Geoengineering Impacts on Rice in China

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Abstract: Geoengineering with 5 Tg SO_2 injected into the stratosphere from the tropics for 20 years would produce significant climate changes, including cooling and reduction of solar radiation and precipitation, which are all important factors controlling agricultural productivity. We used the Decision Support System for Agrotechnology Transfer (DSSAT) crop dynamic model to simulate geoengineering impacts on rice yield in 24 provinces in China. We first evaluated the model by forcing it with daily weather data and management practices for the period 1980-2008 for 24 provinces, and compared the results to observations of rice yields in China. Then we perturbed observed weather data using climate anomalies for a 20-year geoengineering simulation and another 5 years after the stop of sulfate injection. We perturbed each year of the 30-year climate record with anomalies from each year of the 25-year geoengineering and post-geoengineering simulations for different regions in China. We found that rice production would decline 11±3% (13±4 Mt) in the 20-year geoengineering period, and would slowly recover in the 5-year post geoengineering period with rice production reduction by 7±4% (-8±4 Mt) compared with control run. This reduction is mainly caused by temperature reduction, which is also the reason of different regional responses to geoengineering. Provinces in the south increased rice yield slightly by 5±2% due to release from heat stress, while cold regions in the north showed strong negative impacts, with a rice yield reduction of 60±18%. Increasing fertilizer usage could compensate for the negative impact of geoengineering on rice production. With an additional 50 kg/ha N-fertilizer, rice production in 24 provinces increased 17±2% (17±1 Mt), but it also causes other environmental problems.

Motivation

Sulfate injection into the stratosphere is one of the most discussed geoengineering schemes to deliberately manipulate the climate system and counteract global warming, while manifold uncertainties and risks still exist. Among them, possible food supply change is one of the most important. Some previous modeling work showed reduction of summer precipitation in East Asia and India (Figure 1). These regional climate anomalies could extensively influence agriculture productivity by reducing the food supply for billions of people.

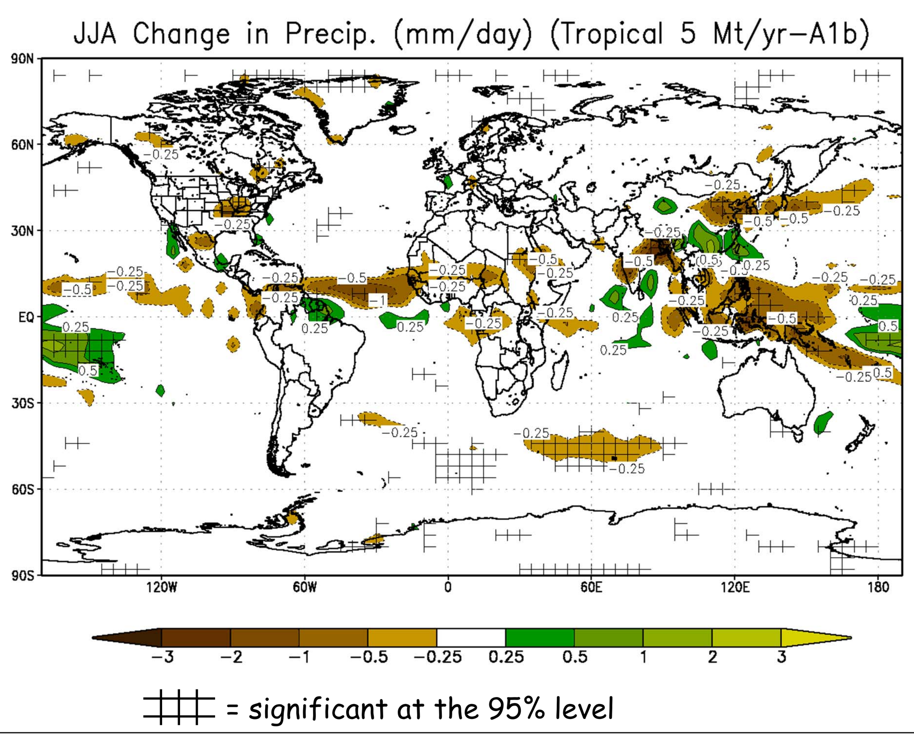

Figure 1. Average precipitation change in Northern Hemisphere summer in the second 10-year period of the geoengineering simulation with tropical injection of 5 Tg SO_2 into the stratosphere [*Robock et al.*, 2008].

Since China is strongly influenced by the summer monsoon system and it is one of the most important rice production countries, our study first focuses on geoengineering impacts on rice in China.

