SUPPLEMENT:

High-resolution mapping of air quality across Europe: an ensemble machine and deep learning framework integrating multi-scale spatial predictors (CHROMAP v1.0)

Table S1: Hyper-parameters used in CHROMAP after cross-validation. Description of hyperparameters specific to each model in https://scikit-learn.org/stable/supervised_learning.html.

| Air quality indicator	Ridge	Random Forest	XGBoost	Multilayer perceptron
Average NO_2	alpha = 2.9	n_estimators = 500, min_samples_split = 10, min_samples_leaf = 2, max_features = sqrt, max_depth = 10, bootstrap = True	subsample = 1.0, sampling_method = uniform, n_estimators = 1000, min_child_weight = 1, max_depth = 5, max_delta_step = 5, learning_rate = 0.01, lambda = 10, gamma = 1, colsample_bytree = 0.5, alpha = 100	solver = adam, momentum = 0.9, learning_rate_init = 0.001, learning_rate = constant, hidden_layer_sizes = (150, 150, 150), alpha = 0.0001, activation = logistic
Average O_3	alpha = 3.5	n_estimators = 500, min_samples_split = 5 , min_samples_leaf = 2 , max_features = sqrt , max_depth = 10, bootstrap = True	subsample = 0.7, sampling_method = uniform, n_estimators = 1000, min_child_weight = 5, max_depth = 2, max_delta_step = 3, learning_rate = 0.3, lambda = 100, gamma = 0.4, colsample_bytree = 0.5, alpha = 100	solver = lbfgs, momentum = 0.7, learning_rate_init = 0.01, learning_rate = constant, hidden_layer_sizes = (100, 100, 100), alpha = 0.5 , activation = identity
SOMO35	alpha = 10.9	n_estimators = 1500, min_samples_split = 5, min_samples_leaf = 2, max_features = auto, max_depth = 50, bootstrap = True	subsample = 1, sampling_method = uniform, n_estimators = 1500, min_child_weight = 1, max_depth = 6, max_delta_step = 0, learning_rate = 0.3, lambda = 1, gamma = 0, colsample_bytree = 1, alpha = 0	solver = lbfgs, momentum = 0.5, learning_rate_init = 0.2, learning_rate = constant, hidden_layer_sizes = (50), alpha = 0.1, activation = identity
Average $PM_{2.5}$ and PM_{10}	alpha = 2.0	n_estimators = 1000, min_samples_split = 5, min_samples_leaf = 2, max_features = sqrt, max_depth = 30, bootstrap = True	subsample = 0.5, sampling_method = uniform, n_estimators = 1500, min_child_weight = 7, max_depth = 5, max_delta_step = 7, learning_rate = 0.01, lambda = 10, gamma = 0.4, colsample_bytree = 1.0, alpha = 1	solver = adam, momentum = 0.9, learning_rate_init = 0.001, learning_rate = invscaling, hidden_layer_sizes = (150), alpha = 0.5, activation = tanh
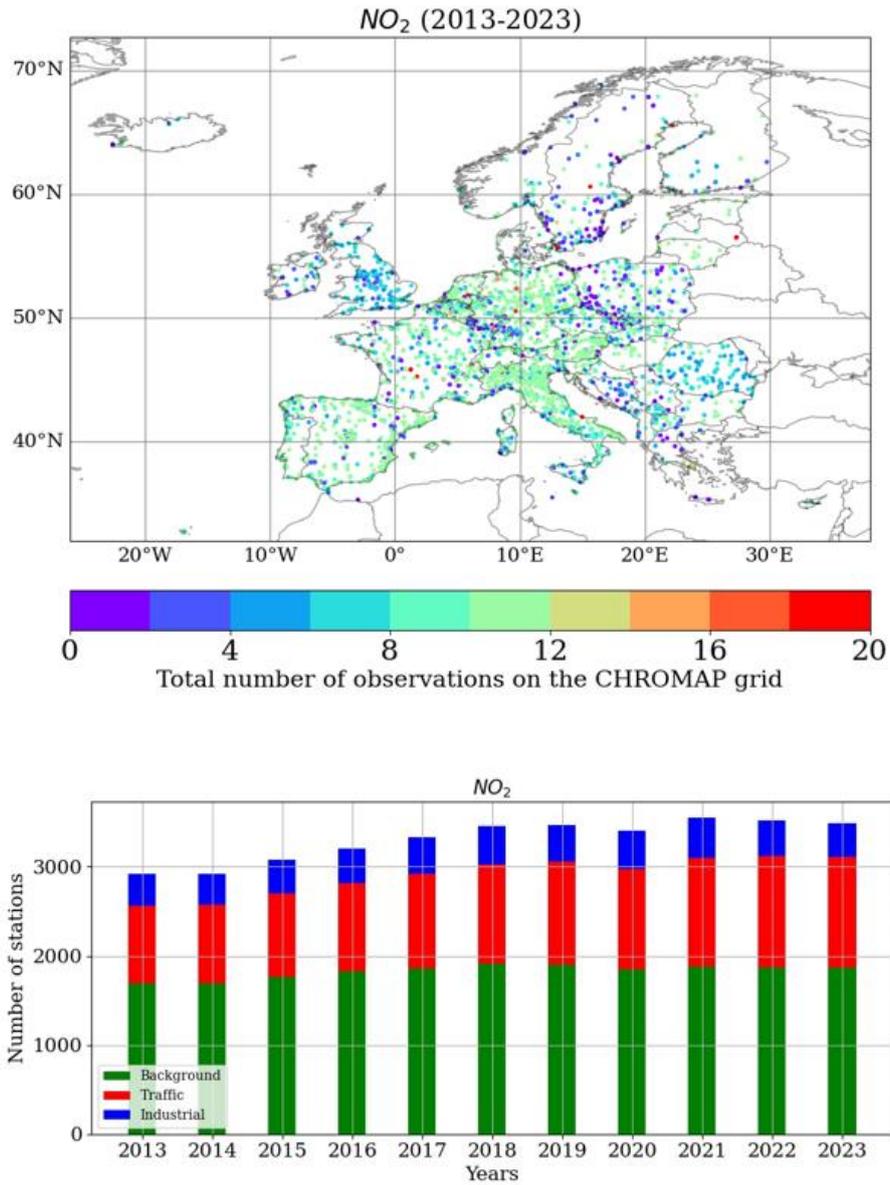
Figure S1: Distribution of in-situ NO₂ concentration observations used in CHROMAP. Spatial distribution of the total number of observations on the grid between 2013 and 2023 (top panel). Temporal evolution of the number of observations by type ("Background", "Traffic", and "Industrial") (bottom panel).
