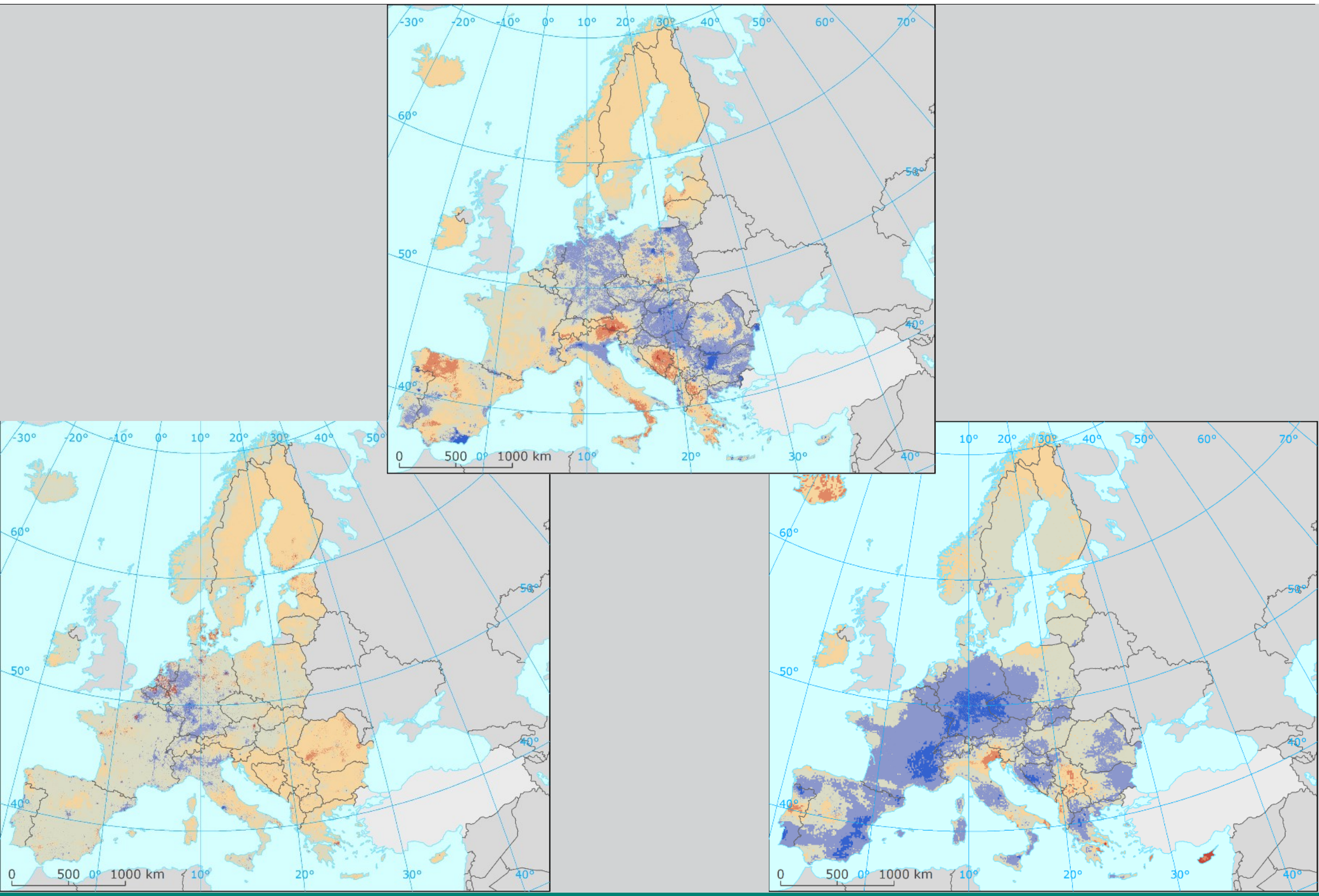
Interim European air quality maps for 2021

PM_{10}, NO_2 and ozone spatial estimates based on non-validated UTD data



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Summary

This report presents the interim air quality maps for 2021, which are based on the non-validated up-to-date measurement data and the CAMS Ensemble Forecast modelling results, together with other supplementary data.

The interim maps and further assessment present the annual average particulate matter (PM_{10}) concentration, the annual average nitrogen dioxide (NO_2) concentration and the ground-level ozone (O_3) concentration (in terms of SOMO35).

The share of population living in the considered European area exposed to annual average PM_{10} concentration above the limit value (LV) is estimated to be 0.4 %.

The share of population living in the considered European area exposed to annual average NO_2 concentration above LV is estimated to be 1.3 %.

The share of population living in the considered European area exposed to O_3 concentration values above 6 000 $\mu g/m^3 \cdot d$ (in terms of SOMO35) is estimated to be 11 %.

The share of population exposed to concentration above the 2021 WHO Air Quality Guideline levels is much more higher, i.e. 60 % and 77 % of the considered European population for annual average PM_{10} and NO_2 concentration, respectively.

Population-weighted concentration of the PM_{10} and NO_2 annual averages show quite steady decrease in the period 2005-2021, the lowest concentration in this period was recorded in 2020.

Population-weighted O_3 concentration show no trend due to the dependence of O_3 levels on current meteorological conditions.

1 Introduction

European wide air quality (AQ) annual maps have been routinely constructed under the ETC HE (and the previous consortia) since 2005 (Horálek, 2022b and references therein). The mapping methodology combines monitoring data, chemical transport model results and other supplementary data using a linear regression model followed by kriging of the residuals produced from that model ('residual kriging'). Separate mapping layers (rural, urban background and urban traffic, where relevant) are created separately and subsequently merged together into the final map. In order to reflect the three steps applied, the methodology is called *Regression – Interpolation – Merging Mapping (RIMM)*. The regular maps (i.e. maps presented under the ETCs regular mapping reports, e.g. Horálek et al., 2022b) are based on the validated air quality monitoring data as stored in the EEA's AQ e-reporting database (in the so-called E1a data set), the EMEP (or another CTM) modelling results and other supplementary data. Due to the time schedule of the production and availability of the validated AQ measurement data, the regular RIMM maps of a year Y are typically available in May of year Y+2. Thus, the regular 2021 maps based on the validated data will be available ca. in May 2023.

This report presents the interim air quality maps for 2021, which are based on the non-validated up-to-date (UTD) measurement data (as available in the E2a data set of the AQ e-reporting database) and the CAMS Ensemble Forecast modelling results, together with other supplementary data. The reason for production of these interim maps is their earlier availability. The interim maps creation was developed and evaluated, and consequently the interim maps were recommended for regular production, see Horálek et al. (2021a, 2021b). In order to overcome an obstacle of data gaps of the E2a data in some areas, the use of so-called pseudo stations data in the areas with the lack of E2a stations was tested, based on the regression relation between the E2a data from a year Y and the validated E1a data from a year Y-1, together with the ratio of the modelling results from years Y and Y-1. The regular interim maps production was recommended for PM_{10}, NO_2 and ozone – not for $PM_{2.5}$ and not for the area of Türkiye[1], due to the lack of the relevant monitoring data. The use of the pseudo station data in the interim mapping has been recommended for PM_{10} and NO_2. For ozone, the data coverage of the E2a data is larger and the interim ozone maps might be constructed without the use of the pseudo stations. The mapping area of the interim maps covers all of Europe apart from Belarus, Moldova, Ukraine and the European parts of Russia, Türkiye and Kazakhstan. Due to the EEA´s decision not to present results for the United Kingdom following its exit of the European Union in 2020, this report does not present the mapping results for the United Kingdom although they have been calculated using the E2a data reported to the EEA.

In the report, interim 2021 maps for the PM_{10} annual average, the NO_2 annual average and the ozone indicator SOMO35 are presented. Also, the difference between the five-year mean 2016-2020 and 2021 and the inter-annual difference between 2020 and 2021 are discussed. Next to this, population exposure estimated based on the concentration maps is briefly shown. However, in Horálek et al. (2021b) only the spatial maps have been examined, not the exposure estimates. Thus, in this report, we provide basic exposure estimates only, not the detailed information for individual countries. The exposure estimates are presented for five large European regions (Northern Europe, Western Europe, Central Europe, Southern Europe and South-Eastern Europe), for the EU-27 and for the whole mapping area. Apart from this, the evolution of the overall population-weighted concentration in the 17-year period 2005-2021 is also shown.

Apart from the 2021 interim maps, this report also presents the validation of the interim maps for 2020 as presented in Horálek et al. (2022a), based on the validated E1a data for 2020. It also presents the

[1] In this report, new official name Türkiye is used for this country, instead of its earlier name Turkey.

exposure tables based on the interim maps for 2020 and validates them against the exposure tables based on the regular maps (Horálek et al., 2022b).

Chapter 2 describes briefly the methodological aspects and documents the input data applied in the interim 2021 mapping. Chapters 3, 4, and 5 present the concentration maps and basic exposure estimates for PM_{10}, NO_2 and ozone, respectively. Chapter 6 brings the conclusions. Annex 1 provides the technical details of the maps and their uncertainty estimates. Annex 2 provides the validation of the interim maps for 2020, it also presents and validates the exposure tables based on the 2020 interim maps.

2 Methodology and data used

2.1 Methodology

2.1.1 Spatial mapping methodology

The mapping methodology used in the Regression – Interpolation – Merging Mapping method (RIMM) as routinely used in the spatial mapping under the ETC/EH and its predecesors (Horálek et. al., 2022b) consists of a linear regression model followed by kriging of the residuals from that regression model (residual kriging):

$$\hat{Z}(s_0) = c + a_1X_1(s_0) + a_2X_2(s_0) + \cdots + a_nX_n(s_0) + \hat{\eta}(s_0) \qquad (2.1)$$

where $\hat{Z}(s_0)$ is the estimated concentration at a point s_o,
$\hat{Z}(s_0)X_1(s_0)$ is the chemical transport model (CTM) data at point s_o,
$X_2(s_0),\ldots, X_n(s_0)$ are *n-1* other supplementary variables at point s_o,
$c, a_1, a_2,,\ldots, a_n$ are the *n+1* parameters of the linear regression model calculated based on the data at the points of measurement,
$\hat{\eta}(s_0)$ is the spatial interpolation of the residuals of the linear regression model at point s_o, based on the residuals at the points of measurement.

For different pollutants and area types (rural, urban background, and for PM_{10} and NO_2 also urban traffic), different supplementary data are used, see Annex 1. The spatial interpolation of the regression residuals is carried out using ordinary kriging, according to

$$\hat{\eta}(s_0) = \sum_{i=1}^{N} \lambda_i \eta(s_i) \qquad \text{with } \sum_{i=1}^{N} \lambda_i = 1, \qquad (2.2)$$

where $\hat{\eta}(s_0)$ is the interpolated value at a point s_o,
N is the number of the measurement points used in the interpolation, which is fixed based on the variogram; in any case, $20 \le N \le 50$,
$\eta(s_i)$ is the residual of the linear regression model at the measurement point s_i,
$\lambda_1,\ldots, \lambda_N$ are the estimated weights based on the variogram, see Cressie (1993).

For PM_{10}, prior to linear regression and interpolation, a logarithmic transformation to measurements and CTM modelled concentrations is executed. After interpolation, a back-transformation is applied.

Separate map layers are created for rural and urban background areas on a grid at resolution of 1x1 km^2 (for PM_{10} and NO_2) and 10x10 km^2 (for ozone), and for urban traffic areas at 1x1 km^2 (for PM_{10} and NO_2). The rural background map layer is based on rural background stations, the urban background map layer on urban and suburban background stations and the potential urban traffic map layer is based on urban and suburban traffic stations. Subsequently, the separate map layers are merged into one combined final map at 1x1 km^2 resolution, according to

$$\hat{Z}_F(s_0) = \left(1 - w_U(s_0)\right) \cdot \hat{Z}_R(s_0) + w_U(s_0)\left(1 - w_T(s_0)\right) \cdot \hat{Z}_{UB}(s_0) + w_T(s_0) \cdot \hat{Z}_{UT}(s_0) \quad \text{for } PM_{10} \text{ and } NO_2$$
$$= \left(1 - w_U(s_0)\right) \cdot \hat{Z}_R(s_0) + w_U(s_0) \cdot \hat{Z}_{UB}(s_0) \quad \text{for ozone} \qquad (2.3)$$

where $\hat{Z}_F(s_0)$ is the resulting estimated concentration in a grid cell s_o for the final map,
$\hat{Z}_R(s_0)$, $\hat{Z}_{UB}(s_0)$ and $\hat{Z}_{UT}(s_0)$ are the estimated concentrations in a grid cell s_o for the rural background, urban background and urban traffic map layers, respectively,
$w_U(s_0)$ is the weight representing the ratio of the urban character of the grid cell s_o,
$w_T(s_0)$ is the weight representing the ratio of areas exposed to traffics in a grid cell s_o.

The weight $w_U(s_0)$ is based on the population density, while the weight $w_T(s_0)$ is based on the buffers around the roads. For details of the methodology and its motivation, see Horálek et al. (2022b and references therein).

In all calculations and map presentations, the EEA standard projection ETRS89-LAEA5210 is used. The interpolation area covers the whole Europe apart from Belarus, Moldova, Ukraine and the European parts of Russia and Kazakhstan. As mentioned above, the United Kingdom is not presented in the main maps. In the validation of the the interim maps for 2020 in Annex 2, the whole area of these maps as presented in (Horálek et al., 2022a) is considered (including the United Kingdom).

2.1.2 Pseudo station data estimation

In order to supplement the E2a measurement data, which are affected by some spatial gaps, in the mapping procedure of PM_{10} and NO_2 maps we also use data from so-called *pseudo stations.* These data are concentration estimates at the locations of stations with no E2a data for the actual year Y, but with the validated E1a data for the year Y-1. As tested in Horálek et al. (2021b), these estimates are based on the relation between E2a data from year Y and validated E1a data from year Y-1, and also the ratio of the modelling or satellite data in years Y and Y-1 is used. The estimates are calculated based on the equation

$$\hat{Z}_Y(s) = c + a_1.Z_{Y-1}(s) + a_2.\frac{M_Y}{M_{Y-1}}.Z_{Y-1}(s) \qquad (2.4)$$

where $\hat{Z}_Y(s)$ is the estimated concentration value at a station *s* for the year *Y*,
$Z_{Y-1}(s)$ is the measurement value at a station *s* for the year *Y-1,* based on the E1a data,
$M_Y(s)$, $M_{Y-1}(s)$ are the modelling or the satellite data at a station *s* for the years *Y* and *Y-1*,
c, a_1,, a_2 are the parameters of the linear regression model calculated based on the data at the points of all stations with measurements for both *Y* and *Y-1* years.

All background stations (either classified as rural, urban or suburban) are handled together for estimating values at background pseudo stations, while all traffic stations used are applied for estimating values at traffic pseudo stations.

