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Rice yield simulation in Nanjing with climate and diffuse radiation fraction change scenarios

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Outline

- Background
- Materials and Methods
- Results
- Discussion and Conclusion

Background

- In all aspects of the human society economy, agriculture's response to climate change may be the most sensitive. Research on the effect of future climate change on crop yield, helps to consider adapting to the environment early, so that the potential loss can minimize as far as possible.
- Aiming at the effects of global climate change on crop yield, a series of studies has been carried out. But these studies are mainly considered the factors such as temperature, precipitation, CO_2 concentration which impact the crops. There is less research for the impact of solar radiation especially the diffuse radiation changes on the crop.

Background

- In this study, we chose the rice which grows in Nanjing in the plains of Yangtze river delta. Based on modifying and verifying rice model ORYZA2000, we simulated the rice yield from 2016 to 2100 responding to the changes in temperature and CO_2 concentration , especially the changes in diffuse radiation fraction caused by atmospheric aerosol optical depth (AOD) under RCP2.6, RCP4.5, RCP6.0, RCP8.5 four scenarios in the IPCC AR5.

Materials and Methods

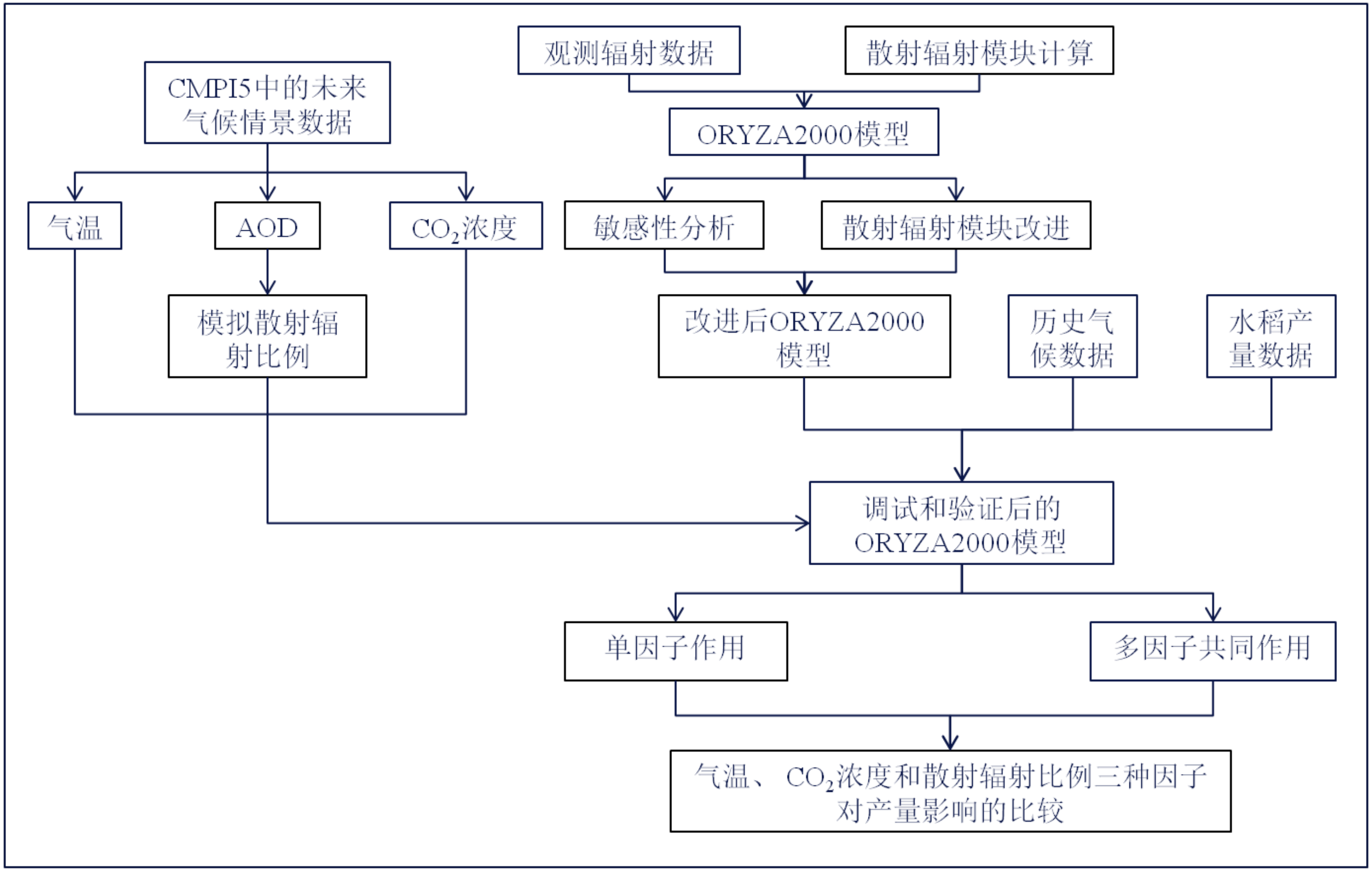

Fig.1 Technology roadmap

Materials and Methods

- ORYZA2000

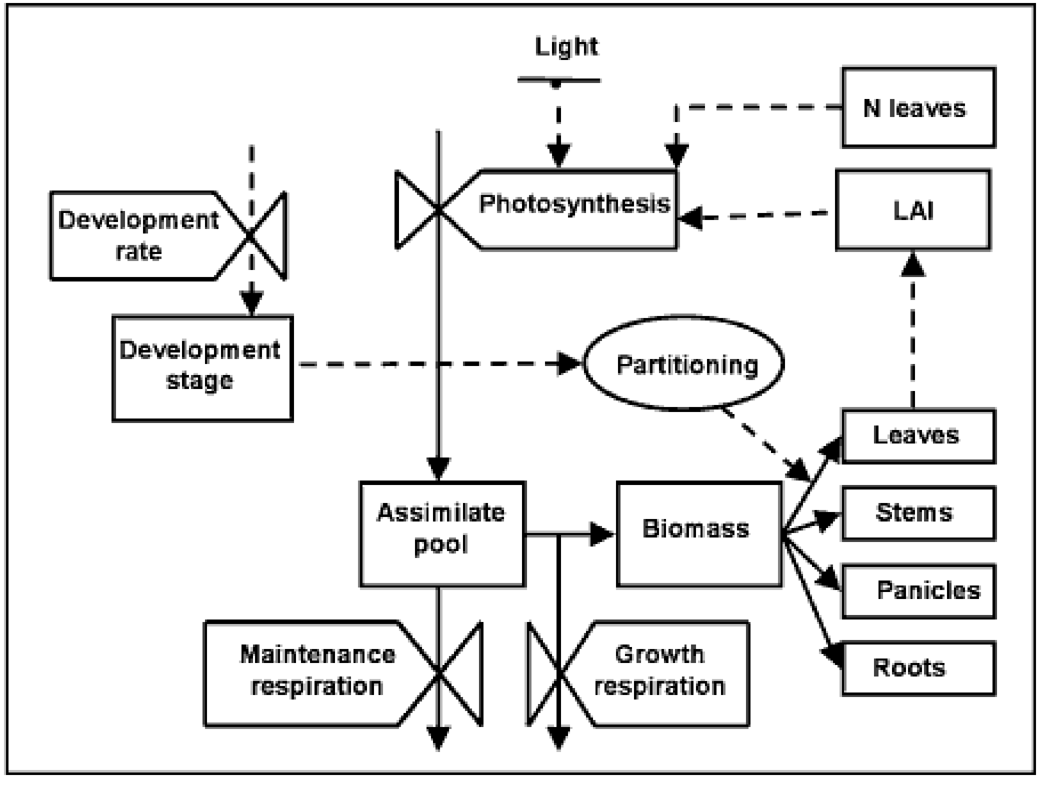

Fig.2 A schematic representation of ORYZA2000

Materials and Methods

- CMIP5

the fifth phase of Coupled Model Intercomparison Project

RCP2.6 RCP4.5 RCP6.0 RCP8.5

The labels for the RCPs provide a rough estimate of the radiative forcing in the year 2100 (relative to preindustrial conditions). For example, the radiative forcing in RCP8.5 increases throughout the twenty-first century before reaching a level of about 8.5 W m^{-2} at the end of the century.

AOD: GISS-E2-H

Temperature and CO_2 concentration: BCC_CSM1.1

