Impacts of reductions in emissions of multipollutants over 2005-2030 on regional air quality and climate

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Introduction

Many societal activities lead to multipollutants emit to the atmosphere that affect both air quality and climate which vary from region to region and activity to activity. We use three global coupled chemistry-climate models (CACTUS, GISS-PUCCINI, and NCAR-CESM) to estimate how future reductions in emissions of multipollutants and extra measures in China may provide benefits in both air quality and climate.

Methodology

➢ Emissions

- In support of the recent UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone (UNEP, 2011), 2005 and the three 2030 scenarios were developed at the IIASA using the GAINS model.

➢ Model Description

- The CACTUS model

- The CACTUS model has a unified tropospheric chemistry-aerosol simulation within the GISS GCM II' (Liao et al., 2009). It includes a detailed simulation of tropospheric O_3-NO_x-hydrocarbon chemistry, as well as sulfate, nitrate, ammonium, BC, POA, SOA. The chemical mechanism includes 225 chemical species and 346 reactions for simulating gas-phase species and aerosols.

- The GISS-PUCCINI

- The GISS model for Physical Understanding of Composition-Climate interactions and Impacts incorporates gas-phase, sulfate, BC, nitrate and SOA chemistry within the GISS ModelE GCM. The scheme includes 156 chemical reactions among 50 species. The aerosol indirect effects allow aerosol nucleation to affect the number of cloud droplets for warm clouds, but do not include aerosol-ice nucleation.

- The NCAR CESM

- The NCAR Community Earth System Model (CESM) using 3-mode modal aerosol scheme can simulate aerosol indirect effects for both water and ice clouds. This version does not have coupled gas-phase chemistry, and has no nitrate and ammonium simulation.

➢ Experiments

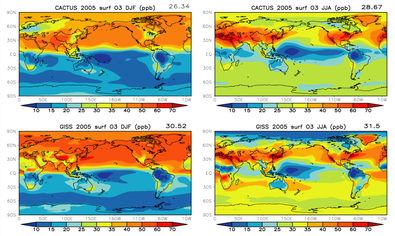
- We perform simulations for year 2005 (E2005) and the three 2030 scenarios (E2030_REF, E2030_LOWGWP, and E2030_LOWEST) as listed in Table 1 using the three models mentioned above.

Table 1. Summary of simulations.

Simulations	Emissions
E2005	Year 2005 worldwide emissions
E2030_REF	Year 2030 reference case worldwide emissions, assuming that all agreed air quality policies are being implemented.
E2030_LOWGWP	Year 2030 reference emissions plus CH4 + BC Group 1 measures in China
E2030_LOWEST	Year 2030 reference emissions plus CH4 + all BC measures in China

Results

➢ Simulated year 2005 concentrations of O_3 and aerosols



Concentrations of O_3 in populated regions, such as eastern China, the eastern US, and Europe, are about 50-70 ppbv in JJA, because of the strong photochemistry in summer.

Figure 1. Simulated year 2005 surface-layer O_3 concentrations for DJF and JJA.

The $PM_{2.5}$ concentrations exceed 40 μg m^{-3} over eastern China and are in the range of 5-15 μg m^{-3} over the eastern US. The NCAR CESM has low bias because it does not simulate nitrate aerosol.

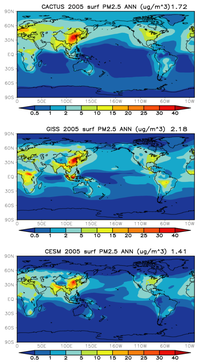


Figure 2. Simulated year 2005 annual mean surface-layer $PM_{2.5}$ concentrations.

➢ Simulated year 2005 AODs

In the CACTUS model, AODs are simulated to be 0.5-0.7 over Europe and Eastern Asia, and of 0.2-0.4 in Eastern US. AODs simulated over populated areas are 0.1-0.3 in the NCAR CESM, because nitrate aerosol is not included in the model.

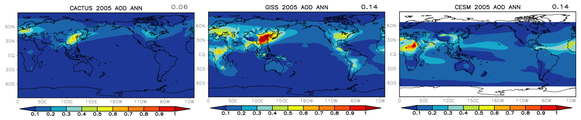


Figure 3. Year 2005 annual mean AODs at the wavelength of 550 nm.

➢ Impacts of reductions in emissions on year 2030 O_3 air quality

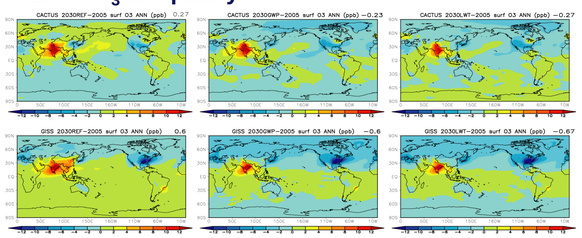


Figure 4. Simulated differences in surface-layer O_3 between 2030 and 2005.

In the case of E2030_REF, the CACTUS predicts reductions of O_3 of about 4-6 ppbv in northern China, whereas the GISS-PUCCINI predicts increases in O_3 throughout China. In the cases of E2030_LOWGWP and E2030_LOWEST, both models predict small reductions of 0-4 ppbv in eastern China. The predicted different changes in regional O_3 can be explained by different local VOCs/NO_x ratios in the models.

