

Supplementary Information for

Irrigation Cooling Effect on Local Temperatures in the North China Plain Based on an Improved Detection Method

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Text S1. Sensitivity tests of parameters in the moving window

The moving window searching strategy includes five parameters, namely, the number of pixels covered by the side length of the square moving window (P), the minimum number of remaining non-irrigated pixels (N), and the threshold value of elevation and average air temperature (Δ and ΔT). The Δ was set to 50 m according to Yang et al. (2020). Based on ΔLST , we tested the sensitivity of P , ΔT , and N to the ICE by setting different values around the defaults. It was used to study the dependence of the ICE magnitude assessment on these parameters. The defaults of P , ΔT , and N were $P=31$, $\Delta T=0.3^{\circ}\text{C}$, and $N=15$; and we set P , ΔT , and N to three different values ($P=51$, 41, and 21; $\Delta T=0.7$, 0.5, and 0.2°C ; and $N=20$, 10, and 5), respectively, then conducted comparison experiments of one parameter with other two parameters fixed. The sensitivity test settings and test results were shown in Table TS1.

Table TS1. Sensitivity tests of the parameters in the moving window

Setting	P (pixel)	ΔT ($^{\circ}\text{C}$)	N (pixel)	ΔLST ($^{\circ}\text{C}$)							
				Spring		Summer		Growth		Year	
				Day	Night	Day	Night	Day	Night	Day	Night
A	51	0.3	15	-0.48	-0.11	-0.12	-0.07	-0.24	-0.11	-0.19	-0.10
B	41	0.3	15	-0.43	-0.10	-0.12	-0.07	-0.22	-0.10	-0.16	-0.09
C	31	0.2	15	-0.37	-0.10	-0.11	-0.07	-0.18	-0.10	-0.14	-0.09
D	31	0.3	10	-0.36	-0.10	-0.11	-0.07	-0.18	-0.10	-0.13	-0.09
E	31	0.3	15	-0.37	-0.10	-0.11	-0.07	-0.18	-0.10	-0.13	-0.09
F	31	0.3	20	-0.37	-0.10	-0.10	-0.07	-0.18	-0.10	-0.13	-0.09
G	31	0.3	5	-0.35	-0.09	-0.10	-0.07	-0.18	-0.09	-0.13	-0.08
H	31	0.5	15	-0.34	-0.09	-0.10	-0.07	-0.17	-0.09	-0.13	-0.09
I	31	0.7	15	-0.32	-0.09	-0.09	-0.06	-0.15	-0.09	-0.11	-0.08
J	21	0.3	15	-0.29	-0.08	-0.09	-0.06	-0.14	-0.09	-0.10	-0.08

Note: E is the default setting in the study.

References:

Yang, Q., Huang, X., & Tang, Q. (2020). Irrigation cooling effect on land surface temperature across China based on satellite observations. *SCIENCE OF THE TOTAL ENVIRONMENT*, 705, 135984

Text S2. Assess the impact of crop type differences in non-irrigated areas on our result

This study analyzed the temperature effect of agricultural irrigation over the North China Plain based on the moving window search strategy. Irrigation effect was characterized as the difference between the central irrigated pixel and all adjacent non-irrigated crop pixels that meet the constraint conditions within the moving window. However, not all non-irrigated crop pixels used for comparison are consistent with the crop type of the central irrigated pixel. This might cause bias to our results. To clarify this issue, we add the distribution maps of crop planting areas to the moving window and perform our moving window search strategy again. The distribution maps of crop planting areas in the North China Plain can be obtained from the National Tibetan Plateau Data Center [1], covering the study period 2001-2015, with a spatial resolution of 0.0025° , provided by Li et al. [2]. It was resampled to 1 km using the nearest neighbor interpolation. The spatial intersection of this product and the cropland map used in our research is the area of this analysis (**Figure TS1**). Figure TS1 shows that the main cropping system, winter wheat and summer maize rotation, is more than 50% in the study area. Therefore, we selected the winter wheat and summer corn from the region for analysis.

