Supplementary materials for manuscript entitled: Methane Emissions Associated with the Conversion of Marshland to Cropland and Climate Change on the Sanjiang Plain of Northeast China from 1950 to 2100

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Supplementary material A: Information of the counties and administrative farms on the Sanjiang Plain.

The Sanjiang Plain of northeast China covers 23 counties: Baoqing, Boli, Fujin, Fuyuan, Hegang, Huachuan, Huanan, Hulin, Jiamusi, Jidong, Jixi, Jixian, Luobei, Mishan, Muling, Qitaihe, Raohe, Shuangyashan, Suibin, Tangyuan, Tongjiang, Yilan and Youyi counties as well as three administrative farms: Baoquanling, Hongxinglong, and Jiansanjiang administrative farms (Fig. 1). The Baoquanling and Hongxinglong administrative farms were founded in 1949 and are located on the northwest and central parts of the Sanjiang Plain, respectively. The Jiansanjiang administrative farm was founded in 1956 and is located on the northeast part of the area.

During the 1950s and 1960s, the administrative divisions in some counties changed. These changes included: Jixi and Jidong counties; Jixian, Shuangyashan and Youyi counties; Huanan, Huachuan and Qitaihe counties; Fujin, Fuyuan, Suibin and Tongjiang counties. To isolate the influence of administrative division change in the area or CH_4 emission, the related counties were grouped together when analyzing the change in the area or CH_4 emission of marshland/rice paddies.

Supplementary material B: Parameter values for the main kinds of marshland in the Sanjiang Plain

Table B1 Parameter values for *Deyeuxia angustifolia* and *Carex lasiocarpa* marshland sites

Marshland Type	α_0	a_1	a_2	D_1 (cm)	D_2 (cm)
Deyeuxia angustifolia	1.1	0.012	0.02	0	-15
Carex lasiocarpa	1.25	0.011	0.005	0	-15

Supplementary material C:

Table C1 Parameter values for uncertainty analysis

Parameters	Description	Baseline(Minimum, Maximum)	References
CH4MOD			
RVI	Rice variety index	1 (0.9－1.1)	Huang et al. (2004); This study
GY(kg ha^{-1})[a]	Rice grain yield	-- (±10%)	Statistical yearbook of Heilongjiang province; This study
OM(g m^{-2})[a]	Organic matter input	-- (±10%)	Huang et al. (2006); This study
SAND[a]	Soil sand fraction	-- (8—81)	The soil database developed by the Institute of Soil Sciences, Chinese Academy of Sciences
$CH4MOD_{wetland}$			
VI	Vegetation index	2.4 (2.16－2.64)[b] 2.8(2.52－3.08)[c]	Li et al. (2010); This study
W_{max}(g m^{-2})	Maximum aboveground biomass	450 (260－650)[b] 485(385－700)[c]	Guo et al. (2008); Hao (2006); He (2001); Ni (1996); Wang et al. (1993); Yang et al. (2002); Yang et al. (2006); Zhou et al. (2006); Zhou et al. (2009); Zhang et al. (2007)
GDD_{max} (℃ ·d)	Required accumulated temperature for reaching W_{max}	2000(1200－2500)	Yang et al. (2002); Ma et al. (1996)
SOM(g kg^{-1})	Soil organic matter	246[a], 70[b](12.5－550.7)	The soil database developed by the Institute of Soil Sciences, Chinese Academy of Sciences
SAND[a]	Soil sand fraction	-- (8－81)	The soil database developed by the Institute of Soil Sciences, Chinese Academy of Sciences

[a] Inputs of GY, OM and SAND are at the scale of a county or an administrative farm. The minimum and maximum values of GY and OM were set to be ±10% of the baseline.

