EUCLIPSE Deliverable 1.3: Report on the implementation of ESM versions with COSP software

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1 Introduction

This document reports on the progress of the implementation of the CFMIP (Cloud Feedback Model Intercomparison Project) Observation Simulator Package (COSP) in the numerical models participating in EUCLIPSE. These are the institutes that paricipate in this task:

- UK Met Office (UKMO),
- Laboratoire de Météorologie Dynamique/Institut Pierre Simon Laplace (LMD/IPSL),
- Max-Planck Institut für Meteorologie (MPI-M),
- Météo-France Centre National de Recherches Météorologiques (MF-CNRM),
- Koninklijk Nederlands Meteorologisch Instituut (KNMI).

These centres will be running the following models as part of EUCLIPSE:

- UKMO: HadGEM2
- LMD/IPSL: LMDZ5
- MPI-M: ECHAM6
- MF-CNRM: CNRM-CM5
- KNMI: EC-Earth

COSP can be run in two different configurations. In-line, implemented within the numerical model, and off-line as stand alone software. In the in-line implementation, COSP is called from within the model in run-time, and the outputs are passed to the model's standard output system. For the off-line version, instantaneous COSP inputs have to be generated from the model, and then COSP is run independently.

2 Results from COSP for all participating models

This section describes the progress in the implementation of COSP in the participating models, and shows examples of the COSP outputs for the different models. All the figures show outputs from the three instrument simulators (ISCCP, CALIPSO and CloudSat) from which outputs are requested for the EUCLIPSE experiments. They show global and tropical (15^{o}S-15^{o}N) averages of the following variables:

- ISCCP: histograms of cloud top pressure versus optical depth
- CALIPSO: histograms of scattering ratio as a function of height
- CloudSat: histograms of radar reflectivity as a function of height

2.1 HadGEM2

HadGEM2 is the climate configuration of the Met Office Unified Model (MetUM) used for the experiments of the 5th IPCC Assessment Report (AR5). HadGEM2 is an evolution of HadGEM1 [*Johns et al.*, 2006], and aims to improve two key features of the performance of HadGEM1: the simulation of ENSO and a reduction of land-surface temperature biases over northern continents. The main differences of HadGEM2 with respect to HadGEM1 are documented in *Collins et al.* [2008].

COSP has been implemented in the global configurations of the MetUM (i.e. it can be run in the NWP model as well as in the climate model), both off-line and in-line. Figure 1 shows the results of the in-line implementation applied to HadGEM2. These are results from one July of a coupled atmosphere-ocean run with preindustrial forcings.

2.2 LMDZ5

Here we present COSP outputs from a version of the IPSL atmospheric model named LMDZ5. This is a grid-point general circulation model with a resolution of 96x96 in the horizontal (roughly 3.75 degrees and 1.875 degrees in longitude and latitude, respectively), and 39 hybrid levels in the vertical.

The physical package of LMDZ5 includes many novelties compared to its previous version LMDZ4 [*Hourdin et al.*, 2006], in particular: a new parameterization of boundary layer thermals [*Rio and Hourdin*, 2008], a new parameterization of convective cold pools [pools of cold air generated by the reevaporation of convective precipitation *Grandpeix and Lafore*, 2010; *Grandpeix et al.*, 2010], and a modified convection scheme (still based on the *Emanuel* [1991] parameterization, but heavily modified by J-Y Grandpeix so that the convective mass flux can be controled by several subcloud-layer processes: turbulence, convective thermals, cold pools, etc. This model version is able to simulate satisfactorily the diurnal cycle of deep convection over land [*Rio et al.*, 2009].

Clouds are still represented by a combination of two statistical cloud schemes [*Bony and Emanuel*, 2001; *Treut and Li*, 1991], as described in [*Hourdin et al.*, 2006]. Note that a new statistical cloud scheme coupled to the representation of boundary-layer thermals has been developed [Jam et al., submitted], that is currently in test. Hopefully, it will be used in the version of the IPSL model named IPSL-CM5b, that will be one of the two IPSL model versions used in CMIP5. Cloud microphysical properties are represented as described in [*Bony and Emanuel*, 2001].

