Performance of the CARMA sectional aerosol microphysical model in CESM2

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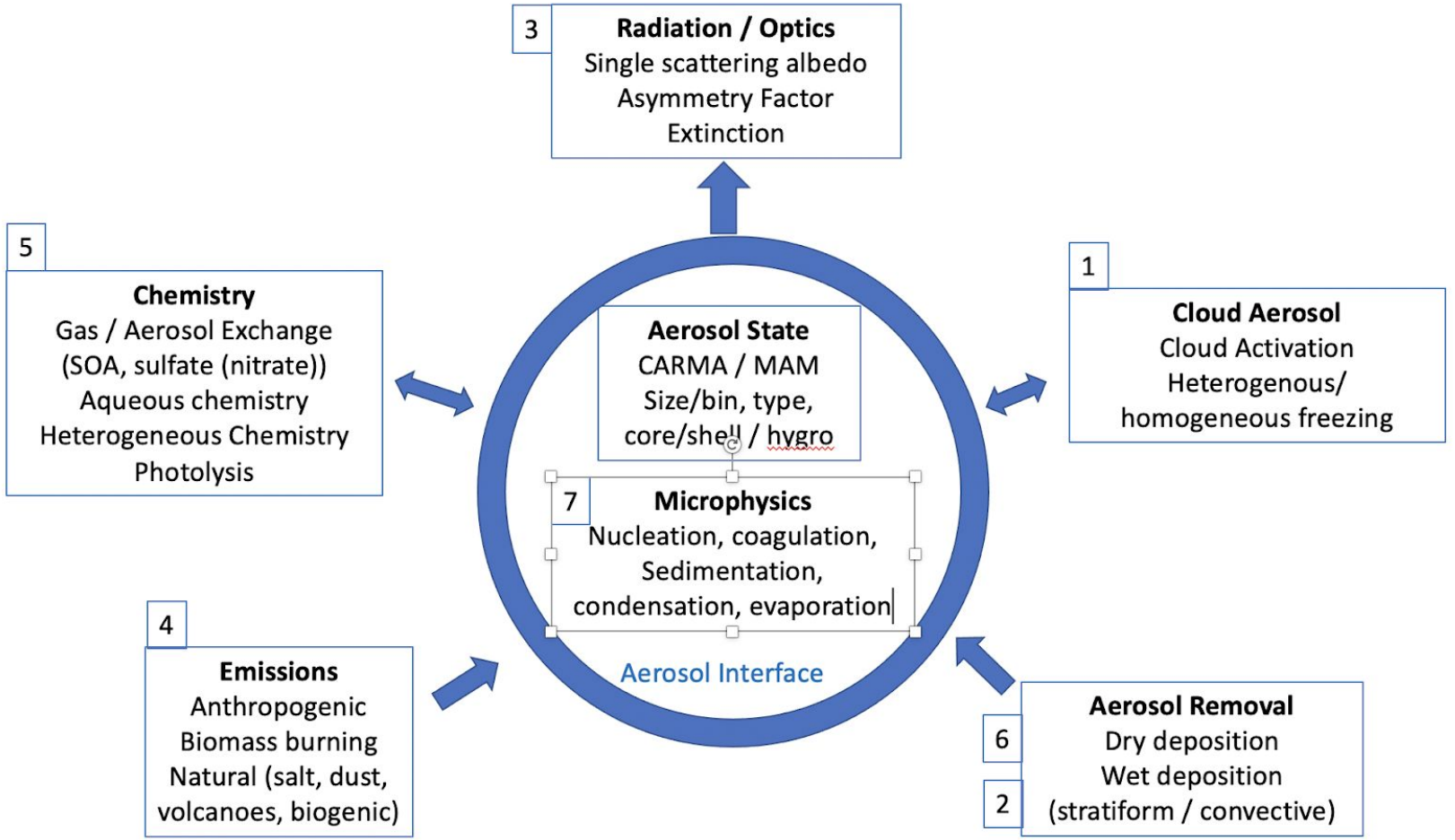
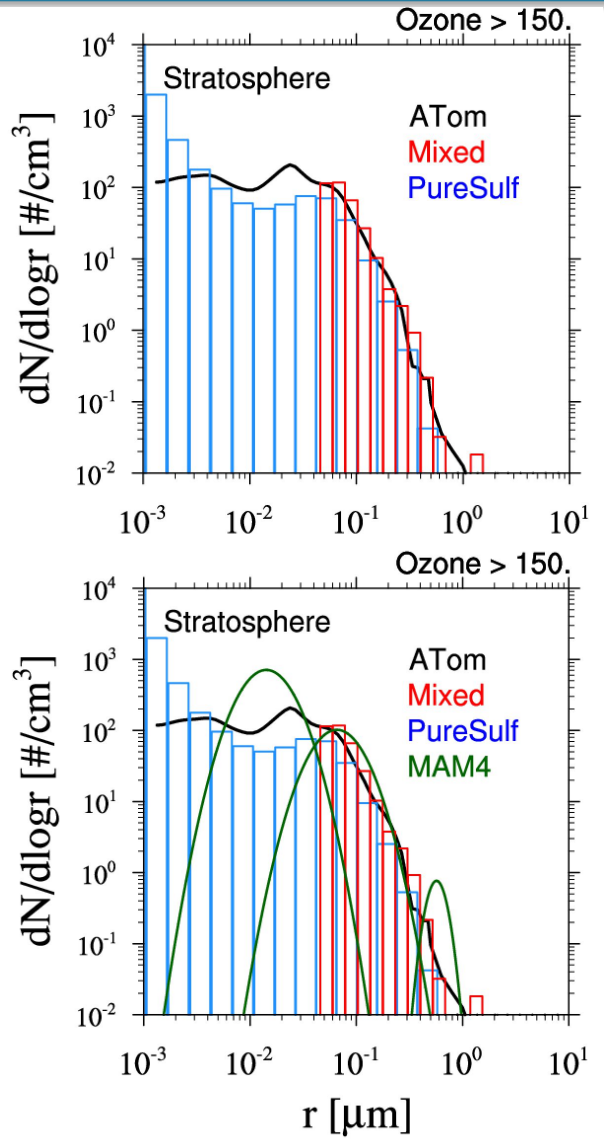
Coupling of CARMA to CESM2

Community Aerosol and Radiation Model for Atmospheres (CARMA): Sectional aerosol model for both troposphere and stratosphere





CESM2 Implementation and Performance

CARMA implementation into CESM2

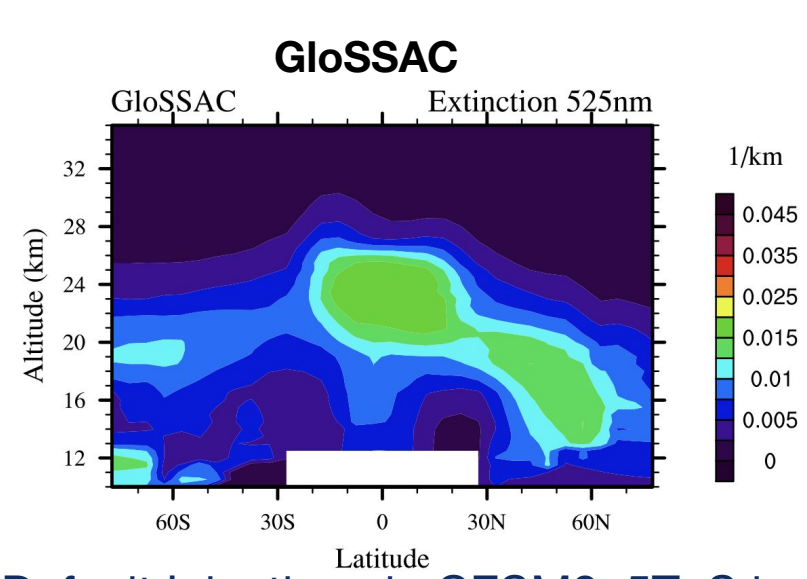
Two compsets have been developed and tested (both nudged to MERRA2)

