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Background concentrations in Norway: Temporal Averaging and Uncertainty Assessment

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Scientific report

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Summary

In recent years, a system for providing spatially and temporally continuous estimates of background concentrations of the primary air pollutants in Norway has been developed at the Norwegian Institute for Air Research (NILU) (Schneider et al., 2011; Schneider and Obracaj, 2013). Based on both a spatial and temporal component, the system provides estimates of the background concentrations of PM_{10}, $PM_{2.5}$, O_3, and NO_2 for a typical situation in Norway. The spatial resolution is 0.1 degrees (roughly equivalent to 10 km × 10 km) and the temporal resolution is hourly.

In this report we describe additional work undertaken in order to upgrade the spatial component of the system and to quantify and communicate the quite significant uncertainty that is inherent in the estimates. The two major objectives addressed as part of this work were:

1. Perform an update of the spatial component such that it is computed as the average of three years of data, thus eliminating the potential bias which is introduced by using only a single specific reference year.
2. Quantify the approximate uncertainty in the background estimates and communicate this uncertainty to the users on the project website at `http://www.luftkvalitet.info/ModLUFT/Inngangsdata/Bakgrunnskonsentrasjoner/BAKGRUNNproj.aspx`.

In a first task, the spatial component of the system was therefore upgraded to three years of data, namely 2008 to 2010 (and 2007, 2008, and 2010 in the case of $PM_{2.5}$). Separate maps were created for these years and for each species using geostatistical techniques and the final estimate was computed by combining the spatial estimates with information about the temporal behavior of a typical year (expressed as the average annual time series at multiple air quality stations in Norway).

In a second task, the uncertainty in the background concentrations for a typical year as provided by the system was quantified by comparing the resulting estimates against station observations. It was made sure that the data provided by these stations had not been used by either the spatial or the temporal component of the system, in order not to introduce a validation bias. The validation methodology is presented and the main results are shown for each species.

Finally, the last section of the report summarizes the work done and provides an overview of some of the limitations of the current system, discusses potential sources of error, and recommends a possible path forward in order to improve the system in the future.

1 Introduction

Many applications require approximate estimates of the spatial and temporal dynamics of background concentrations of the main air pollutants. The spatial distribution of some air pollutants is mapped operationally for the European Environment Agency by the European Topic Centre on Air Quality and Climate Change Mitigation (ETC/ACM) (Denby et al., 2005; Horálek et al., 2005, 2007, 2008, 2010; De Smet et al., 2010; Denby et al., 2011a,b).

However, these maps are not routinely produced for NO_2 and only partially for O_3 and further do not provide any information on the temporal variability that can be found at a particular location throughout the year. For this reason a prototype system for providing the approximate spatial and temporal patterns of background concentrations of PM_{10}, $PM_{2.5}$, O_3, and NO_2 over Norway has been developed at the Norwegian Institute for Air Research in recent years. The following sections summarize the basic principles of the system and describe some of the more recent work.

1.1 The prototype system

The system is based on two components, namely a spatial and a temporal component. Together, these two components are supposed to represent a typical year in Norway, based on long-term averages in order to eliminate inter-annual variability. The spatial component consists of interpolated observations of background stations throughout Norway. A geostatistical approach is then used to obtain the best possible estimates. The temporal component is constructed using a long-term time series of around 5 to 10 years of hourly observations at all relevant Norwegian stations for the various species. These data are acquired from the *Airbase* European air quality database.

A combination of the two components was then accomplished by averaging several years of hourly measurements on an annual as well as on a daily basis. The resulting time series for a typical year and a typical day were further smoothed to ensure that the observations are representative of cyclical temporal patterns and do not just reflect short-term variability. The representative annual and daily time series are subsequently converted from absolute concentrations given in $\mu g\ m^{-3}$ to anomalies from the long-term mean at the station given in percent. This ensures the applicability of the temporal information for neighboring areas with differing mean annual background concentrations.

Due to the often short time series available at each station and the associated small sample size, random noise which is not representative of the overall long-term temporal variability is abundant in the time series and needs to be removed before using the relative anomalies for estimating concentrations at other locations. Such a task can for example be performed by using a moving average filter. However, for practical purposes this smoothing was performed here in the operational application by applying a two-dimensional low-pass filter on an hour-by-hour anomaly matrix for an average year. This results in a simultaneous smoothing of both the annual and daily average time series. An example is shown in Figure 1. It should be noted that the application of the filter was performed while the matrix was augmented by itself on all four sides in order to avoid erroneous edge effects caused by the filter.

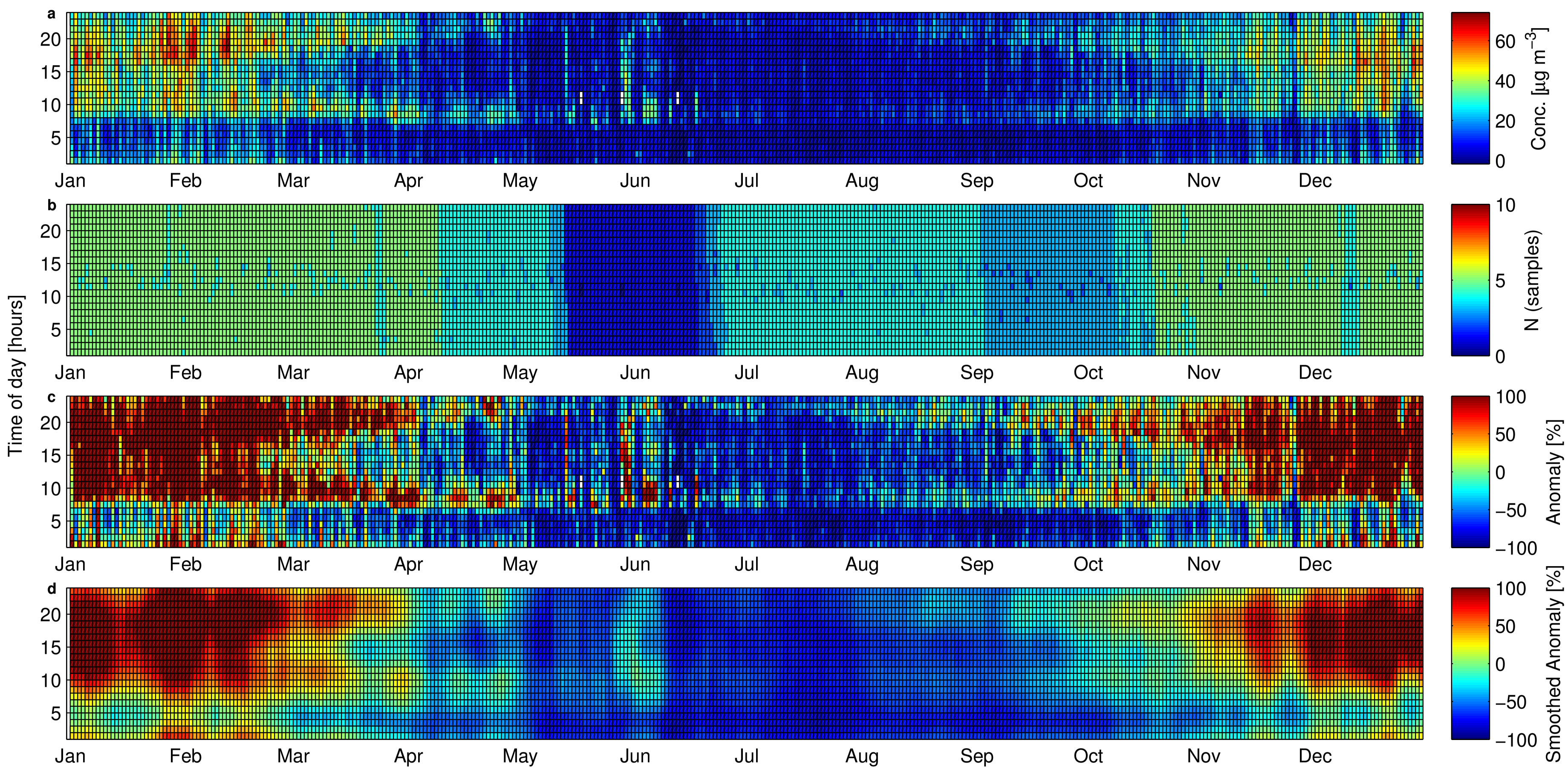

Figure 1 – NO_2 at station *NO0075A Barnehagen*: Annual matrices of hourly averages computed over entire available time series, shown as a) Observations, b) number of years with available data, c) the anomaly computed from the long-term mean, and d) the anomaly from the long-term mean smoothed using a low-pass filter.

The smoothed relative anomalies can then be applied to neighboring locations with different absolute annual mean concentrations, and as such the average concentration can be estimated for a certain location given a certain day of the year and a time of day.

The final report submitted to Klif for the 2011 work (Schneider et al., 2011) describes in detail the basic methodology of the prototype system and some first results.

1.2 Evaluation of new data sources

Additional data sources such as satellite imagery and high-resolution model output were evaluated in 2012 (Schneider and Obracaj, 2013). As it has been shown in the past that satellite data of atmospheric composition can be quite valuable for monitoring air quality (e.g. Schneider and van der A, 2012), the goal of the first task of that work was to evaluate the potential of satellite data for mapping background concentrations, and in particular the concentrations of NO_2, in Norway. As such, a suitable NO_2 satellite product was first selected. The choice fell on a currently experimental high-resolution version of the standard OMNOe2 product produced by NASA from the OMI (Ozone Monitoring Instrument) sensor. A statistical relationship was established between an annual average tropospheric NO_2 column dataset derived from this product and annual average NO_2 concentrations derived from Airbase station data.

The obtained linear regression model was then subsequently used as an auxiliary dataset in combination with kriging of resulting residuals to generate a map of average NO_2 concentration in Norway. The results indicate that high-resolution OMI satellite data of tropospheric NO_2 columns can be very helpful as an auxiliary variable in mapping air quality. Using the additional spatially distributed NO_2 data from the OMI instrument provided significantly better mapping results than geostatistical interpolation of station data alone (as measured using the root mean squared error in a cross-validation exercise).

As a second major task, the 2012 work investigated the usability of high-resolution output from the CHIMERE chemical transport model to improve the mapping procedure. The evaluation was carried out for the four species NO_2, O_3, PM_{10}, and $PM_{2.5}$ and consisted of a direct comparison of time series observed in 2009 at several air quality station in southern Norway with hourly time series derived from the CHIMERE model at the exact same locations. Direct comparisons of the time series were complemented by various scatterplots and linear regression models were fitted to the resulting relationships. The results indicate that at the level of hourly temporal sampling the model is generally not able to well replicate the high-frequency temporal variability. This shows in overall very weak correlations with R^2 values in the range of 0 to 0.2. One exception is O_3, for which generally stronger relationships with R^2 values of 0.4 to 0.6 were found. These results in combination with the fact that only one year of high-resolution hourly model data was available and only the very southern part of Norway was covered by the model domain hindered the operational use of this data for supporting the temporal component of the background mapping procedure.

However, the spatial component can still benefit from the high-resolution model data when using a similar residual kriging approach as used for integrating the satellite data. In addition, rapidly increasing computational power will mostly eliminate these

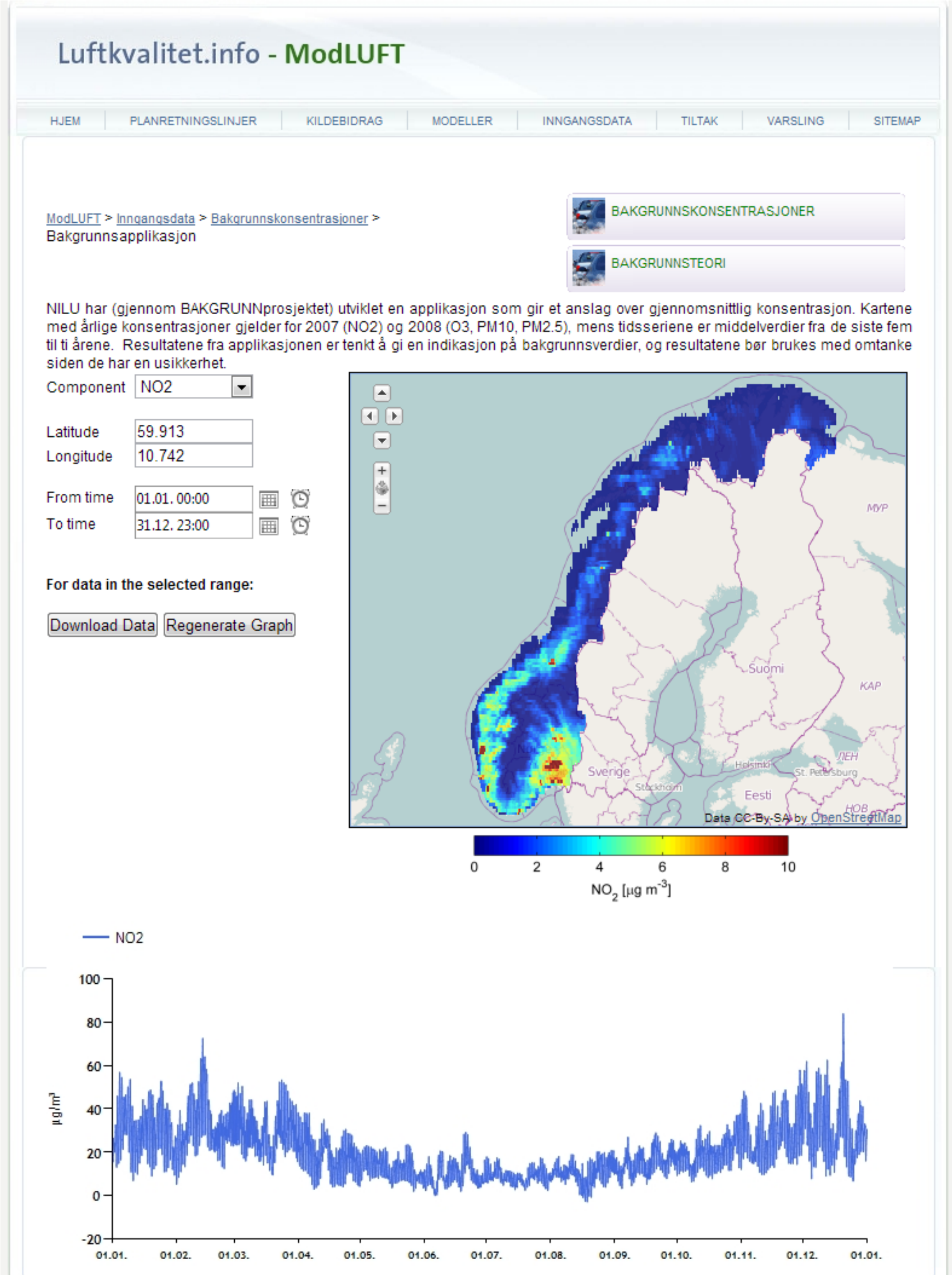

Figure 2 – Screenshot of the mapping component of the online web mapping application used for visualizing the results and providing access to the data, here showing background concentrations of NO_2 throughout all of Norway and the corresponding time series for central Oslo. The website can be found at `http://www.luftkvalitet.info/ModLUFT/Inngangsdata/Bakgrunnskonsentrasjoner/BAKGRUNNproj.aspx`.

issues in the near future. While the available dataset from the CHIMERE model unfortunately did not cover all of Norway and the developed methodology could thus not be integrated in the temporal component of the operational mapping procedure, access to other datasets will be able to change this in future. For example, the Unified EMEP (European Monitoring and Evaluation Programme, (Fagerli et al., 2011)) model

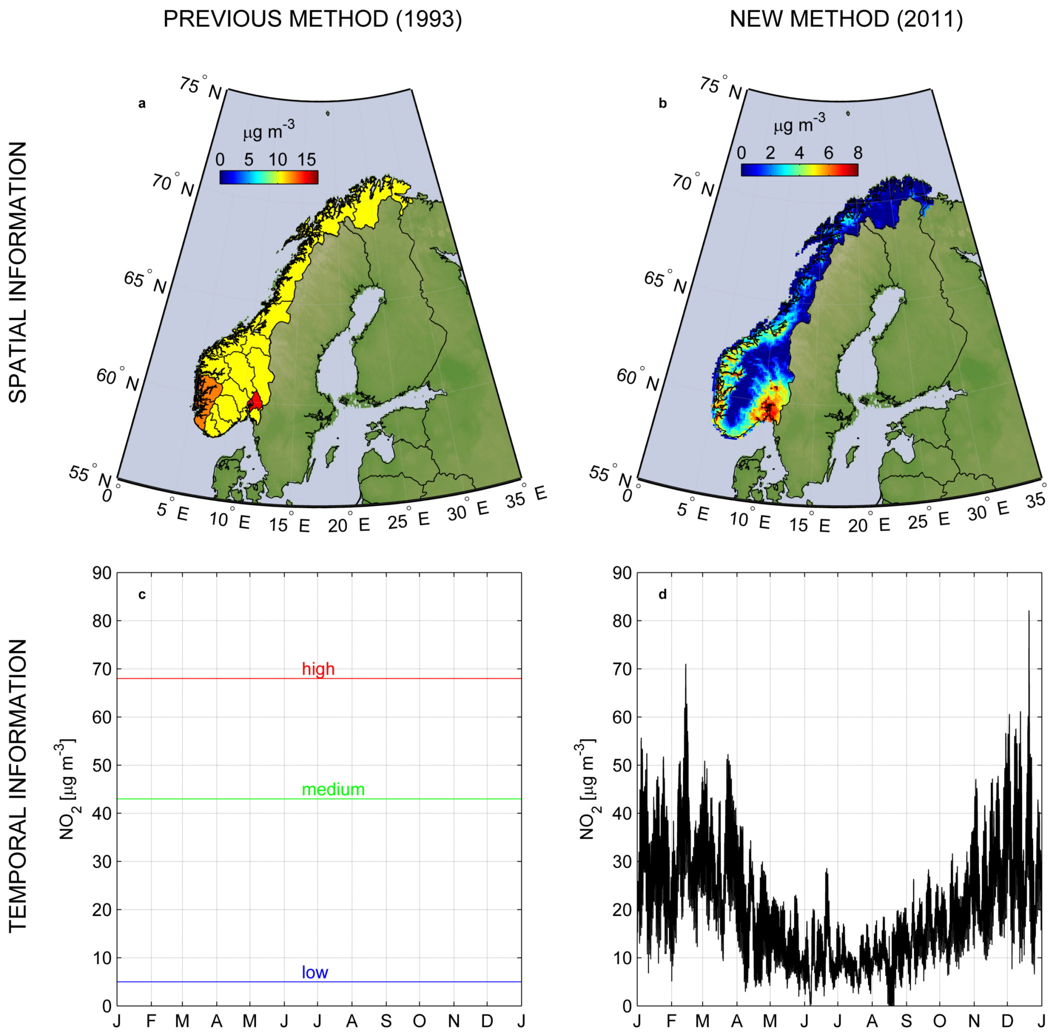

Figure 3 – Comparison of the information content about background concentrations obtained from the previous method and the method described in this report, shown for the example of NO_2. Panel a) shows 1993 VLUFT data for rural areas for the medium-level class, panel b) shows the annual mean background concentrations for 2008 derived using the method presented here, panel c) shows an example of temporal information available from VLUFT (or lack thereof), here for Akershus county, and panel d) shows the temporal concentration information at Kjeller in Akershus county for a typical year as derived by the method presented here. Note that the values from VLUFT given in panel a) are "episodic high hourly concentrations" and are thus not directly comparable to the annual mean values shown in panel b). (From Schneider et al. (2011))

(Simpson et al., 2003) has been run at a 10 km spatial resolution and its domain includes all of Norway. Unfortunately, this dataset could not be made available for the purposes of this study as the uncertainties in the high-resolution output are currently still too high to be used outside of a research environment (Michael Gauss, met.no, personal communication). However, improvements to the EMEP model are ongoing and it is likely that a future version will be made available for use in mapping Norwegian air quality.