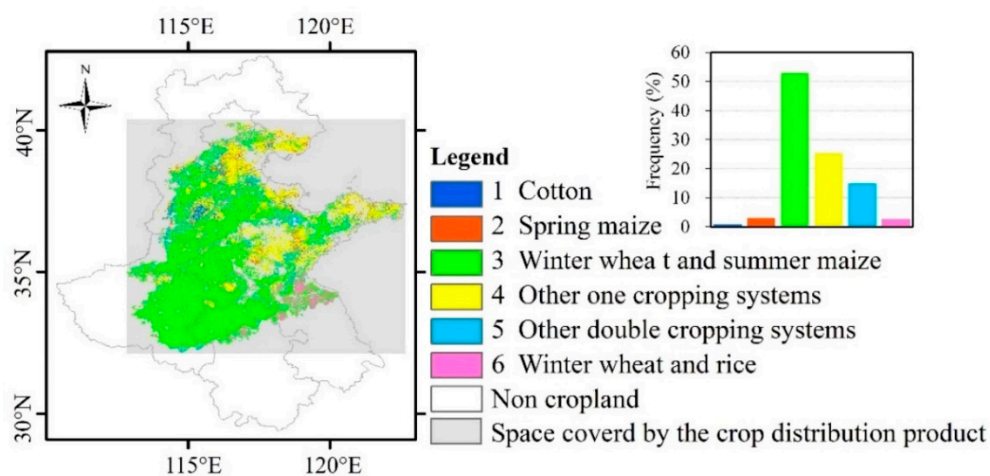


Figure TS1. Distribution of various crop planting areas in the North China Plain in 2010.

In this analysis, the abbreviations involved are explained as follows:

ΔLST_{crops} : the daytime land surface temperature (LST) difference between the central irrigated wheat or maize pixel and all adjacent non-irrigated crop pixels remaining within the moving window used in this study;

$\Delta LST_{wheat \text{ or } maize}$: the daytime LST difference between the central irrigated wheat or maize pixel and its adjacent non-irrigated same crop pixels remaining within the same moving window;

Non-irrigated LST_{crops} : the average daytime LST of all non-irrigated crop pixels remaining within the moving window;

Non-irrigated LST_{wheat} and LST_{maize} : the average daytime LST of all non-irrigated wheat pixels and non-irrigated maize pixels remaining within the moving window, respectively.

