

Open-source LOTOS-EUROS v3.1.7 Validation Report

v3.0.2 versus v3.1.7

TNO 2026 R10685 – 26 March 2026

Open-source LOTOS-EUROS v3.1.7 Validation Report

v3.0.2 versus v3.1.7

Author(s)	H. J. Jonas and A. J. Segers and R. Kranenburg and L. Geers and A. M. M. Manders-Groot
Classification report	TNO Public
Number of pages	95 (excl. front and back cover)
Number of appendices	0
DOI	https://dx.doi.org/10.82135/z38x-cn84 .

All rights reserved

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

©2026 TNO

Contents

Contents	3
1 Changes	5
1.1 Functional Changes	5
1.2 Technical Changes	5
1.3 Bugfixes	6
2 Introduction.....	7
2.1 Updated free path length	8
2.2 Updated interpolation of wind vectors	8
2.3 Road dust resuspension emission factor	9
3 Method	11
3.1 Simulation Details.....	11
3.2 Measurement Evaluation	11
4 Results.....	13
4.1 Impact updated interpolation wind vectors	13
4.2 Impact v3.0.2 versus v3.1.7	16
4.3 Gas Species.....	17
4.3.1 Ozone.....	17
4.3.2 Nitrogen Dioxide.....	30
4.3.3 Nitrogen Monoxide.....	36
4.3.4 Ammonia.....	40
4.3.5 Sulphur Dioxide	44
4.4 Particulate Matter Species	49
4.4.1 PM2.5	49
4.4.1.1 Total PM2.5	49
4.4.1.2 Nitrate (PM2.5)	57
4.4.1.3 Ammonium (PM2.5).....	61
4.4.1.4 Sulphate Corrected (PM2.5).....	66
4.4.2 PM10	71
4.4.2.1 Total PM10	71
4.4.2.2 Sodium (PM10)	79
4.4.2.3 Organic Carbon (PM10)	82
4.4.2.4 Elementary Carbon (PM10)	84
4.4.2.5 Mineral Dust (PM10)	86
4.5 Budgets	87
4.5.1 NHx.....	87
4.5.1.1 NHx Dry.....	87
4.5.1.2 NHx Wet.....	88
4.5.2 NOy	89
4.5.2.1 NOy Dry.....	89
4.5.2.2 NOy Wet.....	90
4.5.3 SOx	91
4.5.3.1 SOx Dry.....	91
4.5.3.2 SOx Wet	92

5 Conclusions.....93

References.....94

Signature 95

1 Changes

1.1 Functional Changes

The functional changes are the updates that influence the model results. The functional changes are:

- › Updated computation of free path length for sedimentation (discussed in Section 2.1).
- › Support radon tracer.
- › Define land use and other maps per region.
- › Support for worldwide runs
- › Support EDGAR/v8.1 emissions, CAMS-GLOB-TEMPO/v5.1 time profiles, and TNO Emission Atlas v0.5.
- › Corrected interpolation of wind vectors from input meteo to model grid (discussed in Section 2.2).
- › Removal of the SO₂ to sulphuric acid reaction (R51) in CB7 as it was acting as a double SO₂ conversion in addition to R52.

1.2 Technical Changes

The technical changes are mainly to speed-up the code, remove deprecated modules, and improving user-friendliness.

The technical changes are:

- › Resubmit script in run directory.
- › Restructured output settings.
- › Option to write output to temporary runtime directory and pack while moving to output directory.
- › Harmonized consistency checks on emission tables.
- › Removed deprecated modules, a.o. the Dims module.
- › Included OpenMP in advection.
- › Restructured configuration of regions and run type (default, bound, zoom). The keys *my.domain* and *my.grid* are replaced by *my.region*.
- › Updated boundary condition settings to use the 'cifs2' files from 2018 onwards. The "cifs2" files collect from operational "0001" and "0079" IFS runs are supposed to include all tracers relevant for the troposphere. See *base/rc/lotos-euros-bound-cams-rea-nrt.rc* for more info.

1.3 Bugfixes

The bugfixes are:

- › The road dust resuspension routine applied a gravimetric soil water correction factor multiple times (discussed in Section 2.3).
- › Updated configuration for CBM7 chemistry for zoom runs and labelling. Not all CBM7 species were automatically selected to output.
- › Fix stripes of empty emissions when using coarser grained emissions on very high resolution grid and large number of parallel subdomains (*par.ndom*).

2 Introduction

This LOTOS-EUROS open-source v3.1.7 release is meant to make worldwide simulation available again after the release of the Three-Tiered Land-Use Approach in LOTOS-EUROS v3.0. This new version comes with (worldwide) land-use maps supported by the Three-Tiered Land-Use Approach and can be run with emissions from EDGAR/v8.1 emissions, CAMS-GLOB-TEMPO/v5.1 time profiles, and TNO Emission Atlas v0.5.

Included with these land use map, the deposition parameter file (*deposition-parameters_LOTOS_v3.1.7.nc*) is extended with two forest classes:

- › fbd_aln: Broadleaf deciduous forest – Alder (*Alnus* spp.)
- › fbe_qcs: Broadleaf evergreen forest – Oak (*Quercus* spp.)

which are copies of the fbe_aln and fbe_qcs landuse-vegetation classes but with the LAI (Leaf Area Index) of the default deciduous and evergreen forest classes fbd_def and fce_def, respectively.

This validation report focusses on the European domain. Therefore, the impact of using these new maps is not discussed here. Instead, the impact in this report is due to the updated computation of free path length for sedimentation, updated interpolation of wind vectors from input meteo, and the road dust resuspension routine bugfix. Other updates that may lead to changes in model results such as the removal of the SO₂ to sulphuric acid reaction (R51) in CB7 and the bugfix of stripes of empty emissions are not evaluated. The former only impact the model when using CB7 which is not used in default settings (validation report on impact available upon request); the latter was only visible when using e.g. the CAMS-REG emissions on the NL-2×2 grid and *par.ndom*>60 which is not a common or default setting.

The previously published user guide and the reference guide of LOTOS-EUROS v3.0.0 can be found in Ref. [1] and [2], respectively. In addition, on the Gitlab page of LOTOS-EUROS open-source, the user guide can also be found.

This report is organized as follows. First, the three updates are explained in Section 2.1 to 2.3. In the method Section 3, the simulation details and the comparison to the EEA and EBAS observation data is explained. The Result Section 4 is divided in two parts: the impact of the wind vector interpolation update, and the impact of all updates together. We end with concluding remarks in Section 5.

Conclusions and Recommendation:

- › The wind vector interpolation update has the largest impact showing a checkerboard pattern of maximal $\pm 1\%$ concentration change in areas with varying wind speed such as mountainous regions.
- › The updated free path length definition shows a maximal impact of 0.2-0.4% concentration increase of PM2.5 species.
- › The road resuspension bugfix leads to increased emissions ($>0.5 \mu\text{g m}^{-3}$) in areas with much traffic such as cities.
- › The updates do not have a large impact ($<1\%$) on the simulation result and model performance.
- › We recommend a model update from version v3.0.2 to v3.1.7 as it gives improved functionality but not large impact.

2.1 Updated free path length

The free path length in air λ_{air} is a parameter used for the deposition of aerosols. It was previously defined as

$$\lambda_{\text{air,old}} = 2.332 \cdot 10^{-5} \frac{T_{\text{surf}}}{P_{\text{surf}}} \quad (2.1)$$

where T_{surf} is the surface temperature, and P_{surf} the surface pressure. This simplistic version of λ was suitable for simulating with limited number of vertical layers in the past.

However, this more simplistic calculation of λ turned out to give values that were 25 to 28% lower than the actual formula (see Seinfeld and Pandis Eq (8.6) at p 455 in Ref. [3]):

$$\lambda_{\text{air}} = \frac{2\eta}{P\sqrt{8RTx_{\text{m,air}}/\pi}} \quad (2.2)$$

where η is the viscosity, T the temperature, P the pressure, $x_{\text{m,air}}$ the air mass, and R the gas constant. With the viscosity given in Eq.2.3:

$$\eta = 1.496 \cdot 10^{-6} \frac{T^{1.5}}{T + 120.0} \quad (2.3)$$

2.2 Updated interpolation of wind vectors

In a simulation on very high resolution "patch" pattern was seen in the computed concentrations. This was especially visible in higher layers, but also visible below (see Figure 2.1). It could be traced back to a problem in the interpolation of wind vectors from the original ECMWF meteo to the model grid cells.

Issues:

- › The region definition contains a setting whether input meteorology should be averaged over a model grid cell (if meteo is on higher resolution), or interpolated (if meteo is on coarser resolution). This was however not used when computing the wind vector in the center of the grid cell.

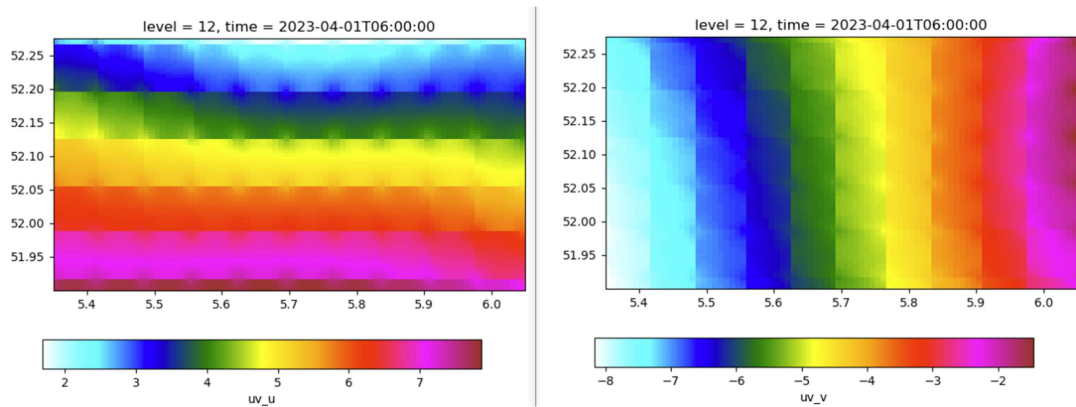


Figure 2.1: Example of u- and v-wind speed in the high-resolution simulation before the wind vector interpolation update. A *patchy* pattern is observed.

- › The interpolation routine uses a common grid for the u and v part of the input meteo. This was defined using 2D arrays of corners, similar as used for WRF meteo. However, this does not seem to work correctly when ECMWF meteo is used where latitudes are ordered north-to-south.

The changes will have impact on the computed mass fluxes, and therefore on the advection of all species. Note that a patch pattern in the vertical mass flux cannot be avoided when running at a (much) higher resolution than the meteo input (see Figure 2.2). A note on this has been added to the chapter on Horizontal grid in the User Guide.

2.3 Road dust resuspension emission factor

For the calculation of the road dust resuspension, the gravimetric soil-water content is rescaled by the fraction of water-containing land use classes in the gridcell and is used to determine the emission factor. This rescaling was applied multiple times leading to a lower emission factor for road dust resuspension in most areas. The bugfix thus leads to increased resuspension of road dust.

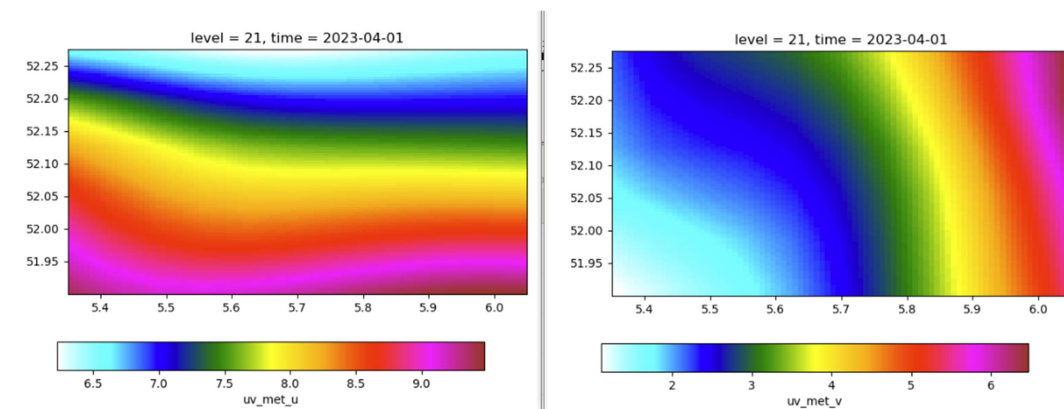


Figure 2.2: Example of u- and v-wind speed in the high-resolution simulation after the wind vector interpolation update. The observed pattern is much smoother.

3 Method

3.1 Simulation Details

The impact of the functional changes were tested by LOTOS-EUROS simulations over 2018 with a spin-up period of 10 days on the European (MACC) domain (W15-E35; N35-N70, 0.5x0.25 ° resolution). The emissions are CAMS-REG v8.1 emission, with biogenic emissions using tree-specific emission factors, soil-NO_x emissions, sea salt emissions, desert dust, road resuspension and agricultural dust emissions and GFAS wildfire emissions (from MACC) were used. Climatological boundaries from EMEP, Isaacson and Logan are used together with 3-hourly results from the CAMS-nrt product. This basically implies that for the most important tracers, the CAMS-nrt product is used. Additionally, time profiles from CAMS-TEMPO v5.1 are used. These profiles have a detailed profile specified per country and sector.

The reference run is the LOTOS-EUROS open-source version v3.0.2 and the test run is the LOTOS-EUROS open-source version v3.1.7.

3.2 Measurement Evaluation

The model results are compared to a subset of the EBAS¹ and EEA² measurement stations. The filtering is done on the following criteria:

- › For the gas species and total PM_{2.5} and PM₁₀, the measurement station has at least 75% of data coverage on the hourly or daily timescale.
- › For the other PM species such as nitrate and sulphate, the measurement station has at least 15% of data coverage on the daily timescale.
- › The measurement station has a maximum altitude of 700 m.

For the selected measurement stations, the root mean squared error (RMSE), the coefficient of determination (R^2), and the normalized mean bias (NMB) are listed for all species.

The RMSE (Eq. 3.1), R^2 (Eq. 3.2), and NMB (Eq. 3.3) are defined as:

$$RMSE = \sqrt{\frac{\sum_{i=0}^n (X_{sim,i} - X_{obs,i})^2}{n}} \quad (3.1)$$

$$R^2 = \left(\frac{Cov(X_{sim}, X_{obs})}{\sqrt{Var(X_{sim}) \cdot Var(X_{obs})}} \right)^2 \quad (3.2)$$

$$NMB = \frac{\sum_{i=0}^n (X_{sim,i} - X_{obs,i})}{\sum_{i=0}^n X_{obs,i}} \quad (3.3)$$

¹<https://ebas.nilu.no>

²<https://www.eea.europa.eu/en/datahub>

where the sum i to n runs over timestamps of the available experimentally observed data X_{obs} , and corresponding simulated data X_{sim} . The Var and Cov are the variance and covariance, respectively.

In addition, we show the diurnal cycle (only if applicable in case of hourly experimental observations), timeseries and scatter comparison of the simulated concentrations to the measurement stations listed in Table 3.1 with their locations shown in Figure 3.1. These measurement stations are chosen as they are spread over the European domain, not in elevated areas and are located areas which are not directly influenced by emissions. These stations are representative for a larger area compared to the resolution of the longitudinal and latitudinal resolution.

Table 3.1: Measurement stations' station code, name, country, longitude, latitude and altitude.

	Station Code	Name	Country	Lon [°E]	Lat [°N]	Altitude [m]
1	NL0644R	Cabauw Wielsekade	The Netherlands	4.92	51.97	1
2	SI0008R	Iskrba	Slovenia	14.87	45.57	520
3	ES0014R	Els Torms	Spain	0.72	41.40	470
4	SE0014R	Råö	Sweden	11.91	57.39	5
5	DE0002R	Waldhof	Germany	10.76	52.80	74
6	HR0011A	Kopacki Rit	Croatia	18.83	45.70	0

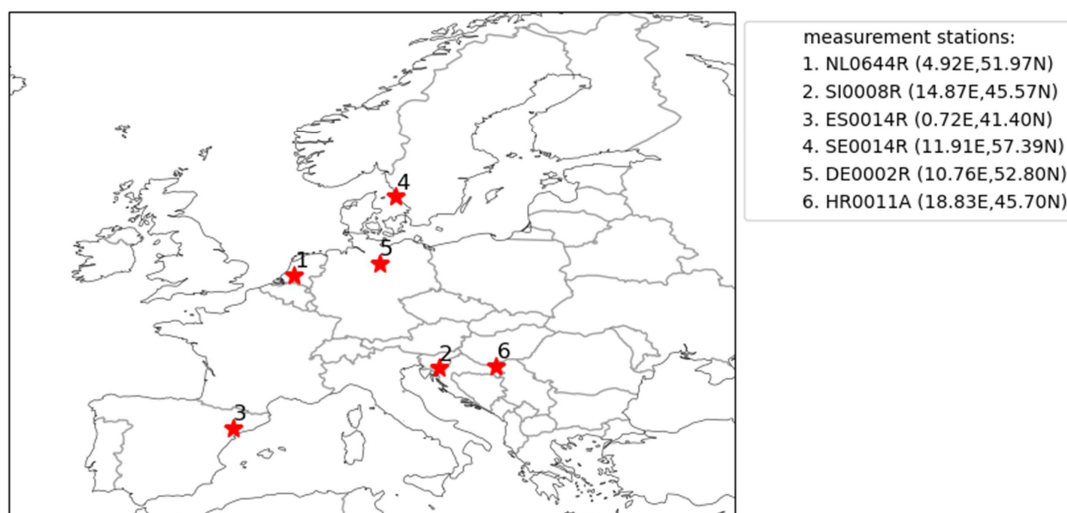


Figure 3.1: Locations of the measurement stations indicated by the red stars and numbered 1 to 6. The legend shows their coordinates.

4 Results

4.1 Impact updated interpolation wind vectors

Before the impact on between model version v3.0.2 and v3.1.7 is evaluated, we would like to showcase the impact of the updated interpolation of the wind vectors. The wind vectors define transport of all species in the model. Therefore, an effect is observed on all species of the model. Here, we present concentrations of ozone and organic carbon (PM_{2.5}) in Figure 4.2 and 4.1, and the NH_x wet deposition in Figure 4.3, respectively.

Specifically, in organic carbon – which is a non-reactive species – the impact of the wind vector interpolation update on the transport is observed. A checkerboard pattern of +1% and -1% in the relative difference is observed in the southern part of Europe, northern Africa and in Norway. For ozone, this effect is diminished as ozone is reactive. Still we observe a noisy pattern of $\pm 1\%$ in the Balkan, Turkey, Greece and the Alps. In the NH_x wet deposition, the checkerboard relative difference pattern are also suppressed and shows north-south lines patterns near Ireland and between The Netherlands and Norway.

Overall, the updated interpolation of the wind vectors does not result in large changes in transport patterns, and its impact on the simulated concentrations is small ($\pm 1\%$) and located in regions where the wind vector locally varies such as mountainous regions.

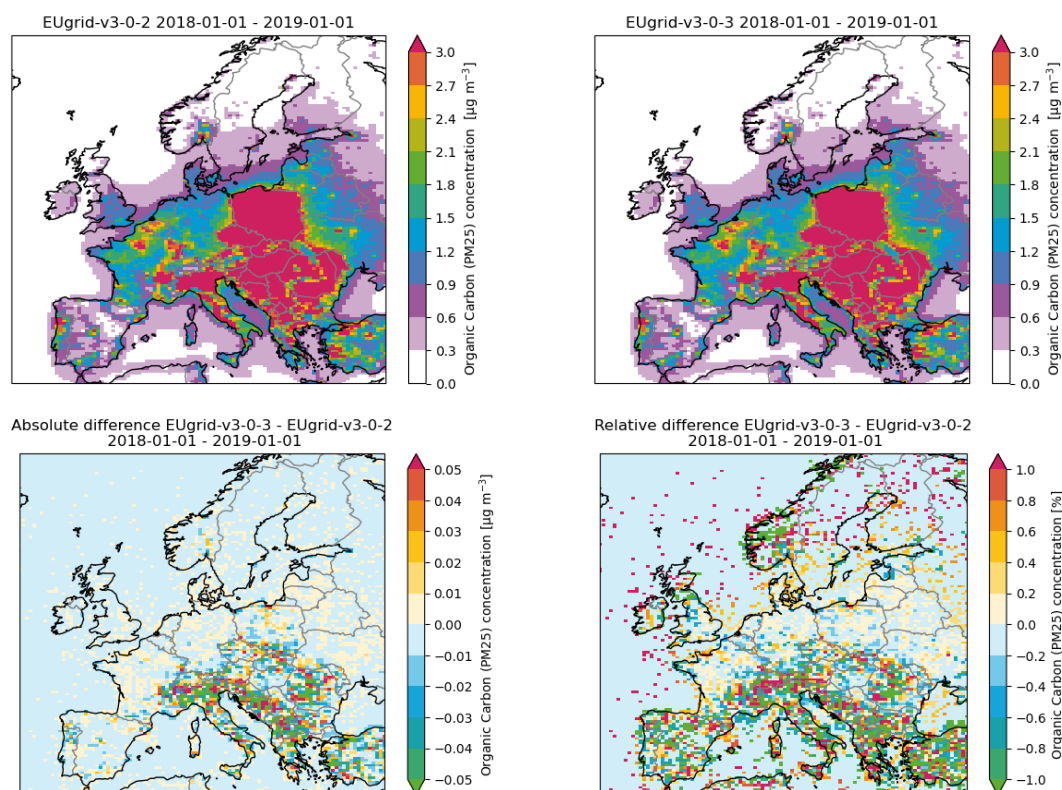


Figure 4.1: Wind vector interpolation update | Averaged concentration map comparison for Organic C (PM_{2.5}) from the interpolation update on the wind vectors.

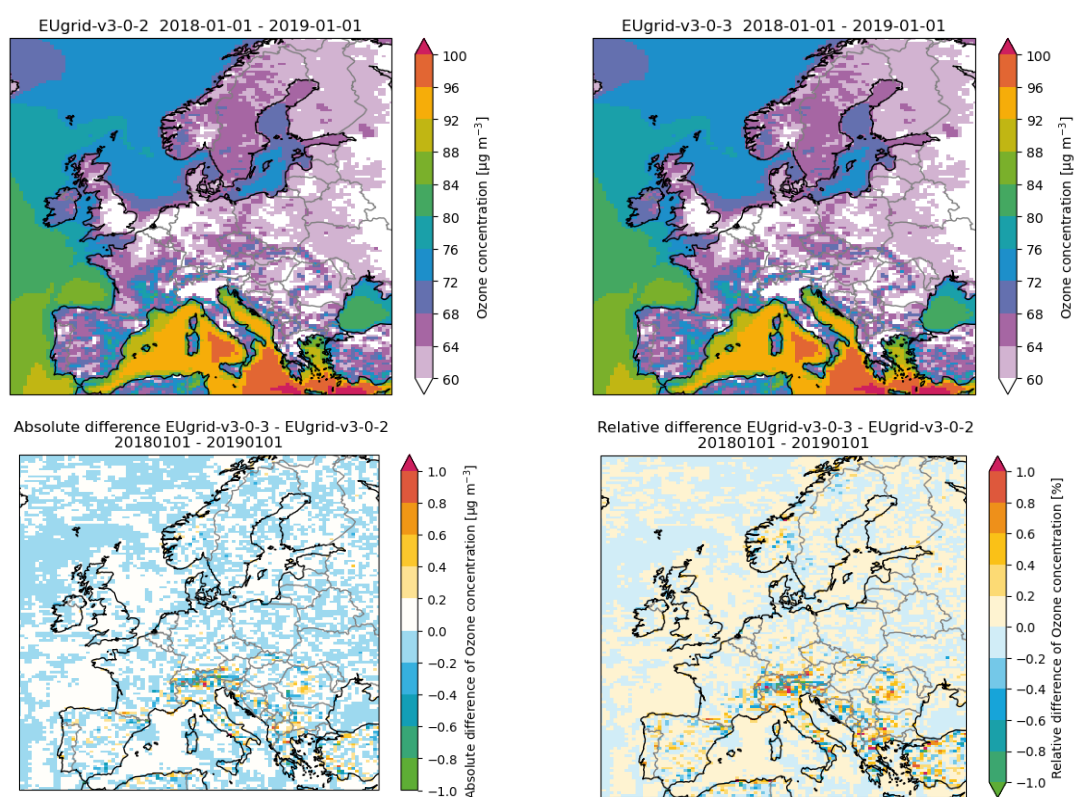


Figure 4.2: Wind vector interpolation update | Averaged concentration map comparison for O_3 from the interpolation update on the wind vectors.

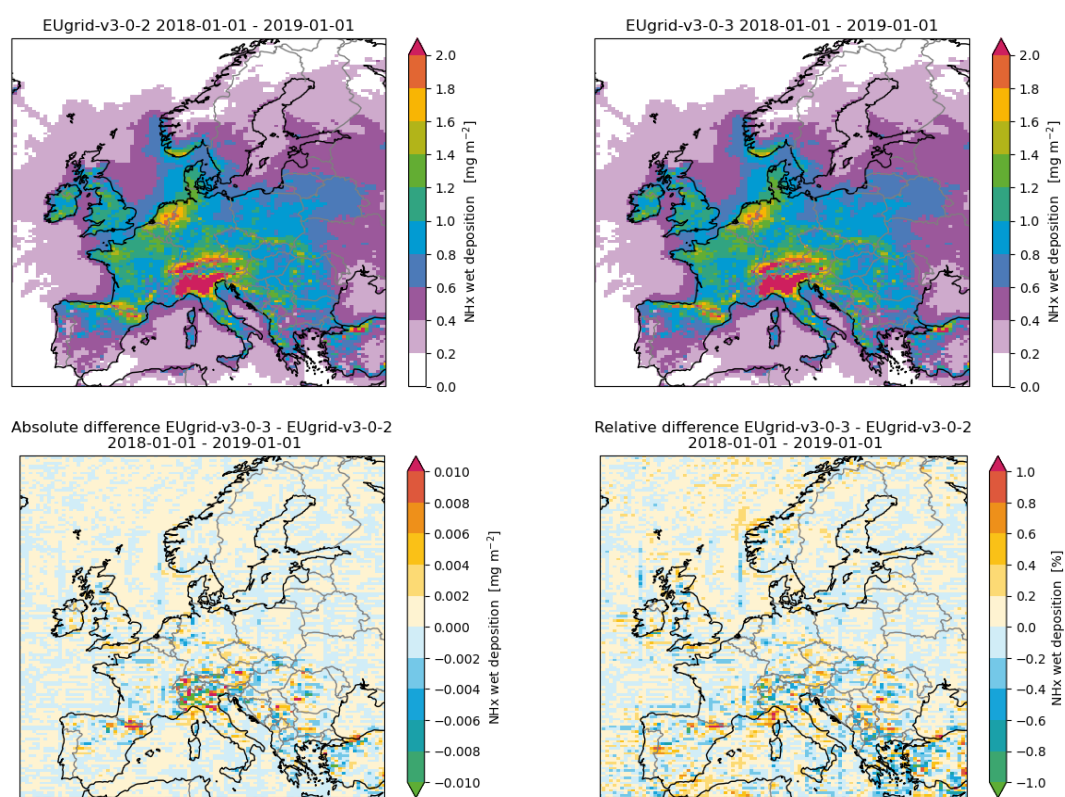


Figure 4.3: Wind vector interpolation update | Averaged concentration map comparison for NH_x wet deposition from the interpolation update on the wind vectors.

4.2 Impact v3.0.2 versus v3.1.7

Now we inspect the results of the impact from v3.0.2 versus v3.1.7 which includes both the update of the wind vector interpolation, the update of the free path length, and the bugfix of the road dust resuspension. The gas species are: ozone, nitrogen dioxide, nitrogen monoxide, ammonia, sulphur dioxide in Section 4.3.1 to 4.3.5. The particulate matter PM2.5 species are: total PM2.5, nitrate, ammonium, and sulphate in Section 4.4.1.1 to 4.4.1.4. The particulate matter PM10 species are: total PM10, sodium, organic carbon, elementary carbon, and mineral dust in Section 4.4.2.1 to 4.4.2.5. The wet and dry deposition of NH_x , NO_y and SO_x are shown in Section 4.5.1.1 to 4.5.3.2.

The biggest impact is assigned to the wind vector interpolation update. The difference patterns shown in Section 4.1 coincide with the patterns in the maps of the gas species, PM species, and budgets in Sections 4.3, 4.4, and 4.5, respectively. Namely, the checkerboard pattern of $\pm 1\%$ relative difference in mountainous areas for all species and the north-south lines patterns near Ireland and between The Netherlands and Norway in the wet deposition budgets.

The update in the definition of the free path length affects the deposition velocity of particles, mainly the smaller ones as they are mostly affected by Brownian motion. In the assessment of the impact of this specific update (not shown in this report), a deposition flux decrease of about 0.3% for fine inorganic aerosols and 0.1% for coarse inorganic aerosols was shown. Indeed, the particulate matter PM2.5 species in Section 4.4.1.1 to 4.4.1.4 show a small increase of concentration around 0.2-0.4% observed outside the regions that are impacted by the wind vector interpolation update such as on sea, Germany, Poland and The Netherlands.

Lastly, the impact of bugfix on the calculation of the road resuspension emission is shown by increase of mineral dust (PM10) in Section 4.4.2.5 and total PM10 in Section 4.4.2.1. The increased road dust emission is observed throughout Europe, with the largest impact in areas with much traffic such as cities. For example, in Paris and Madrid an increase of $>0.5 \mu\text{g m}^{-3}$ is observed.

All developments have little impact on the comparisons to the EBAS and EEA measurement stations listed in Table 4.1 to 4.12 and the figures of the six measurement stations shown for all available species. Most changes in RMSE, R^2 , and NMB are fractional (<0.01).

4.3 Gas Species

4.3.1 Ozone

Ozone concentrations are mainly impacted by the wind vector interpolation update.

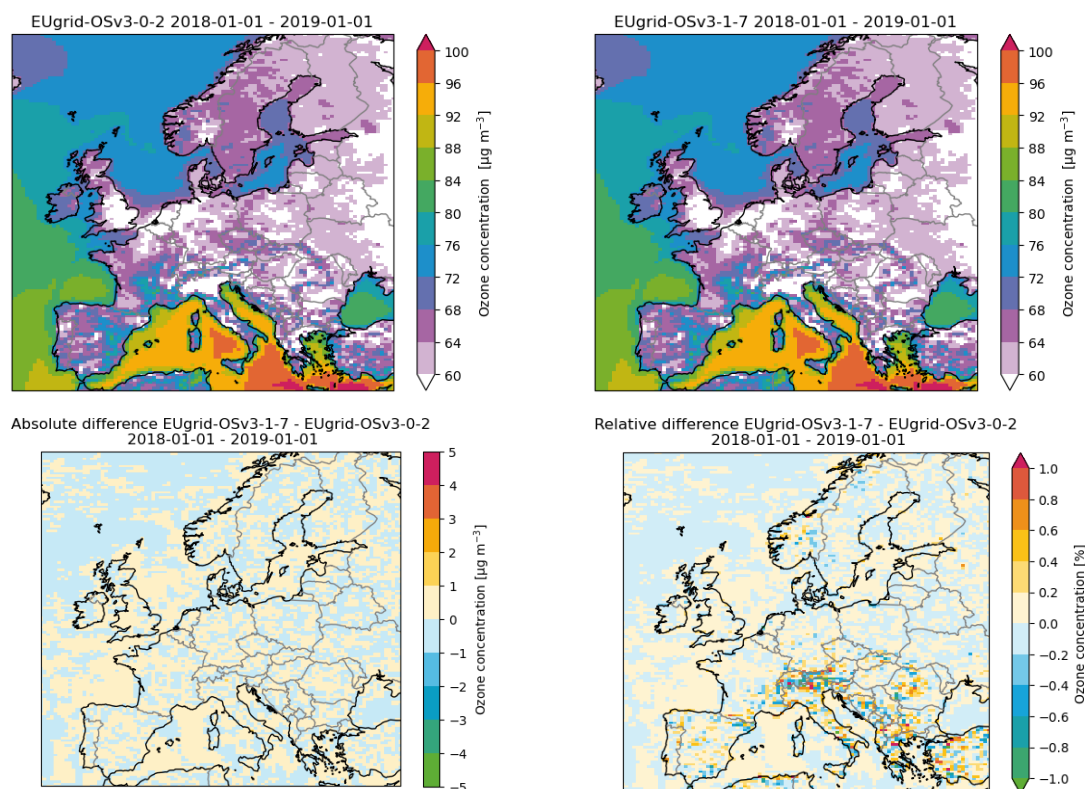


Figure 4.4: Averaged concentration map comparison for O₃

Measurement validation for O₃

Table 4.1: Statistics for O₃

O ₃		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EEA	1h	20.714	0.557	0.122	20.714	0.557	0.122	-0.0	-0.0	0.0
EBAS	1h	18.067	0.525	0.04	18.06	0.525	0.04	-0.006	-0.001	-0.0

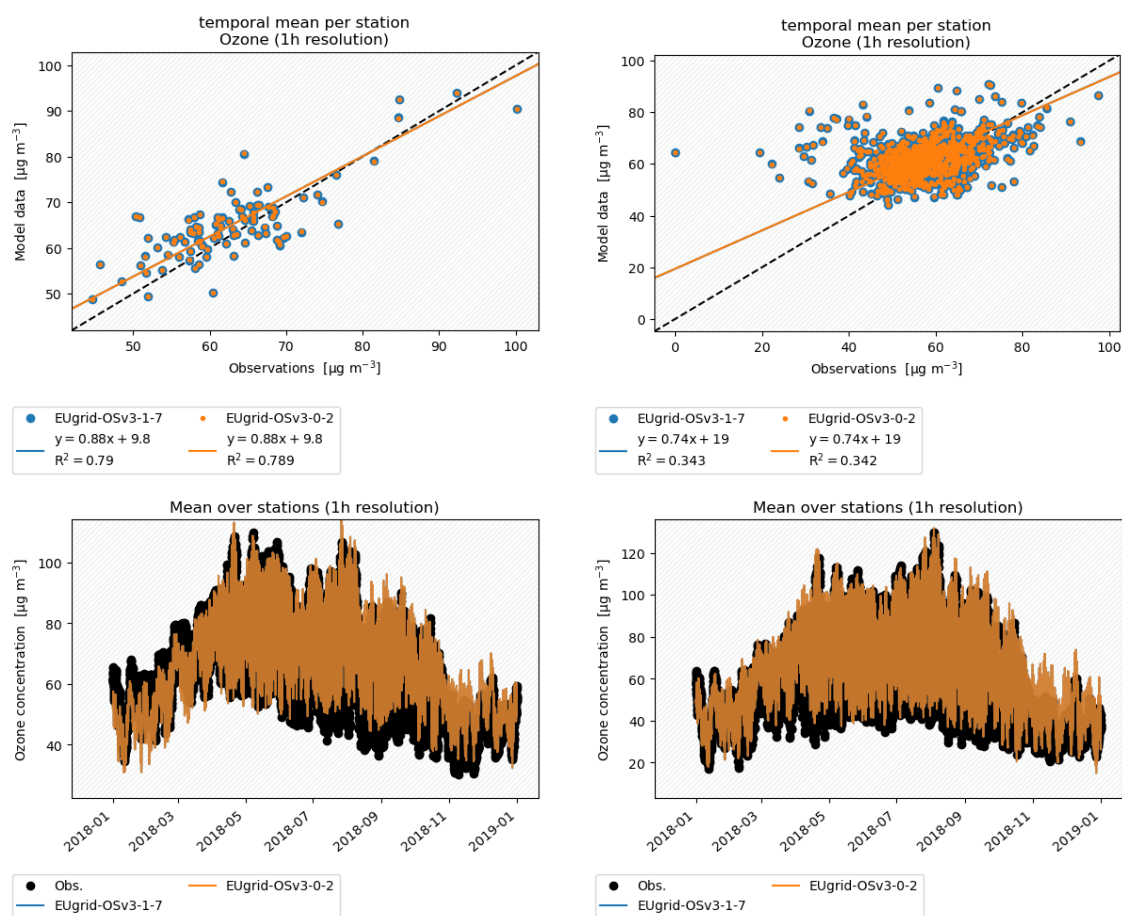


Figure 4.5: Station means – O₃ | EBAS (left), EEA (right), annual mean (top), spatial mean (bottom)

