MACC Work Package G-AER 1 Implementation and evaluation of GLOMAP-mode in the IFS. Deliverables D_G-AER_1.6, D_G-AER_1.8, D_G-AER_4.1

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Abstract

The microphysical aerosol scheme GLOMAP-mode has been incorporated into the ECMWF Integrated Forecast System (IFS), and is known as IFS-GLOMAP. By including a detailed representation of aerosol microphysics, the new IFS-GLOMAP system represents a significant improvement in predictive capability over the GEMS aerosol system. In particular, IFS-GLOMAP transports both aerosol mass and number concentrations in several size modes, giving much enhanced information on aerosol properties. The new IFS-GLOMAP system is shown to perform well against a range of observational datasets of both number and mass concentration. Specifically, sulphate mass is very well reproduced in polluted regions, but is underestimated in remote marine regions due to lack of emission of the marine biogenic gas dimethyl-sulphide. Sea-salt mass is presently strongly overestimated as a result of the emission scheme used. Elemental carbon mass concentration is biased slightly low against observations. The current implementation of IFS-GLOMAP is driven by existing GEMS aerosol sources, which do not include emissions of precursor species, thus organic carbon mass concentrations are substantially underestimated. IFS-GLOMAP does a reasonable job reproducing CN and CCN number concentrations in comparison to observational datasets. A range of improvements are scheduled during the MACC-II project to bring the IFS-GLOMAP system up to an operational standard.

1 Introduction

As part of work package G-AER 1 of the Monitoring Atmospheric Composition and Climate (MACC) project (Task G-AER-1.1), the aerosol module of the United Kingdom Chemistry and Aerosol (UKCA) model, known as GLOMAP-mode, has been incorporated in the European Centre for Medium-range Weather Forecasts (ECMWF) Integrated Forecast System (IFS) model. The implementation of GLOMAP-mode into the IFS is an upgrade over the simpler aerosol scheme incorporated in the IFS as part of the 'Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data' (GEMS) project. The two aerosol schemes will be referred to here as IFS-GEMS and IFS-GLOMAP. GLOMAP-mode is a size-resolved aerosol microphysics scheme, allowing new particle formation and growth by condensation, coagulation and cloud-processing to influence IFS aerosol forecasts for the first time. IFS-GLOMAP will give enhanced information about aerosol properties (over IFS-GEMS), both globally and as boundary conditions for sophisticated regional and local-scale aerosol models. The size-resolved aerosol properties will also improve air quality forecasts, and make assessments of aerosol direct and indirect radiative effects more realistic.

This document reports on the implementation of GLOMAP-mode in the IFS, and contrasts the output against the existing mass only aerosol scheme (IFS-GEMS). Comparisons against observed mass and number concentrations are also shown.

1.1 GLOMAP-mode

The GLOMAP-mode aerosol module was originally developed in an offline chemical transport model (CTM) framework, and is described fully in Mann et al. (2010). GLOMAP-mode has already been implemented in the UK Met Office Unified Model (UM) as part of the UK Chemistry and Aerosol (UKCA) composition-climate model (www.ukca.ac.uk, Johnson et al., 2010). UKCA is an extended version of the third generation Hadley Centre Global Environmental Model (HadGEM3, Hewitt et al., 2011) and GLOMAP-mode has also become known as UKCA-mode. GLOMAP-mode uses a two-moment (mass and number) microphysical representation of the aerosol size distribution, and assumes log-normal modes. Each mode is an internal mixture of aerosol components (water, sulphate, sea-salt, dust, elemental and organic carbon - EC and OC respectively) with some modes containing just one or two of these components. Advected quantities are number density for each mode, and mass density for each component in each mode, with the water component not transported (assumed to be in equilibrium with the gas phase). GLOMAP-mode benefits directly from being implemented in the CTM alongside a more sophisticated sectional aerosol scheme, GLOMAP-bin (Spracklen et al., 2005), and has recently been improved to compare better to the bin scheme (Mann et al., submitted). Further technical details regarding GLOMAP-mode should be sought from Mann et al. (2010) and Mann *et al.* (submitted).

