TNO Built Environment and Geosciences

Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek / Netherlands Organisation for Applied Scientific Research

Laan van Westenenk 501
P.O. Box 342
7300 AH Apeldoorn
The Netherlands

www.tno.nl

P +31 55 549 34 93
F +31 55 541 98 37

TNO-report

2006-A-R0241/B

Summary of the contribution of TNO to the UBA-project FKZ 202 43270

Date	July 2006
Authors	P.J.H. Builtjes A. Bleeker * H.A.C. Denier van der Gon M. Schaap A.J.H. Visschedijk *at ECN since Sept. 2004
Order no.	64114
Keywords	Air quality, air pollution modelling, emissions
Intended for	Freie Univ. Berlin, Inst. für Meteorologie

All rights reserved.
No part of this publication may be reproduced and/or published by print, photoprint, microfilm or any other means without the previous written consent of TNO.

In case this report was drafted on instructions, the rights and obligations of contracting parties are subject to either the Standard Conditions for Research Instructions given to TNO, or the relevant agreement concluded between the contracting parties.
Submitting the report for inspection to parties who have a direct interest is permitted.

© 2006 TNO

Contents

1. Introduction

The purpose of the overall project is the development of models to identify the emission sources, with a special focus on traffic- in the frame of 22. BimSchV- Documentation, Improvements, Validation and Abatement strategies, focusing on Germany.

The main activities in the project have been carried out by the Free Univ. Berlin, Inst. für Meteorology, focusing on further development and application of the Chemical Transport Model-CTM- RemCalgrid-RCG. Model runs have also been performed in the project by EURAD-Köln.
The tasks of TNO focused on creating part of the required input data needed by RCG to perform model runs, focusing on improvement and extension of the data bases (Fortschreibung und Ergänzung Datenbasen).
The tasks of TNO in the overall project were the following:

1) Determination of gridded European anthropogenic emission data for NO_x, SO_2, NMVOC, NH_3, CO, PM_{10}, $PM_{2.5}$ and CH_4 for the year 2000.

2) Creating an update of the forest data over Europe.

3) Review concerning the treatment of seasalt.

4) Review concerning the treatment of windblown dust.

The determination of the European gridded anthropogenic emission data has been the main activity of TNO, the other activities were much more limited in scope.
In the following chapters the results of the 4 tasks will be summarized.

2. The anthropogenic emission data base

TNO developed the gridded anthropogenic emission data to provide the RCG model with the state-of –the –art and consistent data for the substances NO_x, SO_2, NMVOC, CH_4, NH_3,PM and CO, on a high geographical resolution (0.25 x 0.125 lonlat, which is on average about 15 x 15 km^2), covering Europe (excluding Island), for the reference year 2000. The decision was made that starting from the TNO experts estimates, the emission sectoral totals should be made conform to the latest country submission to EMEP for the year 2000, whenever available. This means that the sectoral totals for each country have been scaled to be identical with the official EMEP data.
TNO focused on obtaining a spatial distribution that is as accurate and realistic as possible and that provides full geographical coverage over Europe, from Ireland to Kazakhstan. The TNO methodology is consistent, transparent and documented. It is based on, among other items, recent data on a wide range of point source emissions, agricultural/vegetation spatial distribution patterns, traffic intensities/road maps and rural/urban population distribution. Additionally, the emission data provide full and up-to-date coverage of off-shore emission sources, including sea shipping and oil and gas production.
In a separate report (Visschedijk and Denier van der Gon, 2005), the development and the results of the anthropogenic emissions are presented in detail. The emission data base has been put on CD-Rom, and send to the Inst.of Meteorology by March 2005.

3. Creating an update of the forest data over Europe.

Starting point has been the so-called Pelinda data base, as has been described in Builtjes *et al.*, 2003. This Pelinda land use data base has been developed and used by REM3/Calgrid in previous projects. In recent years, also the socalled Corine land use data base has been set-up by EEA, using the data provided by countries. The advantage of Corine is that it is an official data base, the disadvantage, untill recently, was that it did not cover the whole of Europe because some countries did not provide data. The advantage of Pelinda is that it covers the whole of Europe, the disadvantage that it is not an official data base. Because using an official data base is preferred, the Pelinda data base has been replaced.
Furthermore, recently much more detailed forest information became available, which would make it possible to make state-of-the-art calculations of biogenic emissions.
This resulted in the following two tasks:

I) Replacing Pelinda with a new land use data base.

