Air quality in Norwegian cities in 2015

Evaluation Report for NBV Main Results

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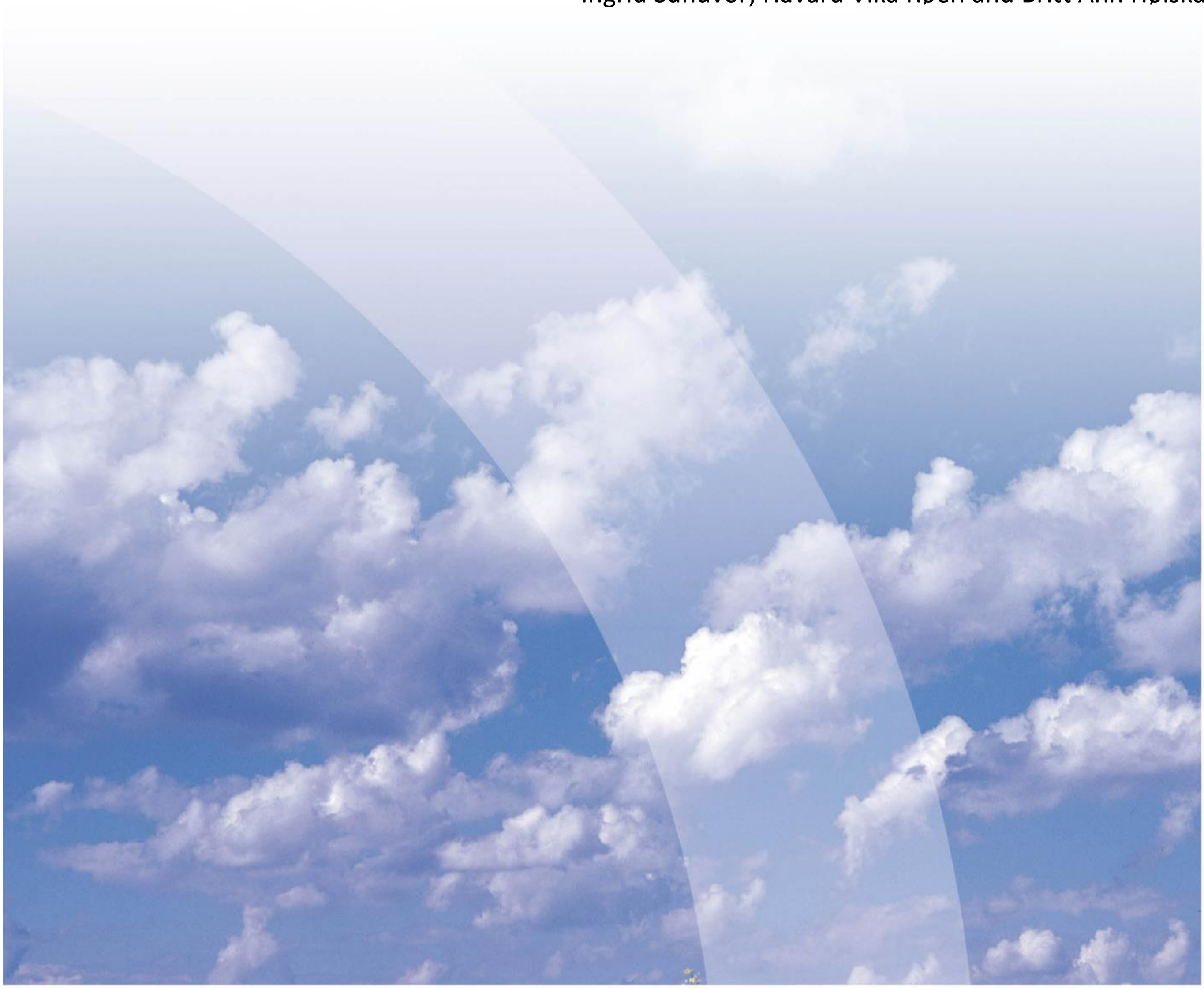

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ABSTRACT

This report documents the final deliveries of the first phase of development of the Norwegian Air Quality Planning Tool, also called "Nasjonalt Beregningsverktøy" or NBV. The main purpose of NBV is to provide a common methodological and information platform for local air quality modelling applications. The system is addressed to local and regional environmental authorities, air quality experts and consulting companies. It is intended to help them meet the requirements of current air quality legislation, to support local air quality planning and facilitate air quality good practices where people live.

The report constitutes a comprehensive user guide for the NBV services available at http://www.luftkvalitet-nbv.no. It presents each of the different products developed at NBV, documents how the product has been calculated, provides recommendations on how best to use it for planning purposes and explains the main strengths and limitations of each product. The report also includes an extensive validation of the air quality information currently available at NBV.

NORWEGIAN TITLE

Luftkvalitet i norske byer i 2015 – statusrapport for Nasjonalt Beregningsverktøy (NBV)

KEYWORDS

Air quality	Local and urban pollution	Modeling results

ABSTRACT (in Norwegian)

Beregningsverktøyet er utviklet som et samarbeid mellom NILU – Norsk institutt for luftforskning og Meteorologisk institutt (MET), under ledelse av Miljødirektoratet og i samarbeid med Vegdirektoratet, Helsedirektoratet og Folkehelseinstituttet. Arbeidet begynte i 2014 på oppdrag fra Klima- og miljødepartementet (KLD), Samferdselsdepartementet (SD) og Helse- og omsorgsdepartementet (HOD).

Denne rapporten beskriver produktene som er tilgjengelige på web-portalen http://www.luftkvalitet-nbv.no og dokumenterer metoder og data som er benyttet i utarbeidelsen av de ulike produktene. Rapporten beskriver også kort hvordan de ulike produktene bør brukes og peker på mulige anvendelser og begrensninger. Alle data på web-portalen er åpent tilgjengelig for alle og kan lastes ned til videre bruk.

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Preface

This report documents the final deliveries of the first phase of development of the Norwegian Air Quality Planning Tool, also called "Nasjonalt Beregningsverktøy" or NBV. The main purpose of NBV is to provide a common methodological and information platform for local air quality modelling applications. The system is addressed to local and regional environmental authorities, air quality experts and consulting companies. It is intended to help them meet the requirements of current air quality legislation, to support local air quality planning and facilitate air quality good practices where people live.

The report constitutes a comprehensive user guide for the NBV services available at http://www.luftkvalitet-nbv.no. It presents each of the different products developed at NBV, documents how the product has been calculated, provides recommendations on how best to use it for planning purposes and explains the main strengths and limitations of each product.

The report also includes an extensive validation of the air quality information currently available at NBV. It is an evaluation report that integrates deliverable AP2_D5 on the validation of NBV V1 emission estimates and deliverable AP4_D4 on the validation of air quality data based on these emission estimates. Validated air quality data and input information for 2015 with focus on nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$) are presented here for the main city areas in Norway: Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger.

Throughout this report, we explain the choices made in the development of the products, taking into account the need for common methodologies and identifying synergies with the Better City Air (Bedre Bylyft) project. In the end, we provide recommendations for the future evolution of the NBV web-service and the Norwegian Air Quality Planning Tool.

The NBV technical development work has been carried out as a collaboration between the Norwegian Institute for Air Research (NILU) and the Norwegian Meteorological Institute (MET). The work has been led by the Norwegian Environment Agency in cooperation with the Norwegian Public Roads Administration, the Norwegian Institute of Public Health and the Norwegian Directorate of Health. Work began in 2014 on behalf of the Ministry of Climate and Environment, the Ministry of Transport and Communications and the Ministry of Health and Care Services. The first phase of the development work was completed by the end of 2016 and the NBV web-service was launched on 7th February 2017.

The authors are thankful to Christoffer Stoll for the development of the application to retrieve traffic data and to Morgan Kjølerbakken and Rune Åvar Ødegård for their support when defining the technical architecture of the system. We are also thankful to Randi Nordby Henriksen for her invaluable help in the elaboration of this report. Thanks are also due to the members of the Scientific Committee of the project, in particular Isabella Kasin, Pål Rosland and Sigmund Guttu for their comments, feedback and discussions and to the members of the Bedre Byluft Forum for their guidance and support throughout the project.

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Sammendrag

Alle vil bo der lufta er best – og med det nye nasjonale beregningsverktøyet (NBV) får myndigheter og byplanleggere en webtjeneste som hjelper dem i arbeidet med å sikre god luftkvalitet i norske byer og tettsteder.

Beregningsverktøyet er utviklet som et samarbeid mellom NILU – Norsk institutt for luftforskning og Meteorologisk institutt (MET), under ledelse av Miljødirektoratet og i samarbeid med Vegdirektoratet, Helsedirektoratet og Folkehelseinstituttet. Arbeidet begynte i 2014 på oppdrag fra Klima- og miljødepartementet (KLD), Samferdselsdepartementet (SD) og Helse- og omsorgsdepartementet (HOD). Første fase i utviklingsarbeidet er nå ferdig og resultatene er tilgjengelige på http://www.luftkvalitet-nbv.no

Målgruppen for NBV er først og fremst eksperter på luftkvalitet i forvaltningen, i fagmiljøene og i konsulentselskapene. NBV er utviklet for å støtte planleggingsarbeidet som gjøres på lokal plan for å sikre god luftkvalitet der folk skal bo og ferdes.

Denne rapporten beskriver produktene som er tilgjengelige på web-portalen og dokumenterer metoder og data som er benyttet i utarbeidelsen av de ulike produktene. Rapporten beskriver også kort hvordan de ulike produktene bør brukes og peker på mulige anvendelser og begrensninger. Alle data i web-portalen er åpent tilgjengelig for alle og kan lastes ned til videre bruk.

Den nye webtjenesten gir tilgang til tre typer data som er viktige for lokal luftkvalitet; meteorologiske data, utslippsdata og luftkvalitetsdata. Disse dataene vises i et enkelt format, og representerer den lokale luftkvalitetssituasjonen i Norge basert på kvalitetssikrede tall fra 2015.

Beregningsverktøyet inneholder følgende produkter:

- Forurensningskart
- Befolkningseksponering
- Luftsonekart
- Utslippskilder
- Kildebidrag
- Nedlasting av data

Produktene er tilgjengelig via NBV-webløsningen, som inneholder to supplerende kartløsninger. Den enkleste løsningen gir rask oversikt over de dataene som finnes i verktøyet. En velger by, produkt, komponenter (NO_2, $PM_{2.5}$ og PM_{10}) med tilhørende informasjon, og får visualisert dataene på kart med en fargeskala som viser nivåinndelingen. Det avanserte kartet er beregnet på brukere med GIS-ekspertise, og her kan man velge mellom ulike lag og ulike kartframstillinger, samt om man vil se én eller flere forurensningstyper samtidig.

Alle data i web-løsningen er åpne og kan fritt brukes av konsulenter, lokale myndigheter og andre interessenter for videre studier av lokal luftkvalitet i norske byer og tettsteder. Dette er grunnen til at web-løsningen ikke bare inneholder resultater fra luftkvalitetsberegninger, men også inngangsdata (utslipp og meteorologiske data) som er benyttet i beregningene. Både meteorologiske data og utslippsdata kan lastes ned og brukes som inngangsdata i andre spredningsmodeller for luftkvalitet. Luftkvalitetsdataene fra NBV kan brukes som

bakgrunnsverdier for mer detaljerte byplanleggingsstudier, for eksempel i forbindelse med konsekvensutredninger og vurderinger etter T-1520. NBV gir også informasjon om bidragene fra ulike kilder til totale utslipp og hvor mye de enkelte kildene bidrar til konsentrasjonene. For hver by finner man informasjon om hva trafikk, vedfyring, skipsutslipp og bakgrunnsverdier betyr for luftkonsentrasjonene over forskjellige deler av byen. Slik informasjon er meget relevant for forvaltningen, fordi disse opplysningene kan brukes i tiltaksanalyser og planlegging av effektive tiltak.

Luftkvalitetsdataene som er tilgjengelige nå er representative for 2015. Dette gjelder både luftkvalitets- og utslippsdata. Det er viktig å påpeke at de meteorologiske forholdene naturlig endres fra år til år, og at dette kan gi relativt store utslag for konsentrasjonsnivåene: både konsentrasjonsnivåer og den romlige fordelingen kan endres mye. Dette betyr at de konsentrasjonskartene, luftsonekartene og eksponeringstallene som vises på NBV-løsningen nå er representative for 2015, og kan avvike mye fra det man finner for et annet år. «EUs IPR 2011/850/EU» anbefaler generelt at det for denne typer analyser brukes meteorologiske data basert på et gjennomsnitt over 3 eller 5 år i stedet for data for bare ett bestemt meteorologisk år. Dette er grunnen til at det i dag finnes to forskjellige år med meteorologiske data på NBV-nettsiden (2010 og 2015), og et tredje år er også samlet for fremtidig bruk (2016). Ytterligere veiledning fra myndighetene anbefales å ta høyde for meteorologisk variabilitet i planarbeid under T-1520.

Det er også viktig å være oppmerksomhet på hvilke begrensninger den romlige oppløsningen av modellen har for bruken av resultatene. Beregningene som vi presenterer her er basert på meteorologiske data og utslippsdata med en oppløsning på 1x1km, med unntak av linjekilder (trafikkutslipp). Modelloppsettet som er benyttet her gir en beskrivelse av konsentrasjonsfelt ned til 100x100m langs hovedveiene. Dette innebærer at enhver tolkning av luftkvalitetsverdier og grenser på mindre skala enn dette ikke er signifikant.

Det er her kun foretatt luftkvalitetsberegninger for 2015, men i løsningen er meteorologiske data tilgjengelig for både 2015 og 2010. Meteorologiske data for 2010 kan brukes til å vurdere ekstremværsituasjoner for NO_2 i forbindelse med tiltaksvurderinger. Systemet er tilrettelagt slik at nye oppdateringer kan forekomme jevnlig, slik at brukerne får tilgang til felles kvalitetssikrede data. Luftkvalitetsdataene som er tilgjengelige i NBV er representative for 2015. Dette skyldes at det i beregningene er benyttet meteorologiske felt for 2015. Som nevnt ovenfor, er det viktig å ta høyde for meteorologisk variabilitet når resultatene brukes som basis for politiske vedtak eller vurderinger knyttet til gjeldende lovverk. På NBV er det meteorologiske data tilgjengelig for tre ulike år: 2010, 2015 og 2016, noe som gjør det mulig å foreta beregninger for flere ulike meteorologiske år i fremtiden.

Meteorologiske data kan lastes ned og dekker hele Norge med en 2,5 km oppløsning og er også tilgjengelig for alle NBV-byer i 1km-oppløsning. De meteorologiske dataene er validert i henhold til internasjonale valideringsrutiner og valideringsresultatene er presentert i Denby et. al. (2016). Rapporten inneholder også en sammenligning av meteorologiske felt ved 1km når disse beregnes dynamisk, med tilsvarende data basert på nedskalering fra dynamiske beregninger med en grovere oppløsning (2,5km). Sammenligningen viser små forskjeller og det ble derfor anbefalt at for fremtidige versjoner av NBV skulle de meteorologiske feltene beregnes kun med 2,5 km oppløsning og deretter nedskaleres i byområdene til 1 km.

Alle opplysninger tilgjengelige via NBV er vitenskapelig validert i henhold til internasjonale retningslinjer. Dette gjelder både for meteorologi, utslipp og luftforurensning. Utslipps- og luftkvalitetsdata er validert i henhold til retningslinjer/metoder utarbeidet av det europeiske nettverket for modellering under luftkvalitetsdirektivet (FAIRMODE). I tillegg er beregningene validert mot målinger som er utført i de aktuelle byene i Norge: Bergen, Grenland, Nedre Glomma, Oslo, Trondheim og Stavanger.

Valideringen av modellberegningene viser relativt god overensstemmelse mellom modellerte og observerte verdier. For NO_2 er det ingen systematisk under- eller overestimering når man vurderer alle byene under ett. I forbindelse med evalueringen av NO_2 resultatene for Bergen, ble det identifisert en feil i utslippene fra skipstrafikken. Dette ble bekreftet av DNV GL som har utarbeidet utslippsdataene for Kystverket. Skipsutslippene som ble rapportert til Kystverket før 2016 har i ettertid vist seg å være for høye, noe som først og fremst er tilfelle for utslipp fra offshore skip. Skipsutslippene for Bergen ble korrigert, noe som resulterte i betydelig bedre overensstemmelse mellom beregnede og observerte NO_2-verdier for Bergen. Det er ikke gjort tilsvarende korrigeringer av skipsutslippene for de øvrige byene, men det anbefales at det undersøkes om denne feilen også kan gi vesentlige endringer i skipsutslippene for andre byer.

Konsentrasjonene av $PM_{2.5}$ er noe overestimert sammenlignet med observasjoner, og PM_{10}-verdiene er generelt underestimert i vår- og høstmånedene. Den systematiske underestimeringen av PM_{10}-konsentrasjonene om våren og høsten skyldes antagelig at veistøvbidraget underestimeres. En ny parameterisering av vegstøvutslipp er nylig implementert i Bedre Byluft-prosjektet, og vil være tilgjengelig for NBV slik at PM_{10}-estimatene kan forbedres i nær fremtid.

Den viktigste kilden til usikkerhet i luftkvalitetsestimatene er relatert til utslippsdata. To forskjellige sett med utslipp er presentert i løsningen: NBV_V0 som tilsvarer utslippsdata som brukes i dagens varslingssystem for byene (Bedre byluft) og NBV_V1 som tilsvarer oppdaterte utslippsestimater utviklet som en del av dette prosjektet. NBV_V0 utslippsestimatene er dokumentert i López-Aparico et al. (2015) og evaluert i López-Aparicio et al. (2017).

NBV_V0-utslippsestimatene er basert på utslippsinformasjon fra ulike år og forskjellige grunnlagsdata er benyttet for de ulike byområdene. Ved utarbeidelse av NBV_V1-utslippsestimatene er derimot samme metodikk og grunnlagsdata benyttet for alle byene og de oppdaterte utslippsdataene representerer utslipp for perioden 2012 - 2015. Utslippsdataene er basert på nasjonale statistiske data, samt tilgjengelig informasjon om utslipp fra andre kilder som industri og skip.

Vedfyringsutslippene ble i utgangspunktet basert på forbrukstall fra Statistisk sentralbyrå. I forbindelse med evaluering av $PM_{2.5}$ verdiene ble det klart at disse utslippene resulterte i en signifikant overestimering av $PM_{2.5}$ i alle byer. Dette stemmer med tilsvarende beregninger gjort i andre studier. Vedfyringsutslippene er korrigert i NBV_V1 for å gi bedre overensstemmelse med observasjonene. Det er behov for å få bedre forståelse av vedfyringsutslippene i Norge. Det anbefales derfor at det settes i verk målekampanjer og andre undersøkelser som kan gi bedre estimater på vedfyringsutslippene i framtiden.

Executive Summary

Everyone wants to live where the air is clean - and with the new National Air Quality Planning Tool (NBV), environmental authorities and city planners get a web service that helps them plan better air quality in Norwegian cities and agglomerations.

The Norwegian Air Quality Planning Tool (NBV) has been developed as a collaboration between NILU and MET, under the direction of the Norwegian Environment Agency in cooperation with the Norwegian Public Roads Administration, the Norwegian Institute of Public Health and the Norwegian Directorate of Health. Work began in 2014 on behalf of the Ministry of Climate and Environment, the Ministry of Transport and Communications and the Ministry of Health and Care Services. The first phase has now been completed and results are available at http://www.luftkvalitet-nbv.no

This report constitutes a comprehensive user guide for the services available at the NBV web-portal. The NBV web-service has been developed to support local air quality planning, solving tasks related to existing regulations. The system is addressed to local and regional environmental authorities, air quality experts and consulting companies. It is intended to help them meet the requirements of current air quality legislation, to support local air quality planning and facilitate the improvement of air quality where people live. While the NBV web-portal facilitates total open access to data and information on air quality across main Norwegian cities, this report presents each of the products in NBV, documents how they have been calculated, provides recommendations on how best to use them for assessment and planning purposes, and explains the main strengths and limitations of each product.

The new NBV web-service provides access to three types of key data for local air quality. These are: meteorological data, emission data and air quality data. These data have been compiled following a common methodological approach that guarantees the comparability of the data across Norwegian cities. The data represents the current local air quality situation in Norway based on quality-assured values for 2015.

The products developed in the Norwegian Air Quality Planning tool are:

- Air pollution indicator maps
- Air quality zones
- Exposure calculations
- Emission data
- Main contributors to pollution
- Data downloads

The products are available through the NBV web-portal, which consists of two complementary visualization and mapping solutions. The first solution provides a quick overview of the data contained in the tool. You select the city, the product, the air pollution components (NO_2, $PM_{2.5}$ and PM_{10}) and associated information, and you can visualize the data on the map with a color scale that shows pollution levels. The second solution is an advanced mapping system, intended for users with GIS-expertise, where you can choose between different layers of information and different map designs, as well as choose one or more pollutants at a time.

Openness and free access to the data is an important characteristic of the NBV web-portal. All products are freely available and have been developed under an open source reciprocal license. These data can be freely used by consultants and local environmental authorities in further studies of local air quality in Norwegian cities and agglomerations. This is also the reason why the data available includes not only air quality results, but also input information on emission and meteorological data. Both meteorological data and emission data can be used as input data in dispersion models for air quality. In addition, the air quality data from NBV can be used as background-values for more detailed urban planning studies, such as under regulation T-1520.

A note of caution is necessary when considering policy relevant data such as the high resolution maps on air quality zones or data on population exposure to air pollution. Such data is significantly dependent on the meteorological conditions. The natural year-to-year variability of meteorological conditions results in important changes on both the extension of air quality zones and the number of population exposed to air pollution. EUs implementing Decision 2011/850/EU generally recommends that for such policy relevant analysis, 3-yearly or 5-yearly averaged data is used instead of simply data for one specific meteorological year. This is the reason why at present, two different years with meteorological data are provided in the NBV website (2010, 2015) and a third one has also been compiled for future use (2016). Additional guidance from the Norwegian Environmental Authorities is recommended as to how to account for meteorological variability in planning applications under T-1520.

Caution is also advised when it comes to spatially resolve city areas. The calculations that we present here are based on meteorological and emission information provided in 1x1km, except for line sources. The dispersion model set-up allows a description of air quality fields down to 100x100m along main roads. This implies that any interpretation of air quality values and borders beyond this limit is not significant.

The air quality data currently available is representative of 2015. This is because meteorological fields of 2015 have been used for the air quality calculations. However, as indicated above, meteorological variability is important when using the data for policy and regulatory applications. Therefore, the meteorological data available for NBV covers three years: 2010, 2015 and 2016, to allow also for future policy relevant calculations. The meteorological data is downloadable as 3D meteorological, covers Norway with a 2,5km resolution and is also available for all NBV cities in 1km resolution. Verification results for the 2015 meteorological data following international operational forecast validation routines, can be found in Denby et al. (2016). The report also includes a comparison of the meteorological fields at 1km when calculated dynamically or by downscaling from dynamic calculation at coarser resolution (2,5km). The comparison shows small differences and is the basis for a recommendation that in future version of NBV, the meteorological fields will be calculated only at 2,5km resolution and downscaled in city areas to 1km.

All information available through NBV is documented and scientifically validated following international performance standards. This applies to meteorological data, emissions and air pollution data and sets a standard for what may be required in Norway in terms of air quality performance indicators. The quality of the emission data and the EPISODE air pollution dispersion model in NBV has been estimated following the benchmarking activities promoted within the framework of the Forum for air quality modelling in Europe (FAIRMODE). In addition, emission data and air quality results for 2015 have been also evaluated here against observations at the main city areas in Norway: Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger.

Validation of the NBV air quality values in comparison with observations shows reasonable correlation results for all pollutants in the NBV-cities. NO_2 values show no systematic error behavior across stations. However, the evaluation of the model results for NO_2 in Bergen revealed errors in the emission data for the shipping sector. The shipping emission data used in NBV were provided by Kystverket for 2015 and were calculated by DNV GL. After communication with DNV-GL, they confirmed that NO_x-emissions reported to Kystverket before 2016 for the offshore supply ships were incorrect and subject to an overestimation that needed to be corrected for any further use. DNV GL has provided NBV with correcting factors to be applied for the shipping emissions for Bergen for 2015 and the model results agree better with measurements after the correction. However, the shipping emissions for the other cities have not been corrected at this stage. Therefore, it is important to keep in mind that the identified error in the emission data may affect the NO_2 results in other cities with offshore activities.

The concentrations of $PM_{2.5}$ are slightly overestimated with respect to observations and PM_{10} values are generally underestimated in spring and autumn. This systematic underestimation of the PM_{10} concentrations in spring and autumn is probably related to the contribution of road dust emissions in those periods. A new parametrization of road dust emissions is currently implemented in Bedre Byluft, and will be available to NBV so that the PM_{10} estimates can be improved in the near future.

The most important source of uncertainty in the current air quality estimates is to the emission input data. Two different sets of emissions are presented: NBV_V0 corresponding to the emission fields currently used in the Bedre Byluft forecasting system and NBV_V1 corresponding to improved emission estimates developed under this project. The NBV_V0 emission estimates are documented in López-Aparico et al. (2015) and evaluated in López-Aparicio et al. (2017). The NBV_V0 emission estimates are based on emission information from different years and on different methodologies, hence emissions are not consistently compiled for the different city areas. In contrast, the NBV_V1 information has been updated consistently across all sectors for all Norwegian cities in NBV and represent emissions for the period 2012-2015. The NBV_V1 data has been updated according to national statistics and available information for industrial, residential heating and shipping emissions and using a simplified approach for road dust emissions.

In the case of emissions from wood burning from residential heating, the data from national statistics when evaluated against observations, show a significant overestimation of the observed values. The NVB_V1 thus have been adjusted to correct for this fact. Further evaluation in cooperation with local authorities is necessary in order to assess the reasons for the discrepancy between reported emissions and observed air concentrations for $PM_{2.5}$. It is recommended to carry out a series of measurement campaigns at city level, focusing on $PM_{2.5}$, black carbon and the carbonaceous part of the aerosol, preferably using multi wavelength aethalometers for source allocation purposes. Wood burning emissions remain at this point the largest single source of uncertainty in the NBV results.

Air quality in Norwegian cities in 2015
Evaluation Report for NBV Main Results

1 Introduction

In October 2015, the EFTA Surveillance Authority issued a Judgement of the Court declaring that "the Kingdom of Norway had failed to fulfil its obligations under the Act referred to at point 14c of Annex XX to the Agreement on the European Economic Area (Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe) by surpassing the limit values of sulphur dioxide (SO_2), particulate matter (PM_{10}) and nitrogen dioxide (NO_2) in ambient air in certain zones in Norway variously for the years 2008 to 2012 and by failing to comply with the air quality plan obligation set out there in". Apart from drawing the attention to the fact that exceedances of air quality limit values took place in different areas in the given period, the judgement from the EFTA court pointed out to a significant drawback in Norwegian air quality management practices, namely, the lack of a systematic approach to the elaboration plans and programs to control air pollution.

Anticipating this judgement, the Norwegian Ministry of Climate and the Environment (KLD), Ministry of Transport and Communications and the Ministry of Health and Care Services initiated already in 2014 a project to facilitate the creation of a national tool to support the elaboration of air quality plans and control programs, the Norwegian Air Quality Planning Tool project or NBV.

Different factors have contributed to the lack of a systematic approach to the elaboration of plans and programs in Norway, but one important reason has been the lack of available information. In particular, there is missing information on input data such as emissions and meteorology which makes it possible to evaluate the situation in Norwegian cities and forms the basis to calculate the effect of abatement measures. This is why the first phase of the project to support the creation of the Norwegian Air Quality Planning tool has precisely focussed on the compilation of meteorological and emission data in a consistent way throughout Norway.

The Norwegian Air Quality Planning Tool (NBV) is developed to support local air quality planning, solving tasks related to existing regulations. The system is addressed to local and regional environmental authorities, air quality experts and consulting companies. It is intended to help them meet the requirements of current air quality legislation, to support local air quality planning and facilitate the improvement of air quality where people live.

The first phase of the NBV project provides access to three types of key data for local air quality. These are: meteorological data, emission data and air quality data. These data have been compiled following a common methodological approach that guarantees the comparability of the data across Norwegian cities.

While the NBV web portal facilitates total open access to data and information on air quality across main Norwegian cities, this report presents each of the products available in NBV, documents how they have been calculated, provides recommendations on how best to use them for assessment and planning purposes and explains the main strengths and limitations of each product.

In chapter 2, the methodologies used are presented and validation in international fora are summarized and documented. Chapter 3 presents each of the different products developed at NBV and constitutes a comprehensive user guide for the NBV services available at http://www.luftkvalitet-nbv.no. Chapter 4 includes an extensive validation of the air quality information currently available at NBV. Validated air quality data and input information for 2015 with focus on nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$) are evaluated for the main city areas in Norway: Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger. To complement the validation chapter, this report contains an extensive appendix with detailed information for each city on the validation of air quality values in comparison with observations (Appendix A). Finally, in Chapter 5, conclusions and recommendations for the future are presented.

2 Methodologies used in NBV

A short description of the methods used for calculating the input meteorological data, air pollution emissions in urban areas and air pollution dispersion calculations that are at the core of the Norwegian Air Quality Planning Tool (NBV) is given here, together with a short description of how these methods have been validated.

2.1 AROME Meteorology

The meteorological data for the NBV system is produced by the meteorological model AROME (Application of Research to Operations at MEsoscale), coupled to the surface model SURFEX. AROME is a high resolution model which was developed in the second half of the 2000s in Météo-France with the aim to improve local forecasts. The development was done for a chosen horizontal grid of 2.5 km, which allows to explicitly resolve deep convection systems by the model dynamics (Seity et al., 2011). In this way, improvements were possible on forecasting especially dangerous convective phenomena (thunderstorms, flood risk, heavy precipitation) and low-level conditions (wind, temperature, ground state, fog, heat islands, etc) (Bouttier and Roulet, 2008). The model was declared valid for operational use in December 2008. AROME forecasts showed better physical realism than the previous forecasting system. This physical realism was attributed to its mesoscale physics-dynamics and data assimilation scheme (Seity et al., 2011). The need to forecast the localization and intensity of high-impact meteorological events has pushed horizontal resolution to even finer scales of up to 1 km (Amodei et al., 2015).

The AROME-MetCoOp system is run operationally by the Norwegian Meteorological Institute (MET) and their partners to produce meteorological forecasts at 2.5 km resolution for all of Norway. In addition, MET run until 2016 the three regions that cover the largest cities ,for the Bedre Byluft forecasts system at 1 km resolution. The meteorological forecast data is operationally generated and regularly validated, but it is not operationally stored. Alternatively, MET has carried out re-analysis of the data when a specific year with meteorological fields needs to be stored.

As part of the Norwegian Air Quality Planning Tool, the operational forecast data was archived and processed by MET to secure the completeness of the data. The meteorological data consists of 3D spatial meteorological fields required as input for air quality dispersion model calculations that are carried out by the Norwegian institute for air research (NILU). These data are also freely available to the public and methods for distribution have been provided either through the NBV web portal or directly through METs THREDDS data distribution server. The 3D data cover the whole of Norway.

The meteorological data available for NBV covers three years: 2010, 2015 and 2016. For 2010, reanalysis of the 3D meteorological fields have been carried out. The 2010 data covers Norway with a 2,5km resolution and is also available for all NBV cities in 1km resolution. The meteorological data for 2015 and 2016 is no longer a re-analysis but has been directly archived from the forecast chain. This has the advantage that meteorological data is available for use very short after the actual period is completed. For 2015 and 2016 data from the AROME-MetCoOp forecasts, at 2.5 km resolution, have been archived to provide coverage for all of Norway. In addition, the three regions used in the Bedre Byluft forecasts system that cover the largest cities, at 1 km resolution, have also been archived during the project.

A comparison between the meteorology at 2.5 and 1 km has been carried out in Denby et al. (2016). The report provides an analysis of the meteorological models ability to describe inversion strengths, important for air quality applications. The results show that both model resolutions provide very satisfactory predictions for wind, temperature and precipitation and that statistically there is no significant difference between 1 and 2.5 km resolution, when compared to measurement stations. Based on these and previous results it is recommended to streamline the Bedre Byluft and NBV production lines by using solely 2.5 km AROME-METCoOp data in the future and that eventually the 1km can be interpolated from the 2.5 km operational runs. In this way better synergies with the operational Bedre Byluft system are secured.

2.2 Emission data

The emission data compiled and developed in NBV is documented in detail in López-Aparicio and Vo Thanh (2015). The report contains detailed information on the compilation of emission data for all seven (7) city domains. It documents for the first time in a consistent manner the emission data used under the Better City Air (Bedre Byluft) project. The Better City Air emissions are the basis of the version NBV_V0 emission estimates, except for Oslo where emissions from 2013 are used according to (Høiskar et al, 2014). These emission values are based on emission information from different years which is not consistently compiled for the different city areas. Table 2.2.1. summarizes the different origin of the data in NBV-V0 and shows how the inventory relies on information from many different years. By contrast, the NBV_V1 emission inventory version has been updated consistently across all sectors for all Norwegian cities with information for the year 2013. The NBV_V1 data has been updated according to national statistics and available information for industrial and shipping emissions, following the methodology described in detail by López-Aparicio and Vo Thanh (2015) and using a simplified approach for road dust emissions.

Table 2.2.1. Year of origin of the emission information in NBV_V0 for the different sector and the different city areas. (from López-Aparicio and Vo Thanh, 2015).

Urban areas	On-road Traffic	Residential Heating	Shipping	Off-road mobile combustion	Industry
Bergen	2012	2003	1995/1998	1995/1998	1995/1998
Drammen	2012	2012	n.a.	2012	2012
Grenland	2012	1998	n.a.	n.a.	1991
Nedre Glomma	2012	2012	n.a.	n.a.	2012
Oslo	2013	2002	2013	1995	2013
Stavanger	2012	1998	1995/1998	1995/1998	1995/1998
Trondheim	2012	2005	2005	2005	2005
SNAP sectors	SNAP7	SNAP 2	SNAP 8	SNAP 8	SNAP 3-4

The annual emission totals in NBV_V0 for the different source sectors and the 7 city domains are summarized in Table 2.2.2 for NOx emissions, in Table 2.2.3 for PM_{10} emissions and in Table 2.2.4 for $PM_{2.5}$ emissions.

Table 2.2.2: Emissions for NOx as compiled for NBV_V0 . Units: [tons/year]

NOX emissions	Bergen	Drammen	Grenland	Nedre Glomma	Oslo	Stavanger	Trondheim
Traffic	1477	1100	602	1323	4730	1361	776
Domestic heating	21	13	61		30	20	26
Shipping	421				759	918	80
Industry	18	113	4414	514	33	78	68
Other sources	206	239			601	242	153
TOTAL	2142	1465	5077	1837	6153	2619	1102

Table 2.2.3: Emissions for PM_{10} as compiled for NBV_V0 . Units: [tons/year]

PM_{10} emissions	Bergen	Drammen	Grenland	Nedre Glomma	Oslo	Stavanger	Trondheim
Traffic	217	297	192	277	728	296	167
Domestic heating	522	344	383	528	548	280	633
Shipping	5				18	10	3
Industry	1	105	903	55	2	5	7
Other sources	20	31			37	22	20
TOTAL	766	777	1479	860	1331	613	831

Table 2.2.4: Emissions for $PM_{2.5}$ as compiled for NBV_V0 . Units: [tons/year]

$PM_{2.5}$ emissions	Bergen	Drammen	Grenland	Nedre Glomma	Oslo	Stavanger	Trondheim
Traffic	52	40	29	35	164	48	34
Domestic heating	522	344	383	528	548	280	633
Shipping	5				18	10	3
Industry	1	105	903	55	2	5	7
Other sources	20	31			37	22	20
TOTAL	601	520	1315	617	767	365	697

These NBV_V0 emissions have been evaluated in comparison with other emission inventories in López-Aparicio et al. (2017). There, the NBV_V0 fine scale bottom-up emission inventories are compared with three regional top-down emission inventories: EC4MACS, TNO_MACC-II and TNO_MACC-III, downscaled to the same city areas. The study, carried out within the framework of FAIRMODE, shows the capabilities of the benchmarking emission system to identify inconsistencies in the inventories, and to evaluate the reason behind discrepancies as a mean to improve both bottom-up and downscaled emission inventories.

The comparison shows discrepancies in nitrogen oxides (NO_x) and particulate matter ($PM_{2.5}$ and PM_{10}) when evaluating both total and sectorial emissions. The three regional top-down emission inventories underestimate NO_x and PM_{10} traffic emissions by approximately 20-80% and 50-90%, respectively. The main reasons for the underestimation of PM_{10} emissions from traffic in the regional top-down inventories are related to non-exhaust emissions due to resuspension, which are included in the bottom-up NBV emission inventories but are missing in the official national emissions, and therefore in the downscaled top-down regional inventories. The reason behind the underestimation on NO_x traffic emissions by the regional inventories may be the activity data. The fine scale NO_x traffic emissions in NBV are based on the actual traffic volume data at the road link and are much higher than the NO_x emissions downscaled from national estimates based on fuel sales.

López-Aparicio et al. (2017) identified important discrepancies in $PM_{2.5}$ emissions from wood burning for residential heating among all the inventories. These discrepancies are associated with the assumptions made for the allocation of emissions. In the EC4MACs inventory, such assumptions imply high underestimation of $PM_{2.5}$ emissions from the residential combustion sector in urban areas, which ranges from 40 and 90% compared with the bottom-up inventories. The study indicates that in three of the seven Norwegian cities there is need for further improvement of the emission inventories due to missing sources. It also shows that data from the regional emission inventories cannot be readily used in Norway, as there are important missing sources in particular from resuspension, road traffic and biomass burning in the downscaled emissions if intended for use in urban areas.

The benchmarking carried out for NBV project within FAIRMODE, has been a way of validating the NBV_V0 emission data. The study has strengthened our trust on the urban emission inventories for Oslo, Bergen, Stavanger and Trondheim. For the three other Norwegian cities, this study shows the need for further improvement of the urban emission inventories: in Grenland and Nedre Glomma there are missing sources from small combustion and off-road sectors, while the inconsistencies identified in Drammen make recommendable a revision of the inventory methodology.

Still, for emission inventories, indirect validation through comparison of model results based on the emission data with observations is a powerful method. The results from NBV_V0 validation are shown in Appendix A and summarized in Chapter 4. The comparison of modelled results with observations confirmed the results from López-Aparicio et al.(2017) and the need for updating the data. For the elaboration of the NBV-V1 emission inventory, we followed the update methodologies recommended in López-Aparicio and Vo Thanh (2015) and we carried out an evaluation of the data versus observations. The resulting emission data are summarized in Table 2.2.5 for NOx emissions, in Table 2.2.6 for PM_{10} emissions and in Table 2.2.7 for $PM_{2.5}$ emissions

Table 2.2.5: Emissions for NO_x as compiled for NBV_V1 . Units: [tons/year]

NOX emissions	Bergen	Drammen	Grenland	Nedre Glomma	Oslo	Stavanger	Trondheim
Traffic Exhaust	1442	1100	602	1323	4730	1361	776
Traffic Non-Exhaust							
Domestic heating	28	13	61		30	20	27
Shipping	1686	67	386	77	675	1438	210
Industry	18	69	2311	514	33	78	68
Other sources	231	221			601	242	153
TOTAL	3405	1470	3360	1914	6069	3139	1233

Table 2.2.6: Emissions for PM_{10} as compiled for NBV_V1 . Units: [tons/year]

PM10 emissions	Bergen	Drammen	Grenland	Nedre Glomma	Oslo	Stavanger	Trondheim
Traffic Exhaust	27	42	22	35	243	48	28
Traffic Non-Exhaust	201	268	171	242	776	248	139
Domestic heating	429	344	227	277	1576	299	192
Shipping	57	2	11	2	32	41	7
Industry	1	15	278	55	2	5	7
Other sources	13	29			37	22	20
TOTAL	728	700	709	610	2665	663	394

Table 2.2.7: Emissions for $PM_{2.5}$ as compiled for NBV_V1 . Units: [tons/year]

$PM_{2.5}$ emissions	Bergen	Drammen	Grenland	Nedre Glomma	Oslo	Stavanger	Trondheim
Traffic Exhaust	30	42	22	35	243	48	28
Traffic Non-Exhaust	18	7	7	6	30	10	6
Domestic heating	429	344	227	277	1576	299	192
Shipping	57	2	11	2	32	41	7
Industry	1	15	278	55	2	5	7
Other sources	13	27			37	22	20
TOTAL	548	438	545	374	1919	425	261

2.3 The EPISODE dispersion model

EPISODE is the core of the NBV system. EPISODE is a dispersion model developed at the Norwegian Institute for Air Research (NILU) for air quality studies at the local scale. Moreover, it is an important tool for regulatory and policy in air quality in Norway. It consists of an Eulerian 3D grid model with embedded subgrid Gaussian and Lagrangian models, which take care of the dispersion from different type of sources (point, line, and area sources) (Slørdal et al., 2003). The Eulerian part of the model consists of a numerical solution of the atmospheric (mass) conservation equation of the pollutant species in a three-dimensional Eulerian grid. The Lagrangian part consists of separate subgrid-models for line- and point-sources. The line source model is an integrated Gaussian type model, while the point source model is a Gaussian puff trajectory model. Point sources are for example stack emissions from industry. Line sources are typically emissions from traffic. Area sources are emissions dispersed in space as for example the emissions from house heating in a city.

The model is typically used to calculate air pollution concentrations in cities and urban areas from multiple emission sources such as road traffic, shipping, domestic heating and industry. The model calculates hourly average concentrations as gridded values and in a set of irregularly placed receptor points. The output of the model in hourly frequency is used for calculating long-term average concentrations and other statistical parameters. Traditionally EPISODE has been applied for the calculation of airborne species such as SO_2, CO, NO_X[1], NO_2, PM_{10} and $PM_{2.5}$. Calculations of NO_2 are based on a simplifying assumption of photochemical equilibrium between NO, NO_2 and O_3 for each time step. For urban scale application, there is no deposition considered be it dry or wet.

The evaluation of the EPISODE model in FAIRMODE and the methodology used for mapping in high resolution are presented in the two following subsections.

2.3.1 Benchmarking EPISODE model results in FAIRMODE

The EPISODE model results have been benchmarked against other European model results within the framework of FAIRMODE. The results are documented in Janssen et al. (2017) and show results comparable with those of state-of-art models used in Europe for air policy applications. The results are within European legislation demands on Model Quality Objective (MQO).

[1] $NO_X = NO_2 + NO$

EPISODE performance was evaluated using the benchmarking tool DELTA (http://aqm.jrc.ec.europa.eu/index.aspx) to assess the "fitness" of EPISODE. The DELTA software was developed in the Joint Research Centre (European Commission) in the framework of FAIRMODE (Forum for air quality modelling in Europe). The objective of the tool is to allow standardized evaluations and quality assurances of air quality models for support of initiatives related to the European Union Air Quality Directive. In this way, it is defined a Model Quality Objective (MQO) as follows:

$$MQO=\frac{\sum_{i=1}^{N}(M_i-O_i)^2}{2\sum_{i=1}^{N}U(O_i)^2}$$

Where M_i is the list of the model results for one station and O_i the correspondent observational list. N is the number of elements in the list (number of paired model results and observations in a specific period). U is the uncertainty in the observations, which is also considered the margin of tolerance in the model results. DELTA tool considers the results as fulfilling the MQO when it differs from the observed values by 2U or less. Moreover, in the DELTA framework it is considered that a model is successful when the MQO is fulfilled for at least 90% of the air quality stations in the analysis. The latter means that the success of a model in the DELTA tool is closely linked to the number of air quality stations used in the analysis. In the Oslo domain we have available observations of NO_2, $PM_{2.5}$, and PM_{10} from 8, 6, and 9 stations, respectively. We think this is a minimum number acceptable, which means that in Norway we can only apply the DELTA tool in the Oslo domain considering that for other cities the number of air quality stations is lower. Moreover, the scope of the "fitness" of the model lays on the nature of the stations. Specifically, for the domain Oslo most of the stations available are traffic data stations and therefore it is within this scope that EPISODE can be evaluated.