In the offline CTM framework, GLOMAP-mode does not affect the meteorology in the model, which is determined directly from ECMWF re-analyses. In the UM however, a module known as RADAER (Bellouin, 2010) allows the direct radiative effects from the GLOMAP-mode simulated aerosol to feedback on the simulated meteorology via the online radiative transfer scheme. Optical properties (e.g. aerosol optical depth, absorption) from the GLOMAP-mode simulated size-resolved aerosol are calculated online in HadGEM3-UKCA within RADAER. The indirect radiative effects from GLOMAP-mode also feedback on the dynamics in HadGEM3-UKCA by

perturbed cloud albedo and autoconversion.

1.2 IFS-GEMS

The pre-existing aerosol scheme incorporated in the IFS is described in Morcrette *et al.* (2009). In contrast to GLOMAP-mode, the IFS-GEMS aerosol scheme is single-moment, meaning number concentration is not transported. Although the same aerosol types and emissions are used in IFS-GEMS as in IFS-GLOMAP, mass-only schemes have to use an external mixing assumption. The simpler representation of aerosol is computationally cheaper, but aerosol optical properties and cloud condensation nuclei (CCN) derived from the transported masses are based on a prescribed size distribution which may cause biases in simulated direct and indirect radiative effects.

2 Implementation

GLOMAP-mode as at version 'v1 gm5' has been incorporated in the IFS, initially at cycle CY36R2. Initial development has been undertaken in a branch containing (but not calling) the IFS-GEMS aerosol routines. Expected developments and refinements to this implementation are outlined in Section 4. This initial implementation uses the IFS-GEMS aerosol sources and sinks, to facilitate comparison between IFS-GLOMAP and IFS-GEMS.

2.1 Emissions, dry deposition and sedimentation

As with IFS-GEMS aerosol, the IFS-GLOMAP code is called from the main physics routine 'callpar'. Emissions are handled by the interface routine 'ukca_mode_ems_ifs' (equivalent to aer_phy2 in IFS-GEMS), which subsequently calls 'ukca_mode_ems'. The 'ukca_mode_ems' routine is taken unmodified from the CTM version of GLOMAP-mode. All emissions are those implemented in the IFS-GEMS aerosol scheme, including the interactively calculated emissions (dust and sea-salt). The IFS-GEMS sea-salt emission scheme calculates sea-salt fluxes in three size bins. For the present implementation in IFS-GLOMAP the largest bin (5.0 to $20 \,\mu$ m) is neglected as it is considered too large for the standard modes in IFS-GLOMAP. Mass and number emissions are calculated in 'ukca_mode_ems', and passed back up to 'callpar' in units of kg m⁻² s⁻¹ in the ZCFLX array. The IFS-GLOMAP simulations presented here do not contain emissions of dust however.

The 'ukca_mode_ems_ifs' routine also handles dry deposition and sedimentation fluxes, based on the routines and velocities used in IFS-GEMS. The internal mixing assumption in IFS-GLOMAP requires that an (assumed) dominant aerosol type be selected to represent each mode when using the IFS-GEMS removal routines. These are outlined in Table 1. The dominant aerosol type determines which dry deposition or sedimentation velocity is used for both the mass and number removal in IFS-GLOMAP.

Mode	Dominant aerosol component
Nucleation soluble	Sulphate
Aitken soluble	Sulphate
Accumulation soluble	Sea-salt
Coarse soluble	Sea-salt
Aitken insoluble	Elemental carbon
Accumulation insoluble	Dust
Coarse insoluble	Dust

Table 1: Assumed dominant aerosol component in each mode.

2.2 SO_2 oxidation, aerosol wet removal and negative concentration correction

After the updating of surface fluxes in 'ukca_mode_ems_ifs' and the calculation of the vertical diffusion and mixing in 'callpar', a temporary routine based on the IFS-GEMS 'aer_phy3' routine is called: 'ukca_mode_scavso4_gems'. This routine is a development stage of the implementation, and currently handles the oxidation of SO_2 , aerosol removal by precipitation, and the correction of any negative aerosol concentrations that have arisen during advection.