Materials and Methods

- Rice yield

Model calibration: Luoqiao rice experiment yield in 2014

Model validation: Average yield in Jiangsu province from Jiangsu statistical yearbook during 2010-2014

- Historical climate

T_{max} T_{min} V_p and Wind speed: ***Daily value data set of China's ground climate***

Daily values of radiation: ***Daily value data set of China's radiation***

Materials and Methods

- ORYZA2000 estimate the instantaneous short-wave radiation at three representative moments using three-point Gaussian integration.
- The diffuse radiation fraction is calculated from the atmospheric transmission using an empirical function.

$$S_{df} / S_g = 1 \qquad S_g / S_o \le 0.22$$

$$S_{df} / S_g = 1 - 6.4(S_g / S_o - 0.22)^2 \qquad 0.22 < S_g / S_o \le 0.35$$

$$S_{df} / S_g = 1.47 - 1.66 S_g / S_o \qquad 0.35 < S_g / S_o \le 1$$

$$S_o = S_{cs}[1 + 0.033\cos(360 t_d / 365)]\sin\beta$$

Table 1. The relationship between radiation and AOD in MODIS

	散射辐射	直接辐射
春季	R=4.61*AOD+4.74	R=-8.39*AOD+20.88
夏季	R=3.97*AOD+6.29	R=-7.56*AOD+19.10
秋季	R=3.57*AOD+3.51	R=-5.63*AOD+12.80
冬季	R=3.92*AOD+2.31	R=-3.79*AOD+10.58

Materials and Methods

- Sensitivity analysis

$$\beta = \Delta Yield / \Delta pb$$

$$VR = 100 \times \frac{\left| run_{+10\%} - run_{-10\%} \right|}{run_{ref}}$$

- Model validation

$$AE = \frac{\frac{1}{N}\sum_{i=1}^{N}\left| x_i - x_{oi} \right|}{\overline{x_{oi}}}$$

$$NRMSE = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - x_{oi} \right)^2}}{\overline{x_{oi}}}$$

Results

Table 2. Sensitivity coefficient and percent change of yield and dry weight above ground for diffuse radiation fraction

FRDIF增加量	产量变化量（kg hm^{-1})	敏感度系数	变化百分率
50%	134	268	
40%	190	475	
30%	199	663	
20%	168	840	
10%	100	1000	
0%			2.10
-10%	-132	1320	
-20%	-291	1455	
-30%	-478	1593	
-40%	-690	1725	
-50%	-925	1850	

FRDIF增加量	地上部分干重变化（kg hm^{-1})	敏感度系数	变化百分率
50%	169	338	
40%	272	680	
30%	300	1000	
20%	260	1300	
10%	158	1580	
0%			1.96
-10%	-211	2110	
-20%	-471	2355	
-30%	-778	2593	
-40%	-1132	2830	
-50%	-1522	3044	