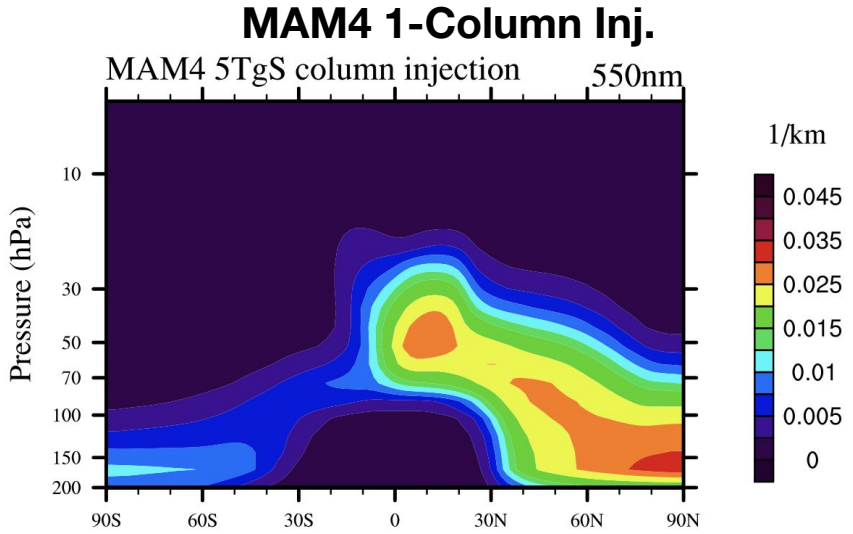
- WACCM-MA (with middle atmosphere chemistry) 1.9x2.5 horizontal resolution
- CAMchem (with troposphere/stratosphere (TS1) chemistry) 0.9x1.25 resolution

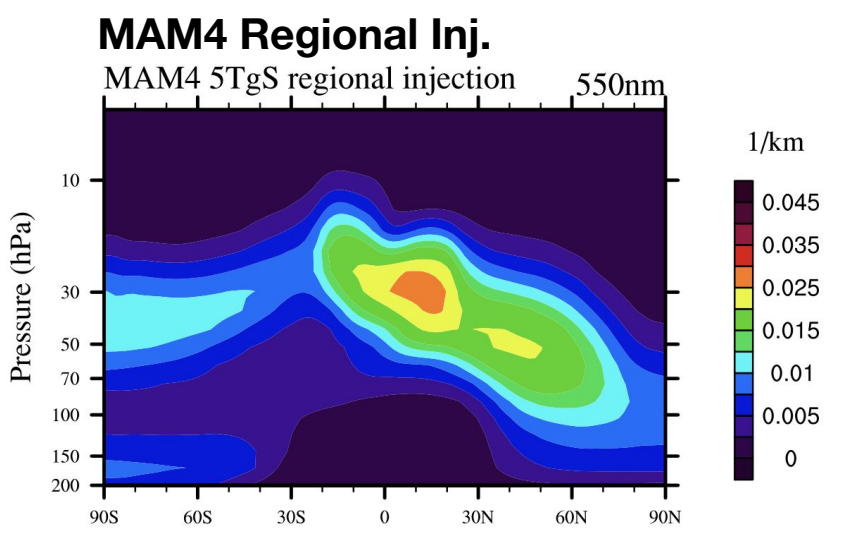
Simulations are performed from 1990-1995 (Mt Pinatubo period) and 2000-2020.

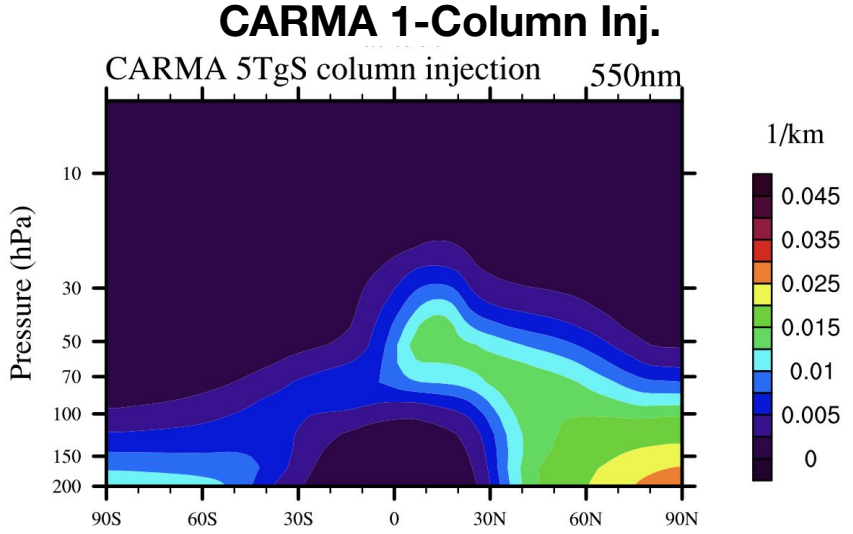
Model configuration	CAMchem	WACCM-MA	CAMchem	WACCM-MA
Horizontal Resolution	0.9x1.25	1.9x2.5	0.9x1.25	1.9x2.5
Top of Model	42km	150km	42km	150km
Chemistry	TS1	MA	TS1	MA
Aerosol	CARMA	CARMA	MAM4	MAM4
Number of Aerosol Tracers	220	140	27	19
Throughput	2.6 yrs/day	2.5 yrs/day	3.6 yrs/day	9.2 yrs/day
Model Cost (Core hours/yr)	31 K	11 K	7.5 K	2.3 K
Nucleation Scheme	Zhao	Zhao	Vehkamäki	Vehkamäki

