Aerosols in LMDZ model

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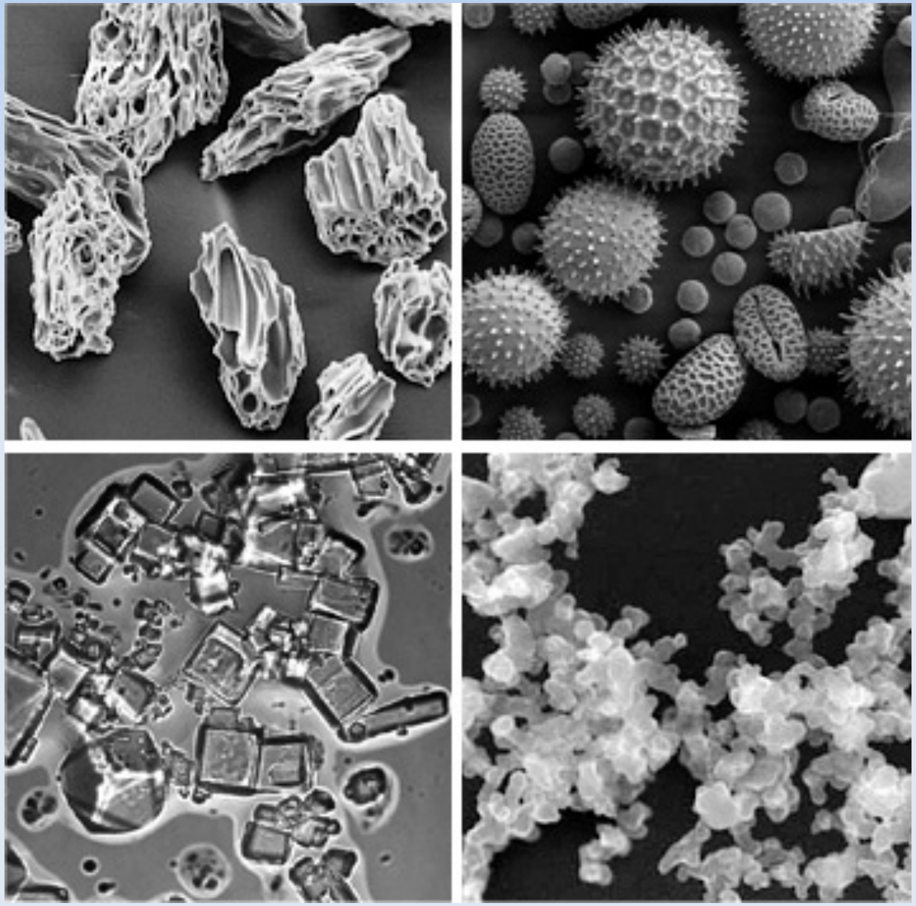
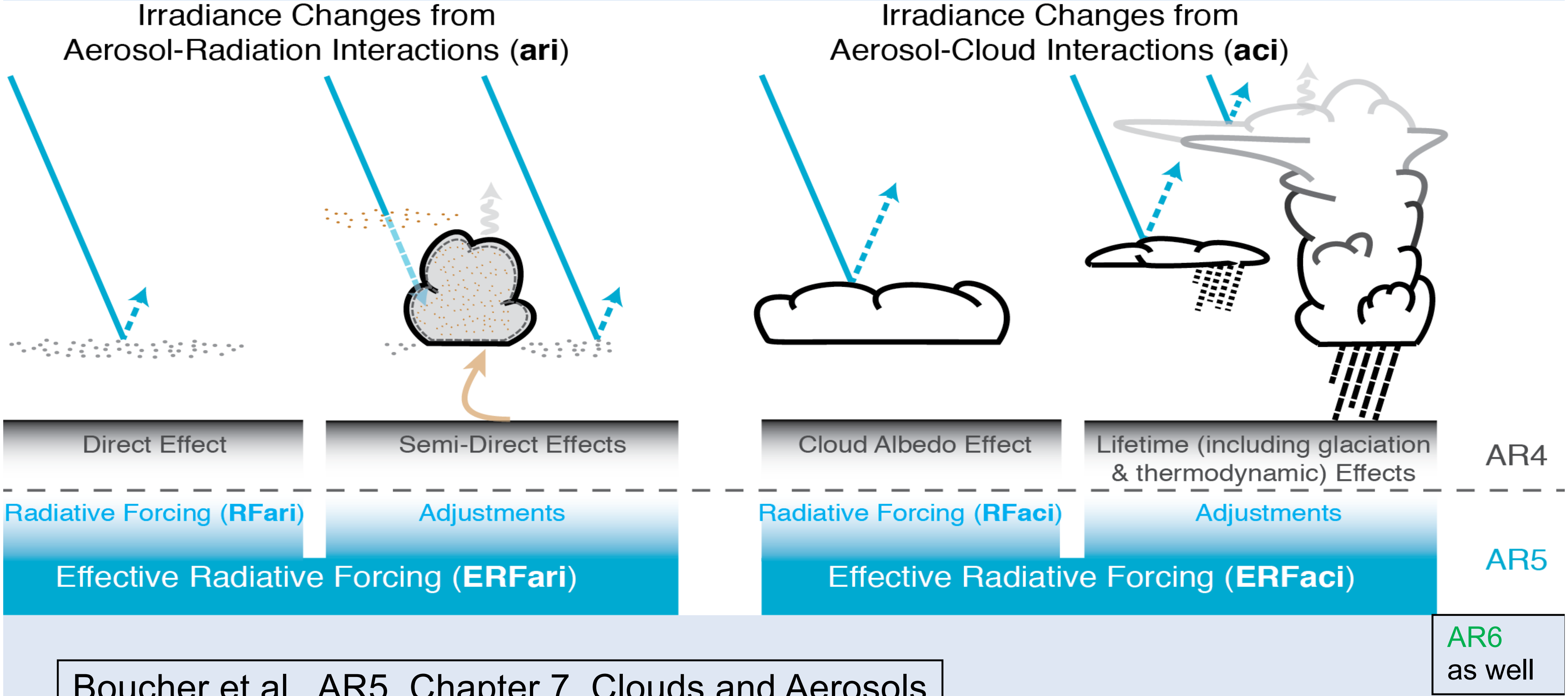
Atmospheric aerosols