COSP v1.3 has been implemented off-line in a development version of LMDZ5, IPSL-CM5b. Figure 2 shows the results for one month (August) of a climatological atmospheric simulation with this model.

2.3 ECHAM6

ECHAM6 is based on ECHAM5 *Roeckner et al.* [2003, 2006] but contains several new features. In particular, the original six-band short-wave radiation scheme derived from *Fouquart* *and Bonnel* [1980] has been replaced by the more advanced 14-band short-wave counterpart of the Rapid Radiation Transfer Model [RRTM, *Mlawer*, 1997; *ECMWF*, 2009, and references therein]. In addition, the Tiedtke/Nordeng cumulus convection scheme [*Nordeng*, 1994] has been modified to take into account sub-grid variability of boundary layer potential temperature as function of turbulent kinetic energy (TKE). The single-moment stratiform cloud scheme consists of three prognostic equations for water vapor, liquid water, and ice, a bulk microphysics scheme [*Lohmann and Roeckner*, 1996], and a simple cloud cover scheme based on relative humidity [*Sundqvist et al.*, 1989]. Furthermore, ECHAM6 has been coupled to a new land surface scheme [JSBACH, *Raddatz et al.*, 2007].

Figure 3 shows preliminary results from a test run with the ECHAM6 model. This particular test run has been performed at T63 horizontal resolution using 47 vertical levels (T63/L47) with most additional levels relative to ECHAM5 L31 in the stratosphere and upper troposhere. Sea-surface temperatures for June 2007 have been prescribed and results are shown after a one-month initial spin up. In the current implementation of COSP in ECHAM6, convective clouds are assumed to cover a negligible grid fraction (consistent with the assumptions in the deep convection scheme), so cloud cover and condensate mixing ratios are set to zero for convective clouds. Deep convection does, however, influence the results through detrainment in the upper troposphere. Effective radii for liquid droplets are calculated from the liquid water content based on prescribed droplet numbers (N_l). Within the atmospheric boundary layer N_l=220$\times$10^6 m^{-3} over land and N_l=80$\times$10^6 m^{-3} over sea. Above the boundary layer, N_l decreases exponentially to N_l=50 m^{-3} in the upper troposphere over both land and ocean [*Roeckner et al.*, 2003]. As in the radiation scheme, the volume mean droplet radius is related to the effective droplet radius by a fixed ratio [1.077 for marine and 1.143 for continental clouds, *Martin et al.*, 1994]. The effective radius of ice is empirically related to the ice water content as in *Lohmann and Roeckner* [1996]. For precipitation, the snow and rain mixing ratios are computed from the precipitation fluxes as calculated in the stratiform and convective microphysical parameterizations, respectively. For convective precipitation, the total precipitation as diagnosed in the Tiedtke/Nordeng scheme is split into snow and rain based on the local temperature (the melting temperature is 0°C).

2.4 CNRM-CM5

The CNRM-CM5 climate model consists of the ARPEGE-Climat version 5.2 atmospheric GCM coupled to the NEMO3.2 oceanic GCM, the Gelato sea-ice model, and the ISBA land surface model. The ARPEGE-Climat atmospheric GCM is a spectral model derived from the ARPEGE-IFS NWP model. It is here used at a T127 truncation (256x128 Gaussian grid, i.e. about 1.4$^{\mathrm{o}}$horizontal resolution) and with 31 sigma-pressure vertical levels comprised between the surface and 10 hPa.

As far as the atmospheric physics is concerned, the main modification to version 5.1 [*Déqué*, in press] is the introduction of a new radiative scheme. First, the former ECMWF longwave radiation scheme has been replaced by the Rapid Radiation Transfer Model (RRTM) which has been developed at Atmospheric and Environmental Research Inc. (USA) to obtain an accuracy in the calculation of fluxes and heating rates consistent with the best line-by-line models.