II) Inserting new tree species information in the land use data base.

Ad. I) Starting point has been the official Corine/Phare Land Cover Data from the EEA, which should replace the existing Pelinda land use data base.

Smiatek, FI-Garmisch Partenkirchen, has taken this Corine data-base and has made it complete, filled in the parts where no data were available, using for that mainly the Pelinda data base.
This Corine/ Smiatek data base covers Europe completely.

The Smiatek data base has a grid resolution over Europe of 0.01667 lat-long, with is about 2 x 2 km^2.
For Germany the resolution is a factor 4 finer, so about 1 x 1 km^2.
The underlying information for some parts of Europe has even a finer resolution, but the basic information over Europe is on 2 x 2 km^2. The data base has 13 land cover categories, and per grid the main land cover category is given, although more refined information is available for parts of Europe. As an example, over Germany on 1 x 1km^2, percentages of the categories are given. The focus in this study is to have a coherent data base over Europe, so detailed refinements are not included. Concerning forest, the data base includes the categories: Deciduous, Coniferous and Mixed forest.

II) The Corine/Smiatek data base has been enhanced using the tree species map for Europe made by Renate Koeble, JRC Ispra. Koeble used Corine as basis. This map/data base contains 115 tree species, on a grid of 1 x 1 km^2, with also percentages per grid, like Smiatek for Germany.

In parts of the area, especially Russia, the Koeble tree map gives no information.

This leads to two possibilities: Start with Corine/Smiatek, and fill this in with Koeble, or start with Koeble, and fill this in with Corine/Smiatek.
TNO has used both procedures, so has created two maps.
It is however recommended to use in CTM's the Corine/Smiatek data base filled in with Koeble, because this results in a map with a higher official status. This map is created by the following procedure: when Koeble has no information, the three Smiatek forest categories are maintained. So, the full tree data base contains 115 + 3 categories.

The main purpose for modelling has been to create a land-use data base covering Europe with the same grid resolution as for the anthropogenic emissions: 0.125 x 0.25 lat-long, about 15 x 15 km^2.This data base should be used to calculate the biogenic emissions over Europe.

The 0.125 x 0.25 lat-long database delivered to the Inst. of Meteorology contains per grid the percentage of the 10 categories (13-3 forest) and the 115 tree classes, and if applicable with again the 3 forests categories.
This means a land use data base on grids of 0.125 x 0.25 lat-long with in total 128 categories with percentage per grid. It should be noted that the Koeble tree species data base contains within the 1 x 1 km^2 also the percentage of the tree species. These basic data have been used to create the 0.125 x 0.25 percentages.

In addition to the 0.125 x 0.25 data base, a second database on the Smiatek grid of 2 x 2 km^2 has been made. In that case per grid of 2 x 2 km^2 only the tree species with the highest percentage has been kept, to avoid an overload of information. This leads to a data base with one category per grid, but with the maximum of 128 different categories.

In summary, the Pelinda data base has been replaced by the new Corine/Smiatek land use data base. In this data base the detailed forest data have been incorporated. The different data bases have been put on CD-Rom and send to the Inst. of Meteorology by Sept. 2004.

A final remark should be made concerning land use data bases. Current practice is that European CTM's use different land use data bases. As an example, the Unified EMEP model is not using the official Corine data base. Most CTM's use a land use data base which is used in NWP and similar meteorological models. Because the land use data base has a large impact on calculated concentrations and depositions, it is strongly recommended that the sensitivity of different land use data base in calculated concentrations is investigated, and that attempts are made to come to harmonisation, resulting in one, generally accepted data base.

4. Review concerning the treatment of seasalt

In the beginning of the project a review concerning the treatment of sea salt has been performed to define a starting point to include sea salt in RCG calculations.

The generation of sea salt spray/ aerosol over the sea is driven by the surface wind. Bubble bursting during white cap formation is the main mechanism, sea salt spray through spume drops under the wave breaking is thought to be of minor importance.