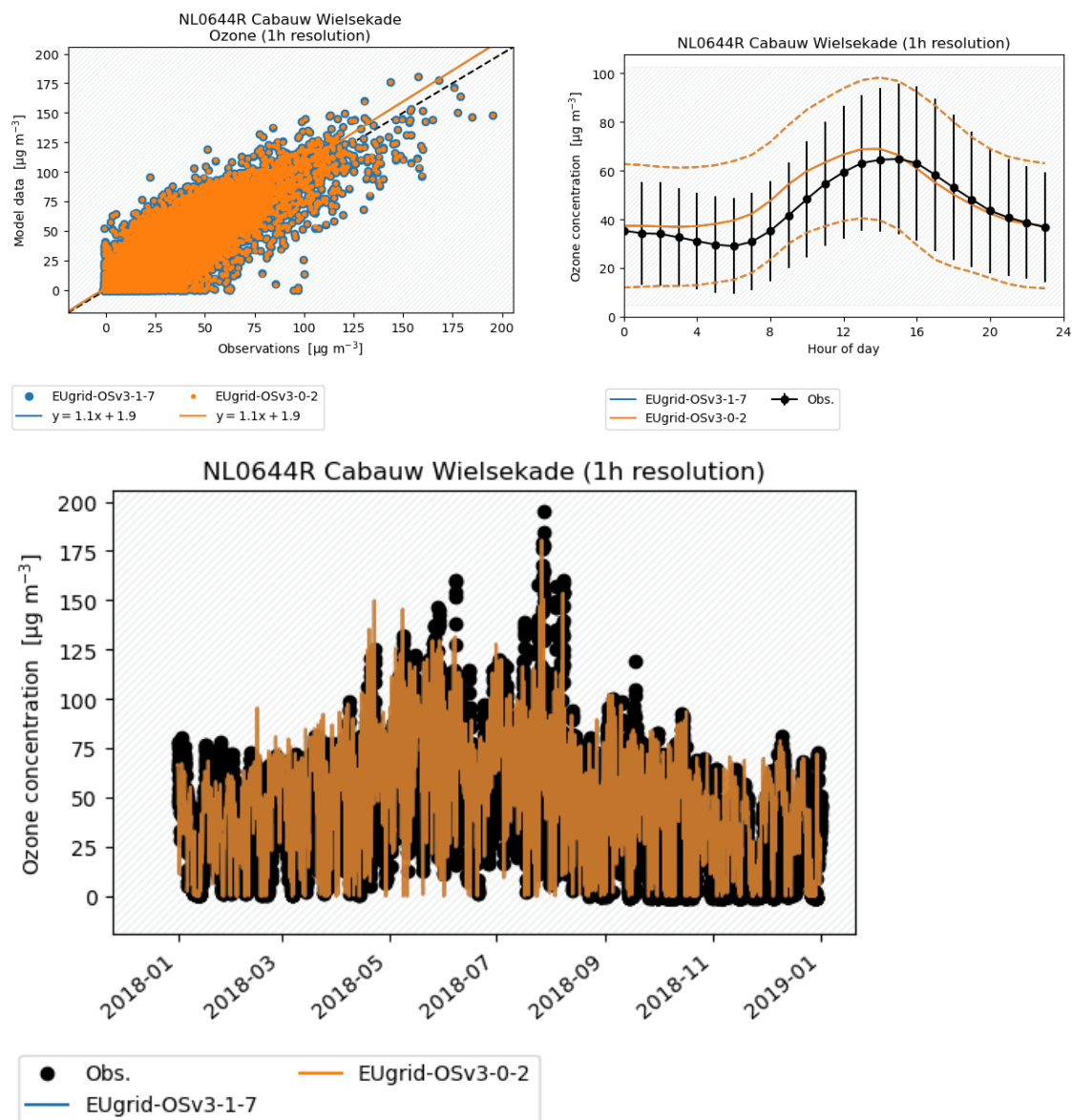


Figure 4.6: Station NL0644R (EBAS) – O_3

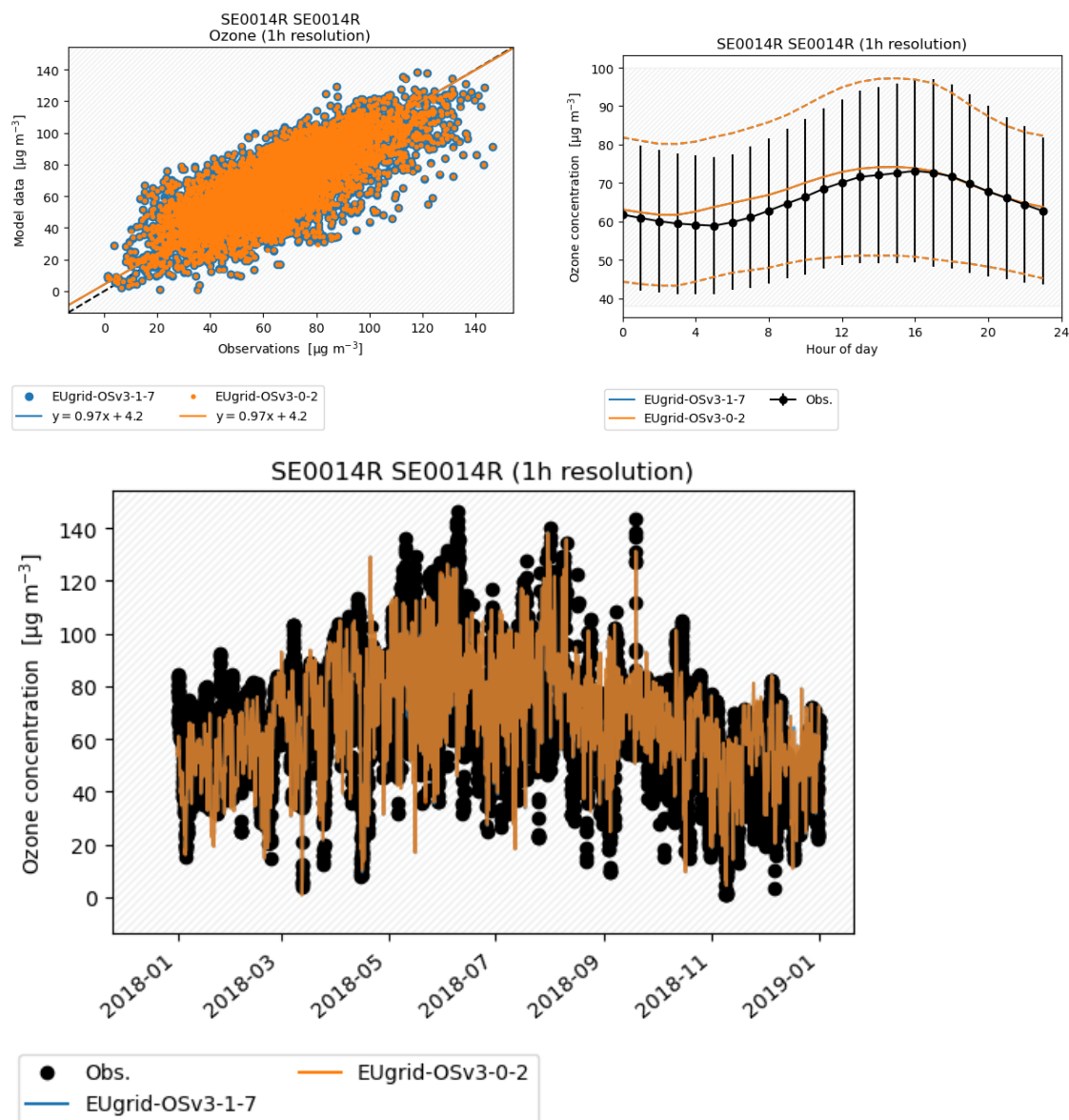


Figure 4.7: Station SE0014R (EBAS) – O_3

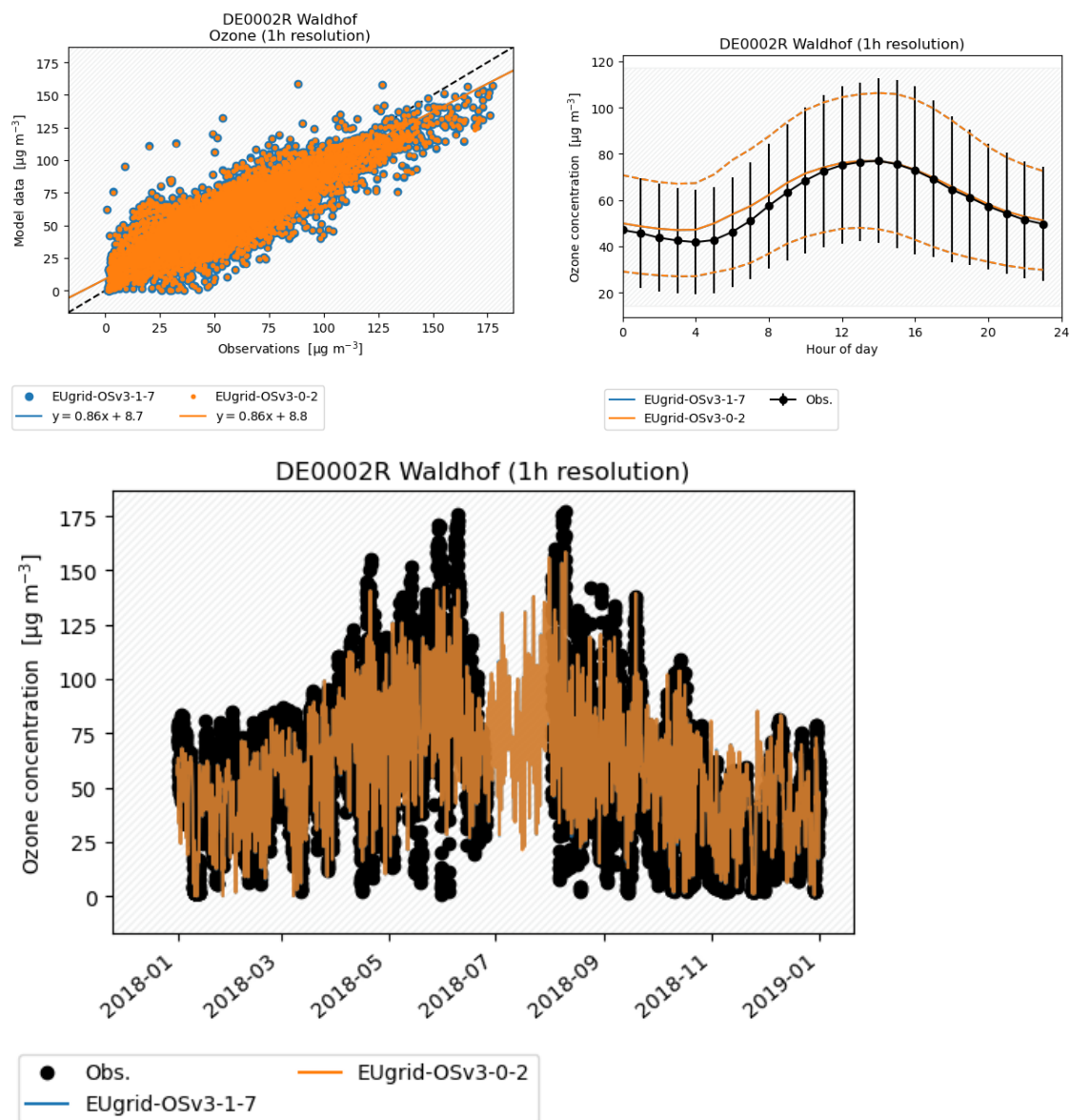


Figure 4.8: Station DE0002R (EBAS) – O_3

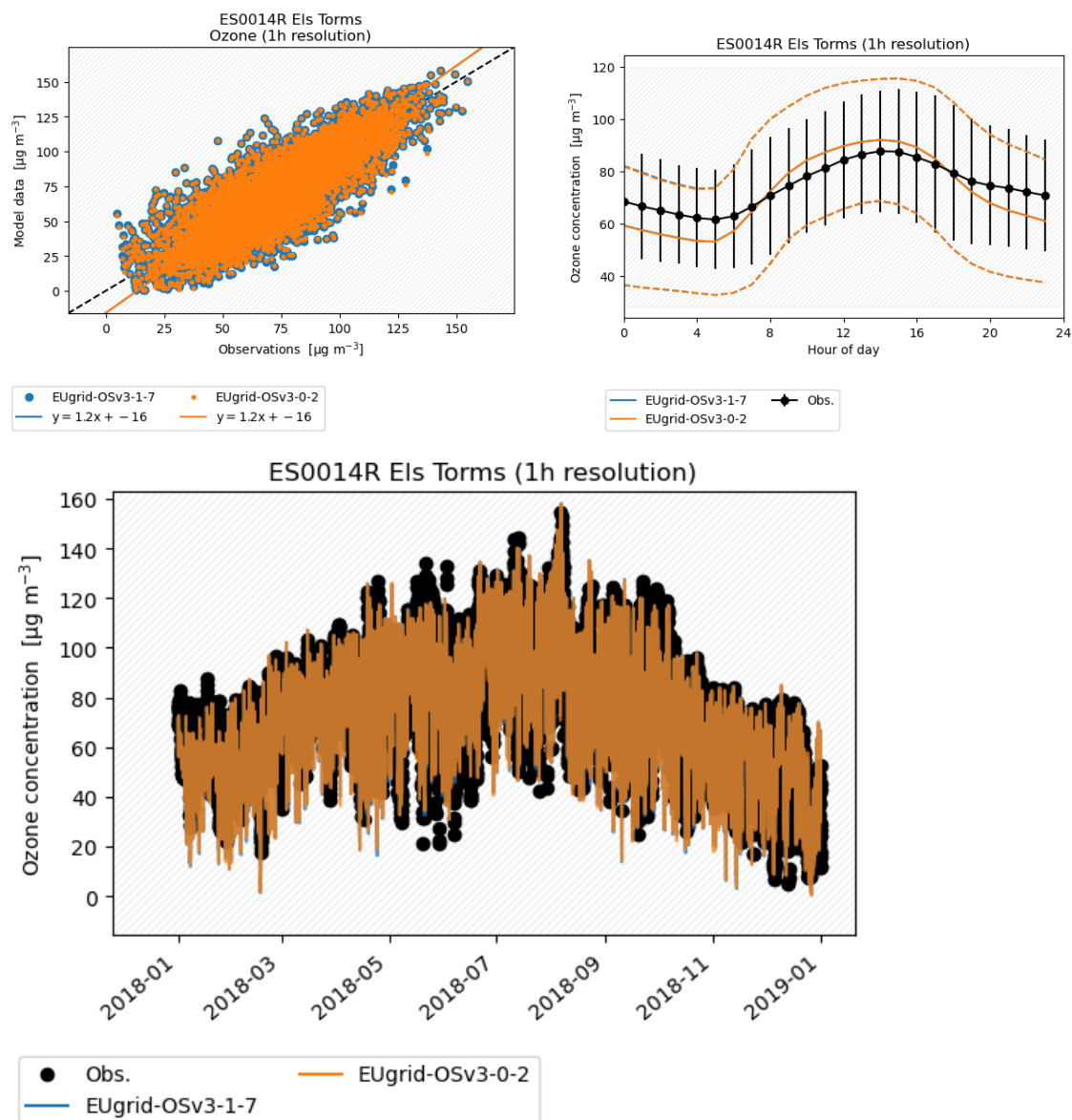


Figure 4.9: Station ES0014R (EBAS) – O_3

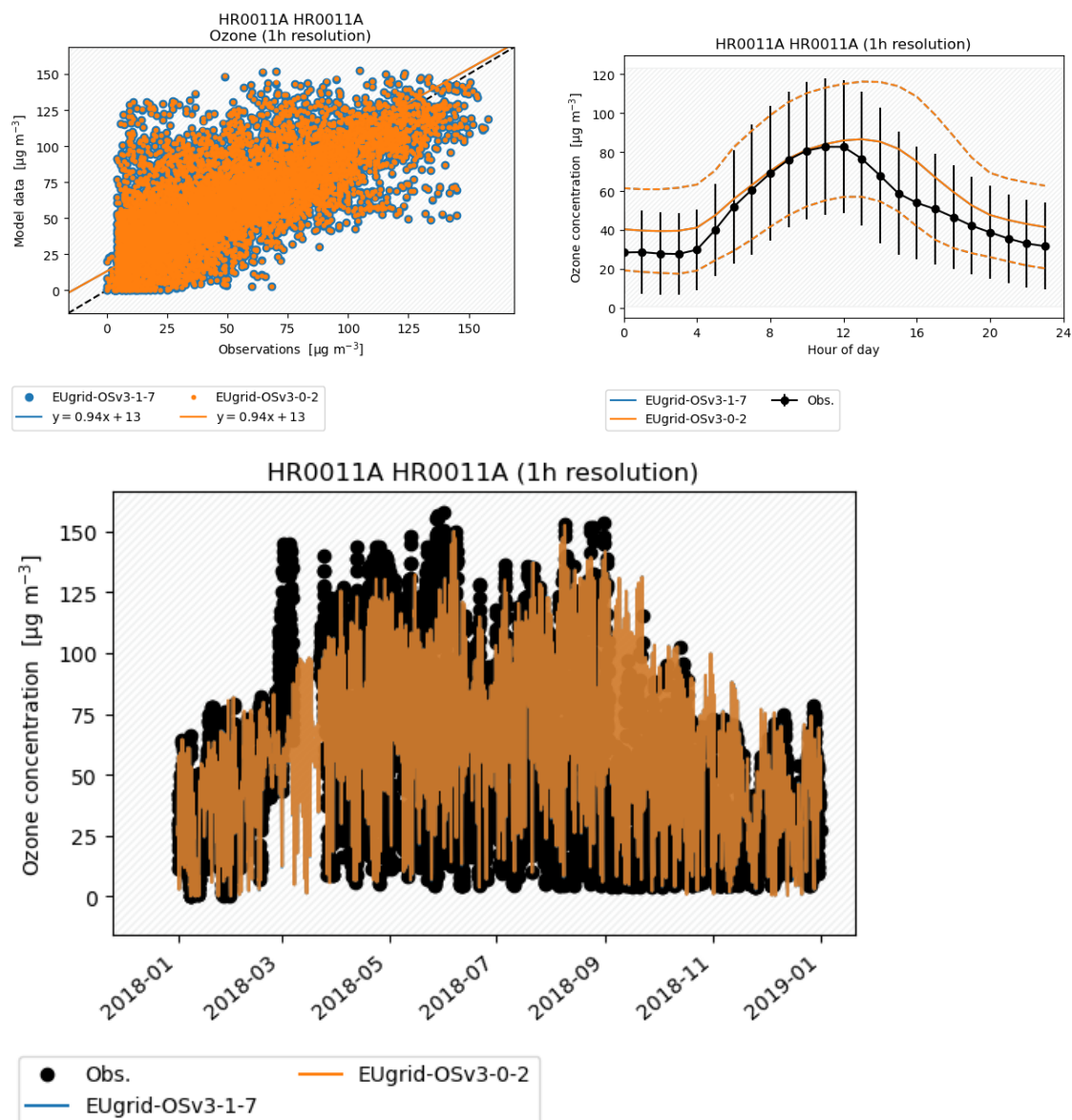


Figure 4.10: Station HR0011A (EEA) – O₃

Measurement validation for O₃ MDA8

Table 4.2: Statistics for O₃ MDA8

O ₃ MDA8		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EEA	1h	15.101	0.589	0.067	15.098	0.588	0.067	-0.003	-0.0	0.0
EBAS	1h	13.349	0.604	0.046	13.342	0.604	0.046	-0.007	0.0	0.0

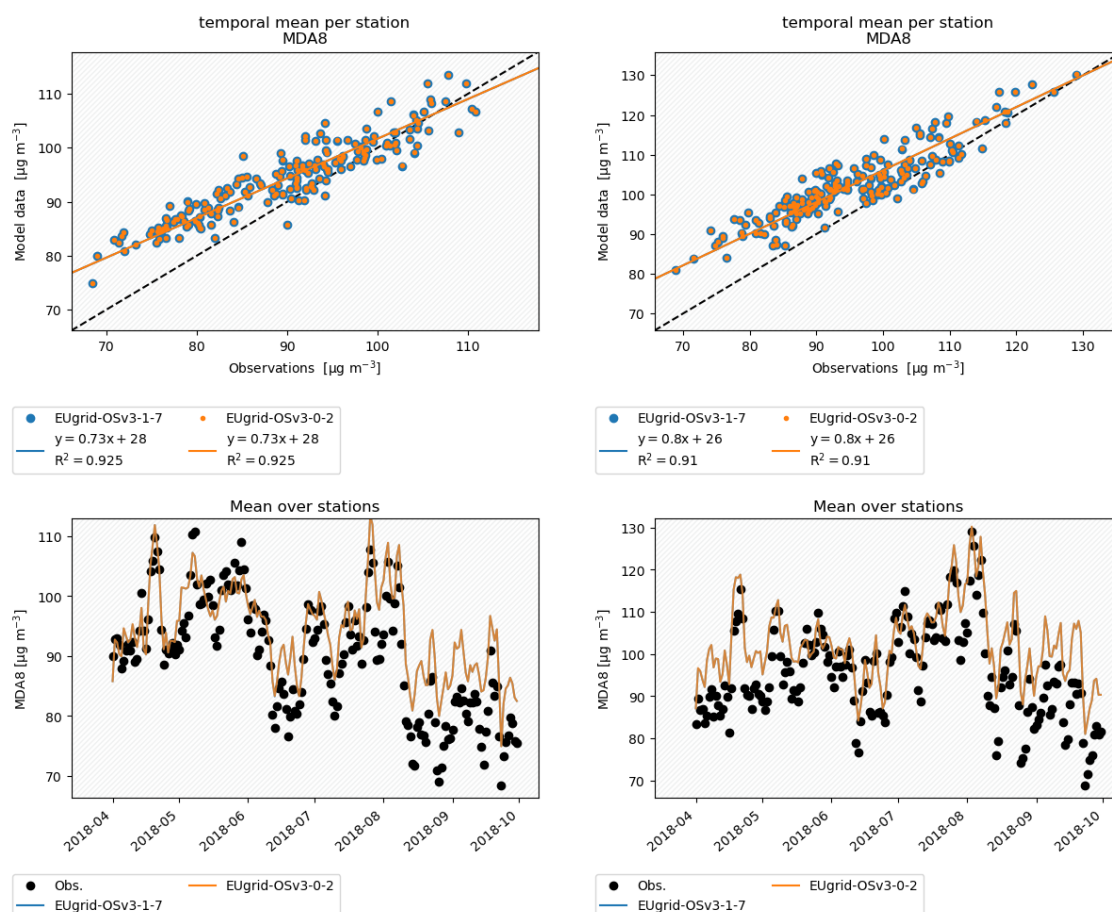


Figure 4.11: Station means – O₃ MDA8 | EBAS (left), EEA (right), annual mean (top), spatial mean (bottom)

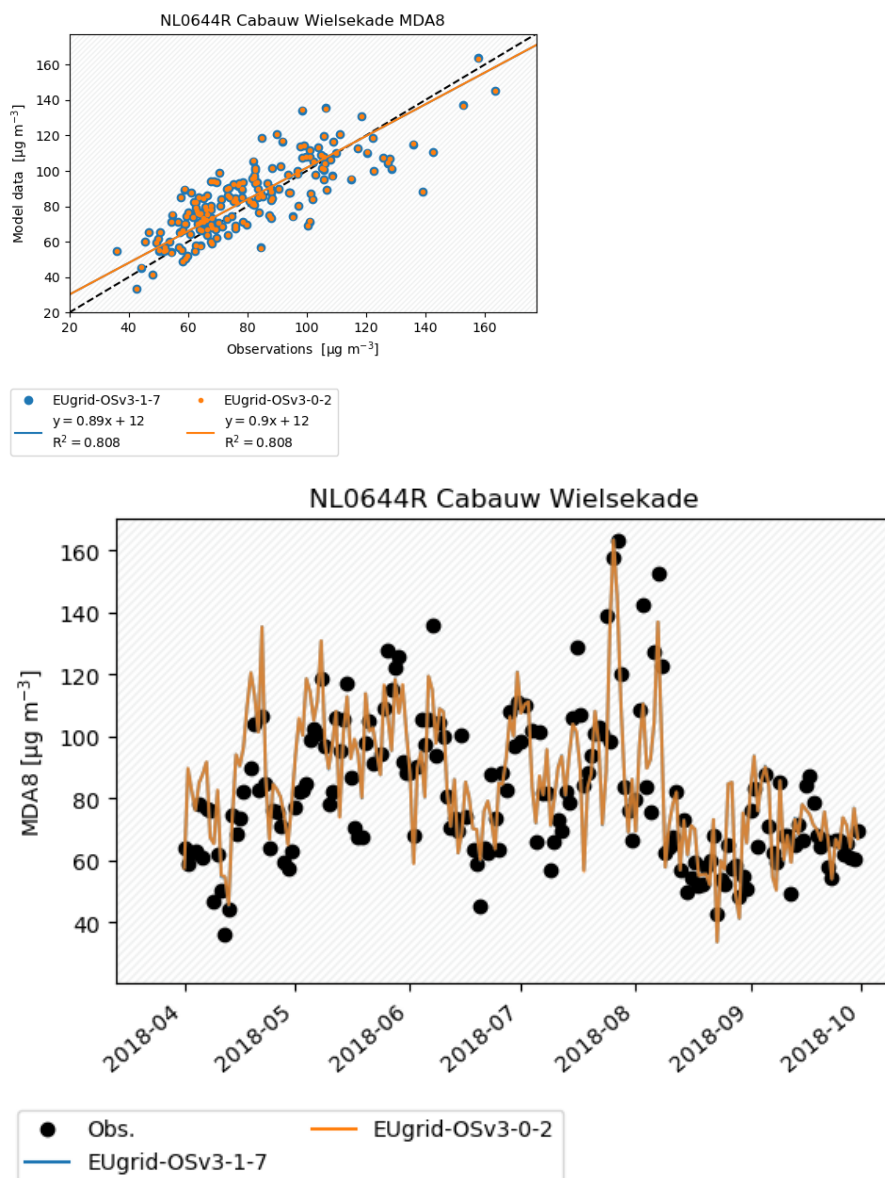


Figure 4.12: Station NL0644R (EBAS) – O₃ MDA8

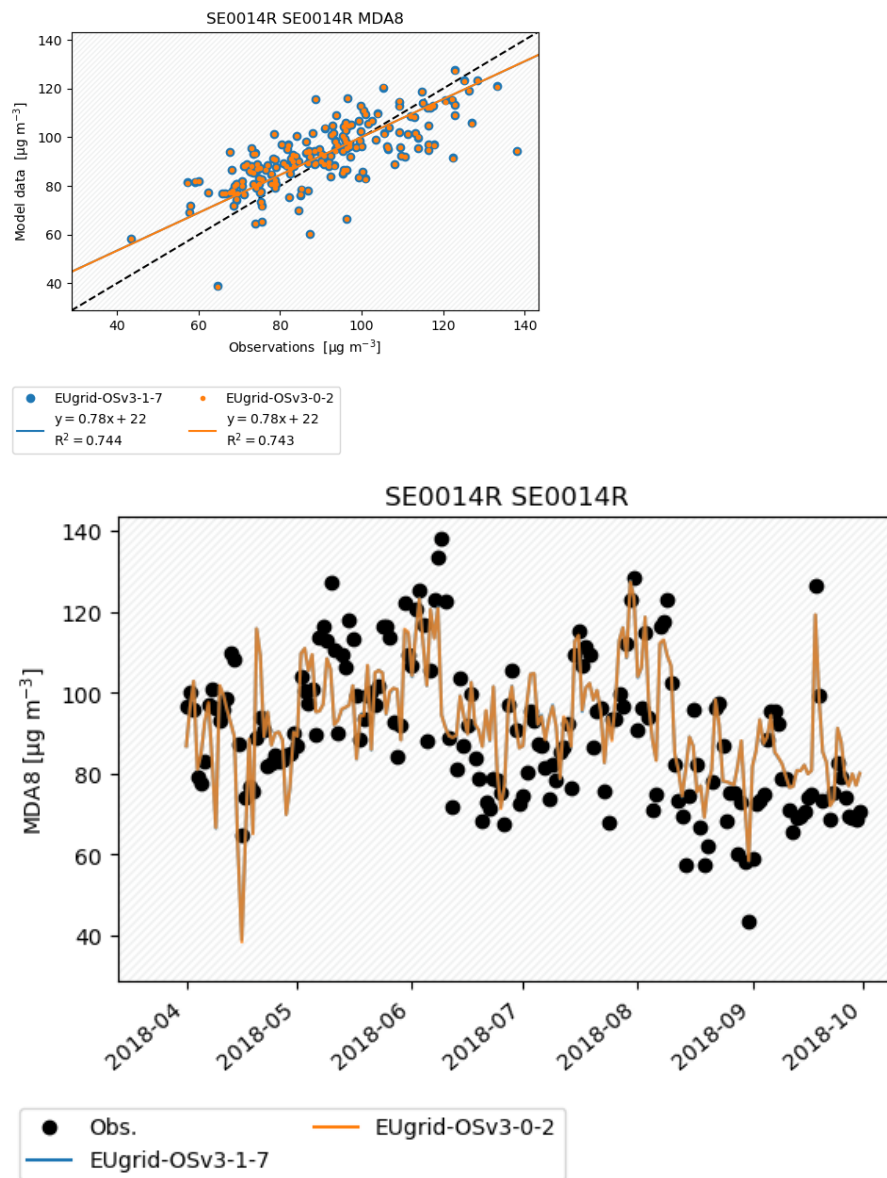


Figure 4.13: Station SE0014R (EBAS) – O₃ MDA8

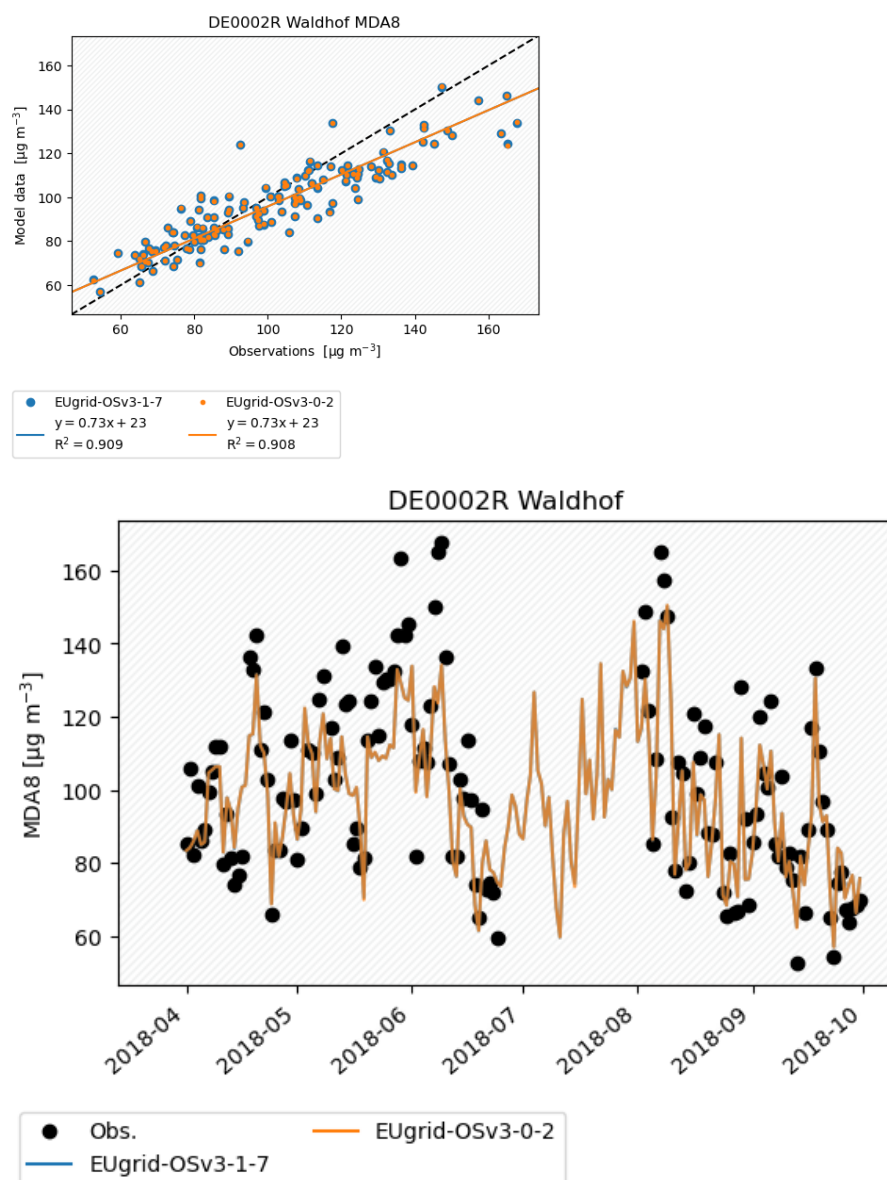


Figure 4.14: Station DE0002R (EBAS) – O₃ MDA8

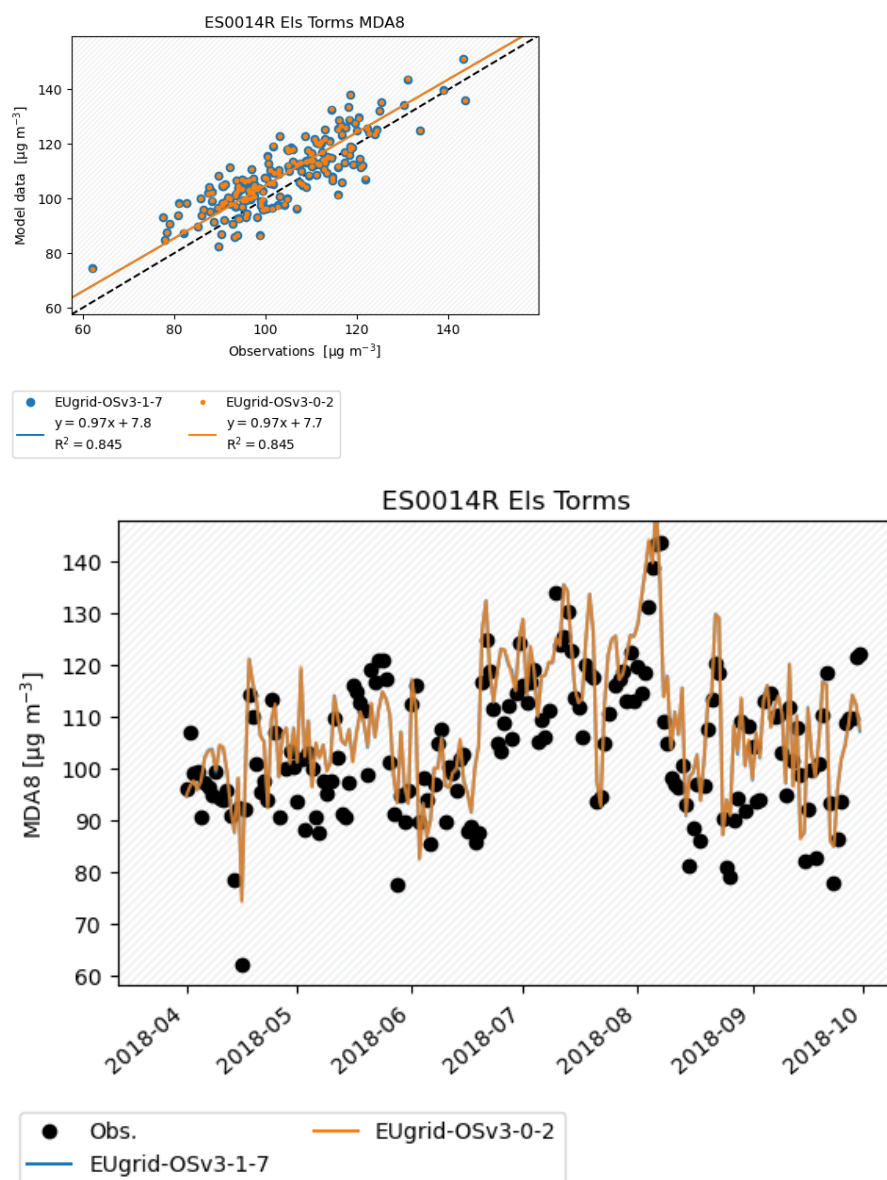


Figure 4.15: Station ES0014R (EBAS) – O₃ MDA8

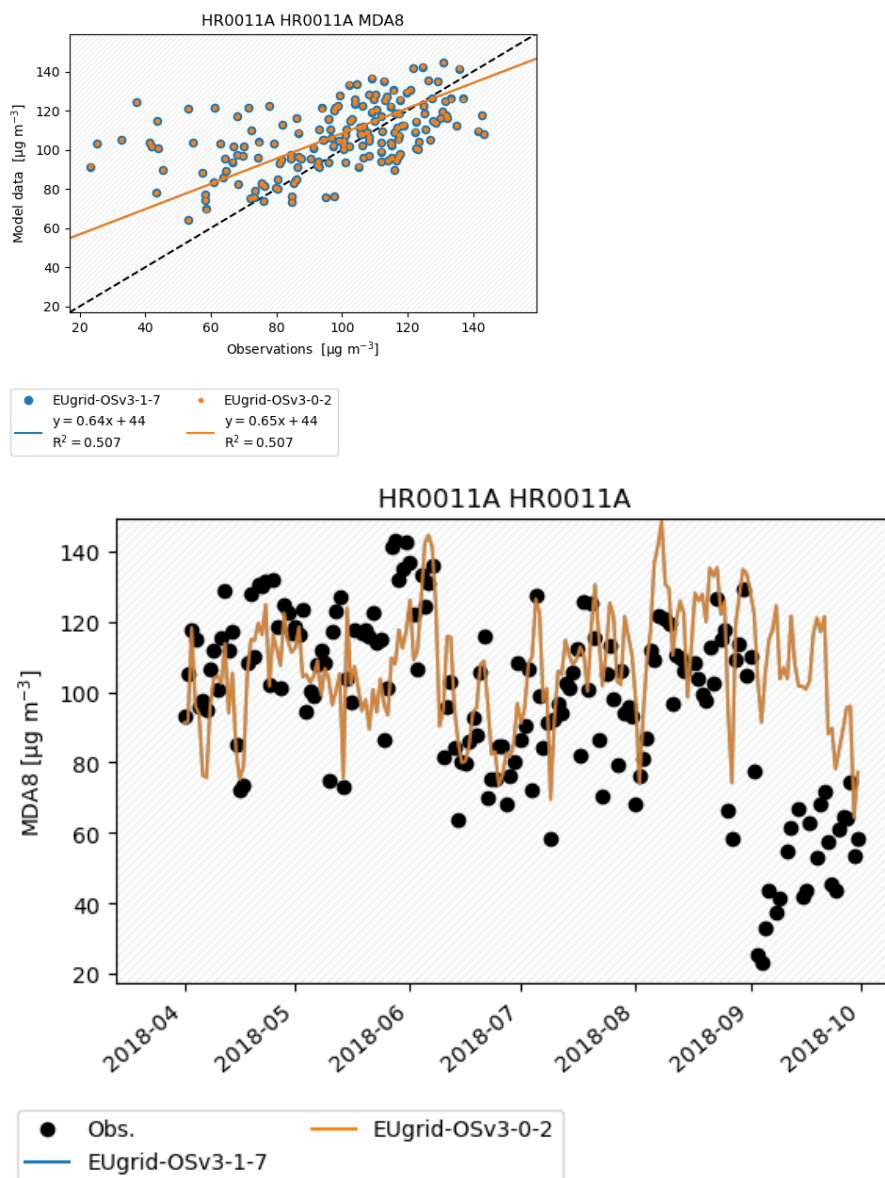


Figure 4.16: Station HR0011A (EEA) – O₃ MDA8

4.3.2 Nitrogen Dioxide

Nitrogen dioxide concentrations are mainly impacted by the wind vector interpolation update.

