Outbreak analysis with a logistic growth model shows COVID-19 suppression dynamics in China

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Abstract

China experienced an outbreak of a novel coronavirus, SARS-CoV2, from mid-January till mid-March 2020. Here we review the curves of epidemic growth and decline of the virus in China using a phenomenological logistic growth model to summarize the dynamics of the outbreak using three parameters that characterize the epidemic's timing, rate and peak. During the initial phase, the number of cases doubled every 2.7 (range 2.2 – 4.4) days. The rate of increase in the number of reported cases peaked approximately 10 days after suppression measures were started on 23-25 January 2020. The peak in the number of reported sick cases occurred on average 18 days after the start of measures. From the time of starting measures till the peak, the number of cases increased by a factor 38.5 in the province Hubei, and by a factor 9.5 for all of China (range: 6.2-20.4 in the other provinces). Complete suppression took up to 2 months (range: 23-57d.), during which period severe restrictions, social distancing measures, testing and isolation of cases were in place. The suppression of the disease in China has been successful, acting as a beacon of hope for countries outside China where the epidemic is still in a phase of increase and authorities need to decide their course of action.

The coronavirus SARS-CoV2 emerged in Wuhan, Hubei province, China, in late 2019. From there it spread, first in Hubei, then across China during the spring holiday, and finally across the world. Currently (as of 24 March 2020), the virus has been reported from 196 countries and the cumulative number of cases outside China is now about four times as large as the cumulative number of cases in China[1]. In mainland China, few new cases have been reported since 18 March, and most new cases have originated from outside China[2]. Thus, the SARS-CoV-2 outbreak in China appears to be, for now, under control.

Virtually the entire global population is susceptible to SARS-CoV2 infection and no vaccine is available yet. Unless a successful NPI (Non-Pharmaceutical Intervention) strategy is implemented in the early stages of transmission, an exponential global proliferation threatens to overwhelm the health care systems of many countries. Three NPI strategies are being discussed for managing the current COVID-19 epidemic: (1) suppression, (2) mitigation, and (3) containment[3]. In **suppression**, strict measures are taken to reverse the epidemic spread, essentially by bringing the effective reproduction number R_e (the number of new cases per existing case) below one[4,5]. Social distancing is a key factor in suppression[6]. In **mitigation** the aim is not to necessarily stop all transmission, but rather to reduce the rate of transmission and in effect lower the number of infected people at any given time[3,7]. It has been suggested that mitigation strategies might prevent inundation of the health care system by "flattening" the peak of sick people"[3]. However, even in the most optimistic scenarios for mitigation, healthcare capacity is likely to be still seriously overwhelmed, as it was in Wuhan in February 2020 and as is now in Italy in March 2020. Herd immunity has been suggested as a component of mitigation, but is only a viable option once a vaccine is available because up to 20% of people with confirmed infection develops serious symptoms and needs hospitalization or intensive care [8]. The proportion of unreported cases is uncertain (86% before measures but

later on 16-21% in the whole of China according to Li, et al. [9]; 59% or more in Wuhan according to Wang, et al. [10]). If underreporting is accounted for, the proportion of infected people requiring hospitalization is still in the order of 3% or more. **Containment** is based on intensive surveillance of possible cases, testing, followed by isolation of infected people and their contacts. Containment is only possible if the virus is not freely circulating in a population. Currently, because in many countries outside of China the virus is circulating within the population, these countries are practicing suppression. Policy makers may ask:

(1) How long it will take for the epidemic to peak after suppression measures have been implemented?
(2) What will the peak number of sickness cases be?
(3) How long do suppression measures need to be maintained to suppress the virus to sufficiently low incidence to allow containment (search and quarantine flare-ups of the virus)?

