Aerosols and chemistry

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Overview

1. Why (focus on) aerosols?
2. The OsloAero aerosol scheme in NorESM
3. Emissions
4. (Other aerosol schemes)
5. Structure of the aerosol code
6. AeroTab : off-line generated look-up tables
7. Stratospheric aerosol
8. Boundary conditions
9. Structure of the code
10. Full-chemistry scheme
11. Modifying the aerosol/chemistry scheme
12. New features in the future

0. Aim / context

Context

- Specific Aerosol scheme “OsloAero” developed and implemented on top of existing CESM code

Aim of this presentation

- Get a flavour of the structure of the code
- Get a flavour of the functioning of the aerosol scheme
- Present content to grasp in 45 minutes and content to look through later
- Treat only limited amount of topics (many topics left out)

Names used

- OsloAero (the aerosol scheme), CAM-Oslo (CAM including the OsloAero scheme - old name), CAM-Nor (CAM including the OsloAero scheme, but also other non-NCAR changes)

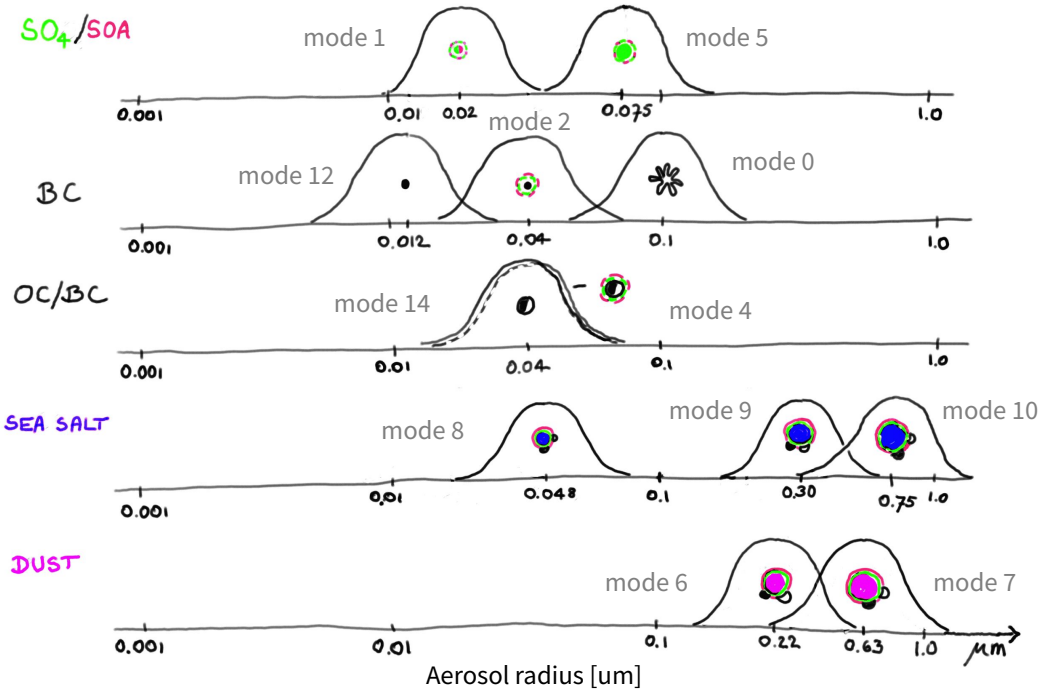
1. Motivation : why aerosols?

Climate change over the past century has been mitigated by aerosols. Knowing the aerosol impact allows us to better constrain the impact of GHGs.

Aerosol plays

- a direct role in radiation (**aerosol-radiation interaction**)
- an indirect role on radiation/precipitation by impacting cloud droplet and ice crystal numbers (**aerosol-cloud interaction**)
- a role by **changing the albedo** when deposited on snow/ice (black carbon and dust)
- (a role in **air pollution**)

2. The OsloAero aerosol scheme



Focus on **tropospheric** aerosol (natural and anthropogenic).

Consists of **12 log-normal modes** with specified NMR (number median radius) and sigma.

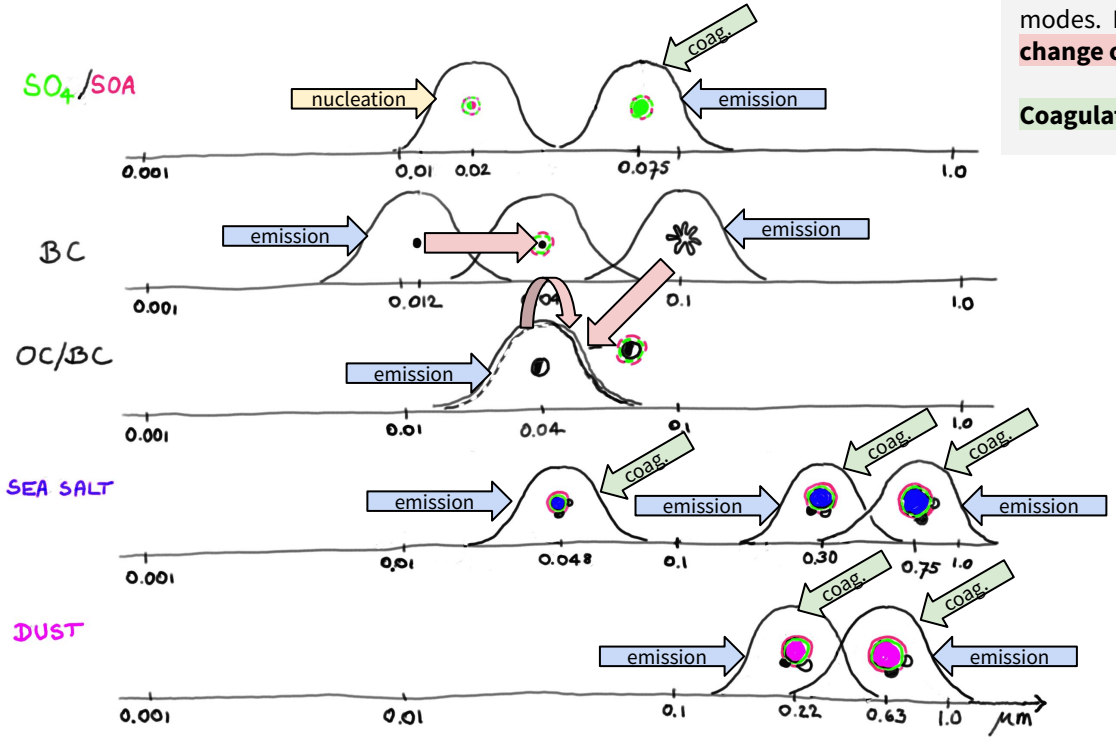
Aerosol **composition** (6) :

- BC (black carbon)
- OM (organic matter)
- SO_4 (sulfate)
- SS (sea salt)
- DST (mineral dust)
- SOA (second organic aerosol)

No nitrate, no ammonium (only implicit ammonium).

In many aspects, SOA has the same properties as OM.

The aerosol processes



Aerosol dynamics

Initial aerosol from **nucleation** (1 mode)

Initial aerosol from **emissions** (9 modes).

Condensation of low volatile gases on all aerosol modes. Leads to **growth** (all modes) and possible **change of class** (2 modes).

Coagulation of 6 smaller modes to 6 larger modes

Aerosols are transported and removed

Aerosol is transported (large-scale winds, convection, turbulence, …)

Aerosol is affected by below cloud scavenging, gravitational settling, dry deposition, and activation.

Role of aerosol for climate

Interaction with **radiation**

Impact **cloud droplet number/size** through activation.

Change **albedo of snow/ice** when deposited

The aerosol scheme in the code

	NMR (um)	SIGMA	Core/background		Condensate/coagulate					
0	0.0626	1.6	**BC_AX**							
1	0.012	1.8	**SO4_NA**	**SOA_NA**	SO4_A1	SOA_A1				
2	0.024	1.8	**BC_A**		SO4_A1	SOA_A1				
4	0.04	1.8	**OM_AI**	**BC_AI**	SO4_A1	SOA_A1	SO4_A2	SO4_AC		
5	0.075	1.59	**SO4_PR**		SO4_A1	SOA_A1	SO4_A2	SO4_AC	BC_AC	OM_AC
6	0.22	1.59	**DST_A2**		SO4_A1	SOA_A1	SO4_A2	SO4_AC	BC_AC	OM_AC
7	0.63	2.0	**DST_A3**		SO4_A1	SOA_A1	SO4_A2	SO4_AC	BC_AC	OM_AC
8	0.0475	2.1	**SS_A1**		SO4_A1	SOA_A1	SO4_A2	SO4_AC	BC_AC	OM_AC
9	0.3	1.72	**SS_A2**		SO4_A1	SOA_A1	SO4_A2	SO4_AC	BC_AC	OM_AC
10	0.750	1.6	**SS_A3**		SO4_A1	SOA_A1	SO4_A2	SO4_AC	BC_AC	OM_AC
12	0.024	1.8	**BC_N**							
14	0.04	1.8	**OM_NI**	**BC_NI**						
					SO4_A1	*SOA_A1*	*SO4_A2*	*SO4_AC*	*BC_AC*	*OM_AC*

externally mixed

internally mixed

- 12 lognormal modes : numbered from 0-14, but no mode 3, 11, 14 anymore
- Amount is described by mass (kg aerosol/kg air) - no number
- **Background tracers** and **process tracers**
- When activated : transfer to corresponding **20 cloud tracers** (no large scale transport, as short life time)

