Update on aerosol developments for CESM2

Xiaohong Liu[1], Xi Zhao[1], Yang Shi[1], Ziming Ke[1],
Susannah Burrows[2]

[1]Texas A&M University
[2]Pacific Northwest National Laboratory

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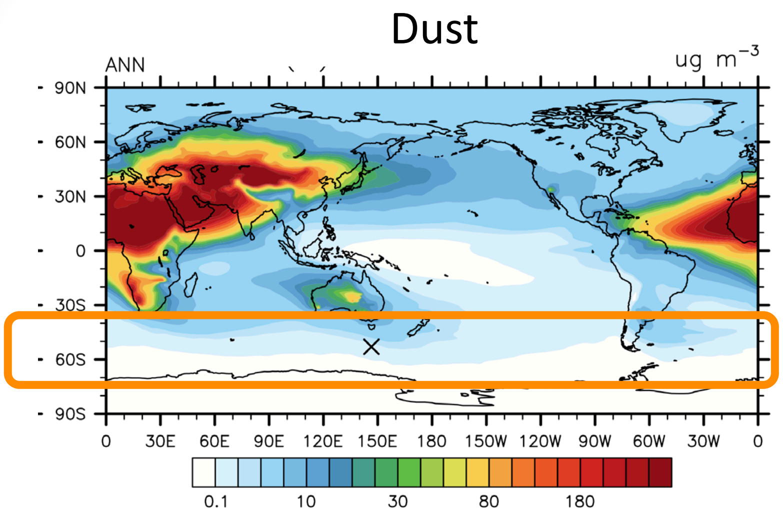
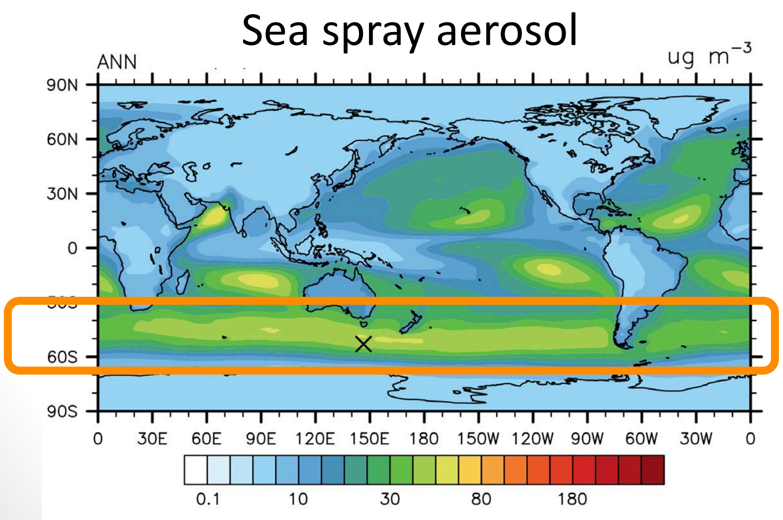
Outline

- Marine organic aerosol and impacts on Southern Ocean mixed-phase clouds
- MAM4 to MAM7

Marine Organic Aerosols - Motivation

Burdens of dust versus sea spray aerosol





Dust: important INP (Ice Nucleating Particles)

- **Amount**
- **Efficiency**

Over Southern Ocean

- **Limited dust**
- **Abundant SSA**

Emission of Marine Organic Aerosols (MOA)

- The mass fraction of organic aerosol $F_{MOA/SSA}$ defined as :
- $F_{MOA/SSA} = \frac{M_{MOA}}{M_{sea\ spray}} = \frac{M_{MOA}}{M_{MOA}+M_{sea\ salt}}$