Second, the ECMWF shortwave radiation scheme has been upgraded to account better for the spectral variations of the cloud optical properties. The cloud fraction and the liquid/ice water content are still diagnostic variables (for both large-scale and convective clouds) and are provided in all layers by the cloud scheme. While they are computed at each model time step (i.e. every 30 min), the full radiative calculations are made every 3 hours so that they assume fixed cloud properties within each 3-hour interval. Other modifications relative to AR4 include the use of an improved land surface model which is based on a 3-layer soil hydrology and has a more sophisticated subgrid runoff scheme [*Alkama et al.*, 2010].

As far as COSP is concerned and whatever the length of the simulation is, CNRM has made the choice of an off-line implementation, which is feasible given the limited resolution of the ARPEGE-Climat configuration within CNRM-CM5. All COSP inputs are archived every 3 hours from ARPEGE outputs and used to drive COSP using either NCOL=20 subcolumns for the long global simulations (ISCCP and lidar simulators) or NCOL=150 subcolumns for the short curtain-mode simulations (lidar and radar simulators). The choice of NCOL for radar and lidar simulators has been made following numerical tests taking NCOL=1000 as reference reflectivity and lidar scattering ratio and computing the RMS differences with NCOL=20 to 500. The 150 sub-column value corresponds to a compromise between computation time and gain in RMS. The COSP output data sets have been separated in low (0-3 km), mid (3-8.5 km), high clouds (8.5-16 km), showing as expected that the total RMS value is mainly resulting from the low level clouds.

As far as the COSP namelist is concerned, the other following options have been used:

- Inputs related to radar: use_reff=.true., use_precipitation_fluxes=.true.
- Inputs related to lidar: OVERLAP=3 and only 8 hydrometeors (no graupel)
- Inputs related to ISCCP: Topheight=1 and Topheight_Direction=2

As far as the microphysical settings are concerned, note that some tables in cosp_constants.f90 are not completely fixed and could be slightly modified given the crude microphysics used in the ARPEGE-Climat model.

In order to illustrate the implementation of the 3 cloud simulators, bin-level histograms of ISCCP cloud fraction and of Calipso/Cloudsat cloud frequency (CFAD) have been plotted for June 2008 (Figure 4) after averaging the results either globally or within the tropics (15^{o}S-15^{o}N).

2.5 EC-Earth

The EC-Earth model (http://ecearth.knmi.nl) is the result of an effort of a consortium of meteorologists and Earth system scientists from ten European countries. The consortium consists of scientists from national meteorological services, academia, and high-performance computing centres, designed to bridge the gap between numerical weather prediction and Earth system modelling. The EC-Earth model is used for basic research, for developing climate projections and predictions and for delivering climate information to users.

The atmospheric model of EC-Earth version 2, which is the current reference version, is based on ECMWFs Integrated Forecasting System (IFS), cycle 31R1, corresponding to the current seasonal forecast system of ECMWF. The standard configuration runs at T159 horizontal spectral resolution (corresponding to a 320x160 gaussian grid, about 1.1 degree horizontal resolution) with 62 vertical levels. In fact some aspects of a newer IFS cycle have been implemented additionally, including a new convection scheme [*Bechtold et al.*, 2008] and the new land surface scheme H-TESSEL [*Balsamo et al.*, 2009]. The ocean component is based on version 2 of the NEMO model [*Madec*, 2008] with a horizontal resolution of nominally 1 degree and 42 vertical levels. The sea ice model is the LIM2 model. The ocean/ice model is coupled to the atmosphere/land model through the OASIS 3 coupler [*Valcke*, 2006].

The COSP software v1.3 has been implemented in-line in the EC-Earth source code and is executed at every radiation time-step of 3 hours. As an example, we show COSP output from an AMIP simulation for May 2007 in Figure 5.