The DELTA tool uses the paired results of simulations and observations. In this way, the evaluation with DELTA tool respects the numerical model, the simulation setup, and the period of the observations. The simulation setup includes model options, model domain and input data. The EPISODE performance analysis was done with the results produced in the study of scenario assessment done for Oslo/Bærum for 2013 and reported in Høiskar et al. (2014).

The analysis of the EPISODE performance based on its results in Høiskar et al. (2014) showed that it is very good for the simulation of hourly concentrations of NO_2 and daily concentrations of $PM_{2.5}$, with 100% of the air quality stations in Oslo fulfilling the Model Quality Objective. For daily concentrations of PM_{10}, EPISODE fulfilled the DELTA model quality objectives in winter (90% of the stations fulfil the MQO), but not all the year (66% of the stations fulfil MQO). Regarding annual indicators, the percentage of stations fulfilling the MQO is for NO_2, $PM_{2.5}$, and PM_{10} of 75%, 75%, and 44%. The DELTA tool is very stringent in the case of annual averages and discussions within FAIRMODE have taken place in order to analyse if it is correct to have such a high standard for this set of statistics. We think that in the case of PM_{10} the inclusion of NORTRIP will be an important asset in producing results which fulfil the DELTA tool MQO.

It should be mentioned here that the evaluation of MQO and benchmarking in FAIRMODE is valid only for the specific application of the model that is evaluated, in this case, the evaluation was carried out for Oslo, and for the year 2013. This means that in another city, using different meteorological year and with different emissions, the same dispersion model (in this case EPISODE) may give a different result. This is why it is always important to test the same model under as many different conditions as possible. The larger the record of MQO analysis, the more robust we can consider the model results.

In this sense, the evaluation of modelled 2015 results versus observations carried out in Chapter 4 and Appendix A for the 7 cities and under two different emission estimates, extends and complements the tests carried out in FAIRMODE for 2013. It is recommended that the results in this report for all cities in 2015 are used for further benchmarking using the FAIRMODE MQO tool.

2.3.2 Mapping methods and high resolution maps

In order to make maps of air quality, concentrations must be modelled throughout the model domain. The model simulations are carried out in 1x1km using the EPISODE model and then emissions are incorporated as line sources so that the final resolution of the results is 100x100m.

In order to create maps at 100 m resolution, the model domain is populated with a large number of receptor points. These receptor points are placed with higher density near roads, out to the extent of the road link influence distance (400 m), the distance to which the line source model is applied. Outside of this region receptor points are placed every 500 m in a regular grid as these sample only from the grid model. The mapping process consists of pre-processing of receptor points and post-processing for creating the maps as follows:

1. Road links of length > 15 m are selected
2. For each selected road link receptor points are placed on both sides of the road at 75 m intervals and at 15 m, plus half a road width, distance from the road link.
3. This is repeated at distances of 55, 125, 250 and 450 m from the road. For each increasing distance the space between the receptor points, parallel to the road, increase from the initial 75 m to 100, 150, 200 and 300 m.
4. A 500 m square grid of regular receptor points is then added to cover the entire model domain in areas where the grid model alone is used to calculate concentrations
5. The position of all the receptor points is then assessed. All receptor points within 20 m of roads are removed so that no receptor points are close than this distance.

   6, Receptor points within 25 m of other receptors are also removed as this is the specified maximum resolution.

The model then calculates concentrations at all the mapping receptor points and saves the annual mean concentrations, the number of exceedances above the prescribed limit value and the related percentiles for each limit value. The model also saves the same type of concentration data for each model grid.

The EPISODE model calculates concentrations at the receptor points by adding line source and grid model concentrations. No interpolation of the gridded concentrations is applied, often leading to clearly visible 'grid shapes' in the receptor point concentration data. To obtain smoother variations in the map, related to gridded concentrations, the receptor data is post-processed. The gridded concentration fields are interpolated, using a cubic spline interpolation, at all receptor points. The original gridded concentrations are then subtracted from all receptor points and the interpolated gridded concentrations are added back. This creates a smooth concentration surface for the grid model contribution but does not change the line source contribution.

The new receptor point data is then linearly interpolated to a 20 m sub-grid throughout the entire model domain creating a high resolution map. This interpolated sub-grid is then aggregated into 100 m grids by taking the mean of the sub-grids. Maximum sub-grid values are also calculated for each 100 m grid but are not used in the maps. In this way the 20m sub-grid interpolation is used as a numerical integration method to determine the means in the 100 m mapping grids. Further detail can be found in Denby et al. (2014).

3 Products from NBV in 2015

In this chapter, we present all the products developed as part of the Norwegian Air Quality Planning tool (NBV). Each product is presented in a separate section, where we provide recommendations on how best to use it for planning purposes and we carefully explain their main strengths and limitations.

The products developed in the Norwegian planning tool are:

1) Air pollution indicator maps
2) Air quality zones
3) Exposure calculations
4) Emission data
5) Main contributors to pollution
6) Data downloads

All products are based on calculations carried out with the EPISODE air pollution model. The model is described in chapter 2 and has been benchmarked following European FAIRMODE standards as documented in Janssen et al. (2017). All calculations use the same input data consisting of: a) meteorological data for the year 2015 operationally calculated by the AROME-MetCoOp system with a spatial resolution of 1x1km (Denby et al., 2016) and b) emission input data, NBV_V1, which has been developed as part of the NBV with a common methodology for all cities. The NBV_v1 emission data is documented in chapter 2 of this report. Further, the emission compilation methodology is documented in Lopez-Aparicio and Vo Thanh (2015) and results from NBV_V0 have been benchmarked against other emission estimates in Lopez-Aparicio et al (2017).

3.1 Air pollution indicator maps

Air pollution maps for each of the 7 cities are provided for nitrogen dioxide (NO_2) and particulate matter (both $PM_{2.5}$ and PM_{10}). These pollutants have been selected as they are priority components of air pollution in cities and are regulated under European Directive 2008/50/EC) and Norwegian law (Forurensningsforskriften, kap. 7). All maps show calculated concentrations for 2015 in µg /m^3. The resolution on these maps is 100x100 m for the model results based on NBV_V1 emissions and 1x1km for the model results based on NBV_V0 emissions.

The air pollution indicators shown in the maps are yearly mean averages and maximum hourly values. These indicators follow the air pollution regulations in the Norwegian air pollution regulation (Forurensningsforskriften, section 7) for the protection of human health. Table 3.1.1 shows the limit value established by the current regulation, while Table 3.1.2 shows the current upper threshold values. While exceedance of the limit values over permitted values implies non-compliance with air pollution regulations, exceedance of the upper threshold values triggers the need for the elaboration of air quality plans and evaluation of possible control actions.

Table 3.1.1 Limit values according to current Norwegian legislation.

Pollutant	Averaging time	Limit value	Allowed number of exceedances per calendar year
Nitrogen dioxide (NO_2) - Yearly mean limit value	1 year	40 µg/m^3 NO_2	0
Nitrogen dioxide (NO_2) – Hourly mean value	1 hour	200 µg/m^3 NO_2	18
Particulate matter (PM_{10}) – Yearly mean value	1 year	25 µg/m^3 PM_{10}	0
Particulate matter (PM_{10}) – Daily mean value	1 day	50 µg/m^3 PM_{10}	30
Particulate matter ($PM_{2.5}$) – Yearly mean value	1 year	15 µg/m^3 $PM_{2.5}$	0

Table 3.1.2 Upper threshold values according to current Norwegian legislation that trigger need for plans and programs

Pollutant	Averaging time	Upper threshold value	Allowed number of exceedances per calendar year
Nitrogen dioxide (NO_2) - Yearly mean value	1 year	32 µg/m^3 NO_2	0
Nitrogen dioxide (NO_2) – Hourly mean value	1 hour	140 µg/m^3 NO_2	18
Particulate matter (PM_{10}) – Yearly mean value	1 year	22 µg/m^3 PM_{10}	0
Particulate matter (PM_{10}) – Daily mean value	1 day	35 µg/m^3 PM_{10}	30
Particulate matter ($PM_{2.5}$) – Yearly mean value	1 year	12 µg/m^3 $PM_{2.5}$	0

3.1.1 How to use them

The air quality indicator maps in the Norwegian planning tool are provided both as yearly mean values and as short term values. For the short term indicator maps, the values presented are those of the 19th highest hourly mean values over the calendar year for NO_2 and for PM_{10}, it is those of the 31st highest daily mean values over the calendar year. With this choice of indicators, the maps provide a good way to quickly evaluate the status of air quality in an area.

The color scale in the air pollution indicator maps reflects the current limit values and upper threshold limits. In all maps, red zones indicate areas above allowed limit values, while the orange zones indicate areas with values above the upper threshold values but below limit values. The persistent existence of orange areas in an urban area will trigger the need for elaboration of plans and programs to control air quality in the area.

The air quality indicator maps are valuable to assess the air quality status in a particular area. The information in the maps can be used directly down to a resolution of 100x100m and for surface level. The maps do not resolve details beyond that horizontal scale because the model set-up does not allow for further detail.

The spatial resolution and configuration of the dispersion model used as basis for the elaboration of the air quality indicator maps determines the level of detail that can be derived from the actual maps. To illustrate this fact, indicator maps are provided for the Oslo-Bærum domain in two different resolutions, at 1x1km resolution and at 100x100m, in Figure 3.1.1. Differences between the two resolutions are significant at road level, as expected, because the fine scale resolution allows to account for the sub-grid variability that arises in relation with line and point sources inside the gridded domain. Differences between the two sets of indicator maps may also be observed in background areas, but these differences are not significant. They originate mainly due to round-off errors in the plotting routines. The comparison of these two different sets of indicator maps in Oslo-Bærum shows how important it is to include a sub-grid treatment of emission and concentrations in the dispersion model, such as EPISODE does, for the analysis of the results and their usefulness in assessment applications.

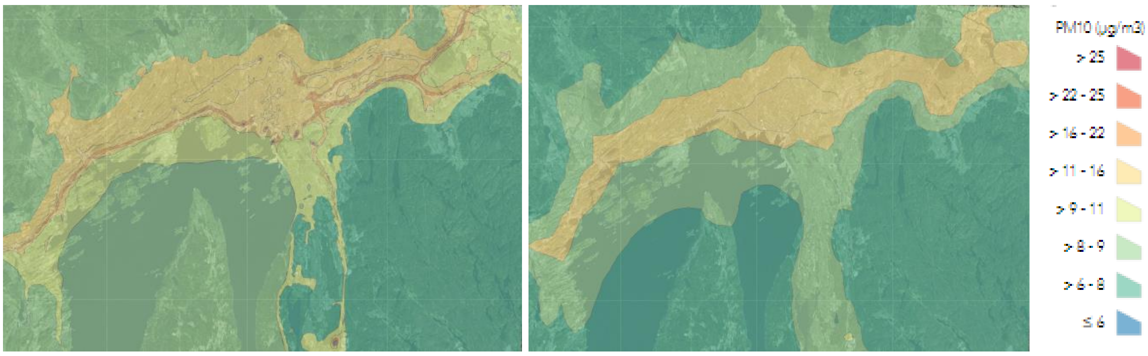

Figure 3.1.1. Modelled yearly mean of PM_{10} concentrations for 2015 in the Oslo-Bærum domain. The right panel shows results with standard 1x1km resolution. The left panel shows the same results taking into account sub-grid variability with a 100x100m resolution. Units:[µg/m^3]

All maps based on NBV_V0 emissions are given with 1x1km resolution, while the maps using NBV_V1 emissions are provided with 100x100m resolution. The validation of results in Chapter 4 shows that the model results using NBV_V1 emissions are generally in better agreement than those using the NBV_V0 emissions. We have chosen not to present the NBV_V0 estimates with the same resolution as NBV_V1 to indicate that the maps from NBV_V0 do not have the same level of accuracy than the maps using NBV_V1 as basis. The recommendation is to use only the indicator maps based on the latest version of the emission data, that is NBV_V1.

3.1.2 Strengths and limitations

The main strength of these indicators maps is that they are calculated with a common methodology across all cities that is both documented and validated, following state-of-art validation and benchmarking routines. Since the methodology used for compiling the air pollution concentrations is common to all the calculated areas, the maps can be used to compare air pollution levels across the different Norwegian cities. The maps are useful for the assessment of air pollution and for long-term planning.

When used for long-term planning purposes, it is important to consider that the actual indicator maps represent the situation for the year 2015. Given the existing year-to-year meteorological variability and the fact that emissions also vary from place to place in the different years, the indicator maps are not valid for other than 2015. For long-term planning purposes, indicator maps from additional years need to be compiled.

These maps are thus valuable for assessment and planning applications. However, the fact that the maps are based on modelled values involves an inherent limitation in their use for reporting compliance. The modelled values are subject to both systematic and random errors in comparison with observations. These errors are known through regular validation and can be accounted for. Therefore, for compliance applications, the data from the indicator maps should be complemented with information on the model performance against observations. For compliance applications, it is recommended to use a combination of measured and modelled values, preferably through the use of data fusion or data assimilation techniques.

3.2 Air quality zones

Air quality zones are calculated according to the national regulations provided in the T-1520 Guidelines for air quality treatment in area planning. The T-1520 guidelines provide advice on how air quality should be handled in municipal area planning. They are part of the "Planning and Building Regulations" and shall help to ensure that the use of land and building areas is as beneficial as possible for the individual and for society, facilitating good living environments and promoting the health of the population.

The T-1520 guidelines specify how air quality zones are to be determined. The air quality zones provided by the Norwegian Air Quality Planning Tool are based on model calculations alone. They identify and define red and yellow zones based on the modelled concentrations of NO_2 and PM_{10}. The concentration indicators chosen for the elaboration of the air quality zones are provided in Table 3.2.1.

As it can be seen from direct comparison of the values in Table 3.2.1 with the values in Tables 3.1.1. and 3.1.2., the red zone delimitation for long-term planning is more restrictive than the compliance with daily limit values with respect to PM_{10} concentrations in terms of the number of exceedances allowed. The delimitation of the yellow zones is more stringent than the upper threshold value (the value that triggers the need for elaboration of plans and programs) with respect to PM_{10} concentrations, in term of the number of exceedances allowed. However, for NO_2 concentrations, it is not obvious which of the two indicators is more restrictive, either the winter mean value of 40 $\mu g/m^3$ NO_2 as requested in the air quality zone determination or the yearly mean upper threshold value of 32 $\mu g/m^3$ NO_2.

Table 3.2.1. Criteria for the determination of air quality zones.

Component	Yellow Zone	Red Zone
PM_{10} concentrations	Daily mean values above 35 µg/m^3 PM_{10} allowed a maximum of 7 days per calendar year	Daily mean values above 50 µg/m^3 PM_{10} allowed a maximum of 7 days per calendar year
NO_2 concentrations	Winter mean values above 40 µg/m^3 NO_2 not allowed Winter mean values defined for the period from 1st November to 30rd April	Yearly mean values above 40 µg/m^3 NO_2 not allowed

3.2.1 How to use them

It is the responsibility of the environmental authorities in each urban area or municipality to produce their own air quality zone maps.

The elaboration of the air quality zone maps needs to follow the guidelines in to T-1520[2] and the environmental authorities are given different choices on the method they may want to use to elaborate the air quality zone maps, either based on 1) measurement data, 2) model data or 3) a combination of both. The guidelines explicitly explain that the most robust method to elaborate air quality zone maps is the third one: i.e using a combination of measurements and model data. Most municipalities have up to now developed their own air quality zones based solely on monitoring data. The air quality zone maps developed under NBV are based solely on model data. It is not the role of NBV to develop air quality zone maps, this is the responsibility of the local environmental authorities. Still, NBV can support the work of the national authorities by making the data of the modelled air quality zones available. If desired, local environmental authorities can combine the air quality zone maps in NBV with appropriate data from measurements to derive an improved air quality zone maps under their responsibility.

Those who need to use air quality zone maps to fulfill obligations in connection with the planning- and building act (Plan- og bygningsloven) or guideline T-1520 must make sure with the local authorities that they are using the right version of air quality zone map for their analysis.

In areas defined as Yellow Zones, the municipality should exercise caution in allowing the construction of buildings for use with a purpose that can be sensitive to air pollution, such as hospitals or kindergartens. The municipality should exercise caution in allowing the establishment of new activities and substantial expansion of existing activities if it causes a significant increase in air pollution. Areas defined as Red Zones, are not suitable for residential

[2] http://www.miljokommune.no/Temaoversikt/Forurensing/Luftkvalitet/Luftkvalitet-i-arealplanlegging/

use that is sensitive to air pollution due to the high air pollution levels expected in that areas. Red zones are also not suitable for the establishment of new business or substantial expansion of existing activities if it causes a significant increase in air pollution.

Consequently, the delimitation of air quality zones is highly relevant for area planning as it adds an environmental perspective to the growth and development of different city areas.

As mentioned above, the air quality zone maps in the Norwegian Air Quality Planning Tool (NBV) are not to be used as official air quality zone maps in planning applications, unless explicitly approved by the local authorities. They are meant only as reference to allow an expert comparison of the air quality zones in different cities across Norway.

3.2.2 Strengths and limitations

The main strength of these NBV air quality zone maps is that they are calculated with a common methodology across all cities. The methodology is both documented and validated and follows state-of-art validation and benchmarking approaches. Since the methodology used for compiling the air pollution concentrations is common to all the calculated areas, the air quality zone maps can be used to compare air pollution zone across the different Norwegian cities. In this way, air quality experts can carry out a first evaluation of the validity of specific results in different areas in Norway.

The information in the air quality zone maps can be used down to a resolution of 100x100m and for surface level. However, the air quality zone maps do not resolve details beyond that horizontal scale. Caution is advised when interpreting the limit between red, yellow and open zones beyond the model spatial resolution as this has important consequences for planning applications.

Given the existing year-to-year meteorological variability and the fact that emissions also vary from place to place in the different years, high variability is expected in air quality zones calculated from one year to another. An example of the effect of year-to-year meteorological variability in the air quality zone maps is given in Figure 3.2.1 for the Oslo and Bærum domain.

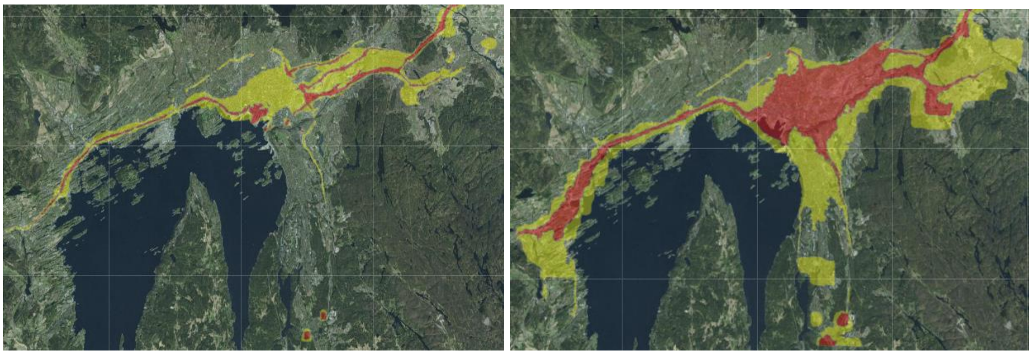

Figure 3.2.1. Air quality zones calculated for the Oslo and Bærum domain using the same dispersion model and the same emissions (NVB_v1) but using different meteorological year. Left Panel: Air quality zone for 2015; Right Panel Air quality zone for 2013.

The air quality zones calculated for the Oslo and Bærum domain in Figure 3.2.1. use exactly the same dispersion model and the same emissions (NVB_V1). The only difference between the two panels is the meteorological year used for the calculations. The air quality zones are largely determined by the exceedance of annual and seasonal mean values of nitrogen dioxide. In 2013, the NO_2 air concentrations were generally higher that in 2015, resulting in a larger number of registered exceedances and in a larger extension of the area with registered concentrations above the winter and annual limit values in Table 3.2.1. The consequences for planning applications can be appreciated in comparing the two panels in Figure 3.2.1. If the air quality zone maps for 2013 are used officially for planning applications, the restrictions to establishment of new business or substantial expansion of existing activities will be considerably larger than in air quality zone maps for 2015 are used instead.

The T-1520 Guidelines for air quality treatment in area planning from 2012 recognise the importance of meteorological variations but do not provide recommendations on how to deal with these variations in planning applications. The work carried out in this NBV project provides a good example of the difficulties met by municipalities when implementing the area planning regulations. In international fora dealing with the planning and control of air pollution, such as under the EU IPR and under the UN-Convention on Long-Range Transport of Air Pollution (LRTAP), the recommendation is generally to make planning decisions on the basis of averages from minimum 5 meteorological years, or alternative use 3 year averages, one of them representing worse-case conditions.

It is recommended that local environmental authorities elaborate their air quality zone maps based on a combination of modelled results (for example from NBV) and observations, and that they take into account the meteorological variability by combining results of 3-5 different years. Further guidance on how to deal with meteorological variability on the elaboration of air quality zones is necessary in Norway under the T-1520 Guidelines.

3.3 Exposure calculations

The effect of air pollution on people's health is generally provided on the basis of population exposure indicators. In the Norwegian Air Quality Planning Tool, the health exposure indicator is defined as the number of people living inside an area where air quality levels exceed the regulatory short and long-time limit values established under Norwegian legislation (Forurensningsforskriften, kap. 7) and listed in Table 3.1.1.

The exposure numbers in NBV are calculated on the basis of where people live. Individual health exposure refers however to the concentration of air pollution that the population is exposed to. How much pollution the individual is exposed to will depend on where people are staying at any time and can vary widely from individual to individual. It should be noted that individual exposure is not currently provided in NBV.

Exposure numbers have been calculated using the high-resolution concentration maps of 100 x 100m grid with spatially distributed modelled concentrations of NO_2, PM_{10} and $PM_{2.5}$. Population data was obtained from Statistics Norway and provides the number of people living in each building in the different domain areas by 1st January 2016. The population data was aggregated to the same 100x100m resolution as the concentration maps. The health exposure numbers for each domain were calculated by identifying the number of people living in an area where modelled air concentration are above the regulatory short and long-time limit values established under Norwegian legislation .

The exposure numbers in Table 3.3.1. show the number of people in 2015 living in areas with pollution levels above the limit values for each of the 7 city domains in NBV. Each model domain may include several municipalities. The numbers in Table 3.3.1 represent the exposure numbers for the whole model domain, whereas Table 3.3.2 shows the exposure numbers per municipality within the domains.

Table 3.3.1: Number of people within the modelling domains living in areas with pollution levels above the long-term and the short-term limit values for NO_2, PM_{10} and $PM_{2.5}$. Calculations valid for 2015.

NBV domains	NO_2 Annual mean	NO_2 Hourly mean	PM_{10} Annual mean	PM_{10} Daily mean	$PM_{2.5}$ Annual mean
Bergen	246	27	28	0	0
Drammen	869	75	5	24	0
Grenland	0	0	0	0	0
Nedre Glomma	0	0	0	0	0
Oslo and Bærum	7035	229	122	122	0
Stavanger	712	0	0	0	0
Trondheim	0	0	0	0	0

Table 3.3.1: *Number of people within the different municipalities in the modelling domains, living in areas with pollution levels above the long-term and the short-term limit values for NO_2, PM_{10} and $PM_{2.5}$. Calculations valid for 2015.*) Refers to the part of the municipality inside the modelling domain.*

Municipalities in the NBV domains	NO_2 Annual mean	NO_2 Hourly mean	PM_{10} Annual mean	PM_{10} Daily mean	$PM_{2.5}$ Annual mean
Bergen	246	27	28	0	0
Drammen	869	75	0	7	0
Skien*	0	0	0	0	0
Porsgrunn*	0	0	0	0	0
Sarpsborg*	0	0	0	0	0
Fredrikstad*	0	0	0	0	0
Oslo	6803	229	122	122	0
Bærum	232	0	0	0	0
Stavanger	712	0	0	0	0
Sandnes*	0	0	0	0	0
Trondheim	0	0	0	0	0

3.3.1. How to use them

The exposure numbers In NBV are indicators for how many people within a municipality or region live in areas where air pollution reaches levels that may affect their health.

For planning purposes, the numbers can be used to identify and prioritize measures that aim at reducing the levels of pollution in areas where people are likely to be exposed to high pollution levels. The exposure numbers may also be used to rank and evaluate the effect of different measures against each other.

3.3.2. Strengths and limitations

The main strength of the NBV exposure calculations is that they are based on highly resolved maps with 100x100m resolution. The accuracy of exposure calculations depends on the capability of the model to resolve sufficiently the areas where people live. It is always important that the resolution of the model and the resolution of the population data are in agreement.

It is important to point out that year-to-year meteorological variability also causes large variability in the air pollution levels: both the concentration levels and their distribution in the city can change. This means that the number of people that lives in areas with high air pollution will significantly change from one year to another. Population exposure is in fact a very sensitive indicator so that large differences in population exposure can be expected from small air quality concentration changes.

Annual average values of NO_2 can typically vary by 3 - 10µg/m^3 from one year to another at a measurement station due to different meteorological conditions. Table 3.3.3 below shows an example of how dramatic are the differences in population exposure due to typical inter-annual variations of nitrogen dioxide concentrations. The example is documented in Høiskar et al. (2016) and show how variations in concentration by 12,5-20% can give rise to significantly changes in population exposure numbers, ranging over two orders of magnitude.

Table 3.3.3. The table illustrates calculated differences in population exposure to NO_2 annual mean concentrations for different scenarios (From Høiskar et al., 2016)

	Annual mean NO_2				
Scenarios	+10 µg/m^3	+5 µg/m^3	40 µg/m^3	-5 µg/m^3	-10 µg/m^3
Reference	194 100	37 900	8 800	2 000	500
Scenario 1	113 700	16 900	3 900	1 000	200
Scenario 2	83 000	12 400	2 300	600	200
Scenario 3	87 400	14 800	2 600	600	200

3.4 Emission data

Information on emissions is provided in the NBV website in three different ways as emission maps, pies and tables. Two versions of the emission data are provided for all city domains, NBV-V0 and NBV_V1, except for Oslo, where information on emissions are consistent and documented in Høiskar et al. (2014). Emission data version NBV_V0 corresponds to emission data currently used in the Better City Air (Bedre Byluft) project, while version NBV_V1 is prepared as part of this project. Version NBV_V1 contains updated emission data and has been developed with common methodology for all cities.

The emission data maps show the spatial distribution of annual emissions of the various components (NOx, PM_{10} and $PM_{2.5}$) in tons per year. Total emissions are displayed as grid values with a horizontal resolution of 1 x 1km. In addition, the spatial distribution of emissions from traffic are displayed in separate maps as lines sources. Emissions from other sources than traffic are all displayed in a common map, named under the common name 'Other'. These emissions are shown as grid emissions with 1x1 km resolution and include domestic heating, shipping, industrial and off-road emissions , where applicable.

The total annual emission values per sector are displayed for each city domain as tables and pies. The tables show the annual emission per sector and component in tons per year, where emissions from the different activity sectors are specified in the relevant categories and the term “other sources” in these tables should not be confused with the aggregated information denominated as “Other” in the emission maps. The pies show the percentage contribution of each emission sector to the total annual emissions. The information provided in the pies is consistent with the information provided in the tables and the term “other sources” correspond to those identified in the tables for emissions.

3.4.1 How to use them

The information on the horizontal spatial distribution of the emissions provided in the NBV emission maps allows direct validation of the data by local experts. It is also useful information for local scale planning applications (such as under T-1520) as it allows to identify the main sources in the neighborhood of a specific planning area. Used in combination with the information on air concentration dispersion patterns from the air pollution indicator maps, these data can help determining how different emissions will affect air quality in the planning area.

NBV_V1 is considered to be a better estimate of emissions for the year 2015 than the original version NBV_V0. This recommendation is based on the fact that NBV_V1 uses an updated methodology to derive the emissions and provides better results from validation with observations (see conclusions in Chapter 4). In the NBV website, total emissions from NBV_V0 are therefore not shown, but the maps with traffic emissions and with “Other” gridded emissions for NBV_V0 are presented. These sector emission maps are useful for comparison between the two versions, to show where the main differences between the inventories are located.

In the download section, both emission versions can be retrieved, to allow for possible sensitivity studies on the influence of emissions in air concentrations. Additionally, the comparison of emission maps with their respectively derived air quality indicator maps allows to further to understand the influence of emission data in the distribution of air concentration in each city domain in NBV.

3.4.2 Strengths and limitations

As it has been identified before, a main strength of the NBV calculations is that it uses the same methodology over the different areas so that results are comparable across the different domains. Still, emissions vary significantly from place to place and local understanding of the emission is required to secure reliable air quality assessments and control strategies. The NBV emission work has shown the importance of process-based (bottom-up) emission approaches to compile urban scale emission data (see López-Aparicio et al., 2017) but it is still subject to significant uncertainties.

The validation work of the emission data carried out through comparison of derived air concentrations with observations has shown room for improvement in certain activity sectors, in particular for domestic heating, shipping, off-road and traffic non-exhaust emissions (see Chapter 4). Even for traffic exhaust emissions, which are presently the best estimated sector, there is a possibility to improve emissions from traffic in municipal roads that are currently not included in the National Roads Database (NVDB) by carrying out activity counting campaigns in cooperating with local authorities.

It is recognized that emission data remains a key source of uncertainty for NBV results. The emission data can be improved with regular yearly updates. The emission work in NBV has pointed out the significance of year-to-year emission variability in particular for the domestic heating sector, and for shipping emissions. Industrial emission can also vary significantly from one year to the other, when plants revise their activities, or either open or close. It is recommended to continue the effort initiated under the NBV project by updating emission data at least every two years, aiming at building a robust update system to allow for regular yearly emission estimates.

3.5 Main contributors to pollution

The contribution of different emission sources to air pollution concentrations of NO_2, PM_{10} and $PM_{2.5}$ is presented in percentage maps at the NBV website. The maps provide information about how much the different emission sectors contribute in percentage to the total air concentrations. The percentage calculations are presented for annual mean concentrations. The emission sectors considered are traffic, shipping, domestic heating, industry and "other", which includes off-road emissions. In addition to the contribution from specific emission sectors, information is also provided as to how important is the contribution of background concentrations to the air pollution levels in the modelled domain. Background concentrations are introduced as boundary conditions in the calculations and can be interpreted as the concentrations in air originating from outside the city domain.

The contribution from background air concentrations to pollution levels is significant for all components and is generally larger for $PM_{2.5}$ than for PM_{10}, and while it is generally smaller for NO_2, it is still significant also for this component. As indicated in Figure 3.5.1., the contribution from background concentrations is larger in the borders of the modelled domain and becomes less significant in the city center where local pollution sources become more relevant.

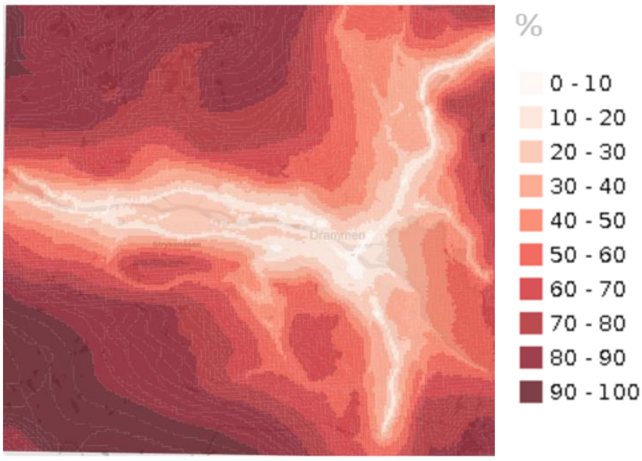

Figure 3.5.1: Percentage contribution from background air concentrations to the annual mean air pollution levels of NO_2 in Drammen in 2015. Units: Percentage [%]

The relative contributions from the different sources only apply to the year (2015) and for the emissions in NBV-V1 for which they are calculated. These contributions will change under different meteorological conditions or if the emissions from one or more sources change. The relative contributions apply also only for annual air pollution values. For other indicators, such as highest values over threshold limits, the contributions of different sources may differ.

3.5.1 How to use them

The relative contributions from the different sources to annual pollution levels in the city domains constitute important information for planning applications. Such information is politically highly relevant because it identifies which sources should be targeted in different areas when planning future control scenarios. This is a first step toward the elaboration of future scenarios and can be used in combination with the emission maps in NBV to support emission planning.

3.5.2 Strengths and limitations

Again, a main strength of the NBV calculations is that it uses the same methodology over the different areas so that results are comparable across the different domains. However, these source contributions will vary from year to year and also if one or more emission sources change. In addition, there are also uncertainties related to the calculations, although it is less than the natural variability from year to year estimates. Therefore, for any planning applications, it is recommended instead of an average of the source contributions for at least 3 to 5 years.

A well-established principle in air pollution management is related to the principle "polluter pays". The percentage contribution maps provided in NBV should not be used directly as base for allocation of liability and costs pursuant to Chapter 7, Section 7-5 of the Pollution Control Regulations, for the same limitations explained above. It is recommended instead the use of an average of the source contributions for at least 3 to 5 years if such information is to be used at all for liability or cost distributions.

3.6 Data downloads

Three types of data are available for download at the NBV website: a) meteorological data , b) emission data and c) air concentration data

a) **Meteorological data**: Meteorological data for 2010 and 2015 are available as hourly 3D fields for the main parameters requested as input to air quality dispersion models. Meteorology data for 2015 has a resolution of 1x1km. For 2010 there are available data with both 1x1km and 2.5x2.5km resolution. The data is provided as monthly files (12 files, one for each month) for each of the seven city domains. The format of these files is NetCDF.

   Meteorology data for other locations in Norway can be downloaded at a 2.5km resolution by specifying coordinates for the current location. The coordinate data is provided at surface level and can be downloaded as CSV.

   The meteorological data are documented in the reports Denby et al. (2015) and Denby et al. (2016). Using meteorology data, please refer to these reports and acknowledge the origin of the data as meteorological data from the Norwegian NBV project.

b) **Emission data**: Annual emission totals in each of the seven city domains are provided for 2015 for the two emission inventory versions NBV_V0 and NBV_V1. The emission data is provided in gridded form with a resolution of 1x1km.There are three files for each component (NOx, PM_{10} and $PM_{2.5}$ emissions): one file for total emission, one for traffic emissions and one including all other emissions except traffic. The traffic emission file includes both exhaust and non-exhaust emission estimates and line sources are aggregated to grids of 1x1km to allow comparison with the other emission files. The format of these files is ASCII.

   The emission data are documented in the report López-Aparicio and Vo Thanh (2015) and in the publication López-Aparicio et al. (2017). Using emission data, please refer to these and acknowledge the origin of the data as emission data from the Norwegian NBV project.

c) **Air concentration data**: Air concentration data for 2015 are available as 3D fields and surface values for the three main components (NO_2, PM_{10} and $PM_{2.5}$). Air concentration data is provided as hourly data for 2015 and has a resolution of 1x1km. The data is provided for each component as monthly files (12 files, one for each month) for each of the seven city domains. The format of these files is NetCDF.

   The air concentration data is documented in this report. Using air concentration data, please refer to Tarrasón et al. (2017) and acknowledge the origin of the data as concentration data from the Norwegian NBV

3.6.1 How to use them

The three types of data provided by NBV can be used in different ways, but are mainly intended for air pollution dispersion applications for assessment, forecasting and planning purposes. The data can be used as input or boundary conditions and the different versions and years available provide a good basis for sensitivity expert analysis.

Meteorological data, either in 3D or at surface level, can be used as input for different dispersion model calculations. The data is currently available in the website as hourly data for the years 2015 and 2010, so that analysis of annual meteorological variations can be carried out for these two years. In addition, meteorological data for 2016 has been compiled and it is envisaged that the continuation of the project, in synergy with Bedre Byluft, will facilitate the availability of further meteorological years. Such capability will allow for yearly updates of the meteorological data.

Emission data is also intended to be used as input data for air pollution dispersion applications. The two different versions can be used to support expert sensitivity analysis of the emissions, but for assessment and planning applications, it is recommended the use of NBV-V1. When the emission data is used as input in dispersion model, information on the temporal and vertical distribution of emissions is further necessary. Such information has not been provided here as it varies in requirements from model to model. So, for further use of the emission data from NBV, it would be desirable to carry out a survey on how best to provide such additional temporal and spatial information on emission. The emission data is considered valid for 2013-2015, and it is not recommended to use these emission data for other years. However, the emission data can be used as basis for further scenario calculations with appropriate assumptions for evolution and extrapolation.

Air concentration data is provided as 3D hourly values, including surface level values for each component with 1x1km resolution. The data can be used for comparison with other model estimates and in the context of T-1520 application it can be used as boundary conditions for local scale model applications. The data is valid for the year 2015 and should not be used for other years because of the expected variability from year to year estimates. For any planning applications, it is recommended instead of an average of the air concentrations for at least 3 to 5 years.

3.6.2 Strengths and limitations

The main strength of the NBV data is its availability. All data is downloadable from the NBV website, either in the form of graphs and shapefiles or directly as data files. The data are also documented and validated with common methods across all cities, following state-of-art validation and benchmarking approaches. Limitations in the use of the data are identified and recommendations for improvement have been provided.

Concerning the download capabilities, data is available in a set of standard formats. These involve NETCDF format for meteorological and air concentration data, CSV for meteorological coordinate data and ASCII files for emission gridded data. In addition, mapping information is available as PDF or as SHAPE files. These standard formats were identified as the most relevant ones to allow for different users. Once the data is downloaded and used extensively, further recommendations can be gathered from expert users as to how the data downloading capabilities are to evolve.

4 Evaluation of results

This chapter presents a summary of the current evaluation of the NBV model results for 2015 carried out as a direct comparison with available measurements. The validation of air quality levels for nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$) in comparison with observations is an essential way to understand the validity not only of the model results but also of the emissions used as input to the calculations. Detailed results of the comparison with observations are documented in Appendix A for the main city areas in Norway and have served as basis for the analysis summarized below.

Tables 4.1., 4.2. and 4.3. show summary statistics for the validation of model results with observations at available measurement stations in 2015 for respectively NO_2, PM_{10} and $PM_{2.5}$. Validation results are presented by city area, that is, Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger, and per measurement station in each area. The validation results are presented for results of the dispersion model run with the two different emission sets available in NBV, namely NBV_V0 and NBV_V1. This is the case for all cities except for Oslo, where there is already a consolidated emission inventory, denominated here as NBV_V1 for consistency with the other city estimates. In Oslo, only one set of modelled concentrations are evaluated. The comparison of the evaluation results for the two sets of emission data allows a further reflection on the quality of the emission data and the need for further development of the emission estimates.

The model performance with the use of NBV_V0 emission estimates is regularly documented within the framework of the Bedre Byluft project (Denby et al. 2016) An added value of the current NBV model validation is that, for the first time, the evaluation covers a whole year, and not only the winter season as it is usual in Bedre Byluft. This is also the reason why the model performance may differ when compared to previous Bedre Byluft estimates, as those hold for the season from 1st October to 30th April. Another relevant added-value of the current NBV model validation is the evaluation of the new emission dataset, NBV-V1 not currently implemented in Bedre Byluft.

4.1 NO_2

The evaluation of the model results for NO_2 show a general improvement of the correlation coefficient when the emissions used as input to the model calculations are updated to NBV_V1. Correlation coefficients for hourly data over the whole year vary between 0.4 and 0.6 and except for stations in Trondheim and Stavanger, the updated emission dataset of NBV-V1 generally show an increased correlation coefficient than results with NBV_V0. The performance of the model in terms of bias and root square mean error varies from station to station. This is due to the particular conditions of the measuring station and type of sources affecting the air concentrations in the station and its surroundings.

The sources affecting NO_2 concentrations are primarily traffic emissions, but there can also be contributions from industrial NO_x emissions, off-road sector and/or from shipping emissions. Traffic emissions have been updated regularly under the Bedre Byluft project, so that there is no difference between the NO_x traffic emissions between NBV_V0 and NBV_V1. The main differences between two inventories are related to industrial and shipping emissions.