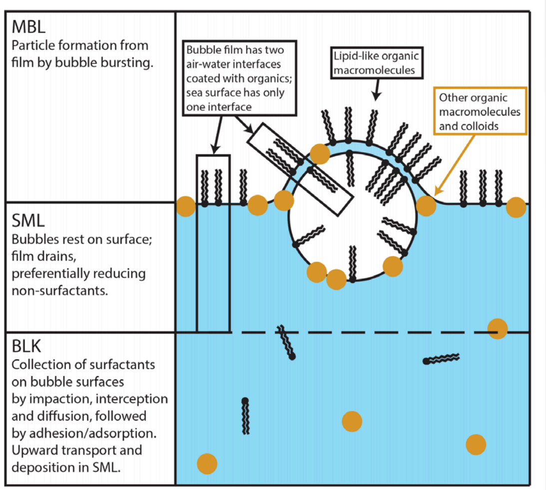


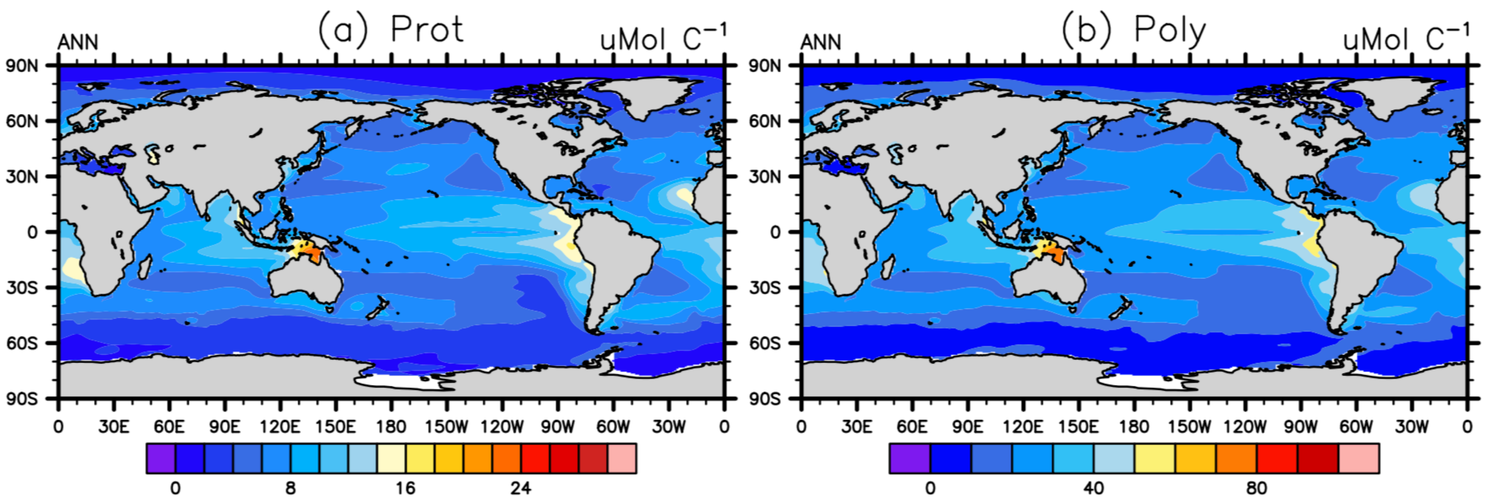
Figure 1. Conceptual schematic of bulk water (BLK), SML, and MBL aerosol enrichment processes.

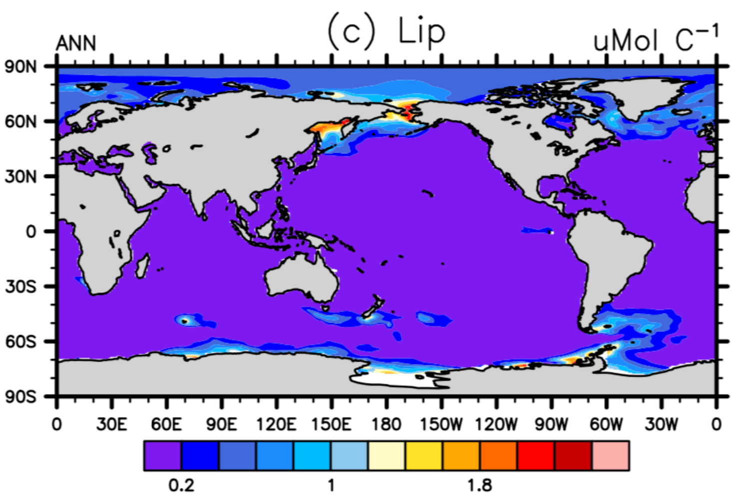
A physically based framework for modeling the organic fractionation of sea spray aerosol from bubble film Langmuir equilibria [Burrows et al., 2014]

- **OCEANFILMS [Borrows et al. 2014]**
  - $M_{MOA} = S_m \times \theta$
    - S_m is the organic mass per m^2 at saturation
    - θ is the surface coverage fraction of organics
      - $\theta = \frac{\alpha \times C_M}{1+\alpha \times C_M}$
        - α is the Langmuir parameters
        - C_M is mass concentration of organic matters in seawater
  - $F_{MOA/SSA} = \frac{S_m \times \frac{\alpha \times C_M}{1+\alpha \times C_M}}{S_m \times \frac{\alpha \times C_M}{1+\alpha \times C_M} + M_{sea\ salt}}$

Emission

- Protein, polysaccharide, and lipid in ocean water





Species	polysaccharides	proteins	Lipids
Molecular weights [g mol^{-1}]	250000	66463	284
mass at saturation [g m^{-2}]	0.1376	0.00219	0.002593
Langmuir parameters [m^{3} mol^{-1}]	90.58	25175	18205

Implementation

- Community Earth System Model version 2 (CESM2)
  - Prescribed climatological sea surface temperature (SST)
  - Resolution: 0.9*1.25 degree with 32 vertical level
  - Simulation time: 6 years
    - analysis 2-6 years

- 4MODE_MOM:
  - marine organic aerosol is added to MAM4

[Burrows et al., 2014]

Table 1. species in MAM4 modes

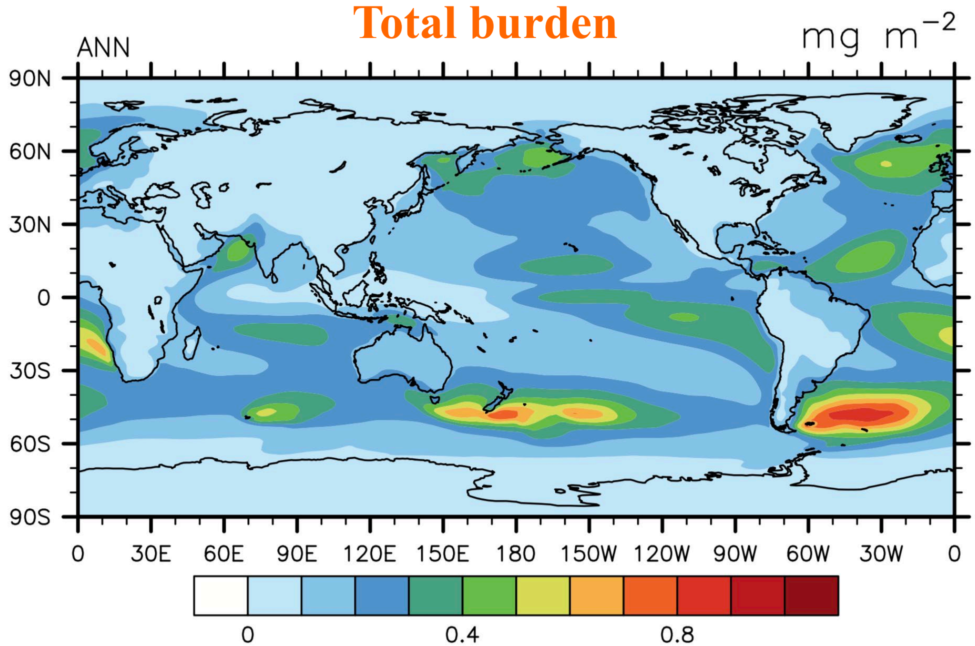
Accumulation	Aitken	Coarse	Primary carbon
num_a1	num_a2	num_a3	num_a4
so4_a1	so4_a2	dst_a3	pom_a4
pom_a1	soa_a2	ncl_a3	bc_a4
soa_a1	dst_a2	so4_a3	
bc_a1	ncl_a2		
dst_a1	**mom_a2**		
ncl_a1			
mom_a1			