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



Boucher et al., AR5, Chapter 7, Clouds and Aerosols

Aerosols in LMDZ

Online

INCA Chemistry Model
-Natural aerosol emissions
- photochemistry (NMHC/NOx/O3)
- wet and dry deposition …

LMDZ5-AP

libIGCM
IPSL-CM5A2-INCA

LMDZ6-NP

libIGCM
IPSL-CM6A-INCA

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

LMDZ6 – NP with RRTM
General Circulation Model

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

LMDZ6 – NP with RRTM
General Circulation Model

libIGCM CM6.1.11
IPSL-CM6A-INCA

Offline

Climatologies of natural and anthropogenic aerosol concentrations

LMDZ6 – NP with RRTM
General Circulation Model

LMDZ6/7 – with ecRad
General Circulation Model

Aerosols: running w or w/o INCA

- LMDZ with INCA:

  interactive tropospheric aerosols

  - parameter in config.def : aerosol_couple = y

  - requires libIGCM environment

- LMDZ without INCA: prescribed aerosol concentrations or optical properties ;

  - parameter in config.def, aerosol_couple = n

INCA aerosols in LMDZ-NP

- (Re)unified 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
- Used in AerChemMIP ; also to prepare CMIP6 aerosol climatologies

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: sea 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 < flag_aerosol <= 6:
  gcm.e reads aerosol data from **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)

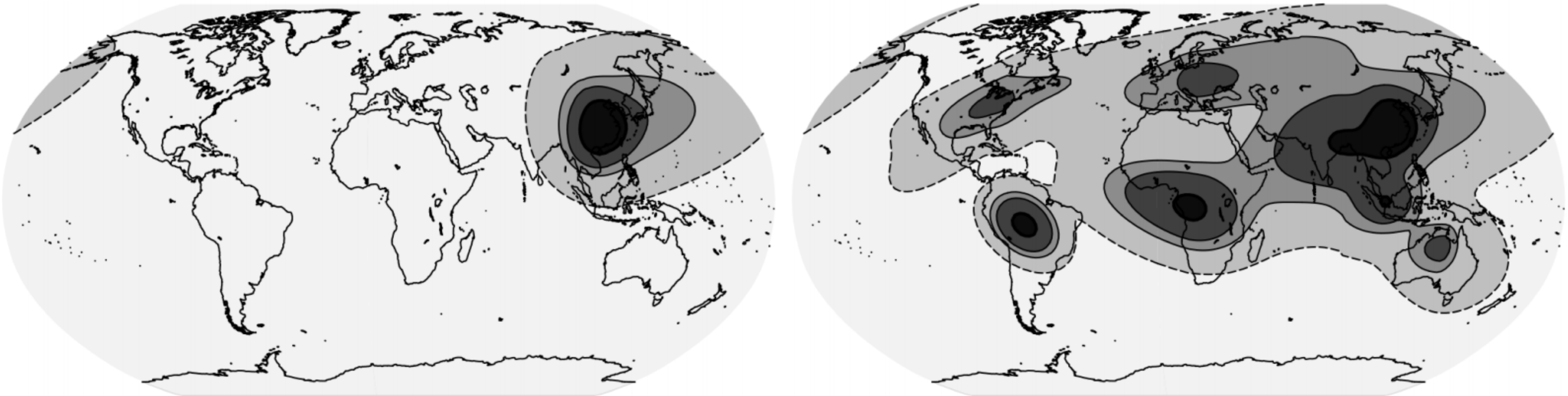
- Input files should contain concentrations of aerosols of all the desired types (according to flag_aerosol) with nitrates being optional
- Input files should already be horizontally regridded to the LMDZ grid
- Providing the input on a different vertical grid is OK.