Process tracers (44 ⟶6)

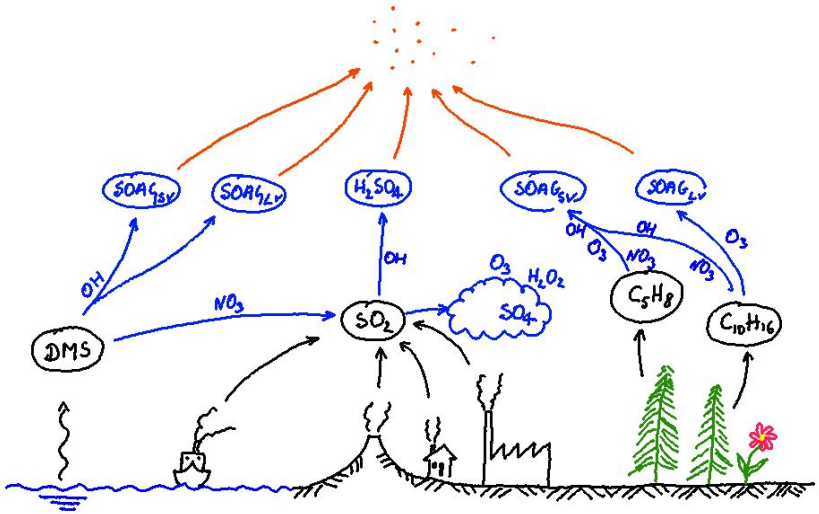
- *_A1* : from condensation
- *_A2* : from aqueous phase processing
- *_AC* : from accumulation

Process tracers (44) are lumped together (6) for transport (large-scale transport, diffusion, convection), dry deposition, below-cloud scavenging, …

These 6 lumped tracers have a specific synthetic size (for dry deposition, gravitational settling, wet scavenging, …)

Ideally they should have the behaviour of the background tracers they live on.

Chemistry (secondary aerosol formation)



8 gas-phase species		
DMS	dimethyl sulfide	
SO_2	sulphur dioixde	
H_2SO_4	sulphuric acid	condensate, nucleate
H_2O_2	hydrogen peroxide	
C_5H_8	isoprene	
$C_{10}H_{16}$	monoterpene	
SOAG(sv)	semi-volatile organic vapour	condensate
SOAG(lv)	low-volatile organic vapour	condensate, nucleate

4 prescribed 3D climatologies (monthly)
OH, NO_3, O_3, HO_2
Daily cycle imposed on OH and NO_3

Limited number of chemical reactions
$HO_2 + HO_2 \rightarrow H_2O_2$
$H_2O_2 + OH \rightarrow H_2O + HO_2$
$DMS + OH \rightarrow SO_2$
$DMS + NO_3 \rightarrow SO_2 + HNO_3$
$SO_2 + OH + M \rightarrow H_2SO_4 + M$
$DMS + OH \rightarrow 0.75\ SO_2 + 0.5\ HO_2 + 0.029$ SOAG(lv) + 0.114 SAOG(sv)
$C_{10}H_{16} + O_3 \rightarrow 0.15$ SOAG(lv)
$C_{10}H_{16} + OH \rightarrow 0.15$ SOAG(sv)
$C_{10}H_{16} + NO_3 \rightarrow 0.15$ SOAG(sv)
$C_5H_8 + O_3 \rightarrow 0.025$ SOAG(sv)
$C_5H_8 + OH \rightarrow 0.025$ SOAG(sv)
$C_5H_8 + O_3 \rightarrow 0.025$ SOAG(sv)

Only one photolysis reaction
$H_2O_2 + h\nu \rightarrow 2\ OH$

2 aqueous phase reactions
$SO_2 + O_3 \rightarrow SO_4$
$SO_2 + H_2O_2 \rightarrow SO_4$

3. Aerosol and aerosol-precursor emissions

		Prescribed					Interactive		
		Anthropogenic	Aviation	Biomass burning	Volcanoes	CH_4 oxidation	Land surface	Vegetation	Ocean
(gas)	SO_2	file	file	file	file				
	DMS								interactive
	Isoprene							interactive	
	Monoterpenes							interactive	
	H_2O					file			
(aerosol)	BC	file	file	file					
	POM	file	file	file					interactive
	SO_4	file	file	file	file				
	Mineral dust						interactive		
	Sea salt								interactive

Remarks :

1. Sulfur emissions : 97.5% as SO_2 (gas-phase) and 2.5% as SO_4 (aerosol-phase)
2. Volcanic emissions : only from tropospheric outgassing
3. DMS : uses the DMS water concentration in the upper-ocean layer
4. BC emissions : for fossil fuel combustion, 10% as BC(ax) and 90% as BC(n)
5. Most emission datasets contain OC (organic carbon) whereas the model describes OM (organic matter) : OC to OM ratio of 1.4 (fossil fuel) and 2.6 (biomass burning)

Prescribed emissions : emission heights

		Sector	Height range	Details
Biomass burning	AGRI	Agricultural waste burning	0-0.1 km	
	BORF	Boreal forest fires	0-3 km	0-0.1 km (10%), 0.1-0.5 km (10%), 0.5-1km (20%), 1-2 km (20%), 2-3 km (40%)
	DEFO	Fires used in deforestation	0-1 km	0-0.1 km (20%), 0.1-0.5 km (40%), 0.5-1km (40%)
	PEAT	Peat fires	0-0.1 km	
	SAVA	Savanna, grassland and shrubland fires	0-1 km	0-0.1 km (20%), 0.1-0.5 km (40%), 0.5-1km (40%)
	TEMF	Temperate forest fires	0-2 km	0-0.1 km (20%), 0.1-0.5 km (20%), 0.5-1km (20%), 1-2 km (40%)
Anthropogenic	AGR	Agriculture	Surface	
	ENE	Energy	0.15-0.35 km	8 height levels (0.05 km thick each)
	IND	Industrial	0.15-0.35 km	8 height levels (0.05 km thick each)
	TRA	Transportation	Surface	
	DOM	Residential, commercial, other	Surface	
	SOL	Solvents production and application	Surface	
	WST	Waste	Surface	
	SHP	International shipping	Surface	
Aviation	AIR	Aviation	0-15.25 km	25 levels (0.61 km thick)
Volcanoes	CONT	Continuous outgassing	0-7.5 km	30 levels (0.25 km thick)
	EXPL	Explosive	0-7.5 km	30 levels (0.25 km thick)
Methane	H_2O	CH_4 oxidation	992- 0.000006 hPa	70 pressure levels (from WACCM simulation)

Remarks :

1. Specified height (in m or km) is interpreted as height above earth surface
2. H_2O emissions are on pressure levels

Prescribed emissions : time and space

STEP 1 : Time and units specification in the emission files	
date	Date (YYYYMMDD) for when emissions are valid (often middle of month)
datesec	Seconds in the day for when emissions are valid
units	molecules cm^{-3} s^{-1} (surface emissions) or molecules cm^{-3} s^{-1} (3D emissions)

STEP 2 : Time+ species specification in the namelist				
Surface emissions				
srf_emis_type	CYCLICAL	SERIAL	INTERP_MISSING_MONTHS	FIXED
srf_emis_cycle_yr	<year>			
srf_emis_fixed_ymd				
srf_emis_fixed_tod				
srf_emis_specifier	(list of species and corresponding file name)			
3D emissions				
ext_frc_type	CYCLICAL	SERIAL	INTERP_MISSING_MONTHS	FIXED
ext_frc_cycle_yr	<year>			
ext_frc_fixed_ymd				
ext_frc_fixed_tod				
ext_frc_specifier	(list of species and corresponding file name)			

Examples	
Preindustrial	Contains 12 months - srf_emis_type=CYCLICAL - srf_emis_cycle_yr=1850
Historical (1850-2014)	Contains 12*165 months + Dec 1849 + Jan 2015 srf_emis_type=INTERP_MISSING_MONTHS or SERIAL
Scenarios (2015-2100)	Contains (2015, 2020, 2030, …, 2100 + Dec 2014 + Jan 2101) srf_emis_type=INTERP_MISSING_MONTHS

STEP 3 : Actions by CAM	
Read emissions	All fields with dimension 3 or 4 are interpreted as emissions (independent of the name of field)
Interpolate in space (horizontal and vertical)	Not mass conservative - therefore try to give on same grid as CAM
Interpolate in time	Linear interpolation in time between two nearest given data points
Interpolate in space	This interpolation is not completely mass-conservative

Interactive (natural) emissions

Dust emissions
DEAD scheme (in CLM) calculates online emissions in 4 bins
These bins are mapped to the 2 dust modes in OsloAero : DST_A2 and DST_A3.
There is a global scaling factor in the namelist (atm_in) : `dust_emis_fact=0.24D0` (total amount is inverse proportional to this factor)
There is an array describing the fraction ending up in the 2 modes : real(r8), parameter :: `emis_fraction_in_mode(numberOfDustModes) = (/0.13_r8, 0.87_r8 /)`
`oslo_aero_dust.F90`

Isoprene and monoterpene emissions
MEGAN2.1 (in CLM) calculates online emissions of around 31 species
Some of these species are received (and summed-up) by CAM as defined in drv_flds_in
`megan_specifier = 'isoprene = isoprene','monoterp = myrcene + sabinene + limonene+ carene_3 + ocimene_t_b + pinene_b + pinene_a'`
`chemistry.F90`