As part of this initial implementation, the SO_2 oxidation scheme is retained from the IFS-GEMS aerosol scheme, deriving a conversion rate based on latitude using the 'aer_so2so4' routine. However, instead of oxidising directly to SO_4 , the approach taken here is to split the oxidation products of SO_2 according to the assumed method of production, gas- or aqueous-phase (which is assumed to vary with the gridbox fractional cloudiness). This is necessary as IFS-GLOMAP treats the two products differently, with implications for the calculated size distribution. Gas-phase production of H_2SO_4 is determined by:

$$\Delta H_2 SO_4 = \Delta SO_4 \times (1.0 - Fractional cloudiness)$$
(1)

Aqueous-phase production of SO_4 is determined by:

$$\Delta SO_4 \text{ aqueous} = \Delta SO_4 \times (\text{Fractional cloudiness}) \tag{2}$$

where Δ SO₄ is the output from 'aer_so2so4'. Note that units are also accounted for, but for simplicity are not reproduced here.

Wet removal is also handled in 'ukca_mode_scavso4gems', using the IFS-GEMS routines and the dominant aerosol assumptions as in Table 1. Aerosol is assumed not to be nucleation scavenged from the nucleation and Aitken soluble modes.

Negative tracer concentrations arising during the advection calculations are corrected in the routine 'aer_negat', as in IFS-GEMS.

2.3 Aerosol microphysics

The IFS-GLOMAP aerosol microphysics are controlled by the 'ukca_aero_step' routine, which is called from the 'ukca_aero_step_ifs' interface, itself called from 'callpar'. The 'ukca_aero_step' routine is analogous to 'aer_phy3' in IFS-GEMS. IFS-GLOMAP, GLOMAP-mode (in the CTM) and UKCA-mode (in the UM) share a standard version of 'ukca_aero_step' and subsequently called routines, thus maintaining commonality. The 'ukca_aero_step_ifs' interface handles the conversion of variable names and units to those expected in 'ukca_aero_step', and subsequently calculates tracer tendencies (in units of kg kg⁻¹ s⁻¹) for use in the ZTENC array in 'callpar'. Various switches for controlling options within IFS-GLOMAP are also contained within 'ukca_aero_step_ifs'.

This approach allows the core GLOMAP-mode routines to be essentially preserved, so that any changes in the original GLOMAP-mode model can be easily and quickly incorporated in other frameworks.

3 Evaluation – IFS-GLOMAP first results

This section presents the first results from GLOMAP-mode incorporated in the IFS. Modelled aerosol mass concentrations from IFS-GLOMAP are compared against those from IFS-GEMS and also from observations. Unlike IFS-GEMS, IFS-GLOMAP specifically simulates size-resolved number concentrations and these are also presented and compared against observations.

This preliminary evaluation of the initial IFS-GLOMAP implementation against GEMS is primarily based on a 12-month annual mean for the year 2003. The simulation was spun-up from a zero-aerosol atmosphere for one month. The IFS-GLOMAP job identifier is b0vk (cycle CY36R2). The IFS-GEMS aerosol job identifier is b0s3 (cycle CY36R1). In both IFS-GLOMAP and IFS-GEMS, means are calculated from 12-hourly instantaneous output. There is currently no facility available in the IFS to calculate three-dimensional means online.

3.1 IFS-GLOMAP mass concentrations

Figure 1 shows a comparison of modelled surface SO_2 concentrations against EMEP (as in Stier *et al.*, 2005) and CASTNET (as in Malm *et al.*, 2002). The Pearson correlation coefficient (r) and mean normalized bias (b) of the comparisons is shown in Table 2. In both Europe and North America, SO_2 concentrations are overestimated by IFS-GLOMAP. GLOMAP-mode has also been shown to overestimate SO_2 concentrations in Europe (bias 1.94), but reproduces North American SO_2 observations very well (Mann *et al.*, 2010).

