



Energy research Centre of the Netherlands

Dry deposition of acidifying components on forest

Sensitivity study on the influence of detailed tree height data on dry deposition estimates

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Acknowledgement

This study has been performed under contract of Informus GmbH, Berlin. The ECN project number was 8.27607. The work was carried out on request of the German Umwelt Bundes Amt (UBA) in the framework of the GSE-Forest Monitoring program (<http://www.gmes-forest.info/pages/about.htm>).

The joint ESA-EU initiative Global Monitoring of Environment and Security ([GMES](#)) and the EU initiative INfrastructure for SPatial InfoRmation in Europe ([INSPIRE](#)) form the framework for the GSE FM program. The European GMES initiative partly implements its work through GMES Service Elements (GSEs), i.e. user-oriented information systems providing key environmental information to European, national, and local users.

Abstract

In this study we compare the results of a high resolution dry deposition model for Germany using two different land use data sets. The default data set is a combination of the Corine 2000 land use dataset plus inventory based average tree heights per tree class and Bundesland. The alternative is a combination of GSE-FM derived tree species and tree heights with the Corine land use map. The tree height is an important factor in deposition modelling for forested areas as this determines to a large extent the surface resistance to uptake of the pollutants, as rougher surfaces induce higher turbulence and thus cause higher uptake rates.

The use of the high resolution GSE-FM satellite based product allows for a more detailed calculation of the dry deposition rates of acidifying components over Germany. The GSE-FM derived tree height estimates appear more realistic at the 1 by 1 km pixel level, with lower tree heights at forest edges, higher tree coverage in non-forested pixels and areas with variations in heights within the larger forested regions.

The average dry deposition loads over the study area (German Bundesland of Sachsen-Anhalt) go down by about 7%. The reductions are largest for coniferous areas, where the average dry deposition goes down by 16%. Reductions can be much larger for individual 1 by 1 km pixels (up to a factor of two or more), especially on the edges of forested regions, where tree height and cover is generally lower. Only a small amount of pixels show higher total dry deposition rates.

Contents

List of tables	4
List of figures	4
1. Introduction	5
2. Dry deposition theory and outline of the IDEM model	6
2.1 General	6
2.2 Model domain	6
2.3 Modelled components	8
2.4 Meteorological input	9
2.5 Concentration input	9
2.6 IDEM Dry Deposition Module: DEPAC	10
2.6.1 Theory of dry deposition parameterisation	10
2.6.2 Influence of land use classification on dry deposition parameterisation	13
2.6.3 Aerodynamic and Quasi-laminar Boundary Layer Resistances	13
2.6.4 Surface resistance parameterisation for gases	14
2.6.5 Dry deposition of particles	17
3. Results for the Landeskreis Lauenberg 2006 data set	20
4. Results for the Sachsen-Anhalt 2007 dataset	23
5. Conclusions and discussion	30
References	31

List of tables

Table 2.1	IDEM land use types from Corine2000.....	7
Table 2.2	Average tree height per tree type and per Bundesland.....	7
Table 2.3	IDEM required fields in meteorological input.....	9
Table 2.4	Schmidt and Prandtl number correction in equation for R_b (HICKS ET AL., 1987) for different gaseous species, and the diffusion coefficient ratio of water to the pollutant i (PERRY, 1950)	14
Table 2.5	Molecular (for gases) and Brownian (for particles) diffusivities (D ; $\text{cm}^2 \text{s}^{-1}$) for a range of pollutants, and the deduced values of Schmidt number (Sc). The viscosity of air is taken to be $0.15 \text{ cm}^2 \text{s}^{-1}$. From HICKS ET AL. (1987).....	14
Table 2.6	Surface resistance values ($s \text{ m}^{-1}$) for soil surfaces (R_{soil}), snow-covered surfaces (R_{snow}) and water surfaces (R_{wat}). From ERISMAN ET AL. (1994B)	16
Table 2.7	Parameterisations of E values for different components and conditions. From ERISMAN AND DRAAIJERS (1995)	19
Table 4.1	Specification of the GSE-FM data product.....	23
Table 4.2	Percentage forested land cover in old dominant land cover classes of $1 \times 1 \text{ km}$ pixels according to the new data product for Sachsen-Anhalt	24
Table 4.3	Average potential acid dry deposition flux [$\text{eq}/(\text{ha} \cdot \text{yr})$] in 2004 as a function of land use class for Sachsen-Anhalt in 2004, when calculated with the IDEM model using either Corine land use data or the GSE-FM high resolution product.....	26

List of figures

Figure 2.1	Outline of the EMEP and IDEM model (from BLEEKER ET AL. 2000, modified	6
Figure 2.2	Dominant land use categories on the $1 \times 1 \text{ km}^2$ grid over Germany (source: CORINE LAND COVER)	8
Figure 2.3	Resistance analogy approach in dry deposition models	15
Figure 3.1	The ratio of the fraction of landcover with deciduous forest with the GSE-FM product and Corine 2000 for Landeskreis Lauenburg	20
Figure 3.2	Tree height [m] for deciduous trees in Landeskreis Lauenburg according to the inventory data+Corine 2000 (top) and according to the high resolution GSE-FM product (bottom)	21
Figure 3.3	Comparison of calculated potential dry acid deposition for the year of 2002 in Landeskreis Lauenburg when applying the two tree height products	22
Figure 4.1	Comparison of $1 \times 1 \text{ km}$ pixels containing 1% forest or more for the Corine-2000 land use map (left) and the GSE-FM product (right)	24
Figure 4.2	Comparison of percentage land cover by forest between Corine 2000 (left) and the GSE-FM product (right)	25
Figure 4.3	Comparison of the average calculated tree height (decimeter) for the Corine 2000 based method (left) and the GSE-FM product (right).....	25
Figure 4.4	Comparison of the 2004 total potential dry deposition flux of acidifying components in $\text{mol}/\text{ha}/\text{yr}$ when using the Corine-2000 derived surface parameters (left) and when using the GSE-FM based parameters (right)	26
Figure 4.5	Relative dry deposition flux of potential acid when comparing Corine-2000 based land use and forest data with GSE-FM derived data	28
Figure 4.6	Comparison between the histograms of the dry deposition rates calculated using the Corine and the GSE-FM derived land use data	29

1. Introduction

In this study we compare the results of a high resolution dry deposition model for Germany using two different land use data sets. The default data set is a combination of the Corine 2000 land use dataset plus inventory based average tree heights per tree class and Bundesland. The alternative is a combination of GSE-FM derived tree species and tree heights with the Corine land use map. The tree height is an important factor in deposition modelling for forested areas as this determines to a large extent the surface resistance to uptake of the pollutants, as rougher surfaces induce higher turbulence and thus cause higher uptake rates.

Accurate estimates of the mean tree height as a function of location is therefore an important factor in describing the correct dry deposition flux to those pixels that are dominated by forest land cover. For Bundesländer with a high percentage of forest land cover the total dry deposition rate may also be influenced by the values for the tree heights.

The dry deposition model employed is the IDEM model, described in more detail in Chapter 2. It is used in other projects to calculate the dry and wet deposition of acidifying compounds for Germany on a grid resolution of 1 by 1 km, taking into account the temporal changes (3 hourly) in meteorology and air pollutant concentrations as well as the spatial variation in land cover. Currently the main use of the data is the calculation of the exceedance of critical loads for sensitive ecosystems. Forest ecosystems are among the important ecosystems that are considered in these critical load assessments.

In Chapter 3 we present the results of a preliminary dataset for a limited area that was developed as a first test set for the approach. In Chapter 4 we present the results for a larger dataset that covers the Bundesland of Sachsen-Anhalt. In Chapter 5 we present the conclusions drawn from both results.

2. Dry deposition theory and outline of the IDEM model

2.1 General

The dry deposition of the components considered in this project is calculated by a model called the Integrated Deposition Model (IDEM), using the so called dry deposition inference method (ERISMAN, 1992; ERISMAN & BALDOCCHI, 1994; VAN PUL ET AL, 1992, 1995). The IDEM model integrates the retrieval of spatial data concerning land use etc., and time dependent data like meteorological and concentration data with the deposition calculations. The method uses high resolution meteorological and modelled concentration data, and up to date land-use map based on the CORINE-2000 data. The outline of the IDEM model is presented in Figure 2.1.

Dry deposition fluxes are calculated in IDEM by calculation of dry deposition velocities and applying these on modelled concentrations for the same height. In the inference method it is assumed that a constant flux layer exists between a reference height and the surface. To fulfil this condition the air and the surface layer need to be in equilibrium, with no chemical reactions taking place in the surface layer and no advection. Only then the deposition flux at the reference height is equal to that at the surface. The reference height has to be chosen so that it lies within the surface layer and that the concentration at that height is not severely influenced by local deposition, so that using concentration data from a relatively coarse resolution model or measurement network is allowed. In IDEM the reference height is taken at 50m above ground level (ERISMAN, 1992).

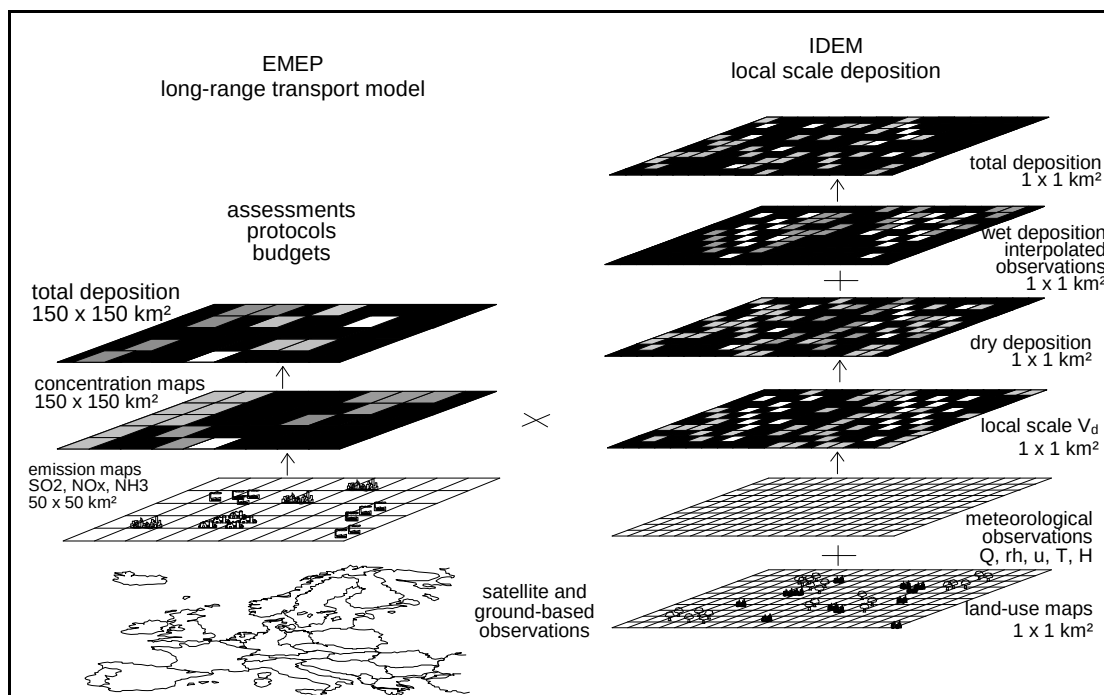


Figure 2.1 Outline of the EMEP and IDEM model (from BLEEKER ET AL. 2000, modified)

2.2 Model domain

The IDEM model domain for the calculations described in this report was a 1x1km² grid covering Germany. The grid consists of 750 data points in West-East direction and 1000 data points in North-South direction. IDEM was provided with land use data and data describing the

German Federate State ('Bundesland') for each pixel. Table 2.1 shows the updated land-use classification based on the CORINE-2000 dataset, using 9 different land-use classes. Furthermore in this version of IDEM the land-use classification is given as a percentage for each of the 9 new land-use classes per 1x1 km grid cell. The resulting roughness length (z_0) of each 1x1 km grid cell is calculated as the logarithmic weighted average of the corresponding z_0 's per land use class. Dry deposition fluxes and velocities are calculated for each grid cell for each land use class separately (using the grid cell average roughness length) and afterwards the weighted average flux per cell is calculated and taken as the average flux for that grid cell.