[b] for *Carex lasiocarpa* marshland

[c] for *Deyeuxia angustifolia* marshland

Supplementary material D: Description of the RCP scenarios for AR5

A set of new scenarios referred as “Representative Concentration Pathways (RCPs)” were identified for the fifth IPCC assessment report (AR5) (Moss et al., 2008). Four RCP scenarios have been derived from integrated assessment models (IAM) (Bernie, 2010). RCP 8.5 is a “high pathway” for which radiative forcing reaches >8.5 W m^{-2} by 2100 and continues to rise for some amount of time. It has an approximate CO_2 equivalent concentration of 1370 ppm in 2100. RCP 6.0 and RCP 4.5 are two intermediate “stabilization pathways” in which radiative forcing is stabilized at approximately 6 W m^{-2} and 4.5 W m^{-2} after 2100. The approximate CO_2 equavalent concentrations are 850 ppm and 650 ppm, representatively. RCP 2.6 is a pathway where radiative forcing peaks at approximately 3 W m^{-2} before 2100 and then declines 2.6 W m^{-2} in 2100. The peak approximate CO_2 equavalent concentration reaches 490 ppm before 2100 under RCP 2.6. These scenarios include time paths for emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover. Those scenarios were reported in the IPCC expert meeting report (Moss et al., 2008) (http://www.ipcc.ch/ipccreports/supporting-material.htm).

Supplementary material E: Model validation and sensitivity analysis

Fig. E1 shows the seasonal patterns of the simulated and observed standing water depth and CH_4 emissions for a *Deyeuxia angustifolia* marsh site (Fig. E1a and c) and a *Carex lasiocarpa* marsh site (Fig. E1b and d) on the Sanjiang plain. The model can basically simulate the seasonal variations in standing water depth (Fig. E1a and b) and CH_4 fluxes (Fig. E1c and d). The empirical water table model underestimated the standing water depth from April to July 2003 and overestimated the standing water depth from September to October 2003 for the *Deyeuxia angustifolia* site (Fig. E1a). Correspondingly, a systematic negative discrepancy occurred during the period from April to July 2003, and a positive discrepancy occurred during the period from September to October 2003 between the modeled and observed CH_4 emissions from the *Deyeuxia angustifolia* site (Fig. E1c). For the *Carex lasiocarpa* site, the empirical water table model underestimated the standing water depth from April to July of 2004 and 2005 (Fig. E1b). However, the simulated CH_4 flux matches the observed flux well during the same period (Fig. E1d). This correspondence occurred because in $CH4MOD_{wetland}$, CH_4 emissions are not sensitive to the standing water depth when it is aboveground for a period (Li et al., 2010), which is in agreement with the observation of Thomas et al. (2009) that the soil redox potential decreases to a certain limit and maintains that level when the standing water depth is above the soil surface for a given amount of time.

Fig. E2 shows the observed and simulated CH_4 emissions from the Sanjiang Plain. Using 273 datasets, regression of the observed versus simulated CH_4 fluxes produced an R^2 of 0.49 with a slope of 0.87 (P<0.001) (Fig. E2a). The performance of $CH4MOD_{wetland}$ was good for the total annual/seasonal CH_4 amounts (Fig. E2b). Regression of the computed and observed annual CH_4 amounts yielded an R^2 of 0.74 with a slope of 1.00 (n=7, P<0.01) (Fig. E2b).

The sensitivity analysis shows that the environmental drivers (T_{air} and WD) are the most sensitive contributors to the CH_4 flux (Table E1). The response of the CH_4 fluxes to the standing water depth was more sensitive in a seasonally flooded wetland

(*Deyeuxia angustifolia* site) than in a continuously flooded wetland (*Carex lasiocarpa* site) (Table E1). Among the model input parameters, the plant input parameter (W_{max}) was more sensitive to the model output than the other input parameters (Table E1). The soil input parameters (*SAND*, ρ and *SOM*) were not sensitive to the CH_4 fluxes (Table E1).

Table E1 Model sensitivity analysis

Environmental drivers/ Model input	Baseline		Change	ΔCH_4/ $CH_{4\_baseline}$ (%)			
				2003		2004	
	DA[a]	CL[b]		DA	CL	DA	CL
T_{air} (℃)	-	-	+2/-2	+28.8/-23.9	+27.3/-19.2	+41.5/-31.5	+23.4/-19.7
WD (cm)	-	-	+5/-5	+269.9/-90.0	121.8/-57.7	398.2/-42.3	+13.2/-5.5
VI	2.8	2.4	+10%/-10%	+6.6/-6.6	+5.5/-5.5	+5.2/-5.1	+4.6/-4.9
W_{max} (g m^{-2})	485	450	+10%/-10%	+10.0/-10.0	+10.9/-10.7	+8.3/-8.5	+10.1/-10.4
GDD_{max} (℃ ·d)	2000	2000	+10%/-10%	+2.5/-4.0	+1.9/-3.8	+1.2/-0.7	+1.3/-1.1
SAND	47	56	+10%/-10%	+0.2/-0.2	+0.4/-0.3	+0.2/-0.2	+0.3/-0.3
ρ (g cm^{-3})	1	0.74	+10%/-10%	+0.2/-0.2	+0.5/-0.4	+0.3/-0.3	+0.4/-0.4
SOM (g kg^{-1})	70	246	+10%/-10%	+0.2/-0.2	+0.5/-0.4	+0.3/-0.3	+0.4/-0.4

