Effect of changes in climate and emissions on future aerosol levels in China

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Introduction

The concentrations of aerosols in the atmosphere are determined by emissions, chemical reactions, transport, and deposition, all of which can be influenced by climate change. Previous studies that examined the impacts of climate change on air quality were mostly for regions in the United States and Europe. This work investigates the potential effects of projected climate and emission changes on aerosol levels in China, using the GISS Model III/GEOS-Chem simulations. Effects of climate change alone, emission changes alone, and both climate and emission changes on aerosol levels over 2000-2050 are studied.

Methodology

- The GEOS-Chem simulations are driven by the global meteorological fields archived from the GISS Model III simulations [*Wu et al.*, 2007]. Both the GISS Model III and the Global Change and Air Pollution (GCAP) version of the GEOS-Chem model have a horizontal resolution of 4° latitude by 5° longitude and with 23 vertical layers. The meteorological fields are available for present day (years 1999-2001) and years 2049-2051. Future climate change driven by the changes in greenhouse gases was simulated based on the IPCC scenario A1B.
- We consider the coupled ozone-NOx-hydrocarbon and aerosol chemistry [*Bey et al.*, 2001; *Park et al*., 2004; *Liao et al.*, 2007] with all tracers listed by *Liao et al.* [2007].
- Both natural and anthropogenic emissions of aerosol precursors and aerosols are considered in the simulations. The climate sensitive natural emissions are summarized in Table1. Year 2050 anthropogenic emissions follow the Integrated Model to Assess the Greenhouse Effect (IMAGE) model for [*Streets et al.*, 2004].

Table 1. Predicted Changes in Natural Emissions Due to Predicted Climate Change (IPCC A1B Scenario)

	Global		EChina	
Species	**2000**	**2050**	**2000**	**2050**
DMS (Tg S/yr)	15.7	16.1	0.01	0.01
NOx (Tg N/yr)	11.3	13.0	0.4	0.5
Lightning	4.8	5.6	0.2	0.3
Soil	6.5	7.4	0.2	0.2
Biogenic HCs (Tg C/yr)				
Isoprene	449.2	566.3	15.2	19.2
Monoterpenes	130.0	158.2	4.1	4.9

Table 2. Present-Day and 2050 (IPCC A1B Scenario) Anthropogenic Emissions of Aerosols/Aerosol Precursors

	Global		EChina	
Species	**2000**	**2050**	**2000**	**2050**
SO_2 (Tg S/yr)				
Aircraft	0.07	0.07	0.002	0.002
Anthropogenic	61.09	81.68	10.00	6.701
Biomass burning	1.22	2.01	0.016	0.025
Biofule	0.27	0.26	0.065	0.042
Ship	4.23	5.39	0.035	0.052
NH_3 (Tg S/yr)				
Anthropogenic	28.31	42.86	4.86	4.03
Biomass burning	4.98	5.22	0.06	0.06
Biofuel	1.37	1.44	0.22	0.15
NOx (Tg N/yr)				
Aircraft	0.52	0.52	0.01	0.01
Anthropogenic	24.29	48.76	2.90	5.62
Biomass burning	6.50	8.11	0.08	0.10
Biofuel	2.25	2.14	0.48	0.31
Fertilizer	0.47	0.95	0.06	0.04
OC (Tg C/yr)				
Anthropogenic	2.69	1.03	0.61	0.16
Biomass burning	23.38	13.58	0.29	0.28
Biofuel	7.05	2.95	1.31	0.57
BC (Tg C/yr)				
Anthropogenic	3.45	2.24	0.87	0.27
Biomass burning	2.85	2.95	0.04	0.04
Biofuel	1.63	0.62	0.36	0.15

Figure 1. Predicted changes in surface temperature, precipitation, and boundary layer (PBL) height from the present day (1999–2001) to future (2049–2051).