Here, we analyze with a phenomenological logistic model the epidemics of SARS-CoV2 in China and 20 of its provinces that reported more than 150 cases. The logistic model is widely used in ecology to analyze boom and bust population dynamics[11]. Logistic models are not as widely used in human disease epidemiology as more mechanistic SIR and SEIR models[12-14] because the parameters lack a strict mechanistic interpretation in terms of transmission rate and disease etiology (e.g. latency period, incubation period and infectious period). However, this disadvantage is compensated by the usefulness of the parameters for describing the outbreak dynamics in time. We do not imply that logistic models can replace established epidemiological models, but we do argue that phenomenological models, given the urgency and severe consequences of the worldwide SARS-CoV2 outbreak for public health

84 management, have a place along mechanistic models to inform on disease dynamics[15]. Using
85 data from China, logistic models shows the key disease dynamic parameters before and after
86 suppression policies were implemented[16].
87
88 The cumulative number of cases (confirmed by testing or based on clinical symptoms) was
89 described very well by a logistic growth pattern with R^2 greater than 0.99 for all provinces,
90 except Shandong (R^2>0.98, Table A1). Three provinces enacted suppression measures on 23
91 January, five implemented measures on 24 January, and the remaining 12 provinces started
92 measures on 25 January. The time scale for the increase was $c = 3.91$ d. for China
93 (excluding Hubei, range 3.13 - 6.39) and 4.13 d. for Hubei (Table A1), indicating doubling
94 times of c * ln(2) = 2.7 d. (range 2.2 – 4.4 d) and 2.9 d. for China (excluding Hubei) and for
95 Hubei, respectively, during the early epidemic. Some lack of fit during the early phase of the
96 epidemic (before measures) suggests the actual doubling times may be even shorter than these
97 estimates (Table A1).
98
99 The number of reported active sick cases (total infected minus recovered minus deceased) in
100 Hubei peaked 25 days after suppression measures were implemented, which in the model also
101 indicates the peak of number of deaths on the same day. Outside Hubei, the peak number of
102 reported sick cases (and peak of daily number dying) was on average reached 18 days after
103 the start of suppression (Table 1). The rate of daily increase in reported cases peaked 17 days
104 after the start of suppression measures in Hubei, and on average 10 days after the start of
105 measures in the other provinces (range: 8 to 15 days). When assuming a reporting delay of 6
106 days[9], the actual peak in the rate of increase occurred at 11 days in Hubei and at 4 days in the
107 other provinces, and the actual peak in the number of sick cases peaked at 19 days in Hubei
108 and at 12 days after the start of measures, in the other provinces.

109

110 The relative rate of increase in the number of cases at the time of the peak rate was rather
111 consistent among provinces, with an average of 0.11 cases/case/day for Hubei and 0.12
112 cases/case/day for the rest of China (range: 0.08 to 0.15). Between suppression
113 implementation and the peak number of reported cases, the number of active cases in Hubei
114 increased by a factor 38.5, while in other provinces it increased by a factor of 9.5 with
115 considerable variation between provinces (range: 6.2 in Hainan and Chongqing to 20.4 in
116 Heilongjiang). If a 6-day reporting delay is included in the estimate of the factor increase
117 from the start of measures to the peak, then this multiplication factor is diminished to a value
118 of 9.5 for Hubei and an average of 2.6 for the other provinces. The daily death rate of the
119 active sick people was 0.34 percent per day for Hubei, much higher than in other provinces
120 (on average 0.05 percent per day, ranging between 0 in Jiangsu Province (see also Sun, et al.
121 [17]) and 0.18 percent per day in Hainan Province, Appendix 3), which indicates that on the day
122 of peak sick in Hubei (50,000 cases), 150 individuals died. Cumulative to 10 March, the
123 modelled logistic curve showed that for China (excluding Hubei) 0.85% of the reported cases
124 died which is close to the actual value of 0.86%. The death rate was overestimated in Hubei as
125 6.7%, compared to the actual 4.5%, due to the actual daily death rate declining during the
126 later stages of the epidemic.