Plots of annual mean surface mass concentrations of sulphate, sea-salt, black carbon and organic carbon from IFS-GLOMAP are shown in Figure 2. Observations from different networks of monitoring stations are over-plotted on the model maps. Observed mass concentrations are those from Mann *et al.* (2010): global (from University of Miami) and European observations (from EMEP) as in Stier *et al.* (2005); North American observations (IMPROVE) as in Malm *et al.* (2002). The mean normalized bias (b) and Pearson correlation coefficient (r) statistics of the IFS-GLOMAP and observations comparison from Figure 2 are shown in Table 2. Annual



Figure 1: Surface annual mean concentrations from IFS-GLOMAP of SO_2 compared against EMEP (left) and CASTNET (right) observations.

	Dataset	b	r
SO_2	EMEP	4.17	0.37
SO_2	CASTNET	1.72	0.81
Sulphate	EMEP	0.05	0.66
Sulphate	IMPROVE	0.09	0.98
Sulphate	University of Miami	-0.34	0.97
Sea-salt	University of Miami	2.70	0.31
Elemental carbon	IMPROVE	-0.24	0.70
Organic carbon	IMPROVE	-0.80	0.38

Table 2: Summary statistics (mean normalized bias b and Pearson correlation coefficient r) from the comparisons between IFS-GLOMAP and observed mass concentrations. See also Figure 2.

mean mass burdens for IFS-GLOMAP are shown in Table 3. Also shown are the median burdens as calculated from the AeroCom intercomparison (Textor *et al.*, 2006).

	IFS-GLOMAP	IFS-GEMS	AeroCom	GLOMAP-mode
$\overline{\text{SO}_2 (\text{TgS})}$	0.27	0.19	-	0.30
Sulphate (TgS)	0.68	0.20	0.66	0.52
Sea-salt (Tg)	28.07	22.83*	6.39	4.93
Elemental carbon (TgC)	0.11	0.07	0.21	0.14
Organic carbon (TgC)	0.54	0.44	1.21	0.82

Table 3: Mass burdens from IFS-GLOMAP, IFS-GEMS, and the AeroCom median (Textor *et al.*, 2006). Also shown are burdens from GLOMAP-mode, as run in a chemical transport model (Mann *et al.*, 2010). The sulphate burden is expressed in units of Tg of sulphur. Elemental and organic carbon burdens are expressed in units of Tg of carbon. * IFS-GEMS sea-salt burden does not include the largest size bin, for consistency with IFS-GLOMAP.

The comparisons shown in Figure 2 and Table 2 give a good indication of the overall model performance in predicting mass. Sea-salt surface mass concentrations are currently overestimated by a factor of 2.70 on average. It is already known that the sea-salt emission scheme from IFS-GEMS and implemented in IFS-GLOMAP here, overestimates the sea-salt emission flux. The next iteration of IFS-GLOMAP will use the size-resolved sea-salt emission routines (after Gong & Barrie, 2003) developed and tested in GLOMAP-mode, and should lead to a lower sea-salt burden (see Section 4).

IFS-GLOMAP reproduces observed surface sulphate mass concentrations for Europe (EMEP observations) and North America (IMPROVE observations) very well (Table 2). There is a



Figure 2: Surface annual mean mass concentrations from IFS-GLOMAP of sulphate, sea-salt, black carbon and organic carbon. Also shown are observed surface concentrations from different networks.

clear low bias when comparing IFS-GLOMAP sulphate concentrations against the remote observations in the University of Miami dataset however. This low bias is likely due to there being no source of the marine biogenic gas dimethyl-sulphide (DMS), which contributes significantly to sulphate mass in the marine boundary layer. The IFS-GLOMAP sulphate burden (Table 3) is a factor of three higher than that predicted by IFS-GEMS, but compares very well with both the AeroCom median and GLOMAP-mode burdens. The vertical distribution of SO₂ and sulphate from both IFS-GLOMAP and IFS-GEMS is shown in Figure 3. The difference in SO₂ between IFS-GLOMAP and IFS-GEMS arises due to SO₂ in IFS-GLOMAP not being wet removed. Given the relative simplicity of the SO₂ oxidation scheme currently implemented, the quality of these results is very encouraging.