The formula most used in current CTM's is the formula by Monahan *et al.*, 1986. Another formula is given by Gong *et al.*, 1997.
In Vignatti *et al.*, 2001, based on an extensive study and literature review, the so-called CAT-Coastal Aerosol Transport- Model has been developed and tested.

An intercomparison of the different seasalt modules, and a validation against observed concentrations, and their impact on PM_{10} and $PM_{2.5}$ has not taken place in Europe, but is strongly recommended. Also an overview and compilation of all European sea salt observations would add to our understanding of the importance of sea salt.

The conclusions is that both the Monahan and the Gong approach are recommended models.

5. Review concerning the treatment of windblown dust

In the beginning of the project a review concerning the treatment of windblown dust has been performed to define a starting point to include windblown dust in RCG calculations.

5.1 Introduction

Current modelling of the concentrations of PM_{10} and $PM_{2.5}$ shows in general lower values than observed. There seems to be a tendency that the underestimation is largest for rural areas (especially in summer), somewhat less for urban, and still a bit lesser for street levels. This observation however does not show up in all studies, and has to be judged with care.
The general opinion concerning the cause of this underestimation mentions the lack of (proper modelling) of sea-salt and windblown dust. The treatment of sea-salt is rather well understood and in general only relevant at distances up to about 50 km from the coast.

Concerning windblown dust, there are major gaps in the actual know-how. Furthermore, the impact of windblown dust can be substantial, and not only in episodic situations.
A study in the Netherlands (Visser *et al.*, 2001) gives an estimated yearly averaged concentration of natural windblown dust of 7-9 $\mu gr/m^3$ and of 1-3 $\mu gr/m^3$ of industrial/anthropogenic windblown dust. Other estimates in the Dutch National Aerosol Programme give a lower value for natural windblown dust of 4-6 $\mu gr/m^3$. This means that accurate modelling of PM_{10} and $PM_{2.5}$ requires proper treatment of windblown dust.

5.2 Definitions

Windblown dust is often also referred to as mineral dust or crustal material. Si, and especially Al are used as tracers of crustal material. (The chemical composition of the earth crust contains an average of about 30% Si and 10% Al-and about 50% O. See Möller, 2003 for an overview).
Windblown dust, however, also contains other material then crustal, like for example organic material from plants. Also agricultural dust emissions from agriculture areas could be mentioned, blown away by the wind.
Windblown dust can also have industrial sources, like coal-piles and handling of material. Other related sources are construction and demolition works, road abrasion and resuspension by moving traffic from dust deposited on roads. These sources are however no windblown dust sources in the strict sense, because they are not primarily a function of wind speed.

A useful distinction might be made between windblown dust from natural sources like sand/deserts/ farmland, from biological sources like plants and from anthropogenic sources like coal piles.
A preliminary definition/working definition of windblown dust: Particulate Matter up till PM_{10} emitted due to wind, so emission from this source is zero at zero wind speed.

5.3 Processes

Particles can be emitted in two ways: In a direct action of the wind, and in a more indirect way via saltation of particles - the hopping motion of rather large particles due to wind -followed by abrasion of the surface by these saltating particles when they return to the surface. Abrasion can also occur in other ways, for example by driving vehicles, but this should be distinguished from wind-driven saltation.
The driving force is given by the friction velocity u* , which is proportional to the wind speed at a certain height, for example 10 m.
The most accepted formula for the emission by direct action of wind is:

$$Fd = 3.6\ (u^*)\ 3$$

Fd is in $\mu gr/m^2$ s.
(See Loosmore and Hunt, 2000.)
The impression is given that this formula holds for fine particles, with a diameter of less than 5 µm.

Saltation followed by abrasion is studied in detail by Gillette, 1974, 1989.
The current formula is:

$$Fd = 12000\ (u^*)3\ \ (u^* - u^*thr.)$$

u*thr. is a threshold friction velocity as a function of soil type/ soil structure, humidity and vegetative residue- and so is a function of season-, ranging from 0.4 m/s for bare, dry land of a most erodible soil type to 1.6 m/s for range land with least erodible soil type, see Claiborn *et al.*, 1998.
It is suggested that this formula holds for particles with a diameter of less than 10 µm, and that hereof 10% is in the fraction below 5 µm. However, in a more recent study by Claiborn, 2000, it is estimated that of the total PM_{10}, 30% is in the fraction below 2.5 µm.
It should be noted that in this formula the Fd is proportional to the friction velocity to the power 4. The Gillette study in 1974 gives a proportionality to the power 3.