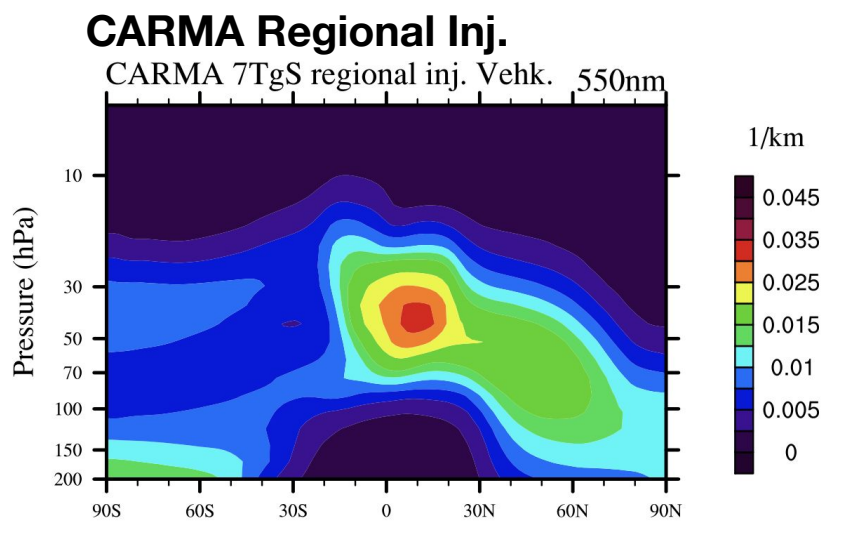
WACCM-MA: Mt Pinatubo Period 1991-1995







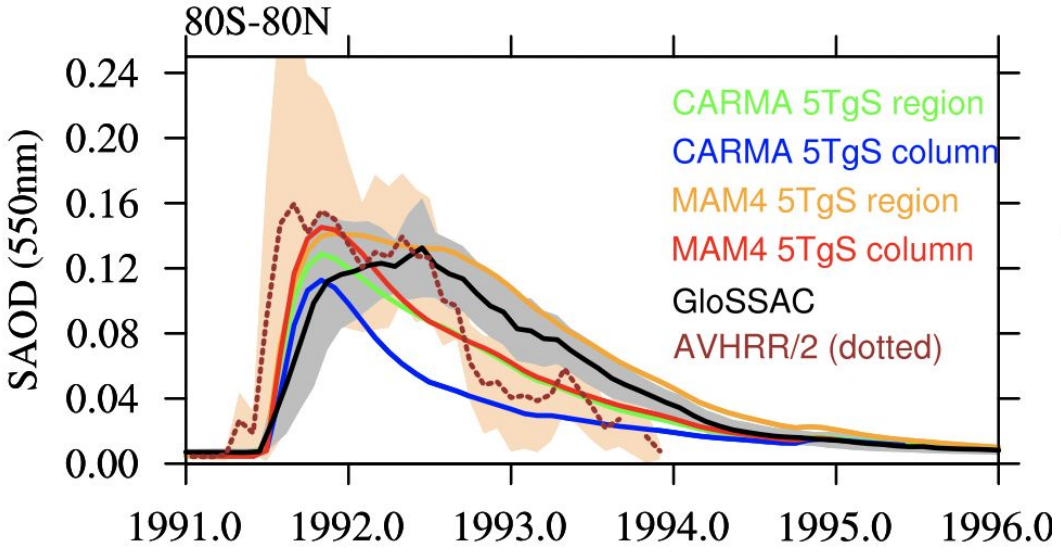


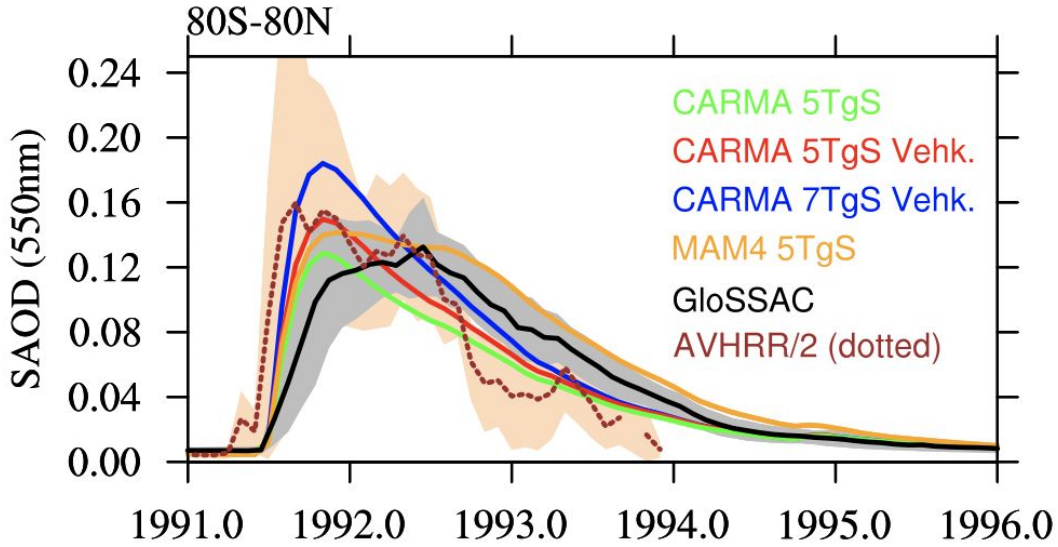


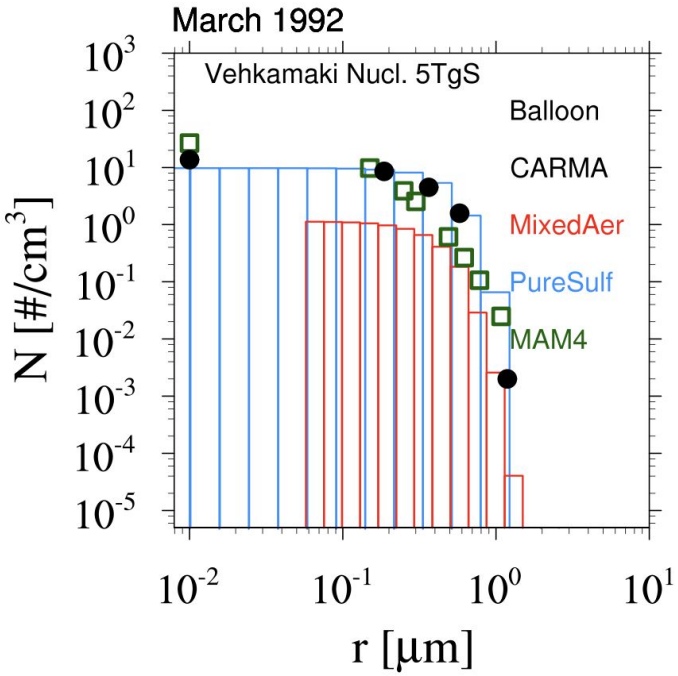
Default Injections in CESM2: 5TgS in one column

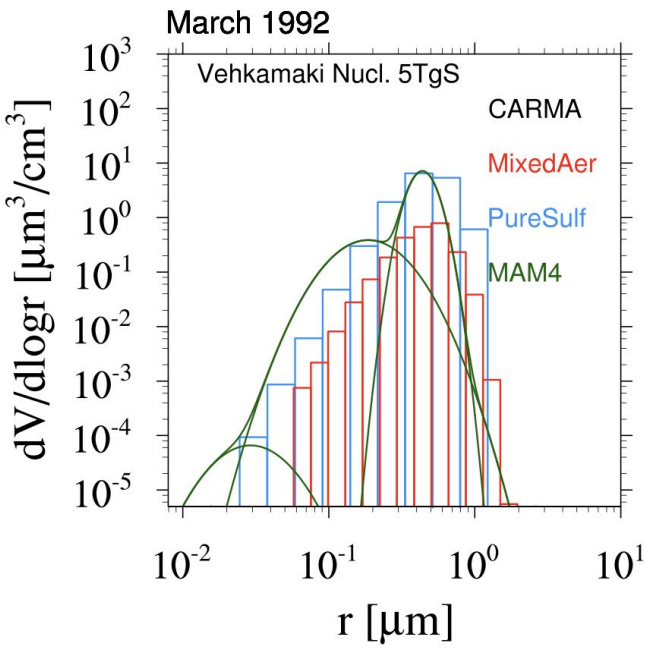
- Regional injections of SO_2 improves distribution of both CARMA and MAM4
- CARMA reproduce observations best with higher injections (7TgS) (more in line with observations), due to differences in nucleation scheme