Table 4.1: Summary evaluation results for NO_2 in 2015 for all city domains. Units:[µg/m3]

Domain	**AQ Station - NO_2**	**Emission version**	**Obs mean**	**Model mean**	**Bias**	**RMSE**	**R**	**Frequency**
Bergen	Danmarksplass	NBV_V0	38,00	42,70	4,70	31,13	0,42	hourly
Bergen	Danmarksplass	NBV_V1	38,00	31,91	1,91	27,00	0,58	hourly
Bergen	Rådhuset	NBV_V0	30,10	24,45	-5,65	22,60	0,40	hourly
Bergen	Rådhuset	NBV_V1	30,10	20,78	-9,32	21,14	0,53	hourly
Drammen	Bangeløkka	NBV_V0	36,27	39,39	3,12	25,39	0,44	hourly
Drammen	Bangeløkka	NBV_V1	36,27	42,61	6,34	25,28	0,46	hourly
Grenland	Lensmannsdalen	NBV_V0	21,83	12,03	-9,80	20,41	0,31	hourly
Grenland	Lensmannsdalen	NBV_V1	21,83	26,08	4,25	19,59	0,47	hourly
Grenland	Øyekast	NBV_V0	13,35	23,53	10,18	21,33	0,36	hourly
Grenland	Øyekast	NBV_V1	13,35	19,03	5,68	16,59	0,50	hourly
Nedre Glomma	St. Croix	NBV_V0	30,89	24,91	-5,98	23,37	0,54	hourly
Nedre Glomma	St. Croix	NBV_V1	30,89	40,15	9,26	24,59	0,59	hourly
Oslo	Akebergveien	NBV_V1	31,00	31,86	0,86	21,76	0,53	hourly
Oslo	Alnabru	NBV_V1	32,94	41,66	8,72	32,94	0,37	hourly
Oslo	Bygdøy Alle	NBV_V1	50,64	33,02	-17,62	32,65	0,49	hourly
Oslo	Grønland	NBV_V1	27,49	29,60	2,11	22,26	0,58	hourly
Oslo	Hjortnes	NBV_V1	44,37	37,03	-7,34	36,66	0,50	hourly
Oslo	Kirkeveien	NBV_V1	35,11	28,01	-7,10	23,51	0,56	hourly
Oslo	Manglerud	NBV_V1	41,54	31,99	-9,55	31,78	0,46	hourly
Oslo	Rv 4, Aker sykehus	NBV_V1	31,02	48,13	17,11	35,06	0,51	hourly
Oslo	Smestad	NBV_V1	46,40	30,17	-16,23	32,35	0,45	hourly
Stavanger	Kannik	NBV_V0	33,89	34,09	0,20	27,76	0,38	hourly
Stavanger	Kannik	NBV_V1	33,89	36,92	3,03	29,15	0,38	hourly
Stavanger	Våland	NBV_V0	18,15	17,51	-0,64	16,56	0,43	hourly
Stavanger	Våland	NBV_V1	18,15	23,91	5,76	21,45	0,41	hourly
Trondheim	Bakkekirke	NBV_V0	21,99	21,44	-0,55	17,50	0,46	hourly
Trondheim	Bakkekirke	NBV_V1	21,99	22,00	0,01	19,28	0,39	hourly
Trondheim	Elgseter	NBV_V0	31,85	28,10	-3,75	24,65	0,44	hourly
Trondheim	Elgseter	NBV_V1	31,85	30,68	-1,17	25,32	0,42	hourly

Table 4.2: Summary evaluation results for PM_{10} in 2015 for all city domains. Units:[μg/m^3]

Domain	AQ Station - PM_{10}	Emission version	Obs mean	Model mean	Bias	RMSE	R	Frequency
Bergen	Danmarksplass	NBV_V0	16,47	20,03	3,56	11,59	0,42	daily
Bergen	Danmarksplass	NBV_V1	16,47	19,45	3,01	10,69	0,50	daily
Bergen	Rådhuset	NBV_V0	13,13	14,46	1,33	9,05	0,44	daily
Bergen	Rådhuset	NBV_V1	13,13	13.30	0,17	7,57	0,47	daily
Drammen	Bangeløkka	NBV_V0	23,60	15,76	-7,84	22,57	0,23	daily
Drammen	Bangeløkka	NBV_V1	23,60	15,29	-8,31	22,51	0,23	daily
Grenland	Lensmannsdalen	NBV_V0	22,66	19,51	-3,15	23,35	0,17	daily
Grenland	Lensmannsdalen	NBV_V1	22,66	14,38	-8,28	20,12	0,24	daily
Grenland	Øyekast	NBV_V0	14,71	23,38	8,67	19,13	0,23	daily
Grenland	Øyekast	NBV_V1	14,71	12,55	-2,16	10,44	0,38	daily
Nedre Glomma	St. Croix	NBV_V0	14,80	13,85	-0,95	10,42	0,49	daily
Nedre Glomma	St. Croix	NBV_V1	14,80	14,97	0,17	9,43	0,52	daily
Oslo	Akebergveien	NBV_V1	14,85	14,05	-0,80	8,70	0,57	daily
Oslo	Alnabru	NBV_V1	22,52	19,17	-3,35	19,29	0,43	daily
Oslo	Bygdøy Alle	NBV_V1	18,79	15,03	-3,76	12,25	0,54	daily
Oslo	Hjortnes	NBV_V1	23,86	16,78	-7,08	17,25	0,50	daily
Oslo	Kirkeveien	NBV_V1	20,17	13,29	-6,88	12,59	0,53	daily
Oslo	Manglerud	NBV_V1	20,98	16,10	-4,88	13,81	0,48	daily
Oslo	Rv 4, Aker sykehus	NBV_V1	14,28	19,14	4,86	15,51	0,49	daily
Oslo	Smestad	NBV_V1	22,78	18,70	-4,08	16,39	0,45	daily
Oslo	Sofienbergparken	NBV_V1	15,56	13,28	-2,28	9,19	0,47	daily
Stavanger	Kannik	NBV_V0	22,25	16,32	-5,93	14,56	0,35	daily
Stavanger	Kannik	NBV_V1	22,25	17,47	-4,78	14,07	0,39	daily
Stavanger	Våland	NBV_V0	15,37	14,31	-1,06	7,55	0,42	daily
Stavanger	Våland	NBV_V1	15,37	15,74	0,37	8,30	0,39	daily
Trondheim	Bakkekirke	NBV_V0	14,30	18,62	4,32	19,11	0,14	daily
Trondheim	Bakkekirke	NBV_V1	14,30	8,32	-5,98	10,06	0,17	daily
Trondheim	Elgseter	NBV_V0	12,24	18,28	6,04	17,79	0,31	daily
Trondheim	Elgseter	NBV_V1	12,24	9,87	-2,37	7,78	0,42	daily

Table 4.3: Summary evaluation results for $PM_{2.5}$ in 2015 for all city domains. Units:[µg/m³]

Domain	AQ Station $PM_{2.5}$	Emission version	Obs mean	Model mean	Bias	RMSE	R	Frequency
Bergen	Danmarksplass	NBV_V0	7,87	11,42	3,55	9,19	0,54	daily
Bergen	Danmarksplass	NBV_V1	7,87	10,10	2,23	8,55	0,54	daily
Bergen	Rådhuset	NBV_V0	6,85	8,95	2,10	8,03	0,32	daily
Bergen	Rådhuset	NBV_V1	6,85	7,64	0,79	6,38	0,35	daily
Grenland	Lensmannsdalen	NBV_V0	8,01	13,89	5,88	14,28	0,50	daily
Grenland	Lensmannsdalen	NBV_V1	8,01	8,19	0,18	6,28	0,52	daily
Grenland	Øyekast	NBV_V0	7,21	20,04	12,83	19,58	0,27	daily
Grenland	Øyekast	NBV_V1	7,21	8,63	1,42	7,59	0,48	daily
Nedre Glomma	St. Croix	NBV_V0	9,64	8,84	-0,80	6,84	0,64	daily
Nedre Glomma	St. Croix	NBV_V1	9,64	8,33	-1,31	5,32	0,68	daily
Oslo	Akebergveien	NBV_V1	8,28	7,73	-0,55	4,48	0,69	daily
Oslo	Alnabru	NBV_V1	13,90	8,90	-5,00	10,71	0,44	daily
Oslo	Bygdøy Alle	NBV_V1	8,80	8,68	-0,12	6,60	0,50	daily
Oslo	Hjortnes	NBV_V1	8,58	8,67	0,09	4,99	0,64	daily
Oslo	Kirkeveien	NBV_V1	8,86	8,96	0,10	5,25	0,60	daily
Oslo	Manglerud	NBV_V1	8,28	7,24	-1,04	4,04	0,54	daily
Oslo	Rv 4, Aker sykehus	NBV_V1	6,54	8,88	2,34	4,78	0,66	daily
Oslo	Smestad	NBV_V1	8,38	9,28	0,90	5,91	0,48	daily
Oslo	Sofienbergparken	NBV_V1	9,00	8,52	-0,48	6,37	0,48	daily
Stavanger	Kannik	NBV_V0	10,07	8,72	-1,35	4,91	0,54	daily
Stavanger	Kannik	NBV_V1	10,07	9,63	-0,44	5,16	0,56	daily
Stavanger	Våland	NBV_V0	7,38	7,64	0,26	4,42	0,48	daily
Stavanger	Våland	NBV_V1	7,38	8,64	1,26	5,24	0,48	daily
Trondheim	Bakkekirke	NBV_V0	6,93	14,17	7,24	18,27	0,34	daily
Trondheim	Bakkekirke	NBV_V1	6,93	4,97	-1,96	4,48	0,36	daily
Trondheim	Elgseter	NBV_V0	5,23	12,21	6,98	15,48	0,61	daily
Trondheim	Elgseter	NBV_V1	5,23	5,29	0,06	2,87	0,66	daily

The update of industrial emissions in Grenland seems to have contributed to a significant improvement in the hourly correlation coefficients and reduced the bias and RMSE at Øyekast station. In this case, the industrial information included in NBV_V0 dated back to 1991 and it contained industrial activity that is currently closed-down. The NBV_V1 update has resulted in more accurate industrial emission values. The information was updated based on the official reporting from industrial emissions to the Environmental Agency for 2013 (http://www.norskeutslipp.no/).

With respect to shipping emissions, the initial version of NBV_V1 emissions was to update the shipping emission values in Bergen and Stavanger from the 1995/1998 estimates included in NBV_V0 to new 2015 data from the Norwegian Coastal authority (Kystverket).

Similarly, in Trondheim, the data was updated from the 2005 estimates in NBV_V0 to 2015 data from Kystverket. However, an initial validation of the NO_2 concentrations derived with the new emission versus observations at Danmarksplass in Bergen revealed significant overestimation errors in concentrations, which could later be related to errors in the shipping emission data. The shipping emission data used in NBV has been provided by Kystverket for 2015 and were calculated by DNV GL. After communication with DNV-GL, they confirmed that indeed NOx emission reported to Kystverket before 2016 for the offshore supply ships were too high and needed to be corrected for any further use. DNV GL has provided NBV correcting factors to be applied for the shipping emissions for Bergen for 2015 and the model results agrees well with measurements after the correction. However, the shipping emissions in NBV_V1 for all the other cities have not been corrected at this stage. Therefore it is important to keep in mind that the identified error in the emission data may affect the NO_2 results in cities with off-shore activities.

4.2 PM_{10}

Another interesting problem identified by the evaluation of model concentrations versus observations is with respect to particulate matter. Table 4.2 summarises the results evaluation of the modelled PM_{10} concentrations with available observations. The comparison shows a general improvement of the correlation coefficient when the emissions used as input to the model calculations are updated to NBV_V1. The correlation coefficient values for daily PM_{10} concentrations with the updated emissions are generally around 0.5. The modelled values of PM_{10} are generally underestimated, despite the fact that $PM_{2.5}$ concentrations are more generally overestimated. This is possibly a compensation of errors between the fine and the coarse fractions contributing to PM_{10}. As it is shown in Appendix A, PM_{10} values are generally underestimated in spring and autumn. This systematic underestimation of the PM_{10} concentrations in spring and autumn is probably related to the contribution of road dust emissions in those periods. A new parametrization of road dust emissions is currently implemented in Bedre Byluft, and will be available to NBV so that the expectation is that the PM_{10} estimates can be improved in the future.

4.3 $PM_{2.5}$

The evaluation of the modelled $PM_{2.5}$ concentrations is summarised in Table 4.3 above. The results of the comparison show the highest correlation with observations for $PM_{2.5}$ than for other components, with correlation values generally above 0.5. The results also show a general improvement of the correlation coefficient when the emissions used as input to the model calculations are updated to NBV_V1.

As indicated in Table 4.3, $PM_{2.5}$ concentrations were largely overestimated by the model with the original emission used under the Bedre Byluft program, those referred here as NBV_V0 emissions. With the updated emission inventory NBV_V1, the model results show no significant bias and the root mean square errors (RMSE) are significantly reduced. This is because the NBV_V1 emission estimates include a correction of the domestic wood burning emissions. Air concentrations of $PM_{2.5}$ are determined to a significant extent by domestic heating emissions although background concentrations and traffic and industrial emission play also a significant role. So, the relatively good results of the model calculations using NBV_V1 emissions serve to highlight the existing problems related domestic wood burning emissions.

In order to explain the current available observations of $PM_{2.5}$, domestic emissions from wood burning derived from national statistics data and Norwegian certified emission factors need to be adjusted. The adjustment factor varies from city to city but is generally above a factor of 2. Further evaluation in cooperation with local authorities is necessary in order to assess the reasons for the discrepancy between reported emissions and observed air concentrations for $PM_{2.5}$.

It is recommended to carry out a series of measurement campaigns at city level, focusing on black carbon and the carbonaceous part of the aerosol and $PM_{2.5}$. Such campaigns should preferably use multi wavelength aethalometers for source allocation purposes and be designed to provide a better insight on the contribution of wood burning emissions to air concentrations of the aerosol in city areas. An example of such measurement campaign is currently carried out in Lillestrøm, Skedsmo (Hak, pers.comm., 2017) and can provide some insight on the benefits of the method to better understand the actual emission values of wood burning over Norway. Wood burning emissions remain at this point the largest single source of uncertainty in the NBV results.

5 Conclusions

The main strength of the NBV-products is their open availability via the web portal at http://www.luftkvalitet-nbv.no and the fact that they are produced using a common documented methodology over the different urban areas. Results are thus comparable across Norway.

The NBV-maps have an improved spatial resolution from the commonly used 1x1km and include highly resolved maps with 100x100m resolution. This makes the products very useful for urban assessment and planning applications. However, caution is advised when interpreting the values beyond this spatial resolution, as the maps are not recommended to be used directly for building and roads regulatory applications.

The air quality products in NBV are based on calculations carried out with the EPISODE air pollution dispersion model. All calculations use the same input data consisting of: a) meteorological data for the year 2015 operationally calculated by the AROME-MetCoOp system with a spatial resolution of 1x1km (Denby et al., 2016) and b) emission input data documented in Lopez-Aparicio and Vo Thanh (2015). Two different sets of emissions are available: NBV_V0 corresponding to the emission fields currently used in the Bedre Byluft forecasting system and NBV_V1 corresponding to improved emission estimates developed under this project. The NBV_V0 emission estimates are based on emission information from different years and are not consistently compiled for the different city areas. In contrast, the NBV_V1 information has been updated consistently across all sectors for all Norwegian cities.

All information available through NBV is documented and scientifically validated following international performance standards. This applies to meteorological data, emissions and air pollution data and it sets a standard for what may be required in Norway in terms of air quality performance indicators. The quality of the emission data and the EPISODE air pollution dispersion model in NBV has been estimated following the benchmarking activities promoted within the framework of the Forum for air quality modelling in Europe (FAIRMODE, Janssen et al., 2017; Lopez-Aparicio et al., 2017). In addition, air quality results for 2015 have been evaluated against observations at the main city areas in Norway: Bergen, Drammen, Grenland, Nedre Glomma, Oslo, Trondheim and Stavanger, as presented in this report.

The validation of air quality levels for nitrogen dioxide (NO_2) and particulate matter (both PM_{10} and $PM_{2.5}$) in comparison with observations is a useful way to understand the validity, not only of the model results but also of the emissions used as input to the calculations. The evaluation of the model results for NO_2 in Bergen revealed errors in the shipping emission data that were corrected for this city. However, it is important to keep in mind that the identified error in the emission data may affect the NO_2 results in cities with offshore activities. Concentrations of $PM_{2.5}$ are slightly overestimated with respect to observations, and PM_{10} values are generally underestimated in spring and autumn. This systematic underestimation of the PM_{10} concentrations in spring and autumn is related to the contribution of road dust emissions in those periods. A new parametrization of road dust emissions is currently implemented in Bedre Byluft, and will be available to NBV so that the PM_{10} estimates could be improved in the future.

The main source of uncertainty in the current air quality estimates is related to emission data. This applies to road dust emissions as indicated above, and, more specially, to domestic heating emissions from wood burning. The 2015 $PM_{2.5}$ emissions from wood burning used in NBV_V1 were adjusted from the official data based on national statistics activity data and certified emission factors. The adjustment factor was derived on the basis of comparison with observations. It varied from city to city, but it was generally above a factor of 2. Further evaluation in cooperation with local authorities, is necessary in order to assess the reasons for the discrepancy between reported emissions and observed air concentrations for $PM_{2.5}$. It is recommended to carry out a series of measurement campaigns at city level, focusing on black carbon and the carbonaceous part of the aerosol and $PM_{2.5}$ and preferably using multi wavelength aethalometers for source allocation purposes. Wood burning emissions remain at this point the largest single source of uncertainty in the NBV $PM_{2.5}$ results.

An important limitation of the current system is that is has been implemented only for one year, so that the products are only representative of 2015 conditions. Given the existing year-to-year meteorological variability and the fact that emissions also vary from place to place in the different years, high variability is expected for the NBV-products from one year to another. It is generally recommended that for such policy relevant analysis, 3-yearly or 5-yearly averaged data is used instead of simply data for one specific meteorological year. This is the reason why at present, different years with meteorological data are provided in NBV. Additional guidance from the Norwegian Environmental Authorities is recommended as to how to account for meteorological variability in planning applications under T-1520.

Still, the current estimates of emission, meteorology and air concentration data are our best assessment of the status of air quality in Norway in present times. The data compiled under the Norwegian Air Quality Planning Tool has sufficient accuracy, is transparent and has been documented as to allow further use in planning and assessment of air quality. All products in NBV are openly available to support air quality assessment and air quality planning activities by different groups of experts. The limitations of the data are clearly documented and that sets the premises for further use and interpretation of the results.