As a third and final task of the 2012 work, a web mapping application was developed in order to visualize both the spatial and temporal components of the background concentrations in Norway. Based on the open-source GeoServer software, the application is integrated within the ModLuft web portal 2 providing information about the National Information Center for the modeling of air quality. The tool provides freely zoom-able and pan-able maps of Norwegian background concentrations of the four species NO_2, O_3, PM_{10}, and $PM_{2.5}$. In addition, the user can display time series at any freely chosen location in Norway and download the data. Figure 2 shows the tool in action. The website can be found at `http://www.luftkvalitet.info/ModLUFT/Inngangsdata/Bakgrunnskonsentrasjoner/BAKGRUNNproj.aspx`.

Figure 3 shows a comparison of the information content provided by the updated background concentration as opposed to the previously used 1993 VLUFT data set. Compared to the previously used VLUFT dataset, the method presented here has clear advantages in that it provides a significantly higher information density in both the spatial as well as the temporal dimension. The method provides quantitatively reasonable estimates of background concentrations, although the uncertainty at the hourly level is quite high. The main source of uncertainty is the low number of suitable background stations located in Norway. A major advantage of the technique is further that it can be easily updated with new data (Schneider and Obracaj, 2013).

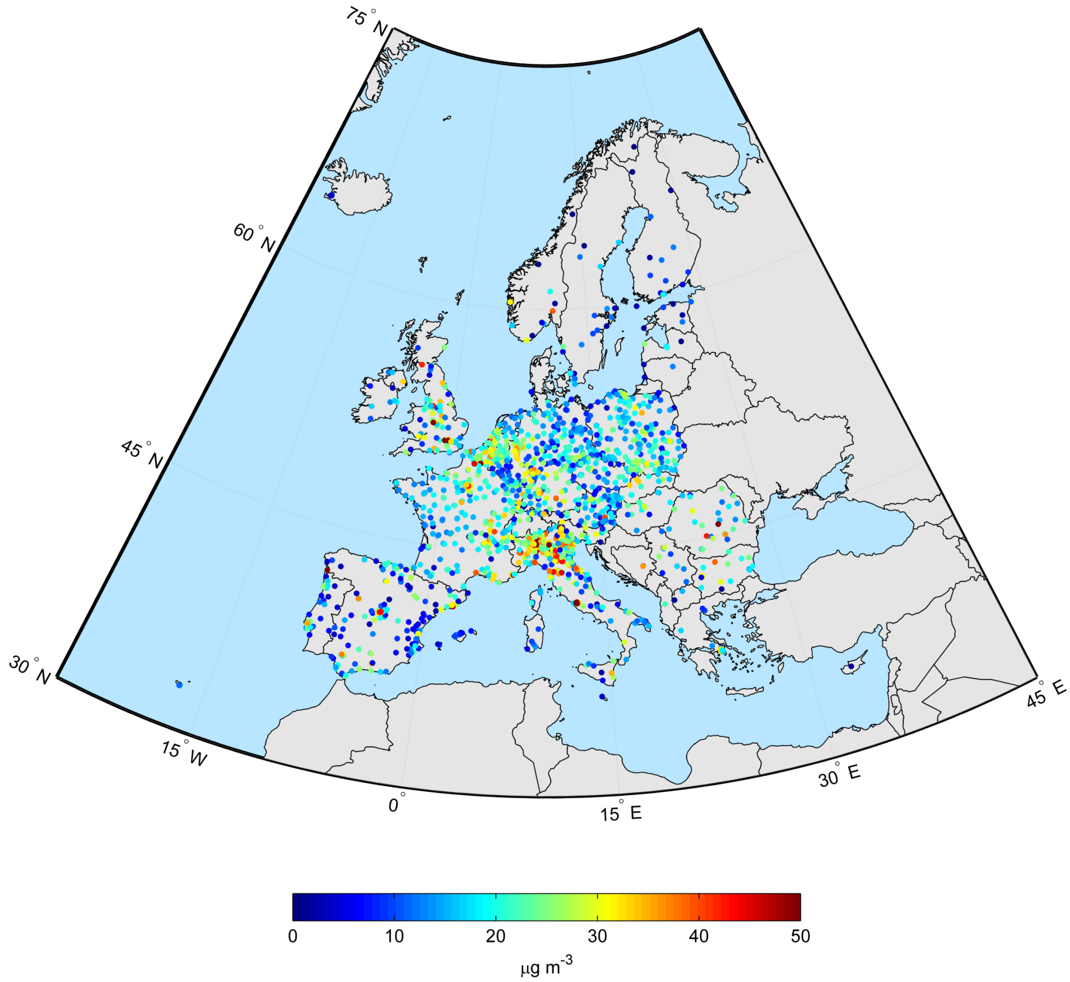

Figure 4 – Map showing the 2009 average NO_2 concentration measured at all Airbase background stations. (from Schneider et al. (2011))

2 Extension of the spatial component

The first major task of this year's work consisted of extending the spatial component of the background atlas system to be based on a multi-annual average rather than just an individual year. In the following the underlying methodology is described and some of the results are highlighted.

2.1 Methodology

For PM_{10} and $PM_{2.5}$ gridded annual average data were obtained from the website of the European Environmental Agency. These are based on the methodology developed within the framework of the European Topic Centre on Air Quality and Climate Change Mitigation (ETC/ACM) and is described in a series of reports (Denby et al., 2005; Horálek et al., 2005, 2007, 2008, 2010; De Smet et al., 2010; Denby et al., 2011a,b). No such maps are available for NO_2 and O_3, so the spatial component for these species was estimated using a geostatistical approach following a simplified version of the approach used by ETC/ACM. The approach is briefly described in the following based on the more detailed information available in Schneider et al. (2011).

Table 1 – Overview of Norwegian background air quality stations that were used for temporal characterization. All station data was acquired from AirBase. Note that not all stations provide data for all air quality indicators and that stations not listed here were not considered due to short time series or other reasons. (from Schneider et al. (2011))

Station ID	Station Name	City	Lat. [deg]	Long. [deg]	Elevation [m]
NO0075A	Barnehagen	LILLEHAMMER	61.121	10.467	210
NO0001R	Birkenes		58.383	8.250	190
NO0081A	Bærum		59.952	9.645	80
NO0070A	Grimmerhaugen	AALESUND	62.472	6.166	21
NO0077A	Gruben	MO I RANA	66.310	14.194	10
NO0062A	Haukenes		59.200	9.400	25
NO0056R	Hurdal		60.367	11.067	300
NO0045R	Jeløya		59.433	10.600	5
NO0055R	Karasjok		69.467	25.217	333
NO0039R	Kårvatn		62.783	8.883	210
NO0016A	Nedre Storgate	DRAMMEN	59.746	10.207	20
NO0041R	Osen		61.250	11.783	440
NO0043R	Prestebakke		59.000	11.533	160
NO0015A	Rådhuset	BERGEN	60.395	5.327	5
NO0052R	Sandve		59.200	5.200	40
NO0072A	Skøyen	OSLO	59.920	10.733	10
NO0073A	Sofienbergparken	OSLO	59.356	10.766	25
NO0063A	Stener Heyerdahl	KRISTIANSAND	58.090	7.586	12
NO0015R	Tustervatn		65.833	13.917	439
NO0065A	Våland	STAVANGER	58.961	5.731	33
NO0080A	Øyekast		59.133	9.645	40

Raw data from air quality stations was used for both spatial mapping using residual kriging as well as for temporal decomposition of the time series. All station data was obtained from the *European Air quality dataBase*, AirBase (`http://acm.eionet.europa.eu/databases/airbase/`). However, different datasets were acquired for each component. For the geostatistical analysis, annual mean concentrations were acquired for all European background stations in order to achieve a large enough sample size for variogram modeling and regression analysis (see Figure 4). For the temporal characterization, only data for Norwegian stations were acquired for all four species, however this was done for the entire available record and at an hourly temporal resolution.

Table 1 lists all background air quality stations located in Norway for which data was retrieved for the temporal component from the AirBase database. Traffic and industrial stations were not used because of their limited spatial representativeness. Therefore, only background stations (urban, suburban, and rural) were considered. The geographical context is shown in Figure 5 which shows the location of all background air quality stations in Norway with suitably long time series for each component.

The background maps are created using a geostatistical technique, namely residual kriging with auxiliary variables. Kriging is an interpolation technique that makes use of a model of spatial autocorrelation (usually in the form of a variogram model) to infer optimal estimates of a variable at a given set of locations (Isaaks and Srivastava, 1989; Cressie, 1993; Goovaerts, 1997; Wackernagel, 2003).

The mapping procedure applied here is based on the previous work by Horálek et al. (2007), Horálek et al. (2010), and Denby et al. (2011a) and involves a linear regression analysis against an auxiliary variable in conjunction with kriging of the residuals. It should be noted that the cited work incorporates a procedure for separately mapping urban and rural areas and then combining the interpolated maps

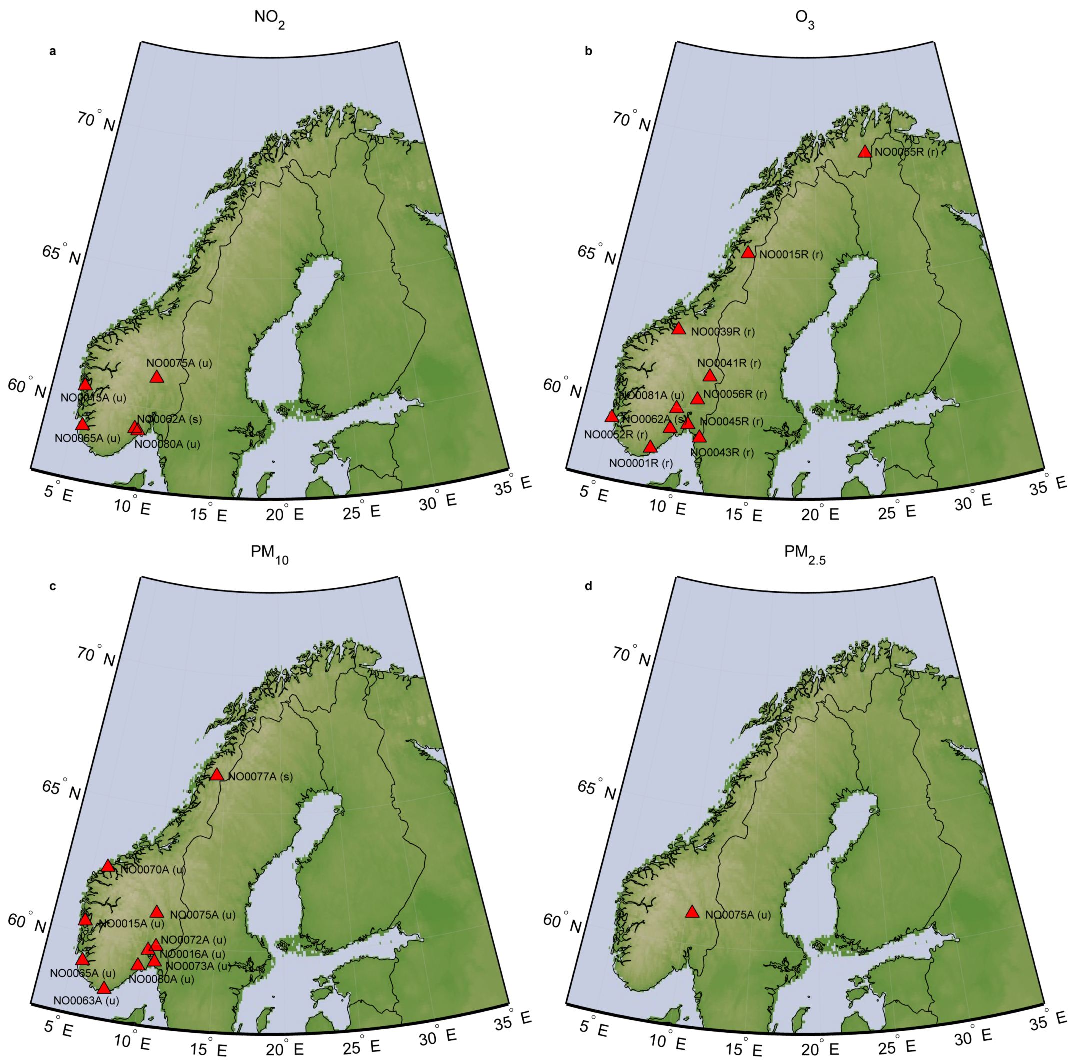

Figure 5 – Location of the Norwegian background air quality stations whose data was used in this project for purposes of spatial mapping and temporal decomposition for a) NO_2, b) O_3, c) PM_{10}, and d) $PM_{2.5}$. The station type is indicated in the label as (u) for urban, (s) for suburban, and (r) for rural. Note that only stations with sufficiently long time series are shown.

using a merging technique. This part of the algorithm was not implemented in the mapping procedure for this project.

The concentration $\hat{Z}(s_0)$ is mapped at a given location s_0 using the model

$$\hat{Z}(s_0) = c + a_1 X_1(s_0) + a_2 X_2(s_0) + \ldots + a_n X_n(s_0) + \eta(s_0) \qquad (1)$$

where $c, a_1, a_2 \ldots a_n$ are parameters of the multiple linear regression and $X_1(s_0) \ldots X_n(s_0)$ are the values of the auxiliary variables used at location s_0. Finally, $\eta(s_0)$ represents the results of the ordinary kriging of the residuals at location s_0. While equation 1 provides a general methodology for incorporating multiple auxiliary variables, only single auxiliary variables were tested here in order to evaluate the impact of each auxiliary variable individually (with one exception mentioned later on). The first step in the process was therefore to establish a linear relationship between the annual average NO_2 concentration at each station and the respective auxiliary variable at each station. This task was performed throughout all background stations in Europe available within AirBase (with exception of those stations used for validation) in order to obtain a representative relationship.

Kriging makes use of a model describing the spatial autocorrelation. Most often, the semivariogram $\gamma(h)$ at a certain lag distance h is used to describe this. Different types of models are then fitted to the empirical semivariogram, with a spherical and Gaussian models probably being the most common.

Several spatially exhaustive auxiliary variables are used which guide the interpolation process in areas of low station density. They are briefly described in the following sections.

One of the primary auxiliary datasets used in the residual kriging process was output from a chemical transport model. More specifically, Europe-wide annual average concentrations were obtained from the Unified EMEP (European Monitoring and Evaluation Programme, (Fagerli et al., 2011)) model (Simpson et al., 2003), which has been developed under the auspices of the Convention on Long-range Transboundary Air Pollution (CLRTAP). The Unified EMEP model is a Eulerian chemical transport model that has been developed at the EMEP/MSC-W (Meteorological Synthesizing Centre West of EMEP) and has been extensively validated (Fagerli et al., 2003; Schulz et al., 2013). Emissions used for the model are described in Vestreng et al. (2007). The modeled annual average concentrations were acquired as a grid with a 50 × 50 km horizontal spatial resolution. They were resampled to the final grid resolution used here of 10 km × 10 km through cubic convolution. This auxiliary variable was used for residual kriging of all species.

As for elevation, the GTOPO30 dataset was used (Gesch et al., 1999). It provides a digital elevation model (DEM) at a spatial resolution of 30 arcseconds. The dataset is available from the United States Geological Survey at `https://lta.cr.usgs.gov/GTOPO30`. This auxiliary variable was used for residual kriging of O_3.

Information about population density was acquired from the Gridded Population of the World (GPW) dataset, which is available at `http://sedac.ciesin.columbia.edu/data/collection/gpw-v3`. The data is available at a spatial resolution of 2.5 arc-minutes. This auxiliary variable was used for residual kriging of NO_2.

Building upon the results documented in Schneider and Obracaj (2013), satellite data of tropospheric NO_2 column was further used as an auxiliary variable as part of the residual kriging procedure. The OMNOe2 product produced by NASA from the OMI (Ozone Monitoring Instrument) sensor was used for this purpose. This auxiliary variable was used for residual kriging of NO_2 only.

2.2 Results

2.2.1 PM_{10}

Figure 6 shows the resulting 2008 to 2010 average concentration of PM_{10} over Norway. The individual annual averages for these years are shown in Appendix A. It is apparent from the figures in the appendix that the interannual variability can be quite large and that therefore the multi-annual average shown in Figure 6 offers a better estimate of the typical situation.

The highest annual average PM_{10} values are found in the greater Oslo area with values of mostly over 15 μg m^{-3}. In the southwestern part of the country around Stavanger

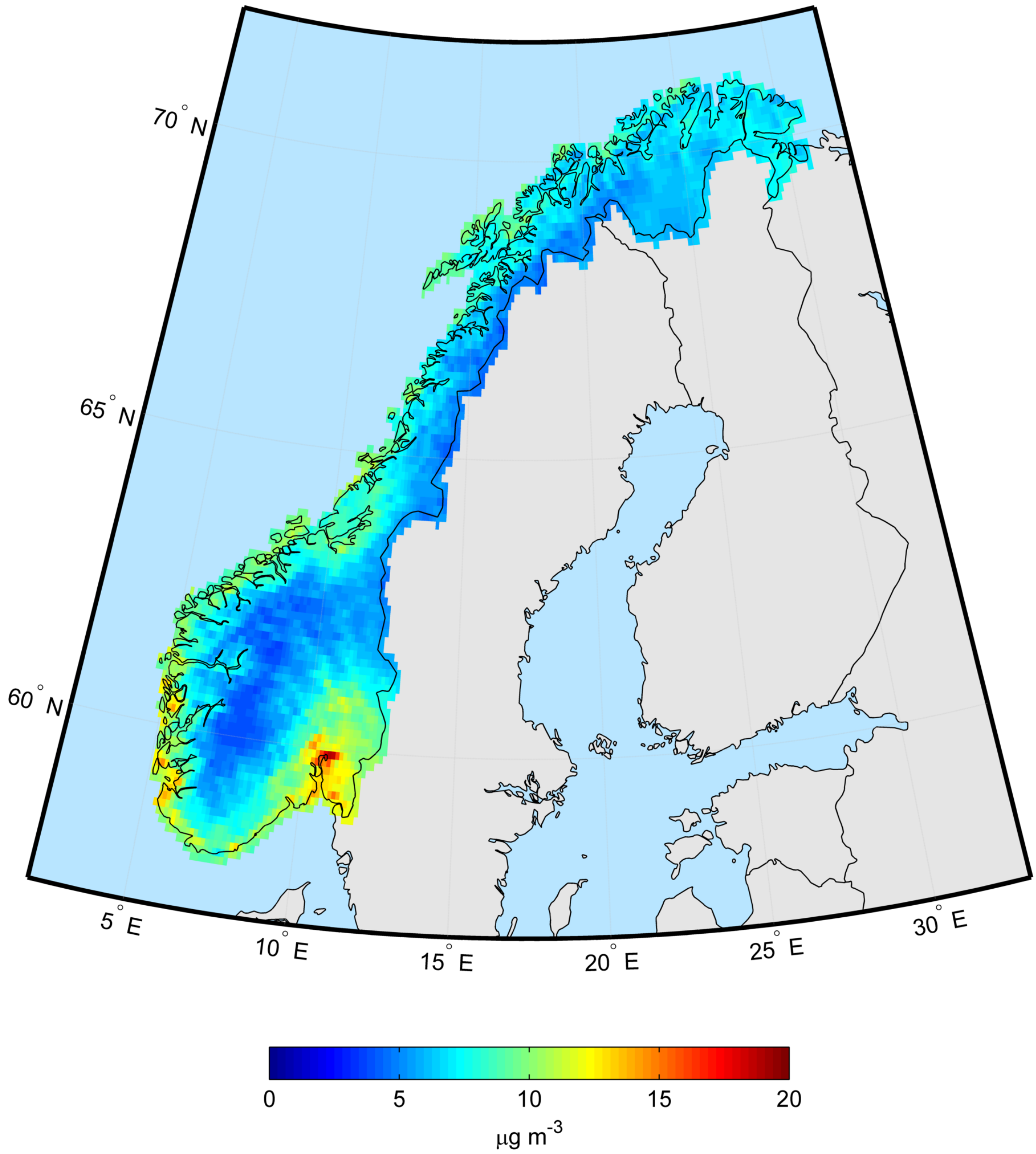

Figure 6 – Average PM_{10} concentrations computed for the years 2008 through 2010 over Norway, as computed from data provided by the ETC/ACM. The individual annual averages for these years are shown in Appendix A.

and Bergen, relatively high concentrations can be found as well. To some extent high PM_{10} concentrations of up to 10 $\mu g\ m^{-3}$ can even be observed along the coast outside of urban areas. These levels are not caused by anthropogenic emissions but are due to sea salt which gets introduced into the background estimates through the EMEP model. In the mountainous areas of Norway as well as in most regions further away from the coastline the annual average PM_{10} concentrations are estimated to be quite low with only around 5 $\mu g\ m^{-3}$.