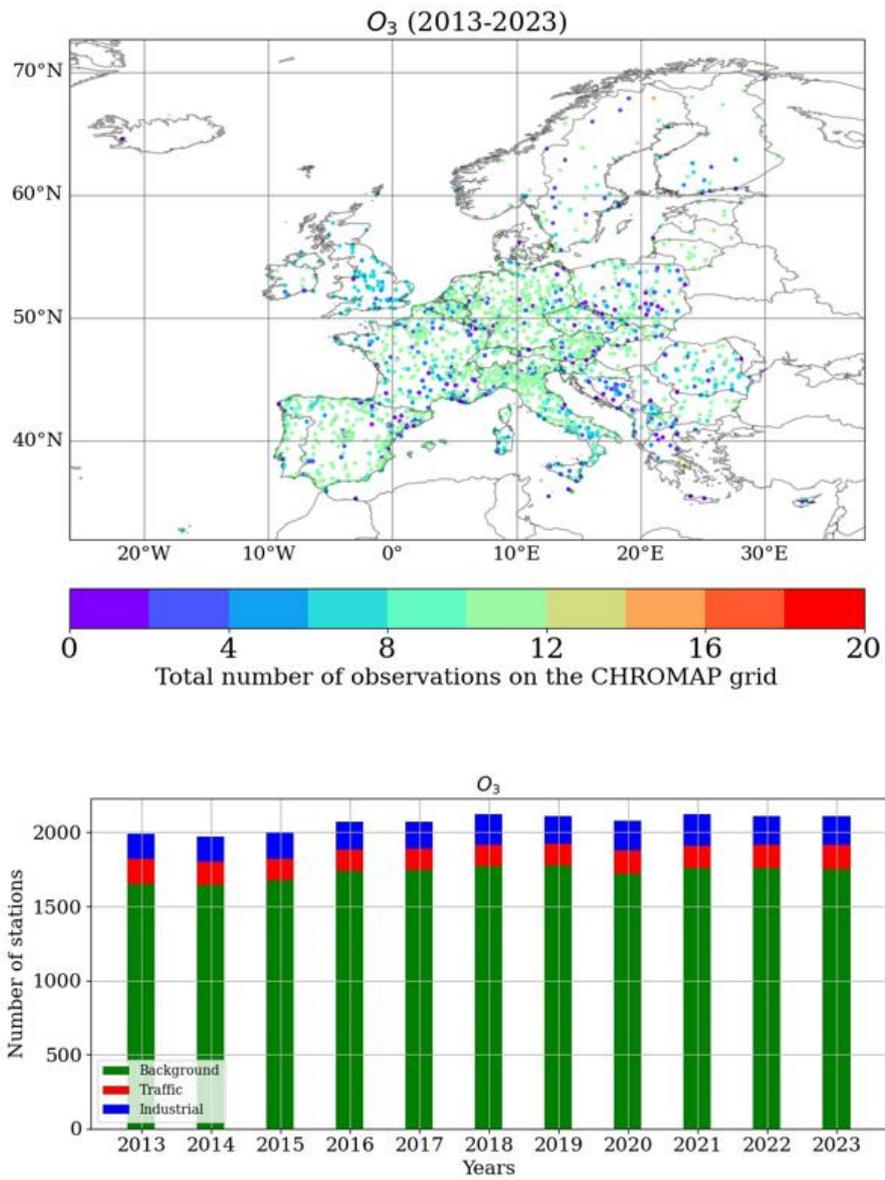
O_3 (2013-2023)

Total number of observations on the CHROMAP grid

O_3

Figure S2: Same as Figure S1 for O_3.