Method

To study geoengineering impacts on rice, first we evaluated the DSSAT crop model by forcing it with daily weather observations from 198 weather stations and agricultural practices in China, and compared the results with the records of rice yields in 24 provinces in China from 1980 to 2008. Then we perturbed each of the 30 years of observations by 25 1-year climate anomalies from a geoengineering simulation (20 years with 5 Tg SO_2 injection and 5 years after the stop of injection). Therefore, for each year of the geoengineering event, there are 30 simulations of rice growth in 24 provinces in China. In total, there are 30×25×24 (18,000) simulations.

Method (cont.)

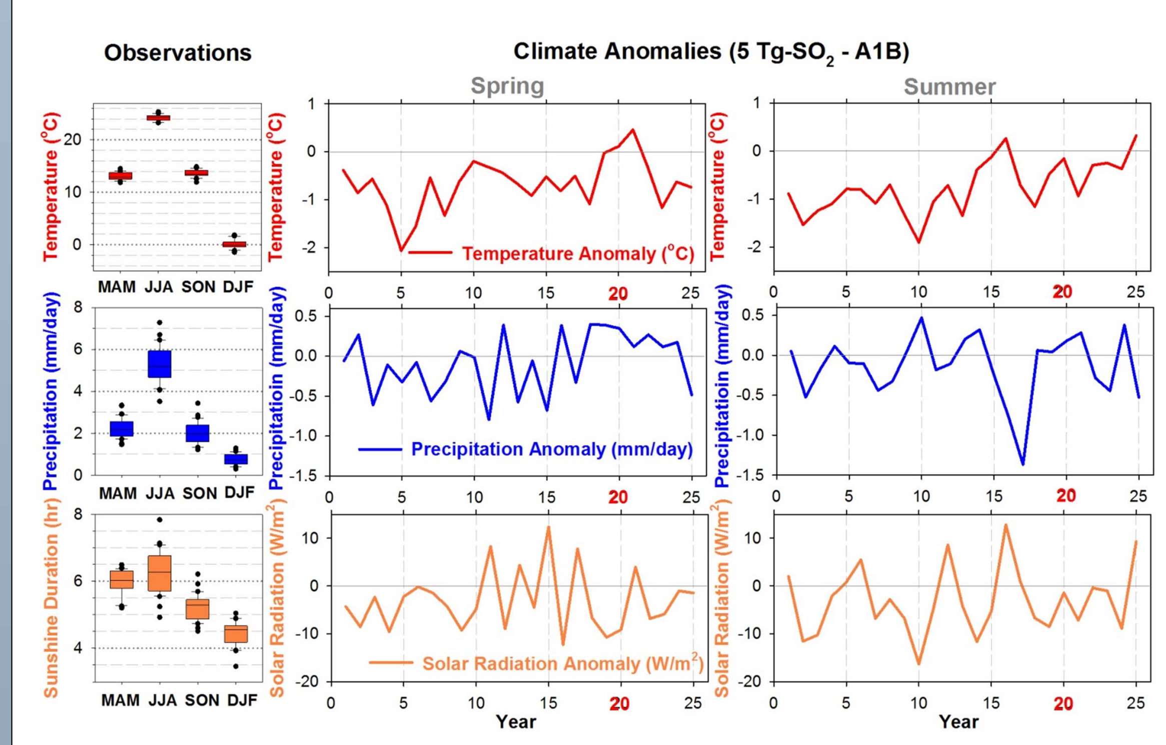

Figure 2. The left panels are the seasonal averages of temperature, precipitation and solar duration in the five major provinces for rice production. The middle and right panels are the monthly average climate anomalies (compared to an A1B scenario) of 5 Tg SO_2 geoengineering input to the stratosphere plus A1B forcing in the top five rice production provinces. The anomalies are used to perturb the observations.

Spring and summer are two seasons important to rice growth. With 5 Tg SO_2 injected into the stratosphere from the tropics, average temperature anomalies in rice production regions referring to A1B scenario showed reductions by 0.7±0.5ºC in spring and 0.8±0.5ºC in summer (Figure 2).