The following options have been chosen within COSP:

- Number of subcolumns NCOL=20
- Vertical grid: use_vgrid = true and csatgrid=true
- Input related to ISCCP: isccp_topheight = 1, isccp_topheight_direction = 2
- Inputs related to lidar: overlap = 3 (max/random) and 8 hydrometeors (no graupel)
- Inputs related to radar: use_reff = true, use_precipitation_fluxes = true

2.6 Figures

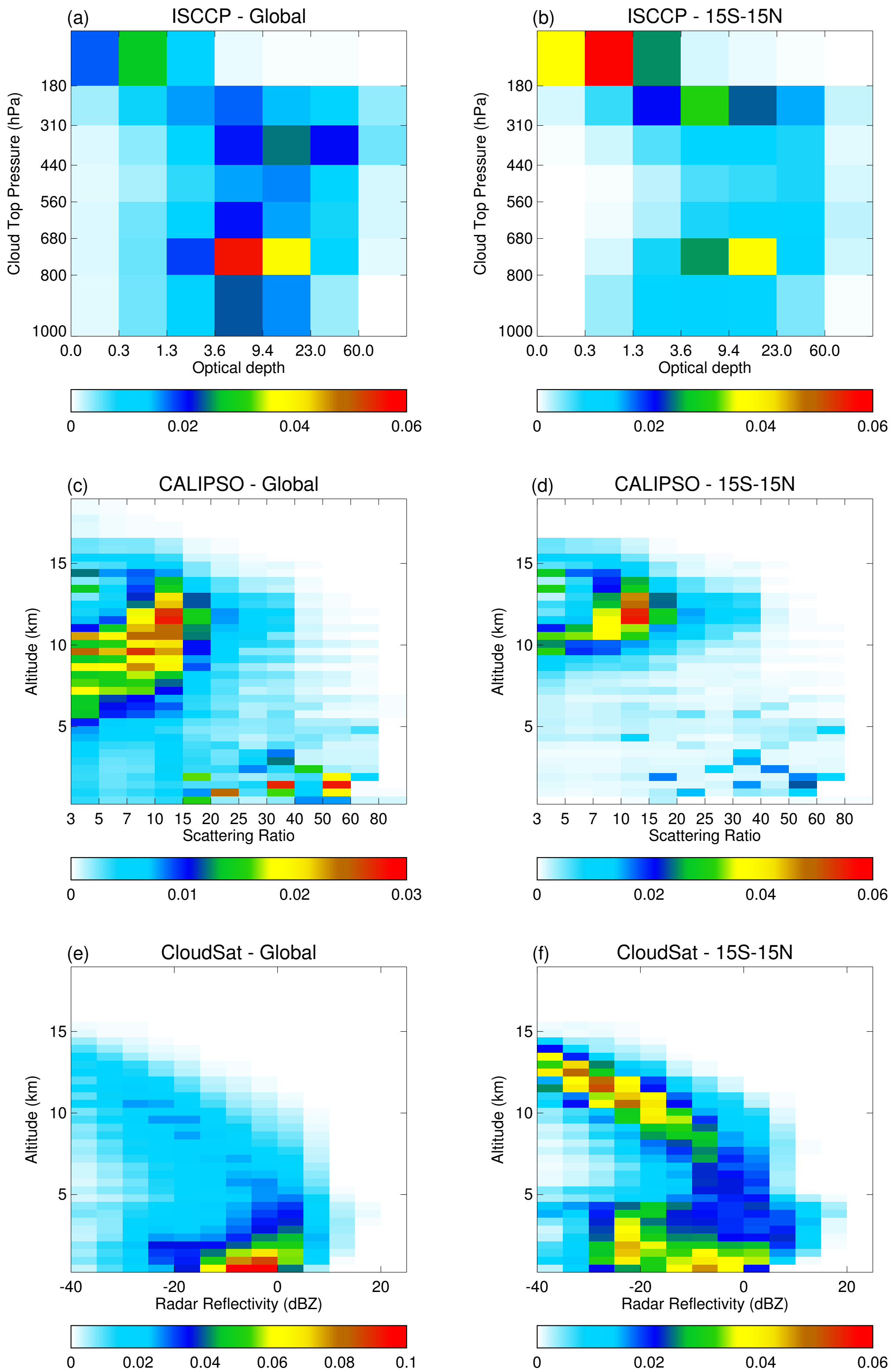

Figure 1. COSP outputs from one July of an atmosphere-ocean coupled simulation of HadGEM2 with preindustrial forcings. The left-hand side column shows globally-averaged results, and the right-hand side column shows averages over the tropical belt (15°S-15°N): (a,b) ISCCP histograms, (c,d) CALIPSO histograms, and (e,f) CloudSat histograms.