Results

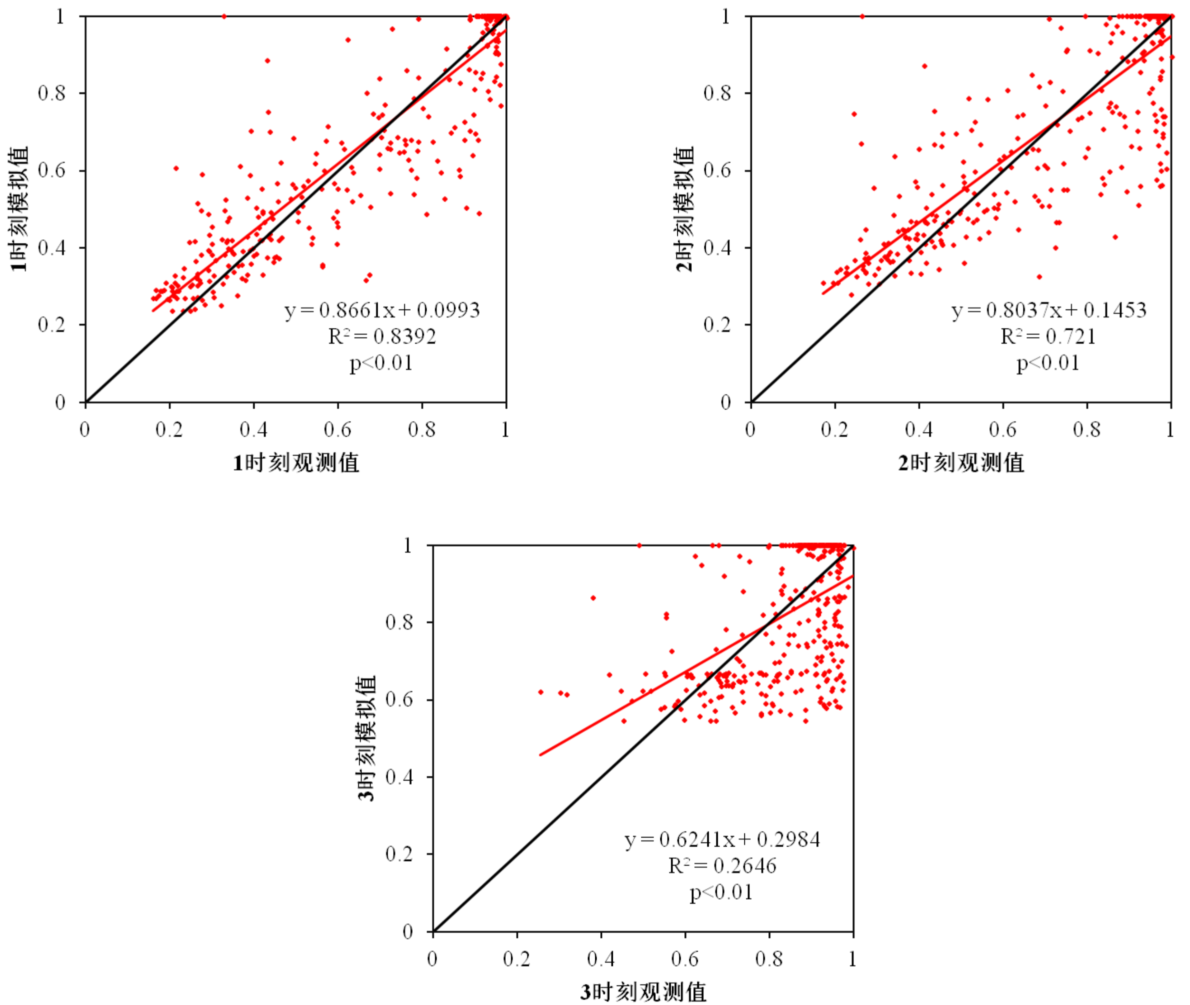

Fig 3. Comparison of simulated diffuse radiation fraction with observed value at three representative time