SOMO35 (2013-2023)

Total number of observations on the CHROMAP grid
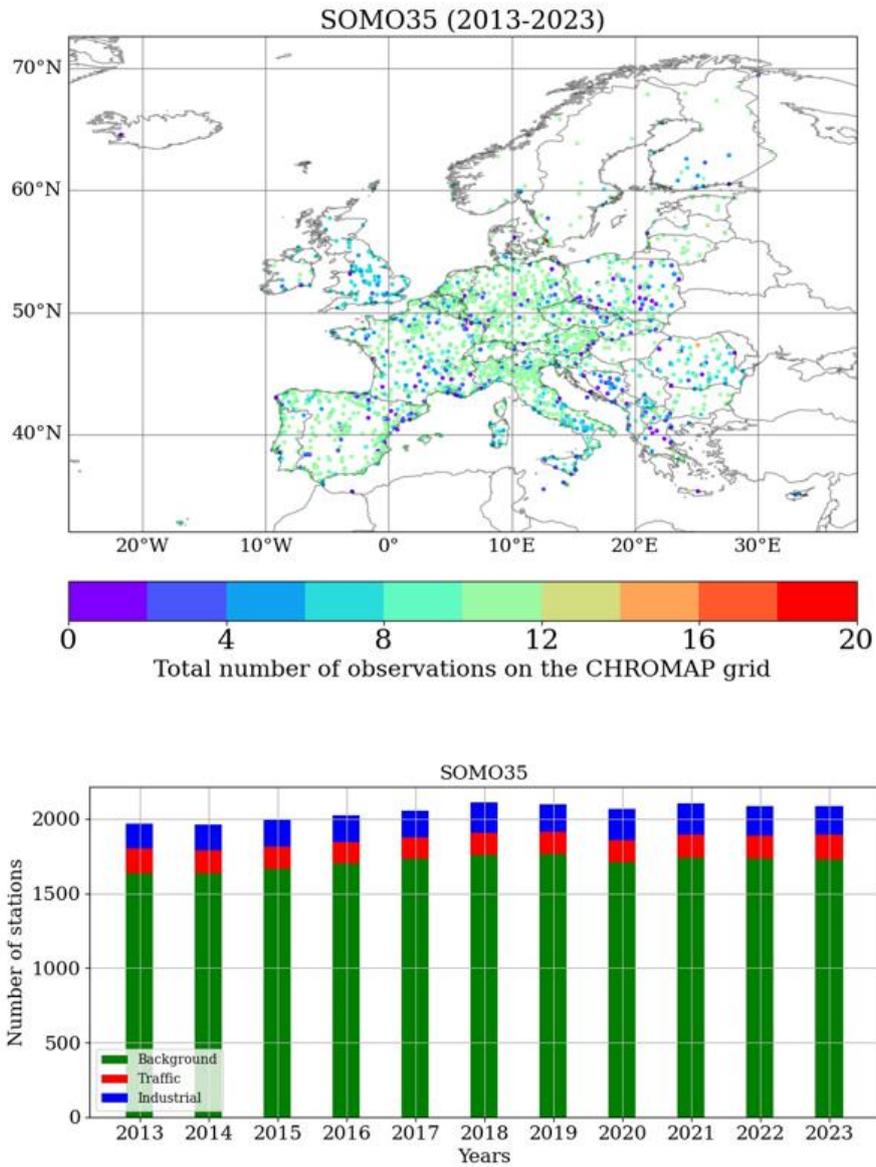
SOMO35

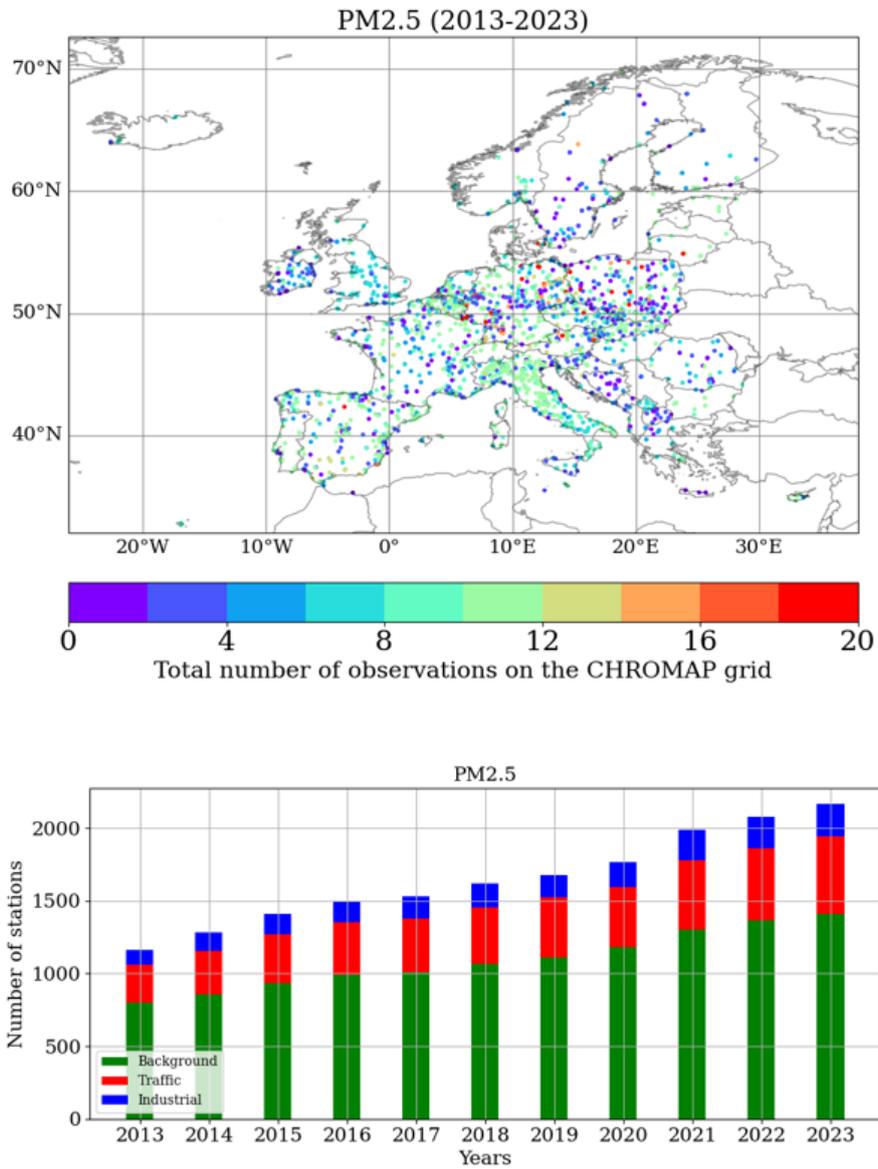**Figure S3: Same as Figure S1 for SOMO35.**

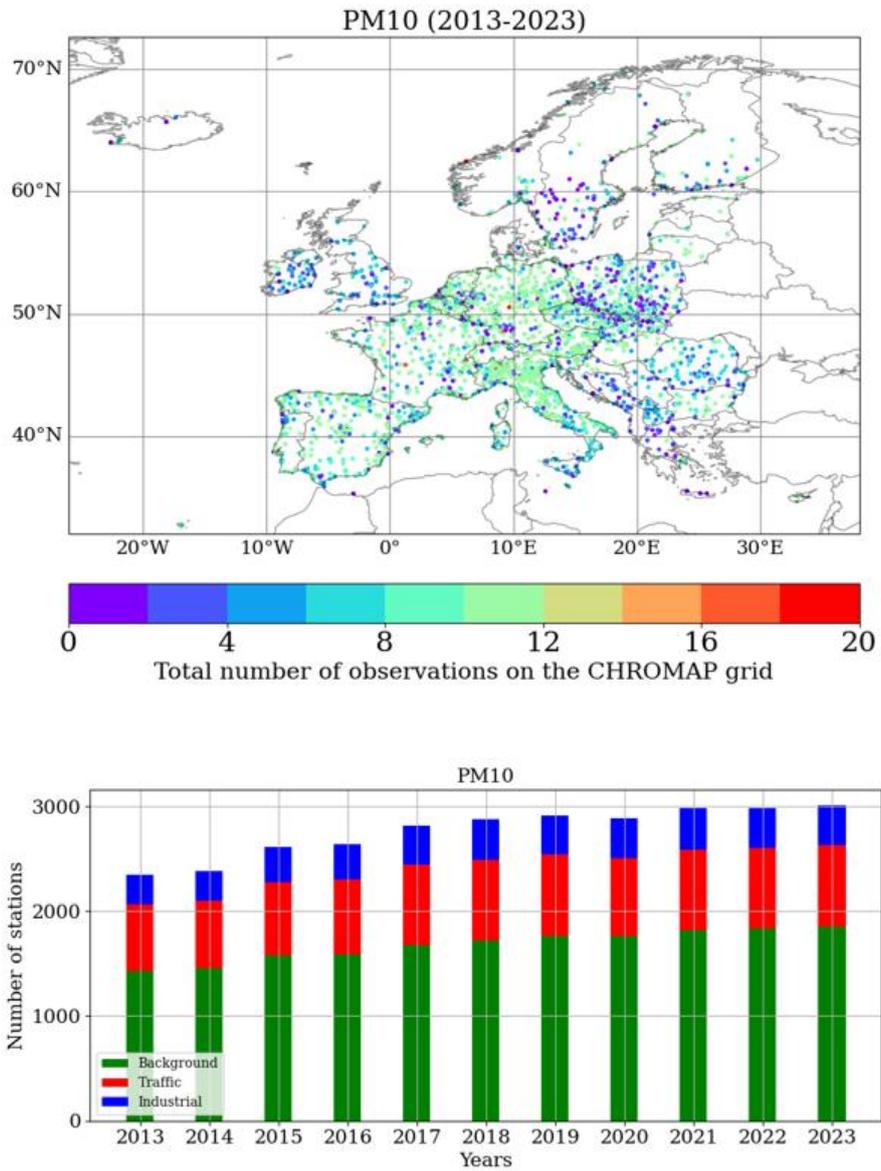**Figure S4: Same as Figure S1 for PM2.5.**