➢ Impacts of reductions in emissions on year 2030 $PM_{2.5}$ air quality

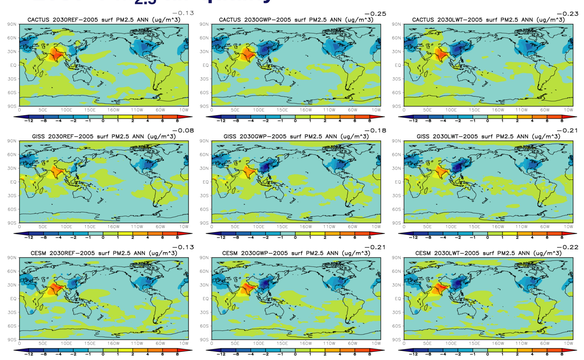


Figure 5. Simulated differences in surface-layer $PM_{2.5}$ between 2030 and 2005.

In eastern China, reductions in $PM_{2.5}$ concentrations are about 1-4 μg m^{-3} in all models in the case of E2030_REF, and the reductions in E2030_LOWGWP and E2030_LOWEST are about 4-12 μg m^{-3}. In the latter two 2030 cases, the percentage reductions in surface-layer $PM_{2.5}$ concentrations in eastern China relative to 2005 are about 20-40% in the CACTUS model and 40-60% in the GISS-PUCCINI and NCAR CESM.

➢ Radiative forcing over 2005-2030 as a result of the changes in tropospheric O_3 and aerosols

- Radiative forcing by tropospheric O_3

The maximum negative forcings of 0.1-0.3 W m^{-2} are found over the mid-high latitudes in the Northern Hemisphere and the maximum positive forcings exceed 0.3 W m^{-2} are simulated over the tropical regions, corresponding to the large increases in O_3 concentration over or near India.

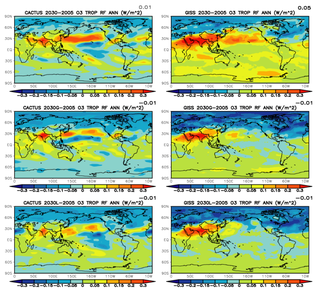
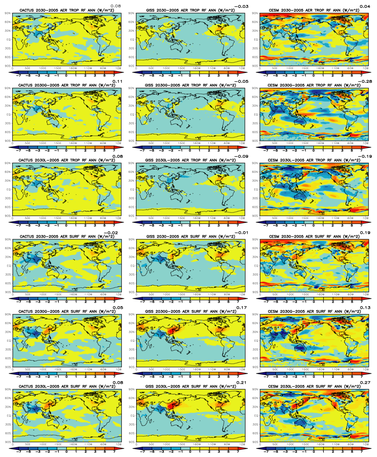


Figure 6. Simulated tropopause O_3 radiative forcing as a result of the changes in O_3 over 2005-2030.

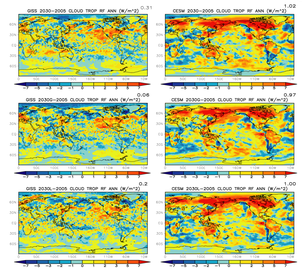
- Aerosol direct radiative forcing at the tropopause and the surface



The tropopause aerosol direct radiative forcing is -3 to +2 W m^{-2} in China. The sign of the forcing is determined by the ratio of BC to scattering aerosols. The surface positive forcings are predicted to be 2-5 W m^{-2} over the US and Europe, and can exceed 7 W m^{-2} over eastern China.

Figure 7. Simulated direct aerosol forcing at the tropopause (top three rows) and the surface (bottom three rows) as a result of the changes in aerosols over 2005-2030.

- Aerosol indirect radiative forcing at the TOA



On an annual and global mean basis, aerosol indirect radiative forcings are positive, because indirect effect is determined by soluble aerosol species. Also forcing values have large uncertainties.

Figure 8. Simulated indirect aerosol forcing at the TOA as a result of the changes in aerosols over 2005-2030.

Conclusion

1. Based on emissions inventories used, reductions in emissions have small impacts on year 2030 regional O_3 air quality, but they can be very helpful for reducing $PM_{2.5}$ concentrations in eastern China. In the cases of E2030_LOWGWP and E2030_LOWEST, the percentage reductions in surface-layer $PM_{2.5}$ concentrations in eastern China relative to 2005 are about 20-40% in the CACTUS model and 40-60% in the GISS-PUCCINI and NCAR CESM.
2. Over 2005-2030, the total forcing (O_3+aerosol direct and indirect) is likely to be positive.

References

[1] United Nations Environment Programme & World Meteorological Organization, "Integrated Assessment of Black Carbon and Tropospheric Ozone", 2011.

[2] Liao, H., Y. Zhang, W.-T. Chen, F. Raes, and J. H. Seinfeld, Effect of chemistry-aerosol-climate coupling on predictions of future climate and future levels of tropospheric ozone and aerosols, J. Geophys. Res., 114, D10306, doi:10.1029/2008JD010984, 2009.

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