These formulas indicate that only for u* very close to the threshold, emissions by the direct action of the wind have some importance.
For fine particles, below 5 µm, and with 10% in the fraction below 5 µm for saltation-abrasion, and with only 0.1 m/s above the threshold, the emission due to the direct action of the wind is about only 3% of the emission by saltation-abrasion.

It is clear that relative humidity and wetness of the surface will have a large impact on the emissions of windblown dust. During rainy weather, emissions will be zero. Information on the impact of relative humidity is limited (see Loosmore and Hunt, 2000 showing some increase in emissions going from a relative humidity of 60-70% down to 40-50%). It might well be that a threshold relative humidity exists above which emissions go to zero.

A number of studies exist that are not focused on the more agricultural areas as described above, but on deserts and arid regions. An example is the study by Dentener *et al.*, 1996 studying the role of mineral aerosol in the global troposphere. The approach taken by Dentener distinguishes between normal days and days with dust storms and has access to a global land use database. By a statistical approach the concentrations in the air (mass size distribution and number size distribution) are calculated. In this method wind speed effects are only indirectly taken into account.
Park and In, 2003, studied the long range transport of yellow sand over Korea. They use a formula for Fd based on a study by Westphal *et al.*, 1987. The Fd is proportional to u* to the power 4, and is zero below a certain threshold u* c.q. wind speed. The threshold wind speed is a function of the source region (Gobi, sand, loess, mixed soil), and lies between 6 and 9.5 m/s. There is also a threshold relative humidity, depending on the source region, above which there is no emission, relative humidity threshold between 30 (!) and 60%. Finally they use the US Geological Survey satellite data to determine the vegetation coverage and associated dust emission reduction factor (for example 0.5 for grassland, and 0.9 for deciduous forest).

The KNMI-TM 3 global model incorporates the windblown dust method of Marticorena, 1997.

5.4 The land use data bases

The calculated wind blown dust emissions are also dependent on the land use data base. The Corine/Smiatek data base, see Chapter 3, contains the following land cover categories relevant for windblown dust: arable land, pastures and bare soil. As an example, bare soil contains both rocks, and sand dunes close to the coast. Next to the choice of a proper wind blown dust formula, also the proper use of the land use data base is a major uncertainty in treating windblown dust.

5.5 Some remarks

- Windblown dust will be emitted, transported and subsequently deposited somewhere, after which the deposited dust can be emitted again (leap-frog process like for POPs and DDT etc). This is an important process and might lead to double counting. Resuspension from road dust by traffic is an example, the dust on the road will/might contain not only abrasion of tires and brakes, and of the surface, but also deposited windblown dust. Only detailed speciated observations will enable a proper source contribution.
- There might be a minimal fetch of a surface area above which windblown dust is a real emission source, and below it is not. (might this be 1 km?)
- Recently, in CTM's also the approach by Zender, 2003 is used, like in Vautard *et al.*, 2006. The approach has similarities with the approach by Loosmore and Hunt, 2000.
- Dust emissions from the treatment like ploughing in agriculture, are also an important source, and might be more important than the dust emissions by wind from agricultural areas, see www.zalf.de.

5.6 Some conclusions

CTM's should use the Claiborn/Loosmore-Hunt approach, or the approach by Zender. It is recommended that an intercomparison study should be performed to investigate the impact of using different windblown dust models.
It is also recommended to give careful attention to the land use data bases.

6. Conclusions

A coherent and consistent anthropogenic emission data base over Europe on grids of 0.125 x 0.5 lat-long has been made for the year 2000.
An updated land use data base including detailed forest data has been made over Europe on grids of 0.125 x 0.5 lat-long, based on information using grids of 2 x 2 km^2.
At the start of the project a review has been made concerning the treatment of sea salt, and of windblown dust in the models.