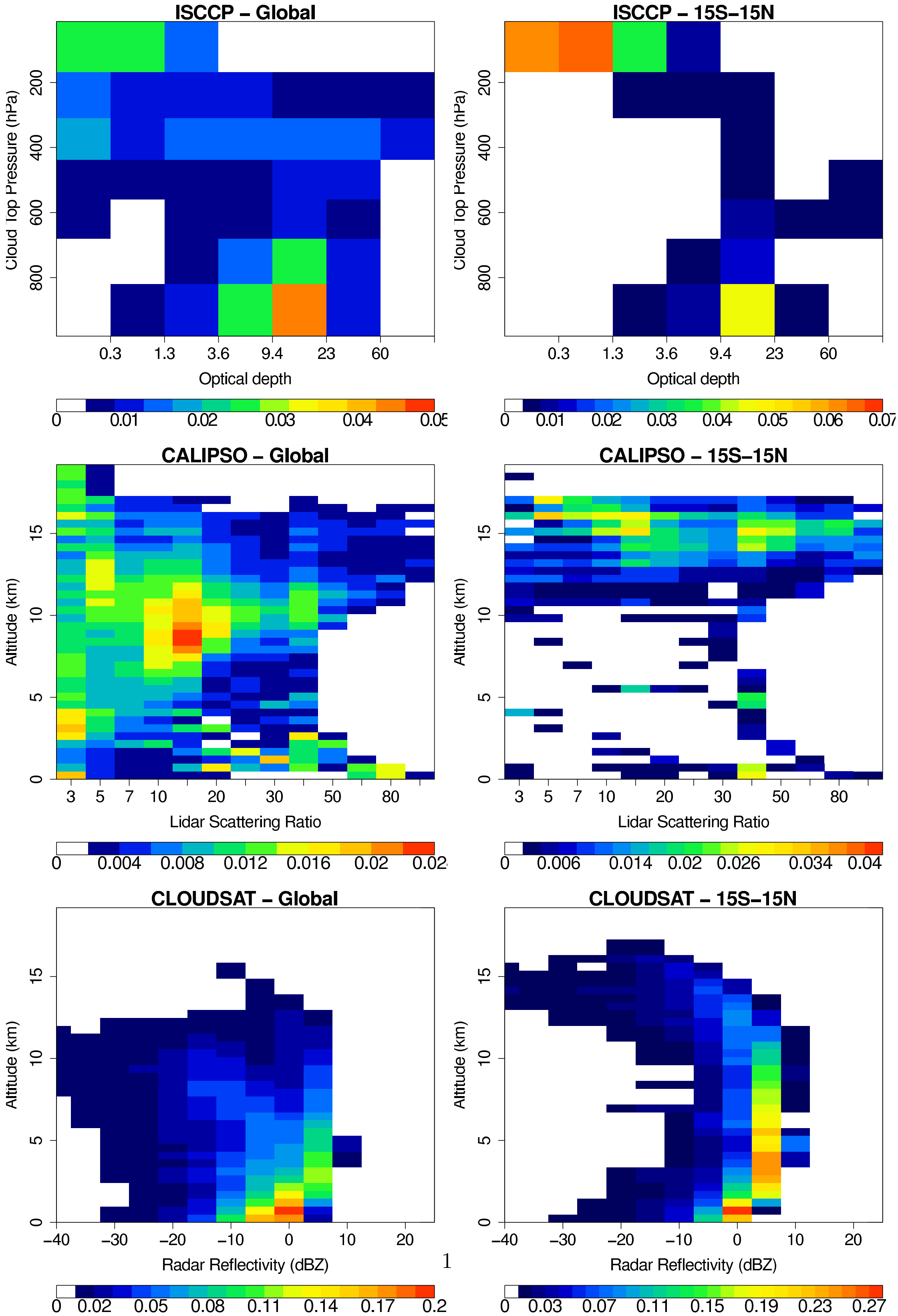

Figure 2. As Fig. 1, but for one month (August) of a climatological atmospheric simulation with a development version of LMDZ5.

