## CAMS Service Evolution


# D5.1 Uncertainties in CAMS emission temporal profiles

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# 1 Executive Summary

This deliverable presents the methodology and results of quantifying the range of uncertainty associated with the emission temporal profiles currently used in CAMS global and regional production systems for air quality modelling efforts. The uncertainties were estimated per temporal resolution (i.e., month of the year, day of the week and hour of the day) and sector, country and species dependency being also considered for those sectors for which information was available and for which it is known that the temporal variation can significantly vary from one country/pollutant to another.

To quantify the uncertainty in the emission temporal profiles, an ensemble of profiles was created for each sector/country/species and temporal resolution based on closely related activity statistics and surrogates, including electricity production statistics, traffic congestion statistics, energy consumption statistics and air traffic statistics, among others. The constructed profiles are from different years / countries, so that the full range of possibilities is included. The sectors originally envisaged to be covered included the energy industry, residential and commercial combustion activities and road transport. However, the final dataset also includes uncertainty information related to the temporal distribution of industrial combustion sources, aviation, shipping and agricultural activities.

As a result of the work performed in CAMEO WP5, we produced one global and one regional set of temporal profiles and associated uncertainties that reports the mean value and standard deviation of the temporal weight factors per each month-of-the-year, day-of-the-week and hour-of-the-day and sector, as well as country and pollutant for specific cases. The resulting dataset follows the format of the CAMS-GLOB-TEMPO and CAMS-REG-TEMPO datasets developed under the framework of the CAMS2_61 emission services, to facilitate its integration into the CAMEO and CAMS modelling activities. We refer to the final datasets as CAMEO-TEMPO-GLOB_Unc_v1_0 and CAMEO-TEMPO-REG_Unc_v1_0, respectively.

This document provides a brief description of the methods and data considered to develop the emission temporal uncertainty products, as well as guidance on the use of the resulting datasets to support the modelling works performed in CAMEO WP6.

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# 2 Introduction

## 2.1 Background

Monitoring the composition of the atmosphere is a key objective of the European Union's flagship Space programme Copernicus, with the Copernicus Atmosphere Monitoring Service (CAMS) providing free and continuous data and information on atmospheric composition.
The CAMS Service Evolution (CAMEO) project will enhance the quality and efficiency of the CAMS service and help CAMS to better respond to policy needs such as air pollution and greenhouse gases monitoring, the fulfilment of sustainable development goals, and sustainable and clean energy.
CAMEO will help prepare CAMS for the uptake of forthcoming satellite data, including Sentinel-4, -5 and 3MI, and advance the aerosol and trace gas data assimilation methods and inversion capacity of the global and regional CAMS production systems.
CAMEO will develop methods to provide uncertainty information about CAMS products, in particular for emissions, policy, solar radiation and deposition products in response to prominent requests from current CAMS users.
CAMEO will contribute to the medium- to long-term evolution of the CAMS production systems and products.
The transfer of developments from CAMEO into subsequent improvements of CAMS operational service elements is a main driver for the project and is the main pathway to impact for CAMEO.
The CAMEO consortium, led by ECMWF, the entity entrusted to operate CAMS, includes several CAMS partners thus allowing CAMEO developments to be carried out directly within the CAMS production systems and facilitating the transition of CAMEO results to future upgrades of the CAMS service.
This will maximise the impact and outcomes of CAMEO as it can make full use of the existing CAMS infrastructure for data sharing, data delivery and communication, thus supporting policymakers, business and citizens with enhanced atmospheric environmental information.

## 2.2 Scope of this deliverable

### 2.2.1 Objectives of this deliverables

This deliverable presents the methodology and results of quantifying the uncertainties associated with the temporal profiles currently used in CAMS global and regional production systems for modelling efforts. The uncertainties were estimated per temporal resolution (i.e., month of the year, day of the week and hour of the day) and sector, country and species dependency being also considered for those sectors for which information is available and for which it is known that the temporal variation can significantly vary from one country/pollutant to another. The objective of this document is also to provide guidance on the use of the temporal profiles and associated uncertainty information to support the modelling works performed in CAMEO WP6.

### 2.2.2 Work performed in this deliverable

In this deliverable the work as planned in the Description of Action (DoA, WP5 T5.1) was performed.

### 2.2.3 Deviations and counter measures

No deviations have been encountered.

### 2.2.4 CAMEO Project Partners:

| | |
|---|---|
| ECMWF | EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS |
| Met Norway | METEOROLOGISK INSTITUTT |
| BSC | BARCELONA SUPERCOMPUTING CENTER-CENTRO NACIONAL DE SUPERCOMPUTACION |
| KNMI | KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT-KNMi |
| SMHI | SVERIGES METEOROLOGISKA OCH HYDROLOGISKA INSTITUT |
| BIRA-IASB | INSTITUT ROYAL D'AERONOMIE SPATIALEDE BELGIQUE |
| HYGEOS | HYGEOS SARL |
| FMI | ILMATIETEEN LAITOS |
| DLR | DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV |
| ARMINES | ASSOCIATION POUR LA RECHERCHE ET LE DEVELOPPEMENT DES METHODES ET PROCESSUS INDUSTRIELS |
| CNRS | CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS |
| GRASP-SAS | GENERALIZED RETRIEVAL OF ATMOSPHERE AND SURFACE PROPERTIES EN ABREGE GRASP |
| CU | UNIVERZITA KARLOVA |
| CEA | COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES |
| MF | METEO-FRANCE |
| TNO | NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO |
| INERIS | INSTITUT NATIONAL DE L ENVIRONNEMENT INDUSTRIEL ET DES RISQUES - INERIS |
| IOS-PIB | INSTYTUT OCHRONY SRODOWISKA - PANSTWOWY INSTYTUT BADAWCZY |
| FZJ | FORSCHUNGSZENTRUM JULICH GMBH |
| AU | AARHUS UNIVERSITET |
| ENEA | AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE |

# 3 Methods

To quantify the uncertainty in the emission temporal profiles, three different approaches with different levels of complexity were considered based on the amount of information available for each sector and temporal resolution. The methods are expressed in three tiers of decreasing complexity:

- The **Tier 3 method** is regarded as the most complete and detailed method. For each sector, ensembles of profiles were created (and for each country and/or species if information was available) and temporal resolution (monthly, weekly, hourly) based on proxies linked to their temporal emission variability. The selected activity statistics were used to compute collections of monthly profiles per year, daily profiles per week and hourly profiles per day. The resulting ensembles of temporal profiles were then used to compute the mean value and standard deviation associated to each time step (i.e., month-of-the-year, day-of-the-week, hour-of-the-day), which is used to represent the uncertainty linked to the temporal profiles. Uncertainties from the chosen proxy to construct the temporal profiles, e.g. electricity production statistics for the energy sector or natural gas consumption statistics for the residential combustion sector, are assumed to result in systematic errors, which are more difficult to consider. Similarly, uncertainties derived from the quality of the proxy data considered to derive the profiles are ignored, because we lack information on this.
- The **Tier 2 method** is similar to Tier 3, but the ensembles of profiles are constructed using surrogates that only partially represent the temporal distribution of a specific sector. These ensembles are used to compute relative standard deviation per time step (i.e., month-of-the-year, day-of-the-week, hour-of-the-day), and country if possible, and are then combined with the temporal factors provided by the CAMS-GLOB-TEMPO and CAMS-REG-TEMPO datasets. This method is used for those sectors for which the temporal distribution of emissions relies on many parameters and the information to quantify and combine their associated uncertainty is very limited. An example of this is agricultural emissions (i.e., livestock and agricultural soils), whose temporal distribution depends on meteorology, crop calendars, ventilation rates in farms and manure management techniques, among others.
- The **Tier 1 method** is a simple method in which a priori uncertainties (i.e., relative standard deviation) were assumed based on the uncertainty information obtained from the sectors covered with the Tier 3 and Tier 2 approaches. This method was used for those sectors for which no activity data or surrogates were available to derive ensembles of profiles.

Table 1 and Table 2 summarise the emission sources and temporal resolutions covered by the current work according to the sector classifications considered in the CAMS-GLOB-ANT and CAMS-REG emission inventories, which are the emission datasets considered in the modelling activities performed in CAMEO WP6. For each source and temporal resolution, we indicate the tier method considered to derive the uncertainties (T1 to T3, i.e., simple to more complex) and if the resulting profiles and associated uncertainties are country(c)-, sea(s)- and/or pollutant(p)-dependent. Note that for the global dataset of temporal profiles and associated uncertainties only monthly and hourly profiles were computed, as the current version of the ECMWF's Integrated Forecasting System (IFS) assumes a flat weekly distribution of anthropogenic emissions. Similarly, global hourly profiles were computed without considering country-dependencies, since IFS cannot currently handle this feature for this temporal resolution. The sectors originally envisaged to be covered in this work included energy industry, residential/commercial combustion activities and road transport. However, the final dataset is also considering uncertainties related to all the other sectors reported by the CAMS-GLOB-ANT and CAMS-REG emission inventories.

**Table 1 Summary of the sources and temporal resolutions covered by the set of global temporal profiles and associated uncertainties (CAMEO-TEMPO-GLOB_Unc_v1_0). For each source and temporal resolution, we indicate the tier method considered to derive the uncertainties (T1 to T3, i.e., simple to more complex) and if the resulting profiles and associated uncertainties are country(c)-, sea(s)- and/or pollutant(p)-dependent.**

| Description | Monthly (∑=12) | Hourly (∑=24) |
|---|---|---|
| ene (energy) | **T3** (c) | **T3** (c) |
| ref (refineries) | **T3** (c) | **T3** |
| ind (manufacturing industry) | **T3** (c) | **T3** |
| res (residential combustion) | **T2** | **T3** |
| fef (fugitives) | **T1** | **T1** |
| slv (solvents) | **T1** | **T1** |
| tro (road transportation) | **T2** (c) | **T3** |
| shp (ships) | - | **T1** |
| tnr (Off road transportation) | **T1** | **T1** |
| swd (solid waste and wastewater) | **T1** | **T1** |
| agl (agriculture livestock) | **T2** (c,p) | **T3** |
| awb (agriculture waste burning) | **T3** (c) | **T3** |
| ags (agriculture soil) | **T2** (c,p) | **T2** |

**Table 2 Summary of the sources and temporal resolutions covered by the set of European regional temporal profiles and associated uncertainties (CAMEO-TEMPO-REG_Unc_v1_0). For each source and temporal resolution, we indicate the tier method considered to derive the uncertainties (T1 to T3, i.e., simple to more complex) and if the resulting profiles and associated uncertainties are country(c)-, sea(s)- and/or pollutant(p)-dependent.**