Ocean sea-salt emissions
OsloAero calculates sea-salt emissions for 3 modes : SS_A1, SS_A2 and SS_A3
`oslo_aero_seasalt.F90`

Ocean DMS emissions
The flux of DMS is calculated using the upper-ocean DMS water concentration.
If BLOM/iHAMOCC is part of the simulation, DMS is calculated interactively in the ocean. If not, an upper-ocean DMS climatology can be prescribed (monthly frequency). Climatologies available based on observations (Kettle et al., 1999; Lana et al., 2011) or based on fully-coupled NorESM simulations.
`oslo_aero_ocean.F90`

Ocean POM emissions
OsloAero calculates POM emissions for OM_NI
Uses a proxy for the OM content of the upper ocean.
Uses the fluxes calculated for the smallest sea-salt mode (SS_A1).
`oslo_aero_ocean.F90`

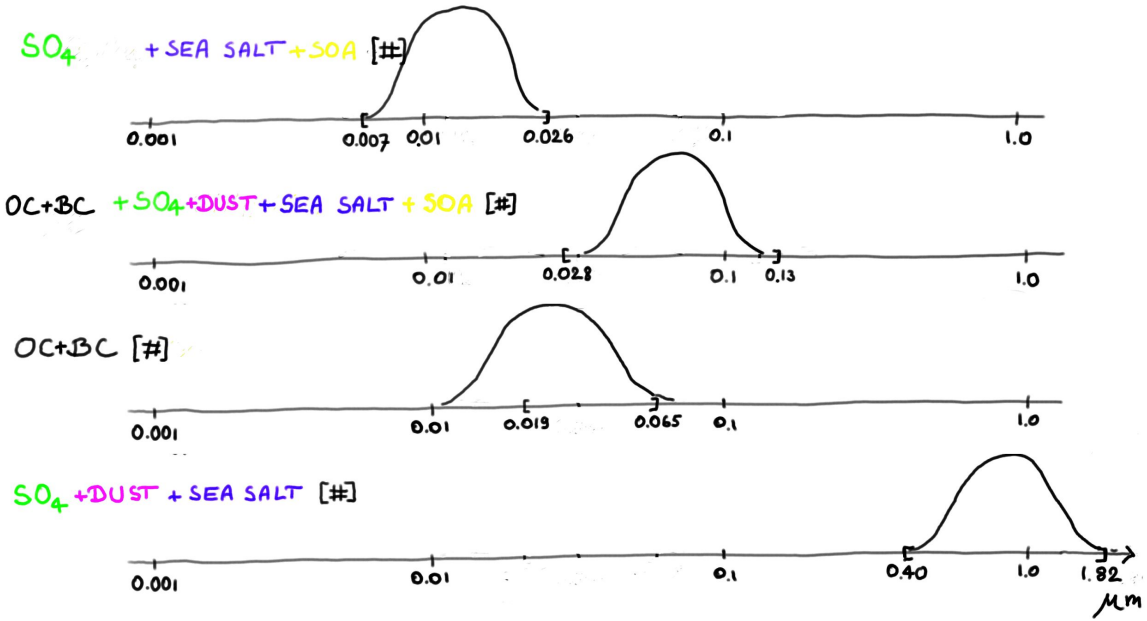
4. Other aerosol scheme : MAM4 (CESM)

4 log-normal modes

19 aerosol-phase species (including number)

5 gas-phase species

4 oxidant climatologies

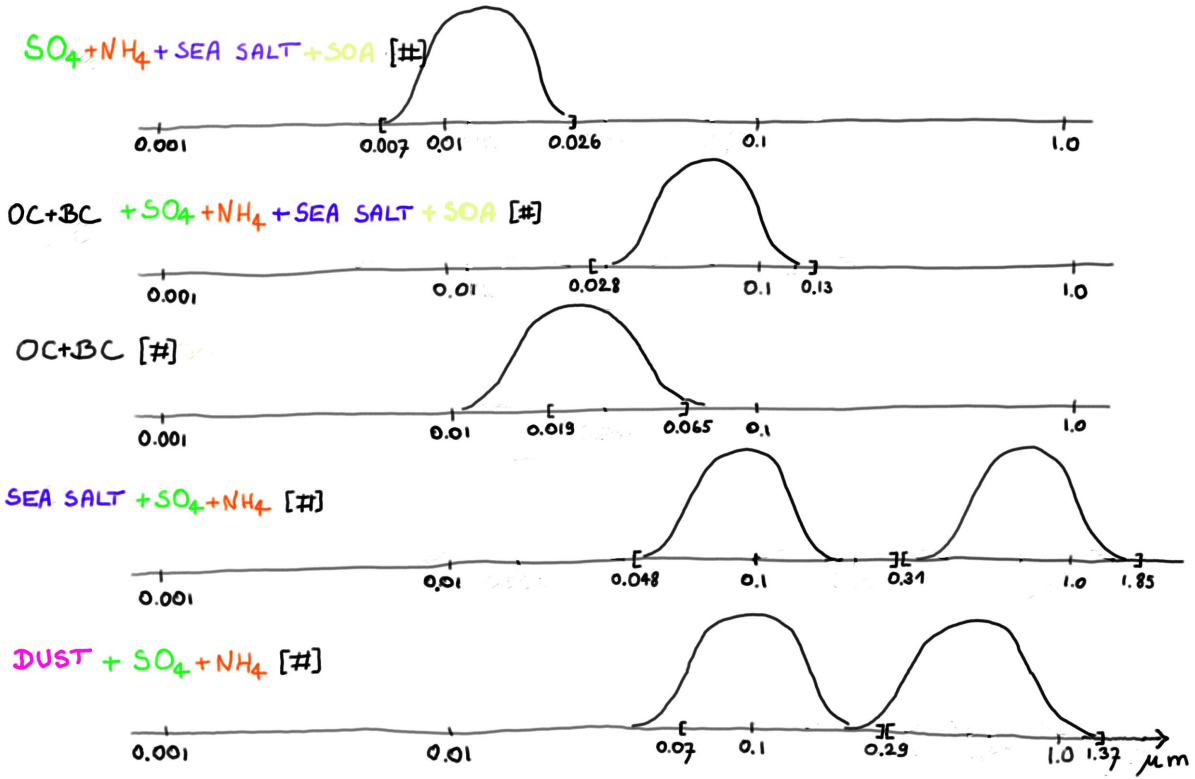


Other aerosol scheme : MAM7 (CESM)

7 log-normal modes

31 aerosol-phase species (including number)

6 gas-phase species



5. Structure of the aerosol/chemistry code

cam/src/chemistry		
(1)	cam/src/chemistry/mozart/	contains routines common to the various chemistry schemes
(2)	cam/src/chemistry/pp_trop_mam3/ cam/src/chemistry/pp_trop_mam4/ cam/src/chemistry/pp_trop_mam7/ cam/src/chemistry/**pp_trop_mam_oslo/** … cam/src/chemistry/pp_trop_strat_mam4_vbs/ cam/src/chemistry/pp_trop_strat_mam4_vbs_ext/ … cam/src/chemistry/**pp_tropstrat_mam_oslo/** … cam/src/chemistry/pp_waccm_mad_mam4/ …	contain different version of the same 16 F90-files + 1 file (chem_mech.in) with definition of the chemical species, chemical reactions, photolysis reactions, species allowing 3D emissions, oxidant climatologies, …
(3)	cam/src/chemistry/aerosol/ cam/src/chemistry/bulk_aero/ cam/src/chemistry/modal_aero/	contains F90-files specific for CESM aerosol schemes : bulk aerosol, MAM4, MAM7
(4)	cam/src/chemistry/oslo_aero/src	contains F90-files specific for OsloAero aerosol scheme
(5)	cam/src/chemistry/oslo_aero/src_cam	contains CESM F90-files slightly modified for OsloAero aerosol scheme
(6)	cam/src/NorESM/	contains CESM F90-files modified for OsloAero and for NorESM

Structure of the code

(2) cam/src/chemistry/pp_trop_mam_oslo					
chem_mech.doc	mo_adjrxt.F90	mo_indprd.F90	mo_lu_solve.F90	mo_prod_loss.F90	mo_sim_dat.F90
chem_mech.in	mo_exp_sol.F90	mo_lin_matrix.F90	mo_nln_matrix.F90	mo_rxt_rates_conv.F90	m_rxt_id.F90
chem_mods.F90	mo_imp_sol.F90	mo_lu_factor.F90	mo_phtadj.F90	mo_setrxt.F90	m_spc_id.F90

(4) cam/src/chemistry/oslo_aero/src			
aero_model.F90	oslo_aero_condtend.F90	oslo_aero_hetfrz.F90	oslo_aero_ocean.F90
oslo_aero_aerocom.F90	oslo_aero_control.F90	oslo_aero_linear_interp.F90	oslo_aero_optical_params.F90
oslo_aero_aerocom_tables.F90	oslo_aero_depos.F90	oslo_aero_logn_tables.F90	oslo_aero_seasalt.F90
oslo_aero_aerodry_tables.F90	oslo_aero_diurnal_var.F90	oslo_aero_microp.F90	oslo_aero_share.F90
oslo_aero_coag.F90	oslo_aero_dust.F90	oslo_aero_ndrop.F90	oslo_aero_sox_cldaero.F90
oslo_aero_conc.F90	oslo_aero_dust_sediment.F90	oslo_aero_nucleate_ice.F90	oslo_aero_sw_tables.F90