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** add a set of anthropogenic plumes on top of the natural aerosols
  - function of (month, year) for 1850 <= year <= 2023

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

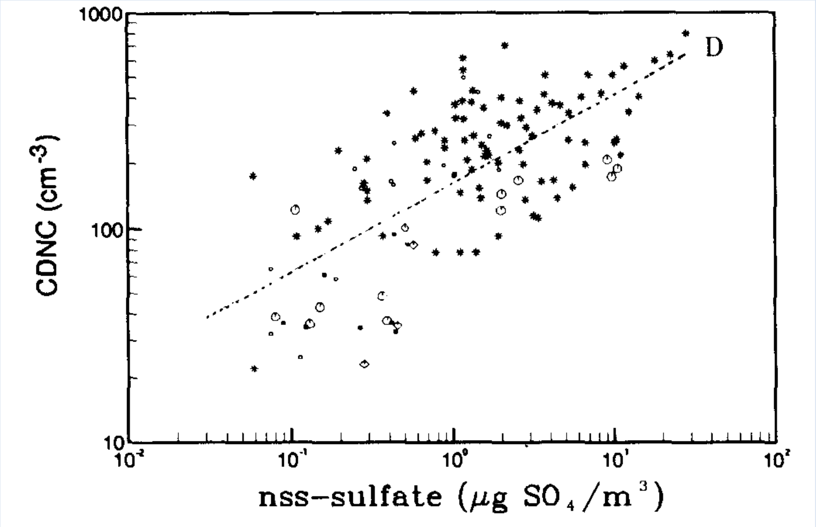
- You can choose ok_ade and ok_aie independently
- flag_aerosol must be ≥ 1 if ok_ade or ok_aie is y
- If ok_ade or ok_aie is y and forcing diagnostics are requested (e.g. topswad, solswad, topswai and solswai, ...) then double radiation calls w/ and w/o anthropogenic aerosols are automatically called
- Note : 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
(recommended values)