2.1.3 Methodology for uncertainty analysis

The uncertainty estimation of the interim maps is based on cross-validation using the E2a data. The cross-validation computes the spatial interpolation for each point of measurement from all available information except from the point in question (i.e. it withholds data of one point and then makes a prediction at the spatial location of that point). This procedure is repeated for all points of measurement in the available set. The predicted and measurement E2a values at these points are compared using statistical indicators and scatter plots. The main indicators used are root mean square error (RMSE), relative root mean square error (RRMSE) and bias (mean prediction error, MPE):

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\hat{Z}(s_i) - Z(s_i)\right)^2} \qquad (2.5)$$

$$RRMSE = \frac{RMSE}{\bar{Z}}.100 \qquad (2.6)$$

$$bias(MPE) = \frac{1}{N}\sum_{i=1}^{N}\left(\hat{Z}(s_i) - Z(s_i)\right) \qquad (2.7)$$

where $Z(s_i)$ is the air quality measured indicator value at the i^{th} point, $i = 1, \ldots, N$,
$\hat{Z}(s_i)$ is the air quality estimated indicator value at the i^{th} point using other information, without the indicator value derived from the measured concentration at the i^{th} point,
$\bar{Z}$ is the mean of the indicator values $Z(s_1), \ldots, Z(s_N)$, as measured at points $i = 1, \ldots, N$,
N is the number of the measuring points.

Other indicators are R^2 and the regression equation parameters *slope* and *intercept*, following from the scatter plot between the predicted (using cross-validation) and the observed concentrations.

RMSE and RRMSE should be as small as possible, bias (MPE) should be as close to zero as possible, R^2 should be as close to one as possible, slope a should be as close to one as possible, and intercept c should be as close to zero as possible (in the regression equation $y = a.x + c$).

It should be mentioned that the uncertainty estimates are valid only for areas covered by the E2a measurements. The complete validation of the interim maps including the areas not covered by the E2a data might be done when the validated E1a data are available.

2.1.4 Population exposure calculation and estimation of trends

Population exposure and population-weighted concentration for large regions, for EU-27 and for the whole presented area are calculated based on the air quality maps (and map layers) and population density data, as described in Horálek et al. (2022b). For detecting and estimating the trends in time series of annual values of population exposure, the non-parametric Mann-Kendall's test for detecting the presence of the monotonic trend and the non-parametric Sen's method for estimating the slope of a linear trend are executed, see Gilbert (1987).

2.1.5 Geographical division of Europe used for the assessment

The tables of population exposure and population-weighted concentration present the country grouping of the following large regions: 1) Northern Europe: Denmark (including Faroes), Estonia, Finland, Iceland, Latvia, Lithuania, Norway, Sweden ; 2) Western Europe: Belgium, France north of 45°, Ireland, Luxembourg, Netherlands, 3) Central Europe: Austria, Czechia, Germany, Hungary, Liechtenstein, Poland, Slovakia, Slovenia, Switzerland; 4) Southern Europe: Andorra, Cyprus, France south of 45°, Greece, Italy, Malta, Monaco, Portugal, San Marino, Spain; 5) South-eastern Europe (SE): Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Montenegro, North Macedonia, Romania, Serbia (including Kosovo under the UN Security Council Resolution 1244/99).

2.2 Data used

2.2.1 Air quality monitoring data

For the interim maps, we have used air quality station 2021 monitoring data coming from the E2a data set of the Air Quality e-Reporting database (EEA, 2022). The data of the up-to-date (UTD) dataflow E2a are being provided on an hourly basis from most of the EEA's member and cooperating countries and from the United Kingdom.

For the purposes of the pseudo stations calculations and for the validation of the interim maps, the 2020 data of the E1a data set of the Air Quality e-Reporting database (EEA, 2022) have been used. The data of the dataflow E1a is submitted to EEA by the reporting countries every September and covers the year before the delivery. This E1a data set has been supplemented with several EMEP rural stations from the database EBAS (NILU, 2022) not reported to the Air Quality e-Reporting database.

The following pollutants and aggregations are considered:
PM_{10} – annual average [μg/m^3], years 2020 (E1a) and 2021 (E2a),
Ozone – SOMO35 [μg/m^3·d], years 2020 (E1a, for validation only) and 2021 (E2a),
NO_2 – annual average [μg/m^3], years 2020 (E1a) and 2021 (E2a).

For PM_{10} and NO_2 we use the stations classified as background (for all the three types of area, i.e. rural, suburban and urban), and also traffic for the types of area suburban and urban. For ozone, we use only data from stations classified as background (for the three types of area). In the mapping, rural background stations are used for the rural layer, urban and suburban stations for the urban background layer and urban and suburban traffic stations for the urban traffic layer (Section 2.1).

Table 2.1 shows the number of the stations used in the interim mapping of PM_{10} and NO_2. In the RIMM mapping (as described in Section 2.1) of the year 2021, E2a 2021 stations are used, together with pseudo stations derived from E1a stations of the year 2020. The pseudo stations are located at the places of the E1a 2020 stations with no E2a data for year 2021 (labelled "For pseudo 2021"). The rest of the E1a 2020 stations (with both E1a data for 2020 and E2a data for 2021, labelled "For regression") are used for estimation of the parameters of the linear regression for the pseudo stations calculation (see Eq. 2.4). Table 2.2 shows the number of the stations used in the interim mapping of ozone. In the ozone interim mapping, E2a 2021 stations are used. No pseudo stations for ozone are used, due to quite complete spatial coverage of the E2a ozone data.

Table 2.1: Number of stations used in interim mapping 2021 for each station type, for PM_{10} (left) and NO_2 (right)

Station type	PM_{10}				NO_2			
	E1a 2020			E2a 2021	E1a 2020			E2a 2021
	Total	For regression	For pseudo 2021	Mapping 2021	Total	For regression	For pseudo 2021	Mapping 2021
Rural background	375	263	112	273	474	384	90	398
Urban/suburb. backgr.	1323	983	340	1049	1400	1140	260	1227
Urban/suburb. traffic	707	564	143	594	1127	718	409	764

Table 2.2: Number of stations used in interim mapping 2021 for each station type, for ozone

Station type	Ozone
	E2a 2021
	Mapping 2021
Rural background	496
Urban/suburb. backgr.	1078

2.2.2 Chemical transport modelling (CTM) data

The CAMS Ensemble Forecast data as provided by the Copernicus Atmosphere Monitoring Service (CAMS) at a regional scale over Europe have been used. The European regional production consists of an ensemble of nine air quality models run operationally. For further details of individual models, see Marécal et al. (2015). The models provide (together with other products) a 72-hour forecast made available at 07:00 UTC the day of the forecast. The forecast data product is available on an hourly time resolution and at a spatial resolution of 0.1° x 0.1°, i.e. ca. 10x10 km^2. Each model forecast is combined into an ensemble forecast by taking the median of all nine models.

All the models used in the CAMS ensemble products were run using the TNO-MACC emissions representative of 2011 (Kuenen et al., 2014) and 2019 (Kuenen et al., 2021) and the meteorology for 2020 and 2021 (i.e. the weather forecast) provided by the European Centre for Medium Range Weather Forecasts (ECMWF) operationally. For details, see Copernicus (2022a).

The CAMS Ensemble Forecast data for 2020 and 2021 from the Copernicus (2022b) have been used. All modelling data have been aggregated into the annual statistics and converted into the reference EEA 1x1 km^2 (for PM and NO_2) and 10x10 km^2 (for ozone) grids. The pollutants and parameters used are the same as for the monitoring data.

2.2.3 Satellite data

Data from the TROPOspheric Monitoring Instrument (TROPOMI) onboard of the Sentinel-5 Precursor satellite (Veefkind et al., 2012) was used. Their spatial resolution is approximately 5.5 km by 3.5 km. The product used is the S5P_OFFL_L2__NO2 product (van Geffen et al., 2020) and it provides the tropospheric vertical column density of nitrogen dioxide (NO_2), i.e. a vertically integrated value over the entire troposphere. All overpasses for a specific day were then mosaicked and gridded into the reference EEA 1x1 km^2 grid in the ETRS89 / ETRS-LAEA (EPSG 3035) projection. The daily gridded files have been subsequently averaged to an annual mean. The annual mean has been aggregated from cloud-free high-quality daily data only. The parameter used is

NO_2 – annual average tropospheric vertical column density (VCD) [number of NO_2 molecules per cm^2 of earth surface], years 2020 and 2021.

2.2.4 Other supplementary data

Meteorological data

The meteorological data used are the ECWMF data extracted from the CDS (Climate Data Store, https://cds.climate.copernicus.eu/cdsapp#!/home). Specifically, the hourly data of the reanalysed data set ERA5-Land in 0.1°x0.1° resolution have been used. In the coastal areas (where the data from ERA5-Land are not available), the same parameters from the reanalysed data set ERA5 in 0.25°x0.25° resolution have been applied. The hourly data have been derived into the parameters needed, aggregated into the annual statistics and converted into the reference EEA 1x1 km^2 (for PM and NO_2) and 10x10 km^2 (for ozone) grids. For details, see Horálek et al. (2022b). Meteorological parameters used are *wind speed* (annual mean for 2021, in m.s^{-1}), *relative humidity* (annual mean for 2021, in percentage) and *surface net solar radiation* (annual mean of daily sum for 2021, in MWs.m^{-2}).

Altitude

The altitude data field (in m) of Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) has been used, with an original grid resolution of 15x15 arcseconds coming from U.S. Geological Survey Earth Resources Observation and Science, see Danielson and Gesch (2011). The data were converted into the EEA reference grids in 1x1 km^2 and 10x10 km^2 resolutions. Next to this, another aggregation has been executed based on the 1x1 km^2 grid cells, i.e., the floating average of the circle with a radius of 5 km around all relevant grid cells.

Land cover

CORINE Land Cover 2018 – grid 100 x 100 m^2, Version 2020_20 (EU, 2020) is used. The 44 CLC classes have been re-grouped into the 8 more general classes. In this paper, we use five of these general classes, namely high density residential areas (HDR), low density residential areas (LDR), agricultural areas (AGR), natural areas (NAT), and traffic areas (TRAF). For details, see Horálek et al. (2022b). Two aggregations are used, i.e., into 1x1 km^2 grid and into the circle with radius of 5 km. The aggregated grid value represents for each general class the total area of this class as percentage of the total area of the 1x1 km^2 square or the circle with radius of 5 km.

Population density and Road data

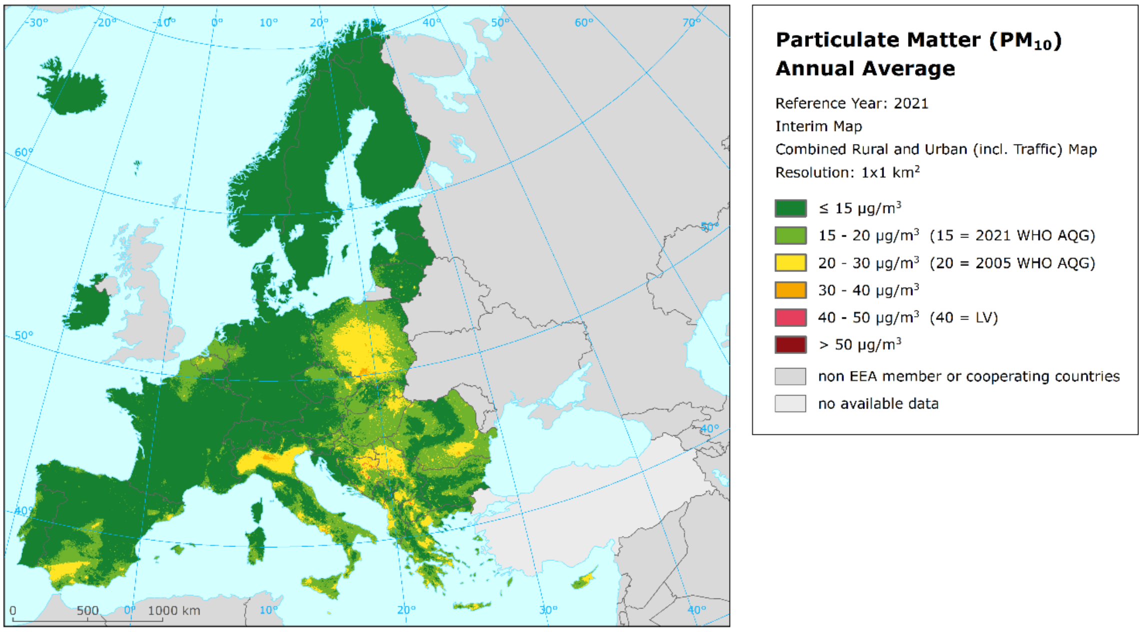
Population density (in inhabitants.km^{-2}, census 2011) is based on Geostat 2011 grid dataset (Eurostat, 2014). For regions not included in the Geostat 2011 dataset we use as alternative sources JRC and ORNL data. For details, see Horálek et al. (2022b).

GRIP vector road type data is used (Meijer et al., 2018). Based on these data (i.e., buffers around the roads), traffic map layers (Section 2.1) are merged into the final maps (Horálek et al., 2022b).

3 Particulate matter

Map 3.1 presents the interim map for the PM_{10} annual average 2021, as the result of interpolation and merging of the separate map layers as described in Annex 1, Section A1.1. Red and dark red areas indicate concentrations above the EU annual limit value (LV) of 40 µg/m^3. Dark green indicates the areas where the PM_{10} annual average concentration is below the 2021 WHO Air Quality Guideline level of 15 µg/m^3 (WHO, 2021).

Map 3.1: Interim concentration map of PM_{10} annual average, 2021



The map shows concentrations above the annual LV only in urban areas around the Balkan cities (North Macedonia, Serbia and Croatia). Besides these countries, the Po Valley in Italy, Poland and parts of Spain, Romania and Greece are the areas with the highest PM_{10} concentrations reaching 30-40 µg/m^3. Most of the south-eastern area plus Hungary and parts of Spain, Benelux, Slovakia, Czechia and Poland shows PM_{10} levels between 15-20 µg/m^3. Annual average PM_{10} concentration below 15 µg/m^3 can be found in the rest of Europe.