WACCM-MA: Mt Pinatubo Period 1991-1995





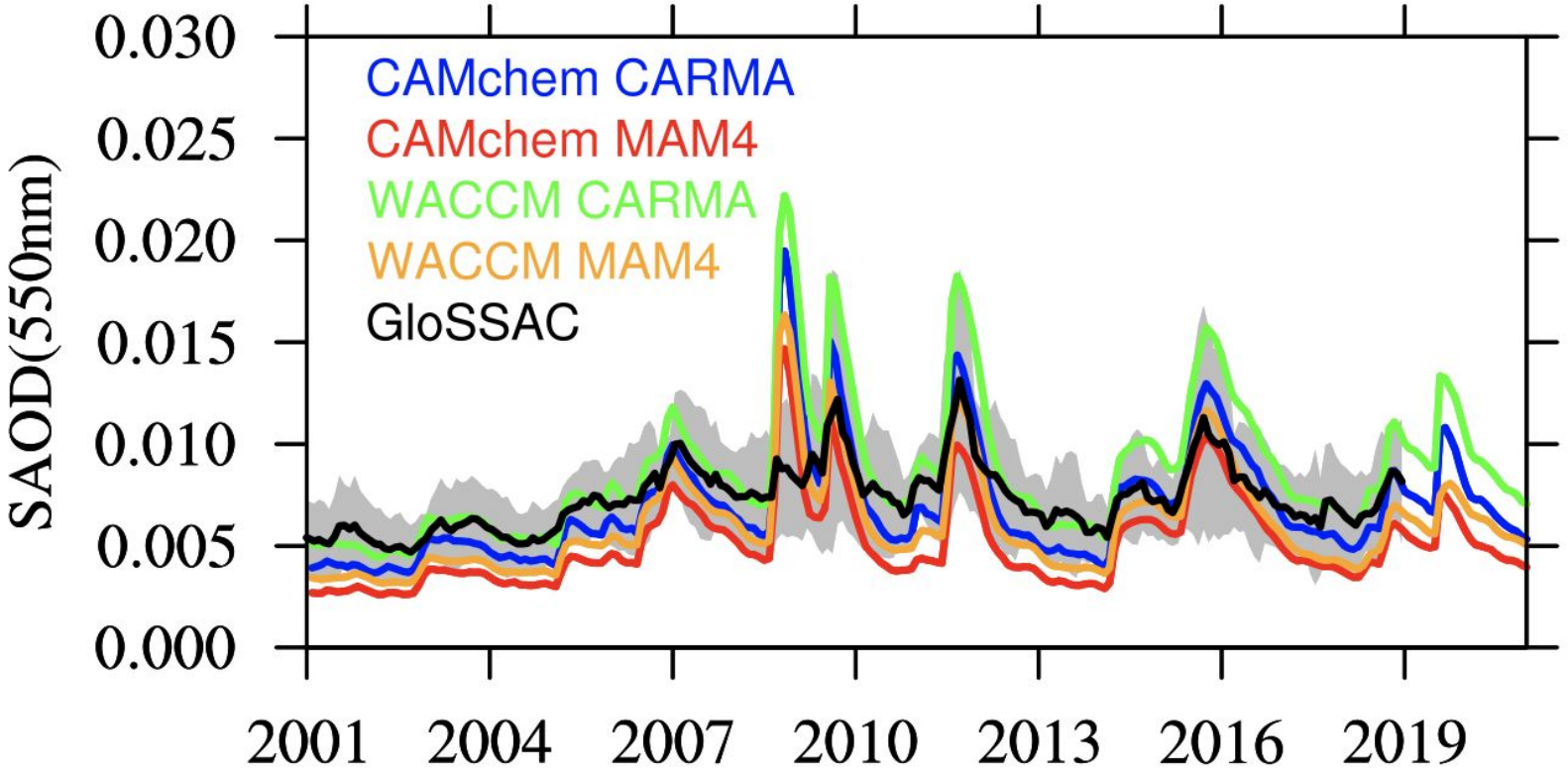


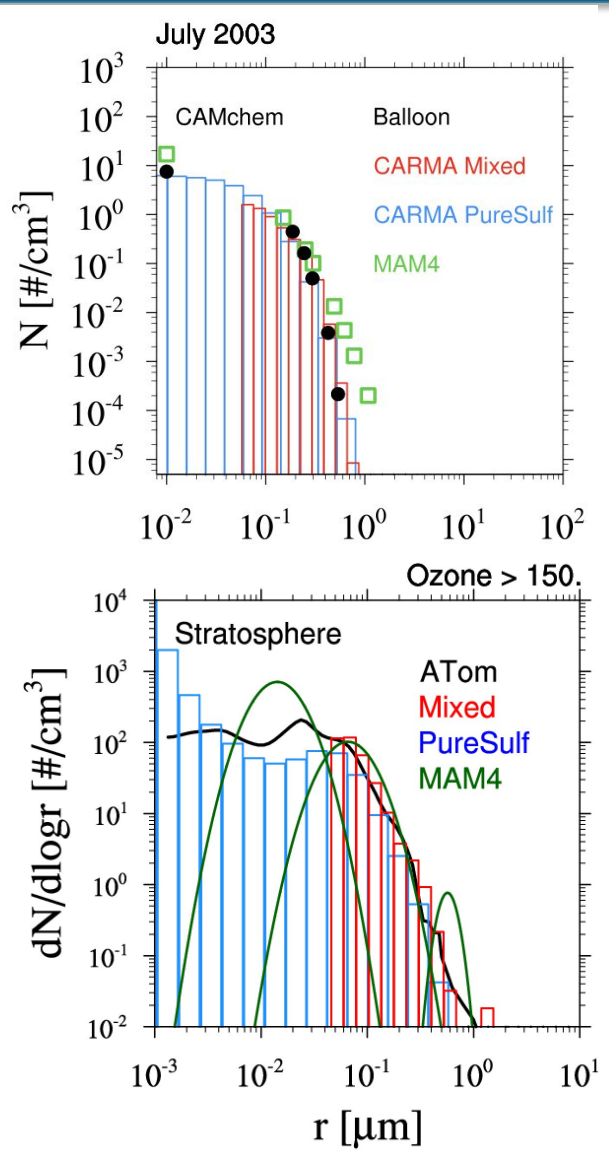


- Comparisons to observations: MAM4 bins are not able to reproduce the observed number distribution.
- CARMA performs well but overestimates the number of the largest bin, may need larger range of the distribution to simulate Mt Pinatubo
- Possible shortcomings for solar climate interventions

Stratospheric Background / Small volcanoes

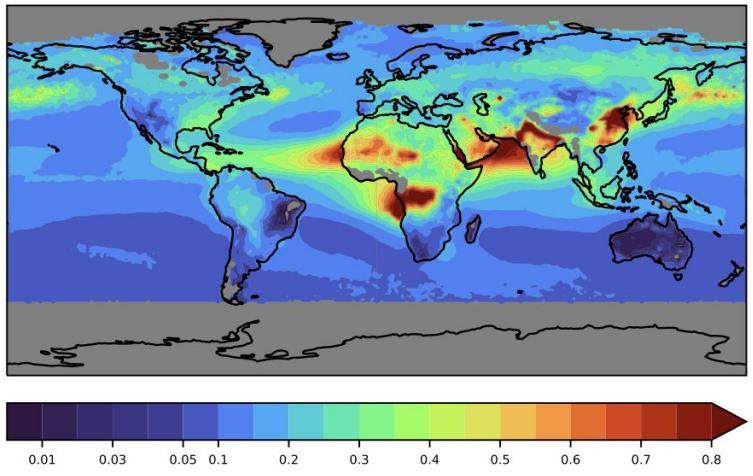
Representation of CARMA / MAM4 between 2001-2020



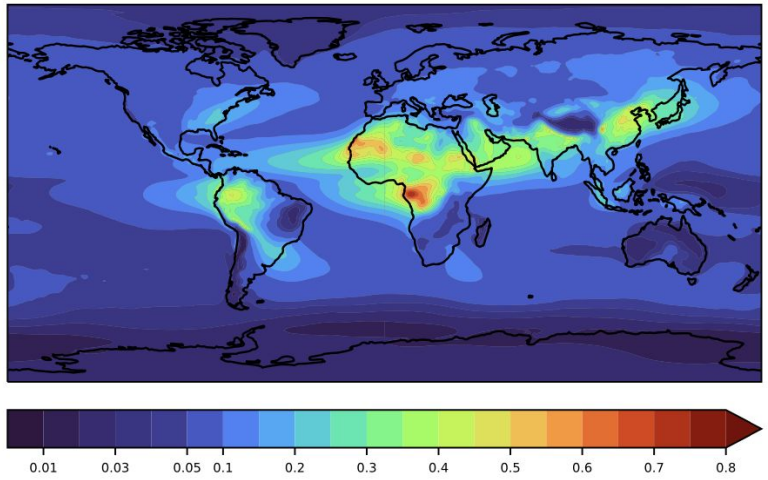


Tropospheric AOD: 2000-2020

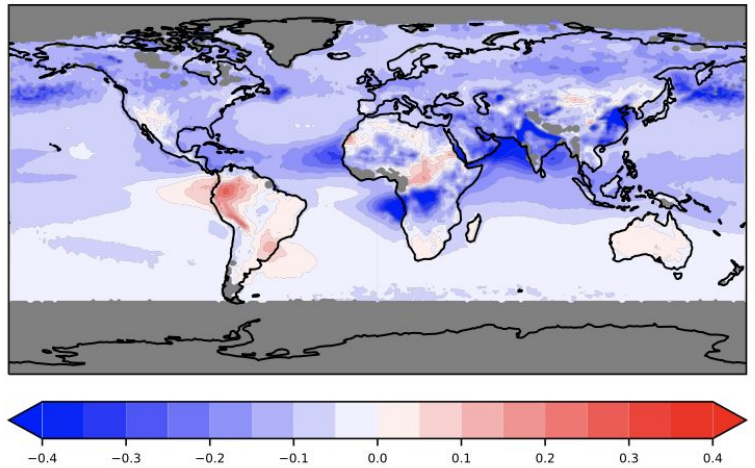
Terra MODIS AOD 550 nm 2001-2020 Jun-Jul-Aug



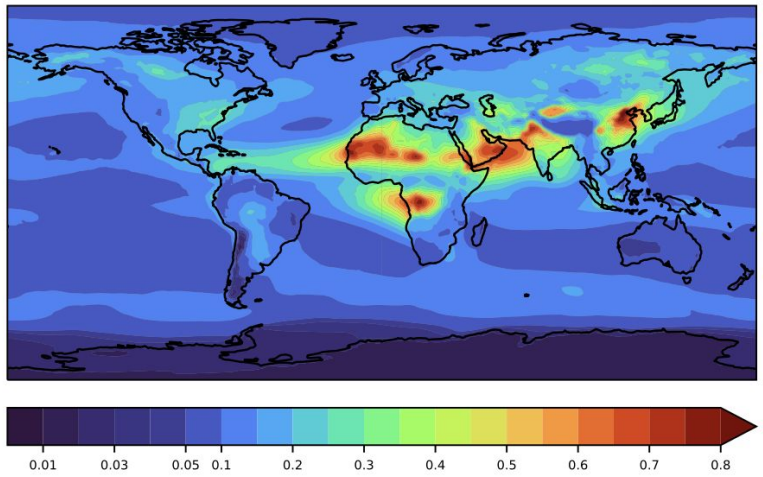
CARMA AOD 550 nm 2001-2020 Jun-Jul-Aug



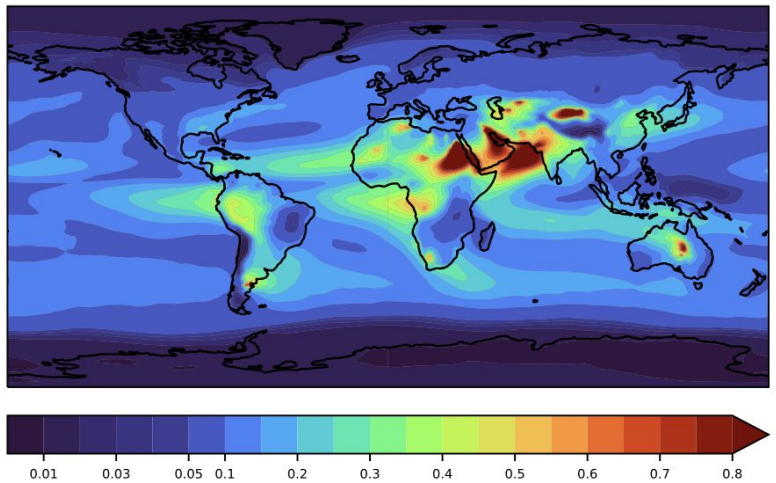
CARMA - Terra MODIS AOD 550 nm 2001-2020 Jun-Jul-Aug



