CAMS: Reanalysis data documentation

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Introduction

Here we document the CAMS reanalysis datasets, the CAMS global reanalysis (EAC4) which currently covers the period 2003 - December 2023, and CAMS global greenhouse gas reanalysis (EGG4) which currently covers the period 2003-2020.

The CAMS reanalysis is the latest global reanalysis data set of atmospheric composition (AC) produced by the Copernicus Atmosphere Monitoring Service, consisting of 3-dimensional time-consistent AC fields, including aerosols, chemical species and greenhouse gases, through the separate CAMS global greenhouse gas reanalysis (EGG4). The data set builds on the experience gained during the production of the earlier MACC reanalysis and CAMS interim reanalysis.

The CAMS reanalysis was produced using 4DVar data assimilation in CY42R1 of ECMWF's Integrated Forecast System (IFS), with 60 hybrid sigma/pressure (model) levels in the vertical, with the top level at 0.1 hPa. Atmospheric data are available on these levels and they are also interpolated to 25 pressure, 10 potential temperature and 1 potential vorticity level(s). "Surface or single level" data are also available.

Generally, the data are available at a sub-daily and monthly frequency and consist of analyses and 48h forecasts, initialised daily from analyses at 00 UTC.

The data are archived in the ECMWF data archive (MARS) and can be obtained from the Atmosphere Data Store.

The IFS model and data assimilation system

The 4DVar data assimilation uses 12 hour assimilation windows from 09 UTC to 21 UTC and 21 UTC to 09 UTC.

The IFS model documentation for various model cycles can be found on https://www.ecmwf.int/en/publications/ifs-documentation. The model used in the CAMS reanalyses includes several updates to the aerosol and chemistry modules on top of the standard CY42R1 release, which are listed below. Please note that 42r1 documentation is not available on the page, but the code for the earlier and later cycles is available for reference.

Aerosol model

- Updated aerosol optical properties, especially for organic matter (Bozzo et al., 2017).
- Bug fixes to sedimentation, which was unreasonably weak for some dust and sea-salt bins, with corresponding re-tuning of sea-salt scavenging.
- SO_2 dry deposition velocities updated to match those used in the chemistry scheme (from SUMO).
- New parametrisation of anthropogenic Secondary Organic Aerosol (SOA) production, proportional to non-biomass-burning CO emissions.
- More detailed SO_2 to sulfate aerosol conversion with dependence on temperature and relative humidity, and overall decrease in the conversion timescale especially at high latitudes.
- Increased sulfate dry deposition velocity over ocean.
- Mass fixer extended to aerosol species.
- Scaling of biomass-burning Black Carbon (BC) emissions using the ratio of BC AOD (CAMS interim reanalysis) / BC AOD (CAMS interim control run).
- 80% of SO_2 emissions are released in the two lowest model levels (as an update of tendencies) rather than at surface (fluxes)

Chemistry mechanism

The chemical mechanism of the IFS is an extended version of the Carbon Bond 2005 (CB05) chemical mechanism as implemented in CTM Transport Model 5 (TM5). In the CAMS reanalysis the model as documented in Flemming et al. (2015) and Flemming et al. (2017) is used with the following updates:

- Update of heterogeneous rate coefficients for N2O5 and HO2 based on clouds and aerosol
- Modification of photolysis rates by aerosol
- Dynamic tropopause definition based on T profile for coupling to stratosphere and tropospheric mass diagnostics
- Monthly mean VOC emissions calculated by the MEGAN model using MERRA reanalysed meteorology (Sindelarova et al., 2014) for the period 2003-2017. From 2018 onwards emissions adopt a climatology of the biogenic MEGAN-MACC emissions based on monthly data for 2011-2017.
- Bugfixes, in particular for diurnal cycle of dry deposition whose correction has decreased ozone dry deposition (about 15-20%)
- The version number for the chemistry scheme is CHEM_VER=15

Greenhouse Gases

The model configuration for greenhouse gases is based on the specification of the following components documented in the listed papers below:

- Emissions for CO2 are documented in Agusti-Panareda et al. (2014), Massart et al. (2016).
- Bias correction for CO2 ecosystem fluxes based on the Biogenic Flux Adjustment Scheme is documented by Agusti-Panareda et al. (2016)
- Emissions and loss rate for CH4 is documented in Massart et al. (2014)
- Mass fixer configuration for CO2 and CH4 is documented by Agusti-Panareda et al. (2017) and Diamantakis and Agusti-Panareda (2017).

Emission datasets

The emissions datasets used to produce the CAMS reanalyses are listed in Table 1. They include the MACCity anthropogenic emission, GFAS fire emissions, MEGAN biogenic emissions and several GHG emission datasets.

Anthropogenic emissions used were not adjusted for any COVID-19 lockdowns in 2020.

Table 1: *Emission datasets used in the CAMS reanalysis*

Data set	Version/Period
MACCity anthropogenic emissions	MACCity (trend: ACCMIP + RCP8.5) & CO emission upgrade Stein et al. (2014)
GFAS	v1.2: 20030101-
Dry deposition	Sumo dry deposition
VOC emissions	Monthly mean VOC emissions calculated by the MEGAN model using MERRA reanalysed meteorology (Sindelarova et al., 2014)
CO2 ocean fluxes	Takahashi et al. (2009) climatology
CO2 emissions from aviation	Based on ACCMIP NO emissions from aviation scaled to annual total CO2 from EDGAR aviation emissions.
CO2 ecosystem fluxes bias corrected with BFAS	Based on CHTESSEL (modelled online in C-IFS)
CO2 anthropogenic emissions	EDGARv4.2FT2010 (2003-2010)
CH4 wetland emissions	LPJ-HYMN climatology (Spanhi et al., 2011)
CH4 total emissions	based on EDGARv4.2FT2010 , LPJ-HYMN wetland climatology and other natural sources/sinks (2003-2010)
CH4 chemical sink	based on Bergamaschi et al. (2009) dataset
CH4 anthropogenic emissions	EDGARv4.2FT2010 (2003-2010)

Data organisation and access

The data is now available only from the Atmosphere Data Store (ADS), either interactively through its download web form or programmatically using the CDS API service:

- CAMS global reanalysis (EAC4)
- CAMS global reanalysis (EAC4) monthly averaged fields
- CAMS global greenhouse gas reanalysis (EGG4)
- CAMS global greenhouse gas reanalysis (EGG4) monthly averaged fields

Please have a look at How to migrate to CDS API on the Atmosphere Data Store (ADS) for more details.