2.2.2 $PM_{2.5}$

Figure 7 shows the average concentration of $PM_{2.5}$ over Norway computed over the years 2007, 2008, and 2010. The reason why the average was not computed over the period 2008-2010 as for the other species is that $PM_{2.5}$ for the year 2009 was not

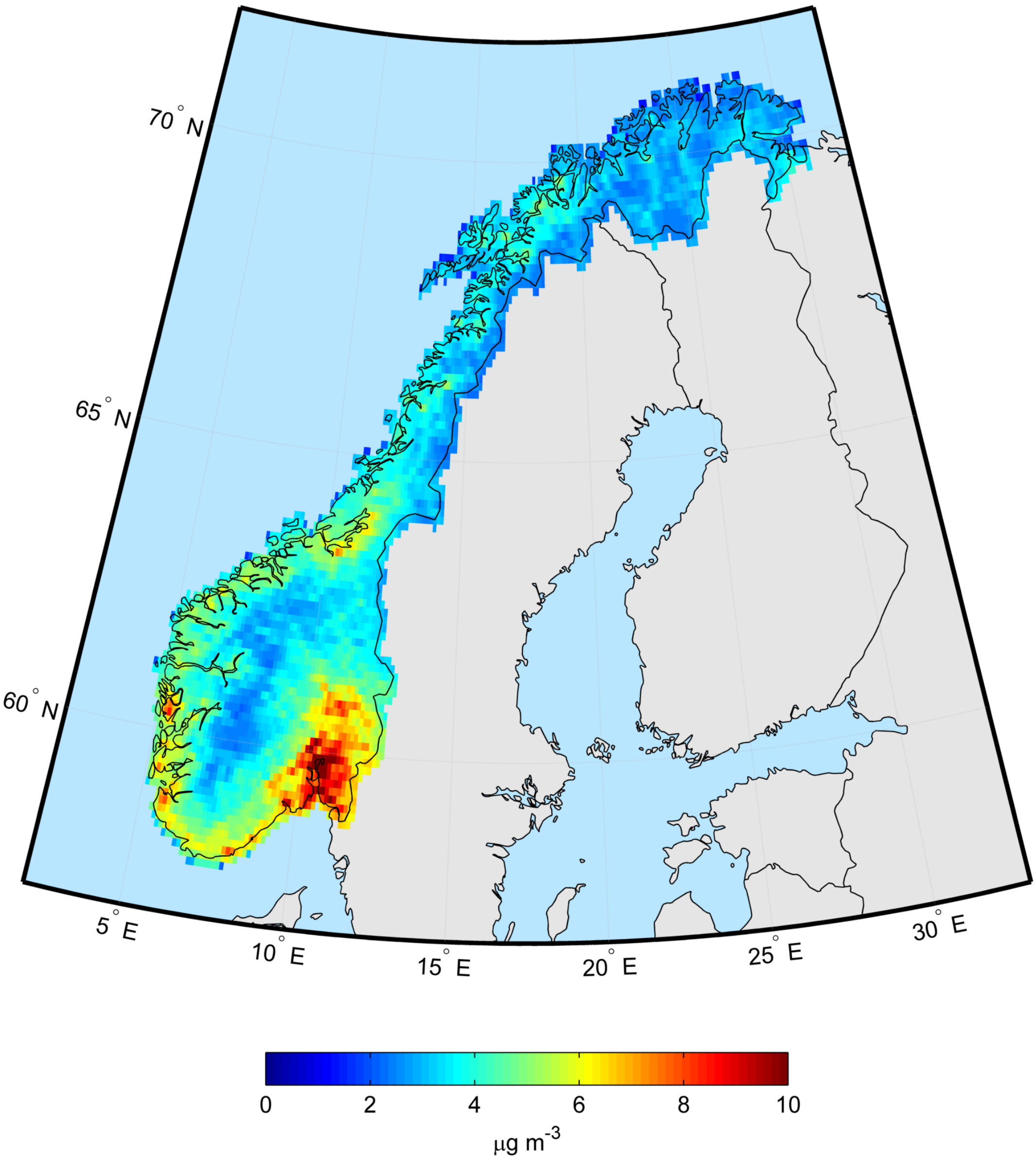

Figure 7 – Average $PM_{2.5}$ concentrations computed for the years 2007, 2008 and 2010 over Norway, as computed from data provided by the ETC/ACM. The individual annual averages for these years are shown in Appendix B

produced by the ETC/ACM. In order to keep the series consistent for computing the 3-year average, it was therefore decided to substitute the year 2009 by 2007 rather than computing the 2009 average in-house using a slightly different methodology and thus possibly introducing a bias in the results. The multi-annual average map for $PM_{2.5}$ looks quite similar to that of PM_{10} (Figure 6) in terms of the major spatial patterns.

Note, however, that due to the overall lower concentrations of $PM_{2.5}$ the color scale for the figures is quite different. Just as for PM_{10}, the highest concentrations can be found in the greater Oslo area. The entire region reaches concentrations consistently over 8 $\mu g\ m^{-3}$. More hotspots can be seen over the major urban areas along the coast, such as Bergen, Stavanger, Kristiansand, and Trondheim. In the less densely populated regions along the coast annual average values of around 6 $\mu g\ m^{-3}$ can be observed. As in the case for PM_{10} these are most likely caused by the impact of

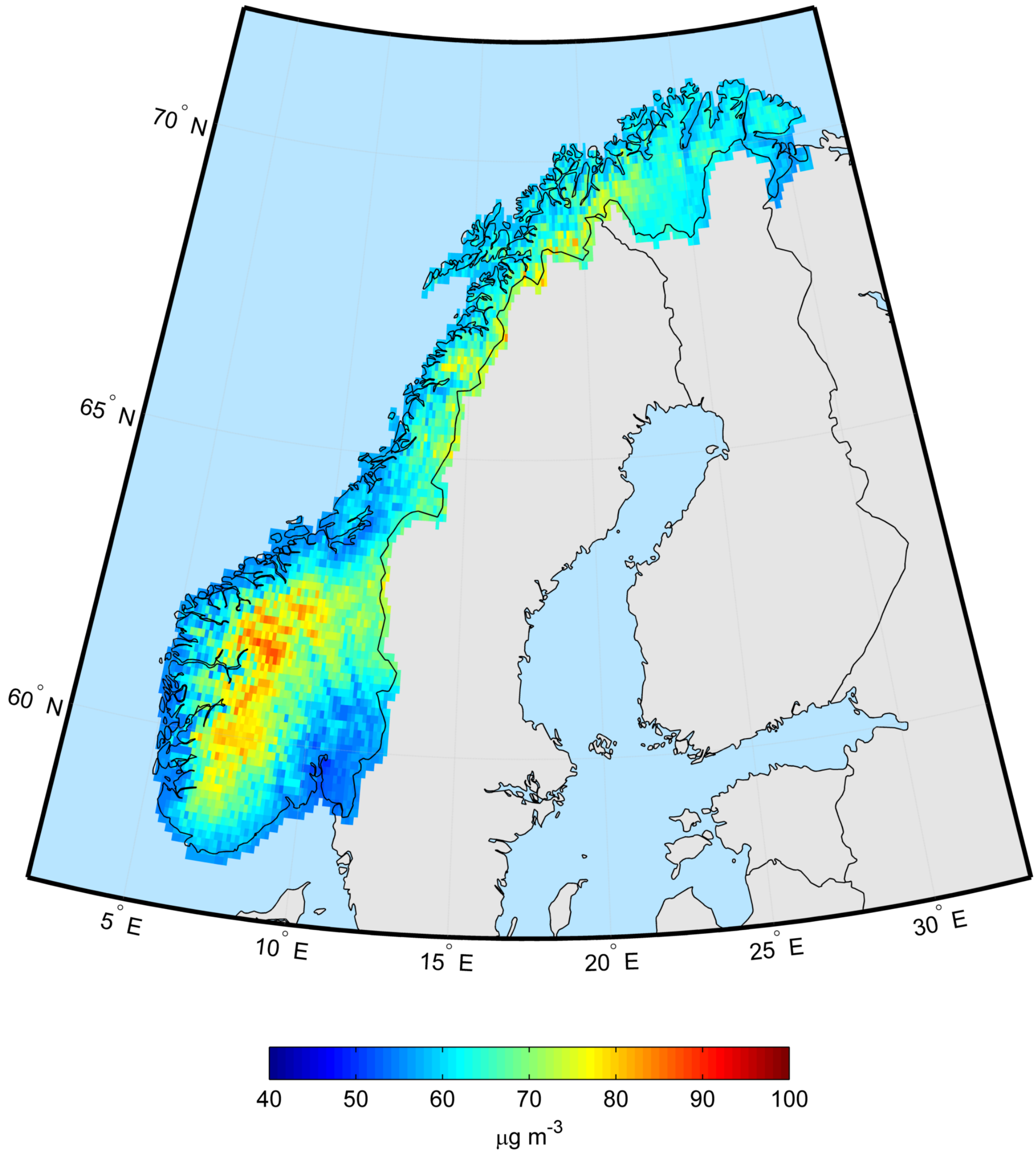

Figure 8 – Average O_3 concentrations computed for the years 2008 through 2010 over Norway, computed using residual kriging of station data combined with spatially distributed auxiliary datasets. The individual annual averages for these years are shown in Appendix C

the EMEP model auxiliary dataset and its representation of sea salt. In the rest of the country, i.e. in the mountainous areas in the southern Norway but also in the Finnmark region very low concentrations of around 2 μg m^{-3} can be observed.

2.2.3 O_3

Figure 8 shows the multi-annual average concentration of O_3, computed for the years 2008 through 2010. Only the EMEP model output and digital elevation data were used for the residual kriging of O_3. A strong dependence on elevation is quite clearly visible in the map with lowlands and valleys exhibiting lower average O_3 concentrations of around 50 μg m^{-3}, whereas the higher elevations further away from the coastline show higher annual average O_3 concentrations of 70 μg m^{-3} to 80 μg

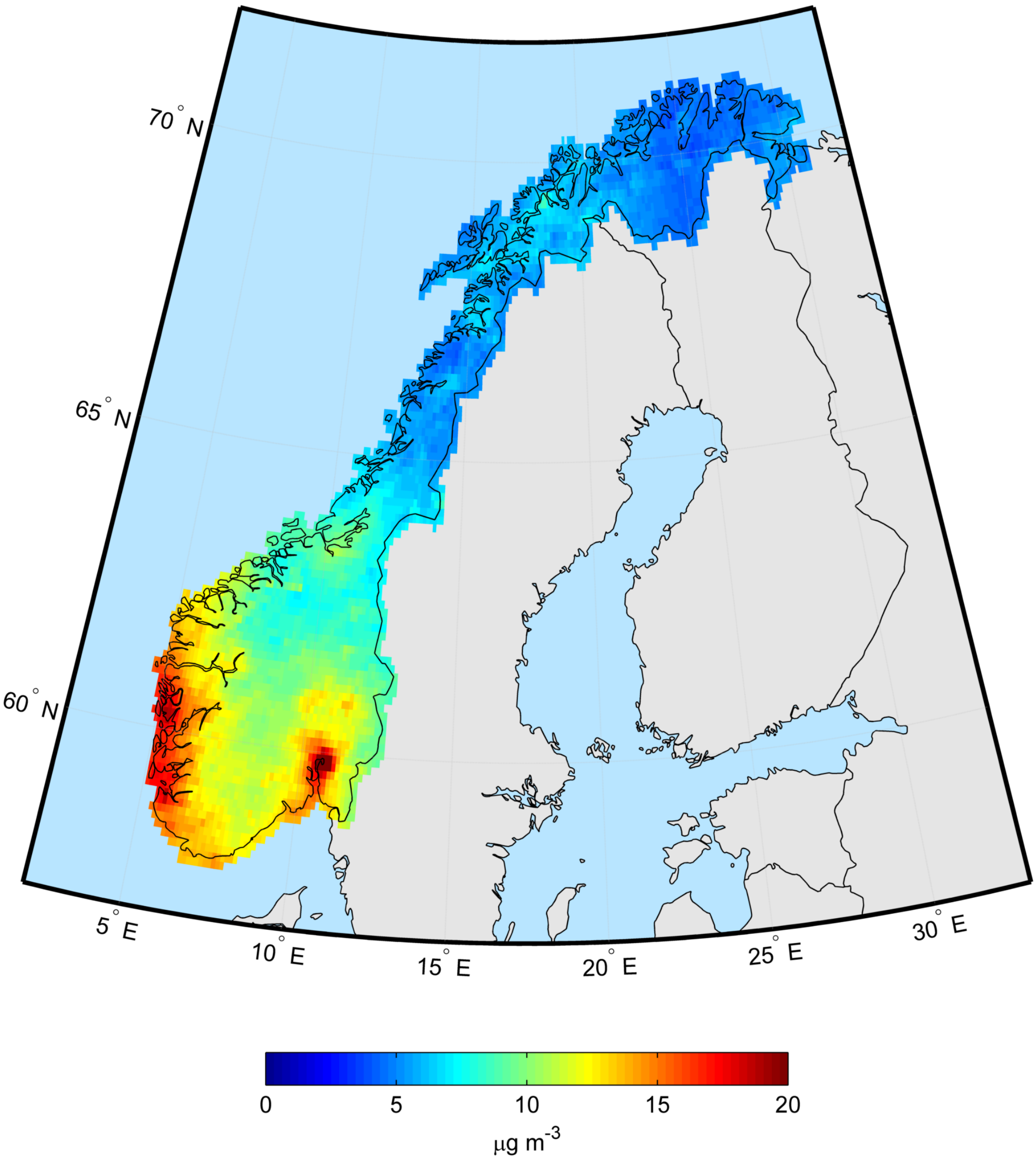

Figure 9 – Average NO_2 concentrations computed for the years 2008 through 2010 over Norway, computed using residual kriging of station data combined with spatially distributed auxiliary datasets. The individual annual averages for these years are shown in Appendix D

m^{-3}, and even reaching 90 $\mu g\ m^{-3}$ in some locations at very high elevations beyond 2000 m.

2.2.4 NO_2

Finally, Figure 9 shows the multi-annual average NO_2 concentrations in Norway, computed for the years 2008 through 2010. As would be expected the Figure shows quite a stark contrast between the more populated south of Norway and the north. The highest concentrations are found directly over Oslo and reach annual averages of over 20 $\mu g\ m^{-3}$ in some locations. Similarly high NO_2 concentration can be found over the area of Bergen and Stavanger. Towards the north the concentrations drop quite rapidly and only reach values between 0 μg m^{-3} and 5 μg m^{-3} anywhere north of Trondheim.

It should be noted here that the spatial patterns computed for NO_2 using residual kriging appear quite different from those obtained within the framework of the ETC/ACM. While NO_2 is usually not mapped operationally by the ETC/ACM, a propotype NO_2 map was created for 2007 and this dataset has been used previously in the system for calculating the background concentrations over Norway. As mentioned before, the mapping procedure used here is based on the ETC/ACM but is simplified in the sense that it does not compute separate maps for urban and rural stations (Horálek et al., 2010) which was found to be impractical in Norway due to the already extremely low station density.

While this simplification has been considered to be reasonable for the other species, the steep gradients between urban and rural regions inherent to NO_2 might not be represented appropriately using the simplified methodology. It was anticipated that such steep gradients in the spatial patterns could to some extent be described using the auxiliary dataset on population density. However, in the multiple linear regression step of the procedure the satellite-based tropospheric NO_2 columns were actually weighted more strongly than population density, thus introducing the generally more smooth gradients that are inherent to the long-term average NO_2 maps produced from satellite data (Schneider and Obracaj, 2013).

Further work will be necessary in future to determine if a variant of the urban/rural split should be implemented over Norway as well or if the satellite-based NO_2 maps used as an auxiliary variable should be replaced by a different variable that can better represent the steep spatial gradients that are generally found for NO_2 between urban and rural areas.

2.3 Updates to website

The data accessible on the project website at `http://www.luftkvalitet.info/ModLUFT/Inngangsdata/Bakgrunnskonsentrasjoner/BAKGRUNNproj.aspx` was updated to include the newly calculated time series based on the 3-year average.

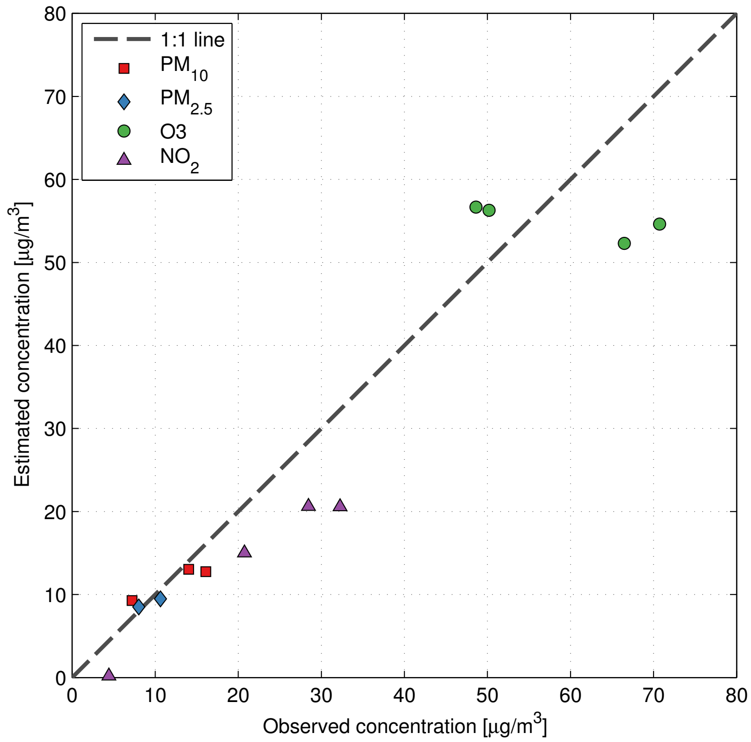

Figure 10 – Scatterplot showing the observed and estimated overall averages for all four species and all validation stations.

3 Uncertainty assessment

Estimating the uncertainty associated with the spatial and temporal predictions provided by the background dataset can be accomplished using two alternative techniques. One way is to take a theoretical approach to uncertainty assessment and separately estimate the uncertainty of the spatial component (e.g. from the kriging uncertainty and the multiple linear regression) and the temporal component (possibly using small-scale temporal variability as a proxy), and then combine the two. This method has the advantage of not requiring access to any validation dataset as it is purely theoretical, however it is quite complex and might not be able to give a good indication of the actual uncertainty a user could expect as it is not based on true observations.

A second method, and also the approach selected here, is to directly compare the final result with station observations that were not previously used in either the spatial or the temporal component. This approach has the advantage that it provides a realistic estimate of the expected error as it based on a true comparison with what would be expected at given location and point in time. The drawback is that it requires previously unused station observations, which, due to the scarcity of air quality stations in Norway, are rare overall. However, for each species there are a small number of stations whose observations have not been reported to the Airbase database for various reasons and which have also not been used within the temporal component for the averaging of the long-term time series. Such stations typically have only relatively short time series, such as stations set up for short-term campaigns, or they are using instrumentation which might not be in line with the requirements for official reporting.

Table 2 – List of stations used for validation of O_3. Note that for some of the stations the exact measurement location was not recorded and therefore an approximate location was assigned (accurate to within about ± 1 km).

