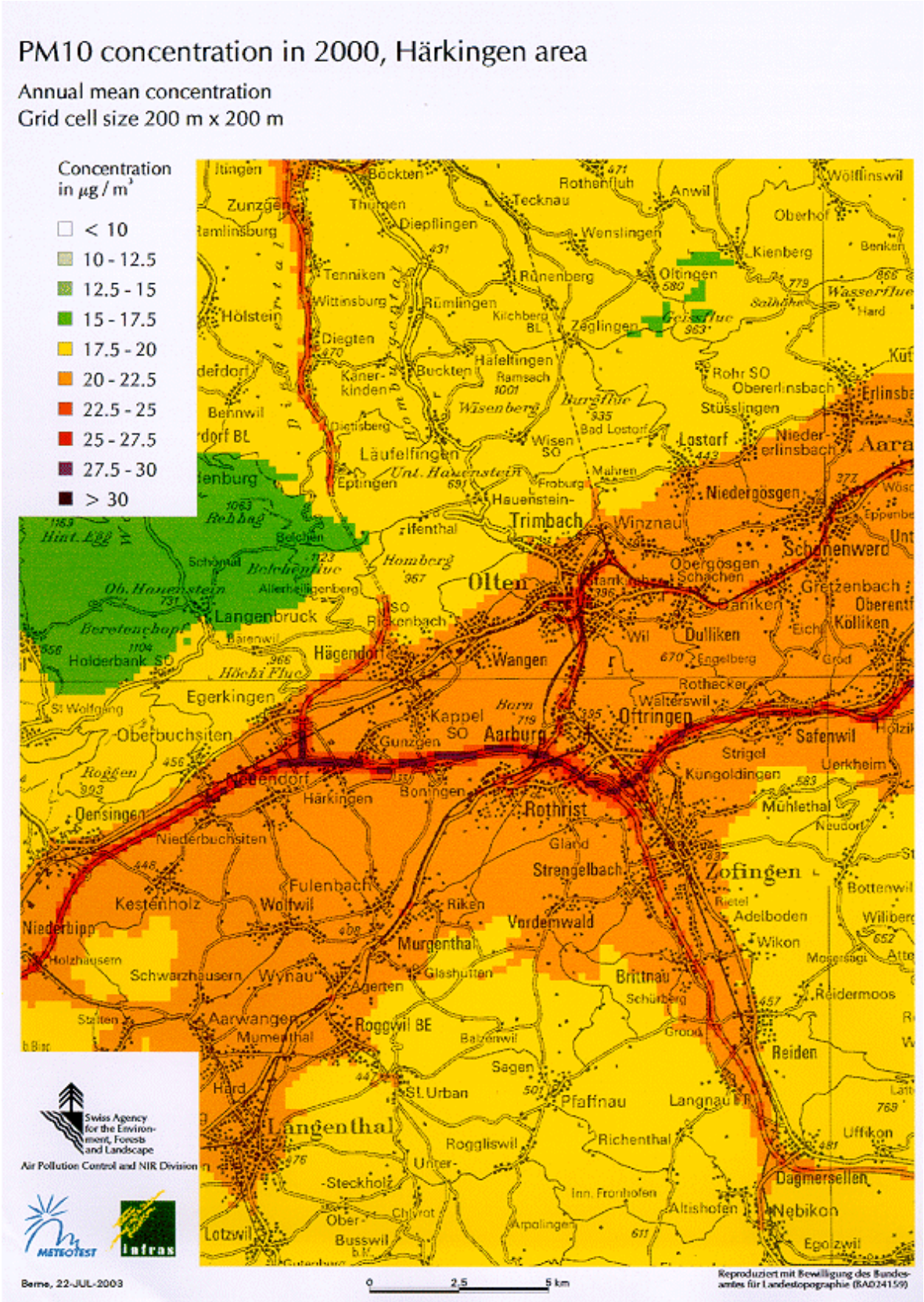

PM10 concentration in 2000, Härkingen area
Annual mean concentration
Grid cell size 200 m x 200 m
Concentration in µg / m³
< 10
10 - 12.5
12.5 - 15
15 - 17.5
17.5 - 20
20 - 22.5
22.5 - 25
25 - 27.5
27.5 - 30
> 30
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
METEOTEST
Infras
Berne, 22-JUL-2003
0 2.5 5 km
Reproduziert mit Bewilligung des Bundesamtes für Landestopographie (BA024159)