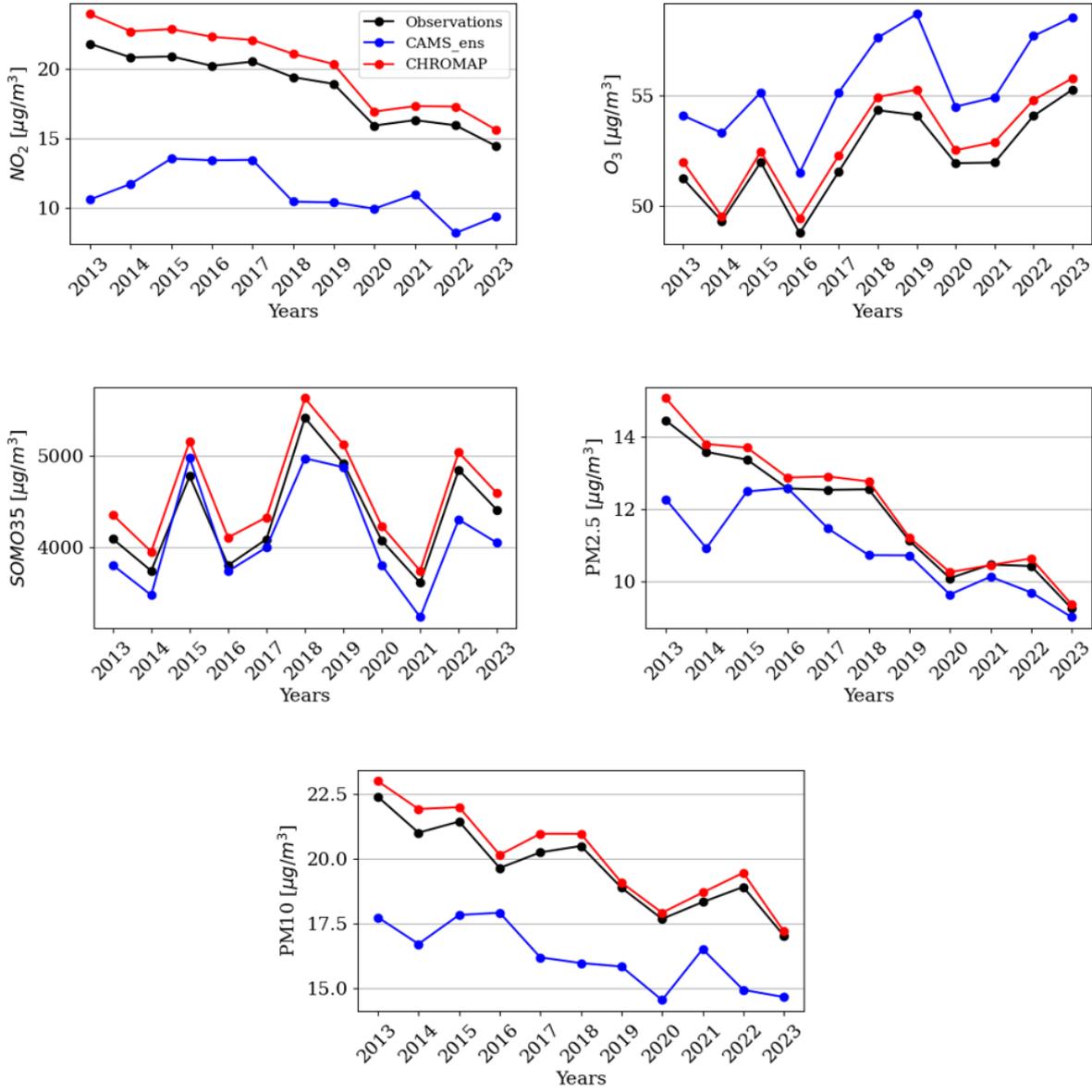**Figure S5: Same as Figure S1 for PM10.**

Figure S6: Annual evolution of median concentrations: observations (in black), compared to co-located CHROMAP (in red) and CAMS_ens (in blue) estimates