Station name	Location	Type	Latitude	Longitude
Drammenselva	Drammen	Urban Background	59.740	10.209
Grev Wedelsplass	Drammen	Urban Background	59.742	10.210
Tjeldbergodden	Tjeldbergodden	Industry	63.410	8.722
Herdleværet	Herdleværet	Industry	60.569	4.816

Figure 10 shows a scatter plot of the average observed and estimated concentration for all validation stations and all species. It is clear from the figure that overall the estimated long-term averages agree quite well with the observations. All points are reasonably close to the 1:1 line. In particular, good agreement can be seen for the validation stations for PM_{10} and $PM_{2.5}$. All four validation points for NO_2 are slightly below the 1:1 line, indicating that the estimated long-term average is too low.

For all of the validation plots shown in the following sections it should be noted that the uncertainty derived from them is likely to represent the worst-case scenario. It is impossible for a relatively crude statistical model such as it was used here to be able to replicate random short-term variability in space and time. For this reason, the system for providing background concentrations contains a smoothing step which removes unwanted high-frequency temporal variability from the original observations using a low-pass filter. This was done in order to provide a better estimate of the general background concentration for a ”typical“ year.

The validation, however, was carried out by comparing the background estimates of a typical year directly with hourly observations at background stations without eliminating their inherent high-frequency temporal variability. If a multi-annual temporal average at the validation stations had been used instead, the validation results likely would have exhibited significantly less error. This was done intentionally in order to provide the user with a very conservative estimate of the accuracy which can be expected from the system.

3.1 O_3

Figure 11 shows time series of the observed and estimated hourly O_3 concentrations at four validation stations throughout Norway. It can be seen that overall the estimate background concentrations follow the observed values quite well, in particular at the *Drammenselva* and *Grev Wedelsplass* stations. The seasonal cycle is modeled quite well for all four stations. At the *Drammenselva* and *Grev Wedelsplass* stations the overall range of the O_3 concentrations throughout the year is captured quite well, although the estimates cannot quite replicate the relatively low minimum values observed during the winter months.

For the stations at *Tjeldbergodden* and *Herdleværet* there are only quite short time series of approximately one year of observations available. The overall range of the observations at *Tjeldbergodden* is captured quite well by the background estimates although the daily maxima are not replicated appropriately. At the *Herdleværet* station the background estimates are biased low and cannot capture the high daytime maxima during the summer.

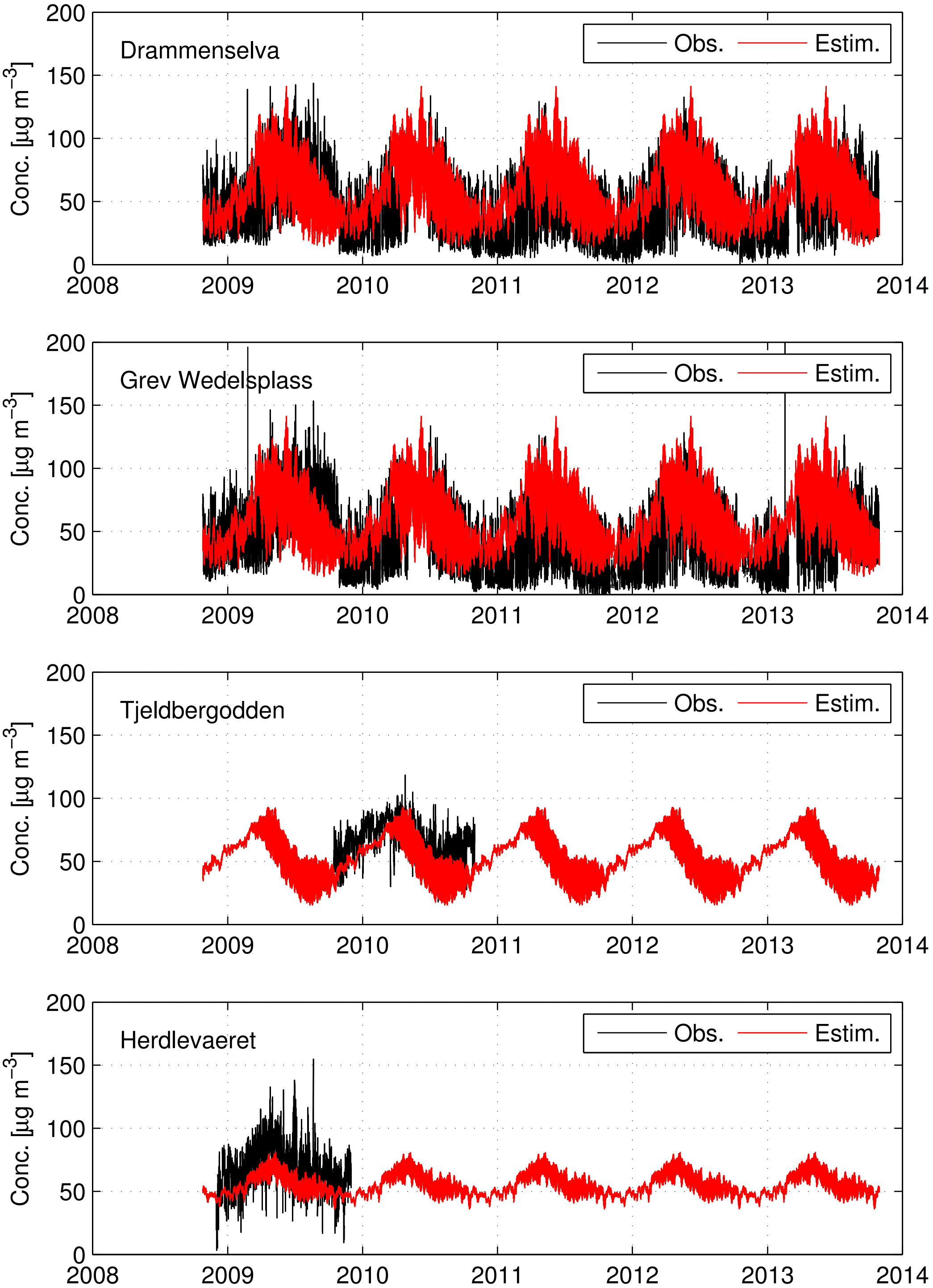

Figure 11 – Time series of observed and estimated hourly O_3 concentrations at four validation stations throughout Norway.

Figure 12 provides scatter cloud plots showing the relationship between the full time series of observed and estimated hourly O_3 concentrations at four validation sites throughout Norway. While the quite large number of validation points makes it challenging to recognize patterns, it appears as if for low concentration less than 50 μg m^{-3} there is not a very strong relationship between the observations and the estimates, although the overall mean value is in the right order of magnitude.

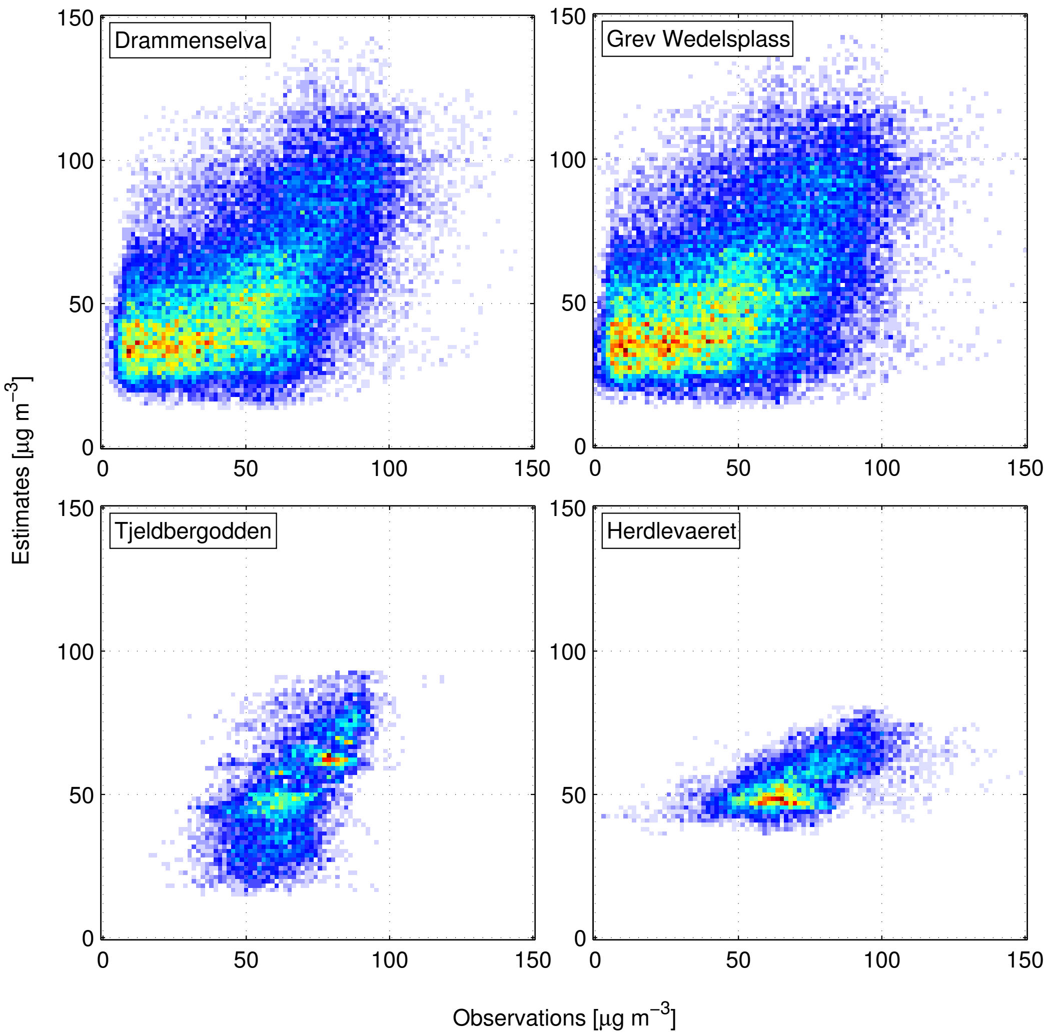

Figure 12 – Scattercloud plots of observed and estimated hourly O_3 concentration at four validation stations throughout Norway. In order to improve the readability of the plots, the color scale indicates the number of pairings found for each bin, with red indicating the highest and light blue/white the lowest number.

For concentrations greater than 50 μg m^{-3} there is a linear relationship between observations and estimates, however it is associated with a significant scatter.

For the *Tjeldbergodden* and *Herdleværet* stations, a linear relationship between the observations and the estimates is considerably more obvious, although the slope is different. The relationship at *Tjeldbergodden* has a slope of close to 1, whereas the relationship at *Herdleværet* has a lower slope and therefore does not quite follow the imaginary 1:1 line.

It should be noted though that the time series of observations at these two stations are significantly shorter than at the *Drammenselva* and *Grev Wedelsplass* stations and it is possible that for a longer time series they would exhibit similar patterns as observed for the latter stations.

Table 3 shows the uncertainty statistics obtained at the O_3 validation stations. The highest absolute uncertainty for O_3 was calculated for the *Grev Wedelsplass* station (25.6 μg m^{-3}), which also translates into the highest relative uncertainty with 52.7 %. The lowest absolute uncertainty with 13.7 μg m^{-3} was found at the *Tjeldbergodden*

Table 3 – Summary statistics of uncertainty estimates at the O_3 validation stations.

Station	Abs. uncertainty [µg m^{-3}]	Rel. uncertainty [%]
Drammenselva	23.5	46.9
Grev Wedelsplass	25.6	52.7
Tjeldbergodden	13.7	20.6
Herdleværet	13.8	19.5
Average	19.2	34.9
Median	18.7	33.8

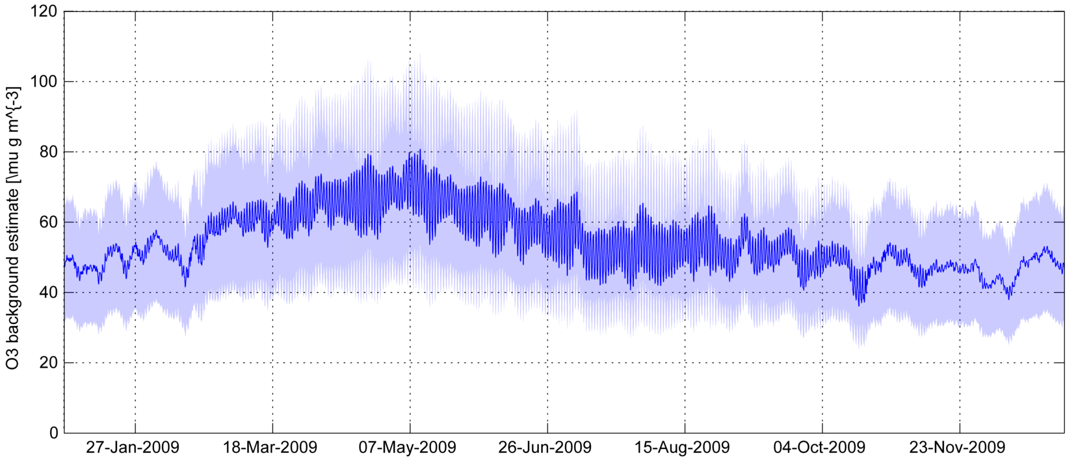

Figure 13 – Example of the estimated O_3 time series of background concentrations at the *Herdleværet* station with uncertainty.

station, whereas the lowest relative uncertainty was calculated for the *Herdleværet* station with a value of 19.5 %. Based on that information, the overall absolute uncertainty of the hourly background estimates for O_3 was estimated as the median to be 18.7 μg m^{-3} with the median relative error calculated as 33.8%.

Figure 13 shows an example of an estimated hourly time series for O_3 and the associated uncertainty computed from the four validation stations.

3.2 PM_{10}

The validation of PM_{10} background estimates was carried out for the three stations listed in Table 4. All three stations are urban background stations and they are located at three distinctly different regions of Norway.

Table 4 – List of stations used for validation of PM_{10}. Note that for some of the stations the exact measurement location was not recorded and therefore an approximate location was assigned (accurate to within about ± 1 km).

Station name	Location	Type	Latitude	Longitude
Fuglenes	Hammerfest	Urban Background	70.670	23.664
Bytårnet skole	Moss	Urban Background	59.432	10.667
Våland	Stavanger	Urban Background	58.961	5.731

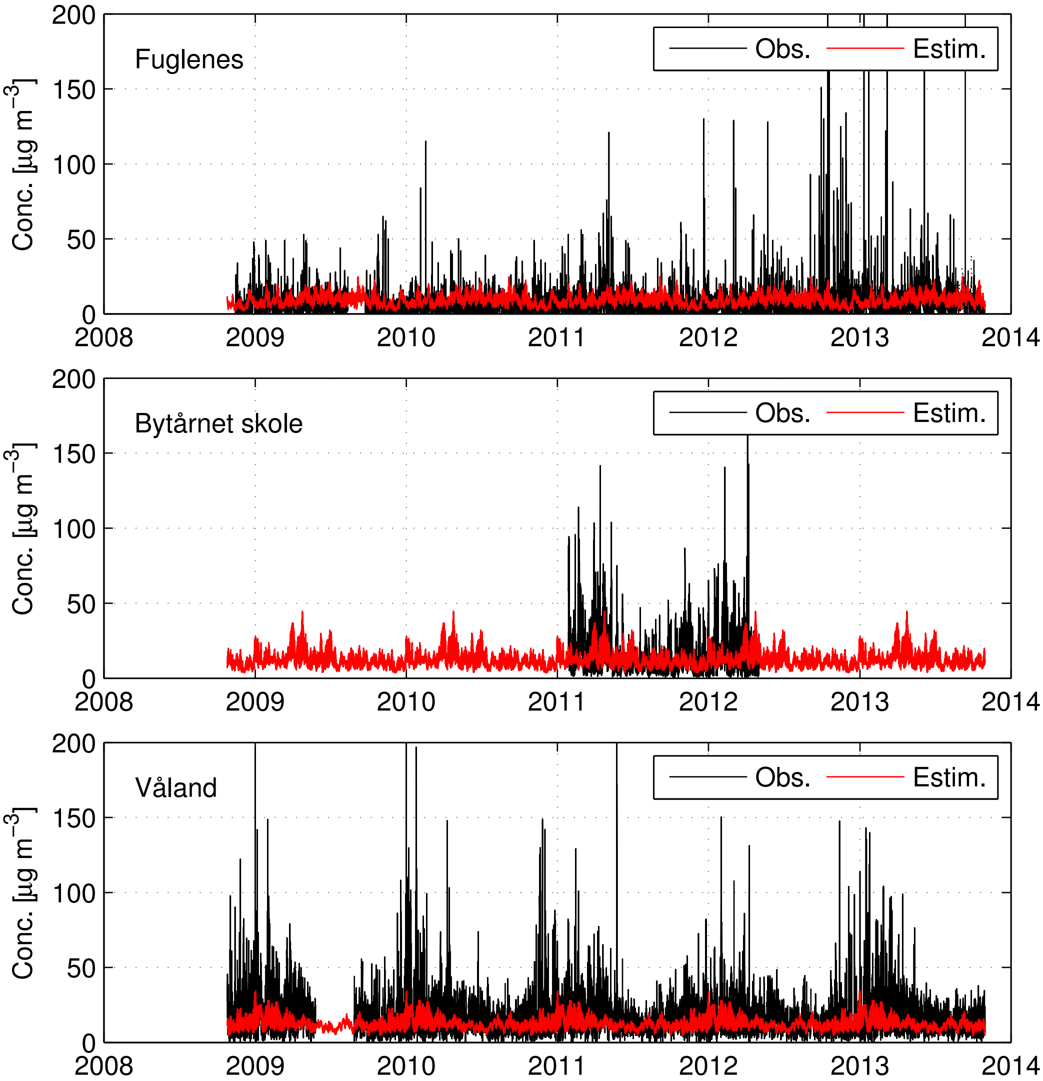

Figure 14 – Time series of observed and estimated hourly PM_{10} concentrations at three validation stations throughout Norway.

Figure 14 shows time series of the hourly observations and background estimates. At the *Fuglenes* validation station the long-term background concentration with values between 0 μg m^{-3} and 30 μg m^{-3} is captured quite well, but individual spikes in the observations reaching beyond 100 μg m^{-3}, which occur particularly in 2012 and 2013 are not. No strong seasonal cycle is visible in either the observations or the estimates.

At the validation station *Bytårnet skole* the time series of observations only encompasses approximately one year. Again, the estimates capture the overall magnitude of the background concentrations quite well but are not able to reproduce the observed peak values which reach well beyond 100 μg m^{-3}. While there is no strong seasonal cycle visible in the background estimates, slightly increased estimated concentrations during the spring month do correspond in time with the observed peak concentrations, which are presumably due to re-suspension from road dust. The relatively high observed concentrations during this period are underestimated by roughly 50% however.

Table 5 – Summary statistics of uncertainty estimates at the PM_{10} validation stations.

Station	Abs. uncertainty [µg m^{-3}]	Rel. uncertainty [%]
Fuglenes	9.9	137.6
Bytårnet skole	13.5	96.1
Våland	11.7	72.4
Average	11.7	102.1
Median	12.3	90.2

Finally, the validation station *Våland* shows a quite similar behavior as the other two stations for PM_{10} in that the background estimates are able to provide a reasonable range for the base concentrations, but fail to reproduce the high variability in observed hourly concentrations throughout the year, which regularly reach beyond 50 μg m^{-3} and in some cases even exceed 100 μg m^{-3}. The annual cycle of PM_{10} concentrations with the highest values during the winter months and lowest values during the summer is well reproduced at these stations – however the overall range of concentrations is not.

It needs to be reiterated at this point that the background estimates are based on station data that had the high-frequency temporal variability intentionally removed, and as such it is not expected for the background estimates to be able to replicate occasional peak events. However, they should be capable of simulating more long-term temporal variability on the order of weeks or months that occurs in all or most years.

