Supplement of Atmos. Chem. Phys., 15, 5903–5928, 2015
http://www.atmos-chem-phys.net/15/5903/2015/
doi:10.5194/acp-15-5903-2015-supplement

Atmospheric
Chemistry
and Physics
Open Access

Supplement of

A multi-model evaluation of aerosols over South Asia: common problems and possible causes

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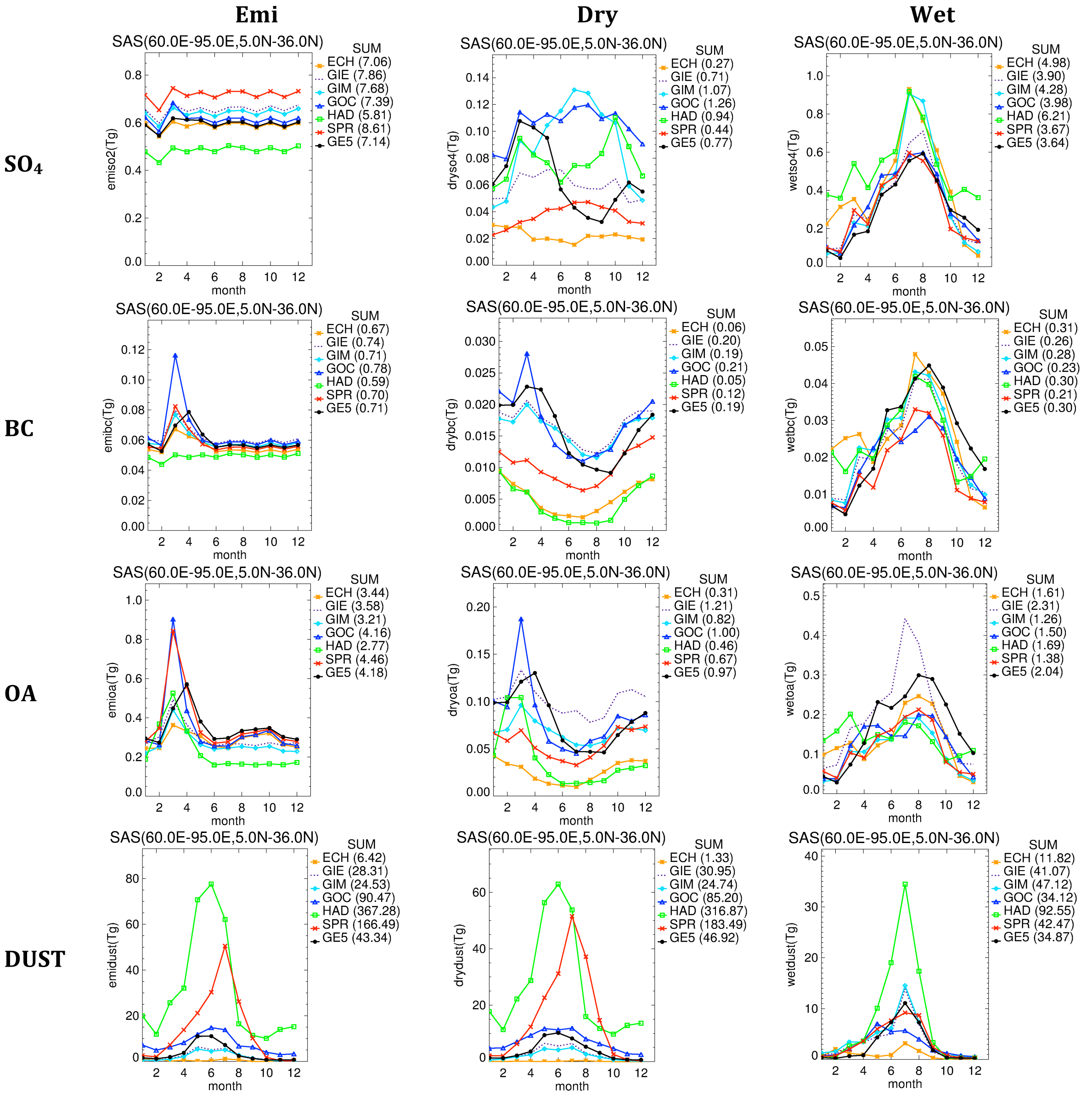

Figure S1. The monthly variation of aerosol parameters over South Asia (60°E–95°E; 5°N–36°N. Land only) for 2006 in multi-models. Total emission from different emitting sources (left column), dry(middle column) and wet deposition(right column). Note that SO_4 emission is replaced by SO_2 emission here.

