Answer to the Reviewers for the manuscript Colette et al., “Copernicus Atmosphere Monitoring Service - Regional Air Quality Production System v1.0” submitted to Geosc. Scient. Mod. Dev., 2024.

The authors would like to express their gratitude for the very relevant comments provided by two reviewers and GMD editors which will greatly help to improve the quality of the article. We have addressed all the comments and questions raised in the review using the following colour coding in the present answer:

- Reviewer comments are displayed in black (RC1, RC2)
- Authors answers are displayed in blue (AA)
- Text modifications are displayed as indented bullet points and in track changes (red underlined)

In this document we reply in three distinct sections separated by page breaks: (i) Referee Comments #1, (ii) Referee Comments #2, and (iii) editor comments.

RC1: One of the questions I had when reading the manuscript concerned the overarching ideas on how to decide on the best use and exploitation of knowledge that is encompassed by the large consortium that is contributing to this service. Providing an ensemble median product based on results from any of the individual contributing members appears very robust as a baseline solution, but I could imagine that, especially for products of more experimental nature, other choices could be made, by making use of distributed expertise and knowledge across teams.

AA: several alternative post-processing methods are indeed being developed to complement the robust and basic median of the eleven CTMs. Such approaches were mentioned in the original manuscript in the conclusion & perspectives (Section 5), but since some products became available in the meanwhile, this section was modified and the corresponding paragraph was modified accordingly in Section 4.1:

- [Section 4.1] Using the median to compute such an ensemble is a very robust approach to cope with potential missing members, and it has been shown to outperform individual models for average performances (Galmarini et al., 2004). It is however a very conservative approach and developments are ongoing, in particular to improve the skills of the system to capture air quality exceedance detections by making use of machine learning algorithm coupled to the raw CAMS regional forecasts. Firstly, optimised forecasts at observation sites are produced operationally for 4 pollutants (PM10, PM2.5, NO2 and O3) at thousands of AQ e-reporting stations throughout Europe on a daily basis and for the 96hr forecast period. This product is referred to as CAMS-MOS (Model Output Statistics)[1]. The underlying algorithm is a random forest using as predictor air pollutant concentration in the ENSEMBLE CTM as well as meteorological variables (temperature at 2m, relative humidity, wind speed and boundary layer height) (Bertrand et al., 2022). It is trained on a daily basis using the past 3 days of observations. As such, CAMS-MOS is a statistical model of the meteorological dependant ENSEMBLE error, which proved very effective in improving the forecast skills in detecting exceedances of air quality information thresholds. Second, an weighted ensemble forecast at the same resolution as the CTMs (10x10km2) has been developed. It consists of an optimum weighting of the 11 models calibrated on the past 7 days, but in this case the weights are constant and uniform and not dependent on meteorological predictors. CAMS-MOS is already available in the ADS as an operational product. But the weighted ensemble is still experimental. With the rapid development of machine learning and artificial intelligence, such experimental products will be further developed in the future.
- [Section 5] A large part of the research effort in relation to the Regional Production is related to Chemistry-Transport deterministic modelling. But there are also interesting prospects in the coupling between machine learning and physical and chemical modelling. The Regional Service already produces operationally optimised ~~is about to launch operational~~ forecasts at station level on the basis of Model Output Statistics which relies on ~~or any other~~ Machine Learning ~~Postprocessing which promises~~ to offer ~~open~~ unprecedented performance in particular for air quality threshold detection (Bertrand et al., 2022). Novel methodologies to compute the ENSEMBLE model from the eleven individual production and move away from the conservative median approach are also under consideration.

RC1: Table 1 and general description: It would be useful to add a row in the table to compare the assimilation aspects to specify if this includes only the optimization of IC or also optimization of other

[1]https://confluence.ecmwf.int/display/CKB/CAMS+Regional%3A+European+Air+Quality+Forecast+Optimised+at+Observation+Sites+data+documentation (accessed 24 April 2025)

processes, such as emissions and deposition, as it appears that some of the models also optimize the surface fluxes. Also, this emission optimization procedure appears to be inconsistent with one of the 'strict requirements' set to the ENSEMBLE members, i.e. to use specified emissions. Can the authors comment on this potential discrepancy?

AA : Indeed in some of the models the data assimilation method involves the optimisation of emissions or deposition to close the gap between the modelled concentrations and observations. With respect to the strict requirement on the use of specified emissions, this is true and complied with in all models for the forecasts. For the analysis, also with data assimilation methods based on optimisation of concentrations, the analysed concentrations are pulled away from the state that is physically related to the emissions and therefore will not be strictly relatable anymore to specified required emissions. Table 1 was modified to include more information on this matter, and the following lines were added in the general description :

- [Section 2.6.1] The common requirement to use CAMS-REG emissions in all CTMs is strictly enforced for the forecast. For the analysis, in one of the models (**Erreur ! Source du renvoi introuvable.**) analysed concentrations are pulled away from the state that is physically related to the emissions and therefore will not be strictly relatable anymore to specified required emissions. But none of the models use inverse modelled emissions based on observation in the forecast.

RC1: Throughout the individual, contributing model descriptions, please try to adhere better to the same formulation, esp. when referring to the boundary conditions for chemical and aerosol compounds. Either refer to it as the IFS-COMPO forecasts or the CAMS-Global forecasts.

AA: this has been made more consistent referring to CAMS-Global throughout the manuscript (many instances, including in Table 1&2) and explicated as:

- [Section 2.5]: The chemical boundary conditions are also obtained from ECMWF but using the configuration including chemistry of the IFS: IFS-COMPO referred to as CAMS-Global in this article ~~including chemistry~~ (Flemming et al., 2015; Rémy et al., 2019) operating at approximately 40km spatial resolution. CAMS-Global ~~This configuration of the IFS model~~ runs forecasts twice daily from 00 and 12 UTC and the data are available every hour (for surface fields) and every 3 hours (for model- and pressure-level fields). The model results are made available for further use as boundary conditions of regional models through different dissemination routes including the MARS archive server of ECMWF, a dedicated ftp access for the regional CAMS operational models and the atmosphere data store (ADS) of Copernicus.

line 157 ff: What defines this selection of trace gases / aerosol types that is requested from individual models? For instance, I wonder if there is an interest in nitric acid, and sulfate as fraction of PM. On the other hand, I am a bit surprised to see a use case for glyoxal as an official product. There are different quality assurance limits

AA The following paragraph was added in Section 2 to explain the rationale for selection of output species. This revision was also an opportunity to update the list of species available as of April 2025.

- [Section 2.2] The list of output species has been expanding gradually over the years. The choice of selected species accounts for user requests, especially with regards to downstream modelling needs (in the case where the CAMS regional system is used as forcing boundary conditions for smaller scale nested models), understanding air pollution episodes, and availability of observation data for evaluation and quality control (which is essentially focusing on PM_{10}, $PM_{2.5}$, NO_2, O_3 and pollens at present, but research grade measurement of the EMEP Monitoring Programme or the ACTRIS European Research Infrastructure are consider to strengthen the quality control procedures).