Users with access to MARS can browse the data on the MARS catalogue under class=mc and expver=eac4 for the CAMS global reanalysis and under class=mc and expver=egg4 for the CAMS global greenhouse gas reanalysis.

Data organisation in MARS

	CAMS global reanalysis (EAC4)	CAMS global greenhouse gas reanalysis (EGG4)
Stream	• oper: sub-daily • mnth: synoptic monthly means • moda: monthly means of daily means	• oper: sub-daily • mnth: synoptic monthly means • moda: monthly means of daily means
Type	• an: analyses • fc: forecasts	• an: analyses • fc: forecasts
Levtype	• sfc: surface or single level • pl: pressure levels • pt: potential temperature levels • pv: potential vorticity level • ml: model levels	• sfc: surface or single level • pl: pressure levels • ml: model levels

Spatial grid

The CAMS reanalysis data have a resolution of approximately 80 km. The data are available either as spectral coefficients with a triangular truncation of T255 or on a reduced Gaussian grid with a resolution of N128. These grids are so called "linear grids", sometimes referred to as TL255.

> ⚠ On the ADS the fields were interpolated from their native representation to a regular 0.75°x0.75° lat/lon grid.
>
> Vorticity and divergence were also used to pre-calculate u and v on the same grid.

Temporal frequency

For sub-daily data for the CAMS reanalysis (stream=oper, for MARS users) the analyses (type=an) are available 3-hourly. The daily forecast, run from 00 UTC, has 3-hourly steps from 0 to 48 hours for the 3D model level and pressure level fields, and hourly steps from 0 to 48 hours for the surface fields.

> ⚠ Note that the surface fields from the CAMS global greenhouse reanalysis (egg4) are only available 3-hourly from 2013 onwards

Monthly means

Several parameters are also available as synoptic monthly means, for each particular time and forecast step (stream=mnth) and as monthly means of daily means, for the month as a whole (stream=moda).

Monthly means for analyses and instantaneous forecasts are created from data with a valid time in the month, between 00 and 23 UTC, which excludes the time 00 UTC on the first day of the following month. Monthly means for accumulations and mean rates are created from data with a forecast period falling within the month. For example, monthly means of daily means for accumulations and mean rates are created from contiguous data with forecast periods spanning from 00 UTC on the first day of the month to 00 UTC on the first day of the following month.

> ⚠ Note that monthly means are available only on model level 60.

Data format

Model level fields are in GRIB2 format. All other fields are in GRIB1, unless otherwise indicated.

Level listings

Pressure levels: 1000/950/925/900/850/800/700/600/500/400/300/250/200/150/100/70/50/30/20/10/7/5/3/2/1

Potential temperature levels: 300/315/320/330/350/370/395/475/600/850

Potential vorticity level: 2000

Model levels: 1/to/60, which are described at L60 model level definitions.

CAMS global reanalysis (EAC4) Parameter listings

PLEASE NOTE: any data labelled as "slow-access" is stored on MARS tapes instead of disk. Retrieval of this data will be MUCH SLOWER than disk-resident data. You should not select any tape-resident data unless absolutely required for your purposes.

Table1: Fast-access main variables (single-level)

name	units	Variable name in ADS	shortName	paramId
10m u-component of wind	m s^{-1}	10m_u_component_of_wind	10u	165.128
10m v-component of wind	m s^{-1}	10m_v_component_of_wind	10v	166.128
2m dewpoint temperature	K	2m_dewpoint_temperature	2d	167.128
2m temperature	K	2m_temperature	2t	168.128
Black carbon aerosol optical depth at 550 nm	~	black_carbon_aerosol_optical_depth_550nm	bcaod550	211.210
Dust aerosol optical depth at 550 nm	~	dust_aerosol_optical_depth_550nm	duaod550	209.210
Land-sea mask	(0 - 1)	land_sea_mask	lsm	172.128
Mean sea level pressure	Pa	mean_sea_level_pressure	msl	151.128
Organic matter aerosol optical depth at 550 nm	~	organic_matter_aerosol_optical_depth_550nm	omaod550	210.210
Particulate matter d < 1 µm	kg m^{-3}	particulate_matter_1um	pm1	72.210
Particulate matter d < 2.5 µm	kg m^{-3}	particulate_matter_2.5um	pm2p5	73.210
Particulate matter d < 10 µm	kg m^{-3}	particulate_matter_10um	pm10	74.210
Sea salt aerosol optical depth at 550 nm	~	sea_salt_aerosol_optical_depth_550nm	ssaod550	208.210
Sulphate aerosol optical depth at 550 nm	~	sulphate_aerosol_optical_depth_550nm"	suaod550	212.210
Surface Geopotential	m^2 s^{-2}	surface_geopotential	~	51.162
Total aerosol optical depth at 469 nm	~	total_aerosol_optical_depth_469nm	aod469	213.210
Total aerosol optical depth at 550 nm	~	total_aerosol_optical_depth_550nm	aod550	207.210
Total aerosol optical depth at 670 nm	~	total_aerosol_optical_depth_670nm	aod670	214.210
Total aerosol optical depth at 865 nm	~	total_aerosol_optical_depth_865nm	aod865	215.210
Total aerosol optical depth at 1240 nm	~	total_aerosol_optical_depth_1240nm	aod1240	216.210
Total column carbon monoxide*	kg m^{-2}	total_column_carbon_monoxide	tcco	127.210
Total column ethane*	kg m^{-2}	total_column_ethane	tc_c2h6	45.218
Total column formaldehyde*	kg m^{-2}	total_column_formaldehyde	tchcho	128.210
Total column hydrogen peroxide*	kg m^{-2}	total_column_hydrogen_peroxide	tc_h2o2	3.218
Total column hydroxyl radical*	kg m^{-2}	total_column_hydroxyl_radical	tc_oh	30.218
Total column isoprene*	kg m^{-2}	total_column_isoprene	tc_c5h8	16.218
Total column nitric acid*	kg m^{-2}	total_column_nitric_acid	tc_hno3	6.218