The scatter cloud plots corresponding to the PM_{10} validation data can be found in Figure 15. The figures do not indicate very strong relationships between the observed concentrations and the estimated values. The strongest relationship can be observed at the *Våland* station, although the slope of the linear relationship is significantly less than 1, indicating the overall underestimation of hourly background concentrations. The vertical stripes visible in the plot for the *Fuglenes* stations are caused by the observation being only available in integer format rather than as floating point values.

Table 5 shows the uncertainty statistics computed for the three PM_{10} validation stations. The highest absolute uncertainty was observed at the *Våland* station with a value of 11.7 μg m^{-3}, whereas the highest relative uncertainty was found for the *Fuglenes* station, with a value of 138%. With 9.9 μg m^{-3}, the lowest absolute uncertainty was found for the *Fuglenes* station, whereas the lowest relative uncertainty was calculated as 72% for the *Våland* station. Overall, the median absolute uncertainty was found to be 12.3 μg m^{-3} and the median relative uncertainty for PM_{10} was found to be a value of 90.2%.

3.3 $PM_{2.5}$

Only two stations were available for the validation of $PM_{2.5}$ background estimates. The stations and their metadata are listed in Table 6. Both stations are urban background stations and are located in the towns of Moss and Stavanger.

Figure 16 shows the observed and estimated time series of $PM_{2.5}$ at the two validation stations. The length of the observation time series at the station *Bytårnet skole* is relatively short and only encompasses most of 2011 and early 2012. As could be observed for the validation of the PM_{10} time series, the lower level of the observations

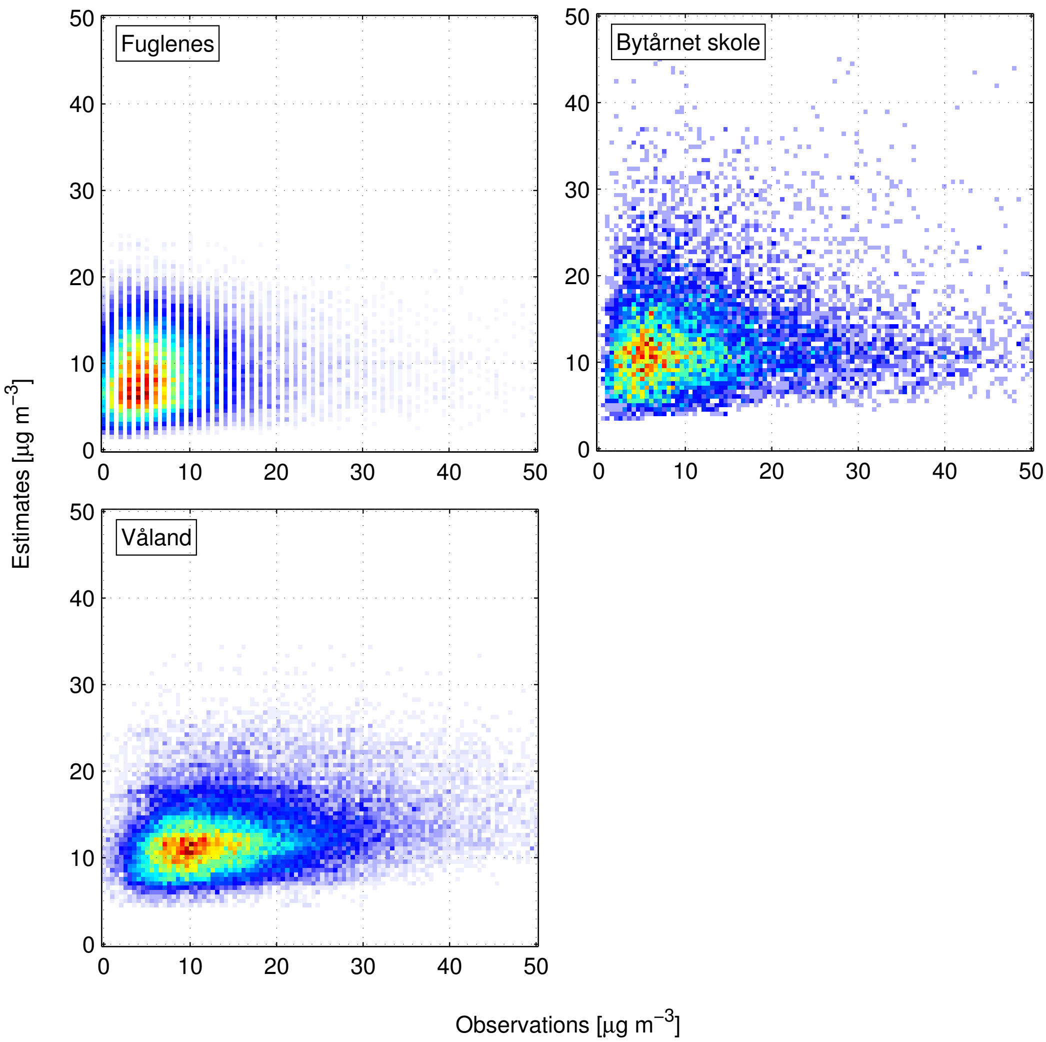

Figure 15 – Scattercloud plots of observed and estimated hourly PM_{10} concentration at four validation stations throughout Norway. In order to improve the readability of the plots, the color scale indicates the number of pairings found for each bin, with red indicating the highest and light blue/white the lowest number. Note that the striping patterns in the case of the Fuglenes station is due to the observations only being reported as integers and not as floating point numbers.

Table 6 – List of stations used for validation of $PM_{2.5}$. Note that for some of the stations the exact measurement location was not recorded and therefore an approximate location was assigned (accurate to within about ± 1 km).

Station name	Location	Type	Latitude	Longitude
Bytårnet skole	Moss	Urban Background	59.432	10.667
Våland	Stavanger	Urban Background	58.961	5.731

is again well captured by the estimates, however the overall range is underestimated. Many hourly observations at *Bytårnet skole* reach values above 50 μg m^{-3} whereas the highest predicted hourly background concentrations in the winter and spring months reach roughly 30 μg m^{-3}.

The *Våland* station provides a significantly longer time series of observations, ranging from 2009 all the way through 2013. The comparison between observations and

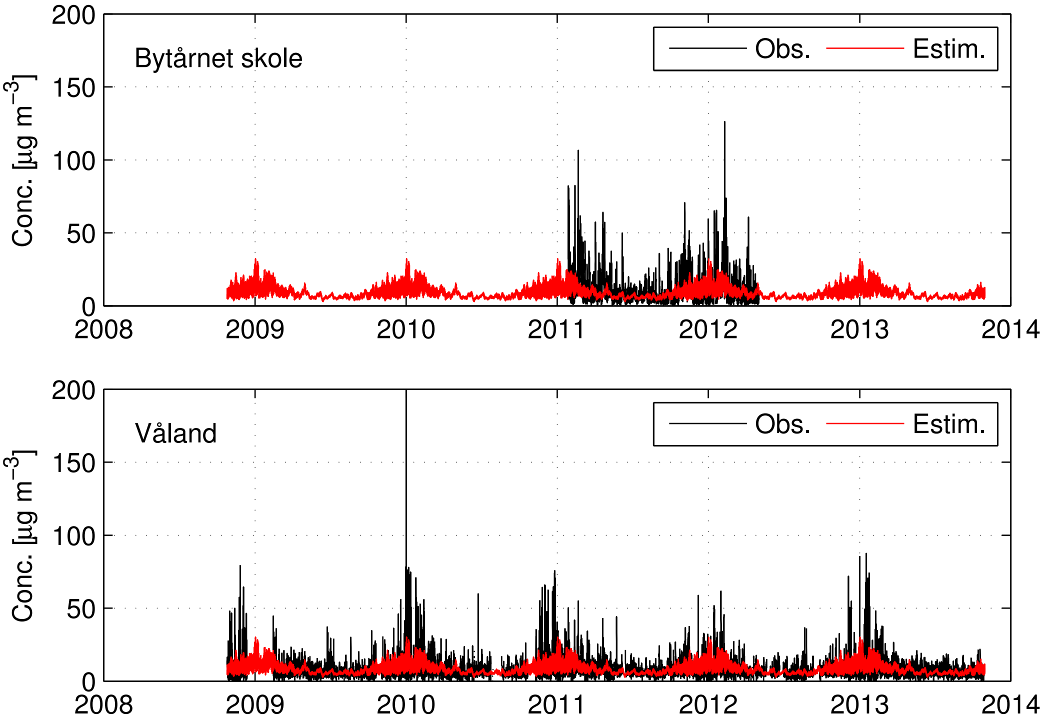

Figure 16 – Time series of observed and estimated hourly $PM_{2.5}$ concentrations at two validation stations throughout Norway.

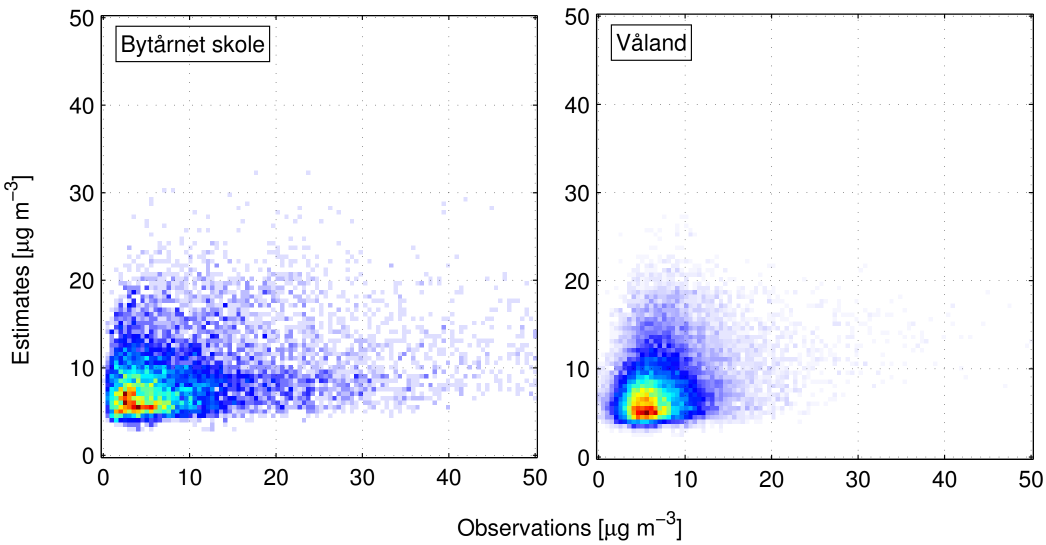

Figure 17 – Scattercloud plots of observed and estimated hourly $PM_{2.5}$ concentration at two validation stations throughout Norway. In order to improve the readability of the plots, the color scale indicates the number of pairings found for each bin, with red indicating the highest and light blue/white the lowest number.

estimations shows a similar picture as for the *Bytårnet skole* station. The overall level of $PM_{2.5}$ concentration is captured quite well, but the total range of observations is underestimated, particularly during the winter months when the estimate hourly values only reach approximately 50% of the hourly value of the observations in many cases.

Table 7 – Summary statistics of uncertainty estimates at the $PM_{2.5}$ validation stations. Note that in this case since there are only 2 stations, median and mean are identical.

Station	Abs. uncertainty [μg m^{-3}]	Rel. uncertainty [%]
Bytårnet skole	10.2	95.7
Våland	6.5	80.7
Average	8.3	88.2
Median	8.3	88.2

Table 8 – List of stations used for validation of NO_2. Note that for some of the stations the exact measurement location was not recorded and therefore an approximate location was assigned (accurate to within about ± 1 km).

Station name	Location	Type	Latitude	Longitude
Drammenselva	Drammen	Urban Background	59.740	10.209
Grev Wedelsplass	Drammen	Urban Background	59.742	10.210
Fuglenes	Hammerfest	Urban Background	70.670	23.663
Våland	Stavanger	Urban Background	58.961	5.731

Figure 17 shows the corresponding scatter cloud plots. While they do not indicate very strong relationships between observations and estimations at either station, they do show that the majority of hourly pairs in the 0 μg m^{-3} to 10 μg m^{-3} range (red areas in the plot) are located very close to the 1:1 line, thus indicating that the estimates are very close to the observed values.

Interestingly, while high observations of more than 20 μg m^{-3} tend to be underestimated, there is a slight overestimation of very low concentrations of less than 5 μg m^{-3}. This is particularly obvious in the case of the *Bytårnet skole* validation station. This behavior is most likely due to the smoothing procedure using a low-pass filter which was applied during the calculation of the background estimates.

It should be noted here that only a single station in Norway fulfilled all the originally adopted criteria (see Schneider et al. (2011)) of a sufficiently long time series for being used for calculating the annual and daily temporal patterns for $PM_{2.5}$. Therefore, the annual time series provided by the estimation system will have the same temporal variability throughout all of Norway and will only differ in terms of their absolute values.

Table 7 shows the uncertainty values derived from the two validation stations. Both the lowest absolute and relative uncertainty was found for the *Våland* station, with 6.5 μg m^{-3} and 80.7%, respectively. The highest absolute and relative uncertainties were found at the *Bytårnet skole* station. The overall uncertainty derived from these two validation stations was 8.3 μg m^{-3} or 88.2%.

3.4 NO_2

A total number of four stations were available for validation of the background estimates of NO_2. All four are urban background stations. The two stations *Drammenselva* and *Grev Wedelsplass* are located very close to each other in Drammen, whereas the other two stations are located in Hammerfest and Stavanger. For a list of the stations including their metadata see Table 8.

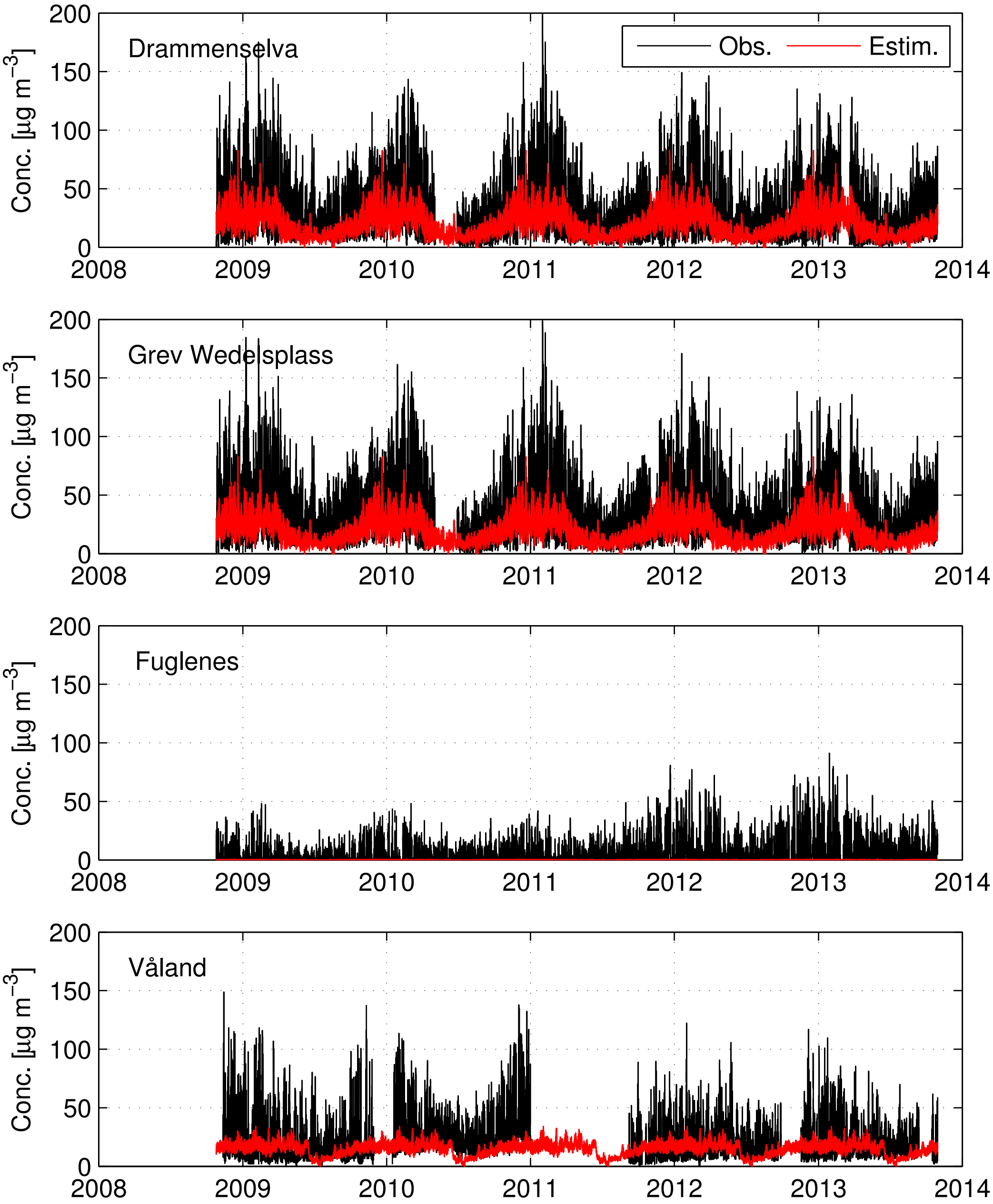

Figure 18 – Time series of observed and estimated hourly NO_2 concentrations at four validation stations throughout Norway.

Figure 18 shows the time series of the observations and background estimates of NO_2 at the four stations. In contrast to the figures shown for some of the other species, a distinctly different behavior can be observed at several of the NO_2 validation stations (with exception of the two Drammen stations).

The behavior at both the *Drammenselva* and *Grev Wedelsplass* stations is nearly identical. The background estimates perform very well at simulating the annual cycle with a winter maximum and a summer minimum. However, the estimates fail to capture the daily peak concentrations, particularly in the winter months, and only reach approximately 50% of the observed values in many cases. At the *Fuglenes* station, however, the situation is entirely different. Here, the estimates are essentially zero throughout

Table 9 – Summary statistics of uncertainty estimates at the NO_2 validation stations.

Station	Abs. uncertainty [μg m^{-3}]	Rel. uncertainty [%]
Drammenselva	20.1	70.8
Grev Wedelsplass	20.8	64.6
Fuglenes	7.5	168.8
Våland	15.6	75.1
Average	16.0	94.8
Median	17.9	72.9

the entire period and completely fail provide values that are reasonably close to the observations. The reason for this behavior is an extremely low and unrealistic annual average NO_2 estimate for Fuglenes coming out of the spatial component. While this value is scaled by the typical annual time series, the predicted annual mean value for this grid cell is so low that the scaling does not make a difference. At the *Våland* station, the estimates tend to be on the low side compared to the observations and do not capture the high hourly maxima. The range of the spans 0 μg m^{-3} to 30 μg m^{-3}, whereas the observations frequently exceed 50 μg m^{-3} in summer and 100 μg m^{-3} in the winter months. There is no strong relationship between observations and estimates in terms of the annual cycle.

Figure 19 shows the corresponding scatter cloud plots. At both the *Drammenselva* and *Grev Wedelsplass* stations a weak but clear linear relationship between the observations and estimates is visible. The slope of the linear relationship is less than 1 in both cases thus confirming the conclusion from Figure 18 that the estimates are biased low. As would be expected from the time series plots, the scatter cloud plot at the Fuglenes station does not show a relationship between observation and estimates due to a complete underestimation of the annual mean NO_2 value at this location with already very low observed NO_2 concentrations.

The scatter cloud plot at the *Våland* validation station shows overall a reasonably good correspondence between observations and estimates in terms of the overall magnitude of the concentrations. However, no clear linear relationship is visible. For high observed concentrations of over 40 μg m^{-3}, the estimates are generally around 20 μg m^{-3} and thus confirm the clear underestimation that was already visible in the time series plot (Figure 18).

Table 9 shows the uncertainty statistics computed at the four NO_2 validation stations. The highest absolute uncertainty with 20.8 μg m^{-3} was found at the *Grev Wedelsplass* station, with the *Drammenselva* station a close second. The lowest absolute uncertainty was found at the *Fuglenes* station, however this is only due to the very low average NO_2 concentrations at this location. When this value is converted into a relative uncertainty it becomes nearly 170 %, thus clearly reflecting that the estimates at Fuglenes are not usable.

