The Innovation, Volume *2*

Supplemental Information

Contribution of Temperature Increase to Restrain the Transmission of COVID-19

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Supplemental Materials

This file includes:

Figs. S1 to S10

Tables S1, S3 to S6 (Table S2 is provided as another individual excel file.)

Other Supplemental Materials for this manuscript include the following:

Table S2: The increasing trend of the confirmed COVID-19 cases during Jan. 23–Feb. 21, 2020 and their fitting parameters using a Logistic model for the selected 27 provinces and 99 cities.

Data S1: The data of daily increased COVID-19 cases with and without corrections from the NHC website report.

Data S2: Human mobility index used to indicate of the individual movement among the concerned provinces or cities in our study. Sourced from the Baidu Co. service (see the website: http://qianxi.baidu.com/.

Data S3: The temperature and relative humidity during the study period in our study.

Supplementary Code: The analysis R code for the key calculations.

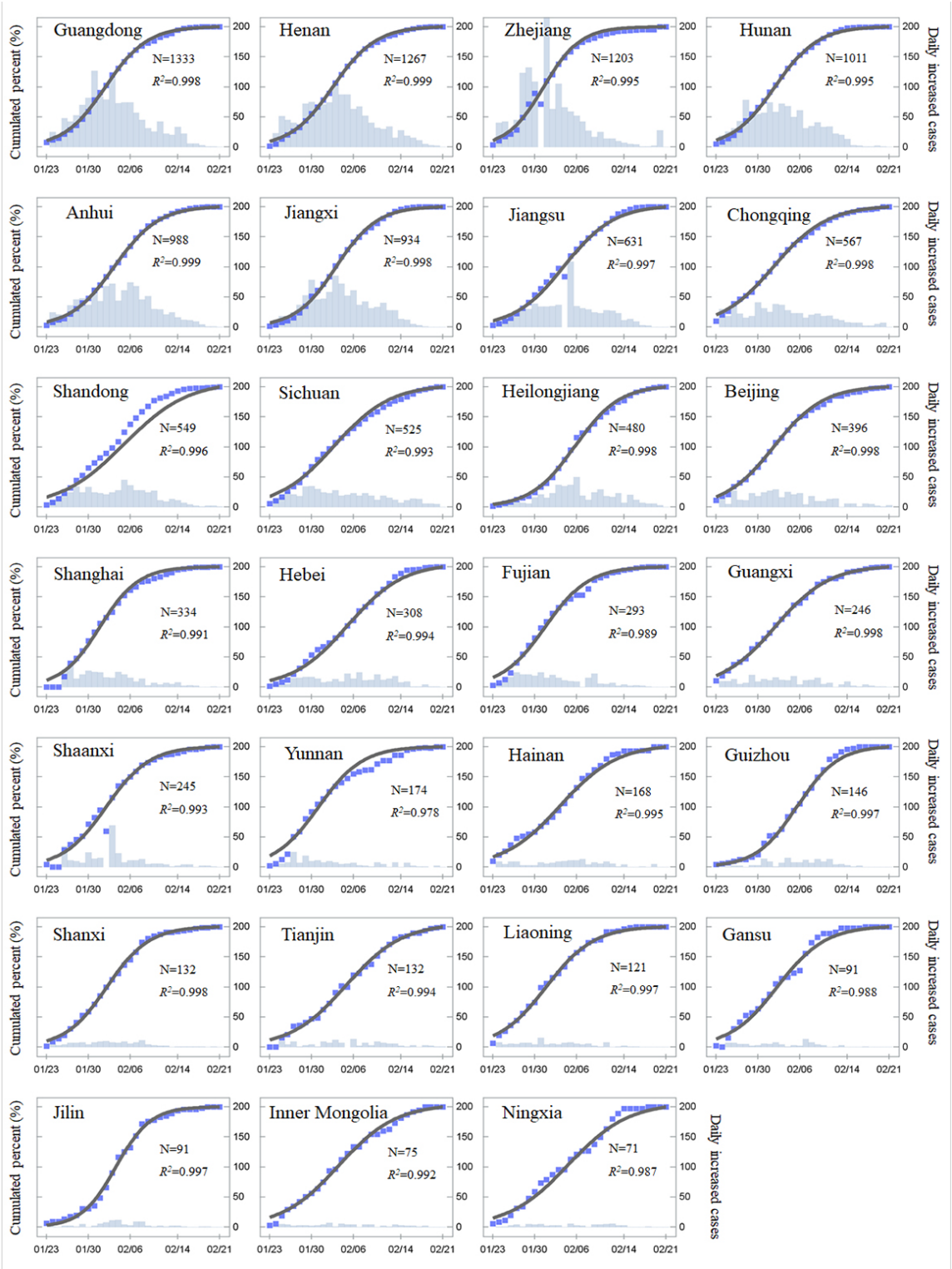

Figure S1. The fitting curve of the increase trend of the COVID-19 cases in the individual 27 provinces of Chinese Mainland.