Table 2. list of simulations

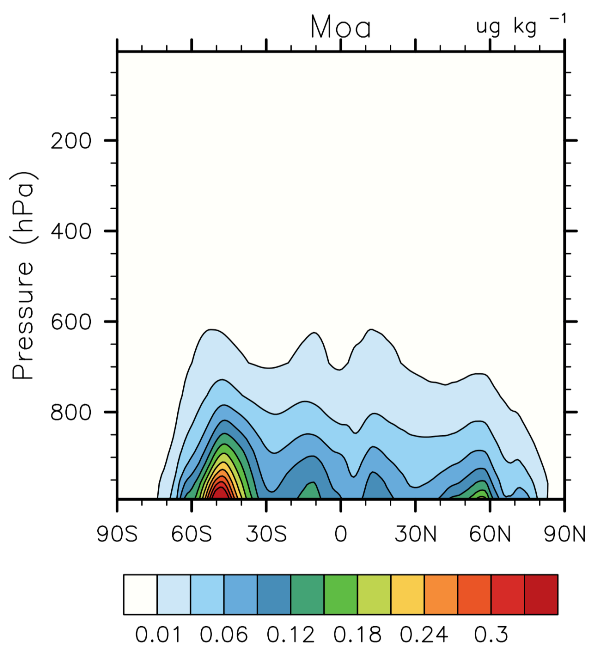
Name	Emission of MOA	MOA ice nucleation	
CESM2	--	--	Baseline
B14	Burrows et al. [2014]	--	CCN effect
B14_M18	Burrows et al. [2014]	McCluskey et al. [2018]	INP effect

Distribution of MOA in CESM2

Total burden



Zonal mean distribution



The marine organic aerosols vary with latitude (max at 45 S), and altitude (boundary layer).