Results

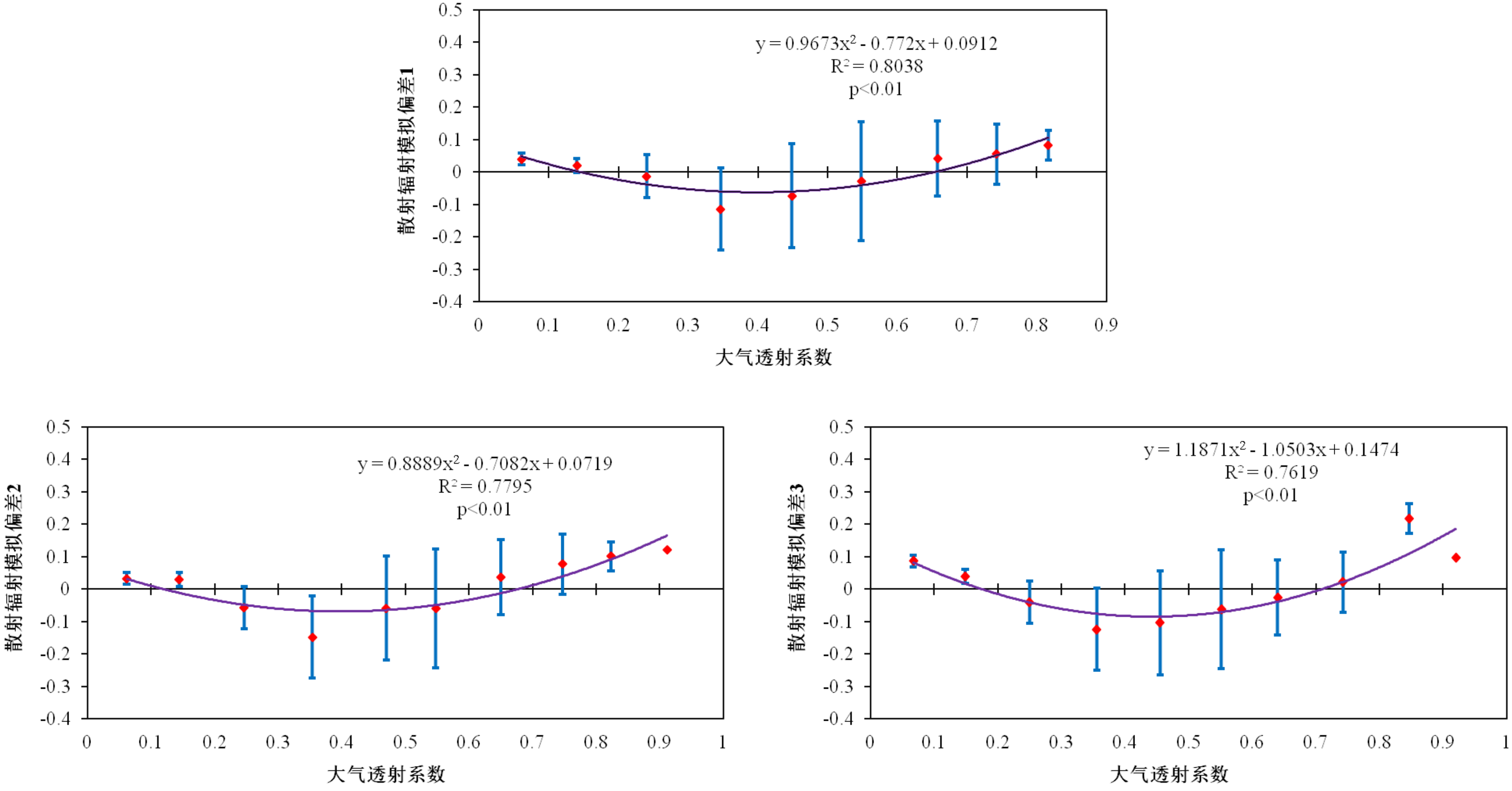

Fig 4. The changes in errors of simulated diffuse radiation with atmospheric transmission(error bar is standard deviation)

Results

Table 3. Comparison between diffuse radiation simulated value and observed value

时刻	改进前均方根误差	改进后均方根误差
1时刻	0.13	0.12
2时刻	0.16	0.14
3时刻	0.18	0.16

Results

Table 4. Calibrated parameters of development rate

DVRJ	DVRI	DVRP	DVRR
0.000673	0.000758	0.000695	0.001599

Table 5. Calibrated parameters of specific leaf area

发育时期DVS	比叶面积参数
0.00	0.0049
0.26	0.0049
0.35	0.0049
0.50	0.0046
0.65	0.0026
0.80	0.0017
1.00	0.0017
2.00	0.0012