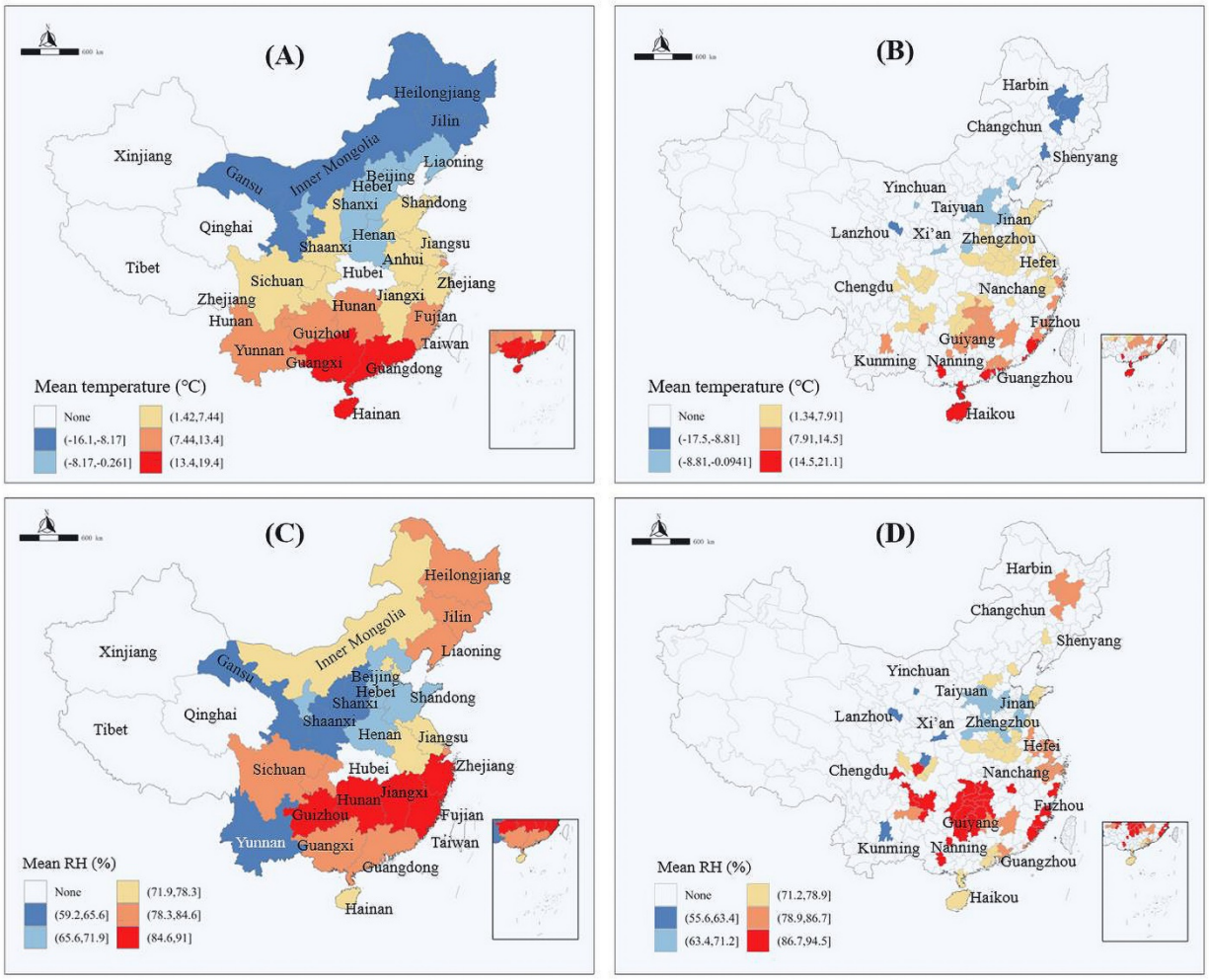

Figure S2. Geographic distributions of the average temperature in the province (A) and city (B) levels, and the average relative humidity in the province (C) and city (D) levels during Jan 14 – Feb 21, 2020. Only the large typical cities were marked.

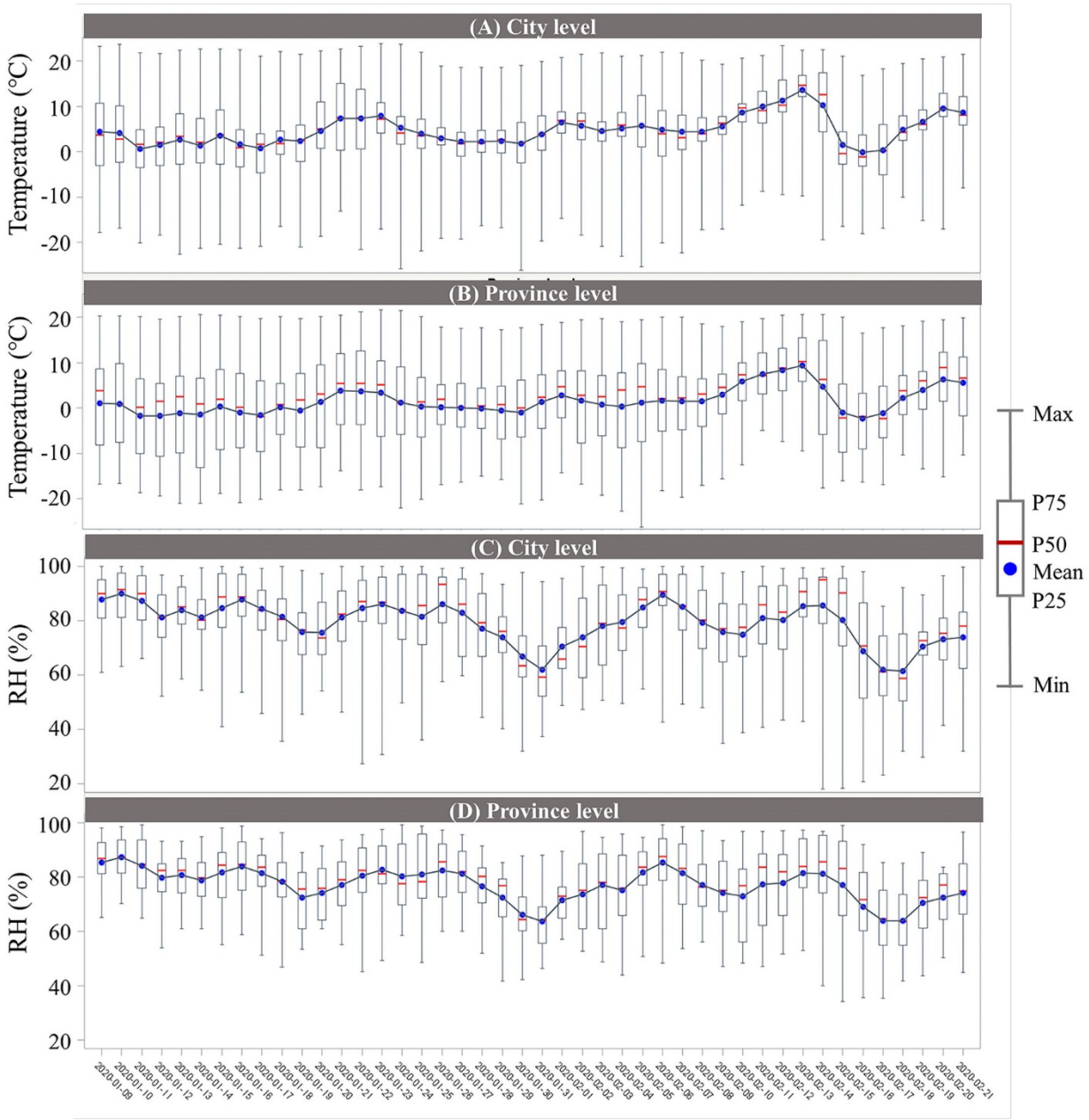

Figure S3. Distributions of the temperature in the city (A) and province (B) levels, and relative humidity in the city (C) and province (D) levels during Jan 14 – Feb 21, 2020. Data was shown with minimum (Min), maximum (Max), mean value (Mean), and 25%, 50%, and 75% percentiles, respectively.