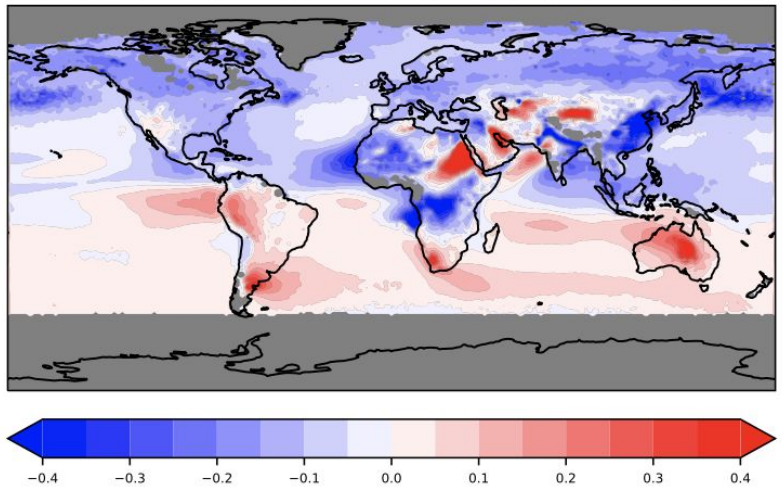
MERRA2 AOD 550 nm 2001-2020 Jun-Jul-Aug



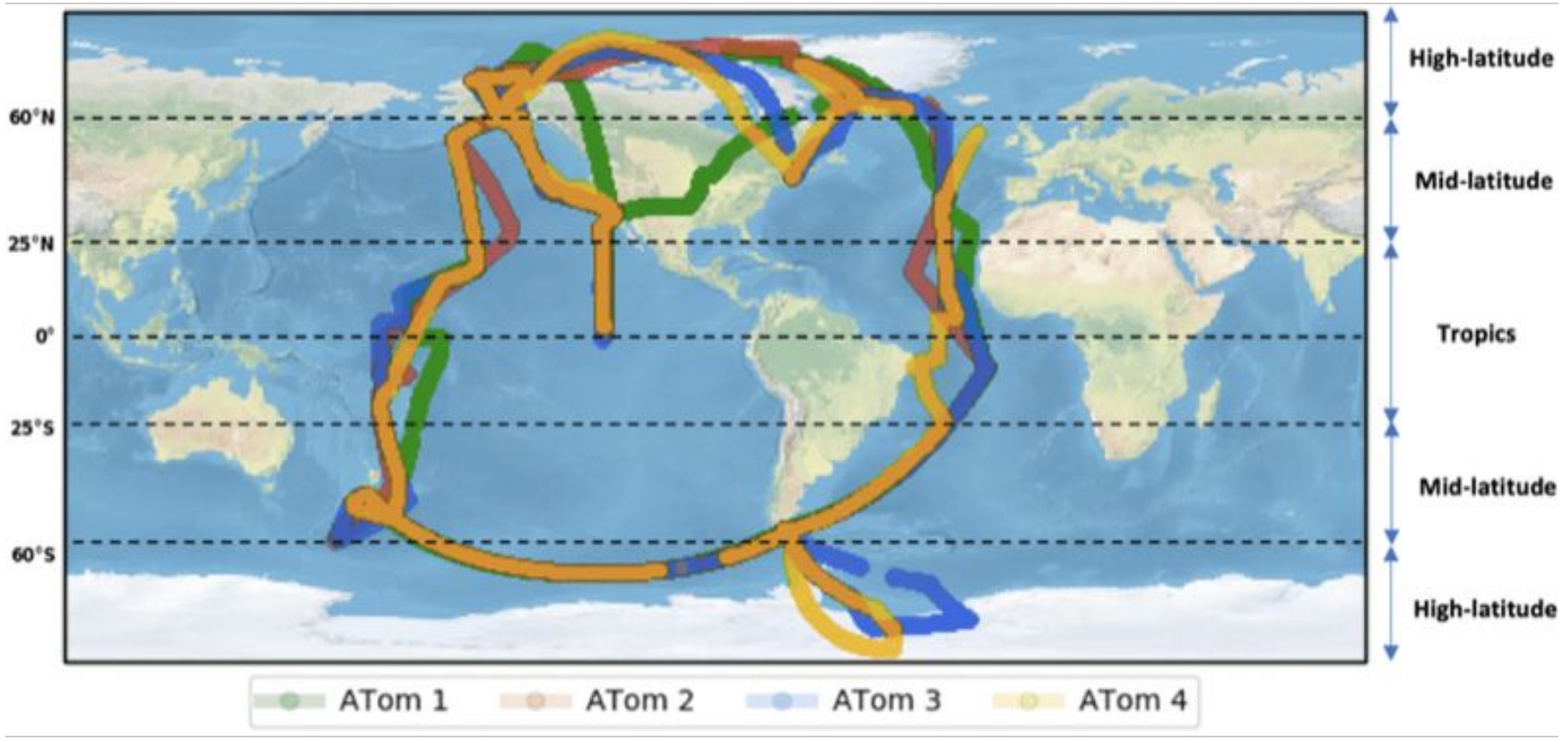
MAM4 AOD 550 nm 2001-2020 Jun-Jul-Aug



MAM4 - Terra MODIS AOD 550 nm 2001-2020 Jun-Jul-Aug



NASA: Atmospheric Tomography Mission (ATom) Aircraft Mission



Regional Averages for the Evaluation:

Atlantic / Pacific

30N – 60N

30N – 30S

30S – 60S

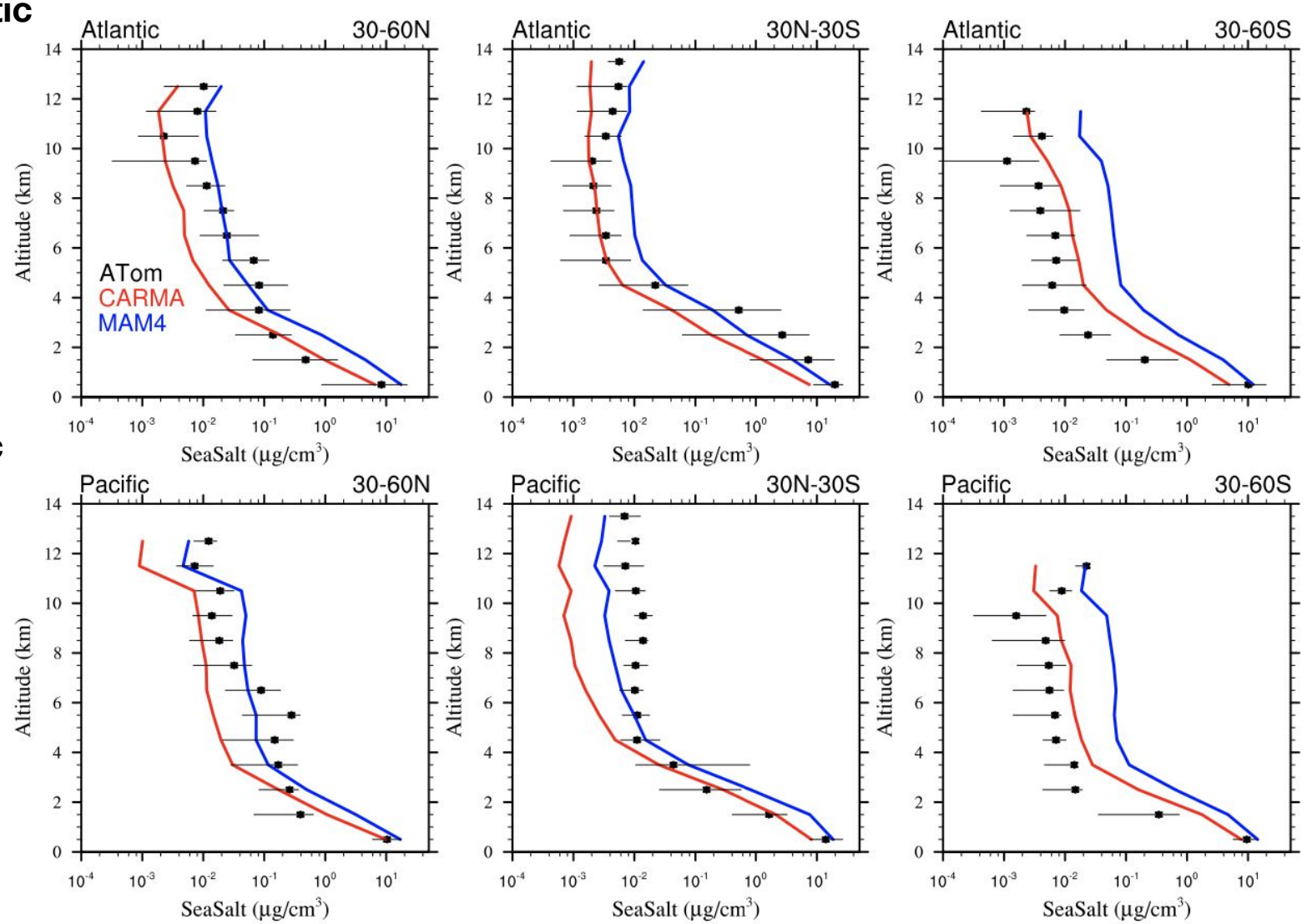
Brock et al., 2021: Aerosol properties dataset

Flight tracks for NASA DC-8 for the four ATom campaigns: ATom1 (August-September 2016, green), ATom2 (JanuaryFebruary 2017, red), ATom3 (September-October 2017, blue) and ATom4 (April-May 2018, yellow).