[a] DA represents *Deyeuxia angustifolia* site

[b] CL represents *Carex lasiocarpa* site

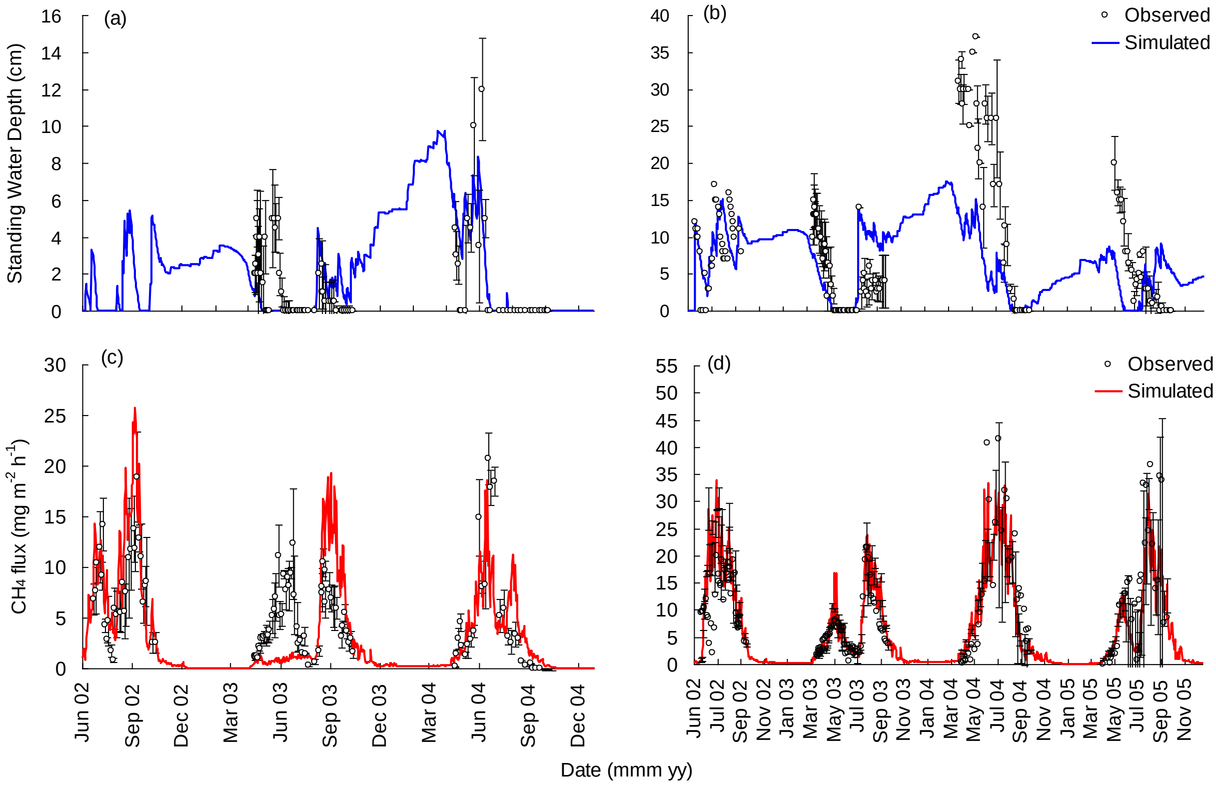

Fig. E1 Comparison of simulated and observed seasonal patterns of standing water depth and CH_4 fluxes on the Sanjiang Plain. (a) Standing water depth and (c) CH_4 flux for *Deyeuxia angustifolia* site; (b) Standing water depth and (d) CH_4 flux for *Carex lasiocarpa* site. The vertical bars are standard deviations from 3 sampling replicates.