- [Section 2.2] As of January April 20254, the list of species in the NRT/FC includes the following gases: ozone (O_3), nitrogen oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), glyoxal (CHOCHO), formaldehyde (HCHO), ammonia (NH_3), total Non-Methane Volatile Organic Compounds (NMVOC), total Peroxy-Acetyl Nitrates (PANs). Particulate matter (PM) are included as : $PM_{2.5}$ (smaller than 2.5µm), PM_{10} (smaller than 10µm). The following tracers in the $PM_{2.5}$ fraction are also provided: sulphate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+), total secondary inorganic aerosols (SIA), total elemental carbon (EC), EC fraction related to residential emissions, total organic matter. In the PM_{10} fraction, the tracers include desert dust, sea salt and wildfires. In addition, six pollen species are included: birch, olive, grass, alder, mugwort and ragweed.

RC1: line 1228: "the evaluation is performed on about one third of the stations, deliberately left out of the assimilation workflow" : is this selection of stations fixed over time, or does it vary?

AA: The following sentence was added to clarify the update cycle of this selection, but further details were also provided on the splitting process as explained more precisely in the answer to RC2 comments:

- [Section 2.3] This classification is revised on an annual basis for each new production cycle of IRA and VRA to take into account the evolution of the network.

Also, how does the distribution of uncertainty in the CAMS regional system look like, e.g. in terms of spatial, temporal variability, and for different compounds.. if not going into specific details, could you indicate to what extent you assess this.

AA : the distribution of uncertainty in the system is not assessed on a systematic basis while it is right that it would constitute a very relevant source of information. The available information is in the Evaluation and Quality Control (reports and interactive viewers introduced in Section 4.3) and in the envelope forecast (plume plots, formerly provided as EPS Gram) as in Figure 6:

- [Section 4.3] The results of the CAMS regional production system are made available publicly on the website https://atmosphere.copernicus.eu/european-air-quality-forecast-plots where maps and time series of the various air pollutant and pollen species can be displayed. The results of the median ENSEMBLE as well as each individual model are available for both forecast and analysis products. Daily means, daily maxima, and hourly fields are available. The list of vertical levels available for interactive plotting on the website is: surface, 100m, 1000m, 3000m and 5000m (note that more vertical levels are available on the ADS). The model spread can also be assessed by selecting any grid point in the map to display the time series of the 4 day forecast including modelled dispersion which provides an information on the uncertainty in the ensemble forecast (Figure 6).

RC1: line 1261: “For this example, for the year 2021, the ENSEMBLE median has the best success ratio, but some individual models still outperform in terms of probability of detection.”. Given the importance of a good performance of the CAMS analysis for regulatory purposes, and considering that the ENSEMBLE is not the best product with respect to this metric, do the authors have recommendations on either selecting an alternative, individual ensemble member if one wants to get the best product? related, do you have an understanding what is the cause for this, with the aim to improve the ENSEMBLE product?

AA: We added a sentence in Section 4 to explain that it is not possible to point a single optimal model since such a selection is very dependent on the targeted pollutant/metric/year/area etc… But it is right that this comparison is also steering the mutual improvement of individual models which strive to improve continuously their performances.

- [Section 4.2] In the European Air Quality regulation, detrimental air quality situations are identified in terms of various exceedance levels depending on the air pollutants. For PM_{10}, the daily mean concentrations should not exceed 50µg/m^3 more than 35 days (EC, 2008). The performance of the CAMS Regional reanalyses in capturing that threshold can be assessed through the performance diagram presented in Figure 4. On the x-axis the success ratio is the number of hits divided by the number of hits and false alarms. On the y-axis, the probability of detection is the number of hits divided by the number of hits and misses. For this example, for the year 2021, the ENSEMBLE median has the best success ratio, but some individual models outperform in terms of probability of detection. It is not possible to point one single model which would outperform systematically the ENSEMBLE (the best performing model will vary depending on the targeted pollutant, threshold, geographic area, etc.). Therefore the reference product remains the median ENSEMBLE which provides the best scores for conservative annual average metrics, but interested users can refer to the annual evaluation report to select alternative depending on their specific needs.

RC1: To what extent is performance improvement seen for the final reanalysis product compared to NRT analysis and interim analysis?

AA: The Evaluation and Quality Control reports document systematically (i) the performances of the forecast compared to the analysis, (ii) the validated versus the interim reanalyses. Such discussion was considered to enter in too much details in terms of model performance for this model description article, but it would deserve a closer focus in a future evaluation article.

RC1 For further (mostly technical) comments I refer to the annotated manuscript attached here.

AA All of these comments were addressed in the revised manuscript. Only those that deserve an answer to the reviewer are copied below.

RC1 L37: why ‘full’?

AA: the following change is proposed

- [Abstract]: The Copernicus Atmosphere Monitoring Service (CAMS) delivers a wide range of ~~full,~~ free and open products in relation to atmospheric composition at global and regional scales.
- [Introduction]: It provides a wide range of ~~full,~~ free, open, and quality assured products in relation to global and regional air quality, inventory-based emissions, observation-based surface

fluxes of greenhouse gases and from biomass burning, solar energy, ozone and UV radiation, and climate forcings (Peuch et al., 2022).

RC1 Figure 1: preferably do not refer to numbers in CAMS 81 and CAMS 22, but rather 'CAMS emissions team' etc.

AA: Figure 1 was changed to account for this comment.

François

RC1 Line 166: Which observations are used for analysis? For which species the user can expect larger constraints by observed quantities, compared to otherspecies?

AA: the following clarification was added

- [Section 2.2] Note that observations are ~~not~~ available for assimilation only for NO_2, O_3, PM_{10}, and $PM_{2.5}$. ~~for all of those species, i~~Individual components contributing to the total PM_{10} or $PM_{2.5}$ mass are scaled according to the assimilation of total PM_{10} or $PM_{2.5}$ measurements, and pollen species are not assimilated.

RC1 Line 166 how is NMVOC as species definied in this context?

AA: the following clarification was added

- [Section 2.2] (NMVOC, defined as the sum of the mass of the carbon atoms of all the VOC species of the chemical scheme of the model, excluding the methane and PANs species, and expressed in unit µg/m^3 of carbon atoms),

RC1 Line 242 As some of the modeling systems will adopt a data assimilation strategy that includes emission optimization, I wonder to what extent this prescription holds (and remains useful) in the present / future system configurations

AA : futher details are now available regarding assimilation strategies. Only one of the model includes emissions optimization, and none of them uses inverse modelled emissions for the forecast. So this prescription indeed still holds.