| Sector | Monthly (∑=12) | Weekly (∑=7) | Hourly (∑=24) |
|---|---|---|---|
| A_PublicPower | **T3** (c) | **T3** (c) | **T3** (c) |
| B_Industry | **T3** (c) | **T3** | **T3** |
| C_OtherStationaryComb | **T2** (c) | **T3** | **T3** |
| D_Fugitives | **T1** | **T1** | **T1** |
| E_Solvents | **T1** | **T1** | **T1** |
| F1_RoadTransport_gasoline | **T2** (c,p) | **T3** (c) | **T3** (c) |
| F2_RoadTransport_diesel | **T2** (c,p) | **T3** (c) | **T3** (c) |
| F3_RoadTransport_LPG | **T2** | **T3** (c) | **T3** (c) |
| F4_RoadTransport_nonexhaust | **T2** (c,p) | **T3** (c,p) | **T3** (c,p) |
| G_Shipping | **T3** (s) | **T3** | **T1** |
| H_Aviation | **T3** (c) | **T3** (c) | **T3** |
| I_OffRoad | **T1** | **T1** | **T1** |
| J_Waste | **T1** | **T1** | **T1** |
| K_AgriLivestock | **T2** | **T1** | **T3** |
| L_AgriOther (awb) | **T3** (c) | **T1** | **T3** |
| L_AgriOther (fert) | **T2** | **T1** | **T2** |

The following sections briefly present the methodologies and datasets considered to compute the profiles and associated uncertainties for each one of the sectors.

## 3.1 Public power / energy industry

The temporal profiles and associated uncertainties computed for this sector are linked to the ene sector in the CAMS-GLOB-ANT and the GNFR_A category in CAMS-REG inventories. Ensembles of monthly, weekly, and hourly temporal profiles per country were estimated from fossil fuel-related electricity production statistics reported by multiple national transmission system operators (Guevara et al., 2024), under the assumption that emissions from this sector largely depend upon the combustion of fossil fuels in power and heat plants. This approximation is consistent with the definition of the ene and GNFR_A sector in the CAMS-GLOB-ANT and CAMS-REG_AP/GHG datasets. Note that for all cases statistics for the year 2020 were excluded to avoid including the impact of the COVID-19 mobility restrictions.

For the global scale, the constructed country-dependent hourly profiles were averaged per day of the year globally by taking into account the amount of $CO_2$ emissions per country reported by the Emissions Database for Global Atmospheric Research version 8 (EDGARv8) for the energy sector. We considered $CO_2$ as it is a good representative of fuel consumption and activity data.

For countries with no information, we considered the mean relative standard deviation per time step derived from countries with information and combined it with the temporal weight factors reported by the CAMS-GLOB-TEMPOv4.1 and CAMS-REG-TEMPOv4.1 datasets. This was done because the CAMS-GLOB-TEMPOv4.1 and CAMS-REG-TEMPOv4.1 datasets already include a gap filling procedure in which countries with no data were assigned with profiles from other countries with similar climatological and socio-demographic characteristics.

## 3.2 Manufacturing industry

The temporal profiles and associated uncertainties computed for this sector are linked to the ind sector in the CAMS-GLOB-ANT and the GNFR_B category in CAMS-REG inventories. For European countries, ensembles of monthly temporal profiles per country were estimated by performing a weighted average of the monthly industrial production index (IPI) values for each individual industrial division, making use of the fossil-fuel related energy consumed in each of these industrial divisions (i.e., solid fossil fuel, manufactured gases, peat and peat products, oil shale and oil sands, natural gas, oil and petroleum products, renewables and biofuels, non-renewable waste). Only the largest energy-intensive industrial divisions were considered to derive the country-dependent averaged monthly IPI values (i.e., basic metals, chemical and petrochemical, non-metallic minerals, paper and pulp and food, beverages, and tobacco). Information on monthly IPI values and annual energy consumption per industrial division for the year 2015 to 2021 were derived from Eurostat statistics. For non-European countries, we considered manufacturing industrial production statistics reported between 2015 and 2021 by the Organisation for Economic Co-operation and Development (OEDC). In both cases, the resulting profiles were estimated excluding 2020 due to the COVID-19 restrictions.

Due to the lack of country-specific data, fixed ensembles of weekly and hourly profiles were constructed making use of reported industrial natural gas consumption statistics. For the weekly profiles, we considered French daily natural gas consumption statistics in the industrial sector provided for the years 2015 to 2022 by GRTGaz, while the ensemble of hourly profiles was developed making use of hourly natural gas consumption statistics for the manufacturing industry sector for 2022 provided by the UK national gas.

## 3.3 Refineries

The temporal profiles and associated uncertainties computed for this sector are linked to the ref sector in the CAMS-GLOB-ANT inventory. No equivalent sector exists in the CAMS-REG dataset, as emissions from these industrial facilities are reported within the GNFR_B category.

Ensembles of monthly profiles at the country level were estimated from national refinery production statistics compiled for different countries and years from multiple sources of information, including Eurostat (EU27 countries, 2013 to 2022), U.S. Energy Information Administration (US, 2003 to 2022), Australian Petroleum Statistics (Australia, 2010 to 2022), Brazil's National Agency for Petroleum, Natural Gas and Biofuels (Brazil, 2000 to 2022), Government of India Ministry of Petroleum and Natural Gas (India, 2015 to 2019) and the Joint Organisations Data Initiative (JODI) for other countries and the years 2015 to 2022. As done in other sectors, information for the year 2020 was excluded in all cases to avoid including the impact of the COVID-19 restrictions.

The resulting country-dependent ensembles of temporal profiles were then used to compute the mean value and standard deviation associated to each time step. For countries with no information, a global averaged profile and associated uncertainty is considered.

For the weekly and hourly scales, we consider the fixed profiles and associated uncertainties constructed for the manufacturing industry sector.

## 3.4 Other stationary combustion sources

The temporal profiles and associated uncertainties computed for this sector are linked to the res sector in CAMS-GLOB-ANT and the GNFR_C category in CAMS-REG.

