Implementation of modules for surface emissions, aircraft emissions and NO emissions from lightning into the ECMWF Integrated Forecast System

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Abstract

The surface emission module and a scheme for NO aircraft and lightning emissions for ECMWF's Integrated Forecast System (IFS) is presented. Chemistry-IFS (C-IFS) applies the same surface emission data as the TM5 model. Two data set have been used: (i) monthly data prepared for the GEMS and MACC projects as well as data used in POLARCAT inter-comparison project (POLMIP). A parameterisation of NO lightning emissions has been developed, which is based on three different parameterisations of flash rate densities using parameters of the IFS convection scheme.

Contents

1. Introduction

Correct emission data are important for the correct simulation of atmospheric composition by C-IFS. At this development stage, C-IFS applies surface emission data that have been already tested by the TM5 model. Besides the monthly TM5 emission data used in the GEMS and MACC projects (consisting of RETRO, REAS GFEDv2 ORCHIDEE and GEIA), an emission data set specially prepared for the POLARCAT inter-comparison project has been applied.

Lightning emissions of NO play an important role in tropospheric chemistry. The total source strength and the horizontal and vertical distribution are still subject to scientific debate (Schumann and Huntrieser, 2007). C-IFS is an appropriate tool for further developing and testing parameterisations of lightning and the associated emissions because comprehensive information about convective activity and clouds is available during the model run. In turn, lightning observations may provide useful data for evaluating the performance of the IFS convection scheme.

The processing of the emissions from various data sources (anthropogenic, biogenic and biomass burning) has to be done before the start of C-IFS. The required calculations are mostly sequential and would consume unnecessary computing time if they were done as part of a highly parallel model code. Currently, the data for the model forecast are processed from the pre-prepared monthly or daily data.

At a later stage, the SUMO model will produce biogenic emission data, which reflect better the actual meteorological situation. Further, the NRT biomass burning emission data sets produced in the D-FIRE subproject can be used for C-IFS.

2. Emission input data and budgets

Table 1 lists species requiring surface emission data and respective budgets for the following data sources. The data have been prepared in the IFS resolutions T159 and T255.

POLMIP emissions:

- Anthropogenic: Streets-ARCTAS-v1.2, VOCs speciated according to RETRO species, as in ACCMIP & MACCity
- Fires (bb): FINNv1 from Christine Wiedinmyer, Sep. 2010
- Biogenic, Soil, Ocean, Volcano: from MACCity, provided by Claire Granier et al.

TM5 GEMS emissions are the same as described in more detail in Huijnen et al. (2010), and are only prepared for the chemistry scheme TM5-chem-v3.0:

- Anthropogenic: REAS - RETRO
- Fires (bb): GFEDv2
- Biogenic, Soil, Ocean, Volcano: ORCHIDEE (Lathiere et al.), GEIA (Guenther et al. , 1995)

Species	Anthrop GEMS	Fires GEMS	Bio GEMS	Anthrop Streets	biomass b FinnV1	Bio POLMIP	Aircraft/ Lightning
CO	592	391	179	591	328	96	
CH2O	1.15	25.2	0.3	2.97	4.69	4	
PAR (Tg C)	54.8	7.3	162.8	39.0	5.8	0.4	
ETH (Tg C)	5.5	3.2	3.9	5.8	2.4	15.5	
OLE (Tg C)	3.2	0.9	1.8	2.8	0.8	0	
ALD2 (TgC)	0.96	0.5	9.6	1.1	4.1	6.1	
ISOP	0	0	565	0.	0.79	523	
SO2	108	2.3	29	124	2.2	0	
DMS	0	0	1.7	0	0	1.7	
NH3	45.5	9.6	12.9	41.8	4.3	0	
MGLY	3.5	0.15	0	0	1.8	0	
Rn	0	0	122e-10	0	0	122e-10	
NO	70.5	10.9	19.9	69.9	12.4	10.6	1.5/8.7
CH3OH	-	-	-	0.92	5.23	159	
HCOOH	-	-	-	6.7	1.7	0	
MCOOH	-	-	-	6.6	7.5	0	
C2H6	-	-	-	6.3	1.6	0.14	
ETHOH	-	-	-	5.23	0.04	0	
C3H8	-	-	-	5.6	0.37	0.02	
C3H6	-	-	-	3.0	1.5	6.1	
TERP	-	-	-	0	0.27	96.6	
ISPD	-	-	-	2.1	4.6	0.5	

Table 1 List of species with emission in C-IFS and annual totals in Tg species for different data sets. The GEMS emission dataset is currently prepared for the chemistry scheme as described in Huijnen et al., 2010 only.