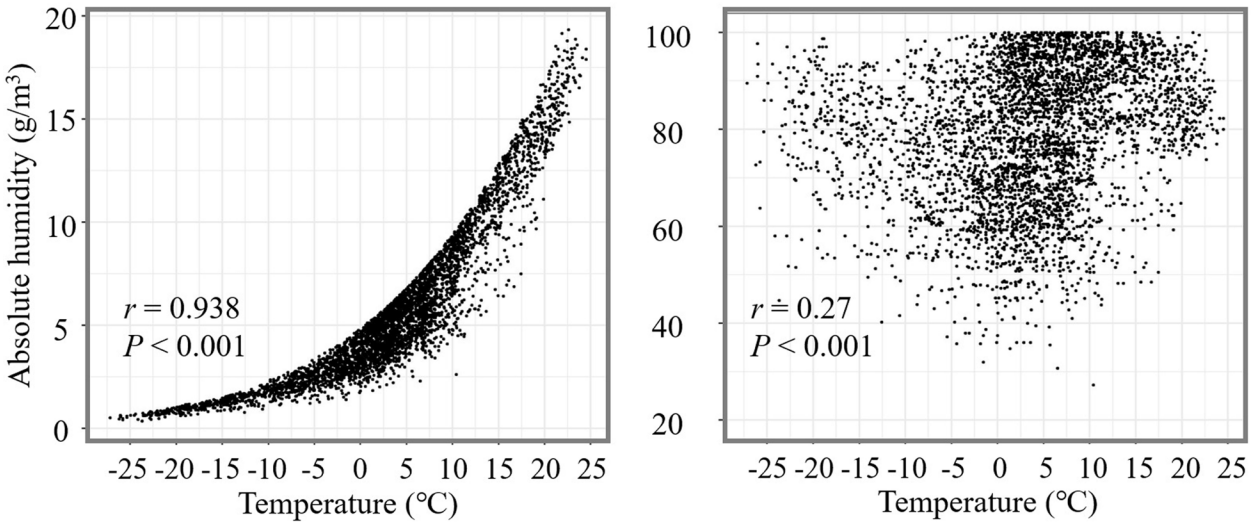

Figure S4. Scatter diagrams between the environmental temperature and absolute humidity (A) and relative humidity (B).

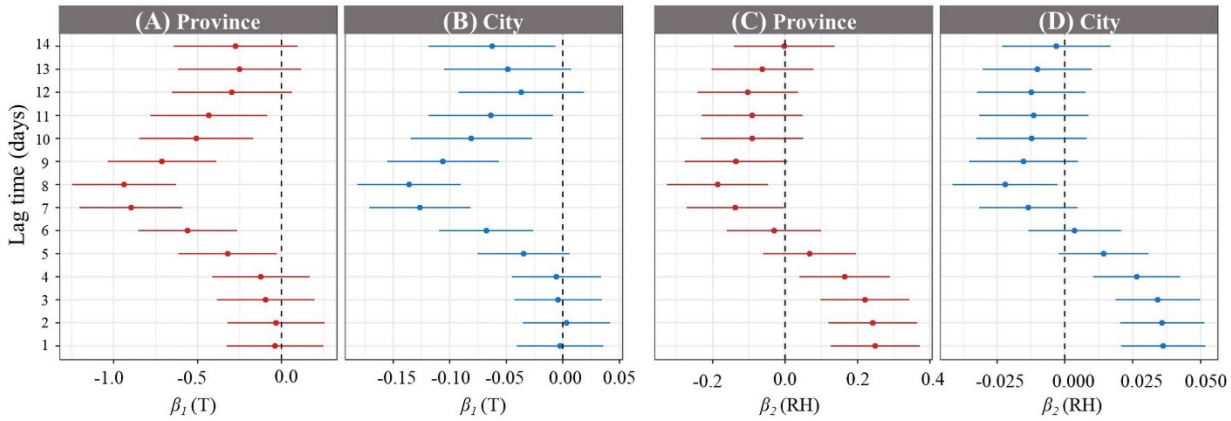

Figure S5. Associations of the ambient temperature (A: province level; B city level) and relative humidity (RH) (C: province; D: city) with the transmission rate of COVID-19 without adjusting for the mobility index, respectively. Transmission rate was defined as the increase rate of cumulated confirmed cases per-day in a logistic growth model (Eq. (1)). The regression coefficients (β_1 and β_2) were obtained using a linear mixed-effect model as the follows: $R_{[t,\,s]} = \beta_1 T_t + \beta_2 RH_t + \beta_3 WS_t + \beta_4 PR_t + \beta_5 PD_t + \gamma(L)$. This formula incorporated five fixed terms ($\beta_{1\text{-}5}$) to model the effects of temperature (T), relative humility (RH), wind speed (WS), precipitation (PR), population density (PD), and a random intercept (γ) to control for the location (L)-specific effects. Data was shown with the estimated value with 95% confidence interval.