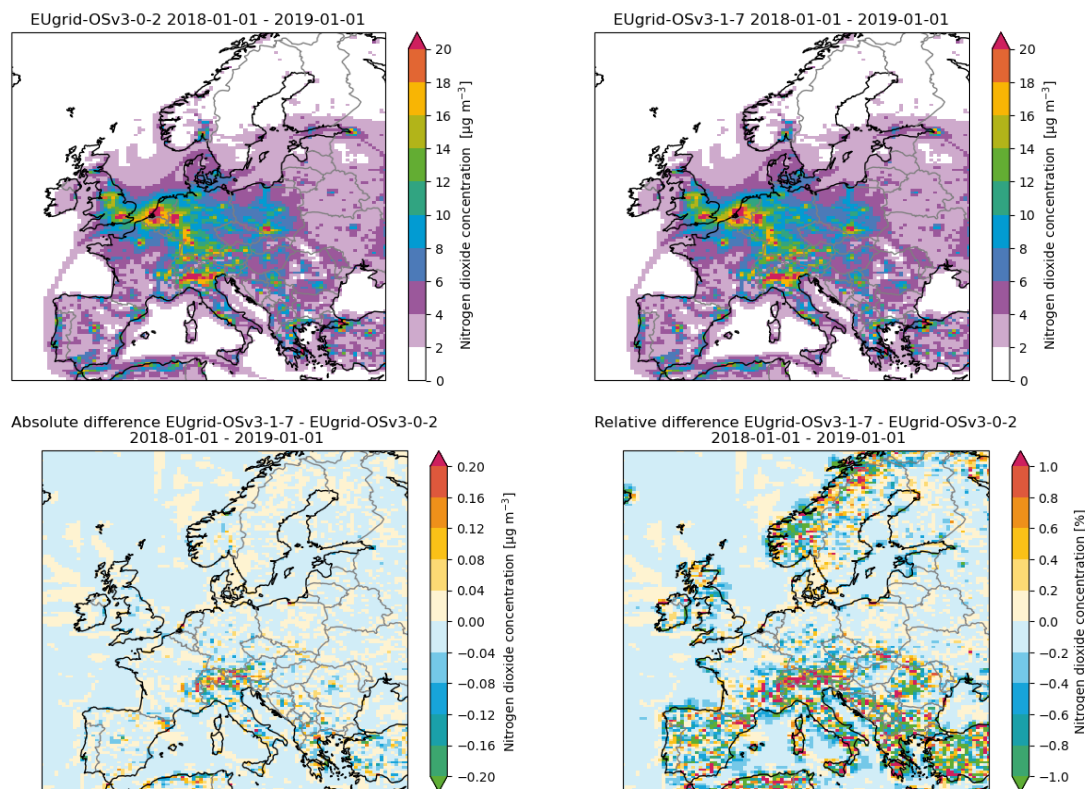


Figure 4.17: Averaged concentration map comparison for NO₂

Measurement validation for NO₂

Table 4.3: Statistics for NO₂

NO ₂		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1d	3.748	0.317	0.818	3.75	0.319	0.818	0.002	0.001	-0.0
EBAS	1h	5.972	0.331	0.176	5.968	0.331	0.176	-0.004	0.001	-0.0
EEA	1h	13.373	0.288	-0.314	13.373	0.288	-0.315	-0.0	0.0	-0.0

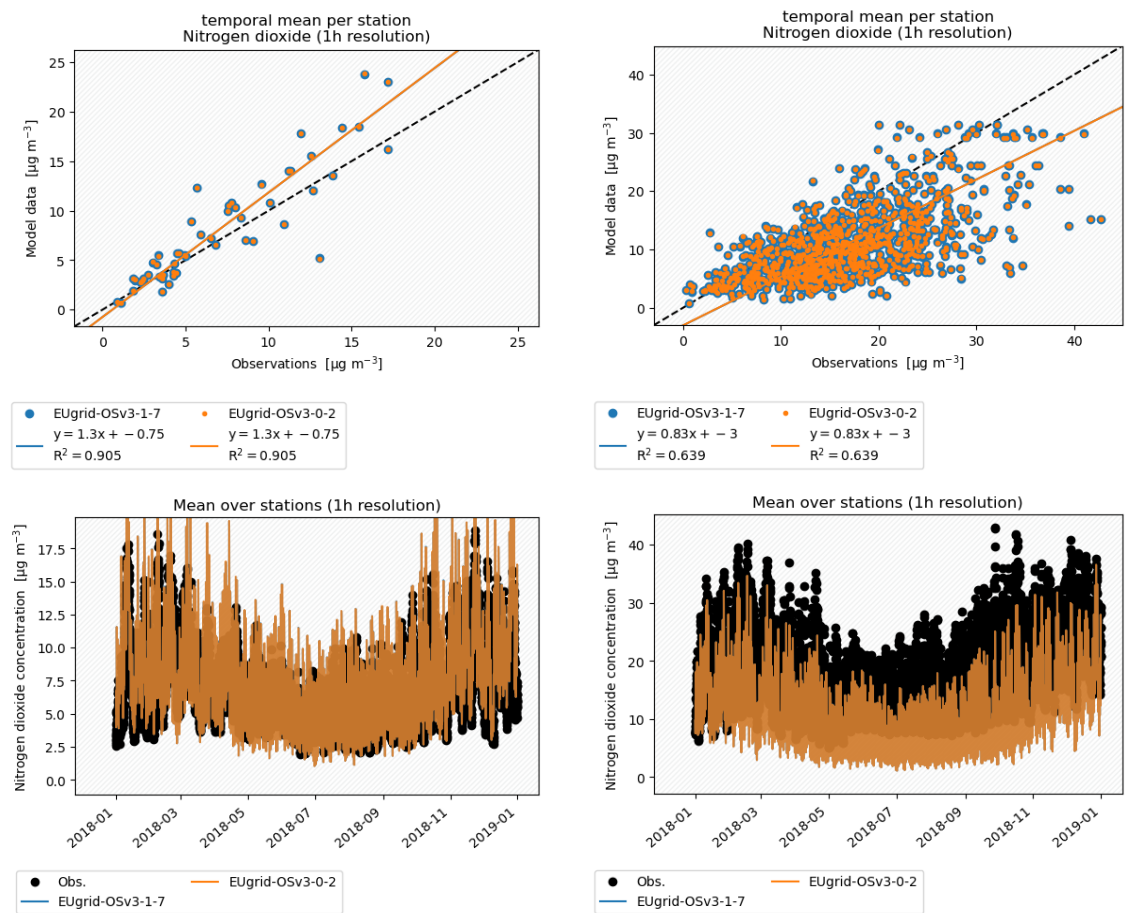


Figure 4.18: Station means – NO₂ | EBAS (left), EEA (right), annual mean (top), spatial mean (bottom)

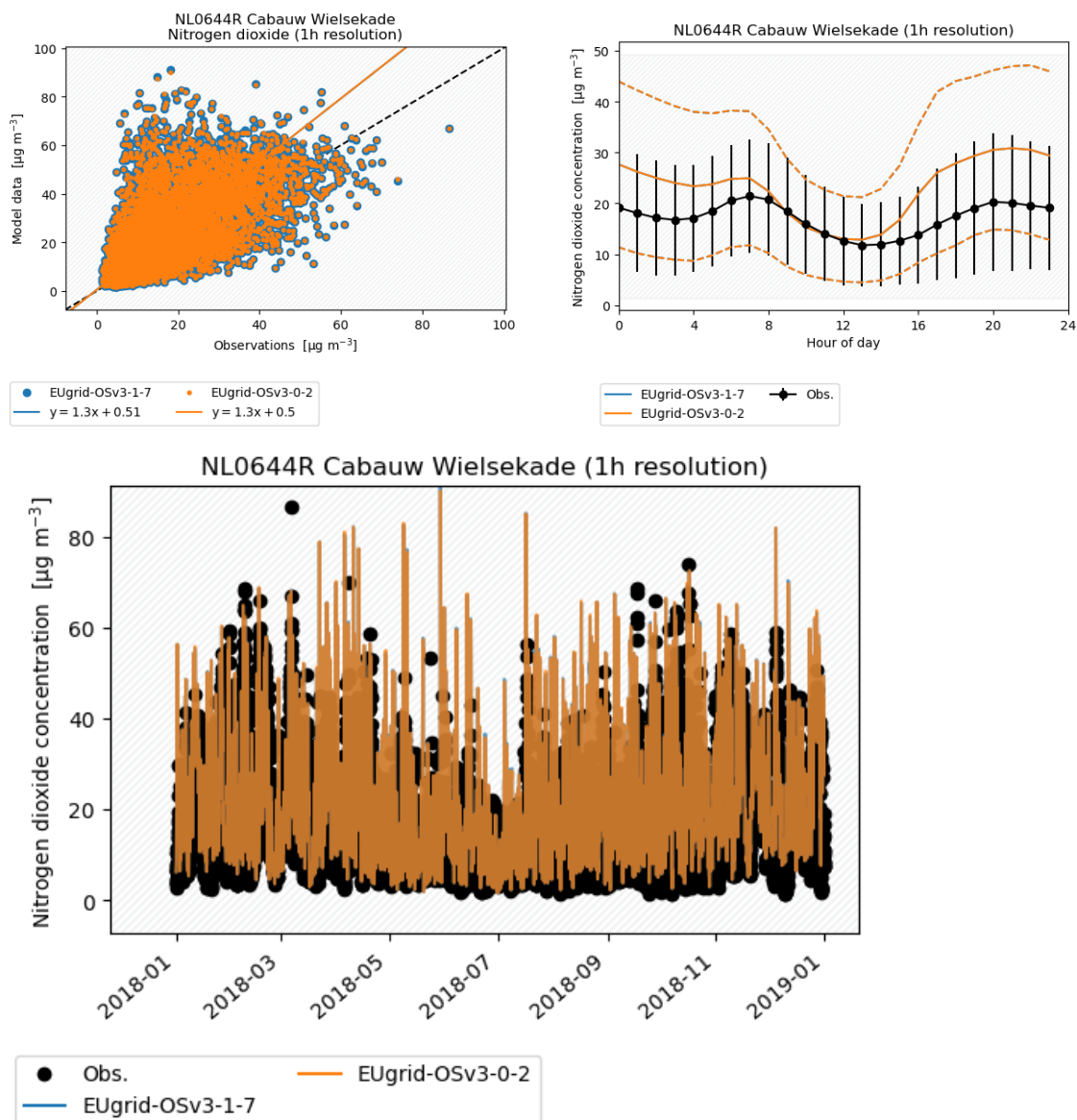


Figure 4.19: Station NL0644R (EBAS) – NO_2

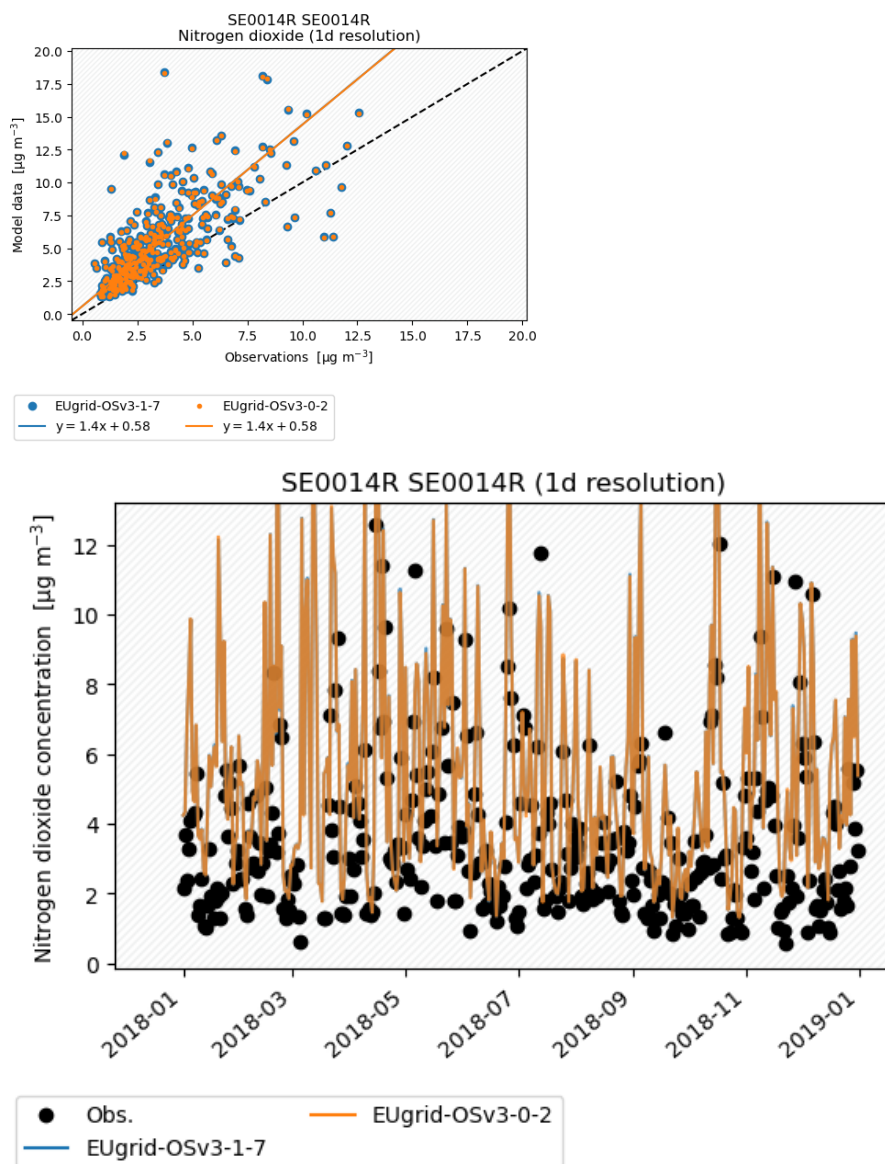


Figure 4.20: Station SE0014R (EBAS) – NO_2

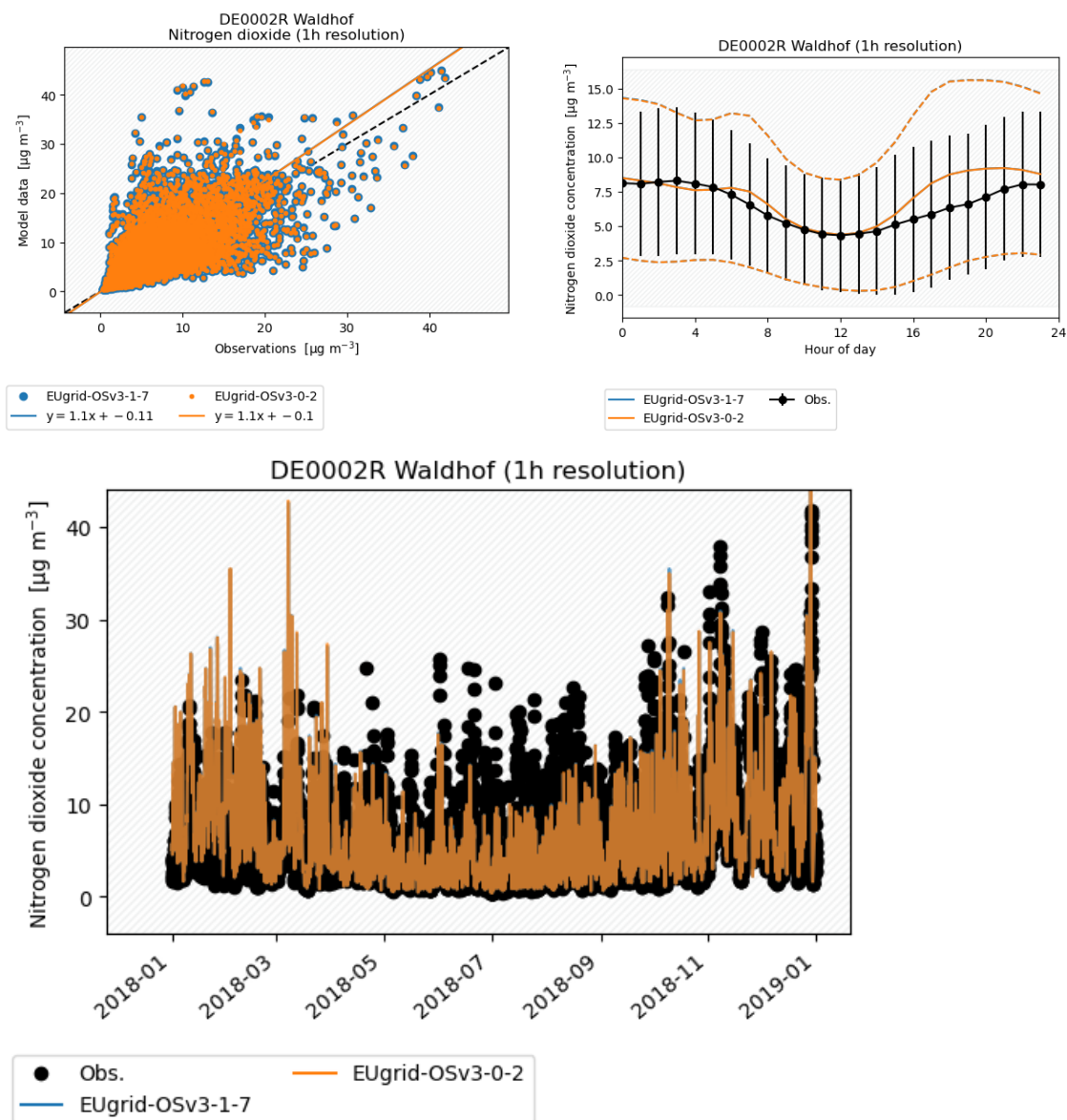


Figure 4.21: Station DE0002R (EBAS) – NO_2

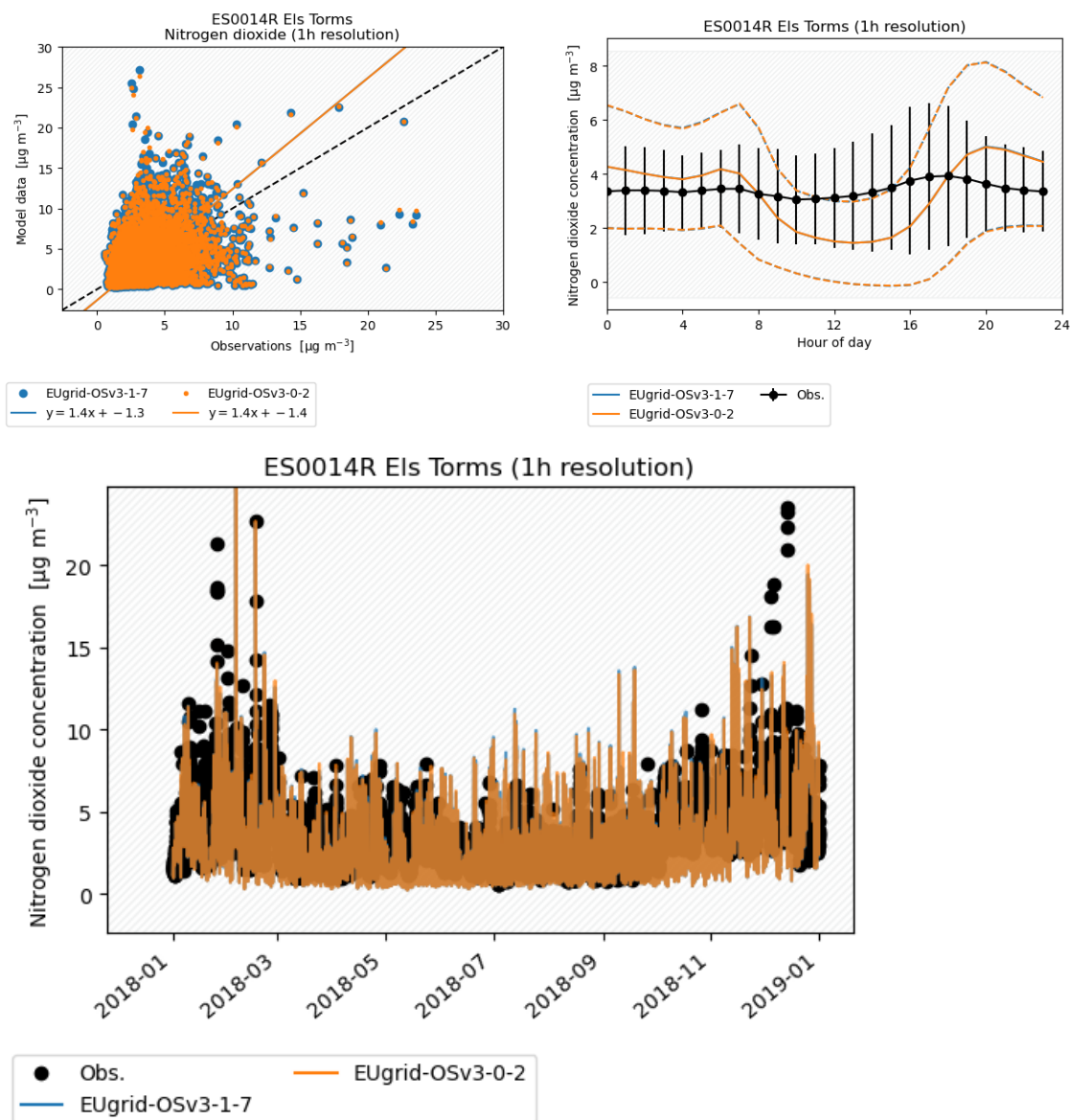


Figure 4.22: Station ES0014R (EBAS) – NO₂

4.3.3 Nitrogen Monoxide

Nitrogen monoxide concentrations are mainly impacted by the wind vector interpolation update.

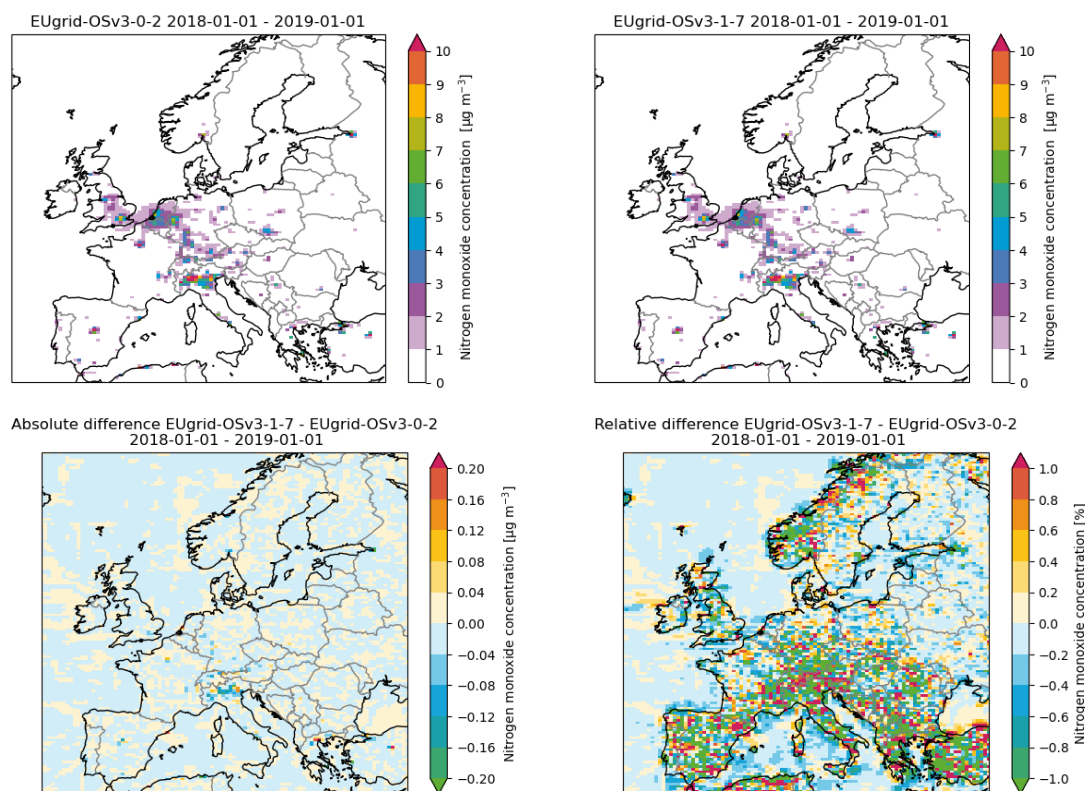


Figure 4.23: Averaged concentration map comparison for NO

Measurement validation for NO

Table 4.4: Statistics for NO

NO		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1h	2.529	0.165	-0.111	2.519	0.166	-0.113	-0.01	0.0	-0.002

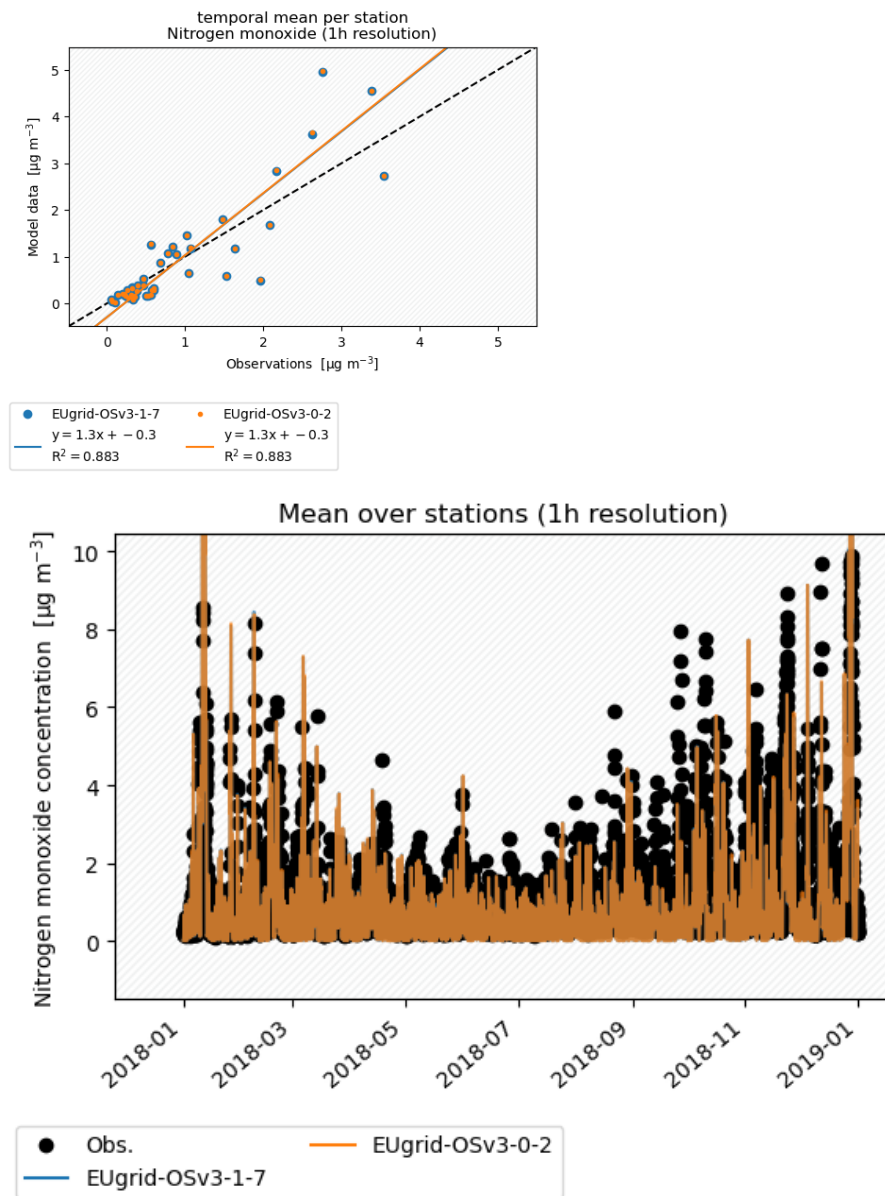


Figure 4.24: Station means (EBAS) – NO | annual mean (top), spatial mean (bottom)

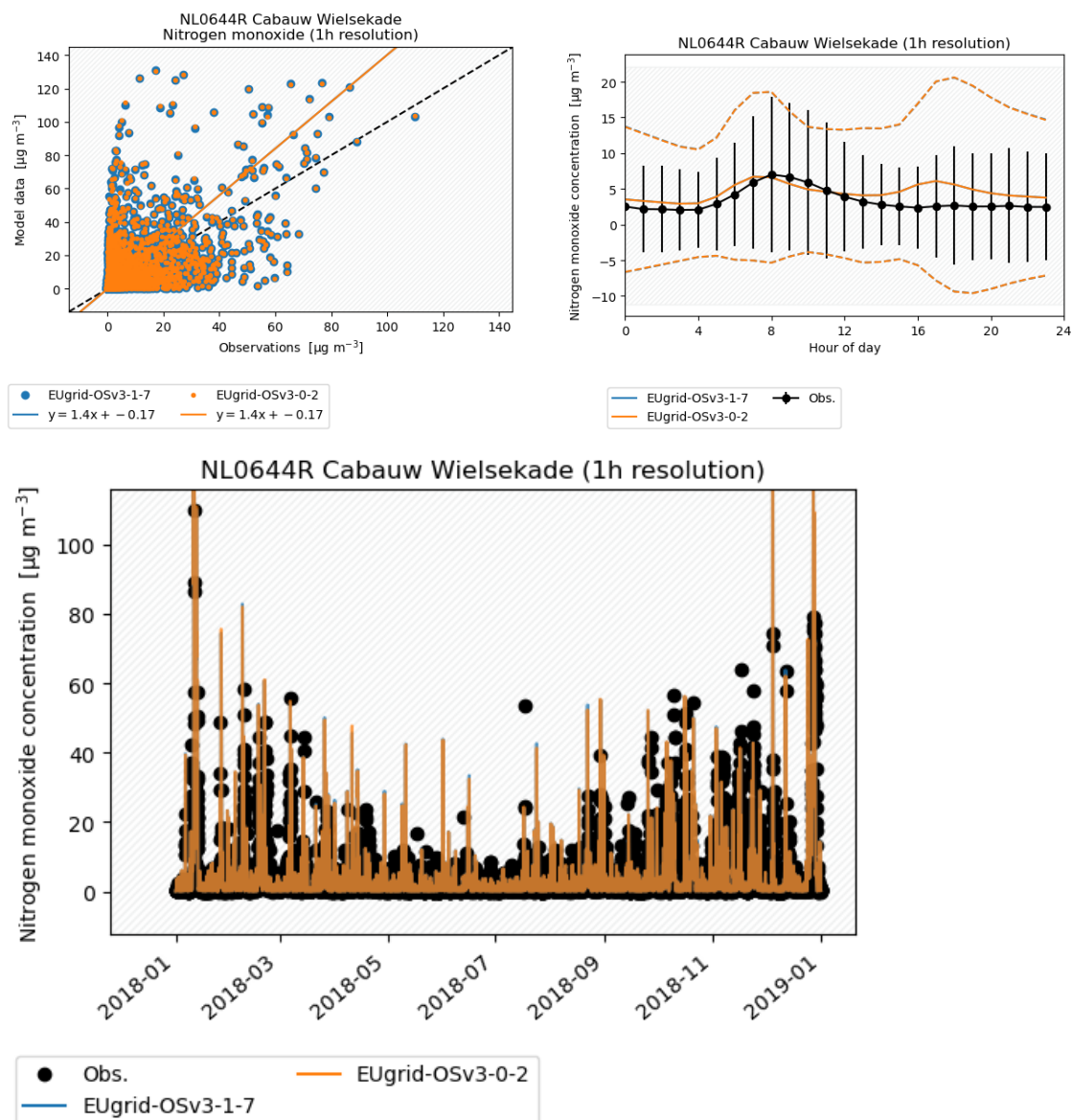


Figure 4.25: Station NL0644R (EBAS) – NO

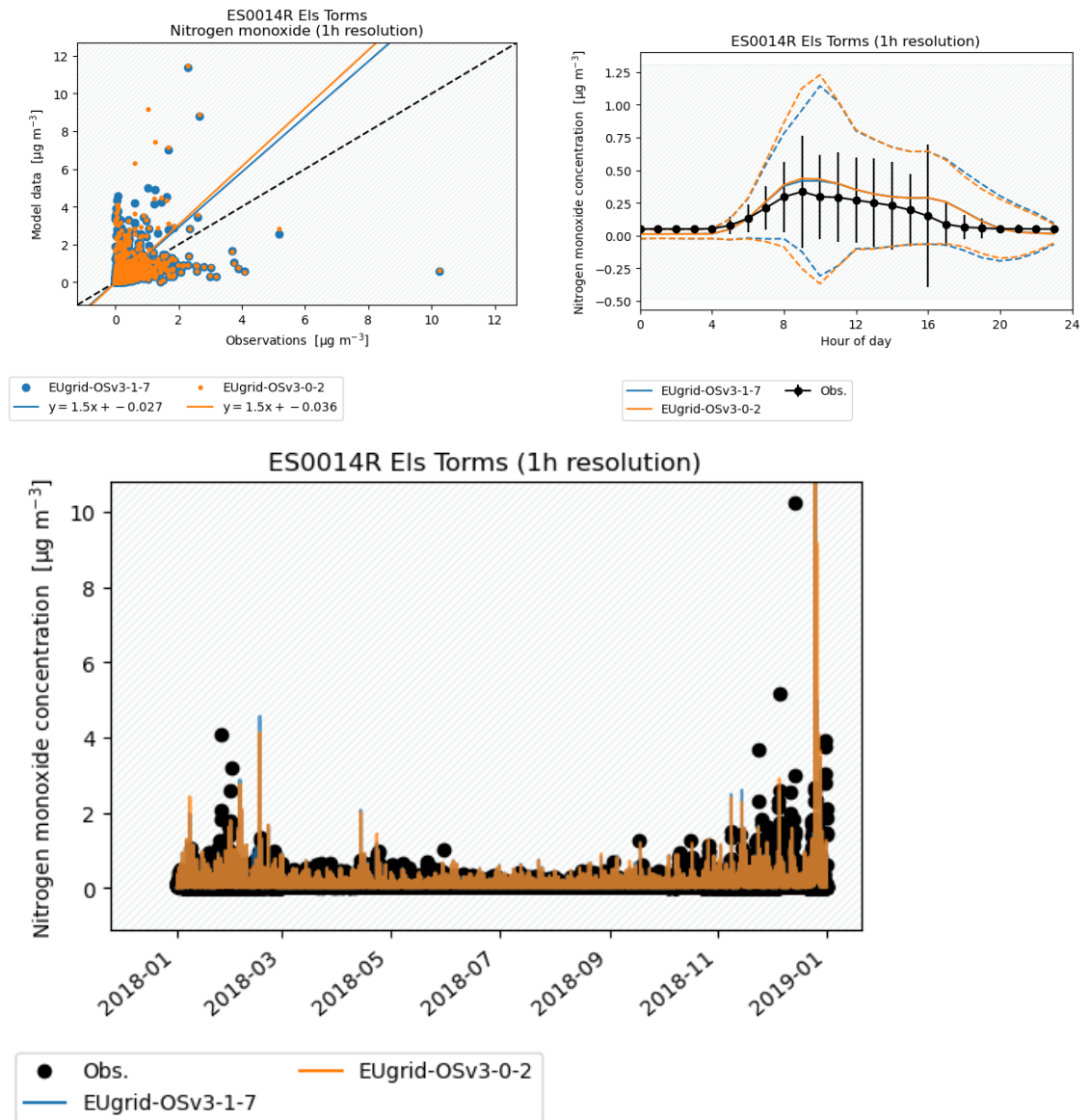


Figure 4.26: Station ES0014R (EBAS) – NO

4.3.4 Ammonia

Ammonia concentrations are mainly impacted by the wind vector interpolation update.

