GEM-AQ Fact sheet

1.1 Assimilation and forecast system: synthesis of the main characteristics

Discretisation	Horizontal resolution	0.1° x 0.1° lat-lon spherical grid
	Number of vertical levels	28
	Top altitude	10hPa
	Depth of lower most layer	tbc
	Number of lower layers	14 below 5km
Initial & boundary conditions & meteorology	Meteorological driver	D-1 12:00 UTC IFS, Xhrly
	Boundary values	CAMS-Global IFS
	Initial values	Previous forecast
Emissions: natural & biogenic	In-domain soil and road dust emissions	Marticorena and Bergametti, 1995
	In-domain sea-salt emissions	Gong-Monahan (Gong, 2003b)
	Birch, Grass, Olive, Ragweed, Alder, Mugwort Pollen provided by FMI	yes
	Biogenic emissions	MEGAN-MACC climatology
	Soil NOx	none
	Wildfiles emissions	last available 24h cycle over D-2 and D-1 cycled for AN (D-1) and FC (D+0 and D+1, zero for the remaining days)
Chemistry/ Physics	Gas phase chemistry	Modified ADOM IIB mechanism, 51 species and 120 reactions
	Heterogeneous chemistry	Hydrolysis of N2O5
	Aerosol size distribution	12 bins from 10nm to 20.5µm
	Inorganic aerosols	Gong et al., (2003)
	Secondary organic aerosols	not included
	Aqueous phase chemistry	SO2 oxidation
	Dry deposition: gases	resistance approach
	Dry deposition: aerosols	gravitational settling
	Wet deposition	
Assimilation	Assimilation method	Optimal Interpolation
	Assimilated surface pollutants	NO2, O3, PM2.5, PM10
	assimilated satellite	
	Frequency of assimilation	Hourly

1.2 Model Overview

The GEM-AQ is an on-line chemical weather forecasting model (Kaminski et al., 2008).

1.3 Model geometry

The GEM-AQ model can be configured to simulate atmospheric processes over a broad range of scales, from the global scale down to the meso-gamma scale. An arbitrarily rotated latitude-longitude mesh focuses resolution on any part of the globe. In CAMS, the model is run in the limited area mode with a resolution of 0.1° x 0.1° on a spherical coordinate system. The coordinates are the following: lower-left (17.4N / 22.1W), upper-right (58.6N/ 86.6E), and are generated internally based on lower-left corner, grid extend and the numerical equator location. In the vertical, GEM-AQ uses the generalised sigma vertical coordinate system. It has terrain-following sigma surfaces near the ground that transform to pressure surfaces higher in the atmosphere. The model top is set at 10 hPa.

1.4 Forcing Meteorology

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 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.

1.5 Chemical initial and boundary conditions

Chemical species of the CAMS Global IFS forecast for the previous day are used at with a temporal resolution of 3 hours (Table 2). For dust aerosols, the three available size bins from the IFS model are distributed uniformly over the 10 corresponding bins in GEM-AQ. For organic matter aerosol, black carbon and sulphates, the same log-normal based profile was applied. For organic aerosol and black carbon, hydrophobic and hydrophilic components were summed as "total organic aerosol" and "total black carbon aerosol" before applying size-bin distribution profiles.

1.6 Emissions

The common annual anthropogenic emissions CAMS-REG are implemented as explained in Section 3.2. In those emissions, the following fields are available: SO2, NOx, CO, NMVOC, NH3, PM10 and PM2.5. Based on this information, emission fluxes for 15 gaseous species (9 hydrocarbons and 6 inorganics) and 4 aerosol components (primary organic aerosol, black carbon, sulphates, nitrates) are derived. Total emission flux for each aerosol component are distributed into 12 bins in the GEM-AQ aerosol module.

Anthropogenic emissions are distributed within the 7 lowest model layers (up to 1350 m) with different injection height profiles for each of the GNFR sectors. Temporal profiles modulating annual and diurnal variation of emission fluxes for each GNFR are used.
For biogenic emissions, monthly averaged MEGAN-MACC dataset valid for 2010 was used in order to avoid short-term variability of reactive biogenic VOC generated on-line in the model.