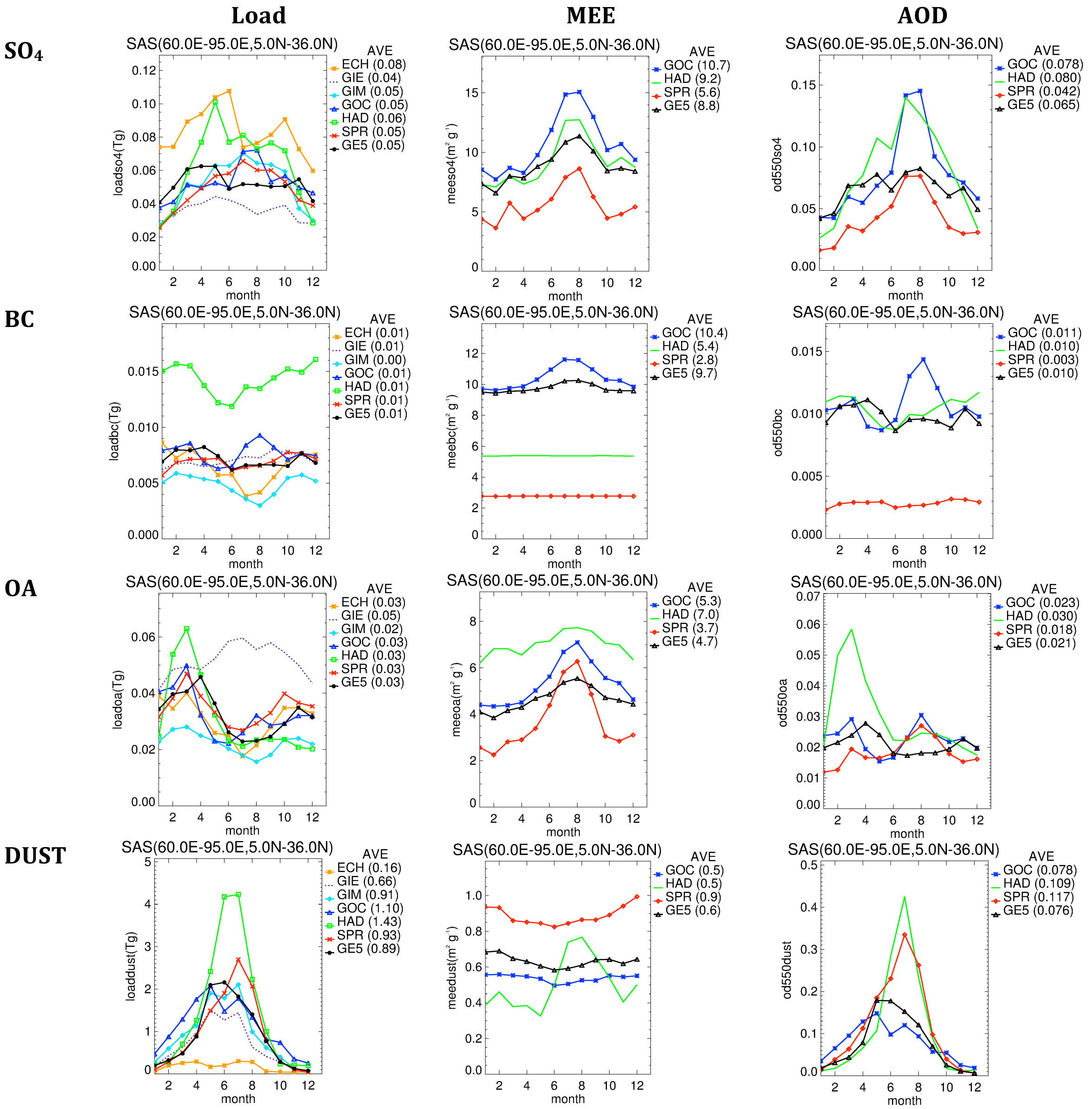

Figure S2. The monthly variation of aerosol parameters over South Asia (60°E–95°E; 5°N–36°N. Land only) for 2006 in multi-models. Load (left column), Mass Extinction Efficiency (middle column) and AOD(right column).

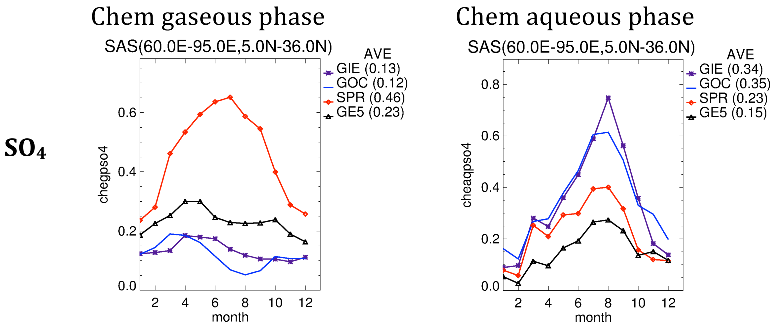

Figure S3. The monthly variation of aerosol parameters over South Asia (60°E–95°E; 5°N–36°N. Land only) for 2006 in multi-models. Chemical production of SO_4 in gaseous phase (left), chemical production of SO_4 in aqueous phase (right).

NOTE: the summary of Figure S1-3 is included in the Section 5 of the manuscript.

Table S1. The relationship of mass extinction efficiency (MEE) and single scattering albedo (SSA) with refractive indices: BC.

CASE[1]	Real[2]	Imaginary[3]	MEE[4]	SSA[5]	Note
1	1.75	0.44	5.4890E-16 m^2 /unit vol	0.2087	Used by HAD, GOC, SPR, GE5
2	1.85	0.71	7.5665E-16 m^2 /unit vol	0.1958	Used by ECH, GIE, GIM
3	1.75	0.71	7.6798E-16 m^2 /unit vol	0.1746	The same real part as CASE 1, the same imaginary as CASE 2
4	1.75	0.79[6]	8.2873E-16 m^2 /unit vol	0.1723	The same real part as CASE 1, but with imaginary part recommended by Bond and Bergstrom (2006)