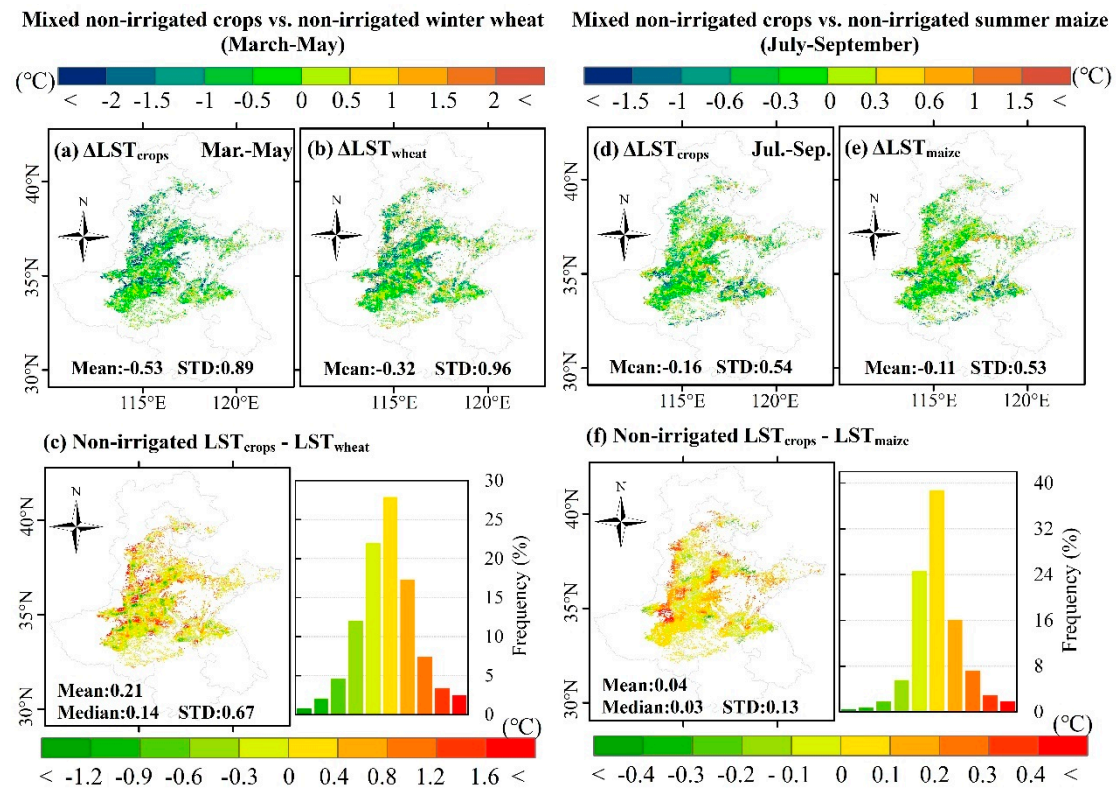


Figure TS2. Comparison of the ΔLST_{crops} and $\Delta LST_{wheat/maize}$ (a-b, d-e), and (c-f) the spatial patterns and frequency distributions of the LST differences between the mixed non-irrigated crops (LST_{crops}) and the non-irrigated winter wheat (LST_{wheat}) and summer maize (LST_{maize}). The spatial data were the average values during the growing season (winter wheat: March-May; summer maize: July-September) from

2001 to 2015. Negative ΔLST indicates irrigation cooling effect on LST, and the lower the value, the greater the cooling effect.

Figure TS2 shows that across the study areas, the average ΔLST_{crops} is smaller than the average $\Delta LST_{wheat/maize}$, and the average non-irrigated LST_{crops} is higher than the average non-irrigated $LST_{wheat/maize}$ during the growing season. This indicates that the LST difference caused by different crops in the non-irrigated areas does cause biases to our results, which is about 0.21 °C and 0.04 °C during the main growing season of winter wheat and summer maize across the study areas. Without distinguishing crop types, the irrigation cooling effect (ICE) would be slightly overestimated. However, the biases are much small compared to the detected ICE magnitudes (approximately -0.53 °C and -0.16 °C, Figure TS2 (a, d)). In addition, the non-irrigated LST_{crops} and $LST_{wheat/maize}$ have the same spatial patterns (Figure TS3), and their differences are mainly concentrated near the average values (Figure TS2(c,f)). These findings indicate that the uncertainty caused by cultivating different crops is acceptable, and it is unlikely to have had a significant influence on the identified ICE.