The regional average tree heights ('TH') used to calculate roughness lengths of forests is listed in Table 2.2.

Table 2.1 IDEM land use types from Corine2000.

Land use type	Roughness length (m)		Canopy height (m)
	summer	winter	
Arable (agriculture)	0.1	0.05	0.5
Coniferous forest	0.085 x TH*		see Table 5.2
Deciduous forest	0.06 x TH*	0.09 x TH*	see Table 5.2
Mixed forest	0.085 x TH*		see Table 5.2
Pasture	0.05	0.03	n.a.
Semi-natural	0.1		n.a.
Water	0.0002		n.a.
Urban	1.0		n.a.
Other	0.01		n.a.

* TH = Tree Height (m); n.a. = not applicable

Table 2.2 Average tree height per tree type and per Bundesland

Bundesland	Deciduous	Coniferous	Mixed
Brandenburg	19.3	14.6	15.3
Mecklenburg-Vorpommern	21.0	16.8	18.4
Sachsen	17.1	15.2	15.6
Sachsen-Anhalt	19.6	15.2	16.6
Thuringen	21.1	16.4	17.9
Schleswig-Holstein	19.3	16.4	18.0
Niedersachsen	17.7	14.8	15.9
Saarland	17.8	17.8	17.7
Rheinland-Pfalz	18.6	18.4	18.5
Hessen	21.8	19.8	20.8
Baden-Wurtemberg	21.6	22.1	21.7
Bayern	18.2	21.0	20.2
Nordrhein-Westphalen	18.7	17.4	18.1
Germany average	19.4	17.4	18.0

In Figure 2.2 the dominant land use categories following the Corine2000 classification scheme on the 1x1km² grid over Germany are shown.

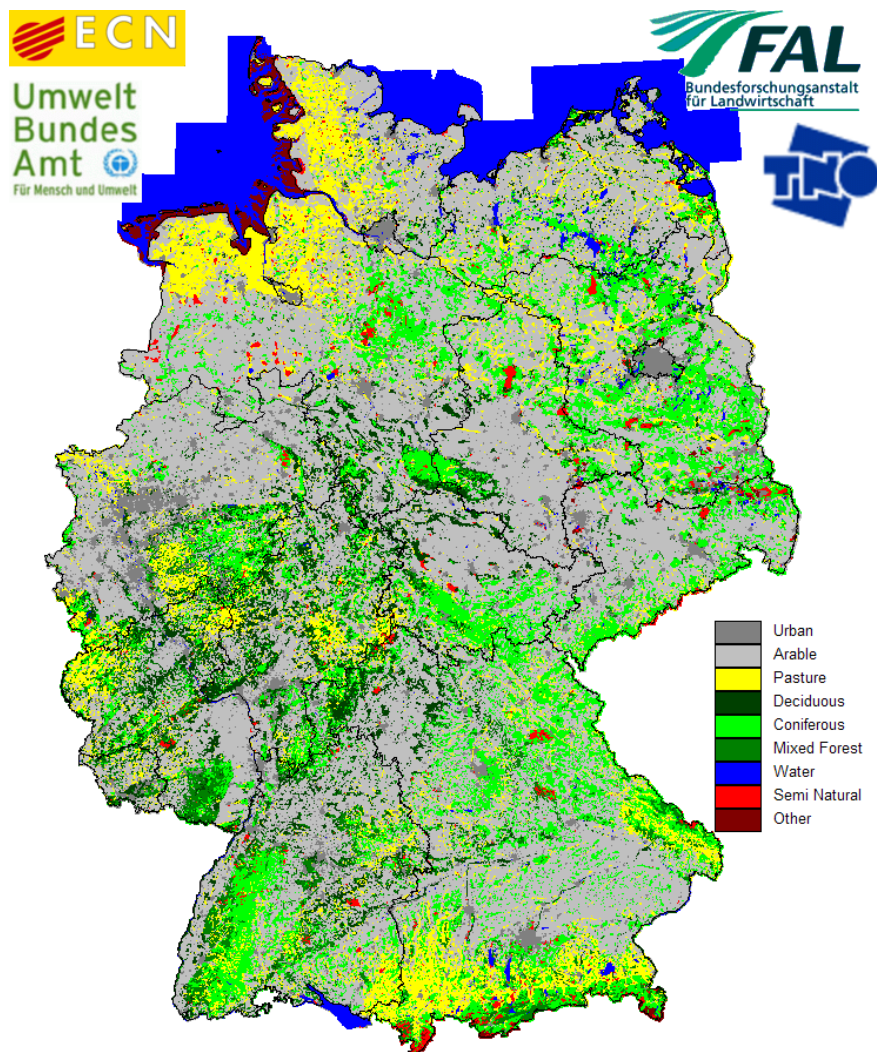


Figure 2.2 Dominant land use categories on the 1x1km² grid over Germany (source: CORINE LAND COVER)

2.3 Modelled components

In IDEM the dry deposition velocities are calculated for the following components:

- Ammonia; NH₃
- Ammonium; NH₄
- Sulphur dioxide; SO₂
- Sulphate (aerosol); SO₄
- Nitrogen monoxide; NO
- Nitrogen dioxide; NO₂
- Nitric Acid; HNO₃
- Nitrate aerosol; NO₃
- Base Cations; Na, Mg, Ca, K

The following definitions are used for certain groups of components:

- **NO_y** = NO+NO₂+HNO₃+NO₃
- **NH_x** = NH₃+NH₄
- **SO_x** = SO₂+SO₄
- **Total Acid** = NO_y+NH_x+SO_x
- **BC** = Ca+K+Mg

2.4 Meteorological input

IDEM requires detailed meteorological input data. In the calculations described in this report, data was used from the ECMWF MARS (European Centre for Medium-Range Weather Forecasts Meteorological Archival Retrieval System) [<http://www.ecmwf.int/>] database. For the period of calculations in this study (2004) the re-analysed data is not yet available, so the standard analysed fields from the MARS database were used. The resolution of the data used is 0.5 by 0.5 degree longitude and latitude. The time interval between the records is six hours. The data is stored in so called GRIB (GRid In Binary format) files. IDEM accesses these GRIB files directly using text index files to locate the requested data in the compressed binary GRIB data files. The de-assimilation of assimilated analysed data in the ECMWF databases is carried out by slightly modified software provided by Paul James [http://www.forst.tu-muenchen.de/EXT/LST/METEO/stohl/flextra/ecmwf_extr.html]. The data fields required by IDEM are listed in Table 2.3.

Table 2.3 *IDEM required fields in meteorological input*

Abbreviation	Description	Abbreviation	Description
WU	Wind speed in EW direction at 10 m	LSP	Large scale precipitation
WV	Wind speed in NS direction at 10 m	SD	Snow depth
MSL	Atmospheric pressure at surface level	GLRad	Global radiation
T2	Temperature at 2 m height	TCC	Total Cloud Cover
HF	Sensible Heat flux	SSWE	Surface stress in WE direction
TS	Soil temperature	SSNS	Surface stress in NS direction
CVP	Convective precipitation		

Atmospheric stability is determined by mechanically induced turbulence caused by the friction of wind at the surface and thermally induced turbulence caused by cooling or heating of the surface by exchange of long wave (infrared) radiation. The thermal turbulence is expressed as a function of the sensible heat flux (HF), the mechanical turbulence is expressed as a function of the friction velocity (u_*). It is possible to derive the atmospheric stability from the ECMWF input, as this contains values for both Sensible Heat flux and friction velocity (through SSWE, SSNS; cf. Table 2.3). The values obtained are, however, values that are representative for the 0.5 by 0.5 degree grid cell. In IDEM we derive from wind speed, cloud cover, radiation and local surface roughness a localised version of the energy balance on the 1x1km² grid and use this in the dry deposition calculation scheme. The surface energy budget scheme from BELJAARS & HOLTSLAG (1990) is used in an optimised version. This leads to a presumably much higher accuracy then using the ECMWF values.

The IDEM model interpolates all meteorological data to the 1x1km² grid using weighted distance averaging. This avoids visual block effects in some of the calculated data when sharp gradients in for example wind speed exist between 0.5x0.5 degree meteorological grid data cells.

2.5 Concentration input

The model can use concentration data in the latitude-longitude projection as well as in the EMEP projection. For the year 2004 the concentration data was obtained from the TNO LOTOS/EUROS Eulerian transport model, the data is provided by TNO used has a resolution of 0.5x0.25 degree horizontal and 3 hours time resolution. Internally IDEM interpolates the data to the 1x1 km resolution using inverse distance weighted averaging.

Also the concentration data can be and is for the calculations in this report interpolated to the 1x1km² grid using weighted distance averaging. The concentration data is used by IDEM in the same native binary format in which the input files were provided by TNO.

2.6 IDEM Dry Deposition Module: DEPAC

The approach followed in this project for estimating dry deposition velocity involves using larger scale atmospheric models and gridded fields of surface meteorological data to produce a regular grid of deposition velocity values.