Structure of the code

(5) cam/src/chemistry/oslo_aero/src_cam			
File	**Based on …**	**File**	**Based on …**
chemistry.F90	mozart/	mo_srf_emissions.F90	mozart/
micro_mg_data.F90	physics/cam/	mo_usrrxt.F90	mozart/
mo_chm_diags.F90	mozart/	radiation.F90	physics/rrtmg/
mo_drydep.F90	mozart	radlw.F90	physics/rrtmg/
mo_gas_phase_chemdr.F90	mozart	radsw.F90	physics/rrtmg/
mo_neu_wetdep.F90	mozart/	runtime_opts.F90	control/
mo_photo.F90	mozart/	vertical_diffusion.F90	physics/cam/
mo_setaer.F90	mozart/	zm_microphysics.F90	physics/cam/
mo_setsox.F90	aerosol/		

Structure of the code

(6) cam/src/NorESM		
File	**Based on**	**Remarks**
cam_diagnostics.F90	physics/cam/	
cldfrc2m.F90	physics/cam/	
ctem.F90	dynamics/fv/	extra diagnostics output
macrop_driver.F90	physics/cam/	
micro_mg1_0.F90	physics/cam/	
micro_mg2_0.F90	physics/cam/	
micro_mg_cam.F90	physics/cam/	
module_random_forests.F90		specific to OsloAero
phys_control.F90	physics/cam/	
physpkg.F90	physics/cam/	
zm_conv.F90	physics/cam/	
zm_conv_intr.F90	physics/cam/	
fv/dp_coupling.F90	dynamics/fv/	
fv/metdata.F90	dynamics/fv	key to nudge only U,V and PS - modifications to nudging

Where are species, reactions, … defined

cam/src/chemistry/pp_trop_mam_oslo/chem_mech.in

```
BEGSIM
  SPECIES

      Solution
 SO2, H2SO4
 DMS -> CH3SCH3, H2O2
 SO4_NA->H2SO4, SO4_A1->H2SO4, SO4_A2->NH4HSO4
 SO4_AC->H2SO4, SO4_PR->H2SO4, BC_N->C
 BC_AX->C, BC_NI->C, BC_A->C, BC_AI->C
 BC_AC->C, OM_NI->C, OM_AI->C, OM_AC->C
 DST_A2->AlSiO5, DST_A3->AlSiO5
 SS_A1->NaCl, SS_A2->NaCl, SS_A3->NaCl
* Approximate soa species with those of monoterpene oxidation products
* based on Paasonen et al. (2010); Taipale et al. (2008).
 SOA_NA->C10H16O2, SOA_A1->C10H16O2
 SOA_LV ->C10H16O2, SOA_SV->C10H16O2
 monoterp -> C10H16, isoprene -> C5H8
 H2O
   End Solution

      Fixed
 M, N2, O2, O3, OH, NO3, HO2
      End Fixed

      Col-int
 O3 = 0.
 O2 = 0.
      End Col-int

   End SPECIES
```

molecular composition

H_2O should be last species

oxidants ++

species with long lifetime

species with short lifetime

```
  Solution Classes
     Explicit
     End Explicit
     Implicit
       DMS, SO2, H2O2
       SO4_NA, SO4_A1, SO4_A2
       SO4_AC, SO4_PR, BC_N
       BC_AX, BC_NI, BC_A, BC_AI
       BC_AC, OM_NI, OM_AI, OM_AC
       DST_A2, DST_A3
       SS_A1, SS_A2, SS_A3 , H2SO4
       SOA_NA, SOA_A1
       SOA_LV,SOA_SV, monoterp, isoprene
       H2O
     End Implicit
  End Solution Classes
```

Where are species, reactions, … defined

Where are species, reactions, … defined

cam/src/chemistry/pp_trop_mam_oslo/mo_sim_dat.F90

species names

species masses

species with 3D emissions

fixed species names

```
solsym(: 30) = (/ 'SO2             ','H2SO4           ','DMS             ','H2O2            ','SO4_NA          ', &
                  'SO4_A1          ','SO4_A2          ','SO4_AC          ','SO4_PR          ','BC_N            ', &
                  'BC_AX           ','BC_NI           ','BC_A            ','BC_AI           ','BC_AC           ', &
                  'OM_NI           ','OM_AI           ','OM_AC           ','DST_A2          ','DST_A3          ', &
                  'SS_A1           ','SS_A2           ','SS_A3           ','SOA_NA          ','SOA_A1          ', &
                  'SOA_LV          ','SOA_SV          ','monoterp        ','isoprene        ','H2O             ' /)

adv_mass(: 30) = (/    64.064800_r8,    98.078400_r8,    62.132400_r8,    34.013600_r8,    98.078400_r8, &
                       98.078400_r8,   115.107340_r8,    98.078400_r8,    98.078400_r8,    12.011000_r8, &
                       12.011000_r8,    12.011000_r8,    12.011000_r8,    12.011000_r8,    12.011000_r8, &
                       12.011000_r8,    12.011000_r8,    12.011000_r8,   135.064039_r8,   135.064039_r8, &
                       58.442468_r8,    58.442468_r8,    58.442468_r8,   168.227200_r8,   168.227200_r8, &
                      168.227200_r8,   168.227200_r8,   136.228400_r8,    68.114200_r8,    18.014200_r8 /)

crb_mass(: 30) = (/     0.000000_r8,     0.000000_r8,    24.022000_r8,     0.000000_r8,     0.000000_r8, &
                        0.000000_r8,     0.000000_r8,     0.000000_r8,     0.000000_r8,    12.011000_r8, &
                       12.011000_r8,    12.011000_r8,    12.011000_r8,    12.011000_r8,    12.011000_r8, &
                       12.011000_r8,    12.011000_r8,    12.011000_r8,     0.000000_r8,     0.000000_r8, &
                        0.000000_r8,     0.000000_r8,     0.000000_r8,   120.110000_r8,   120.110000_r8, &
                      120.110000_r8,   120.110000_r8,   120.110000_r8,    60.055000_r8,     0.000000_r8 /)

fix_mass(:  7) = (/ 0.00000000_r8, 28.0134800_r8, 31.9988000_r8, 47.9982000_r8, 17.0068000_r8, &
                    62.0049400_r8, 33.0062000_r8 /)
```

```
extfrc_lst(:  7) = (/ 'SO2             ','BC_NI           ','BC_AX           ','BC_N            ','OM_NI           ', &
                      'SO4_PR          ','H2O             ' /)

frc_from_dataset(:  7) = (/ .true., .true., .true., .true., .true., &
                            .true., .true. /)

inv_lst(:  7) = (/ 'M               ', 'N2              ', 'O2              ', 'O3              ', 'OH              ', &
                   'NO3             ', 'HO2             ' /)
```

Information on the aerosol scheme :

cam/src/chemistry/oslo_aero/src/oslo_aero_share.F90

#modes

background modes

For some processes (e.g., condensation, coagulation), the modes are resolved in 44 bins

tracers in mode

tracers in background mode (core)

```
! Define lognormal size parameters for each size mode (dry, at point of emission/production)
integer, parameter :: nmodes    = 14
integer, parameter :: nbmodes   = 10
integer, parameter :: nbands    = 14 ! number of aerosol spectral bands in SW
integer, parameter :: nlwbands = 16 ! number of aerosol spectral bands in LW
integer, parameter :: nbmp1     = 11 ! number of first non-background mode
integer, parameter :: max_tracers_per_mode = 7

integer, parameter :: numberOfExternallyMixedModes = 4    !Modes 0;11-14 (13 is not used in lifecycle)
integer, parameter :: numberOfInternallyMIxedMOdes = 9    !Modes 1-10 (3 is not used in lifecycle)
integer, parameter :: numberOfProcessModeTracers = 6

integer,  parameter :: nBinsTab = 44                    ![nbr] number of tabulated bins

real(r8), parameter :: rTabMin = 1.e-9_r8               ![m] smallest lookup table size
real(r8), parameter :: rTabMax = 20.e-6_r8              ![m] largest lookup table size
real(r8), parameter :: rMinAquousChemistry = 0.05e-6_r8 !Smallest particle which can receive aquous chemistry mass
real(r8), parameter :: sq2pi = 1._r8/sqrt(2.0_r8*pi)
real(r8), parameter :: smallConcentration = 1.e-100_r8  !duplicate, sync with smallNumber in Const
real(r8), parameter :: smallNumber = 1.e-100_r8

integer, parameter :: n_tracers_in_mode(0:nmodes) = (/ 1, 4, 3, 0, 5, 7, 7, 7, 7, 7, 7, 0, 1, 0, 2 /)
integer, parameter :: n_background_tracers_in_mode(0:nmodes) = (/ 1,2,1,0,2,1,1,1,1,1,1,0,1,0,2 /)
```