Total column nitrogen dioxide*	$kg\ m^{-2}$	total_column_nitrogen_dioxide	tcno2	125.210
Total column nitrogen monoxide*	$kg\ m^{-2}$	total_column_nitrogen_monoxide	tc_no	27.218
Total column ozone*	$kg\ m^{-2}$	total_column_ozone	tco3	206.128
Total column peroxyacetyl nitrate*	$kg\ m^{-2}$	total_column_peroxyacetyl_nitrate	tc_pan	13.218
Total column propane*	$kg\ m^{-2}$	total_column_propane	tc_c3h8	47.218
Total column sulphur dioxide*	$kg\ m^{-2}$	total_column_sulphur_dioxide	tcso2	126.210
Total column water vapour*	$kg\ m^{-2}$	total_column_water_vapour	tcwv	137.128

PLEASE NOTE: *Total column (in $kg\ m^{-2}$) is available at the surface (model level 60 for MARS users). Total column refers to the total amount of the selected variable in a column of air extending from the surface of the Earth to the top of the atmosphere (model level 1 for MARS users). Total column can also be referred to as total <selected variable>, or vertically integrated <selected variable>.

Table 2: Fast-access main variables (multi-level)

name	units	Variable name in ADS	shortName	paramId
Carbon monoxide*	$kg\ kg^{-1}$	carbon_monoxide	co	123.210
Dust aerosol (0.03 - 0.55 µm) mixing ratio*	$kg\ kg^{-1}$	dust_aerosol_0.03-0.55um_mixing_ratio	aermr04	4.210
Dust aerosol (0.55 - 0.9 µm) mixing ratio*	$kg\ kg^{-1}$	dust_aerosol_0.55-0.9um_mixing_ratio	aermr05	5.210
Dust aerosol (0.9 - 20 µm) mixing ratio*	$kg\ kg^{-1}$	dust_aerosol_0.9-20um_mixing_ratio	aermr06	6.210
Ethane*	$kg\ kg^{-1}$	ethane	c2h6	45.217
Formaldehyde*	$kg\ kg^{-1}$	formaldehyde	hcho	124.210
Hydrogen peroxide*	$kg\ kg^{-1}$	hydrogen_peroxide	h2o2	3.217
Hydrophilic black carbon aerosol mixing ratio*	$kg\ kg^{-1}$	hydrophilic_black_carbon_aerosol_mixing_ratio	aermr09	9.210
Hydrophilic organic matter aerosol mixing ratio*	$kg\ kg^{-1}$	hydrophilic_organic_matter_aerosol_mixing_ratio	aermr07	7.210
Hydrophobic black carbon aerosol mixing ratio*	$kg\ kg^{-1}$	hydrophobic_black_carbon_aerosol_mixing_ratio	aermr10	10.210
Hydrophobic organic matter aerosol mixing ratio*	$kg\ kg^{-1}$	hydrophobic_organic_matter_aerosol_mixing_ratio	aermr08	8.210
Hydroxyl radical*	$kg\ kg^{-1}$	hydroxyl_radical	oh	30.217
Isoprene*	$kg\ kg^{-1}$	isoprene	c5h8	16.217
Nitric acid*	$kg\ kg^{-1}$	nitric_acid	hno3	6.217
Nitrogen dioxide*	$kg\ kg^{-1}$	nitrogen_dioxide	no2	121.210
Nitrogen monoxide*	$kg\ kg^{-1}$	nitrogen_monoxide	no	27.217
Ozone*	$kg\ kg^{-1}$	ozone	o3	203
Peroxyacetyl nitrate*	$kg\ kg^{-1}$	peroxyacetyl_nitrate	pan	13.217
Propane*	$kg\ kg^{-1}$	propane	c3h8	47.217
Sea salt aerosol (0.03 - 0.5 µm) mixing ratio*	$kg\ kg^{-1}$	sea_salt_aerosol_0.03-0.5um_mixing_ratio	aermr01	1.210
Sea salt aerosol (0.5 - 5 µm) mixing ratio*	$kg\ kg^{-1}$	sea_salt_aerosol_0.5-5um_mixing_ratio	aermr02	2.210
Sea salt aerosol (5 - 20 µm) mixing ratio*	$kg\ kg^{-1}$	sea_salt_aerosol_5-20um_mixing_ratio	aermr03	3.210
Specific humidity*	$kg\ kg^{-1}$	specific_humidity	q	133
Sulphate aerosol mixing ratio*	$kg\ kg^{-1}$	sulphate_aerosol_mixing_ratio	aermr11	11.210
Sulphur dioxide*	$kg\ kg^{-1}$	sulphur_dioxide	so2	122.210
Temperature	K	temperature	t	130
U-component of wind	$m\ s^{-1}$	u_component_of_wind	u	131
V-component of wind	$m\ s^{-1}$	v_component_of_wind	v	132

PLEASE NOTE: *In the CAMS Global Reanalysis, this variable is the mass mixing ratio at different pressure or model levels in kg kg^{-1}

Table 3: Slow-access additional variables (single-level radiation)

name	units	Variable name in ADS	shortName	paramId
Near IR albedo for diffuse radiation	(0 - 1)	near_ir_albedo_for_diffuse_radiation	alnid	18.128
Near IR albedo for direct radiation	(0 - 1)	near_ir_albedo_for_direct_radiation	alnip	17.128
Snow albedo	(0 - 1)	snow_albedo	asn	32.128
UV visible albedo for diffuse radiation	(0 - 1)	uv_visible_albedo_for_diffuse_radiation	aluvd	16.128
UV visible albedo for direct radiation	(0 - 1)	uv_visible_albedo_for_direct_radiation	aluvp	15.128