Comparison of modeled MOA with observations

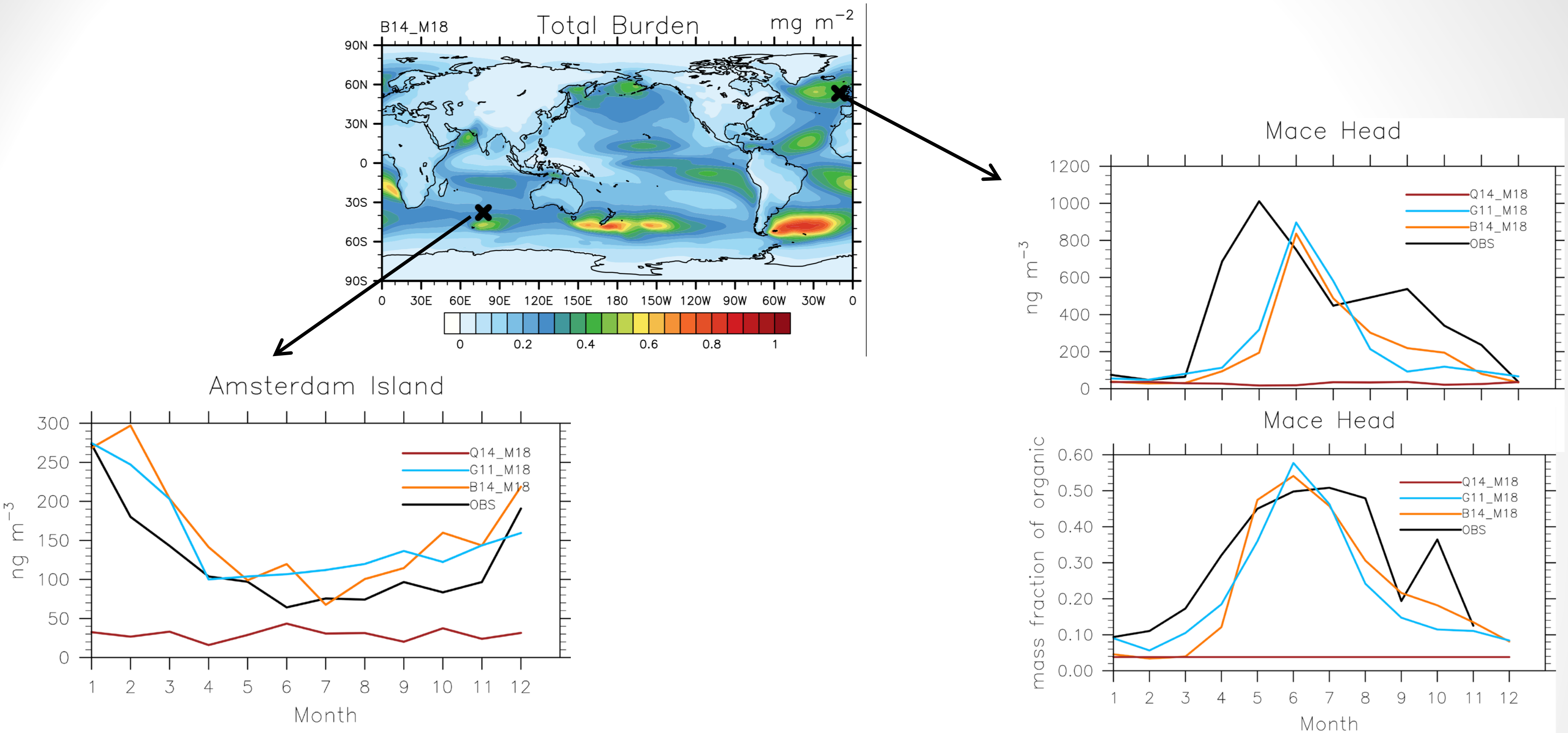


Figure 2. Monthly average concentration of MOA at Mace Head (a), Ireland and Amsterdam Island (b); and monthly averaged mass fraction of organic at Mace Head (c),

The maximum concentration/mass fraction of MOA: summer – late spring

Ice nucleation parameterizations

- INPs from SSA

[McCluskey et al., 2018]
SSA

$$N_i = N_{tot} S_{ae} n_s(T)$$

$$n_s(T) = e^{(-0.545(T-273.15)+1.0125)}$$

N_{tot} SSA number concentration
S_{ae} SSA surface area

[Wilson et al., 2015]
MOA

$$N_{IN,T} = TOC \times e^{(11.2186-(0.4459\times T))}$$

- INPs from dust

[Niemand et al., 2012]

$$N_i = N_{tot} S_{ae} n_s(T)$$

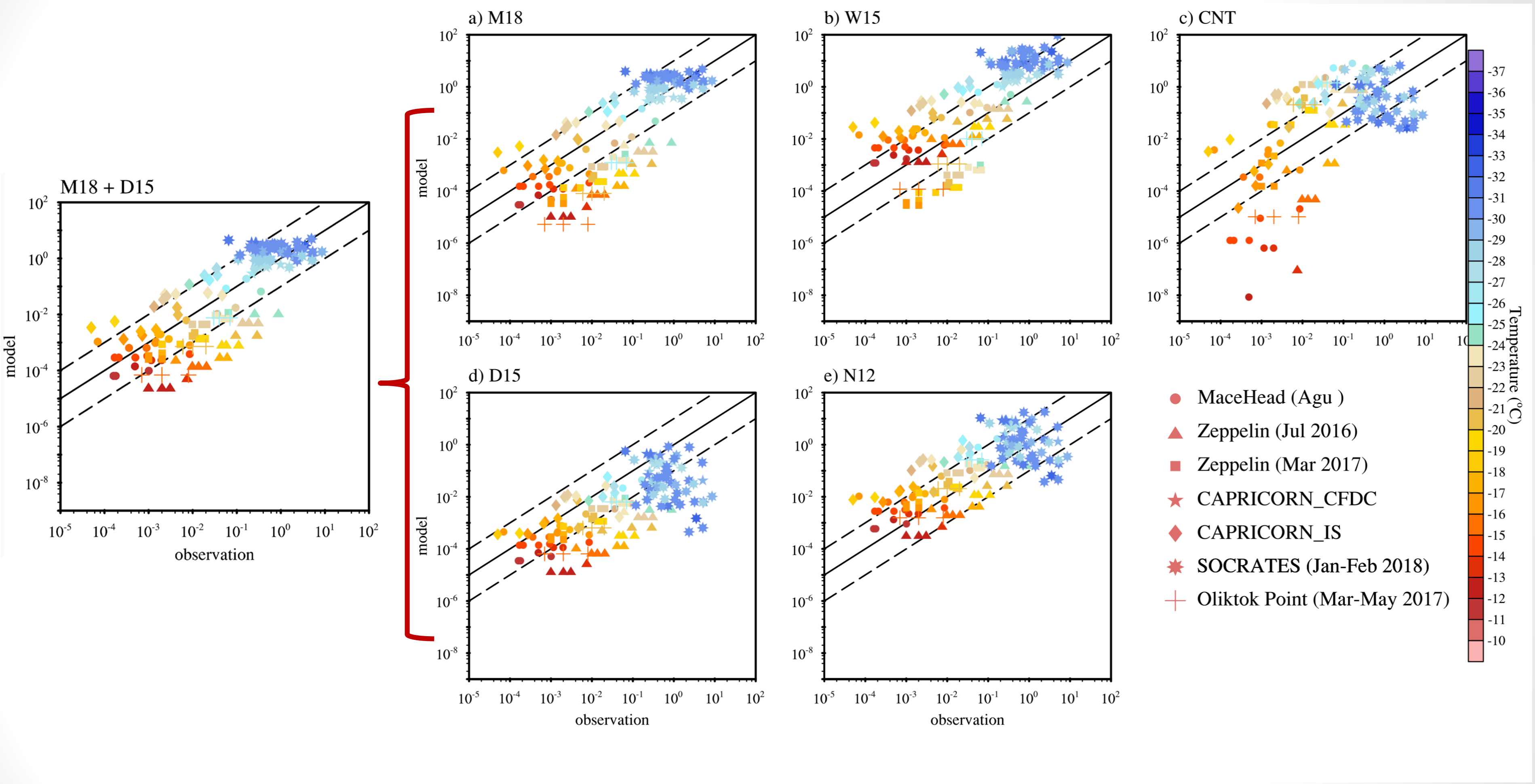
$$n_s(T) = e^{(-0.517(T-273.15)+8.934)}$$