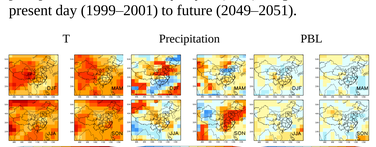
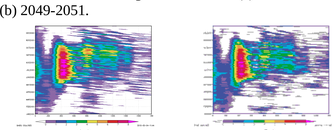


Figure 2. Time-longitude distribution of summer meridional wind averaged 5°S-5°N for (a) 1999-2001 and (b) 2049-2051.



Natural emissions:

➢DMS emissions are not important in eastern China (10°S-56°N,75°E-150°E).

➢Over 2000-2050, NOx emissions from soil and lightning are predicted to increase by about 15% globally and by 19% in eastern China.

➢Relative to present-day, year 2050 biogenic emissions of isoprene and monoterpenes are predicted to increase by 25% globally and in eastern China.

Changes in anthropogenic emissions from 2000 to 2050:

➢Anthropogenic SO_2 emissions increase by 34% globally but decrease by 33% in eastern China.

➢NOx emissions are predicted to increase by 78% globally and by 72% in eastern China.

➢BC emissions are predicted to decrease by 27% globally and by 64% in eastern China.

➢OC emissions are predicted to decrease by 47% globally and by 54% in eastern China.

Meteorology:

➢Temperatures generally increase by 1-2 K in all seasons from present day to future over China. The increases in temperature are the largest in western China in DJF.

➢Precipitation is predicted to increase by about 50% over northern China in DJF and over the whole eastern China in SON. About 40% decreases in precipitation are found in southeastern China in DJF and in northern China in MAM.

➢The boundary layer height in China is predicted to generally decrease by up to 20% from present day to 2050, except that the PBL height increases by about 20% in southeastern China in DJF.

➢In 40-65 ° E, cross-equatorial flows in summer are weaker in future than in present-day.

Predictions for Present-day Aerosols

Figure 3. Present-day (1999-2001 meteorology and emissions) predictions of surface-layer sulfate, nitrate, BC, and OC aerosols in China.

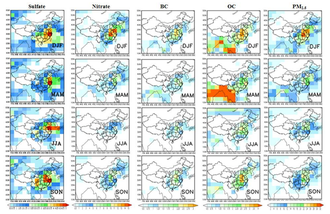


Table 3. Comparisons of the observed and the GEOS-Chem simulated $PM_{2.5}$ concentrations.

Location	Concentrations (μg m^{-3})				References
	Summer		Winter		
	GEOS-Chem	Observed	GEOS-Chem	Observed	
Beijing (116.5°E, 39.9°N)	19.5	117.2±48.3 104.1±45.1 77.3±55.7 93.29±56.26 88.99 107±61 71 59.2	17.4	126.5±66.1 175.9 257.6±85.8 135.7±96.6 214.23±159.34 122.09 182±107 108	*Cao et al.* [2007] *He et al.* [2001] *Dan et al.* [2004] *Sun et al.* [2004] *Wang et al.* [2005] *Duan et al.* [2006] *Zhang et al.* [2006] *Xu et al.* [2007] *Wu and Wang* [2007]
Changchun (125.2°E, 45.5°N)	13.2	59.6±21.9	14.3	140.5±28.6	*Cao et al.* [2007]
Qingdao (120.2°E,36.0°N)	40.4	30.1±16.1	44.0	127.9±58.5	*Cao et al.* [2007]
Tianjin (117.1°E, 39.0°N)	19.5	103.2±27.9	17.4	179.4±87.8	*Cao et al.* [2007]
Xi'an (108.6°E, 34.2°N)	5.2	130.8±58.5	4.4	375.2±143.5	*Cao et al.* [2007]
Yulin (109.5°E, 38.2°N)	3.1	50.5±23.2	2.4	150.6±77.3	*Cao et al.* [2007]
Chongqing (106.3°E, 29.4°N)	16.4	116.3±38.1	15.4	311.8±114.1	*Cao et al.* [2007]
Guangzhou (113.1°E, 23.1°N)	26.1	78.1±29.7 49.1±9.3	27.9	105.9±71.4 156.0±93.6	*Cao et al.* [2003, 2004] *Cao et al.* [2007]
Hong Kong (115.1°E, 25.2°N)	27.7	31±16.9 40.1±14.0	30.6	54.5±22.9 64.0±29.6	*Cao et al.* [2003, 2004] *Cao et al.* [2007]
Hangzhou (120.1°E, 30.2°N)	52.4	90.6±40.8	54.4	168.6±54.6	*Cao et al.* [2007]
Shanghai (121.3°E, 31.1°N)	40.6	52.2±19.4 35.85 59.7	48.3	151.1±95.4 93.91	*Cao et al.* [2007] *Ye et al.* [2003] *Wu and Wang* [2007]
Nanjing (118.5°E, 32.0°N)	40.6	69.1	48.3	139.5	*Huang et al.* [2006]
Wuhan (114.2°E, 30.4°N)	33.1	70.8±21.3	34.5	166.6±72.7	*Cao et al.* [2007]
Xiamen (118.0°E, 24.3°N)	35.1	25.2±15.8	39.6	70.2±32.2	*Cao et al.* [2007]
Shenzhen (114.1°E, 24.3°N)	27.7	47.1±16.7	30.6	60.8±18.0	*Cao et al.* [2003, 2004]
Zhuhai (113.3°E, 22.2°N)	26.1	31.0±20.0	27.9	59.3±23.7	*Cao et al.* [2003, 2004]