- [Section 2.6.1] The common requirement to use CAMS-REG emissions in all CTMs is strictly enforced for the forecast. For the analysis, in one of the models (**Erreur ! Source du renvoi introuvable.**) analysed concentrations are pulled away from the state that is physically related to the emissions and therefore will not be strictly relatable anymore to specified required emissions. But none of the models use inverse modelled emissions based on observation in the forecast.

RC1 Line 251: What about ammonia (NH3) emissions?

AA: the following clarification was added

- [Section 2.6.2] They include soil emissions for (i) mineral dust resuspension, (ii) soil NOx or even (iii) sea salt within the European domain, but the agriculture related NH3 emissions are issued from the anthropogenic emission inventory.

RC1 Line 263 Considering this uniformity on model assumptions (as well as the larger difficulty wrt validation compared to most trace gases and aeroso), is there still value to have this simulated by all ensemble members?

AA : This remark made us realise that the original formulation was not really correct. The pollen emissions are following a unified approach. Transport processes are left open to individual team. As can be noted in the actual production, there is indeed some model spread in the results.

- [Section 2.6.3] Their implementation in the individual operational CAMS models differ in terms of advection and deposition strategies, but as ~~is more uniform than~~ for the anthropogenic air pollutants, the emission terms are coordinated following ~~as they all rely on~~ the original documentation of (Sofiev et al., 2013) and subsequent updates for additional species.

RC1 L288 This refers to ECMWF Operational meteorological Forecasts (on high horizontal resolution), or?

AA This was clarified but since it applies to all model, we modified the common description of Section 2 rather than in L288 of the CHIMERE section

- [Section 2.5] The meteorological fields used to force the individual operational CTMs are from the European Centre for Medium-Range Weather Forecasts (ECMWF) operational ~~IFS (Integrated Forecasting System) daily~~ meteorological forecasts at high resolution based on the IFS model (Integrated Forecasting System).~~of the European Centre for Medium-Range Weather Forecasts (ECMWF).~~

RC1 : L388 I think lightning NOx is not covered by GEIA / Yienger and Levy?

AA: Thank you for pointing this out. We have indeed made a mistake in the description here. The text on line 386-387 has been changed to

- [Section 3.2.5] ~~Soil and lightning~~ NOx emissions from soil are based on data from the Global Emissions Inventory Activity (Yienger and Levy, 1995) and from lightning they are from {Price, 1997 #1520}.

RC1 Line 511 If no satellite obs are assimilated in current systme then there is no need to mention

AA : we agree to remove this statement

AA we also took the opportunity to revise a few minor elements in the EMEP description

- [Section 3.3.2] Vertically the model uses 20 levels defined as ~~sigma~~ hybrid coordinates.
- [Table 1] after 'CAMS-GLOB-SOIL' add "v2.4 (Simpson et al., 2023)
- [Table 1] after EmChem19a refer to Bergström et al., 2022
- [Table 1] in Aerosol uptake - change "and O3" to "NO3 and O3, and hydrolysis of N2O5 (Stadtler et al., 2018)".
- [Table 1] Aqueous phase cite Jonson et al., 2000
- [Table 1] in Dry dep gases cite Simpson et al., 2012
- [Table 1] in Dry dep aerosol cite Venkatram and Pleim, 1999
- [Table 1] in Wet dep cite Berge, 1993 and Simpson et al., 2012

RC1 Line 598 please check this sentence - was the modeling of satellite retrieved NO2 really the purpose of these manuscripts?

AA : these articles were focusing on comparing model results with satellite retrievals. But this they are not crucial for the general description of GEM-AQ or forecast application, this sentence could inded be removed.

RC1 Line 687 Out of interest, Shouldn't 'emissions' be included in the equation, for relevant tracers (NO2, SO2, ..). And for deposition velocity the gridbox average value is selected, right?

AA The emissions are taken into account in another model process and inserted into either the model surface layer or higher layers depending on the emission height profile. This sentence relates to the step where we determine the 2.5 meter concentration based on the surface layer concentration. And yes the average deposition velocity for the gridcel is used.

- [Section 3.6.2] For output purposes, the concentrations at measuring height (usually 2.5 m) are diagnosed by assuming that the flux is constant with height and equal to the deposition velocity times the concentration at height *z* (taken as average over the grid cell).

RC1 Line 743 now it's beginning 2025 - so it's in?

AA Unfortunately due to the associated increased runtime with the inclusion of VBS, we would not be able to provide the model output before the required deadline for the analysis. Options for solving this issue are being investigated. The corresponding sentence was modified :

- [Section 3.6.8] Inorganic aerosol chemistry is represented using ISORROPIA II (Fountoukis and Nenes, 2007) and secondary organic aerosols formation based on a VBS scheme (Bergström et al., 2012a; Zare et al., 2014) will be included in the operational forecast version in the future~~at the end of 2023~~.

RC1 : L756 : about model geometry « I do not understand this sentence, pls clarify »

AA To clarify what MATCH is doing, we propose the following change:

- [Section 3.7.2] The model's geometry is taken from the input weather data. To reduce computational costs, the vertical resolution is reduced compared to the ECMWF operational model by merging pairs of IFS vertical layers, while retaining the use of hybrid vertical coordinates. The horizontal resolution in the MATCH simulation matches that of the meteorological forcing, which is currently provided on a 0.1° latitude–longitude grid. ~~The vertical resolution is reduced with respect to the ECMWF operational model by combining pairs of IFS layers; hybrid vertical coordinates are used. The horizontal geometry of the MATCH simulation is the same as the meteorological forcing (currently a lat-lon grid with 0.1° resolution).~~

RC1 L786 this sentence belongs to the 'chemistry' section I think?

AA This is a good point, we moved the sentence:

- [Section 3.7.8] Exception is made for the isoprene oxidation for which the chain of reactions is following the Carter-1 chemical mechanism, which has proven to give the comparable results with fewer reactions (Carter, 1996; Langner et al., 1998)

RC1 Line 793 please specify which GFAS parameter. (e.g. see description in other model contributions)

AA: the following clarification was added

- [Section 3.7.5] The GFAS biomass burning emissions are taken into the model mapping the following species into the MATCH chemical mechanism: NOx, SO_2, CO, CH_4, C_2H_4, C_2H_6, C_3H_6, C_4H_{10}, C_8H_{10}, benzene, toluene, CH_3OH, C_2H_5OH, formaldehyde, acetaldehyde, OC, BC, $PM_{2.5}$, and PM_{10}. ~~Half of these grid emissions are vertically distributed between the surface and the top of the plume (GFAS parameter) according to a parabolic curve, and the other half is~~

~~uniformly distributed among the same levels.~~ The vertical injection is made by a parabolic curve with central height taken from the GFAS INJH parameter. In case the injection height is missing for a GFAS emission cell this is assigned from some neighbour height present. The diurnal emission profile is based on the D-1 GFAS hourly data filled up with GFAS data for D-2 for the not yet available hours in D-1. This diurnal hourly profile is repeated throughout the forecast.