Results

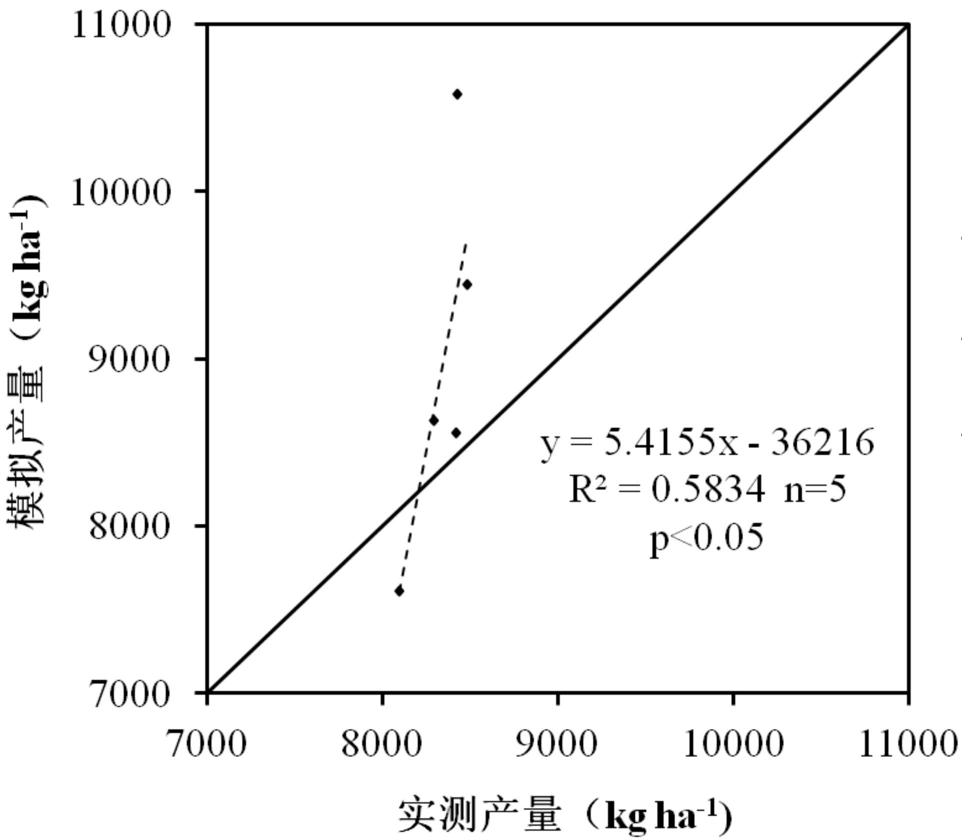

Fig 5. Comparison between the observed and simulated rice yield

Table 6. Tests of simulated yield

t	*R*	*AE*	*NRMSE*
2.05	0.764	9.74%	13.02%

Results

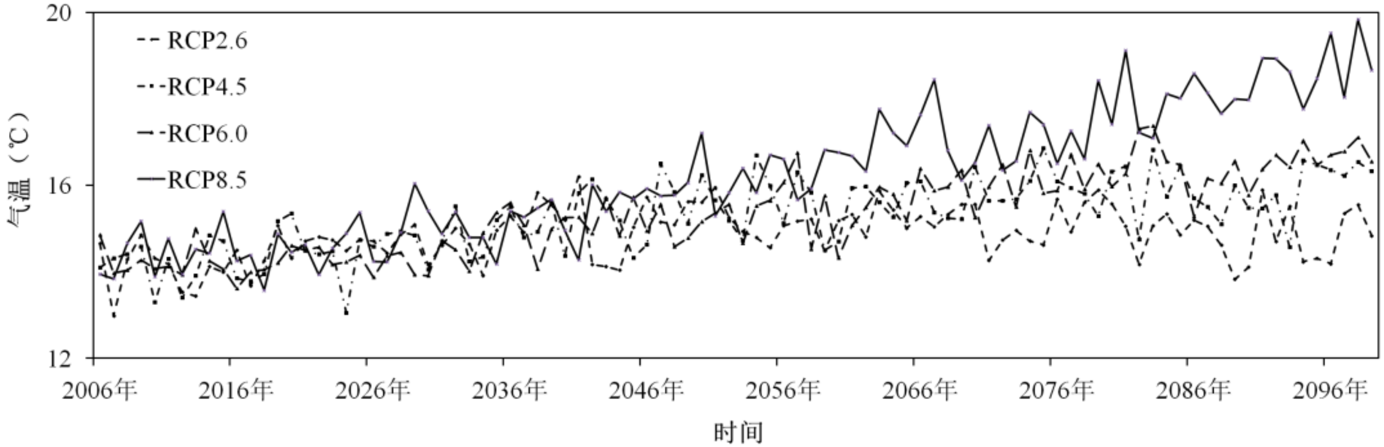

Fig 6. The average temperature in 2006-2100

Table 7. Changes of temperature in 2016-2100 relative to baseline (2015)

	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	平均气温（℃）	相对增幅	平均气温（℃）	相对增幅	平均气温（℃）	相对增幅	平均气温（℃）	相对增幅
2016-2020	14.36	2.62%	14.42	3.03%	14.09	0.71%	14.31	2.25%
2021-2030	14.67	4.87%	14.44	3.22%	14.24	1.74%	14.82	5.92%
2031-2040	14.99	7.13%	14.92	6.64%	14.85	6.12%	15.08	7.78%
2041-2050	15.08	7.74%	15.55	11.1%	15.14	8.23%	15.79	12.9%
2051-2060	15.06	7.63%	15.47	10.6%	15.42	10.2%	16.18	15.7%
2061-2070	15.32	9.48%	15.72	12.3%	15.73	12.4%	17.04	21.8%
2071-2080	15.10	7.88%	15.94	13.9%	16.16	15.5%	17.16	22.6%
2081-2090	14.73	5.25%	15.80	12.9%	16.38	17.1%	17.99	28.6%
2091-2100	14.95	6.85%	16.03	14.6%	16.68	19.2%	18.76	34.1%

Results

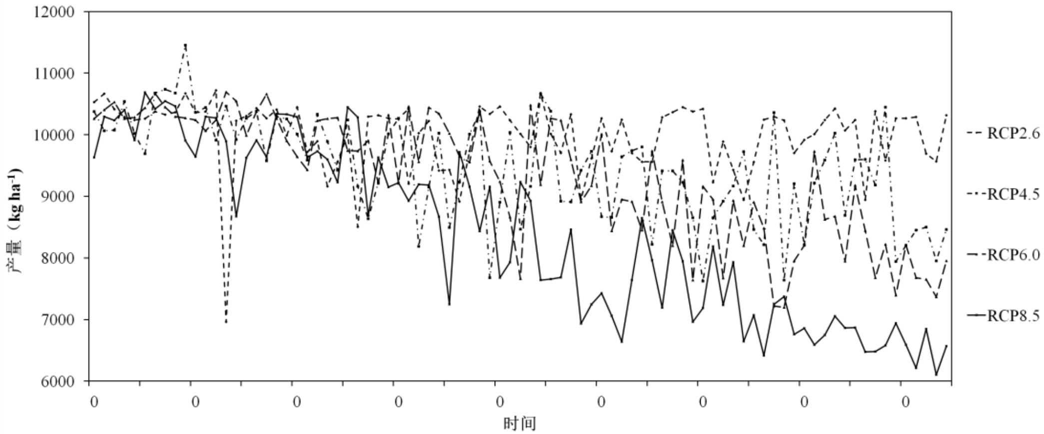

Fig 7. Changes of yield responding to the changes of temperature in 2006-2100

Table 8. Changes of yield with changes of temperature in 2016-2100 relative to baseline (2015)

	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	产量（kg ha-1）	相对增幅	产量（kg ha-1）	相对增幅	产量（kg ha-1）	相对增幅	产量（kg ha-1）	相对增幅
2016-2020	10426.64	-0.96%	10215.60	-2.97%	10347.00	-1.72%	10093.13	-4.13%
2021-2030	10064.57	-4.40%	10433.43	-0.90%	10389.40	-1.32%	10079.63	-4.26%
2031-2040	10018.57	-4.84%	10000.85	-5.01%	10102.08	-4.05%	9832.04	-6.61%
2041-2050	9852.67	-6.42%	9532.82	-9.45%	9891.89	-6.04%	9338.40	-11.3%
2051-2060	10006.44	-4.96%	9302.77	-11.6%	9443.61	-10.3%	8511.72	-19.1%
2061-2070	9812.08	-6.80%	9388.71	-10.8%	9293.63	-11.7%	7540.33	-28.4%
2071-2080	9894.47	-6.02%	8901.16	-15.4%	8698.07	-17.4%	7569.20	-28.1%
2081-2090	10068.54	-4.37%	8961.58	-14.9%	8292.97	-21.2%	6897.24	-34.5%
2091-2100	9953.55	-5.46%	8833.52	-16.1%	7976.88	-24.2%	6566.32	-37.6%