for NO₂ (top left), O₃ (top right), SOMO35 (middle left), PM2.5 (middle right) and PM10 (bottom).
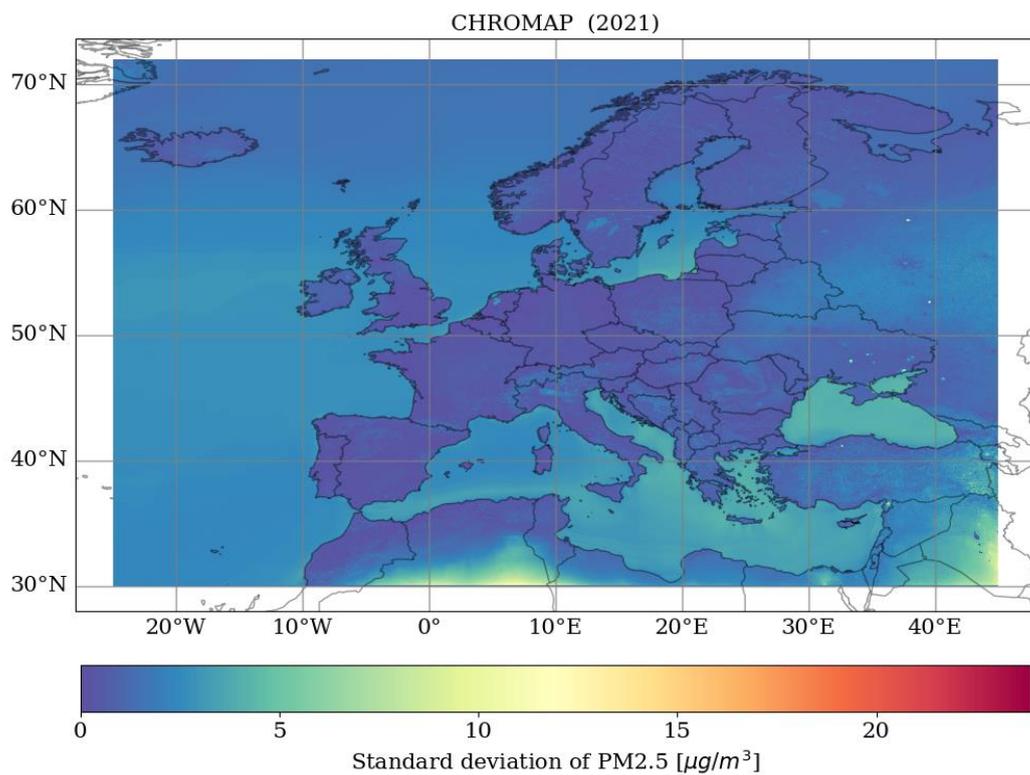
Figure S7: Example of CHROMAP output at a resolution of 500m across Europe for the standard deviation of PM2.5 in 2021.
