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# IMPROVEMENT OF THE PREDICTIVE QUALITY OF CAMS FORECASTS FOR OZONE AND PM10 IN COMPARISON WITH MEASURED VALUES

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**Abstract**: The Copernicus Atmosphere Monitoring Service (CAMS) provides, inter alia, daily forecasts for the next 96 hours in hourly resolution for various pollutants. These forecasts are based on the results of chemical transport models and their ensemble. Due to their horizontal grid resolution, the CAMS ensemble usually provides too low maximum ozone concentrations in comparison with measurements at background stations. This has a negative impact on the correct prediction of threshold value exceedances at very high ozone concentrations. The project presented here explored to what extent the predictive quality of CAMS ozone forecasts for Germany can be improved by post-processing with different correction techniques, particularly with regard to the detection of limit value exceedances. In addition, interpolation of the correction factors derived at measurement locations onto the CAMS grid and subsequent correction of the CAMS forecasts are discussed. A corresponding study was carried out for CAMS PM10 forecasts.

***Key words:*** *CAMS, forecast, ozone, PM10, correction, threshold exceedances, FAIRMODE DELTA tool.*

## INTRODUCTION

The Copernicus Atmosphere Monitoring Service (CAMS) provides data on atmospheric pollution. These are the results of seven chemical transport models (CTM) and their ensemble (CAMS, 2016). These models provide daily forecasts for the next 96 hours in hourly resolution for various pollutants such as ozone and PM10. The CTM simulations are being carried out in a horizontal grid of about 10 km grid size and thus only cover the regional background. In comparison with measurements at background stations, the CAMS ensemble usually provides too low maximum ozone concentrations. This has a negative impact on the correct prediction of threshold value exceedances at very high ozone concentrations for information and, if necessary, warning of the population in accordance with the Air Quality Directive 2008/50/EC.

Since the late 1990s, the German Federal Environment Agency has been publishing maps of nationwide ozone forecasts for information purposes. In the past, ozone forecasts were based on a statistical method which was replaced by forecasts from the CAMS ensemble. The project described here (IVU Umwelt, 2018) on behalf of the German Federal Environment Agency explored to what extent the predictive quality of the CAMS ozone forecasts for Germany can be improved by post-processing, particularly with regard to the detection of limit value exceedances. A corresponding study was carried out for the CAMS-PM10 forecasts.

The post-processing of the CAMS forecasts was carried out in three steps:

1. correction of CAMS forecasts at measurement locations using measurement data
2. interpolation of the correction factors determined at the measurement locations onto the grid which the CAMS prognoses are available on
3. application of the interpolated correction factors to the CAMS forecasts

To identify suitable correction techniques three different correction techniques were implemented:

- hybrid forecast (McKeen et al. ,2005; Kang et al., 2008)
- multiplicative correction (McKeen et al. ,2005; Borrego et al., 2011)
- Kalman filter (Delle Monache et al., 2006; Kang et al., 2008).

The CAMS forecast data at the measurement locations were corrected with the selected correction technique for each hour based on the CAMS forecast data and the measurement data of the respective previous days. After correcting the CAMS data, based on the hourly values (1HMV), further relevant quantifying parameters were determined according to 2008/50/EC for the measured and for the corrected CAMS time series for ozone and PM10. For ozone, this was the maximum one hour mean value per day (1DMAX) and the maximum eight-hour mean value per day from hourly running eight-hour mean values (8DMAX). For PM10, the daily mean value (1DMW) was determined.

As a basis for the evaluation of both the uncorrected CAMS raw data and the implemented correction techniques, 16 different metrics were determined for the hourly mean values (1HMV) and the derived quantifying parameters 1DMAX, 8DMAX and 1DMW. Among these metrics are Root Mean Square Error (RMSE), Mean Fractional Bias (MFB), Fractional Gross Errors (FGE), Hit Rate and False Alarm Rate (FAR). The metrics were determined individually for each station and merged into box whisker plots to represent the range of metrics across all stations.

In addition to the statistical evaluation, the DELTA tool for "Assessment & Planning" Version 5.6 β (Thunis & Cuvelier, 2018; FAIRMODE, 2017), which was developed as part of the FAIRMODE initiative, was applied to the original and to the corrected CAMS forecasts. The "Assessment Target Plot" in benchmark mode and the "Forecast-Sigmoid Target Plot" in forecast mode were used to analyse the model results.

The evaluation of the original and of the corrected CAMS forecasts was performed for the year 2016 for ozone and PM10 and for two selected pollutant episodes from the years 2015 (ozone) and 2017 (PM10). This article is focused on the 2016 annual time series and on the first day of forecast.