However, the relative uncertainty for hourly estimates found at the other validation stations was around 70% and thus represents a much more reasonable value given that the estimates are supposed to indicate the average background concentration for a typical year and are not intended to replicate the exact observations for a specific time and location. The median relative uncertainty for NO_2 was found to be 72.9% and this value was further used for estimating the uncertainty estimates of NO_2 at other locations.

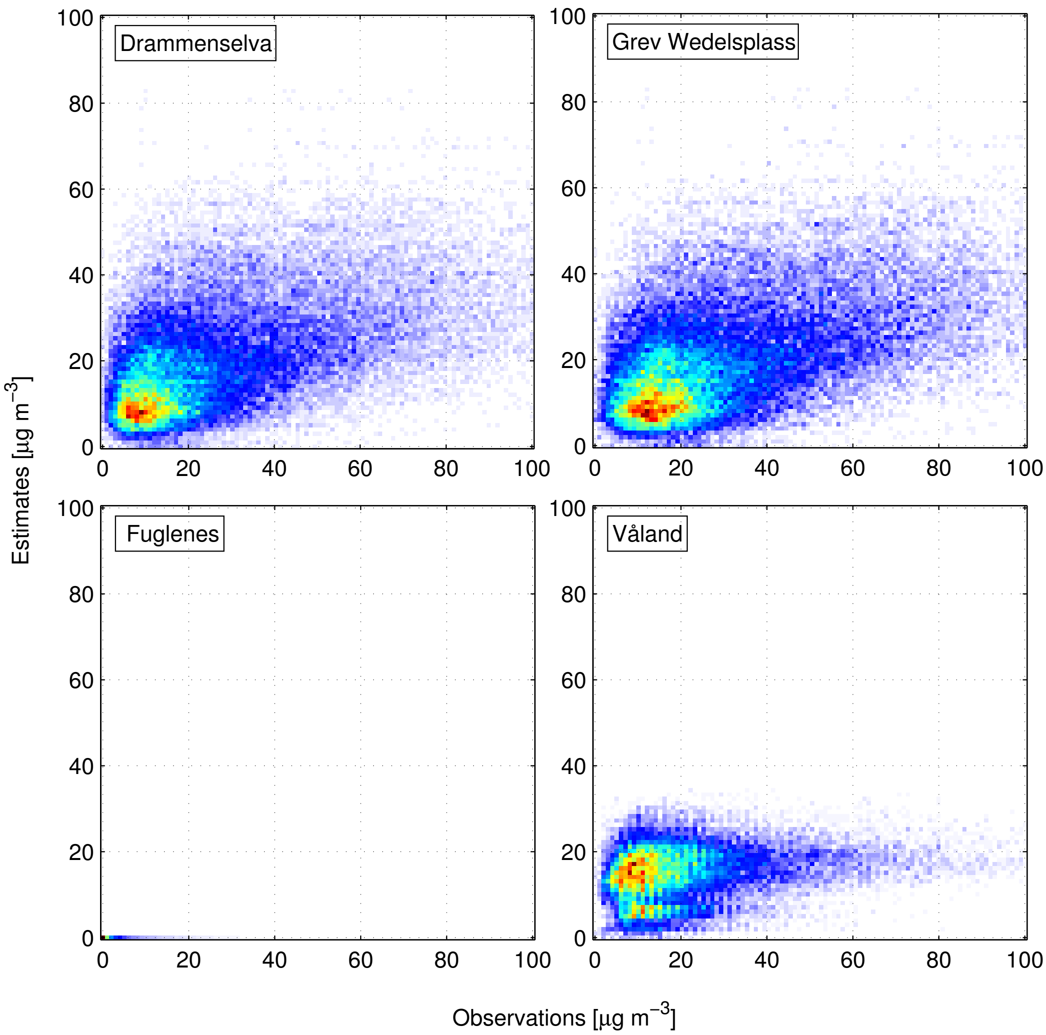

Figure 19 – Scattercloud plots of observed and estimated hourly NO_2 concentration at four validation stations throughout Norway. In order to improve the readability of the plots, the color scale indicates the number of pairings found for each bin, with red indicating the highest and light blue/white the lowest number.

3.5 Updates to website

The project website located at `http://www.luftkvalitet.info/ModLUFT/Inngangsdata/Bakgrunnskonsentrasjoner/BAKGRUNNproj.aspx` was updated to better reflect the uncertainties involved in the estimation of the background concentrations. This was done separately for each species based on the statistics derived at the validation stations (shown in the last section). More specifically, the species-dependent median relative uncertainty derived from the validation stations was used to visualize the uncertainty for the four species.

The time series provided on the website are now shown together with the uncertainty estimates in order to directly give the user a feel for the possible error associated with the data. Figure 20 shows an illustrative example of how the uncertainty estimates are provided with the time series plots in the updated website. Note that the uncertainty estimates given there are just an example and do not necessarily reflect the real values.

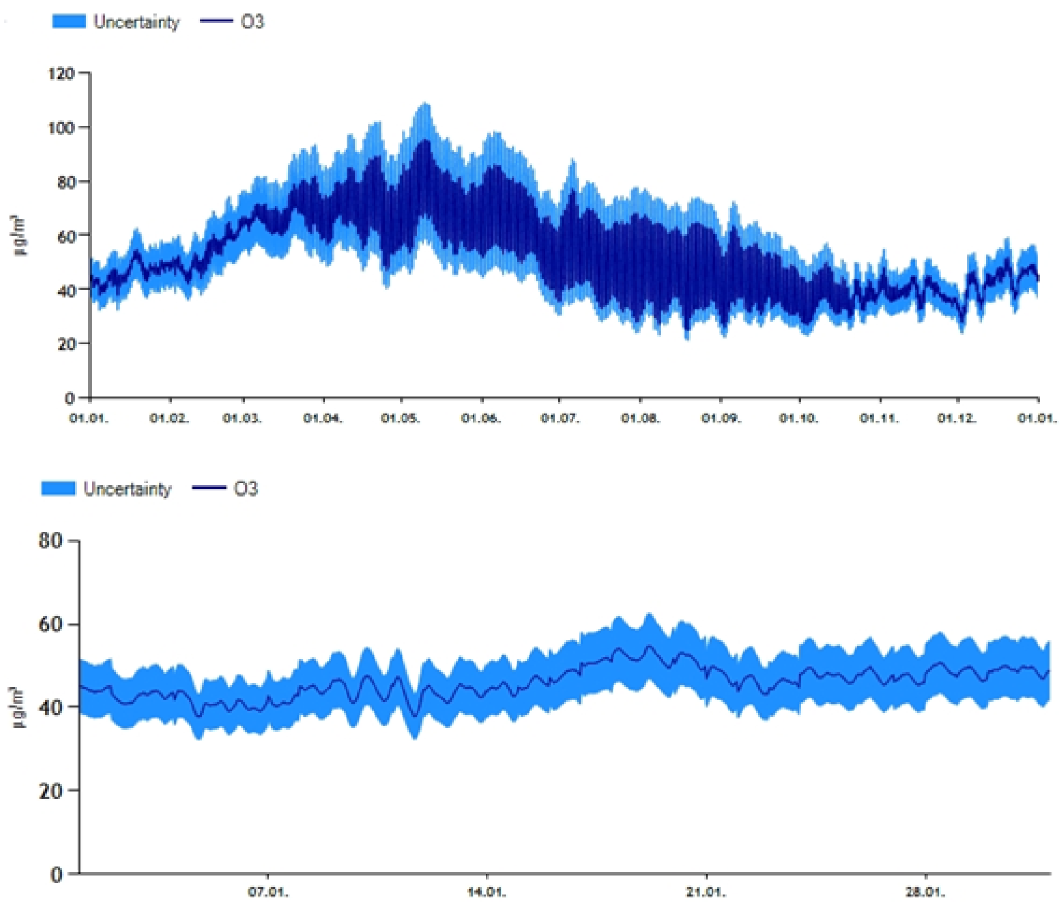

Figure 20 – Examples showing how the uncertainty for time series is shown on the website. Note that the uncertainty values shown here do not reflect the actual values but rather are for illustration purposes.

4 Summary and Recommendations

4.1 Summary

A system for providing approximate spatial and temporal estimates of the surface background concentrations of PM_{10}, $PM_{2.5}$, NO_2, and O_3 for a typical year in Norway has been established at NILU in recent years. In 2013, the system was further improved and expanded by carrying out two main tasks: Firstly the spatial component of the system was extended from previously a single year to a 3-year average, thus decreasing the impact of inter-annual variability. Secondly, a preliminary validation of the background estimates was carried out and an approximate uncertainty was calculated for four species in the dataset and is now communicated to the user on the project website.

The validation results indicate that overall the average estimated concentrations follow the average observed concentration fairly well (see Figure 10). This is particularly true for PM_{10} and $PM_{2.5}$. The averaged estimates for O_3 and NO_2 also follow the averaged observations relatively closely, although NO_2 is clearly underestimated at all four validation stations.

In terms of quantitative uncertainty estimates for the hourly estimates at the level of individual species, O_3 is the parameter which was found to have the lowest uncertainty of all four species. While the median absolute uncertainty for hourly O_3 estimates was found to be 18.7 μg m^{-3}, the median relative uncertainty was only 33.8 %. Both PM_{10} and $PM_{2.5}$ had significantly higher uncertainties, with a median relative uncertainty for the hourly estimates of 90 % and 88 %, respectively. Finally, as already mentioned, the hourly estimates for NO_2 also showed quite high relative uncertainties with a value of 73 %.

4.2 Recommendations for follow-up work

One of the main recommendations for follow-up work is to establish an ongoing update mechanism of the system with the newest available data on an annual basis in future. For the temporal component this can be easily accomplished by utilizing the latest air quality information from the European Airbase database for the previous year and thus continuously lengthen the available time series of station data in Norway and further increase the representativeness of the annual average computed at the stations, which represents the temporal variability of a typical year.

For the spatial component it is suggested to continuously update the system with the most recent data while at the same time keeping the 3-year averaging period for the spatial component. This can be accomplished by establishing a rolling mean over the last 3 years.

In order to reduce the cost for continuous updating and keeping the associated resources to a minimum, it is further recommended to automate the updating procedure to the largest extent possible. This can be accomplished relatively easily for many parts of the system, and in fact for quite a few tasks generic code has already been implemented and only a few modifications need to be carried out to fully automate them. This applies in particular to the update mechanism of the temporal component, which can be completely automated to include the newest data on an annual basis as long as the data formats used by EEA's Airbase database do not change significantly.

Other parts of the system, however, cannot be fully automated, for instance the geostatistical interpolation procedure for the spatial component, which requires some manual intervention and control in correctly estimating the semivariogram model for properly describing the spatial autocorrelation of the station dataset.

As for further recommendations, it was noted during the validation phase that the spatial component provides somewhat unrealistic results in some cases, and in particular the spatial patterns obtained when mapping the background concentrations for NO_2. The gradients between urban and rural areas are much smoother than would be expected for this species. It was attempted to address this problem to some extent by including a population density dataset as an auxiliary dataset in the NO_2 mapping procedure but the impact was surprisingly low. It is therefore recommended to investigate if a separate rural/urban mapping approach with a subsequent merging as it is carried out operationally by the ETC/ACM would be beneficial, at least for the NO_2 mapping.

It is crucial that users of the background dataset and the online application are aware of the substantial uncertainties of the provided estimates. A first step was taken in this work by calculating the approximate uncertainty associated with the different air pollutants and displaying the uncertainty in the datasets provided through the project website. Nonetheless it is important for the users to always keep in mind that the estimates provided are only indications of typical conditions and are not able to accurately reflect the true hourly concentrations at a given point in space and time.

It is thus suggested that the estimates are used only for general guidance when addressing air quality issues in Norway. It is highly discouraged to use the data for critical quantitative applications without taking into account the significant uncertainty associated with the data.

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Appendix

A PM_{10} annual averages

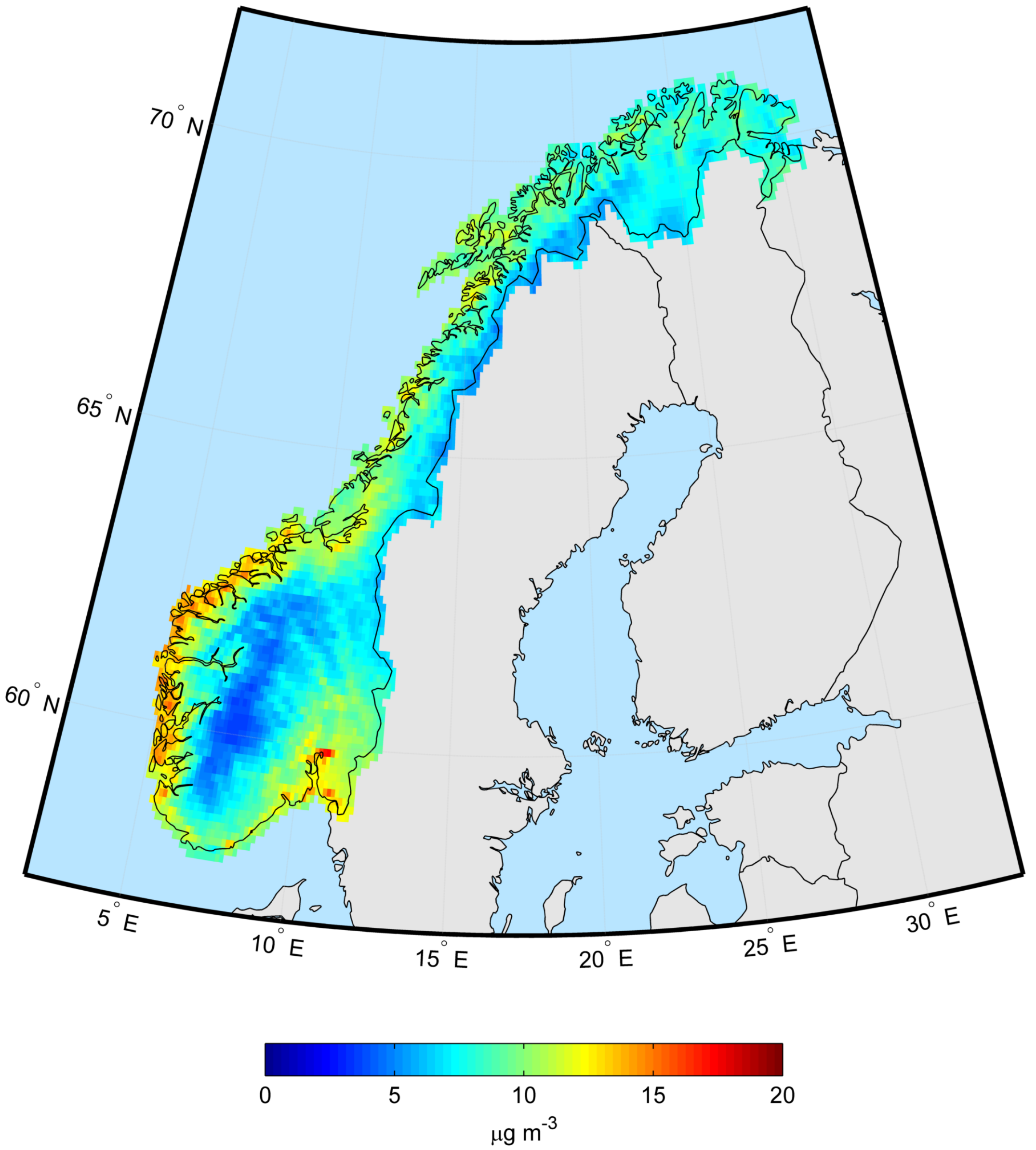

Figure 21 – Annual average PM_{10} concentrations for 2008 over Norway.

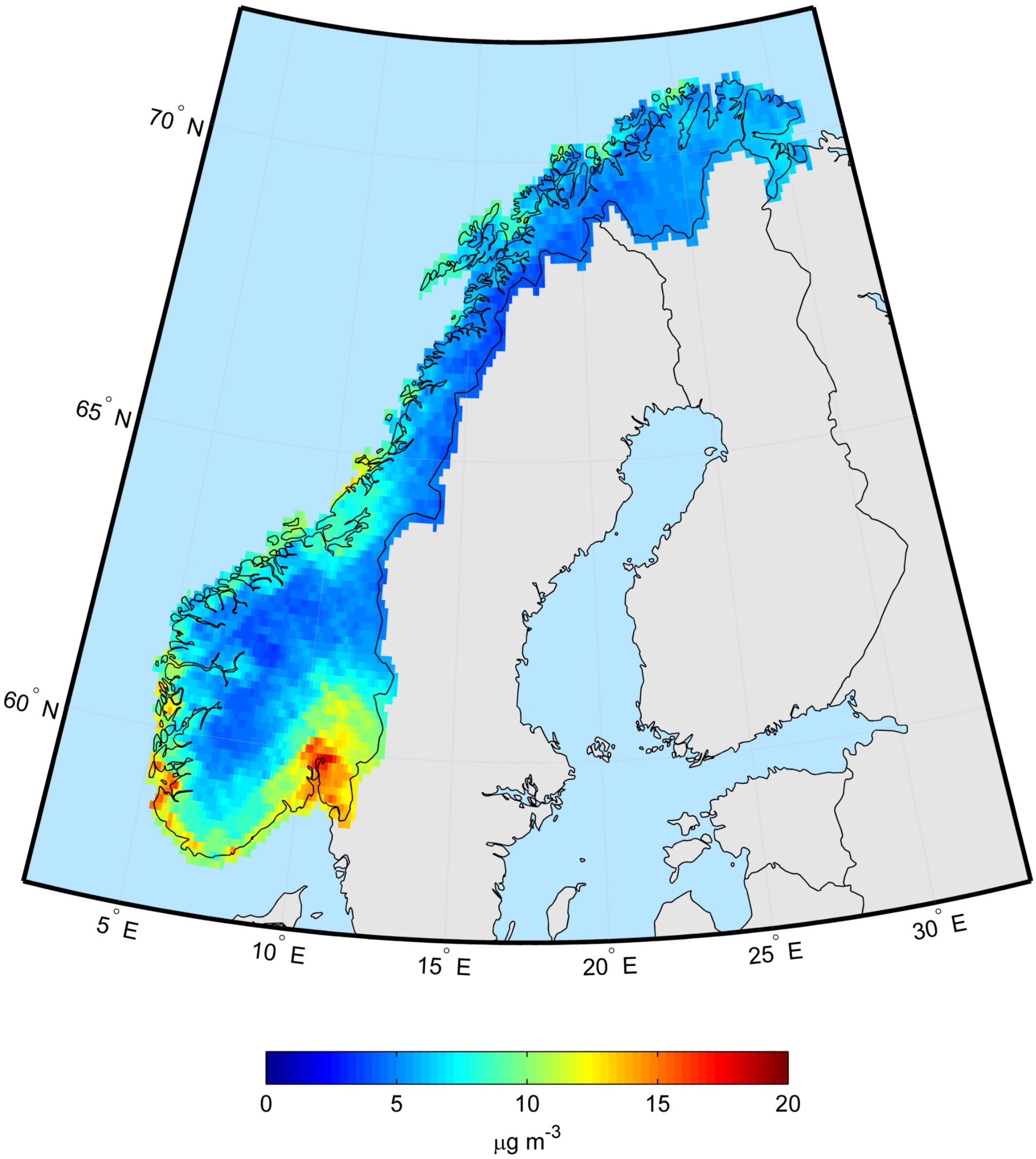

Figure 22 – Annual average PM_{10} concentrations for 2009 over Norway.