6 References

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Appendix A

Validation with observations

Bergen, Danmarksplass

NO_2

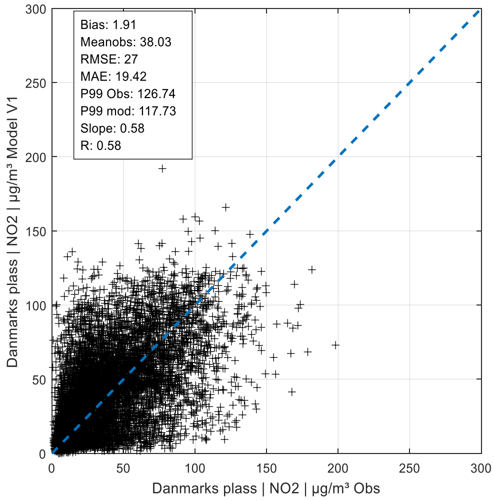


Figure A 1: Yearly value NO_2 in Danmarksplass, V1

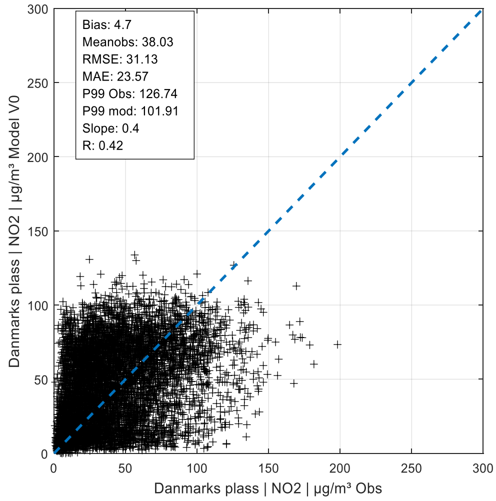


Figure A 2:Yearly value NO_2 in Danmarksplass, V0

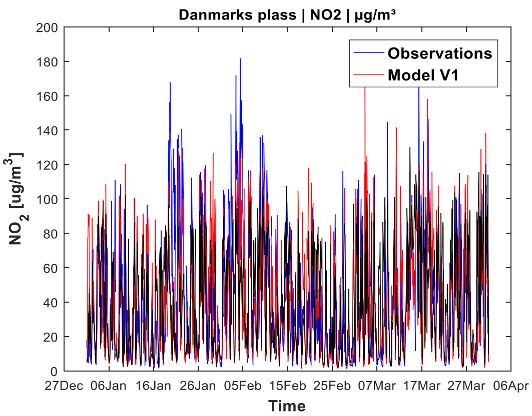


Figure A 3: Timesheet NO_2 in Danmarks plass

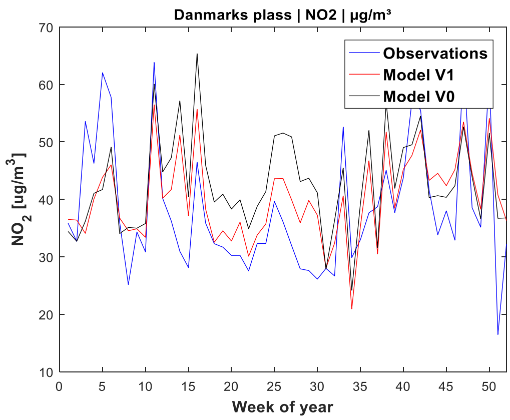


Figure A 4: Week of year NO_2 in Danmarks plass

Bergen, Rådhuset

NO_2

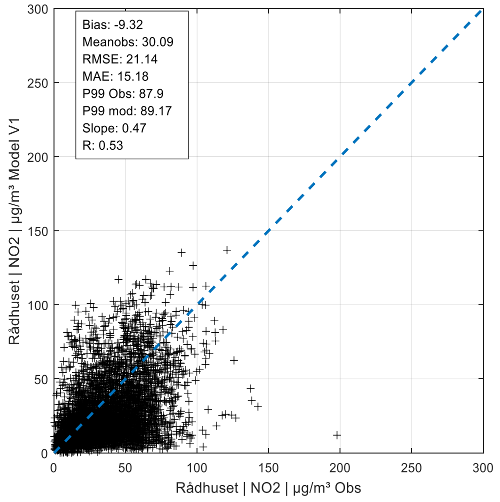


Figure A 5: Yearly value NO_2 in Rådhuset, V1

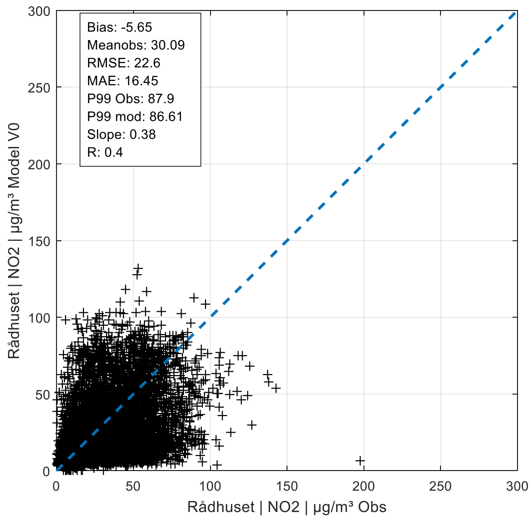


Figure A 6: Yearly value NO_2 in Rådhuset, V0

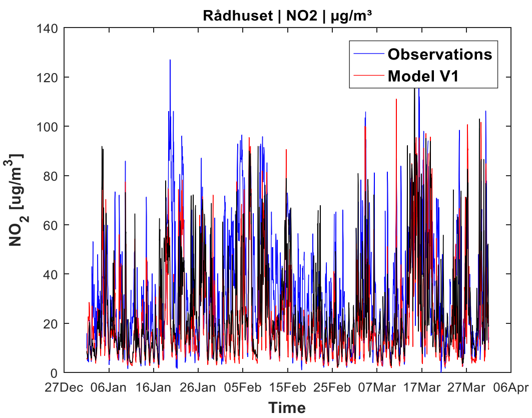


Figure A 7: Timesheet NO_2 in Rådhuset

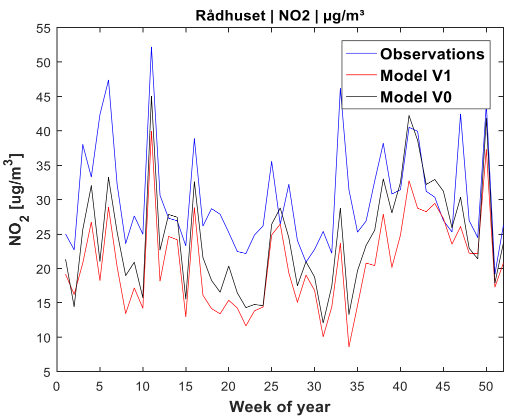


Figure A 8: Week of year NO_2 in Rådhuset

Bergen, Danmarks plass

PM_{10}

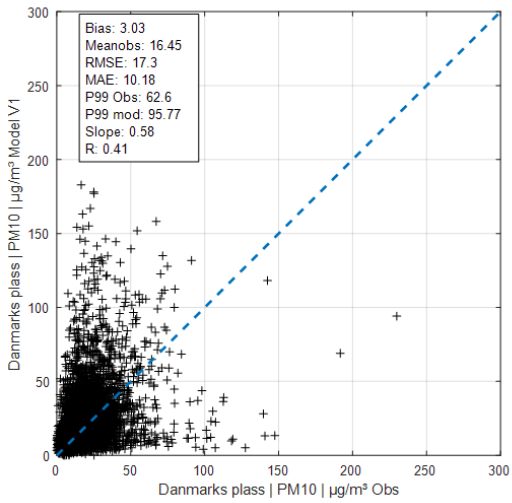


Figure A 9: Yearly value PM_{10} in Danmarksplass, V1

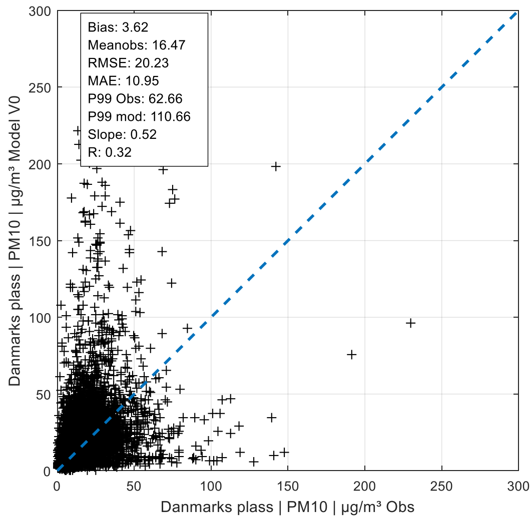


Figure A 10: Yearly value PM_{10} in Danmarksplass, V0

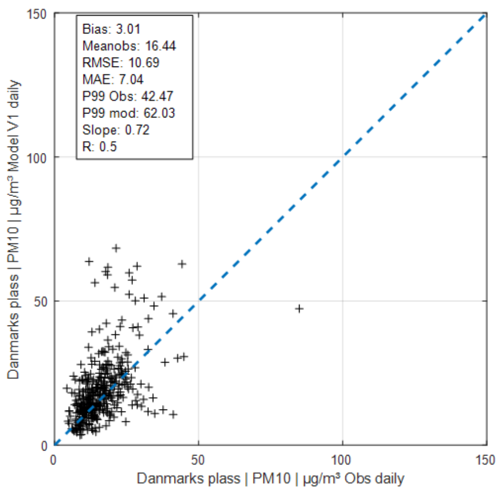


Figure A 11: Daily value PM_{10} in Danmarks plass, V1

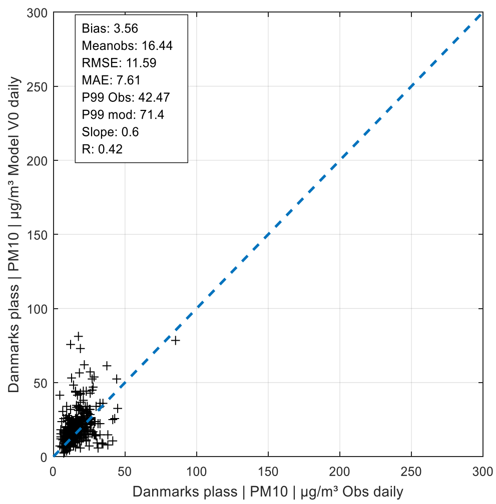


Figure A 12: Daily value PM_{10} in Danmarks plass, V0

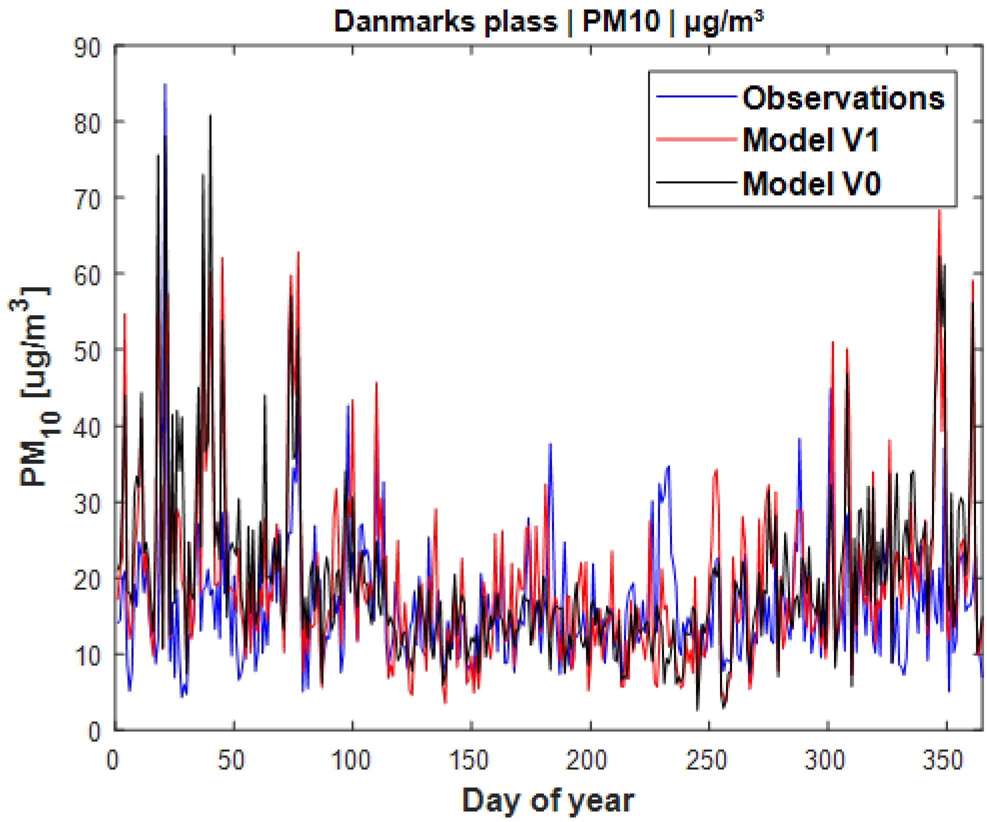


Figure A 13: Day of year PM_{10} in Danmarks plass

Bergen, Rådhuset

PM_{10}

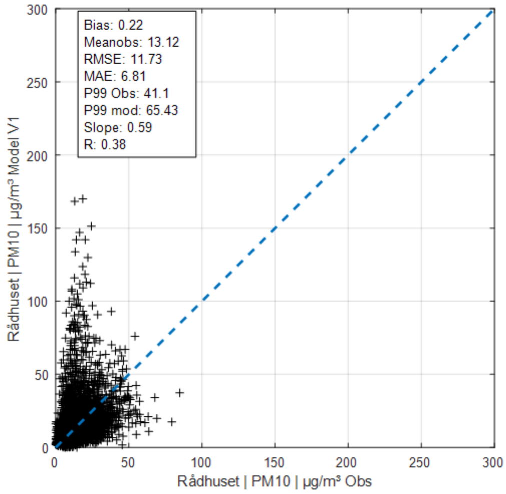


Figure A 14: Yearly value PM_{10} at Rådhuset, V1

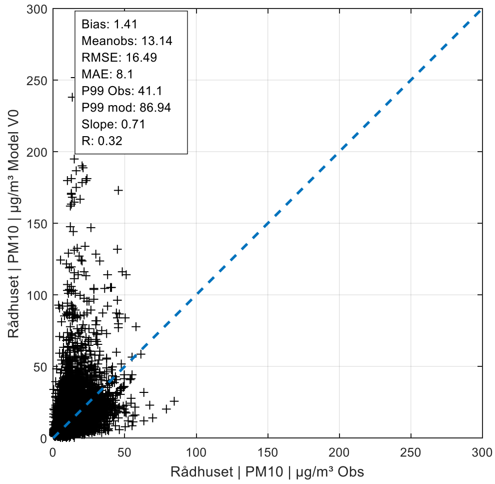


Figure A 15: Yearly value PM_{10} at Rådhuset, V0

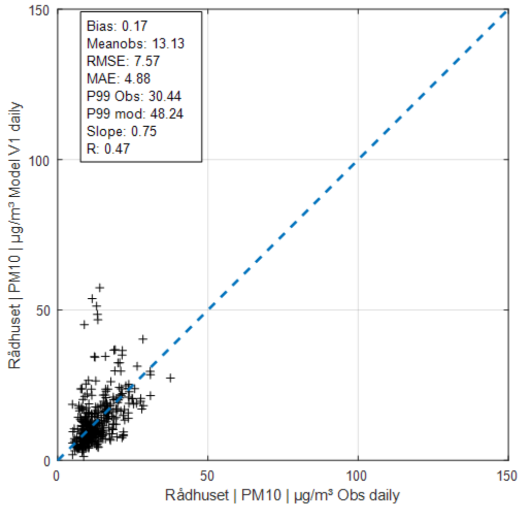


Figure A 16: Daily value PM_{10} at Rådhuset, V1

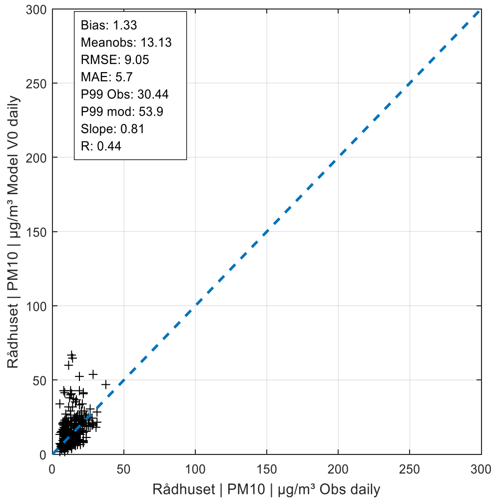


Figure A 17: Daily value PM_{10} at Rådhuset, V0

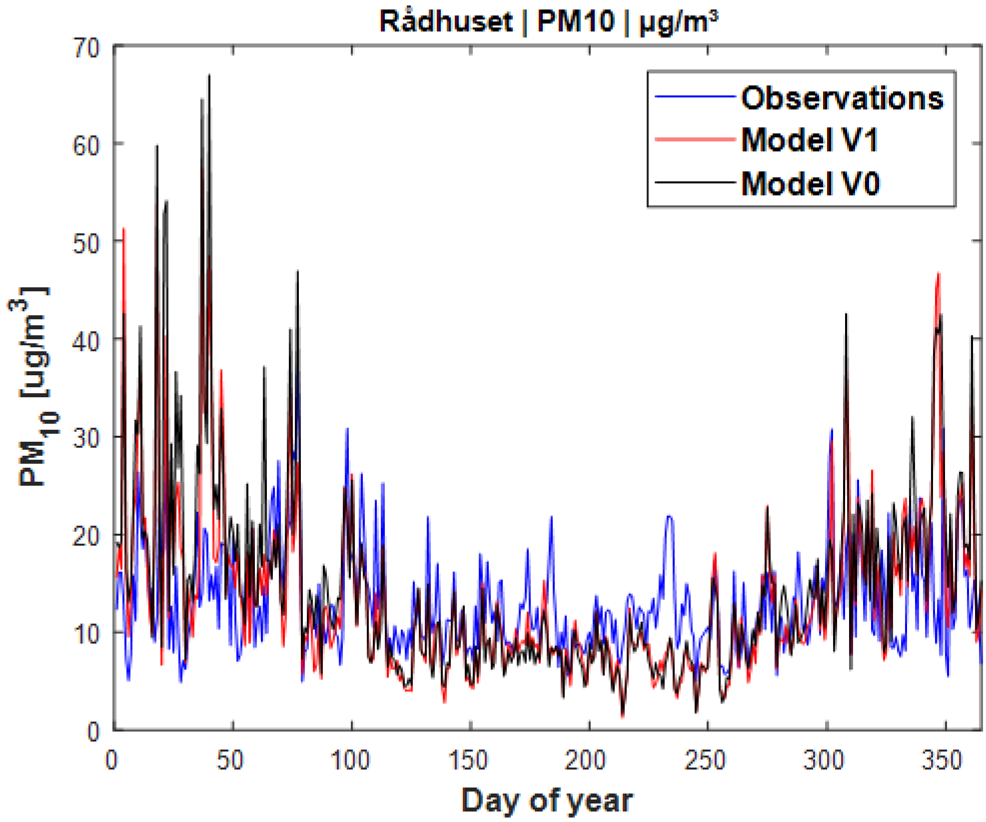


Figure A 18: Day of year PM_{10} at Rådhuset

Bergen, Danmarksplass

$PM_{2.5}$

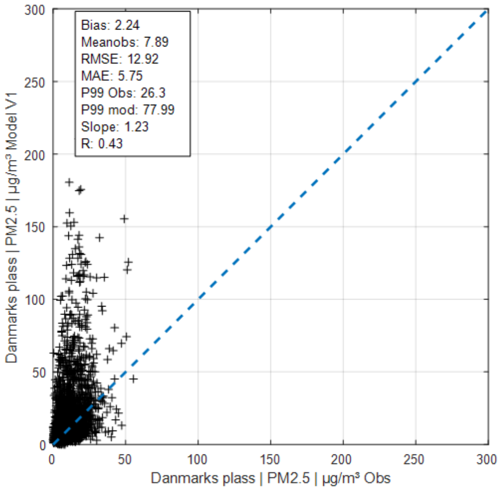


Figure A 19: Hourly values $PM_{2.5}$ at Danmarksplass, V1

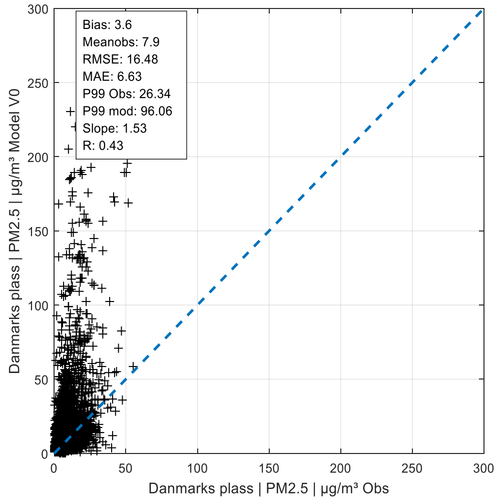


Figure A 20: Hourly values $PM_{2.5}$ at Danmarksplass, V0

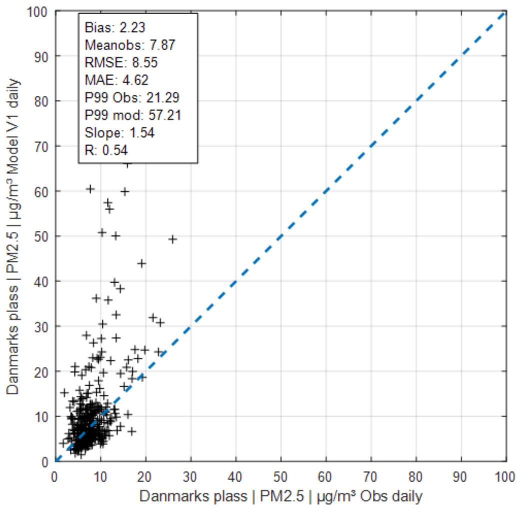


Figure A 21: Daily value $PM_{2.5}$ at Danmarksplass, V1

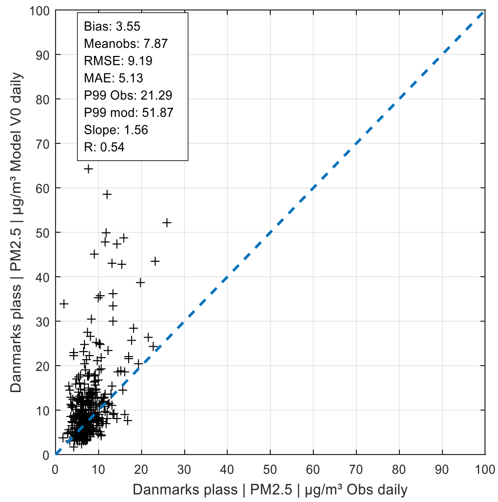


Figure A 22: Daily value $PM_{2.5}$ at Danmarksplass, V0

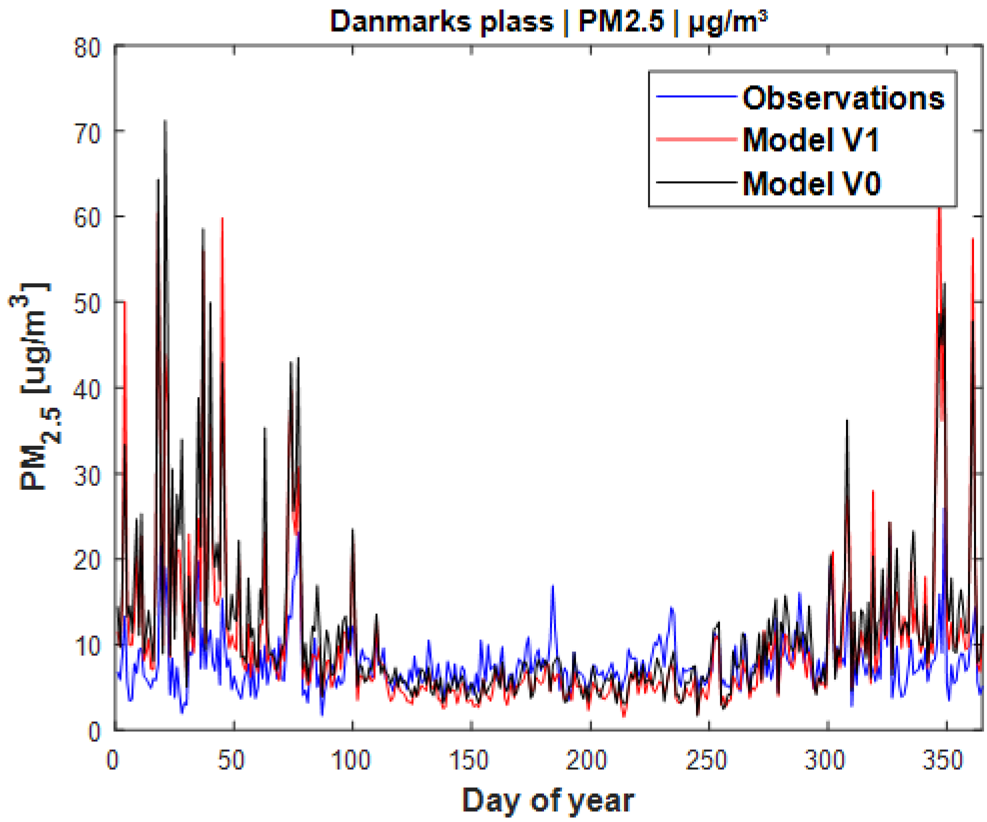


Figure A 23: Day of year $PM_{2.5}$ at Danmarksplass

Bergen, Rådhuset

$PM_{2.5}$

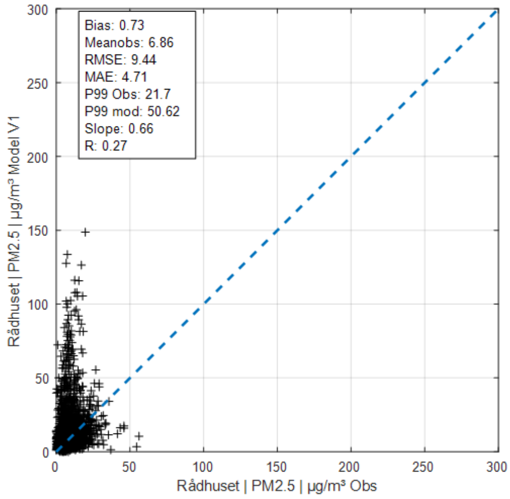


Figure A 24: Yearly value $PM_{2.5}$ at Rådhuset, V1

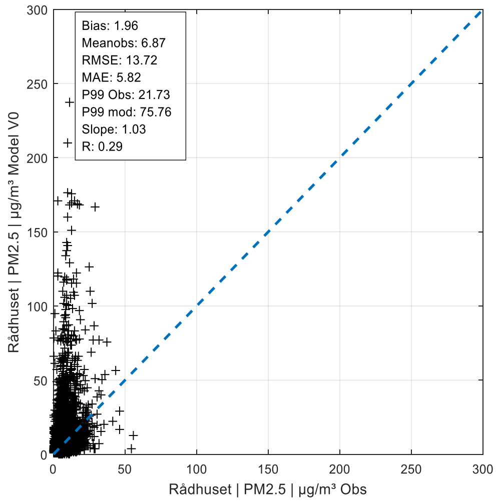


Figure A 25: Yearly value $PM_{2.5}$ at Rådhuset, V0

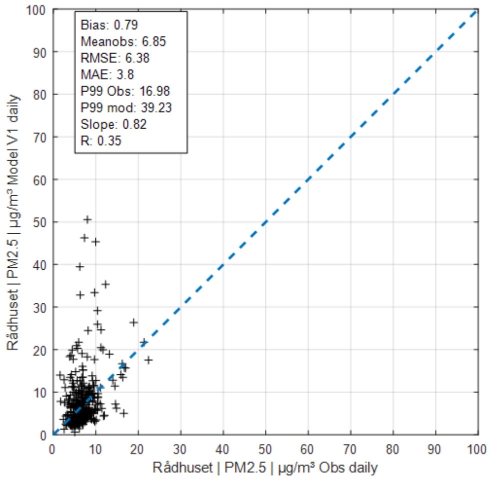


Figure A 26: Daily value $PM_{2.5}$ at Rådhuset, V1

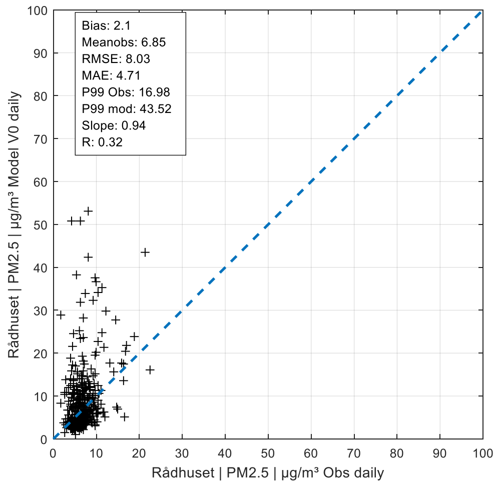


Figure A 27: Daily value $PM_{2.5}$ at Rådhuset, V0

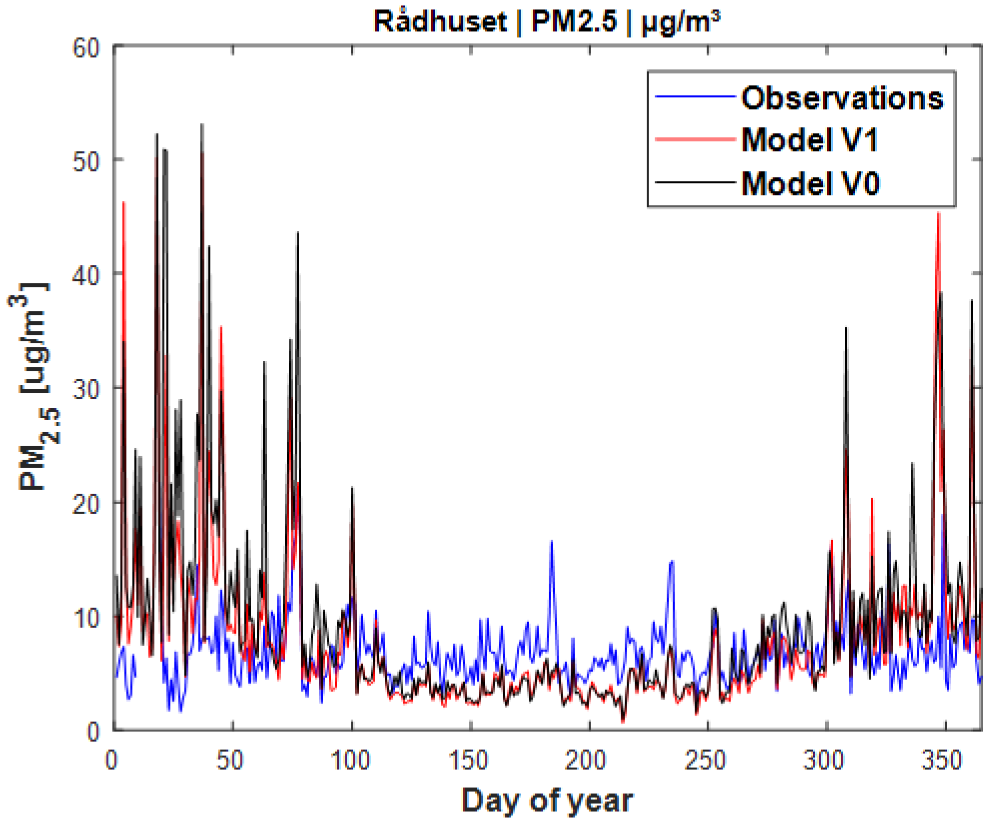


Figure A 28: Day of year $PM_{2.5}$ at Rådhuset

Drammen, Bangeløkka

NO_2

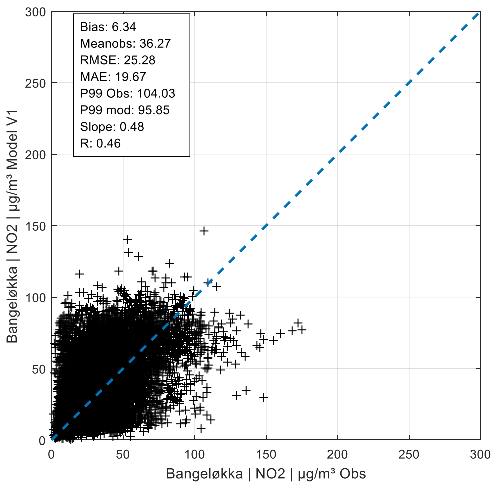


Figure A 29: Hourly values NO_2 in Bangeløkka, V1

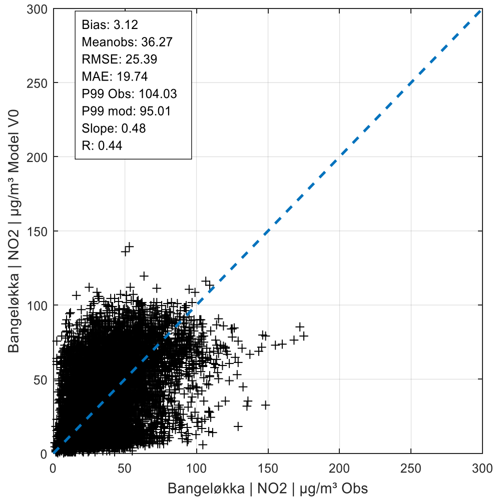


Figure A 30: Hourly values NO_2 in Bangeløkka, V0

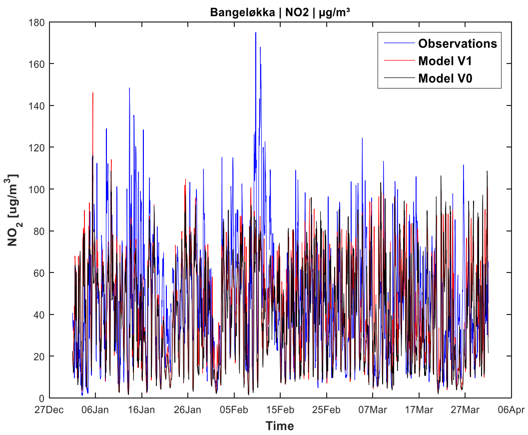


Figure A 31: Timesheet NO_2 in Bangeløkka

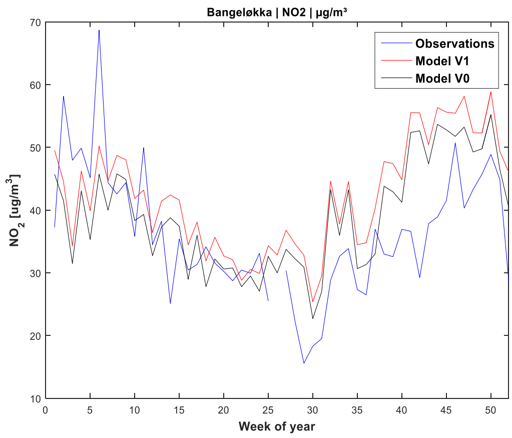


Figure A 32: Week of year NO_2 in Bangeløkka

Drammen, Bangeløkka

PM$_{10}$

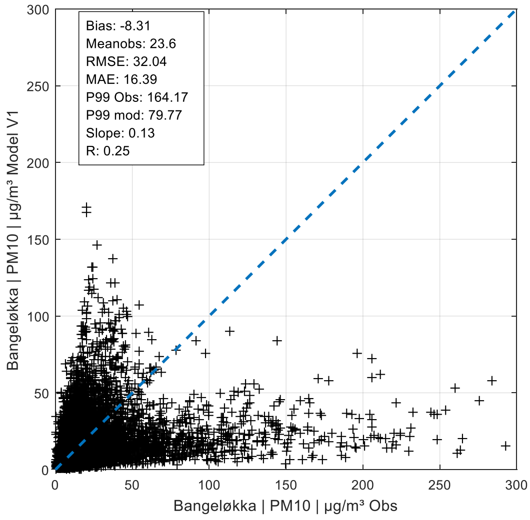


Figure A 33: Hourly values PM$_{10}$ in Bangeløkka, V1

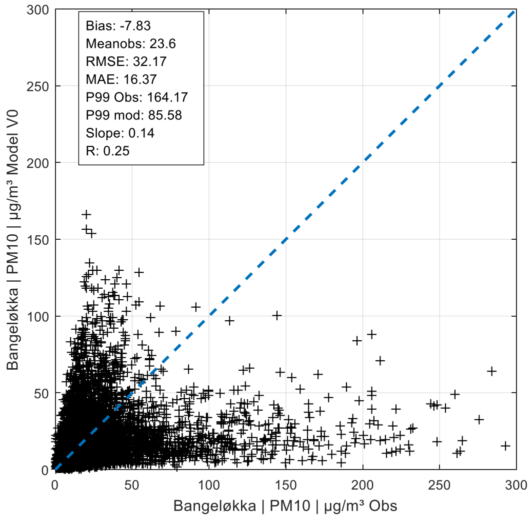


Figure A 34: Hourly values PM$_{10}$ in Bangeløkka, V0

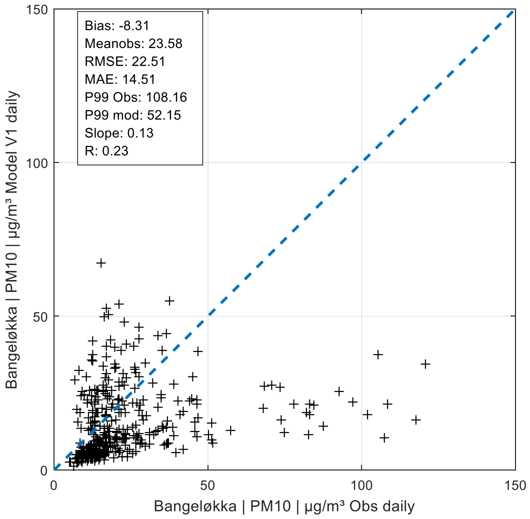


Figure A 35: Daily values PM$_{10}$ in Bangeløkka, V1

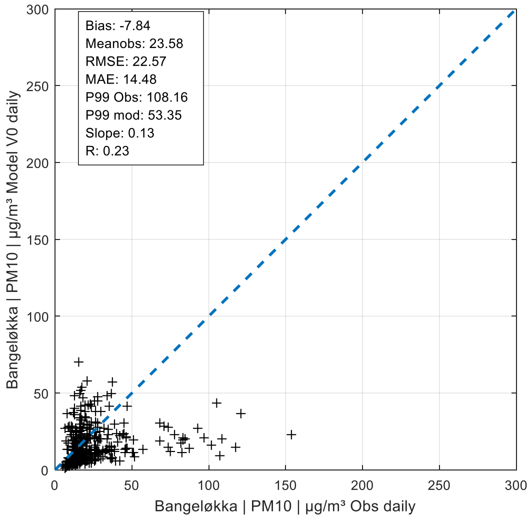


Figure A 36: Daily values PM$_{10}$ in Bangeløkka, V0

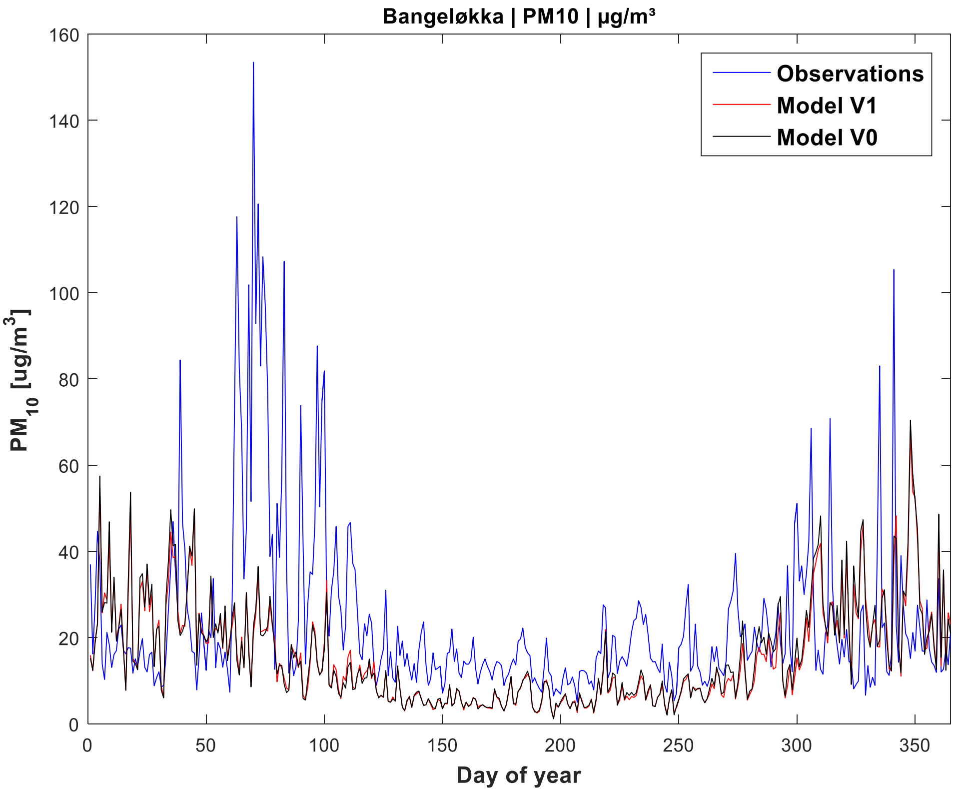


Figure A 37: Day of year PM_{10} in Bangeløkka

Drammen

$PM_{2.5}$

There are no measurements of $PM_{2.5}$ in Drammen. It has therefore not been possible to evaluate the model results against measurements for this component.