Results

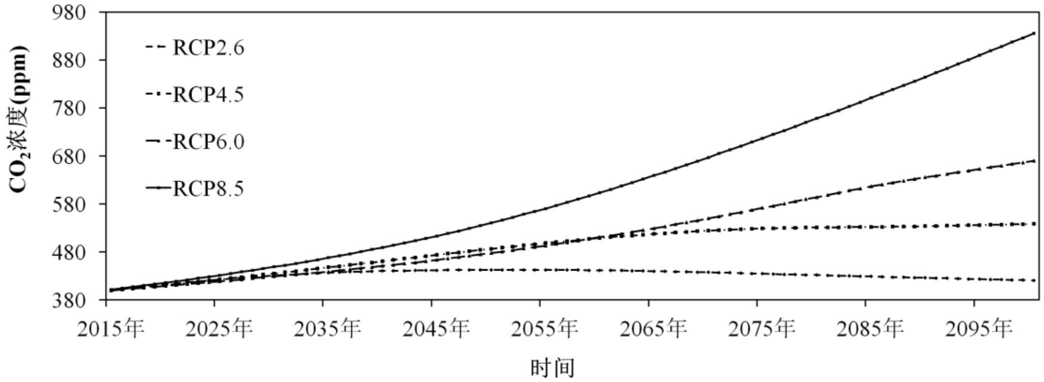

Fig 8. The average CO_2 concentration in 2006-2100

Table 9. Changes of CO_2 concentration in 2016-2100 relative to baseline (2015)

	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	CO_2浓度(ppm)	相对增幅	CO_2浓度(ppm)	相对增幅	CO_2浓度(ppm)	相对增幅	CO_2浓度(ppm)	相对增幅
2016-2020	407.52	1.71%	406.65	1.49%	405.41	1.18%	409.99	2.32%
2021-2030	423.09	5.59%	424.01	5.82%	420.05	4.83%	433.42	8.17%
2031-2040	436.73	9.00%	449.13	12.09%	440.42	9.92%	470.33	17.38%
2041-2050	441.86	10.28%	475.04	18.56%	465.03	16.06%	516.54	28.92%
2051-2060	442.37	10.41%	499.33	24.62%	495.26	23.61%	574.18	43.30%
2061-2070	439.64	9.72%	518.03	29.29%	531.69	32.70%	643.29	60.55%
2071-2080	434.28	8.38%	528.91	32.00%	574.02	43.26%	721.27	80.01%
2081-2090	428.55	6.96%	532.41	32.88%	618.07	54.26%	805.50	101.0%
2091-2100	423.18	5.61%	536.21	33.83%	654.56	63.36%	894.65	123.3%

Results

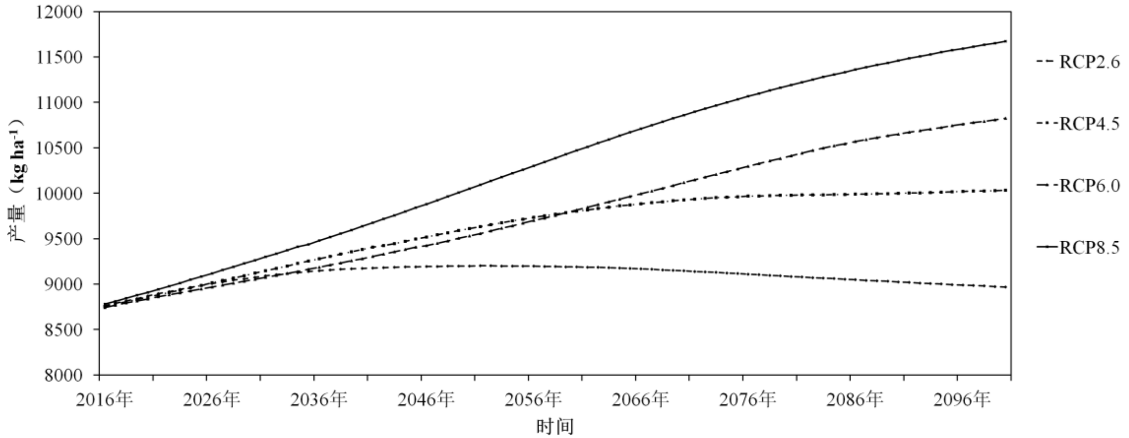

Fig 9. Changes of yield responding to the changes of CO_2 concentration in 2006-2100

Table 10. Changes of yield with changes of CO_2 concentration in 2016-2100 relative to baseline (2015)

	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	产量（kg ha^{-1}）	相对增幅	产量（kg ha^{-1}）	相对增幅	产量（kg ha^{-1}）	相对增幅	产量（kg ha^{-1}）	相对增幅
2016-2020	8815.86	0.95%	8805.88	0.83%	8791.44	0.67%	8844.41	1.27%
2021-2030	8991.39	2.96%	9000.85	3.06%	8957.59	2.57%	9101.55	4.22%
2031-2040	9138.27	4.64%	9264.52	6.08%	9175.94	5.07%	9463.78	8.36%
2041-2050	9191.68	5.25%	9506.18	8.85%	9415.71	7.81%	9861.28	12.9%
2051-2060	9196.84	5.31%	9721.35	11.3%	9685.66	10.9%	10281.13	17.7%
2061-2070	9168.72	4.99%	9876.15	13.1%	9981.16	14.3%	10688.68	22.4%
2071-2080	9112.30	4.34%	9961.55	14.1%	10281.73	17.7%	11048.08	26.5%
2081-2090	9051.33	3.64%	9988.38	14.4%	10553.32	20.8%	11344.69	29.9%
2091-2100	8992.76	2.97%	10017.11	14.7%	10749.74	23.1%	11581.28	32.6%