To quantify the uncertainty in the monthly temporal profiles, an ensemble of country-dependent profiles was created using the heating degree day (HDD) approach, which is an indicator used as a proxy variable to reflect the daily energy demand for heating a building (Quayle and Diaz, 1980, Guevara et al., 2021). Uncertainty ranges were defined for the two key input parameters of the HDD approach, namely the critical temperature or temperature threshold (Tb), above which a building needs no heating (i.e., heating appliances will be switched off), and the non-heating fraction (f), which defines the share of residential/commercial combustion emissions that are not related to space heating but to other activities that remain constant throughout the year such as water heating or cooking. For these two parameters, uncertainty ranges were defined using the information provided by Ciais et al. (2022) and Eurostat et al. (2023), respectively (i.e., Tb=14.8 ±1.8 ºC; f=0.17 (+134%/-65%)).

Monthly gridded profiles were created using outdoor temperature data provided by ERA5 (Hersbach et al., 2020). Two years were selected (2018 and 2021), which resulted in a total of 18 ensemble members per country. The resulting country-dependent ensembles were used to derive monthly relative standard deviation values, which were then combined with the country-dependent climatological (2000 to 2022) monthly profiles reported by the CAMS-GLOB-TEMPOv4.1 and CAMS-REG-TEMPOv4.1 datasets.

Due to the lack of country-specific data, fixed ensembles of weekly and hourly profiles were constructed making use of reported residential natural gas consumption statistics. For the weekly profiles, we considered French daily natural gas consumption statistics in the residential sector provided for the years 2015 to 2022 by GRTGaz, while the ensemble of hourly profiles was developed making use of hourly natural gas consumption data provided by 300 anonymised digital gas meters from Belgium for the year 2022 (Fluvius, 2024).

As reported in Guevara et al. (2021), hourly profiles in the residential sector present a significant fuel-dependency. In Europe, residential wood burning activities tend to present an intense peak during the evening hours, but not during the morning, in contrast to natural gas combustion. It is actually a common practice in European countries to use fireplaces and other types of wood-burning appliances mainly in the evening. Considering that, an ensemble of residential wood burning hourly profiles was developed taking into account information reported in the literature (Finstad et al., 2004, Gröndahl et al., 2010, Athanasopoulou et al., 2017 and Lopez-Aparicio et al., 2022). The profile and associated uncertainty derived from this ensemble is considered for the PM emissions reported under the GNFR_C category in CAMS-REG. For CAMS-GLOB-ANT, we do not consider this species dependency, as in many non-European countries wood is significantly used not only for space heating but also for cooking activities. Therefore, the profile and associated uncertainties derived from Fluvius (2024) is assumed for all pollutants.

## 3.5 Road transport

The temporal profiles and associated uncertainties computed for this sector are linked to the tro sector in CAMS-GLOB-ANT and the GNFR_F1, F2, F3 and F4 categories in CAMS-REG. In the CAMS-GLOB-TEMPOv4.1 and CAMS-REG-TEMPOv4.1 datasets, the monthly distribution of emissions from these sectors are computed considering a combination of urban and interurban traffic activity and meteorological parametrisations, as reported in Guevara et al., (2021).

To quantify the uncertainty in the monthly temporal profiles, an ensemble of country-dependent profiles was created using the city-level TomTom congestion statistics collected between July 2021 and March 2024. Profiles at the city level were averaged at the country level considering the annual average level of congestion and number of inhabitants of each city. Only the top 3 cities in terms of inhabitants were considered for each country, in order to ensure that the ensemble and resulting range of uncertainty is mainly representing hotspot regions. The resulting ensembles were used to compute country-dependent monthly relative standard deviation values, which were then combined with the temporal weight factors reported by the CAMS-GLOB-TEMPOv4.1 and CAMS-REG-TEMPOv4.1 datasets. For countries with no information, we considered the mean relative standard deviation per time step derived from countries with information.

Ensembles of weekly profiles at the country level were constructed using the TomTom congestion statistics and following the same procedure as the one described for the monthly profiles. The resulting ensembles were used to compute the mean value and standard deviation associated to each time step and country. For countries with no information, we considered the mean relative standard deviation per time step derived from countries with information and combined it with the temporal weight factors reported by the CAMS-GLOB-TEMPOv4.1 and CAMS-REG-TEMPOv4.1 datasets.

Ensembles of hourly profiles at the country level were constructed following the same procedure as the one described for the weekly profiles. At the European regional scale, we distinguish the hourly profiles according to the day of the week (i.e., weekday, Saturday, Sunday). This distinction is not considered for the global profiles, as IFS cannot handle day-of-the-week hourly profiles.

## 3.6 Shipping

The temporal profiles and associated uncertainties developed for maritime traffic emissions are reported under the shp sector in CAMS-GLOB-ANT and the GNFR_G category in CAMS-REG.

At the European regional scale, monthly temporal profiles and associated uncertainties were estimated as the sea-region level using as input the daily AIS-based CAMS-GLOB-SHIPv3.2 emission inventory (Jalkanen et al., 2016). $CO_2$ emissions reported for the years 2014 to 2022, excluding the year 2020 due to the COVID-19 restrictions were considered to create the sea-dependent ensembles of profiles. These ensembles were then used to compute monthly weight factors and standard deviation for each time step and sea region. A similar strategy was followed to derive the weekly profiles and associated uncertainties.

For CAMEO_GLOB_TEMPO_Unc_v1_0 we did not compute the uncertainty associated with the monthly distribution of shipping emissions, as CAMS-GLOB-ANT directly uses as input the AIS-based monthly emissions estimated by CAMS-GLOB-SHIP, which are based on direct measurements of shipping activity data and therefore the uncertainty is assumed to be very insignificant.