Table 4: Slow-access additional variables (single-level chemical vertical integrals)

name	units	Variable name in ADS	shortName	paramId
Total column acetone*	kg m^{-2}	total_column_acetone	tc_ch3coch3	52.128
Total column aldehydes*	kg m^{-2}	total_column_aldehydes	tc_ald2	12.128
Total column ethanol*	kg m^{-2}	total_column_ethanol	tc_c2h5oh	46.218
Total column ethene*	kg m^{-2}	total_column_ethene	tc_c2h4	10.128
Total column formic acid*	kg m^{-2}	total_column_formic_acid	tc_hcooh	43.218
Total column methane*	kg m^{-2}	total_column_methane	tc_ch4	4.218
Total column methanol*	kg m^{-2}	total_column_methanol	tc_ch3oh	42.128
Total column methyl peroxide*	kg m^{-2}	total_column_methyl_peroxide	tc_ch3ooh	7.218
Total column olefins*	kg m^{-2}	total_column_olefins	tc_ole	11.218
Total column organic nitrates*	kg m^{-2}	total_column_organic_nitrates	tc_onit	15.218
Total column paraffins*	kg m^{-2}	total_column_paraffins	tc_par	9.218
Vertically integrated mass of dust aerosol (0.03 - 0.55 µm)	kg m^{-2}	vertically_integrated_mass_of_dust_aerosol_0.03-0.55um	aermssdus	43.215
Vertically integrated mass of dust aerosol (0.55 - 9 µm)	kg m^{-2}	vertically_integrated_mass_of_dust_aerosol_0.55-9um	aermssdum	44.215
Vertically integrated mass of dust aerosol (9 - 20 µm)	kg m^{-2}	vertically_integrated_mass_of_dust_aerosol_9-20um	aermssdul	45.215
Vertically integrated mass of hydrophilic black carbon aerosol	kg m^{-2}	vertically_integrated_mass_of_hydrophilic_black_carbon_aerosol	aermssbchphil	78.215
Vertically integrated mass of hydrophilic organic matter aerosol	kg m^{-2}	vertically_integrated_mass_of_hydrophilic_organic_matter_aerosol	aermssomhphil	62.215
Vertically integrated mass of hydrophobic black carbon aerosol	kg m^{-2}	vertically_integrated_mass_of_hydrophobic_black_carbon_aerosol	aermssbchphob	77.215
Vertically integrated mass of hydrophobic organic matter aerosol	kg m^{-2}	vertically_integrated_mass_of_hydrophobic_organic_matter_aerosol	aermssomhphob	61.215
Vertically integrated mass of sea salt aerosol (0.03 - 0.5 µm)	kg m^{-2}	vertically_integrated_mass_of_sea_salt_aerosol_0.03-0.5um	aermssssss	19.215
Vertically integrated mass of sea salt aerosol (0.5 - 5 µm)	kg m^{-2}	vertically_integrated_mass_of_sea_salt_aerosol_0.5-5um	aermssssm	20.215
Vertically integrated mass of sea salt aerosol (5 - 20 µm)	kg m^{-2}	vertically_integrated_mass_of_sea_salt_aerosol_5-20um	aermssssl	21.215
Vertically integrated mass of sulphate aerosol	kg m^{-2}	vertically_integrated_mass_of_sulphate_aerosol	aermsssu	87.215

PLEASE NOTE: *Total column (in kg m^{-2}) is available at the surface (model level 60 for MARS users). Total column refers to the total amount of the selected variable in a column of air extending from the surface of the Earth to the top of the atmosphere (model level 1 for MARS users). Total column can also be referred to as total <selected variable>, or vertically integrated <selected variable>.

Table5: Slow-access additional variables (single-level meteorological)

name	units	Variable name in ADS	shortName	paramId
High cloud cover	(0 - 1)	high_cloud_cover	hcc	188.128
High vegetation cover	(0 - 1)	high_vegetation_cover	cvh	28.128
Lake cover	(0 - 1)	lake_cover	cl	26.128
Leaf area index, high vegetation	$m^2\ m^{-2}$	leaf_area_index_high_vegetation	lai_hv	67.128
Leaf area index, low vegetation	$m^2\ m^{-2}$	leaf_area_index_low_vegetation	lai_lv	66.128
Lifting threshold speed	$m\ s^{-1}$	lifting_threshold_speed	aerlts	53.210
Low cloud cover	(0 - 1)	low_cloud_cover	lcc	186.128
Low vegetation cover	(0 - 1)	low_vegetation_cover	cvl	27.128
Mean altitude of maximum injection	m	mean_altitude_of_maximum_injection	mami	119.210
Medium cloud cover	(0 - 1)	medium_cloud_cover	mcc	187.218
Sea-ice cover	(0 - 1)	sea_ice_cover	sicgrd	31.129
Sea surface temperature	K	Sea surface temperature	sst	34.128
Skin reservoir content	m of water equivalent	skin_reservoir_content	src	198.128
Skin temperature	K	skin_temperature	skt	235.128
Snow depth	m of water equivalent	snow_depth	sd	141.128
Soil clay content	%	soil_clay_content	aerscc	54.210
Soil type	~	soil_type	slt	43.128
Surface pressure	Pa	surface_pressure	sp	134.128
Surface roughness	m	surface_roughness	sr	173.128
Total cloud cover	(0 - 1)	total_cloud_cover	tcc	164.128
Total column water	$kg\ m^{-2}$	total_column_water	tcw	136.128
Type of high vegetation	~	type_of_high_vegetation	tvh	30.128
Type of low vegetation	~	type_of_low_vegetation	tvl	29.128