Figure 44

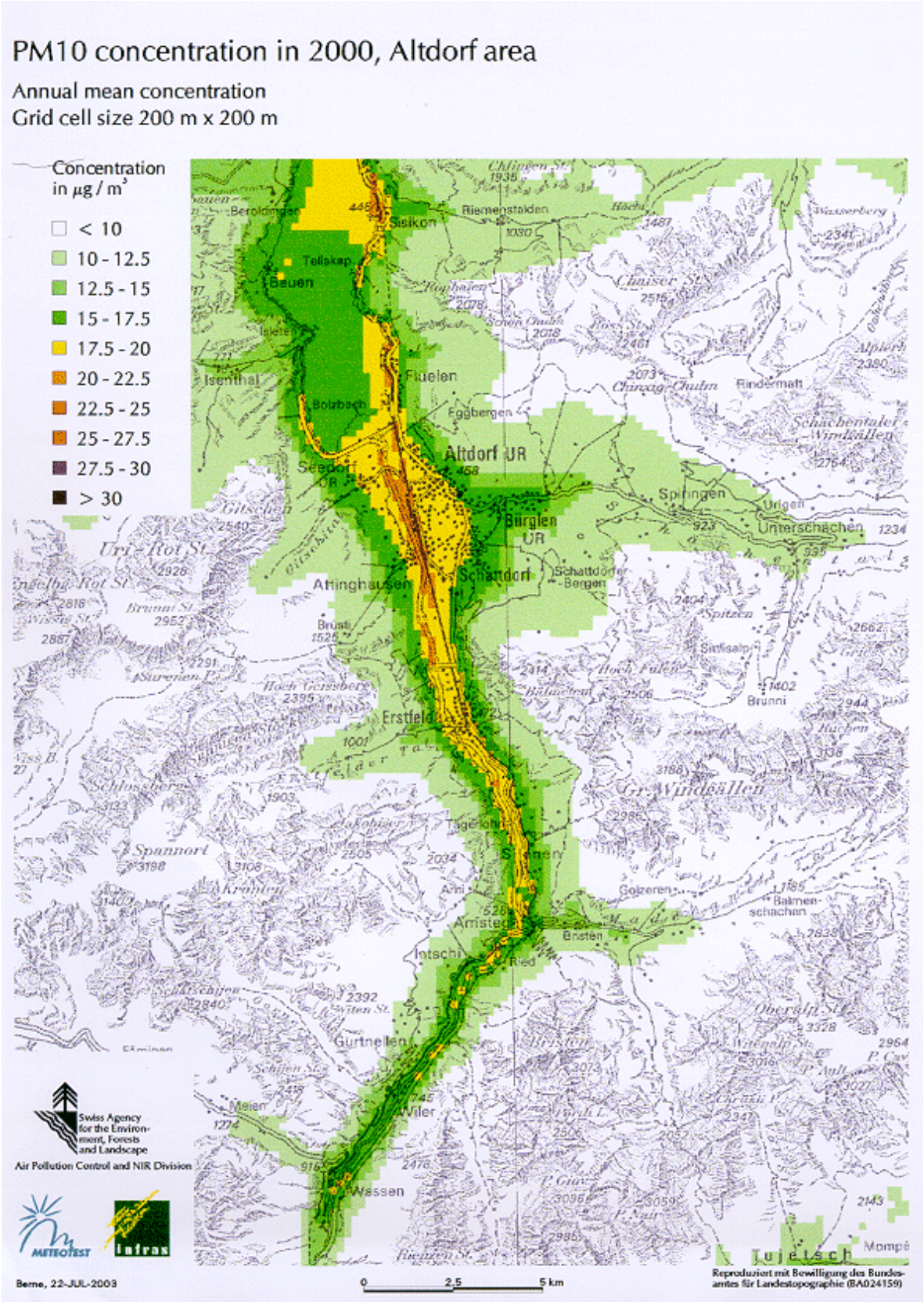

PM10 concentration in 2000, Altdorf area
Annual mean concentration
Grid cell size 200 m x 200 m
Concentration in µg / m³
< 10
10 - 12.5
12.5 - 15
15 - 17.5
17.5 - 20
20 - 22.5
22.5 - 25
25 - 27.5
27.5 - 30
> 30
Altdorf UR
Schattdorf
Bürglen UR
Seedorf UR
Flüelen
Attinghausen
Erstfeld
Silenen
Amsteg
Intschi
Gurtnellen
Wiler
Wassen
Göschenen
Unterschächen
Spiringen
Isenthal
Bauen
Sisikon
Riemenstalden
Eggbergen
Bolzbach
Schattdorfer Bergen
Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control and NIR Division
METEOTEST
Infras
Berne, 22-JUL-2003
0 2.5 5 km
Reproduziert mit Bewilligung des Bundesamtes für Landestopographie (BA024159)

Figure 45