Results

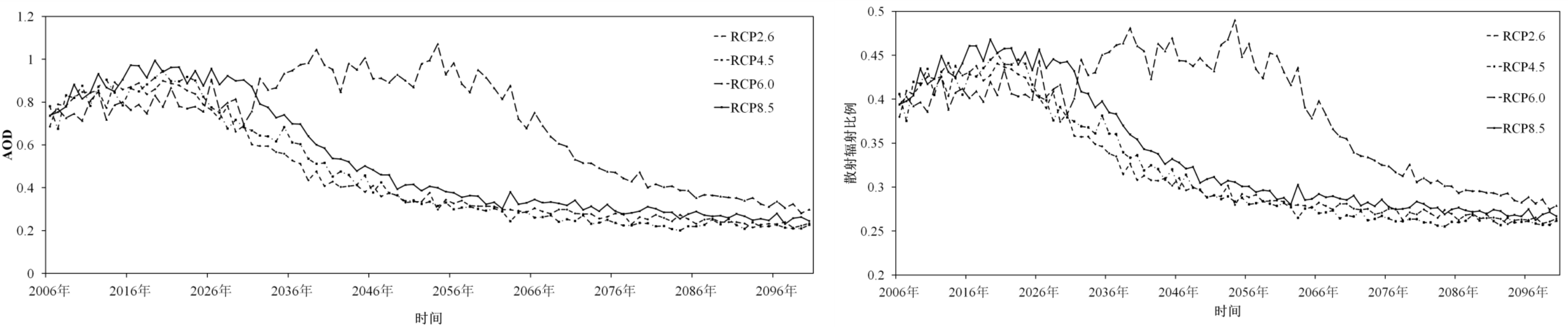

Fig 10. The average AOD and diffuse radiation fraction in 2006-2100

Table 11. Changes of AOD in 2016-2100 relative to baseline (2015)

	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	AOD	相对增幅	AOD	相对增幅	AOD	相对增幅	AOD	相对增幅
2016-2020	0.87	1.45%	0.89	3.74%	0.78	-8.98%	0.96	11.60%
2021-2030	0.79	-8.42%	0.80	-6.38%	0.79	-7.68%	0.92	7.09%
2031-2040	0.53	-38.55%	0.60	-29.81%	0.92	7.71%	0.71	-16.99%
2041-2050	0.39	-54.98%	0.41	-51.81%	0.93	8.05%	0.48	-44.35%
2051-2060	0.33	-61.59%	0.32	-63.27%	0.94	9.72%	0.38	-56.13%
2061-2070	0.30	-65.60%	0.27	-68.66%	0.72	-15.76%	0.33	-61.36%
2071-2080	0.27	-69.10%	0.24	-72.25%	0.47	-44.69%	0.30	-64.89%
2081-2090	0.25	-70.66%	0.22	-73.81%	0.38	-55.74%	0.28	-67.86%
2091-2100	0.23	-73.38%	0.22	-74.47%	0.32	-62.43%	0.26	-70.07%

Results

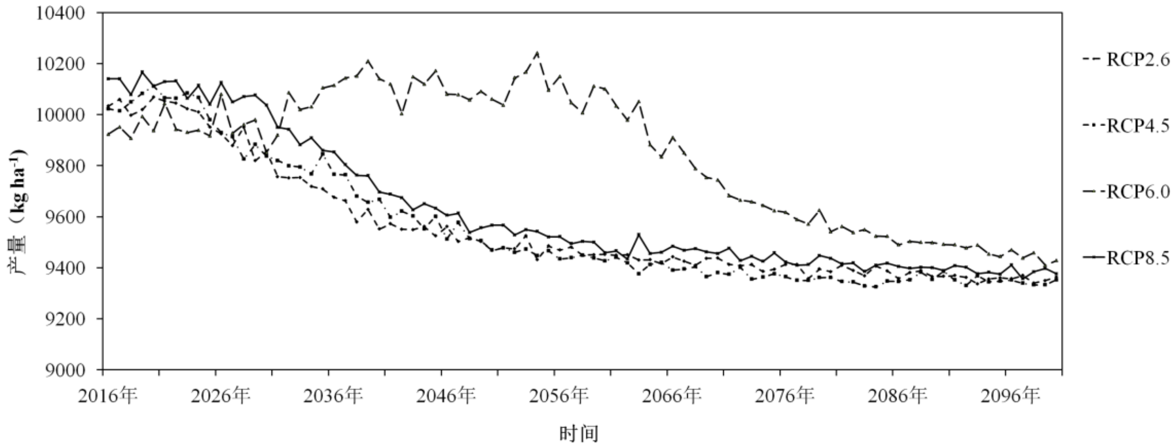

Fig 11. Changes of yield responding to the changes of diffuse radiation fraction in 2006-2100

Table 12. Changes of yield with changes of diffuse radiation fraction in 2016-2100 relative to baseline (2015)

	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	产量（kg ha^{-1}）	相对增幅	产量（kg ha^{-1}）	相对增幅	产量（kg ha^{-1}）	相对增幅	产量（kg ha^{-1}）	相对增幅
2016-2020	8329.23	-0.28%	8346.48	-0.07%	8251.93	-1.21%	8405.41	0.63%
2021-2030	8259.32	-1.12%	8270.79	-0.98%	8264.08	-1.06%	8373.29	0.25%
2031-2040	8033.34	-3.82%	8097.62	-3.05%	8376.29	0.28%	8195.20	-1.88%
2041-2050	7910.56	-5.29%	7930.98	-5.05%	8377.02	0.29%	7991.40	-4.32%
2051-2060	7859.87	-5.90%	7844.46	-6.08%	8391.05	0.46%	7900.19	-5.42%
2061-2070	7827.40	-6.29%	7801.66	-6.60%	8202.43	-1.80%	7859.28	-5.91%
2071-2080	7799.78	-6.62%	7773.67	-6.93%	7985.97	-4.39%	7830.43	-6.25%
2081-2090	7787.06	-6.77%	7761.41	-7.08%	7898.60	-5.44%	7808.32	-6.52%
2091-2100	7765.76	-7.03%	7756.51	-7.14%	7847.32	-6.05%	7791.05	-6.72%