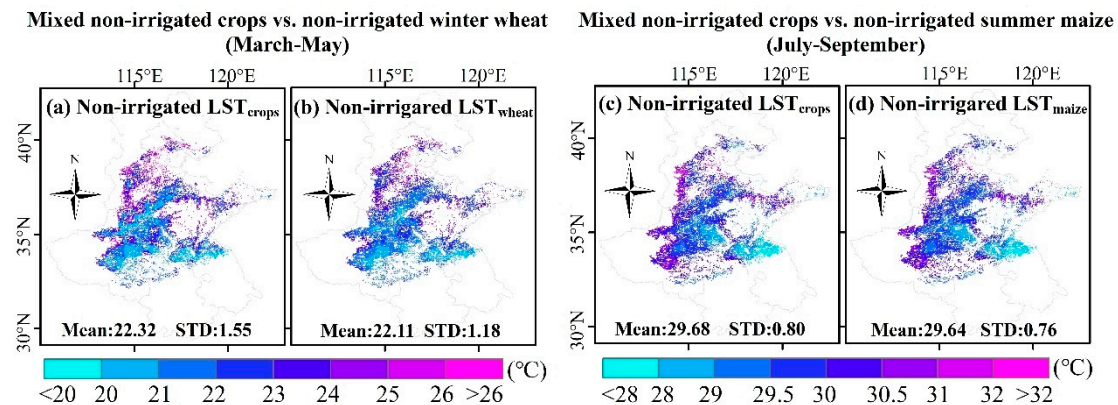


Figure TS3. Spatial patterns of the average LST of mixed non-irrigated crops (LST_{crops}) and non-irrigated wheat and maize (LST_{wheat} and LST_{maize}) during the growing season (winter wheat: March-May; summer maize: July-September) from 2001 to 2015.

References:

- [1] Lei, H. (2022). Distribution maps of crop planting areas in the North China Plain (2001 - 2018). National Tibetan Plateau Data Center. <https://doi.org/10.1016/j.compag.2021.106222>.
- [2] Li, J., Lei, H. (2021). Tracking the spatio-temporal change of planting area of

winter wheat-summer maize cropping system in the North China Plain during 2001-2018. Computers and electronics in Agriculture. 187, 106222.