Table 6: Slow-access additional variables (multi-level chemical)

name	units	Variable name in ADS	shortName	paramId	Note
Acetone*	$kg\ kg^{-1}$	acetone	ch3coch3	52.217	
Acetone product*	$kg\ kg^{-1}$	acetone_product	aco2	53.217	Model-level only
Aldehydes*	$kg\ kg^{-1}$	aldehydes	ald2	12.217	
Amine*	$kg\ kg^{-1}$	amine	nh2	40.217	
Ammonia*	$kg\ kg^{-1}$	ammonia	nh3	19.217	Model-level only
Ammonium*	$kg\ kg^{-1}$	ammonium	nh4	21.217	Model-level only
Dimethyl sulfide*	$kg\ kg^{-1}$	dimethyl_sulfide	dms	18.217	Model-level only
Dinitrogen pentoxide*	$kg\ kg^{-1}$	dinitrogen_pentoxide	n2o5	33.217	Model-level only
Ethanol*	$kg\ kg^{-1}$	ethanol	c2h5oh	46.217	
Ethene*	$kg\ kg^{-1}$	ethene	c2h4	10.217	
Formic acid*	$kg\ kg^{-1}$	formic_acid	hcooh	43.217	
Hydroperoxy radical*	$kg\ kg^{-1}$	hydroperoxy_radical	ho2	28.217	Model-level only
Lead*	$kg\ kg^{-1}$	lead	pb	26.217	Model-level only
Methacrolein MVK*	$kg\ kg^{-1}$	methacrolein_mvk	ispd	50.217	Model-level only
Methacrylic acid*	$kg\ kg^{-1}$	methacrylic_acid	mcooh	44.217	Model-level only
Methane (chemistry)*	$kg\ kg^{-1}$	methane_chemistry	ch4_c	4.217	
Methane sulfonic acid*	$kg\ kg^{-1}$	methane_sulfonic_acid	msa	22.217	Model-level only

Methanol*	kg kg^{-1}	methanol	ch3oh	42.217	
Methyl glyoxal*	kg kg^{-1}	methyl_glyoxal	ch3cocho	23.217	Model-level only
Methyl peroxide*	kg kg^{-1}	methyl_peroxide	ch3ooh	7.217	
Methylperoxy radical*	kg kg^{-1}	methylperoxy_radical	ch3o2	29.217	Model-level only
Nitrate*	kg kg^{-1}	nitrate	no3_a	51.217	Model-level only
Nitrate radical*	kg kg^{-1}	nitrate_radical	no3	32.217	Model-level only
Olefins*	kg kg^{-1}	olefins	ole	11.217	
Organic ethers*	kg kg^{-1}	organic_ethers	ror	36.217	Model-level only
Organic nitrates*	kg kg^{-1}	organic_nitrates	onit	15.217	
Paraffins*	kg kg^{-1}	paraffins	par	9.217	
Pernitric acid*	kg kg^{-1}	pernitric_acid	ho2no2	34.217	Model-level only
Peroxides*	kg kg^{-1}	peroxides	rooh	14.217	Model-level only
Peroxy acetyl radical*	kg kg^{-1}	peroxy_acetyl_radical	c2o3	35.217	Model-level only
Propene*	kg kg^{-1}	propene	c3h6	48.217	Model-level only
Radon*	kg kg^{-1}	radon	ra	181.210	Model-level only
Stratospheric ozone tracer*	kg kg^{-1}	stratospheric_ozone_tracer	o3s	24.217	Model-level only
Terpenes*	kg kg^{-1}	terpenes	c10h16	49.217	Model-level only

PLEASE NOTE: *In the CAMS Global Reanalysis, this variable is the mass mixing ratio at different pressure or model levels in kg kg^{-1}

Table 7: Slow-access additional variables (multi-level meteorological)

name	units	Variable name in ADS	shortName	paramId	Note
Fraction of cloud cover	(0 - 1)	fraction_of_cloud_cover	cc	248	Model-level only
Geopotential	m^{2} s^{-2}	geopotential	z	129	Model-level **1** only
Potential vorticity	K m^{2} kg^{-1} s^{-1}	potential_vorticity	pv	60.128	Pressure-level only
Relative humidity	%	relative_humidity	r	157.128	Pressure-level only
Specific cloud ice water content	kg kg^{-1}	specific_cloud_ice_water_content	ciwc	247	Model-level only
Specific cloud liquid water content	kg kg^{-1}	specific_cloud_liquid_water_content	clwc	246	Model-level only
Specific rain water content	kg kg^{-1}	specific_rain_water_content	crwc	75	Model-level only
Specific snow water content	kg kg^{-1}	specific_snow_water_content	cswc	76	Model-level only
Vertical velocity	Pa s^{-1}	vertical_velocity	w	135	

CAMS global greenhouse gases reanalysis (EGG4) Parameter listings

Table 1: Single-level radiation variables

name	units	Variable name in ADS	Note
Downward UV radiation at the surface	J m^{-2}	downward_uv_radiation_at_the_surface	
Forecast albedo	(0 - 1)	forecast_albedo	
Photosynthetically active radiation at the surface	J m^{-2}	photosynthetically_active_radiation_at_the_surface	
Snow albedo	(0 - 1)	snow_albedo	
Sunshine duration	s	sunshine_duration	
Surface net solar radiation	J m^{-2}	surface_net_solar_radiation	

Surface net solar radiation, clear sky	J m^{-2}	surface_net_solar_radiation_clear_sky	
Surface net thermal radiation	J m^{-2}	surface_net_thermal_radiation	
Surface net thermal radiation, clear sky	J m^{-2}	surface_net_thermal_radiation_clear_sky	
Surface solar radiation downward, clear sky	J m^{-2}	surface_solar_radiation_downward_clear_sky	
Surface solar radiation downwards	J m^{-2}	surface_solar_radiation_downwards	
Surface thermal radiation downward, clear sky	J m^{-2}	surface_thermal_radiation_downward_clear_sky	
Surface thermal radiation downwards	J m^{-2}	surface_thermal_radiation_downwards	
TOA incident solar radiation	J m^{-2}	toa_incident_solar_radiation	
Top net solar radiation	J m^{-2}	top_net_solar_radiation	
Top net solar radiation, clear sky	J m^{-2}	top_net_solar_radiation_clear_sky	
Top net thermal radiation	J m^{-2}	top_net_thermal_radiation	
Top net thermal radiation, clear sky	J m^{-2}	top_net_thermal_radiation_clear_sky	