1.7 Solver, advection and mixing

The set of non-hydrostatic Eulerian equations (with a switch to revert to the hydrostatic primitive equations) maintains the model's dynamical validity right down to the meso-gamma scales. The time discretization of the model dynamics is fully implicit, 2 time-level (Côté et al., 1998ab). The spatial discretization for the adjustment step employs a staggered Arakawa C grid that is spatially offset by half a mesh length in the meridional direction. It is second-order accurate, whereas the interpolations for the semi-Lagrangian advection are of fourth-order accuracy.
Deep convective processes are handled by Kain-Fritch convection parameterisation (Kain and Fritch, 1990). The vertical diffusion of momentum, heat and tracers is a fully implicit scheme based on turbulent kinetic energy (TKE) theory.

1.8 Deposition

The effects of dry deposition are included as a flux boundary condition in the vertical diffusion equation. Dry deposition velocities are calculated from a `big leaf' multiple resistance model (Wesely, 1989; Zhang et al., 2002) with aerodynamic, quasi-laminar layer, and surface resistances acting in series. The process assumes 15 land-use types and takes snow cover into account.

1.9 Chemistry and aerosols

The gas-phase chemistry mechanism currently used in the GEM-AQ model is based on a modification of version 2 of the Acid Deposition and Oxidants Model (ADOM) Venkatram et al. (1988), derived from the condensed mechanism of Lurmann (1986). The ADOM-II mechanism comprises 47 species, 98 chemical reactions and 16 photolysis reactions. In order to account for background tropospheric chemistry, 4 species (CH3OOH, CH3OH, CH3O2, and CH3CO3H) and 22 reactions were added. All species are solved using a mass-conserving implicit time stepping discretization, with the solution obtained using Newton's method. Heterogeneous hydrolysis of N2O5 is calculated using the on-line distribution of aerosol. Although the model meteorology is calculated up to 10 hPa, the focus of the chemistry is in the troposphere where all species are transported throughout the domain. To avoid the overhead of stratospheric chemistry in this version (a combined stratospheric/tropospheric chemical scheme is currently being developed), we replaced both the ozone and NOy fields with climatology above 100 hPa after each transport time step. Ozone fields are taken from the HALOE (Halogen Occultation Experiment) climatology (e.g. Hervig et al., 1993), while NOy fields are taken from the CMAM (Canadian Middle Atmosphere Model). Photolysis rates (J values) are calculated on-line every chemical time step using the method of Landgraf and Crutzen (1998). In this method, radiative transfer calculations are done using a delta-two stream approximation for 8 spectral intervals in the UV and visible applying pre-calculated effective absorption cross sections. This method also allows for scattering by cloud droplets

and for clouds to be presented over a fraction of a grid cell. The host meteorological model provides both cloud cover and water content. The J value package used was developed for MESSy (Joeckel et al., 2006) and is implemented in GEM-AQ.
The current version of GEM-AQ has 5 size-resolved aerosol types, viz. sea salt, sulphate, black carbon, organic carbon and dust as well as nitrates. The microphysical processes that describe the formation and transformation of aerosols are calculated by a sectional aerosol module (Gong et al., 2003). The particle mass is distributed into 12 logarithmically spaced bins from 0.005 to 10.24-micron radius. This size distribution leads to an additional 60 advected tracers. The following aerosol processes are accounted for in the aerosol module: nucleation, condensation, coagulation, sedimentation and dry deposition, in-cloud oxidation of SO2, in-cloud scavenging, and below-cloud scavenging by rain and snow.

1.10 Assimilation system

Data assimilation in the GEM-AQ modelling system is done with Optimal Interpolation method (Robichaud and Ménard, 2014) and is applied to the forecast. Error statistics are computed with the Hollingsworth - Lönnberg (HL) method (Hollingsworth and Lonnberg, 1986). It estimates the correlation length and the ratio of observation to model error variances by a least-square fit of a correlation model against the sample of the spatial autocorrelation of observation-minus-model residuals.
Currently, data assimilation is done at each forecast hour for O3, NO2, PM10 and PM2.5, using surface observations.