ATom Tropospheric Evaluation: Sea-Salt

Atlantic

Pacific



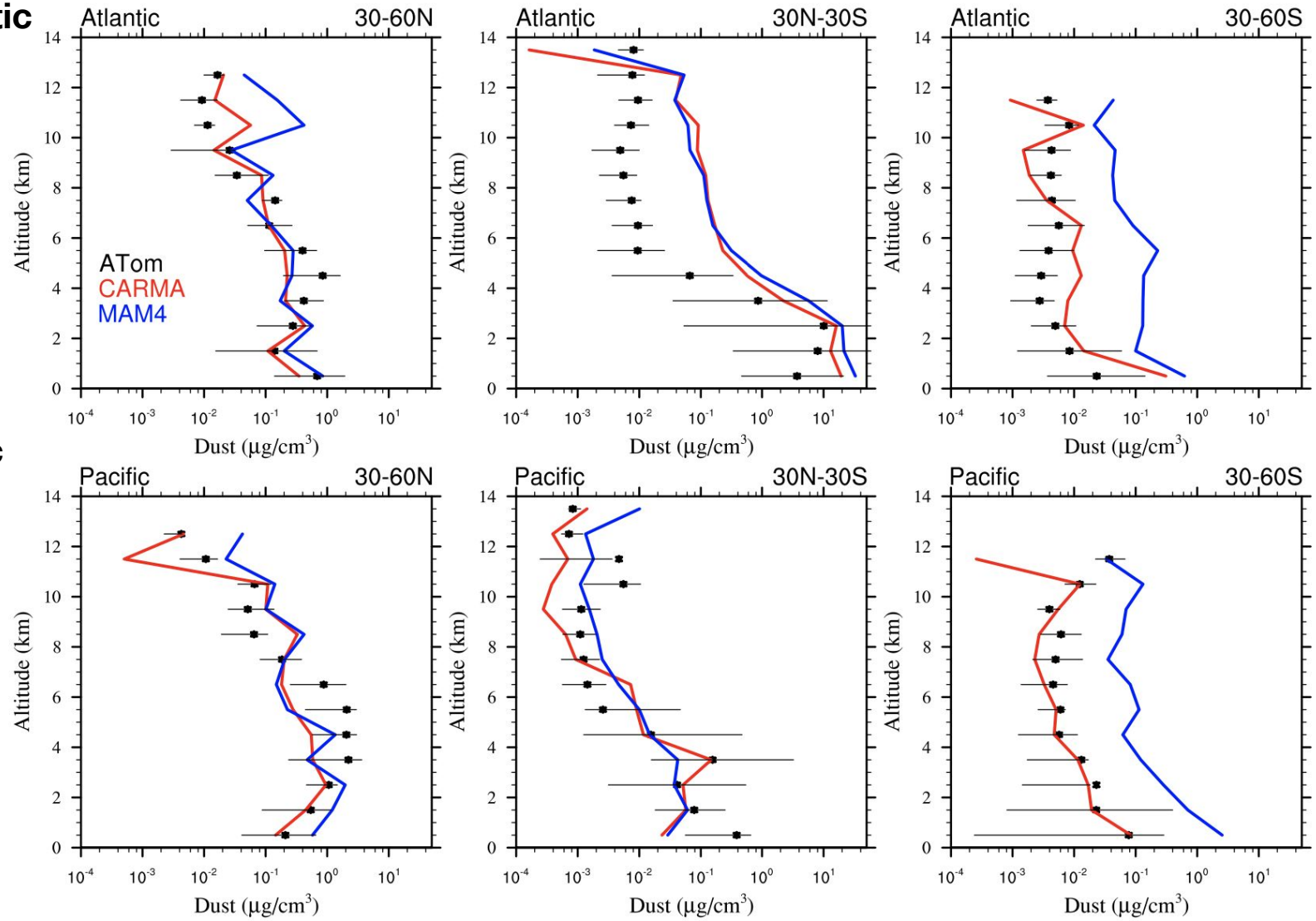
Sea-salt comparisons:

- CARMA shows improved surface values of sea-salt
- Improved representation over the Southern Ocean in CARMA
- Too small values over the tropical Pacific and the NH

ATom Tropospheric Evaluation: Dust

Atlantic

Pacific



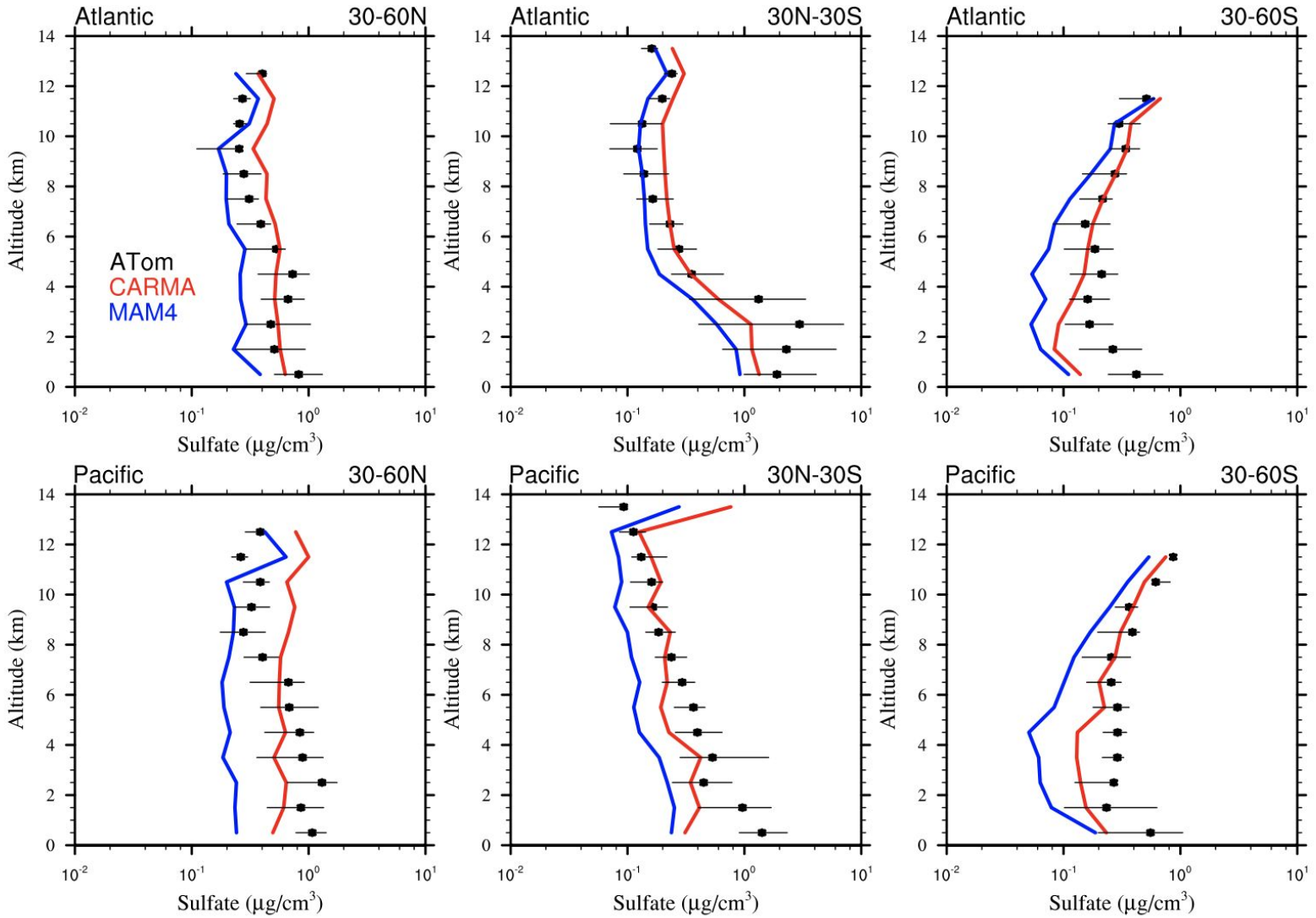
Dust comparisons:

- CARMA shows improved surface values of dust
- Improved representation over the Southern Ocean in CARMA
- Both MAM and CARMA overestimate dust in the Atlantic tropical troposphere above 4km

ATom Tropospheric Evaluation: Sulfate

Atlantic

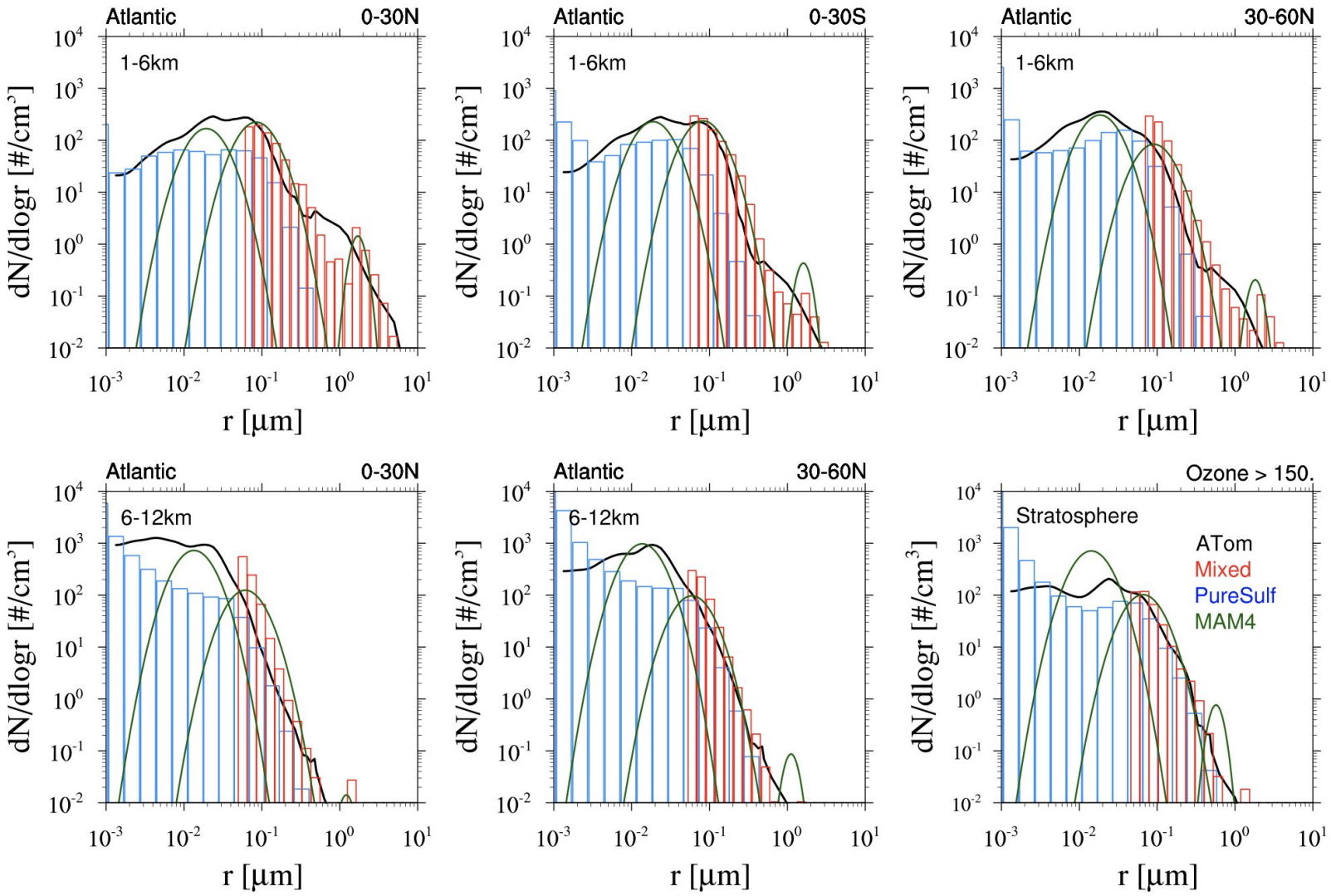
Pacific



Sulfate comparisons:

- CARMA shows improved representation with being somewhat larger than MAM4.
- Both models show an underestimation at the surface, which is likely from the lack of marine sulfate emissions.

ATom Tropospheric Evaluation: Aerosol Size distribution



Sulfate comparisons:

- CARMA reproduces larger bins (from dust etc.) better than MAM4 (mode width is too small)
- CARMA has shortcomings in reproducing Aitken mode mixed aerosol sizes. Mixed group from CARMA does not reach to small enough sizes

Conclusions: More Work!

WACCM-MA CARMA

- Reproduces Mt Pinatubo eruption quite well with the explained details
- Still missing in CESM2 CARMA: Volcanic ash, meteoric smoke, improved PSC model etc. -> requires additional development
- Possible extensions of the pure sulfate mode will further improve large aerosol injection simulations

CAMchem CARMA

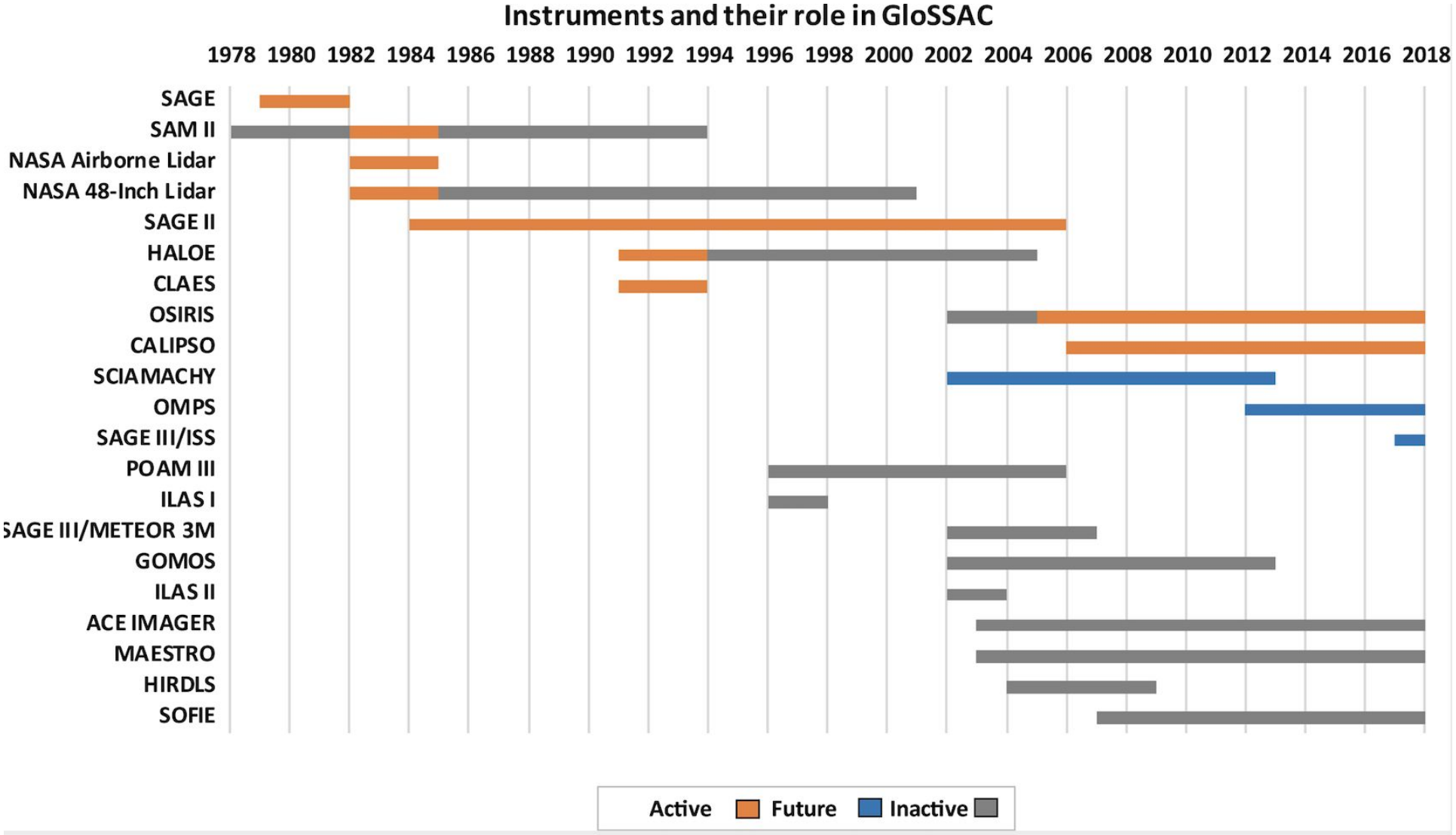
- Reproduces aerosol burden quite well, some shortcomings exists
- Needs for improvements: improved details of how washout of aerosols is done (e.g., evaporation possible for both MAM4 and CARMA), heterogeneous freezing
- Changes in mixed bin sizes: to improve size distribution in the upper troposphere (through organic aerosols)
- Coupling with land / ocean surface fluxes.