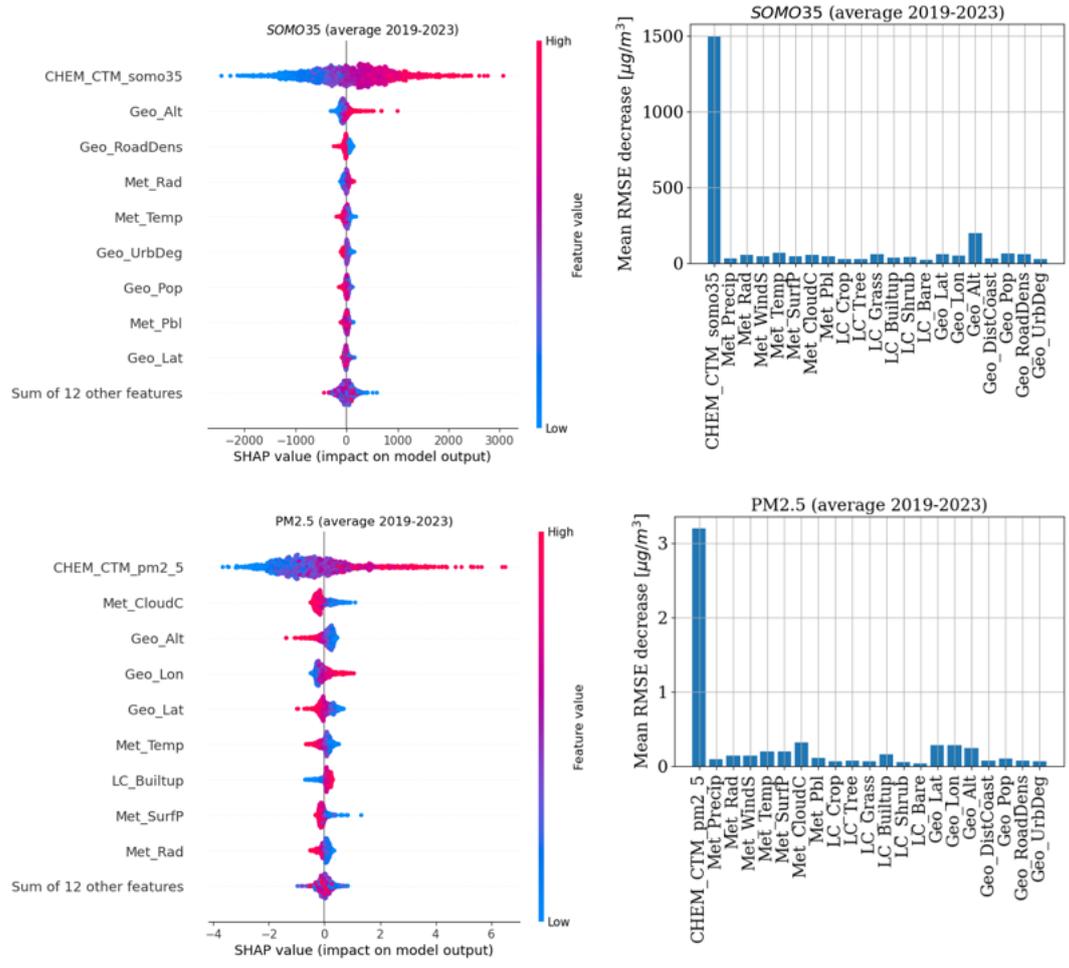
Figure S8: Permutation feature importance expressed as distribution of SHAP values (left) and decrease in RMSE (right panels) for SOMO35 (top) and PM2.5 (bottom).
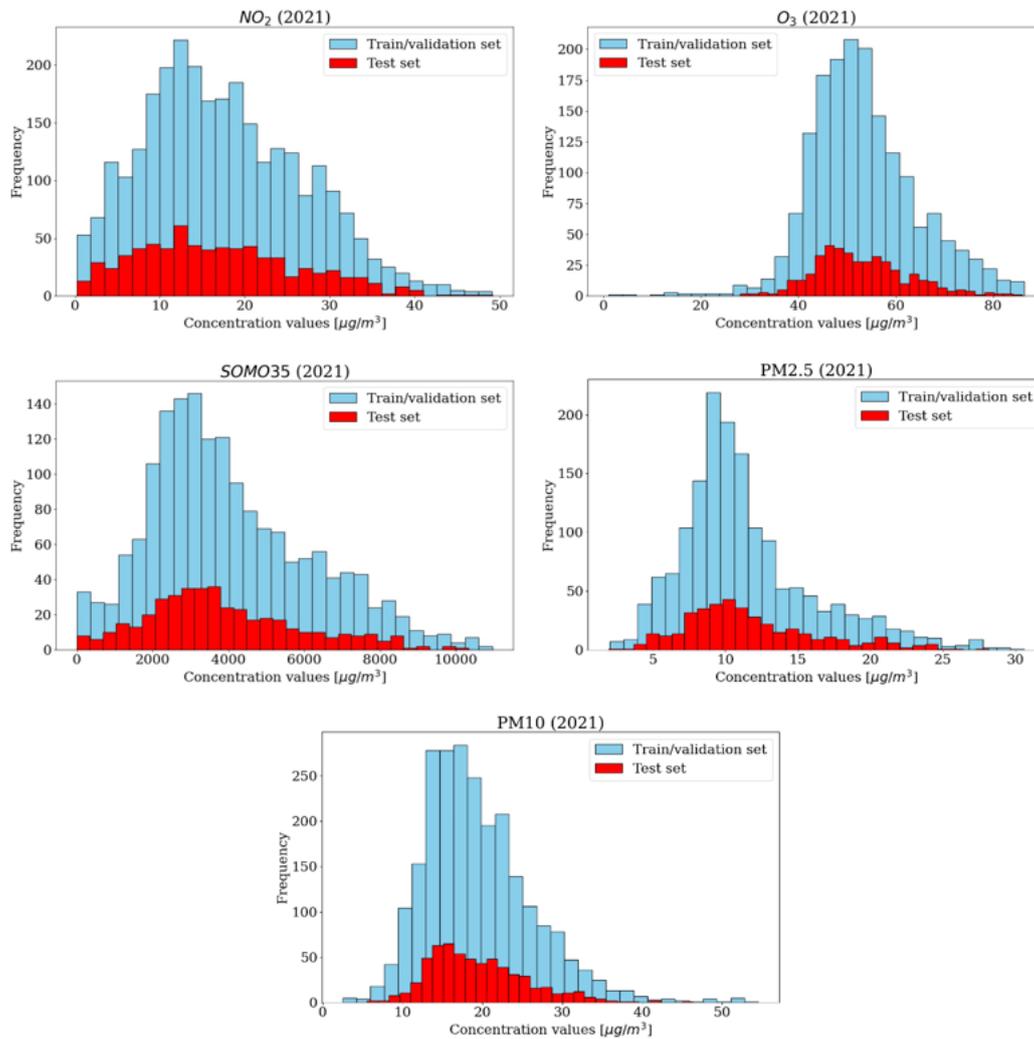
Figure S9: Distribution of values for the training/validation set in blue (80% of total observations) and the independent test set in red (20%) for 2021. From left to right and top to bottom: average NO₂, average O₃, SOMO35, average PM2.5, and average PM10.