Figure 3: Annual zonal mean plots of SO_2 and sulphate from IFS-GEMS (top) and IFS-GLOMAP (bottom).

Both carbon species (EC and OC) are biased low compared to both observations (Figure 2 and Table 2) and the AeroCom median (Table 3). The low-bias is worst for OC but both IFS-GEMS and IFS-GLOMAP are expected to be low, as neither include a representation of secondary organic aerosol.

The implementation strategy (emissions and deposition as in IFS-GEMS) adopted for IFS-GLOMAP enables comparison of IFS-GLOMAP with IFS-GEMS. Comparisons of annual mean surface mass concentrations between IFS-GLOMAP and IFS-GEMS for each component are shown in Figure 4. Burdens from IFS-GLOMAP, IFS-GEMS, AeroCom and GLOMAP-mode are shown in Table 3. The aerosol components (in terms of burdens and surface concentrations) are quite similar between IFS-GEMS and IFS-GLOMAP. IFS-GLOMAP predicts more sulphate than IFS-GEMS, particularly close to the main source regions over Europe, North America and east Asia. There are also reasonable differences apparent in the EC and OC comparisons, which could be related to the different approaches to ageing (and thus removal) applied in IFS-GLOMAP and IFS-GEMS. Specifically, close to source, EC and OC in IFS-GLOMAP and IFS-GEMS are removed at the same rate. However, as ageing proceeds (at different rates in each model), the aged components are subject to different removal, leading to the greater differences in concentration seen in Figure 4.

3.2 IFS-GLOMAP number concentrations

One of the new capabilities offered by IFS-GLOMAP is the ability to predict size-resolved aerosol number concentrations (and by association with mass, aerosol size distributions). This



Figure 4: Absolute (left column) and relative (right column) surface annual mean mass concentration differences between IFS-GLOMAP and IFS-GEMS. Comparisons are (IFS-GLOMAP – IFS-GEMS).

section presents number concentrations and size distributions from IFS-GLOMAP, and also comparisons with observations. The annual mean number concentration of particles larger than 3 nm dry-diameter (condensation nuclei, CN) is shown in Figure 5, and indicates total particle number concentration at observable sizes. Comparisons of CN against observed marine and continental profiles are shown in Figure 6 and Figure 7.

The CN number concentration shown in Figure 5 shows a peak at altitude, in line with what is predicted by the offline version, GLOMAP-mode (not shown). The peak is the result of new particle formation in the free troposphere. Surface concentrations are a maximum over the main industrialized regions, and reach $\sim 5000 \,\mathrm{cm}^{-3}$. Tropical and remote marine CN concentrations



Figure 5: Surface annual mean number concentration of CN from IFS-GLOMAP (left) and zonal mean showing vertical profile (right).



Figure 6: Comparison of annual mean CN concentrations for three zonal marine domains. Monthly maxima and minima are shown by coloured lines. Observations from Clarke & Kapustin (2002).

are on the order of several hundred per cubic centimetre. The simulations presented here do not contain emission of DMS, which is oxidized to SO_2 and so can lead to increased number concentrations via new particle formation (e.g. Korhonen *et al.*, 2008; Woodhouse *et al.*, 2010). The surface marine number concentrations are therefore likely to be an underestimate. However, the comparison shown in Figure 6 shows a very good reproduction of tropical CN number profile (bias -0.14). The northern and southern hemisphere comparisons show a reasonable comparison with the observations, with high biases of 1.17 and 0.42 respectively. The continental CN comparison (Figure 7) show a similarly high bias for the finer aerosol (>5 nm and >15 nm). The story is more complicated than a simple high bias however, as the surface CN concentrations are biased low. The low bias at the surface may be due to lack of a boundary layer nucleation mechanism in the present simulations. The continental comparison for aerosol >than 120 nm shows a significant low bias throughout the column (overall -0.74).

