

Aerosols in LMDz model

Olivier Boucher

With continuous help from T. Lurton, L. Guez, A. Idelkadi,
J. Ghattas, J. Escribano, C. Kleinschmitt, Y. Balkanski,
A. Cozic, A. Sima, N. Lebas, M. Khodri

LMDZ training – 9 January 2024



Aerosol tutorial

Merci
Adriana !

LDMZ tutorial: aerosol effects

LMDZ team

January 2023

This tutorial focuses on how to activate and diagnose aerosol effects in LMDZ.

This document can be downloaded as a pdf file (so you could copy/paste command lines from it):

wget https://lmdz.lmd.jussieu.fr/pub/Training/Tutorials/Tutorial_Aerosols.pdf

1 Prerequisites

If you have already installed the model with the script `install_lmdz.sh` as described in Tutorial #1, then go directly to Section 2 "Activating aerosols".

Otherwise, start by installing the model, as follows (same steps as in Tutorial #1) :

If you don't have a working folder named LMDZ in your home directory, then you create it:

```
cd
mkdir LMDZ
```

Go in this `-/LMDZ` folder. Download the script `install_lmdz.sh`, and run it to install the model in sequential mode (default option `'parallel=none'` in `install_lmdz.sh`), in a folder named `LMDZseq`. The default resolution is `32x32x39` (equivalent to running `install_lmdz.sh` with the option `"-d 32x32x39"`).

```
cd -/LMDZ
wget https://lmdz.lmd.jussieu.fr/pub/install_lmdz.sh
chmod +x install_lmdz.sh
./install_lmdz.sh -name LMDZseq
```

The LMDZ model is now installed in your folder `-/LMDZ/LMDZseq/modips1/modeles/LMDZ`. A "benchmark" simulation was automatically run therein, in the folder `BENCH32x32x39` that can be useful for other exercises. Here you'll work with another Bench archive for the regular resolution `48x36x39`, containing appropriate aerosol files.

2 Activating aerosols

ATTENTION : The input aerosol files must have the same horizontal grid (resolution, zoom if any) as the simulation you want to run. The vertical interpolation will be done online by the model.

For this training session, aerosol files on regular `48x36x39` grid are included in the archive you will work with : `bench_lmdz_48x36x39.tar.gz`.

In the `-/LMDZ/LMDZseq/modips1/modeles/LMDZ` folder, download and unpack the archive `bench_lmdz_48x36x39.tar.gz` :

```
cd -/LMDZ/LMDZseq/modips1/modeles/LMDZ
wget https://lmdz.lmd.jussieu.fr/pub/3DBenches/bench_lmdz_48x36x39.tar.gz
tar -xvf bench_lmdz_48x36x39.tar.gz
```

Go in the new folder `BENCH48x36x39` (created in `modips1/modeles/LMDZ`) and compile the model at the `48x36x39` resolution, using the script `compilegcm.sh`. At the end, check that you have in your folder the executable `gcm.e` :

```
cd BENCH48x36x39
./compilegcm.sh
ll gcm.e
```

2.1 Switching on tropospheric aerosol effects

Aerosols are switched off by default in the basic LMDZ configuration. To switch on aerosols, you need to change some flags in

```
modips1/modeles/LMDZ/BENCH48x36x39/config.def
```

Specifically the following changes should be made:

- `flag_aerosol=6` or any other relevant number
- `ok_ade=y` to activate aerosol-radiation interactions
- `ok_aie=y` to activate aerosol-cloud interactions

As `apr_type=actuel`, only these two aerosol files are required for the simulation:

- `aerosols1980.nc` : 'present-day' aerosol file
- `aerosols.nat.nc` : preindustrial (year 1850) aerosol file

No need to recompile the model. You may just rerun the benchmark experiment.

```
./gcm.e
```

This returns an error message as one additional flag needs to be activated. Return to `config.def` and change the following flag (or add it if it's missing) :

- `ok_cdc=y` to activate the computation of cloud droplet number concentrations as required for `ok_aie=y`.

This time, the model runs, and 3 output files are created : `histhf.nc`, `histday.nc` and `histmth.nc`. As you run by default for 1 day only (`nday=1` in `run.def`), `histmth.nc` will be 'empty' (the variables are listed in it, but no values; `time_counter` contains 0 timesteps ; a minimum of 5 days of run are needed for `histmth.nc` to be filled in).

The following diagnostics for tropospheric aerosols can be made available in the different output files :

- `topswad` : top-of-atmosphere shortwave aerosol direct forcing
- `topswad0` : top-of-atmosphere shortwave aerosol direct forcing in clear-sky
- `topswai` : top-of-atmosphere shortwave aerosol indirect forcing
- `od550aer` : aerosol optical depth at 550 nm
- `od550ltaer` : aerosol optical depth at 550 nm for the fine aerosol mode
- `od550****` : optical depth for the different aerosol tracers, named according to their mode (Accumulation/Coarse/Super-coarse) + Soluble/Insoluble + Name (BC/POM/SO4/NO3/SS/DUST) + M for 'mode' (Ex : CIDUSTM= Coarse Insoluble DUST Mode).