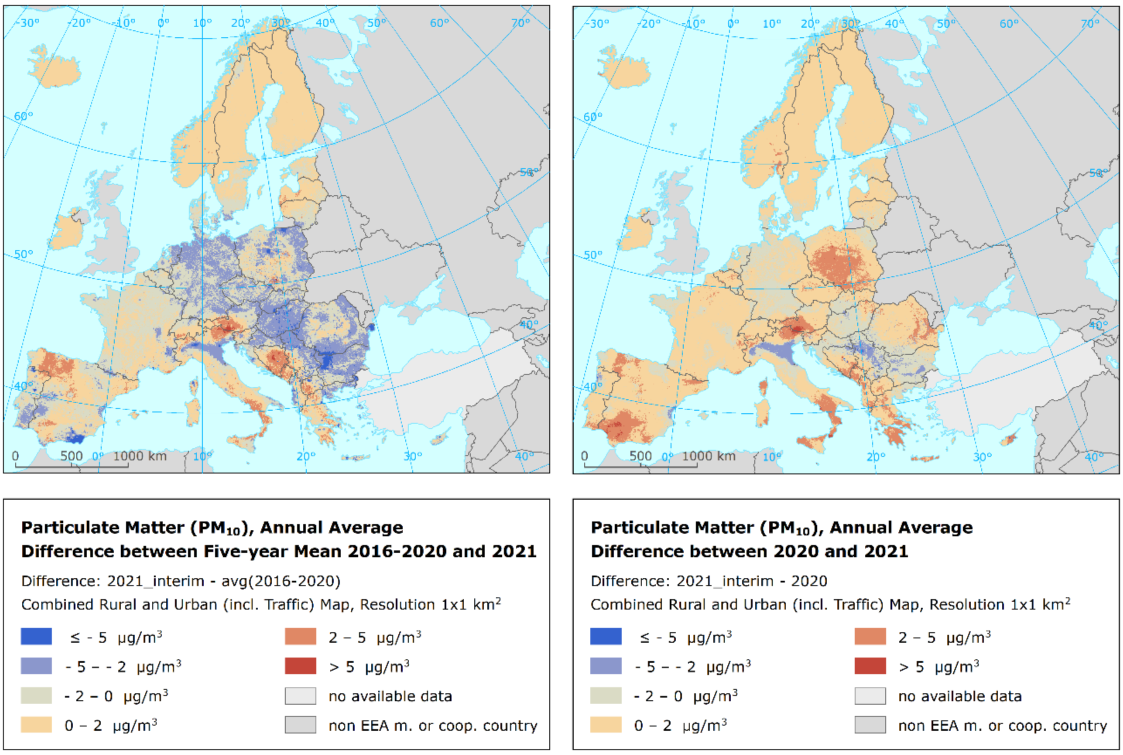
The relative mean uncertainty (Relative RMSE) of this map is 22 % for rural areas and 19 % for urban background areas. However, these uncertaity estimates are based on the non-validated E2a data and are valid only for areas covered by the E2a stations. The complete validation of the interim PM_{10} map can only be done when the validated E1a data for 2021 are available. For such validation of the interim PM_{10} map for 2020 as presented in Horálek et al. (2021a), see Annex 2, Section A2.1.

Map 3.2 shows the difference between the five-year mean 2016-2020 and 2021 and the inter-annual difference between 2020 and 2021 (using the regular maps for 2016-2020 and the 2021 interim map) for PM_{10} annual average. Orange to red areas show an increase of PM_{10} concentration in 2021, while blue areas show a decrease.

Compared to the five-year mean 2016-2020, the highest increase in PM_{10} concentration is shown in Austria, Bosnia and Herzegovina and the north parts of Italy and Spain. On the other hand, the deepest decrease is shown in the southeast of Spain, parts of Bulgaria, Serbia and Italy, almost the whole Hungury and smaller parts of Slovakia, Czechia, Germany and Poland.

Based on the map of the inter-annual difference between 2020 and 2021, an increase of PM_{10} concentration in the whole considered (i.e. presented) European area is shown, with minor exceptions.

Map 3.2: Difference in concentrations between five-year mean 2016-2020 (left) or 2020 (right) and 2021 (based on the interim map) for PM_{10} annual average



Based on the mapping results and the population density data, the population exposure estimates have been calculated. Table 3.1 gives the population frequency distribution for a limited number of exposure classes and the population-weighted concentration for large European regions, for EU-27 and for the total presented area. The exposure estimates for individual countries is not presented, due to their uknown quality. In order to evaluate the quality of the population estimates for individual countries, the comparison of exposure estimates for 2020 based on the interim and the regular maps (Horálek et al., 2021b and 2022b) has been performed, see Annex 2, Section A2.2. The exposure give good results for the total area and the EU-27, but somewhat poorer results for individual countries.

Table 3.1: Population exposure and population-weighted concentration, PM_{10} annual average, 2021, based on the interim map

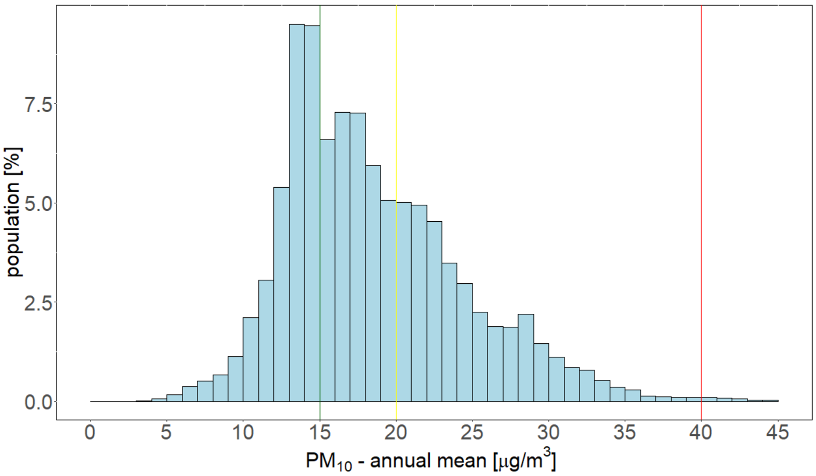
Area	Population [inhbs·1000]	PM_{10} – annual average, exposed population, 2021 [%]						PM_{10} ann. avg.
		< 15	15 - 20	20 - 30	30 - 40	40 - 50	> 50	Pop. weighted
Northern Europe	32 080	83.3	10.3	6.3	0.1			12.1
Western Europe	81 150	37.8	56.8	5.4				15.8
Central Europe	162 777	44.9	27.1	24.4	3.6			17.6
Southern Europe	140 620	13.3	32.6	49.8	4.4			20.8
South-eastern Europe	49 965	4.1	21.7	53.4	16.2	4.3	0.3	25.0
Total	**466 592**	**32.4**	**32.2**	**30.6**	**4.3**	**0.5**	**0.0**	**18.7**
EU-27	**435 073**	**32.0**	**33.8**	**30.6**	**3.5**			**18.4**

Note: The percentage value "0.0" indicates that an exposed population exists, but it is small and estimated to be less than 0.05 %. Empty cells mean no population in exposure.

Based on the interim map, it is estimated that 0.4 % of population living in the considered (i.e. presented) European area has been exposed to concentrations above the EU annual limit value (ALV) of 40 μg/m³ (0 % for the EU-27 population). All of them live in southeastern Europe, where the share is 4.3%. More than 60 % of the considered European population (and about 68 % of the EU-27 population) has been exposed to annual average concentrations above the Air Quality Guideline of 15 μg/m³ recommended by the World Health Organization in 2021 (WHO, 2021). The population-weighted concentration of the PM_{10} annual average for 2021 for the considered European countries and for EU-27 is estimated to be about 18 μg/m³.

Figure 3.1 shows, for the whole mapped area, the population frequency distribution for exposure classes of 1 μg/m³. The highest population frequency is found for classes between 13 and 15 μg/m³. A quite continuous decline of population frequency is visible for classes between 20 and 30 μg/m³ and beyond 35 μg/m³.

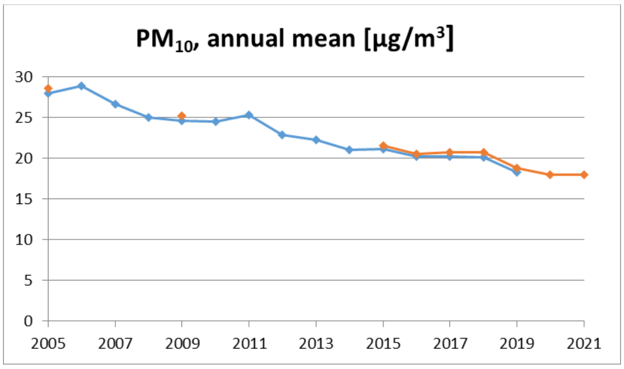
Figure 3.1: Population frequency distribution, PM_{10} annual average 2021, based on an interim map. The 2021 WHO AQG level (15 μg/m³) is marked by the green line, the 2005 WHO AQG level (20 μg/m³) is marked by the yellow line, the EU annual limit value (40 μg/m³) is marked by the red line



Note: Apart from the population distribution shown in graph, it was estimated that 0.02 % of population lived in areas with PM_{10} annual average concentration in between 45 and 60 μg/m³.

For changes in the population-weighted concentration of the PM_{10} annual average in the 17-year period 2005-2021, see Figure 3.2. For the previous years, mapping results as presented in Horálek et al. (2022a and references therein) have been used. Since 2017 results, PM_{10} maps were prepared based on the updated method (taking into account air quality in urban traffic areas). For comparability reasons, results for 2005, 2009 and 2015-2019 are presented in two variants for these pollutants, i.e. based on both the old and the updated methodologies. Other issue is that for the 16-year time series 2005-2020, the overall population-weighted included the United Kingdom. Therefore, for consistency reasons, the population-weighted concentration for the whole area including the United Kingdom is presented also for 2021. This value was easily available, as the mapping domain includes the United Kingdom (see Section 2.1.1).

Figure 3.2: Population-weighted concentration of PM_{10} annual average in 2005-2021, based on both the old (blue) and the updated (red) mapping methodology, where available, and with 2021 interim results



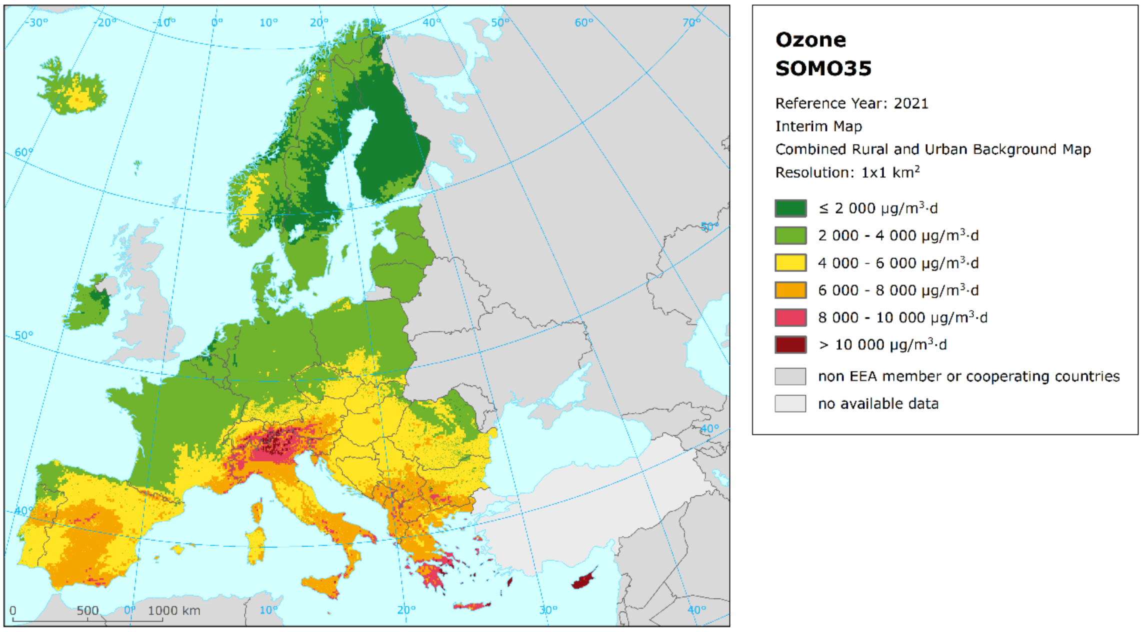
Throughout the whole period 2005-2021, the PM_{10} annual average concentration show quite steady decrease of about 0.6 µg/m^3 per year. One can see that the last two years 2020 and 2021 (based on the interim data) show the lowest results in the 17-year period.

4 Ozone

Map 4.1 presents the interim 2021 map for SOMO35 as a result of merging separate rural and urban interpolated map layers as described in Annex 1, Section A1.2. Red and purple areas show values above 8 000 µg/m^3·d, while the orange areas show values above 6 000 µg/m^3·d.

Generally, southern Europe shows higher ozone SOMO35 concentrations than northern Europe. Higher levels of ozone also occur more frequently in mountainous areas south of 50 degrees latitude than in lowlands.

Map 4.1: Interim concentration map of ozone indicator SOMO35, 2021



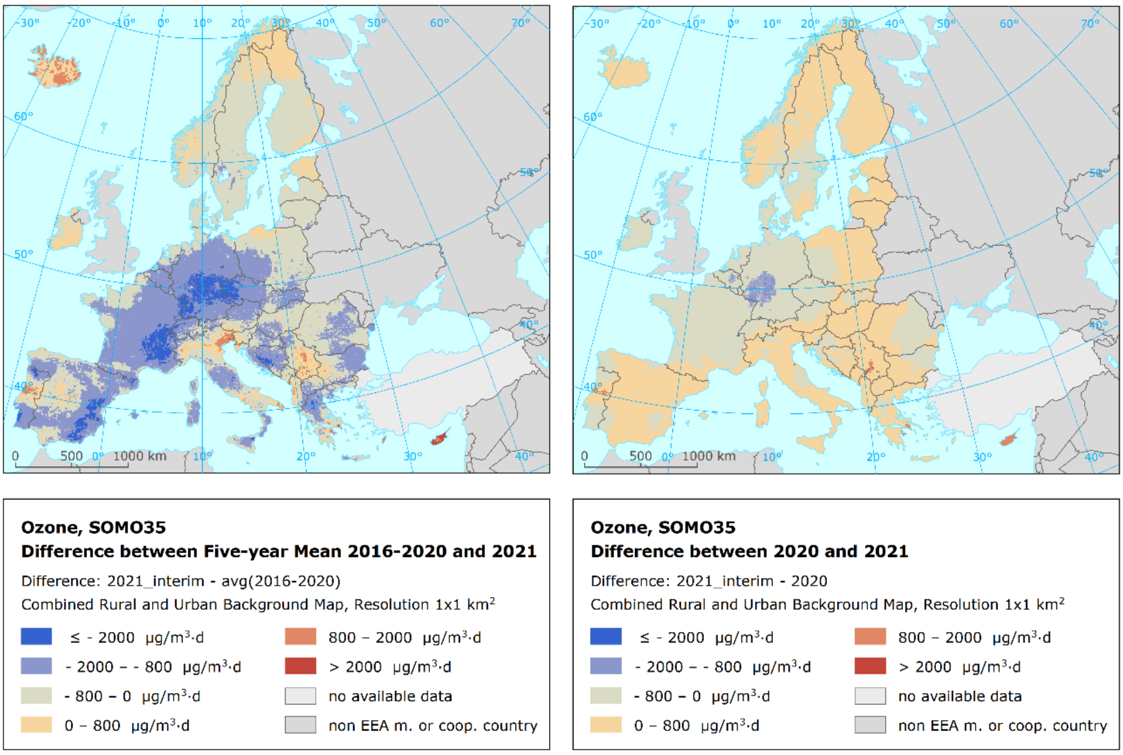
The relative mean uncertainty (Relative RMSE) of this map is 32 % for both rural and urban background areas. However, these uncertaity estimates are based on the non-validated E2a data and are valid only for areas covered by the E2a stations. The complete validation of the interim ozone map can only be done when the validated E1a data for 2021 are available. For such validation of the interim ozone map for 2020 as presented in Horálek et al. (2021a), see Annex 2, Section A2.1.