Sulfate:

➢The highest sulfate concentrations are predicted to be about 5μg m^{-3} in eastern China

Nitrate:

➢Maximum nitrate aerosol concentrations are about 15 μg m^{-3} over eastern China in DJF because of the low temperatures.

BC and OC:

➢The relatively high concentrations of BC and OC (up to 3-4μg m^{-3}) are predicted in DJF in the eastern China because of the winter heating.

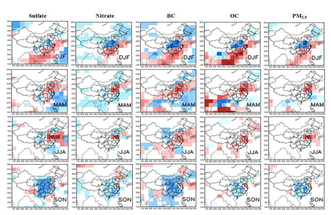
$PM_{2.5}$:

➢$PM_{2.5}$ mass is calculated as [*Liao et al*., 2007]: $[PM_{2.5}]=1.37\times[SO4^{2-}]+1.29\times[NO_3^-]+[BC]+[POA]$ The pattern of $PM_{2.5}$ concentrations is similar to that of nitrate in China. The highest concentrations in eastern China are about 32 μg m^{-3} in DJF and about 16 μg m^{-3} in JJA.

➢The comparisons of the simulated present-day $PM_{2.5}$ concentrations with measurements (Table 3) indicate that the model has a low bia in northern China. The model can reproduce well the concentrations in southern China.

Effect of Changes in Climate Alone

Figure 4. Predicted changes in surface-layer aerosol concentrations due to changes in climate alone from present day to future.



Sulfate/Nitrate/BC/OC/$PM_{2.5}$:

➢In DJF, sulfate, nitrate, BC, OC, and $PM_{2.5}$ are predicted to show similar trends between present day and future, with increased concentrations over southeastern China but decreased concentrations along the Yangtz River. The changes of in $PM_{2.5}$ concentrations are about 2-4 μg m^{-3}. The changes in concentrations can be explained by the changes in precipitation; In DJF, precipitation decreases approximately 40% in southeastern China and increases by about 50% in northern China (Figure 1).

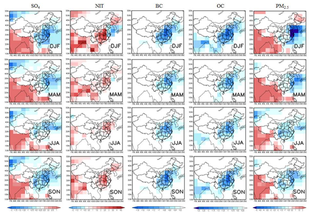
➢In MAM, sulfate, nitrate, BC, OC and $PM_{2.5}$ concentrations are predicted to generally increase in China. $PM_{2.5}$ concentrations increase by about 3μg m^{-3} in eastern China. Again the changes in concentrations can be attributed to the predicted changes in precipitation.

➢In JJA, aerosol concentrations are predicted to increase in southeastern China, especial in the lower reach of the Yangtz River, with the $PM_{2.5}$ concentration increased by 3μg m^{-3} in these areas. Predicted changes in concentrations do not appear to be the result of a single dominant factor. In JJA, PBL was predicted to decrease by about 10% eastern China, leading to higher concentrations. Further more, the cross-equatorial flows are much weaker in summer in future than in present day (Figure 2), which bring less clean air to China in future and contribute to higher concentrations in southeastern China.