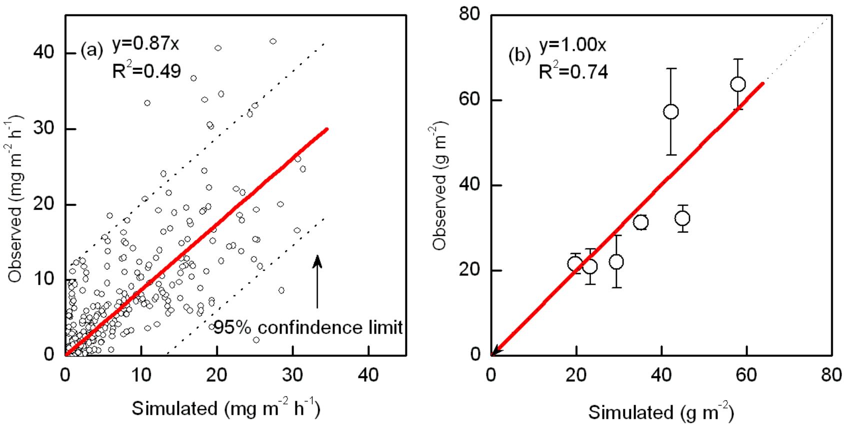

Fig. E2 Observed vs. simulated CH_4 emissions from *Deyeuxia angustifolia* site (June 2002– December 2004) and C*arex lasiocarpa* site (June 2002– December 2005) on the Sanjiang Plain. (a) CH_4 fluxes, dashed lines are 95% confidence limits. (b) Total amount of annual/seasonal CH_4 emissions, dashed line is 1:1, the vertical bars are standard deviations from 3 sampling replicates.

Supplementary material F: The spatial pattern of the area variation in marshland and irrigated rice due to the conversion of marshland to cropland.

Table F1 shows the change of the marshland area and irrigated rice cultivation area for a county or at the scale of an administrative farm due to the conversion of marshland to cropland from 1960s－2000s relative to the 1950s. During this period, the marshland area decreased by 1031.9 $\times 10^3$ ha in the 23 counties, and 1150.0 $\times 10^3$ ha in the 3 administrative farms relative to the 1950s.

Among the counties, the conversion of marshland to cropland mainly happened on the northeast and east of the Sanjiang Plain (Table F1). The marshland loss amounted to 375.4 $\times 10^3$ ha in the northeast counties, including Fujin, Fuyuan, Raohe, Suibin and Tongjiang over the past 6 decades, accounting for ~36% of the 23 counties. Marshland in Baoqing and Hulin counties, which are located in the eastern part of the area decreased by 87.9 $\times 10^3$ ha and 74.8 $\times 10^3$ ha, respectively, occupying 16% of the total marshland area lost in the 23 counties. Among the administrative farms, marshland loss amounted to 293.1 $\times 10^3$, 384.2 $\times 10^3$, and 472.7 $\times 10^3$ ha, on Baoquanling, Hongxinglong and Jiansanjiang administrative farm, respectively, accounting for 13.4%, 17.6% and 21.7% of the total decrease in marshland area from 1960s－2000s relative to the 1950s, respectively.

The irrigated rice area mainly increased on the administrative farms; they accounted for 61% of the total increase in irrigated rice area on the Sanjiang Plain over the past 6 decades. The increases were 95.3 $\times 10^3$ ha, 145.7 $\times 10^3$ ha and 292.7 $\times 10^3$ ha on Baoquanling, Hongxinglong and Jiansanjiang administrative farms, respectively (Table F1).