Map 4.2 shows the difference between five-year mean 2016-2020 and 2021 and the inter-annual difference between 2020 and 2021 (using the regular maps for 2016-2020 and the 2021 interim map) for the ozone indicator SOMO35. Orange to red areas show an increase of ozone concentration in 2021, while blue areas show a decrease.

Compared to the five-year average 2016-2020, the highest increase of ozone concentrations (in terms of SOMO35) has been observed in smaller parts of Italy, Portugal, Serbia, Greece, Cyprus and Iceland. Contrary to that, one can see a decline or no change in the rest of Europe.

Based on the map of the inter-annual difference between 2020 and 2021, an increase of ozone concentrations (in terms of SOMO35) has been observed in southern, south-eastern, northern and parts of central Europe. Contrary to that, one can see a decline in central Germany or mild decline or no change in the rest of Europe.

Map 4.2: Difference concentrations between five-year mean 2016-2020 (left) or 2020 (right) and 2021 (based on the interim map) for ozone indicator SOMO35



Based on the mapping results and the population density data, the population exposure estimate has been calculated. Table 4.1 gives the population frequency distribution for a limited number of exposure classes and the population-weighted concentration for large European regions, for EU-27 and for the total mapping area. The exposure estimates for individual countries is not presented, due to their uknown quality. In order to evaluate the quality of the population estimates for individual countries, the comparison of exposure estimates for 2020 based on the interim and the regular maps (Horálek et al., 2021b and 2022b) has been performed, see Annex 2, Section A2.2. This analysis shows that the exposure estimates give good results for the total area and the EU-27, but somewhat poorer results for individual countries.

Table 4.1: Population exposure and population-weighted concentration, ozone indicator SOMO35, 2021, based on an interim map

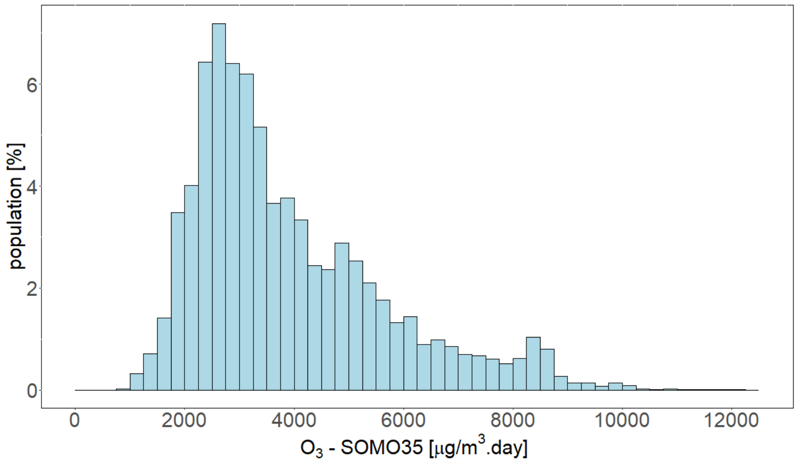
Area	Population [inhbs·1000]	Ozone - SOMO35, exposed population, 2021 [%]						Ozone - SOMO35
		< 2000	4000	6000	8000	10000	> 10000	Pop. weighted
Northern Europe	32 080	46.0	54.0	0.0				2 050
Western Europe	81 150	13.6	85.1	1.2	0.0	0.0		2 595
Central Europe	162 777	2.3	75.8	21.0	0.9	0.1	0.0	3 428
Southern Europe	140 620	0.7	18.2	42.4	24.5	13.5	0.7	5 635
South-eastern Europe	49 965	10.7	44.8	36.1	8.3	0.1		3 806
Total	**466 592**	**7.7**	**55.2**	**24.2**	**8.6**	**4.1**	**0.2**	**3 894**
EU-27	**435 073**	**7.3**	**57.8**	**22.0**	**8.4**	**4.4**	**0.2**	**3 873**

Note: The percentage value "0.0" indicates that an exposed population exists, but it is small and estimated to be less than 0.05 %. Empty cells mean no population in exposure.

Based on the interim map, it is estimated that more than 11 % of the considered European population (13 % of the EU-27) lived in areas with SOMO35 values above 6 000 µg/m^3·d. The population-weighted concentration of the SOMO35 for 2021 for the considered European population is estimated to be about 3 600 µg/m³·d (3 900 µg/m³·d for the EU-27).

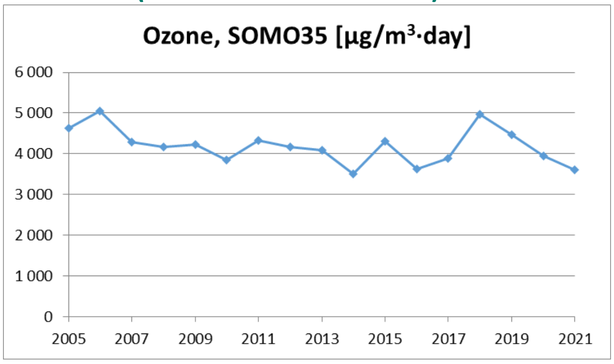
Figure 4.1 shows, for the whole mapped area, the frequency distribution of SOMO35 for population exposure classes of 250 µg/m³·d. The highest frequencies are found for classes between 2 000 and 4 000 µg/m³·d. One can see a decline of population frequency for exposure classes between 4 000 and 6 000 µg/m³ and a continuous mild decline of population frequency for classes above 6 000 µg/m³·d.

Figure 4.1: Population frequency distribution, ozone indicator SOMO35, 2021



For changes in the population-weighted concentration in the period 2005-2021, see Figure 4.2. Like for PM_{10}, the population-weighted concentration for the whole area including the United Kingdom is presented for the whole period including the 2021, for consistency reasons. No trend is observed for the SOMO35, since ozone levels in individual years depend mainly on the meteorological conditions of the given year.

Figure 4.2: Population-weighted concentration of the ozone indicator SOMO35 in 2005-2021 (interim results for 2021)

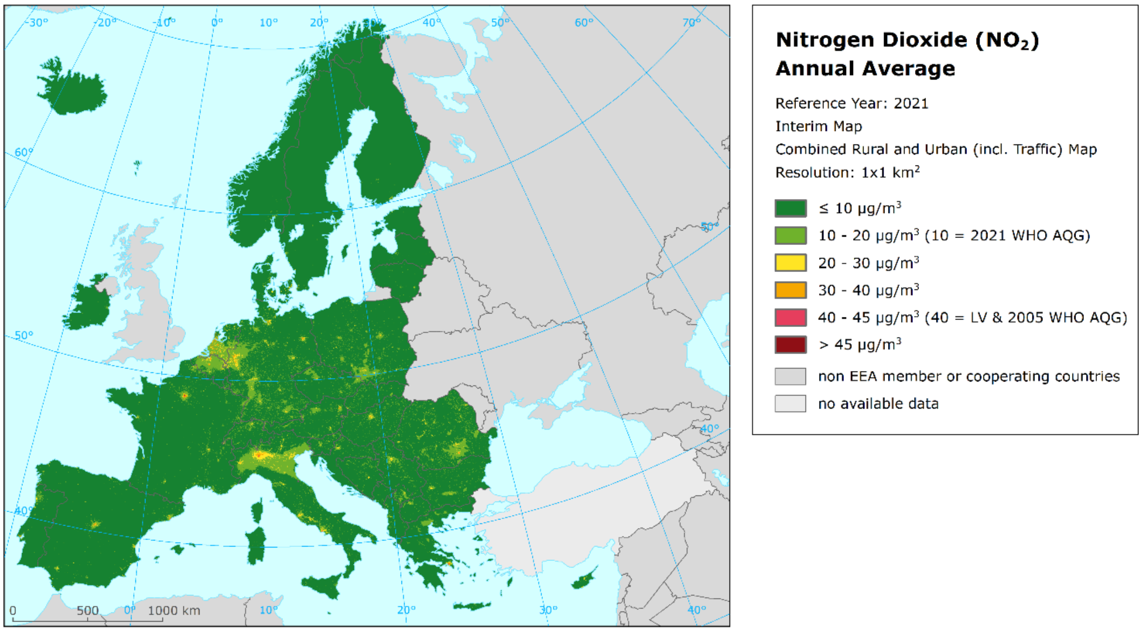


5 NO_2

Map 5.1 presents the interim map for the NO_2 annual average 2021, as the result of interpolation and merging of the separate map layers as described in Annex 1, Section A1.3. Red and purple areas indicate concentrations above the annual limit value (LV) of 40 µg/m^3. Dark green areas indicate concentrations below 10 µg/m^3 (being the new 2021 WHO Air Quality Guideline level (WHO, 2021)).

The areas with concentrations above the annual limit value of 40 µg/m^3 for NO_2 include urbanized parts of some large cities, particularly Paris, Rome, Naples, Milan, Madrid, Barcelona and Thessaloniki. Some other cities show NO_2 levels above 30 µg/m^3, e.g. in Spain, France, Italy, and Romania. Most of the European area shows NO_2 levels below 10 µg/m^3. Some larger areas above 10 µg/m^3 can be found in the Po Valley, the Benelux, the German Ruhr region, in the Île de France region and around Rome.

Map 5.1: Interim concentration map of NO_2 annual average, 2021



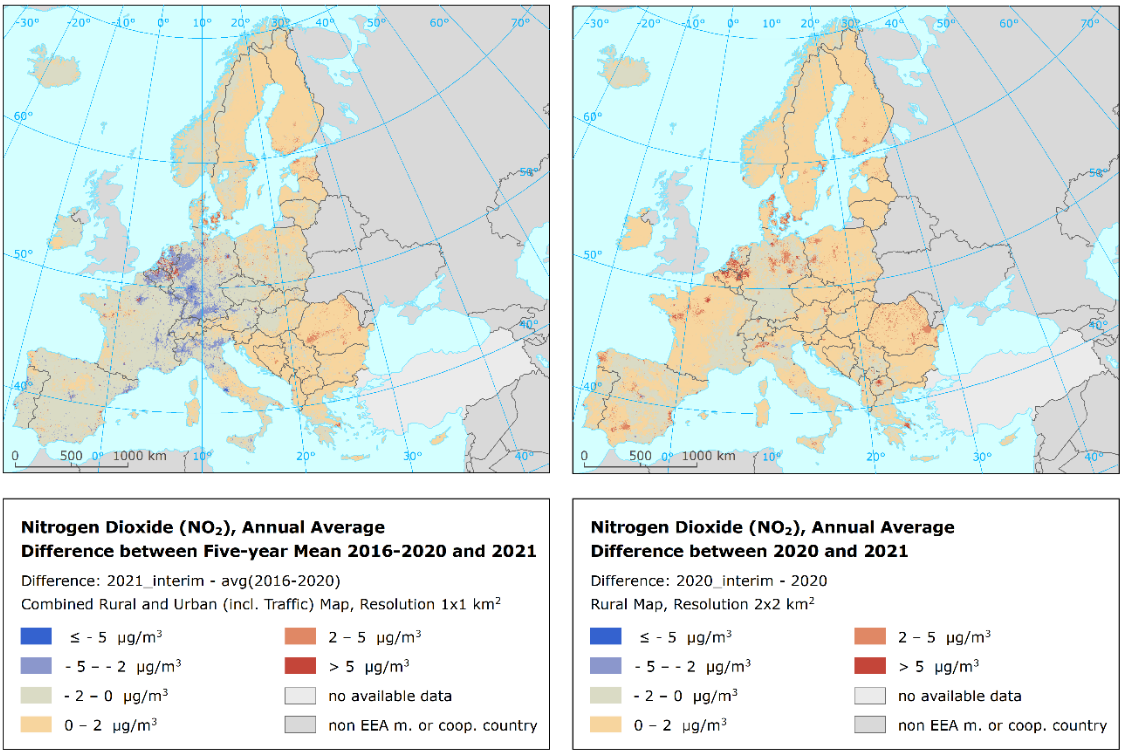
The relative mean uncertainty (Relative RMSE) of this map is 27 % for rural areas and 24 % for urban background areas. However, these uncertaity estimates are based on the non-validated E2a data and are valid only for areas covered by the E2a stations. The complete validation of the interim NO_2 map can only be done when the validated E1a data for 2021 are available. For such validation of the interim NO_2 map for 2020 as presented in Horálek et al. (2021a), see Annex 2, Section A2.1.

Map 5.2 shows the difference between five-year mean 2016-2020 and 2021 and the inter-annual difference between 2020 and 2021 (using the regular maps for 2016-2020 and the 2021 interim map) for the NO_2 annual average. Orange to red areas show an increase of NO_2 concentration in 2021, while blue areas show a decrease.

Compared to the five-year average 2016-2020, the highest increase of NO_2 annual average concentrations in 2021 has been especially observed in south-eastern Europe, further in parts of Southern Europe, in Northern Europe and in some urban areas in the Benelux. Contrary to that, one can see a decline or no change in the rest of Europe.

Based on the map of the inter-annual difference between 2020 and 2021, no change or an increase of NO_2 concentration has been observed in the total mapping area. The highest increase is observed especially in areas around European cities and towns.

Map 5.2: Difference concentrations between five-year mean 2016-2020 (left) or 2020 (right) and 2021 (based on the interim map) for NO_2 annual average



Based on the mapping results and the population density data, the population exposure estimate has been calculated. Table 5.1 gives the population frequency distribution for a limited number of exposure classes and the population-weighted concentrations for large European regions, for EU-27 and for the total mapping area. The exposure estimates for individual countries is not presented, due to their uknown quality. In order to evaluate the quality of the population estimates for individual countries, the comparison of exposure estimates for 2020 based on the interim and the regular maps (Horálek et al., 2021b and 2022b) has been performed, see Annex 2, Section A2.2. The estimates give good results for the total area and the EU-27, but somewhat poorer results for individual countries.