127

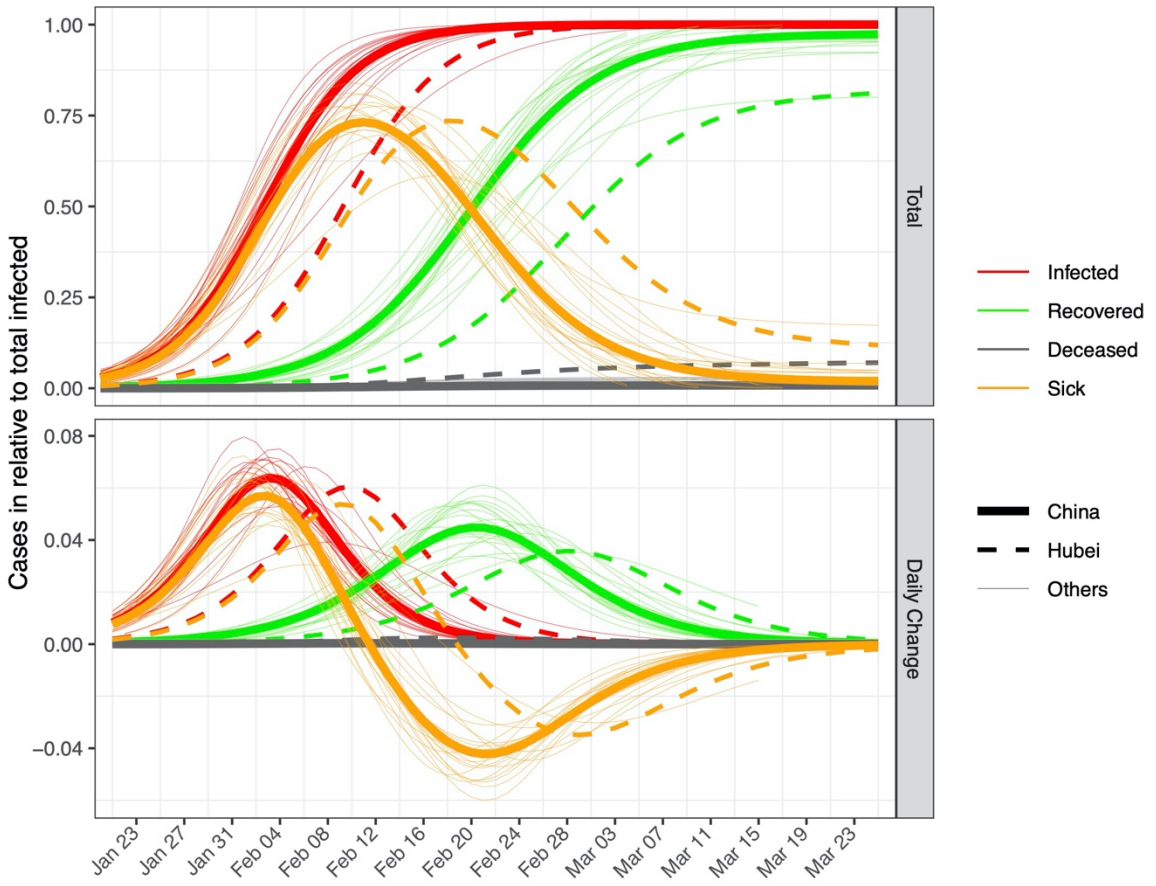

Fig. 1. Fitted epidemic curves based on the observed data of SARS-CoV2 in China excluding Hubei (thick solid lines), Hubei (dashed lines), and 19 other provinces (thin solid lines). The y-axis of the top panel shows the number of cases relative to the maximum cumulative infected for each region (the value *a*, see method). The bottom panel shows the daily change on the same relative scale. Red, green and grey colors indicate confirmed, recovered and deceased cases. Orange color indicates the number of "active" sick cases (relative to total infected, top panel), i.e. infected and not yet recovered or deceased, and the daily changes (bottom panel), with negative values in the lower panel indicating that the number of active cases is decreasing. Fitted and observed values for the true number can be found in Fig. A1 and Fig. A2 for normal scale and in Fig. A3 and Fig. A4 for log scale.

