New Development and Evaluation of E3SM-MOSAIC: Spatial Distributions and Radiative Effects of Nitrate Aerosol

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Coupled MOZART-MOSAIC-MAM4 in E3SMv1



| | | NO3 | NH4 | Dust | Са | CO3 | Na | Cl | BC | РОМ | SOA | MOA |
|--------------------|----------|--------------|--------------|----------------|----------------|----------------|--------------|--------------|--------------|--------------|--------------|--------------|
| MAM4 (modified) | Accum | √ | ✓ | √ | ✓ | \checkmark | ✓ | ✓ | \checkmark | \checkmark | \checkmark | \checkmark |
| | Aitken | \checkmark | \checkmark | <mark>√</mark> | <mark>√</mark> | <mark>√</mark> | \checkmark | \checkmark | | | \checkmark | \checkmark |
| | Coarse | \checkmark | \checkmark | \checkmark | \checkmark | \checkmark | \checkmark | \checkmark | \checkmark | \checkmark | \checkmark | \checkmark |
| | P-Carbon | | | | | | | | \checkmark | \checkmark | | \checkmark |

Model Experiments

| | CESM2 | E3SMv1 | E3SMv1 Aitken Dust |
|---|---------------|---------------|--------------------|
| Resolution | 0.9x1.25 32 L | ne30, 72 L | ne30, 72 L |
| Run period | 2000-2007 | 2000-2001 | 2000-2001 |
| Meteorology | Free running | MERRA2 U, V | MERRA2 U, V |
| Emission | CMIP6+MEGAN | CMIP6+MEGAN | CMIP6+MEGAN |
| Aerosol Module | MAM4 | Enhanced MAM4 | Enhanced MAM4 |
| Aitken Dust | Yes | No | Yes |
| Gas Phase Chemistry | MOZART-TS2 | MOZART-TS1 | MOZART-TS1 |
| Geometric Standard Dev (accum, aitken, coarse) | 1.6, 1.6, 1.2 | 1.8, 1.6, 1.8 | 1.8, 1.6, 1.8 |

- We first enabled MOZART gas-phase chemistry in E3SMv1 and coupled it with MOSAIC and MAM4.
- Aitken dust is added to E3SMv1, like in CESM2, because we found that E3SMv1 without Aitken dust has a much stronger cloud radiative effect associated with nitrate aerosol (-1.13 W m⁻²)

Nitrate Mass Budget

| Global Mean | CESM2 | E3SMv1 | E3SMv1 Aitken Dust |
|---------------|----------|-----------|--------------------|
| TM1 (Tg) | 0.1059 | 0.2224 | 0.1297 |
| TM2 (Tg) | 0.0025 | 0.0278 | 0.0075 |
| TM3 (Tg) | 0.2957 | 0.1259 | 0.1364 |
| TM (Tg) | 0.4040 | 0.3761 | 0.2736 |
| AQCH1 (Tg/yr) | 93.4806 | 122.8006 | 119.2154 |
| AQCH2 (Tg/yr) | 2.4468 | 1.2108 | 3.3616 |
| AQCH3 (Tg/yr) | 0.7424 | 0.2287 | 0.2726 |
| AQCH (Tg/yr) | 96.6698 | 124.2402 | 122.8496 |
| GAEX1 (Tg/yr) | -69.9467 | -189.4480 | -101.1778 |
| GAEX2 (Tg/yr) | -0.1477 | 91.2602 | 1.549 |
| GAEX3 (Tg/yr) | 27.2367 | 17.5370 | 18.8449 |
| GAEX (Tg/yr) | -42.8577 | -80.6507 | -80.7839 |
| DD1 (Tg/yr) | -5.6308 | -4.1676 | -3.1310 |
| DD2 (Tg/yr) | -0.0674 | -0.2152 | -0.0788 |
| DD3 (Tg/yr) | -6.2510 | -8.0653 | -8.5757 |
| DD (Tg/yr) | -11.9492 | -12.4482 | -11.7856 |
| WD1 (Tg/yr) | -21.4470 | -21.5413 | -19.4934 |
| WD2 (Tg/yr) | -0.7921 | -0.5418 | -0.6573 |
| WD3 (Tg/yr) | -21.0121 | -8.5120 | -9.3785 |
| WD (Tg/yr) | -43.2512 | -30.5951 | -29.5293 |
| LTime (d) | 2.6717 | 3.1891 | 2.4174 |

- E3SMv1 produces less nitrate burden (TM) than CESM2. The gas-aerosol exchange of nitrate in the Aitken mode (GAEX2) is much larger in E3SMv1 (w/o Aitken-mode dust) than in CESM2.
- GAEX2 significantly drops from 91.26 Tg yr⁻¹ to 1.55 Tg yr⁻¹ after introducing Aitken mode dust.
- The mass fraction of nitrate in E3SMv1 decreases in accumulation mode (TM1) but increases in coarse mode (TM3) after introducing Aitken mode dust.