Table 5.1: Population exposure and population-weighted concentration, NO_2 annual average, 2021, based on interim map

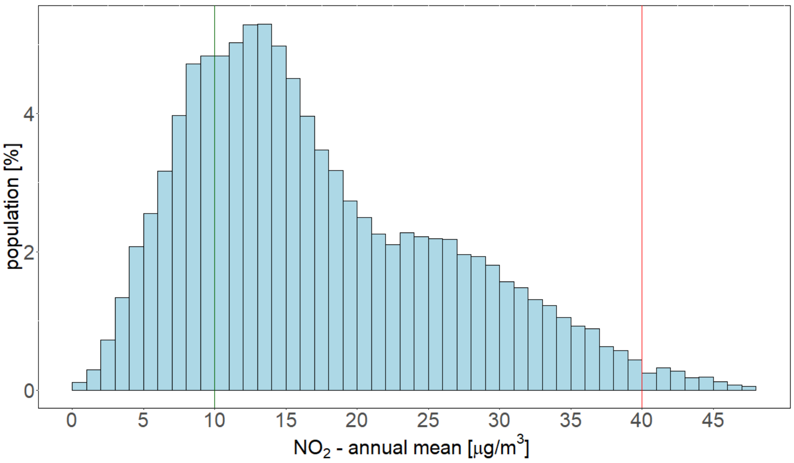
Area	**Population [inhbs·1000]**	**NO_2 – annual average, exposed population, 2021 [%]**						**NO_2 ann. avg.**
		< 10	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 45**	**> 45**	**Pop. weighted**
Northern Europe	32 080	52.5	24.7	20.9	1.9			12.3
Western Europe	81 150	29.0	35.1	15.7	17.4	1.8	1.1	18.0
Central Europe	162 777	20.7	53.9	17.8	7.5	0.1		16.3
Southern Europe	140 620	20.7	36.6	27.8	12.4	2.4	0.1	19.0
South-eastern Europe	49 965	15.9	52.5	24.6	5.4	1.3	0.3	17.7
Total	**466 592**	**23.8**	**43.3**	**21.4**	**10.1**	**1.2**	**0.3**	**17.3**
EU-27	**435 073**	**23.8**	**42.5**	**21.5**	**10.7**	**1.3**	**0.3**	**17.5**

Note: The percentage value "0.0" indicates that an exposed population exists, but it is small and estimated to be less than 0.05 %. Empty cells mean no population in exposure.

Based on the interim map, it is estimated that more than 1 % of population of the considered European area (and almost 2 % of the EU-27 population) has been exposed to concentrations above the EU annual limit value (ALV) of 40 µg/m³. Almost 77 % of the total area population (and about 76 % of the EU-27 population) has been exposed to concentration exceeding 10 µg/m³ (being the new 2021 WHO AQG level). The population-weighted concentration of the NO_2 annual average for 2021 for the considered European population and for the EU-27 is estimated to be about 17 µg/m³.

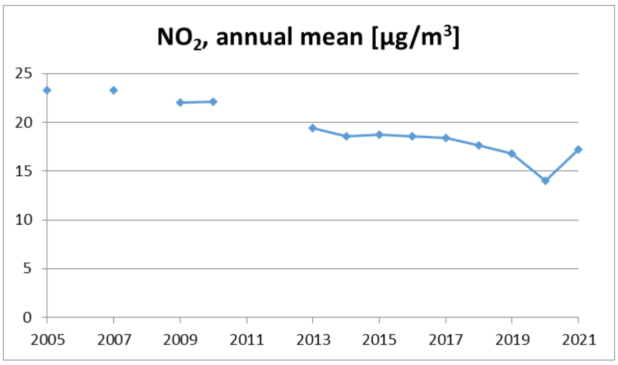
Figure 5.1 shows, for the whole mapped area, the population frequency distribution for exposure classes of 1 µg/m³. One can see the highest population frequency for classes between 8 and 16 µg/m³, continuous decline of population frequency for classes between 16 and 25 µg/m³ and continuous mild decline of population frequency for classes between 25 and 50 µg/m³.

Figure 5.1: Population frequency distribution, NO_2 annual average 2021, based on an interim map. The WHO guideline level (10 µg/m³) is marked by the green line and the annual limit value (40 µg/m³) is marked by the red line



For changes in the population-weighted concentration of the NO_2 annual average in the period 2005-2021, see Figure 5.2. Again, the population-weighted concentration for the whole area including the United Kingdom is presented for the whole period including the 2021, for consistency reasons. The NO_2 concentration (in terms of annual average) shows a decrease of about 0.5 µg/m³ per year. One can see that the interim results for 2021 are approximately at the level of the values of 2018 and 2019, after the extraordinary low concentration of 2020 due to the lockdown measures connected with the SARS-CoV-2 pandemic (in case of NO_2 especially in major cities). Nevertheless, meteorological and dispersion conditons can also have an effect on air pollutant concentrations (e.g. the month of February 2020 was exceptionally warm in Europe, see Copernicus, 2020).

Figure 5.2: Population-weighted concentration of NO_2 annual average in 2005-2021, with 2021 interim results



6 Conclusions

The report presents the interim 2021 maps for PM_{10} annual average, NO_2 annual average and the ozone indicator SOMO35. The maps have been produced based on the non-validated E2a (UTD) data of the AQ e-reporting database, the CAMS Ensemble Forecast modelling data and other supplementary data. Together with the concentration maps, the difference maps between five-year mean 2016-2020 and 2021 and between the years 2020 and 2021 are presented (using the 2016-2020 regular and the 2021 interim maps), as well as basic exposure estimates based on the interim maps.

For PM_{10}, concentrations above the annual limit value (LV) of 40 µg/m^3 are estimated only in urban areas around the Balkan cities (North Macedonia, Serbia and Croatia). About 0.4 % of the considered European population is exposed to levels above the EU annual LV; more than 60 % of the considered European population is exposed to levels above the 2021 WHO PM_{10} Air Quality Guideline of 15 µg/m^3. The population-weighted concentration of the PM_{10} annual average for the considered European countries is estimated to be about 18 µg/m^3.

In the case of NO_2, concentrations above the annual LV of 40 µg/m^3 were estimated in urbanized parts of some large cities, particularly Paris, Rome, Naples, Milan, Madrid, Barcelona and Thessaloniki. It is estimated that ca. 0.2 % of the considered European population is exposed to levels above the EU annual LV. Almost 77 % of the total area population has been exposed to concentration exceeding 10 µg/m^3 (being the new 2021 WHO AQG level). The population-weighted concentration of the NO_2 annual average for the considered European countries is estimated to be about 17 µg/m^3.

In the case of O_3, the southern parts of Europe show higher ozone SOMO35 concentrations than the northern parts. Higher levels of ozone also occur more frequently in mountainous areas south of 50 degrees latitude than in lowlands. The population-weighted concentration of the SOMO35 for 2021 for the considered European population is estimated to be about 3 600 µg/m^3·d (3 900 µg/m^3·d for the EU-27).

Uncertainty estimates based on the cross-validation of the E2a data have been performed for all interim maps. However, these uncertainty estimates are based on the non-validated E2a data and are valid for areas covered by the E2a measurements only. The complete validation of the interim maps should be done when the validated E1a data for 2021 are available.

In the report, population exposure for only large European regions, EU27 and the total mapped area has been presented. The more detailed exposure estimates for particular European countries based on the validated data will be presented in 2023, in the ETC HE regular mapping report on the 2021 air quality maps, based on the validated E1a data.

In order to evaluate the quality of the population estimates for individual countries, the comparison of exposure estimates for 2020 based on the interim and the regular maps has been performed. It can be stated that the exposure estimates give good results for the total area and the EU-27, but somewhat poorer results for individual countries.

List of abbreviations

Abbreviation	Name	Reference
ALV	Annual Limit Value	
AQ	Air Quality	
AQG	Air Quality Guidline level of the WHO	
CLC	CORINE Land Cover	https://land.copernicus.eu/pan-european/corine-land-cover
CORINE	Co-ORdinated INformation on the Environment	https://land.copernicus.eu/pan-european/corine-land-cover
CTM	Chemical Transport model	
ECMWF	European Centre for Medium-Range Weather Forecasts	https://www.ecmwf.int/
EBAS	EMEP dataBASe	https://ebas.nilu.no/
EEA	European Environment Agency	www.eea.europa.eu
EMEP	European Monitoring and Evaluation Programme	https://www.emep.int/
ETC HE	European Topic Centre on Human health and the Environment	https://www.eionet.europa.eu/etcs
EU	European Union	https://european-union.europa.eu
GMTED	Global multi-resolution terrain elevation data	
GRIP	Global Roads Inventory Dataset	
JRC	Joint Research Centre	https://ec.europa.eu/info/departments/joint-research-centre_en
LV	Limit Value	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF
NILU	Norwegian Institute for Air Research	https://www.nilu.no/
NO_2	Nitrogen dioxide	
O_3	Ozone	
ORNL	Oak Ridge National Laboratory	https://www.ornl.gov/
PM_{10}	Particulate Matter with a diameter of 10 micrometres or less	
$PM_{2.5}$	Particulate Matter with a diameter of 2.5 micrometres or less	
R^2	Coefficient of determination	
RIMM	Regression – Interpolation – Merging Mapping	
RMSE	Root Mean Square Error	
SOMO35	Sum of Ozone Maximum daily 8-hour means Over 35 ppb (i.e. 70 µg/m^3)	
UTC	Coordinated Universal Time	
WHO	World Health Organization	https://www.who.int/

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Annex 1
Technical details and uncertainties of interim maps

This Annex 1 presents the technical details on the map creation. Furthermore, uncertainty estimates of the maps are given.

A1.1 PM_{10}

This sections present the technical details and uncertainty estimates of the PM_{10} 2021 annual average interim map as presented in Map 3.1.

Like in Horálek et al. (2021b), first the pseudo stations data have been estimated. The estimates have been calculated based on the E1a measurement data for 2020, the CAMS Ensemble Forecast modelling data for 2020 and 2021, and the regression relation with the E2a measurement data for 2021. Table A1.1 presents the regression coefficients determined for pseudo stations data estimation, based on the 1246 rural and urban/suburban background and 564 urban/suburban traffic stations that have both E1a 2020 and E2a 2021 measurements available (see Section 2.2.1). Next to this, it presents the statistics showing the tentative quality of the estimate.

Table A1.1: Parameters and statistics of linear regression model for generation of pseudo PM_{10} data in rural and urban background and urban traffic areas, for PM_{10} annual average 2021

PM_{10}		Rural and urban background areas	Urban traffic areas
Linear regression model (LRM, Eq. 2.4)	c (constant)	2.4	1.3
	a1 (PM_{10} annual mean 2020, E1a data)	0.472	0.441
	a2 (PM_{10} annual mean 2020 * CAMS ratio 2021/2020)	0.371	0.454
	Adjusted R^2	**0.88**	**0.88**
	Standard Error [μg/m^3]	**2.4**	**2.3**

Based on the E2a data and pseudo data, CAMS Ensemble Forecast modelling data and other supplementary data as used in the regular mapping, the interim PM_{10} annual average map for 2021 has been created (see Map 3.1). Table A1.2 presents the estimated parameters of the linear regression models (*c, a_1, a_2,…*) and of the residual kriging (*nugget, sill, range*) and includes the statistical indicators of both the regression and the kriging of its residuals.

The Table A1.2 shows that the uncertainty of the interim map of PM_{10} annual average expressed by RMSE is about 3 μg/m^3 for the rural areas and 4 μg/m^3 for both the urban background and the urban traffic areas. The relative mean uncertainty (Relative RMSE) of this map is 22 % for rural areas, 19 % for urban background areas, and 18 % for urban traffic areas, respectively. However, these uncertaity estimates are based on the non-validated E2a data and are valid only for areas covered by the E2a stations. The complete validation of the interim PM_{10} map can only be done when the validated E1a data for 2021 are available.

Table A1.2: Parameters and statistics of linear regression model and ordinary kriging in rural, urban background and urban traffic areas for the interim map of PM_{10} annual average 2021

PM_{10}		Annual average		
		Rural areas	Urban b. areas	Urban tr.. areas
Linear regresion model (LRM, Eq. 2.1)	c (constant)	1.70	1.18	1.76
	a1 (log. CAMS-ENS FC model)	0.681	0.69	0.524
	a2 (altitude GMTED)	-0.00019		
	a3 (relative humidity)	-0.03408		
	a4 (wind speed)	-0.008		-0.036
	a5 (land cover NAT1)	-0.0010		
	Adjusted R^2	**0.62**	**0.36**	**0.45**
	Standard Error [μg.m^{-3}]	**0.22**	**0.25**	**0.23**
Ordinary kriging (OK) of LRM residuals	nugget	0.013	0.012	0.019
	sill	0.049	0.048	0.040
	range [km]	390	190	470
LRM + OK of its residuals	**RMSE [μg/m^3]**	**3.1**	**3.7**	**3.7**
	Relative RMSE [%]	**21.6**	**18.9**	**17.9**
	Bias (MPE) [μg/m^3]	**0.0**	**-0.1**	**-0.1**
	R^2 of cross.-val. regr. equation	**0.66**	**0.73**	**0.70**
	Slope of cross-val. regr. equation	**0.68**	**0.74**	**0.71**
	Intercept of cross-val. regr. equation	**4.6**	**4.9**	**5.7**

A1.2 Ozone

Similarly as in Horálek et al. (2022a), no pseudo stations for ozone have been used, due to quite complete spatial coverage of the E2a data. Based on the E2a data, CAMS Ensemble Forecast modelling data and other supplementary data as used in the regular mapping, the interim map of the ozone indicator SOMO35 for 2021 has been created (see Map 4.1). Table A1.3 presents the estimated parameters of the linear regression models (c, a_1, a_2,...) and of the residual kriging (*nugget, sill, range*) and includes the statistical indicators of the regression and the kriging of its residuals.

Table A1.3: Parameters and statistics of linear regression model and ordinary kriging in rural and urban background areas for the interim map of ozone indicator SOMO35 for 2021

Ozone		SOMO35	
		Rural areas	Urban areas
Linear regresion model (LRM, Eq. 2.1)	c (constant)	-402	1303
	a1 (CAMS-ENS-FC model)	0.98	0.83
	a2 (altitude GMTED)	2.71	
	a3 (wind speed)		-380.4
	a4 (s. solar radiation)	*n.sign.*	*n.sign.*
	Adjusted R^2	**0.57**	**0.53**
	Standard Error [μg/m^3·d]	**1506**	**1392**
Ord. krig. (OK) of LRM residuals	nugget	1.3E+06	7.7E+05
	sill	2.0E+06	1.5E+06
	range [km]	310	570
LRM + OK of its residuals	**RMSE [[μg/m^3·d]**	**1456**	**1218**
	Relative RMSE [%]	**32.4**	**31.9**
	Bias (MPE) [μg/m^3·d]	**-10**	**-2**
	R^2 of cross.-val. regr. equation	**0.60**	**0.64**
	Slope of cross-val. regr. equation	**0.60**	**0.66**
	Intercept of cross-val. regr. equation	**1778**	**1291**

Table A1.3 shows that the uncertainty of the interim map of ozone indicator SOMO35 expressed by RMSE is 1456 μg/m^3·d for the rural areas and 1218 μg/m^3·d for the urban background areas. The relative mean uncertainty (Relative RMSE) of this map is 32 % for both the rural and urban background areas. These uncertaity estimates are based on the non-validated E2a data and are valid only for areas covered by the E2a stations. The complete validation of the interim ozone map can only be done when the validated E1a data for 2021 are available.