At the hourly scale, no activity data or proxies were found to derive an ensemble of profiles. We assume a flat distribution, consistent with what we report in the CAMS-TEMPO dataset and assumed a default a priori uncertainty of 25% (relative standard deviation), following the results presented in Section 3.10.

## 3.7 Aviation

The temporal profiles and associated uncertainties developed for air traffic emissions during landing and take-off (LTO) cycles in airports are reported under the GNFR_H category in the CAMS-REG inventory. We did not consider this sector for the CAMS-GLOB-ANT inventory as it is not included in the inventory.

Country-dependent monthly and weekly ensembles of temporal profiles were constructed using airport traffic data reported by Eurocontrol for the year 2016 until 2023. Years 2020, 2021 and 2022 were excluded due to the COVID-19 restrictions. For countries with no information, we considered the mean relative standard deviation per time step derived from countries with information and combined it with the temporal weight factors reported by the CAMS-REG-TEMPOv4.1 dataset.

Concerning hourly profiles, we created a fixed ensemble of profiles making use of the hourly air traffic statistics reported by the Bureau of Transportation Statistics (BTS) which reports detailed arrival and departure air flight statistics per US airport. Despite using a non-European information source to derive profiles for European emissions, we assume that the diurnal variability of air traffic activities follows similar patterns across airports worldwide.

## 3.8 Agriculture: livestock and use of fertilizers

The temporal profiles and associated uncertainties computed for livestock and use of fertilizer are linked to the agl and ags sectors in CAMS-GLOB-ANT and the GNFR_K and GNFR_L categories in CAMS-REG, respectively. These two sources are together responsible for more than 90% of the total anthropogenic $NH_3$ emissions. In the CAMS-GLOB-TEMPOv4.1 and CAMS-REG-TEMPOv4.1 datasets, the monthly distribution of $NH_3$ emissions from these sectors are computed considering parametrisations that take into account temperature, wind speed, crop calendars and farm ventilation rates, as reported in Guevara et al., (2021). Considering the challenge of acquiring and combining uncertainty information related to each of these individual parameters, and also that these two sectors were not originally planned to be included in CAMEO T5.1 activities, we estimated uncertainties related to the monthly distribution of these emissions considering a Tier 2 method.

Country-dependent relative standard deviations were computed by using the European $NH_3$ monthly surface emission estimates derived by DECSO from CrIS (NOAA) observations of NH3 columns for the years 2020 to 2022 (Ding et al., 2017). These data files were generated

by KNMI within the EU project SEEDS. As the satellite-based emissions report total fluxes of $NH_3$ without information on sector contribution, we had to assume that the resulting relative standard deviations are applicable to both livestock and use of fertilizer emissions.

At the weekly scale, no activity data or proxies were found to derive an ensemble of profiles. We assume a flat distribution, consistent with what we report in the CAMS-TEMPO dataset and assumed a default a priori uncertainty of 20% (relative standard deviation), following the results presented in Section 3.10.

At the hourly scale, a fixed ensemble of $NH_3$ hourly profiles was constructed making use of profiles reported by the literature (McGinn et al., 2007; Grant et al., 2020).

## 3.9 Agriculture: agricultural waste burning activities

The temporal profiles and associated uncertainties developed for agricultural waste burning activities are reported under the awb sector in CAMS-GLOB-ANT. In the case of CAMS-REG, we assume that all the criteria pollutants except for $NH_3$ in the GNFR_L sector (i.e. NOx, SOx, NMVOC, CO, PM10 and PM2.5) are mainly related to this activity.

Ensembles of monthly temporal profiles per country were estimated using as a basis the Global Fire Emissions Database version 4 (GFED4) monthly estimates of agricultural waste burning emissions (van der Werf et al., 2017). Original monthly gridded emissions at 0.25x0.25 deg were aggregated at the country level and then normalized to derive monthly temporal profiles for years 2015 until 2022. The resulting ensembles were used to compute the mean value and standard deviation associated to each time step and country. For countries with no information, a global averaged profile and associated uncertainty is considered.

At the weekly scale, no activity data or proxies were found to derive an ensemble of profiles. We assume a flat distribution, consistent with what we report in the CAMS-TEMPO dataset and assumed a default a priori uncertainty of 20% (relative standard deviation), following the results presented in Section 3.10.

At the hourly scale, a fixed ensemble of hourly profiles was constructed making use of profiles reported from the hourly biomass burning emissions product from blended satellite products reported by Li et al., (2022).

## 3.10 Other sectors: use of solvents, waste management, fugitive fossil fuels, non-road mobile machinery

For all these sectors uncertainties were derived using the Tier 1 method. Educated guesses were made for each temporal resolution considering the average relative standard deviations per temporal resolution (monthly, weekly, hourly) obtained for the sectors covered using the Tier 3 and Tier 2 methods at the EU27+UK scale. We considered this world region as it is the one best covered in terms of activity statistics used to construct the ensembles of temporal profiles. Based on this information, we assumed that monthly, weekly and hourly temporal profiles have an a priori uncertainty of 15%, 20% and 25% (relative standard deviation), respectively (Figure 1).