Table F1 Change of marshland and irrigated rice area (1000 ha yr^{-1}) for a county or an administrative farm due to the conversion of marshland to cropland on the Sanjiang Plain

County	1960s		1970s		1980s		1990s		2000s	
(Farm)	Marsh	Rice	Marsh	Rice	Marsh	Rice	Marsh	Rice	Marsh	Rice
Baoqing	-43.9	-0.7	-21.8	-0.9	-32.6	2.4	-37.6	7.5	-87.9	11.4
Boli	-5.9	-2.8	13.8	-2.4	10.6	-2.4	9.5	-1.5	-6.2	-1.5
Fujin	-269.6	-0.6	-293.4	-0.4	-341.9	3.7	-355.6	19.7	-413.9	33.8
Fuyuan	96.9	-0.1	-28.4	-0.1	-45.2	0.3	-54.3	1.7	-100.8	5.8
Hegang	11.7	1.3	34.9	0.4	28.8	4.3	28.7	14.4	19.9	20.6
Huachuan	42.3	-1.2	20.6	-2.4	20.5	9.2	13.7	16.5	-13.3	35.1
Huanan	-63.6	1.4	-55.6	2.3	-66.7	7.6	-76.9	14.9	-88.4	22.4
Hulin	-21.0	-1.9	-4.5	-2.1	-22.0	3.5	-29.0	15.8	-74.8	43.6
Jiamusi	-63.7	3.0	-64.6	0.7	-64.9	1.4	-65.3	8.2	-65.6	21.9
Jidong	3.5	3.2	16.6	7.6	15.1	10.0	11.5	16.3	0.2	26.7
Jixi	-11.0	0.3	-14.3	0.1	-16.6	0.0	-16.6	0.7	-20.3	2.7
Jixian	-88.2	-2.1	-80.6	-1.3	-97.2	-6.0	-116.0	1.0	-135.4	3.6
Luobei	-40.8	-0.2	-2.7	-0.2	-13.4	2.5	-16.3	8.3	-33.6	8.2
Mishan	-21.2	-7.3	0.7	-7.5	-10.9	-1.5	-13.2	3.1	-49.0	19.4
Muling	0.2	-0.4	-3.9	-0.3	-9.1	0.0	-15.7	0.9	-41.7	0.9
Qitaihe	8.7	0.1	14.7	0.2	11.1	3.0	6.9	5.1	1.7	6.3
Raohe	-13.4	-0.5	-9.3	-0.5	-22.2	1.4	-26.7	4.1	-55.4	6.2
Shuangyashan	30.7	1.2	3.7	0.1	1.5	0.1	-1.6	0.3	-5.7	0.6
Suibin	15.2	0.4	43.0	5.2	29.6	5.2	31.1	7.5	23.4	16.1
Tangyuan	-11.3	2.7	4.1	-1.2	2.8	5.9	5.9	7.2	-12.2	15.4
Tongjiang	125.6	0.0	244.8	0.2	209.6	1.7	207.4	4.7	171.3	14.9
Yilan	-7.8	-2.1	1.3	-1.3	-9.3	0.9	-13.6	13.0	-44.2	20.5
Youyi	34.7	0.6	46.1	0.8	26.6	0.9	0.0	0.0	0.0	0.0
(Baoquanling)	-150.6	3.6	-238.1	1.5	-293.1	6.5	-293.1	43.6	-293.1	95.3
(Hongxinglong)	-142.1	1.8	-234.7	1.7	-324.4	7.4	-358.6	64.3	-384.2	145.7
(Jiansanjiang)	-29.0	0.0	-171.3	-0.1	-280.9	5.9	-361.2	76.9	-472.7	292.7
Total (Mha)	-0.61	0.00	-0.78	0.00	-1.29	0.07	-1.54	0.35	-2.18	0.87

*relative to the average 1950s

Supplementary material G: The spatial pattern of the CH_4 variation from the marshland and irrigated rice cultivation due to the conversion of marshland to cropland.

Based on $CH4MOD_{wetland}$ and CH4MOD, Table G1 gives an overview of the CH_4 variation from 1960s－2000s relative to 1950s for a county or at the scale of an administrative farm due to the conversion of marshland to cropland.

For the marshland, the reductions in mean annual amount of CH_4 emissions during the past 6 decades were 166.5×10^3 t, 218.4×10^3 t and 323.0×10^3 t due to the conversion of marshland to cropland on the Baoquanling, Hongxinglong and Jiansanjiang administrative farms, respectively (Table G1). Among the 23 counties, the northeastern and central counties were the main contributors of CH_4 reduction from the marshland (Table G1). The mean annual amount of CH_4 emissions decreased at a rate of 275.9×10^3 t yr^{-1} in Fujin, Fuyuan, Suibin and Tongjiang counties, followed by 80.0×10^3 t yr^{-1} in Jixian, Shuangyashan and Youyi counties, 59.2×10^3 t yr^{-1} in Huanan, Huachuan and Qitaihe counties, and 47.0×10^3 t yr^{-1} in Baoqing county during the past 6 decades.