Nitrate Column Burden and Concentration



- E3SMv1 produces similar spatial distributions of nitrate to CESM2.
- E3SMv1 produces less nitrate burden and concentration than CESM2, especially over the Southern Hemisphere mainly due to lower sea salt in E3SMv1.

Nitrate Cloud Radiative Effect

Shortwave CRE



Longwave CRE



- Shortwave cloud radiative effect associated with nitrate aerosol significantly drops from -1.0 W m⁻² to -0.36 W m⁻², which is close to CESM2, after the Aitken mode dust is treated.
- Longwave radiative effect reduces to -0.0021 W m⁻², while CESM2 produces a longwave warming effect of 0.09 W m⁻².

Ammonium Mass Budget

| Global Mean | CESM2 | E3SMv1 | E3SMv1 Aitken Dust |
|---------------|----------|----------|--------------------|
| TM1 (Tg) | 0.2174 | 0.4400 | 0.3970 |
| TM2 (Tg) | 0.0158 | 0.0190 | 0.0272 |
| TM3 (Tg) | 0.0029 | 0.0018 | 0.0020 |
| TM (Tg) | 0.2362 | 0.4608 | 0.4262 |
| AQCH1 (Tg/yr) | 6.9673 | 6.4122 | 6.9960 |
| AQCH2 (Tg/yr) | 0.1592 | 0.0698 | 0.1640 |
| AQCH3 (Tg/yr) | -0.0040 | -0.0195 | -0.0242 |
| AQCH (Tg/yr) | 7.1224 | 6.4624 | 7.1357 |
| GAEX1 (Tg/yr) | 6.3314 | -3.6434 | 7.1317 |
| GAEX2 (Tg/yr) | 2.2380 | 15.3044 | 3.1560 |
| GAEX3 (Tg/yr) | 0.9394 | -0.2753 | -0.2387 |
| GAEX (Tg/yr) | 9.5087 | 11.3856 | 10.0490 |
| DD1 (Tg/yr) | -3.2339 | -3.5260 | -2.9939 |
| DD2 (Tg/yr) | -0.4632 | -0.4327 | -0.6949 |
| DD3 (Tg/yr) | -0.2640 | -0.2215 | -0.2426 |
| DD (Tg/yr) | -3.9610 | -4.1802 | -3.9314 |
| WD1 (Tg/yr) | -11.6610 | -15.1044 | -14.5228 |
| WD2 (Tg/yr) | -0.4662 | -0.2365 | -0.3937 |
| WD3 (Tg/yr) | -0.5495 | 0.5516 | 0.5429 |
| WD (Tg/yr) | -12.6767 | -14.7893 | -14.3736 |
| LTime (d) | 5.1810 | 8.8665 | 8.4991 |

- E3SMv1 produces larger ammonium burden (TM) than CESM2.
- The gas-aerosol exchange of ammonium in the Aitken mode (GAEX2) is also larger in E3SMv1 (w/o Aitken-mode dust) than in CESM2.
- GAEX2 significantly drops from 15.3 Tg yr⁻¹ to 3.16 Tg yr⁻¹ after introducing Aitken mode dust.

Ammonium Column Burden and Concentration



E3SMv1 produces larger ammonium burden and concentration than CESM2, especially over the Southern Hemisphere.

Sea Salt Column Burden and Concentration



- E3SMv1 produces significantly less sea salt burden and concentration than CESM2.
- Much less sea salt is transported to high altitudes in E3SMv1 than in CESM2.
- Tuning up the sea salt emission doesn't improve the issue much.

Conclusion

- The MOSAIC scheme has been successfully implemented in E3SMv1, which performs reasonably well in simulating spatial distributions of nitrate aerosol with a lower global annual mean burden (0.38 Tg), compared to CESM2. The default E3SMv1 also produces strong cloud radiative effect of -1.13 W m⁻².
- After we add a treatment of Aitken mode dust, the cloud radiative effect of presentday nitrate significantly drops to -0.36 W m⁻², like in CESM2 (-0.33 W m⁻²). It also reduces the nitrate aerosol burden to 0.27 Tg.
- Inclusion of Aitken mode dust substantially reduces the gas-aerosol exchange of nitrate within the Aitken mode, which then shifts the mass fraction of nitrate from the accumulation mode to the coarse mode and reduces CCN number.
- We are doing more simulations and analyses to understand this sensitivity to Aitkenmode dust.