Table 2: Single-level chemical vertical integrals

name	units	Variable name in ADS	Note
CH4 column-mean molar fraction	ppb	ch4_column_mean_molar_fraction	
CO2 column-mean molar fraction	ppm	co2_column_mean_molar_fraction	

Table 3: Single-level emissions

name	units	Variable name in ADS	Note
Accumulated carbon dioxide ecosystem respiration	kg m^{-2}	accumulated_carbon_dioxide_ecosystem_respiration	
Accumulated carbon dioxide gross primary production	kg m^{-2}	accumulated_carbon_dioxide_gross_primary_production	
Accumulated carbon dioxide net ecosystem exchange	kg m^{-2}	accumulated_carbon_dioxide_net_ecosystem_exchange	
Anthropogenic emissions of carbon dioxide	kg m^{-2} s^{-1}	anthropogenic_emissions_of_carbon_dioxide	
Flux of carbon dioxide ecosystem respiration	kg m^{-2} s^{-1}	flux_of_carbon_dioxide_ecosystem_respiration	
Flux of carbon dioxide gross primary production	kg m^{-2} s^{-1}	flux_of_carbon_dioxide_gross_primary_production	
Flux of carbon dioxide net ecosystem exchange	kg m^{-2} s^{-1}	flux_of_carbon_dioxide_net_ecosystem_exchange	
GPP coefficient from biogenic flux adjustment system	dimensionless	gpp_coefficient_from_biogenic_flux_adjustment_system	
Methane loss rate due to radical hydroxyl (OH)	s^{-1}	methane_loss_rate_due_to_radical_hydroxyl_oh	
Methane surface fluxes	kg m^{-2} s^{-1}	methane_surface_fluxes	
Ocean flux of carbon dioxide	kg m^{-2} s^{-1}	ocean_flux_of_carbon_dioxide	
Rec coefficient from biogenic flux adjustment system	dimensionless	rec_coefficient_from_biogenic_flux_adjustment_system	
Wildfire flux of carbon dioxide	kg m^{-2} s^{-1}	wildfire_flux_of_carbon_dioxide	
Wildfire flux of methane	kg m^{-2} s^{-1}	wildfire_flux_of_methane	

Table 4: Single-level meteorological

name	units	Variable name in ADS	Note
10m u-component of wind	m s^{-1}	10m_u_component_of_wind	
10m v-component of wind	m s^{-1}	10m_v_component_of_wind	
2m dewpoint temperature	K	2m_dewpoint_temperature	
2m temperature	K	2m_temperature	
Boundary layer height	m	boundary_layer_height	

Convective available potential energy	J kg^{-1}	convective_available_potential_energy	
Convective inhibition	J kg^{-1}	convective_inhibition	
Convective precipitation	m	convective_precipitation	
Evaporation	m of water equivalent	evaporation	
High cloud cover	(0 - 1)	high_cloud_cover	
Land-sea mask	(0 - 1)	land_sea_mask	
Large-scale precipitation	m	large_scale_precipitation	
Low cloud cover	(0 - 1)	low_cloud_cover	
Mean sea level pressure	Pa	mean_sea_level_pressure	
Medium cloud cover	(0 - 1)	medium_cloud_cover	
Potential evaporation	m	potential_evaporation	
Precipitation type	dimensionless	precipitation_type	
Sea surface temperature	K	sea_surface_temperature	
Sea-ice cover	(0 - 1)	sea_ice_cover	
Skin reservoir content	m of water equivalent	skin_reservoir_content	
Skin temperature	K	skin_temperature	
Snow depth	m of water equivalent	snow_depth	
Surface Geopotential	m^{2} s^{-2}	surface_geopotential	
Surface latent heat flux	J m^{-2}	surface_latent_heat_flux	
Surface sensible heat flux	J m^{-2}	surface_sensible_heat_flux	
Total cloud cover	(0 - 1)	total_cloud_cover	
Total column cloud ice water	kg m^{-2}	total_column_cloud_ice_water	
Total column cloud liquid water	kg m^{-2}	total_column_cloud_liquid_water	
Total column water	kg m^{-2}	total_column_water	
Total column water vapour	kg m^{-2}	total_column_water_vapour	
Total precipitation	m	total_precipitation	
Visibility	m	visibility	

Table 5: Multi-level chemical

name	units	Variable name in ADS	Note
Carbon dioxide	kg kg^{-1}	carbon_dioxide	
Methane	kg kg^{-1}	methane	

Table 6: Multi-level meteorological

name	units	Variable name in ADS	Note
Fraction of cloud cover	(0 - 1)	fraction_of_cloud_cover	
Geopotential	m^{2} s^{-2}	geopotential	
Logarithm of surface pressure	~	logarithm_of_surface_pressure	
Potential vorticity	K m^2 kg^-1 s^-1	potential_vorticity	
Relative humidity	%	relative_humidity	
Specific cloud ice water content	kg kg^{-1}	specific_cloud_ice_water_content	
Specific cloud liquid water content	kg kg^{-1}	specific_cloud_liquid_water_content	
Specific humidity	kg kg^{-1}	specific_humidity	
Specific rain water content	kg kg^{-1}	specific_rain_water_content	
Specific snow water content	kg kg^{-1}	specific_snow_water_content	

Temperature	K	temperature	
U-component of wind	$m\ s^{-1}$	u_component_of_wind	
V-component of wind	$m\ s^{-1}$	v_component_of_wind	
Vertical velocity	$Pa\ s^{-1}$	vertical_velocity	

CAMS global reanalysis (EAC4) Satellite Data

The atmospheric composition satellite retrievals used as input into the CAMS reanalysis EAC4 are listed below. The following abbreviations are used in Table 1. TC: Total column, TRC: Tropospheric column, PROF: profiles, PC: Partial columns, ColAv: Column average mixing ratio, QR= quality flag given by data providers, SOE: Solar elevation, MODORO: Model orography, PRESS_RL= pressure at bottom of layer, LAT: Latitude.