A1.3 NO_2

As a first step for the interim NO_2 annual average 2021 map creation, the pseudo stations data have been estimated, based on the E1a measurement data for 2020, the Sentinel-5P satellite data for 2020 and 2021, and the regression relation with the E2a measurement 2021 data. Table A1.4 presents the regression coefficients determined for pseudo stations data estimation, based on the 1524 rural and urban/suburban background and 718 urban/suburban traffic stations that have both E1a 2020 and E2a 2021 measurements available (see Section 2.2.1). Apart from this, it gives the statistics showing the tentative quality of the estimate.

Table A1.4: Parameters and statistics of linear regression model for generation of pseudo NO_2 data in rural and urban background and urban traffic areas, for NO_2 annual average 2021

NO_2		Rural and urban background areas	Urban traffic areas
Linear regression model (LRM, Eq. 2.4)	c (constant)	0.5	1.7
	a1 (NO_2 annual mean 2020, E1a data)	0.813	0.812
	a2 (NO_2 annual mean 2020 * Sentinel-5P ratio 2021/2020)	0.147	0.119
	Adjusted R^2	**0.94**	**0.91**
	Standard Error [μg/m^3]	**1.7**	**2.7**

Based on the E2a data and pseudo data, CAMS Ensemble Forecast modelling data, Sentinel-5P satellite data and other supplementary data as used in the regular mapping, the interim NO_2 annual average map for 2021 has been created. Table A1.5 presents the estimated parameters of the linear regression models (c, a_1, a_2,...) and of the residual kriging (*nugget, sill, range*) and includes the statistical indicators of both the regression and the kriging of its residuals.

Table A1.5: Parameters and statistics of linear regression model and ordinary kriging in rural, urban background and urban traffic areas for the interim map of NO_2 annual average 2021

NO_2		Annual average		
		Rural areas	Urb. b. areas	Urb. tr. areas
Linear regresion model (LRM, Eq. 2.1)	c (constant)	6.4	15.1	21.88
	a1 (CAMS-ENS-FC model)	0.374	*n.sign.*	*n.sign.*
	a6 (satellite Sentinel-5P)	0.92	1.641	1.761
	a2 (altitude)	-0.0061		
	a3 (altitude_5km_radius)	0.0055		
	a4 (wind speed)	-0.95	-2.031	-2.030
	a7 (population*1000)	0.00079	0.00020	
	a8 (NAT_1km)		-0.0392	
	a9 (AGR_1km)		-0.0280	
	a10 (TRAF_1km)		0.0907	
	a11 (LDR_5km_radius)	*n.sign.*	*n.sign.*	0.0012
	a12 (HDR_5km_radius)		0.1278	0.0642
	a13 (NAT_5km_radius)	-0.0365		
	Adjusted R^2	**0.73**	**0.42**	**0.32**
	Standard Error [μg/m^3]	**2.2**	**5.4**	**7.9**
Ordinary kriging (OK) of LRM residuals	nugget	3	5	17
	sill	4	17	40
	range [km]	186	100	190
LRM + OK of its residuals	**RMSE [μg/m^3]**	**1.8**	**3.8**	**6.3**
	Relative RMSE [%]	**27.0**	**23.8**	**25.7**
	Bias (MPE) [μg/m^3]	**0.0**	**0.0**	**0.0**
	R^2 of cross.-val. regr. equation	**0.80**	**0.61**	**0.50**
	Slope of cross-val. regr. equation	**0.80**	**0.67**	**0.55**
	Intercept of cross-val. regr. equation	**1.4**	**5.1**	**11.2**

Table A1.5 shows that the uncertainty of the interim map of NO_2 annual average expressed by RMSE is about 2 µg/m^3 for the rural areas, 4 µg/m^3 for the urban background areas, and 6 µg/m^3 for the urban traffic areas, respectively. The relative mean uncertainty (Relative RMSE) of this map is 27 % for rural areas, 24 % for urban background areas, and 26 % for urban traffic areas, respectively. However, like for PM_{10} and ozone, these uncertaity estimates are based on the non-validated E2a data and are valid only for areas covered by the E2a stations. The complete validation of the interim NO_2 map can only be done when the validated E1a data for 2021 are available.

Annex 2
Validation of 2020 interim maps

This Annex 2 presents the validation of the 2020 interim maps produced using the up-to-date E2a data as presented in Horálek et al. (2022a), against the validated E1a data (EEA, 2022). Next to this, it presents the exposure tables calculated using the interim 2020 maps and validates them against the exposure estimates calculated using the regular 2020 maps as presented in Horálek et al. (2022b).

A2.1 Concentration maps

This section evaluates the concentration interim maps against the E1a data, using cross-validation.

PM_{10}

Table A2.1 presents the evaluation of the interim PM_{10} annual average 2020 map, against the E1a station data for 2020. Additionally, it also presents the cross-validation evaluation of the regular PM_{10} annual average 2020 map (Horálek et al., 2022b) for the same subsets of the E1a station data, for comparable reasons.

Table A2.1: Validation of interim (left) and regular (right) map of PM_{10} annual average 2020 showing RMSE, RRMSE, bias, R^2 and linear regression from validation scatter plots in rural background (top), urban background (middle) and urban traffic areas (bottom), against two validation sets of stations. Units: µg/m³ except for RRMSE and R^2

PM_{10} – Annual Average											
Area	Validation set	Interim map					Regular map				
		RMSE	RRMSE	Bias	R^2	Regr. eq.	RMSE	RRMSE	Bias	R^2	Regr. eq.
Rural	E1a stations with E2a data	2.5	18.1%	0.1	0.758	y = 0.748x + 3.6	2.5	18.3%	0.0	0.756	y = 0.805x + 2.7
	E1a stations with no E2a data	3.2	22.7%	0.0	0.720	y = 0.669x + 4.5	3.1	22.2%	-0.1	0.720	y = 0.669x + 4.5
Urban background	E1a stations with E2a data	3.6	18.9%	0.0	0.670	y = 0.705x + 5.7	3.6	19.0%	0.2	0.674	y = 0.750x + 5.0
	E1a stations with no E2a data	4.6	23.2%	-0.3	0.683	y = 0.644x + 6.9	4.3	21.6%	0.0	0.724	y = 0.743x + 5.2
Urban traffic	E1a stations with E2a data	3.6	17.8%	-0.1	0.712	y = 0.725x + 5.4	3.6	17.8%	-0.1	0.714	y = 0.745x + 5.1
	E1a stations with no E2a data	4.2	20.8%	0.0	0.574	y = 0.692x + 6.2	4.0	19.8%	0.0	0.607	y = 0.701x + 6.0

One can see that the uncertainty of the interim map is only slightly worse compared to the uncertainty of the regular map. The largest difference is found for urban background areas with no E2a data, which show the bias of -0.3 µg/m³ for the interim map, while no bias for the regular map.

Additionally, the validation of the E2a data and the pseudo station data used in the interim PM_{10} mapping has been performed. Table A2.2 shows the validation of the E2a and the pseudo data, against the E1a station data in the locations of theese stations.

Table A2.2: Validation of E2a and pseudo station data showing RMSE, RRMSE, bias, R^2 and linear regression from validation scatter plots for rural background (top), urban/suburban background (middle) and urban/suburban traffic stations (bottom), PM_{10} annual average 2020. Validation by E1a station data. Units: µg/m³ except for RRMSE and R^2

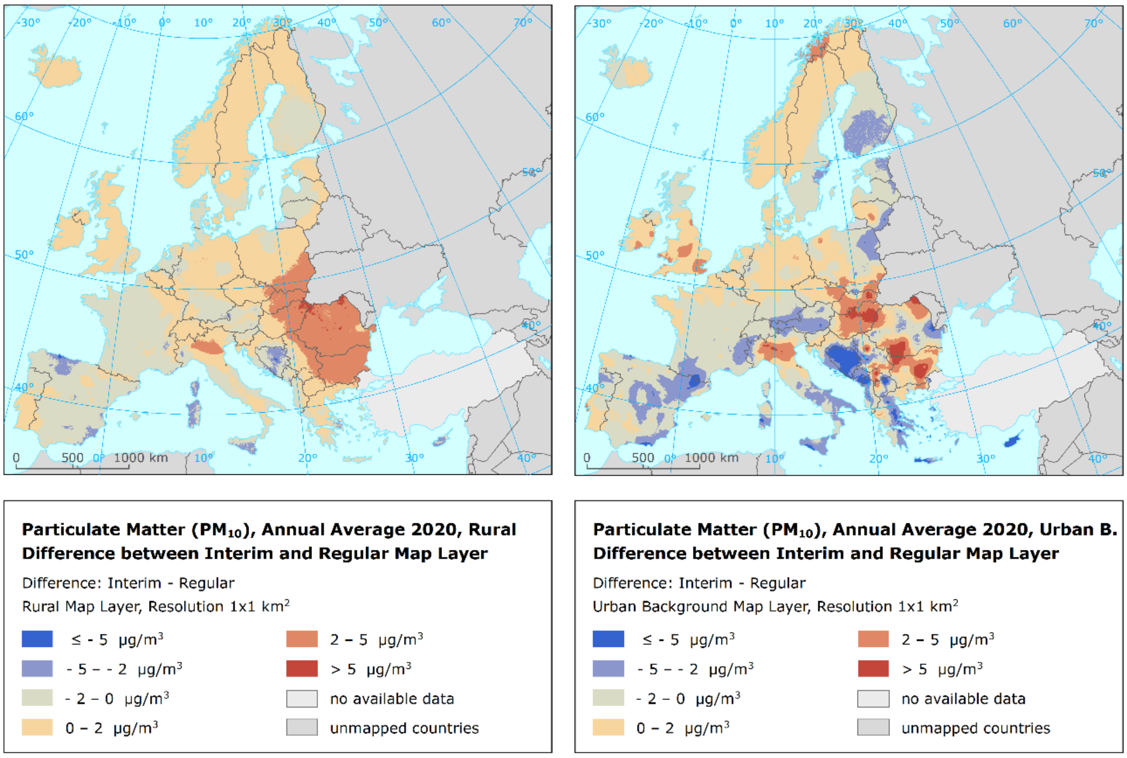
PM_{10} – Annual Average							
Station type	Evaluated set	Validation set	RMSE	RRMSE	Bias	R^2	Regr. eq.
Rural background	E2a stations	E1a stations with E2a data	1.0	7.0%	0.1	0.965	y = 0.980x + 0.4
	Pseudo stations	E1a stations in locations of pseudo stations	1.4	9.9%	0.0	0.928	y = 0.902x + 3.4
Urban/suburban background	E2a stations	E1a stations with E2a data	0.8	4.3%	-0.1	0.983	y = 0.970x + 0.5
	Pseudo stations	E1a stations in locations of pseudo stations	2.8	13.9%	-0.6	0.898	y = 0.791x + 3.5
Urban/suburban traffic	E2a stations (*)	E1a stations with E2a data	1.0	5.1%	-0.2	0.978	y = 0.964x + 0.5
	Pseudo stations	E1a stations in locations of pseudo stations	2.0	9.7%	-0.1	0.904	y = 0.852x + 2.9

(*) Without the outlier station IT1533A (E2a data … 111.5 µg/m³ , E1a data … 32.0 µg/m³).

In general, the results show better agreement of the pseudo data with the E1a data, compared to the validation of the pseudo stations used in the 2017 interim mapping (Horálek et al., 2021a). The bias of -0.6 μg/m^3 for pseudo stations in urban background areas is quite in line with the results of Table A2.1.

Map A2.1 shows the difference between the interim and the regular maps of the PM_{10} annual average 2020, for rural and urban background map layers. One can see the greatest differences in Balkan, Cyprus and Hungary, i.e. in the areas with the lack of the E1a stations, both in the rural and the urban background areas (see Horálek et al., 2022a, Annex).

Map A2.1: Difference between interim and regular map for PM_{10} annual average 2020 in rural (left) and urban background (right) areas. Urban map layer is applicable in urban areas only



Ozone

Table A2.3 shows the evaluation of the interim 2020 map for the ozone indicator SOMO35, against the E1a data for 2020, separately for two subsets of the stations (i.e. for stations with and without the E2a data). Again, it also presents the cross-validation evaluation of the regular 2020 map for SOMO35 (Horálek et al., 2022b) based on the same subsets of the E1a station data, for comparable reasons.

Table A2.3: Validation of interim (left) and regular (right) map of the ozone indicator SOMO35 for 2020 showing RMSE, RRMSE, bias, R^2 and linear regression from validation scatter plots in rural background (top) and urban background (bottom), against two validation sets of stations. Units: μg/m^3·d except for RRMSE and R^2

Ozone – SOMO35												
Area	Validation set	Interim map					Regular map					
		RMSE	RRMSE	Bias	R^2	Regr. eq.	RMSE	RRMSE	Bias	R^2	Regr. eq.
Rural	E1a stations with E2a data	1306	26.6%	88	0.556	y = 0.588x + 2113	1294	26.4%	10	0.560	y = 0.544x + 2248
	E1a stations with no E2a data	1708	30.1%	324	0.602	y = 0.634x + 2400	1833	32.3%	61	0.525	y = 0.560x + 2555
Urban backgr.	E1a stations with E2a data	1102	25.8%	113	0.591	y = 0.684x + 1466	1054	24.7%	7	0.608	y = 0.593x + 1747
	E1a stations with no E2a data	1935	43.3%	151	0.349	y = 0.455x + 2588	1741	38.9%	-27	0.447	y = 0.479x + 2301

The results show that the uncertainty of the interim map is only slightly worse compared to the uncertainty of the regular map. One can see slight positive bias of the interim map.

Additionally, the validation of the E2a data used in the interim O_3 mapping has been performed, see Table A2.4. In the case of ozone, the pseudo stations are not used in the interim mapping.