Air quality models used to study acid deposition and photochemical oxidants contain modules to estimate dry deposition velocities. WESELY (1989) and WALMSLEY & WESELY (1996) described the model used within RADM (Regional Acid Deposition Model; CHANG ET AL., 1987), PADRO ET AL. (1991) evaluated the model included in ADOM (Acid Deposition and Oxidant Model; PLEIM ET AL., 1984; VENKATRAM ET AL., 1988) and VOLDNER ET AL. (1986) developed a dry deposition parameterisation for use in the Canadian Lagrangian acid deposition model. The ADOM and RADM dry deposition modules have appeared in several applications. For example, the RADM module has been adapted for the California Institute of Technology photochemistry airshed model (HARLEY ET AL., 1993), the Urban Airshed Model (UAM; SAI, 1996), studies involving the California Ozone Deposition Experiment (CODE; MASSMAN ET AL., 1994; PEDERSON ET AL., 1995), the Global Chemistry Model (GChM; LEUCKEN ET AL., 1991; BENKOVITZ ET AL., 1994), and EUropean Air Pollution Dispersion model system in western Europe (EURAD; HASS ET AL., 1995). The ADOM module has, for example, been used in the CALGRID photochemical oxidant model (YAMARTINO ET AL., 1992).

Several models have been developed in Europe. VAN PUL ET AL. (1995) described a model, EDACS (European Deposition of Acidifying Components on Small scale), that has been developed for routine estimates of dry deposition across a regular grid covering Europe. Meteorological inputs for this model are derived through interpolation of surface meteorological observations and land-use data that are provided on a 10x20km² grid. This work represents the first attempt to apply a model for routine estimation of spatially (1/6°x1/6°) and temporally (6h) resolved dry deposition that is suitable for combination with wet deposition measurements for determination of annual total deposition. EDACS and the Dutch Empirical Acid Deposition Model (DEADM) have been used with long-range modules to map modelled deposition amounts for sulphur and nitrogen compounds (e.g., ERISMAN & DRAAIJERS, 1995). Concern over the accuracy of estimates of particulate deposition have led to several experimental efforts (e.g., ERISMAN ET AL., 1997). In addition, dry deposition routines for general circulation models coupled with chemistry modules have been carried out for the European Centre Hamburg Model (ECHAM; GANZEVELD & LELIEVELD, 1995).

In areas that contain sharp contrasts in surface characteristics, edge effects, and hilly terrain, the assumptions inherent in the micrometeorological formulations that are commonly used in large-scale and site-specific models are questionable. In mountainous terrain or where patchy forest conditions exist, the approach of measuring the amounts and chemical composition of throughfall and stemflow in forests at specific sites is considered more reliable for some substances, especially sulphur, than the micrometeorological methods (DRAAIJERS ET AL., 1994; LOVETT, 1994; VELTKAMP & WYERS, 1997).

2.6.1 Theory of dry deposition parameterisation

Several articles have reviewed the state of the science in evaluating dry deposition (BALDOCCHI, 1993; ERISMAN ET AL., 1994B; ERISMAN & DRAAIJERS, 1995; RUIJGROK ET AL., 1995; WESELY & HICKS, 2000). WESELY AND HICKS (2000) indicated that although models have been improving and can perform well at specific sites under certain conditions, there remain many

problems and more research is needed. In spite of these problems, given the necessary meteorological and surface/vegetative data, there are a number of models for estimating deposition velocity (V_d) that have been shown to produce reasonable results using currently available information.

Dry deposition processes for gaseous species are generally understood better than for particles. Several dry deposition model formulations have been reported in the literature. These include big-leaf models (HICKS ET AL., 1987; BALDOCCHI ET AL., 1987), multi-layer models (BALDOCCHI, 1988; MEYERS ET AL., 1998) and general dry deposition models (ERISMAN ET AL., 1996). Some of these models have been developed for estimating V_d at specific sites and are used within the framework of monitoring networks (CLARKE ET AL., 1997; MEYERS ET AL., 1991).

Computation of the dry deposition rate of a chemical species requires that the concentration c of the substance of interest is known through model computations or measurement. In most modelling schemes, the mass flux density F is found as

$$F = -V_d(z) \cdot c(z) \quad (2.1)$$

where $c(z)$ is the concentration at height z and V_d is the dry deposition velocity. Estimates of deposition velocities V_d constitute the primary output of dry deposition models, both for large-scale models and site-specific methods of inferring dry deposition from local observations of concentrations, meteorological conditions, and surface conditions (CHANG ET AL., 1987; VENKATRAM ET AL., 1988; MEYERS ET AL., 1991; GANZEVELD AND LELIEVELD, 1995). z is the reference height above the surface. If the surface is covered with vegetation, a zero-plane displacement is included: $z = z - d$. d is usually taken as 0.6-0.8 times the vegetation height (THOM, 1975). The absorbing surface is often assumed to have zero surface concentration and the flux is therefore viewed as being linearly dependent on atmospheric concentration. This holds only for depositing gases and not for gases that might be also emitted, such as NH_3 and NO . For these gases a nonzero surface concentration, a compensation point c_p , might exist, which can be higher than the ambient concentration, in which case the gas is emitted. For these gases the flux is estimated as

$$F = -V_d(z) \cdot [c(z) - c_p] \quad (2.2)$$

V_d provides a measure of conductivity of the atmosphere-surface combination for the gas and it is widely used to parameterise gas uptake at the ground surface (WESELY & HICKS 1977; HICKS ET AL., 1989; FOWLER ET AL., 1989). To describe the exchange of a range of gases and particles with very different chemical and physical properties, a common framework is provided, the resistance analogy (THOM, 1975; GARLAND, 1977; WESELY & HICKS, 1977; FOWLER, 1978; BALDOCCHI ET AL., 1987). In this framework, V_d is calculated as the inverse of three resistances:

$$V_d(z) = \frac{1}{R_a + R_b + R_c} \quad (2.3)$$

The three resistances represent bulk properties of the lower atmosphere or surface. R_a , R_b and R_c must be described by parameterisations. Although this approach is practical, it can lead to oversimplification of the physical, chemical, and biological properties of the atmosphere or surface that affect deposition.

The term R_a represents the aerodynamic resistance above the surface for the turbulent layer. R_a is governed by micrometeorological parameters and has the same value for all substances. R_a

depends mainly on the local atmospheric turbulence intensities. Turbulence may be generated through mechanical forces of friction with the underlying surface (forced convection) or through surface heating (buoyancy or free convection). Unless wind speed is very low, free convection is small compared to mechanical turbulence.

The term R_b represents the quasi-laminar resistance to transport through the thin layer of air in contact with surface elements, and is governed by diffusivity of the gaseous species and air viscosity. For surfaces with bluff roughness elements, values of R_b are considerably larger than for relatively permeable surfaces like a uniform vegetative cover, and the appropriate formulations should be used (TUOVINEN ET AL., 1998).

Considerable variation from model to model is associated with the methods used to evaluate the surface or canopy resistance R_c for the receptor itself. R_c represents the capacity for a surface to act as a sink for a particular pollutant, and depends on the primary pathways for uptake such as diffusion through leaf stomata, uptake by the leaf cuticular membrane, and deposition to the soil surface. This makes R_c complicated, because it depends on the nature of the surface and how the sink capacities for specific surfaces vary as a function of the local microclimate.

The resistance analogy is not used for particles. For sub-micron particles, the transport through the boundary layer is more or less the same as for gases. However, transport of particles through the quasi-laminar layer can differ. Whereas gases are transported primarily through molecular diffusion, particle transport and deposition basically take place through sedimentation, interception, impaction and/or Brownian diffusion. Sedimentation under the influence of gravity is especially significant for receptor surfaces with horizontally oriented components. Interception occurs if particles moving in the mean air motion pass sufficiently close to an obstacle to collide with it. Like interception, impaction occurs when there are changes in the direction of airflow, but unlike interception a particle subject to impaction leaves the air streamline and crosses the laminar boundary layer with inertial energy imparted from the mean airflow. The driving force for Brownian diffusion transport is the random thermal energy of molecules. Transport is a function of atmospheric conditions, characteristics of the depositing contaminant and the magnitude of the concentration gradient over the quasi-laminar layer (DAVIDSON AND WU, 1990).

Which type of transport process dominates is largely controlled by the size distribution of the particles (SEHMEL, 1980; SLINN, 1982). For particles with a diameter $<0.1\mu\text{m}$, deposition is controlled by diffusion, whereas deposition of particles with a diameter $>10\mu\text{m}$ is more controlled by sedimentation. Deposition of particles with a diameter between 0.1 and $1\mu\text{m}$ is determined by the rates of impaction and interception and depends heavily on the turbulence intensity. To describe particle dry deposition, the terms $(R_b+R_c)^{-1}$ on the right-hand side of Equation (2.3) must be replaced with a surface deposition velocity or conductance, and gravitational settings must be handled properly.

Dry deposition models or modules require several types of inputs from observations or from simulations of atmospheric chemistry, meteorology, and surface conditions. To compute fluxes, the concentrations of the substances must be known. Inputs required from meteorological models are values of friction velocity (u^*), atmospheric stability (Monin-Obukhov length scale L), aerodynamic surface roughness (z_0), and aerodynamic displacement height (d). Most dry deposition models also need solar radiation or, preferably, photosynthetically active radiation; ambient air temperature at a specified height; and measures of surface wetness caused by rain and dewfall. All models require a description of surface conditions, but the level of detail depends on the model chosen. Descriptions could include broad land use categories, plant species, leaf area index (LAI), greenness as indicated by the normalised difference vegetation index, various measures of plant structure, amount of bare soil exposed, and soil pH.

2.6.2 Influence of land use classification on dry deposition parameterisation

The deposition velocity for each chemical species can differ by close to an order of magnitude between some land use classes. During daytime SO₂ and O₃ have higher deposition velocities over surface types or canopy types with large leaf area indices (LAIs) due to uptake through the leaf stomata. This uptake is greater in summer or the growing season compared to autumn. The effect of canopy wetness on dry deposition velocities can be significant. Surface roughness also has an important role due to its influence on aerodynamic resistance. This is particularly noticeable for HNO₃ and SO₄²⁻, for which stomatal opening and closing is not important.

2.6.3 Aerodynamic and Quasi-laminar Boundary Layer Resistances

The atmospheric resistance to transport of gases across the constant flux layer is assumed to be similar to that of heat (e.g., HICKS ET AL., 1989). R_a is approximated following the procedures used by GARLAND (1978):

$$R_a(z-d) = \frac{1}{\kappa \cdot u^*} \cdot \left[\ln\left(\frac{z-d}{z_o}\right) - \psi_h\left(\frac{z-d}{L}\right) + \psi_h\left(\frac{z_o}{L}\right) \right] \quad (2.4)$$

in which κ is the Von Karman constant (0.4), u^* is the friction velocity (calculated from the output of the meteorological model), L is the Monin-Obukhov length, d is the displacement height. z_o is the roughness length, which is defined independently for each land use and season category.