Parameter	Instrument	Satellite	Product	Period	Data provider/ Version	Blacklist Criteria (i.e. these data are not used)	Averaging kernels used
O3	SCIAMACHY	Envisat	TC	20020803-20120408	ESA, CCI (BIRA)	QR>0 SOE<6	no
O3	MIPAS	Envisat	PROF	20030127- 20040326 20050127-20120331	ESA, NRT ESA, CCI (KIT)	 QR>0 for CCI data	no
O3	MLS	Aura	PROF	20040803-20180312 NRT: 20180313-	NASA, V4	QR>0	no
O3	OMI	Aura	TC	KNMI reproc: 20041001-20150531 NRT:20150601-	KNMI/NASA, V003	QR>0 SOE<10	no
O3	GOME-2	Metop-A	TC	20070123-20121231 201301-201612 NRT:20170101-20181231	ESA, CCI (BIRA), fv0100 ESA, CCI (BIRA), fv0300	QR>0 SOE<10	no
O3	GOME-2	Metop-B	TC	201301-201612 NRT: 20170101-	ESA, CCI (BIRA), fv0300	QR>0 SOE<10	no
O3	SBUV/2	NOAA-14	PC 13L	200407-200609	NASA, v8.6	QR>0 SOE<6 MODORO > 1000. and PRESS_RL > 450.	no
O3	SBUV/2	NOAA-16	PC 13L PC 13L PC 21L	200301-200706 20111201-20130708 NRT: 20130709-201406	NASA, v8.6	QR>0 SOE<6 MODORO > 1000. and PRESS_RL > 450.	no
O3	SBUV/2	NOAA-17	PC 13L	200301-201108	NASA, v8.6	QR>0 SOE<6 MODORO > 1000. and PRESS_RL > 450.	no
O3	SBUV/2	NOAA-18	PC 13L	200507-201211	NASA, v8.6	QR>0 SOE<6 MODORO > 1000. and PRESS_RL > 450.	no
O3	SBUV/2	NOAA-19	PC 13L PC 21L	200903-20130708 NRT: 20130709-	NASA, v8.6	QR>0 SOE<6 MODORO > 1000. and PRESS_RL > 450.	no
CO	MOPITT	Terra	TC	20020101-20161231 NRT: 2017010-	NCAR, V6 (TIR)	LAT>65. LAT< -65 QR>0 Night time data over Greenland	yes

NO2	SCIAMACHY	Envisat	TRC	20030101-20101231 20110101-20120409	KNMI V1p KNMI V2	QR>0 SOE<6 LAT>60 LAT< -60	yes
NO2	OMI	Aura	TRC	20041001-20101231 20110101-20121231 NRT: 20130101 -	KNMI, COl3 KNMI, Domino KNMI NRT	QR>0 SOE<6 LAT>60 LAT< -60	yes
NO2	GOME-2	Metop-A	TRC	20070418-20171106 NRT:20171112-	AC SAF, GDP4.8	QR>0	yes
NO2	GOME-2	Metop-B	TRC	201301-20171106- NRT: 20171112-	AC SAF, GDP4.8	QR>0	yes
AOD	AATSR	Envisat	TC	20021201-20120331	ESA, CCI (Swansea)	abs(LAT)> 70	no
AOD	MODIS	Terra	TC	20021001-20161231 NRT: 20170101-	NASA, COl6	abs(LAT)> 70	no
AOD	MODIS	Aqua	TC	20021001-20161231 NRT: 20170101-	NASA, Col6	abs(LAT)> 70	no

CAMS global greenhouse gases reanalysis (EGG4) Satellite Data

The atmospheric composition satellite retrievals used as input into the CAMS reanalysis EGG4 are listed below. The following abbreviations are used in Table 1. TC: Total column, TRC: Tropospheric column, PROF: profiles, PC: Partial columns, ColAv: Column average mixing ratio, QR= quality flag given by data providers, SOE: Solar elevation, MODORO: Model orography, PRESS_RL= pressure at bottom of layer, LAT: Latitude.

Parameter	Instrument	Satellite	Product	Period	Data provider/ Version	Blacklist Criteria (i.e. these data are not used)	Averaging kernels used
CO2	SCIAMACHY	Envisat	ColAv	20030101-20120324	ESA CCI (Bremen)	QR>0	yes
CO2	IASI	Metop-A	ColAv	20070701-20150531	LMD v8.0	MODORO > 6000	yes
CO2	IASI	Metop-B	ColAv	20130201-	LMD v4.0	MODORO > 6000	yes
CO2	Tanso	GOSAT	ColAv	20090601-	ESA CCI (SRON)	QR>0	yes
CH4	SCIAMACHY	Envisat	ColAv	20030108-20120408	ESA CCI (SRON) v7.0	MODORO > 6000 QR > 0	yes
CH4	IASI	MetoP-A	ColAv	20070701-20150630	LMD V8.3	MODORO > 6000 LAT<-60. and LSMASK = land	yes
CH4	IASI	Metop-B	ColAv	20130201-	LMD V8.1	MODORO > 6000 LAT<-60. and LSMASK = land	yes
CH4	Tanso	GOSAT	ColAv	20090601-	ESA CCI (SRON)	QR > 0	yes

Validation reports

Validation Reports for the CAMS Global reanalysis and CAMS global greenhouse gas reanalysis can be found on the CAMS Quality Assurance website.

Guidelines

The following advice is intended to help users understand particular features of the CAMS reanalysis data:

- Users who want to use meteorological data only are advised to use the ERA5 meteorological reanalysis.
- MARS users please use the 'GEMS Ozone' (param 210203) and 'Total Column GEMS Ozone' (param 210206) fields. These are produced specifically for CAMS using the full tropospheric chemistry scheme, see also CAMS Global data: What is "GEMS ozone".
- O3 and O3S are quite different in the re-analysis. The reason for that is that O3S was not subject to data assimilation. Hence it represents stratospheric ozone as simulated with the Cariolle scheme. The difference between O3 and O3S in the troposphere is that O3S is only subject to chemical loss and deposition, i.e. tropospheric chemical ozone production does not occur. The only source of O3S in the troposphere is the influx from the stratosphere.