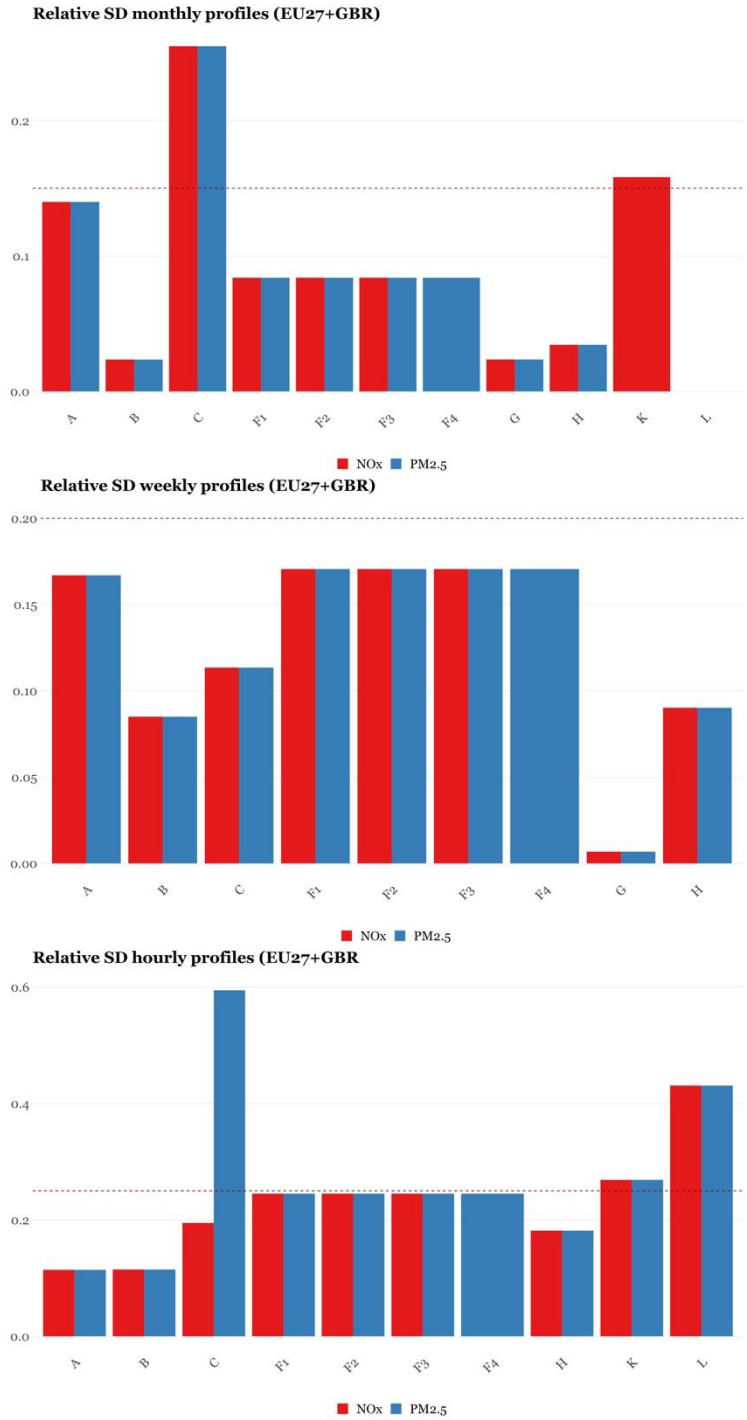


**Figure 1 Average relative standard deviations of monthly, weekly and hourly profiles obtained per GNFR sector at the EU27+UK level. Dashed red line indicate the a priori uncertainties (15%, 20% and 25% relative standard deviation) assumed for the sectors included in the Tier 1 method.**

# 4 Results

Figure 2 and Figure 3 show examples of the resulting temporal profiles and associated uncertainties obtained for selected sectors (energy and road transport) and countries/species. In both figures, the plot on the bottom-right illustrates the globally averaged hourly profile constructed for the CAMEO-TEMPO-GLOB_Unc

For both sectors, results indicate how seasonalities and associated uncertainties can vary significantly between countries due to climatological and socio-economic aspects. For instance, in the case of Spain two clear peaks are observed in winter and summer for the energy monthly profiles, which relate to the increase in electricity production to cover the demand associated with space heating and cooling activities. On the other hand, Poland presents a flatter profile, and the standard deviation is generally lower than the one reported for Spain. For road transport large variations are observed in the shapes of the profiles reported across country, the uncertainty levels being however quite similar.