The function ψ_h is the integrated stability function for heat. This function can be calculated using procedures described in BELJAARS AND HOLTSLAG (1990). Under the same meteorological conditions, the aerodynamic resistance is the same for all gases and in fact also for aerosols. Only for aerosols with a radius > 5µm does the additional contribution of gravitational settling become significant. When the wind speed increases, the turbulence usually increases as well and consequently R_a becomes smaller.

The second atmospheric resistance component R_b is associated with transfer through the quasi-laminar layer in contact with the surface. The transport through the laminar boundary layer takes place for gases by molecular diffusion and for particles by several processes: Brownian diffusion, interception, impaction and by transport under influence of gravitation. None of the processes for particles are as efficient as the molecular diffusion of gas molecules. This is because molecules are much smaller than aerosols and therefore have much higher velocities. For particles with radii < 0.1µm Brownian diffusion is the most efficient process, whereas impaction and interception are relatively important for those with radii > 1µm. For particles with radii between 0.1 and 1µm the transport through the laminar boundary layer is the least efficient (R_b is largest). The laminar boundary layer resistance for most surface types is more or less constant (forest, at sea for a wind speed < 3m/s) or decreases with wind speed (low vegetation).

The quasi-laminar resistance R_b quantifies the way in which pollutant or heat transfer differs from momentum transfer in the immediate vicinity of the surface. The resistance R_b can be approximated by the procedure presented by HICKS ET AL. (1987):

$$R_b = \frac{2}{\kappa \cdot u_*} \cdot \left(\frac{Sc}{Pr} \right)^{2/3} \quad (2.5)$$

where Sc and Pr are the Schmidt and Prandtl number, respectively. Pr is 0.72 and Sc is defined as $Sc = \nu / D_i$, with ν being the kinematic viscosity of air (0.15 cm² s⁻¹) and D_i the molecular diffusivity of pollutant i and thus component specific. The Schmidt and Prandtl number correction in the equation for R_b is listed in Table 2.4 for different gases. Molecular and Brownian diffusivities for a selected range of pollutants, and the deduced values of Schmidt

number are listed in Table 2.5. Usually R_b values are smaller than R_a and R_c . Over very rough surfaces such as forest canopies, however, R_a may approach small values and the accuracy of the R_b estimate becomes important. This is especially the case for trace gases with a small or zero surface resistance.

Table 2.4 *Schmidt and Prandtl number correction in equation for R_b (HICKS ET AL., 1987) for different gaseous species, and the diffusion coefficient ratio of water to the pollutant i (PERRY, 1950)*

Component	$D_{H_2O}^* / D_i$	$(Sc/Pr)^{2/3}$
SO ₂	1.9	1.34
NO	1.5	1.14
NO ₂	1.6	1.19
NH ₃	1	0.87
HNO ₂	1.7	1.24
HNO ₃	1.9	1.34
HCl	1.5	1.14
PAN	2.8	1.73
H ₂ O	1	0.87
O ₃	1.5	1.14

* $D_{H_2O} = 2.27 \cdot 10^{-5} m^2 s^{-1}$

Table 2.5 *Molecular (for gases) and Brownian (for particles) diffusivities (D ; $cm^2 s^{-1}$) for a range of pollutants, and the deduced values of Schmidt number (Sc). The viscosity of air is taken to be $0.15 cm^2 s^{-1}$. From HICKS ET AL. (1987)*

Component	D	Sc
Gaseous species		
H ₂	0.67	0.22
H ₂ O	0.22	0.68
O ₂	0.17	0.88
CO ₂	0.14	1.07
NO ₂	0.14	1.07
O ₃	0.14	1.07
HNO ₃	0.12	1.25
SO ₂	0.12	1.25
Particles (unit density)		
0.001 μm radius	$1.28 \cdot 10^{-2}$	$1.17 \cdot 10^1$
0.01	$1.35 \cdot 10^{-4}$	$1.11 \cdot 10^3$
0.1	$2.21 \cdot 10^{-6}$	$6.79 \cdot 10^4$
1	$1.27 \cdot 10^{-7}$	$1.18 \cdot 10^6$
10	$1.38 \cdot 10^{-8}$	10^7

2.6.4 Surface resistance parameterisation for gases

The surface or canopy resistance R_c is the most difficult of the three resistances to describe, and is often the controlling resistance of deposition flux. The analytical description of R_c has been difficult since it involves physical, chemical and biological interaction of the pollutant with the deposition surface. Over a given area of land, numerous plant, soil, water, and other material surfaces are present, each with a characteristic resistance to uptake of a given pollutant.

R_c values presented in the literature are primarily based on measurements of V_d and on chamber studies. By determining R_a and R_b from the meteorological measurements, R_c can be calculated as the residual resistance. Values of R_c can then be related to surface conditions, time of day,

etc., yielding parameterisations. However, measurements using existing techniques are still neither accurate nor complete enough to obtain R_c values under most conditions. Furthermore, R_c is specific for a given combination of pollutants, type of vegetation and surface conditions, and measurements are available only for a limited number of combinations.

The surface resistance of gases consists of other resistances (Figure 2.3), either determined by the actual state of the receptor, or by a memory effect. R_c is a function of the canopy stomatal resistance R_{stom} and mesophyll resistance R_m ; the canopy cuticle or external leaf resistance R_{cut} ; the soil resistance R_{soil} and in-canopy resistance R_{inc} , and the resistance to surface waters or moorland pools R_{wat} . In turn, these resistances are affected by leaf area, stomatal physiology, soil and external leaf surface pH, and presence and chemistry of liquid drops and films. Based on values from the literature for the stomatal resistance (WESELY, 1989), and on estimated values for wet (due to rain and to an increase in relative humidity) and snow-covered surfaces, the following parameterisation (with the stomatal resistance, external leaf surface resistance and soil resistance acting in parallel) can be applied for routinely measured components (ERISMAN ET AL., 1994b):

vegetative surface:

$$R_c = \left[\frac{1}{R_{stom} + R_m} + \frac{1}{R_{inc} + R_{soil}} + \frac{1}{R_{ext}} \right]^{-1} \quad (2.6)$$

water surfaces:

$$R_c = R_{wat} \quad (2.7)$$

bare soil:

$$R_c = R_{soil} \quad (2.8)$$

snow cover:

$$R_c = R_{snow} \quad (2.9)$$

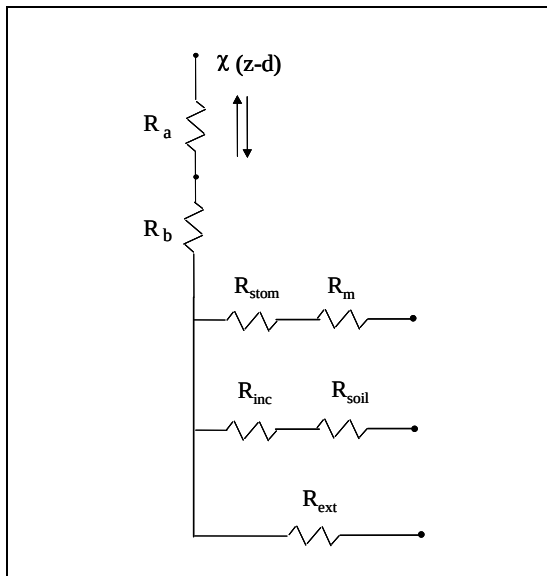


Figure 2.3 Resistance analogy approach in dry deposition models

Table 2.6 shows some surface resistance values for soil surfaces (R_{soil}), snow-covered surfaces (R_{snow}) and water surfaces (R_{wat}).

Table 2.6 *Surface resistance values ($s\ m^{-1}$) for soil surfaces (R_{soil}), snow-covered surfaces (R_{snow}) and water surfaces (R_{wat}). From ERISMAN ET AL. (1994B)*

Gas	Soil surfaces, R_{soil}		Water surfaces, R_{wat}	Soil or water pH	Snow-covered surfaces R_{snow}	Temperature ($^{\circ}C$)
	Wet	Dry				
SO ₂ and	0	1000	0	>4	70 (2-T)	-1<T<1
HNO ₂	500	R _{ext}	500	<4	500	T<-1
	250	Emission: 500		>8	70 (2-T)	-1<T<1
NH ₃	0	50	500	<8	500	T<-1
	emission: 1000	emission:		----	2000	----
NO	2000	1000	0	----	2000	----
NO ₂ and PAN		1000	2000	>2	0	T>-5
HNO ₃ and		0	2000		100	T<-5
HCl	500		0	----	2000	----
O ₃		100	2000			

It is not clear whether R_m is relevant at ambient concentrations (ERISMAN ET AL., 1994b). Therefore, they consider the sum of R_{stom} and R_m to be a new resistance R_{st} , a stomatally controlled resistance which would equal the true stomatal resistance R_{stom} if $R_m=0$. Similarly, they defined a new resistance $R_{fs}=R_{inc}+R_{soil}$, a non-stomatal resistance to express that the uptake could be either direct foliage uptake or soil uptake. Thus, Equation (2.6) reduces to

$$R_c = \frac{R_{st} \cdot R_{fs}}{R_{st} + R_{fs}} \quad (2.10)$$

Combining equations (2.3) and (2.10) yields

$$\frac{1}{V_d} = R_a + R_b + \frac{R_{st} \cdot R_{fs}}{R_{st} + R_{fs}} \quad (2.11)$$

for daytime situations. During the night, when stomata are closed, $R_{st}=\infty$ is assumed and Equation (2.11) can be reduced to

$$\frac{1}{V_d} = R_a + R_b + R_{fs} \quad (2.12)$$

R_{cut} denotes local leaf cuticular resistance. In BROOK ET AL. (1999):

$$R_{cut}(SO_2) = R_{cut}(LUC, season); \quad (2.13)$$

$$R_{cut}(HNO_3) = 20\ sm^{-1}. \quad (2.14)$$

Here LUC denotes land use class. Under wet surface conditions after rainfall or dew R_{cut} is replaced by R_{wcut} , which denotes wet cuticle resistance. For SO₂, under wet/dew conditions it is assumed a constant value of 50 sm^{-1} for both dew-covered and rainfall conditions:

$$R_{wcut}(SO_2) = 50\ sm^{-1} \quad (2.15)$$

HNO₃ uptake is rapid and taken as a constant, regardless of wetness.