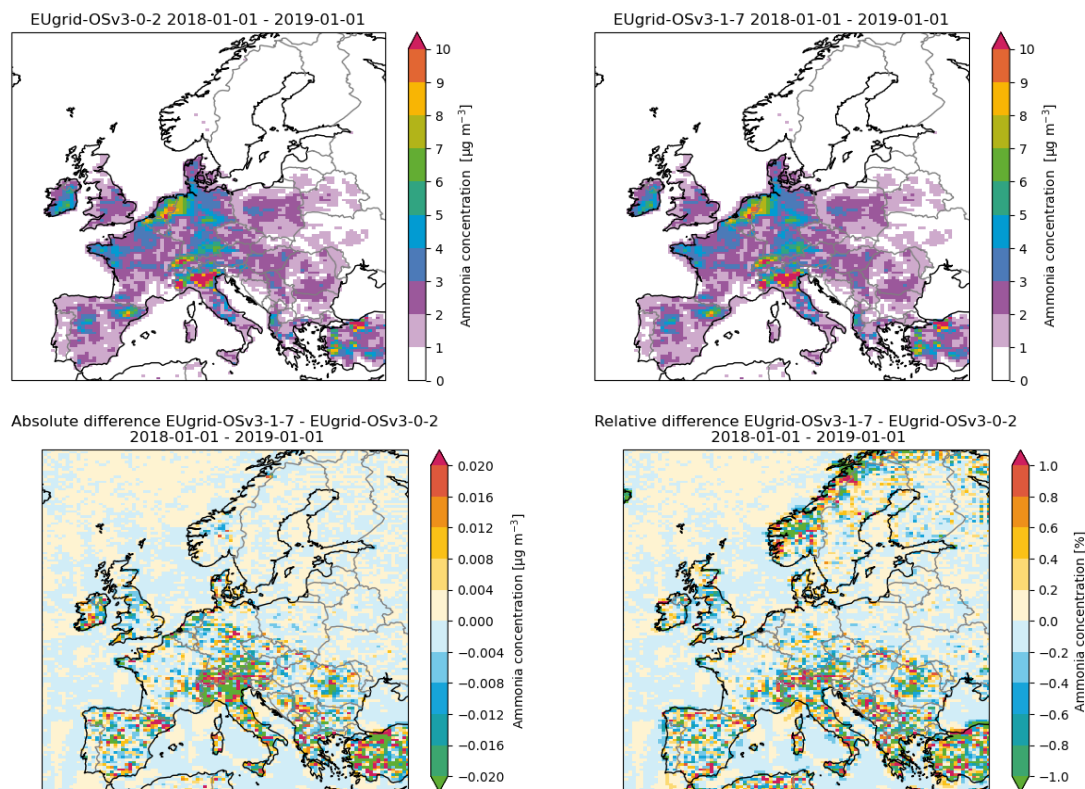


Figure 4.27: Averaged concentration map comparison for NH_3

Measurement validation for NH_3

Table 4.5: Statistics for NH_3

NH_3		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1h	4.366	0.076	-0.354	4.369	0.078	-0.354	0.002	0.003	0.0
EBAS	1d	0.977	0.283	0.234	0.977	0.281	0.234	0.0	-0.001	0.0

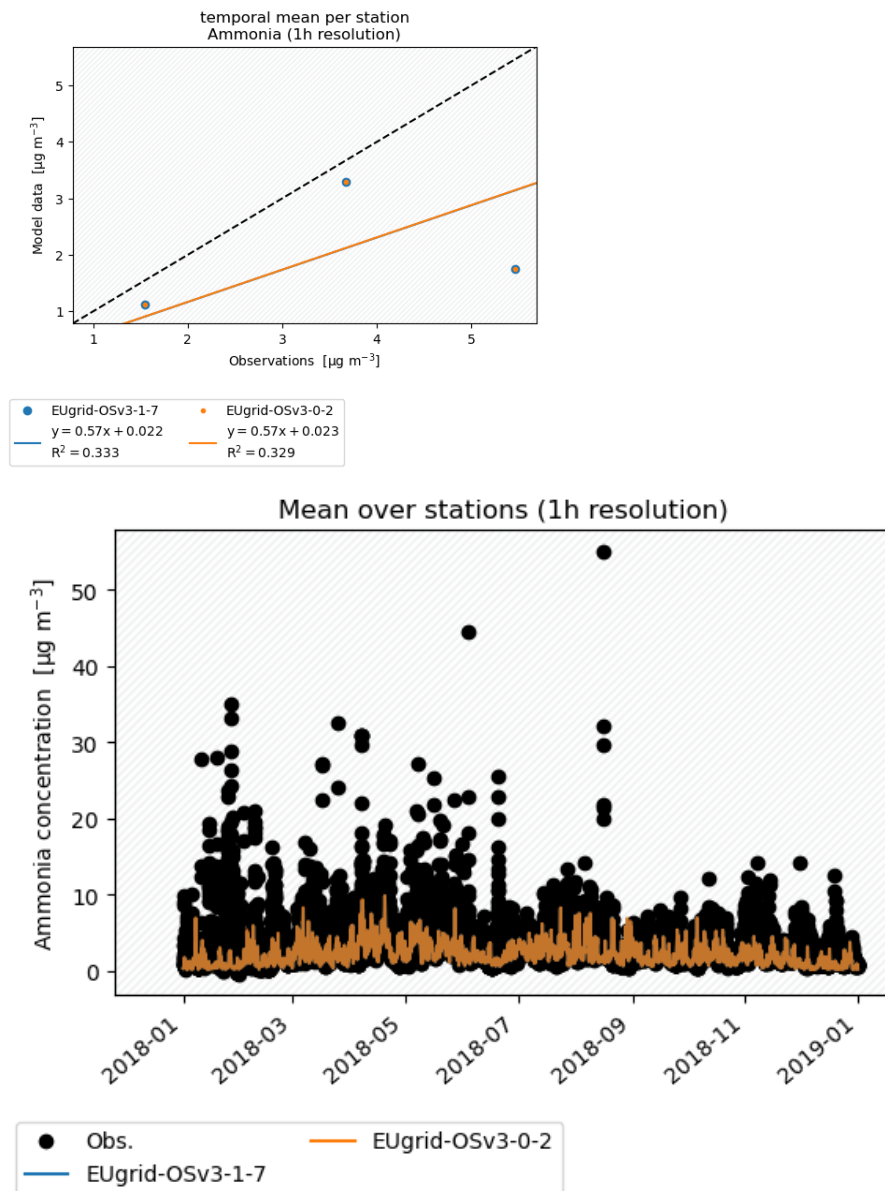


Figure 4.28: Station means (EBAS) – NH_3 | annual mean (top), spatial mean (bottom)

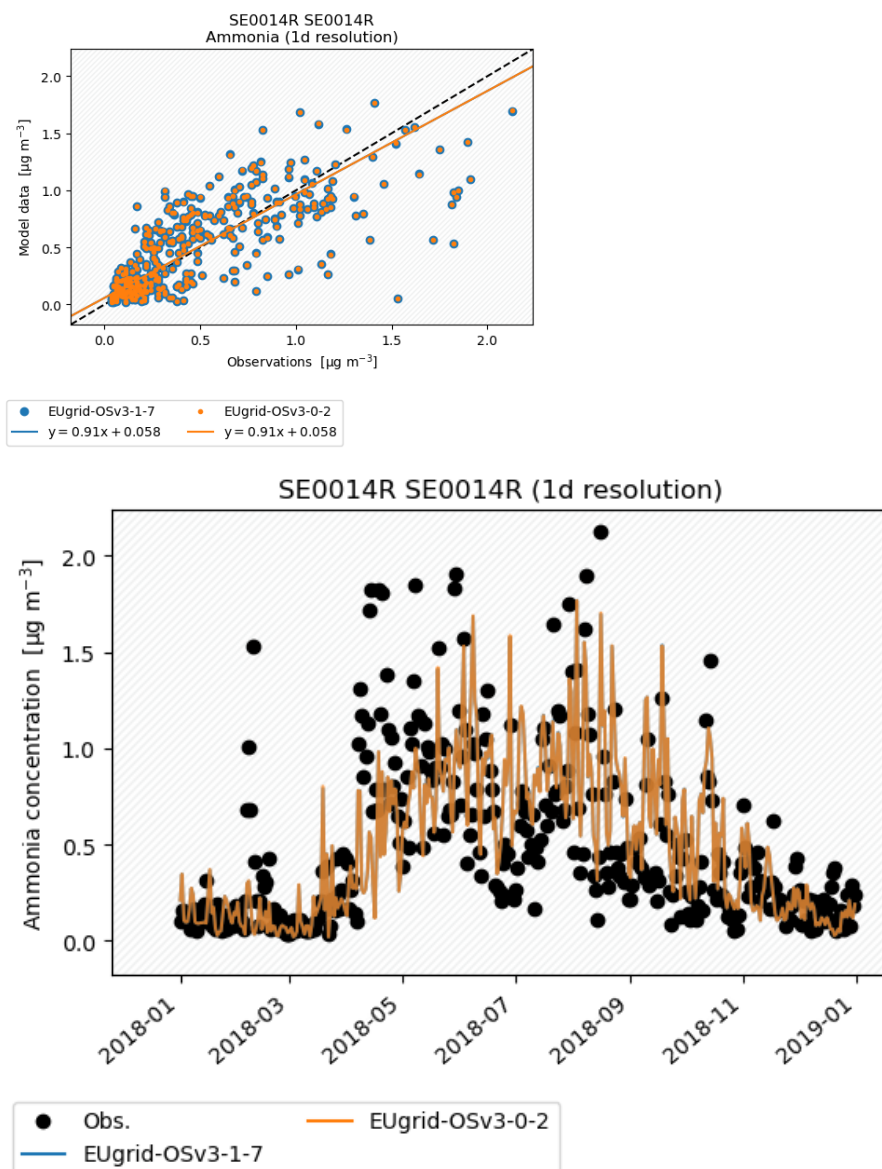


Figure 4.29: Station SE0014R (EBAS) – NH_3

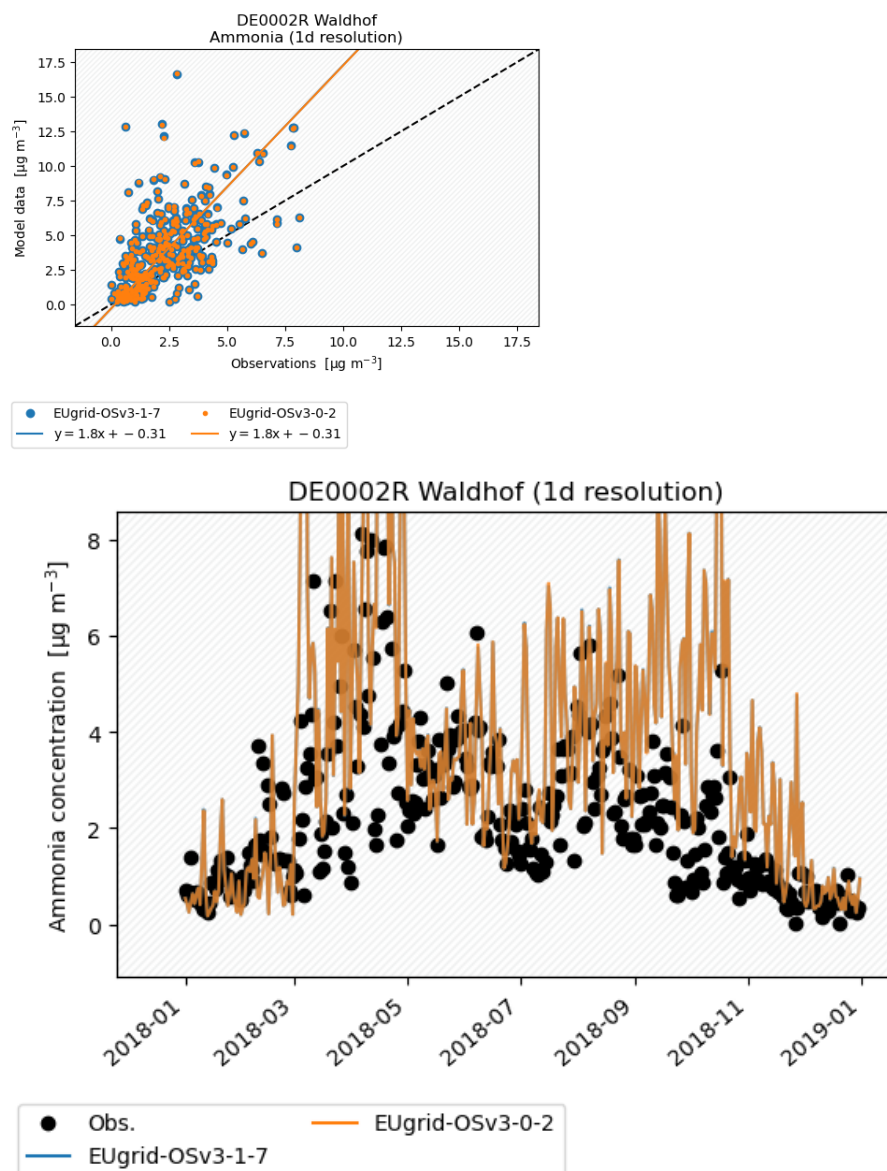


Figure 4.30: Station DE0002R (EBAS) – NH_3

4.3.5 Sulphur Dioxide

Sulphur Dioxide concentrations are mainly impacted by the wind vector interpolation update.

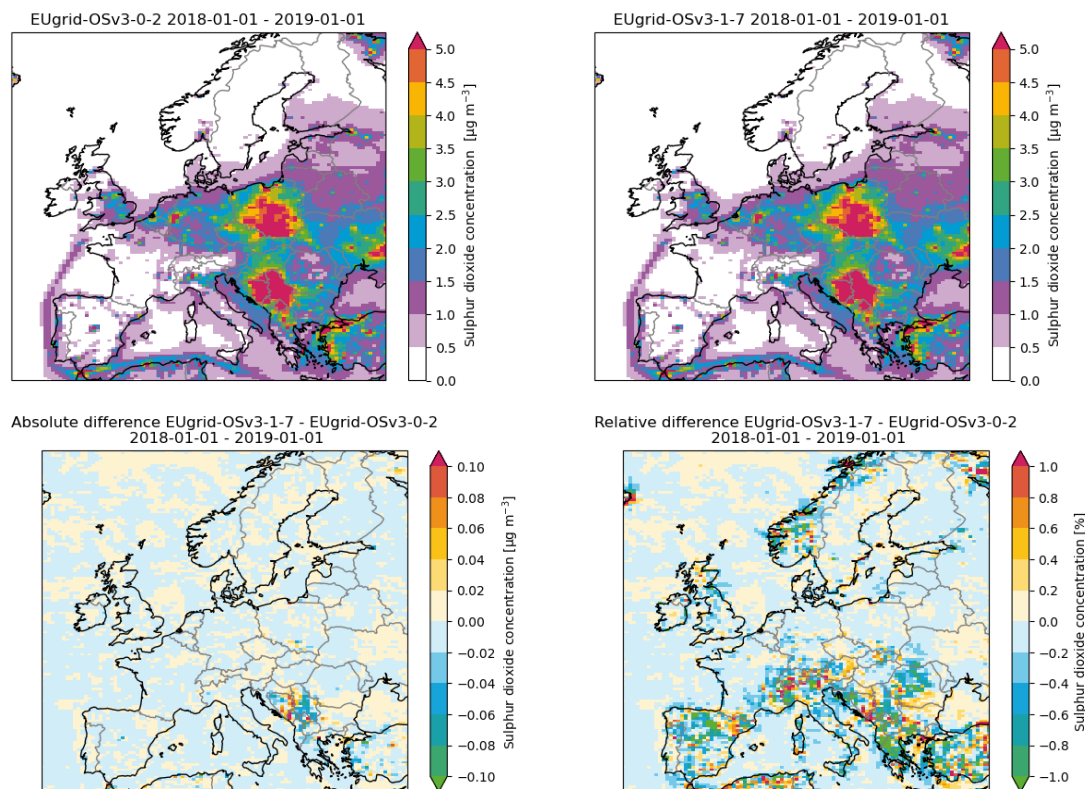


Figure 4.31: Averaged concentration map comparison for SO₂

Measurement validation for SO₂

Table 4.6: Statistics for SO₂

SO ₂		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1h	1.213	0.091	3.377	1.214	0.092	3.376	0.001	0.001	-0.001
EBAS	1d	1.508	0.155	3.517	1.507	0.155	3.511	-0.001	0.0	-0.007
EEA	1h	4.202	0.097	0.052	4.205	0.097	0.052	0.002	-0.0	0.0

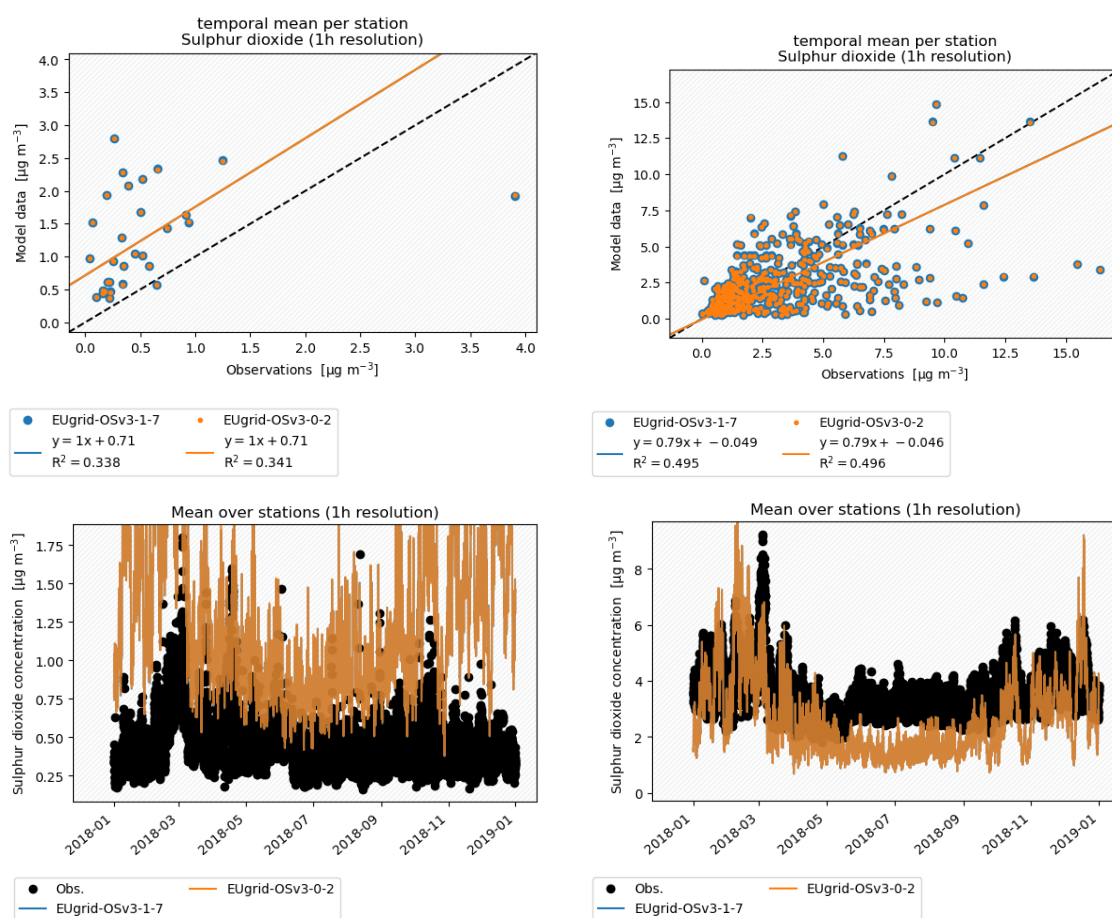


Figure 4.32: Station means – SO₂ | EBAS (left), EEA (right), annual mean (top), spatial mean (bottom)

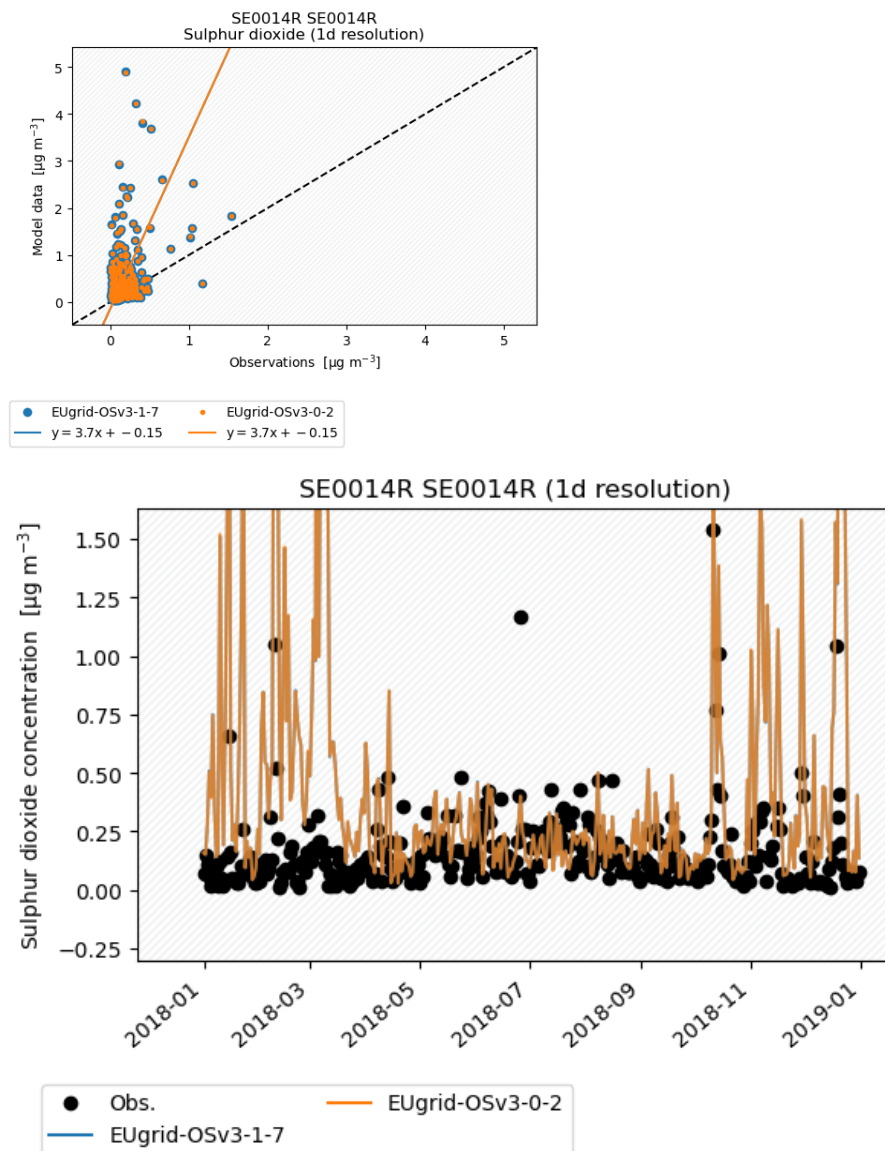


Figure 4.33: Station SE0014R (EBAS) – SO_2

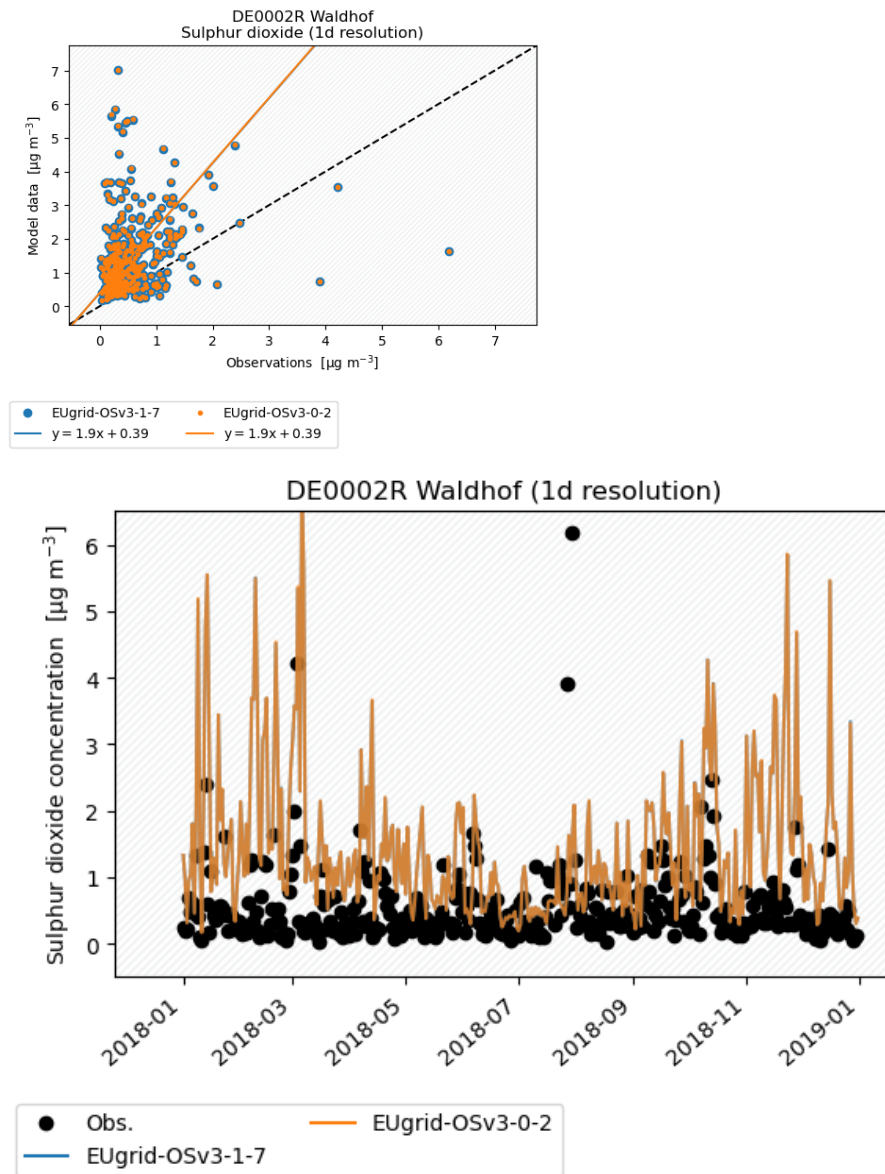


Figure 4.34: Station DE0002R (EBAS) – SO_2

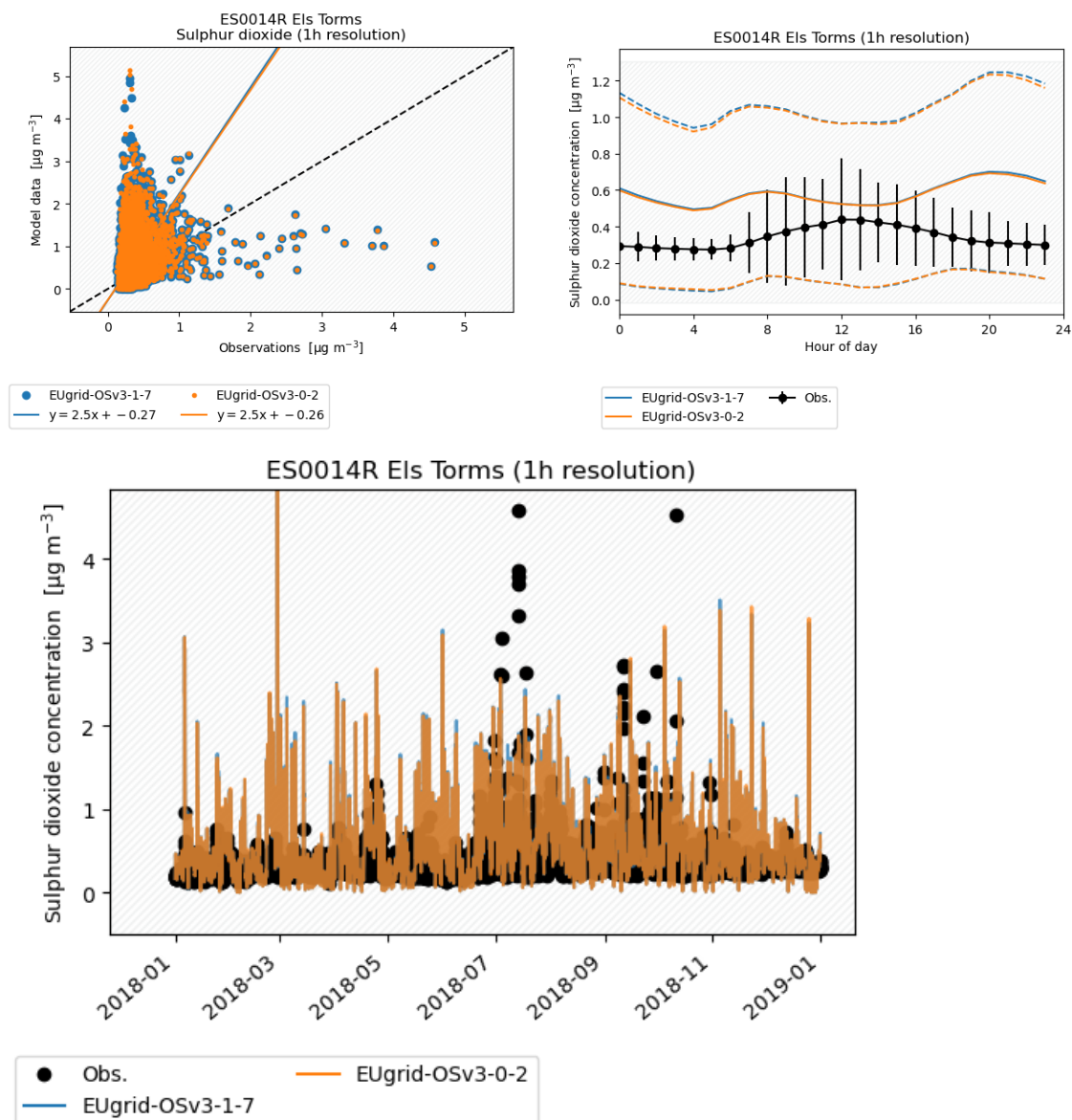


Figure 4.35: Station ES0014R (EBAS) – SO_2

4.4 Particulate Matter Species

4.4.1 PM_{2.5}

4.4.1.1 Total PM_{2.5}

Total PM_{2.5} is mainly impacted by the wind vector interpolation update, and the update of the mean free path length.