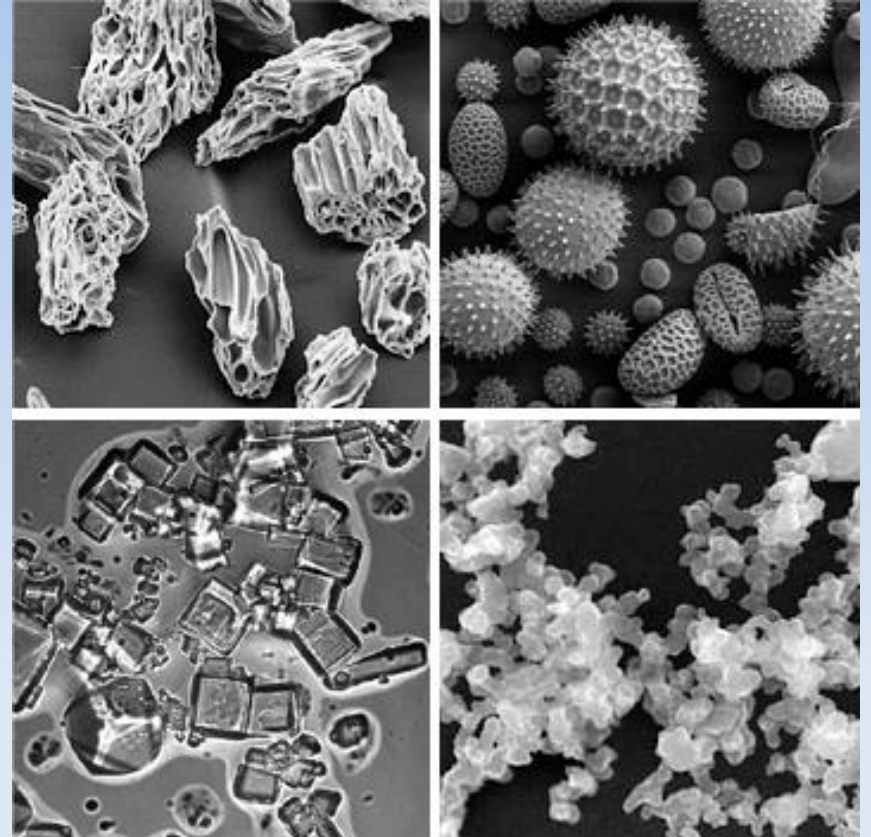
With the default settings in the `BENCH48x36x39` folder (see `phys_out_filelevels` in `config.def`), all aerosol diagnostics are available in `histday.nc`, none of them in `histhf.nc`. To be sure that a given diagnostic (ex : `'topswad'`) will be present in all output files, you can insert in the `config.def` file this type of lines :

```
flag_topswad=0 0 0 0
and then rerun the model.
```

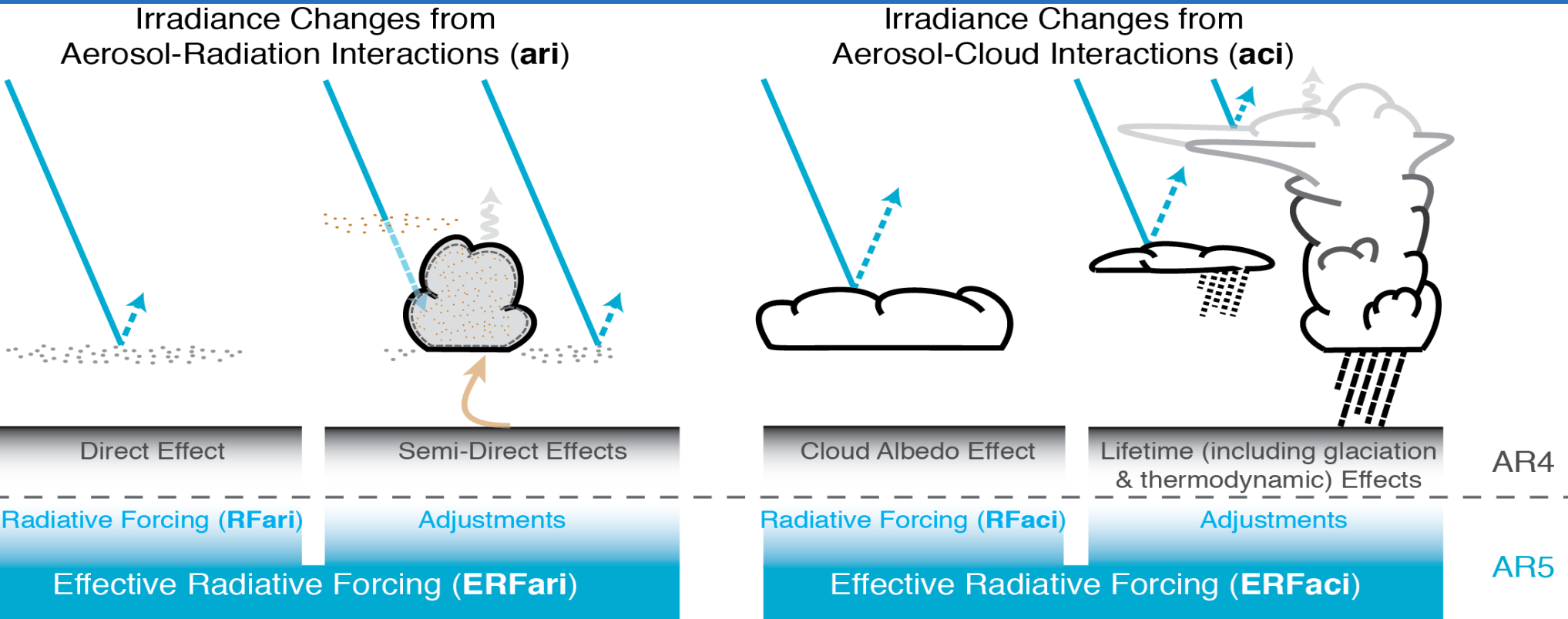
You may visualise the variables that are available in your output files.

Atmospheric aerosols

Particles in suspension in the atmosphere, with size ranging from a few nm to 100 μm , but particularly important for climate between 0.1 and 10 μm . Both natural and anthropogenic sources. Primary and secondary aerosols.