R_g denotes ground surface resistance, which varies depending upon whether the surface is soil, water or snow/ice and whether it is wet or dry.

$$R_g(\text{SO}_2) = 100 \text{ sm}^{-1} \quad (2.16)$$

$$R_g(\text{HNO}_3) = 20 \text{ sm}^{-1} \quad (2.17)$$

For all surface conditions (dry, wet or snow) a small value of 20 sm^{-1} is used for the ground resistance of HNO_3 . For wet soil, a constant value of 100 sm^{-1} is used for SO_2 . There is little information available for resistance over snow or ice surfaces. From the limited amount of data available (see BROOK ET AL., 1999) a value of 200 s m^{-1} is set for $R_g(\text{SO}_2)$ for snow covered surfaces:

$$R_g(\text{SO}_2) = 200 \text{ sm}^{-1} \quad (2.18)$$

2.6.5 Dry deposition of particles

The process of dry deposition of particles differs from that of gases in two respects:

- *Deposition depends on particle size since transfer to the surface involves Brownian diffusion, inertial impaction/interception and sedimentation (all of which are a strong function of particle size).*
- *Presumably the surface resistance for particles less than $10\mu\text{m}$ diameter (HICKS & GARLAND, 1983) is negligible small to all surfaces.*

For submicron particles, the transport through the boundary layer is more or less the same as for gases. However, transport of particles through the quasi-laminar layer can differ. For particles with a diameter $<0.1\mu\text{m}$, deposition is controlled by diffusion, whereas deposition of particles with a diameter $>10\mu\text{m}$ is more controlled by sedimentation. Deposition of particles with a diameter between 0.1 and $1\mu\text{m}$ is determined by the rates of impaction and interception and depends heavily on the turbulence density.

RUIJGROK ET AL. (1997) proposed another parameterisation derived from measurements over a coniferous forest. In this approach, which is simplified from SLINN's (1982) model, V_d is not only a function of u_* , but also of relative humidity (rh) and surface wetness. Inclusion of rh allows to account for particle growth under humid conditions and for reduced particle bounce when the canopy is wet. Dry deposition velocity is expressed as:

$$\frac{1}{V_d} = R_a + \frac{1}{V_{ds}} \quad (2.19)$$

where R_a is the aerodynamic resistance, which is the same as for gaseous species, and V_{ds} is the surface deposition velocity.

For tall canopies V_{ds} is parameterised by RUIJGROK ET AL. (1997) as

$$V_{ds} = E \cdot \frac{u_*^2}{u_h} \quad (2.20)$$

where u_h is the wind speed at the top of the canopy, which is obtained by extrapolating the logarithmic wind profile from reference height z to the canopy height h . u_h can be expressed as:

$$u_h = \frac{u_*}{k} \left(\ln \left(\frac{10 \cdot z_0 - d}{z_0} \right) - \psi_h \left(\frac{10 \cdot z_0 - d}{L} \right) + \psi_h \left(\frac{z_0}{L} \right) \right) \quad (2.21)$$

E is the total efficiency for canopy capture of particles, and is parameterised separately for dry and wet surfaces (RUIJGROK ET AL., 1997).

For dry surfaces, for SO_4^{2-} particles (BROOK ET AL., 1999):

$$E = \begin{cases} 0.005 u_*^{0.28} & \text{rh} \leq 80\% \\ 0.005 u_*^{0.28} \cdot \left[1 + 0.18 \cdot \exp \frac{\text{rh} - 80}{20} \right] & \text{rh} > 80\% \end{cases} \quad (2.22)$$

For wet surfaces, for SO_4^{2-} particles (BROOK ET AL., 1999):

$$E = \begin{cases} 0.08 u_*^{0.45} & \text{rh} \leq 80\% \\ 0.08 u_*^{0.45} \cdot \left[1 + 0.37 \cdot \exp \frac{\text{rh} - 80}{20} \right] & \text{rh} > 80\% \end{cases} \quad (2.23)$$

rh (relative humidity) is taken at the reference height.

ERISMAN AND DRAAIJERS (1995) used the following general form for the calculation of V_d :

$$V_d = \frac{1}{R_a + \frac{1}{V_{ds}}} + V_s \quad (2.24)$$

where V_s is the deposition velocity due to sedimentation, to represent deposition of large particles, and V_{ds} can be estimated from Equation 2.20. Relations for E for different components and conditions are given in Table 2.7. These were derived from model calculations and multiple regression analysis (ERISMAN & DRAAIJERS, 1995).

For the large particles (Na^+ , Ca^{2+} , Mg^{2+}) and for low vegetation (for all particles), the sedimentation velocity has to be added:

$$\begin{aligned} V_s &= 0.0067 \text{ m} \cdot \text{s}^{-1} & \text{rh} \leq 80 \\ V_s &= 0.0067 \cdot e^{\frac{0.0066 \cdot \text{rh}}{1.058 - \text{rh}}} \text{ m} \cdot \text{s}^{-1} & \text{rh} > 80\% \end{aligned} \quad (2.25)$$

Table 2.7 *Parameterisations of E values for different components and conditions.
From ERISMAN AND DRAAIJERS (1995)*

Compound	Wet surface		Dry surface	
	$rh \leq 80\%$	$rh > 80\%$	$rh \leq 80\%$	$rh > 80\%$
NH_4^+	$0.066 \cdot u_*^{0.41}$	$0.066 \cdot u_*^{0.41} \cdot \left[1 + 0.37 \cdot e^{\frac{rh-80}{20}} \right]$	$0.05 \cdot u_*^{0.23}$	$0.05 \cdot u_*^{0.23} \cdot \left[1 + 0.18 \cdot e^{\frac{rh-80}{20}} \right]$
SO_4^{2-}	$0.08 \cdot u_*^{0.45}$	$0.08 \cdot u_*^{0.45} \cdot \left[1 + 0.37 \cdot e^{\frac{rh-80}{20}} \right]$	$0.05 \cdot u_*^{0.28}$	$0.05 \cdot u_*^{0.28} \cdot \left[1 + 0.18 \cdot e^{\frac{rh-80}{20}} \right]$
NO_3^-	$0.10 \cdot u_*^{0.43}$	$0.10 \cdot u_*^{0.43} \cdot \left[1 + 0.37 \cdot e^{\frac{rh-80}{20}} \right]$	$0.063 \cdot u_*^{0.25}$	$0.063 \cdot u_*^{0.25} \cdot \left[1 + 0.18 \cdot e^{\frac{rh-80}{20}} \right]$
$\text{Na}^+, \text{Ca}^{2+}, \text{Mg}^{2+}$	$0.679 \cdot u_*^{0.56}$	$0.679 \cdot u_*^{0.56} \cdot \left[1 + 0.37 \cdot e^{\frac{rh-80}{20}} \right]$	$0.14 \cdot u_*^{0.12}$	$0.14 \cdot u_*^{0.12} \cdot \left[1 - 0.09 \cdot e^{\frac{rh-80}{20}} \right]$

3. Results for the Landkreis Lauenburg 2006 data set

In 2006, ECN received a first sample dataset for the Landkreis Lauenburg in the Bundesland Schlesweg Holstein containing information on forest species and tree height with a resolution of 250x250 meter, derived from remote sensing data as well as additional information (see the GSE-FM S6 Service Operations Report for further detail). The data products were produced by GAF AG who acts as a service provider to UBA-D in the frame of GSE-FM.

After conversion from the Lambert Conformal to the Gauss-Krüger projection and aggregation to the 1x1 km grid used as required by the UBA deposition mapping project the data was fed into the IDEM dry deposition model. Calculations have been performed for the year 2002.

In Figure 3.1 the comparison is made between the landcover for deciduous forest in the study area between the GSE-FM dataset and the Corine 2000 dataset. The latter is currently used in the EDACS setup (section 2.6).

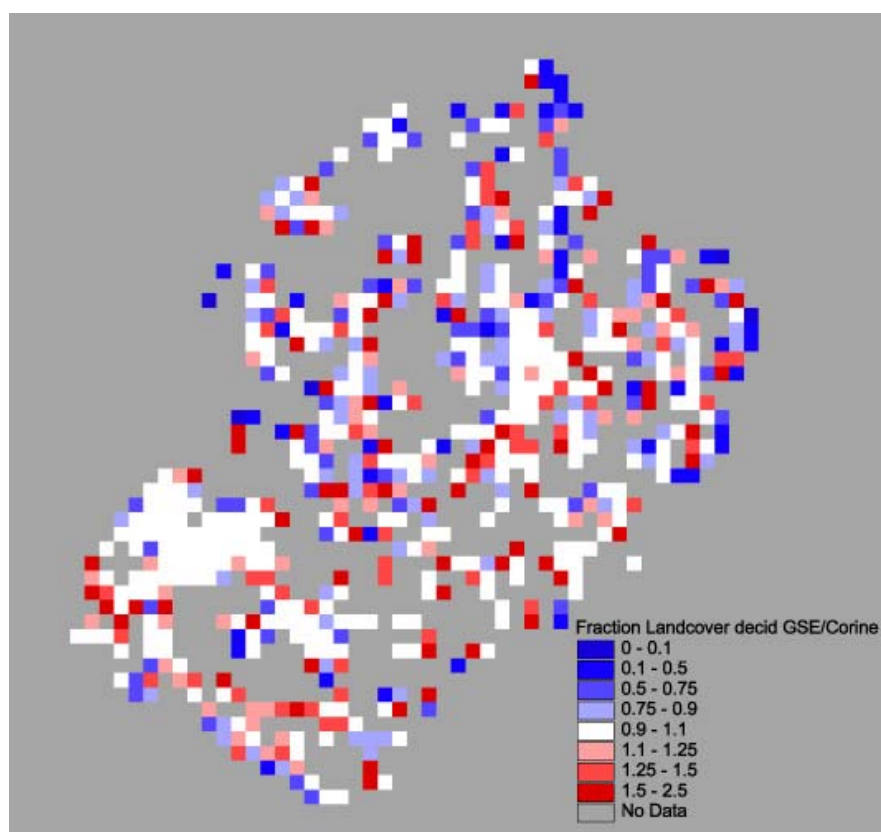


Figure 3.1 *The ratio of the fraction of landcover with deciduous forest with the GSE-FM product and Corine 2000 for Landkreis Lauenburg*

Differences in coverage of deciduous forest between the two products reach 50% or more for individual 1 by 1 km pixels. Even bigger differences are observed at the corners of larger forested areas or in patchy 'stand-alone' forest pixels. In large forested areas differences are within 10%. Clearly the higher spatial variability of the GSE-FM product can be seen in Figure 3.2.