Information on the aerosol scheme

cam/src/chemistry/oslo_aero/src/oslo_aero_share.F90

```
! Define aerosol types and their properties..
integer, parameter :: N_AEROSOL_TYPES      = 5
integer, parameter :: AEROSOL_TYPE_SULFATE = 1
integer, parameter :: AEROSOL_TYPE_BC      = 2
integer, parameter :: AEROSOL_TYPE_OM      = 3
integer, parameter :: AEROSOL_TYPE_DUST    = 4
integer, parameter :: AEROSOL_TYPE_SALT    = 5

! Define aerosol modes
integer, parameter :: MODE_IDX_BC_EXT_AC            = 0  !Externally mixed BC accumulation mode
integer, parameter :: MODE_IDX_SO4SOA_AIT           = 1  !SO4 and SOA in aitken mode, Created from 11 by growth (condensation) of SO4
integer, parameter :: MODE_IDX_BC_AIT               = 2  !Created from 12 by growth (condensation)  SO4
integer, parameter :: MODE_IDX_NOT_USED             = 3  !Not used
integer, parameter :: MODE_IDX_OMBC_INTMIX_COAT_AIT = 4  !Created from 14 by growth (condensation) of SO4 and from cloud processing/wet-phas
integer, parameter :: MODE_IDX_SO4_AC               = 5  !Accumulation mode SO4 (mode will have other comps added)
integer, parameter :: MODE_IDX_DST_A2               = 6  !Accumulation mode dust (mode will have other comps added)
integer, parameter :: MODE_IDX_DST_A3               = 7  !Coarse mode dust (mode will have other comps added)
integer, parameter :: MODE_IDX_SS_A1                = 8  !Fine mode sea-salt (mode will have other comps added)
integer, parameter :: MODE_IDX_SS_A2                = 9  !Accumulation mode sea-salt (mode will have other comps added)
integer, parameter :: MODE_IDX_SS_A3                = 10 !Coarse mode sea-salt (mode will have other comps added)
integer, parameter :: MODE_IDX_SO4SOA_NUC           = 11 !SO4 and SOA nucleation mode
integer, parameter :: MODE_IDX_BC_NUC               = 12 !BC nucleation mode
integer, parameter :: MODE_IDX_LUMPED_ORGANICS      = 13 !not used in lifecycle, but some extra mass goes here when max. allowed LUT conc. are too small
integer, parameter :: MODE_IDX_OMBC_INTMIX_AIT      = 14 !mix quickly formed in fire-plumes
```

Information on the aerosol scheme

NMR Number Median Radius

Sigma of the modes

cam/src/chemistry/oslo_aero/src/oslo_aero_share.F90

```
! Number median radius of background emissions THESE DO NOT ASSUME IMPLICIT GROWTH!!
real(r8), parameter :: originalNumberMedianRadius(0:nmodes) =        &
     1.e-6_r8* (/ 0.0626_r8,                                         & !0
                  0.0118_r8, 0.024_r8, 0.04_r8,  0.04_r8, 0.075_r8,  & !1-5
                  0.22_r8,   0.63_r8,   0.0475_r8, 0.30_r8, 0.75_r8, & !6-10    ! SS: Salter et al. (2015)
                  0.0118_r8, 0.024_r8, 0.04_r8,  0.04_r8    /)        !11-14

! sigma of background aerosols
real(r8), parameter :: originalSigma(0:nmodes) =  &
     (/1.6_r8,                                    & !0
       1.8_r8, 1.8_r8, 1.8_r8, 1.8_r8, 1.59_r8,   & !1-5
       1.59_r8, 2.0_r8, 2.1_r8, 1.72_r8, 1.60_r8, & !6-10   ! SS: Salter et al. (2015)
       1.8_r8, 1.8_r8, 1.8_r8, 1.8_r8  /)          !11-14

!Radius used for the modes in the lifeCycle MAY ASSUME SOME GROWTH ALREADY HAPPENED
real(r8), parameter :: lifeCycleNumberMedianRadius(0:nmodes) = &
     1.e-6_r8*(/ 0.0626_r8, 0.025_r8, 0.025_r8 , 0.04_r8,   0.06_r8,   0.075_r8, &
                 0.22_r8,   0.63_r8,  0.0475_r8, 0.30_r8,   0.75_r8,  &    ! Salter et al. (2015)
                 0.0118_r8, 0.024_r8, 0.04_r8  , 0.04_r8    /)

!Sigma based on original lifecycle code (taken from "sigmak" used previously in lifecycle code)
real(r8), parameter :: lifeCycleSigma(0:nmodes) =  &
     (/1.6_r8, 1.8_r8, 1.8_r8, 1.8_r8, 1.8_r8, &   !0-4
       1.59_r8, 1.59_r8, 2.0_r8,               &   !5,6,7 (SO4+dust)
       2.1_r8, 1.72_r8, 1.6_r8,                &   !8-10  (SS)     ! Salter et al. (2015)
       1.8_r8, 1.8_r8, 1.8_r8, 1.8_r8/)            !11-14
```

Information on the aerosol scheme

cam/src/chemistry/oslo_aero/src/oslo_aero_share.F90

below-cloud scavenging for modes 0-14

“synthetic” radius (NMR) of the 6 process modes

“synthetic” sigma of the 6 process modes

“synthetic” below-cloud scavenging for the 6 process modes

```
!Below cloud scavenging coefficients for modes which have an actual size
real(r8), parameter :: belowCloudScavengingCoefficient(0:nmodes) =     &
     (/ 0.01_r8   ,  0.02_r8 , 0.02_r8   ,  0.0_r8 ,   0.02_r8,   0.01_r8, & !(0-5)
        0.02_r8   ,  0.2_r8  , 0.02_r8   ,  0.02_r8,   0.5_r8,             & !6-10 (DUST+SS)
        0.04_r8   ,  0.08_r8 , 0.0_r8    ,  0.02_r8    /)                     ! SO4_n, bc_n, N/A og bc/oc

! Treatment of process-modes!
! The tracers indices can not be set here since they are not known on compile time
! tracerInProcessMode = (/l_so4_a1, l_so4_a2, l_so4_ac, l_om_ac, l_bc_ac, l_soa_a1 /)

!The process modes need an "efficient size" (Why does A1 have a different size than the others??)
real(r8), parameter :: processModeNumberMedianRadius(numberOfProcessModeTracers) = &
     (/ 0.04e-6_r8, 0.1e-6_r8, 0.1e-6_r8, 0.1e-6_r8, 0.1e-6_r8, 0.04e-6_r8 /)

!The process modes need an "efficient sigma"
real(r8), parameter :: processModeSigma(numberOfProcessModeTracers) = &
     (/ 1.8_r8, 1.59_r8, 1.59_r8, 1.59_r8, 1.59_r8, 1.8_r8  /)

real(r8), parameter :: belowCloudScavengingCoefficientProcessModes(numberOfProcessModeTracers) = &
     (/0.02_r8, 0.01_r8, 0.02_r8, 0.02_r8, 0.02_r8, 0.02_r8 /)
```

Condensation in the aerosol code

3 gases that can condensate to form aerosol

cam/src/chemistry/oslo_aero/src/oslo_aero_cond.F90

```
integer, parameter, public :: N_COND_VAP = 3
integer, parameter, public :: COND_VAP_H2SO4 = 1
integer, parameter, public :: COND_VAP_ORG_LV = 2
integer, parameter, public :: COND_VAP_ORG_SV = 3
```

when some aerosol modes grow through condensation, the aerosol can be transferred to other mode

```
!These are the lifecycle-species which receive mass when
!the externally mixed modes receive condensate,
!e.g. the receiver of l_so4_n mass is the tracer l_so4_na
lifeCycleReceiver(:) = -99
lifeCycleReceiver(chemistryIndex(l_bc_n))   = chemistryIndex(l_bc_a)  !create bc int mix from bc in mode
lifeCycleReceiver(chemistryIndex(l_bc_ni))  = chemistryIndex(l_bc_ai) !create bc int mix from bc in mode
lifeCycleReceiver(chemistryIndex(l_om_ni))  = chemistryIndex(l_om_ai) !create om int mix from om in mode
lifeCycleReceiver(chemistryIndex(l_bc_ax))  = chemistryIndex(l_bc_ai) !create bc int mix from bc in mode
                                                                      !Note Mass is conserved but not nu
```

Coagulation

cam/src/chemistry/oslo_aero/src/oslo_aero_coag.F90

modes which coagulate

```
!These are the modes which are coagulating (belonging to mixtures no. 0, 1, 2, 4, 12, 14)
integer , parameter :: numberOfCoagulatingModes = 6
integer, public :: coagulatingMode(numberOfCoagulatingModes) =    &
     (/MODE_IDX_BC_EXT_AC,            & !inert mode
       MODE_IDX_SO4SOA_AIT,           & !internally mixed small mode
       MODE_IDX_BC_AIT,               & !internally mixed small mode
       MODE_IDX_OMBC_INTMIX_COAT_AIT, & !internally mixed small mode
       MODE_IDX_BC_NUC,               & !externally mixed small mode
       MODE_IDX_OMBC_INTMIX_AIT /)      !externally mixed small mode

!These are the modes which are receiving coagulating material in OsloAero
! (belonging to mixtures no. 5, 6, 7, 8, 9, 10)
integer, public :: receiverMode(numberOfCoagulationReceivers) = &
     (/MODE_IDX_SO4_AC, &
       MODE_IDX_DST_A2, &
       MODE_IDX_DST_A3, &
       MODE_IDX_SS_A1,  &
       MODE_IDX_SS_A2,  &
       MODE_IDX_SS_A3 /)
```