RC1 Line 821 please expand a bit as to describe the aerosol modeling in MATCH

AA: the following clarification was added

- [Section 3.7.8] The photochemistry scheme is based on the EMEP MSC-W chemistry scheme (Simpson et al., 2012), with a modified scheme for isoprene, based on the so-called Carter-1 mechanism (Carter, 1996; Langner et al., 1998). The standard MATCH setup used in CAMS treats particles as bulk aerosol in two size classes, fine ($PM_{2.5}$) and coarse ($PM_{2.5-10}$) particles. Particle formation from gases include secondary inorganic aerosol (ammonium sulphate and nitrate) and secondary organic aerosol. Ammonium nitrate equilibrium is calculated according to {Mozurkewich, 1993 #1521}. Coarse nitrate formation from gas-phase HNO_3 is also included {Strand, 1994 #896}. Secondary organic aerosol formation from oxidation of volatile organic compounds is treated using a volatility basis set scheme based on ~~The SOA description is based on~~ (Hodzic et al., 2016).

RC1 Line 936: Consider to add one/two general references in this section

AA : We added 2 references in

- [Section 3.9.1] The MOCAGE 3D multi-scale Chemistry and Transport Model has been designed for both research and operational applications in the field of environmental modelling. Since 2000, MOCAGE has been allowing to cover a wide range of topical issues ranging from chemical weather forecasting, tracking and backtracking of accidental point source releases, trans-boundary pollution assessment, assimilation of remote sensing measurements of atmospheric composition, to studies of the impact of anthropogenic emissions of pollutants on climate change {Guth, 2018 #1522}{Cussac, 2020 #1523}.

RC1 Line 969 In this section I miss a remark on the solver used in MOCAGE.

AA: the following clarification was added

- [Section 3.9.6] The chemical solver used is a semi-implicit solver as presented in {Cariolle, 2007 #1524}.

RC1 Line 1066 I think this is a typo, shouldn't this be GFASv1.4 (i.e. hourly) or GFASv1.2?

AA Thank you for bringing this to our attention; the product used is indeed the hourly GFASv1.4. This is now amended in the revised manuscript.

RC1 L1207 how is the interpolation towards the target grid done?

AA: the following clarification was added

- [Section 4.1] As explicated in Section **Erreur ! Source du renvoi introuvable.**, there are slight differences in the individual model geometry even if they are as close as possible to the common grid. Five models are operated their forecasts directly on the target grid (CHIMERE, DEHM, EMEP, LOTOS-EUROS, and SILAM), one uses area-weighted interpolation of overlapping polygon (EURAD-IM), and the other models use a bilinear interpolation requirement to deliver model output on the common same grid.

RC2: Figure 1: Are the individual analysis and reanalyses performed by the different modeling groups or by Meteo France (NRT/AN) and INERIS (IRA and VRA)? I think it's the different modeling groups. In that case, maybe the white text boxes "Near Real Time NRT" and "Reanalyses" within the "Production" box could be expanded to "Centralisation of Near Real Time NRT" and "Centralisation of Reanalyses" for further clarification.

AA: Figure 1 has been changed in order to clarify the role of Meteo France / Ineris and the other partners

RC2: Line 155: does the 48 forecast horizon start at midnight UTC or at 08:00 UTC when the forecast is released?

AA: We added the following to clarify this point

- Section 2.2: Hourly near-real time forecasts (NRT/FC) are released every day with a 4 days horizon (from 0 to 96hrs forecasts). They rely on chemistry-transport outputs, some of which are initialised on the basis of the previous analysis (see details in Section 3). The ENSEMBLE NRT/FC fields are made available publicly each day at 08:00 UTC for forecast horizon 0 to 48hrs (day 1 and day 2), and at 10:00 UTC for forecast horizon 49 to 96hrs (day 3 and days 4). All the forecasts are initiated at 00 UTC, the differentiated timing for the 48hr or 96hr lead time is only to account for longer production times.

RC2: Line 166: if the NRT/AN product is created every day, why is it currently only available for 2021 on the ADS? Make sure to define ADS earlier as noted above.

AA: The NRT/AN production is stored with a three years retention period, therefore data for 2022-2025 are available at present. This was already stated in the introduction but now also added in section 4.3 on dissemination:

- [Section 4.3] The results of the CAMS regional production system are made available publicly on the website https://atmosphere.copernicus.eu/european-air-quality-forecast-plots where maps and time series of the various air pollutant and pollen species can be displayed. The results of the median ENSEMBLE as well as each individual model are available for both forecast and analysis products with a three years retention time.

RC2: Lines 164 – 170: It might be good to mention that the methods to create the NRT/AN product will be described in Section 3.

AA: The following was added in

- [Section 2.2]: The CAMS regional system includes both daily 4-days forecasts and several analysis products. All of them are provided from both eleven individual CTMs results and an ENSEMBLE product which is constituted by the median of individual models at each grid point (See also Section 4 on post-processing).

RC2: Lines 171 – 177: Are the IRA and VRA products generated by the individual modeling groups using the same methods used to generate their NRT/AN product (just with updated observational data), or is this performed at INERIS with potentially different methods than those used to generate the NRT/AN product?

AA: This has been clarified :

- [Section 2.2] The daily analyses products are supplemented by an interim reanalysis (IRA) and a validated reanalysis (VRA). Both rely on the same modelling tools as the NRT production, including assimilation strategy. But the observations taken into account differ. Acknowledging that for the NRT/AN production some observations can be missing or not validated, daily analyses are reproduced with a 20 days delay in the IRA. This time gap is considered sufficient to fix most failures in NRT data flows and maximise the number of available measurement data. The interim reanalysis is subsequently consolidated and delivered in the first months of Y+1. Since all observations are only definitively validated by European member states by the end of the following year (Y+1), the full year Y is reprocessed in Y+2 to produce the VRA of the corresponding year. As for NRT, the production of IRA/VRA is also distributed across individual modelling teams which operate their own modelling system. The CRPU (INERIS in the case of reanalyses) defines the common requirements in terms of model setup, input data (meteorology, emissions, and assimilated observations) and centralised the verification and production of the ENSEMBLE product.

RC2: Lines 191 – 192: Please provide details on how this split between distributed vs. withheld data is performed. Is it based on a random selection of stations? Does the selection change every day / month / year or is it fixed in time? Is the split the same between the observational datasets distributed for NRT/AN vs. IRA and VRA?