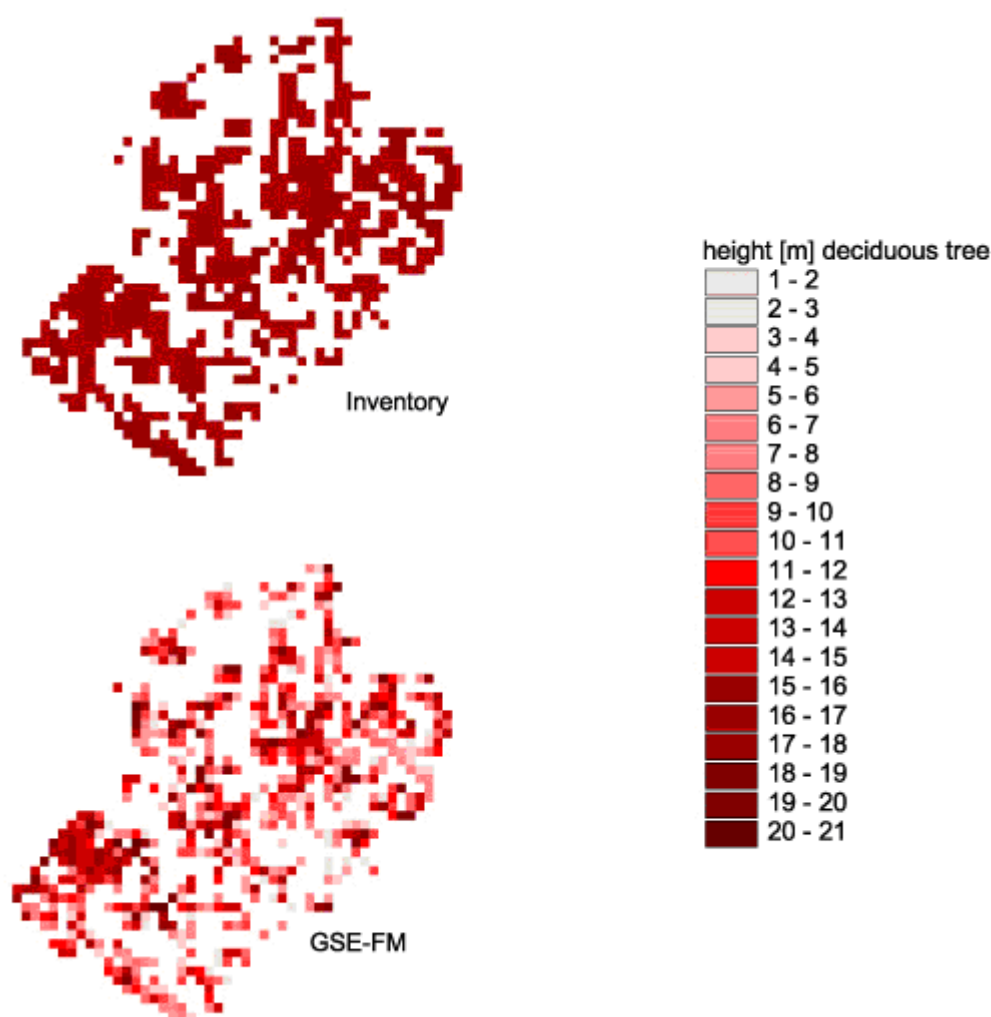


Figure 3.2 *Tree height [m] for deciduous trees in Landeskreis Lauenburg according to the inventory data+Corine 2000 (top) and according to the high resolution GSE-FM product (bottom)*

In Figure 3.2 the tree heights for deciduous forest are compared between the GSE-FM product and the Corine derived values. The Corine derived values apply an average tree height per forest class per Bundesland. This leads to a low variability in modelled tree heights within a Bundesland, the only reason for variability is due to the landuse class mixed forest as this is attributed 50/50 to deciduous and coniferous forest and has a different average tree height.

In Figure 3.3 the results are shown for the comparison of calculated potential dry acid deposition for the year of 2002 with these products as input.

Non-forested pixels do not show variability between both methods, so show a ratio of 1. About half of the forested pixels have relatively similar deposition fluxes, with ratios usually between 0.75 and 1.25. A large number of forested 1 km pixels have significantly higher or lower ratios (values larger than 1.5 or lower than 0.5). A tendency to lower ratios can be observed, meaning that the potential dry acid deposition is on average lower when the GSE-FM tree data is used. This is examined in more detail in the next section using more data for the Bundesland of Sachsen-Anhalt as an example.

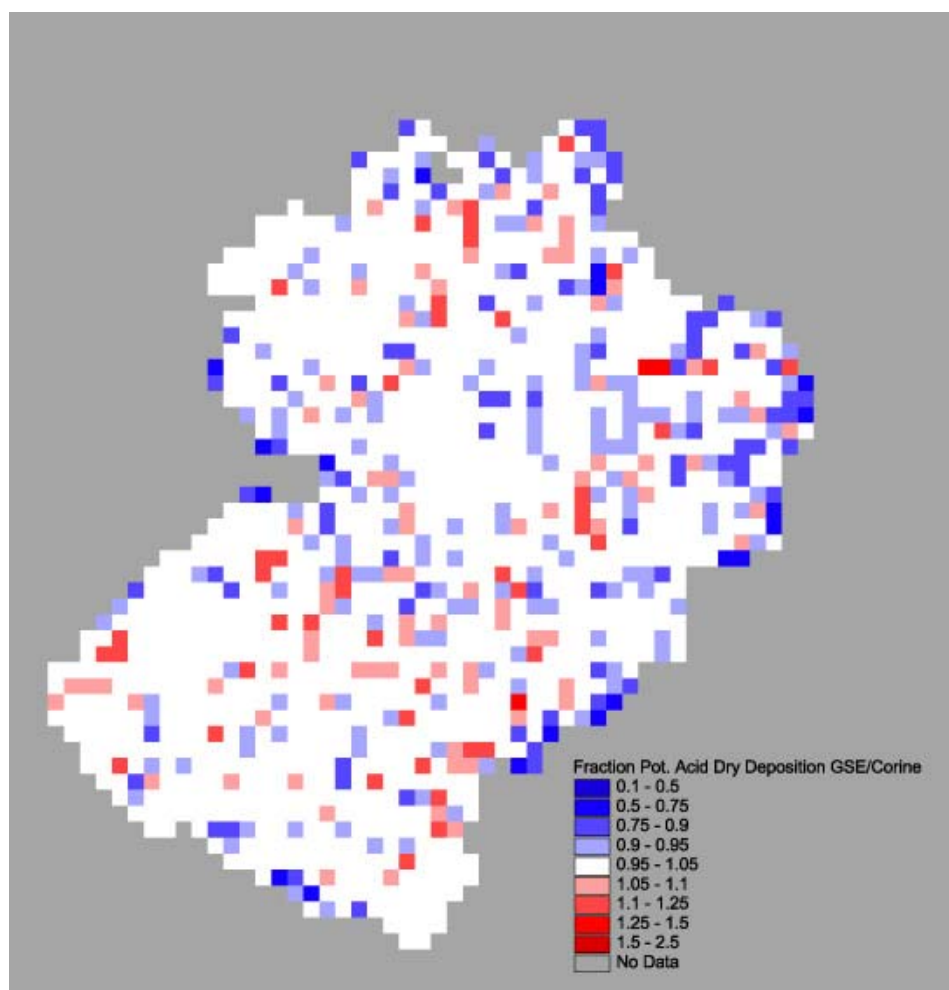


Figure 3.3 *Comparison of calculated potential dry acid deposition for the year of 2002 in Landeskreis Lauenburg when applying the two tree height products*

4. Results for the Sachsen-Anhalt 2007 dataset

In 2007, ECN received a much larger and more extensive dataset for the complete Bundesland of Sachsen-Anhalt containing information on forest species and tree height with a resolution of 250x250 meter, derived from remote sensing data as well as additional information (see the GSE-FM S6 Service Operations Report for further detail). The data products were produced by GAF AG who acts as a service provider to UBA-D in the frame of GSE-FM. The specification of the dataset is given in Table 4.1.

Table 4.1 *Specification of the GSE-FM data product*

Criteria	Specification	
GSE-FM-LFM-FTM-ST-2005.*		
Data type:	Continuous / Positive Integer – 8 bit	
Coding:	0: No data 01: Broad-leaved Forest 02: Coniferous Forest 08: Transitional Woodland / Shrub 10: No Forest	
GSE-FM-FEI-FATI-ST-2005.*		
Data type:	ESRI Shape file with attribute table	
Attribute:	Content:	Value:
Dom_Level_2	I1: Dominating LC/LU Class at CLC Level 2 per 250m grid cell	0: Dominated by another class than Forest or Transitional woodland/shrub 1: Dominated by forest 2: Dominated by Transitional woodland/ shrub
Dom_Level_3_Forest	I2: Dominating LC/LU Class at CLC Level 3 per 250m grid cell within Forest	0: if dominated by another class than Forest. 1: Forest, dominated by Broad-leaved Forest (>75% of the crown cover made up of deciduous trees) 2: Forest, dominated by Coniferous Forest (>75% of the crown cover made up of coniferous trees) 3: Forest, dominated by Mixed Forest (Forests not dominated by one species type, as specified for class 2 and 3)
PercForest	I3: Proportion of the cell covered by forest (CLC class 3.1)	0: Forest Cover below 1%. 1 – 100: Percentages (rounded, no decimals)

Criteria	Specification	
Perc_DecF	I4: Proportion of the cell covered by Broad-leaved Forests (CLC class 3.1.1)	0: Forest Cover below 1%. 1 – 100: Percentages (rounded, no decimals)
Perc_ConF	I5: Proportion of the cell covered by Coniferous Forests (CLC class 3.1.2)	0: Forest Cover below 1%. 1 – 100: Percentages (rounded, no decimals)
Perc_MixF	I6: Proportion of the cell covered by Mixed Forests (CLC class 3.1.3)	0: Forest Cover below 1%. 1 – 100: Percentages (rounded, no decimals)
Perc_TWS	I6: Proportion of the cell covered by "Transitional woodland/ shrub ", (CLC class 3.2.4)	0: Forest Cover below 1%. 1 – 100: Percentages (rounded, no decimals)
AvgHForest	I7: Average height of Forest in the grid cell	0 – 50 Height [m], rounded on decimetres
AvgH_DecF	I8: Average height of Broad-leaved Forests in the grid cell	0 – 50 Height [m], rounded on decimetres
AvgH_ConF	I9: Average height of Coniferous Forests in the grid cell	0 – 50 Height [m], rounded on decimetres
AvgH_MixF	I10: Average height of Mixed Forests in the grid cell	0 – 50 Height [m], rounded on decimetres

After conversion from the Lambert Conformal to the Gauss-Krüger projection and aggregation to the 1x1 km grid as required for the UBA deposition mapping project the data was fed into the IDEM dry deposition model. Calculations have been performed for the year 2004.

In Figure 4.1 a comparison is made between the forest land cover in the study area between the GSE-FM and Corine 2000 datasets. The latter is currently used in the EDACS setup. Table 4.2 shows a comparison of the old dominant land-use data set with the new dataset for average amount of forest per land use class. It can be seen that non-forest pixels in the dominant land-use dataset can contain a substantial amount of forest, up to 14%, and that on average forested pixels contain non-forested areas up to 27% of their area.