$$CDNC = 10^{\,b0 + b1 \log(m\,SO4)}$$



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

AOD in LMDZ6 *historical* runs

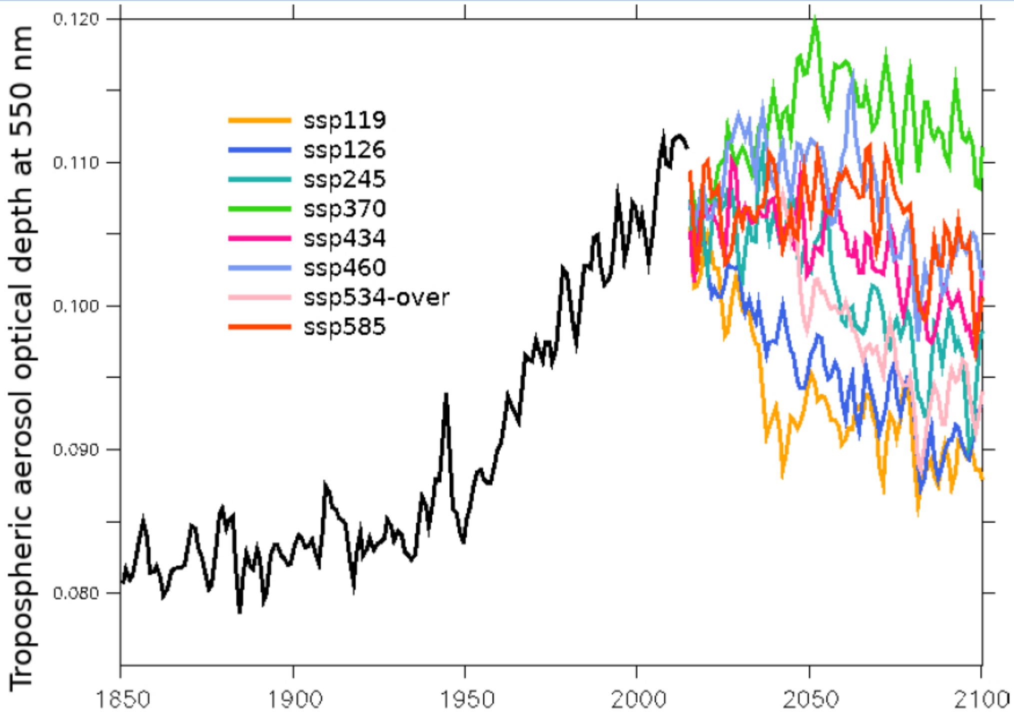


Figure 11. Annual and global mean of the tropospheric aerosol optical depth at 550 nm (unitless) as diagnosed in IPSL-CM6A-LR in the *r1 historical* (black line) and eight different *r1 scenario* experiments (color lines). The running mean entails a gap at the historical/scenario junction.

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

Aerosol IRF & ERF in LMDZ6

Forcing	IRF	ERF - fixed SST
Aerosol-radiation interactions	-0.22	N.A.
Aerosol-cloud interactions	–0.34	N.A.
Aerosol total effect	-0.56	–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 $\mathrm{W\,m^{-2}}$. 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.

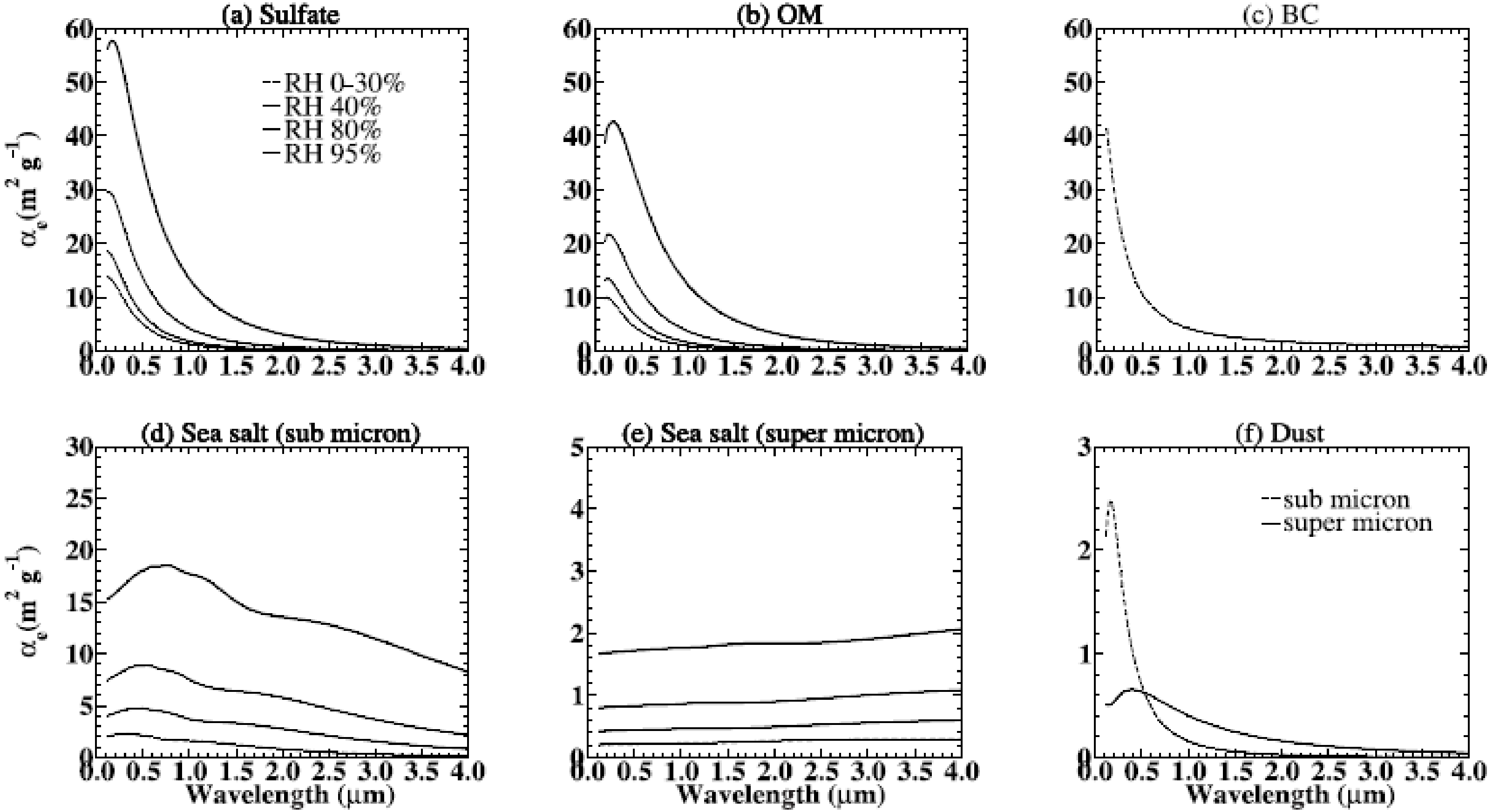
Lurton et al., JAMES, 2020, doi: 10.1029/2019MS001940