Supplementary figures

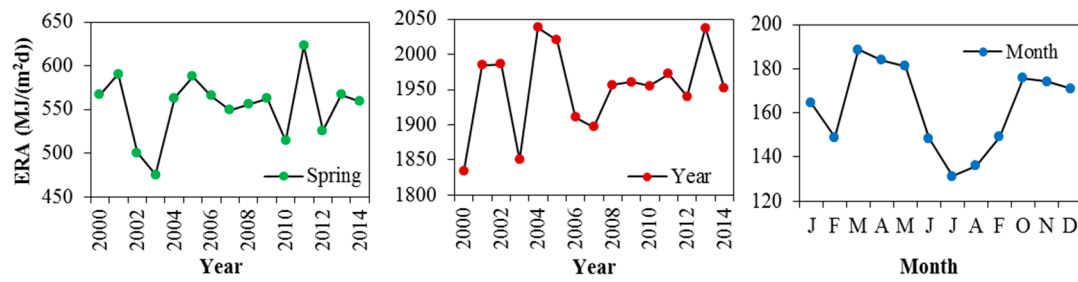


Figure S1. Effective radiation (ERA) in the North China Plain

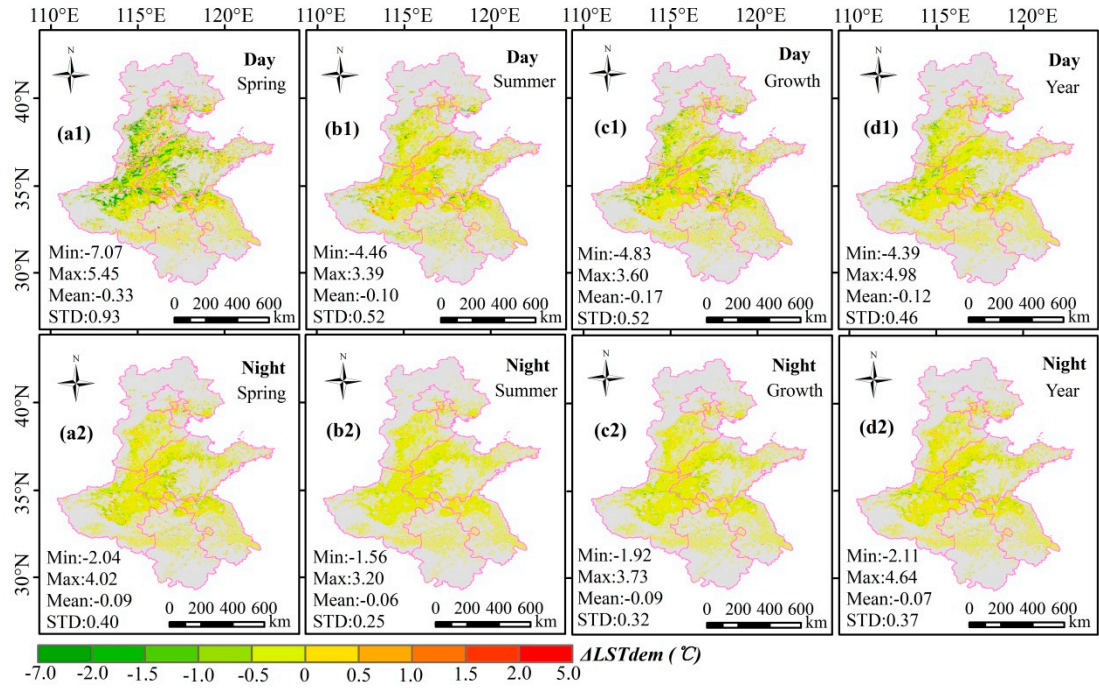


Figure S2. Spatial patterns (a-d) of the average seasonal and annual LST difference (ΔLST_{dem}) between irrigated area and non-irrigated area obtained by the previous algorithm in the NCP from 2000 to 2015. Spring, March-May; Summer, June-August; Growth, the growing season from March to September; Year, the full year from January to December. The gray pixels represent the background.