## EVALUATION OF CORRECTION TECHNIQUES

### Ozone CAMS forecast data

The evaluation of the 1HMV for ozone has shown that the uncorrected CAMS forecast data overestimate the measurement data on average, which is reflected in a positive bias and a positive MFB. The maximum values observed for the 2016 annual time series are underestimated by the CAMS raw data by 20 % in the median for all stations; accordingly, the standard deviation of the CAMS data is also smaller than that of the measurement data. The median for all stations of the correlation coefficients is about 0.8.

For the 8DMAX, the median of the mean values of the CAMS raw data is still higher than that of the measured data, but the difference is smaller than for the 1HMV. Accordingly, bias and MFB also decrease compared to the 1HMV. Maximum values are underestimated by the CAMS data for the 8DMAX as well, as is the standard deviation. As a result, the median hit rate for all stations is only around 13%. The median of the correlation coefficients is just below 0.9. For the maximum daily one hour mean values 1DMAX, the median of the mean values of the CAMS raw data is only slightly above the measured data, Bias and MFB are correspondingly low for this parameter. The underestimation of the measured maximum values by the CAMS data corresponds to that for the 1HMV; accordingly, the standard deviation of the CAMS data is smaller for the 1DMAX than that of the measurement data. Only four exceedances of the information threshold of 180 µg/m³ were measured in 2016, none of these few exceedances was recorded by the CAMS data. The median of the correlation coefficient is close to 0.9 as for the 8DMAX

**Impact of correction techniques**

Basically, each correction technique improves the CAMS raw data. For the 1HMV, the Kalman filter usually produces the best results. The exception to this is the reproduction of the maximum values and the standard deviation, which are reproduced best by the hybrid forecast. This is in line with the results of Kang et al (2008). The metrics of the multiplicative correction are consistently average, especially higher maximum values are attained compared to the Kalman filter. However, the evaluation has shown that multiplicative correction without limiting the correction factor is calculating extremely high concentrations in individual cases. For the 8DMAX and the 1DMAX, the hybrid forecast and the Kalman filter produce the best results, whereby the hybrid forecast, as before, best meets the maximum values and the standard deviation, but now also the mean value, while the Kalman filter has slightly better values for correlation, RMSE, MFB and FGE. For the 8DMAX, the hybrid forecast achieves the highest hit rates due to better reproducing the maximum values.

**Ozone in DELTA tool**

The evaluation of the DELTA tool in benchmark mode for ozone refers exclusively to the 8DMAX. If the DELTA tool is applied to the values measured in 2016 and the CAMS raw data, it becomes apparent that the CAMS raw data for ozone already have a modelling quality indicator (MQI) < 1 for all stations and therefore meet the modelling quality objective (MQO) defined by the DELTA tool. Some of the stations even have an MQI < 0.5, i. e. the RMSE between measurement and model at these stations is smaller than the measurement uncertainty. The 90% percentile of the MQI of all stations is 0.346. By applying the correction techniques, the 90% percentile of the MQI of all stations is only slightly reduced, the lowest value of 0.301 is obtained by using the Kalman filter.

In forecast mode, the MQI of the 2016 CAMS raw data is significantly worse than in benchmark mode. A whole number of stations have an MQI > 1 and are therefore modelled worse than with the persistent model (predicted value is set to value of previous day). The 90% percentile of the MQI of all stations is 1.05 and thus the MQO not met. By applying the correction techniques, the lowest 90% percentile of the MQI of all stations is 0.804, obtained by using the Kalman filter and, thus, meeting the MQO.

**PM10 CAMS forecast data**

The evaluation of the 1HMV for PM10 has shown that the CAMS raw data underestimate the measured data on average, which is also reflected in a negative bias and a negative MFB. Measured maximum values are underestimated in the median for all stations by almost two thirds, correspondingly the standard deviation of the CAMS data is also significantly smaller than that of the measured data. This contrasts with ozone, where the CAMS raw data overestimate the measured values on average and only underestimate the maximum values. The median of the correlation coefficients is 0.5, in contrast to approx. 0.8 for ozone. For the 1DMW, the median of the mean values of the modelled data is lower than that of the measured data, as it is for the 1HMV. 1DMW measured maximum values are underestimated by half in the median, the standard deviation of the model data is about 40 % less than that of the measurement data. As a result, the median hit rate across all stations is 0%. The median of the correlation coefficients is just below 0.6.