Optical properties of tropospheric aerosols (1/2)

Routines to compute optical properties for LMDZ with RRTM

- Extinction coefficient per unit mass
- Single-scattering albedo
- Asymmetry coefficient

Optical properties of tropospheric aerosols (2/2)



Types of tropospheric aerosol

- Accumulation + Coarse -- Soluble SO_4
- Super-coarse + Coarse + Accumulation -- Soluble Sea-Salt
- Coarse Insoluble Dust
- Accumulation -- Soluble + Insoluble -- Black Carbon
- Accumulation -- Soluble + Insoluble -- POM
- Accumulation Soluble + Coarse Soluble + Coarse Insoluble -- NO_3

Radiative effects taken into account

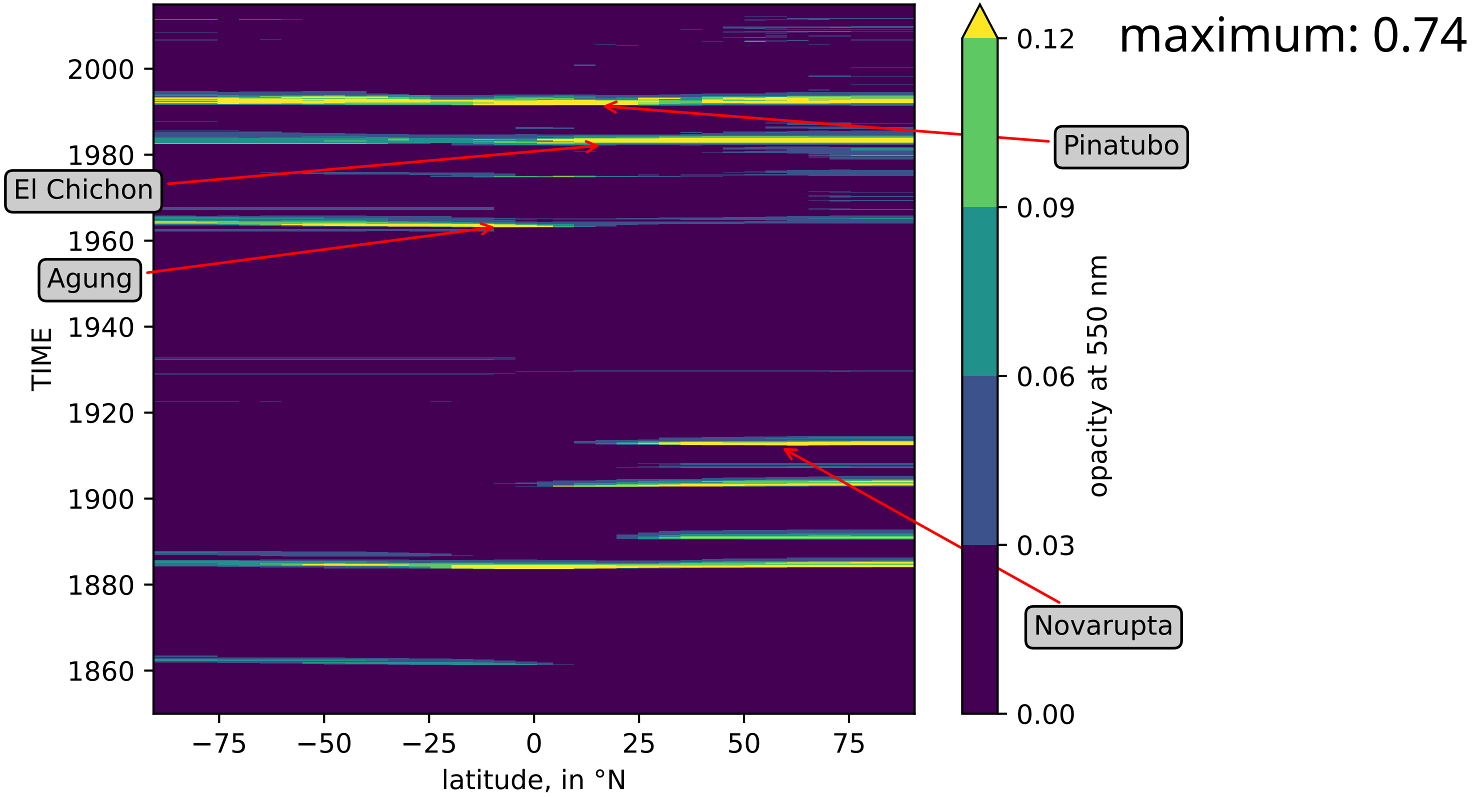
(With RRTM)