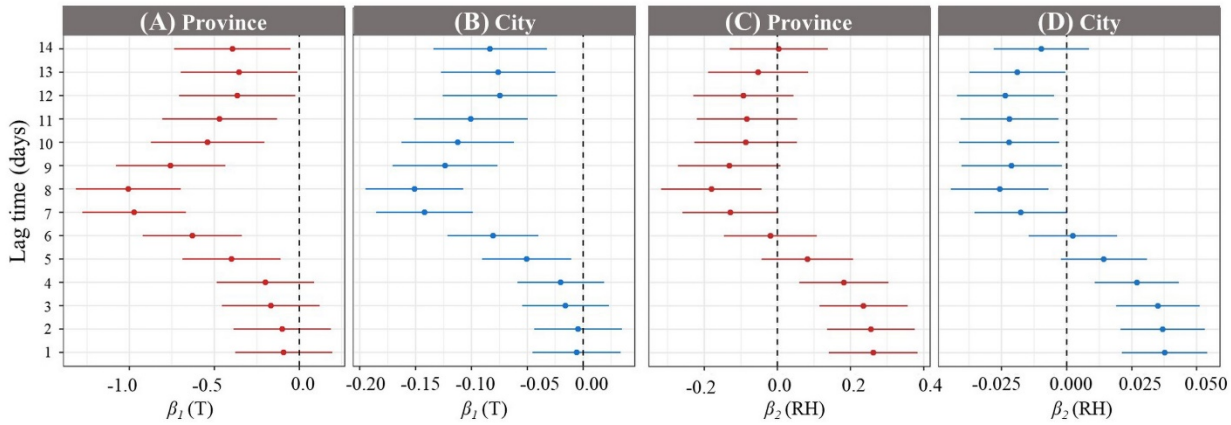

Figure S6. Associations of the ambient temperature (A: province level; B city level) and relative humidity (RH) (C: province level; D: city level) with the transmission rate of COVID-19 using the raw confirmed COVID-19 cases from the NHC website (not including the 200 infected cases in Rencheng Prison of Shandong Province, China), respectively. Transmission rate was defined as the increase rate of cumulated confirmed cases per-day in a logistic growth model (Eq. (1)). The regression coefficients (β_1 and β_2) were obtained using a linear mixed-effect model as the follows: $R_{[t,\ s]} = \beta_1 T_t+\beta_2 RH_t+\beta_3 WS_t+\beta_4 PR_t+\beta_5 MII_t+\beta_6 MOI_t+ \beta_7 PD_t+\gamma(L)$. This incorporated seven fixed terms ($\beta_{1\text{-}7}$) to model the effects of temperature (*T*), relative humility (*RH*), wind speed (*WS*), precipitation (*PR*), population mobility indexes of moving-in (*MII*) and moving-out index (*MOI*), population density (*PD*), and a random intercept (γ) to control for the location (*L*)-specific effects. Data was shown with the estimated value with 95% confidence interval.

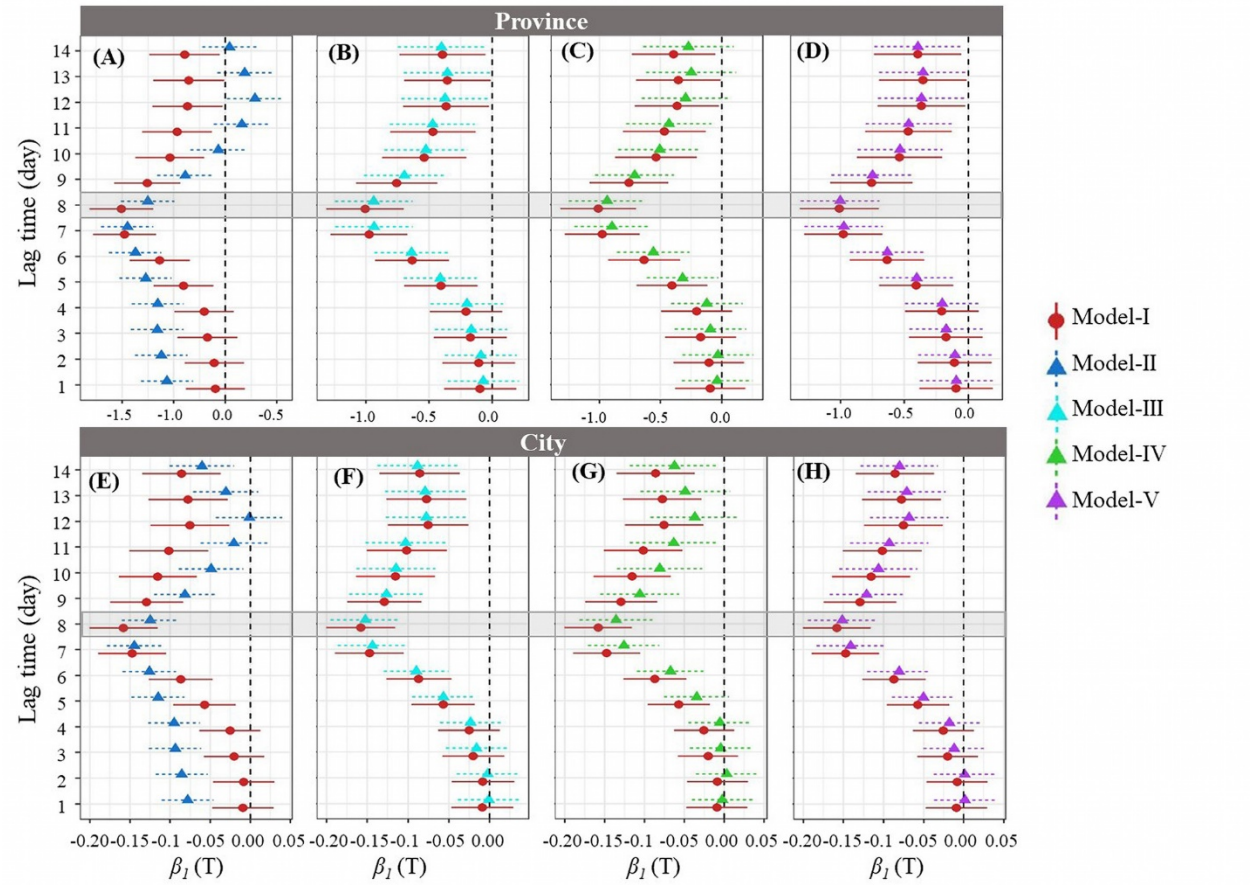

Figure S7. Associations of the ambient temperature (A-D: province level; E-H: city level) with the transmission rate of COVID-19 using the raw confirmed COVID-19 cases. Transmission rate was defined as the increase rate of cumulated confirmed cases per-day in a logistic growth model (Eq. (1)). The regression coefficient (β_1) was obtain using a linear mixed-effect model as the following models:

Model-I [All]: $R_{[t,\,s]} = \beta_1 T_t+\beta_2 RH_t+\beta_3 WS_t+\beta_4 PR_t+\beta_5 MII_t+\beta_6 MOI_t+ \beta_7 PD_t+\gamma(L)$

Model-II [No PR]: $R_{[t,\,s]} = \beta_1 T_t+\beta_2 RH_t+\beta_3 WS_t+\beta_5 MII_t+\beta_6 MOI_t+\beta_7 PD_t+\gamma(L)$

Model-III [No WS]: $R_{[t,\,s]} = \beta_1 T_t+\beta_2 RH_t+\beta_4 PR_t+\beta_5 MII_t+\beta_6 MOI_t+ \beta_7 PD_t+\gamma(L)$

Model-IV [No MII&MOI]: $R_{[t,\,s]} = \beta_1 T_t+\beta_2 RH_t+\beta_3 WS_t+\beta_4 PR_t+ \beta_7 PD_t+\gamma(L)$

Model-V [No PD]: $R_{[t,\,s]} = \beta_1 T_t+\beta_2 RH_t+\beta_3 WS_t+\beta_4 PR_t+\beta_5 MII_t+\beta_6 MOI_t+\gamma(L)$

This incorporated seven fixed terms ($\beta_{1\text{-}7}$) to model the effects of temperature (T), relative humility (RH), wind speed (WS), precipitation (PR), population mobility indexes of moving-in (MII) and moving-out index (MOI), population density (PD), and a random intercept (γ) to control for the location (L)-specific effects. Data was shown with the estimated value with 95% confidence interval. The results at lag time = 8 days were highlighted by a gray rectangle.