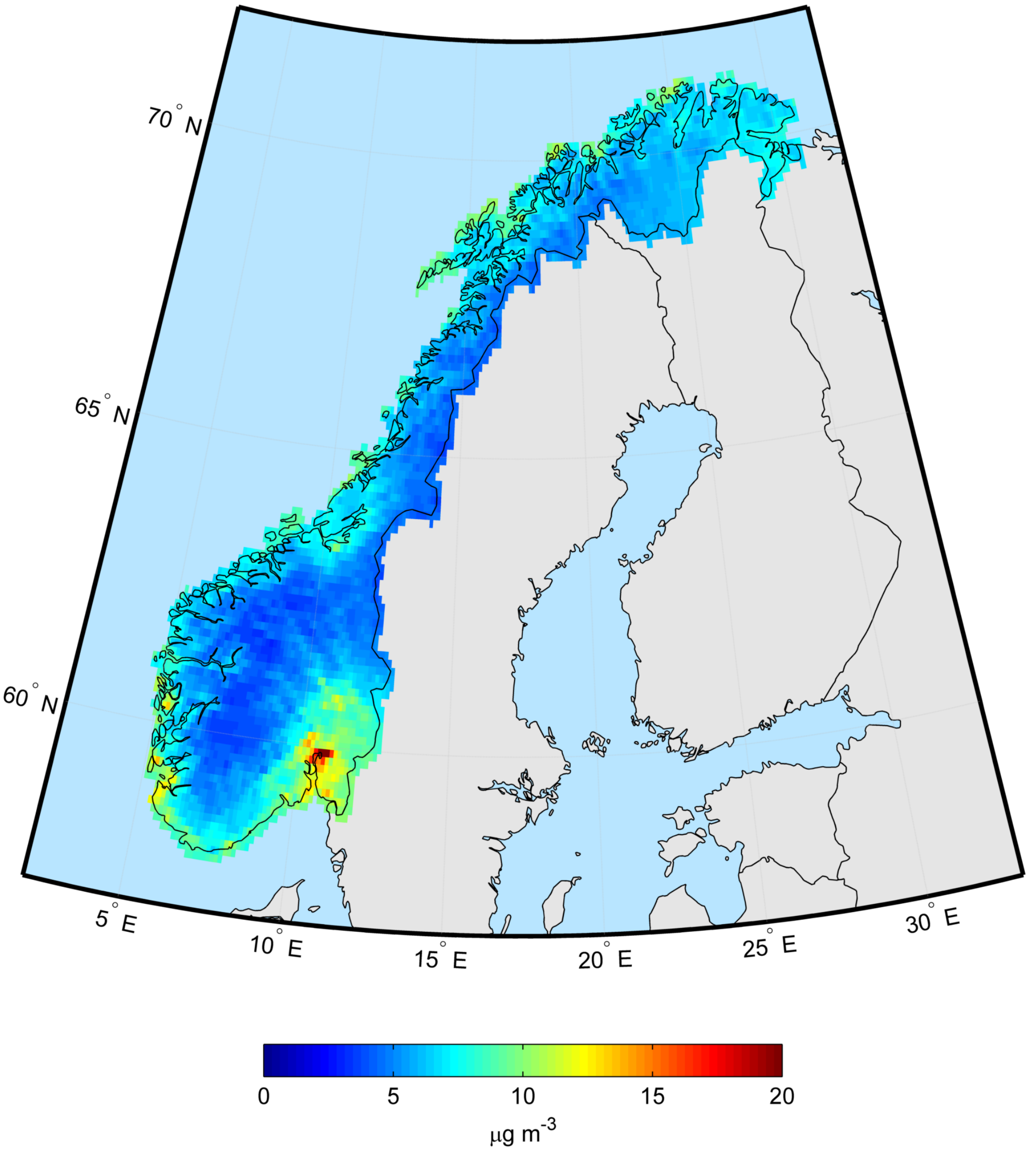

Figure 23 – Annual average PM_{10} concentrations for 2010 over Norway.

B PM$_{2.5}$ annual averages

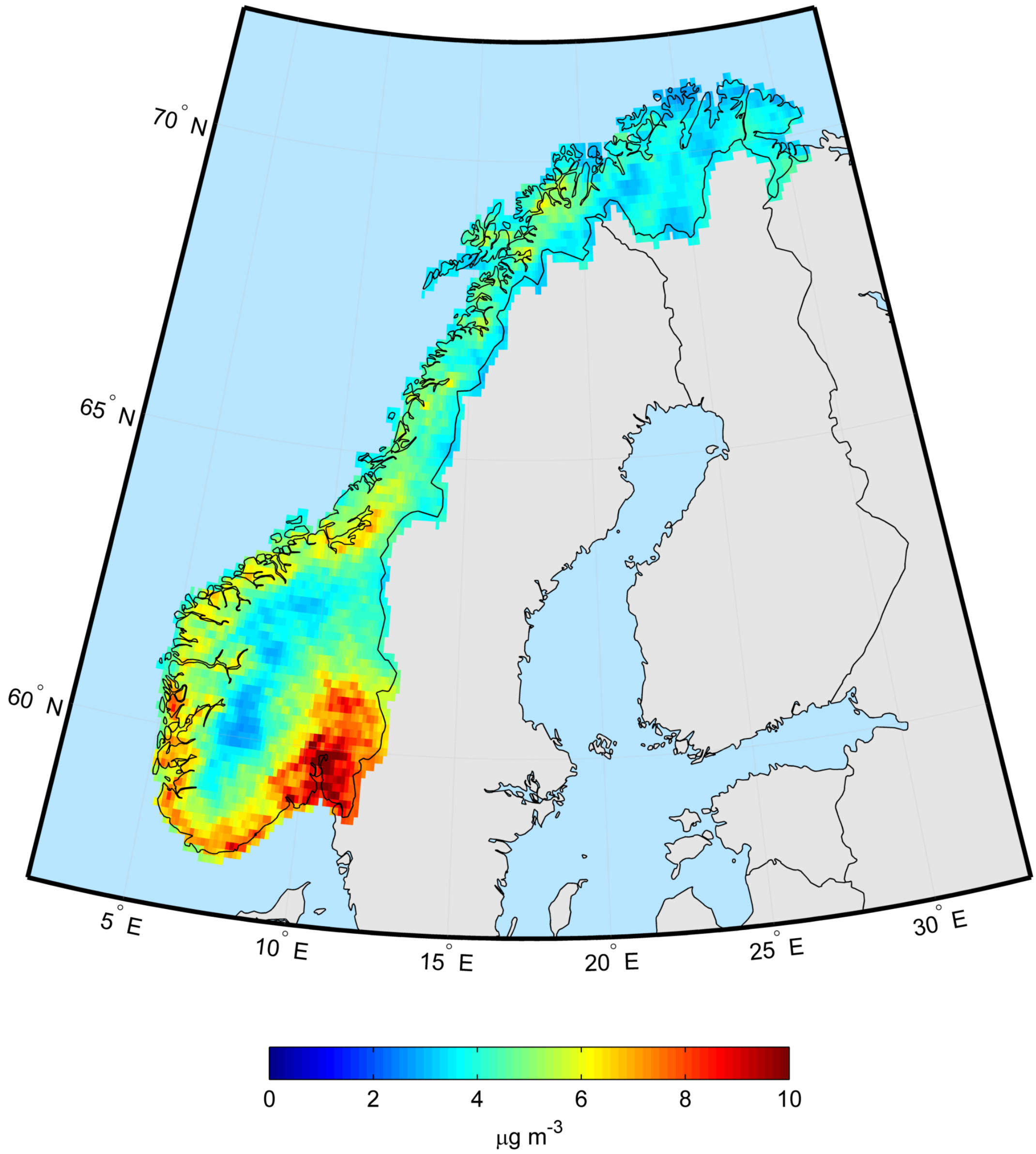

Figure 24 – Annual average PM$_{2.5}$ concentrations for 2007 over Norway.

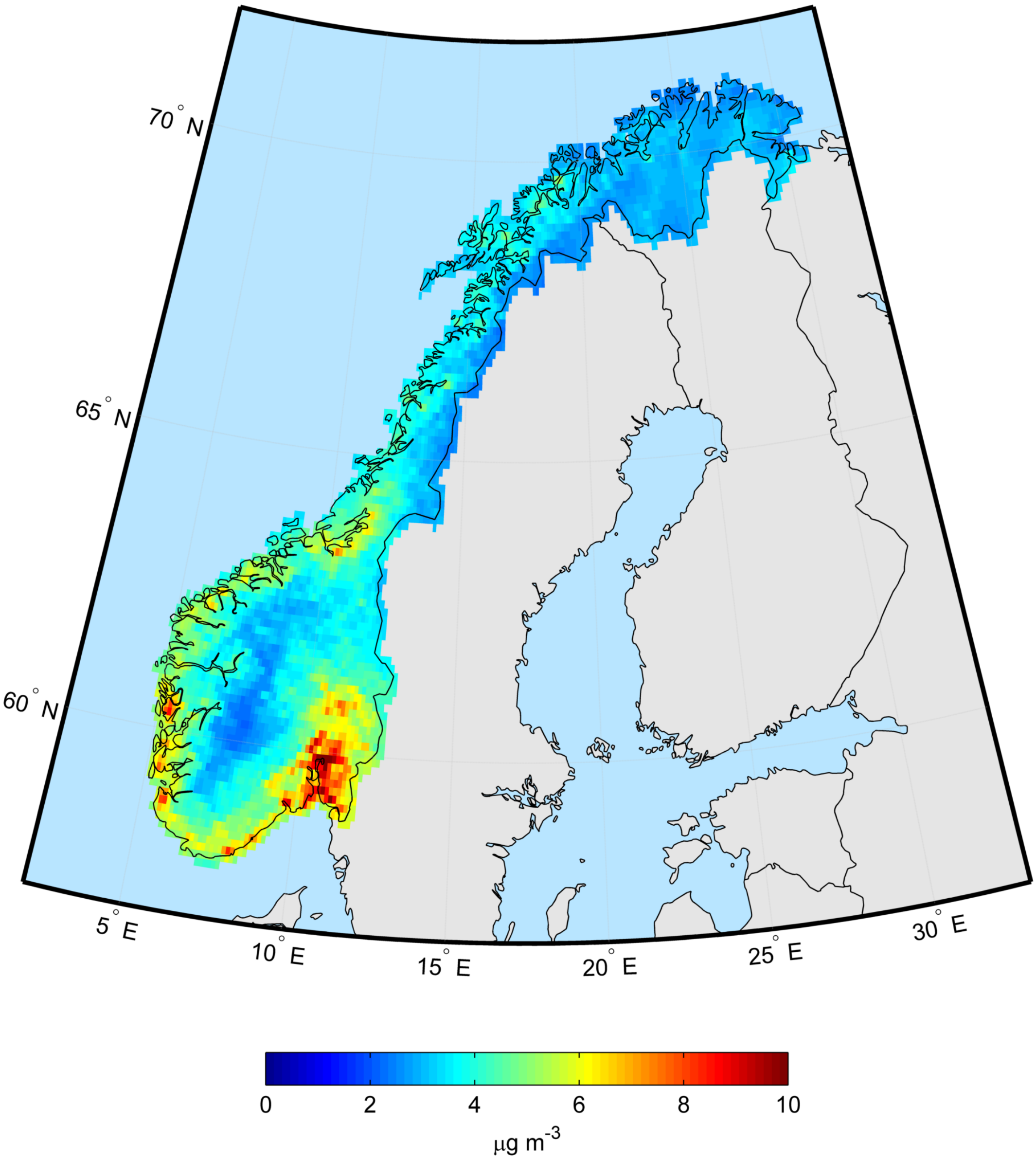

Figure 25 – Annual average $PM_{2.5}$ concentrations for 2008 over Norway.

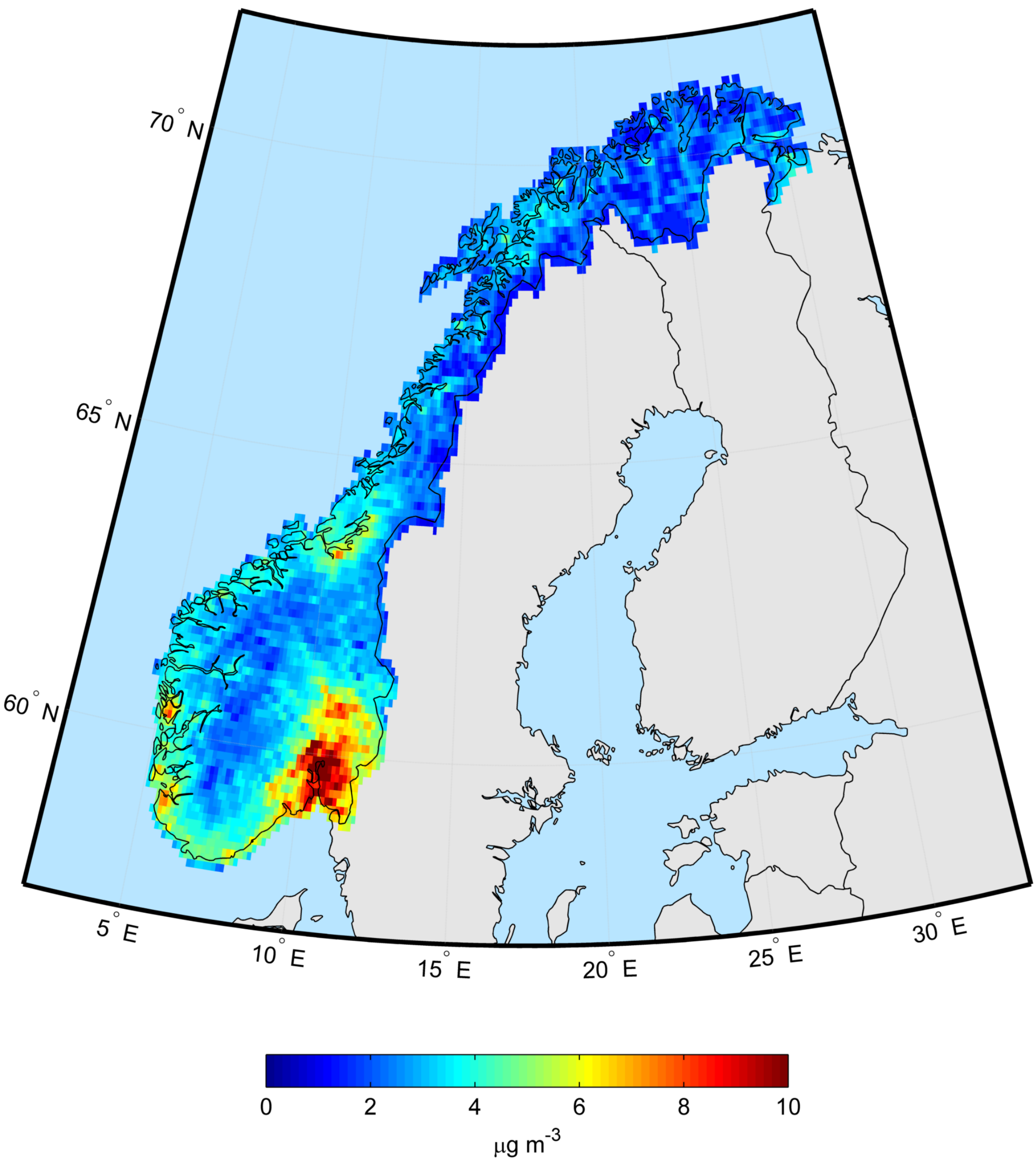

Figure 26 – Annual average $PM_{2.5}$ concentrations for 2010 over Norway.

C O_3 annual averages

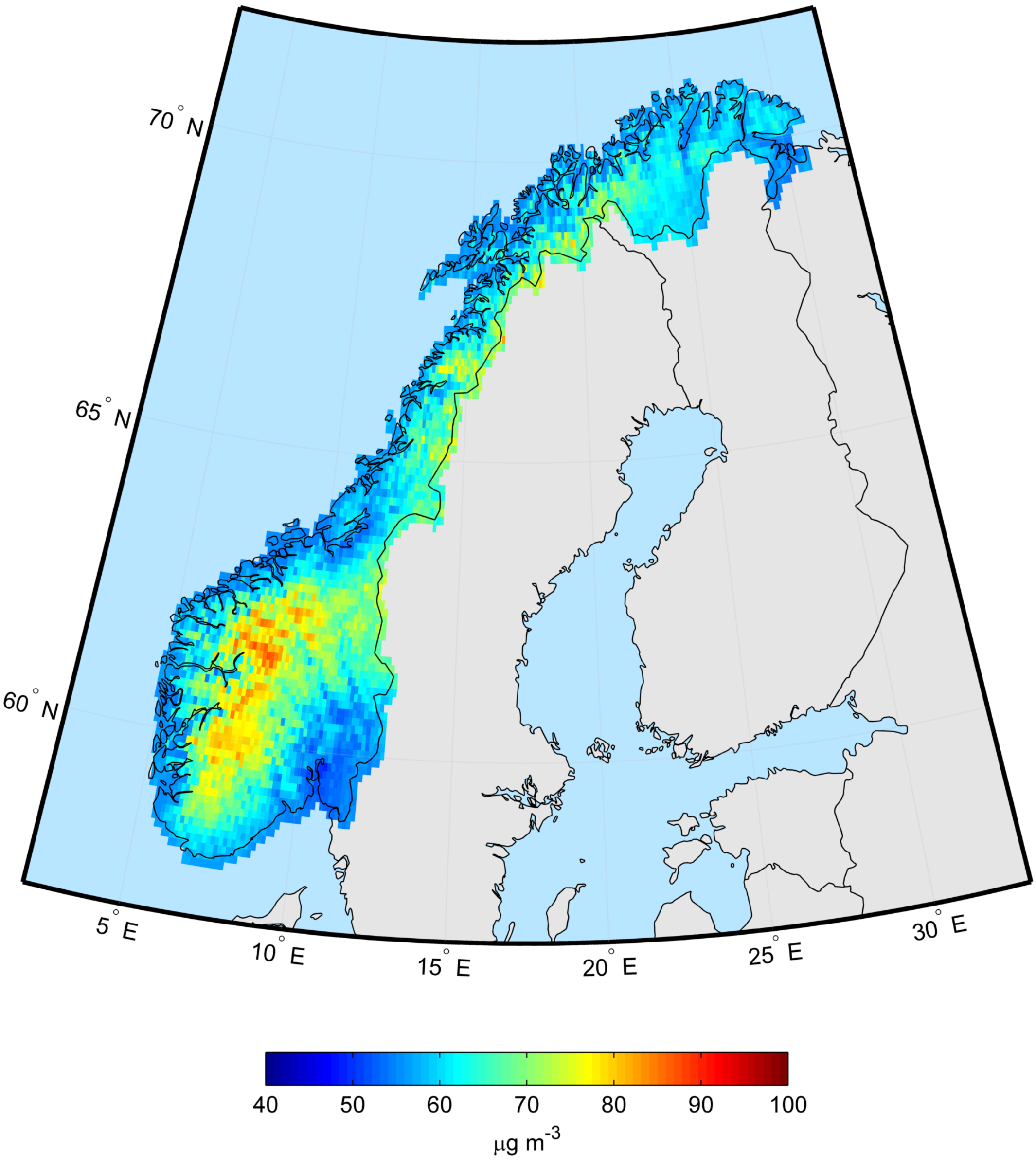

Figure 27 – Annual average O_3 concentrations for 2008 over Norway.