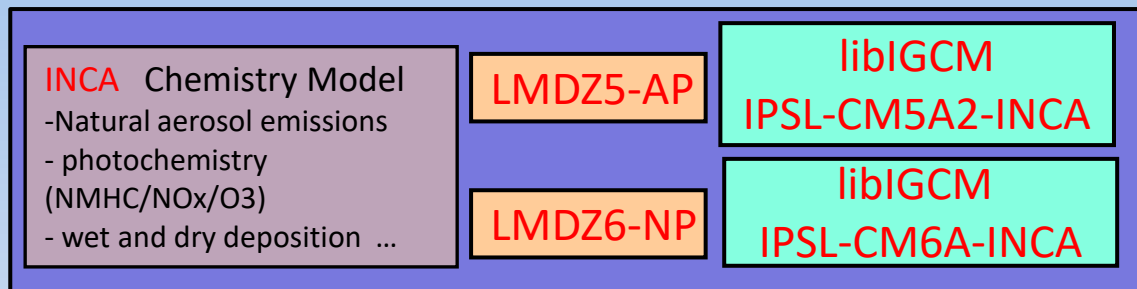
Categorization of aerosol effects



Aerosols in LMDz

Online

Offline



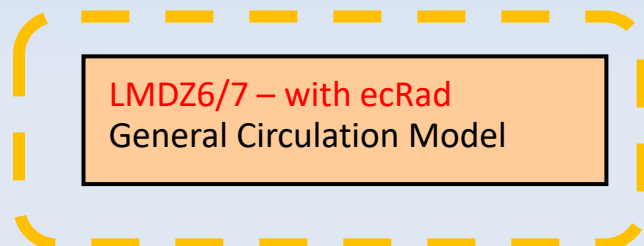
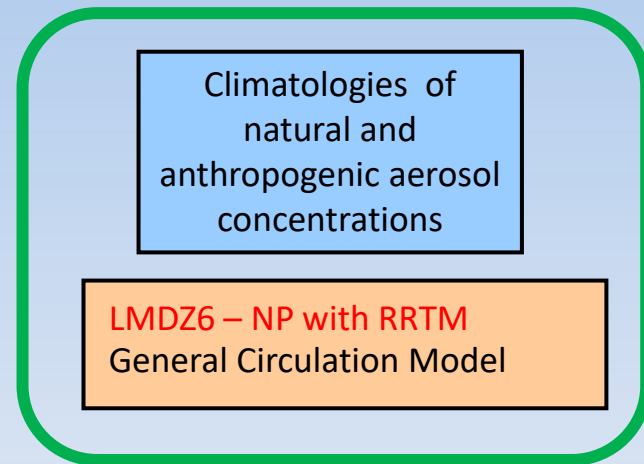
Simple aerosol model with **-dust** compilation option

LMDZ6 – NP with RRTM
General Circulation Model

Sectional stratospheric aerosol model with **-StratAer** compilation option

LMD6 – NP with RRTM
General Circulation Model

libIGCM CM6.1.11
IPSL-CM6A-INCA



Aerosols: running w or w/o INCA

- LMDZ with INCA: runtime parameter in config.def, **aerosol_couple = y**, requires libIGCM environment version with interactive aerosols, management of radiative transfer is somewhat different to that of LMDZ without INCA in AP (old physics) but same in NP + RRTM (new physics) except for a few things
- LMDZ without INCA: runtime parameter in config.def, **aerosol_couple = n**

Available aerosol types

Runtime parameter in config.def **flag_aerosol** (int):

- 0: no tropospheric aerosol
- 1: sulfate
- 2: black carbon
- 3: particulate organic matter
- 4: marine salts
- 5: dust
- 6: all tropospheric aerosols
 - including nitrate in RRTM in CMIP6 climatologies
- 7: anthropogenic aerosols from MACv2SP
 - aerosol plume model from MPI Hamburg
 - see Stevens et al., GMD, doi: /10.5194/gmd-10-433-2017, 2017.

Aerosols: input files

- If $0 < \text{flag_aerosol} \leq 6$:
gcm.e reads aerosol data from two files **aerosols.nat.nc** and may need a second file depending on the value of
- runtime parameter **aer_type** (char) in config.def:
 - **preind**: pre-industrial aerosols **aerosols.nat.nc** only
 - **actuel**: use a climatology of natural + anthropogenic aerosols **aerosols.nat.nc** + **aerosols1980.nc** (fixed name, meaningless)
 - **annuel**: **aerosols.nat.nc** + **aerosolsYYYY.nc**
where YYYY is the current year in the model simulation

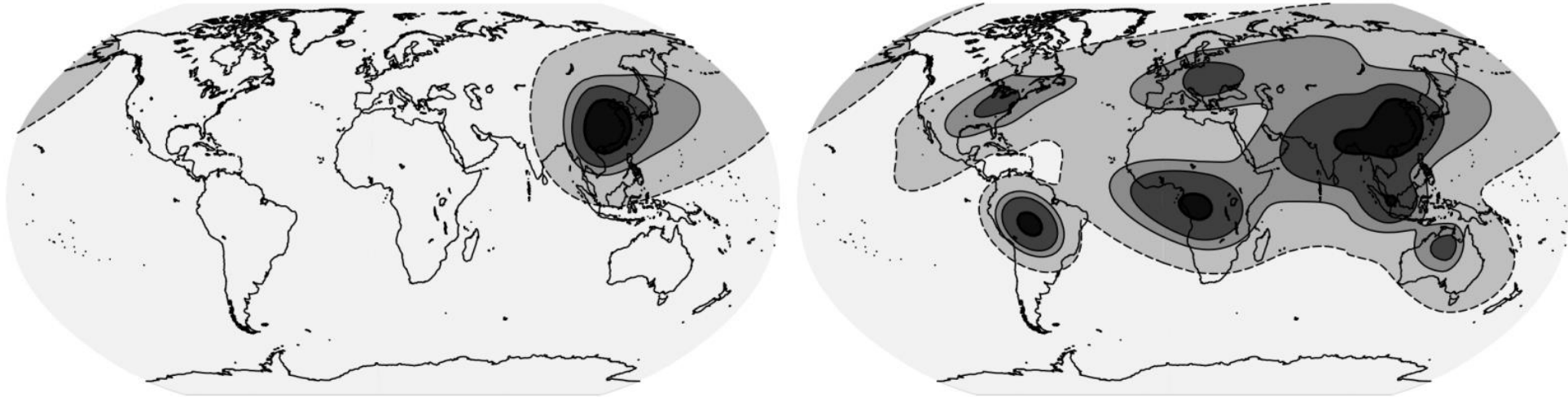
Aerosols: input files (continued)

- Input files should contain concentrations of aerosols of all the desired types (according to `flag_aerosol`) with nitrates being optional
- Input files should already be horizontally regridded to the LMDZ grid
- For LMDZ5 as used in AR5 runs, the input is for 19 layers and regridded online to the klev layers of the model. For LMDZ6 as used in AR6 runs, the input is for 79 layers. But providing the input on a different vertical grid is OK.