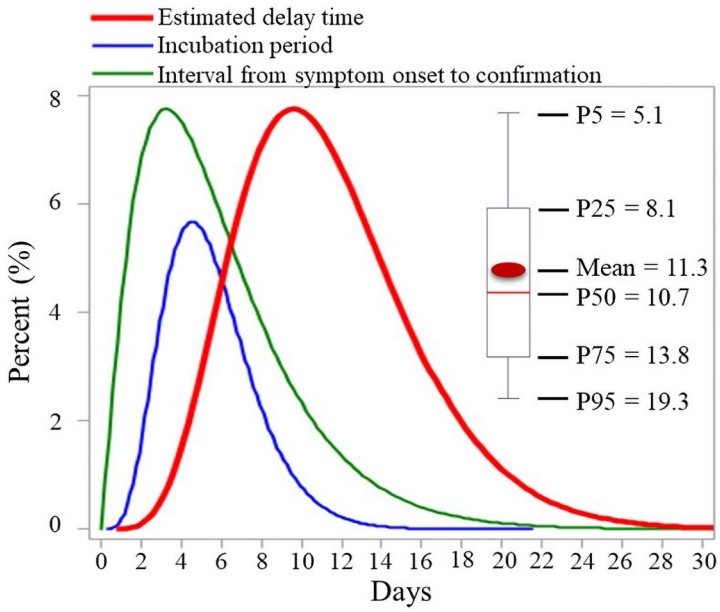

Figure S8. Distribution of the lag time including the incubation time and the interval between the symptom onset and the report of the COVID-19 case confirmation (report interval). The 5%, 25%, 50%, 75%, and 95% percentiles and mean value were 5.1, 8.1, 10.7, 13.8, 19.3, and 11.3 days. The distribution of incubation time and report interval both obey a Gamma distribution with the tuning parameters of ($\boldsymbol{a}$=2.24, $\boldsymbol{b}$=2.59) [1] and ($\boldsymbol{a}$=5.807, $\boldsymbol{b}$=0.948) [2], respectively.

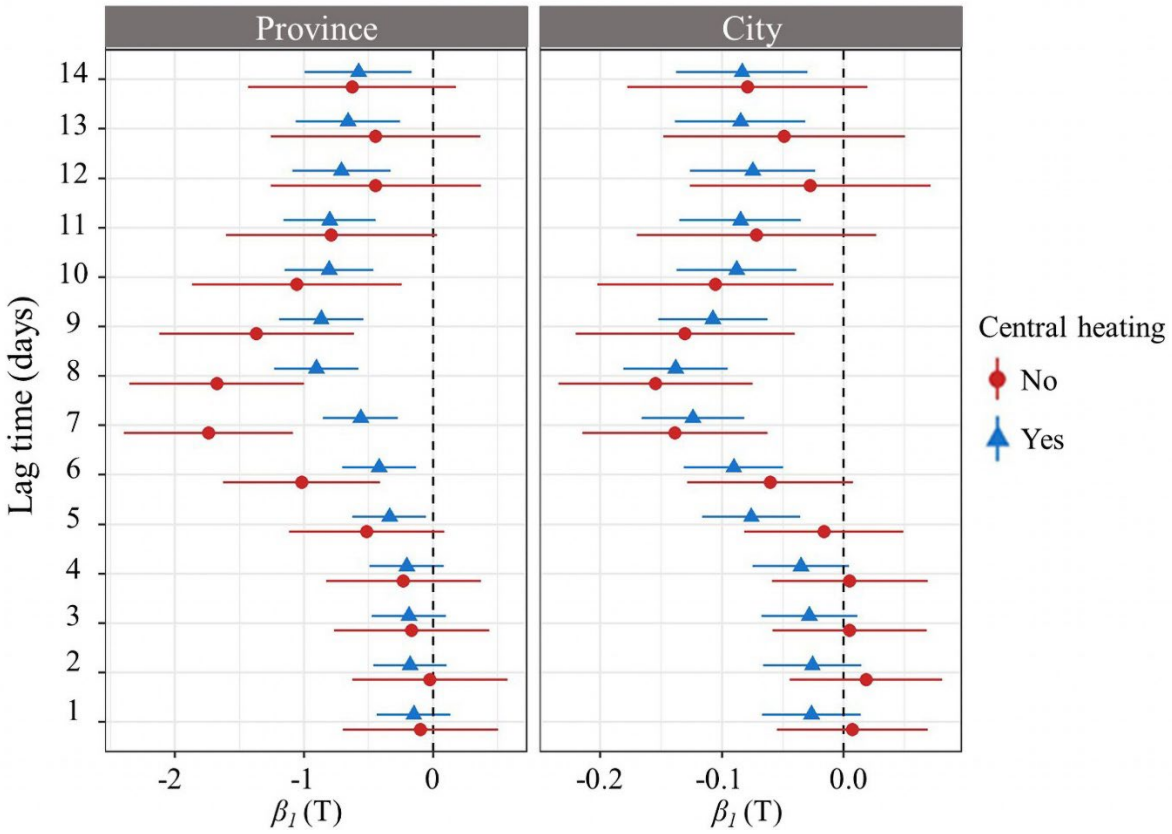

Figure S9. Modification effect of the central heating on the associations of the ambient temperature with the transmission rate of COVID-19 without adjusting for the mobility index in the province and city levels, respectively. Transmission rate was defined as the increase rate of cumulated confirmed cases per-day in a logistic growth model (Eq. (1)). The regression coefficient (β_1) was obtained using a linear mixed-effect model as the follows: $R_{[t,\ s]} = \beta_1 T_t + \beta_2 RH_t + \beta_3 WS_t + \beta_4 PR_t + \beta_5 PD_t + \gamma(L)$. This formula incorporated five fixed terms ($\beta_{1\text{-}5}$) to model the effects of temperature (T), relative humility (RH), wind speed (WS), precipitation (PR), population density (PD), and a random intercept (γ) to control for the location (L)-specific effects. Data was shown with the estimated value with 95% confidence interval.