Grenland, Lensmannsdalen

NO_2

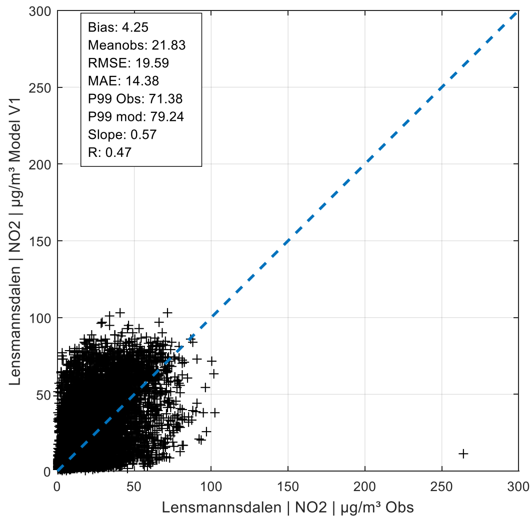


Figure A 38: Yearly value NO_2 in Lensmannsdalen, V1

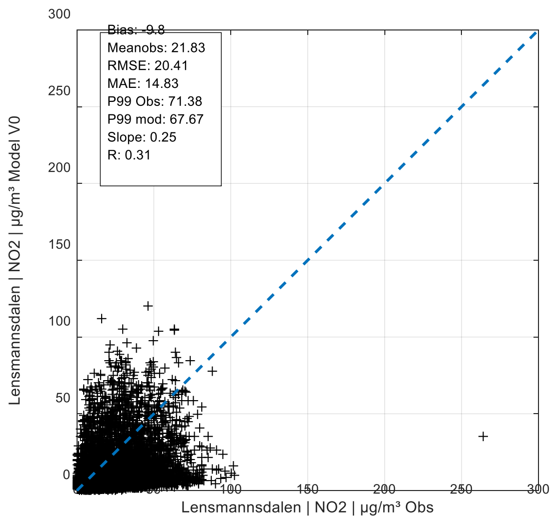


Figure A 39: Yearly value NO_2 in Lensmannsdalen, V0

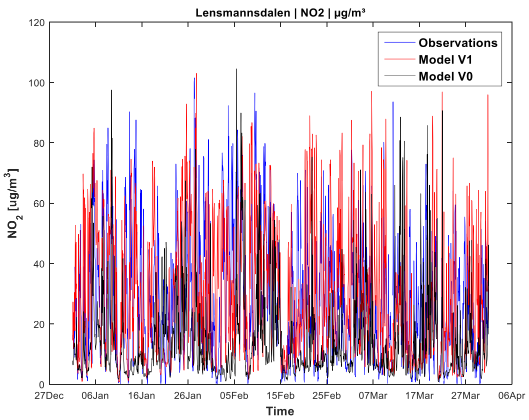


Figure A 40: Timesheet NO_2 in Lensmannsdalen

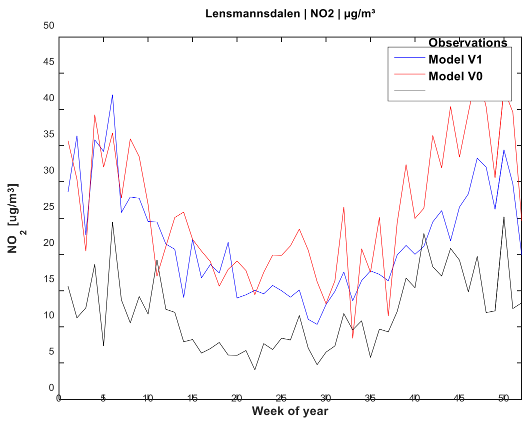


Figure A 41: Week of year NO_2 in Lensmannsdalen

Grenland, Øyekast

NO_2

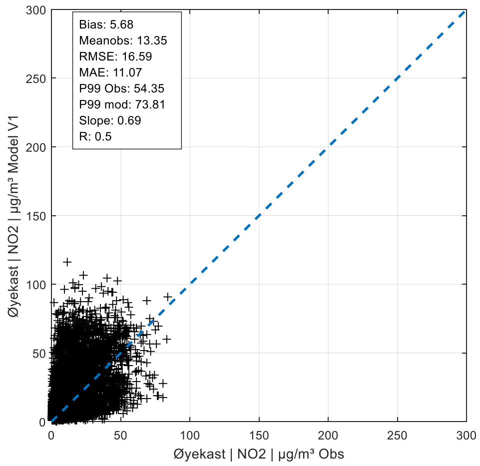


Figure A 42: Yearly value NO_2 in Øyekast, V1

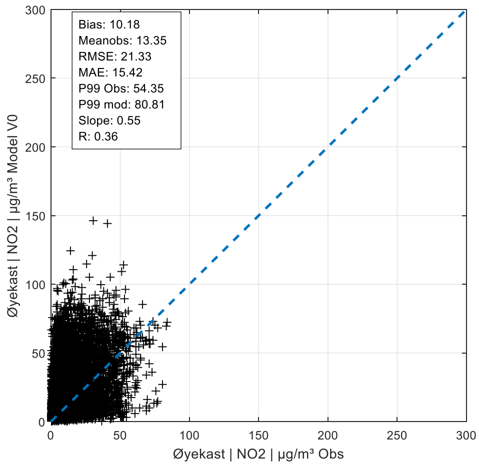


Figure A 43: Yearly value NO_2 in Øyekast, V0

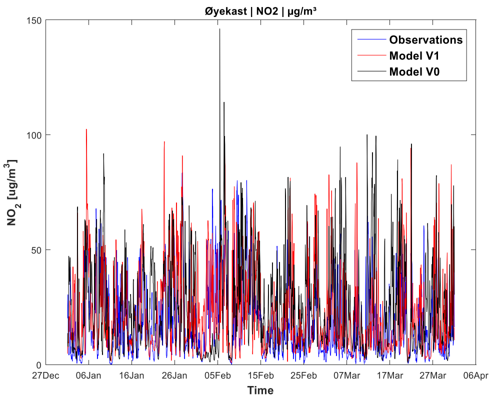


Figure A 44: Timesheet NO_2 in Øyekast

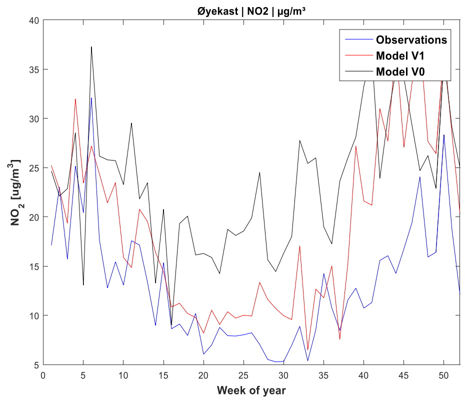


Figure A 45: Week of year NO_2 in Øyekast

Grenland, Lensmannsdalen

PM_{10}

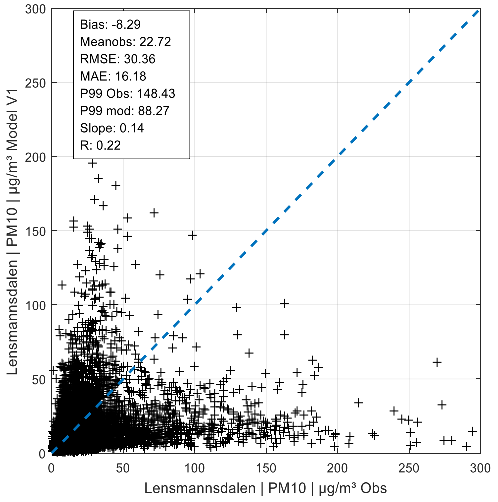


Figure A 46: Yearly value PM_{10} in Lensmannsdalen, V1

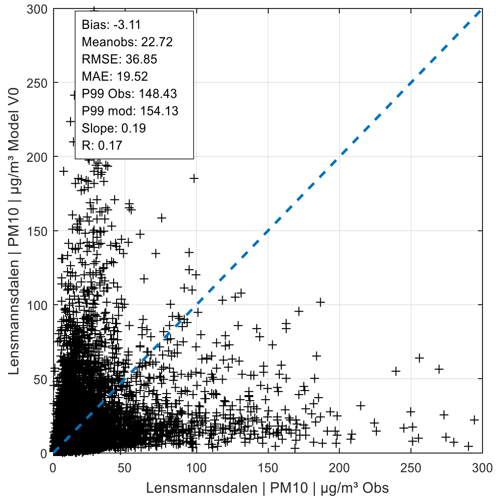


Figure A 47: Yearly value PM_{10} in Lensmannsdalen, V0

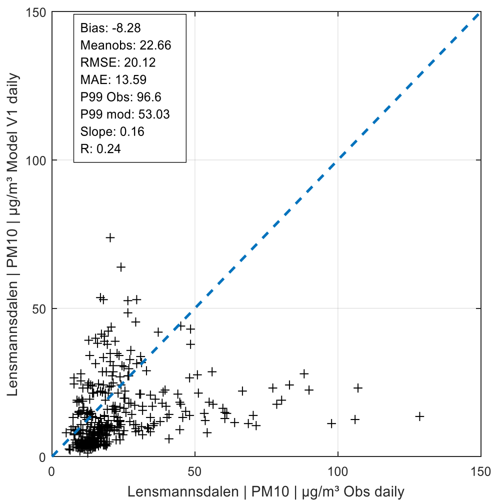


Figure A 48: Daily value PM_{10} in Lensmannsdalen, V1

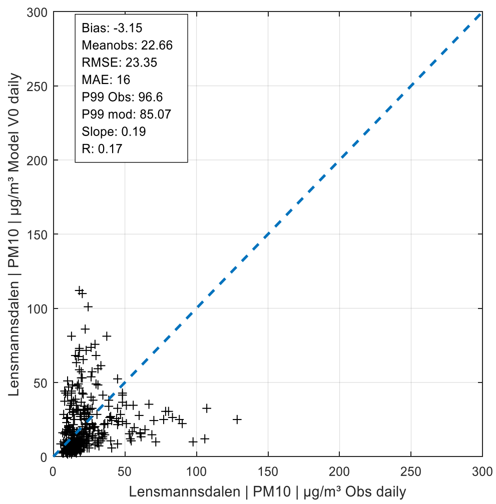


Figure A 49: Daily value PM_{10} in Lensmannsdalen, V0

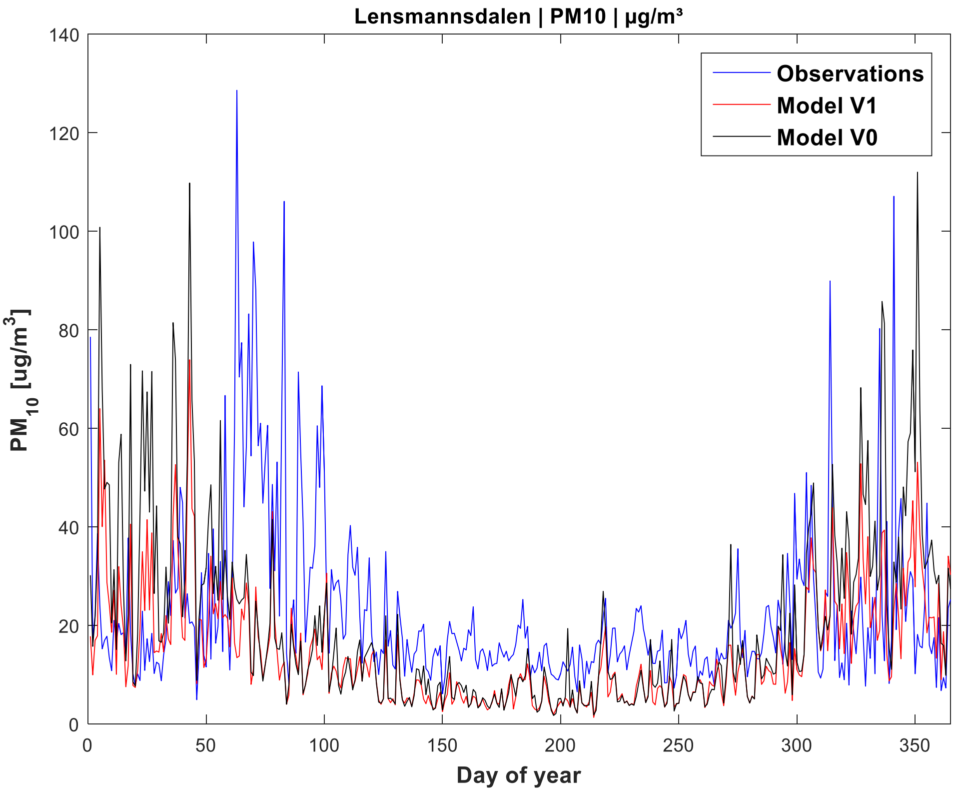


Figure A 50: Day of year PM_{10} in Lensmannsdalen

Grenland, Øyekast

PM_{10}

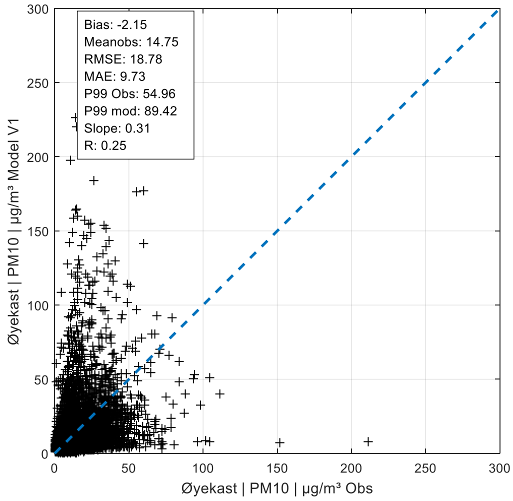


Figure A 51: Yearly value PM_{10} in Øyekast, V1

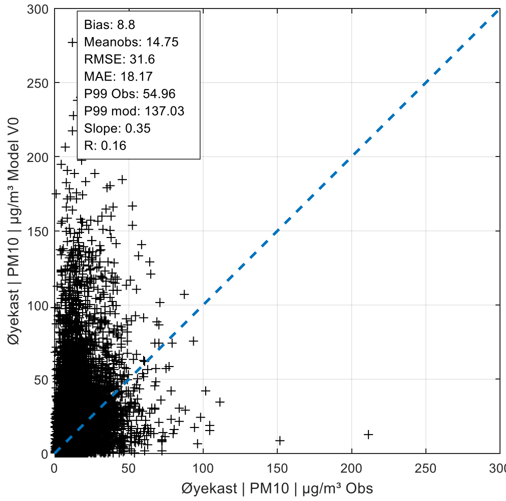


Figure A 52: Yearly value PM_{10} in Øyekast, V0

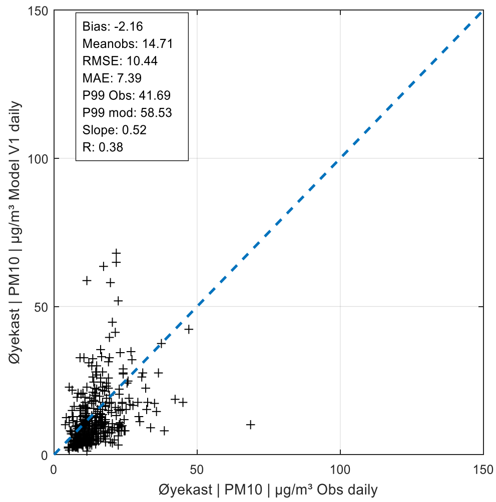


Figure A 53: Daily value PM_{10} in Øyekast, V1

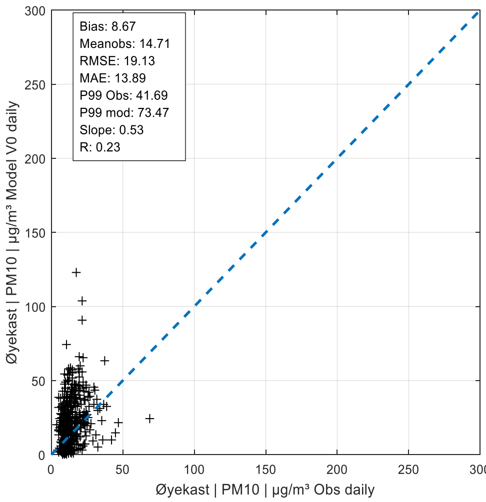


Figure A 54: Daily value PM_{10} in Øyekast, V0

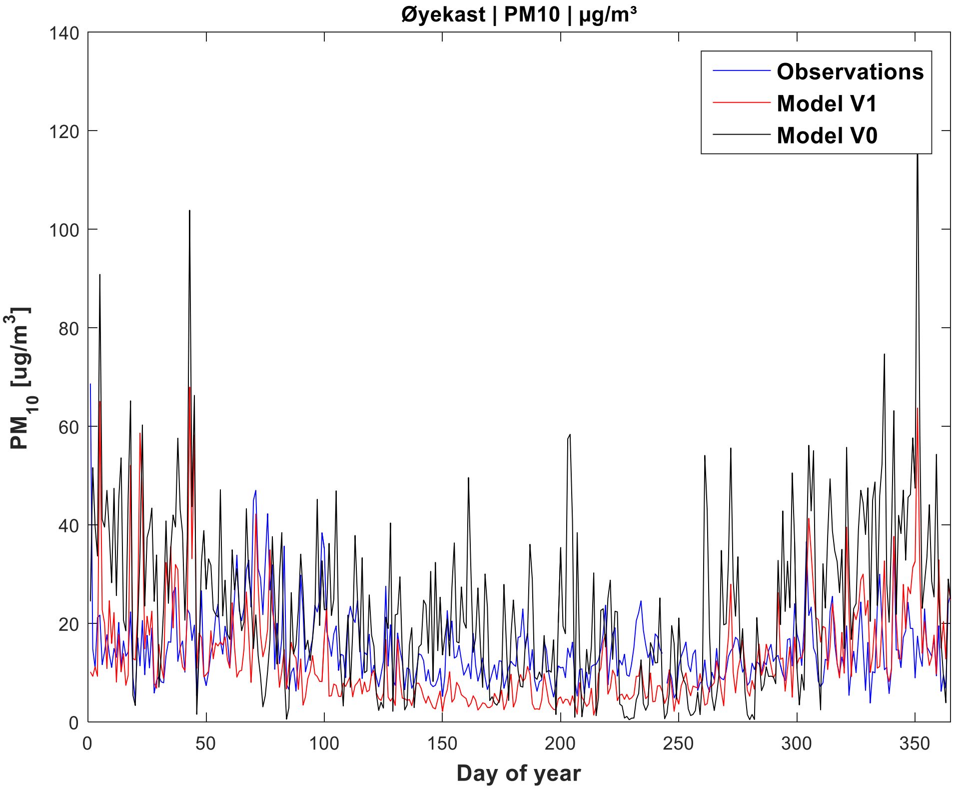


Figure A 55: Day of year PM_{10} in Øyekast

Grenland, Lensmannsdalen

$PM_{2.5}$

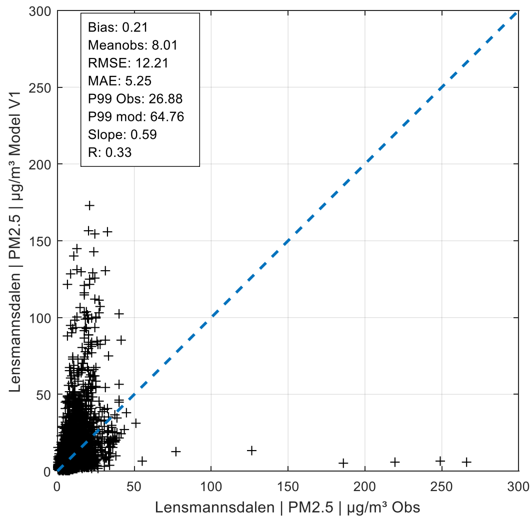


Figure A 56: Hourly values $PM_{2.5}$ in Lensmannsdalen, V1

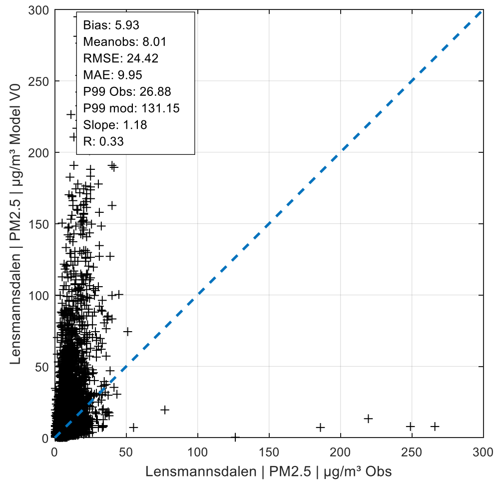


Figure A 57: Hourly values $PM_{2.5}$ in Lensmannsdalen, V0

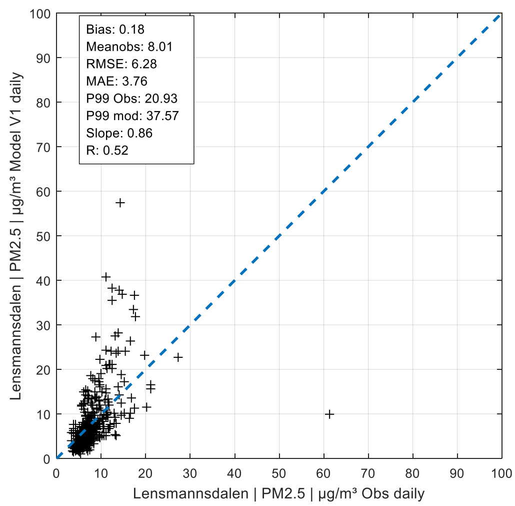


Figure A 58: Daily values $PM_{2.5}$ in Lensmannsdalen, V1

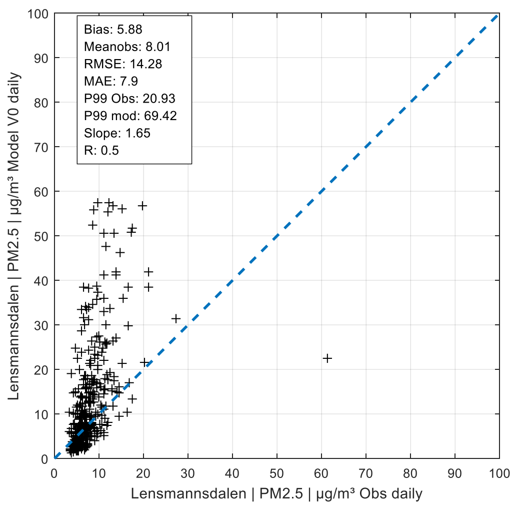


Figure A 59: Daily values $PM_{2.5}$ in Lensmannsdalen, V0

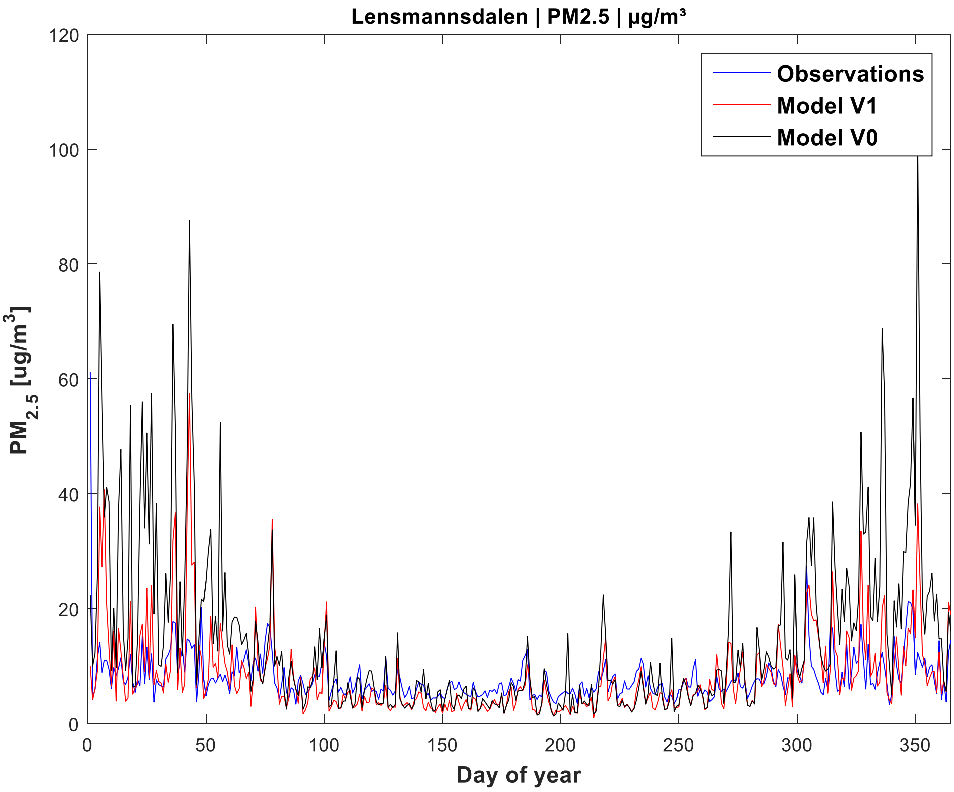


Figure A 60: Day of year $PM_{2.5}$ in Lensmannsdalen

Grenland, Øyekast

$PM_{2.5}$

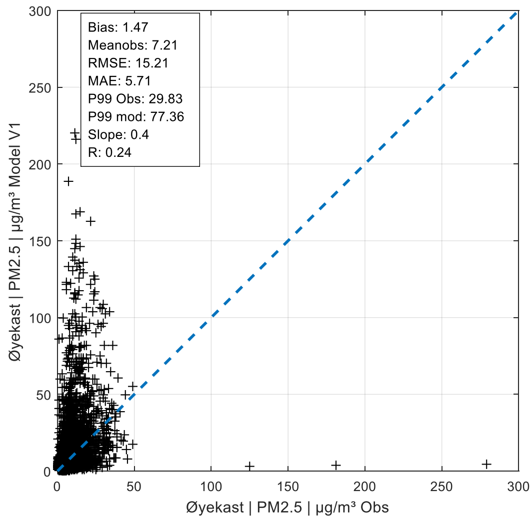


Figure A 61: Hourly values $PM_{2.5}$ in Øyekast, V1

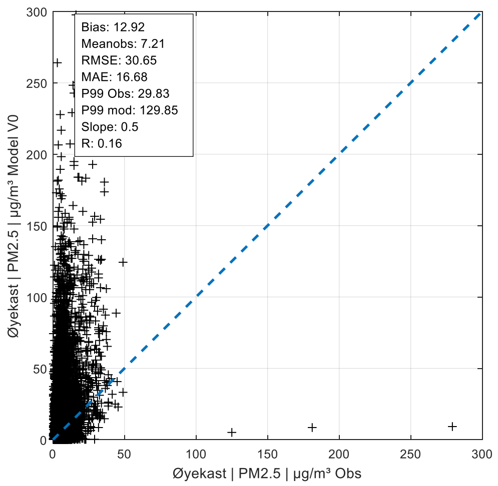


Figure A 62: Hourly values $PM_{2.5}$ in Øyekast, V0

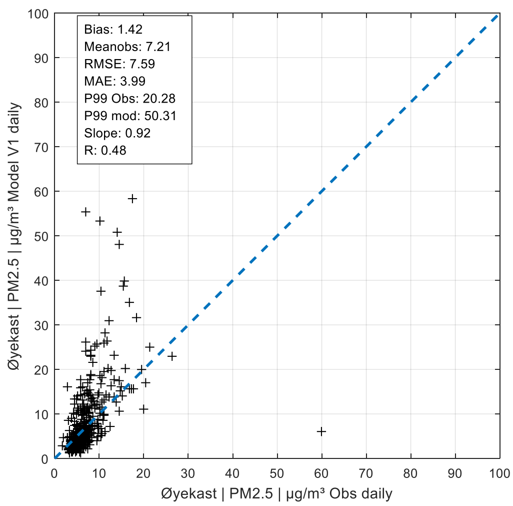


Figure A 63: Daily values $PM_{2.5}$ in Øyekast, V1

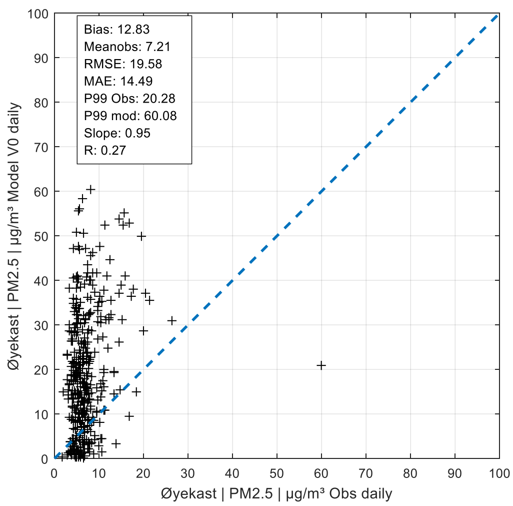


Figure A 64: Daily values $PM_{2.5}$ in Øyekast, V0

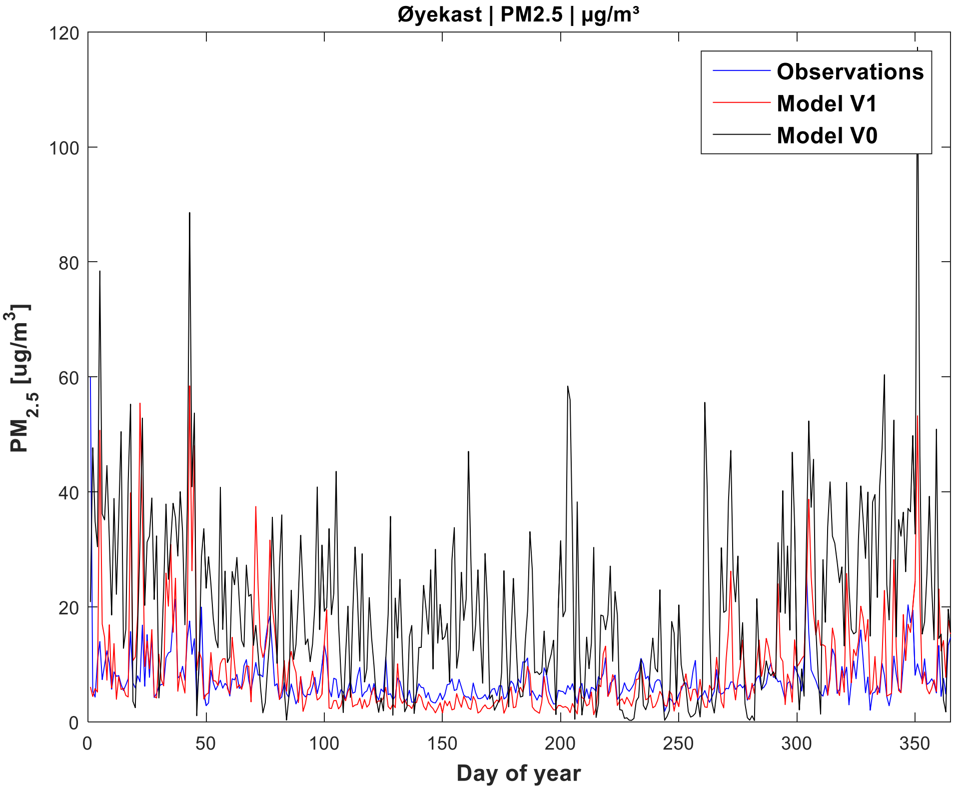


Figure A 65: Day of year $PM_{2.5}$ in Øyekast

Nedre Glomma, St. Croix

NO_2

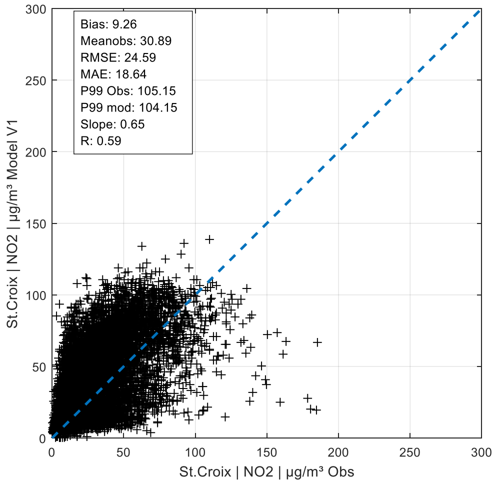


Figure A 66: Yearly value NO_2 in St. Croix, V1

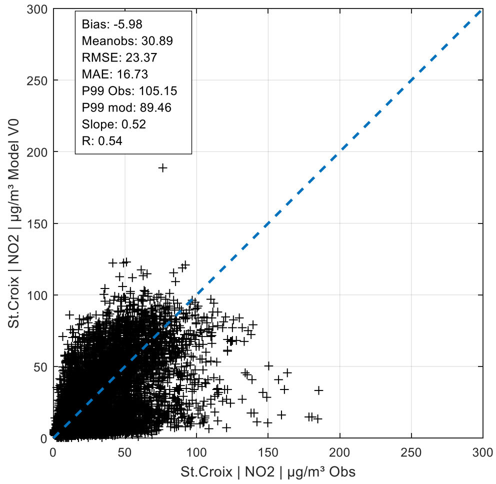


Figure A 67: Yearly value NO_2 in St. Croix, V0

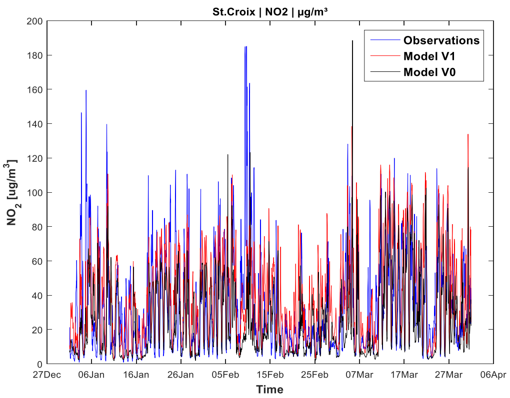


Figure A 68: Timesheet NO_2 in St. Croix

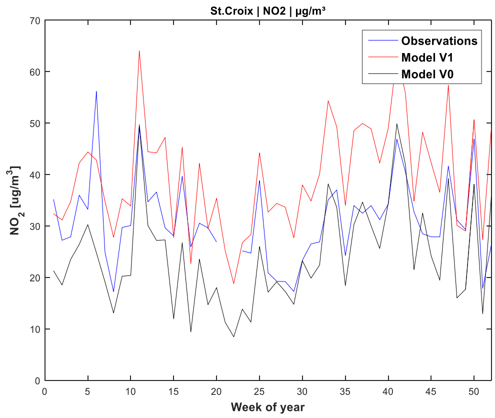


Figure A 69: Week of year NO_2 in St. Croix

Nedre Glomma, St. Croix

PM_{10}

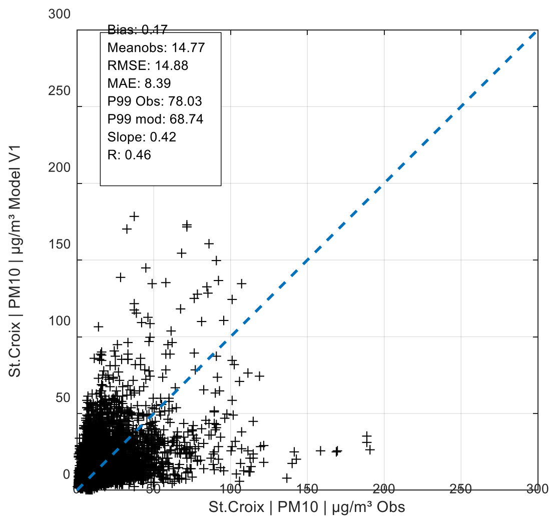


Figure A 70: Hourly values PM_{10} in St. Croix, V1

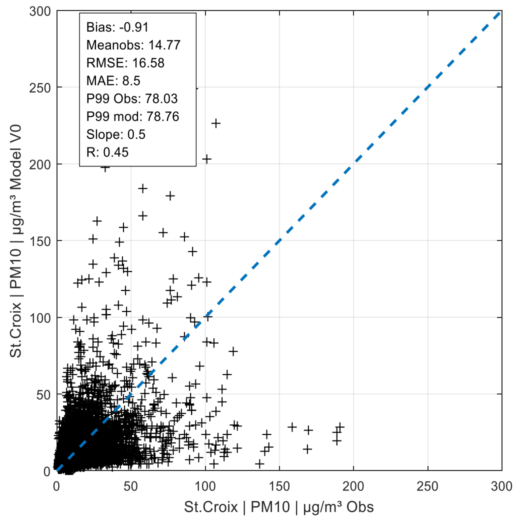


Figure A 71: Hourly values PM_{10} in St. Croix, V0

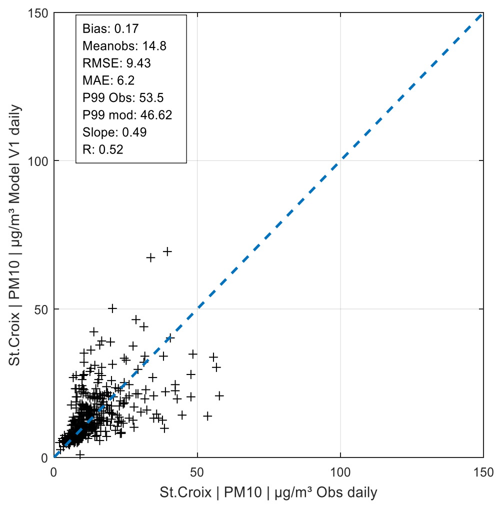


Figure A 72: Daily value PM_{10} in St. Croix, V1

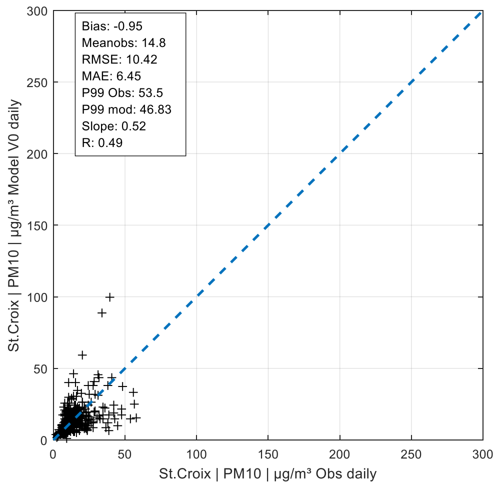


Figure A 73: Daily value PM_{10} in St. Croix, V0

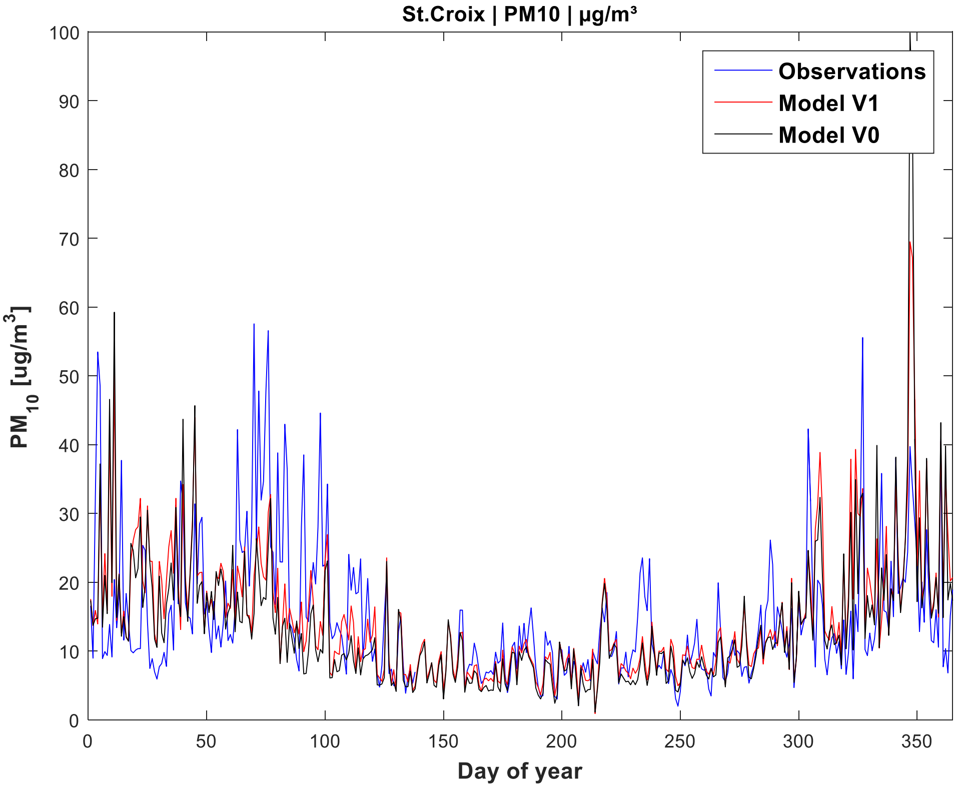


Figure A 74: Day of year PM_{10} in St. Croix

Nedre Glomma, St. Croix

$PM_{2.5}$

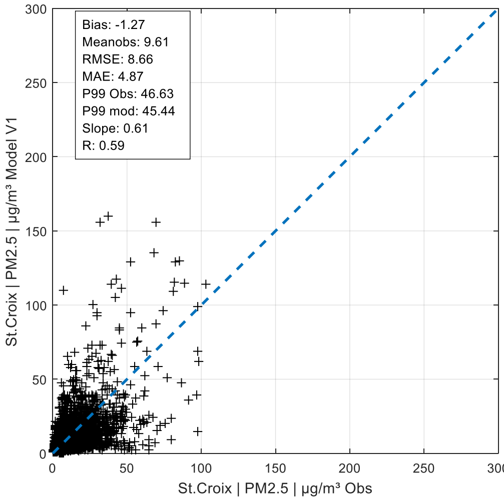


Figure A 75: Yearly value $PM_{2.5}$ in St. Croix, V1

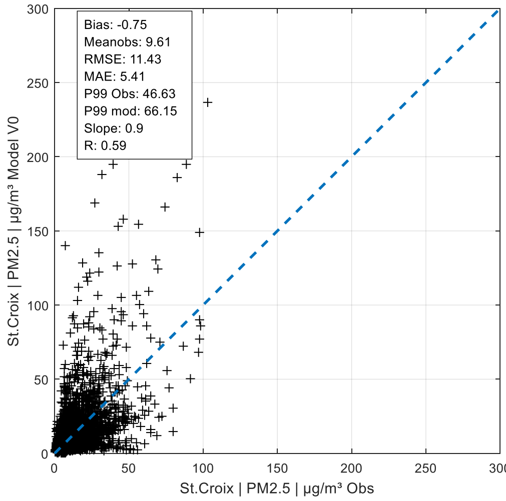


Figure A 76: Yearly value $PM_{2.5}$ in St. Croix, V0

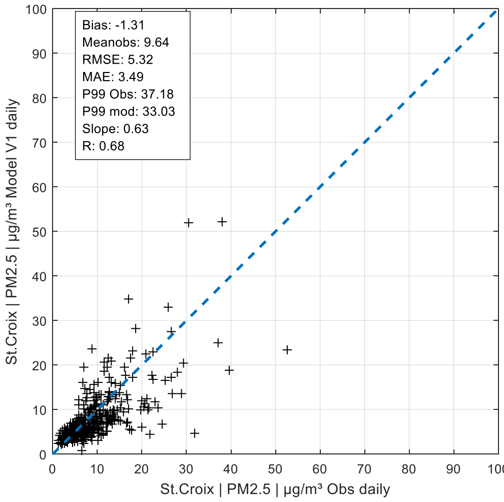


Figure A 77: Daily value $PM_{2.5}$ in St. Croix, V1

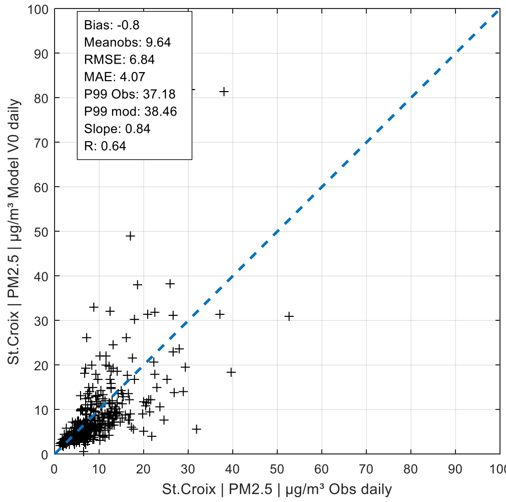


Figure A 78: Daily value $PM_{2.5}$ in St. Croix, V0

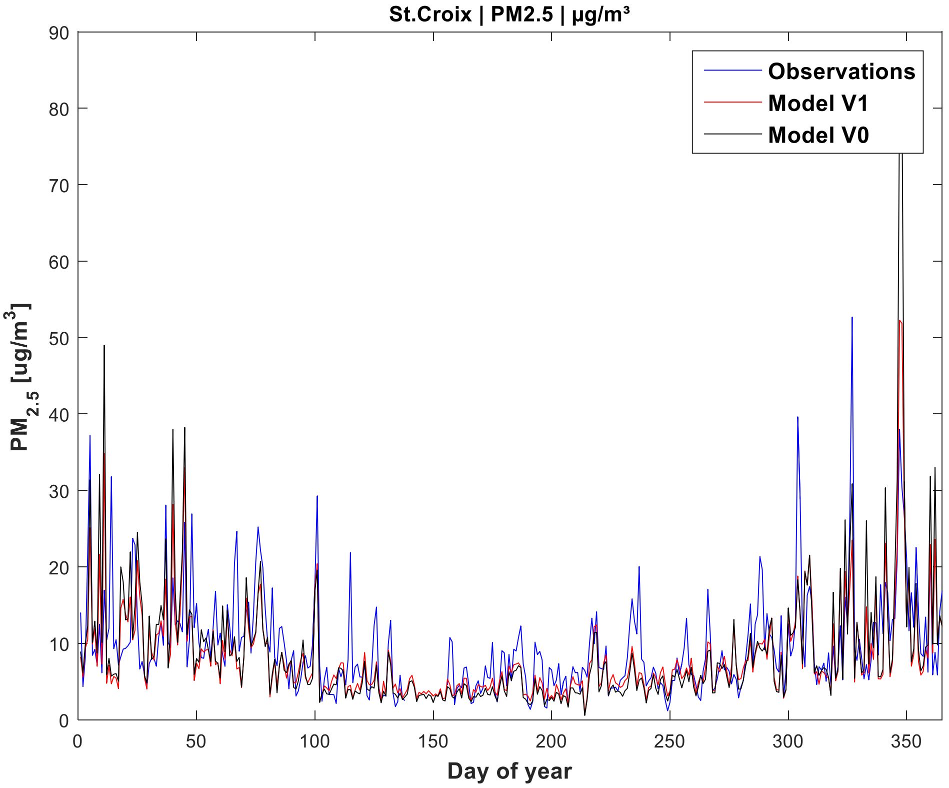


Figure A 79: Day of year $PM_{2.5}$ in St. Croix

Oslo, Åkebergveien

NO_2

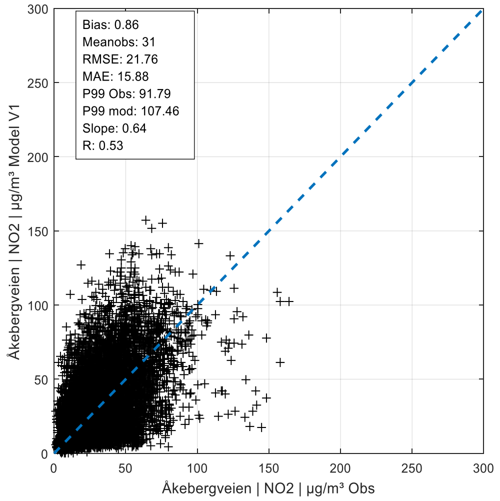


Figure A 80: Yearly value NO_2 in Åkebergveien, V1

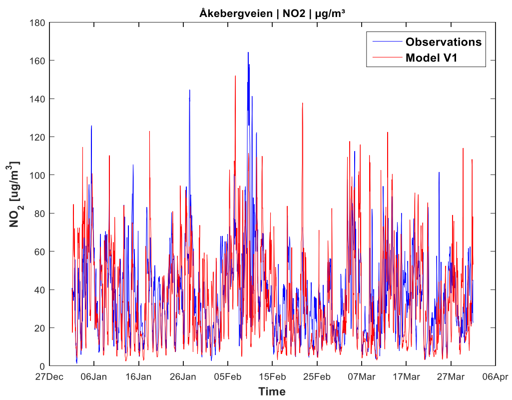


Figure A 81: Timesheet NO_2 in Åkebergveien, V1

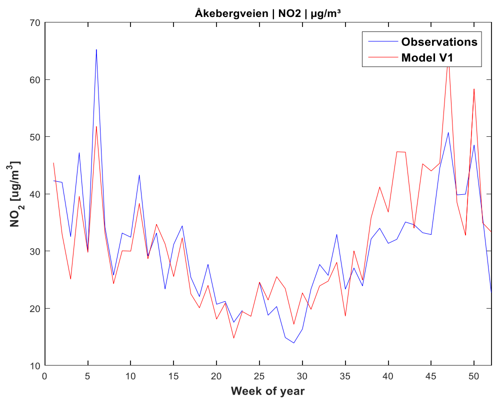


Figure A 82: Week of year NO_2 in Åkebergveien, V1

Oslo, Alnabru

NO_2

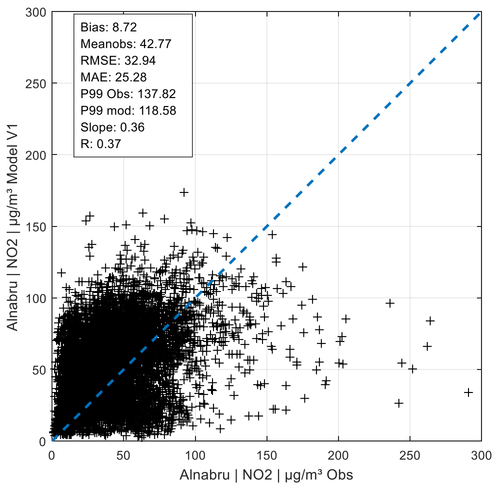


Figure A 83: Yearly value NO_2 in Alnabru, V1

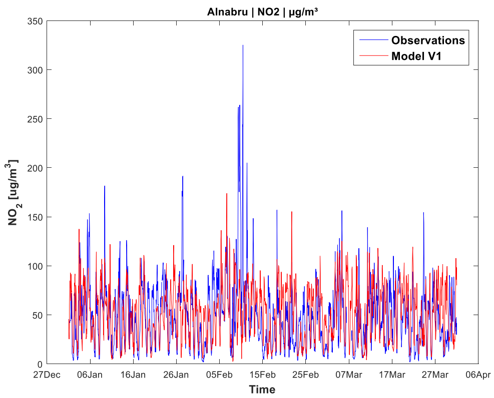


Figure A 84: Timesheet NO_2 in Alnabru, V1

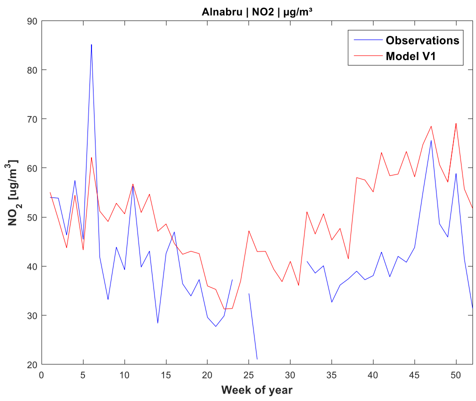


Figure A 85: Week of year NO_2 in Alnabru, V1

Oslo, Bygdøy

NO_2

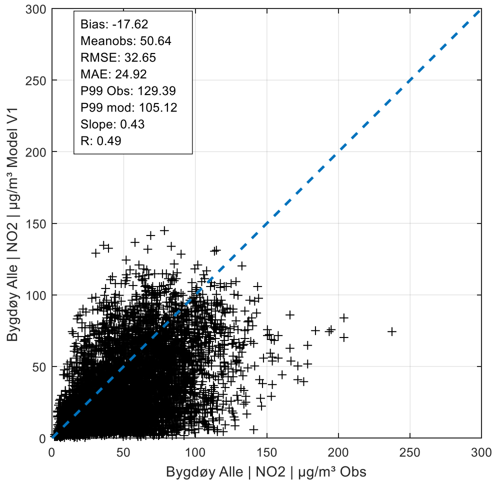


Figure A 86: Yearly value NO_2 in Bygdøy, V1

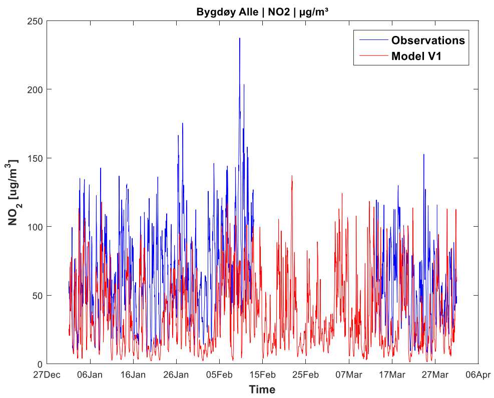


Figure A 87: Timesheet NO_2 in Bygdøy, V1

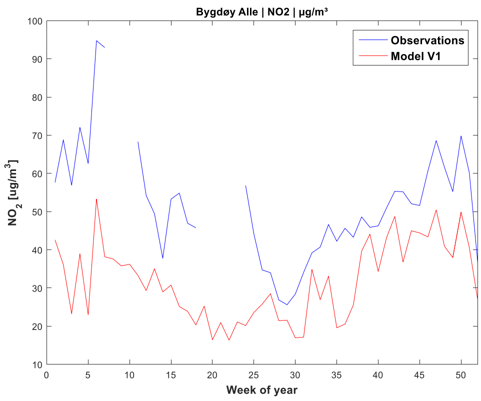


Figure A 88: Week of year NO_2 in Bygdøy, V1

Oslo, Grønland

NO_2

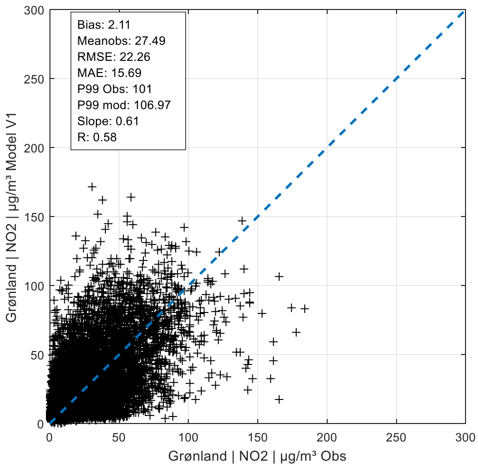


Figure A 89: Yearly value NO_2 in Grønland, V1

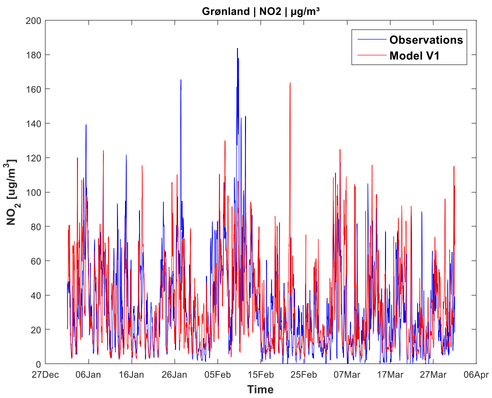


Figure A 90: Timesheet NO_2 in Grønland, V1

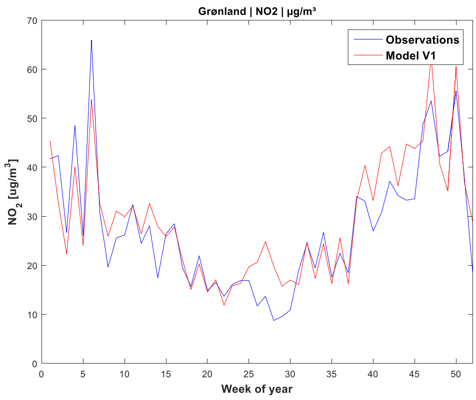


Figure A 91: Week of year NO_2 in Grønland, V1

Oslo, Hjortnes

NO_2

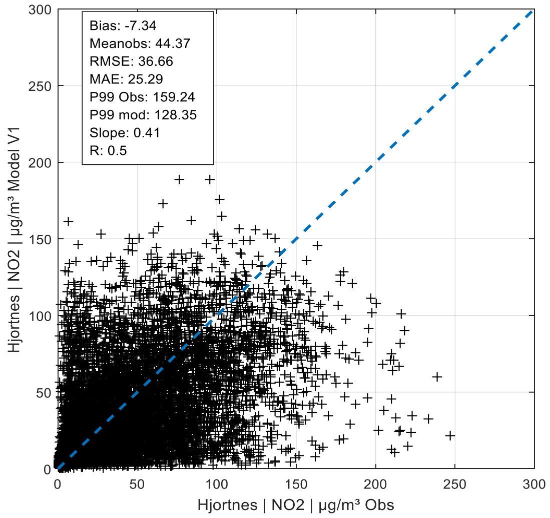


Figure A 92: Yearly value NO_2 in Hjortnes, V1

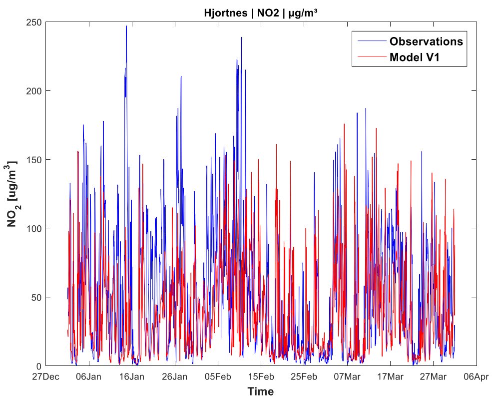


Figure A 93: Timesheet NO_2 in Hjortnes, V1

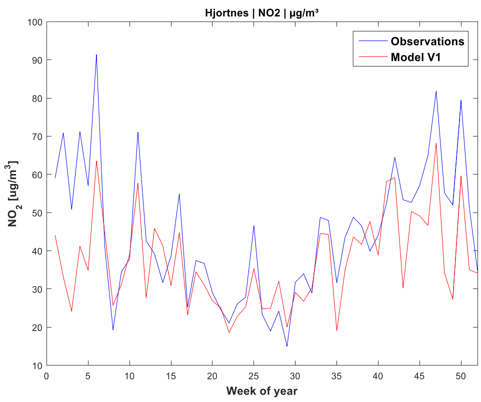


Figure A 94: Week of year NO_2 in Hjortnes, V1

Oslo, Kirkeveien

NO_2

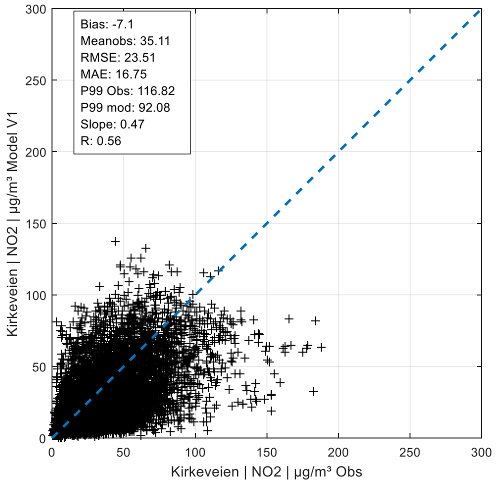


Figure A 95: Yearly value NO_2 in Kirkeveien, V1

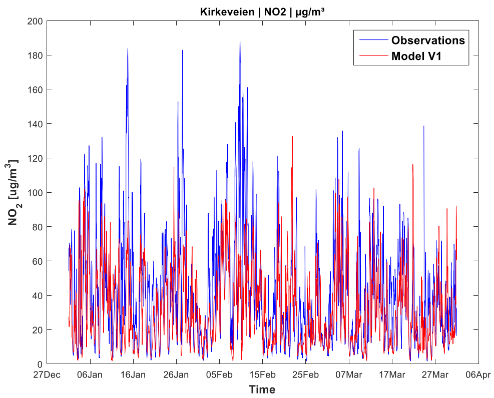


Figure A 96: Timesheet NO_2 in Kirkeveien, V1

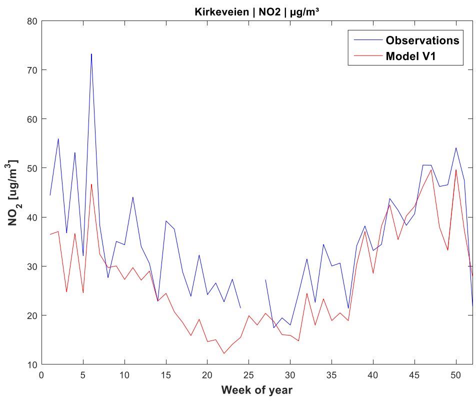


Figure A 97: Week of year NO_2 in Kirkeveien, V1

Oslo, Manglerud

NO_2

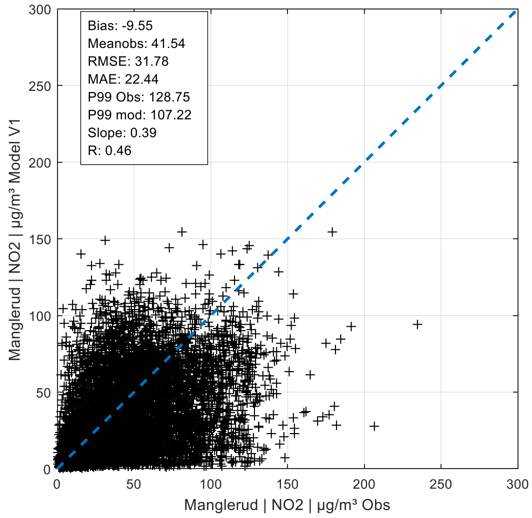
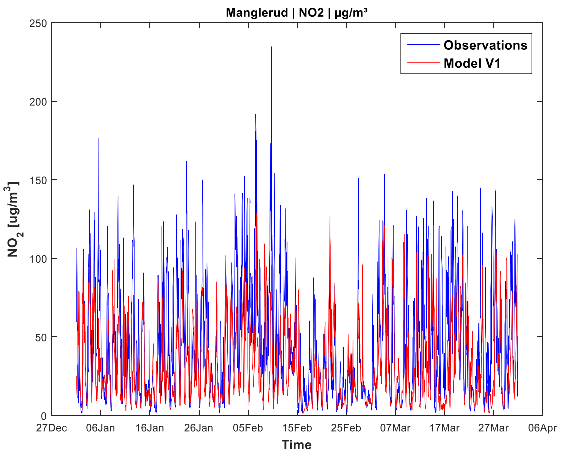