3. Parameterization of lightning NO emissions in C-IFS

NO emissions from lightning are a considerable contribution to the global atmospheric NOx budget. In contrast to the surface emissions, they depend strongly on the simulated meteorological model fields. Therefore they are an interesting subject to explore the interaction between atmospheric composition and meteorological simulation as part of the C-IFS development.

Estimates of the global annual source strength vary between 2 and 20 Tg(N) (IPCC, 2001). 5 Tg(N) is the most commonly assumed value for global CTMs which is about the values of Chinas anthropogenic emission in 2008 (Lin et al, 2010) or about ten times the value of NO emissions from aircraft (Gauss et al., 2006). NO emissions from lightning play an important role in the chemistry of the atmosphere because they are released in the rather clean air of the free troposphere, where they can strongly influence the Ozone budget and hence the OH-HO2 partitioning.

Practically all available parameterisations of the lightning NO emission in CTMs are made of three steps:

1. flash rate densities
2. flash energy release
3. NO emission profile

The estimate of the flashes rate or flash-rate density (flashes per time unit and area unit) is based on parameters of the convection scheme. Potential predicators are cloud height, convective precipitation or an integrated up-draft velocity. The IFS has been extended to calculate flash rate densities using either of the following three parameterisations:

- Convective Cloud Height (Price and Rind, 1992)
- Convective Precipitation (Meijer et al, 2001)
- Convective updraft velocity and ice cloud height (Lopez, personal communication, after Grewe et al., 2001)

These parameterisations distinguish between land and ocean points by assuming about 5-10 times higher flash rates over land. Additional checks on cloud base height, cloud extend and temperature to select only clouds that are likely to generate lightning strokes are implemented. The published coefficients of the parameterisations were derived from field studies and depend on the model resolution. With the current implementation of C-IFS (T159L60), the global flash rates were 22, 48 and 72 flashes per seconds for the schemes by Price and Rind (1992), Meijer et al.(2001) and Lopez (personal communication). It seems therefore necessary to scale the coefficients to get a flash rate in the range of the observed values of about 40-50 flashes per second (Christian et al. 2003) . Maps of the scaled annual flashed rates (40 fl/s) for the three parameterisations together with an observed climatology (OTS/LIS, average 48 fl/s) are shown in Figure 1. All approaches show the main flash activity in the tropics but there are considerable differences in the distribution over land and sea. In particular the observed maximum over the central African continent is not well reproduced by any of the parameterisations. The parameterisation by Meijer et al.(2001) has been used for the C-IFS runs, although it overestimates lightning flash rates over the Indian Ocean and the Pacific.

Cloud to ground (CTG) and cloud to cloud (CTC) flashes are believed to release a different amount of energy, which is proportional to the NO release according to earlier laboratory studies. However, more recent studies suggest a similar value for CTG and CTC energy release based on air craft observations and model studies (Ott et al., 2010). In C-IFS, CTG and CTC fractions are calculated using the approach by Price and Rind (1993), which is based on 4th order function of cloud height above freezing level. The energy release of CTG is 10 times higher than CTC following Price et al. (1997).

The vertical distribution of the NO release is of importance for its impact on atmospheric chemistry. Many CTMs use the suggestion of Pickering et al. (1998) of a C-shape profile, which peaks at the surface and the upper troposphere. Ott et al. (2010) suggest a “backward C-shape” profile which put most of the emission in the middle of the troposphere. In C-IFS the vertical distribution is simulated according to the TM5 model: All CTC and 70% of CTG flash emissions are placed in levels between the temperature of -15°C (5-7 km) and the cloud top. 10% of CTG flash emissions are distribute below -15°C and the surface and the remaining 20% of CTG are put into the lowest 10 model levels.