[DeMott et al., 2015]

$$N_{INP}(T) = a(n_{0.5})^b e^{c(T-273.15)-d}$$

a = 3, b = 1.25, c = -0.46, d=11.6

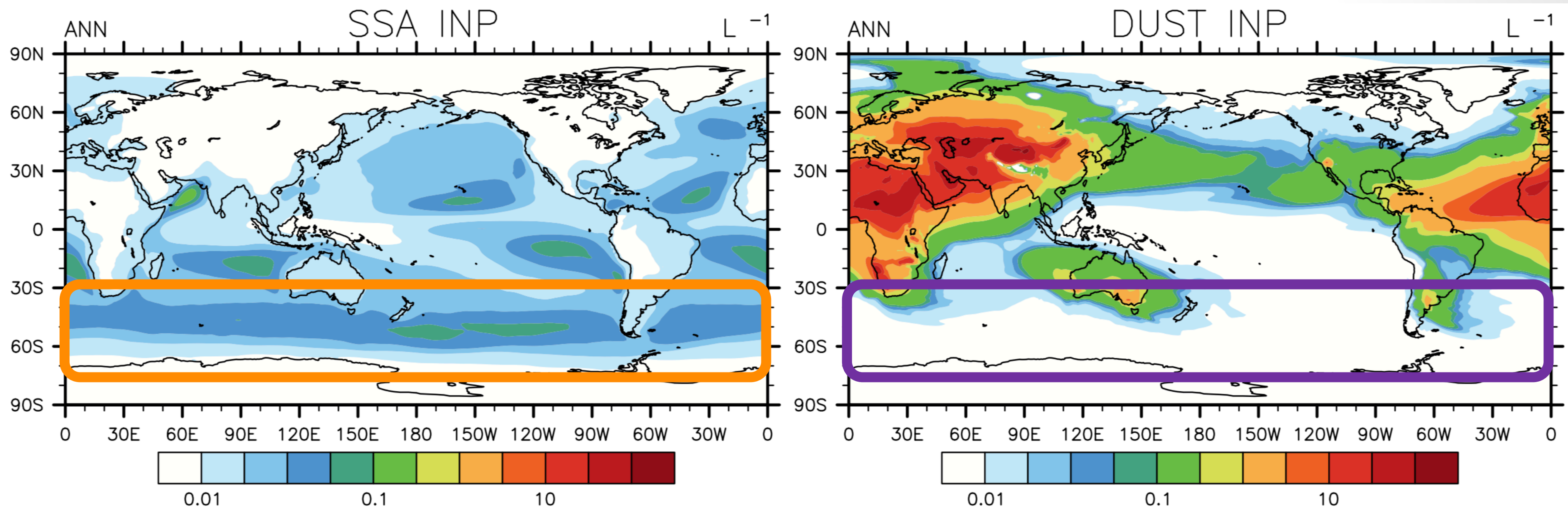
INP concentrations comparison with observations



Comparison of simulated vs. observed INPs concentration for the five simulations. Color bar shows the observed temperature in °C, while different markers represent different field campaigns. Dashed lines outline a range of a factor of 10 about the 1:1 line (solid) in all the panels.

INP concentration: SSA versus DUST

INP concentration at 900 hPa (-25 C)



The SSA INP concentration is spread all over the Ocean, dominant over the Southern Ocean

INP concentration: SSA versus DUST

INP fraction: (SSA/DUST)