These differences will have major impacts on the calculated dry deposition rates, as these are a function of both land cover and surface roughness, which is derived from for example tree species and height.

Table 4.2 *Percentage forested land cover in old dominant land cover classes of 1x1 km pixels according to the new data product for Sachsen-Anhalt*

Urban	9
Arable	8
Deciduous	73
Coniferous	76
Mixed	77
Water	14
Total	21

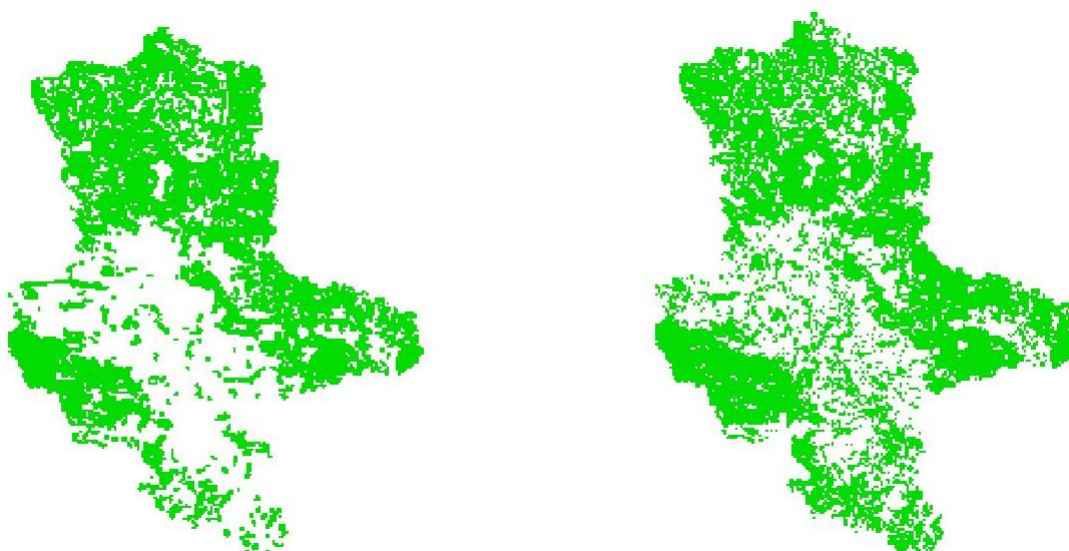


Figure 4.1 *Comparison of 1x1 km pixels containing 1% forest or more for the Corine-2000 land use map (left) and the GSE-FM product (right)*

In Figure 4.1 maps of 1x1 km pixels are shown that have a percentage of landcover with forest of 1% of higher; Corine 2000 information is shown on the left, GSE-FM information is shown on the right. The higher resolution of the GSE-FM product is obvious. More isolated forested pixels exist within the ‘white’ areas in the heart of the Bundesland as well as more unforested pixels within the larger forested (green) regions.

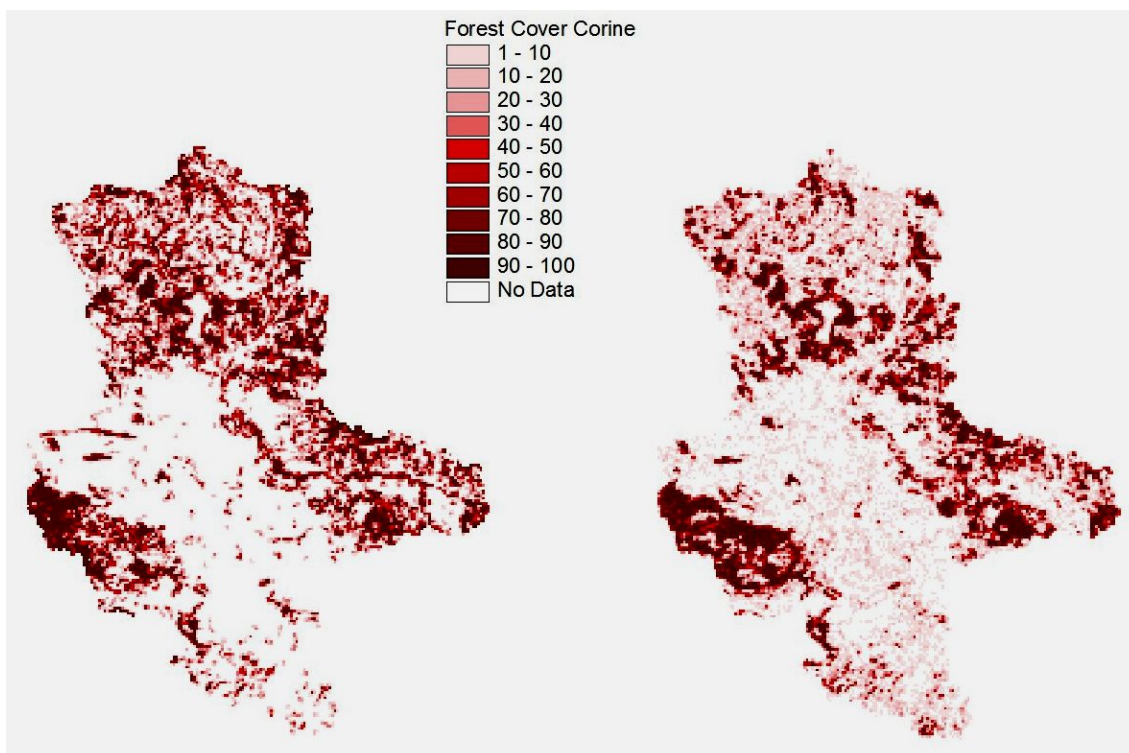


Figure 4.2 Comparison of percentage land cover by forest between Corine 2000 (left) and the GSE-FM product (right)

In Figure 4.2 maps of the percentage of forest land cover are shown: Corine 2000 information on the left, GSE-FM information on the right. The higher resolution of the GSE-FM product is again obvious. The GSE-FM product contains many more pixels with forest land cover between 1-30%. Besides that forest cover appears more dense in highly forested areas, especially in the SW corner of Sachsen-Anhalt. Furthermore the scattered forest patches in the North seem to have less forest cover in the GSE-FM product. Other regions show more areas with some small percentage of forest cover in the GSE-FM product where Corine shows no forest cover at all.

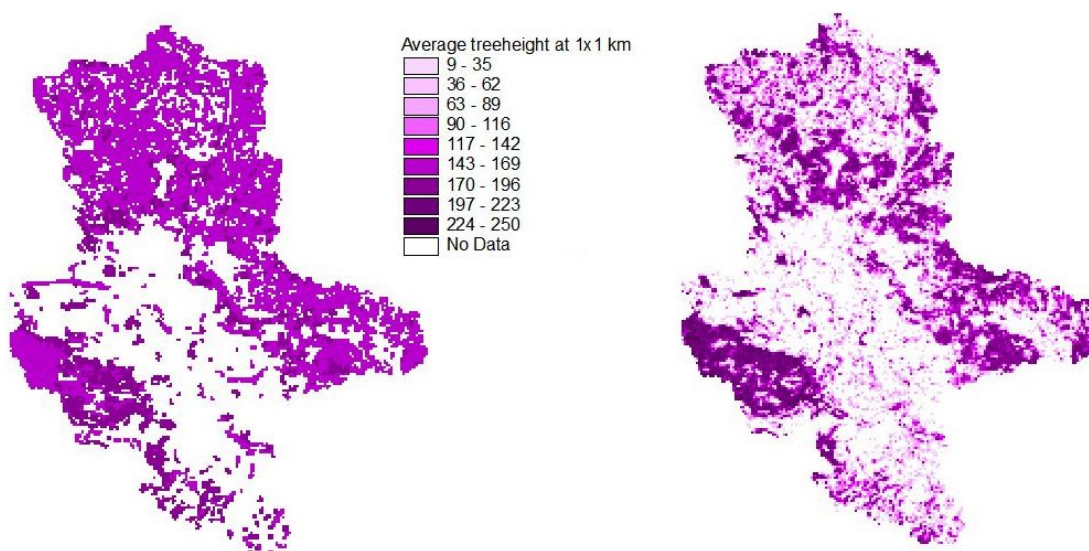


Figure 4.3 Comparison of the average calculated tree height (decimeter) for the Corine 2000 based method (left) and the GSE-FM product (right)

Figure 4.3 shows the average tree height (decimeter) per 1x1 km pixel calculated by the old method, applying Bundesland averaged tree heights per forest type, based on inventory data and

the Corine 2000 land cover map (left) and the result for the average tree heights using the GSE-FM data product which gives tree height estimates and forest land cover percentage (right). The average tree height shows much more variability for the GSE-FM product with a larger range and a larger spatial variability.

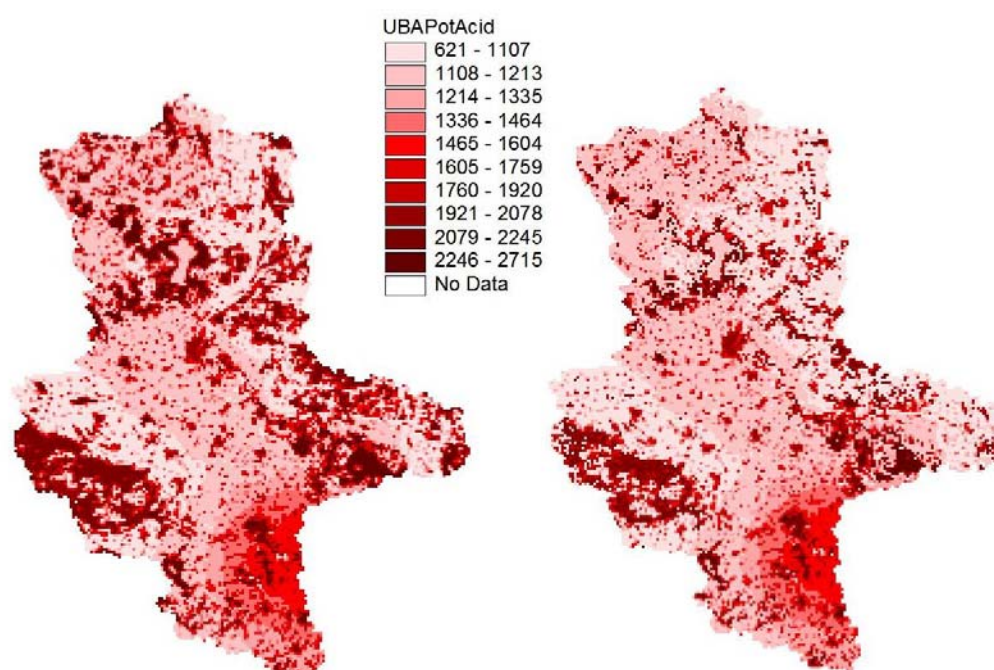


Figure 4.4 Comparison of the 2004 total potential dry deposition flux of acidifying components in mol/ha/yr when using the Corine-2000 derived surface parameters (left) and when using the GSE-FM based parameters (right)

Figure 4.4 shows the results for the calculated dry deposition flux for Potential Acid ($\text{NO}_2 + \text{NO}_3 + \text{HNO}_3 + \text{NH}_3 + \text{NH}_4 + \text{SO}_2 + \text{SO}_4$) for the year 2004 using both products. At first sight the two results seem quite similar, but after more careful examination striking differences start to appear.