Figure A 98: Yearly value NO_2 in Manglerud, V1



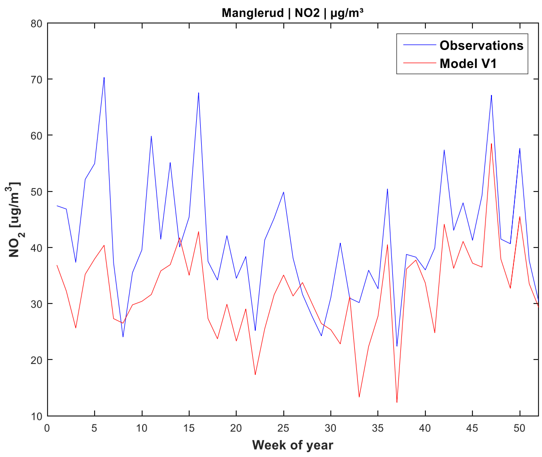


Figure A 99: Timeseet NO_2 in Manglerud, V1

Figure A 100: Week of year NO_2 in Manglerud, V1

Oslo, Aker sykehus

NO_2

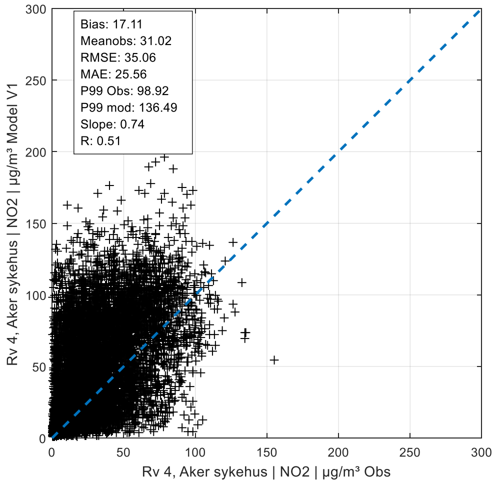


Figure A 101: Hourly values NO_2 in Aker sykehus, V1

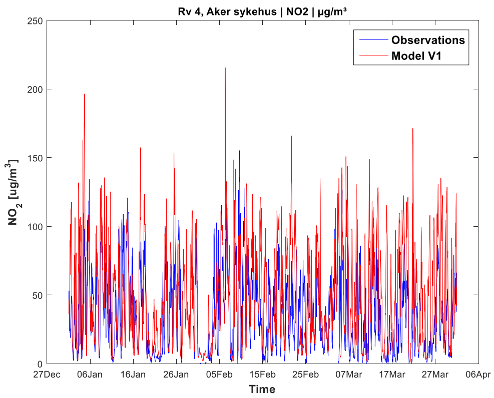


Figure A 102: Timesheet NO_2 in Aker sykehus, V1

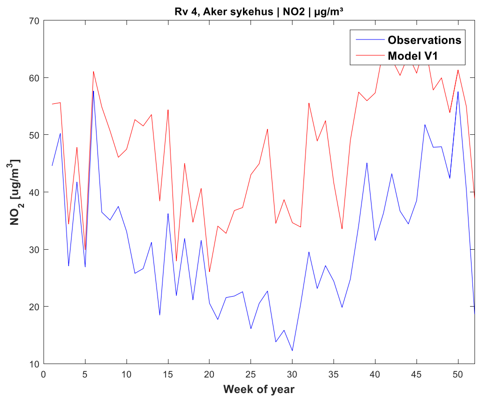


Figure A 103: Week of year NO_2 in Aker sykehus, V1

Oslo, Smestad

NO_2

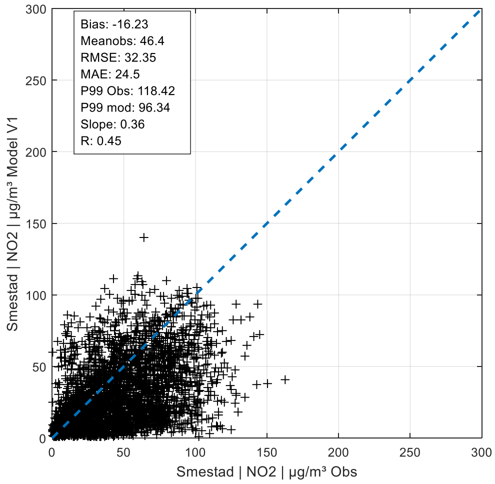


Figure A 104: Yearly value NO_2 in Smestad, V1

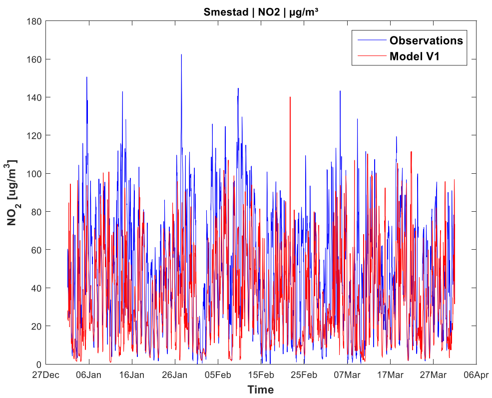


Figure A 105: Timesheet NO_2 in Smestad

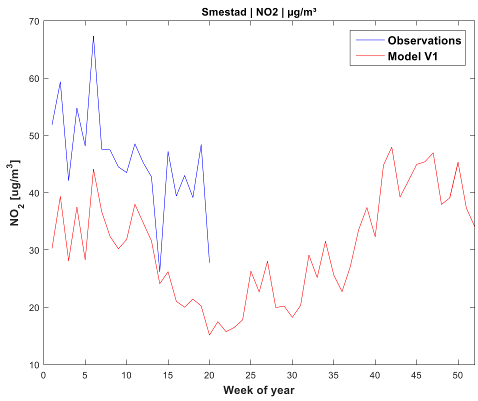


Figure A 106: Week of year NO_2 in Smestad

Oslo, Åkebergveien

PM10

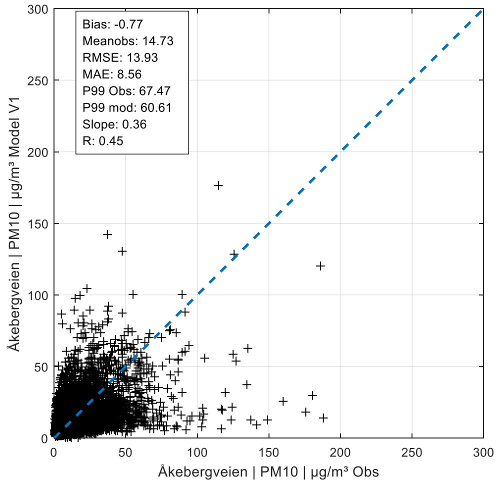


Figure A 107: Hourly values PM_{10} in Åkebergveien, V1

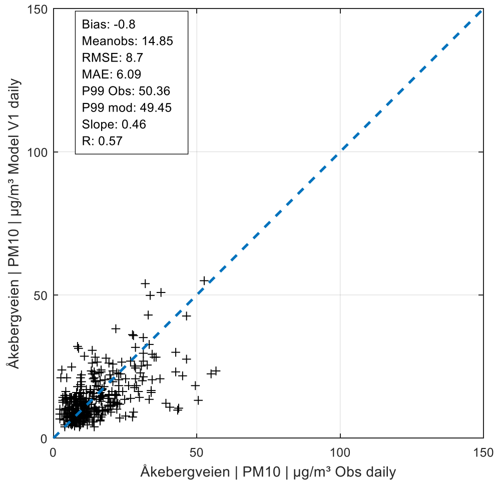


Figure A 108: Daily values PM_{10} in Åkebergveien, V1

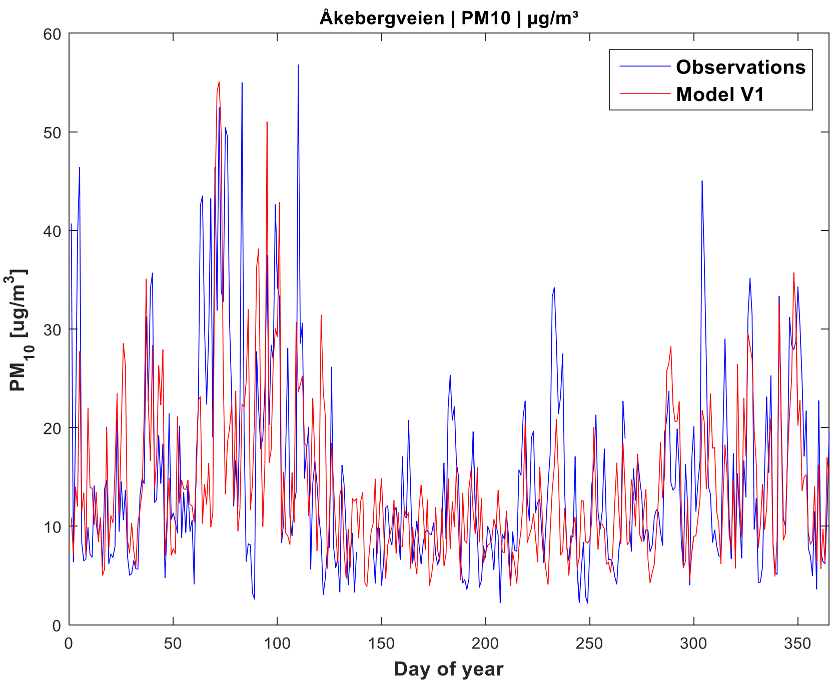


Figure A 109: Day of year PM_{10} in Åkebergveien

Oslo, Alnabru

PM_{10}

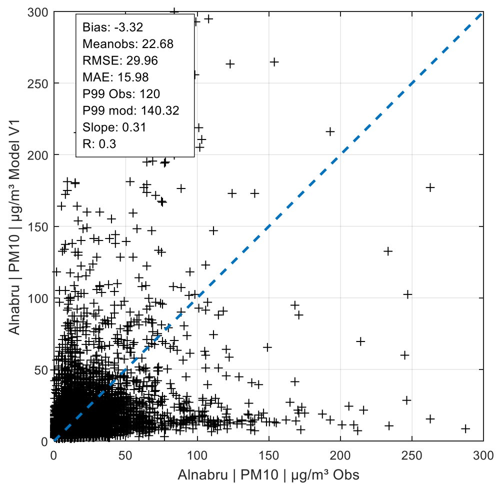


Figure A 110: Hourly values PM_{10} in Alnabru, V1

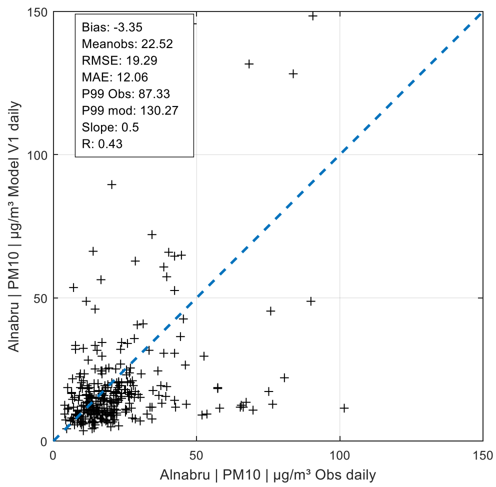


Figure A 111: Daily values PM_{10} in Alnabru, V1

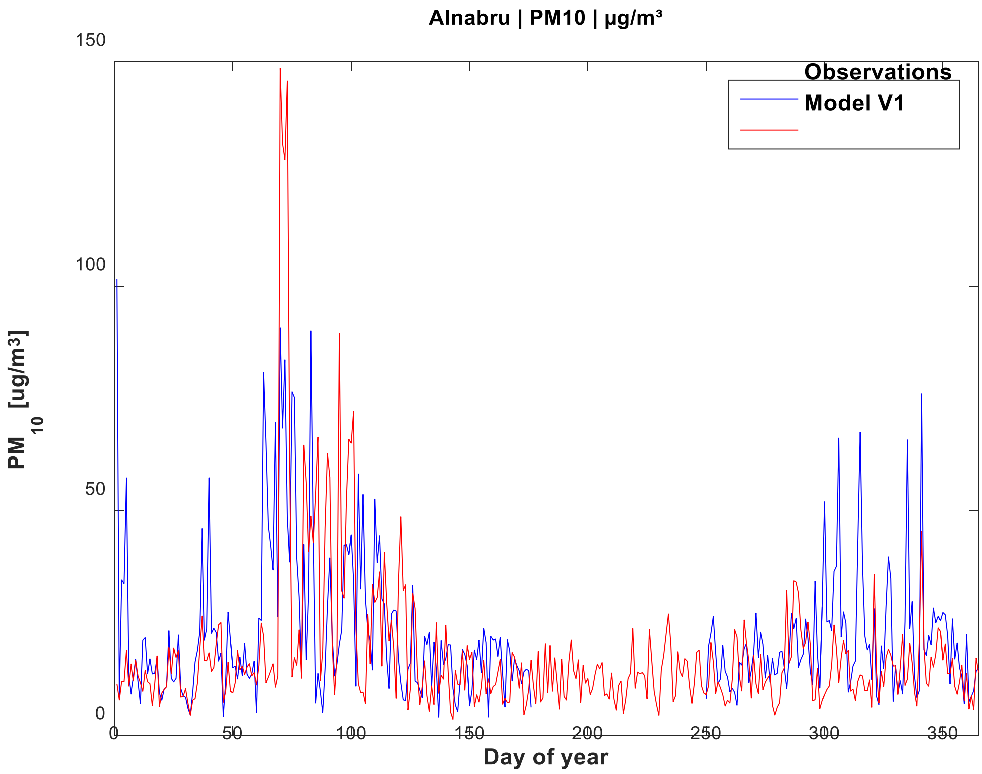


Figure A 112: Day of year PM_{10} in Alnabru

Oslo, Bygdøy Allè

PM_{10}

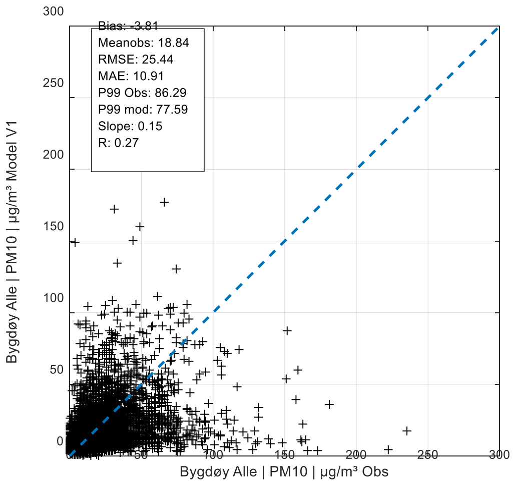


Figure A 113: Hourly values PM_{10} in Bygdøy Allè, V1

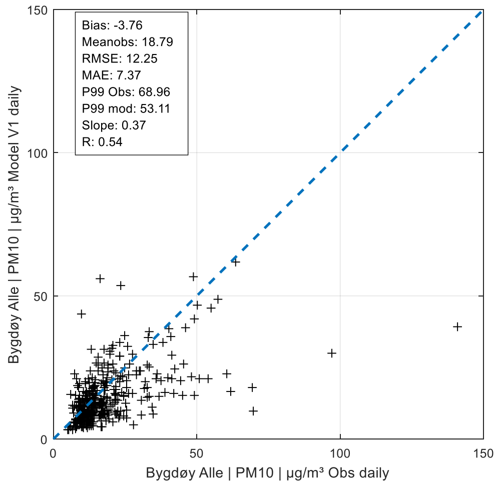


Figure A 114: Daily values PM_{10} in Bygdøy Allè, V1

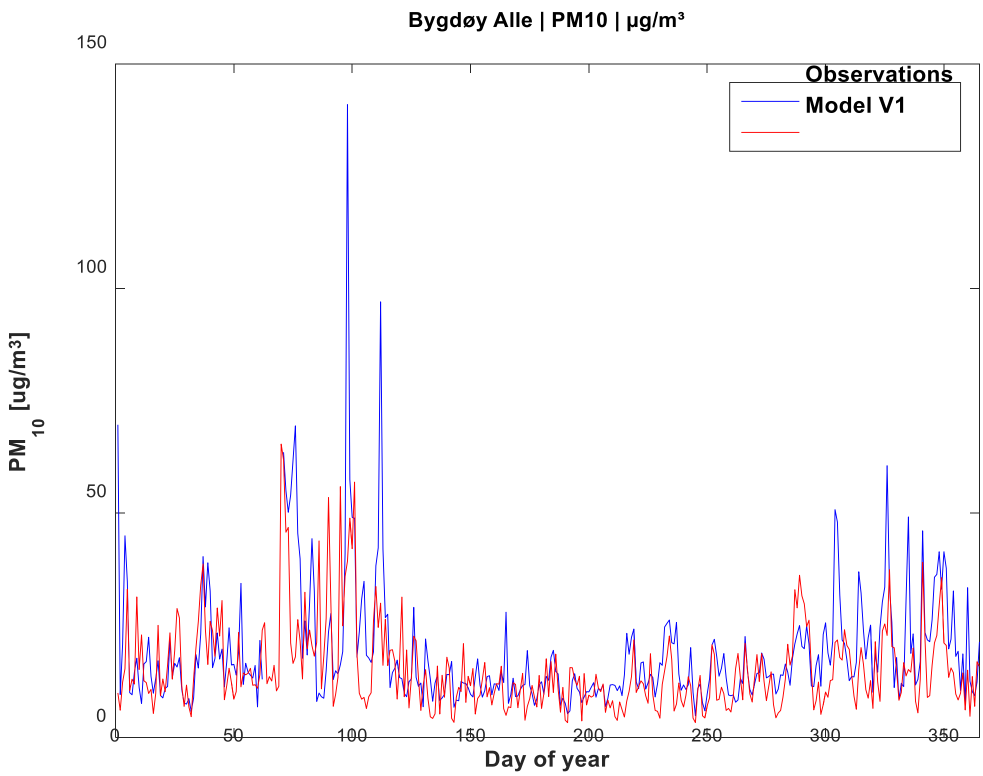


Figure A 115: Day of year PM_{10} in Bygdøy Allè

Oslo, Hjortnes

PM_{10}

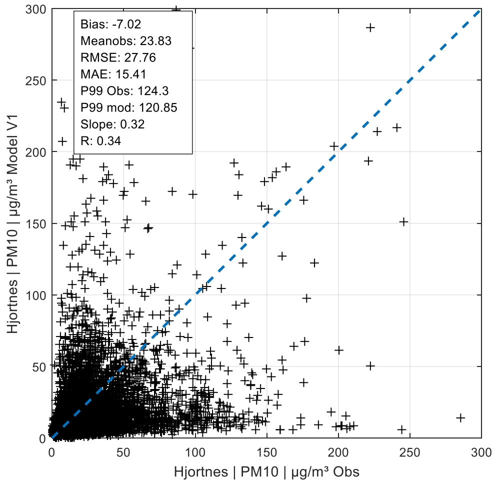


Figure A 116: Hourly values PM_{10} in Hjortnes,V1

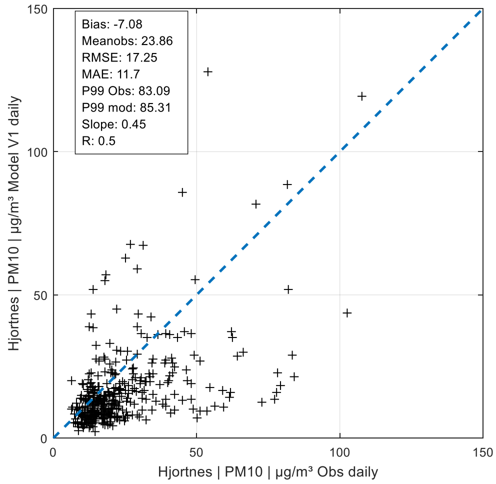


Figure A 117: Daily values PM_{10} in Hjortnes,V1

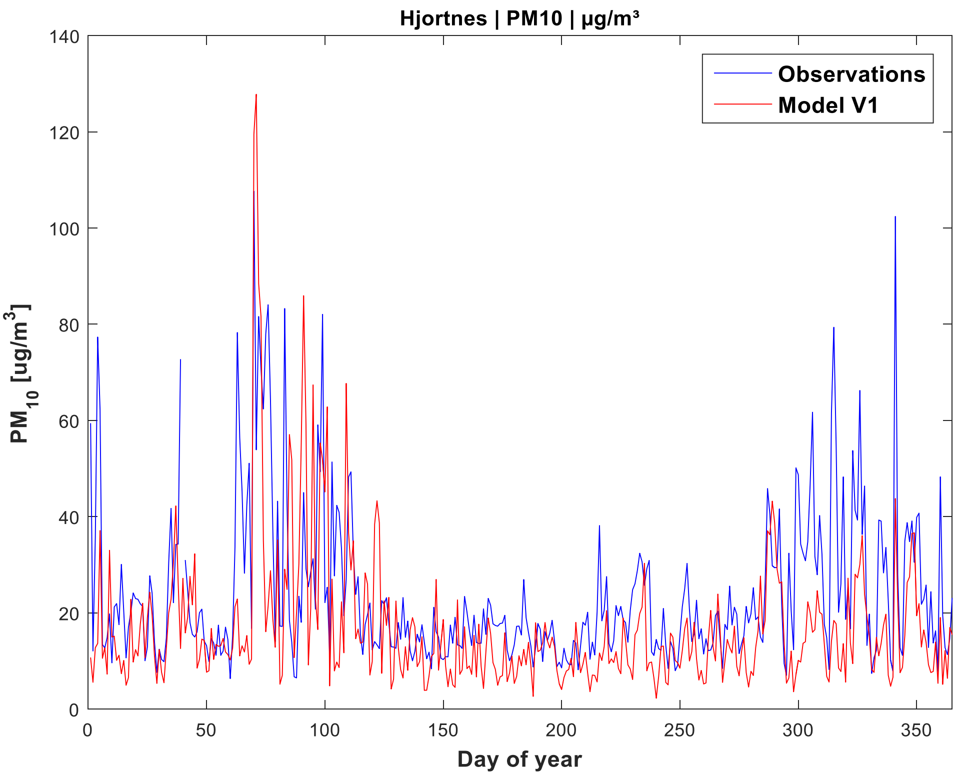


Figure A 118: Day of year $PM_{2.5}$ in Hjortnes

Oslo, Kirkeveien

PM_{10}

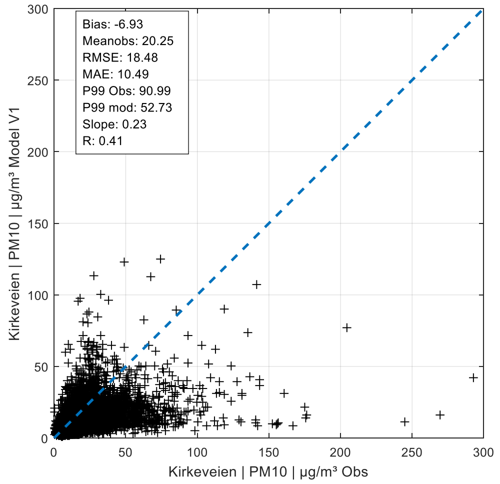


Figure A 119: Hourly values PM_{10} in Kirkeveien, V1

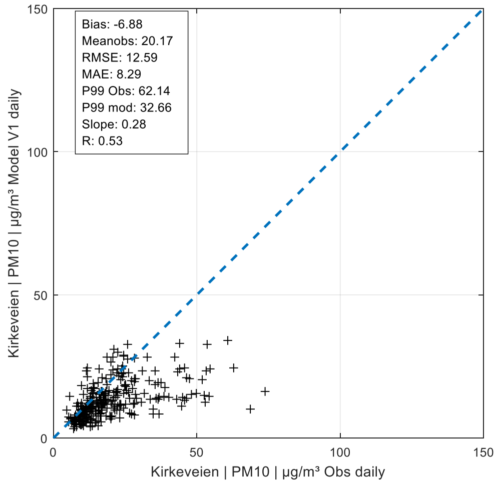


Figure A 120: Daily values PM_{10} in Kirkeveien, V1

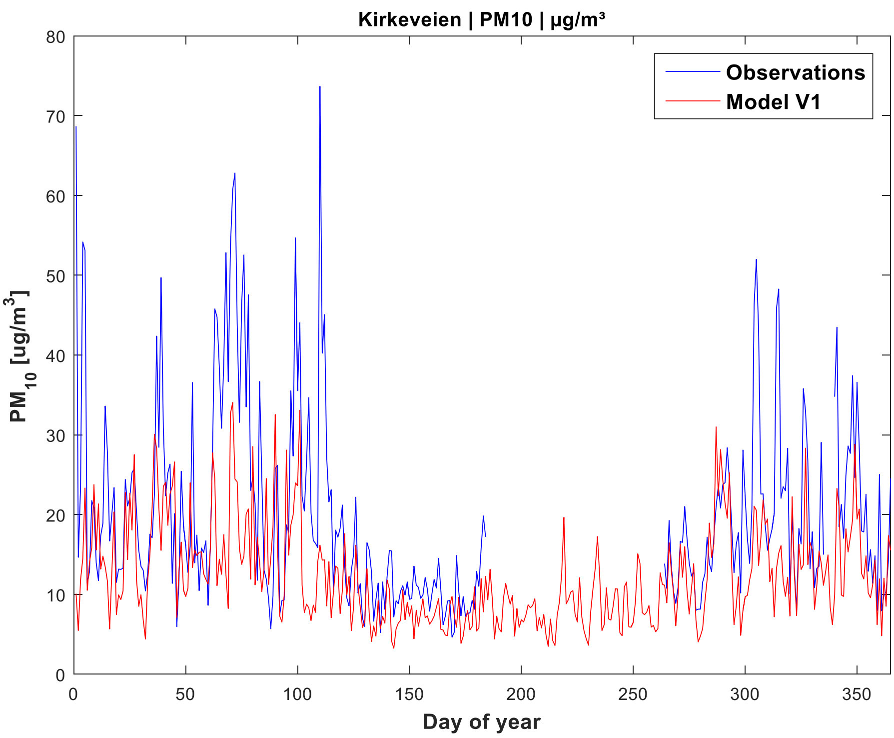


Figure A 121: Day of year PM_{10} in Kirkeveien

Oslo, Manglerud

PM_{10}

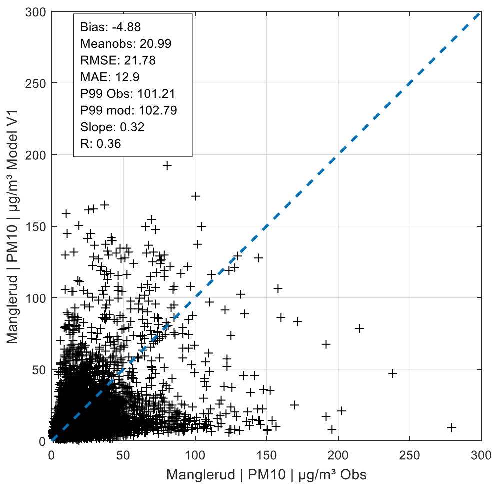


Figure A 122: Hourly values PM_{10} in Manglerud, V1

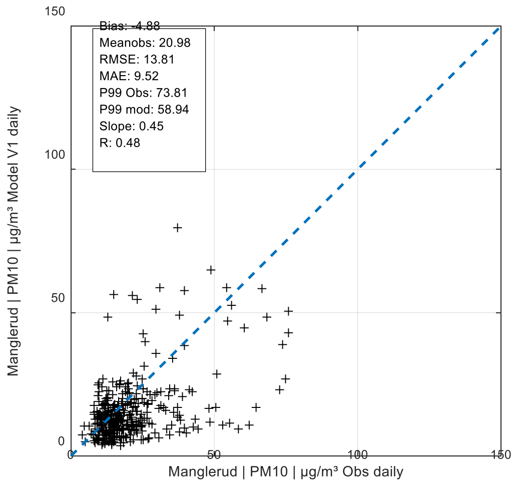


Figure A 123: Daily values PM_{10} in Manglerud, V1

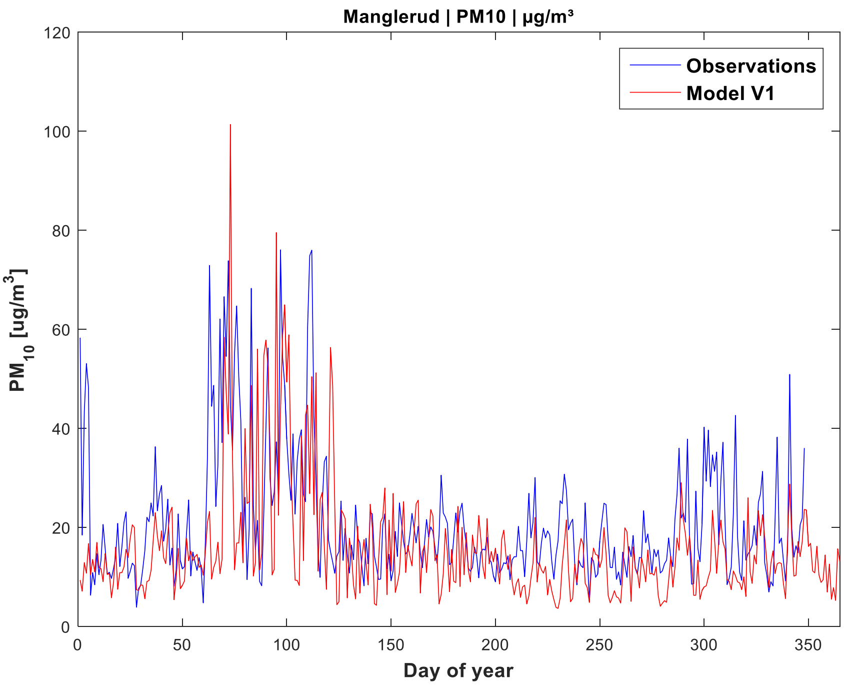


Figure A 124: Day of year PM_{10} in Manglerud

Oslo, Rv4, Aker sykehus

PM_{10}

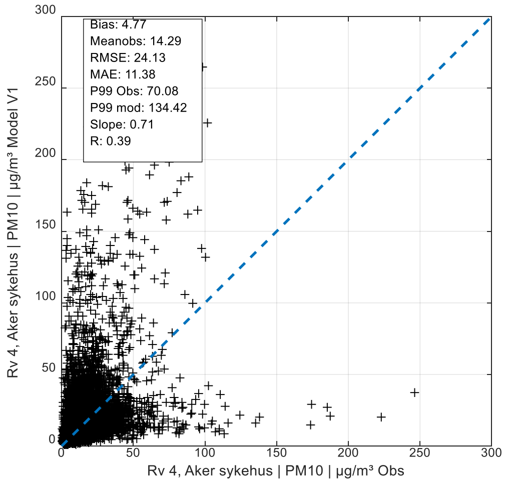


Figure A 125: Hourly values PM_{10} in Aker Sykehus, V1

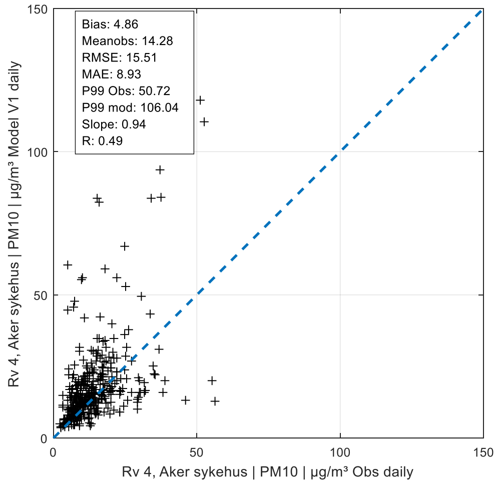


Figure A 126: Daily values PM_{10} in Aker Sykehus, V1

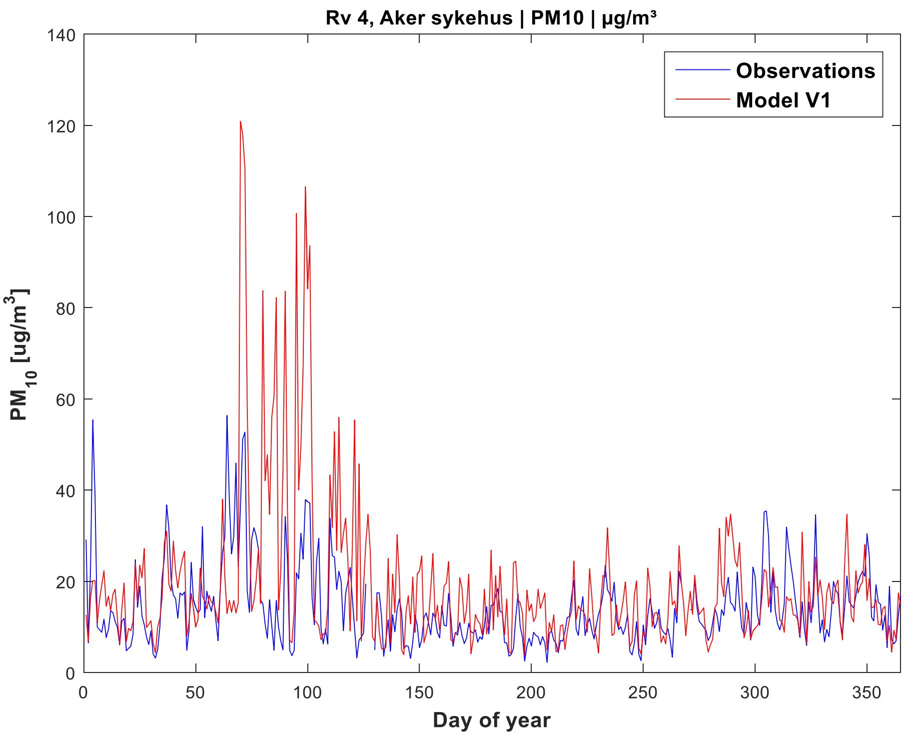


Figure A 127: Day of year PM_{10} in Aker Sykehus

Oslo, Smestad

PM_{10}

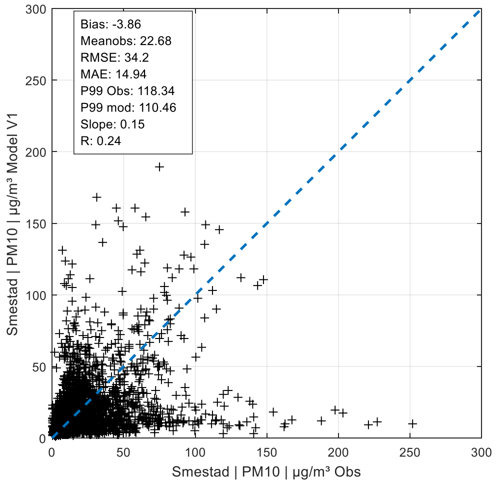


Figure A 128: Hourly values PM_{10} in Smestad, V1

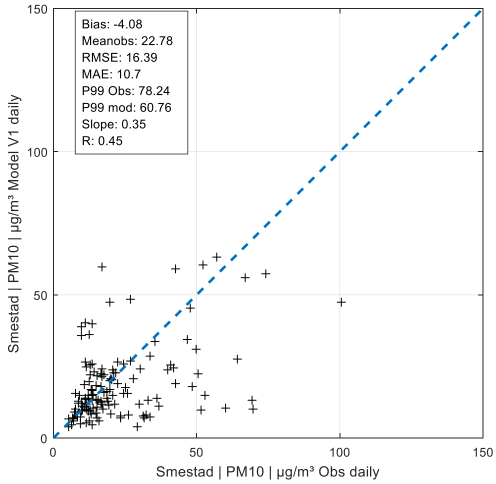


Figure A 129: Daily values PM_{10} in Smestad, V1

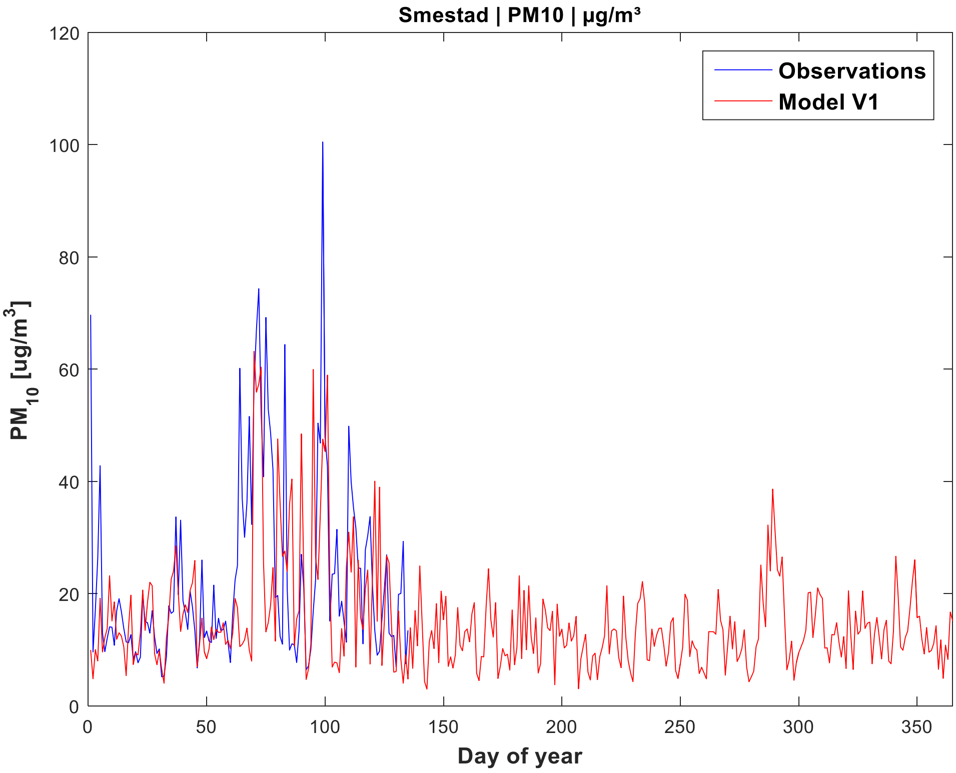


Figure A 130: Day of year PM_{10} in Smestad

Oslo, Sofienbergparken

PM_{10}

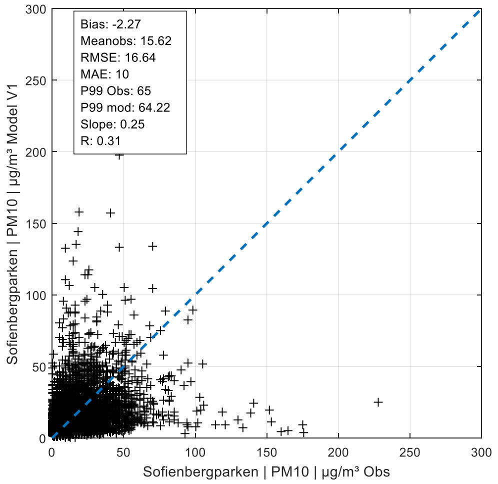


Figure A 131: Hourly values PM_{10} in Sofienbergparken, V1

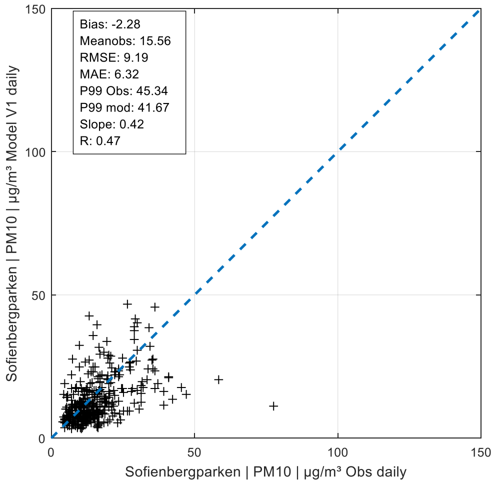


Figure A 132: Daily value PM_{10} in Sofienbergparken, V1

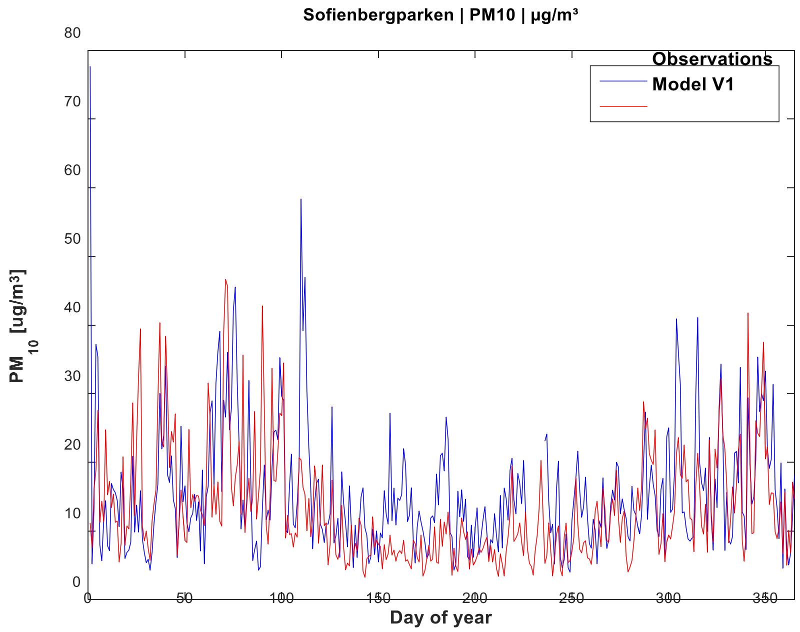


Figure A 133: Day of year PM_{10} in Sofienbergparken

Oslo, Åkebergveien

PM2.5

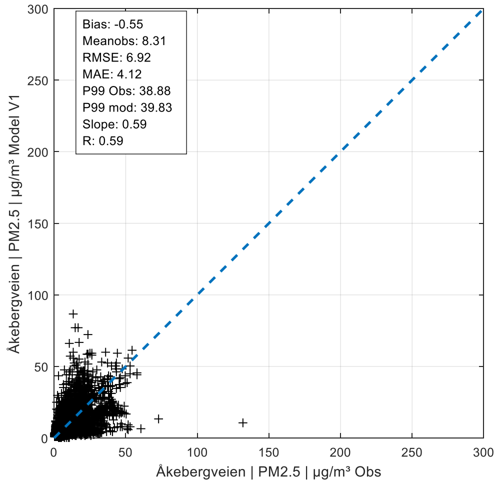


Figure A 134: Hourly values $PM_{2.5}$ in Åkebergveien, V1

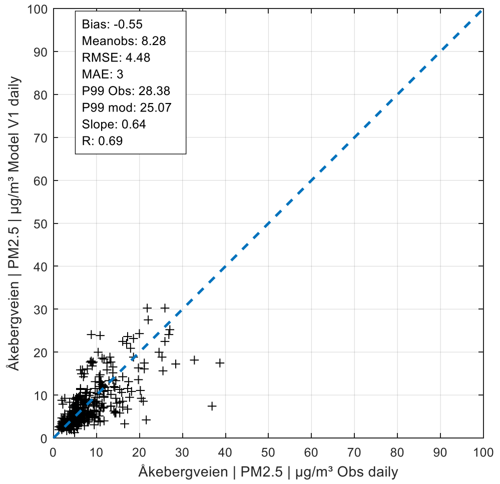


Figure A 135: Daily values $PM_{2.5}$ in Åkebergveien, V1

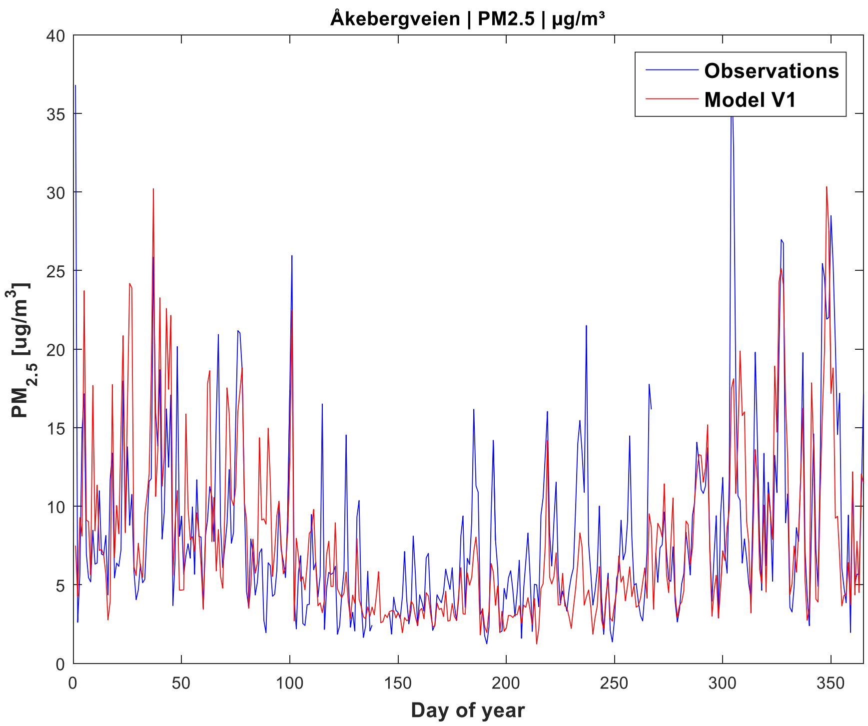
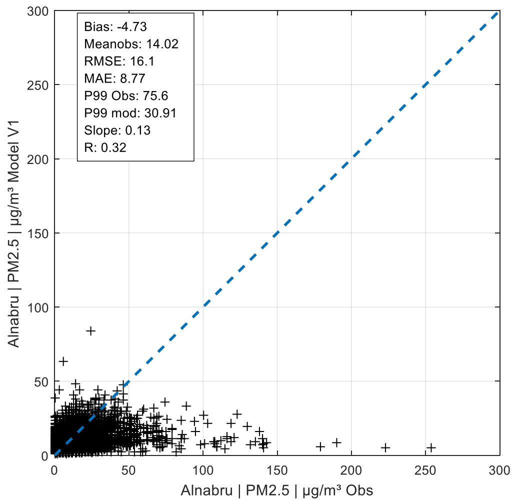


Figure A 136: Day of year $PM_{2.5}$ in Åkebergveien

Oslo, Alnabru

$PM_{2.5}$



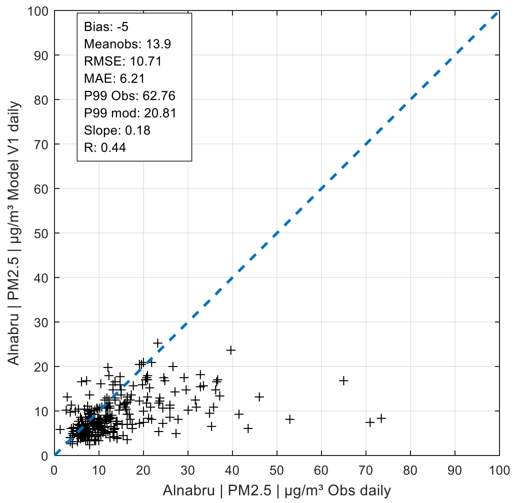


Figure A 137: Hourly values $PM_{2.5}$ in Alnabru, V1

Figure A 138: Daily values $PM_{2.5}$ in Alnabru, V1

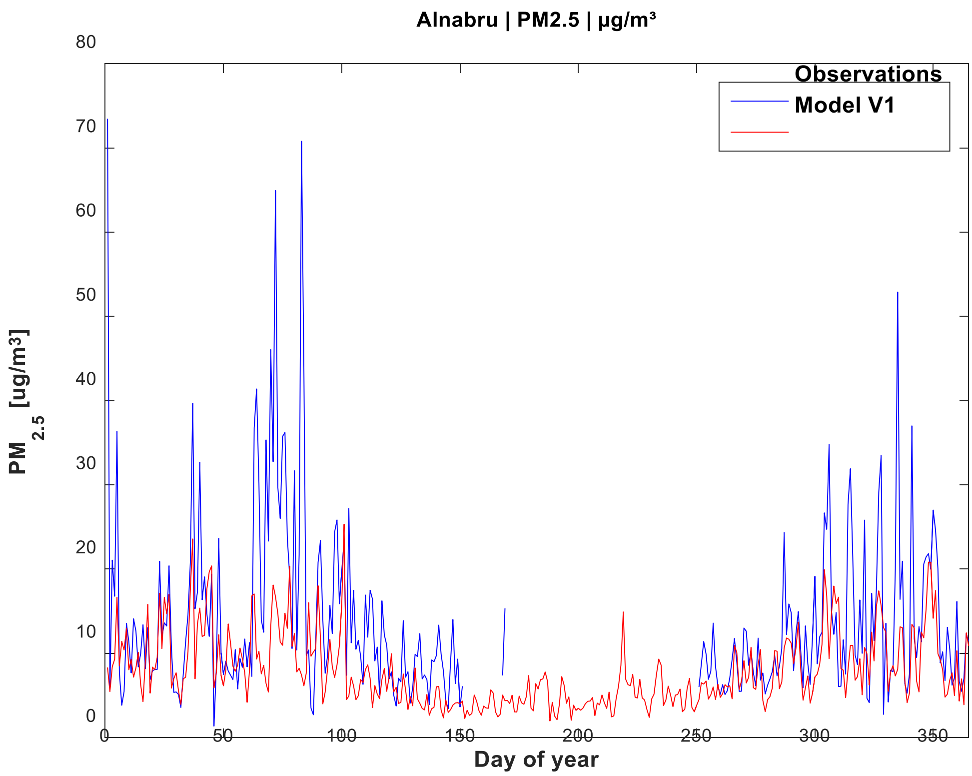


Figure A 139: Day of year $PM_{2.5}$ in Alnabru

Oslo, Bygdøy Allè

$PM_{2.5}$

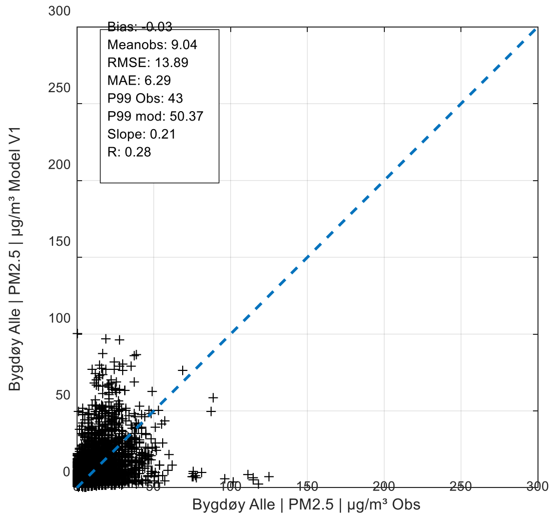


Figure A 140: Hourly values $PM_{2.5}$ in Bygdøy Allè, V1

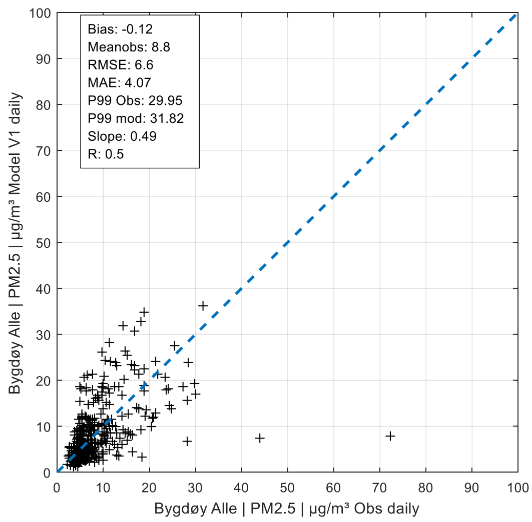


Figure A 141: Daily values $PM_{2.5}$ in Bygdøy Allè, V1

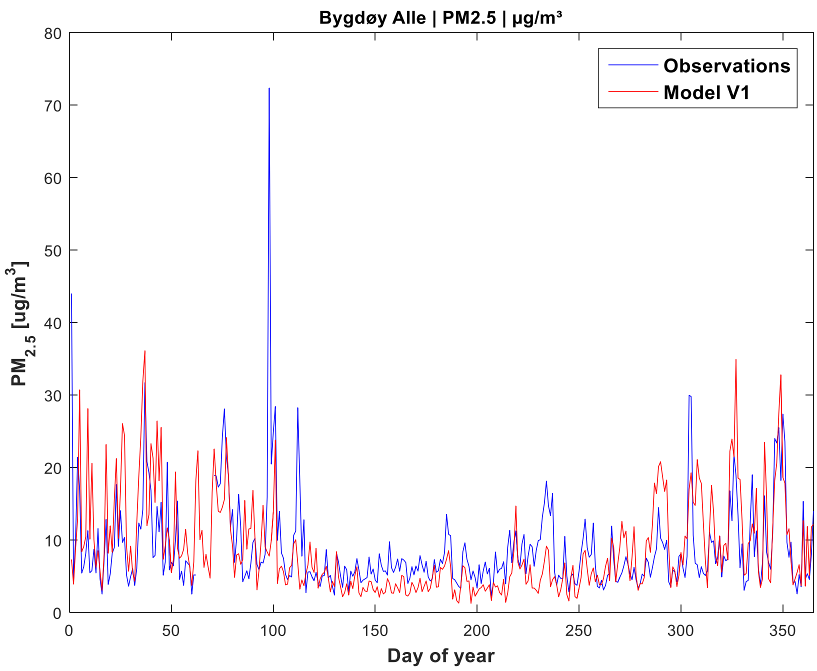
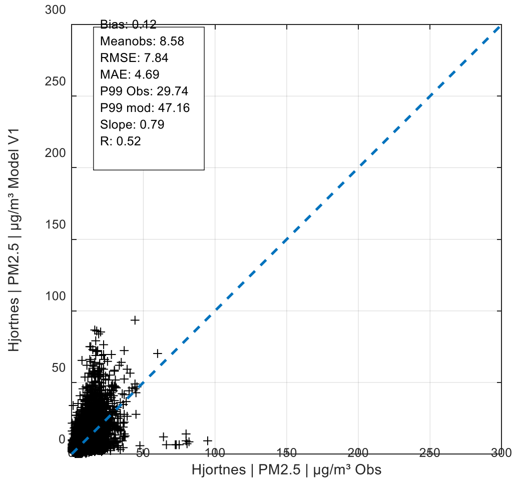