AA: We are grateful for this comment of the reviewer as it is true that this section was missing important information. We clarified how the splitting of stations is done between assimilation dataset and evaluation dataset, for NRT production on one side and for IRA and VRA productions on the other side are computed. We propose the following changes to the original formulation:

- [Section 2.3]: An important step lies in the filtering and selection of data. For the NRT production (both FC and AN), the stations are clustered using ~~where~~ an objective classification which consists in building classes of stations which exhibit similar patterns of ~~is applied based upon the~~ temporal variability ~~patterns of the air pollutant concentrations~~ to differentiate background and proximity stations (Joly and Peuch, 2012). Originally (when the model had a resolution of approximately 20x20km2), only the stations corresponding broadly to suburban and rural typologies were included. But ~~Traffic and industrial sites are excluded from the assimilation strategy, but~~ since November 2020, all stations falling in classes 1-7 of the Joly & Peuch classification are included, which means broadly that urban background sites are taken into account while traffic and industrial sites are excluded~~, whereas earlier than November 2020, only suburban and rural sites were included~~. This way, even if the spatial resolution of the CAMS Regional Production is 10x10km, we ensure the relevance of the modelling setup to capture urban background air quality.
- The design and use of this objective classification is particularly useful in NRT applications, which includes more outlying data than the reanalyses. Such NRT applications are also less used for regulatory applications for which reanalyses are preferred. This is why, the station classification in IRA and VRA follows the standard typology declared by the member states in their reporting (even if it is admitted that it is not exempt from misclassification). In VRA and IRA, stations labelled are traffic and industrial are strictly excluded and only background (urban, suburban, and rural) stations are included.
- Approximately 2-third of the stations' data are distributed by the CRPU for assimilation (both for NRT/AN and IRA&VRA), while the rest of the data are kept for evaluation (see Section 4.2).

- This splitting is first performed using the station list used for VRA and IRA, therefore using only the sites for which member states declared the typology as "background" that are available for the previous years (year-1 for IRA (Y-1) and year-2 for VRA (Y-2)). Stations with less than 1 months of data are removed. The first prerequisite is to treat collocated stations together for the pollutant pairs NO_2/O_3 and $PM_{10}/PM_{2.5}$. This prevents, for example, having the same station for NO_2 assimilation and O_3 evaluation. The second prerequisite is to use a random selection process to ensure a good spatial coverage of stations in the two listings. However, the construction of the assimilation and validation station sets is not entirely random: evaluation stations are always selected near assimilation stations, while spatially isolated stations (typically in remote areas of Europe) are used for assimilation. This classification is revised on an annual basis for each new production cycle of IRA and VRA to take into account the evolution of the network.
- The splitting obtained for the VRA and IRA production is subsequently translated for the NRT production. All the stations from classes 1 to 7 belonging to the set of evaluation of VRA/IRA are tagged for NRT evaluation and all the stations that do not belong to the evaluation of VRA/IRA are tagged for NRT assimilation (AN).

RC2: Line 240: Please provide details (or a reference providing details) on the methods used to adjust the reported emissions that are several years old to current conditions.

AA: the following elements were added to the manuscript to elaborate on the methodology to adjust emission for recent years:

- [Section 2.6.1]: The use of officially reported emissions induces a subsequent delay in the successive updates of the emission datasets. The Emissions for year Y, are reported in March Y+2. Then they undergo verification, gap filling and spatialisation before being considered for implementation in the CAMS Regional production. The emissions being used for the day-to-day forecasts are thus generally based on national emissions reported about 3 years earlier. In order to cope with this limitation, the CAMS-REG emission inventory developed a methodology to extrapolate the officially reported emissions to the most recent historical year. The methodology basically consists in two steps. First, early available relevant activity data for different sectors are used to extrapolate the trend in the activity, which are used to adjust future emissions. Second, for the historical years for which emission data are available from CAMS-REG the trend in these is compared to the trend in the activities. If a significant trend is found (here defined as >3% per year) the trend in the implied emission factor is determined by taking the ratio of the trend in emissions and in activities, which is then projected into the future. The methodology has been validated for historical years and overall works well, but such a method has also limitations, for instance it is not possible to predict sudden events such as closure of power plants or industrial facilities, or implementation of emission reduction techniques in large facilities~~a proxy inventory for the recent years, still based on the officially reported emissions~~. This way, the emission implemented in late 2024~~3~~ in the regional production could be based on an estimate for the year 2023 (CAMS-REG v7.1)~~2~~.

Line 246: Which chemical and aerosol mechanism(s) is the default speciation for NMVOC and PM species provided for?

AA We added the following precisions in the article

- [Section 2.6.2]: NMVOC emissions in CAMS-REG are provided with year-, sector- and country-dependent speciation profiles to breakdown total NMVOC to the 25 Global Emission

InitiAtive (GEIA) species, originally defined under the REanalysis of the TROpospheric chemical composition (RETRO) project {Schultz, 2007 #1528}. Each CAMS individual modelling team performs a remapping of the 25 GEIA NMVOC species to the species of their corresponding gas phase chemical mechanism. Concerning PM, the default profiles provided in CAMS-REG allow splitting coarse and fine PM emissions to primary organic carbon, elemental carbon, sulphates, sodium and others.

RC2: Line 246: Is there any guidance or harmonization on the vertical allocation of emissions from power plants and industrial sources?

AA: There is no specific guidance at present on the vertical allocation of emissions, and the original manuscript was already stating that this "is left open for individual modelling teams ». It is however indeed an important factor and it has been identified as a priority for the next phase of the service. But since it is not yet implemented we decided not to mention it in this description.

RC2 Line 288: Section 2.5 stated that the IFS meteorology is available on a roughly 9 km grid, and Section 2.4 stated that all CTM operate on a domain with about 0.1 degree resolution. Why is a 0.2x0.2 degree grid mentioned here for the forcing meteorology?

AA: Thank you for pointing this out. It was a typo, the IFS are retrieved on an horizontal grid of 0.1°x0.1°. This was changed in the following :

- [Section 3.1.3]: The forcing meteorology is retrieved from the IFS model vertical layers covering the CHIMERE vertical extent on a 0.~~2~~1°x0.~~2~~1° horizontal grid resolution with a temporal resolution of 3 hours.

RC2 Line 364: Same question as for the CHIMERE input meteorology - why is a 0.2x0.2 degree grid mentioned here for the forcing meteorology when the IFS forecast is available at 9 km resolution?

AA: for the DEHM model, the IFS meteorology is indeed still retrieved on a 0.2x0.2 degree resolution for historical reasons. The change to higher resolution is planned but not yet implemented, therefore it was not changed in the article.

RC2 Line 462: In which cases are IFS chemical boundary conditions not available? How often does this happen? Similar information for how this situation is handled in EMEP should be added for all other models, too.

AA: Non-availability of boundary conditions is very rare, typically less than once a year, and can, e.g., be due to delays in the file transfer. The following sentence was added:

- [Section 3.3.4]: In cases where ~~IFS~~ CAMS-Global chemical boundary conditions are not available, default boundary conditions are specified for O_3, CO, NO, NO_2, CH_4, HNO_3, PAN, SO_2, isoprene, C_2H_6, some VOCs, Sea salt, Saharan dust and SO_4, as annual mean concentrations along with a set of parameters for each species describing seasonal, latitudinal and vertical distributions. It should be noted however that unavailability of CAMS-Global is very exceptional (less than once a year), and in general due to data transfer issues.