From the rice paddies, the mean annual amount of CH_4 emissions increased by 28.2×10^3 t, 35.6×10^3 t and 66.0×10^3 t on the Baoquanling, Hongxinglong and Jiansanjiang administrative farms, respectively, from the 1950s to the 2000s (Table G1). A higher increase in the mean annual amount of CH_4 emissions, over 10000 t during the past 6 decades, occurred in the four northeastern counties (Fujin, Fuyuan, Suibin and Tongjiang counties) and in the three western counties (Huachuan, Huanan and Qitaihe counties) (Table G1). The temporal trend in CH_4 emissions for each county/farm was similar to the whole region (Table 2), which has shown a rapid increase since the 1980s (Table G1).

Table G1 CH_4 variation (1000 t yr^{-1}) from marshland and rice fields for a county or an administrative farm due to the conversion of marshland to cropland and climate change on the Sanjiang Plain

County	1960s		1970s		1980s		1990s		2000s	
(Farm)	Marsh	Rice	Marsh	Rice	Marsh	Rice	Marsh	Rice	Marsh	Rice
Baoqing	-27.3	-0.07	-18.3	-0.06	-23.6	0.43	-21.5	1.70	-47.0	3.28
Boli	-3.0	-0.33	5.3	-0.19	6.2	0.04	6.8	1.34	-4.2	3.08
Fujin	-151.8	-0.05	-197.0	-0.01	-185.1	0.63	-176.4	3.69	-243.0	7.38
Fuyuan	41.6	0.00	-61.1	0.00	-32.3	0.03	-17.8	0.27	-85.2	1.28
Hegang	6.9	0.12	18.2	0.06	18.8	0.63	21.1	3.00	14.3	6.08
Huachuan	19.9	-0.26	-3.2	0.03	8.1	1.08	12.6	3.95	-11.6	9.23
Huanan	-34.6	0.12	-33.2	0.26	-36.2	0.97	-40.8	2.45	-48.3	5.18
Hulin	-11.1	-0.16	-6.7	-0.16	-1.2	0.54	13.6	3.11	-22.6	9.65
Jiamusi	-35.3	0.24	-36.2	0.10	-36.2	0.23	-36.4	1.65	-36.5	5.62
Jidong	1.8	0.32	6.3	1.05	9.5	1.52	7.3	3.30	0.1	7.25
Jixi	-5.6	0.06	-7.9	0.22	-7.5	0.32	-7.8	0.58	-10.2	1.23
Jixian	-51.9	-0.12	-56.6	-0.23	-57.3	-0.06	-64.4	1.50	-77.6	2.80
Luobei	-22.9	-0.05	-5.4	-0.02	-2.1	0.42	1.6	1.59	-12.3	2.27
Mishan	-11.5	-0.65	-1.4	-0.49	-3.0	0.62	1.4	2.17	-24.6	6.10
Muling	-0.8	-0.02	-6.5	0.08	0.3	0.33	-3.9	0.59	-20.3	0.70
Qitaihe	3.4	0.01	7.3	0.03	5.6	0.50	3.7	1.00	0.8	1.70
Raohe	-9.8	-0.05	-17.7	-0.04	-12.9	0.14	-10.0	0.90	-35.8	1.60
Shuangyashan	19.8	0.14	2.7	0.02	1.3	0.02	0.3	0.08	-2.3	0.19
Suibin	8.0	0.00	18.2	0.05	16.3	0.75	18.7	1.27	10.5	3.85
Tangyuan	-6.9	0.25	-5.0	0.07	0.4	1.51	7.0	2.66	-9.3	5.91
Tongjiang	59.3	0.00	105.1	0.02	113.5	0.18	125.1	0.81	77.5	3.35
Yilan	-2.7	-0.18	-2.7	-0.04	-2.0	0.45	-1.8	2.94	-25.4	5.79
Youyi	17.0	0.06	23.2	0.10	14.1	0.11	0.0	0.00	0.0	0.00
(Baoquanling)	-86.3	0.35	-135.0	0.38	-166.5	1.56	-166.5	10.63	-166.5	28.16
(Hongxinglong)	-84.5	0.14	-164.4	0.21	-178.1	1.14	-186.6	12.62	-218.4	35.59
(Jiansanjiang)	-46.7	0.00	-215.1	0.00	-158.7	0.89	-155.8	14.78	-323.0	65.96
Total (Tg yr^{-1})	-0.41	0.00	-0.79	0.00	-0.71	0.01	-0.67	0.08	-1.32	0.22