Figure A 142: Day of year $PM_{2.5}$ in Bygdøy Allè

Oslo, Hjortnes

$PM_{2.5}$



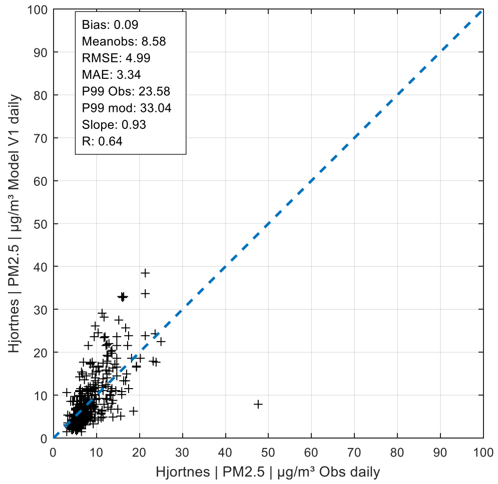


Figure A 143: Hourly values $PM_{2.5}$ in Hjortnes,V1 *Figure A 144: Daily values $PM_{2.5}$ in Hjortnes,V1*

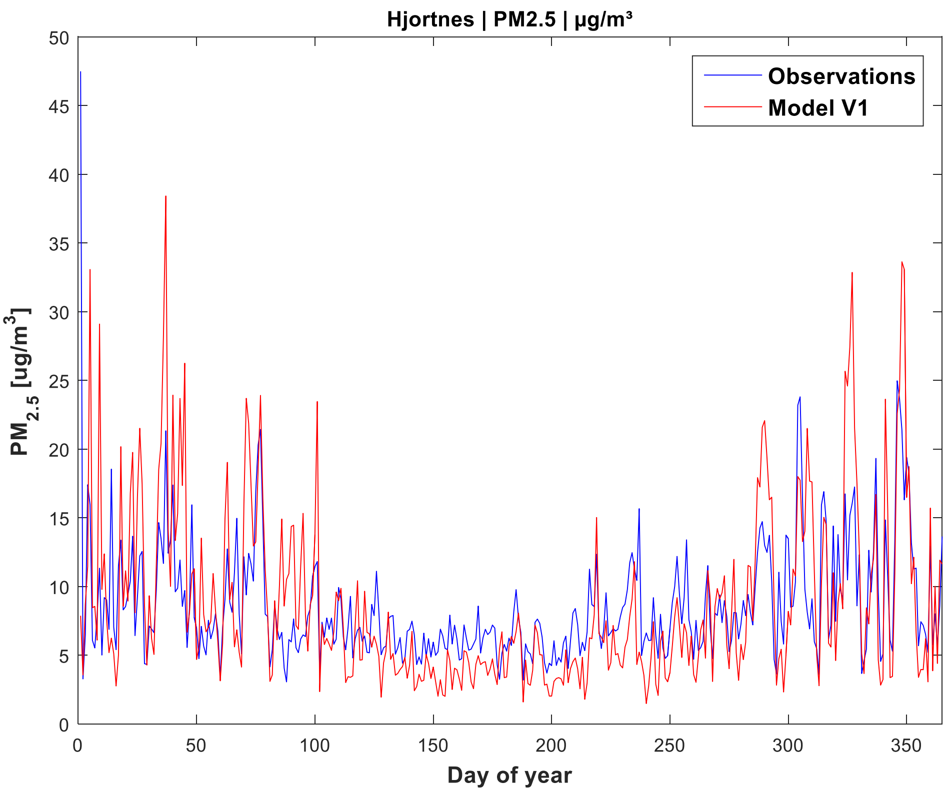


Figure A 145: Day of year $PM_{2.5}$ in Hjortnes

Oslo, Kirkeveien

$PM_{2.5}$

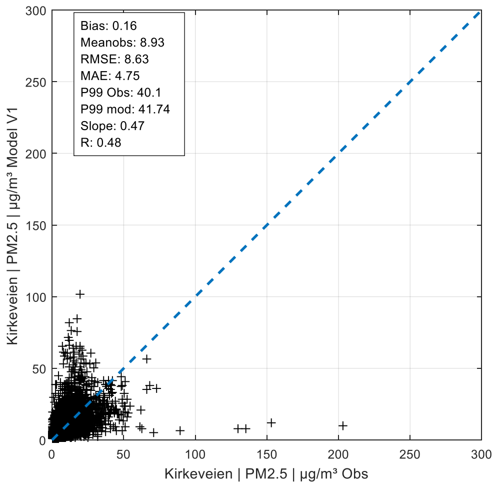


Figure A 146: Hourly values $PM_{2.5}$ in Kirkeveien, V1

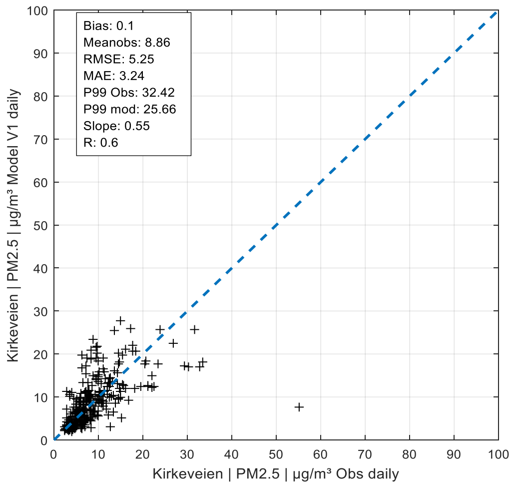


Figure A 147: Daily values $PM_{2.5}$ in Kirkeveien, V1

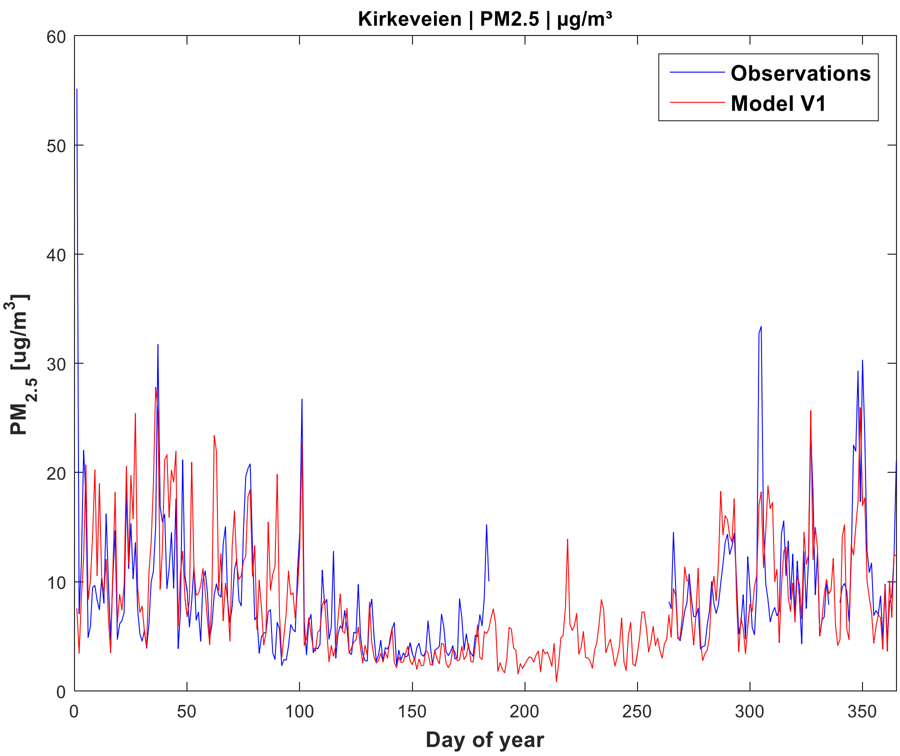


Figure A 148: Day of year $PM_{2.5}$ in Kirkeveien

Oslo, Manglerud

$PM_{2.5}$

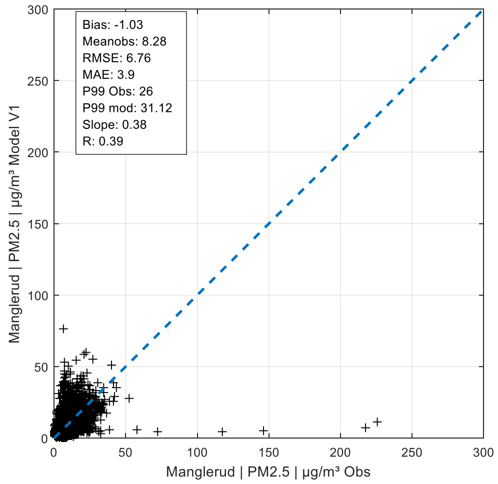


Figure A 149: Hourly values $PM_{2.5}$ in Manglerud, V1

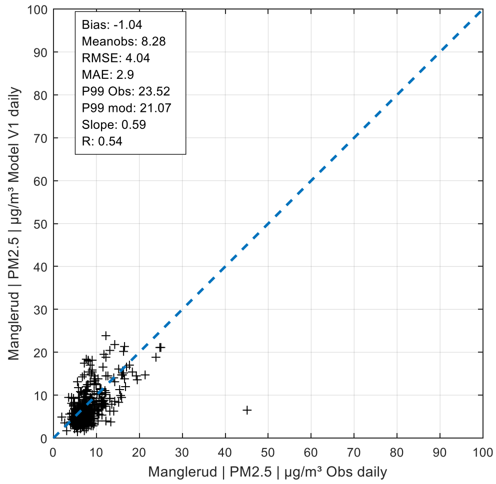


Figure A 150: Daily values $PM_{2.5}$ in Manglerud, V1

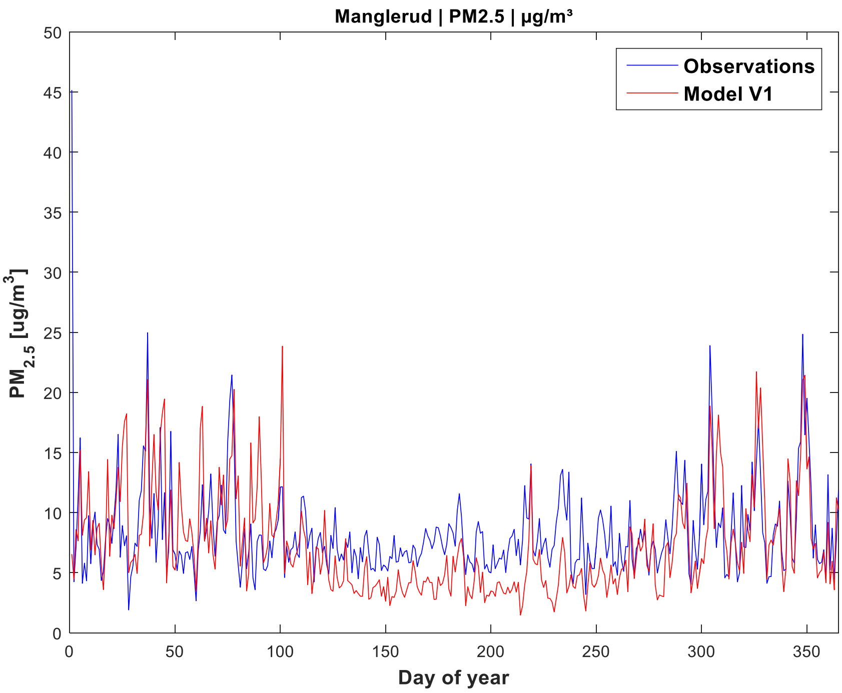


Figure A 151: Day of year $PM_{2.5}$ in Manglerud

Oslo, Rv4, Aker sykehus

$PM_{2.5}$

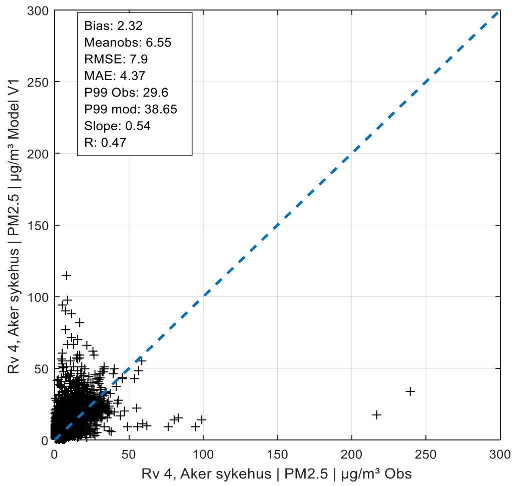


Figure A 152: Hourly values $PM_{2.5}$ in Aker Sykehus, V1

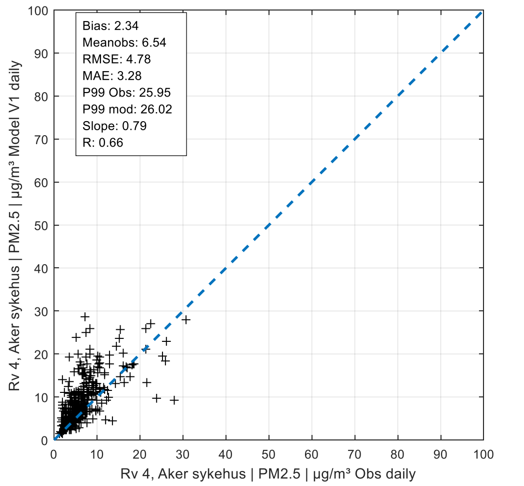


Figure A 153: Daily values $PM_{2.5}$ in Aker Sykehus, V1

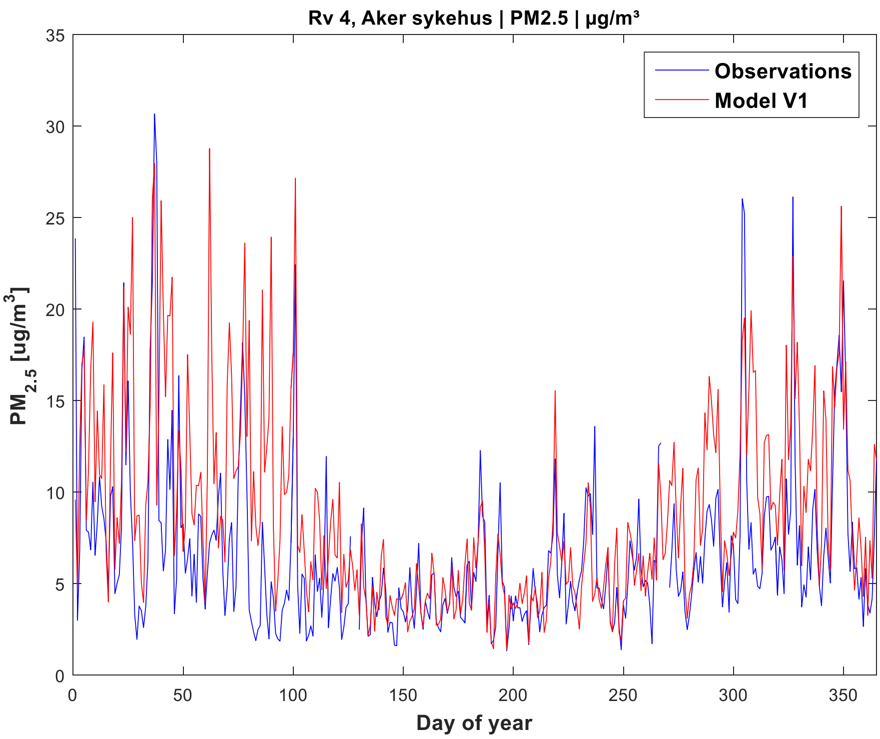


Figure A 154: Day of year $PM_{2.5}$ in Aker sykehus

Oslo, Smestad

$PM_{2.5}$

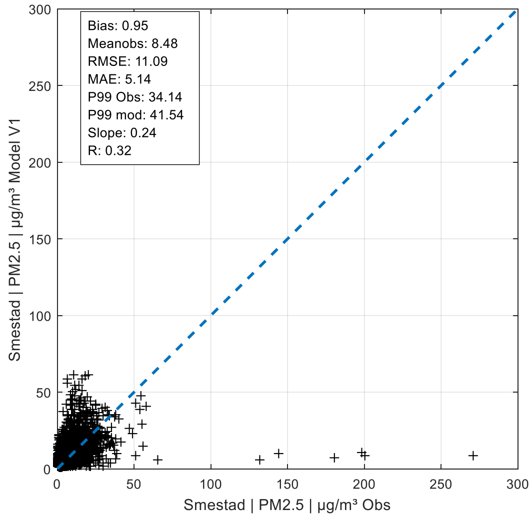


Figure A 155: Hourly values $PM_{2.5}$ in Smestad, V1

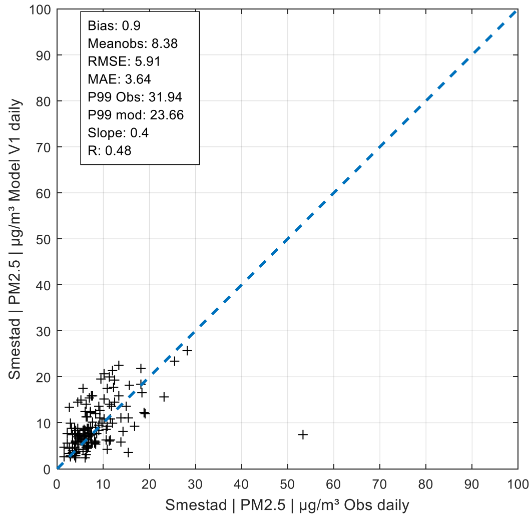


Figure A 156: Daily values $PM_{2.5}$ in Smestad, V1

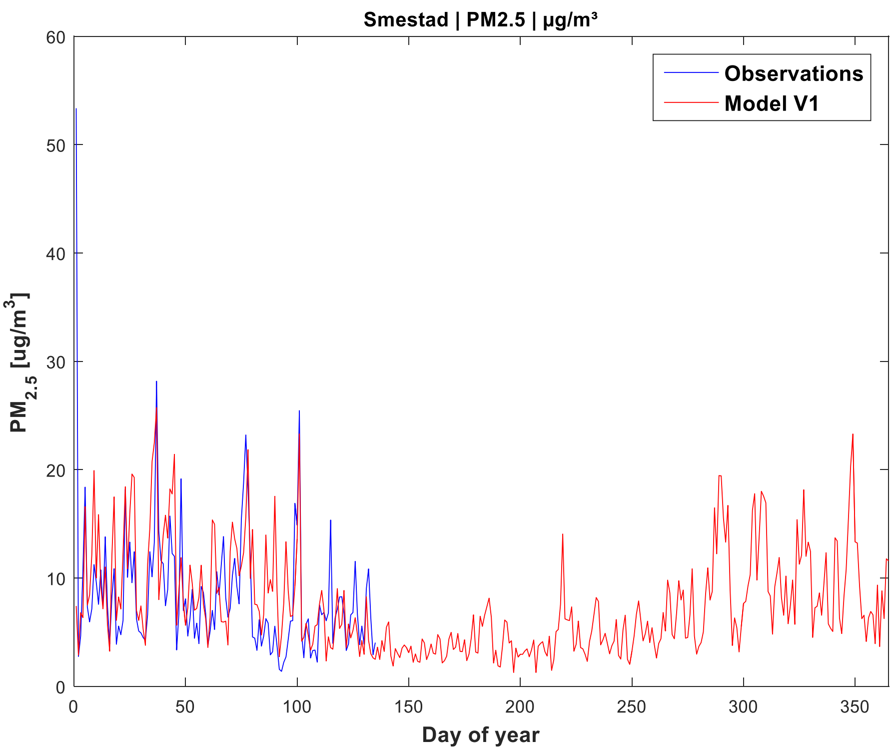


Figure A 157: Day of year $PM_{2.5}$ in Smestad

Oslo, Sofienbergparken

$PM_{2.5}$

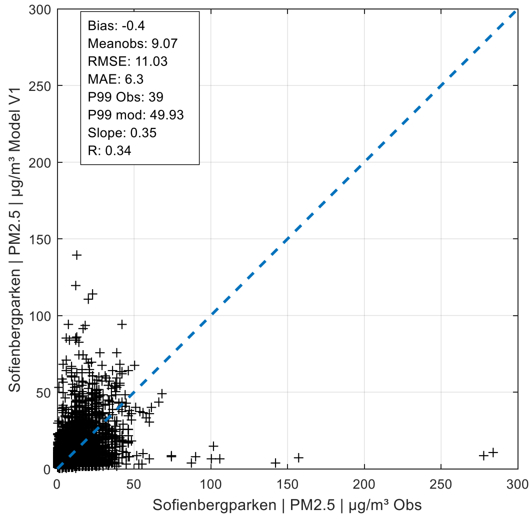


Figure A 158: Hourly values $PM_{2.5}$ in Sofienbergparken, V1

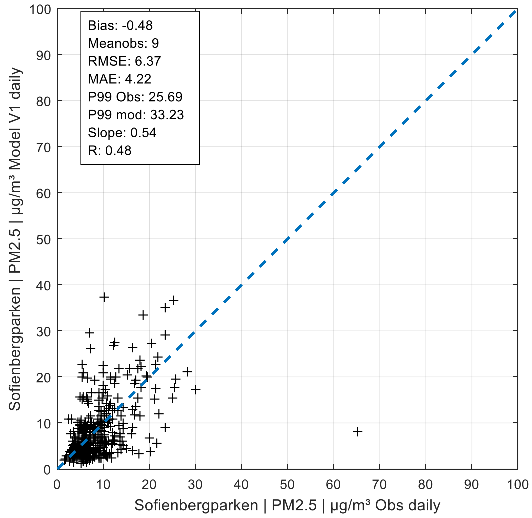


Figure A 159: Daily value $PM_{2.5}$ in Sofienbergparken, V1

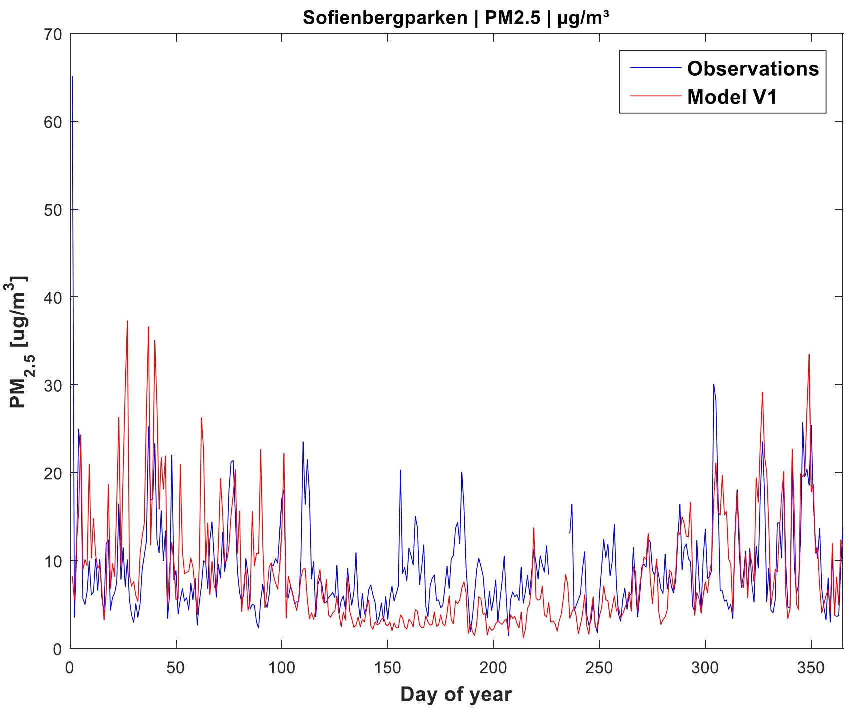


Figure A 160: Day of year $PM_{2.5}$ in Sofienbergparken

Stavanger, Kannik

NO_2

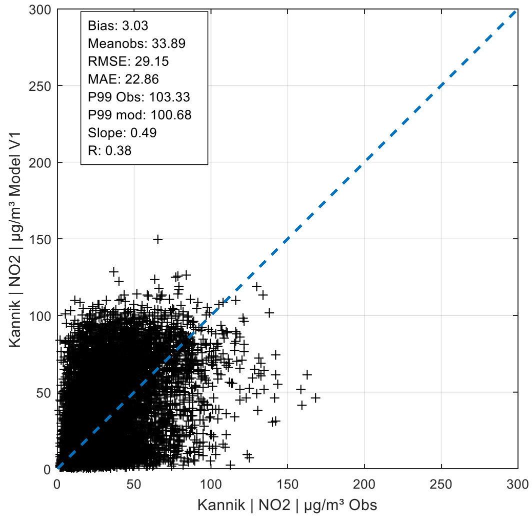


Figure A 161: Hourly values NO_2 in Kannik, V1

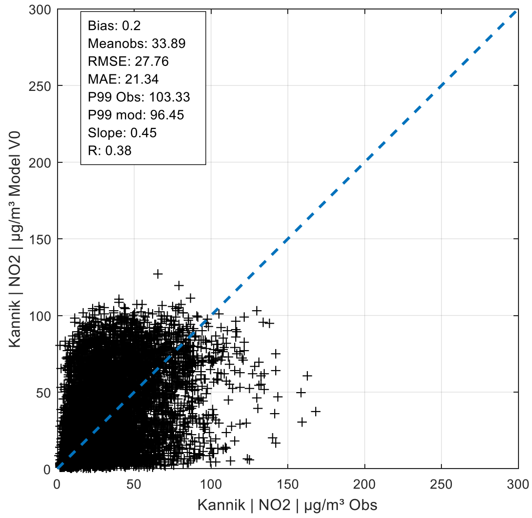


Figure A 162: Hourly values NO_2 in Kannik, V0

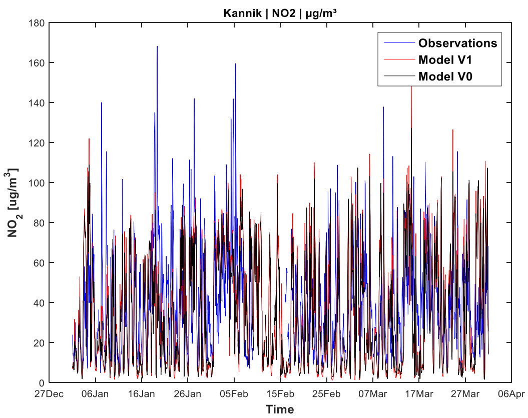


Figure A 163: Timesheet NO_2 in Kannik

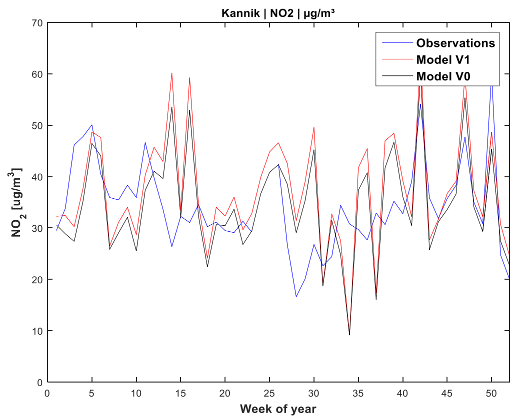


Figure A 164: Week of year NO_2 in Kannik

Stavanger, Våland

NO_2

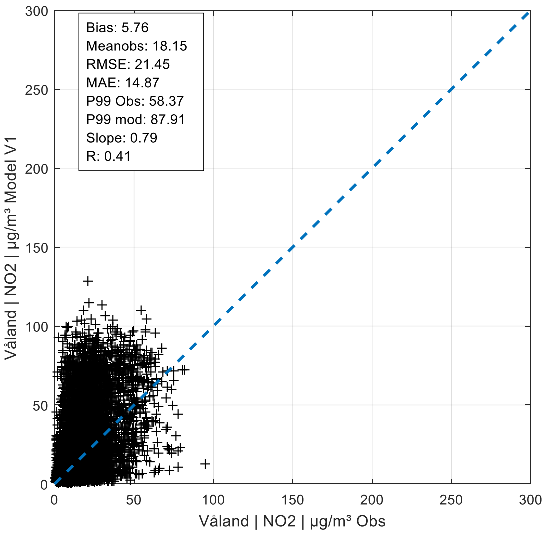


Figure A 165: Hourly values NO_2 in Våland, V1

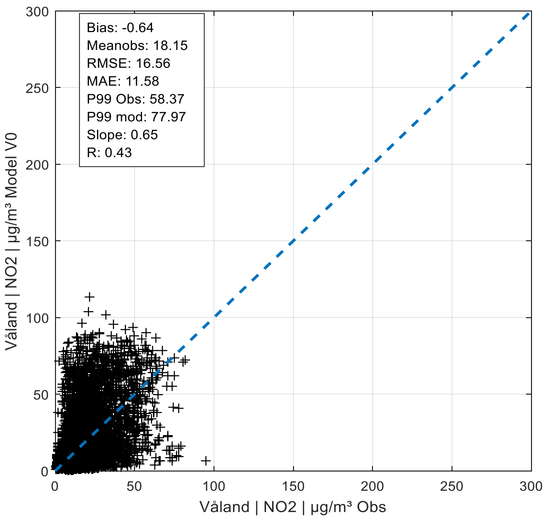


Figure A 166: Hourly values NO_2 in Våland, V0

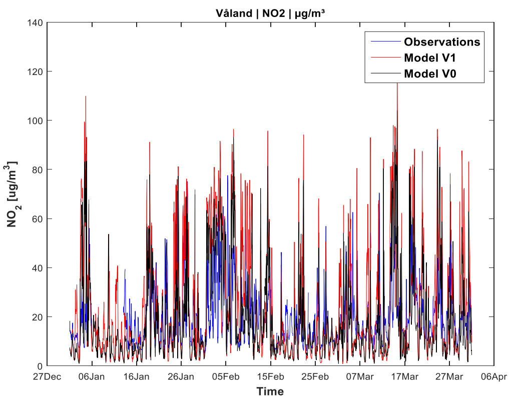


Figure A 167: Timesheet NO_2 in Våland

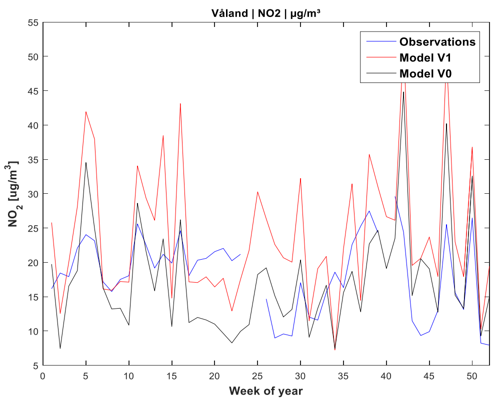


Figure A 168: Week of year NO_2 in Våland

Stavanger, Kannik

PM10

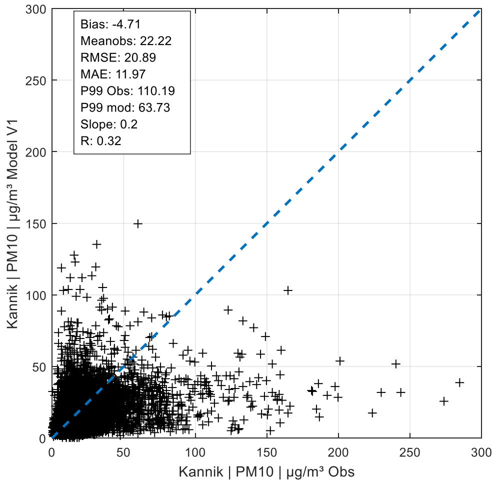


Figure A 169: Hourly values PM_{10} in Kannik, V1

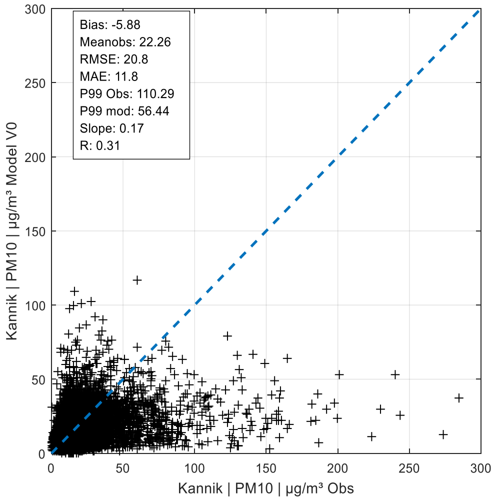


Figure A 170: Hourly values PM_{10} in Kannik, V0

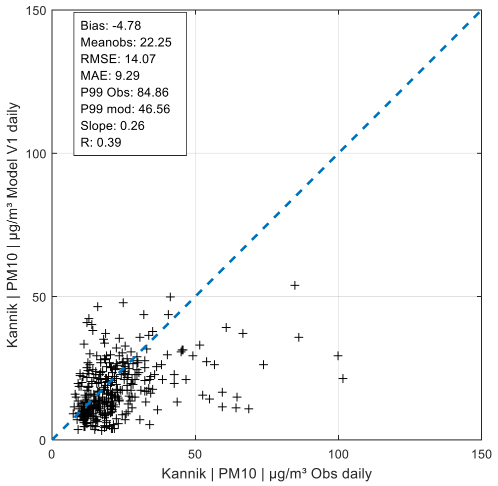


Figure A 171: Daily values PM_{10} in Kannik, V1

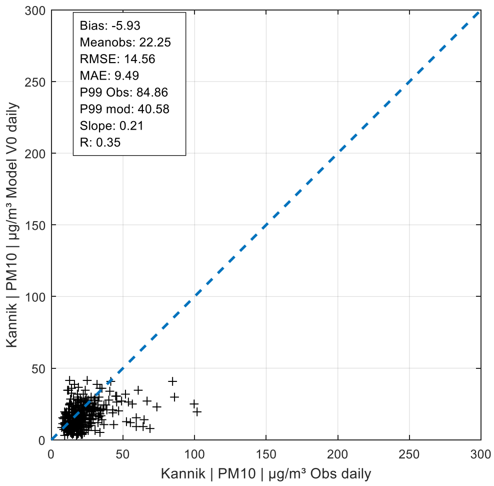


Figure A 172: Daily values PM_{10} in Kannik, V0

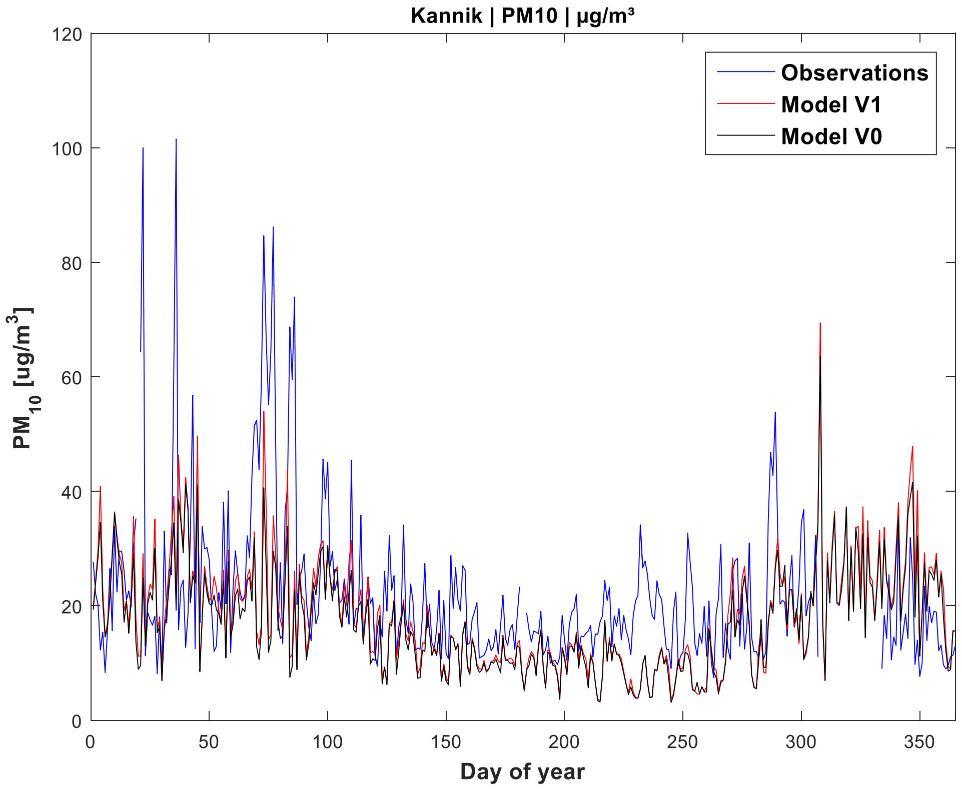


Figure A 173: Day of year PM_{10} in Kannik

Stavanger, Våland

PM_{10}

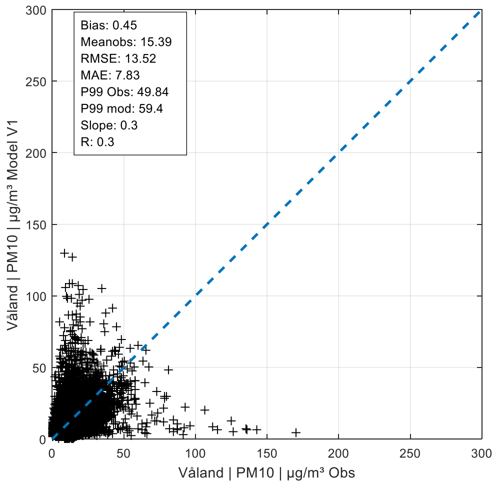


Figure A 174: Hourly values PM_{10} in Våland, V1

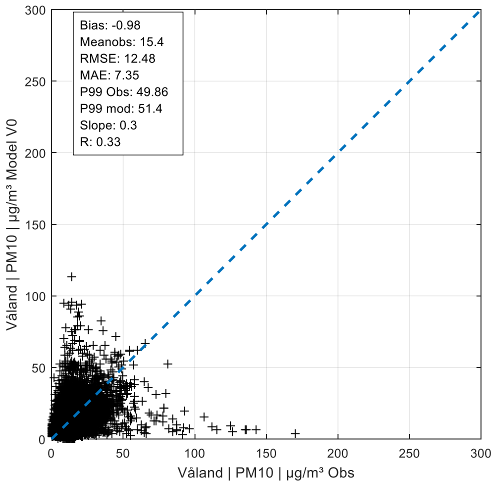


Figure A 175: Hourly values PM_{10} in Våland, V0

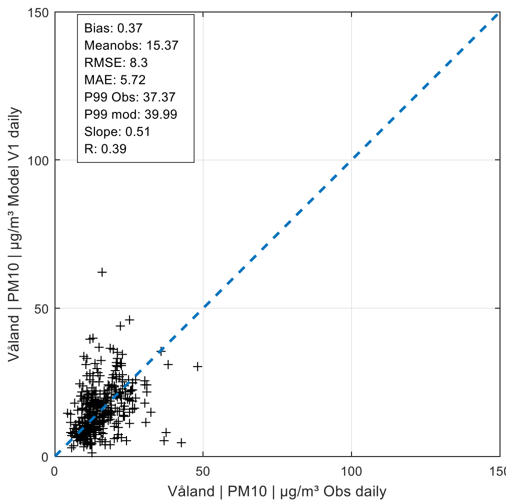


Figure A 176: Daily values PM_{10} in Våland, V1

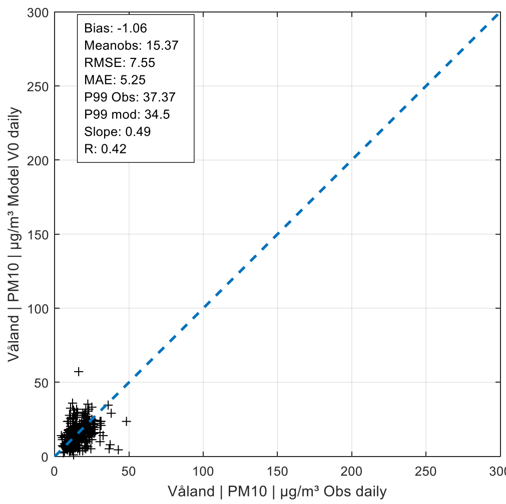


Figure A 177: Daily values PM_{10} in Våland, V0

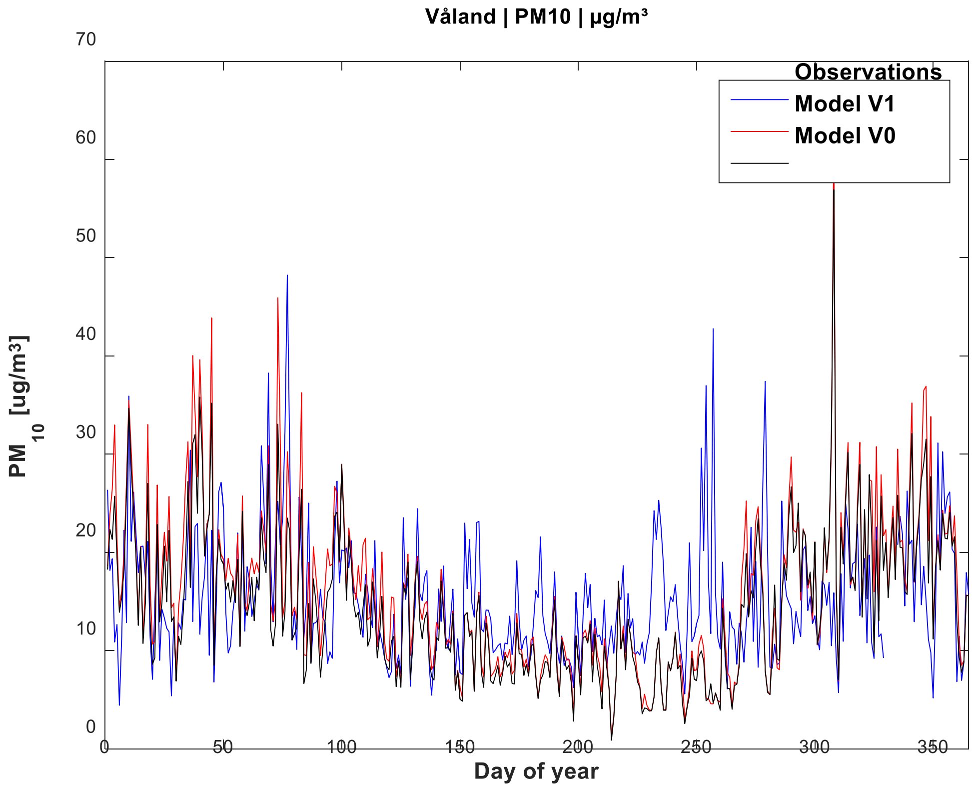


Figure A 178: Day of year PM_{10} in Våland

Stavanger, Kannik

$PM_{2.5}$

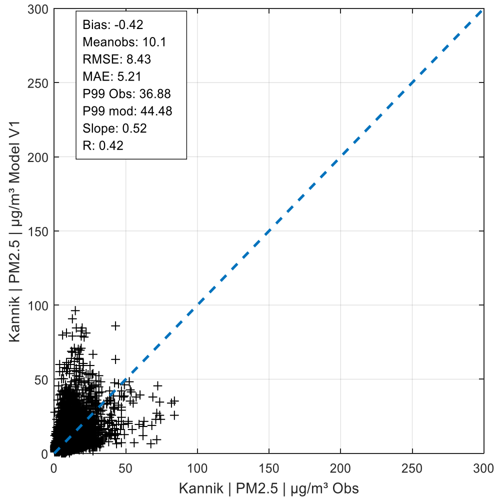


Figure A 179: Hourly values $PM_{2.5}$ in Kannik, V1