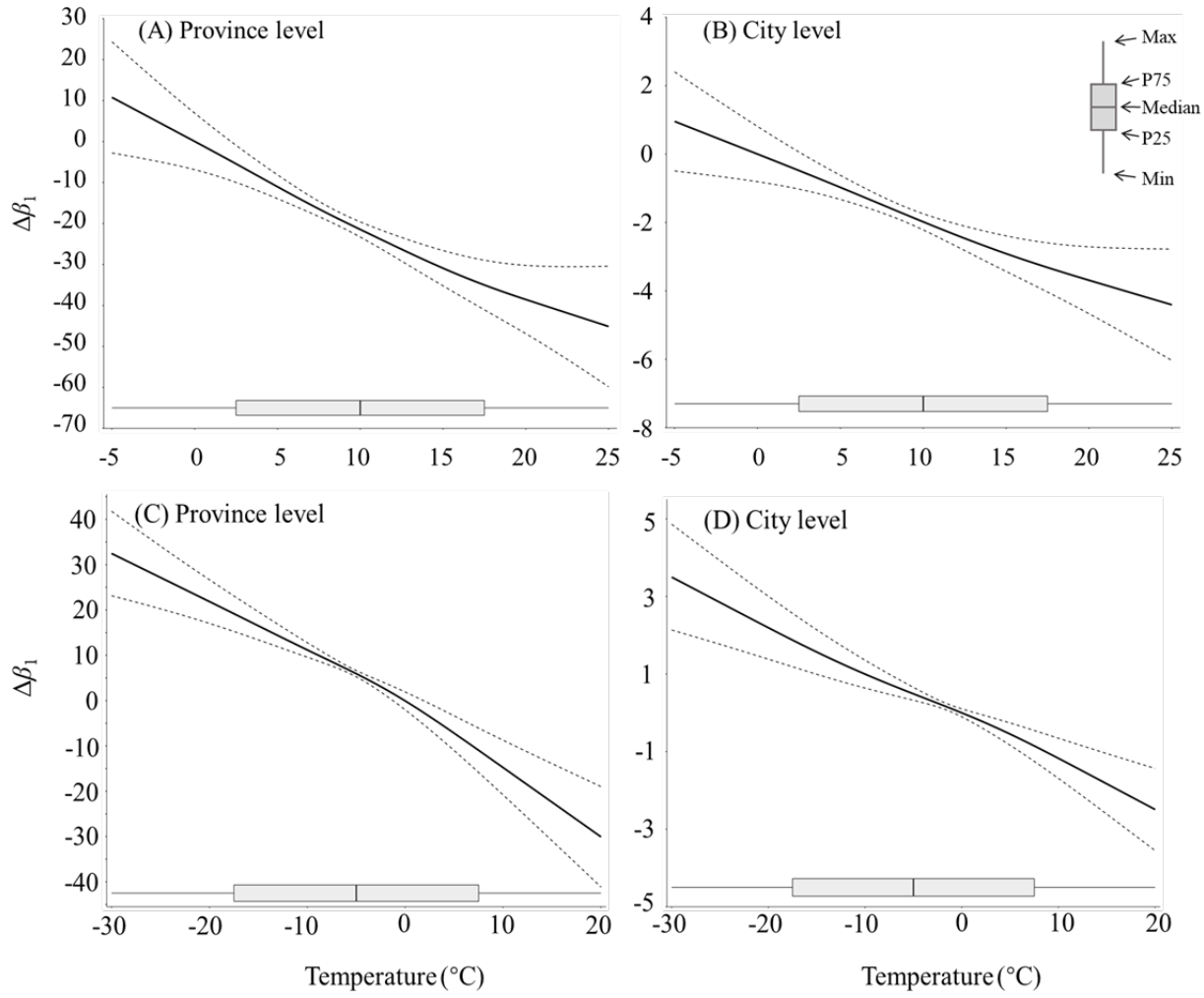

Figure S10. The non-linear relationship between ambient temperature and COVID-19 transmission when LT = 8 days among regions with (C&D) and without (A&B) central heating. Transmission rate was defined as the increase rate of cumulated confirmed cases per-day in a logistic growth model (Eq. (1)). The change of regression coefficient ($\Delta\beta_1$) was obtained using a non-linear mixed-effect model as the follows: $R_{[t,\,s]} = \boldsymbol{g}(T_t) + \beta_2 RH_t + \beta_3 WS_t + \beta_4 PR_t + \beta_5 MII_t + \beta_6 MOI_t + \beta_7 PD_t + \gamma(L)$. This formula incorporated a smoothing spline term ($\boldsymbol{g}$), six fixed terms ($\beta_{2\text{-}7}$) to model the effects of temperature (T), relative humility (RH), wind speed (WS), precipitation (PR), population mobility indexes of moving-in (MII) and moving-out index (MOI), population density (PD), and a random intercept (γ) to control for the location (L)-specific effects. Solid and dot lines represented the estimation of $\Delta\beta_1$ and its 95% confidence interval, respectively. The reference value of temperature was 0°C. Box plots described the distribution of temperature during the period.

Table S1. Detailed data correction operation on the original information reported on the official website of the National Health Commission

Provinces	Events	Details	Correcting the reported data based on the event	Sources [a]
Tianjin	Baodi department store aggregation infection	Cluster of infection of 40 cases; No observed abnormal cumulated number	Keep unchanged.	Reference [3]
Shandong	Prison aggregation infection	Feb. 21, 2020: 200 new cases were confirmed in Rencheng prison	These 200 cases were deleted since 21st Feb, 2020	Website #1:
Zhejiang	Abnormal data	Jan. 31, 2020: "decreased" cumulated cases occurred	Corrected using the reported data from the Zhejiang Health Commissions official website	Website #2:
Zhejiang	Abnormal data in Hangzhou City	Feb. 9, 2020: "decreased" cumulated cases occurred	Kept unchanged. (Original data was consistent with Zhejiang Health Commissions official website	Website #3:
Gansu	Abnormal data in Gannan City	Jan. 21, 2020: "decreased" cumulated cases occurred	Corrected using the reported data from the Gansu Health Commissions official website	Website #4:
Henan	Abnormal data in Yongcheng City	Decreased cumulated cases occurred	Corrected using the reported data from the Henan Health Commissions official website	Website #5:
Heilongjiang	Abnormal data in Suihua City	Feb. 9, 2020: "decreased" cumulated cases occurred	Keep unchanged. (Original data was consistent with Heilongjiang Health Commissions official data)	Website #6:
Nanjing	Abnormal data	Decreased cumulated cases occurred	Corrected using the reported data from the Nanjing Health Commissions official website	Website #7:
Shaanxi	Abnormal data in Xian City	Feb. 2, 2020: "decreased" cumulated cases occurred	Corrected using the reported data from the Shaanxi Health Commissions official website	Website #8:
Sichuan	Abnormal data in Meishan city	Feb. 21, 2020: "decreased" cumulated cases occurred	Corrected using the reported data from the Sichuan Health Commissions official website	Website #9:
Yunnan	Abnormal data in Dali City	Decreased cumulated cases occurred	Corrected using the reported data from the Yunnan Health Commissions official website	Website #10:
Yunnan	abnormal data in Xishuangbanna City	Decreased cumulated cases occurred	Corrected using the reported data from the Yunnan Health Commissions official website	Website #11:

[a] The detailed websites:

Website #1: https://www.yicai.com/news/100515523.html

Website #2: http://www.zjwjw.gov.cn/art/2020/2/1/art_1202194_41865259.html

Website #3: http://www.zjwjw.gov.cn/art/2020/2/10/art_1202101_41894522.html

Website #4: http://wsjk.gansu.gov.cn/single/10910/84364.html

Website #5: http://hnwsjsw.gov.cn/channels/xxgk.shtml

Website #6: http://wsjkw.hlj.gov.cn/index.php/Home/Zwgk/show/newsid/7769/navid/42/stypeid/
Website #7: http://wjw.jiangsu.gov.cn/art/2020/2/5/art_7290_8961839.html
Website #8: http://sxwjw.shaanxi.gov.cn/art/2020/2/3/art_9_67666.html
Website #9: http://wsjkw.sc.gov.cn/
Website #10: http://ynswsjkw.yn.gov.cn/wjwWebsite/web/doc/UU158147060382734153
Website #11: http://ynswsjkw.yn.gov.cn/wjwWebsite/web/doc/UU158230893462979208

Table S3. The interaction effects between temperature and relative humidity on the transmission rate of COVID-19

Parameters [a]	Province level			City level		
	All [b]	Public heating status		All	Public heating status	
		No	Yes		No	Yes
T	-0.31 (-1.35~0.73)	-3.15 (-6.56~0.26)	-0.98 (-2.10~0.14)	-0.08 (-0.23~0.07)	-0.18 (-0.51~0.16)	-0.06 (-0.20~0.08)
RH	-0.19 (-0.33~-0.05)	-0.45 (-0.83~-0.07)	-0.20 (-0.37~-0.03)	-0.02 (-0.04~-0.002)	-0.02 (-0.06~0.01)	-0.04 (-0.06~-0.02)
T×*RH*	-0.01 (-0.02~0.004)	0.02 (-0.02~0.05)	0.002 (-0.014~0.018)	-0.001 (-0.003~0.001)	-0.0001(-0.0039~0.0037)	-0.0008 (-0.028~0.0012)
P [c]	0.17	0.43	0.81	0.28	0.95	0.45

[a] Temperature (*T*) and relative humidity (*RH*);

[b] Including all the locations;

[c] Test for the interaction between the temperature and relative humidity using a linear mixed-effect model as the follows, $R_{[t,\,s]} = \beta_1 T_t+\beta_2 RH_t+\beta_3 WS+\beta_4 PR_t+\beta_5 MII_t+\beta_6 MOI_t+\beta_7 PD_t+\beta_8 T_t\times RH_t+\gamma(L)$, where The regression incorporated seven fixed terms ($\beta_{1\text{-}8}$) to model the effects of temperature (*T*), relative humility (*RH*), wind speed (*WS*), precipitation (*PR*), population mobility indexes of moving-in (*MII*) and moving-out index (*MOI*), population density (*PD*), the interaction between *T* and *RH*, and a random intercept to control for the location (*L*)-specific effects. A total 27 provinces and 99 cities were included when the lag time = 8 days

Table S4. The regression coefficients of temperature associated the transmission rate of COVID-19

Province name	City name	N [a]	β_1 [b]
Province level			
Henan	/	1267	-3.424
Anhui	/	988	-2.021
Hunan	/	1011	-1.955
Jiangxi	/	934	-1.944
Guangdong	/	1333	-1.924
Sichuan	/	525	-1.869
Jiangsu	/	631	-1.837
Zhejiang	/	1203	-1.714
Yunnan	/	174	-1.702
Shanghai	/	334	-1.691
Hainan	/	168	-1.681
Chongqing	/	567	-1.678
Guizhou	/	146	-1.611
Guangxi	/	246	-1.593
Fujian	/	293	-1.582
Heilongjiang	/	480	-1.075
Shandong	/	549	-1.054
Ningxia	/	71	-0.999
Shaanxi	/	245	-0.857
Beijing	/	396	-0.744
Tianjin	/	132	-0.654
Gansu	/	91	-0.641
Hebei	/	308	-0.619
Shanxi	/	132	-0.609
Inner Mongolia	/	75	-0.563
Jilin	/	91	-0.561
Liaoning	/	121	-0.367
City level			
Sichuan	Chengdu	143	-0.404
Guangdong	Shantou	25	-0.350
Hunan	Shaoyang	102	-0.333
Anhui	Fuyang	155	-0.328
Fujian	Xiamen	35	-0.321
Hunan	Yueyang	156	-0.305
Anhui	Liu'an	69	-0.262
Guizhou	Bijie	23	-0.259
Jiangsu	Wuxi	55	-0.253
Jiangsu	Suzhou	87	-0.253
Sichuan	Neijiang	22	-0.252
Guizhou	Guiyang	36	-0.248
Jiangsu	Changzhou	51	-0.241
Guangdong	Zhongshan	66	-0.239
Jiangsu	Nanjing	93	-0.237
Zhejiang	Jiaxing	45	-0.234
Hunan	Yiyang	59	-0.229