modes to coagulate on

```
lifeCycleReceiver(:) = -99
lifeCycleReceiver(chemistryIndex(l_bc_ax))  = chemistryIndex(l_bc_ac)
lifeCycleReceiver(chemistryIndex(l_so4_na)) = chemistryIndex(l_so4_ac) !create so4 coagulate from so4 in mode 1
lifeCycleReceiver(chemistryIndex(l_bc_a))   = chemistryIndex(l_bc_ac)  !create bc coagulate  from bc in mode 2
lifeCycleReceiver(chemistryIndex(l_bc_ai))  = chemistryIndex(l_bc_ac)  !create bc coagulate from bc in mode 4
lifeCycleReceiver(chemistryIndex(l_om_ai))  = chemistryIndex(l_om_ac)  !create om coagulate from om in mode 4
lifeCycleReceiver(chemistryIndex(l_bc_n))   = chemistryIndex(l_bc_ac)  !create bc coagulate from bc in mode 12
lifeCycleReceiver(chemistryIndex(l_bc_ni))  = chemistryIndex(l_bc_ac)  !create bc coagulate from om in mode 14
lifeCycleReceiver(chemistryIndex(l_om_ni))  = chemistryIndex(l_om_ac)  !create om coagulate from om in mode 14
lifeCycleReceiver(chemistryIndex(l_so4_a1)) = chemistryIndex(l_so4_ac) !Create so4 coagulate from so4 condensate
lifeCycleReceiver(chemistryINdex(l_soa_na)) = chemistryIndex(l_soa_a1)

CloudAerReceiver(:) = -99
CloudAerReceiver(chemistryIndex(l_bc_ax))  = chemistryIndex(l_bc_ac)
CloudAerReceiver(chemistryIndex(l_so4_na)) = chemistryIndex(l_so4_a2) !create so4 coagulate from so4 in mode 1
CloudAerReceiver(chemistryIndex(l_bc_a))   = chemistryIndex(l_bc_ac)  !create bc coagulate  from bc in mode 2
CloudAerReceiver(chemistryIndex(l_bc_ai))  = chemistryIndex(l_bc_ac)  !create bc coagulate from bc in mode 4
CloudAerReceiver(chemistryIndex(l_om_ai))  = chemistryIndex(l_om_ac)  !create om coagulate from om in mode 4
CloudAerReceiver(chemistryIndex(l_bc_n))   = chemistryIndex(l_bc_ac)  !create bc coagulate from bc in mode 12
CloudAerReceiver(chemistryIndex(l_bc_ni))  = chemistryIndex(l_bc_ac)  !create bc coagulate from om in mode 14
CloudAerReceiver(chemistryIndex(l_om_ni))  = chemistryIndex(l_om_ac)  !create om coagulate from om in mode 14
CloudAerReceiver(chemistryIndex(l_so4_a1)) = chemistryIndex(l_so4_a2) !Create so4 coagulate from so4 condensate
cloudAerReceiver(chemistryIndex(l_soa_na)) = chemistryIndex(l_soa_a1)
```

6. AeroTab - first use : direct impact of aerosols on radiation

We want to take into account the direct impact of aerosols on SW and LW radiation

Radiation scheme in CAM : RRTMG (Rapid Radiation Transfer Model for GCMs)

Parameters needed : extinction [km^{-1}], single scattering albedo [], asymmetry factor [], based on Mie-calculation

SHORT WAVE			
CAM band	Wavelength [um]	AeroTab band	Remark
14	3.846–12.195	14	large wavelength
1	3.077–3.846	13	
2	2.500–3.077	12	
3	2.150–2.500	11	
4	1.942–2.150	10	
5	1.626–1.942	9	
6	1.299–1.626	8	
7	1.242–1.299	7	
8	0.778–1.242	6	
9	0.625–0.778	5	
10	0.442–0.625	4	
11	0.345–0.442	3	
12	0.263–0.345	2	
13	0.200–0.263	1	small wavelength

LONG WAVE			
CAM band	Wavelength [um]	AeroTab band	Remark
1	3.07692–3.84615	1	small wavelength
2	3.84615–4.20168	2	
3	4.20168–4.44444	3	
4	4.44444–4.80769	4	
5	4.80769–5.55556	5	
6	5.55556–6.75676	6	
7	6.75676–7.19424	7	
8	7.19424–8.47458	8	
9	8.47458–9.25926	9	
10	9.25926–10.2041	10	
11	10.2041–12.1951	11	
12	12.1951–14.2857	12	
13	14.2857–15.873	13	
14	15.873–20	14	
15	20–28.5714	15	
16	28.5714–1000	16	large wavelength

AeroTab : direct impact of aerosols on radiation

Problem : doing Mie-calculation in every 3D grid-point (~500000 grid points,) at every time-step, for 12 modes is not feasible

Solution : do off-line calculation for all 12 modes for different amounts of condensate and coagulate (SOA_A1, SO4_A1, SO4_A2, SO4_AC, BC_AC, OM_AC), for different hygroscopicity values [0-100 %], for the 14 SW + 16 LW wavelength bands

Look-up tables : create files with tabulated values (of extinction, single scattering albedo and asymmetry) for 10 modes separately and for the 14 SW + 15 LW wavelength bands. Discrete values for hygroscopicity, and amount of condensate/coagulate.

Available files

SHORT WAVE		
Short name	File name and path	Used for mode
kcomp0_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp0.out	0
kcomp1_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp1.out	1
kcomp2_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp2.out	2, 12
kcomp3_file	*/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp3.out*	*not used*
kcomp4_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp4.out	4, 14
kcomp5_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp5.out	5
kcomp6_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp6.out	6
kcomp7_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp7.out	7
kcomp8_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp8.out	8
kcomp9_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp9.out	9
kcomp10_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp10.out	10

LONG WAVE		
Short name	File name and path	Used for mode
lwkcomp0_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp0.out	0
lwkcomp1_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp1.out	1
lwkcomp2_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp2.out	2, 12
lwkcomp3_file	*/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp3.out*	*not used*
lwkcomp4_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp4.out	4, 14
lwkcomp5_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp5.out	5
lwkcomp6_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp6.out	6
lwkcomp7_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp7.out	7
lwkcomp8_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp8.out	8
lwkcomp9_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp9.out	9
lwkcomp10_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/lwkcomp10.out	10

```
aerotab_table_dir      = '/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/'
```

Content of the file

/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/kcomp5.out (181440 values = 14*10*6*6*6*6)										
INPUT VALUES							**OUTPUT VALUES**			
kcomp	iband	rh [%]	catot (ug m^{-3})	fac	fbc	faq	omega(iband)	gass(iband)	bext(iband)	kext(iband)
5	1	0	1e-10	0	1e-10	0	1	0.71427	0.74815e-04	0.87375E+01
5	2	0	1e-10	0	1e-10	0	1	0.70381	0.56342E-04	0.65800E+01
…										
5	14	0.995	15	1	1	1	0.35110	0.31631	0.97176E-02	0.62503E+00

INPUT VALUES				
	#	rh [%]	units	discrete values
iband	(#14)	wavelength band number		
rh	(#10)	relative humidity/100	[1]	0, 0.37, 0.47, 0.65, 0.75, 0.8, 0.85, 0.9, 0.95, 0.995
catot	(#6)	total added internally mixed mass	[ug m^{-3}]	1e-10, 0.0015,0.015, 0.15, 1.5, 15
fac	(#6)	OC & BC mass fraction of catot	[1]	0, 0.2, 0.4, 0.6, 0.8, 1.0
fbc	(#6)	BC fraction of OC & BC mass	[1]	1e-10, 0.1, 0.1778, 0.3162, 0.5623. 1.0
faq	(#6)	mass fraction of wet phase sulfate (as $(NH_4)_2SO_4$, of total added sulfate	[1]	0, 0.2, 0.4, 0.6, 0.8 , 1.0

OUTPUT VALUES : for a normalized aerosol size distribution (N = 1 cm^{-3})		
		units
omega	single scattering albedo	[1]
gass	asymmetry factor	[1]
bext	extinction	[km^{-1}]
kext	specific extinction	[m^2g^{-1}]

AeroTab - second use : impact of aerosols on cloud-droplet activation

Aerosol can be the source of a cloud droplet (important for the indirect effect).

Model uses a parameterization/description of Abdul-Razzak and Ghan [2000] for activation : needs lognormal aerosol distribution/population (per mode).

After adding condensate and coagulate to a mode, the modes are not anymore log-normal.

Therefore, find the best log-normal fit through every mode.

Could be done online, but model uses again pre-calculated look-up tables.