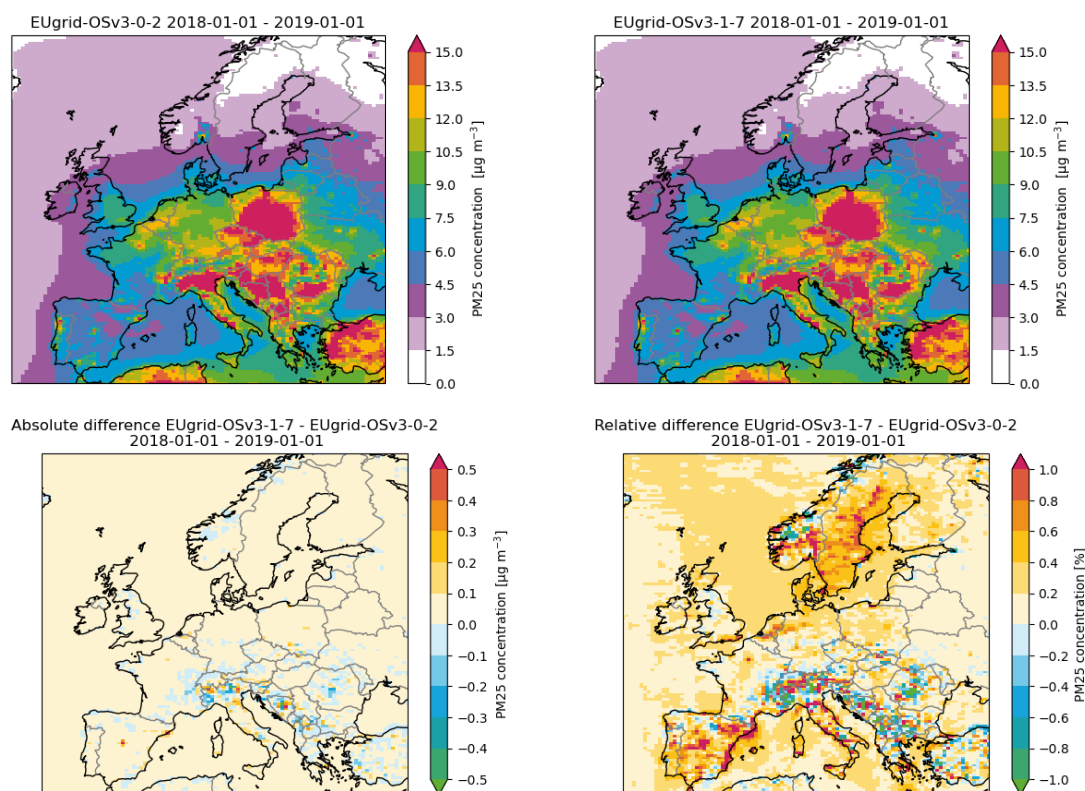


Figure 4.36: Averaged concentration map comparison for PM_{2.5}

Measurement validation for PM_{2.5}

Table 4.7: Statistics for PM_{2.5}

PM _{2.5}		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1d	6.636	0.326	-0.142	6.644	0.326	-0.14	0.007	0.0	0.002
EBAS	1h	6.479	0.303	-0.097	6.483	0.304	-0.096	0.004	0.001	0.002
EEA	1h	10.074	0.343	-0.125	10.091	0.342	-0.122	0.017	-0.0	0.002

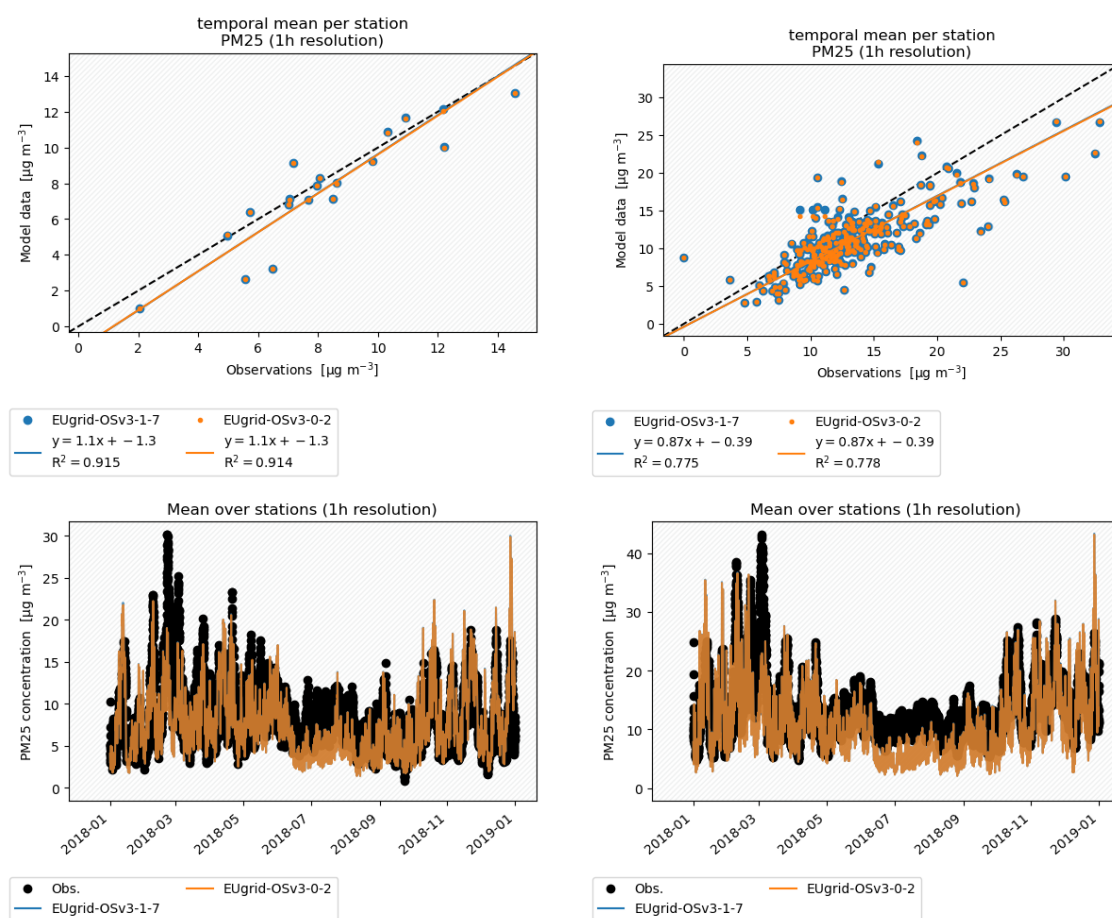


Figure 4.37: Station means – PM_{2.5} | EBAS (left), EEA (right), annual mean (top), spatial mean (bottom)

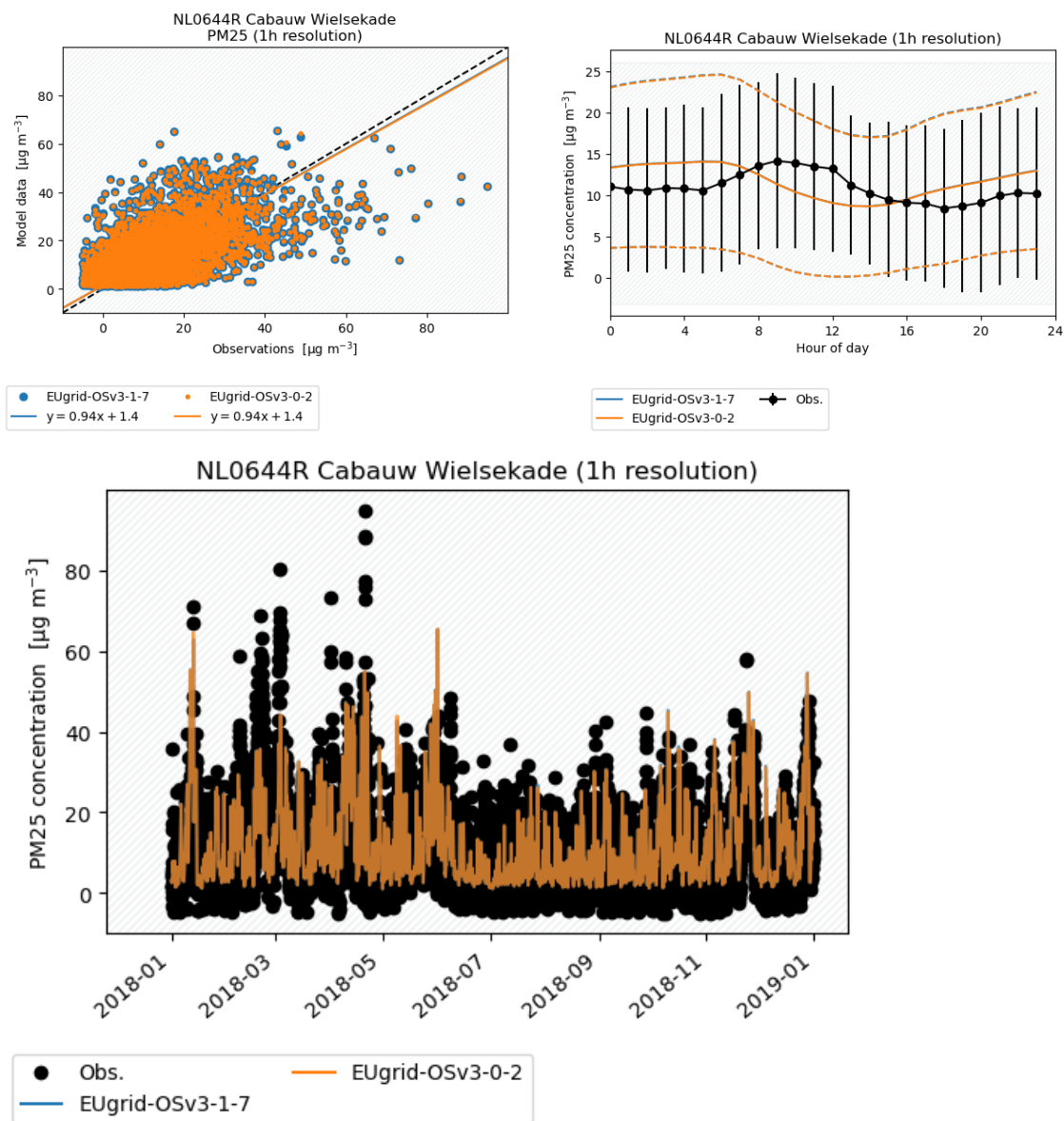


Figure 4.38: Station NL0644R (EBAS) – $\text{PM}_{2.5}$

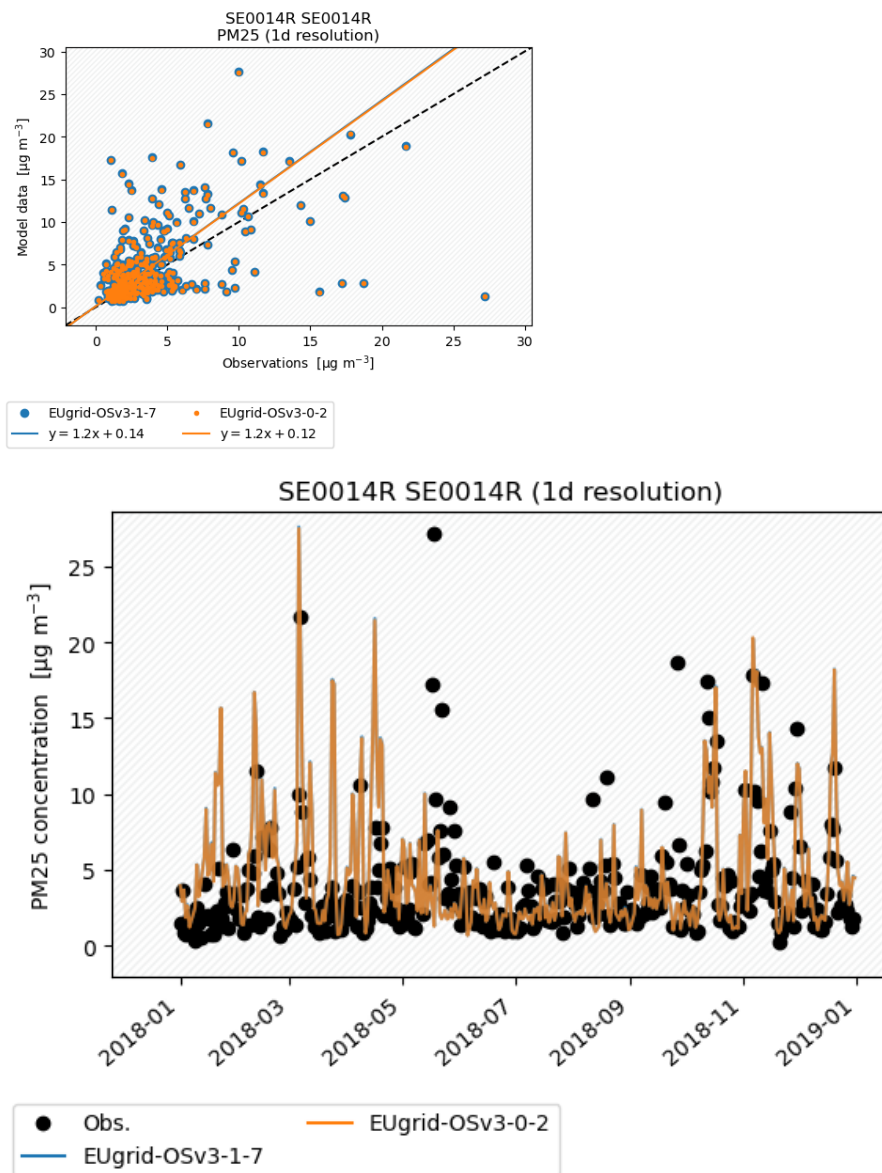


Figure 4.39: Station SE0014R (EBAS) – $\text{PM}_{2.5}$

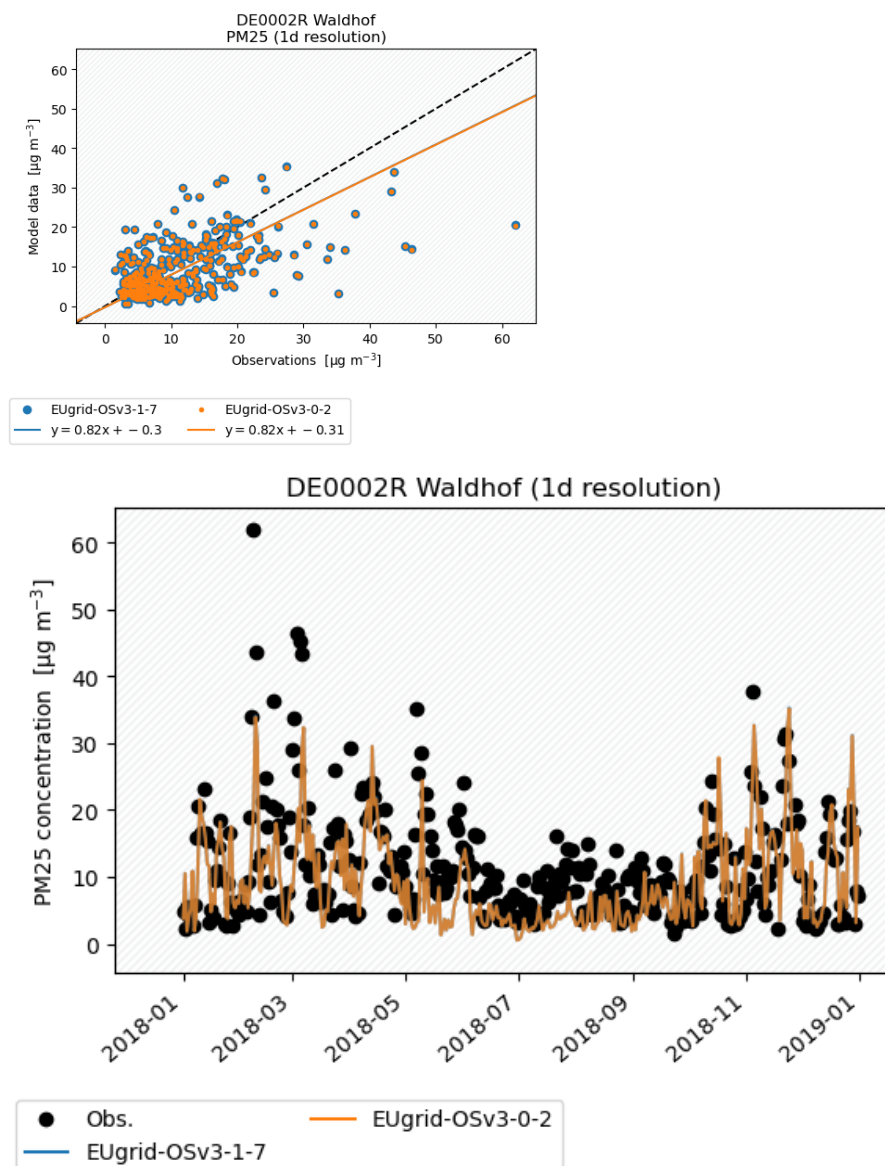


Figure 4.40: Station DE0002R (EBAS) – PM_{2.5}

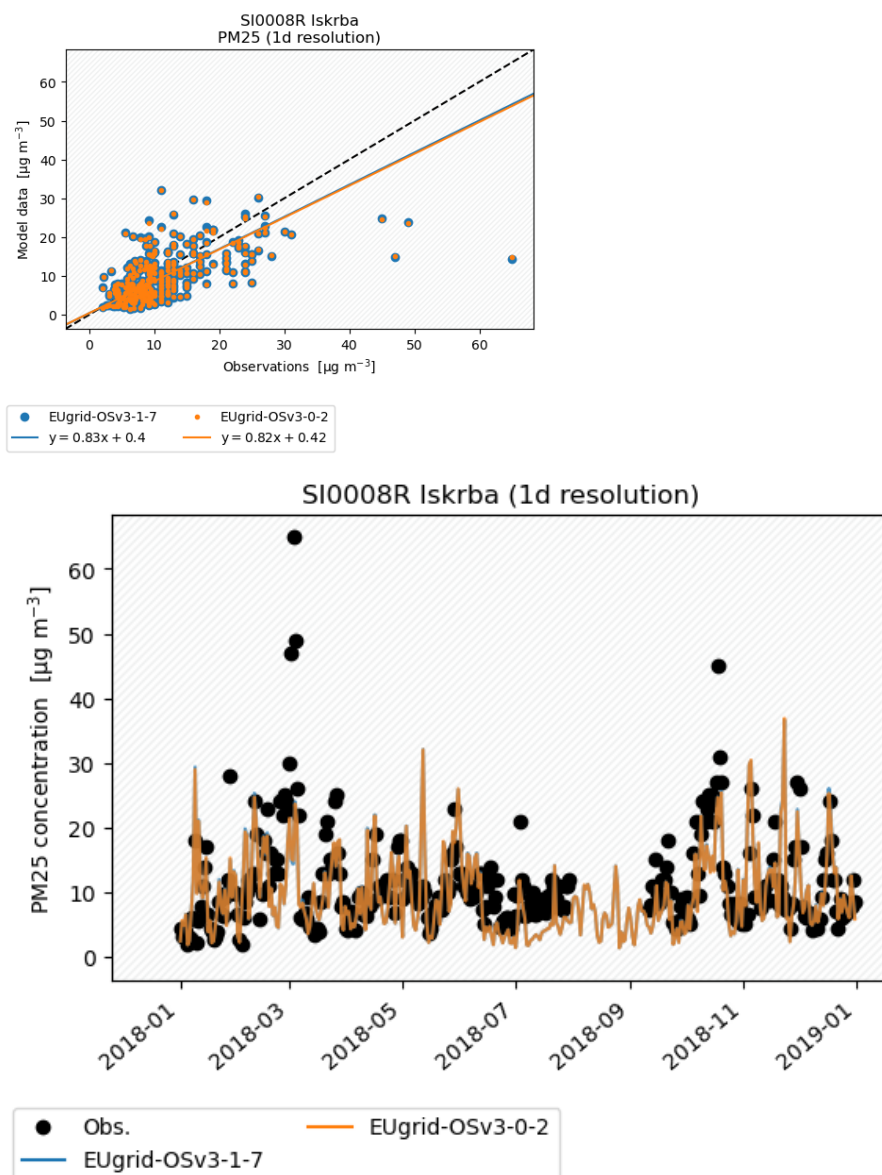


Figure 4.41: Station SI0008R (EBAS) – PM_{2.5}

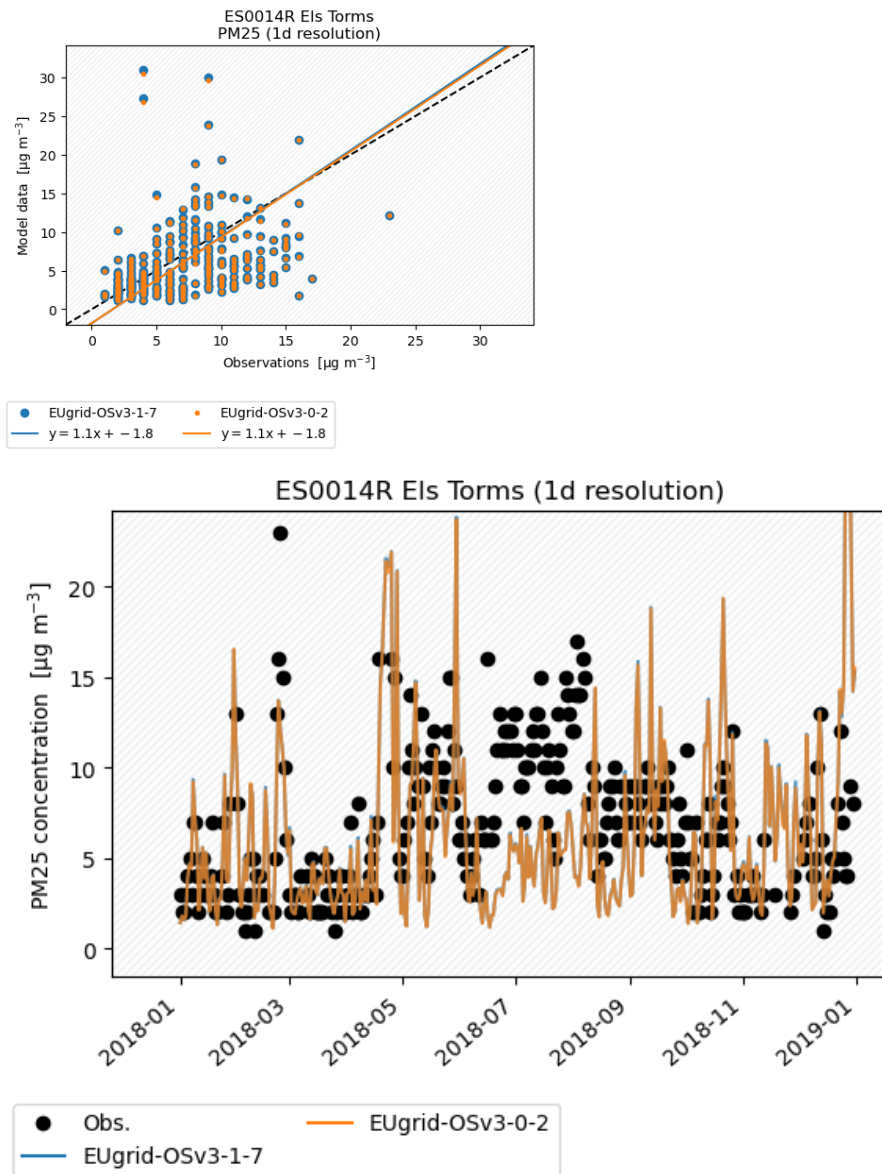


Figure 4.42: Station ES0014R (EBAS) – $\text{PM}_{2.5}$

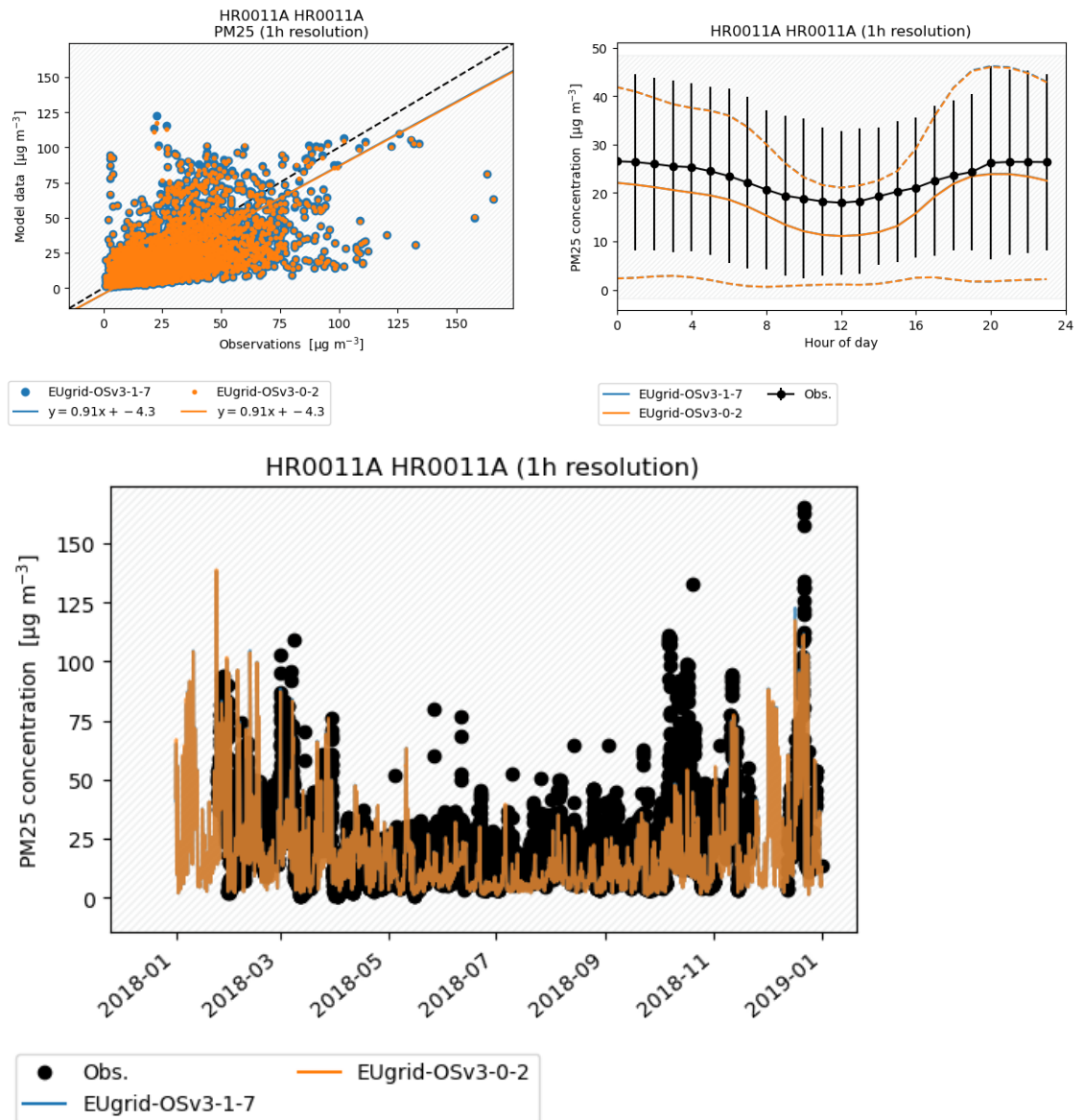


Figure 4.43: Station HR0011A (EEA) – PM_{2.5}

4.4.1.2 Nitrate (PM_{2.5})

Nitrate (PM_{2.5}) is mainly impacted by the wind vector interpolation update, and the update of the mean free path length.

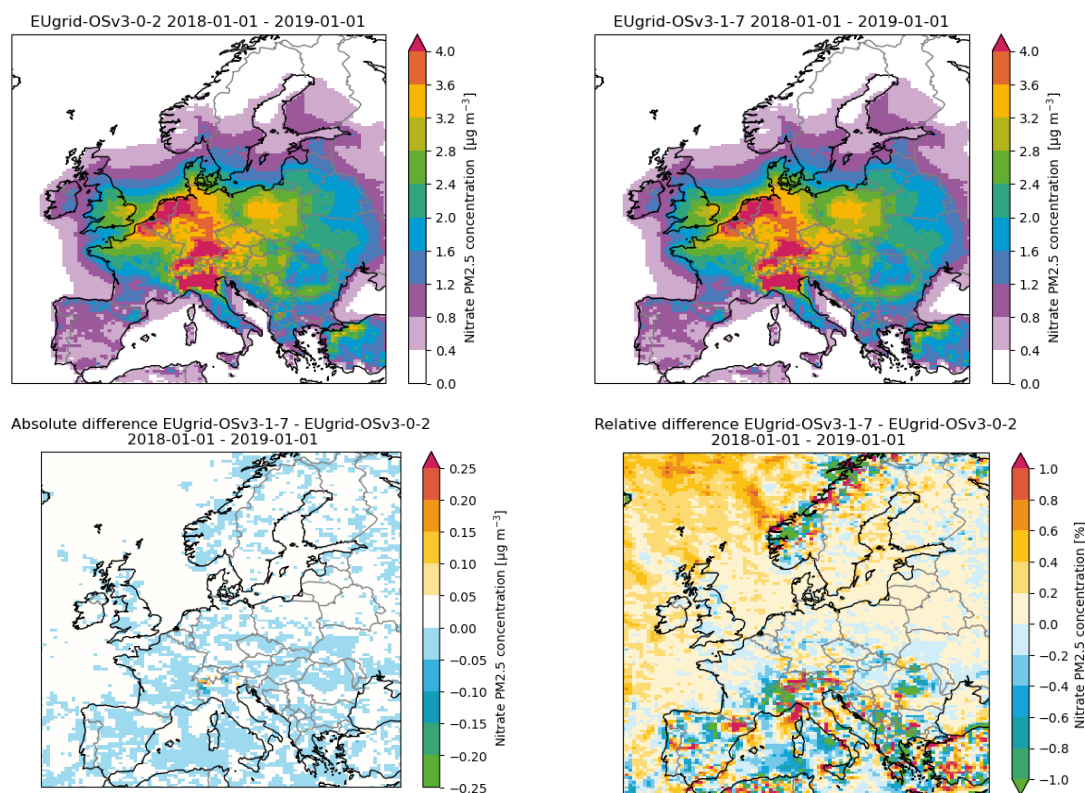


Figure 4.44: Averaged concentration map comparison for NO_3^- (PM_{2.5})

Measurement validation for NO_3^- (PM_{2.5})

Table 4.8: Statistics for NO_3^- (PM_{2.5})

NO_3^- (PM _{2.5})		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1d	2.851	0.131	0.935	2.852	0.134	0.939	0.001	0.003	0.004

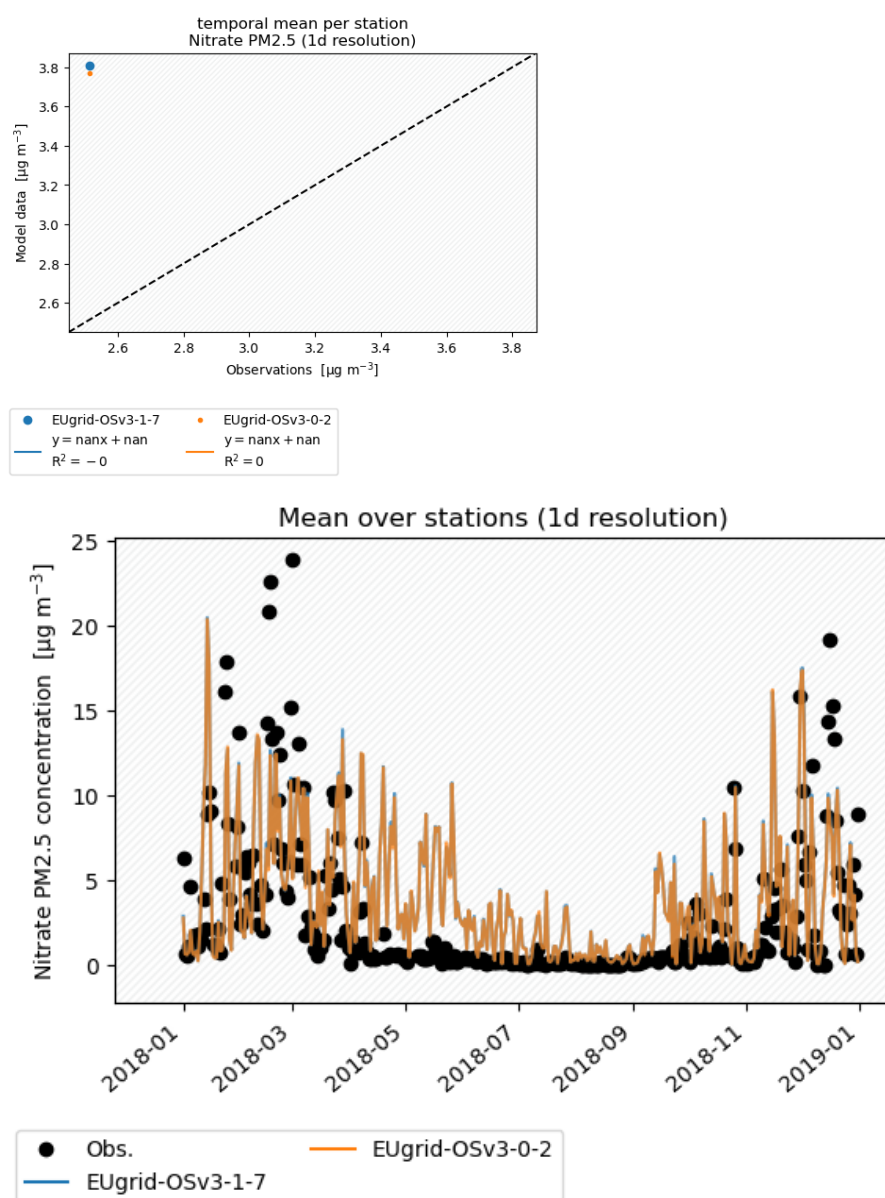


Figure 4.45: Station means (EBAS) – NO_3^- ($\text{PM}_{2.5}$) | annual mean (top), spatial mean (bottom)

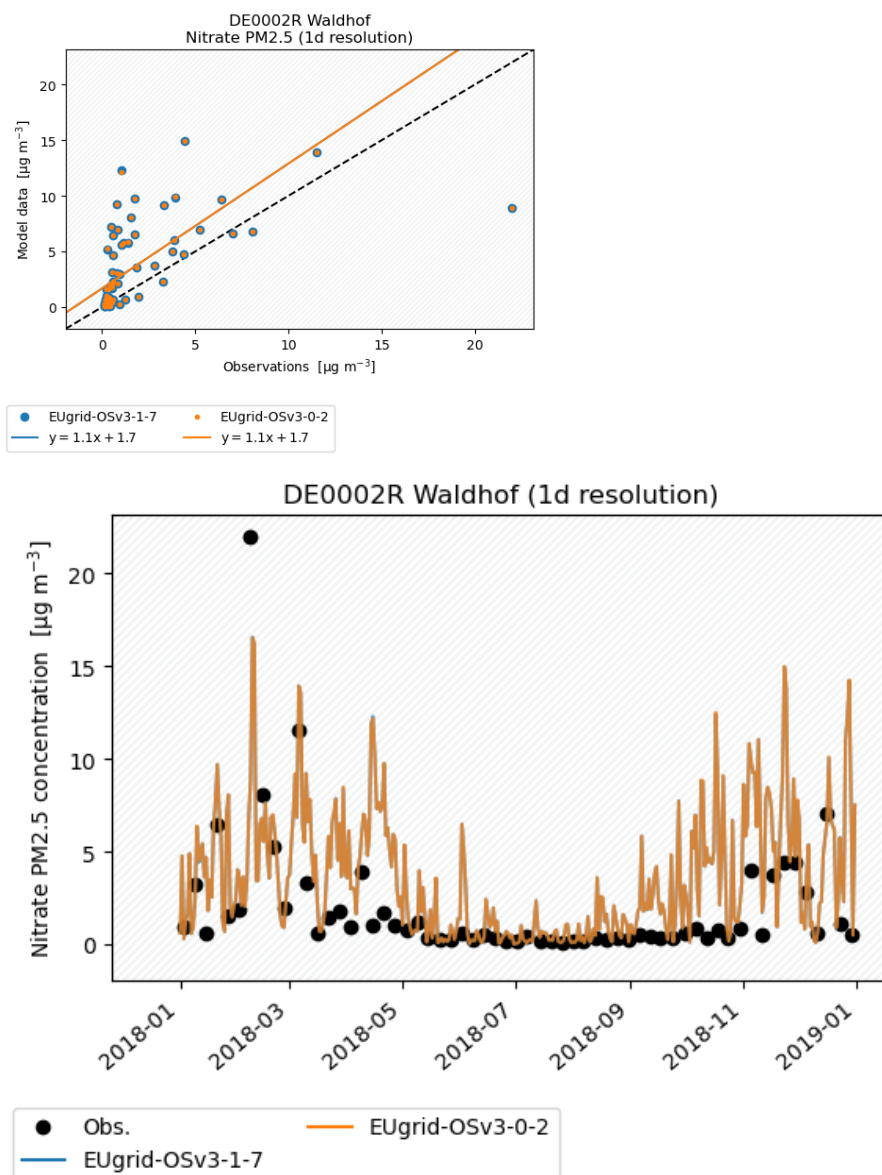


Figure 4.46: Station DE0002R (EBAS) – NO_3^- ($\text{PM}_{2.5}$)

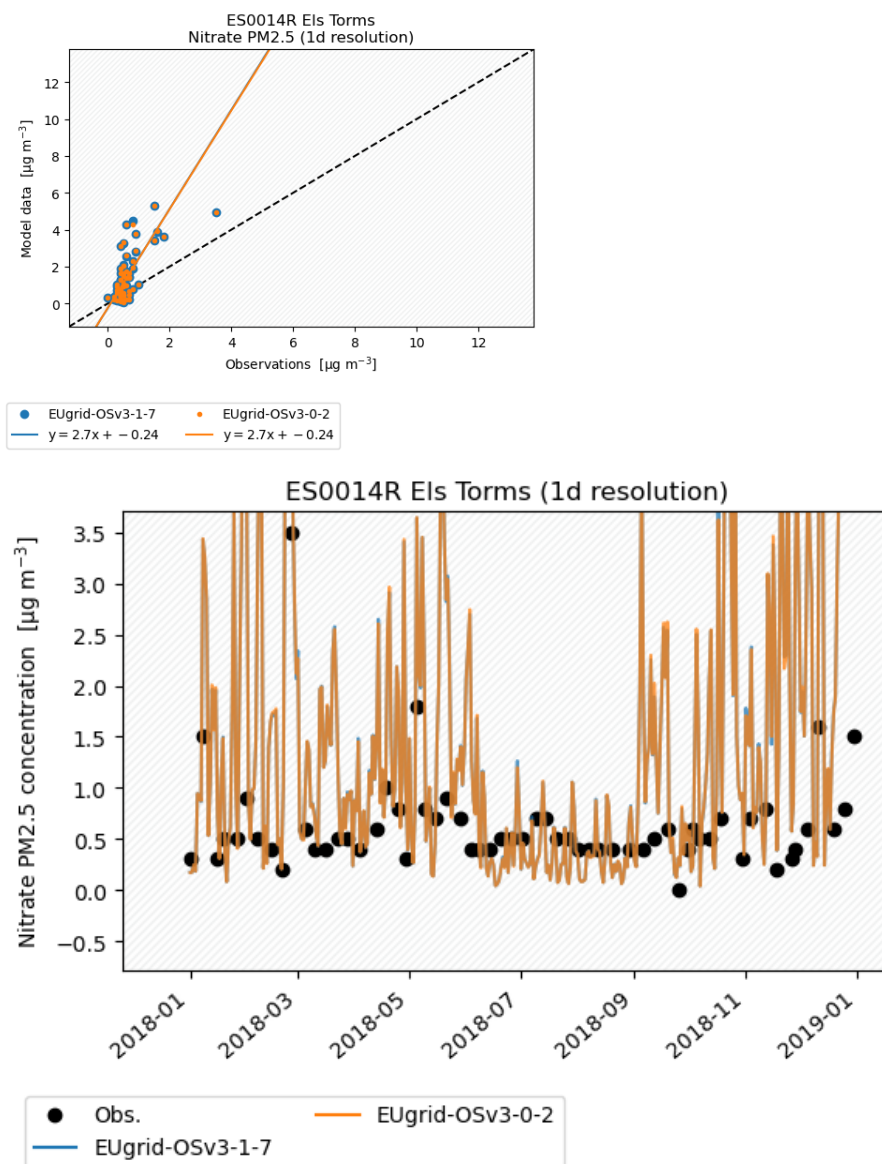


Figure 4.47: Station ES0014R (EBAS) – NO_3^- ($\text{PM}_{2.5}$)

4.4.1.3 Ammonium (PM_{2.5})

Ammonium (PM_{2.5}) is mainly impacted by the wind vector interpolation update, and the update of the mean free path length.