RC2: Line 495: Is this indeed 1300 species, or should it be 130? It seems the Bergström reference shows 158 reactions.

AA: This was a typo, it should have been 130 and has been corrected:

- [Section 3.3.8]: The EmChem19 chemical scheme couples the sulphur and nitrogen chemistry to the photochemistry and organic aerosol formation using about 200 reactions between ca. 1300 species (Bergström et al., 2022; Simpson et al., 2020b; Andersson-Sköld and Simpson, 1999).

RC2 531 – 534: This seems to contradict the statement in Section 2.5 that all models use IFS for their forcing meteorology. In this case, IFS is only used for initial and boundary conditions. Please provide more details on the differences in physics options, land/surface model, land use characterization, etc. between IFS and WRF. Such differences mean that using WRF instead of IFS is not just an improved temporal and spatial interpolation to the EURAD geometry, but actually a distinctly different way to represent meteorology compared to most of the other models used in the ensemble.

AA: The purpose of using WRF to drive EURAD-IM in the CAMS regional production is not to introduce more spread in the meteorological forcing through deliberate choices of different physical and dynamical approaches. It is essentially for historical reasons that it was used as interpolator. In the proposed modification, we emphasize the perspective to replace it with a direct use of IFS in the near future.

- [Section 3.4.3] : The meteorological forcing is obtained from 3-hourly IFS forecasts, but unlike the other models, tThe Weather Research and Forecast (WRF) model is used to compute for the calculation of meteorological fields on the grid needed to drive the EURAD-IM CTM. This intermediate processing is essentially for historical reasons as in the past the IFS temporal and spatial resolution required interpolation for use in the CTM. A direct use the IFS data to dynamically drive EURAD-IM has been developed and is currently in the testing to enter the operational production in the near futureInitial and boundary values for the WRF simulations are derived from 3-hourly IFS meteorological fields. The main motivation to use WRF is to improve the spatial and temporal interpolation of IFS fields towards the EURAD-IM geometry.

RC2: Lines 608 – 613: Similar to the comment above regarding EURAD-IM, this also seems to contradict the statement in Section 2.5 that all models use IFS for their forcing meteorology. In contrast to EURAD-IM, it seems that the relaxation of the GEM internal fields towards the IFS target fields with a 3 hour time scale will maintain greater consistency between GEM and IFS than with the use of just initial and boundary conditions in EURAD-IM, but it would still be good to document differences in GEM physics options and IFS physics options that may influence comparisons to other models.

AA : IFS and GEM are well-established and comparable Numerical Weather Prediction models. Over the course of the CAMS project (7-10 years), each model underwent development and enhancements to individual parameterization modules. Therefore, a comparison (documentation of differences) of "physics options" would be quite challenging, and it falls outside the scope and objectives of this submission. Given that both models are operational, they are compared and evaluated continuously by their respective centres and the WMO. The GEM-AQ model is run as a Limited Area Meteorological weather prediction model, with the IFS model providing nesting boundary conditions. The formulation of this paragraph (lines 608-613) should be qualified and amended to read the following:

- [Section 3.5.3]: The operational IFS model provides meteorological fields for the initial and boundary conditions used by the meteorological part of the GEM-AQ model. The GEM-AQ model is started using the 12-hour forecast (valid at 00:00 UT of the following day) as the initial conditions. The IFS data are used as boundary conditions with a nesting interval of 3 hours. The IFS meteorological fields are computed from spectral coefficients for the target GEM-AQ grid. Meteorological fields, in the GEM-AQ model domain, are constrained within the nesting zone (absorber), which is defined over 10 grid points on each lateral boundary of the limited area domain.

- The operational IFS model provides meteorological fields for initial and boundary conditions used by the meteorological part of the GEM-AQ model. The GEM-AQ model is started using the 12-hour forecast (valid at 00:00 UT of the following day) as initial conditions. The IFS data are used as boundary conditions with a nesting interval of 3 hours. The IFS meteorological fields are computed from spectral coefficients for the target GEM-AQ grid. Meteorological fields, within the GEM-AQ model domain, are constrained and relaxed to the IFS global model every 3 hours. Thus, the meteorological fields are 'dynamically interpolated' by the GEM meteorological model to the required transport and chemistry time steps.

AA: This revision was also an opportunity to reformulate the following:

- [Section 3.5.8]: To avoid the overhead of stratospheric chemistry in this version (a combined stratospheric/tropospheric chemical scheme is currently being developed), both the ozone and NOy fields are replaced with a climatology above 100 hPa after each transport time step. Ozone fields are taken from the HALOE (Halogen Occultation Experiment) climatology (Hervig et al., 1993), while NOy fields are taken from the CMAM (Canadian Middle Atmosphere Model). To avoid the overhead of stratospheric chemistry, the ozone and NOy fields are replaced above 100 hPa with those from the CAMS-Global model. Additionally, stratospheric columns for absorbing species used in photolysis calculations (cf., ozone) are taken from the CAMS-Global model. Photolysis rates (J values) are calculated on-line every chemical time step using the method described in of (Landgraf and Crutzen, 1998).

RC2 Lines 627 – 628: Please provide a reference for these profiles.

AA The Bieser et al., 2011 reference was added: J. Bieser, A. Aulinger, V. Matthias, M. Quante, H.A.C. Denier van der Gon, Vertical emission profiles for Europe based on plume rise calculations, Environmental Pollution, Volume 159, Issue 10, 2011, Pages 2935-2946, doi:10.1016/j.envpol.2011.04.030

RC2: Lines 629 – 630: Please discuss why it is desirable to avoid the effects of short-term variability in biogenic VOC on simulated air quality. Couldn't such effects be important in some situations?

AA : It is right that the formulation of this statement should be modified, as monthly average emissions are influenced by temperature. In contrast to the online approach, this method provides an anticipated variability range, particularly regarding online factors such as meteorological errors and extreme values. The corresponding lines are replaced with the following statement :

- [Section 3.5.5] For biogenic emissions, a temperature-dependent, a monthly averaged MEGAN-MACC (Guenther et al., 2012) dataset for the year 2010 was used specifically to avoid the short-term variability of reactive biogenic VOCs that would otherwise be generated in an online approach. In contrast to the online method, this approach provides an anticipated variability range, particularly by reducing the influence of online factors such as meteorological errors and extreme values.dataset valid for 2010 was used in order to avoid short-term variability of reactive biogenic VOC generated on-line in the model.

RC2 Line 694: Why 15 km instead of the available 9 km noted in Section 2.5

AA This is an oversight, the correct value is 9 km.

- [Section 3.6.3] The meteorological data is retrieved on a regular horizontal resolution of about 9~~15~~ km and for all layers covered by the model's vertical extent.

RC2 Line 702: Please see my earlier comment on line 462 for the EMEP model.