References

[1] Builtjes, P.J.H., M. van Loon, M. Schaap, S. Teeuwisse, A.J.H. Visschedijk, J.P. Bloos. Abslussbericht zum FE-Vorhaben 298 41 252: “Modellierung und Prüfung von Strategien zur Verminderung der Belastung durch Ozon” Contribution by TNO. TNO-Rep. R 2003/166, April 2003.

[2] Claiborn, C. *et al.*. Regional measurements and modelling of windblown agricultural dust: The Columbia Plateau PM_{20} Program. J.Geoph. Res. 103, D16, 19753-19767,1998.

[3] Claiborn, C. *et al.*. Windblown dust contribution to high $PM_{2.5}$ concentrations. J Air Waste Manag. Ass 50 (8), 1440-1445, 2000.

[4] Dentener, F. *et al.* Role of mineral aerosol as a reactive surface in the global atmosphere. J.of Geoph. Res 101, dd 17, 22869, 1996.

[5] Gillette, D.A. On the production of soil erosion aerosols having the potential for long range transport. Atm.Res. 8, 735-744, 1974.

[6] Gillette, D.A. and K.J. Hanson. Spatial and temporal variability of dust production caused by wind erosion in the US. J Geoph. Res. 94, 2197-2206, 1989.

[7] Gong, S.L., L.A. Barrie and J.P. Blanchet. Modelling sea-spray aerosols in the atmosphere. Model development. J. Geoph. Res 102, 3805-3818, 1997.

[8] Loosmore, G.A, and J.R. Hunt. Dust resuspension without saltation. J. of Geoph. Res. 105, D16, 20633-20671, 2000.

[9] Marticorena, B. *et al.* Modelling of the atmospheric dust cycle: Simulation of Saharan dust sources. J. Atmos Sci. 45, 2145-2175, 1997.

[10] Möller, D. Luft, 2003.

[11] Monihan, E.C., D.E. Spiel and K.L. Davidson. A model of marine aerosol generation via whitecaps and wave disruption. In Oceanic Whitecaps and their role in air-sea exchange processes. Ed. Monahan. Reidel, Norwall. Mass. 1986.

[12] Park, S.U and H.J. In Long range transport of severe Asian dust (yellow sand) observed in Korea during 21-23 March, 2002. Proc. 26th ITM, Istanbul, Turkey, 2003.

[13] Vautard, R *et al.* On the contribution of natural Aeolian sources to particulate matter concentrations in Europe: testing hypothesis with a modelling approach. Atm. Env 2006.

[14] Vignatti, E, G. de Leeuw and R. Berkowicz. Modelling coastal aerosol transport and effects of surf-produced aerosols on processes in the marine atmospheric boundary layer J.Geoph. Res 106, D 17, 20225-20238, 2001.

[15] Visschedijk, A.J.H. and H.A.C. Denier van der Gon. Gridded European anthropogenic emission data for NO_x, SO_2, NMVOC, NH_3, CO, PM_{10}, $PM_{2.5}$ and CH_4 for the year 2000. TNO-Rep. B&O-A R 2005/106, Oct. 2005.

[16] Visser, *et al.*. Composition and origin of air borne particulate matter in the Netherlands, RIVM-Rep, 2001.

[17] Westphal, D.L, O.B. Toon, T.N. Carlson. A case study of mobilization and transport of Saharan dust. J.Atm. Sci. 45, 2145-2175, 1988.

[18] Zender, C. Bian, H and Newman, D. Mineral dust entrainment and deposition (DEAD) model: description and 1990s dust climatology J.Geoph. Res. 108, D14,4416, 2003.

7. Authentication

Name and address of the principal:

Freie Univ. Berlin, Inst. für Meteorologie

Name and functions of the co-operators:

P.J.H. Builtjes
A. Bleeker (at ECN since Sept. 2004)
H.A.C. Denier van der Gon
M. Schaap
A.J.H. Visschedijk

Names and establishments to which part of the research was put out to contract:

–

Date upon which, or period in which, the research took place:

January 2004 – May 2006

Signature:

Prof. Dr P.J.H. Builtjes
Project Leader

Approved by:

Dr M.P. Keuken
Team Manager