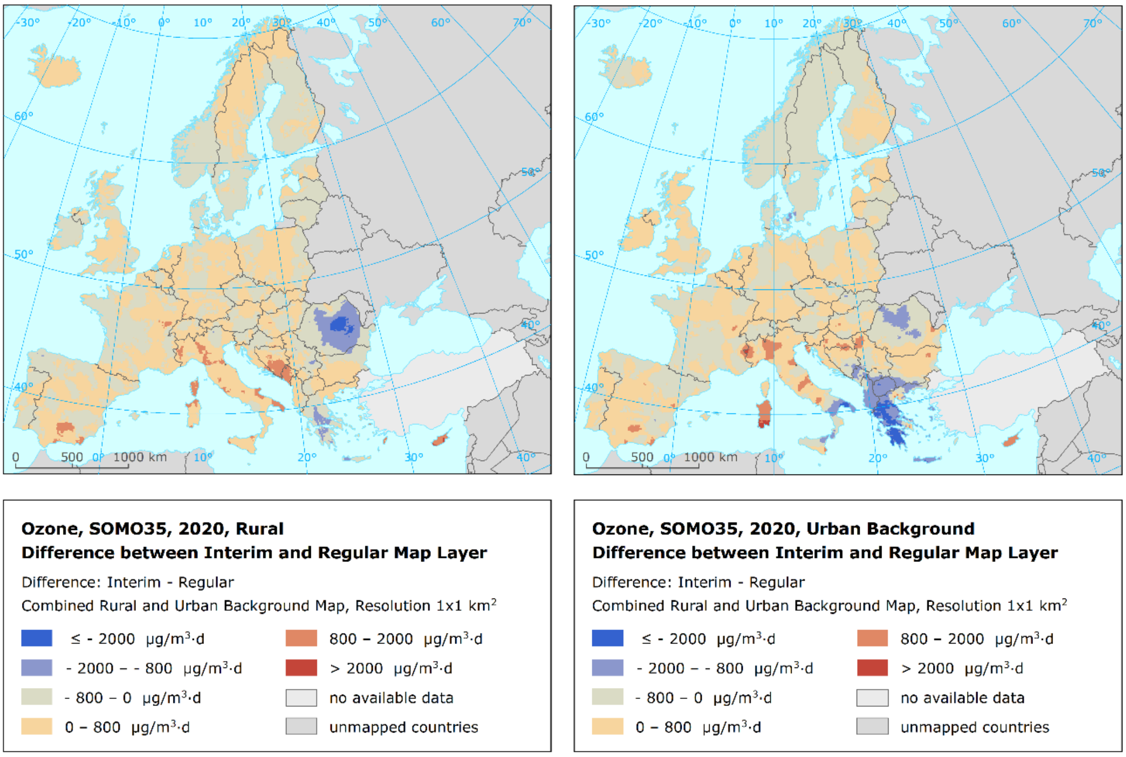
Table A2.4: Validation of E2a data showing RMSE, RRMSE, bias, R^2 and linear regression from validation scatter plots for rural background (top) and urban/suburban background stations (bottom), ozone indicator SOMO35 for 2020. Validation by E1a station data. Units: μg/m^3·d except for RRMSE and R^2

Ozone – SOMO35							
Station type	**Evaluated set**	**Validation set**	**RMSE**	**RRMSE**	**Bias**	**R^2**	**Regr. eq.**
Rural background	E2a stations	E1a stations with E2a data	270	5.5%	108	0.986	y = 1.029x - 36
Urban/suburban background	E2a stations	E1a stations with E2a data	439	10.3%	108	0.949	y = 1.061x - 155

One can see that the E2a data show the bias of cc. 100 μg/m^3·d in both rural and urban background areas compared to the validated E1a data. This is probably the reason of the bias shown in Table A2.3.

Map A2.2 shows the difference between the interim and the regular maps of the ozone indicator SOMO35 for 2020, for rural and urban background map layers. The major differences can be seen in Romania for rural areas and in Greece for urban background areas. In both cases, the main reason probably is in the change of the ozone E1a values compared to the E2a ones (i.e. higher E1a values). Difference in the urban areas of Sardinia is caused by the lack of the E2a stations there. Differences in Cyprus are caused by higher E2a values (both rural and urban background) compared to the E1a ones.

Map A2.2: Difference between interim and regular map for ozone indicator SOMO35 for 2020 in rural (left) and urban background (right) areas. Urban map layer is applicable in urban areas only



NO_2

Table A2.5 presents the evaluation of the interim NO_2 annual average 2020 map, against the E1a station data for 2020. Additionally, it also presents the cross-validation evaluation of the regular NO_2 annual average 2020 map (Horálek et al., 2022b) for the same subsets of the E1a station data, for comparable reasons.

Table A2.5: Validation of interim (left) and regular (right) map of NO_2 annual average 2020 showing RMSE, RRMSE, bias, R^2 and linear regression from validation scatter plots in rural background (top), urban background (middle) and urban traffic areas (bottom), against two validation sets of stations. Units: µg/m³ except for RRMSE and R^2

NO_2 – Annual Average											
Area	Validation set	Interim map					Regular map				
		RMSE	RRMSE	Bias	R^2	Regr. eq.	RMSE	RRMSE	Bias	R^2	Regr. eq.
Rural	E1a stations with E2a data	1.9	28.3%	0.0	0.808	y = 0.786x + 1.4	1.8	27.6%	0.0	0.816	y = 0.819x + 1.2
	E1a stations with no E2a data	2.4	41.3%	-0.1	0.719	y = 0.759x + 1.3	2.4	41.4%	-0.1	0.720	y = 0.770x + 1.3
Urban background	E1a stations with E2a data	3.6	23.5%	-0.2	0.629	y = 0.666x + 4.9	3.6	23.7%	0.0	0.624	y = 0.682x + 4.9
	E1a stations with no E2a data	4.1	27.3%	-0.4	0.565	y = 0.582x + 5.8	4.2	28.1%	0.0	0.547	y = 0.635x + 5.4
Urban traffic	E1a stations with E2a data	5.9	24.1%	-0.4	0.559	y = 0.552x + 11	6.0	24.5%	0.0	0.546	y = 0.591x + 10
	E1a stations with no E2a data	5.5	20.8%	-0.4	0.503	y = 0.501x + 13	5.3	20.0%	0.1	0.540	y = 0.574x + 11

Again, the uncertainty of the interim map is only slightly worse compared to the uncertainty of the regular map.

Additionally, the validation of the E2a data and the pseudo station data used in the interim NO_2 mapping has been performed. Table A2.6 shows the validation of the E2a and the pseudo data, against the E1a station data in the locations of these stations.

Table A2.6: Validation of E2a and pseudo station data showing RMSE, RRMSE, bias, R^2 and linear regression from validation scatter plots for rural background (top), urban/suburban background (middle) and urban/suburban traffic stations (bottom), NO_2 annual average 2020. Validation by E1a station data. Units: µg/m³ except for RRMSE and R^2

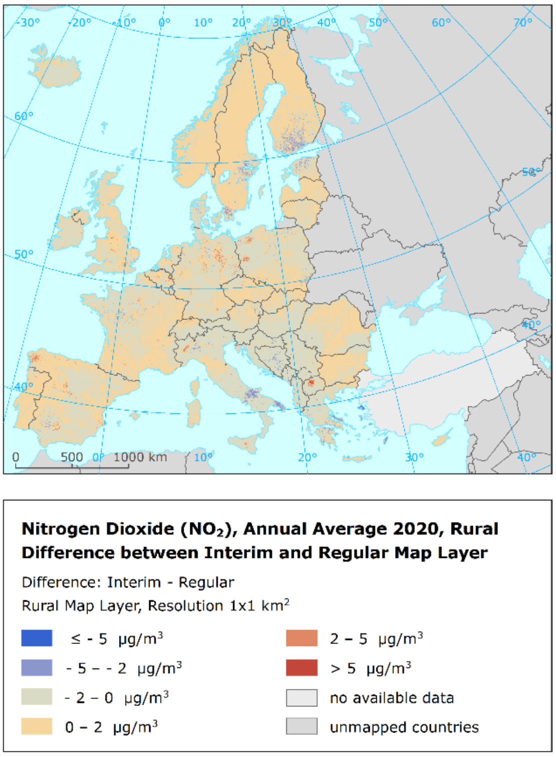
NO_2 – Annual Average							
Station type	Evaluated set	Validation set	RMSE	RRMSE	Bias	R^2	Regr. eq.
Rural background	E2a stations	E1a stations with E2a data	0.4	5.3%	-0.1	0.994	y = 0.970x + 0.1
	Pseudo stations	E1a stations in locations of pseudo stations	1.3	21.6%	0.1	0.926	y = 0.927x + 0.6
Urban/suburban background	E2a stations (*)	E1a stations with E2a data	1.0	6.6%	-0.2	0.972	y = 0.986x
	Pseudo stations	E1a stations in locations of pseudo stations	2.5	16.6%	-0.2	0.835	y = 0.874x + 1.7
Urban/suburban traffic	E2a stations	E1a stations with E2a data	1.3	5.2%	-0.3	0.980	y = 0.989x
	Pseudo stations	E1a stations in locations of pseudo stations	2.5	9.2%	-0.6	0.898	y = 0.891x + 2.3

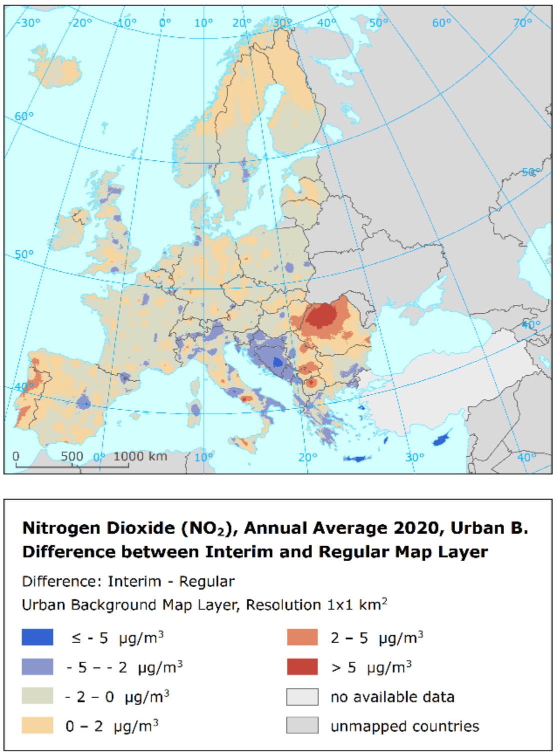
(*) Without the outlier station IT1486A (E2a data … 111.5 µg/m³ , E1a data … 32.0 µg/m³).

In general, the results show slightly worse agreement of the pseudo data with the E1a data in the rural and the urban background areas and quite similar agreement in the urban traffic areas, compared to the validation of the pseudo stations used in the 2017 interim mapping (Horálek et al., 2021a). The worse agreement is probably influenced by the exceptional character of the year 2020. Note that the psaudo data are estimated based on the regression relation between years Y and Y-1.

Map A2.3 shows the difference between the interim and the regular maps of NO_2 annual average 2020, for rural and urban background map layers. The main differences can be seen in the urban areas of the west Balkan (especially Bosnia) and Romania. In the first case, the reason probably is in the lack of the E2a data for Bosnia (where the E1a data show high NO_2 values). In the second case, the reason lies in a surprising lack of several stations with the E2a data (with high NO_2 values) in the E1a data set.

Map A2.3: Difference between interim and regular map for NO_2 annual average 2020 in rural (left) and urban background (right) areas. Urban map layer is applicable in urban areas only





A2.2 Population exposure

This section presents the exposure tables based on the interim maps for 2020 (Horálek et al., 2022a) and validates them against the exposure tables based on the 2020 regular maps (Horálek et al., 2022b).

Table A2.7 shows the population-weighted concentration of PM_{10} annual average and the percentage of population living in areas with concentrations above the PM_{10} annual Limit Value (LV) of 40 µg/m³ for individual countries, for the EU-27 and for the total mapping area, based on both the interim and the regular maps. Next to the values calculated based on the interim and regular maps, the table presents also the differences between the values calculated based on these two different maps.

One can see that for the total area and for the EU-27, both the population-weighted concentration and the population exposed to concentrations above LV show quite similar results in both cases. However, the results for individual countries differ more, specifically in the cases of Cyprus, Andorra, Bosnia and Herzegovina, Montenegro, Hungary and Malta for the population-weighted concentration, and in the cases of Bosnia and Herzegovina, Cyprus, North Macedonia and Serbia for the population living in areas with concentrations above LV. This is in agreement with the differences shown in Map A2.1.

Table A2.8 presents the population-weighted concentration of the ozone indicator SOMO35 for 2020 and the percentage of population exposed to the SOMO35 values above 6000 µg/m³·d, in the same structure as Table A2.7. Again, the table shows a good agreement of the results based on the interim and regular maps for the total area and for the EU-27, while greater differences of these results are estimated for individual countries. The most distinct differences can be seen for North Macedonia, Cyprus and Albania in the case of the population-weighted concentration, and for Monaco, Cyprus, Greece, and Italy in the case of the population living in areas with the SOMO35 values above 6000 µg/m³·d. This outcome corresponds with the differences presented in Map A2.2.

Table A2.7: Population-weighted concentration and percentage of population living in areas with concentrations above the annual LV of 40 µg/m³ for PM_{10} annual average 2020 based on the interim and regular maps and the difference “Interim – Regular”