The following advice is intended to help users understand particular features of the CAMS global greenhouse gas reanalysis (EGG4):

- In the IFS all the tracers are in principle represented as specific ratios, i.e. with respect to the total air mass. However, in the continuity equation the tracers are treated as if they were mixing ratios (with respect to dry air), which means that changes in the humidity do not have an impact on the evolution of the tracer mixing ratio. Because of this, we recommend treating the tracer mixing ratios with respect to dry air but when integrating with pressure in the computation of the total column mass of the tracer, the total pressure should be used (instead of the dry pressure). This is a compromise to keep consistency with the NWP approach which assumes specific ratios and the tracer continuity equation which assumes mixing ratios. For more details on this conundrum, see ECWMF Tech memo https://www.ecmwf.int/sites/default/files/elibrary/2019/19114-dry-mass-versus-total-mass-conservation-ifs.pdf.

Known issues CAMS global reanalysis (EAC4)

- Anthropogenic emissions used were not adjusted for any COVID-19 lockdowns in 2020.
- Validation of AOD with Aeronet data has show there are some hot spots around outgassing volcanoes (in particular Mauna Loa and Mexico City) with high analysis AOD values that degrade the global average RMSE. If calculating global mean statistics it is advisable to exclude those two stations as unrepresentative. This is a side effect of model-resolution orography not resolving the height of the volcanoes that has been unmasked by recent enhancements to the SO2 oxidation scheme which improve aerosol on the global scale.
- During 2003 the ozone analysis has a degraded quality (bigger biases with respect to observations) in Arctic and Antarctic free troposphere because MIPAS and SCIAMACHY data of lower quality were assimilated.
- Between March-August 2004 no ozone profile data were available for assimilation. This affects the vertical structure of the ozone analysis and we see larger biases wrt ozone sondes, especially in the Antarctic.
- From 2013 onwards there is a larger seasonally varying bias in ozone in the free troposphere, particularly in the Arctic and Antarctic that is not seen in the control run. The reason for this bias is a change in the observing system, namely the change from 13-layer SBUV/2 data to 21-layer SBUV/2 data in July 2013 (see Table 2) that unfortunately has an impact on tropospheric ozone. A similar bias is seen in the NRT CAMS ozone analysis which also uses the 21-layer SBUV/2 data after 2013.
- During 2003 the seasonal cycle of the tropospheric column NO2 is not well represented because of the assimilation of SCIAMACHY NO2 data of degraded quality.
- The use of the NOx variable from the CAMS reanalysis (as well as from the CAMS interim re-analysis and the CAMS operational system) is not recommended. The user is advised to download NO and NO2 separately and to add them up. Please note that a conversion of the mass mixing ratios [kg/kg] to volume mixing rations / molar fractions [mol/mol] is needed to do this in a meaningful way.

Because of its relatively short lifetime, NO2 in the CAMS reanalysis is largely affected by the prescribed emissions (e.g. anthropogenic MACCity, GFAS biomass burning) and only to a smaller part by the assimilated observations (see also Inness et al., 2013). Consequently, trends or anomalies calculated from the NO2 reanalysis fields will mainly reflect the trends in the underlying emissions. For example over China, the MACCity emissions have been kept constant since 2012 while more recent emission inventories show a decrease after 2012. This has to be kept in mind when trying to interpret NO2 trends or anomalies calculated from the CAMS reanalysis.

This list will be updated as we become aware of further issues in the CAMS reanalysis.

Known issues CAMS global greenhouse gas reanalysis (EGG4)

- Anthropogenic emissions used were not adjusted for any COVID-19 lockdowns in 2020.
- T surface fields from the CAMS global greenhouse reanalysis are only available 3-hourly from 2013 onwards while they are available hourly from 2003-2012.
- Stratospheric biases in CH4 (under investigation).

This list will be updated as we become aware of further issues in the CAMS reanalysis.

How to cite the CAMS Global Reanalysis

Please acknowledge the use of the CAMS global reanalysis as indicated below:

(1) Acknowledge according to the dataset licence (in this case, please check the licence to use Copernicus products (Clause 5 in particular)) - this should appear in the acknowledgement section of your publication.

(2) Provide the download reference by indicating where data is downloaded from (in the acknowledgement section of your publication) e.g:

Downloaded from the Copernicus Atmosphere Monitoring Service (CAMS) Atmosphere Data Store (ADS) (*<URL to dataset overview page>*)

(3) Cite the relevant dataset (as part of the bibliography in your publication) e.g:

Inness, A, Ades, M, Agustí-Panareda, A, Barré, J, Benedictow, A, Blechschmidt, A, Dominguez, J, Engelen, R, Eskes, H, Flemming, J, Huijnen, V, Jones, L, Kipling, Z, Massart, S, Parrington, M, Peuch, V-H, Razinger M, Remy, S, Schulz, M and Suttie, M (2019): CAMS global reanalysis (EAC4). Copernicus Atmosphere Monitoring Service (CAMS) Atmosphere Data Store (ADS). (Accessed on <DD-MMM-YYYY>), https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-reanalysis-eac4?tab=overview

Inness, A, Ades, M, Agustí-Panareda, A, Barré, J, Benedictow, A, Blechschmidt, A, Dominguez, J, Engelen, R, Eskes, H, Flemming, J, Huijnen, V, Jones, L, Kipling, Z, Massart, S, Parrington, M, Peuch, V-H, Razinger M, Remy, S, Schulz, M and Suttie, M (2019): CAMS global reanalysis (EAC4) monthly averaged fields. Copernicus Atmosphere Monitoring Service (CAMS) Atmosphere Data Store (ADS). (Accessed on <DD-MMM-YYYY>),https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-reanalysis-eac4-monthly?tab=overview

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Further CAMS reanalysis references will be available from the ECMWF website in the future.

An ECMWF newsletter article '***The new CAMS global reanalysis of atmospheric composition***' is available from: https://www.ecmwf.int/node/18821

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- FTP access to CAMS GFAS data
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