The annual mean number concentration of CCN with dry radius >35 nm from IFS-GLOMAP is shown in Figure 8. Modelled vs. observed monthly mean CCN concentrations are also compared in Figure 8. IFS-GLOMAP currently overestimates CCN concentration, with a bias of 2.35. The high bias of sea-salt noted in Section 3.1 likely contributes to the high CCN bias, so correction of this component is a priority.

The full range of aerosol sizes is represented in IFS-GLOMAP. To demonstrate this, number size distributions from three regions are shown in Figure 9. Size distributions provide an insight into the microphysical processes occurring at a given point. For example, the North Atlantic size



Figure 7: Comparison of annual mean number concentrations for three size-ranges from a continental site (north-east Germany). Monthly maxima and minima are shown by coloured lines. Observations from Petzold *et al.* (2002).



Figure 8: Surface annual mean number concentration of CCN from IFS-GLOMAP (left); zonal mean showing vertical profile (middle); modelled vs. observed CCN concentrations from multiple different sites (right) described in Spracklen *et al.* (2011).

distribution shown in Figure 9 shows a well developed 'Hoppel gap', where in-cloud oxidation of activated Aitken mode particles have grown to accumulation mode sizes. The resulting gap is characteristic of marine boundary layer aerosol size distributions.



Figure 9: Annual mean surface aerosol number size distributions for three different locations.

3.3 Computational cost

The extra complexity and greater number of advected tracers (12 for IFS-GEMS vs. 31 for IFS-GLOMAP, depending on configuration) associated with IFS-GLOMAP incur increased computational requirements. IFS-GLOMAP in its current implementation in the IFS is approximately a factor of 3.4 more expensive than an IFS simulation without any aerosol. IFS-GLOMAP is approximately a factor of two more expensive than an equivalent simulation with the IFS-GEMS aerosol scheme in the IFS. The extra cost is expected to be reduced as the code is optimised.

4 Future developments

As already noted, the current implementation of IFS-GLOMAP in the IFS using the existing IFS-GEMS aerosol sources, sinks and chemical processing, is an intermediate step. This step has facilitated a direct comparison between IFS-GEMS aerosol and IFS-GLOMAP, but is not an ideal configuration for the IFS-GLOMAP module and causes high biases in two of the most important aerosol components, sulphate and sea-salt. Projected short- and medium-term upgrades to IFS-GLOMAP in the IFS are outlined below.

4.1 Short-term upgrades

These upgrades are expected during the closing stages of the MACC project, or the initial stages of the follow-on MACC-II project.

- Upgrade to the latest release cycle (CY37R3).
- Upgrade of the IFS-GLOMAP aerosol code to include recent developments, in particular those resulting from the GLOMAP-mode vs. GLOMAP-bin comparison, described in Mann *et al.* (submitted).
- Switching on IFS-GLOMAP interactive primary aerosol emission routines (dust and seasalt) in place of the IFS-GEMS aerosol routines.
- Switching on IFS-GLOMAP removal (dry and wet) routines in place of the IFS-GEMS aerosol routines.
- Inclusion of an oxidation mechanism driven by offline oxidant fields calculated from the IFS-MOZART chemistry model, in collaboration with Johannes Flemming (ECMWF).
- Full coupling of IFS-GLOMAP to the chemical model C-IFS, in conjunction with Johannes Flemming (ECMWF).
- Online calculation of AOD

4.2 Medium-term improvements (expected as part of MACC-II)

A series of more comprehensive improvements to IFS-GLOMAP (some of which are also occurring in other GLOMAP frameworks) is listed below. These are planned to take place as part of the MACC-II project.

- Incorporation of nitrate and associated chemistry within IFS-GLOMAP.
- Modification of existing code for stratosphere, following work done with IFS-GLOMAP in the UM by Slimane Bekki (IPSL, France) and Kathryn Emmerson (formerly University of Leeds). These improvements will require the more comprehensive chemistry upgrade planned in the near future. See also deliverable report D_G-AER_1.3 by Slimane Bekki.