Country	ISO	PM_{10} Annual Average 2020						Country	ISO	PM_{10} Annual Average 2020					
		Population-weighted concentration [µg/m³]			Population above LV [%]					Population-weighted concentration [µg/m³]			Population above LV [%]		
		Interim	Regular	Diff.	Inter.	Reg.	Diff.			Interim	Regular	Diff.	Inter.	Reg.	Diff.
Albania	AL	21.9	24.2	**-2.4**	0.0	0.0	**0.0**	Luxembourg	LU	14.0	14.9	**-0.9**	0.0	0.0	**0.0**
Andorra	AD	7.9	16.6	**-8.7**	0.0	0.0	**0.0**	Malta	MT	21.5	25.2	**-3.7**	0.0	0.0	**0.0**
Austria	AT	12.8	14.6	**-1.8**	0.0	0.0	**0.0**	Monaco	MC	16.9	18.7	**-1.8**	0.0	0.0	**0.0**
Belgium	BE	17.9	17.4	**0.5**	0.0	0.0	**0.0**	Montenegro	ME	21.0	25.1	**-4.1**	0.0	0.0	**0.0**
Bosnia & Herzegovina	BA	28.3	36.2	**-7.8**	8.0	37.3	**-29.3**	Netherlands	NL	16.7	16.5	**0.2**	0.0	0.0	**0.0**
Bulgaria	BG	28.7	26.0	**2.7**	1.0	0.0	**1.0**	North Macedonia	MK	29.9	31.6	**-1.7**	18.1	22.1	**-4.0**
Croatia	HR	22.2	22.7	**-0.5**	0.0	0.1	**-0.1**	Norway	NO	10.0	9.3	**0.7**	0.0	0.0	**0.0**
Cyprus	CY	22.7	32.3	**-9.6**	0.0	9.4	**-9.4**	Poland	PL	23.3	22.7	**0.6**	0.0	0.0	**0.0**
Czechia	CZ	18.8	17.5	**1.3**	0.0	0.0	**0.0**	Portugal (excl. Az., Mad.)	PT	17.5	17.7	**-0.2**	0.0	0.0	**0.0**
Denmark (incl. Faroes)	DK	14.4	14.1	**0.3**	0.0	0.0	**0.0**	Romania	RO	24.5	23.2	**1.3**	0.4	0.0	**0.4**
Estonia	EE	9.9	10.9	**-1.0**	0.0	0.0	**0.0**	San Marino	SM	22.1	20.8	**1.3**	0.0	0.0	**0.0**
Finland	FI	7.6	8.7	**-1.1**	0.0	0.0	**0.0**	Serbia (incl. Kosovo*)	RS	32.9	31.4	**1.5**	16.3	13.7	**2.6**
France (metropolitan)	FR	14.4	15.0	**-0.6**	0.0	0.0	**0.0**	Slovakia	SK	22.6	20.1	**2.5**	0.0	0.0	**0.0**
Germany	DE	14.1	14.2	**0.0**	0.0	0.0	**0.0**	Slovenia	SI	17.6	18.0	**-0.5**	0.0	0.0	**0.0**
Greece	GR	21.8	23.9	**-2.1**	0.0	0.5	**-0.5**	Spain (excl. Canarias)	ES	17.5	18.7	**-1.2**	0.0	0.0	**0.0**
Hungary	HU	25.5	21.5	**4.0**	0.0	0.0	**0.0**	Sweden	SE	9.4	10.3	**-0.9**	0.0	0.0	**0.0**
Iceland	IS	7.7	9.1	**-1.4**	0.0	0.0	**0.0**	Switzerland	CH	12.0	12.6	**-0.6**	0.0	0.0	**0.0**
Ireland	IE	12.8	11.4	**1.4**	0.0	0.0	**0.0**	United Kingdom (& Cr. d.)	UK	15.5	13.9	**1.5**	0.0	0.0	**0.0**
Italy	IT	23.9	23.8	**0.1**	1.0	0.0	**1.0**	**Total (without Türkiye)**		**18.1**	**18.0**	**0.1**	**0.5**	**0.6**	**-0.1**
Latvia	LV	15.6	17.0	**-1.5**	0.0	0.0	**0.0**	**EU-27**		**18.2**	**18.3**	**0.0**	**0.2**	**0.1**	**0.1**
Liechtenstein	LI	9.2	11.3	**-2.1**	0.0	0.0	**0.0**	Kosovo*	KS	28.9	26.7	**2.2**	0.1	0.2	**-0.1**
Lithuania	LT	17.8	18.5	**-0.6**	0.0	0.0	**0.0**	Serbia (excl. Kosovo*)	RS-	33.9	32.6	**1.3**	20.2	16.9	**3.3**

(*) under the UN Security Council Resolution 1244/99

Table A2.8: Population-weighted concentration and percentage of population living in areas with concentrations above 6000 µg/m³·d for ozone indicator SOMO35 for 2020 based on the interim and regular maps and the difference “Interim – Regular”

Country	ISO	Ozone, SOMO35, 2020						Country	ISO	Ozone, SOMO35, 2020					
		Population-weighted concentration [µg/m³·d]			Population above 6000 µg/m³·d [%]					Population-weighted concentration [µg/m³·d]			Population above 6000 µg/m³·d [%]		
		Interim	Regular	Diff.	Inter.	Reg.	Diff.			Interim	Regular	Diff.	Inter.	Reg.	Diff.
Albania	AL	4 951	5 679	**-728**	16.6	0.0	**16.6**	Luxembourg	LU	4 208	4 272	**-64**	0.0	0.0	**0.0**
Andorra	AD	2 242	2 813	**-571**	0.0	0.0	**0.0**	Malta	MT	6 347	6 590	**-243**	67.1	0.0	**67.1**
Austria	AT	4 697	4 584	**112**	4.9	0.0	**4.9**	Monaco	MC	6 710	6 445	**265**	100.0	0.0	**100.0**
Belgium	BE	3 846	3 798	**48**	0.0	37.3	**-37.3**	Montenegro	ME	4 043	4 360	**-317**	11.0	0.0	**11.0**
Bosnia & Herzegovina	BA	4 280	4 045	**235**	1.7	0.0	**1.7**	Netherlands	NL	3 704	3 426	**277**	0.0	0.0	**0.0**
Bulgaria	BG	3 063	2 967	**96**	1.9	0.0	**1.9**	North Macedonia	MK	2 856	4 345	**-1 489**	1.5	22.1	**-20.5**
Croatia	HR	5 259	4 775	**484**	10.2	0.0	**10.2**	Norway	NO	1 786	2 041	**-255**	0.0	0.0	**0.0**
Cyprus	CY	7 729	6 300	**1 429**	99.6	9.4	**90.1**	Poland	PL	3 268	3 216	**53**	0.0	0.0	**0.0**
Czechia	CZ	4 305	4 252	**53**	0.0	0.0	**0.0**	Portugal (excl. Az., Mad.)	PT	3 641	3 585	**56**	0.4	0.0	**0.4**
Denmark (incl. Faroes)	DK	1 737	2 284	**-547**	0.0	0.0	**0.0**	Romania	RO	2 473	2 955	**-482**	0.0	13.7	**-13.7**
Estonia	EE	1 585	1 469	**116**	0.0	0.0	**0.0**	San Marino	SM	5 961	5 387	**575**	16.6	0.0	**16.6**
Finland	FI	1 325	1 362	**-37**	0.0	0.0	**0.0**	Serbia (incl. Kosovo*)	RS	3 230	3 256	**-26**	0.6	0.0	**0.6**
France (metropolitan)	FR	4 289	4 274	**15**	4.1	0.5	**3.6**	Slovakia	SK	3 805	3 867	**-62**	0.0	0.0	**0.0**
Germany	DE	4 260	4 194	**65**	0.8	0.0	**0.8**	Slovenia	SI	5 095	5 011	**85**	19.0	0.0	**19.0**
Greece	GR	6 018	6 181	**-164**	57.5	0.0	**57.5**	Spain (excl. Canarias)	ES	4 586	4 525	**61**	13.4	0.0	**13.4**
Hungary	HU	3 966	4 044	**-78**	0.0	0.0	**0.0**	Sweden	SE	1 811	2 182	**-371**	0.0	0.0	**0.0**
Iceland	IS	1 563	1 582	**-20**	0.0	0.0	**0.0**	Switzerland	CH	5 443	5 388	**55**	8.4	0.1	**8.3**
Ireland	IE	2 045	1 911	**134**	0.0	0.0	**0.0**	United Kingdom (& Cr. d.)	UK	2 335	2 300	**35**	0.0	0.0	**0.0**
Italy	IT	6 511	6 059	**452**	54.7	0.0	**54.7**	**Total (without Türkiye)**		**4 032**	**3 997**	**35**	**11.4**	**9.8**	**1.6**
Latvia	LV	1 767	1 700	**67**	0.0	0.0	**0.0**	**EU-27**		**4 133**	**4 252**	**-119**	**13.0**	**11.6**	**1.4**
Liechtenstein	LI	4 650	4 971	**-321**	2.0	0.0	**2.0**	Kosovo*	KS	3 320	3 900	**-580**	2.1	0.2	**1.9**
Lithuania	LT	2 010	2 044	**-34**	0.0	0.0	**0.0**	Serbia (excl. Kosovo*)	RS-	3 208	3 098	**110**	0.2	16.9	**-16.8**

(*) under the UN Security Council Resolution 1244/99

Table A2.9 shows the population-weighted concentration of NO_2 annual average 2020 and the population exposed to concentrations above the NO_2 annual Limit Value (LV) of 40 µg/m³ for individual countries, for the EU-27 and for the total mapping area, based on both the interim and the regular maps. Again, the differences between the results based on the two maps are also presented.

Table A2.9: Population-weighted concentration and percentage of population living in areas with concentrations above the annual LV of 40 µg/m³ for NO_2 annual average 2020 based on the interim and regular maps and the difference “Interim – Regular”

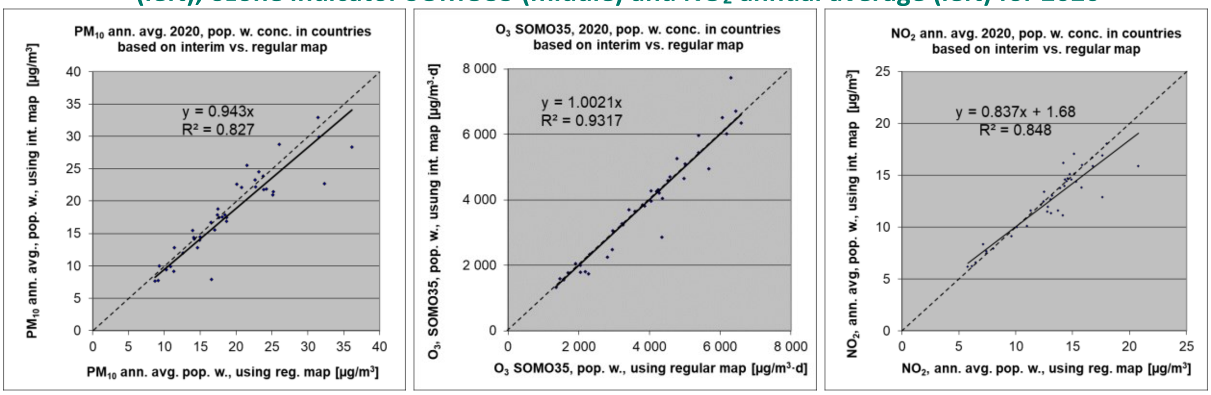
Country	ISO	NO_2 Annual Average 2020						Country	ISO	NO_2 Annual Average 2020					
		Population-weighted concentration [µg/m³]			Population above LV [%]					Population-weighted concentration [µg/m³]			Population above LV [%]		
		Interim	Regular	Diff.	Inter.	Reg.	Diff.			Interim	Regular	Diff.	Inter.	Reg.	Diff.
Albania	AL	11.5	12.8	**-1.3**	0.0	0.0	**0.0**	Luxembourg	LU	13.8	15.8	**-2.0**	0.0	3.3	**-3.3**
Andorra	AD	12.9	17.6	**-4.8**	0.0	0.0	**0.0**	Malta	MT	10.1	11.0	**-0.9**	0.0	0.0	**0.0**
Austria	AT	14.0	14.3	**-0.3**	0.0	0.5	**-0.5**	Monaco	MC	18.1	18.0	**0.1**	0.0	0.0	**0.0**
Belgium	BE	14.6	14.3	**0.2**	0.0	0.5	**-0.5**	Montenegro	ME	11.6	13.7	**-2.1**	0.0	0.0	**0.0**
Bosnia & Herzegovina	BA	11.1	14.1	**-3.0**	0.0	0.2	**-0.2**	Netherlands	NL	16.0	15.8	**0.1**	0.0	0.0	**0.0**
Bulgaria	BG	16.7	16.7	**0.0**	0.0	1.1	**-1.1**	North Macedonia	MK	16.2	14.2	**2.0**	0.0	1.8	**-1.8**
Croatia	HR	11.4	13.1	**-1.7**	0.0	0.3	**-0.3**	Norway	NO	7.9	8.0	**-0.1**	0.0	0.0	**0.0**
Cyprus	CY	15.9	20.8	**-4.9**	0.0	8.4	**-8.4**	Poland	PL	12.7	13.0	**-0.4**	0.0	0.7	**-0.7**
Czechia	CZ	12.5	12.5	**0.0**	0.0	0.0	**0.0**	Portugal (excl. Az., Mad.)	PT	13.4	12.5	**0.9**	0.0	0.2	**-0.2**
Denmark (incl. Faroes)	DK	7.7	7.4	**0.3**	0.0	0.0	**0.0**	Romania	RO	17.1	15.1	**1.9**	0.7	5.9	**-5.2**
Estonia	EE	6.2	5.8	**0.4**	0.0	0.0	**0.0**	San Marino	SM	13.1	13.2	**-0.1**	0.0	0.0	**0.0**
Finland	FI	6.2	6.2	**0.0**	0.0	0.0	**0.0**	Serbia (incl. Kosovo*)	RS	15.1	14.8	**0.3**	0.0	0.4	**-0.4**
France (metropolitan)	FR	12.2	12.2	**0.0**	0.5	2.8	**-2.3**	Slovakia	SK	11.6	11.3	**0.3**	0.0	0.0	**0.0**
Germany	DE	15.2	15.2	**0.0**	0.0	1.9	**-1.9**	Slovenia	SI	11.9	12.8	**-0.9**	0.0	0.0	**0.0**
Greece	GR	15.9	16.8	**-0.9**	2.7	5.7	**-2.9**	Spain (excl. Canarias)	ES	14.7	14.6	**0.1**	0.0	3.2	**-3.2**
Hungary	HU	14.6	14.9	**-0.3**	0.0	2.6	**-2.6**	Sweden	SE	6.6	6.5	**0.1**	0.0	0.0	**0.0**
Iceland	IS	8.3	7.1	**1.2**	0.0	0.0	**0.0**	Switzerland	CH	14.4	14.5	**-0.1**	0.0	0.7	**-0.7**
Ireland	IE	7.5	7.4	**0.1**	0.0	0.0	**0.0**	United Kingdom (& Cr. d.)	UK	13.8	13.9	**-0.1**	0.0	0.7	**-0.7**
Italy	IT	16.9	17.6	**-0.7**	0.1	6.6	**-6.5**	**Total (without Türkiye)**		**14.0**	**14.0**	**-0.1**	**0.1**	**0.2**	**2.2**
Latvia	LV	9.1	9.6	**-0.5**	0.0	0.0	**0.0**	**EU-27**		**14.1**	**14.1**	**-0.1**	**0.0**	**0.2**	**2.6**
Liechtenstein	LI	14.4	15.3	**-0.9**	0.0	0.0	**0.0**	Kosovo*	KS	15.7	14.4	**1.3**	0.0	0.0	**0.0**
Lithuania	LT	10.0	10.1	**-0.1**	0.0	0.0	**0.0**	Serbia (excl. Kosovo*)	RS-	15.0	14.9	**0.1**	0.0	0.5	**-0.5**

(*) under the UN Security Council Resolution 1244/99

Similarly as for PM_{10} and ozone, one can see a good agreement of the results based on the interim and regular maps for the total area and for the EU-27, while some differences of these results are found for individual countries. The greatest differences are found Cyprus, Andorra, Bosnia and Herzegovina and Montenegro in the case the population-weighted concentration, while for Cyprus, Italy and Romania in the case of the population exposed to concentrations above LV.

Figure A2.1 gives scatter plots showing the correlation between population-weighted concentration for individual countries calculated based on the regular and interim maps, for all three pollutants. One can see better agreement for ozone compared to both PM_{10} and NO_2.

Figure A2.1: Correlation between population-weighted concentration for individual countries calculated based on regular (x-axis) and interim (y-axis) maps, for PM_{10} annual average (left), ozone indicator SOMO35 (middle) and NO_2 annual average (left) for 2020



In general, one can conclude that the population exposure estimates based on the interim maps give good results for the total area and the EU-27, while somewhat poorer results for individual countries.

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