Note:

1. In all cases, modal radius = 0.0118 μm, effective radius = 0.039 μm, sigma = 2.0 μm, density =1.0 g/cm^3, wavelength = 550 nm.
2. The real part of refractive index.
3. The imaginary part of refractive index.
4. Mass Extinction Efficiency, proportional to the aerosol optical depth (AOD).
5. Single scattering albedo. The Mass Absorption Efficiency (MAE) = MEE * (1-SSA) and Mass Scattering Efficiency (MSE) = MEE * SSA.
6. This value is recommended by Bond and Bergstrom (2006).

Table S2. The relationship of mass extinction efficiency (MEE) and single scattering albedo (SSA) with refractive indices: dust.

CASE[1]	**Real**[2]	**Imaginary**[3]	**MEE**[4]	**SSA**[5]	**Note**
1	1.52	0.0015	1.5991E-14 m^2 /unit vol	0.9908	Used by HAD
2	1.53	0.0055	1.6432E-14 m^2 /unit vol	0.9675	Used by GOC
3	1.517	0.0011	1.5869E-14 m^2 /unit vol	0.9932	Used by ECH
4	1.564	0.002	1.7659E-14 m^2 /unit vol	0.9884	Used by GIE and GIM
5	1.53	0.002	1.6381E-14 m^2 /unit vol	0.9879	Used by SPR
6	1.53	0.008	1.6469E-14 m^2 /unit vol	0.9535	Used by GE5
7	1.53	0.0011	1.6368E-14 m^2 /unit vol	0.9933	The same real part as CASE 2, the same imaginary as CASE 3