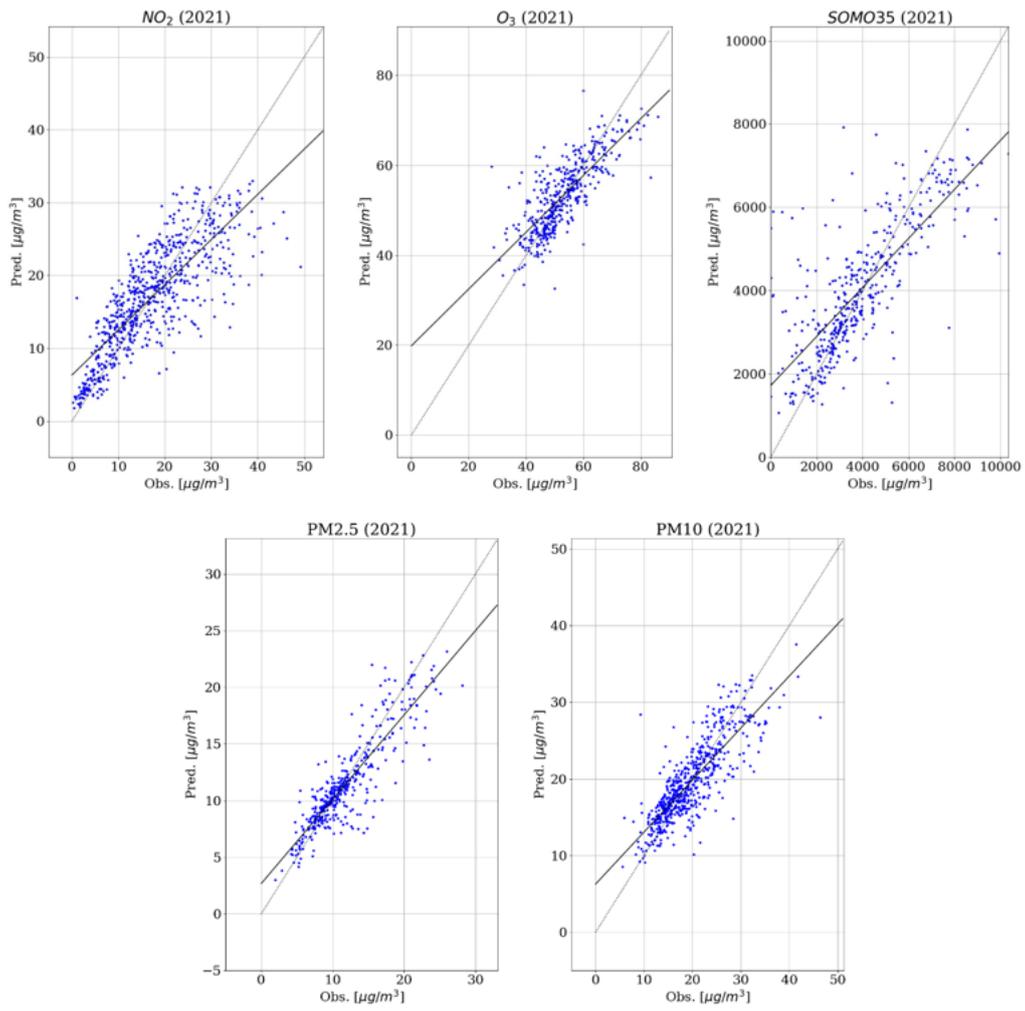
Figure S10: **Scatter plot of concentrations predicted by CHROMAP compared to those observed for the set of independent tests in 2021. From left to right and top to bottom: average NO₂, average O₃, SOMO35, average PM2.5, and average PM10.**
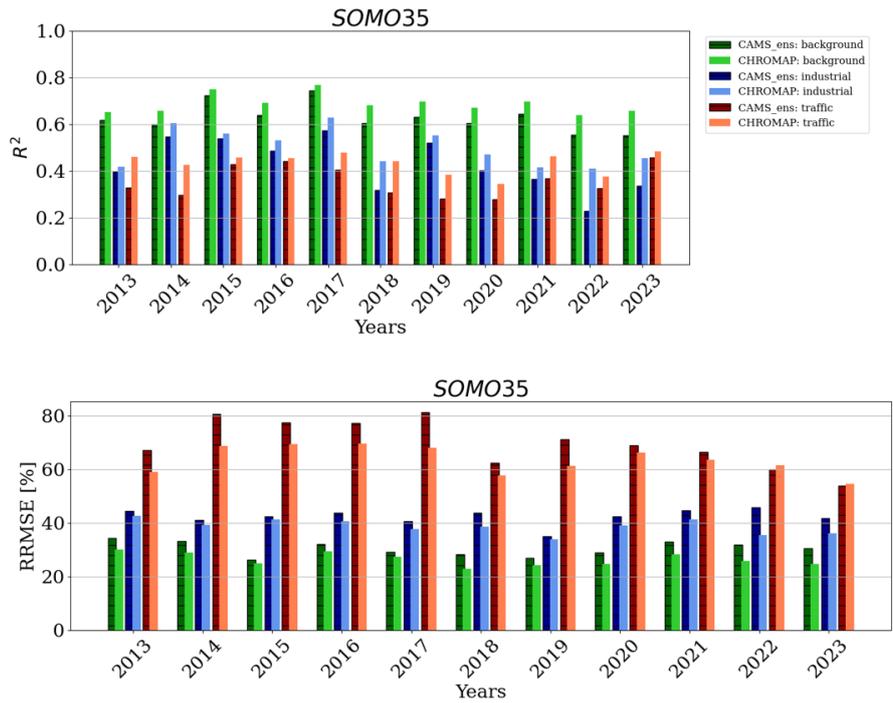
Figure S11: Comparison of performance scores (R^2 in the upper panel and RRMSE in the lower panel) between CHROMAP at 500 m resolution (light bars) and CAMS_ens at 10 km resolution (dark bars) for the SOMO35 indicator. The scores are presented by stations type : background in green, industrial in blue and traffic in red.
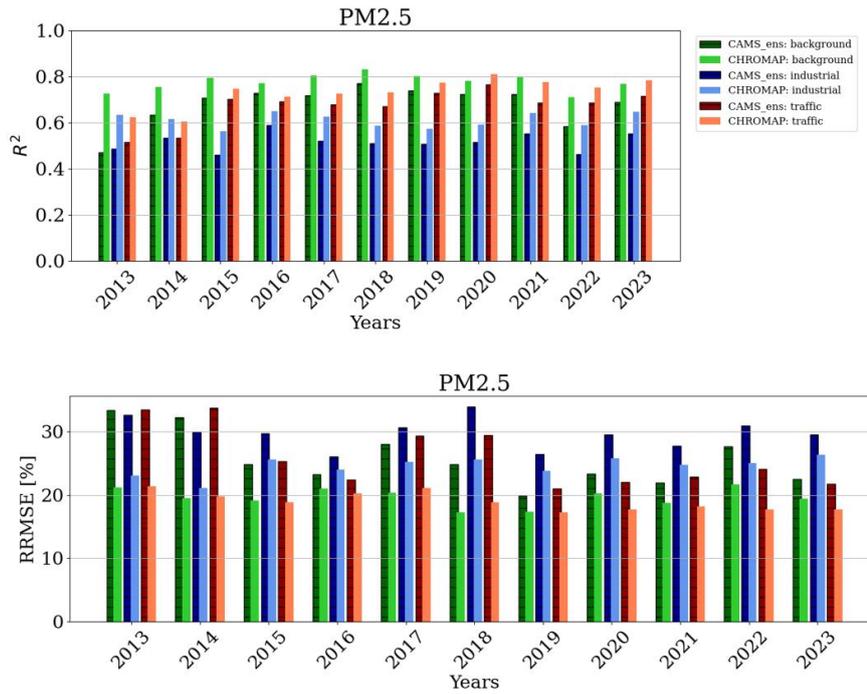
Figure S12: Same as Figure S11 for PM2.5.

Table S2: Population per country considered for exposure calculation (based on GHS-POP product, year 2015).

Austria (incl. Liechtenstein)	8,645,564
Belgium	11,254,347
Bulgaria	7,224,233
Croatia	4,010,755
Cyprus	1,105,078
Czech Republic	10,534,890
Denmark	5,258,260
Estonia	1,266,046
Finland	5,308,457
France (incl. Monaco)	62,867,227
Germany	81,995,106
Greece	10,087,906
Hungary	9,824,123
Ireland	4,529,682
Italy (incl. San Marino and the Vatican)	58,599,608
Latvia	1,938,313
Lithuania	2,963,887
Luxembourg	570,687
Malta	418,022
Netherlands	16,737,238
Poland	38,456,867
Portugal	9,665,683
Romania	19,837,106
Slovak Republic	5,430,580
Slovenia	2,058,687
Spain (incl. Andorra and Gibraltar)	43,509,057
Sweden	9,058,270
Albania	2,776,523
Armenia	2,480,069
Belarus	9,707,227
Bosnia and Herzegovina	3,507,470
Iceland	283,070
North Macedonia	2,115,620
Republic of Moldova	32,44,283
Montenegro	616,827
Norway	4,479,361
Russia European part	73,500,257
Serbia	92,66,806
Switzerland	8,336,841
Turkey	76,842,035
Ukraine	44,610,709
United Kingdom (incl. Guernsey, Jersey and the Isle of Man)	63,993,135