Next steps:

- Perform AMIP style simulations: test transport / chemistry etc.
- Produce a free-running model version for climate studies -> Climate Intervention studies.

Backup

Evaluation: Extinction Coefficients



CARMA for troposphere and stratosphere

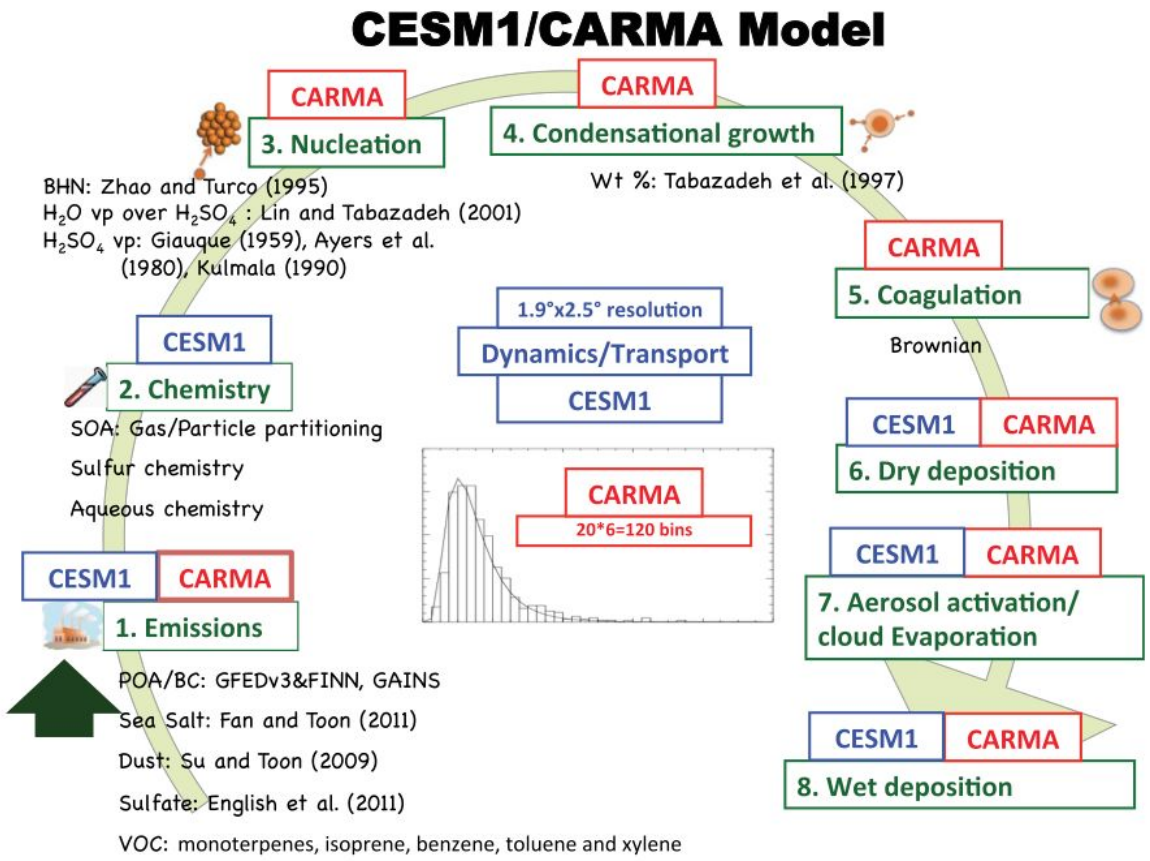
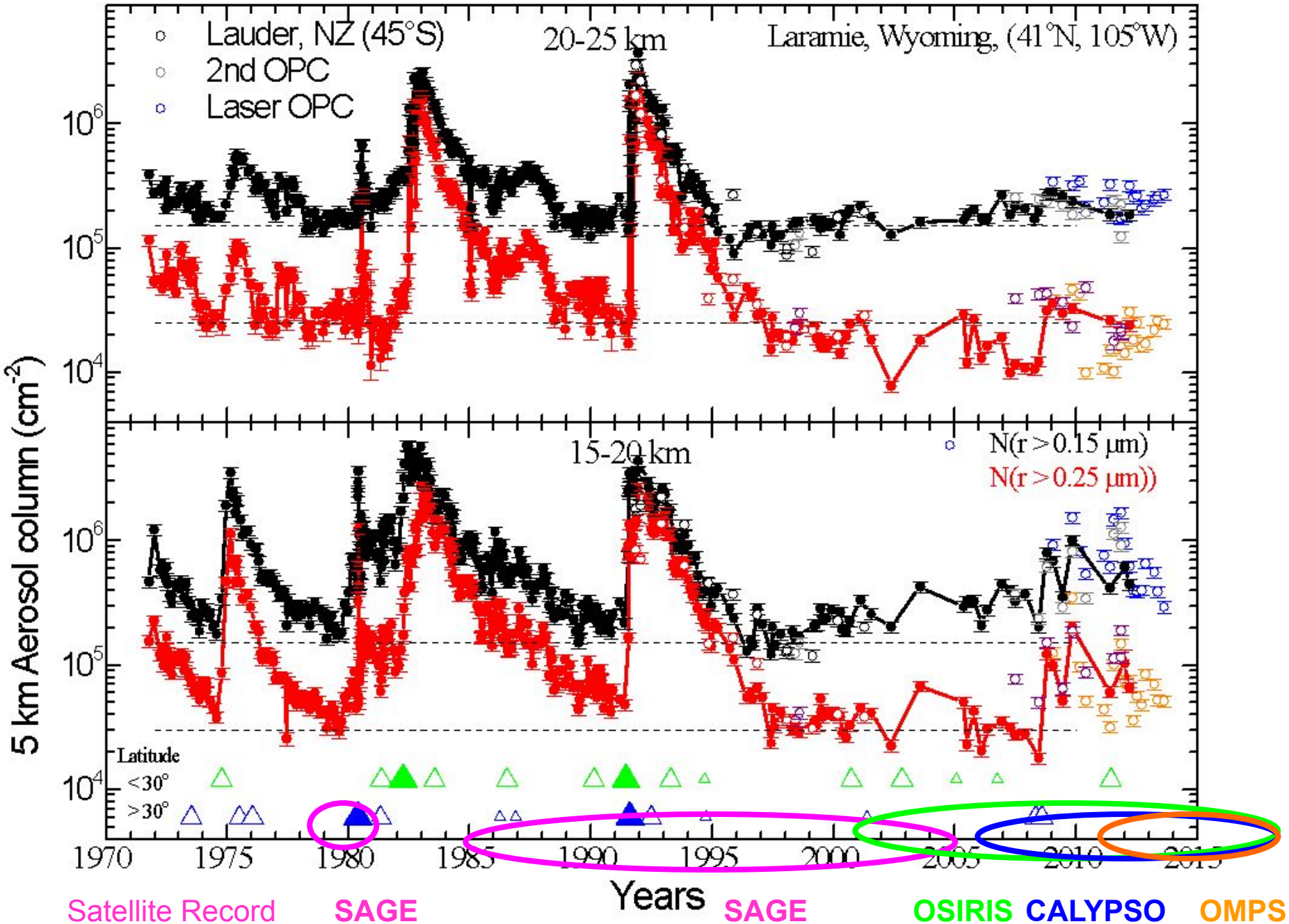


Figure A1. Diagram of the CESM1/CARMA model. In addition to sulfate, the model includes organics, dust, sea salt, black carbon, aqueous chemistry, and aerosol-cloud interactions (activation and evaporation).

Yu et al. 2015 and other papers. Evaluations to:
MODIS, AERONET, SAGE III, CALIPSO, POPS, balloon data, HIPPO, ATOM for troposphere and UTLS (and several wildfire seasons).

University of Wyoming Balloon Optical Particle Counter

Slide courtesy Terry Deshler



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