Aerosols: input files (continued)

- If **flag_aerosol = 7**:
 - requires **aerosols.nat.nc**
 - requires **aerosols1980.nc = aerosols.nat.nc** (fudge)
 - requires input file **MACv2.0-SP_v1.nc**
 - ⇒ does not depend on resolution
 - module **mo_simple_plumes.F90** and routine **macv2sp.F90** adds a set of anthropogenic plumes on top of the natural aerosol
 - function of (month, year) but $1850 \leq \text{year} \leq 2017$

Aerosols: flag_aerosol=7



550 nm AOD with 0.005, 0.05, 0.1 and 0.3 contour levels

Plumes can be selected / deselected if needed

From Stevens et al. (GMD, 10, 433–452, 2017)

See also Fiedler et al. (GRL, doi:10.1029/2023GL104848)

Aerosols: direct and indirect effects

- Runtime parameters `ok_ade` and `ok_aie` (logical) in `config.def` to activate direct and indirect effects of anthropogenic aerosols
- If `ok_ade = n` then direct effect of natural aerosols only (and no anthropogenic aerosols)
- If `ok_aie = n` then indirect effect of natural aerosols only (and no anthropogenic aerosols)

Aerosols: direct and indirect effects

- You can choose `ok_ade` and `ok_aie` independently
- `flag_aerosol` must be ≥ 1 if `ok_ade` or `ok_aie` is `y`
- If `ok_ade` or `ok_aie` is `y` and forcing diagnostics are requested (e.g. `topswad`, `solswad`, `topswai` and `solswai`, ...) then double radiation calls w/ and w/o anthropogenic aerosols are automatically called
- Note that for online aerosols (i.e. INCA) in LMDZ-NP `topswai` and `solswai` diagnostics are meaningless

Aerosols for expert users (1/2)

Runtime parameters in config.def in case **ok_aie** = y

ok_cdnc = y

bl95_b0 = 1.7

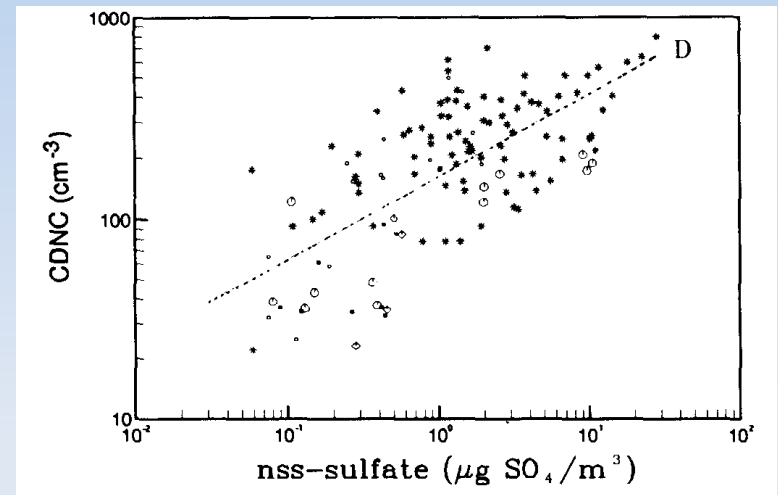
bl95_b1 = 0.2

$$\text{CDNC} = 10^{b_0 + b_1 \log(m \text{ SO}_4)}$$

(recommended values)

Link cloud droplet number concentration to aerosol mass concentration (Boucher and Lohmann, Tellus, 1995)

b0=1.3 and uses mass of all soluble species



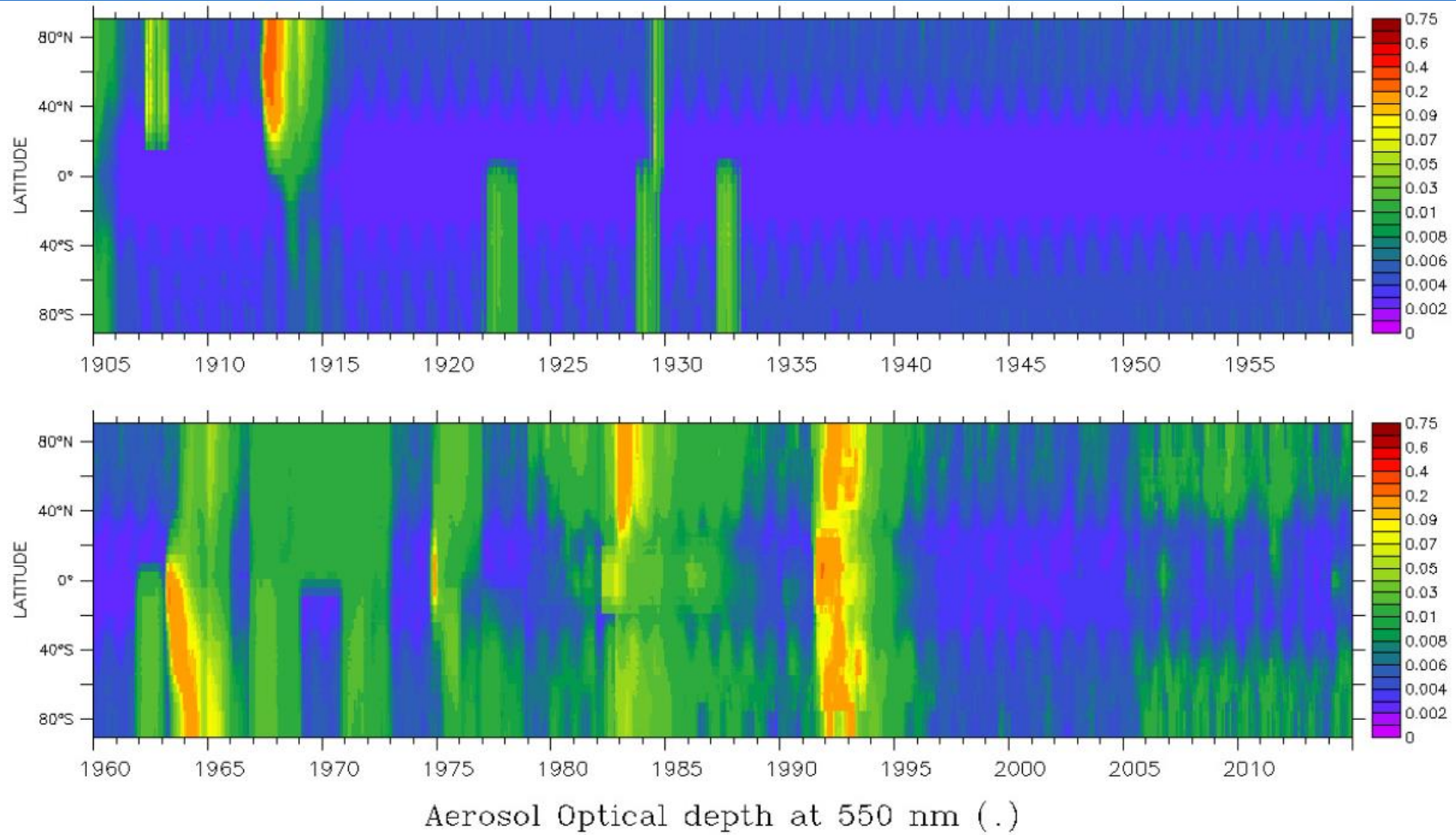
Aerosols for expert users (2/2)