Results

Geoengineering Impacts on Rice

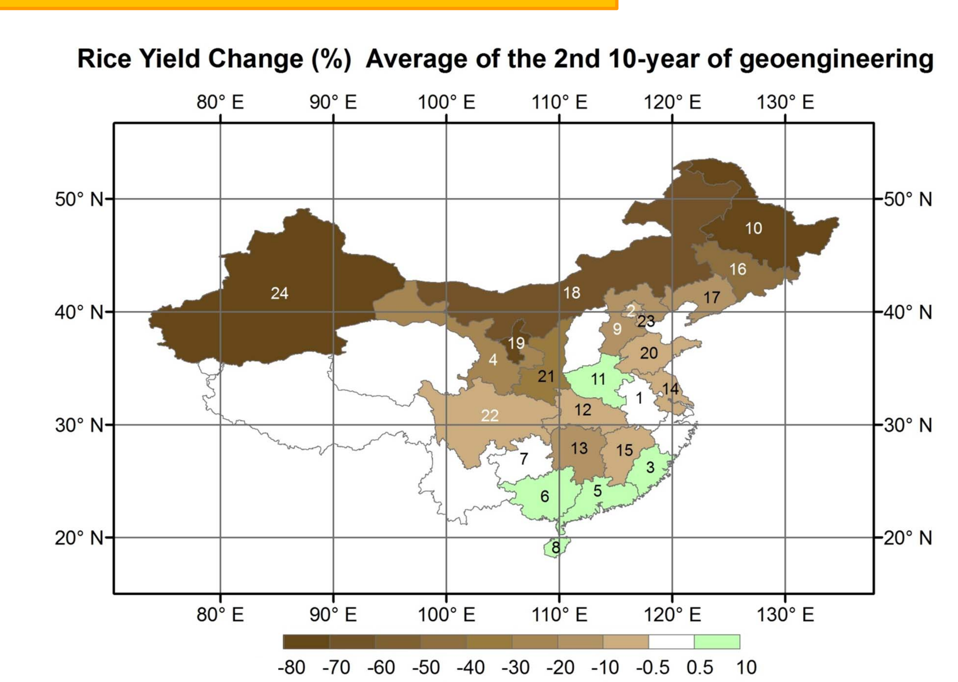

Figure 3. Rice yield change (%) compared to control run, for the average of the second 10-year period of geoengineering. Green indicates rice yield increasing, brown indicates the decline of rice yield. White areas with numbers are rice yield changes within -0.5% to +0.5%, and white areas without numbers are provinces where we did not run the experiment.

Results (cont.)

With fixed planting date, harvest at maturity, non-irrigation, 150 kg/ha N-fertilizer applied when planting, $[CO_2]$ = 386 ppm, rice yield changed by -18±27% in the second 10-year period of geoengineering (Figure 3).

Different regions showed different responses: provinces in the south increased rice yield slightly by 5±2% due to release from heat stress; provinces in the central latitudes showed mildly decreasing rice yield by 8±8%; and cold regions in the north (> 40ºN) have strong negative impacts, with a rice yield reduction of 60±18%.

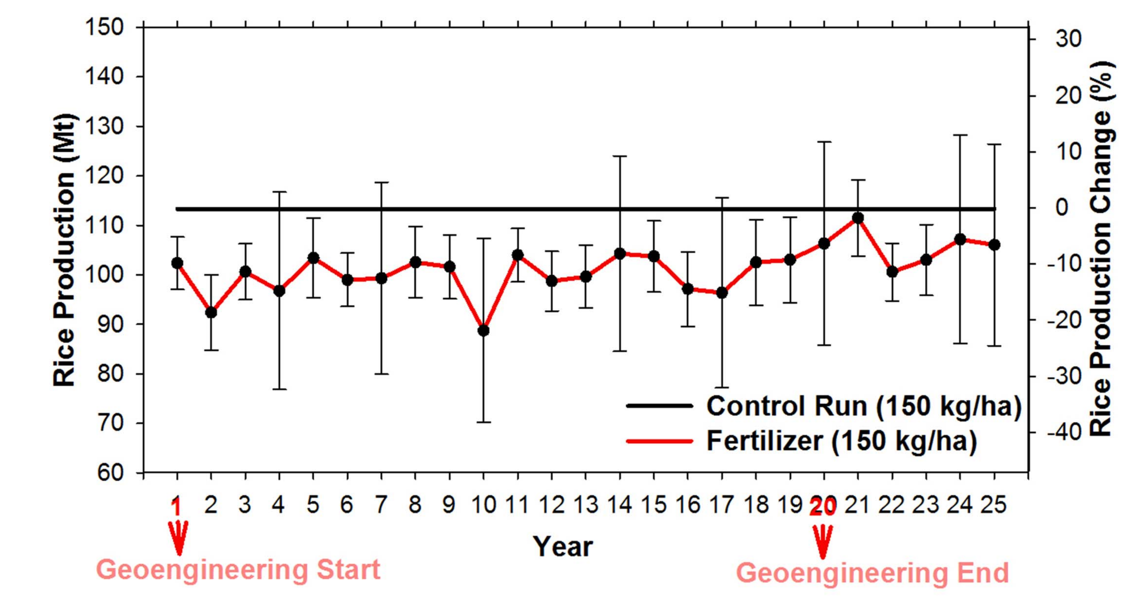

Figure 4. Geoengineering impacts on national rice production in China. The red line is the average of 30 runs, and the whiskers show one standard deviation. The black line is the control run, which is the averaged simulated rice production from 1980 to 2008.