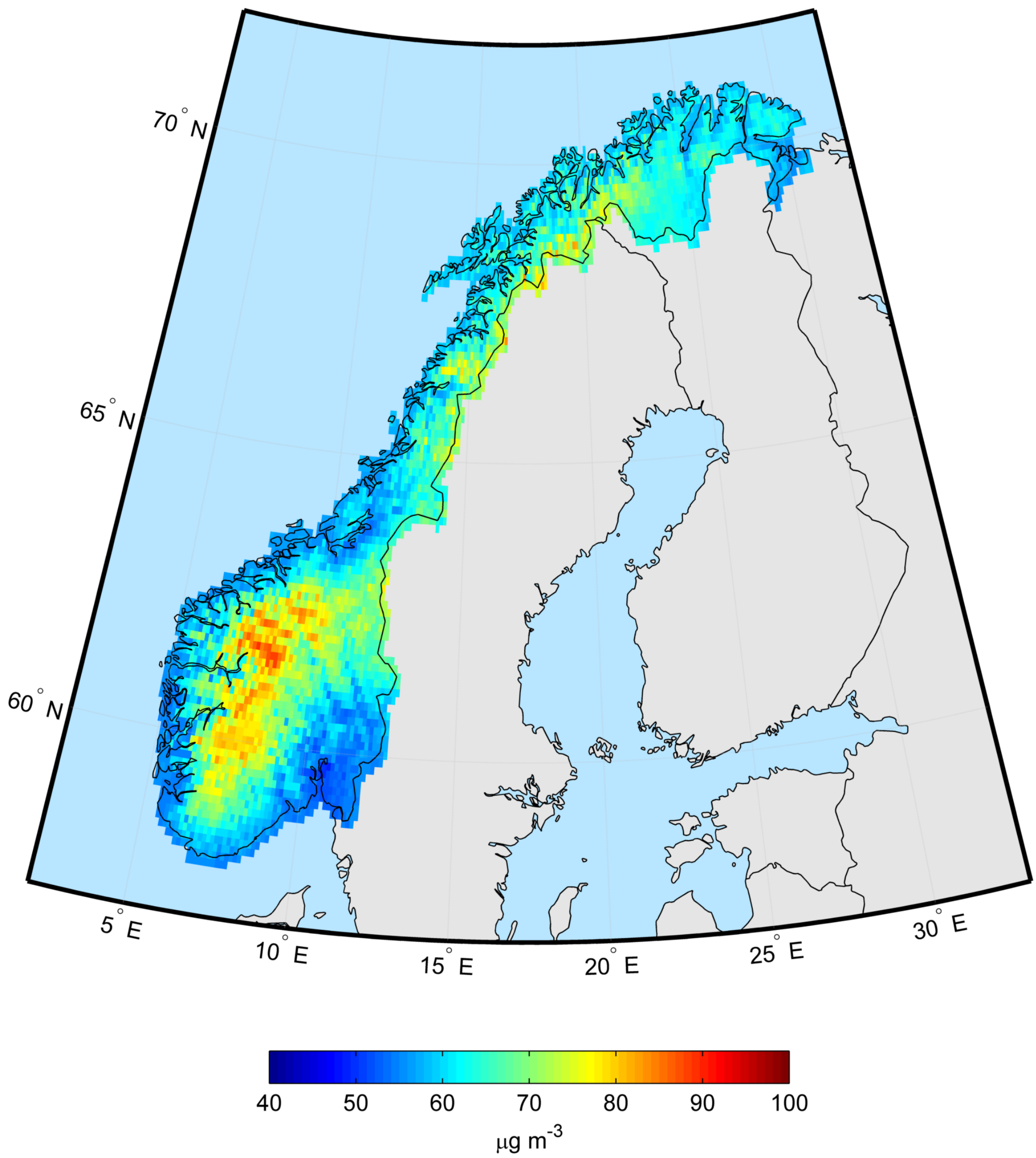

Figure 28 – Annual average O_3 concentrations for 2009 over Norway.

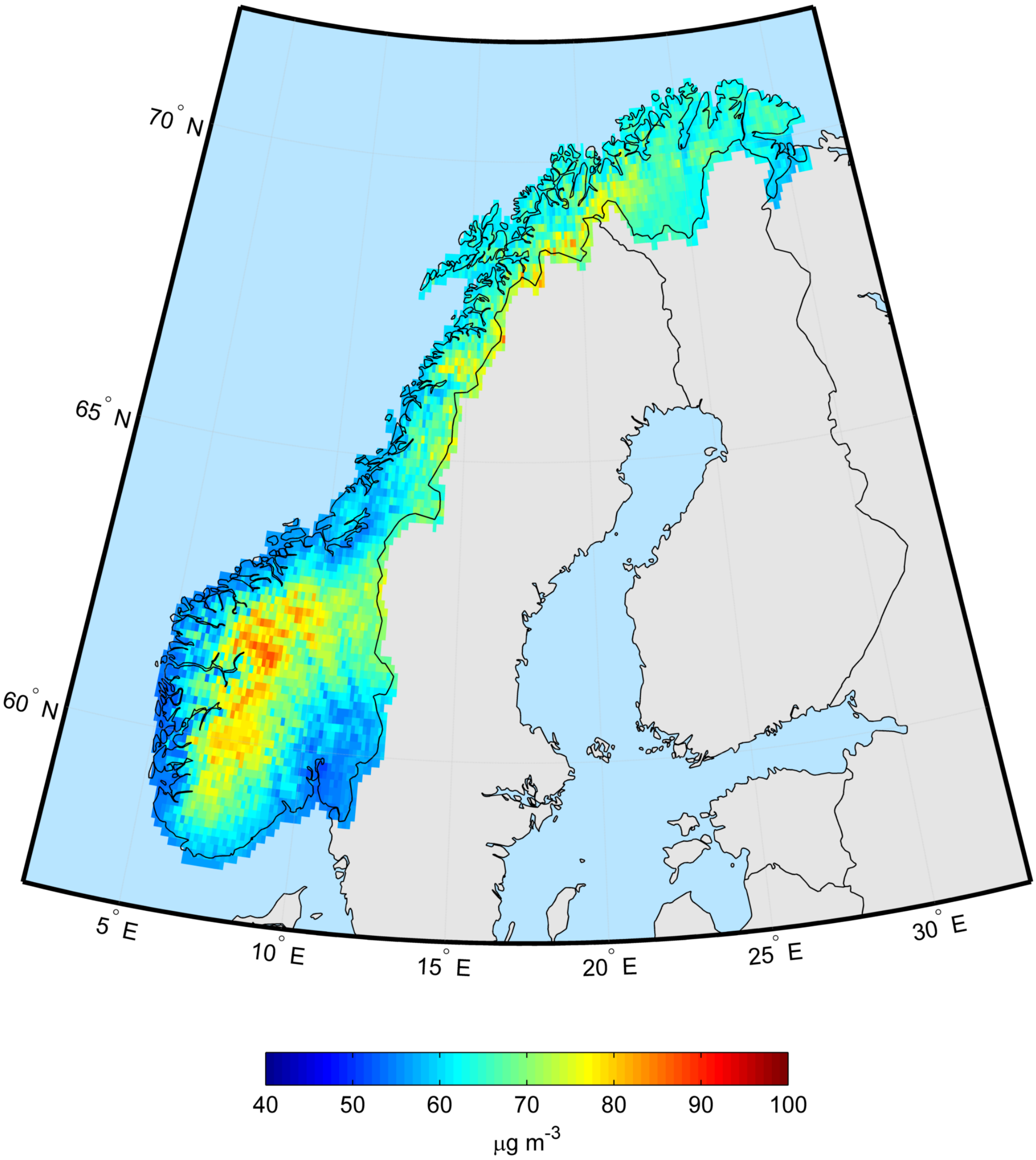

Figure 29 – Annual average O_3 concentrations for 2010 over Norway.

D NO_2 annual averages

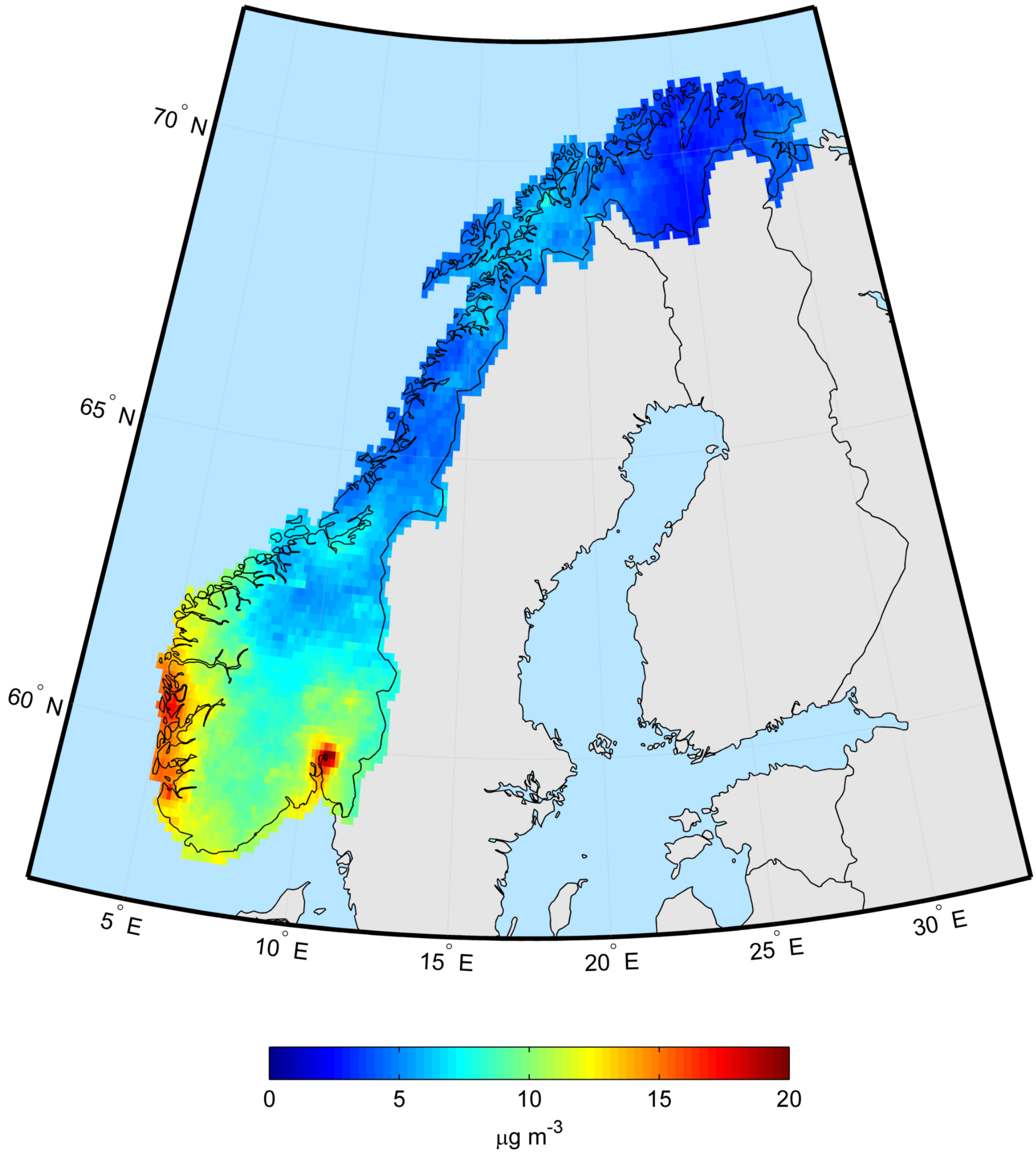

Figure 30 – Annual average NO_2 concentrations for 2008 over Norway.

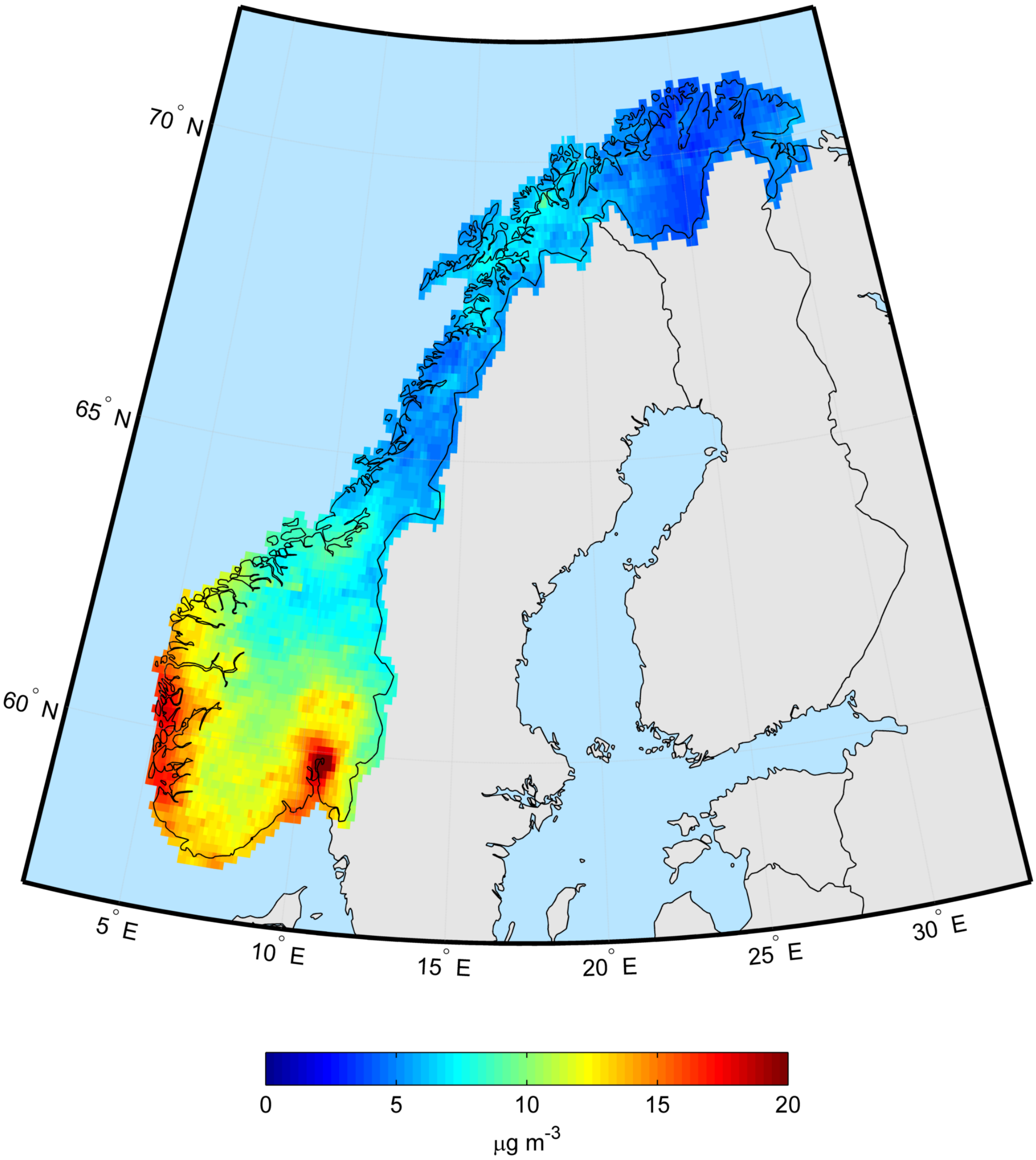

Figure 31 – Annual average NO_2 concentrations for 2009 over Norway.

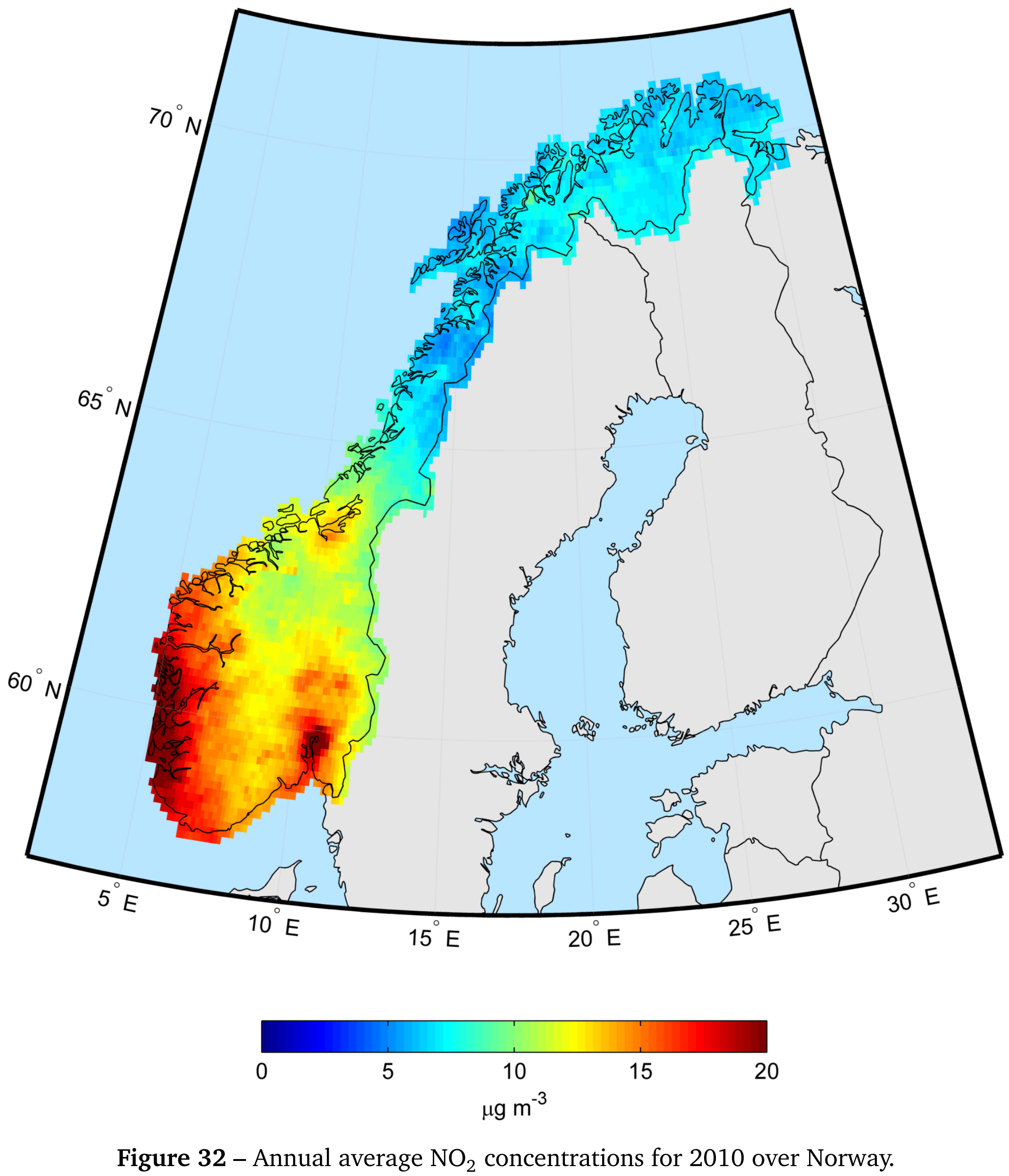

Figure 32 – Annual average NO_2 concentrations for 2010 over Norway.

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ABSTRACT

A system for providing approximate spatial and temporal estimates of the surface background concentrations of PM_{10} , $PM_{2.5}$, NO_2 , and O_3 for a typical year in Norway has been established at NILU in recent years. In 2013, the system was further improved and expanded by carrying out two main tasks: Firstly the spatial component of the system was extended from previously a single year to a 3-year average, thus decreasing the impact of inter-annual variability. Secondly, a preliminary validation of the background estimates was carried out and an approximate uncertainty was calculated for four species in the dataset and is now communicated to the user on the project website. The validation results indicate that overall the average estimated concentrations follow the average observed concentration fairly well. This is particularly true for PM_{10} and $PM_{2.5}$. The averaged estimates for O_3 and NO_2 also follow the averaged observations relatively closely, although NO_2 is clearly underestimated at all four validation stations. In terms of quantitative uncertainty estimates for the hourly estimates at the level of individual species, O_3 is the parameter which was found to have the lowest uncertainty of all four species. While the median absolute uncertainty for hourly O_3 estimates was found to be 18.7 µg m^{-3}, the median relative uncertainty was only 33.8 %. Both PM_{10} and $PM_{2.5}$ had significantly higher uncertainties, with a median relative uncertainty for the hourly estimates of 90 % and 88 %, respectively. Finally, the hourly estimates for NO_2 also showed quite high relative uncertainties with a value of 73 %.

NORWEGIAN TITLE

Bakgrunnskonsentrasjoner i Norge: Periodisk tidsmidling og usikkerhetsvurdering

KEYWORDS		
Air Quality	Environmental Monitoring	

ABSTRACT (in Norwegian)

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|---|---|
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| *B* | *Restricted distribution* |
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