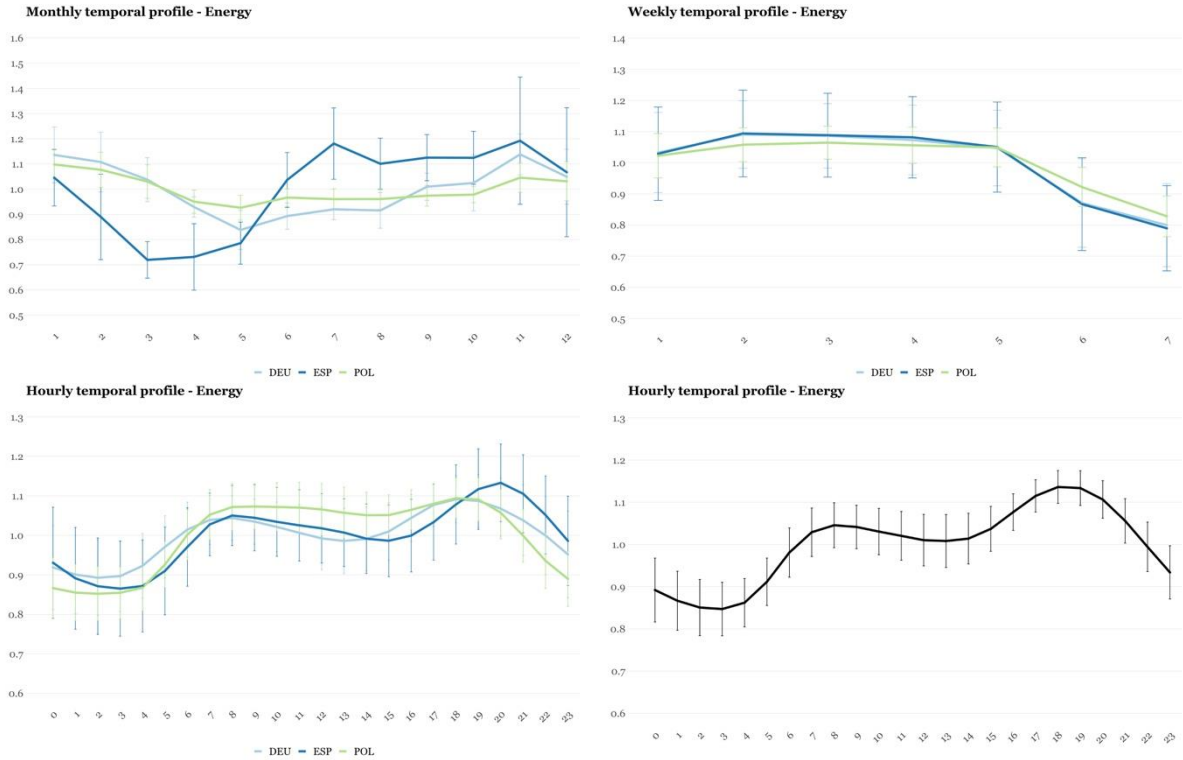


**Figure 2 Monthly, weekly and hourly temporal profiles for the energy sector for selected countries (Germany, DEU; Spain, ESP; Poland, POL) reported by CAMEO-TEMPO-REG_Unc_v1_0 and weighted average global hourly temporal profile reported by CAMEO-TEMPO-GLOB_Unc_v1_0. Error bars represent one standard deviation.**

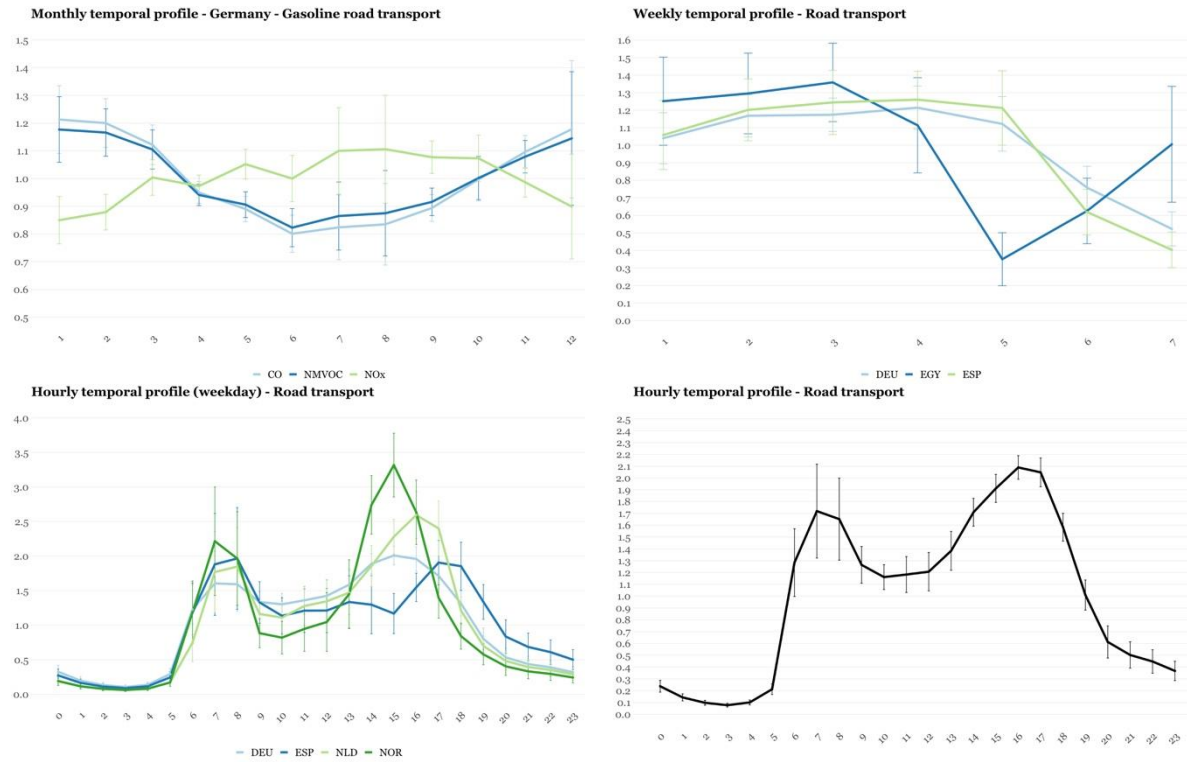


**Figure 3 Monthly (gasoline CO, Germany), weekly (Germany, DEU; Spain, ESP; Egypt, EGY) and hourly (weekdays; Germany, DEU; Spain, ESP; Netherlands, NLD, Norway, NOR) temporal profiles for the road transport sector as reported by CAMEO-TEMPO-REG_Unc_v1_0 and weighted average global hourly temporal profile as reported by CAMEO-TEMPO-GLOB_Unc_v1_0. Error bars represent one standard deviation.**

Figure 4 shows an example of the gridded global monthly emission temporal profiles and associated uncertainties constructed for the refinery sector.