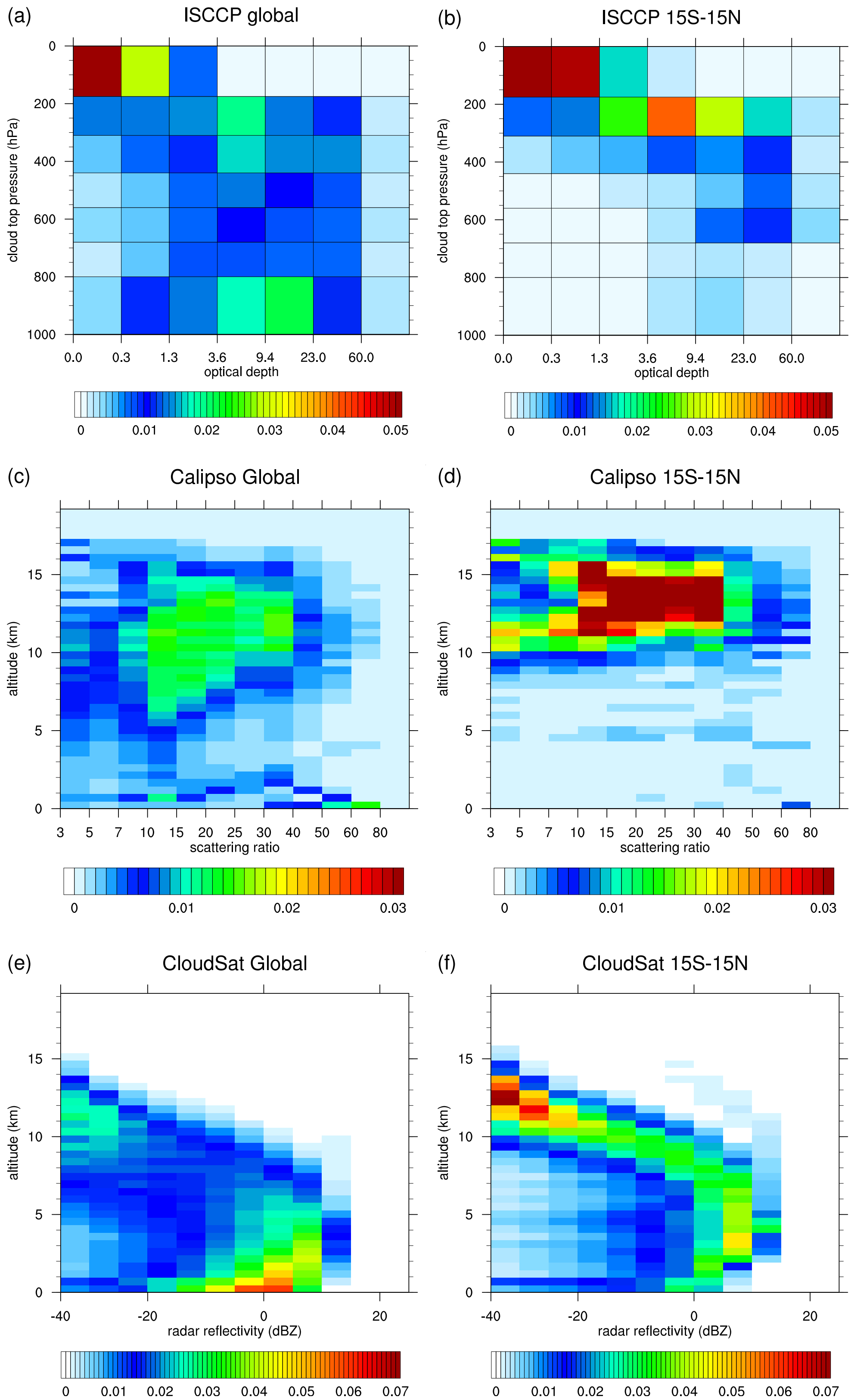

Figure 3. As Fig. 1, but for a T63/L47 test run with the ECHAM6 model.