- If you want to compute at each time step the direct or indirect effect that aerosols would have, but not let those effects impact the simulation (e.g. to get the same meteorology with different RF estimates)
 - Choose `flag_aer_feedback = n` at runtime
 - Choose `flag_aerosol > 0` at runtime
 - Choose `ok_ade = y` or `ok_aie = y` at runtime

Stratospheric aerosols

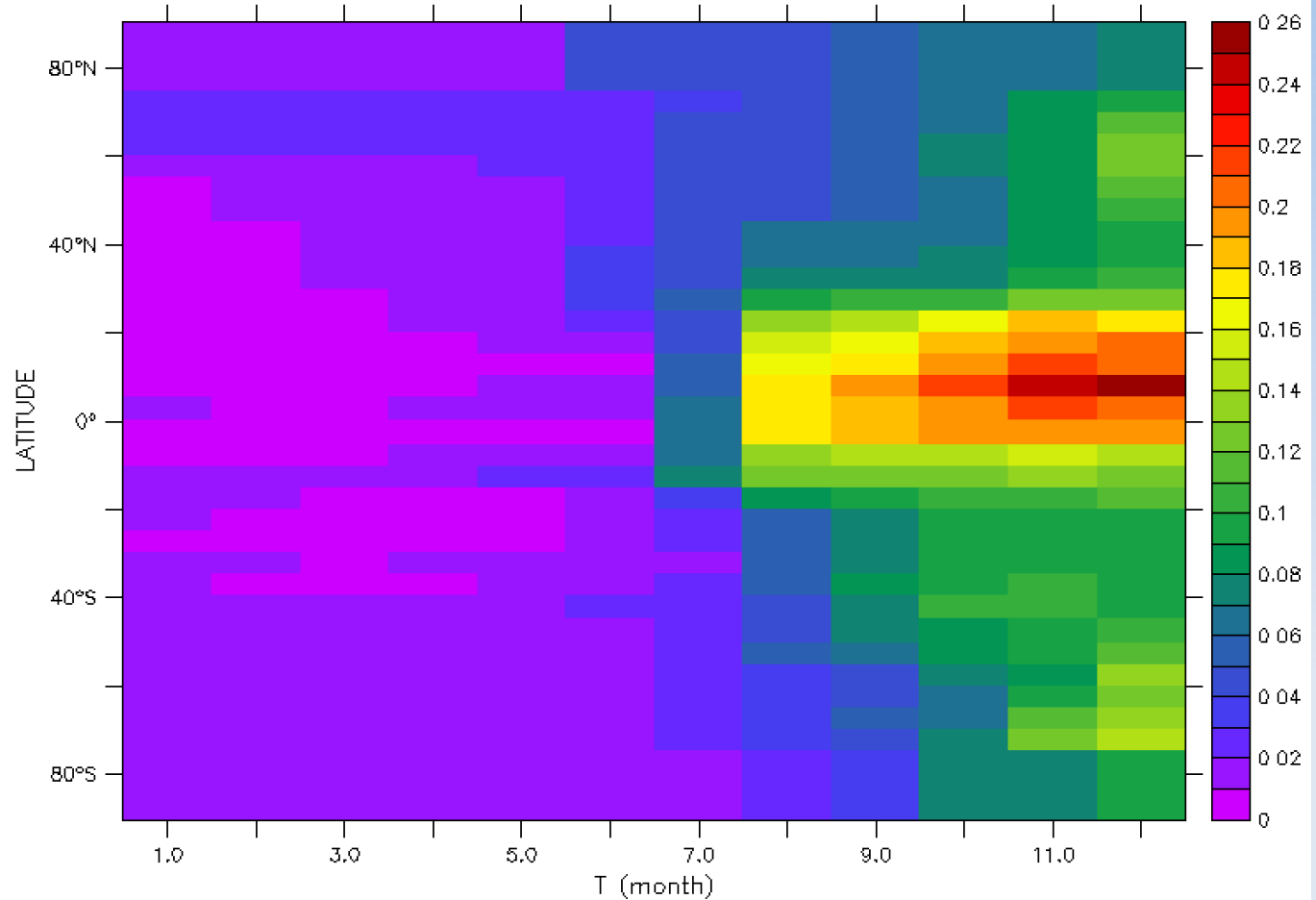
- `flag_aerosol_strat` = 0 (none), 1 (Sato) or 2 (CMIP6)
- gcm.e reads 2D (latitude-height) aerosol data with monthly timestep
- Input data are available over period 1750 to 2010 (Sato) or 2014 (CMIP6)
- A routine exists to prepare input files to various resolutions http://forge.ipsl.jussieu.fr/igcmg/svn/TOOLS/CMIP6_FORCING/AER_STRAT/
- Direct effect in SW (old radiation + RRTM) and in the LW (RRTM only, dependent on aerosol size)

CMIP6 stratospheric aerosols



CMIP6 stratospheric aerosols (zoom)