- Assimilation of fine mode and total AOD using the 4DVAR framework currently used in the IFS (and currently used by the MACC IFS-GEMS aerosol forecast system). This work will be undertaken with Angela Benedetti (ECMWF).
- Reduction of the number of tracers in IFS-GLOMAP, to reduce computation time without significantly reducing model skill.
- Profiling of the IFS-GLOMAP code to establish where performance can be improved, followed by optimization of relevant routines.
- Conversion of GLOMAP-mode code to DOCTOR standard, in line with ECMWF requirements. This change will reduce the portability of improvements made in GLOMAP-mode to IFS-GLOMAP, as significant changes to variable names are required. This step is required however in order for IFS-GLOMAP to be considered as part of the operational suite.

These upgrades will bring the IFS-GLOMAP system up to a 'pre-operational' standard, as outlined in plans for MACC-II.

5 Conclusions

As part of the MACC project, the two-moment (mass and number) microphysical aerosol scheme GLOMAP-mode (Mann *et al.*, 2010) is now integrated in the ECMWF IFS model, and is referred to as IFS-GLOMAP. The IFS-GLOMAP scheme represents an increase in complexity compared to the existing aerosol scheme in the IFS, known as IFS-GEMS, and can predict aerosol number and size information, courtesy of a more physically based representation of aerosol microphysics. The extra complexity associated with IFS-GLOMAP will ultimately lead to improved predictions of aerosol concentrations for assessments of air quality and aerosol-climate interactions from the IFS. Output from IFS-GLOMAP will also be used as boundary conditions for more detailed and higher resolution regional modelling systems. Presently, IFS-GLOMAP uses the same aerosol sources, sinks and SO₂ oxidation scheme as IFS-GEMS. Such an approach enables comparison between IFS-GLOMAP and IFS-GEMS during this initial development stage.

IFS-GLOMAP has been compared against the existing aerosol scheme IFS-GEMS, and also an array of benchmark observational datasets. Surface concentrations of sulphate in IFS-GLOMAP compare very well with observations in polluted domains. IFS-GLOMAP is currently missing a source of DMS, leading to an underestimate of sulphate mass in the remote oceans. IFS-GLOMAP predictions of EC and OC are slightly low against observations from the IMPROVE network (North America), though OC is expected to be biased low in the current implementation, lacking as it does a contribution from secondary organic aerosol. The surface mass concentration of sea-salt is biased high, as is the overall burden. The current emissions scheme is likely responsible for the high sea-salt.

The overestimation of sea-salt mass arising from too-high emissions leads to an overestimation of CCN number concentration in comparison to an extensive observational dataset. Updates to IFS-GLOMAP will improve this comparison. Comparison of marine CN number concentrations against observations show the model resolves the number concentration of vertical profile very well. A similar continental comparison reveals a low bias at the surface, but a high bias at altitude.

Given the current early state of development, the performance of IFS-GLOMAP is very positive when compared to IFS-GLOMAP, observations, and also GLOMAP-mode in the offline framework (Tables 2 and 3). In particular, the sulphate production mechanism and removal processes are optimised for the externally mixed IFS-GEMS aerosol module, and are not strictly applicable to the internally mixed modal configuration of IFS-GLOMAP.

Despite the relatively simple SO_2 oxidation mechanism, the new aerosol microphysics scheme is performing very well, and is capturing aerosol microphysical features (e.g. new particle formation, Hoppel gap) that were beyond the capability of the pre-existing aerosol scheme, IFS-GEMS.

The IFS-GLOMAP implementation described here is the first step in bringing the combined IFS and GLOMAP-mode system to an operational standard. Several upgrades and additions to capability are planned as part of ongoing work that leads into MACC-II. The expected improvements of this work to IFS-GLOMAP include reduced biases versus observations for aerosol mass and number concentrations and reduced computational cost.

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