*relative to the average 1950s

Supplementary material H: Projected change of climate and CH_4 flux on the Sanjiang Plain for the RCP scenarios

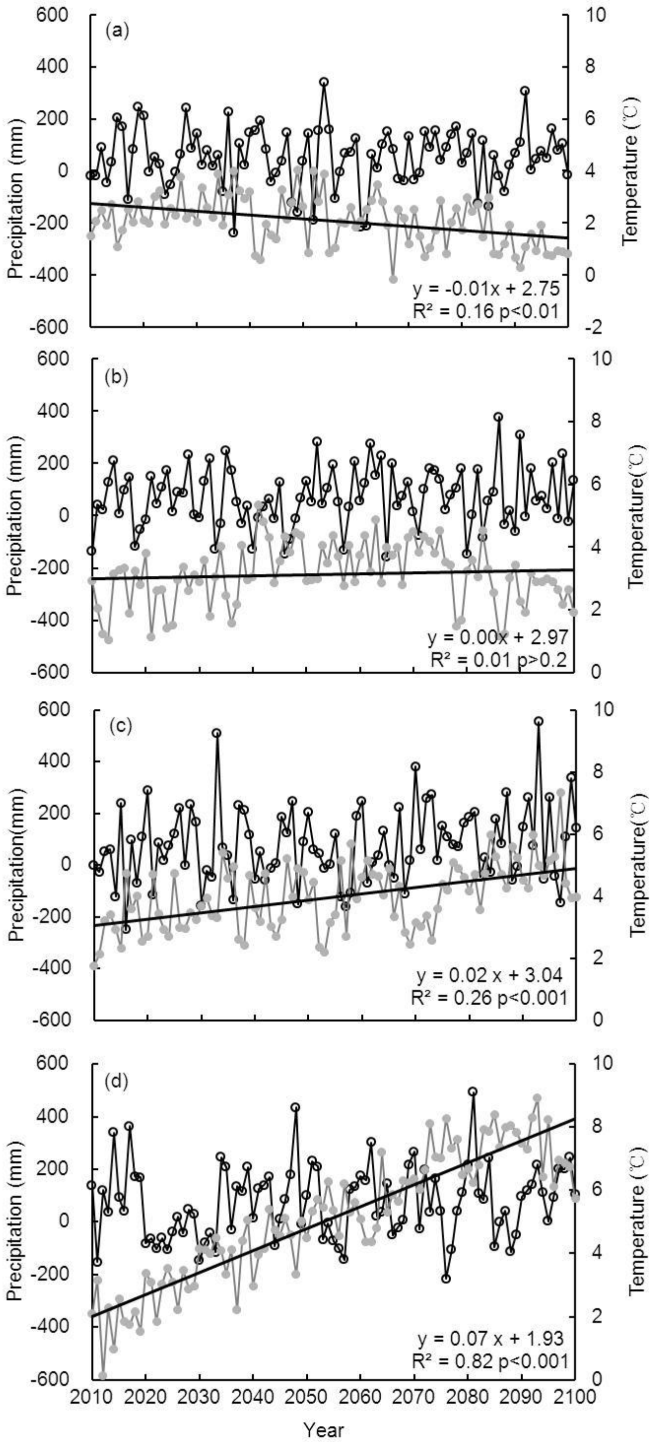

Fig. H1 Projected climate change by FGOALS on the Sanjiang Plain for RCP 2.6 (a), RCP 4.5 (b), RCP 6.0 (c) and RCP 8.5 (d). The hollow and the grey circles represent the area-weighted annual mean precipitation and the air temperature relative to the average 1961 – 1990, respectively.

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