Example:
550 nm AOD
CMIP6 data
Year 1991



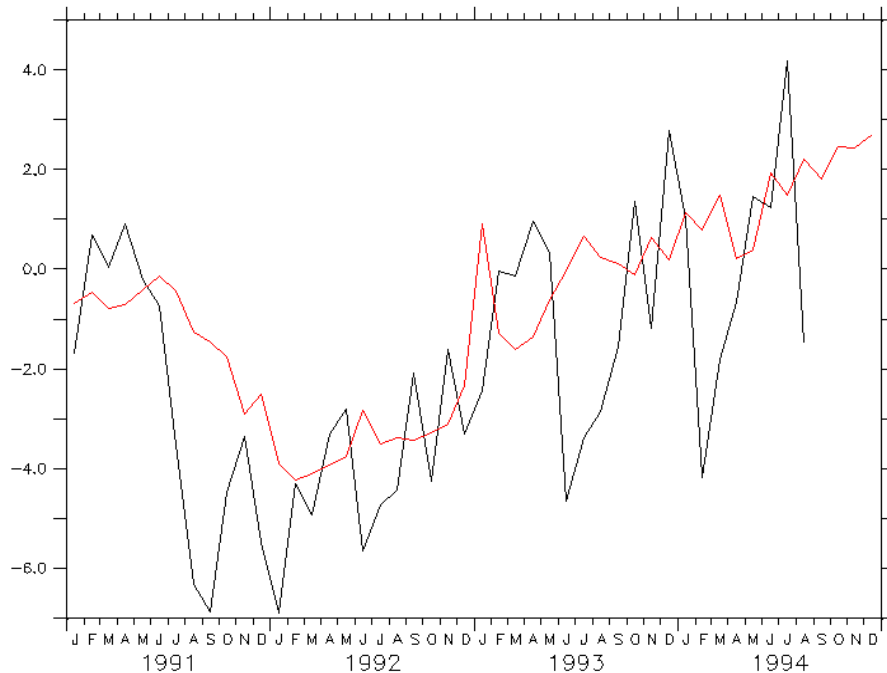
Stratospheric aerosols: Pinatubo

Observations (ERBE) vs Model

SW

CALENDAR: JULIAN

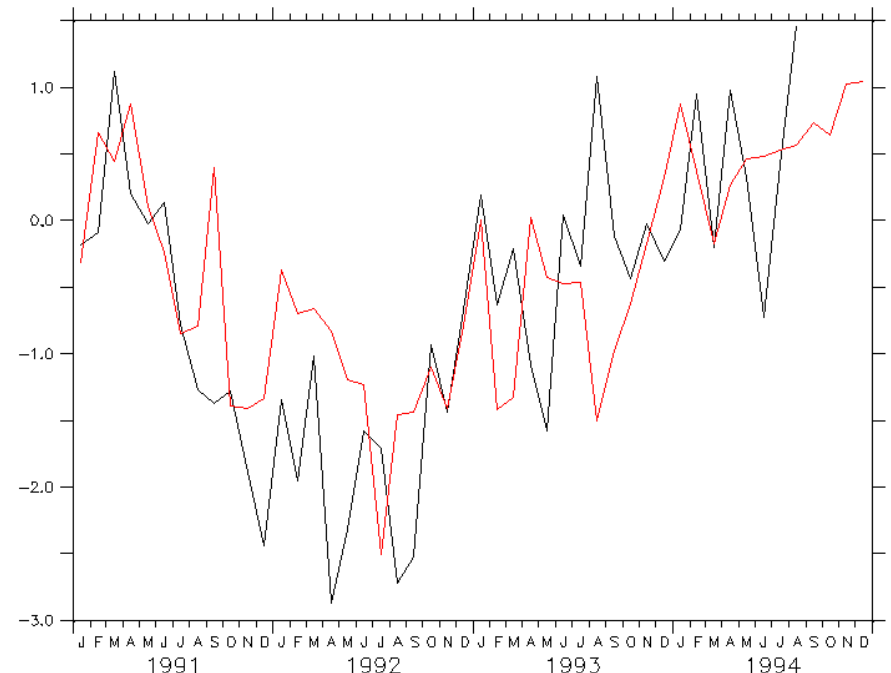
FERRET Ver. 6.67
NOAA/JWEL/1949
15-DEC-2014 10:22:30



LW

CALENDAR: JULIAN

FERRET Ver. 6.67
NOAA/JWEL/1949
15-DEC-2014 10:24:43



Stratospheric aerosols

- Runtime parameter **ok_volcan** (logical)
- If **ok_volcan** = *y* and **ok_ade** = *y*
- The model uses double radiation calls to diagnose the radiative effects and heating rates of stratospheric aerosols instead of that of anthropogenic aerosols
- Runtime parameter **flag_volc_surfstrat** (0, 1, 2)
Decouples surface cooling and stratospheric heating.
Activate forcing surface cooling rate (=1), stratospheric heating rate (=2) or nothing (=0, default)

Forcing diagnostics:

topswad, topswad0, topswai, solswad, solswad0, solswai

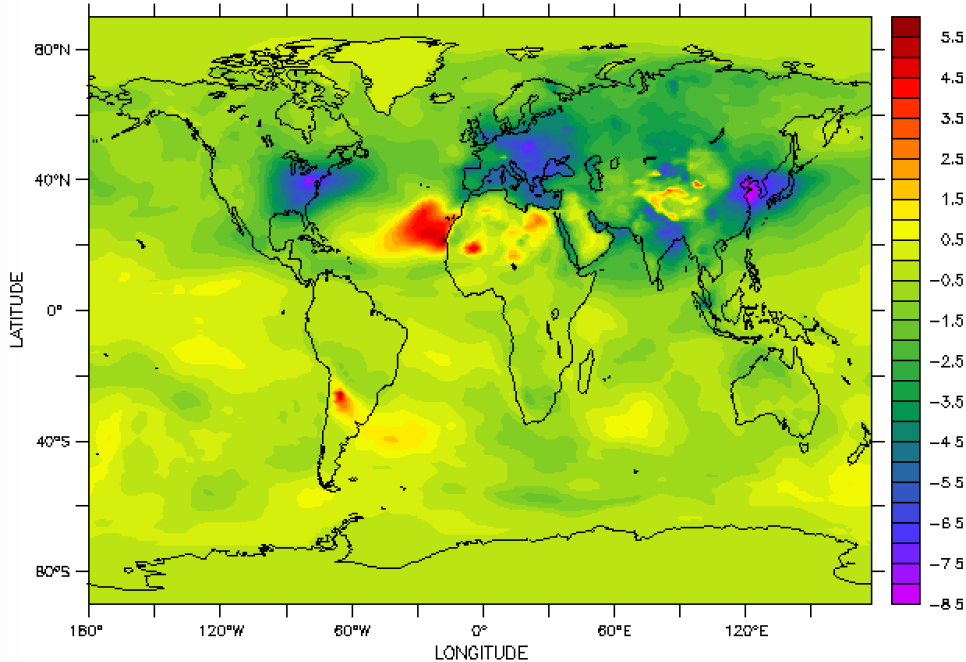
Example: topswad0

TIME : 16-JUL-1991 12:00

Created by xios

DATA SET:
CN818bwa-LR-Int-TESTv0a2_19910101_19911231_IN_NARv0b

15-DEC-2016 09:29:10



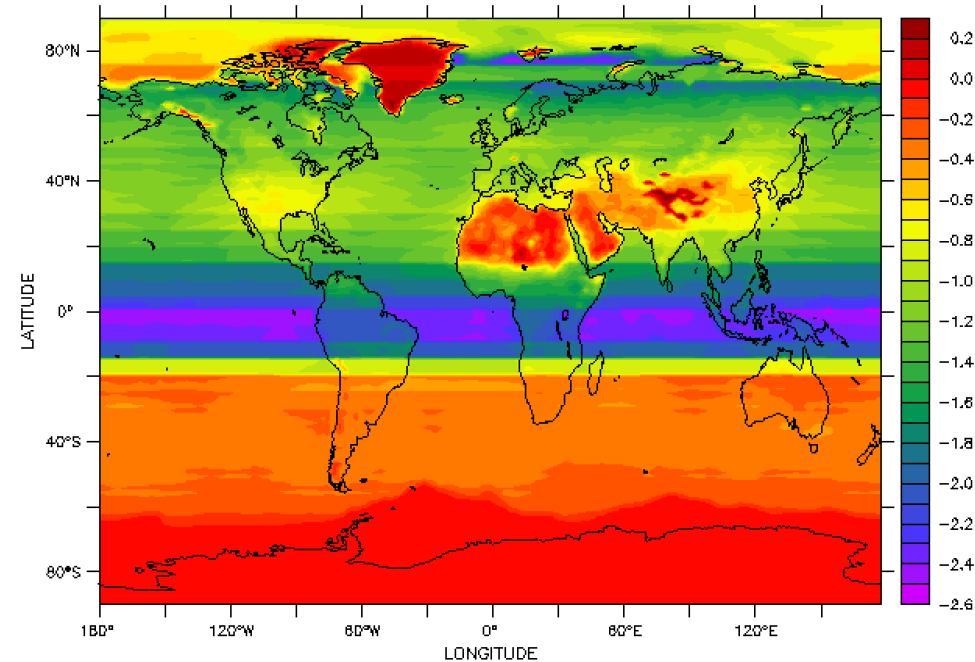
ADE clear-sky at TOA (W/m2)

TIME : 16-JUL-1991 12:00

Created by xios

DATA SET:
CN818bwa-LR-Int-TESTv0a2_19910101_19911231_IN_NARv0b

15-DEC-2016 09:29:26

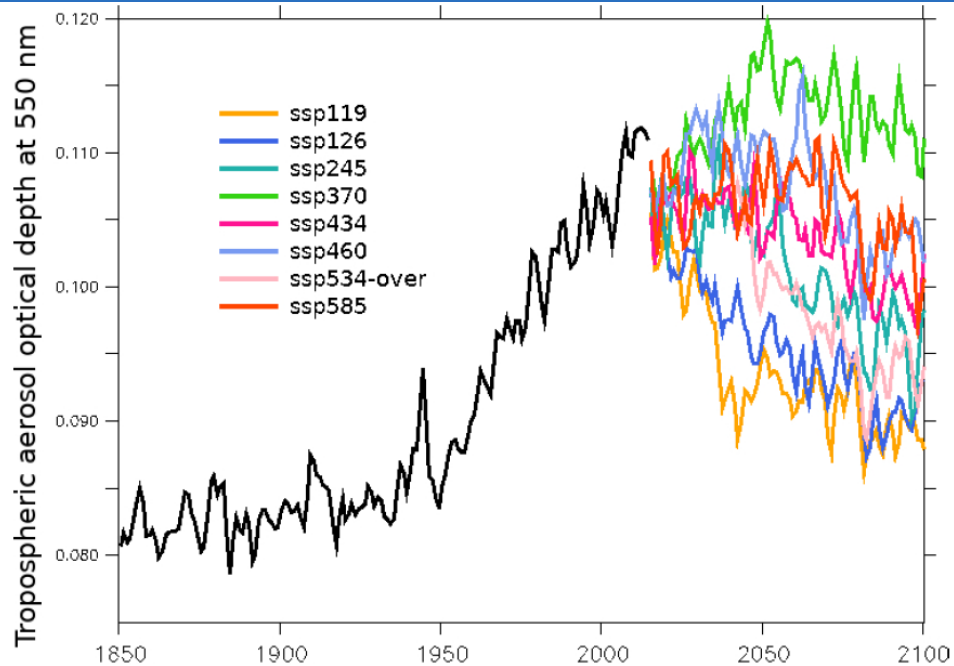


ADE clear-sky at TOA (W/m2)

ok_volcan = n (default)

ok_volcan = y

AOD in LMDZ6 *historical* runs



Lurton et al., JAMES, 2020
doi: 10.1029/2019MS001940

Figure 11. Annual and global mean of the tropospheric aerosol optical depth at 550 nm (unitless) as diagnosed in IPSL-CM6A-LR in the *r1 historical* (black line) and eight different *r1 scenario* experiments (color lines). The running mean entails a gap at the historical/scenario junction.