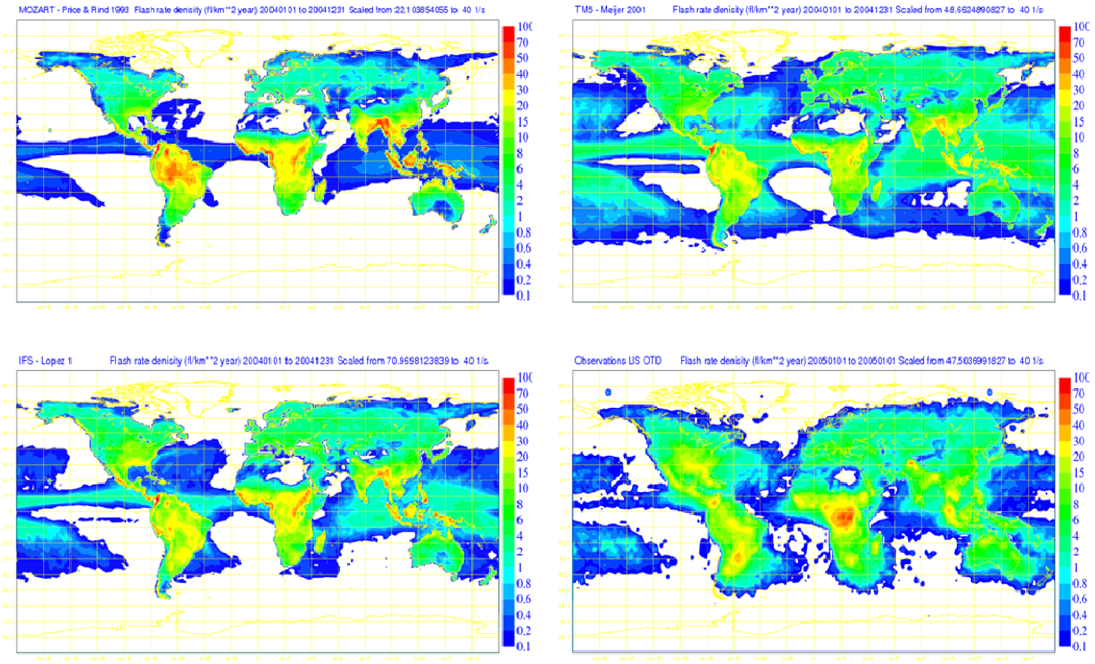

Figure 1 Flash density in flashes/km2 and year from the IFS input data using the parameterisation by Price and Rind (1993) (top, left), Meijer et al. (2001) (top right), Lopez (personal communication) (bottom, left) and observations from the LIS OTD data base (bottom right). All data were scaled to an annual flash density of 40 fl/s.

4. Integration in the IFS code

Surface emissions are presented to the C-IFS as one surface flux field per species, which is valid for the whole model forecast. The surface emissions per species (kg/m2s) are used as lower boundary conditions for the vertical transport by diffusion. The diffusion scheme takes care of the vertical distribution in the planetary boundary layer (PBL). 3D emissions from lightning and aircraft are converted from kg/s into mass mixing ratio tendencies at the end of the physics time step. The names of the new or altered routines in the IFS code can be found in Table 2.

Routine name	called from:	Purpose	Output
culight.F90	callpar.F90	Flash rate densities and NO emissions	3D NO emission from lightning
chem_emi3d.F90	chem_main.F90	Apply 3D emission from lightning and air craft emissions	Chemical tendencies
gems_init.F90	callpar.F90	surface emissions to diffusion scheme	Surface fluxes

Table 2 Fortran routines added to or changed in the IFS code.

5. Conclusions and Outlook

We have presented a first implementation of modules for surface emissions, aircraft emissions and NO emissions from lightning in the ECMWF Integrated Forecast System. The budget analysis of the emissions leads to the conclusion that reasonable emission data are used. The following improvements should be implemented in future versions of C-IFS:

1. Use of input for biogenic emission data from the SUMO model
2. Update of emissions during model run
3. Revisit the NO_x lightning emissions and their vertical resolution

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