Province name	City name	N [a]	β_1 [b]
Hainan	Haikou	39	-0.227
Henan	Nanyang	155	-0.224
Anhui	Wuhu	33	-0.223
Sichuan	Mianyang	22	-0.222
Hunan	Loudi	76	-0.221
Henan	Zhengzhou	157	-0.216
Fujian	Zhangzhou	20	-0.216
Guangdong	Jiangmen	23	-0.215
Guangdong	Zhuhai	98	-0.212
Fujian	Fuzhou	71	-0.212
Anhui	Huainan	27	-0.207
Sichuan	Guang'an	30	-0.206
Anhui	Haozhou	108	-0.205
Anhui	Suzhou	41	-0.205
Yunnan	Kunming	53	-0.205
Zhejiang	Jinhua	55	-0.205
Zhejiang	Shaoxing	42	-0.204
Hunan	Changsha	242	-0.204
Anhui	Hefei	174	-0.202
Jiangsu	Nantong	40	-0.198
Sichuan	Luzhou	24	-0.196
Guangxi	Liuzhou	24	-0.194
Hunan	Xiangtan	35	-0.194
Jiangsu	Huai'an	66	-0.192
Guangdong	Shenzhen	416	-0.188
Sichuan	Dazhou	41	-0.187
Sichuan	Bazhong	24	-0.183
Hunan	Chenzhou	39	-0.174
Henan	Zhumadian	139	-0.174
Heilongjiang	Harbin	197	-0.173
Jiangsu	Taizhou	37	-0.173
Jiangsu	Xuzhou	79	-0.172
Hunan	Zhuzhou	78	-0.168
Hunan	Yongzhou	43	-0.168
Hebei	Tangshan	57	-0.166
Guizhou	Zunyi	32	-0.166
Henan	Shangqiu	91	-0.163
Sichuan	Nanchong	38	-0.161
Guangdong	Zhanjiang	22	-0.158
Guangdong	Dongwan	93	-0.157
Hunan	Huaihua	40	-0.157
Shandong	Yantai	47	-0.155
Zhejiang	Ningbo	157	-0.155
Hunan	Changde	80	-0.154
Guangxi	Nanning	54	-0.154
Jiangsu	Lianyungang	48	-0.153
Henan	Xinxiang	57	-0.152
Guangxi	Guilin	31	-0.150
Shandong	Weifang	44	-0.146

Province name	City name	N [a]	β_1 [b]
Anhui	Bengbu	160	-0.133
Henan	Zhoukou	76	-0.128
Shandong	Linyi	49	-0.124
Ningxia	Yinchuan	33	-0.123
Shandong	Liaocheng	38	-0.123
Henan	Kaifeng	26	-0.122
Hebei	Handan	31	-0.109
Shandong	Qingdao	59	-0.106
Guangdong	Huizhou	62	-0.104
Heilongjiang	Suihua	47	-0.104
Shandong	Dezhou	37	-0.101
Hunan	Hengyang	48	-0.099
Hebei	Xingtai	23	-0.099
Hebei	Baoding	32	-0.098
Shandong	Jinan	47	-0.093
Hebei	Langfang	30	-0.093
Guangdong	Foshan	84	-0.092
Hebei	Shijiazhuang	28	-0.091
Shaanxi	Xi'an	120	-0.088
Henan	Luoyang	31	-0.084
Gansu	Lanzhou	36	-0.082
Jiangxi	Ganzhou	76	-0.080
Henan	Xinyang	270	-0.063
Shanxi	Taiyuan	20	-0.061
Jilin	Changchun	45	-0.058
Liaoning	Shenyang	28	-0.038
Fujian	Quanzhou	46	-0.037
Zhejiang	Hangzhou	169	-0.016
Jiangxi	Nanchang	229	-0.004
Guangdong	Guangzhou	339	0.004
Zhejiang	Wenzhou	504	0.665

[a] Number of subjects;

[b] The regression coefficient (β_1) was obtain using a linear mixed effect model as the follows: $R_{[t,\ s]} = \beta_1 T_t+\beta_2 RH_t+\beta_3 WS+\beta_4 PR_t+\beta_5 MII_t+\beta_6 MOI_t+\beta_7 PD_t+ (T_t|\gamma(L))$. This incorporated seven fixed terms ($\beta_{1\text{-}7}$) to model the effects of temperature (T), relative humility (RH), wind speed (WS), precipitation (PR), population mobility indexes of moving-in (MII) and moving-out index (MOI), population density (PD), a random slope of temperature (T), and a random intercept (γ) to control for the location (L)-specific effects. A total 27 provinces and 99 cities were included when the lag time = 8 days.

Table S5. The accumulated number of COVID-19 cases associated with the increase of ambient temperature during the *D* days at different lag time.

Lag time (Day)	ΔN_M [a] (95% Confidence Interval)
1	-38.2 (-193.2, 116.8)
2	-21.6 (-142.2, 99.1)
3	-121.2 (-387.7, 145.3)
4	-306.4 (-820.8, 208.1)
5	-840.1 (-1605.4, -74.8)
6	-2216.3 (-3367.0, -1065.6)
7	-4177.7 (-5589.5, -2765.9)
8	-4066.6 (-5553.8, -2579.3)
9	-3181.5 (-4798.6, -1564.3)
10	-1882.2 (-3192.5, -571.9)
11	-1010.3 (-1933.2, -87.4)
12	-619.3 (-1459.5, 221.0)
13	-530.4 (-1206.9, 146.1)
14	-569.3 (-1126.9, -11.7)

[a] ΔN_M: The accumulated number of COVID-19 cases associated with the increase of ambient temperature during the D days. Negative values represent decreased number of associated cases were estimated.

Table S6. Stability of SARS-CoV-2 at different environmental conditions and their half times of decay

Incubation time/ hours	Experimental conditions							
	4℃		20℃		28℃		37℃	
	L	H	L	H	L	H	L	H
	Mean value							
0	37000	37000	37000	37000	37000	37000	37000	37000
1	18000	33000	28000	18500	38500	17000	2310	7750
4	8000	18500	18500	3450	1120	725	755	200
8	12000	13500	12000	15000	4450	4100	25	40
24	5900	22500	2900	3000	105	/	/	/
48	12000	11500	225	/	/	/	/	/
72	3250	20000	/	/	/	/	/	/
	Standard deviation							
0	8485	8485	8485	8485	8485	8485	8485	8485
1	8485	9899	5657	3536	10607	2828	1824	71
4	1414	4950	707	636	1386	672	21	283
8	2828	2121	0	2828	71	141	21	14
24	566	7778	283	1414	35	/	/	/
48	2828	4950	106	/	/	/	/	/
72	1485	5657	/	/	/	/	/	/
	Half time [a]							
Estimated	1.97	3.89	4.28	1.19	0.61	0.65	0.85	0.36
95%CI_L	1.18	2.06	2.54	0.98	0.36	0.47	0.43	0.21
95%CI_U	6.06	33.00	13.52	1.50	1.86	1.03	28.72	1.44

[a] The half time of decay was estimated by assuming the first-order decay trend using the first 4-hour residual titers. 95%CI_L and 95%CI_U stand for the low and upper limits of the 95% confidence interval.

Table S2: The increasing trend of the confirmed COVID-19 cases during Jan. 23–Feb. 21, 2020 and their fitting parameters using a Logistic model for the selected 27 provinces and 99 cities.

Data S1. The data of daily increased COVID-19 cases with and without corrections from the NHC website report

Data S2. Human mobility index used to indicate of the individual movement among the concerned provinces or cities in our study. Sourced from the Baidu Co. service (see the website: http://qianxi.baidu.com/)

Data S3. The information of the temperature and relative humidity of the concerned area during the study period.

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