AA the following clarification was added:

- [Section 3.6.4] When the chemical boundary conditions from ~~IFS~~ CAMS-Global are missing (which is very rare, typically less than once a year, and can, e.g., be due to delays in the file transfer or other serious technical issues at ECMWF), the model uses climatological boundary concentrations derived from ~~IFS~~ CAMS-Global data.

RC2 Lines 742 – 743: Has this been implemented now?

AA Unfortunately due to the associated increased runtime with the inclusion of VBS, we would not be able to provide the model output before the required deadline for the analysis. Options for solving this issue are being investigated. The corresponding sentence was modified :

- [Section 3.6.8] Inorganic aerosol chemistry is represented using ISORROPIA II (Fountoukis and Nenes, 2007) and secondary organic aerosols formation based on a VBS scheme (Bergström et al., 2012a; Zare et al., 2014) will be included in the operational forecast version in the future~~at the end of 2023~~.

AA: The description on data assimilation was not up to date, the following sentence was deleted since the vertical set-up is now the same as for the forecasts:

- [Section 3.6.2] ~~For the analyses there are 4 dynamic layers up to 5km agl and a surface layer with a fixed depth of 25 m. The lowest dynamic layer is the mixing layer, followed by 3 reservoir layers. The heights of the reservoir layers are determined by the difference between the mixing layer height and 5 km.~~

RC2: Lines 756 – 759: If "pairs" of IFS layers are combined to generate the MATCH layers, why are the lowest 76 IFS layers lumped into only 26 rather than 38 MATCH layers?

AA: Thanks for pointing that out. This was based on a former description on how the vertical levels were treated in MACTH. This is corrected as:

- [Section 3.7.2] The lowest 78 layers of the ECMWF model are lumped in 39 levels~~The lowest 76 layers of the ECMWF model are lumped in 26 levels~~, which then are used for the air quality simulations.

RC2 Line 762: which model processes use information from CLC/SEI (e.g. deposition?), and how is this information related to the "model geometry" section?

AA Thanks for pointing this out. Yes, the information from CLC/SEI is used in the MATCH model deposition mechanism. We propose to move this statement to the deposition Section:

- [Section 3.7.7.]: Dry deposition of gases and aerosols is modelled using a resistance approach (based on the scheme in (Simpson et al., 2012)), which includes stomatal and non-stomatal pathways for vegetated surfaces. In t~~T~~he current operational system, the model applies this scheme across uses various physiographic tiles of physiography derived from the CLC/SEI inventory[2] (Simpson et al., 2012).

RC2 Line 765: Why is coarser resolution meteorology used for analysis compared to forecasting? If the native IFS resolution is about 9 km, wouldn't interpolating these fields to a coarser 0.2 x 0.2 degree resolution introduce dynamic inconsistencies in the resulting fields?

AA The following was added to explain the rationale for using different resolutions for the analysis and for the forecast

- [Section 3.7.3] The forcing meteorology for MATCH forecasts is retrieved from the 12:00 UTC run of the IFS modelling system on a 0.1°×0.1° spatial grid and with a temporal resolution of one three hour. For the analyses, the 00:00 UTC analysis of the IFS is used at 0.2°×0.2° resolution. The reason for applying a coarser resolution in the analysis is twofold: 1) the delivery time is rather short from when the in-situ observations are available, 2) the analysis increments are on a larger scale. The meteorological variables included are 3D fields of the horizontal wind components (U, V), temperature, specific humidity, cloud cover, cloud water content, cloud ice water content, and surface fields of surface pressure, logarithm of surface pressure, surface temperature, sea surface temperature, snow depth, albedo, roughness height, total cloud cover, precipitation, and volumetric soil water at the surface.

RC2 Line 737: Please see my comments above about discussing how often (and why) this situation happens and then also provide information on how this situation is handed for all other models.

AA: In practice this has never happened, nevertheless a contingency procedure exists:

- [Section 3.7.4] When In the event that the chemical boundary conditions from IFS CAMS-Global would be are missing (which has never happened in practice but could in theory happen due to due to corruption or other technical issues), the model uses seasonal climatological boundary concentrations instead.

RC2 Lines 786 – 788: This seems to be a discussion of chemistry rather than emissions and should therefore be moved to Section 3.7.8

AA This is a good point, we moved the sentence:

- [Section 3.7.8] Exception is made for the isoprene oxidation for which the chain of reactions is following the Carter-1 chemical mechanism, which has proven to give the comparable results with fewer reactions (Carter, 1996; Langner et al., 1998).

RC2 Lines 859 – 862: Are "diffuse emissions" gridded area emissions? Maybe "combined with" would be clearer than "summed up to" to describe the fact that point source emissions were combined with these gridded emissions prior to horizontal interpolation, and then those combined emissions were vertically allocated using GNFR-sector specific vertical allocation profiles provided by TNO in the absence of more detailed plume rise information for point sources.

AA: Indeed, the reviewer was right in inferring that we were referring to gridded emissions

- [Section 3.8.5] The common annual anthropogenic emissions CAMS-REG are implemented as explained in Section 2.5.1. Point emissions are summed up to diffuse gridded emissions for each

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[2] www.sei.org/projects/sei-european-land-cover-map (last accessed 30/10/2024)

GNFR sector, since no information was available about the characterization of the point sources in terms of injection height.

RC2 Line 917: please specify the chemical species represented in the AERO3 module.

AA The list of species was added

- [Section 3.8.8] The aerosols module is AERO3 (Binkowski and Shankar, 1995; Binkowski, 1999). In AERO3 the representation of the particle size is three-modal (Aitken, accumulation and coarse), following lognormal distributions. The aerosol species included are sulphate, nitrate, ammonium, anthropogenic primary and secondary organic aerosol, biogenic secondary organic aerosol, elemental carbon, sea-salt and dust.

RC2 Line 947: Does MOCAGE not require any other meteorological parameters like PBL height, precipitation, soil moisture and temperature, roughness length, albedo, etc? Lines 980 – 983: How does the deposition module obtain the necessary meteorological, surface, and soil fields given the short list of forcing meteorology listed in Section 3.9.3?

AA Indeed, the list was not complete. The paragraph was modified to expand the list for either the atmospheric dynamics or the deposition:

- [Section 3.9.3] The meteorological parameters used for the dynamics calculation in MOCAGE are: horizontal and vertical winds, temperature, humidity, cloud fraction, ~~and~~ surface pressure, albedo, precipitations and incoming radiative flux. The variables relevant for the deposition module are soil humidity and temperature, wind speed and direction, specific humidity, pressure at ground level, and sensible heat flux.

RC2 Line 1037: Why is the IFS data not used at its native resolution of 9 km (Section 2.5)?