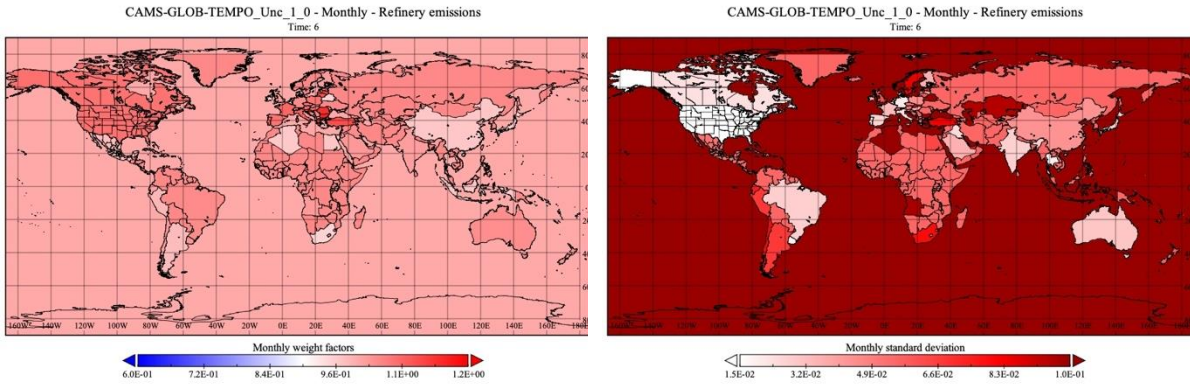


**Figure 4 Monthly temporal profiles and standard deviation values gridded at 0.1x0.1 resolution for the refinery sector for the month of August.**

### 4.1 CAMEO_TEMPO_REG_Unc

The final dataset of European regional emission temporal profiles and associated uncertainties (CAMEO_TEMPO_REG_Unc_v1_0) consists of a collection of CSV files:

- CAMEO_monthly_profiles_uncertainty_v1_0.csv
- CAMEO_weekly_profiles_uncertainty_v1_0.csv
- CAMEO_hourly_profiles_uncertainty_v1_0.csv
-

The following information fields are reported

- **ISO3**: Country code ISO3. For GNFR_G the codes of the sea regions are also included. All codes follow the same nomenclature as in CAMS-REG-AP.
- **POLL**: Name of the pollutant (NOx, CO, NMVOC, SOx, NH3, PM10, PM2.5)
- **GNFR**: Sector category (A, B, C, D, E, F1, F2, F3, F4, G, H, I, J, K, L)
- **DayType** (only for hourly profiles of F1, F2, F3 and F4 sector):
  - Weekday (profile for Monday to Friday)
  - Saturday (profile for Saturday)
  - Sunday (profile for Sunday)
- **Variable**: indicates if the values reported are the mean temporal weight factor (e.g., FM_mean) or the associated standard deviation (e.g., FM_sd)

The sum of all factors is equal to 12 for monthly profiles, 7 for weekly profiles and 24 for hourly profiles.

The format of the final dataset is consistent with the one used to produce the CAMS-REG-TEMPO profiles and it was agreed with WP6 modellers.

### 4.2 CAMEO_TEMPO_GLOB_Unc

The final dataset of global monthly emission temporal profiles and associated uncertainties (CAMEO_TEMPO_GLOB_Unc_v1_0) consists of a collection of NetCDF files constructed using the following naming convention

CAMEO-GLOB-TEMPO_Unc_v1.0_month_<sector>.nc

Where <sector> indicates the pollutant sector: “ene”, “ind”, “ref”, “res”, “tro”, “ags”, “agl”, “awb”, “fef, “slv”, “swd”, “tnr”.

The spatial resolution of the gridded files is 0.1x0.1 degrees, all of them following the same domain descriptions defined in the CAMS-GLOB_ANT emission datasets. For each file, the following abbreviations are used:

- FM → Monthly factor. The sum of all factors is equal to 12.
- SD → standard deviation
- RSD → relative standard deviation

The sector-dependent hourly fixed temporal profiles are available as a CSV file. The following information fields are reported:

- **GNFR**: Sector category (“ene”, “ind”, “ref”, “res”, “tro”, “tnr”, “slv”, “fef”,”swd”, “shp”, “ags”, “agl”, “awb”)
- **POLL**: Name of the pollutant (NOx, CO, NMVOC, SOx, NH3, PM10, PM2.5)
- **Variable**: indicates if the values reported are the mean temporal weight factor (e.g., FM_mean) or the associated standard deviation (e.g., FM_sd)

The sum of all factors is equal to 24.

The format of the final dataset is consistent with the one used to produce the CAMS-GLOB-TEMPO profiles and it was agreed with WP6 modellers.

# 5 Conclusion

In this document we present the methodology and results of quantifying the range of uncertainty associated with the emission temporal profiles currently used in CAMS global and regional production systems for air quality modelling efforts.

As a result of the work performed, we produced one global and one regional set of temporal profiles and associated uncertainties that report the mean value and standard deviation of the temporal weight factors per each month-of-the-year, day-of-the-week and hour-of-the-day and sector, as well as country and pollutant for specific cases. We refer to the final datasets as CAMEO-TEMPO-GLOB_Unc_v1_0 and CAMEO-TEMPO-REG_Unc_v1_0, respectively.

The files can be downloaded from the following FTP server:

Server: es-ftp.bsc.es
Username: mguevara
Password: p5SEEZDU/i8niLLG
Port: 8021

The files are stored in the following paths:
mguevara/cameo

These datasets will support the modelling works performed in CAMEO WP6.

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# Document History

| Version | Author(s) | Date | Changes |
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| 2.0 | Marc Guevara, Angie Albarracín, Aitor Val, Carles Tena, Francesca Macchia, Oriol Jorba | 29/05/2024 | Second version including grammar and editorial comments from internal reviewers |
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# Internal Review History

| Internal Reviewers | Date | Comments |
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