- Shortwave: absorption and scattering
- Longwave:
  - Absorption only, no scattering
  - For tropospheric dust (not for other tropospheric aerosol types)
  - For stratospheric aerosol

Stratospheric aerosols

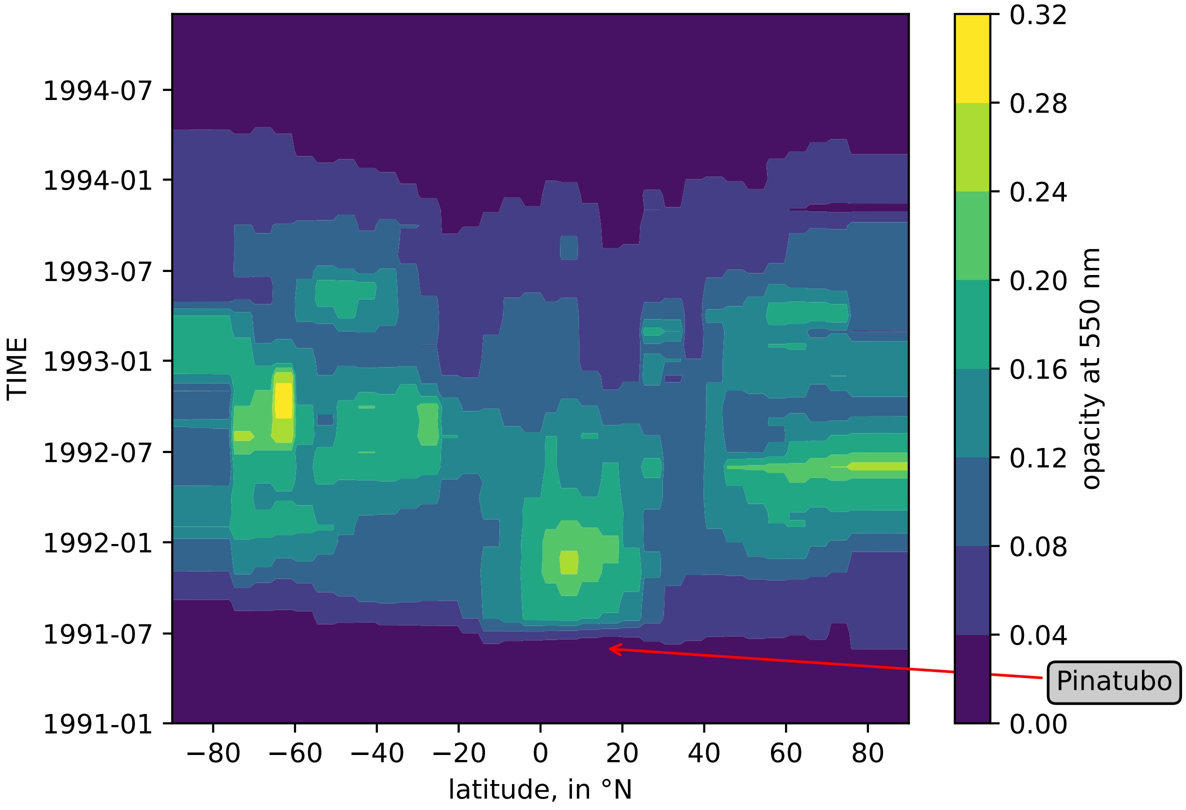
- `flag_aerosol_strat= 2` (CMIP6) instead of default 0 (no stratospheric aerosols)
- Works with the radiative code RRTM
- gcm reads 2D, latitude-vertical level, aerosol opacity with monthly timestep from files `tau[sl]wstrat.2D.nc`
- Note: input is opacity of each layer for stratospheric aerosol instead of extinction per unit mass and concentration for tropospheric aerosol