T = -25 C

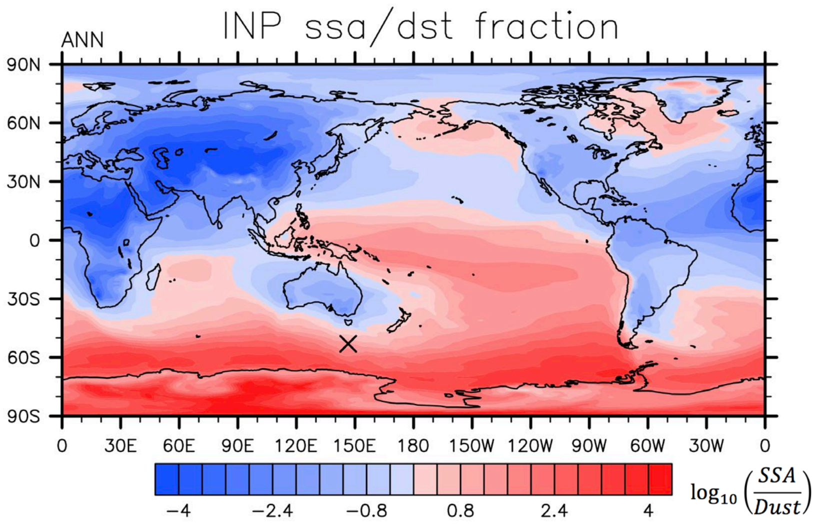


Figure 1 INP fraction at 900hPa

T = -25 C

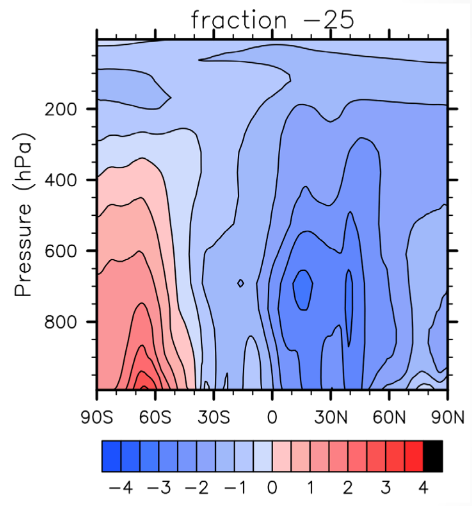
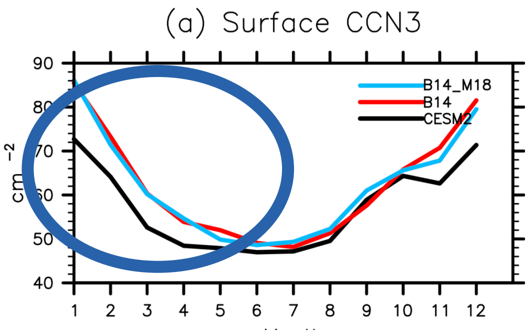


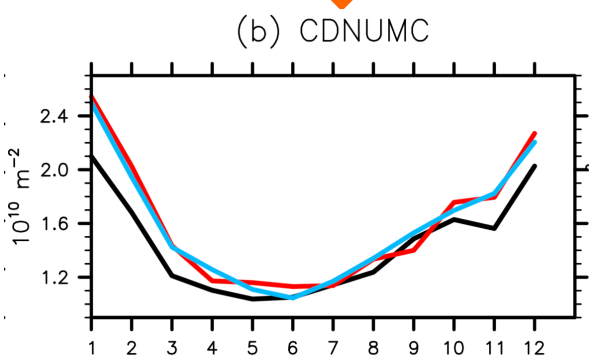
Figure 2 Vertical distribution of INP fraction

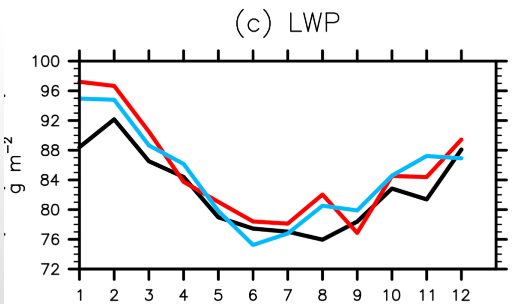
Compared with dust INP,
SSA is dominant INP over Southern Ocean, 1000 times of dust
--- high latitude (40S South)
--- mid-low altitudes (below 400 hPa altitude)

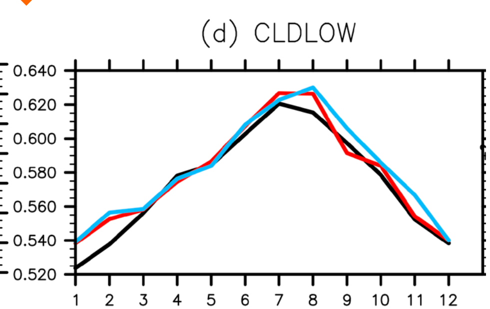
Impact of MOA on clouds and radiation -- SWCF

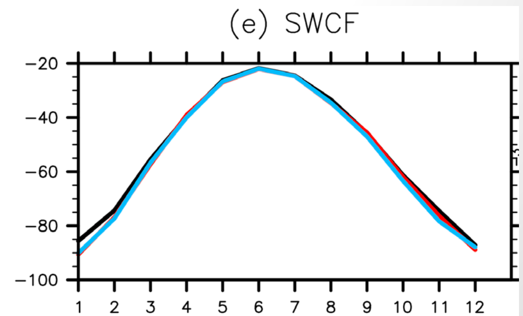
Seasonal cycle (20S – 90S)