**Impact of correction techniques**

As with ozone, each correction technique leads to an improvement of the CAMS forecasts for PM10. For the 1HMV, the Kalman filter produces good metrics for the 2016 annual time series in general, but is surpassed by the hybrid forecast for the maximum values, and the best metrics for the standard deviation are obtained with the multiplicative correction. For the 1DMV, the Kalman filter shows the best values for most metrics, but this time the best reproduction of the maximum values and the standard deviation is not obtained with the hybrid forecast but with the multiplicative correction. With all of the techniques, the median of the hit rates for exceedances of the limit value of 50 µg/m³ does not differ from the zero for the CAMS raw data. However, evaluation of the box whisker plots of the hit rate shows that in the upper quartile up to 50 % and in the maximum up to 100 % of the exceedances of the limit value are detected by the correction techniques. The CAMS raw data detects a maximum of 25% of the exceedances.

**PM10 in DELTA tool**

For PM10, the evaluation of the DELTA tool refers to the 1DMW. For the 2016 annual time series of CAMS PM10 raw data of the 1st forecast day, the MQI of individual stations is larger than 1. The 90% percentile of the MQI of all stations for the CAMS raw data results to 0.947, being just below 1 and, thus, meeting the MQO. Thus, the DELTA tool evaluates the CAMS PM10 forecasts much worse than the CAMS ozone forecasts. Applying the correction techniques leads in any case to an improvement of MQI results for PM10. The MQI of all stations, with a few exceptions for the multiplicative correction, is below 1, and the 90% percentile of the MQI of all stations drops to 0.703 (Kalman filter).

In forecast mode, the MQI of the 2016 annual time series of the CAMS PM10 raw data is significantly worse than in benchmark mode, as it is with ozone. Most stations have an MQI > 1 and are therefore modelled worse than with the persistent model. The 90% percentile of the MQI of all stations amounts to 1.29 on the 1st forecast day, being significantly higher than 1. By applying the correction techniques, the lowest 90% percentile of the MQI is obtained at 0.900 with the Kalman filter.

**Conclusion of evaluation of correction techniques**

In summary, of the correction methods investigated the Kalman filter and the hybrid forecast produce the best forecasts in comparison with the measured data. The Kalman filter often achieves better results in terms of the metrics considered, i. e. higher correlation coefficients and lower values for RMSE, MFB and/or FGE are usually obtained for the corrected forecast data. The 90% percentile of the MQI of all stations is also the lowest in both benchmark mode and forecast mode for the Kalman filter, i. e. after correction with the Kalman filter, the forecast data best meet the quality criteria of the DELTA tool. However, the hybrid forecast often shows better results when it comes to reproducing maximum values and exceedances of threshold or limit values. The multiplicative correction obtains usually medium quality results in terms of the statistical evaluation. In some cases, it also achieves better results than the Kalman filter and the hybrid forecast. However, the influence of the unlimited correction factors is a source of uncertainty leading to extremely high concentrations in individual cases. Due to this, the multiplicative correction should not be used without further studies on limiting the correction factor, e. g. depending on pollutant, location, concentration level.

## INTERPOLATION OF CORRECTION FACTORS

The FLADIS program system (Diegmann et al., 2000; IVU Umwelt, 2016) was used to identify a suitable interpolation method for the correction factors onto the grid of the CAMS data. The suitability of the different interpolation methods for the interpolation of the correction factors was assessed by cross-validation according to VDI 4280 Part 5 (KRdL, 2009). As a result, the global Shepard interpolation with exponent 2 was selected for implementation. Figure 1 shows the result of the spatial correction of a CAMS ozone forecast using the example of the 8DMAX values for August 25, 2016.

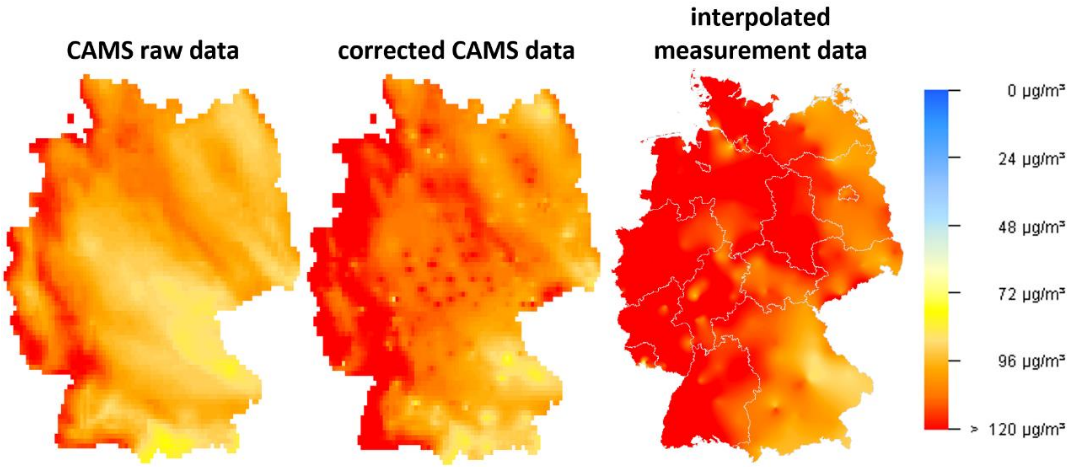


**Figure 1:** Example for spatial correction: Ozone forecast 8DMAX for August 25, 2016. CAMS raw data (left), after correction with the hybrid forecast, interpolation of the correction factors and application of the interpolated correction factors to the CAMS raw data (centre) and interpolated measurement data (right)