Results

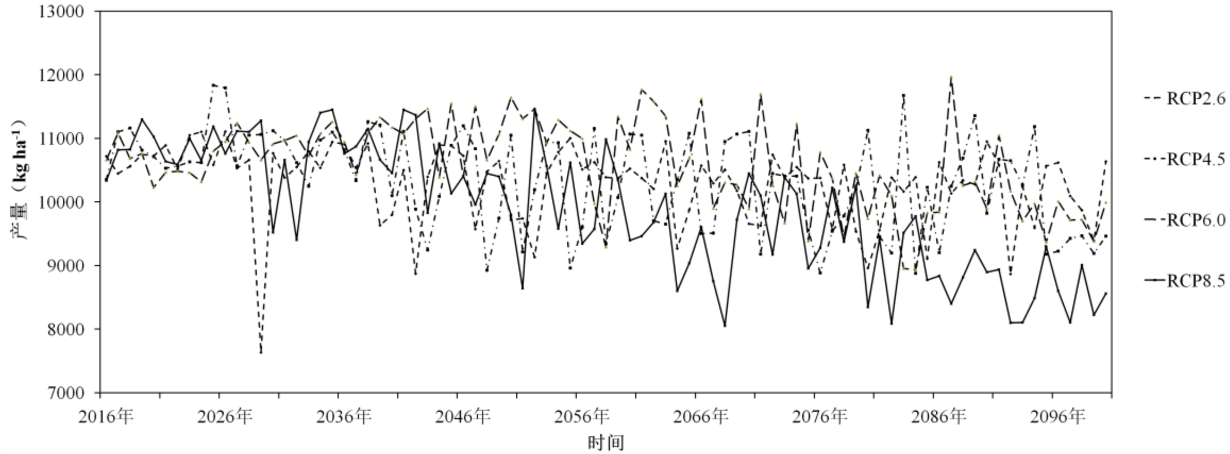

Fig 12. Changes of yield responding to three factors in 2006-2100

Table 13. Changes of yield with changes of three factors in 2016-2100 relative to baseline (2015)

	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	产量（kg ha^{-1}）	相对增幅	产量（kg ha^{-1}）	相对增幅	产量（kg ha^{-1}）	相对增幅	产量（kg ha^{-1}）	相对增幅
2016-2020	10638.89	-4.72%	10828.09	-3.03%	10682.23	-4.33%	10859.39	-2.75%
2021-2030	10483.46	-6.11%	10976.44	-1.70%	10722.22	-3.98%	10783.80	-3.42%
2031-2040	10499.40	-5.97%	10762.13	-3.62%	11002.50	-1.47%	10775.63	-3.50%
2041-2050	10267.11	-8.05%	10296.18	-7.79%	11105.87	-0.54%	10470.93	-6.23%
2051-2060	10352.51	-7.29%	10148.17	-9.12%	10853.89	-2.80%	10051.68	-9.98%
2061-2070	10189.11	-8.75%	10397.23	-6.89%	10762.81	-3.61%	9349.95	-16.3%
2071-2080	10069.40	-9.82%	9953.55	-10.9%	10304.69	-7.72%	9622.66	-13.8%
2081-2090	10192.29	-8.72%	10074.99	-9.8%	10051.34	-9.98%	8975.48	-19.6%
2091-2100	10044.89	-10.0%	9870.99	-11.6%	9906.77	-11.3%	8542.47	-23.5%

Results

Table 14. Changes of yield with three factors change alone and at the same time in 2016-2100 relative to baseline (2015)

	RCP2.6	RCP4.5	RCP6.0	RCP8.5
气温	-5.46%	-16.10%	-24.23%	-37.63%
CO_2浓度	2.97%	14.70%	23.09%	32.61%
散射辐射比例	-7.03%	-7.14%	-6.05%	-6.72%
共同作用	-10.04%	-11.06%	-11.28%	-23.50%

Discussion and Conclusion

- Yield and total aboveground dry matter are sensitive to diffuse radiation fraction changes. Under the current radiation levels, when diffuse radiation fraction increased by about 30%, rice yields and total aboveground dry matter reached the maximum.
- The relationship between simulation errors and atmospheric transmission coefficient is quadratic in the three moments. Therefore, we use the relationships to improve the simulation of radiation module. We found that the root mean square errors decreased 0.01, 0.02, and 0.02 at three moments, respectively.
- By the end of this century, responding to the increase in temperature, rice yield decreased by 5.46%, 16.1%, 24.23% and 37.63% in four scenarios , compared with it in 2015. The yield increased by 2.97%, 14.7%, 23.09%, and 32.61% respectively with increases in CO_2 concentration in the four scenarios. The yield decreased by 7.03%, 7.14%, 6.05%, and 7.03% with decreases in diffuse radiation fraction in the four scenarios by the end of this century.

Discussion and Conclusion

- When three factors change at the same time, the rice yield decline percentage in four scenarios were 10.04%, 11.06%, 11.28% and 10.04% respectively. And, the yield decline in RCP6.0 was similar to that in RCP4.5.
- Fertilization effect of CO_2 concentration can improve the rice yield, but can not be completely offset the decline in yield caused by rising temperatures and decreasing diffuse radiation fraction. The effects of temperature, CO_2 concentration, and the diffuse radiation fraction on rice yield are not linear additivity.
- Therefore, simulating rice yield in the future, the most important factor is temperature. In addition to CO_2 concentration and temperature, the diffuse radiation fraction is also an important factor which cannot be ignored.

Thank you