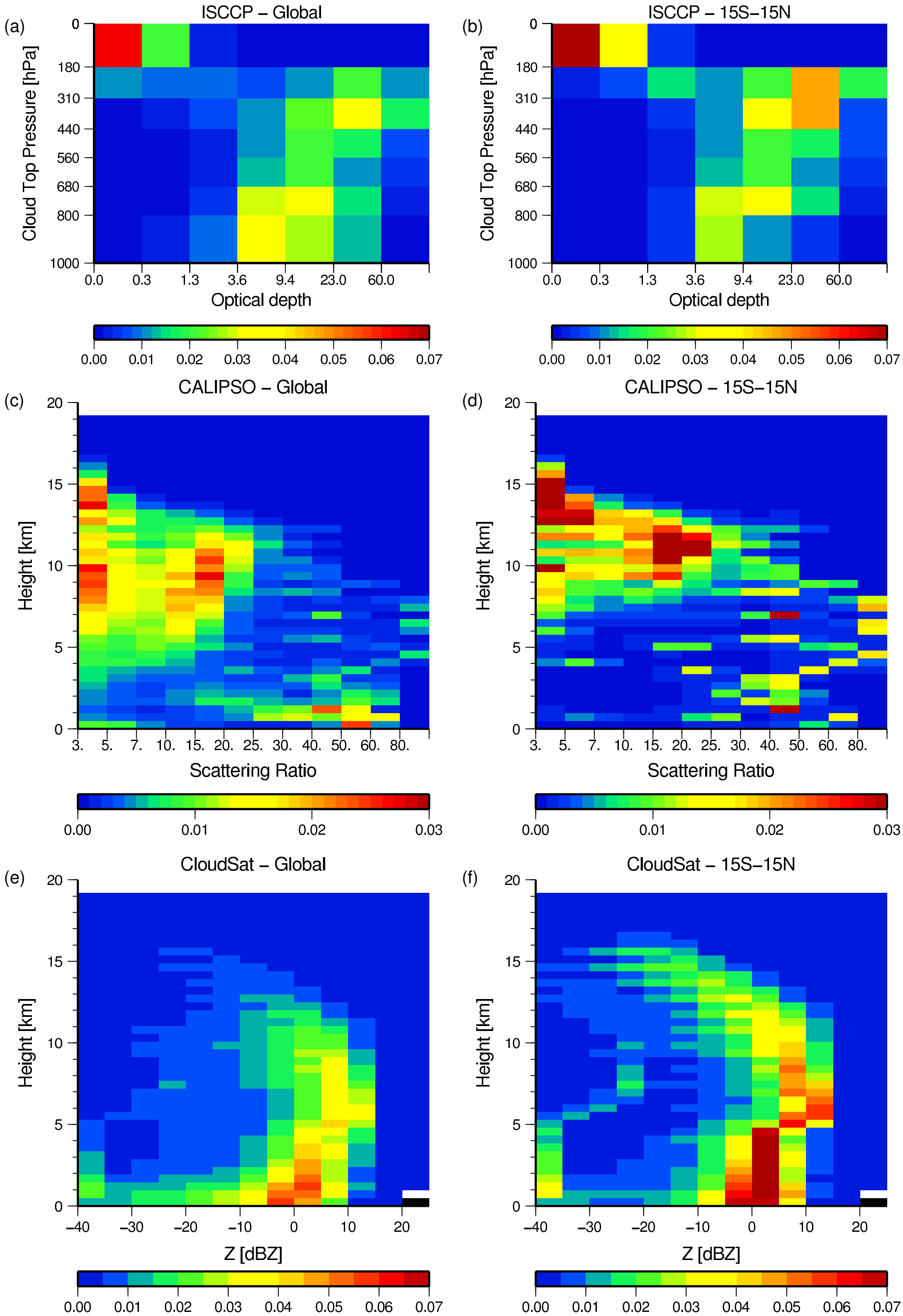

Figure 4. As Fig. 1, but for CNRM-CM5 model.