Aerosol IRF & ERF in LMDZ6

Forcing	IRF	ERF - fixed SST
Aerosol-radiation interactions	-0.38	N.A.
Aerosol-cloud interactions	-0.34	N.A.
Aerosol total effect	-0.73	-0.62±0.024

Table 2. Values of IRF and ERF for LMDZOR-INCA aerosols, for the year 2014, from fixed SST experiments. All forcing estimates are in W m^{-2} . ERF was calculated over 100-year time series, i.e., over the last 25 years of each 30-year member, on 4-member ensembles for each experiment. N.A.: not available. The ERF is not corrected for land surface temperature change.

RRTM (-rrtm true / -rad rrtm)

- Tropospheric and stratospheric aerosols are available in RRTM, but only for the 2 and 6 SW wavebands case (NSW=2 or 6)
- Revised optical properties with routines available
http://forge.ipsl.jussieu.fr/igcmg/svn/TOOLS/CMIP6_FORCING/AER_OPTICS/
- Reunified routine for offline (LMDZ) and online (INCA) aerosols
- LW properties for dust, forthcoming for the rest



ECRAD (-rad ecrad)

Merci
Lionel !

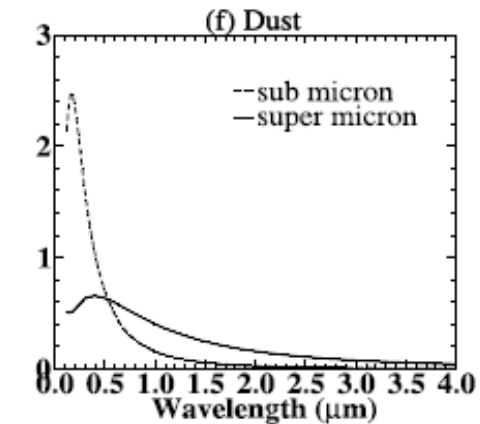
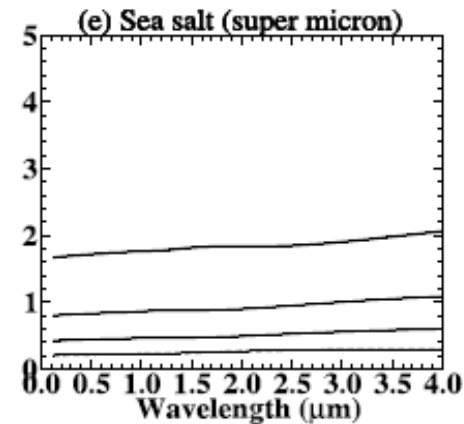
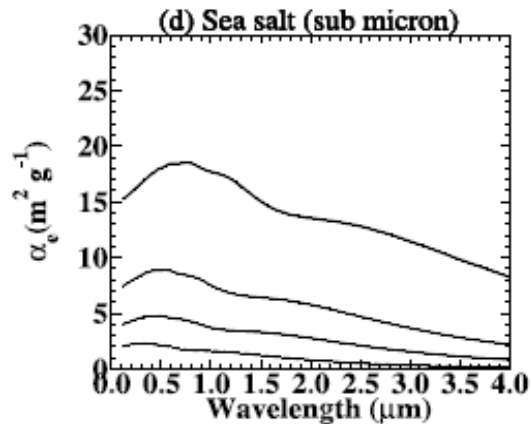
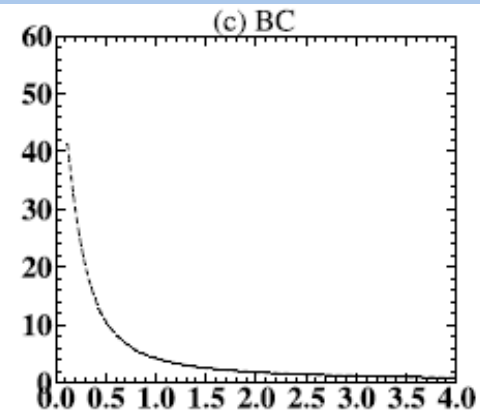
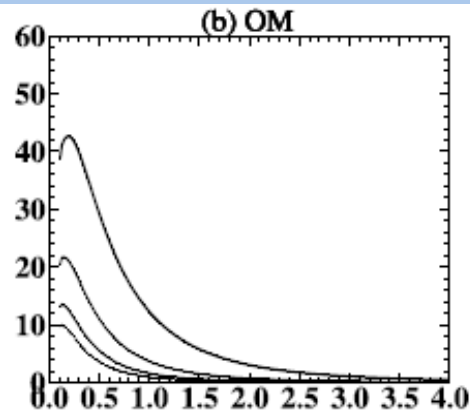
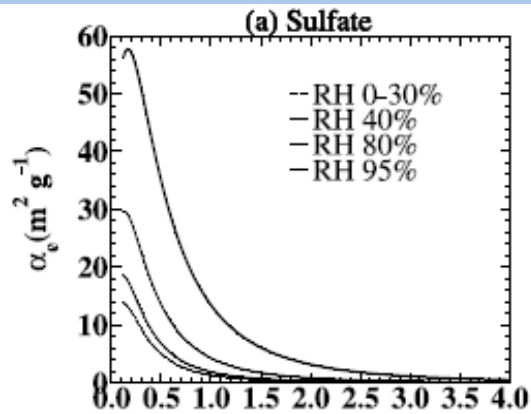
- 14 spectral bands in the SW
- 16 spectral bands in the LW
- Aerosol optical properties as netcdf
- Streamlined routines to create netcdf file

https://gitlab.in2p3.fr/ipsl/lmd/dpao/Aerosol_optics

```
git clone git@gitlab.in2p3.fr:ipsl/lmd/dpao/Aerosol_optics.git
```

- But still a lot to do and test (g-weight, strat aerosols, coupling to INCA, etc)

Aerosol optical properties



Example
only
 $f(\text{RH}, \lambda)$

INCA aerosol in LMDZ-NP

- Reunified aerosol optical properties routine for offline (LMDZ) and online (INCA) aerosols
- Takes into account mixing by boundary layer, thermals and convection (with or without simultaneous scavenging)
- Requires interactive natural sources of aerosols
- Still being improved for AerChemMIP but have been used to prepare CMIP6 aerosol climatologies
- Runs IPSL-CM6 v6.1.11 with libIGCM software