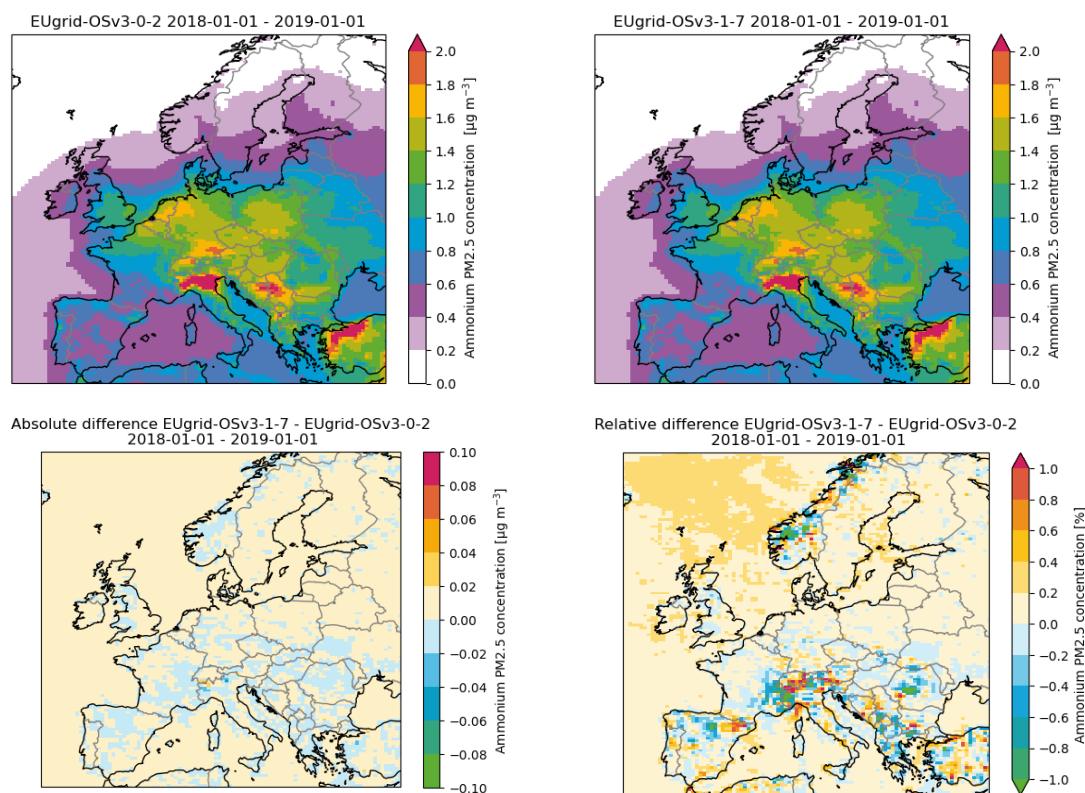


Figure 4.48: Averaged concentration map comparison for NH_4^+ (PM_{2.5})

Measurement validation for NH_4^+ (PM_{2.5})

Table 4.9: Statistics for NH_4^+ (PM_{2.5})

NH_4^+ (PM _{2.5})		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1d	0.978	0.237	0.403	0.985	0.234	0.409	0.007	-0.004	0.006

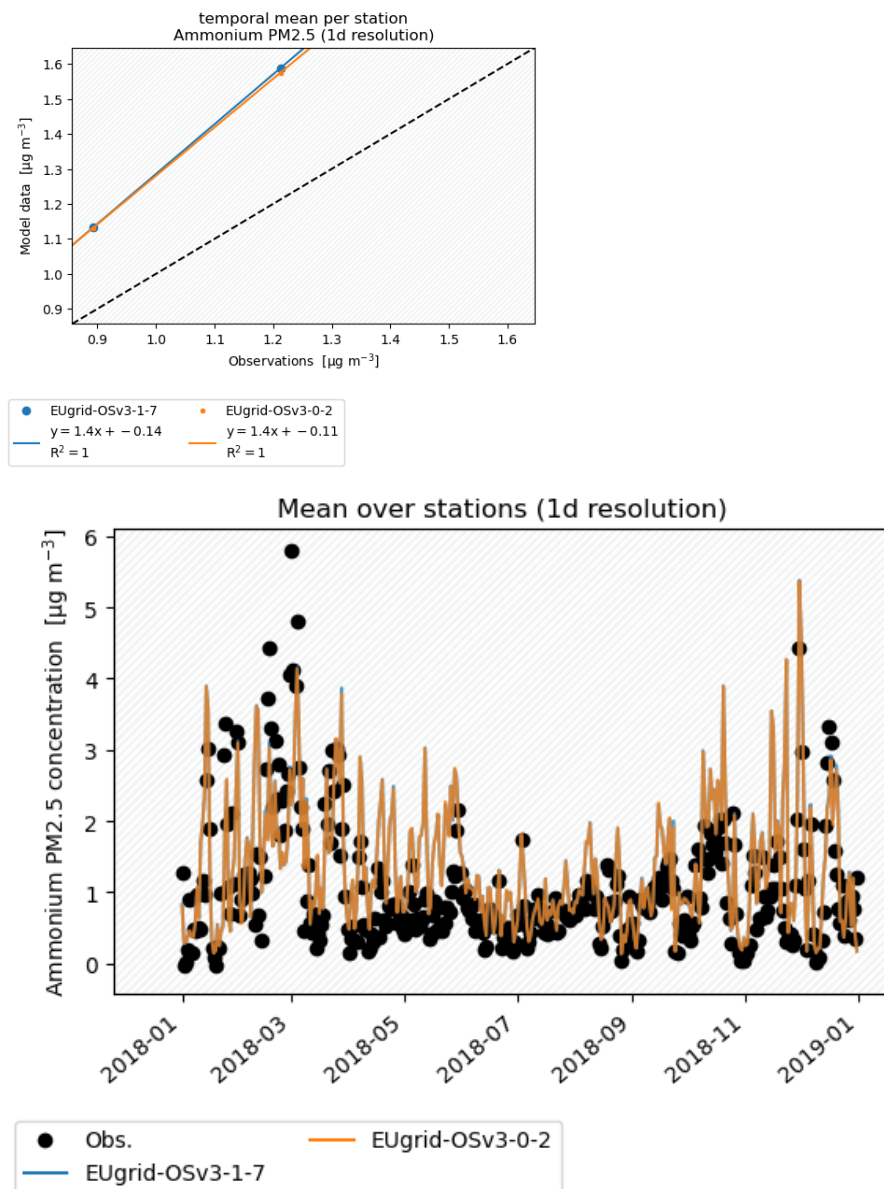


Figure 4.49: Station means (EBAS) – NH_4^+ ($\text{PM}_{2.5}$) | annual mean (top), spatial mean (bottom)

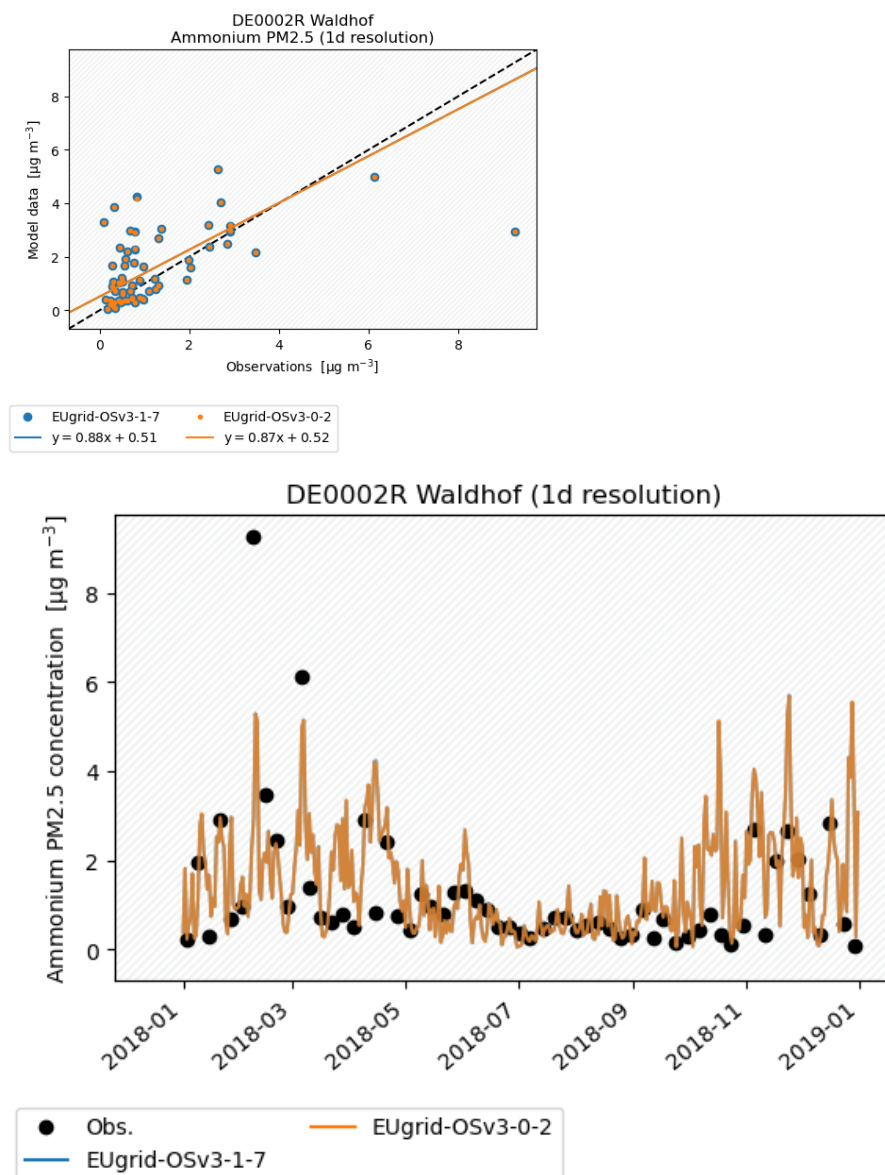


Figure 4.50: Station DE0002R (EBAS) – NH_4^+ ($\text{PM}_{2.5}$)

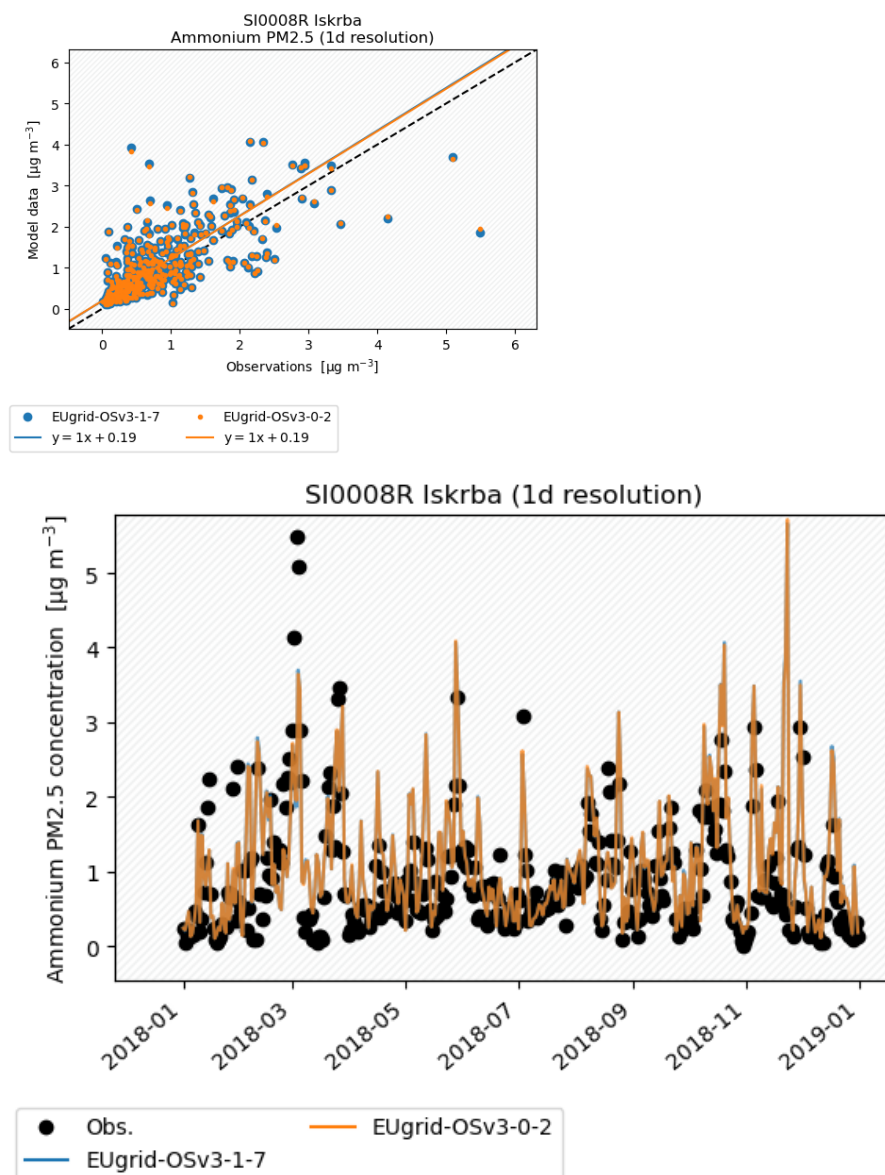


Figure 4.51: Station SI0008R (EBAS) – NH_4^+ ($\text{PM}_{2.5}$)

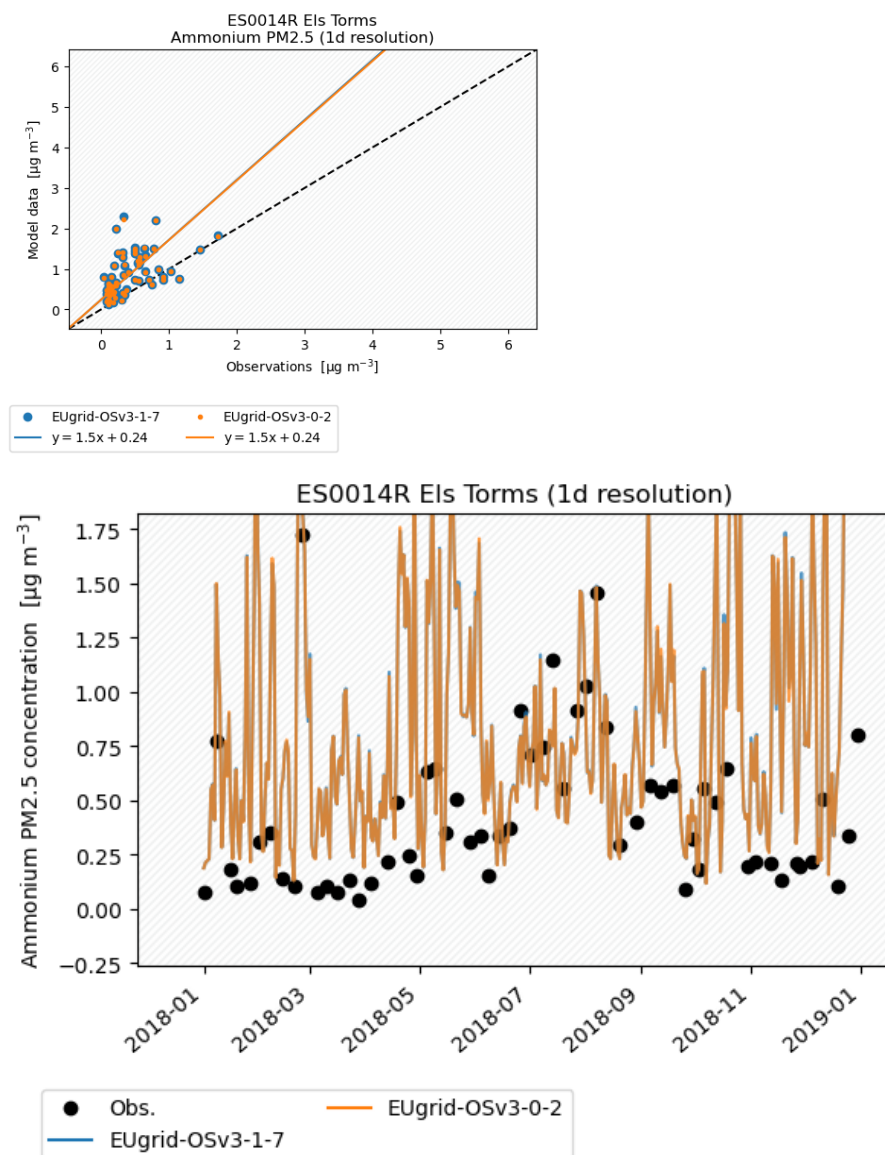


Figure 4.52: Station ES0014R (EBAS) – NH_4^+ ($\text{PM}_{2.5}$)

4.4.1.4 Sulphate Corrected (PM_{2.5})

Sulphate (PM_{2.5}) is mainly impacted by the wind vector interpolation update, and the update of the mean free path length.

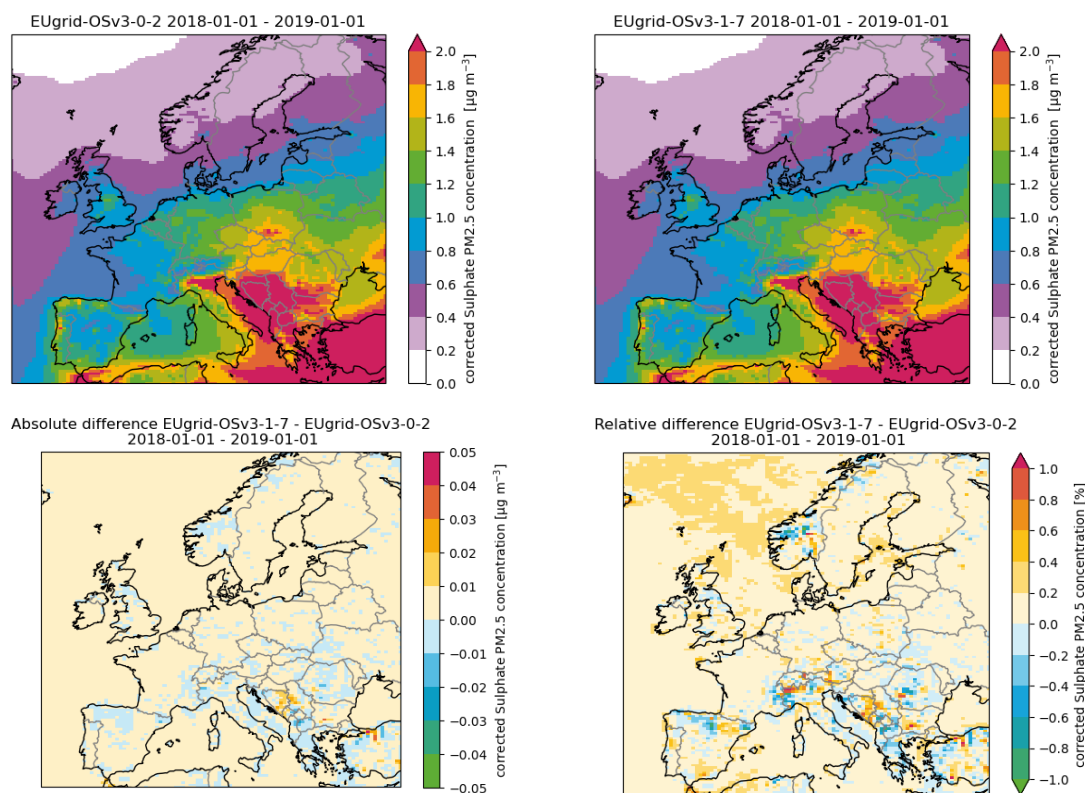


Figure 4.53: Averaged concentration map comparison for SO_4^{2-} (PM_{2.5})

Measurement validation for SO_4^{2-} (PM_{2.5})

Table 4.10: Statistics for SO_4^{2-} (PM_{2.5})

SO_4^{2-} (PM _{2.5})		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1d	1.288	0.187	-0.177	1.29	0.184	-0.174	0.002	-0.003	0.003

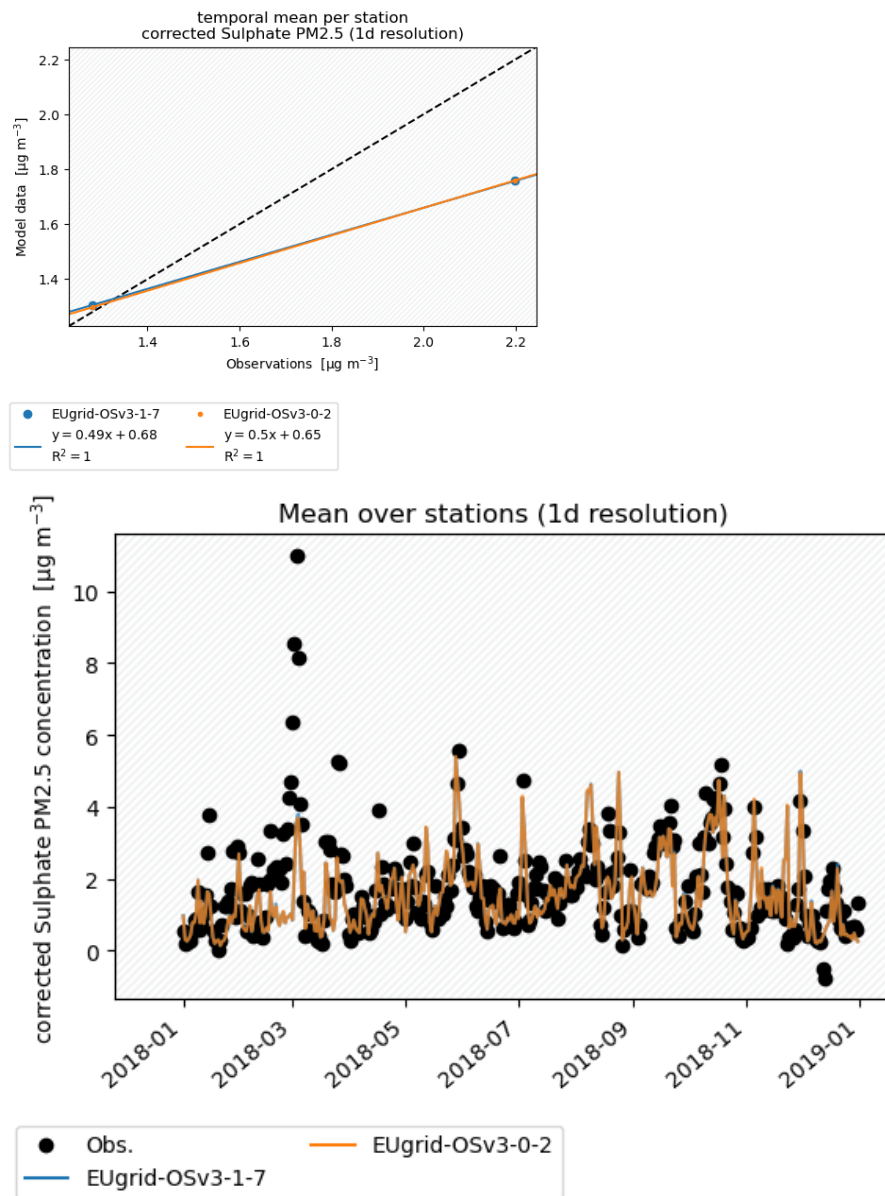


Figure 4.54: Station means (EBAS) – SO_4^{2-} (PM_{2.5}) | annual mean (top), spatial mean (bottom)

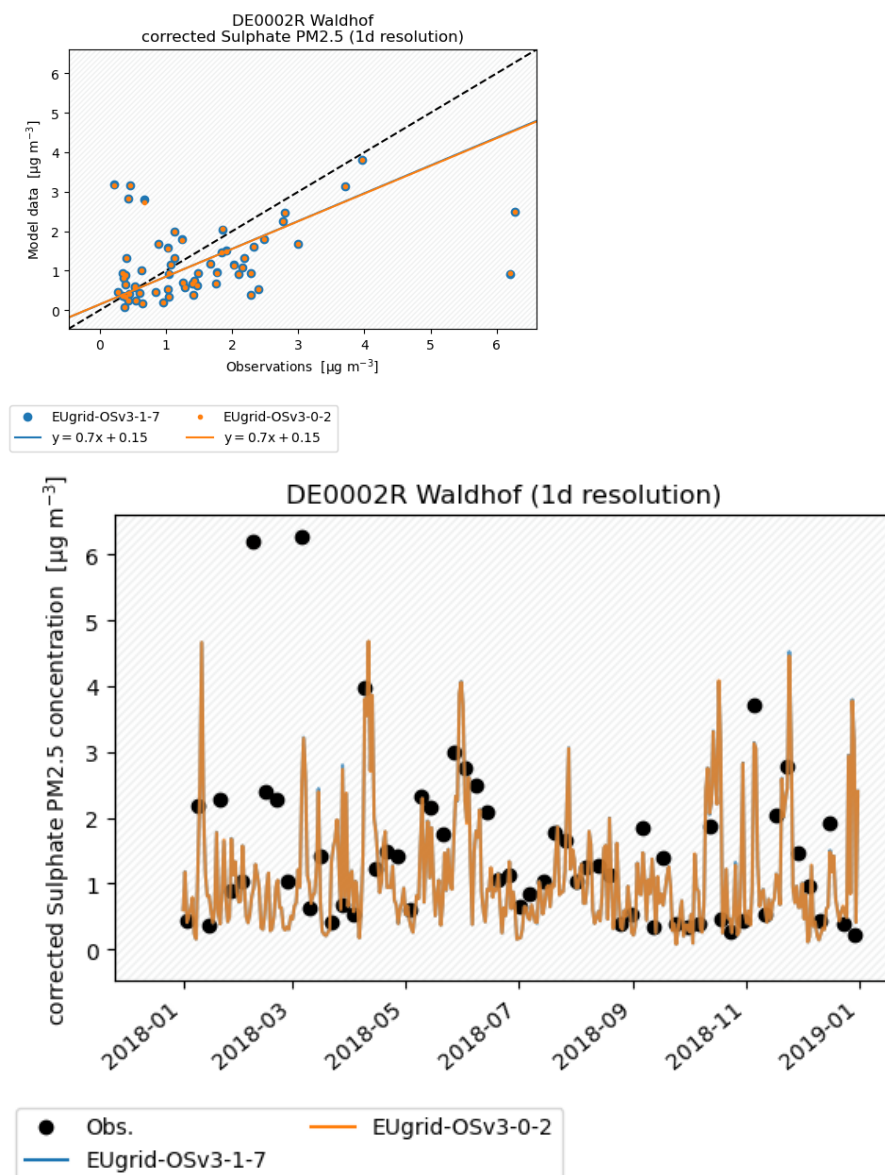


Figure 4.55: Station DE0002R (EBAS) – SO_4^{2-} ($\text{PM}_{2.5}$)

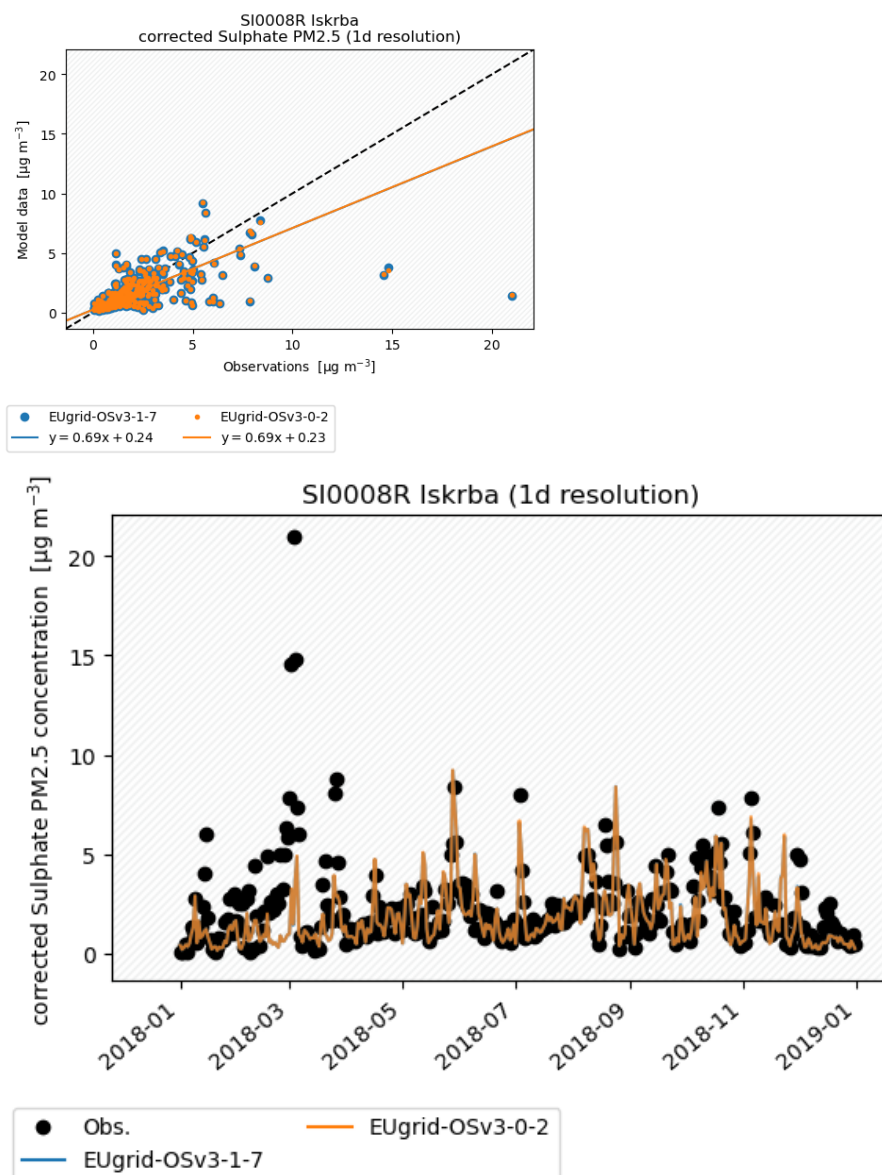


Figure 4.56: Station SI0008R (EBAS) – SO_4^{2-} (PM_{2.5})

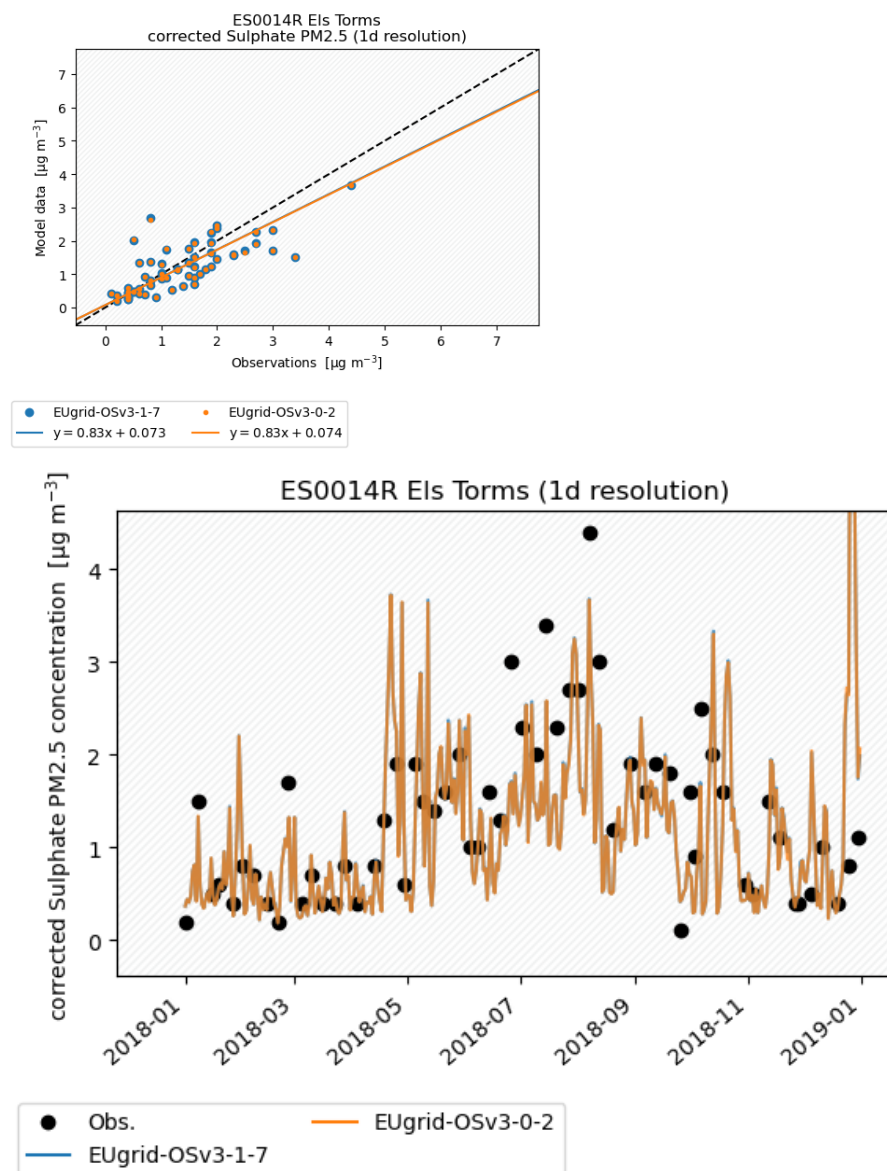


Figure 4.57: Station ES0014R (EBAS) – SO_4^{2-} ($\text{PM}_{2.5}$)

4.4.2 PM₁₀

4.4.2.1 Total PM₁₀

Total PM₁₀ is mainly impacted by the wind vector interpolation update, and the road resuspension emission bugfix.