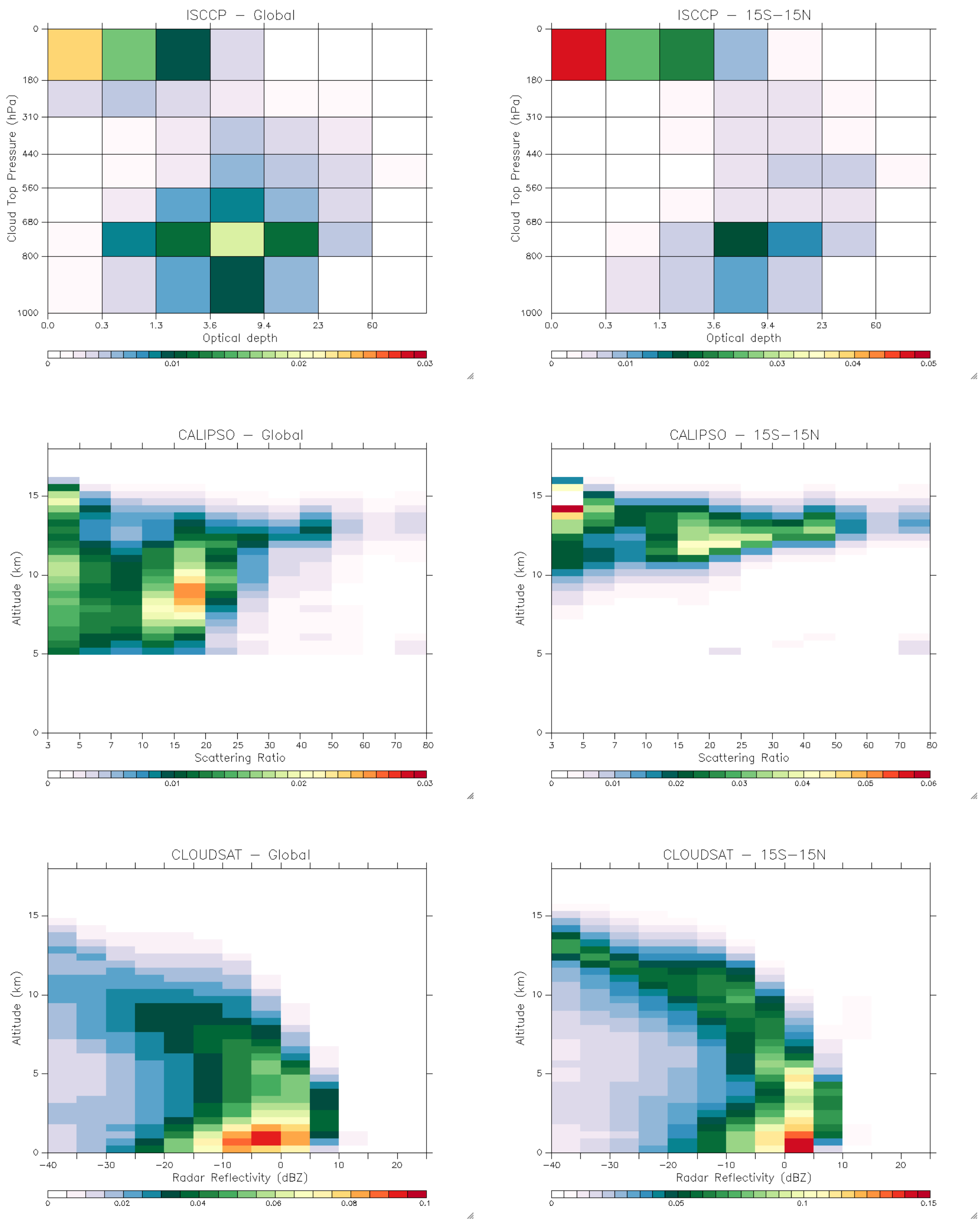

Figure 5. As Fig. 1, but for one month (May 2007) of a climatological atmospheric simulation with EC-Earth.

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