Table 1: Total confirmed infected cases (up to 10th March), emergency action start date and characteristics of logistic growth curves of epidemic progress in mainland China (excluding Hubei) and other 20 provinces with at least 150 cases of SARS-CoV2. Ratio refers to the sick cases at peak to the total number of infected cases at action date.

Region	Total confirmed infected cases	Emergency action start date	Peak date of active sick cases (or peak daily death)	Daily increase peak date	Daily increase end date	Delay from action until sick peak	Delay from action until maximum rate	Time from action to the outbreak end	Time from maximum rate till sick peak	Max Sick cases	Cases at time of maximum daily increase	Total infected cases at maximum daily increase date	Relative rate At peak increase rate (cases/case/d)	Ratio no reporting delay	Ratio 6 days reporting delay
China excluding Hubei	13004	24-Jan	11-Feb	3-Feb	6-Mar	18	10	42	8	9423	823	6692	0.12	9.5	2.6
Hubei	67773	24-Jan	18-Feb	10-Feb	21-Mar	25	17	57	8	49719	4086	36796	0.11	38.5	9.6
Guangdong	1353	23-Jan	10-Feb	3-Feb	24-Feb	18	11	32	7	1009	95	765	0.12	13.7	3.1
Henan	1272	25-Jan	10-Feb	3-Feb	24-Feb	16	9	30	7	947	91	659	0.14	10.0	2.4
Zhejiang	1215	23-Jan	9-Feb	1-Feb	20-Feb	17	9	28	8	926	95	648	0.15	12.4	2.5
Hunan	1018	23-Jan	9-Feb	2-Feb	23-Feb	17	10	31	7	718	72	516	0.14	12.7	2.9
Anhui	990	24-Jan	11-Feb	4-Feb	24-Feb	18	11	31	7	781	70	542	0.13	15.4	3.5
Jiangxi	935	24-Jan	11-Feb	4-Feb	23-Feb	18	11	30	7	731	70	529	0.13	17.3	3.5
Shandong	758	24-Jan	17-Feb	8-Feb	10-Mar	24	15	46	9	451	30	399	0.08	6.3	2.8
Jiangsu	631	25-Jan	11-Feb	4-Feb	24-Feb	17	10	30	7	451	41	337	0.12	8.9	2.5
Chongqing	576	24-Jan	11-Feb	2-Feb	24-Feb	18	9	31	9	416	33	291	0.11	6.2	2.1
Sichuan	539	24-Jan	13-Feb	4-Feb	26-Feb	20	11	33	9	373	28	291	0.10	6.7	2.4
Heilongjiang	482	25-Jan	14-Feb	6-Feb	25-Feb	20	12	31	8	374	33	247	0.13	20.4	4.6
Beijing	435	24-Jan	11-Feb	3-Feb	23-Feb	18	10	30	8	299	24	223	0.11	6.8	2.3
Shanghai	344	24-Jan	9-Feb	2-Feb	19-Feb	16	9	26	7	261	23	190	0.12	7.7	2.1
Hebei	318	24-Jan	12-Feb	5-Feb	25-Feb	19	12	32	7	207	18	161	0.11	10.3	3.1
Fujian	296	24-Jan	10-Feb	1-Feb	18-Feb	17	8	25	9	238	21	149	0.14	8.2	2.2
Guangxi	252	24-Jan	12-Feb	3-Feb	21-Feb	19	10	28	9	195	14	137	0.10	7.1	2.4
Shaanxi	245	25-Jan	11-Feb	2-Feb	19-Feb	17	8	25	9	197	16	126	0.12	6.8	2.1
Yunnan	174	24-Jan	10-Feb	1-Feb	16-Feb	17	8	23	9	145	11	91	0.13	7.1	2.1
Hainan	168	25-Jan	11-Feb	4-Feb	20-Feb	17	10	26	7	120	10	94	0.10	6.2	2.1