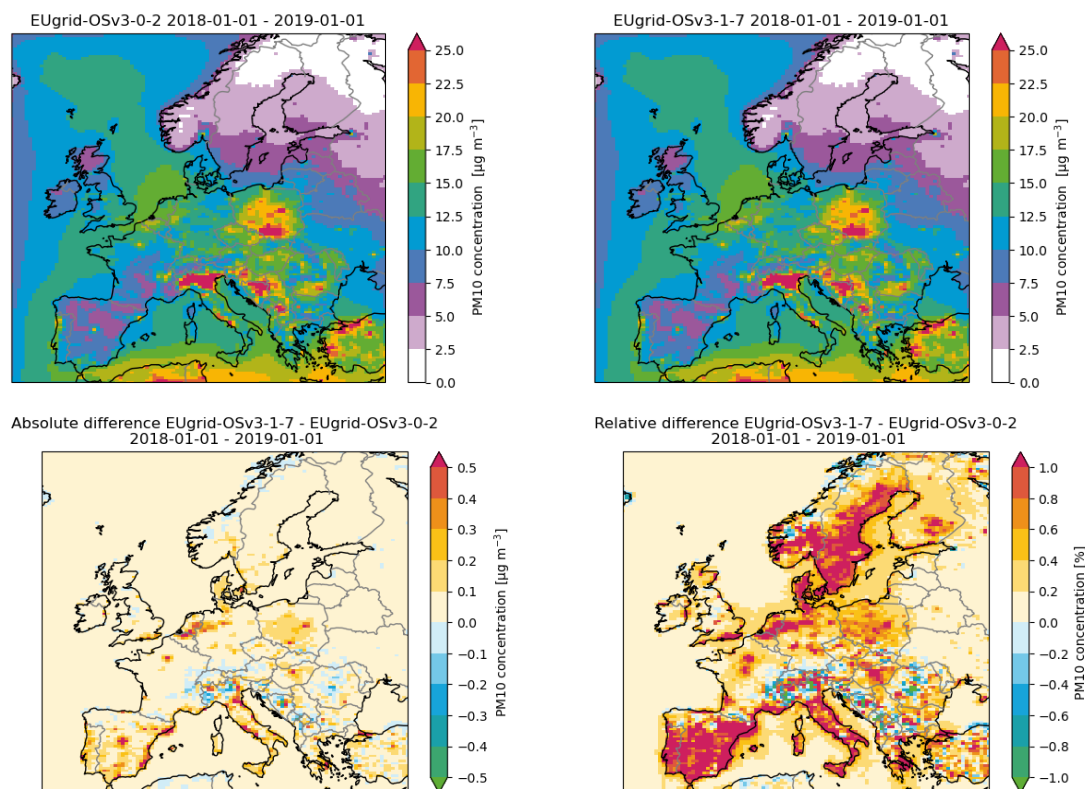


Figure 4.58: Averaged concentration map comparison for PM₁₀

Measurement validation for PM₁₀

Table 4.11: Statistics for PM₁₀

PM ₁₀		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1h	9.556	0.188	-0.13	9.551	0.189	-0.127	-0.005	0.001	0.004
EBAS	1d	8.988	0.29	-0.183	8.968	0.291	-0.178	-0.02	0.001	0.005
EEA	1h	13.305	0.254	-0.193	13.36	0.254	-0.185	0.055	0.0	0.009

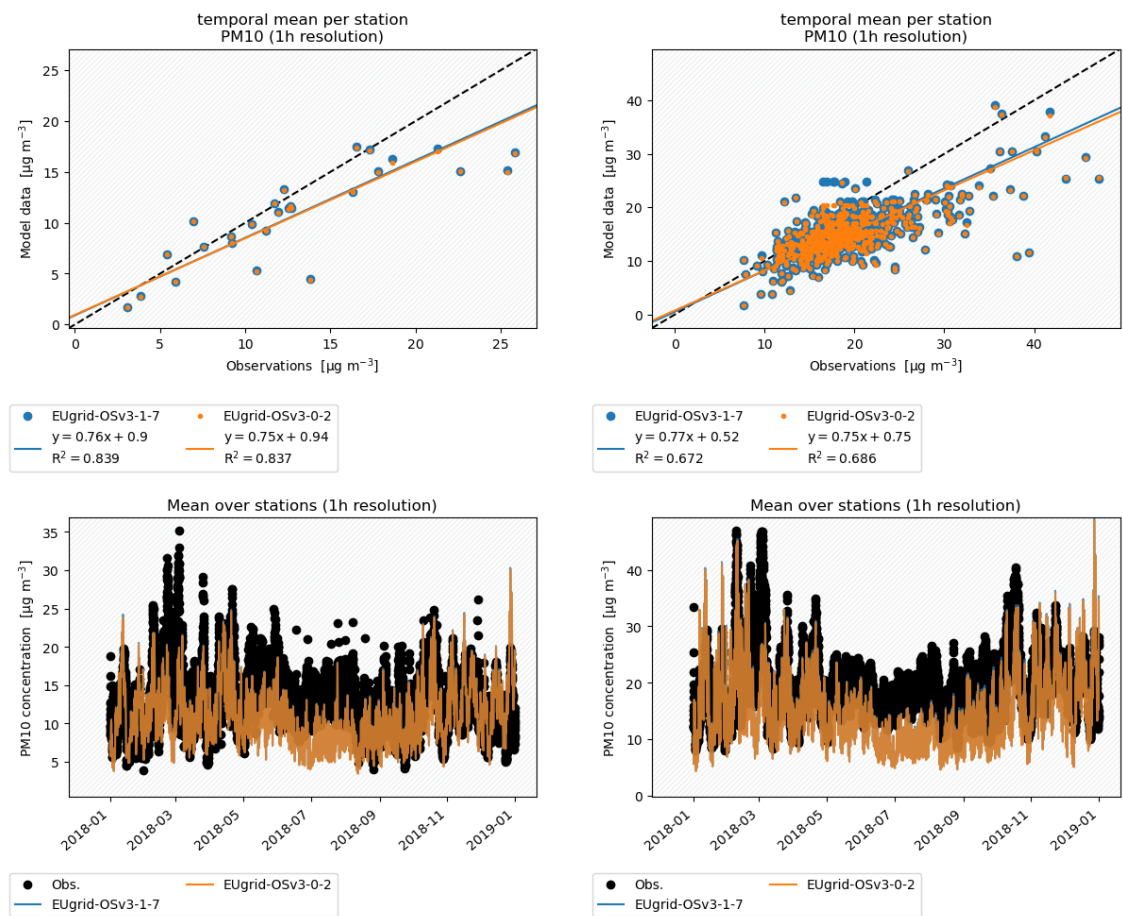


Figure 4.59: Station means – PM_{10} | EBAS (left), EEA (right), annual mean (top), spatial mean (bottom)

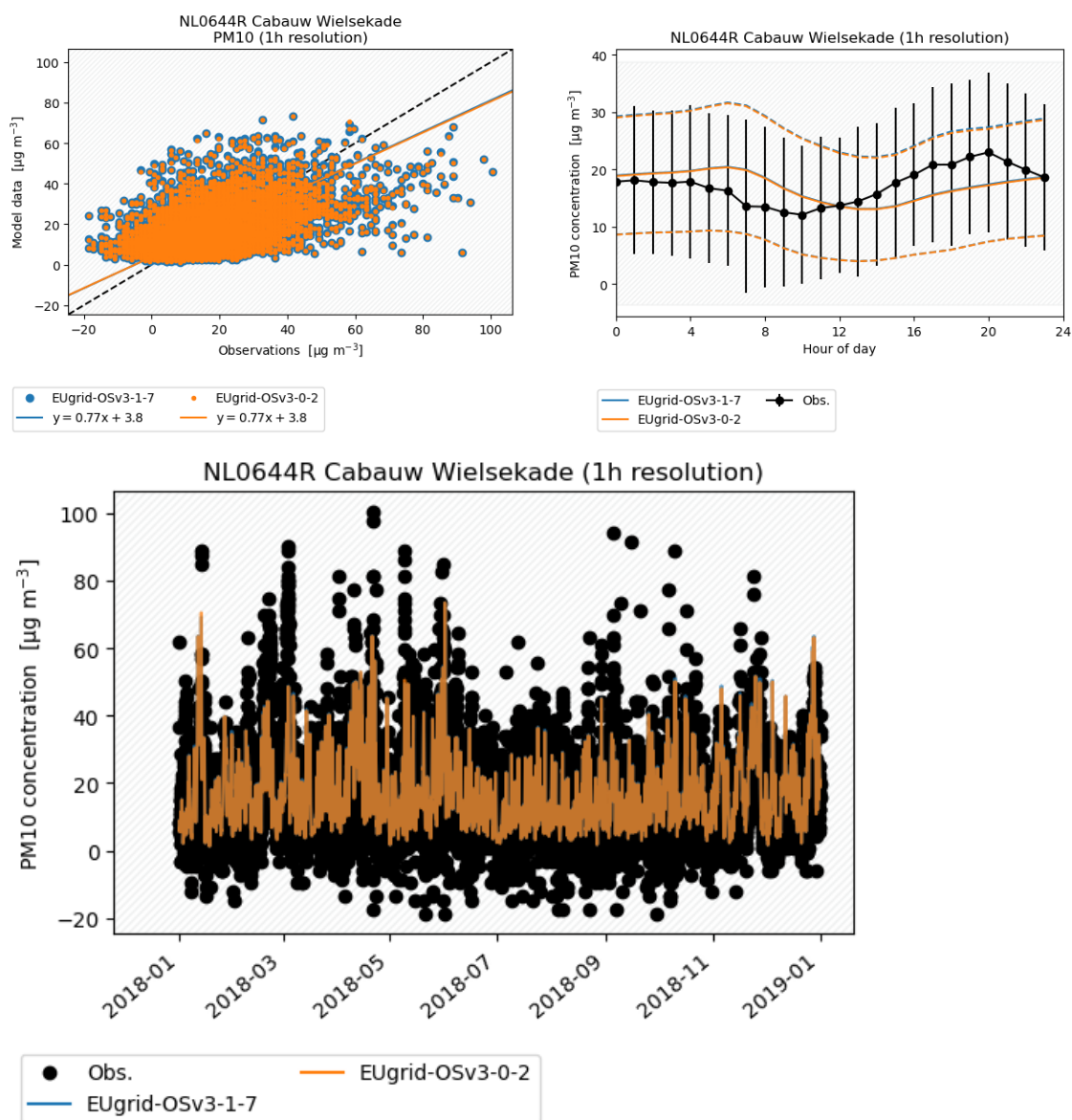


Figure 4.60: Station NL0644R (EBAS) – PM_{10}

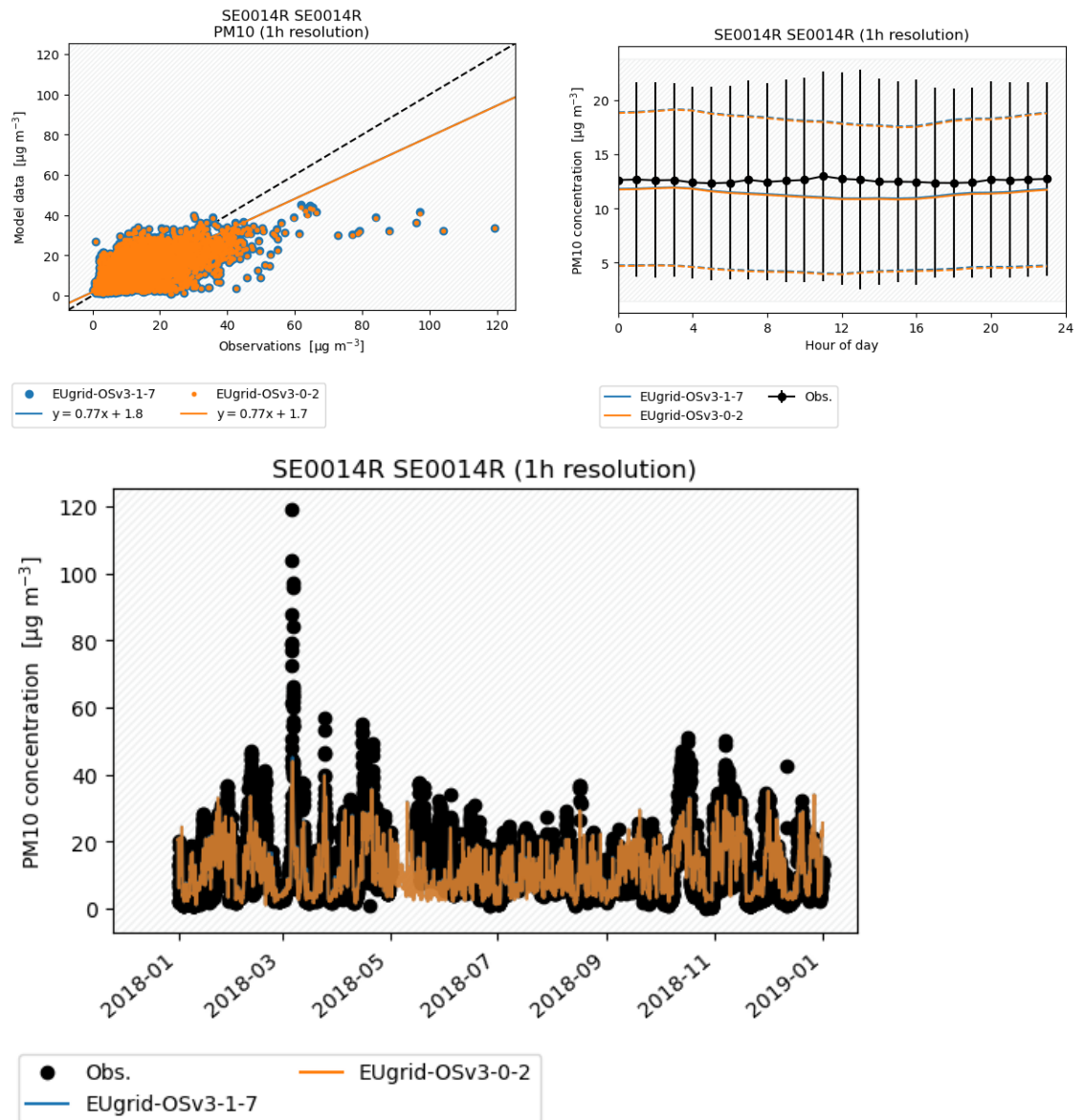


Figure 4.61: Station SE0014R (EBAS) – PM₁₀

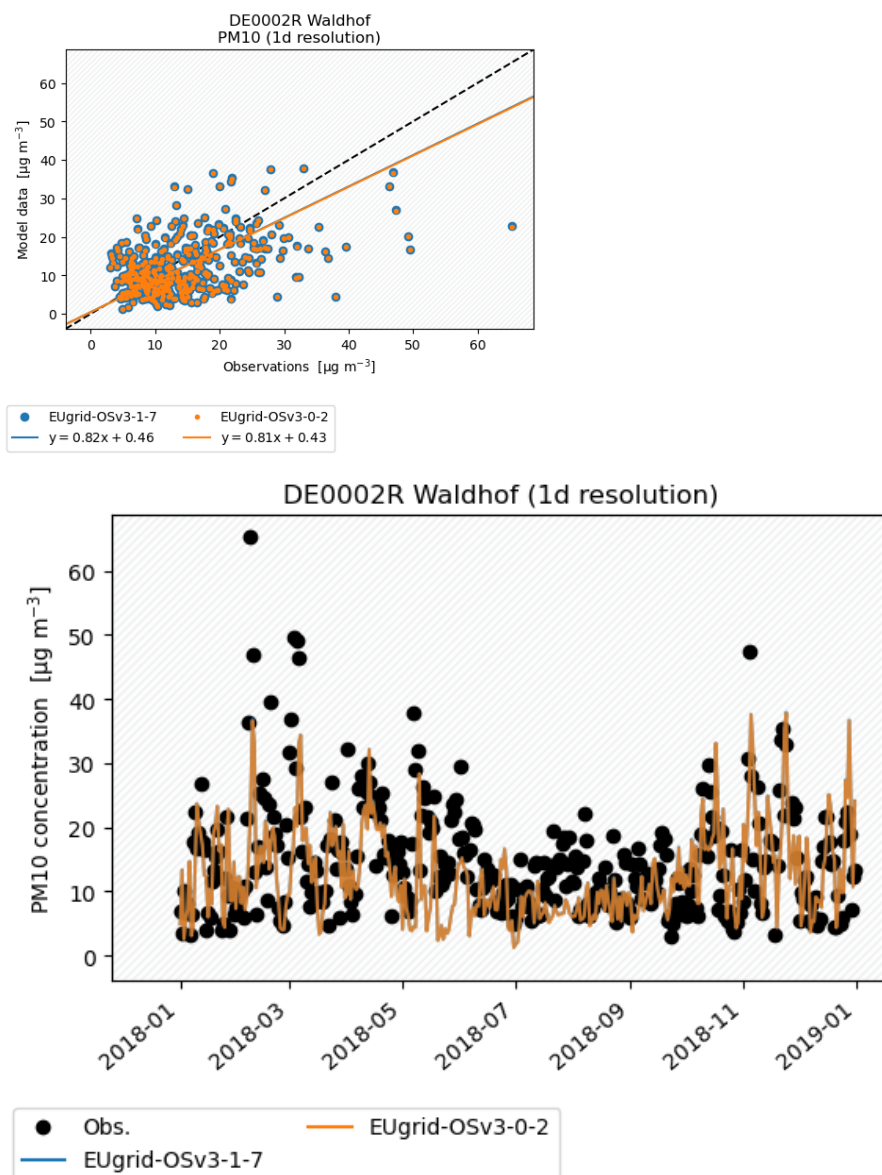


Figure 4.62: Station DE0002R (EBAS) – PM₁₀

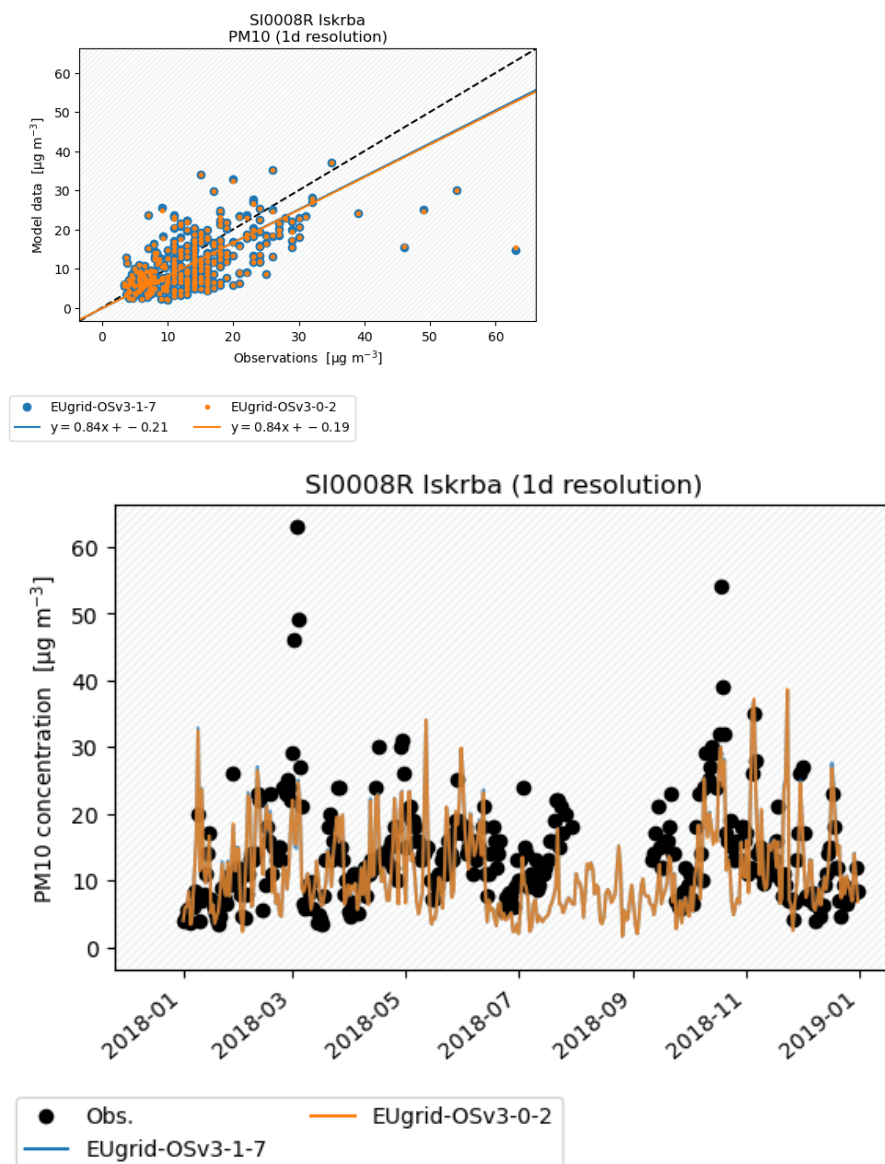


Figure 4.63: Station SI0008R (EBAS) – PM₁₀

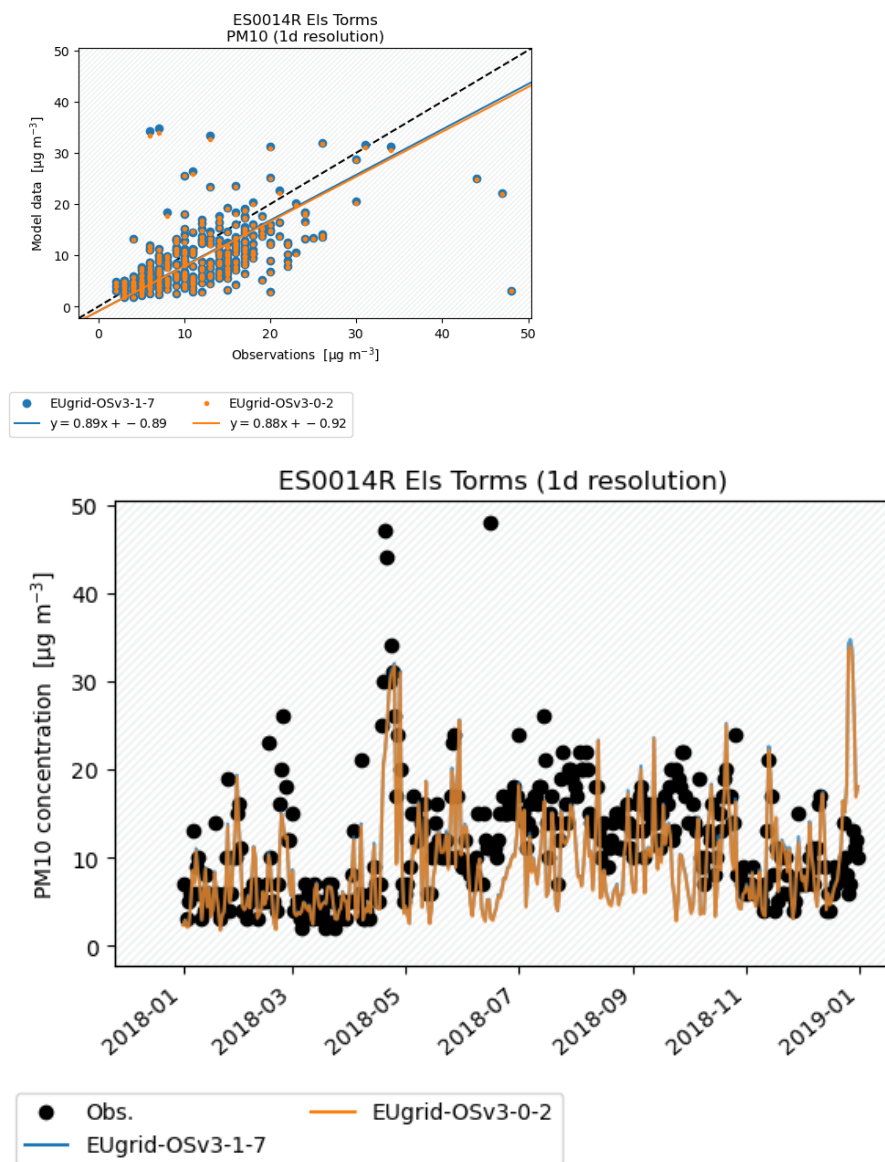


Figure 4.64: Station ES0014R (EBAS) – PM₁₀

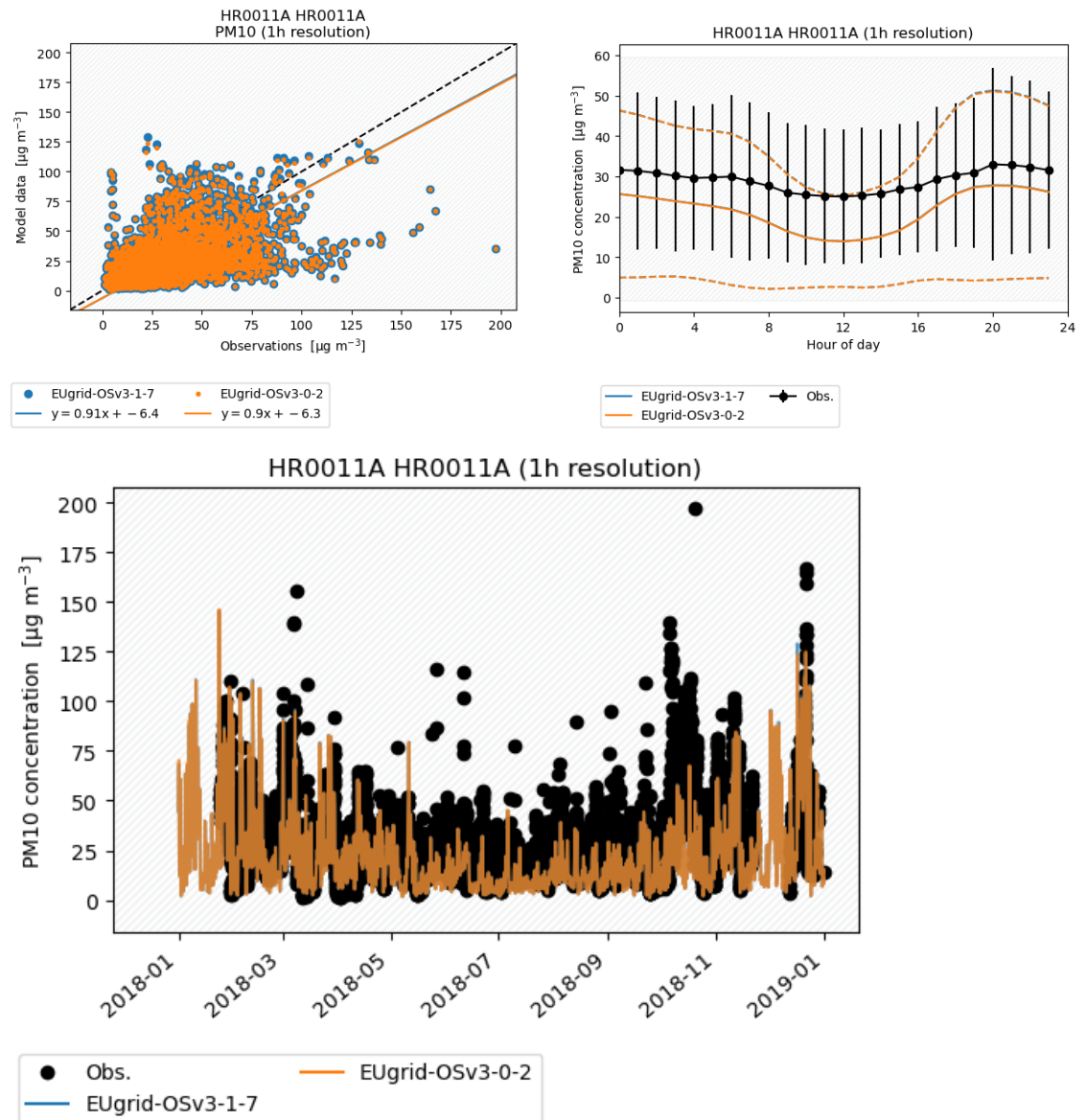


Figure 4.65: Station HR0011A (eea) – PM₁₀

4.4.2.2 Sodium (PM₁₀)

Sodium (PM₁₀) is mainly impacted by the wind vector interpolation update.

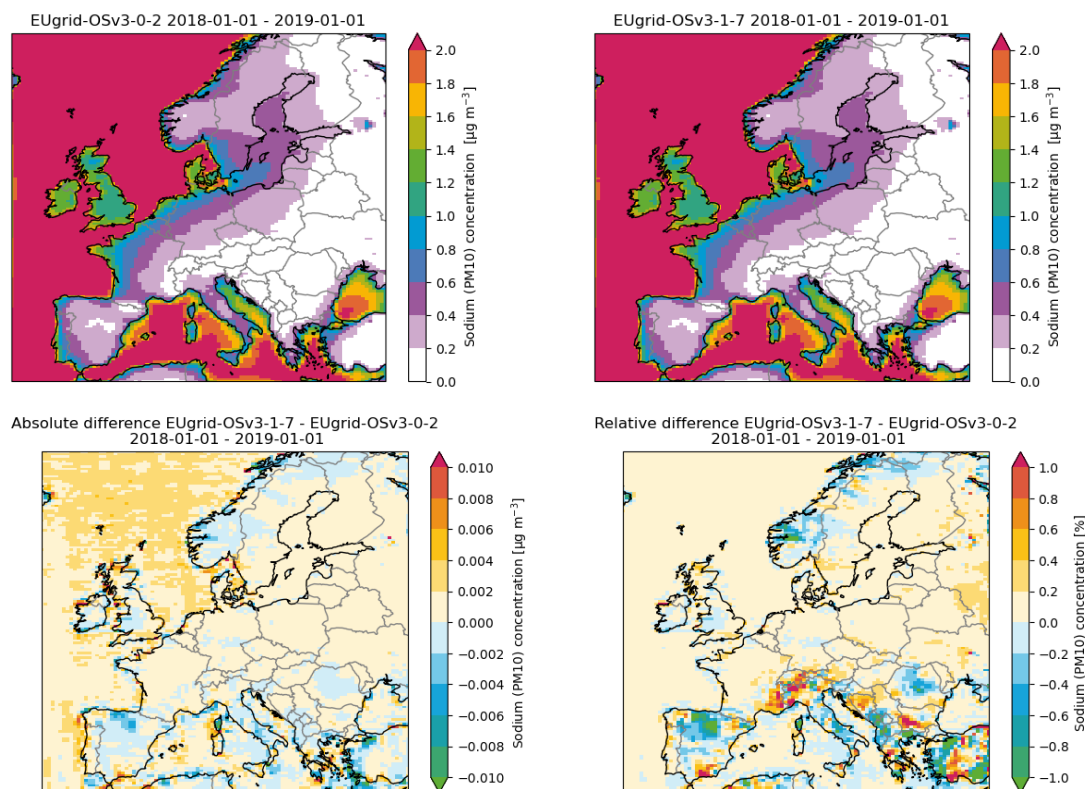


Figure 4.66: Averaged concentration map comparison for Na (PM₁₀)

Measurement validation for Na (PM₁₀)

Table 4.12: Statistics for Na (PM₁₀)

Na (PM ₁₀)		OSv3-0-2			OSv3-1-7			difference		
set	delta time	RMSE	R ²	NMB	RMSE	R ²	NMB	RMSE	R ²	NMB
EBAS	1d	0.858	0.245	0.161	0.858	0.245	0.155	0.0	0.0	-0.006

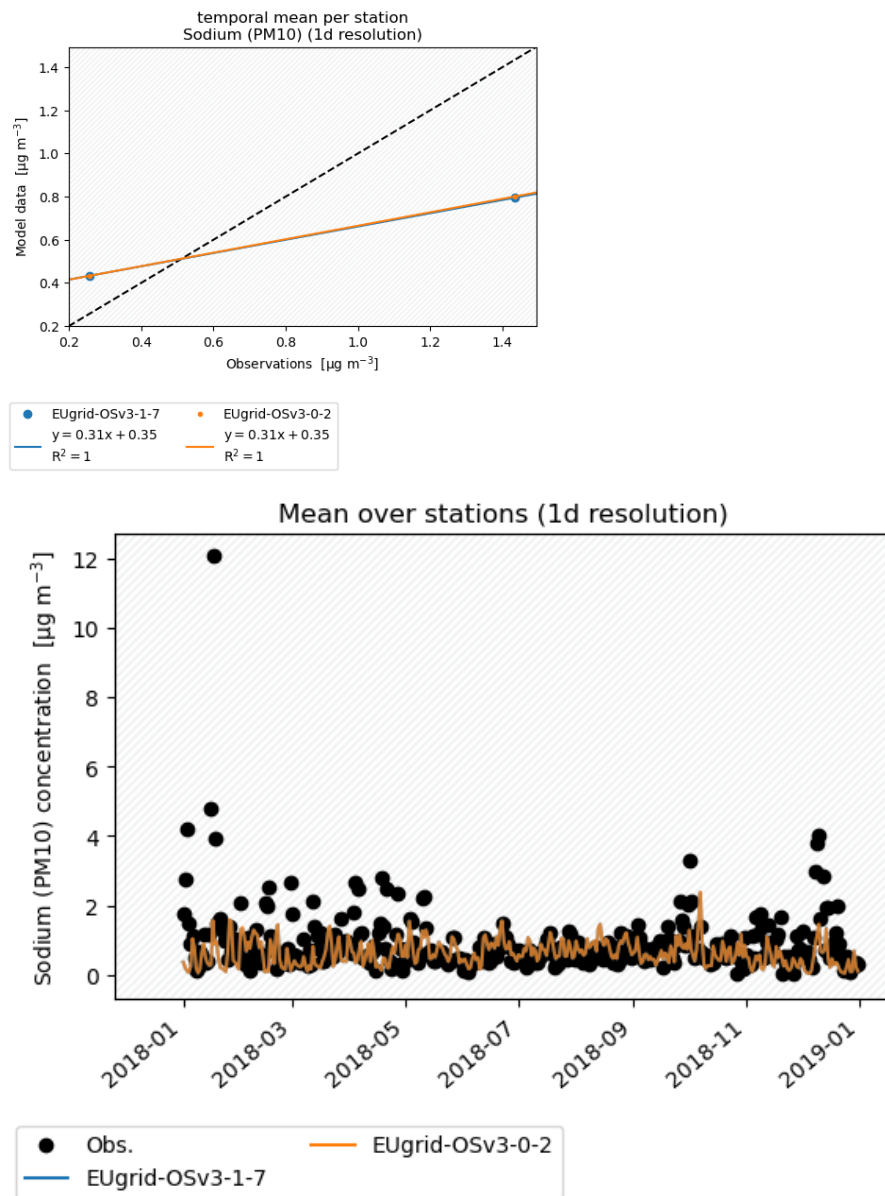


Figure 4.67: Station means (EBAS) – Na (PM₁₀) | annual mean (top), spatial mean (bottom)

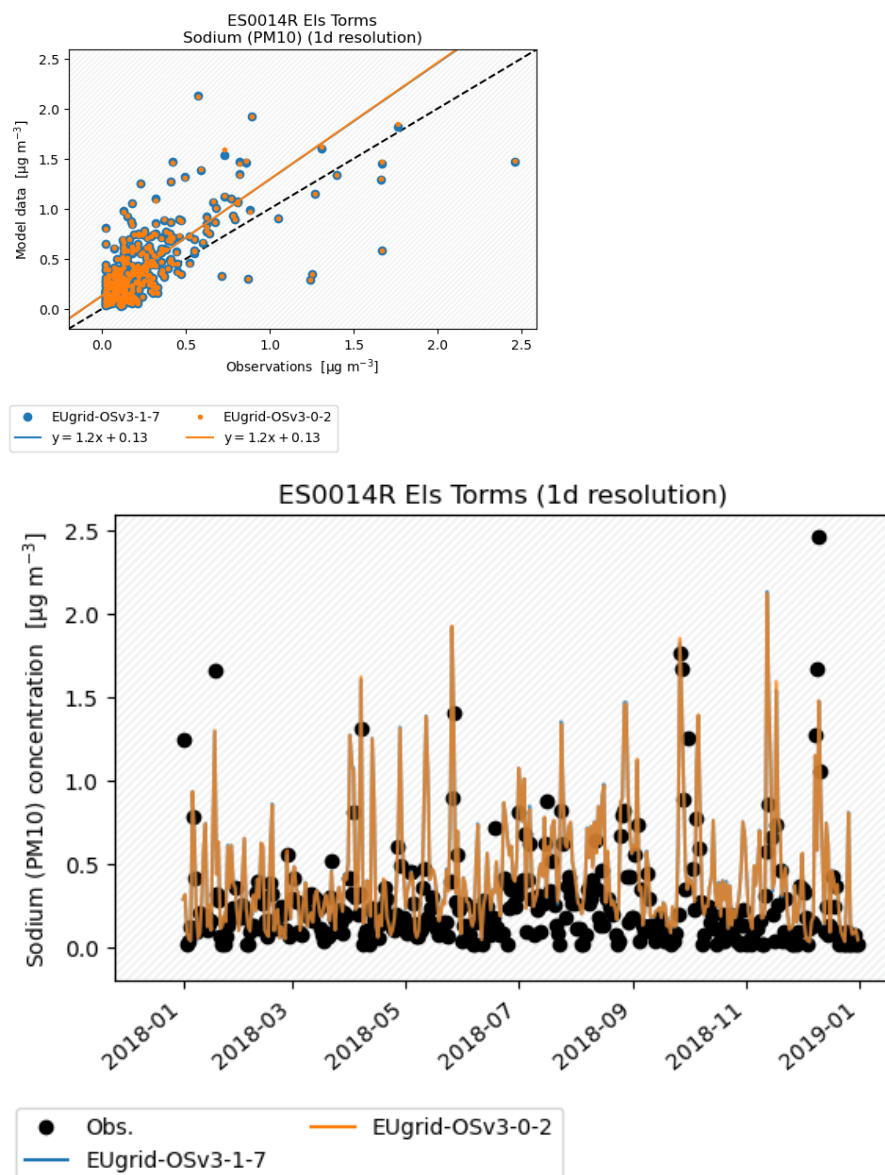


Figure 4.68: Station ES0014R (EBAS) – Na (PM₁₀)

4.4.2.3 Organic Carbon (PM₁₀)

Organic carbon (PM₁₀) is mainly impacted by the wind vector interpolation update.