Besides the influence of surface parameters on the total acid dry deposition, leading to high deposition in forested regions compared to arable and grassland regions, also the influence of the concentration field can be seen on Figure 4.4. The dark shape in the south-east corner of Sachsen-Anhalt is due to high concentrations caused by sources just east of this area.

Table 4.3 Average potential acid dry deposition flux [$\text{eq}/(\text{ha} \cdot \text{yr})$] in 2004 as a function of land use class for Sachsen-Anhalt in 2004, when calculated with the IDEM model using either Corine land use data or the GSE-FM high resolution product

LU	Corine	GSE-FM	Diff. (%)
Urban	1487	1452	2.4
Arable	1360	1291	5.0
Pasture	1314	1254	4.6
Deciduous	1773	1616	8.9
Coniferous	1757	1480	15.8
Mixed Forest	1805	1692	6.2
Water	1297	1242	4.2
Semi Natural	1547	1464	5.3
Other	1445	1391	3.7
Total	1446	1348	6.8

In Figure 4.5 the ratios as percentage between the Corine and GSE-FM derived fluxes are shown for the 1x1 km pixels. From both figures (4.4 & 4.5) we can conclude that the high resolution GSE-FM product in general leads to lower dry deposition fluxes, especially for the edges of forest areas, where deposition rates go down by a factor of two or even more on pixel to pixel basis.

From the results of this project we cannot distinguish exactly the influence of the improved spatial resolution of the GSE-FM product compared to the Corine land use data and the influence of the improved vertical resolution of the tree height data in the GSE-FM product.

The influence of the improved tree height data can be tested separately only by combining either the Bundeswaldinventur tree height data with the GSE-FM derived land use classes or by using the full GSE-FM data set including the improved tree height data. This would require a separate additional analysis.

Our impression is that the overall reduction in dry deposition loads is mainly due to the improved tree height data, with largest influence on coniferous tree heights, and that the improved land use data has an influence only on the spatial distribution of the deposition fluxes.

Deposition fluxes that are more than 10% higher by using the GSE-FM product can only be found in some small areas in the East of Sachsen-Anhalt. Table 4.3 shows the fluxes of Potential Acid for both methods as the average for all pixels as a function of the dominant land use class in those pixels. It is clear that the average reduction in the dry deposition flux can be up to 15% for pixels where coniferous forest is the dominant land use class. For the pixels not dominated by forest the differences are small.

Ratio Highres over Lowres Pot. Acid fluxes (%)

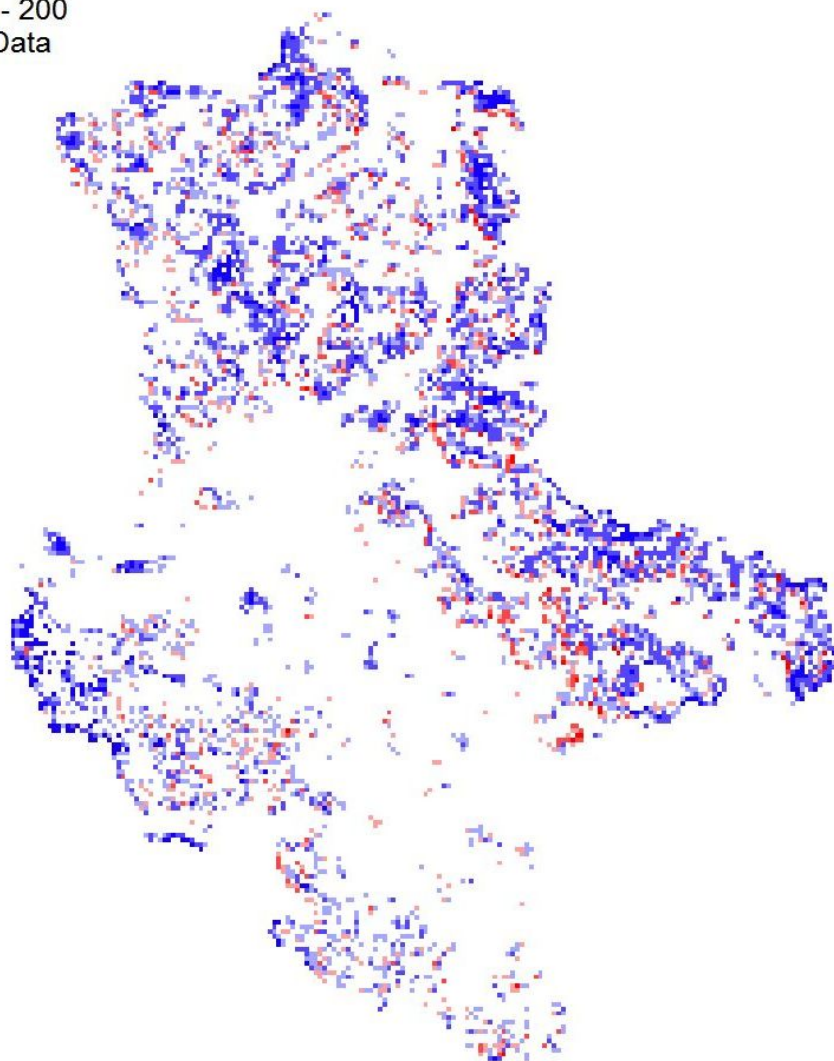
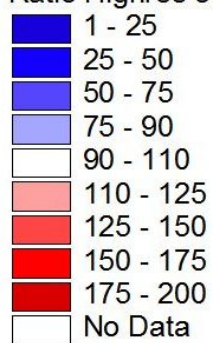


Figure 4.5 *Relative dry deposition flux of potential acid when comparing Corine-2000 based land use and forest data with GSE-FM derived data*

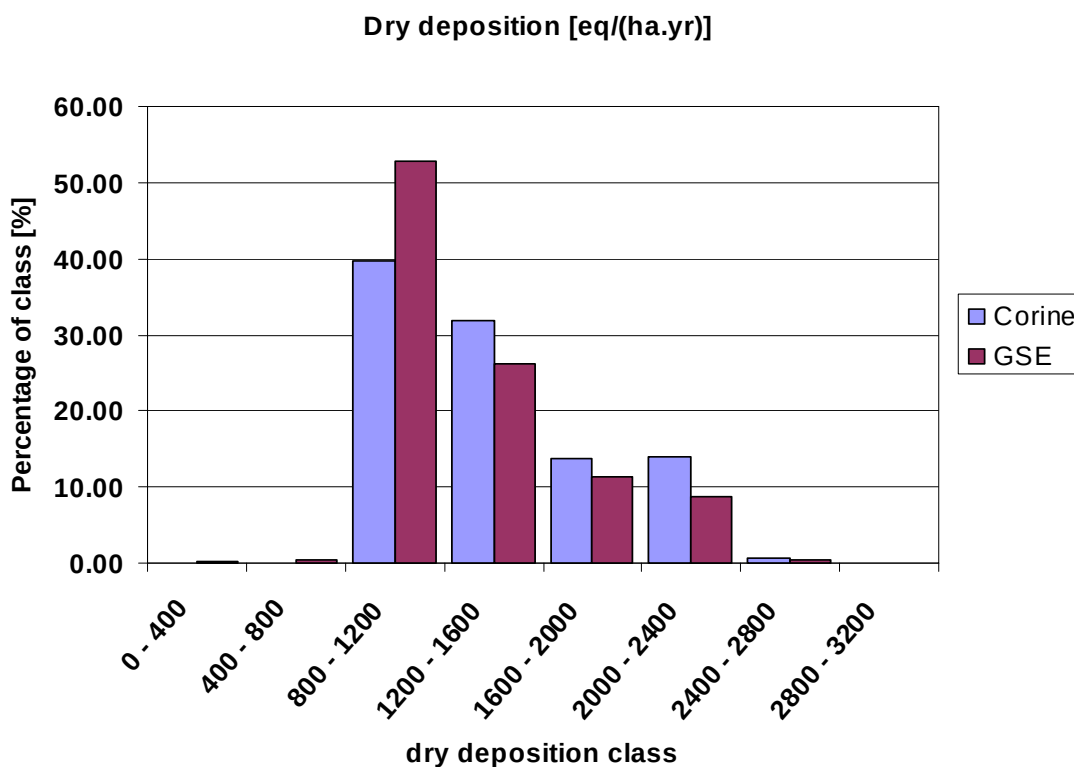


Figure 4.6 *Comparison between the histograms of the dry deposition rates calculated using the Corine and the GSE-FM derived land use data*

Figure 4.6 illustrates the shift to lower dry deposition rates estimated when using the GSE-FM derived land use maps compared to the Corine derived product. In the GSE-FM based calculations about 10% of the pixels more fall in the dominant category 800-1200 eq/(ha.yr) of dry deposition load, and about 5% of the pixels less fall in the higher category of 1200-1600 eq/(ha.yr). This is likely to result in a significant reduction of pixels exceeding the critical load limits imposed by international regulations.

5. Conclusions and discussion

The use of the high resolution GSE-FM satellite based product allows for a more detailed calculation of the dry deposition rates of acidifying components over Germany. The inventory based tree height combined with the Corine 2000 land use database leads to a unrealistic homogeneous tree height estimate. The GSE FM derived tree height estimate seems, on first sight, to be much more realistic at the 1 by 1 km pixel level, with lower tree heights at forest edges, higher coverage by trees in non-forested pixels and more variability in tree heights within the larger forested regions.

Only comparison with high resolution tree inventory data can prove whether the GSE FM product has higher quality and comes closer to reality. This comparison however is out of the scope of this project. In this project we examined the influence of the GSE-FM data product on the dry deposition flux estimates by comparing the results of the use of the two different land use data sets.

We found that the average dry deposition loads over the study area are reduced by about 7%. This is mainly due to lower dry deposition loads over the forested areas. The reductions are largest for coniferous areas, where the average dry deposition goes down with 16%. For individual 1 by 1 km pixels the reductions can be much larger, up to a factor of two or more can be observed, especially on the edges of forested regions.

Higher total dry deposition rates are found only for a small amount of pixels, mainly due to a higher percentage of (higher) trees in the middle east of the Bundesland of Sachsen-Anhalt in the GSE-FM product compared to the Corine+inventory product.

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