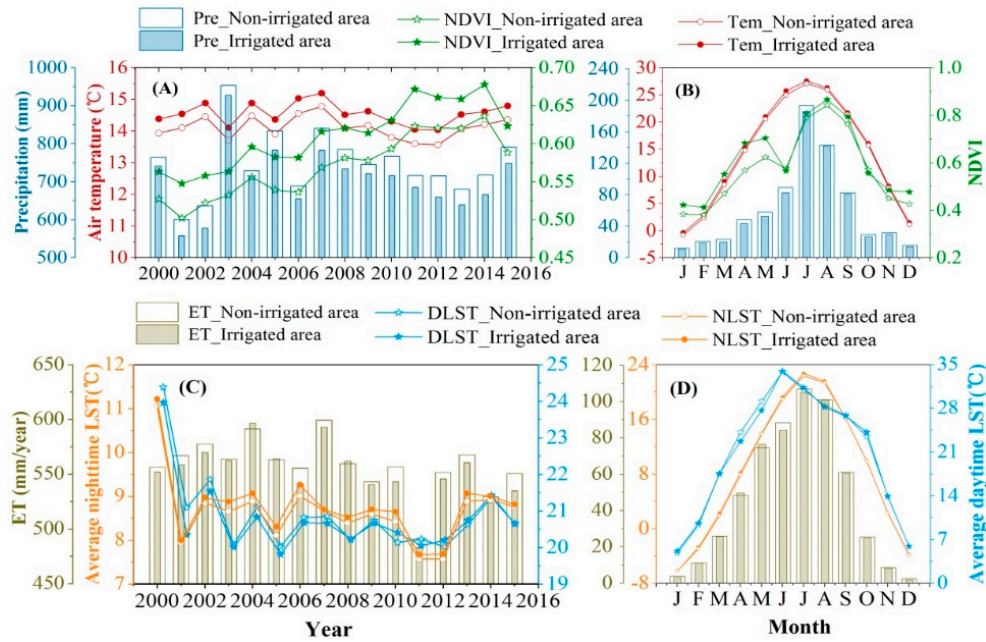


Figure S3. Temporal patterns of the precipitation (Pre), air temperature (Tem), NDVI, ET, daytime LST (DLST), and nighttime LST (NLST) in irrigated and non-irrigated crop areas of the NCP from 2000 to 2015. In the NCP cropland, the temporal variation trends of Pre, Tem, NDVI, ET, and LST in the irrigated areas were the same as those in the non-irrigated areas. The average annual Pre, ET, and daytime LST (DLST) of the non-irrigated areas mainly were greater than those of irrigated areas, while the average yearly Tem, NDVI, and nighttime LST (NLST) were lower (Figs. A and C). The maximums of average Pre, Tem, ET, and NLST appeared in July, and that of the average NDVI and DLST appeared in June and August (Figs. B and D). The differences of average Pre, Tem, NDVI, DLST, and ET between irrigated and non-irrigated areas were relatively apparent during June-July, June-July, March-May, April-May, and June (Figs. B and D), respectively. The seasonal variation of NDVI had two peaks, corresponding to winter wheat and summer corn growing time (Fig. 4 B), respectively. The average spring (March-May) ET of the non-irrigated area was lower than that of irrigated area (Fig. D), which was contrary to the average annual ET (Fig. C). It has to do with less rainfall and more irrigation in spring.