Note:

1. In all case, modal radius = 0.042 µm, effective radius = 1.4 µm, sigma = 2.0 µm, density =2.6 g/cm^3, wavelength = 550 nm.
2. The real part of refractive index.
3. The imaginary part of refractive index.
4. Mass Extinction Efficiency, proportional to the aerosol optical depth (AOD).
5. Single scattering albedo. The Mass Absorption Efficiency (MAE) = MEE * (1-SSA) and Mass Scattering Efficiency (MSE) = MEE * SSA.

Discussions on Table S1 and Table S2

As shown in Table S1, we conducted Mie calculations for BC at 550 nm in CASE1 and CASE2, in which the refractive indices represent those used by the multi-models in this study. Moreover, in CASE3 and CASE4, we also consider additional scenarios with different real or imaginary parts to test the sensitivity of mass extinction efficiency (MEE) and single scattering albedo (SSA). As expected, the MEE and mass absorption efficiency (MAE, equal to MEE×(1-SSA)) of BC are sensitive to changes of imaginary parts, because MAE dominates MEE. The MEE and MAE of BC are larger in the case with larger imaginary part. For example, in comparison of CASE1 with CASE3, given that the real parts are the same but the imaginary part is increased by 60% from 0.44 to 0.77, the MEE and MAE enhance by 40% and 47%, respectively. In addition, given that real parts are the same but the imaginary part increases by 11% from 0.71, that is used by three models in CASE 3, to 0.79 (recommended by Bond and Bergstrom (2006) in CASE4), both the MEE and MAE enhance by 8%. On the other hand, the MEE of BC is less sensitive to the change of real part, but the MAE is sensitive. For example, in comparison CASE3 with CASE2, given that imaginary parts are the same but the real part increase by 5% from 1.75 to 1.85, the MEE and MAE of BC reduces by 1% and 5%, respectively. In contrast, the mass scattering efficiency (MSE, equal to MEE×SSA) is the most sensitive to the increase of real part with MSE enhancing by 14%.

As for a more complicated situation in which both real and imaginary parts are different, the MEE and MAE enhance by ~40% from CASE 1 (representing the models HAD, GOC, SPR, GE5) to CASE 2 (representing the models ECH, GIE, GIM) with increasing both the imaginary and real parts. However, it is not necessary that the models in CASE 2 simulate higher AOD. For example, the model HAD shows higher AOD than the model ECH although the latter has higher real and imaginary parts (Fig. 4a and b). Therefore, this clearly suggests that there are other factors involved such as meteorology and emissions suppressing the simulated AOD by multi-models, as we have pointed out in the paper. Bond and Bergstrom (2006) attempted to increase BC imaginary part to 0.79, but this effort alone cannot remove the low bias of AAOD and AOD in models as suggested by this study. Bond et al. (2013) also pointed out that large differences in modeled horizontal and vertical transport are mostly responsible for the inter-model diversity of BC distributions.

Similarly, we conducted Mie calculation for dust in Table S2. The MEE of dust is dominated by scattering effect at the wavelength of 550nm. As expected, we found that the MEE and MAE of dust are insensitive to the change of imaginary part. For example, with the imaginary part increased by a factor of 7 in comparison with CASE 6 and CASE 7, the MEE and MAE of dust enhance by <1%. On the other hand, the MEE and MAE of dust are relatively sensitive to the change of real part. For example, with the real part increased by 2% in comparison with CASE 4 and CASE 5, both the MEE and MAE of dust enhance by 8%. The dust is minimal in the post-monsoon and the Winter period when the largest discrepancy occurs in models, however, small changes in values of imaginary and real parts of dust would not impact the AOD and AAOD simulations. Again, other factors such as meteorology and emissions are more likely dominant.