Filenames : logntilp (tilpasning = adaptation)

AeroTab - second use : impact of aerosols on cloud-droplet activation

logntilp (tilpasning = adaptation)

LOGNORMAL DISTRIBUTION		
Short name	File name and path	Used for mode
logntilp1_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp1.out	1
logntilp2_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp2.out	2, 12
logntilp3_file	*/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp3.out*	*not used*
logntilp4_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp4.out	4, 14
logntilp5_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp5.out	5
logntilp6_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp6.out	6
logntilp7_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp7.out	7
logntilp8_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp8.out	8
logntilp9_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp9.out	9
logntilp10_file	/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp10.out	10

AeroTab - second use : impact of aerosols on cloud droplet activation

/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/logntilp5.out (1296 values = 6*6*6*6)						
INPUT VALUES					**OUTPUT VALUES**	
kcomp	catot (ug m^{-3})	fac	fbc	faq	r	logsigma
5	1e-10	0	1e-10	0	0.075	0.20140
5	1e-10	0	1e-10	0	0.075	0.20140
…						
5	15	1	1	1	1.102	0.11106

INPUT VALUES				
	#	rh [%]	units	discrete values
catot	(#6)	total added internally mixed mass	[ug m^{-3}]	1e-10, 0.0015,0.015, 0.15, 1.5, 15
fac	(#6)	OC & BC mass fraction of catot	[1]	0, 0.2, 0.4, 0.6, 0.8, 1.0
fbc	(#6)	BC fraction of OC & BC mass	[1]	1e-10, 0.1, 0.1778, 0.3162, 0.5623. 1.0
faq	(#6)	mass fraction of wet phase sulfate (as $(NH_4)_2SO_4$, of total added sulfate	[1]	0, 0.2, 0.4, 0.6, 0.8 , 1.0

OUTPUT VALUES : for a normalized aerosol size distribution (N = 1 cm^{-3})		
		units
r	dry modal mean radius	[um]
logsigma	logarithm (base 10) if standard deviation	[1]

AeroTab - third use : extra aerosol diagnostics

./xmlchange CAM_AEROCOM=TRUE

cam/src/chemistry/oslo_aero/src/oslo_aero_aerocom.F90

uses tables : /cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/AeroTab_8jun17/**aerocomk<xx>.out**

OUTPUT VALUES : for a normalized aerosol size distribution (N = 1 cm^{-3})		
		units
D440_SS	sea-salt aerosol optical depth 440 nm	
D440_DU	mineral aerosol optical depth 440 nm	
D440_SO4	SO4 aerosol optical depth 440 nm	
D440_BC	BC aerosol optical depth 440 nm	
D440_POM	OC aerosol optical depth 440 nm	
D500_SS	sea-salt aerosol optical depth 440 nm	
…		
DLT_SS	sea-salt aerosol optical depth 550 nm with radius < 0.5 um	
DGT_SS	sea-salt aerosol optical depth 550 nm with radius > 0.5 um	
DLT_DUST	mineral aerosol optical depth 550 nm with radius < 0.5 um	
DGT_DUST	mineral aerosol optical depth 550 nm with radius > 0.5 um	
…		

AeroTab - final note

Current tables :
/cluster/shared/noresm/inputdata/noresm-only/atm/cam/camoslo/**AeroTab_8jun17**/aerocomk<xx>.out

Attention : The sizes/properties of aerosol in the NorESM code/simulation should be the same as the sizes/properties of aerosol used to generate the look-up tables.

To generate/modify the tables : https://github.com/NorESMhub/AeroTab

7. Stratospheric aerosol

- No SO_2 emissions from explosive volcanoes emitted into the stratosphere
- No OCS emissions (e.g., from ocean) - would reach the stratosphere (inert in the troposphere) and be a source of SO_2
- Therefore the model misses stratospheric sulphate aerosol in the stratosphere
- We prescribe a climatology of : extinction, single scattering albedo, and asymmetry factor
- For 14 SW + 16 LW wavelength bands, monthly resolution, zonally symmetric

In atm_in (for a preindustrial simulation)

```
&prescribed_volcaero_nl
 prescribed_volcaero_cycle_yr      = 1850
 prescribed_volcaero_datapath      = '/cluster/shared/noresm/inputdata/atm/cam/volc'
 prescribed_volcaero_file          = 'CMIP_CAM6_radiation_average_v3_reformatted.nc'
 prescribed_volcaero_type          = 'CYCLICAL'
```

This climatology is the average of the 1850-2014 timeseries

In atm_in (for a historical simulation)

```
&prescribed_volcaero_nl
 prescribed_volcaero_datapath      = '/cluster/shared/noresm/inputdata/atm/cam/volc'
 prescribed_volcaero_file          = 'CMIP_CAM6_radiation_v3_reformatted.nc'
```

In output : cam.h0 file

Variable	Dimension		Units
ABSVVOLC	(time, lat, lon)	CMIP6 volcanic aerosol absorptive optical depth at 0.442-0.625um	[1]
AODVVOLC	(time, lat, lon)	CMIP6 volcanic aerosol optical depth at 0.442-0.625um	[1]
BVISVOLC	(time, lev, lat, lon)	CMIP6 volcanic aerosol extinction at 0.442-0.625um	[km^{-1}]

8. (Varying) boundary conditions overview

1. Aerosol and aerosol-precursor emissions (2D and 3D)
2. Oxidants (for chemistry)
3. (DMS upper ocean concentration) : needed if running without ocean
4. POM upper ocean concentration
5. Stratospheric aerosol
6. *Stratospheric H_2O emissions (from CH_4 oxidation) - part of the 3D emissions*
7. *Ozone (for radiation)*
8. *Green house gas (GHG) concentrations*
9. *Solar forcing*
10. *(Sea surface temperature (SST) and sea-ice cover (SIC)) : needed if running without ocean*

GHG concentration

pre-industrial (1850) simulation

```
&chem_surfvals_nl
 ch4vmr          =    808.25e-9
 co2vmr          =    284.32e-6
 f11vmr          =    32.11e-12
 f12vmr          =    0.0
 flbc_list             = ' '
 n2ovmr          =    273.02e-9
```

historical simulation

```
&chem_surfvals_nl
 flbc_file             = '/cluster/shared/noresm/inputdata/atm/waccm/lb/LBC_1750-2015_CMIP6_GlobAnnAvg_c180926.nc'
 flbc_list             = 'CO2','CH4','N2O','CFC11eq','CFC12'
 flbc_type             = 'SERIAL'
 scenario_ghg          = 'CHEM_LBC_FILE'
```

Surface concentration are prescribed (can have a latitudinal gradient) + temporal evolution.

Prescribed vertical profile (depends on species, depends on latitude) in the model

Solar forcing

pre-industrial (1850) simulation

```
&solar_data_opts
 solar_data_type                = 'FIXED'
 solar_data_ymd          =    18500101
 solar_htng_spctrl_scl          = .true.
 solar_irrad_data_file          = '/cluster/shared/noresm/inputdata/atm/cam/solar/SolarForcingCMIP6piControl_c160921.nc'
```

historical simulation

```
&solar_data_opts
 solar_htng_spctrl_scl          = .true.
 solar_irrad_data_file          = '/cluster/shared/noresm/inputdata/atm/cam/solar/SolarForcingCMIP6_18491230-22991231_c171031.nc'
```

Oxidants (for chemistry)

Specification

- 3D fields for OH, NO_3, HO_2 and O_3
- monthly frequency
- Taken from CESM2, based on WACCM simulations (often average from an ensemble)

pre-industrial (1850) simulation

```
tracer_cnst_cycle_yr           =    1850
tracer_cnst_datapath           = '/cluster/shared/noresm/inputdata/atm/cam/tracer_cnst'
tracer_cnst_file               = 'tracer_cnst_WACCM6_halons_3DmonthlyL70_1850climoCMIP6piControl001_y21-50avg_c180802.nc'
tracer_cnst_filelist           = ''
tracer_cnst_specifier          = 'O3','OH','NO3','HO2'
tracer_cnst_type               = 'CYCLICAL'
```

historical simulation

```
tracer_cnst_datapath           = '/cluster/shared/noresm/inputdata/atm/cam/tracer_cnst'
tracer_cnst_file               = 'tracer_cnst_halons_3D_L70_1849-2015_CMIP6ensAvg_c180927.nc'
tracer_cnst_filelist           = ''
tracer_cnst_specifier          = 'O3','OH','NO3','HO2'
tracer_cnst_type               = 'INTERP_MISSING_MONTHS'
```

Ozone (for radiation)

Specification

- Zonally symmetric
- 5-daily : to have the onset of the Antarctic ozon hole
- Taken from CESM2, based on WACCM simulations (often average from an ensemble)

historical simulation

```
&prescribed_ozone_nl
 prescribed_ozone_cycle_yr             =    1850
 prescribed_ozone_datapath             = '/cluster/shared/noresm/inputdata/atm/cam/ozone_strataero'
 prescribed_ozone_file          = 'ozone_strataero_cyclical_WACCM6_L70_CMIP6-piControl.001_y21-50avg_zm_5day_c180802.nc'
 prescribed_ozone_name          = 'O3'
 prescribed_ozone_type          = 'CYCLICAL'
```

historical simulation

```
&prescribed_ozone_nl
 prescribed_ozone_datapath             = '/cluster/shared/noresm/inputdata/atm/cam/ozone_strataero'
 prescribed_ozone_file          = 'ozone_strataero_WACCM_L70_zm5day_18500101-20150103_CMIP6ensAvg_c180923.nc'
 prescribed_ozone_name          = 'O3'
 prescribed_ozone_type          = 'SERIAL'
/
```

9. Structure of the code

Information (e.g., which boundary conditions to use) is given to the model mainly by the namelist.