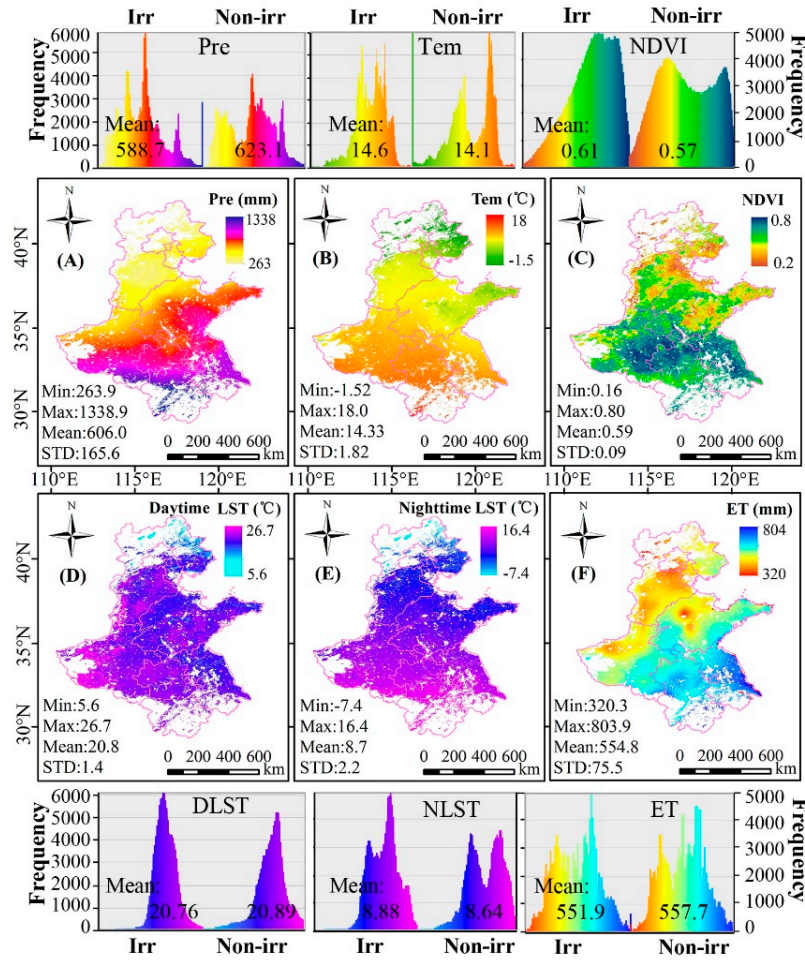


Figure S4. Spatial patterns and frequency distributions of the annual average precipitation (Pre), air temperature (Tem), NDVI, ET, daytime and nighttime LST (DLST and NLST) in irrigated and non-irrigated areas of the NCP cropland from 2000 to 2015; Irr, irrigated areas; Non-irr, non-irrigated areas. The annual average Pre, Tem, NDVI, ET, DLST, and NLST of the NCP cropland all took on apparent spatial heterogeneity, increasing from north to south. And the frequency distributions of them mostly had prominent peaks, pointing to the north and south of the NCP. The mean \pm standard deviation (STD) of them is 606.0 ± 165.6 mm, 14.33 ± 1.82 °C, 0.59 ± 0.09 , 554.8 ± 75.5 mm, 20.8 ± 1.4 °C, and 8.7 ± 2.2 °C, respectively. The annual averages of Pre, DLST, and ET of the irrigated areas were respectively about 34.4 mm, 0.13 °C, and 5.8 mm lower than those of non-irrigated areas. In contrast, the annual averages of Tem, NDVI, and NLST of the irrigated areas were respectively about 0.5 °C, 0.04, and 0.24 °C higher than those of non-irrigated areas.

Supplementary tables

Table S1. Differences between ΔLST_{dem} and ΔLST in the different seasons and administrative districts of the NCP (the difference= $\Delta LST_{dem} - \Delta LST$, °C)

Region	Spring		Summer		Growing season		Full year	
	Day	Night	Day	Night	Day	Night	Day	Nigh
Henan	0.062	0.029	0.007	0.006	0.008	0.019	0.013	0.025
Shandong	0.058	0.033	0.010	0.014	0.025	0.025	0.017	0.030
Hebei	0.054	0.017	0.003	0.008	0.017	0.014	0.016	0.019
Beijing	0.001	0.002	-0.027	0.006	-0.009	0.005	-0.006	0.014
Tianjin	-0.098	-0.033	-0.080	-0.021	-0.082	-0.025	-0.058	-0.026
Jiangsu	0.018	0.030	0.002	0.007	0.009	0.011	0.004	0.021
Anhui	0.007	0.010	-0.007	-0.002	-0.003	0.002	-0.003	0.004
North	0.058	0.026	0.007	0.009	0.017	0.019	0.016	0.025
South	0.013	0.020	-0.002	0.003	0.003	0.007	0.001	0.012
NCP	0.034	0.017	0.005	0.006	0.011	0.013	0.009	0.017

Note: The North mainly includes Henan, Hebei, and Shandong province; the South includes Anhui and Jiangsu province.

Table S2. The percentage (%) of the difference between ΔLST_{dem} and ΔLST in the ΔLST .

Region	Spring		Summer		Growing season		Year	
	day	night	day	night	day	night	day	night
Henan	10.30	20.96	3.41	7.93	8.59	8.91	9.60	21.60
Shandong	11.55	20.64	3.19	12.82	21.54	10.33	11.25	21.19
Hebei	9.67	19.24	4.22	3.79	20.23	4.44	16.60	22.21
Beijing	2.35	2.17	11.35	5.87	13.67	6.33	8.51	12.46
Jiangsu	16.94	25.01	1.00	9.17	17.30	15.24	3.68	21.50
Anhui	17.62	8.80	7.69	1.53	8.76	3.84	3.27	4.39
North	10.47	20.43	0.95	7.18	16.90	7.51	12.00	21.59
South	17.13	17.29	1.31	4.24	7.29	11.67	0.60	13.31
NCP	9.19	17.00	4.55	8.57	5.00	13.00	6.92	18.89

Note: Percentage = $|(\Delta LST_{dem} - \Delta LST)/\Delta LST| * 100$; the North includes Henan, Hebei, and Shandong province; the South includes Anhui and Jiangsu province.

Table S3. The differences of the annual average irrigation cooling effect (ICE) in the NCP quantified by Δ LST and Δ DCT.