On the left, CAMS raw data is given. The comparison with the interpolated 8DMAX of the measurement data for August 25, 2016 (right) shows that the threshold value of 120 µg/m³ for the 8DMAX was exceedances on a large scale in Germany on this day and that the original CAMS forecast clearly underestimates the measured concentrations and particularly does not sufficiently capture the areas with threshold exceedances. The correction of the CAMS forecast by applying the hybrid forecast at the station locations, interpolation of the correction factors determined at the station locations to the grid of the model data and application of the interpolated correction factors to the CAMS raw data (centre) leads to a significant increase in the concentration level and to a better representation of the areas where the threshold value of 120 µg/m³ is exceeded.

## SUMMARY

Based on the analysis presented here, the hybrid forecast is recommended as the correction technique for standard operational use. While all correction techniques significantly improve the forecasts, the hybrid forecast usually shows better behaviour when it comes to capturing maximum values and exceeding threshold values. The multiplicative correction shows good results in the literature. In the course of the systematic evaluation of the correction techniques in this project, however, it became apparent, that even though it achieves good results in some cases the influence of the unlimited correction factors is a source of uncertainty leading to extremely high concentrations in individual cases. In this respect, the multiplicative correction should not be used without further investigation.

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## REFERENCES

Borrego, C.; Monteiro, A.; Pay, M.T.; Ribeiro, I.; Miranda, A.I.; Basart, S.; Baldasano, J.M., 2011: How bias-correction can improve air quality forecasts over Portugal. In: Atmospheric Environment 45 (2011) Nr. 37, S. 6629-6641.

CAMS, 2016: Copernicus Atmosphere Monitoring Service: Regional Production, Description of the operational models and of the ENSEMBLE system. Issued by METEO-FRANCE. October 2016.

Delle Monache, L.; Nipen, T.; Deng, X.; Zhou, Y.; Stull, R., 2006: Ozone ensemble forecasts: 2. A Kalman filter predictor bias correction. Journal of Geophysical Research, 111, D05308. 2006.

Diegmann, V.; Wiegand, G., 2000: FLADIS - A system for extending air pollution point data to continuous spatial information (ac-cording to EU Council Directive 96/62/EC). WIT Press, 2000. - 1-85312-822-8.

FAIRMODE, 2017: Guidance Document on Model Quality Objectives and Benchmarking. Version 2.1. Forum for Air Quality Modelling in Europe (FAIRMODE). http://fairmode.jrc.ec.europa.eu/. 2017

IVU Umwelt, 2016: Benutzeranleitung FLADIS 4.2. 2016.

IVU Umwelt, 2018: Sicherstellung der Ozonprognose. FKZ 3716 51 201 0. Im Auftrag des Umweltbundes-amtes. 2018.

Kang, D.; Mathur, R.; Rao, S.T.; Yu, S., 2008: Bias adjustment techniques for improving ozone air quality forecasts, Journal of Geo-physical Research, 113, D23308. 2008.

KRdL (2009): VDI Richtlinie 4280 Blatt 5 " Planung von Immissionsmessungen - Ermittlung der Unsicher-heit räumlicher Beurteilungen der Luftqualität.". Kommission Reinhaltung der Luft im VDI und DIN. 2009.

McKeen, S.; Wilczak, J.; Grell, G.; Djalalova, I.; Peckham, S.; Hsie, E.-Y.; Gong, W.; Bouchet, V.; Menard, S.; Moffet, R.; McHenry, J.; McQueen, J.; Tang, Y.; Carmichael, G. R.; Pagowski, M.; Chan, A.; Dye, T.; Frost, G.; Lee, P.; Mathur, R., 2005: Assessment of an ensemble of seven real-time ozone forecasts over eastern North America during the summer of 2004. Journal of Geophysical Research. 110, D21307. 2005.

Thunis, P.; Cuvelier, C., 2018: Fairmode DELTA Version 5.6. Concepts / User's Guide / Diagrams. Joint Research Centre, Ispra. 2018.