CMIP6 stratospheric aerosols

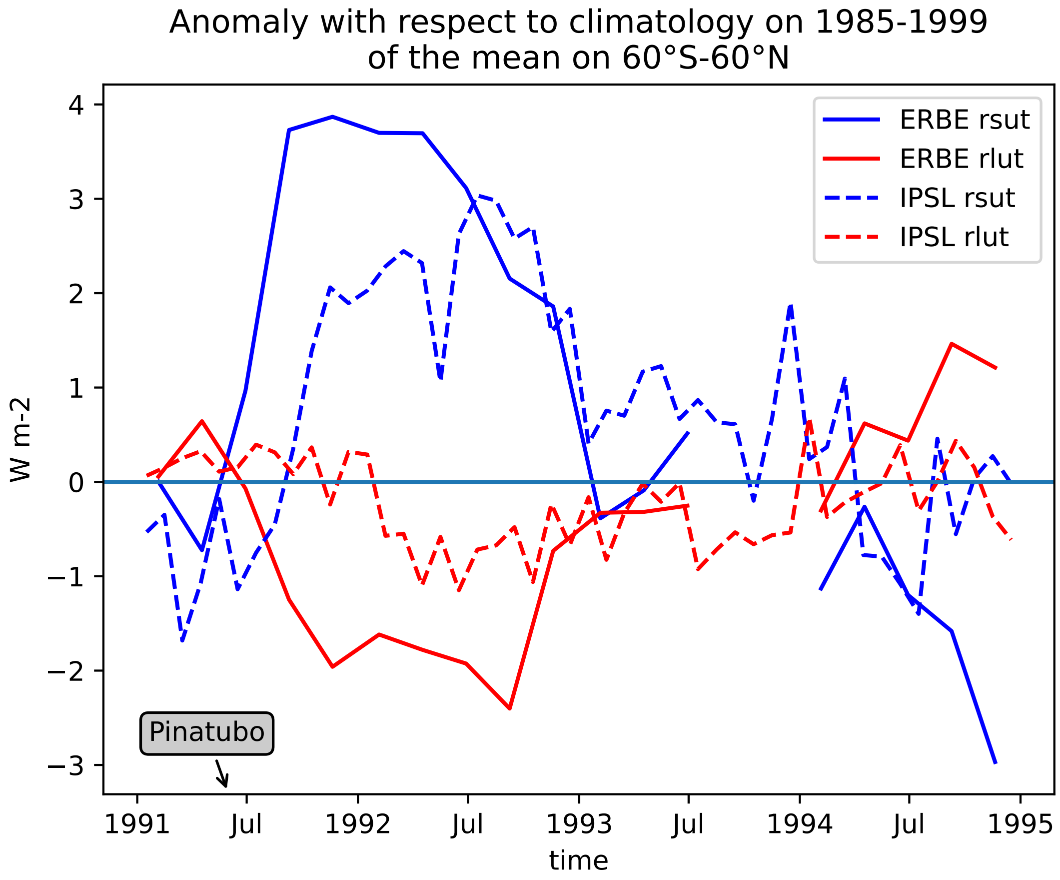


Lurton et al., 2020

Evolution after eruption



Observations versus model



Model:
IPSL-CM6A-LR
Experiment:
CMIP6 historical

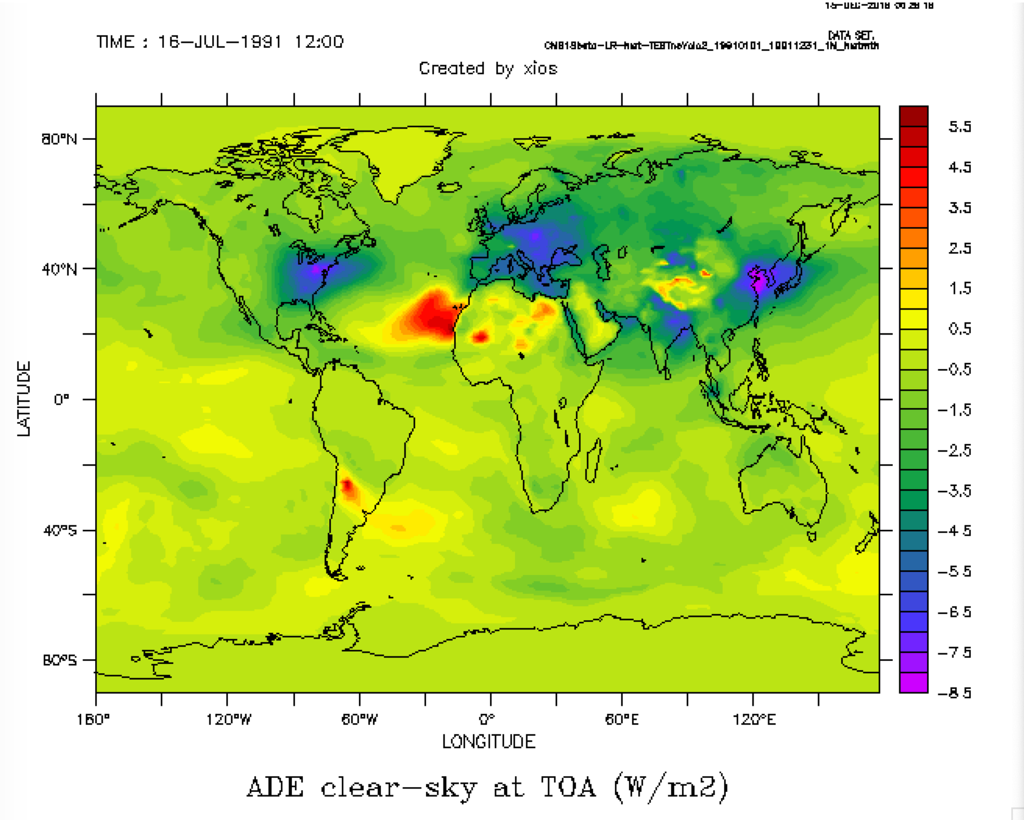
Diagnosis of forcing

- Runtime parameter `ok_volcan` (logical), default is false
- If:

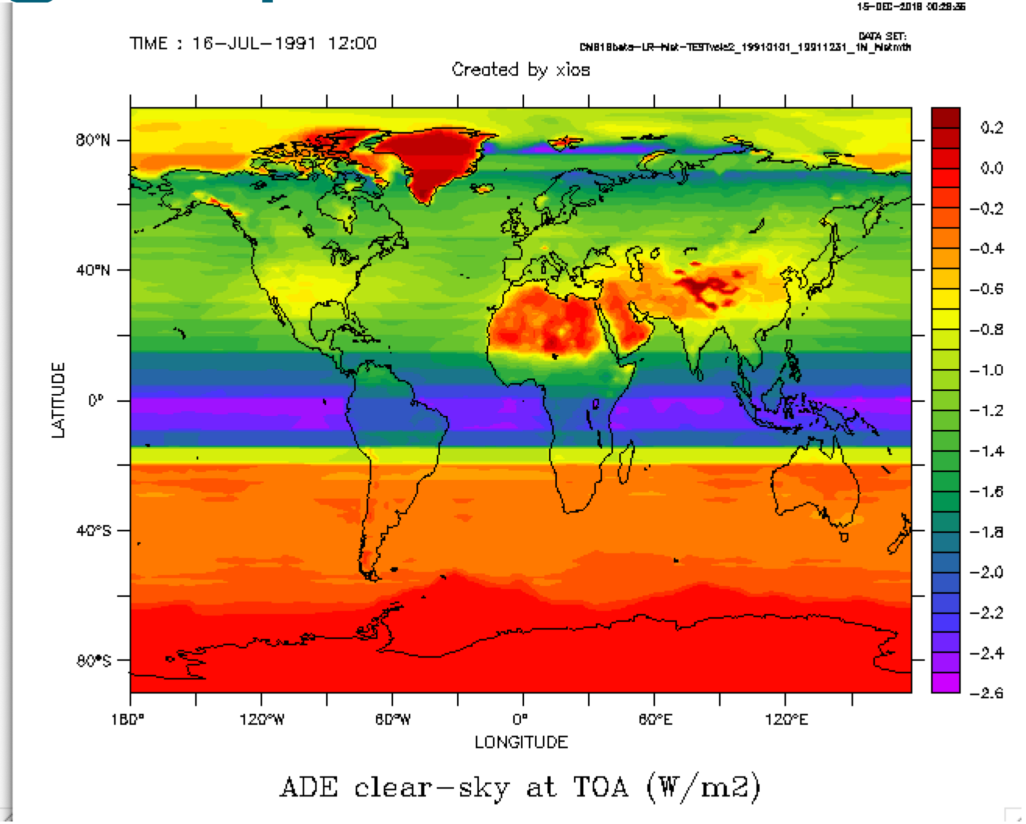
  ```
  flag_aerosol_strat = 2
  ok_volcan = y
  ok_ade = y
  ```

  then the model uses double radiation calls to diagnose the radiative effects and heating rates of stratospheric aerosols instead of that of anthropogenic tropospheric aerosols.

Shortwave forcing: topswad0



ok_volcan = n



ok_volcan = y