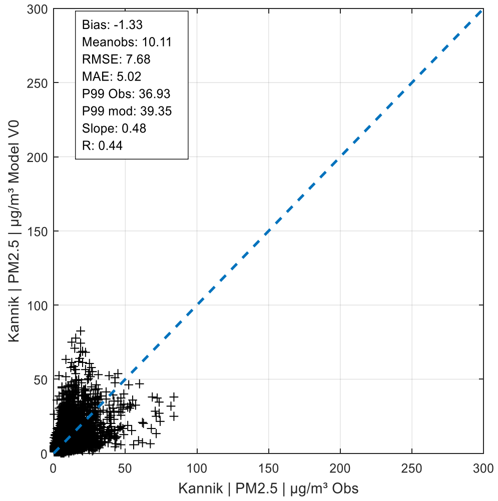


Figure A 180: Hourly values $PM_{2.5}$ in Kannik, V0

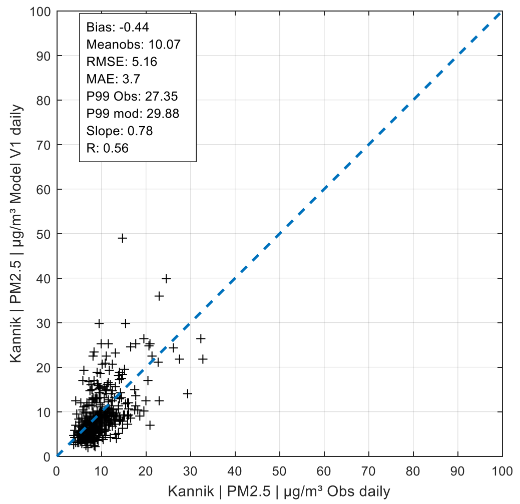


Figure A 181: Daily values $PM_{2.5}$ in Kannik, V1

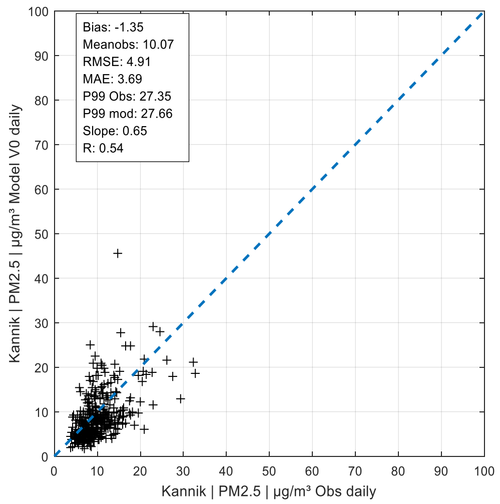


Figure A 182: Daily values $PM_{2.5}$ in Kannik, V0

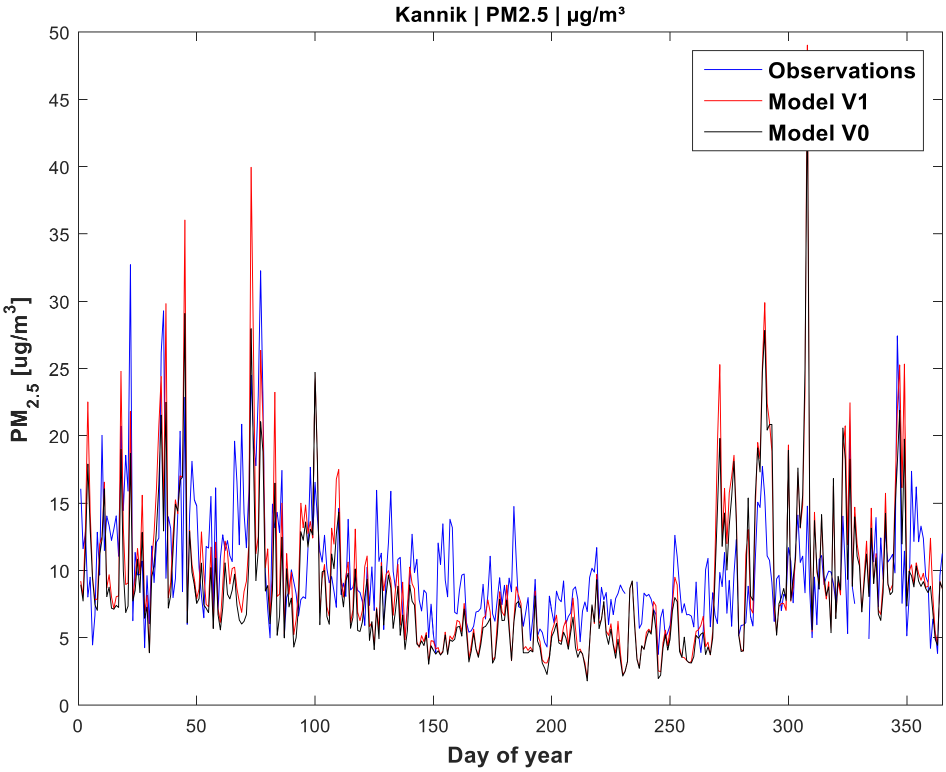


Figure A 183: Day of year $PM_{2.5}$ in Kannik

Stavanger, Våland

$PM_{2.5}$

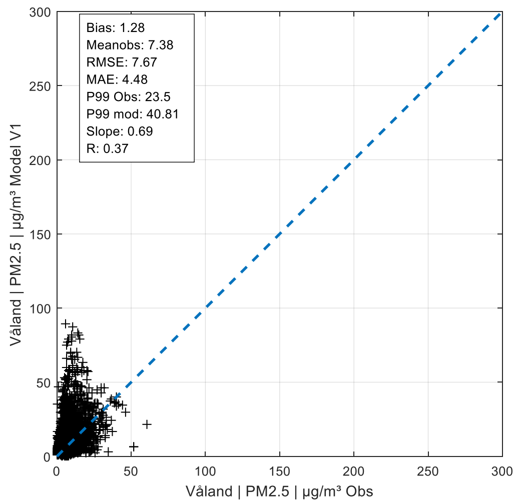


Figure A 184: Hourly values $PM_{2.5}$ in Våland, V1

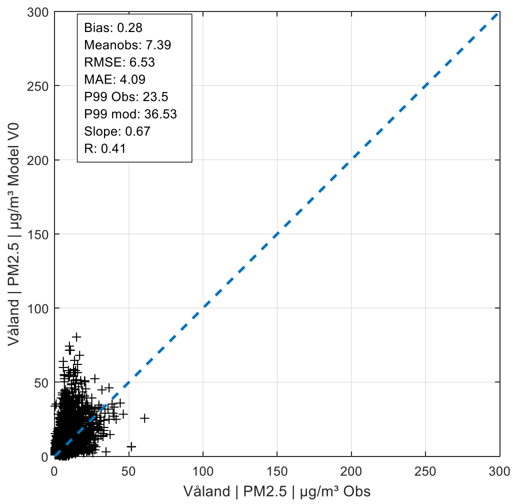


Figure A 185: Hourly values $PM_{2.5}$ in Våland, V0

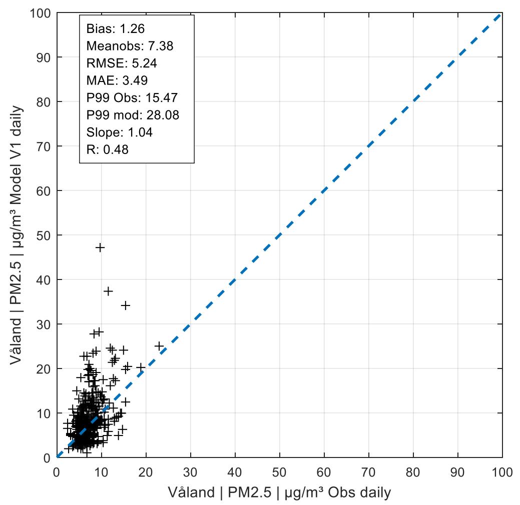


Figure A 186: Daily values $PM_{2.5}$ in Våland, V1

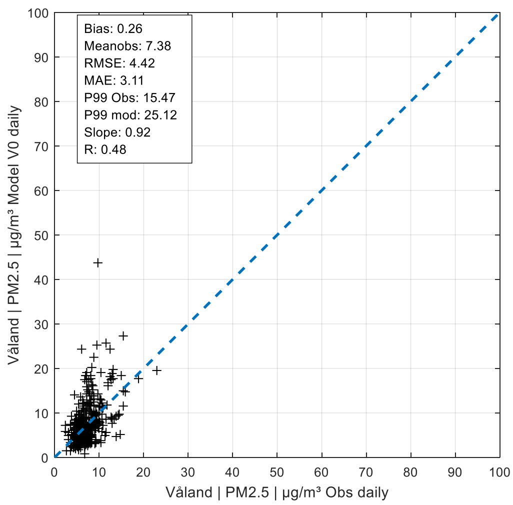


Figure A 187: Daily values $PM_{2.5}$ in Våland, V0

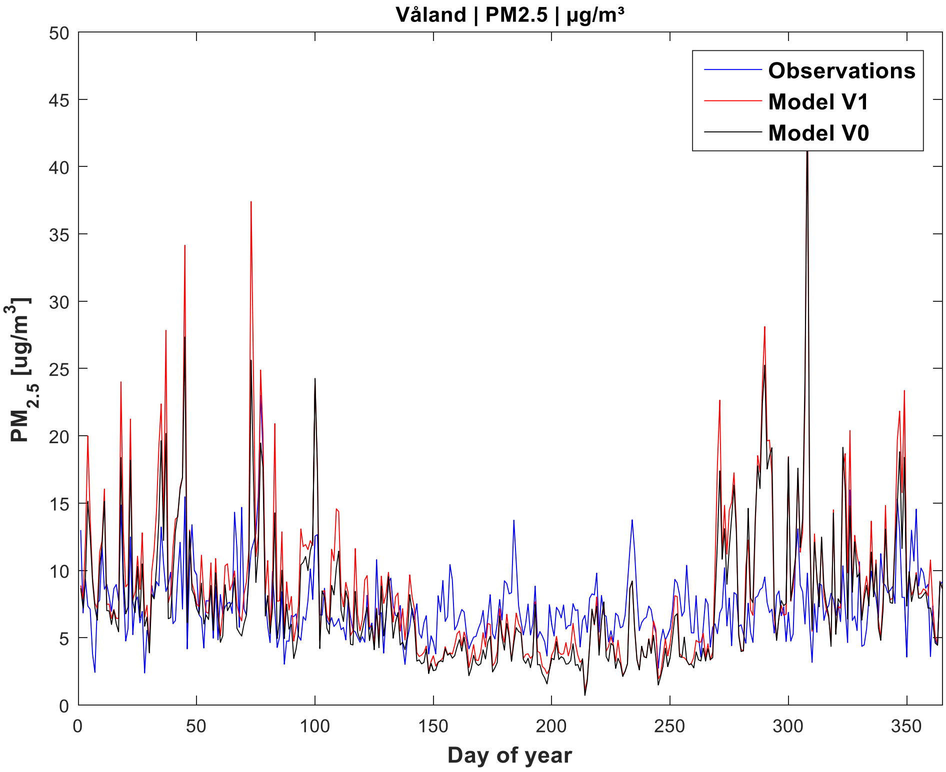


Figure A 188: Day of year $PM_{2.5}$ in Våland

Trondheim, Bakke kirke

NO_2

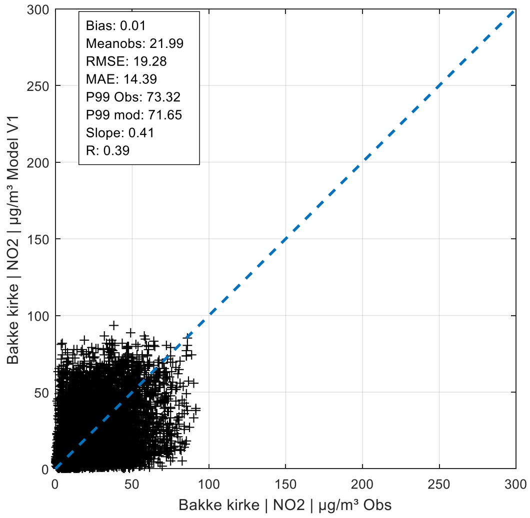


Figure A 189: Hourly values NO_2 in Bakke kirke, V1

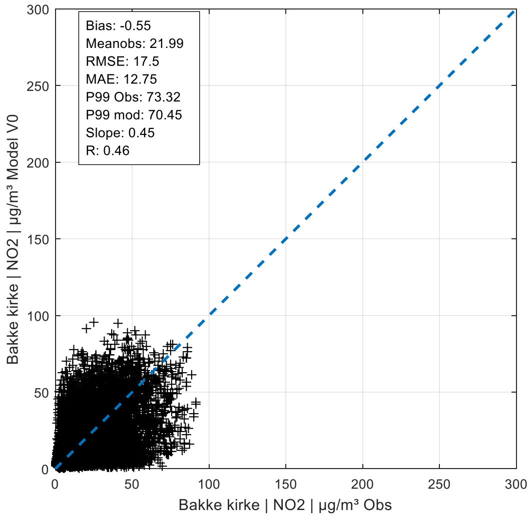


Figure A 190:Hourly values NO_2 in Bakke kirke, V0

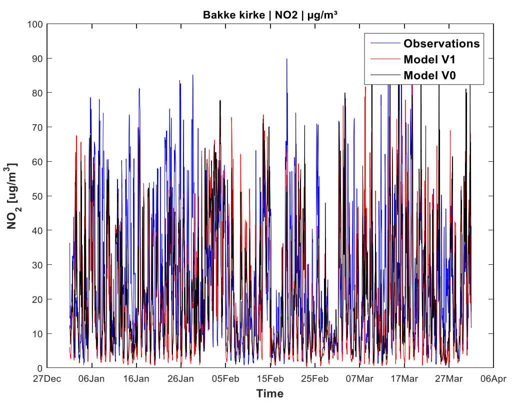


Figure A 191: Timesheet NO_2 in Bakke kirke

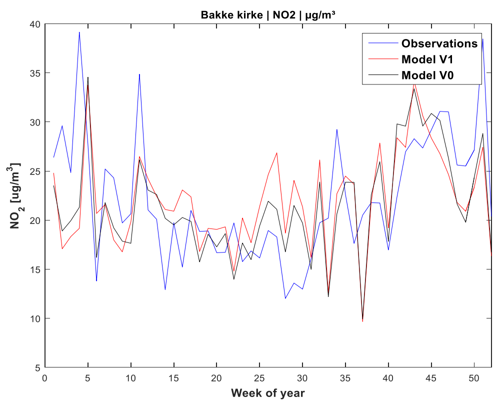


Figure A 192: Week of year NO_2 in Bakke kirke

Trondheim, Elgeseter

NO_2

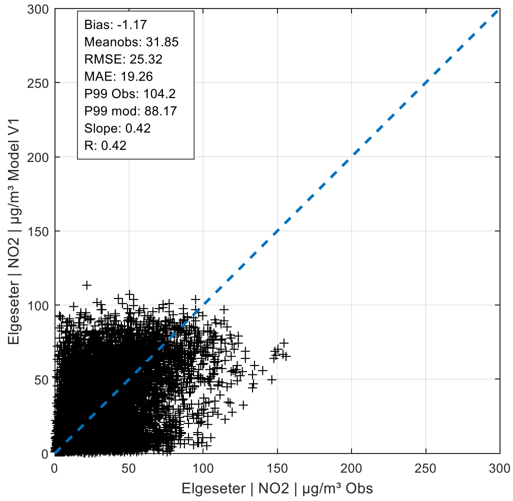


Figure A 193: Hourly values NO_2 in Elgeseter, V1

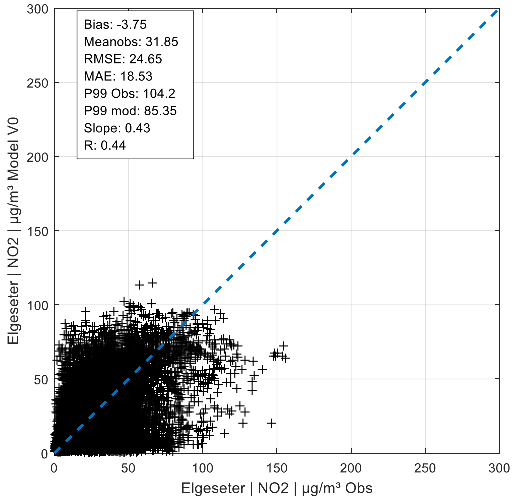


Figure A 194: Hourly values NO_2 in Elgeseter, V0

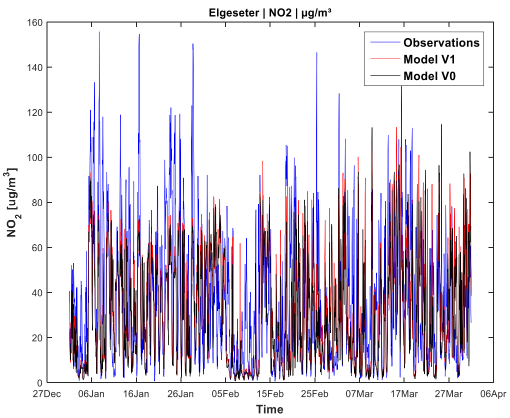


Figure A 195: Timesheet NO_2 in Elgeseter

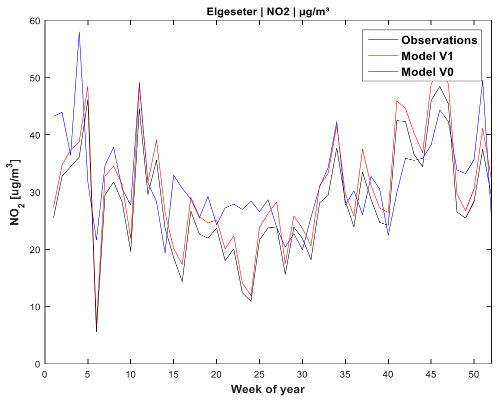


Figure A 196: Week of year NO_2 in Elgeseter

Trondheim, Bakke kirke

PM_{10}

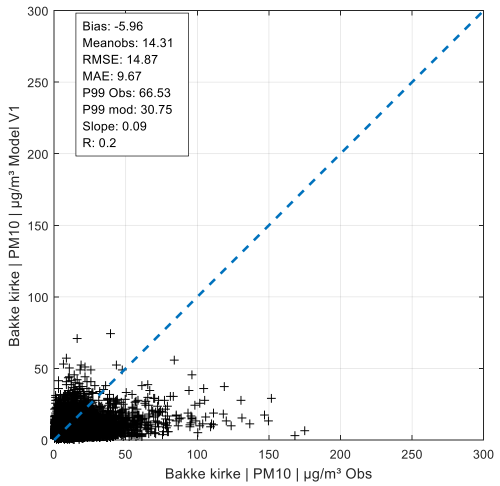


Figure A 197: Hourly values PM_{10} in Bakke kirke, V1

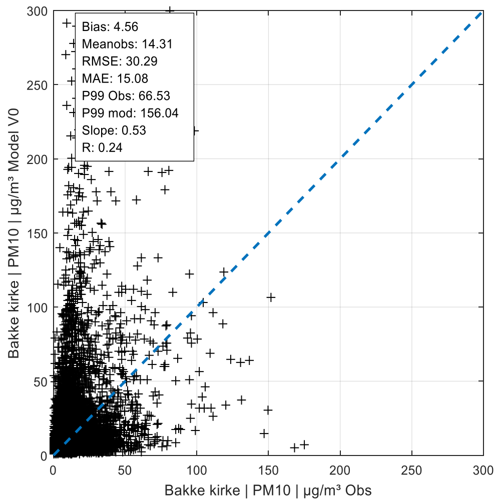


Figure A 198: Hourly values PM_{10} in Bakke kirke, V0

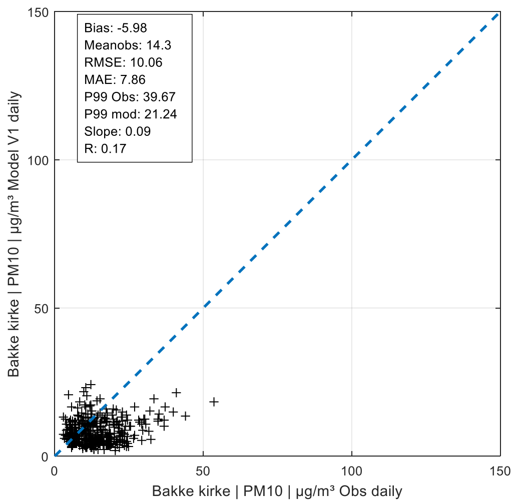


Figure A 199: Daily values PM_{10} in Bakke kirke, V1

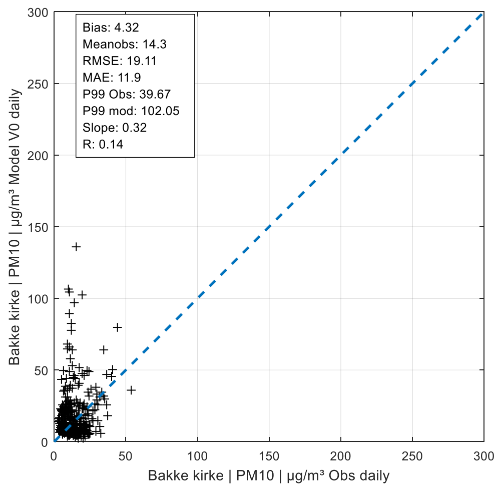


Figure A 200: Daily values PM_{10} in Bakke kirke, V0

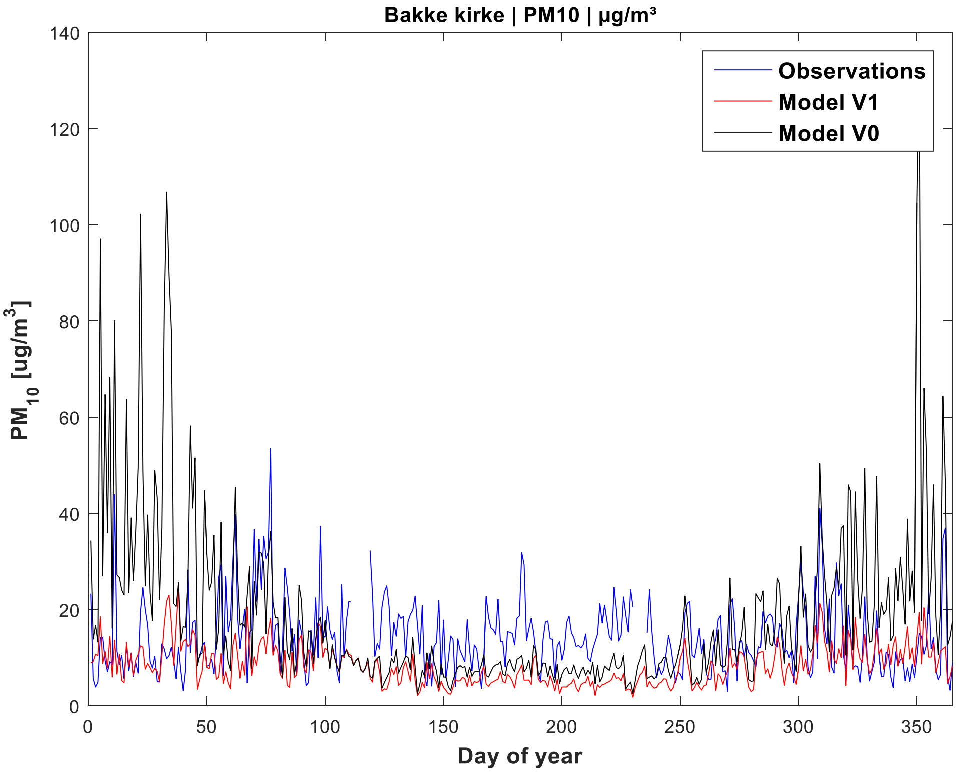


Figure A 201: Day of year PM$_{10}$ in Bakke kirke

Trondheim, Elgeseter

PM_{10}

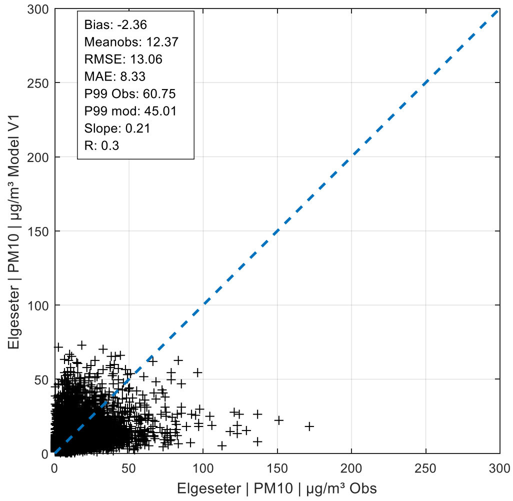


Figure A 202: Yearly value PM_{10} in Elgeseter, V1

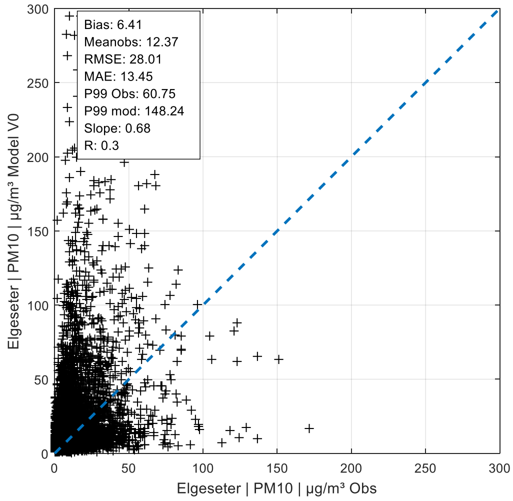


Figure A 203: Yearly value PM_{10} in Elgeseter, V0

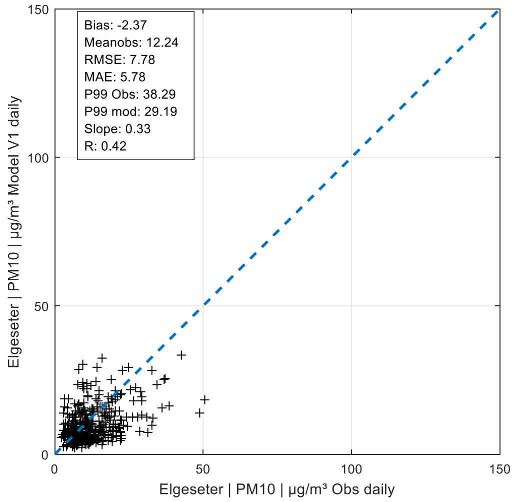


Figure A 204:Daily value PM_{10} in Elgeseter, V1

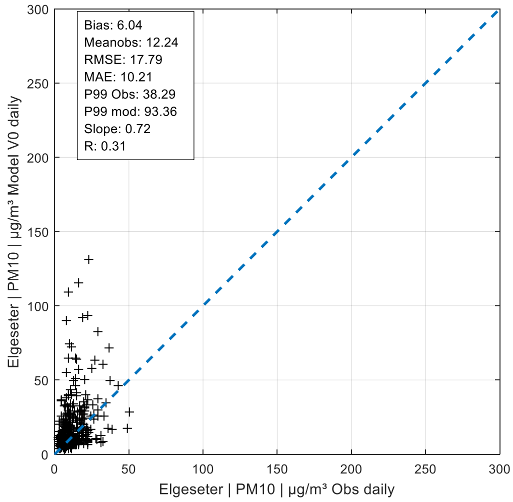


Figure A 205: Daily value PM_{10} in Elgeseter, V0

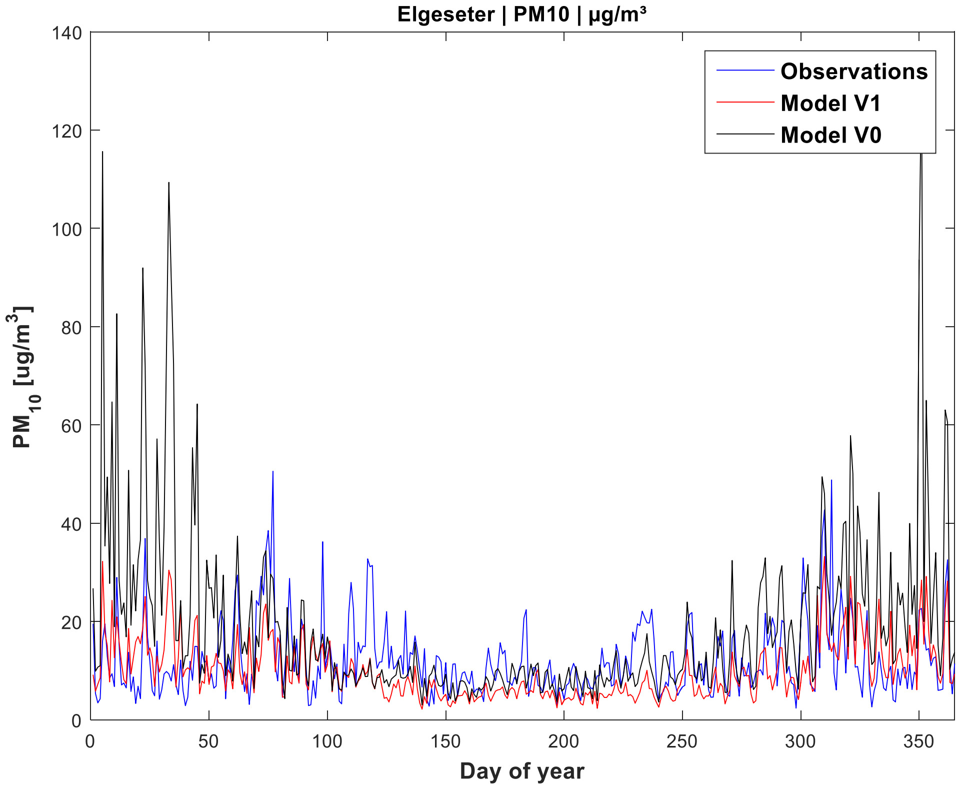


Figure A 206: Day of year PM_{10} in Elgeseter

Trondheim, Bakke kirke

$PM_{2.5}$

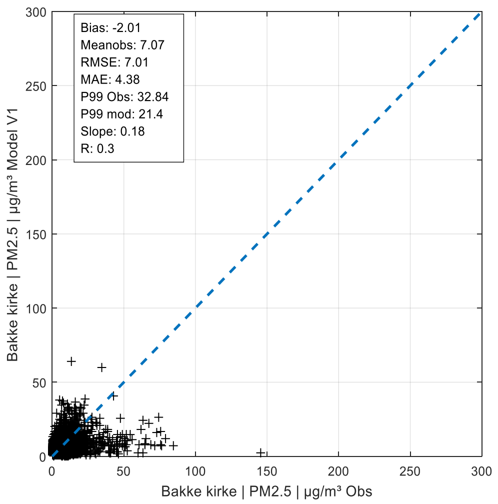


Figure A 207: Hourly values $PM_{2.5}$ Bakke kirke, V1

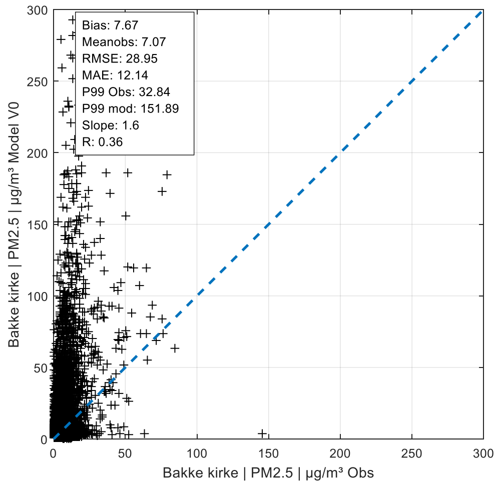


Figure A 208: Hourly values $PM_{2.5}$ Bakke kirke, V0

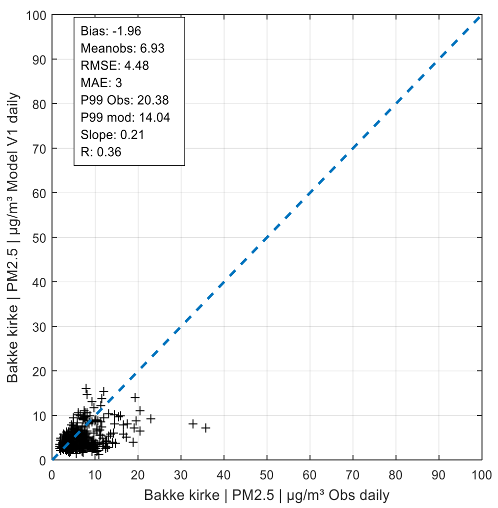


Figure A 209: Daily value $PM_{2.5}$ Bakke kirke, V1

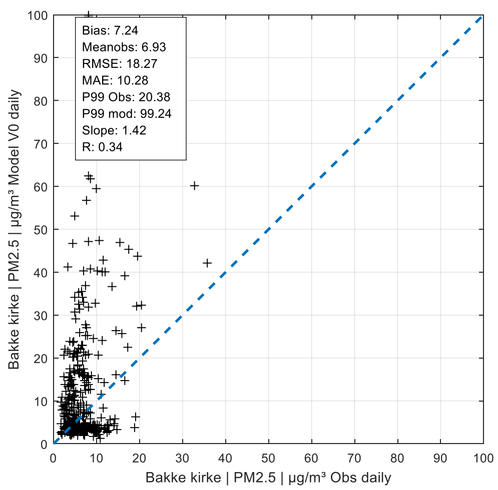


Figure A 210: Daily value $PM_{2.5}$ Bakke kirke, V0

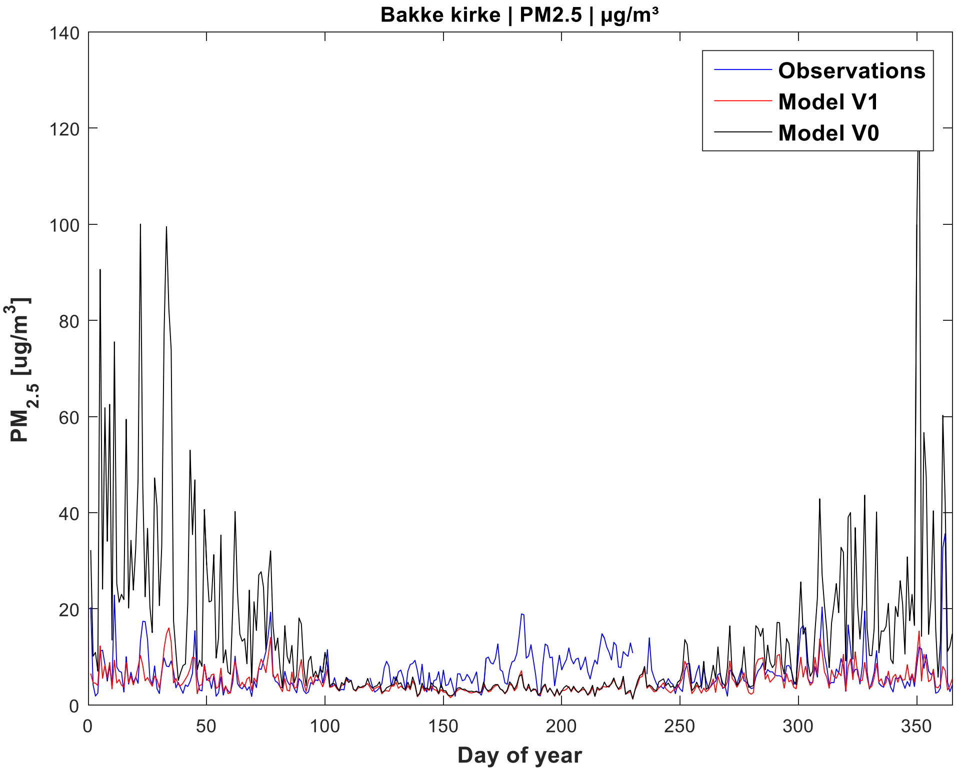


Figure A 211: Day of year $PM_{2.5}$ Bakke kirke

Trondheim, Elgeseter

PM2.5

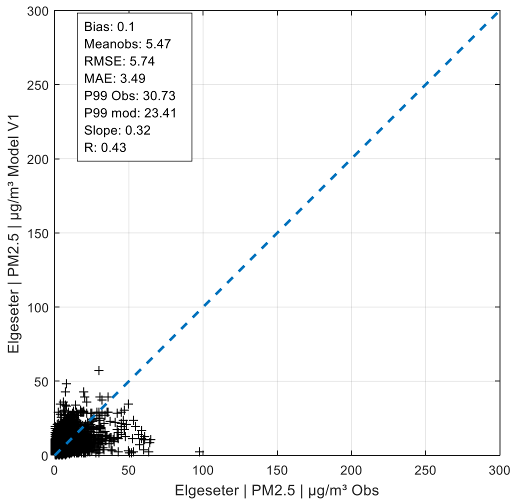


Figure A 212: Hourly values PM$_{2.5}$ in Elgeseter, V1

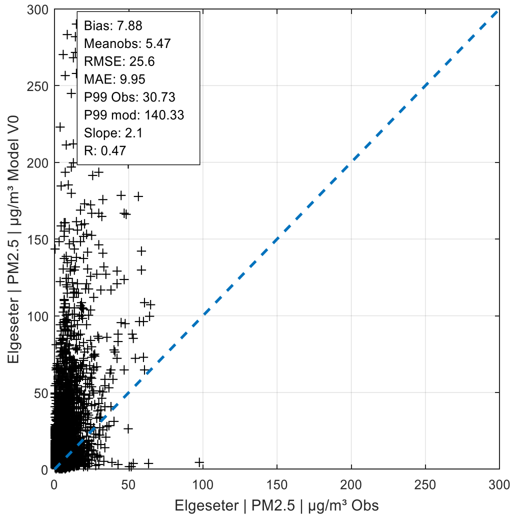


Figure A 213: Hourly values PM$_{2.5}$ in Elgeseter, V0

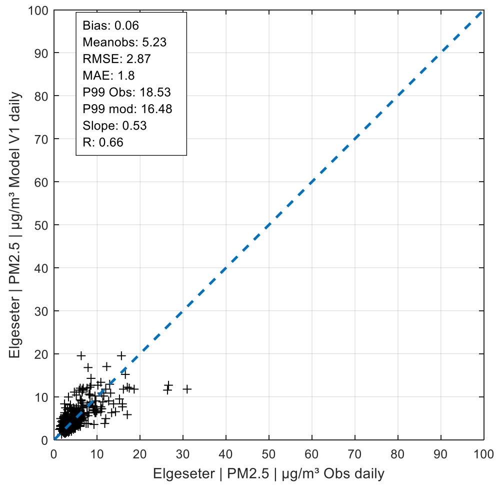


Figure A 214: Daily values PM$_{2.5}$ in Elgeseter, V1

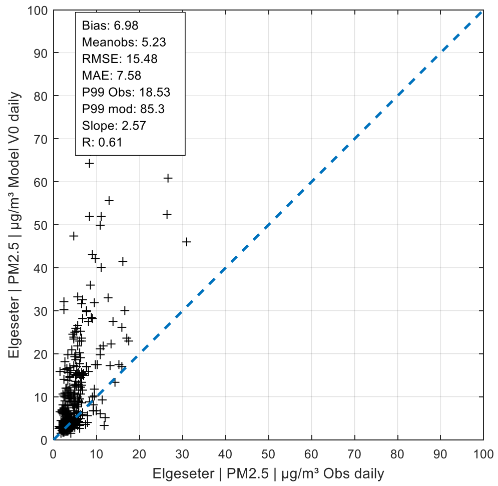


Figure A 215: Daily values PM$_{2.5}$ in Elgeseter, V0

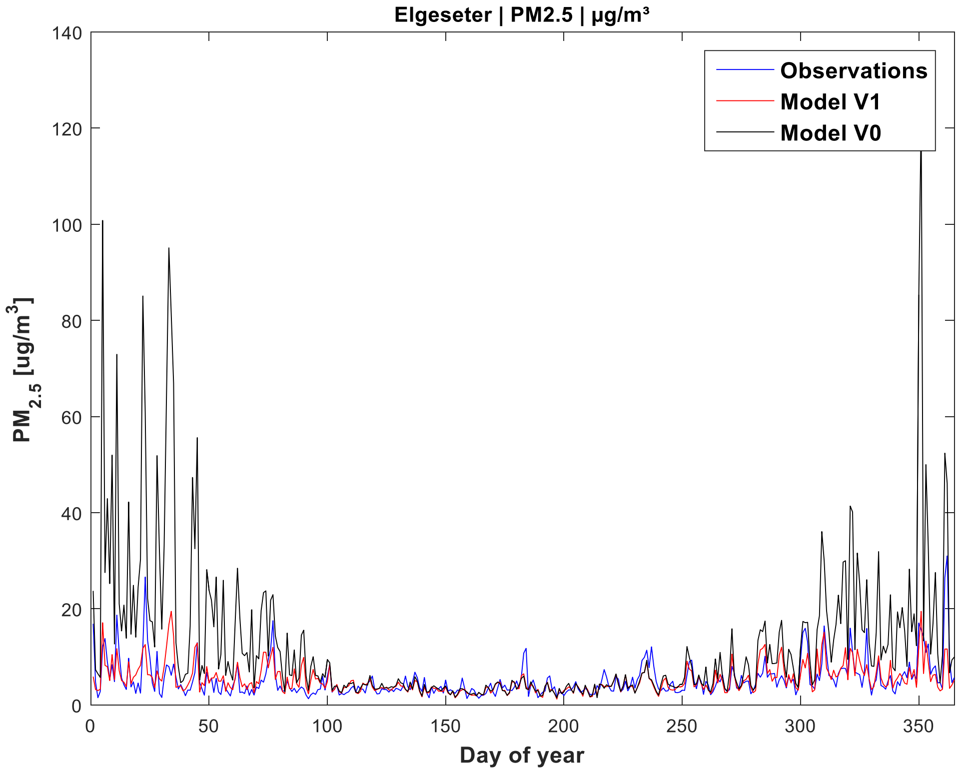


Figure A 216: Day of year $PM_{2.5}$ in Elgeseter

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