We calculated rice production according to rice growing areas in 2008 in those 24 provinces. Compared to the control run, national rice production decreased 11±3% (13±4 Mt) in the 20 year geoengineering run. After shutting off the sulfate injection at the 20^{th} year, rice production recovered slightly, but was still less than for the control run by -7±4% (-8±4 Mt) (Figure 4).

Rice production reduction is mainly caused by a temperature reduction. We tested this hypothesis at two locations, Jiangsu and Shandong, with individually perturbed climate factors (temperature, precipitation and solar radiation). And with temperature change only, rice yield showed a similar reduction to when perturbed by all three factors.

Fertilizer Impacts on Rice

To compensate for the negative impacts of geoengineering on rice, an additional 50 kg/ha N-fertilizer was applied. As a result, rice yields in 24 provinces increased from 0.02±0.03 kg/ha (Guangdong, 5) to 39±10 kg/ha (Sichuan, 22).

Results (cont.)

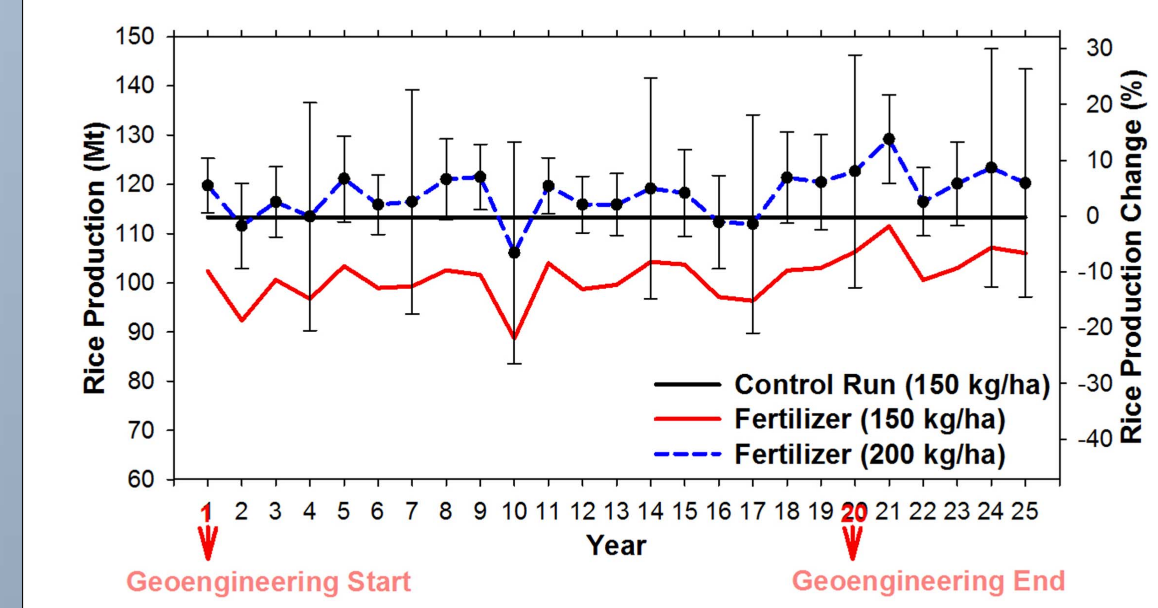

Figure 5. Fertilizer impacts on rice production in China. The blue dashed line is the average of 30 runs with additional 50 kg/ha fertilizer, and the whiskers show one standard deviation. The black line is the control run, the average simulated rice production from 1980 to 2008.

National rice production increased 17±2% (17±1 Mt) with 200 kg/ha N-fertilizer applied compared with using 150 kg/ha N-fertilizer (Figure 5).

Conclusions

For one geoengineering scenario, one climate model and one crop model:

1. Rice production in China decreased 11±3% (13±4 Mt) in response to a 5 Tg SO_2 per year stratospheric injection.
2. Increasing fertilizer from 150 kg/ha to 200 kg/ha could compensate for the reduction of rice production.

Acknowledgments

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Reference

Robock, A., L. Oman, and G. L. Stenchikov (2008), Regional climate responses to geoengineering with tropical and Arctic SO_2 injections. *J. Geophys. Res.*, 113, D16101, doi:10.1029/2008JD010050.