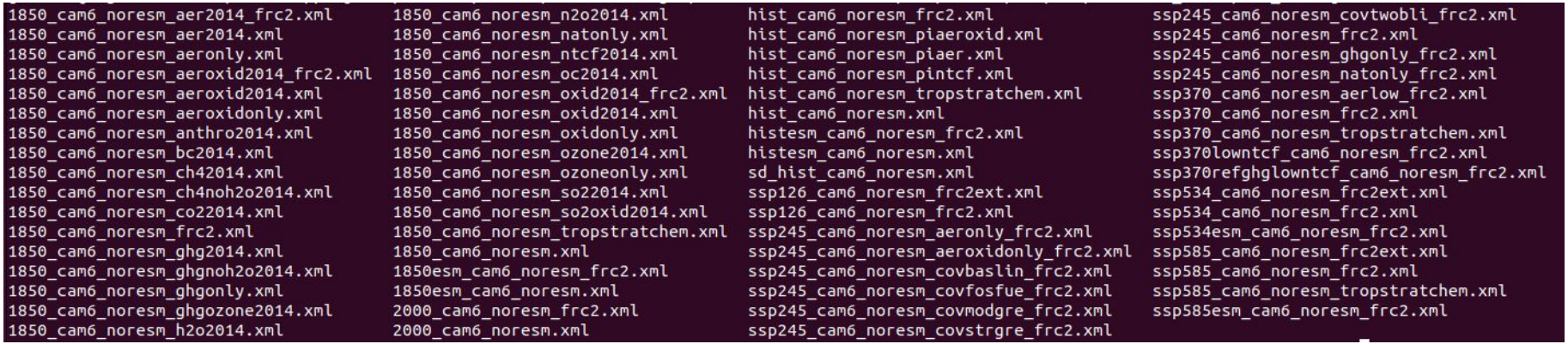
Which information ends up in the namelist (when preparing the simulations) is often determined by the COMPSET name. One can overwrite these settings by using user_nl_cam.

To get a flavour of this process, there are some informative files/directories to look into.

	cam/bld/…	
(1)	cam/bld/build-namelist	Helps to see how the namelist (containing boundary conditions) is created
(2)	cam/bld/configure	Helps to see which source code is compiled
(3)	cam/bld/namelist_files/namelist_definition.xml	Explains what specific namelist variables are/can be
(4)	cam/bld/namelist_files/namelist_defaults_cam.xml	Default value for namelist variables
(5)	cam/bld/namelist_files/use_cases/	Use cases with specific settings for specific compsets

Structure of the code

cam/bld/namelist_files/use_cases/		
(1)	1850_cam6_noresm.xml	pre-industrial conditions
(2)	hist_cam6_noresm.xml	historical evolution 1850-2014
(3)	ssp126_cam6_noresm.xml	future scenario SSP1-2.6 for 2015-2100
(4)	ssp245_cam6_noresm.xml	future scenario SSP2-4.5 for 2015-2100
(5)	ssp370_cam6_noresm.xml	future scenario SSP3-7.0 for 2015-2100
(6)	ssp585_cam6_noresm.xml	future scenario SSP5-8.5 for 2015-2100
(7)	1850_cam6_noresm_aer2014.xml	pre-industrial conditions but 2014 aerosol and aerosol-precursor emissions
(8)	hist_cam6_noresm_piaer.xml	historical evolution 1850-2014, but keeping 1850 aerosol and aerosol-precursor emissions
	…	



10. Full chemistry version : motivation

1. More complete description of aerosols in NorESM (via on-line oxidants)

2. Broader emission impact studies (role of ozone precursor emissions, instead of only role of aerosol precursors)
   Up to now : only impact of emissions from BC, OC, SO_2, …
   Extend to: emissions of NOx , CO, NH_3, NMVOC, …

3. Not anymore dependent on CESM2 (NCAR) to provide oxidant and ozone climatologies (e.g., missing forcing data for SSP5-3.4 overshoot scenario and SSP1-1.9)

4. Possibility for a more Earth-System approach: how do natural emissions that affect radiative balance change under a changing climate?
   Lightning NOx – Biogenic emissions (e.g., isoprene and monoterpenes) – Soil emissions (NOx , CO, . . .) – Permafrost thawing CH_4 emissions – Oceanic halogenated emissions (e.g., bromoform) – . . .

5. Air quality
   More complete representation for air-quality (aerosols + ozone)

Full chemistry

What is it technically? A combination of

- The OsloAero aerosol scheme, and
- Gas-phase chemistry used in some compsets of CESM (trop_strat)

Some differences w.r.t. aerosol-only version

- Many more tracers (205, not all transported) and reactions
- Many more emissions to be specified
- LLGHG gases are now also 3D tracers : CO_2, CH_4, N_2O, CFC-11, CFC-12, …
- Impose surface layer concentration for many LLGHGs, OCS, and ODSs (ozone depleting species)
- No prescribed oxidant climatologies
- No prescribed ozone climatologies
- No prescribed stratospheric AOD, but explicit stratospheric SO_2 emissions
- Factor 2.5 more expensive
- Currently less compsets available

Full chemistry

cam/src/chemistry/pp_tropstrat_mam_oslo/chem_mech.in

For species with a very short lifetime

```
Not-Transported
ACBZO2,
ALKO2,
BENZO2,
BZOO,
C2H5O2,
C3H7O2,
C6H5O2,
CH3CO3,
CH3O2,
DICARBO2,
ENEO2,
EO,
EO2,
HO2,
HOCH2OO,
ISOPAO2,
ISOPBO2,
MACRO2,
MALO2,
MCO3,
MDIALO2,
MEKO2,
NTERPO2,
O1D,
OH,
PHENO2,
PO2,
RO2,
TERP2O2,
TERPO2,
TOLO2,
XO2,
XYLENO2,
XYLOLO2
End Not-Transported
```

```
Solution classes
   Explicit
AOA_NH
BRY
CCL4
CF2CLBR
CF3BR
CFC11
CFC113
CFC114
CFC115
CFC12
CH2BR2
CH3BR
CH3CCL3
CH3CL
CH4
CHBR3
CLY
CO2
E90
H2402
HCFC141B
HCFC142B
HCFC22
N2O
NH_5
NH_50
SF6
ST80_25
NHDEP
NDEP
End Explicit
```

For species with a very long lifetime

More species have 3D emissions

```
Ext Forcing
BC_NI <-dataset
BC_AX <-dataset
BC_N <-dataset
OM_NI <-dataset
SO4_PR <-dataset
* so4_a2 <- dataset
NO <- dataset
NO2 <- dataset
SO2 <- dataset
* SVOC <- dataset
* pom_a1 <- dataset
* pom_a4 <- dataset
* so4_a1 <- dataset
CO <- dataset
* bc_a1 <- dataset
* bc_a4 <- dataset
* num_a1 <- dataset
* num_a2 <- dataset
* num_a4 <- dataset
OH
N
AOA_NH
End Ext Forcing
```

Some artificial (diagnostics) tracers

```
**********                    **********
*** Tracers
**********                    **********
[E90_tau]                E90   -> sink                                    ; 1.29e-07
[NH_50_tau]              NH_50  ->                                         ; 2.31e-07
[NH_5_tau]               NH_5   ->                                         ; 2.31e-06
[ST80_25_tau]            ST80_25  ->                                       ; 4.63e-07
```

Full-chemistry compsets

Fully-coupled (including ocean) compsets	
N1850_tropstratchem	**1850**_CAM60%NORESM%**TROPSTRATCHEM**_CLM50%BGC-CROP_CICE%NORESM-CMIP6_BLOM%ECO_MOSART_SGLC_SWAV_BGC%BDRDDM
NHIST_tropstratchem	**HIST**_CAM60%NORESM%**TROPSTRATCHEM**_CLM50%BGC-CROP_CICE%NORESM-CMIP6_BLOM%ECO_MOSART_SGLC_SWAV_BGC%BDRDDMS
NSSP370_tropstratchem	**SSP370**_CAM60%NORESM%**TROPSTRATCHEM**_CLM50%BGC-CROP_CICE%NORESM-CMIP6_BLOM%ECO_MOSART_SGLC_SWAV_BGC%BDRDDMS
NSSP585_tropstratchem	**SSP585**_CAM60%NORESM%**TROPSTRATCHEM**_CLM50%BGC-CROP_CICE%NORESM-CMIP6_BLOM%ECO_MOSART_SGLC_SWAV_BGC%BDRDDMS

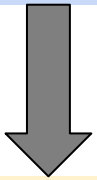
Fixed-SST compsets	
NF1850norbc_tropstratchem	**1850**_CAM60%NORESM%NORBC%**TROPSTRATCHEM**_CLM50%BGC-CROP_CICE%PRES_DOCN%DOM_MOSART_SGLC_SWAV

11. Modifying the chemistry scheme

STEP 1 : Copy chem_mech.in (taken from an) into case-directory.

STEP 2: Modify chem_mech.in : add gas-phase species, chemical reaction rate, photolysis rate, …

STEP3 : ./xmlchange --append CAM_CONFIG_OPTS="--usr_mech_infile `pwd`/my_chem_mech.in"



The new code (16 F90-files) will appear in
<case-directory>/Buildconf/camconf/chem_proc/source

That new code will automatically be used to build the model

Are other processes active : wet/dry deposition, lower boundary conditions, … ?

12. Possible new features in the future

Thinner layers in NorESM3.0 at the surface -> maybe change surface emissions

Updated version of MEGAN (2.1 -> 3.0)

More explicit new particle formation/nucleation (has been developed but not yet implemented)

Online biomass burning emissions from CLM (land model)

Simulations with explicit emissions of CH_4, N_2O, …

Work going on an aerosol scheme with bins instead of modes

13. Take home message

Reasonably complex aerosol description : many modes, use of look-up tables, …

Simplifications through lumped process tracers : the process modes have their own dry deposition, wet deposition, below cloud scavenging, …

Aerosol sizes/properties in model and AeroTab tables must be coherent.

Full-chemistry compset is a new feature of NorESM2.3.

It is possible to modify the chemistry/aerosol scheme (but not very flexible).

Feel free to contact us if useful additional compsets are missing : dirk.olivie@met, oyvindse@met.no, stevenng@met.no