		ANN	DJF	JJA
Global	CCN	-0.44	-1.03	-0.59
	INP	0.06	-0.14	0.28
20-90S	CCN	-0.96	-3.09	-0.19
	INP	0.13	0.36	-0.15

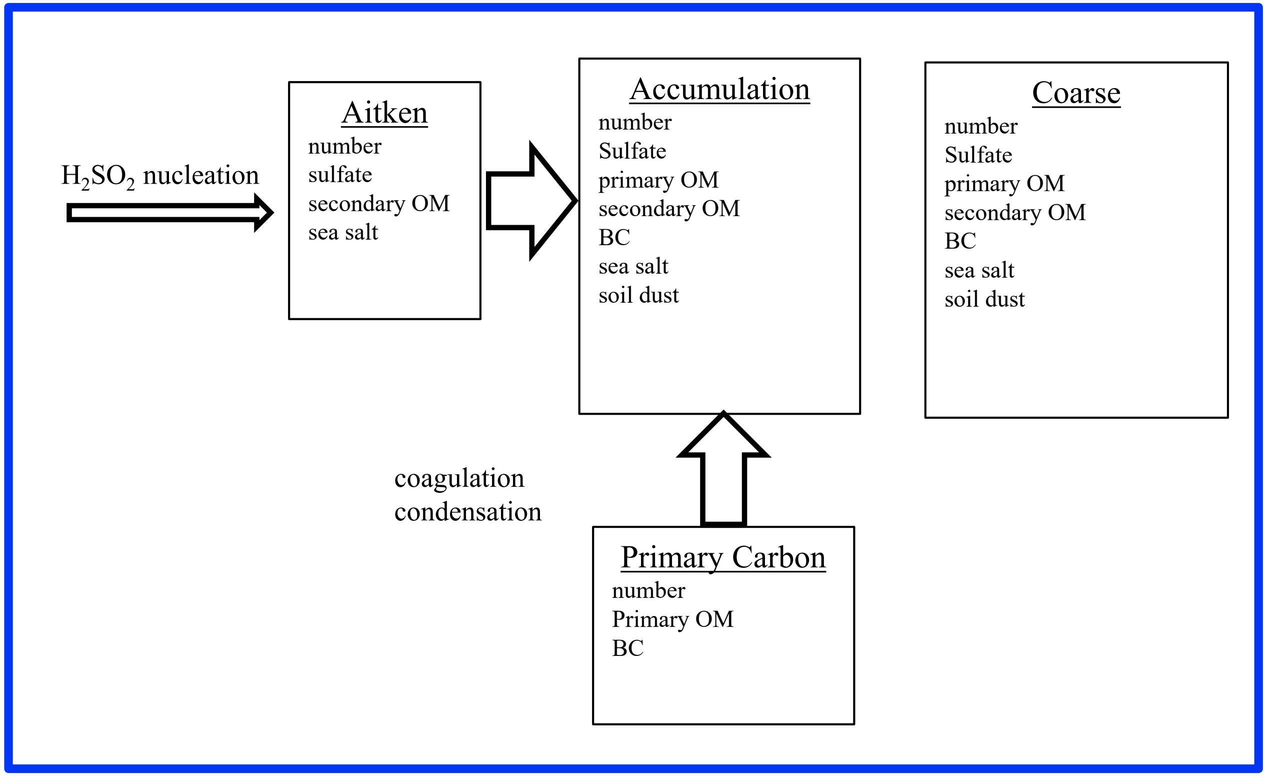
- LWP
- CLOUD_LOW
- CDNUMC

New cloud droplets formed, summer (max)

Summary

- MOA is implemented in CESM2
- SSA INPs
  - Region: spread over the Oceans
    - dominant **over Southern Ocean (SO)**, **1000** times of dust INPs
  - Vertical distribution:
    - Boundary layer: SSA INPs
- Clouds and radiation
  - CCN effect:
    - Cloud properties and cloud forcing vary with time (summer max), region (SO max)
    - Stronger SWCF (-3.1 W m^{-2}) over SO in summer
  - INP effect:
    - Weaker SWCF (0.36 W m^{-2}) over SO in summer