Time scale		ICE (°C)		Difference	MAPE (%)	Average diurnal Δ ICE (°C) and MAPE (%)	
		Δ LST	Δ DCT	Δ ICE (°C)	$ \Delta$ ICE/ Δ LST		
Year	day	-0.132	-0.136	0.004	3.22	-0.006	5.19
	night	-0.090	-0.074	-0.016	17.50		
Spring	day	-0.363	-0.359	-0.004	1.01	-0.018	7.73
	night	-0.096	-0.064	-0.032	33.07		

Note: Δ ICE= Δ LST- Δ DCT; the negative Δ ICE indicate that the ICE quantified by Δ LST is stronger than that quantified by Δ DCT; MAPE = $|\Delta$ ICE/ Δ LST|*100.

Table S4. Difference of the annual average irrigation cooling effect (ICE) in the different administrative districts of the NCP quantified based on Δ LST and Δ DCT

Period and region			ICE (°C)		STD (°C)		Difference (°C)			
			Δ LST	Δ DCT	Δ LST	Δ DCT	Δ ICE	Δ STD		
Full year daytime	North	Henan	-0.206	-0.199	0.506	0.497	-0.007		0.009	
		Hebei	-0.225	-0.177	0.530	0.546	-0.048	-0.010	-0.016	-0.025
		Shandong	-0.147	-0.130	0.416	0.437	-0.017		-0.020	
		Tianjin	-0.134	-0.168	0.546	0.618	0.033		-0.072	
	South	Beijing	-0.034	-0.041	0.433	0.449	0.007		-0.015	
		Anhui	-0.029	-0.033	0.342	0.355	0.005	-0.002	-0.013	-0.010
		Jiangsu	-0.057	-0.048	0.369	0.376	-0.009		-0.007	
Spring daytime	North	Henan	-0.598	-0.529	1.054	0.978	-0.070		0.076	
		Hebei	-0.561	-0.423	1.249	1.206	-0.138	-0.069	0.043	0.003
		Shandong	-0.503	-0.426	0.899	0.892	-0.077		0.007	
		Tianjin	-0.342	-0.353	1.128	1.242	0.011		-0.114	
	South	Beijing	-0.061	-0.079	0.878	0.851	0.017		0.027	
		Anhui	-0.041	-0.018	0.605	0.595	-0.023	-0.022	0.010	0.005
		Jiangsu	-0.109	-0.088	0.601	0.601	-0.021		-0.001	
Full year nighttime	North	Henan	-0.117	-0.069	0.336	0.346	-0.048		-0.010	
		Hebei	-0.085	-0.042	0.369	0.385	-0.043	-0.056	-0.016	-0.032
		Shandong	-0.140	-0.101	0.391	0.412	-0.039		-0.021	
		Tianjin	-0.069	0.027	0.505	0.584	-0.096		-0.079	
	South	Beijing	-0.110	-0.067	0.428	0.460	-0.042		-0.032	
		Anhui	-0.089	-0.062	0.328	0.359	-0.026	-0.032	-0.030	-0.024
		Jiangsu	-0.097	-0.059	0.342	0.361	-0.039		-0.018	
Spring nighttime	North	Henan	-0.138	-0.062	0.376	0.374	-0.076		0.002	
		Hebei	-0.090	-0.017	0.354	0.406	-0.073	-0.091	-0.052	-0.057
		Shandong	-0.158	-0.095	0.423	0.457	-0.063		-0.034	
		Tianjin	-0.094	0.056	0.575	0.718	-0.150		-0.143	
	South	Beijing	-0.084	-0.053	0.390	0.458	-0.032		-0.068	
		Anhui	-0.109	-0.071	0.375	0.407	-0.038	-0.041	-0.032	-0.025
		Jiangsu	-0.120	-0.077	0.379	0.398	-0.043		-0.019	

Note: Δ ICE= Δ LST- Δ DCT, Δ STD= the STD of Δ LST – the STD of Δ DCT; The North includes Henan, Hebei, Shandong, and Tianjin; the South includes Anhui and Jiangsu.