AA One of the challenges in the production workflow is the transfer of input datasets. To optimize this, we dowload IFS data that is cropped to the regional domain and matches the resolution of our model grid as closely as possible. This strategy reduces the amount of data to be transferred and allows us to start the production as soon as the datasets are available in the computing nodes. The following sentence was modified :

- [Section 3.10.3] The forcing meteorology is retrieved from the IFS model on a 0.125°x0.125° horizontal grid resolution (the native resolution is remapped as close as possible to the MONARCH grid to optimise transfer time) with a temporal resolution of 6 hours and dynamically interpolated to the final chemistry grid and time steps using the meteorological component of MONARCH.

RC2 Line 1209: do any models miss any of the required species? If so, how is this handled in the generation of the ensemble?

AA: it is a strong requirement that all model deliver the full list of species:

- [Section 4.1]: . Each of the model deliver the full list of required ~~and for each~~ species.

RC2 Line 1215: Change “Figure 1” to “Figure 2”. Also discuss the reasons why the percentage of forecasts delivered on time is higher than the percentage of analyses delivered on time, given that the timeline for the forecasts is actually stricter than the timeline for the analyses.

AA: Indeed, this can be considered as contradictory. We added the following explanatory elements:

- [Section 4.1] The fact that timeliness of forecast delivery is higher than for analyses might seem counterintuitive as forecast are expected earlier, but this is due to the fact that most analyses are produced later due to the late availability of assimilated observations, and not necessarily used at present as initial conditions of the forecast.

RC2 Line 1229: Please see my earlier comment on Section 2.3 to please more details on how the split between shared vs. withheld observational data is handled and whether it varies across time and/or NRT/AN vs. reanalysis.

AA: this comment was taken into account in the modified Section 2.3

RC2 Line 1238: Will such analysis be performed and shared with the community in future publications?

AA : we added the following sentence to encourage the reader to consult the quality control website and reports until such a publication is elaborated :

- [Section 4.2] Therefore, the performances of individual models contributing to the ENSEMBLE are anonymised as it would be too complex to enter here in the details of the performances of each model, which relate to intrinsic parametrisations. Such analysis is left for a dedicated future publication, but the interested user can also consult the interactive viewers and reference public reports on the Evaluation and Quality Control website to analyse the performances of individual models.

RC2 Line 1247: Please provide a reference for this Key Performance Indicator and also define its acronym.

AA : we are sorry that there is no public reference for the CAMS Key Performance Indicator, but the RMSE acronym was spelled out as "Root mean square error"

RC2 Figure 4: please define "frequency bias"

AA: the following was added in the text supporting Figure 4:

- [Section 4.2] The dashed lines provide the frequency bias defined as the ratio of the total number of predicted exceedances to the total number of observed exceedances.

AA All the following editorial changes from RC2 were implemented in the revised manuscript:

Line 41: add "and" before "SILAM"

Line 49: remove "of" before "in the description"

Line 99: add "and" before "SILAM"

Line 109: introduce the "ADS" acronym referenced later

Line 148: change "disseminating" to "disseminated"

Line 159: add "and" before "total Peroxy-Acetyl Nitrates (PANS)"

Line 219: add a comma before "and the atmosphere data store (ADS) of Copernicus". Also see my note above on defining ADS earlier in the manuscript.

Line 242: No comma is needed before "(NMVOCs)". In addition, NMVOC is already defined on line 159 does not need to be redefined here.

Line 246: Should “ventilation” be “speciation”?

Line 294: add “and” before “snow depth”

Line 695: “augmented by” instead of “substantiated by”?

Line 1204: change “model results deliver” to “models deliver”

Line 1210: change “offer” to “offers”

Line 1227: Insert “and” before “PM2.5”

Line 1236: suggest changing “a couple” to “several”

Line 1300: change “use” to “uses”

Line 1309: change “European” to “Europe”

AA Following editor comments, the section on code availability was substantially revised so that all the codes of the eleven CTM involved in the CAMS Regional System are now publicly available and archived. The following changes were made in Section 7 on Code Availability.

- The CHIMERE v2020 model is available to registered users through the on its dedicated website at https://www.lmd.polytechnique.fr/chimere/, the actual version used in CAMS is -available at https://zenodo.org/records/14724119and for download at https://doi.org/10.14768/8afd9058-909e-4827-94b8-69f05f7bb46d.
- The DEHM model used in CAMS is available at https://zenodo.org/records/14628278for collaborative requests to J. H. Christensen; jc@envs.au.dk.
- The EMEP model is available at https://github.com/metno/emep-ctm under the GPLv3 licence. The model version for CAMS is updated once or twice a year in the frame of the regular updates in the CAMS regional service. The current version is close to the one archived on https://zenodo.org/records/14507729https://doi.org/10.5281/zenodo.4230110.
- The EURAD-IM version 5.11.1 source code used in CAMS is https://doi.org/10.5281/zenodo.15198902. is not publicly available for download, but code and data are available on request by e-mail.
- The GEM model is a free software that can be redistributed and/or modified under the terms of the GNU Lesser General Public License published by the Free Software Foundation. It is available on a repository administered by Environment and Climate Change Canada at https://github.com/ECCC-ASTD-MRD/gem/. GEM-AQ includes an additional source code tree accessed via an interface routine in GEM. The GEM-AQ code used in CAMS is available at https://zenodo.org/records/14720848.
- The air quality part of the GEM-AQ model code is available upon request from the Institute of Environmental Protection. The meteorological part of the GEM-AQ model is available from Environment and Climate Change Canada (https://github.com/ECCC-ASTD-MRD).
- The LOTOS-EUROS model is available to registered users upon user request from the website https://airqualitymodeling.tno.nl/lotos-euros/open-source-version/ the version used in CAMS is available at https://zenodo.org/records/14711996.
- The MATCH model as used in CAMS is available at https://zenodo.org/records/14719885Access for implementation is only granted to the extent it is needed for the Parties concerned to carry out their tasks in the CAMS2_40 project and provided that SMHI can grant Access Rights to the MATCH CTM (Chemistry Transport Model), including version control, build environment, scripting system for production, and the legal restrictions or limits. This includes limitations imposed on licenses of software and data. Access Rights are subject to written request. The Access Rights are granted for the purpose of the CAMS Project only and may be restricted if this results in the infringement of third-party rights. All commercial and third-party software are excluded and no Access Rights are granted.
- The FARM code embedded in the MINNI System as used in CAMS is available at https://zenodo.org/records/14650298 https://hpc-forge.cineca.it/projects/open/20
- The MOCAGE source code used in CAMS is not publicly available at https://doi.org/10.5281/zenodo.14625973for download, but code and data are available on request by e-mail.
- The MONARCH model is available at https://earth.bsc.es/gitlab/es/monarch under the GPLv3 licence. The version used in CAMS is https://zenodo.org/records/5215467.

- The SILAM code is available at https://github.com/fmidev/silam-model under the GPLv3 licence. The model is updated several times a year, including two CAMS-related updates. The version used in CAMS is https://zenodo.org/records/14608973The GitHub release follows the most-recent operational release.