➢In SON, sulfate, nitrate, BC, OC, and $PM_{2.5}$ concentrations decrease in eastern China by up to 0.4, 0.5, 0.2, 0.2, and 1.5μg m^{-3}, respectively. The increased wet removal leads to lower concentrations in eastern China.

Effect of Changes in Anthropogenic Emissions Alone

Figure 5. Predicted change in surface-layer aerosol concentrations due to changes in anthropogenic emissions alone from present day (1999-2001) to future (2049-2051).



Sulfate:

➢Sulfate concentrations in China are predicted to decrease in all seasons because of the domestic reductions in SO2 emissions. The annual mean decreases in sulfate concentrations in eastern China are up to 1.5μg m^{-3}.

Nitrate:

➢Future nitrate aerosol concentrations are predicted to increase in all seasons. Higher NOx emissions in eastern China lead to a general increase of nitrate in China. The largest increases are predicted to be 4-5μg m^{-3} in DJF and 1-2 μg m^{-3} in JJA.

BC and OC:

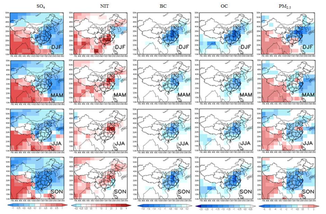
➢Future BC and OC concentrations are predicted to decrease in all seasons because of the domestic reductions in emissions. Over eastern China, the largest decreases in BC and OC are about 3μg m^{-3} in DJF and 1.5 μg m^{-3} in JJA.

$PM_{2.5}$:

➢Future $PM_{2.5}$ concentrations are predicted to decrease in all seasons in eastern China. In DJF, the largest decreases are predicted to be 5-6 μg m^{-3}. In other seasons the annul mean decreases in eastern china are up to 2-3 μg m^{-3}.

Effect of Changes in Both Climate and Anthropogenic Emissions

Figure 6. Predicted changes in surface-layer aerosol concentrations due to changes in anthropogenic emissions and climate from present day to future.



Sulfate/Nitrate/BC/OC/$PM_{2.5}$:

➢Predicted changes in sulfate, BC, and OC concentrations considering both future emissions and future climate are similar to those due to emissions changes alone. Annual mean concentrations of sulfate, BC, OC and PM2.5 are predicted to decrease by up to 1 μg m^{-3}, 1.6 μg m^{-3}, 2μg m^{-3}, and 4 μg m^{-3}, respectively. Annual mean nitrate increases in eastern China by up to 4 μg m^{-3} . For nitrate, climate change slightly mitigates the effects of changes in anthropogenic emissions.

Conclusion

- Climate change alone is predicted to impact aerosol concentrations by about 2-4 μg m^{-3} in China. Changes in concentrations are mainly influenced by changes in precipitation, but changes in concentrations can also be attributed to changes in PBL, cross-equatorial flows, and aerosol thermodynamics.
- The impacts of emission changes on aerosol concentrations are significant. Reductions in future emissions lead to lower concentrations of sulfate, BC, and OC by about 1-3 μg m^{-3}. Nitrate aerosol concentrations are predicted to increase by up to 3 μg m^{-3} owing to higher NOx emissions in eastern China. Future $PM_{2.5}$ concentrations in eastern China are predicted to decrease in all seasons, with an annual mean decrease of up to 3-5 μg m^{-3}.
- The pattern of changes in aerosol concentrations resulted from both future changes in emissions and climate is similar to that simulated with future changes in emissions alone. Annual mean concentrations of sulfate, BC, OC, and $PM_{2.5}$ are predicted to decrease by up to 1 μg m^{-3}, 1.6 μg m^{-3}, 2μg m^{-3}, and 4 μg m^{-3}, respectively. Climate change slightly mitigates the effects of changes in anthropogenic emissions on aerosol levels.

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