MAM4



Widths of lognormal modes

CAM5

- Aitken: 1.6
- Accumulation: 1.8
- Coarse: 1.8
- Primary Carbon: 1.6

CAM6

- Aitken: 1.6
- Accumulation: 1.6
- Coarse: 1.2
- Primary Carbon: 1.6

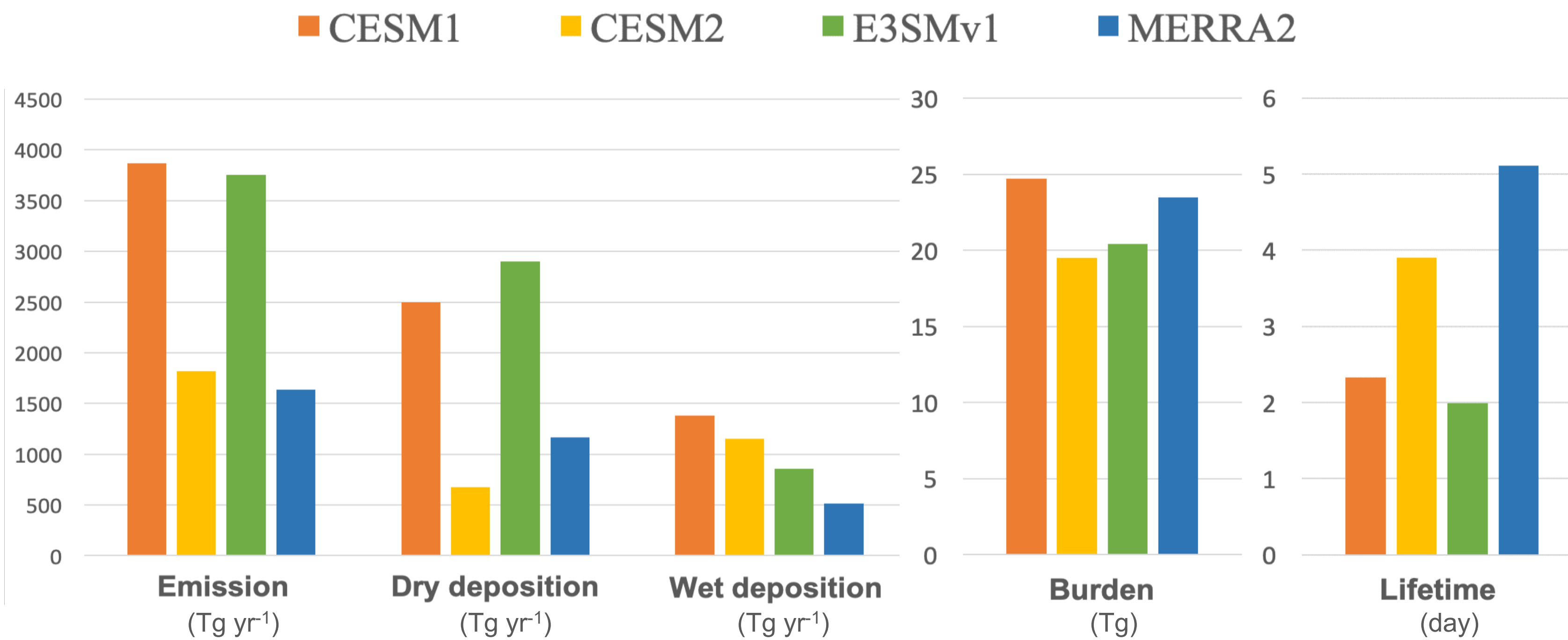
Dust in Models

	Resolution	Aerosol Module	Geometric standard deviations	mass fraction of emission (%)	dust emission scheme
CESM1	1 deg, 30 L	MAM3 (aitken, accum, coarse)	1.8, 1.8	1.1, 98.9	Zender et al. (2003)
CESM2	1 deg, 32 L	MAM4 (aitken, accum, coarse)	1.6, 1.6, 1.2	0.00165, 1.1, 98.9	Zender et al. (2003)
E3SMv1	1 deg, 72 L	MAM4 (accum, coarse)	1.8, 1.8	3.2, 96.8	Zender et al. (2003)
MERRA-2	0.5 deg, 72 L	GOCART (5 bins) Assimilate AOD OBS		6.6, 20.6, 22.8, 24.5, 25.4	Ginoux et al. (2001)

- 2006 to 2009, last 3 years for analysis
- U, V nudged to MERRA-2 reanalysis
- Tuned dust emission, AOD in dusty regions matches MODIS
- Data collocation, orbit sampling, and cloud clearing

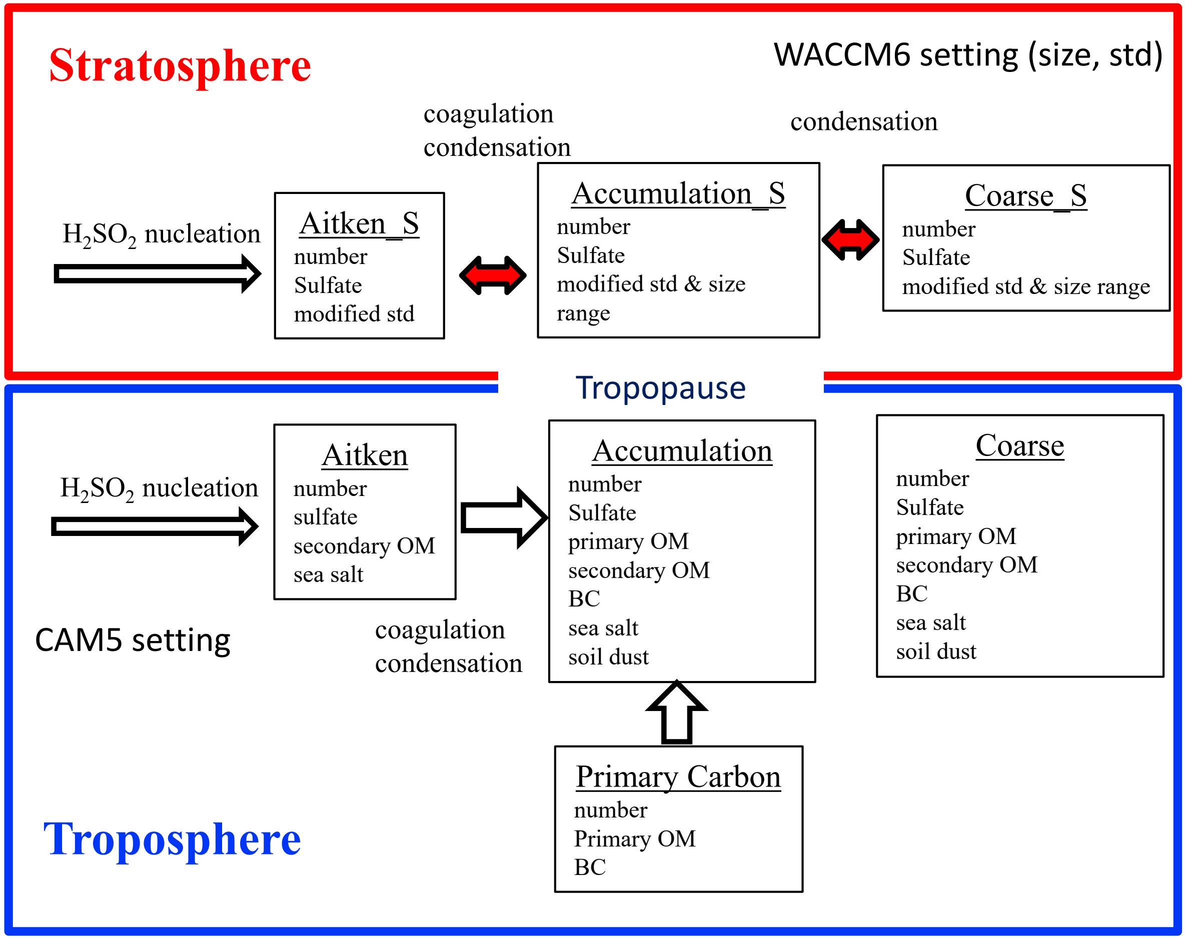
MAM PSD: 0.01 – 0.1 – 1 – 10 μm
GOCART PSD: 0.2 – 2 – 3.6 – 6 – 12 – 20 μm

Dust Mass Budgets



- CESM2 and MERRA-2 have much lower dust emission.
- E3SMv1 has larger dry deposition than CESM1 due to thinner bottom layer.
- MERRA-2 has the longest dust lifetime due to higher fine dust fraction.

MAM7 (or MAM5)



Mode width of lognormal distribution

Stratosphere
- Aitken: 1.6
- Accumulation: 1.6
- Coarse: 1.2

Troposphere
- Aitken: 1.6
- Accumulation: 1.8
- Coarse: 1.8
- Primary Carbon: 1.6

May merge the two Aitken (and accumulation) modes