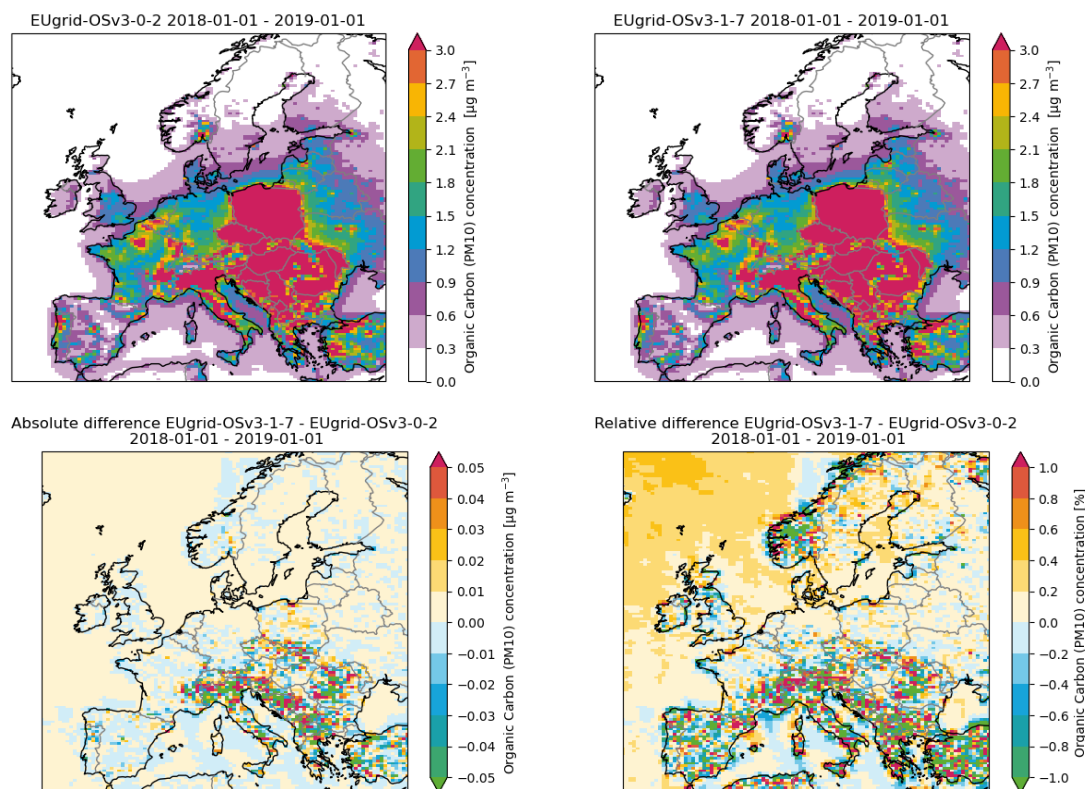


Figure 4.69: Averaged concentration map comparison for Organic C (PM₁₀)

Measurement validation for Organic C (PM₁₀)

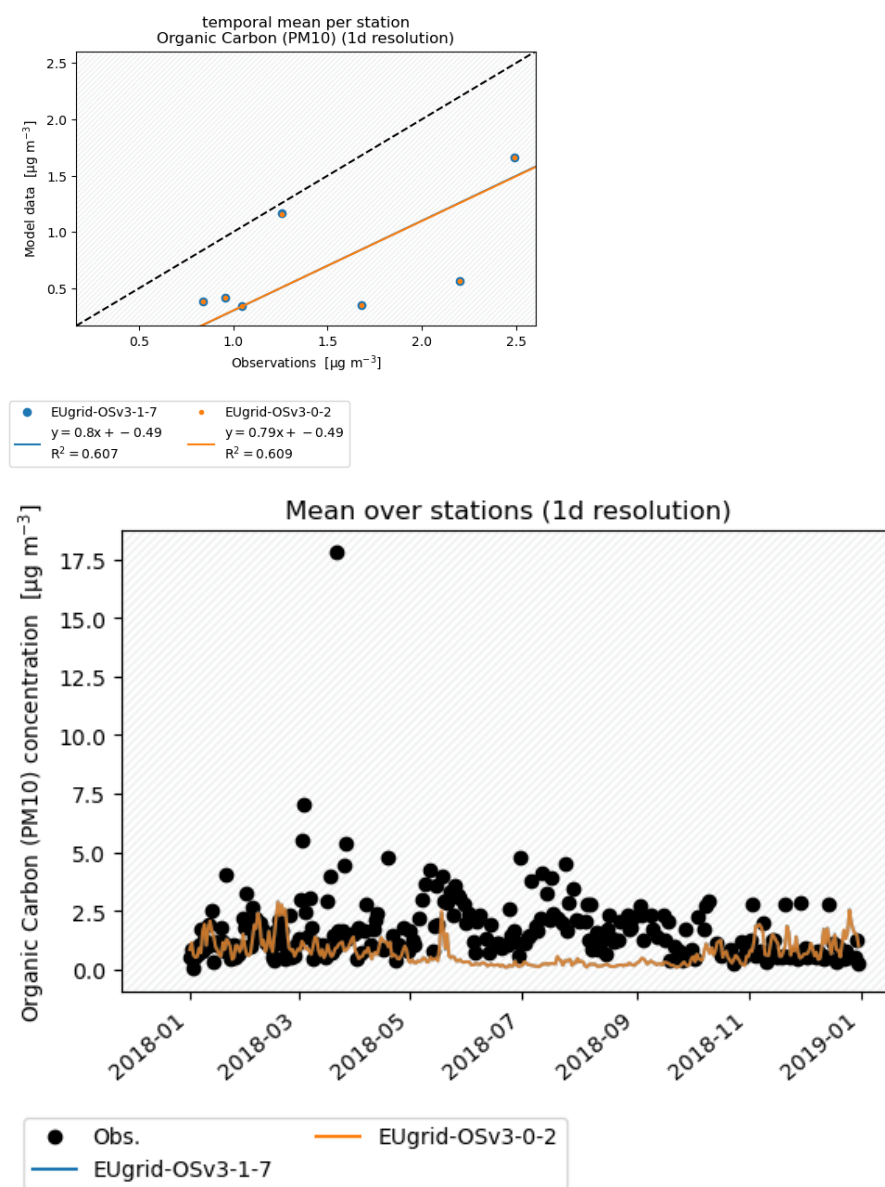


Figure 4.70: Station stationmean (EBAS) – Organic C (PM₁₀)

4.4.2.4 Elementary Carbon (PM₁₀)

Elementary carbon (PM₁₀) is mainly impacted by the wind vector interpolation update.

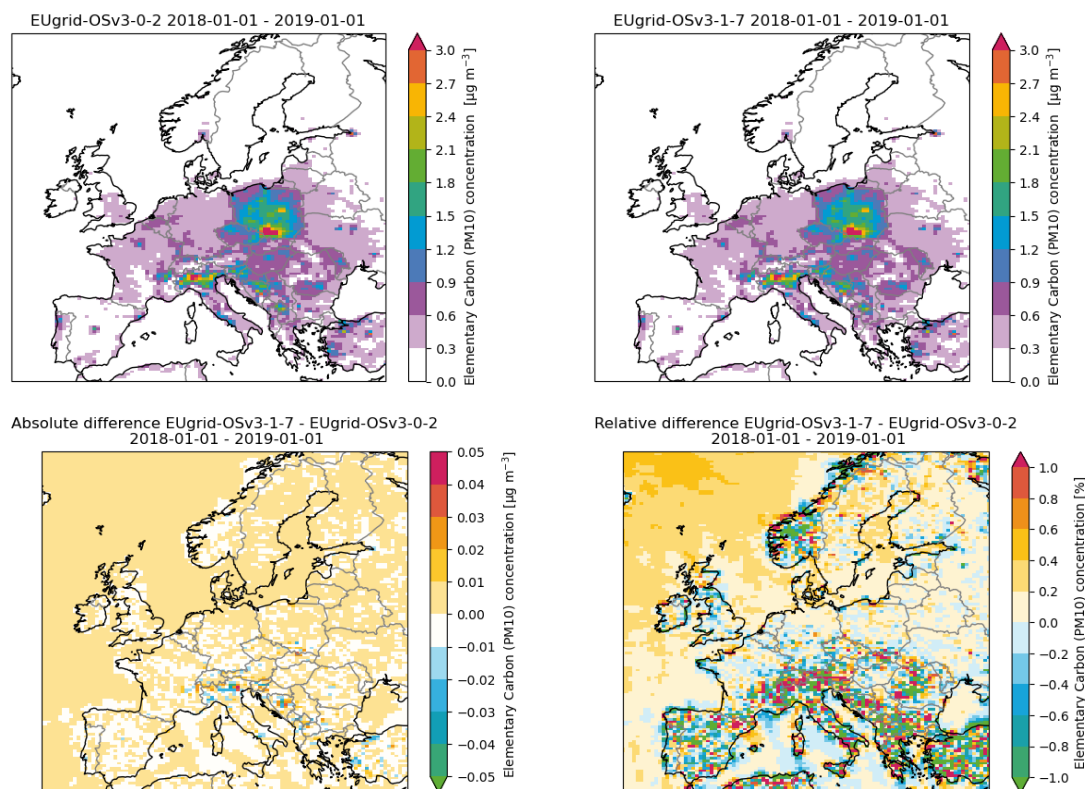


Figure 4.71: Averaged concentration map comparison for Elementary C (PM₁₀)

Measurement validation for Elementary C (PM₁₀)

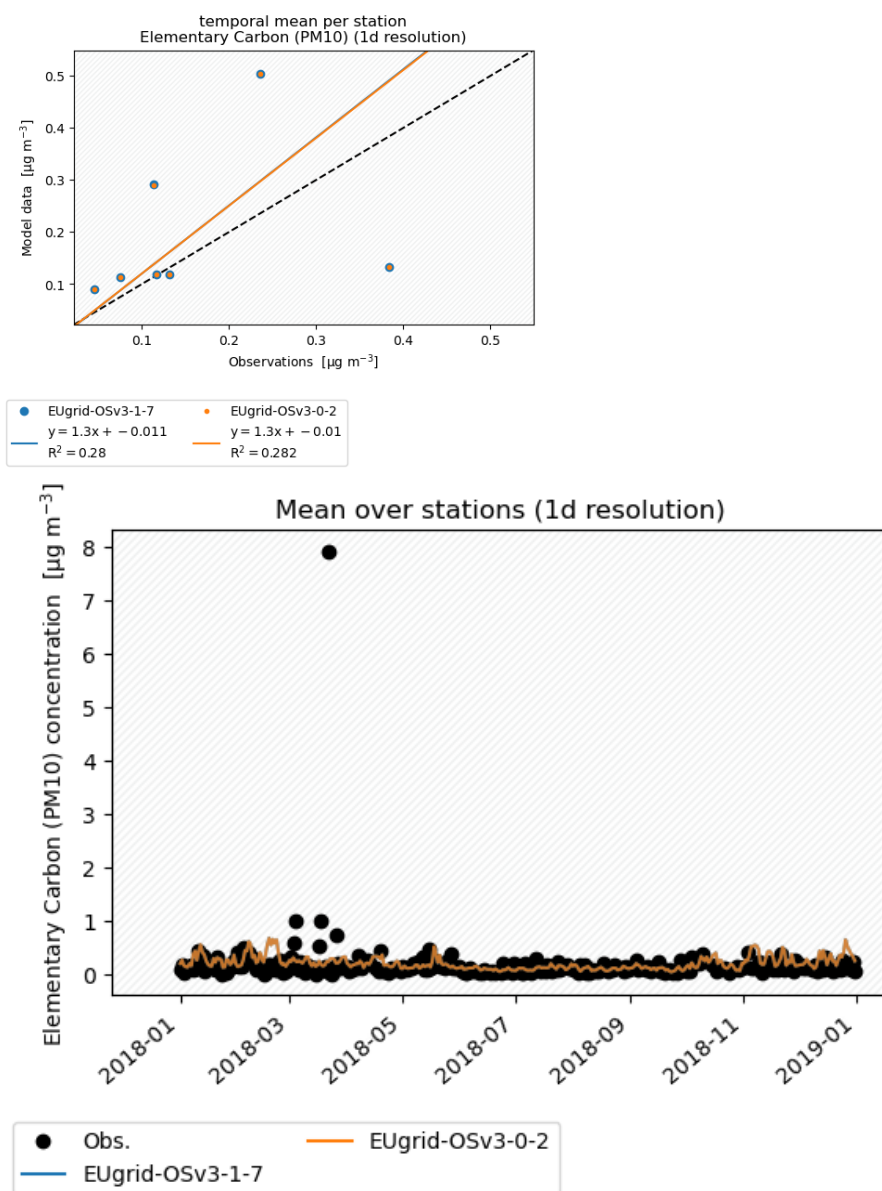


Figure 4.72: Station stationmean (EBAS) – Elementary C (PM₁₀)

4.4.2.5 Mineral Dust (PM₁₀)

Mineral dust (PM₁₀) is mainly impacted by the wind vector interpolation update, and the road resuspension emission bugfix.

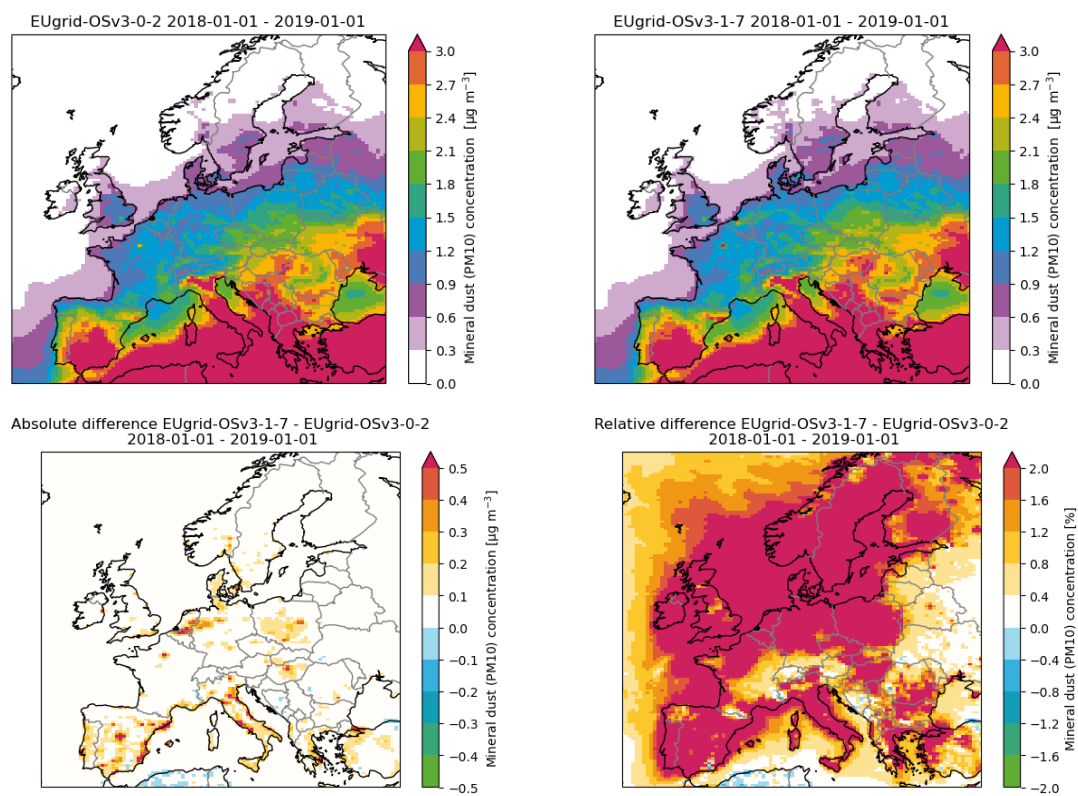


Figure 4.73: Averaged concentration map comparison for Mineral Dust (PM₁₀)

4.5 Budgets

4.5.1 NH_x

4.5.1.1 NH_x Dry

The NH_x dry deposition budget is mainly impacted by the wind vector interpolation update. The ammonium particles impacted by the update of the mean free path length.

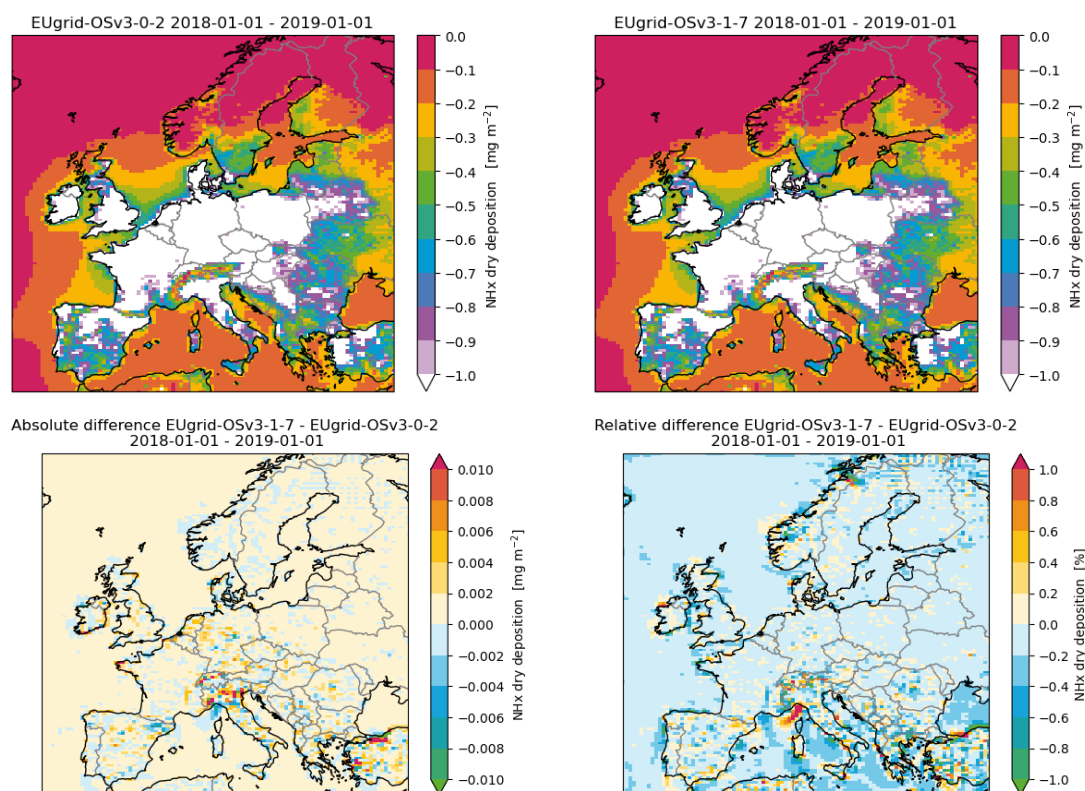


Figure 4.74: Averaged concentration map comparison for NH_x dry deposition

4.5.1.2 NH_x Wet

The NH_x wet deposition budget is mainly impacted by the wind vector interpolation update. The ammonium particles are impacted by the update of the mean free path length.

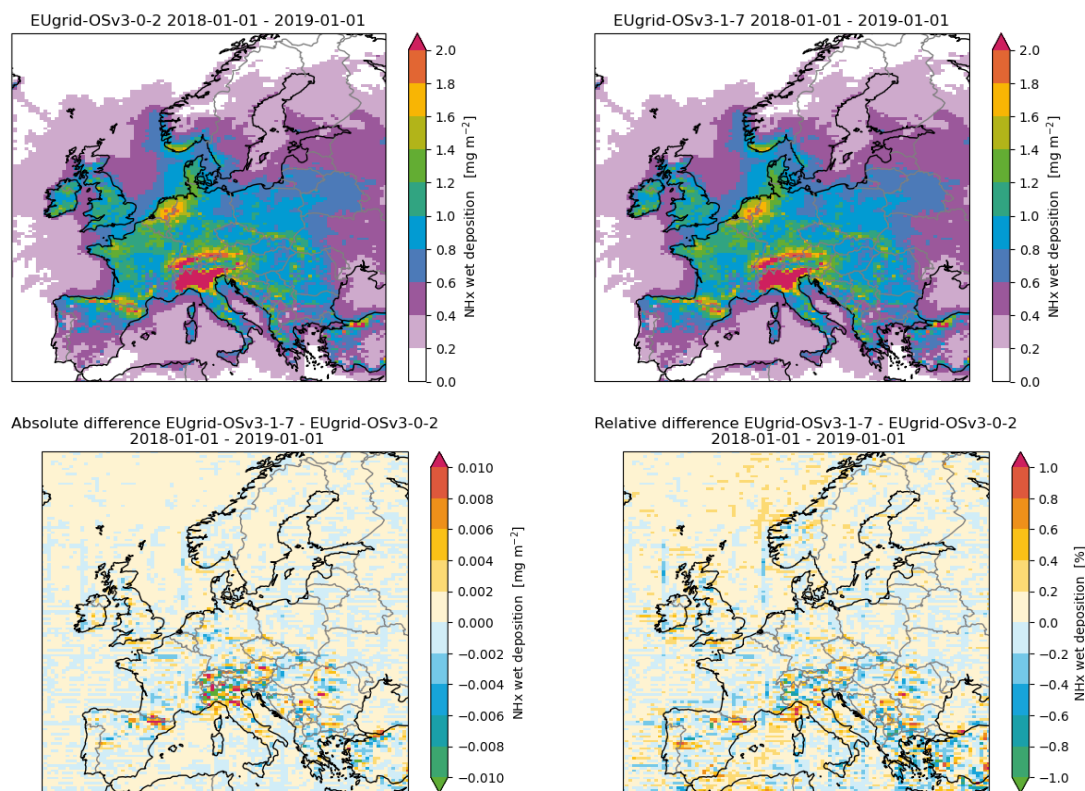


Figure 4.75: Averaged concentration map comparison for NH_x wet deposition

4.5.2 NO_y

4.5.2.1 NO_y Dry

The NO_y dry deposition budget is mainly impacted by the wind vector interpolation update. The nitrate particles are impacted by the update of the mean free path length.

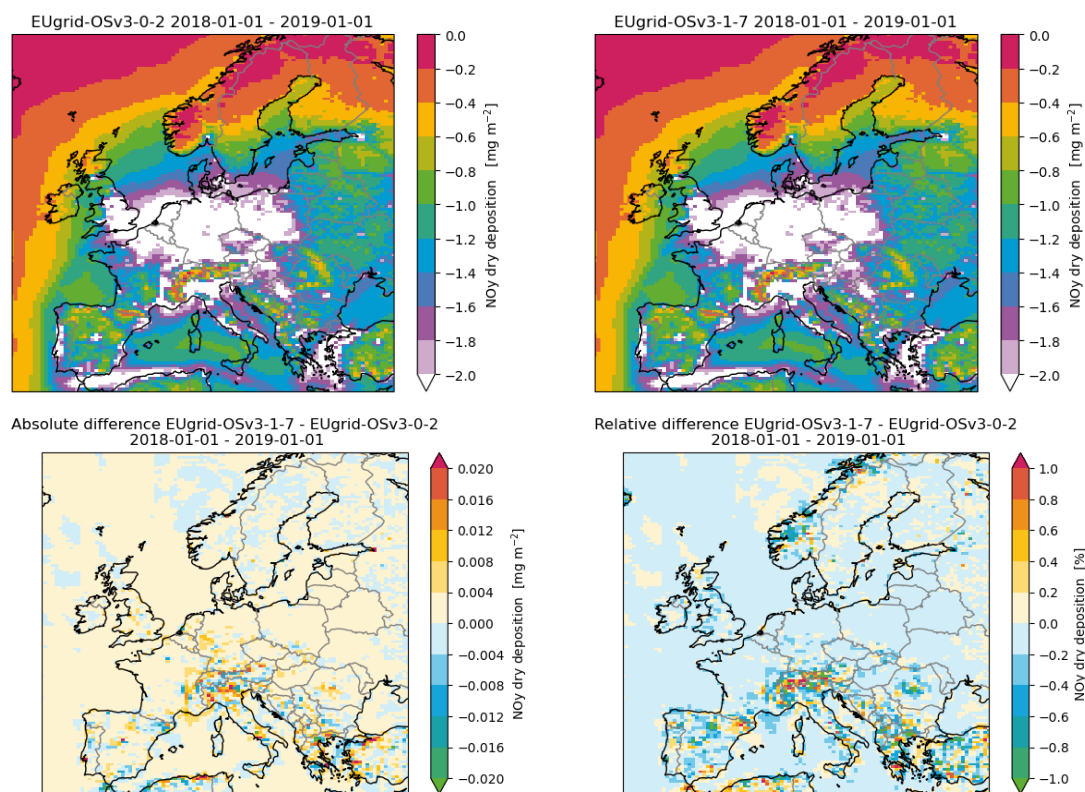


Figure 4.76: Averaged concentration map comparison for NO_y dry deposition

4.5.2.2 NO_y Wet

The NO_y wet deposition budget is mainly impacted by the wind vector interpolation update. The nitrate particles are impacted by the update of the mean free path length.

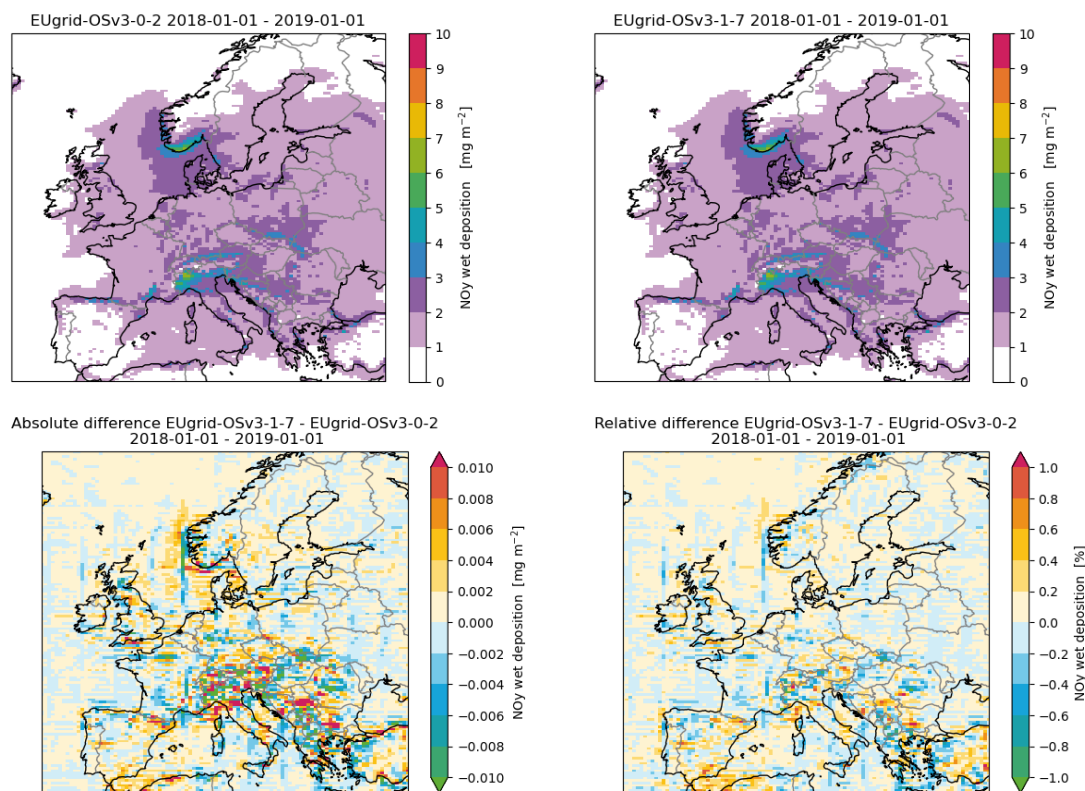


Figure 4.77: Averaged concentration map comparison for NO_y wet deposition

4.5.3 SO_x

4.5.3.1 SO_x Dry

The SO_x dry deposition budget is mainly impacted by the wind vector interpolation update. The sulphate particles are impacted by the update of the mean free path length.

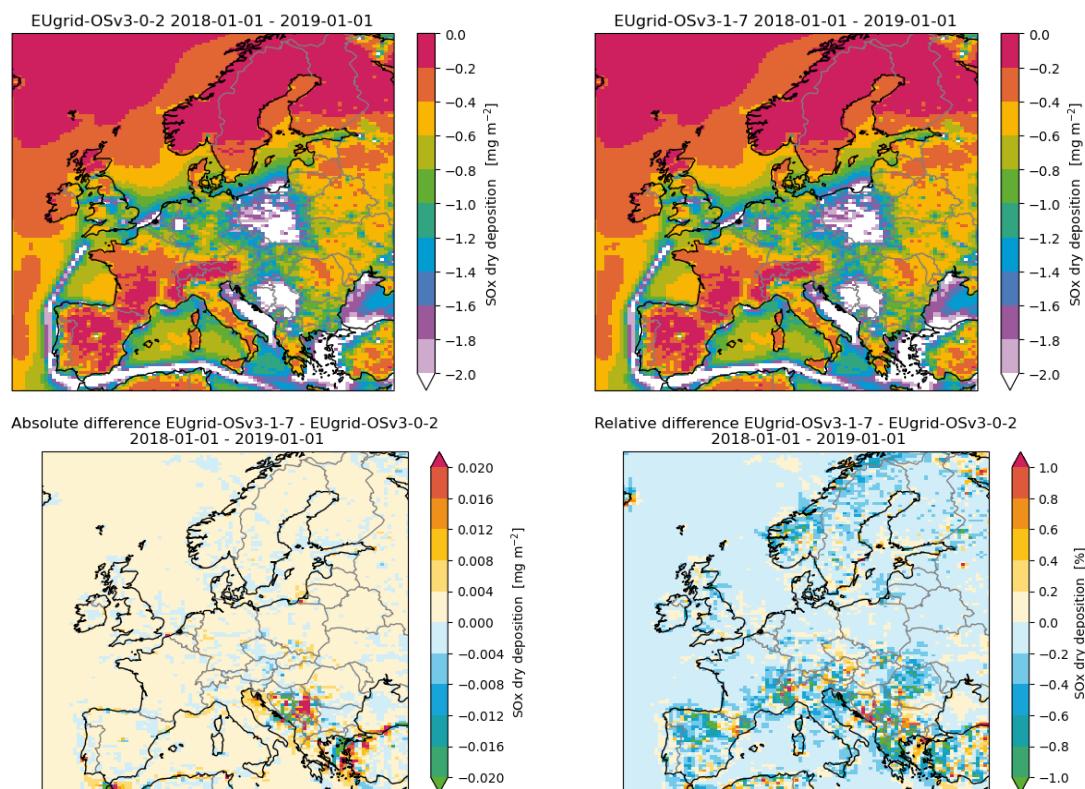


Figure 4.78: Averaged concentration map comparison for SO_x dry deposition

4.5.3.2 SO_x Wet

The SO_x wet deposition budget is mainly impacted by the wind vector interpolation update. The sulphate particles are impacted by the update of the mean free path length.

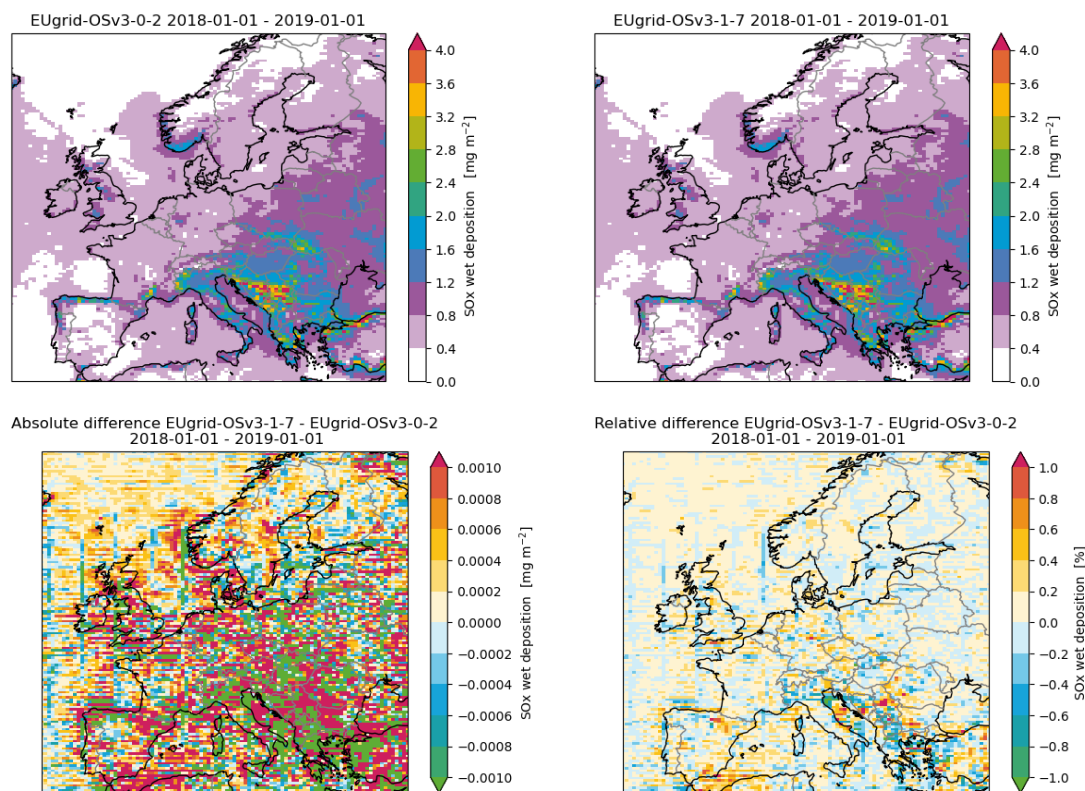


Figure 4.79: Averaged concentration map comparison for SO_x wet deposition

5 Conclusions

The release of open-source LOTOS-EUROS v3.1.7 will enable to user to run LOTOS-EUROS worldwide with land-use maps supported by the Three-Tiered Land-Use Approach and emissions from EDGAR/v8.1 emissions, CAMS-GLOB-TEMPO/v5.1 time profiles, and TNO Emission Atlas v0.5.

There are three updates that lead to changes in concentrations for the gasses, particulate matter and budgets: an update to the wind vector interpolation, the update on the free path length definition, and a bugfix in the calculation of the road resuspension emission.

- › The updated interpolation of the wind vectors does not result in large changes in transport patterns, and its impact on the simulated annual mean concentrations is small ($< \pm 1\%$) and located in regions where the wind vector locally varies such as mountainous regions in such as in the southern part of Europe, northern Africa and in Norway. This pattern is smoothed or suppressed for reactive species such as ozone.
- › The update in the definition of the free path length leads to small increased concentrations of PM_{2.5} species around 0.2-0.4% over the whole simulated European domain.
- › The road resuspension bugfix increases the concentration of mineral dust in areas with much traffic such as cities. The same increase in concentration is observed in the total PM₁₀.

All developments do not lead to significant changes in the evaluation of the RMSE, R^2 and NMB compared to the EBAS and EEA observations. We therefore recommend a model update from version v3.0.2 to v3.1.7, as it gives improved functionality but does not have a large impact.

References

- [1] A. J. Segers et al. *LOTOS-EUROS User Guide v3.0.000*. TNO, 2025, R10850.
- [2] A. J. Segers et al. *LOTOS-EUROS Reference Guide v3.0.000*. TNO, 2025, R10849.
- [3] J. H. Seinfeld and S. N. Pandis. *Atmospheric chemistry and physics : from air pollution to climate change*. Hoboken, N.J. J. Wiley, 2006. ISBN: 0-471-72017-8.

Signature

TNO › Energy & Materials Transition › Utrecht › 26 March 2026

ValidSigned by Sam van Goethem
on 2026-03-26 17:51:17



S. van Goethem
Research Manager

ValidSigned by Astrid Manders-Groot
on 2026-03-27 09:54:01



A. M. M. Manders-Groot
Senior Scientist

Energy & Materials Transition

Princetonlaan 6
3584 CB Utrecht
www.tno.nl