144 Modelled logistic curves show that the total number of infected cases had plateaued by 21
145 March for Hubei and by 6 March for the rest of mainland China, i.e. 57 and 42 days (range:
146 23 to 46 days) after the start of suppression measures (Fig. 1, Table 1). No new cases were
147 reported within mainland China on 18, 19 and 20 March, 2020, with all new cases on those
148 days from oversea travel, signaling the beginning of the end of the outbreak. However
149 isolated cases still occur, e.g. there was one new case on 24 March in Hubei.
150
151 The analysis shown in these figures was continually updated from 1 February to 3 March
152 while the epidemic was progressing[18]. Based on the data up till 16 February 2020, a peak in
153 sick incidence was identified for 12 February, which was proven correct[19]. Thus, logistic
154 models may be used to determine early when suppression measures are expected to result in
155 decreased rate of epidemic growth and a decline in number of sick cases. However, any model
156 shows lack of fit[16]. The logistic model does not capture that the rate of increase in the early
157 epidemic is faster than the rate of decline during the tapering out of the epidemic (Appendix
158 A1). Thus, the logistic underestimates both the early relative growth rate and the increase of
159 the number of sick people from the start of measures till the peak for the Chinese data
160 (Appendix A1). Uncertainties in predictions also result from unknown reporting delay[9].
161 Improvements may be possible by defining better tailored models, and especially, by
162 collecting better data, e.g. more (random) testing.
163
164 The results show that suppression can lead to (almost) complete removal of active virus
165 infected cases from the population, although given that not all active cases have recovered,
166 the outbreak is not completely over. The virus can still be present in asymptomatic individuals
167 or it can be re-introduced from unknown reservoirs or foreign countries. Because the vast
168 majority of the population is not immune to SARS-SoV2, the virus can then rapidly re-

169 establish. Therefore, suppression needs to be followed up by **containment**, a strategy based
170 on strict surveillance, testing of all individuals with symptoms, and followed by isolation of
171 all infected individuals and their recent contacts. Currently, in many provinces, except for
172 Hubei, quarantine restrictions are slowly being lifted, after no new cases have been detected
173 for several weeks, allowing people to return to work and businesses to start up again.
174 Moreover, in of China, schools are preparing to reopen in early April and normal social
175 activities are slowly resuming[20]. These findings indicate that the implemented measures have
176 been effective for controlling SARS-CoV2 transmission in China[21,22].
177
178 Many individuals infected with SARS-CoV2 show minimal or no symptoms. Due in part to
179 asymptomatic carriers, many infected individuals remain untested and unreported. It is
180 estimated that unreported cases were responsible for 77% of the reproduction number of the
181 disease before the start of measures in China and 16-21% thereafter[9,10]. Moreover, about half
182 of infected individuals that develop symptoms do not show symptoms until 5 days after
183 infection, and some not up to 14 days, and maybe even up to 30 days[10,23]. Cases with a long
184 incubation period, if they exist, can contribute to re-emergence of COVID-19 after restrictions
185 are lifted. However, as the experience in China and several other countries/regions (e.g. South
186 Korea, Taiwan, Hongkong, Japan and Singapore) has shown, a containment strategy can
187 prevent the virus from uncontrolled spread if it re-emerges. However, such containment
188 strategies have been implemented in only few countries thus far. Given the worldwide
189 pandemic spread of SARS-CoV2, it seems increasingly unavoidable that worldwide
190 containment will depend on a vaccine. Until a vaccine is ready and accessible, the world
191 population must confront the pandemic by combining suppression and containment in a
192 practical way that minimizes the human and economic costs. As noted by Wu and McGoogan

(2020), "It is not only individual rights that need to be considered. The rights of those who are not infected, but at risk of infection, must be considered as well."

The most important lessons from the outbreak and its control in China are in our opinion:

1. Suppression of SARS-CoV-2 is possible even after widespread community transmission.
2. Suppression can be achieved in one to two months if stringent measures are implemented and maintained.
3. If implementation of stringent suppression measures is delayed, as was the case in Hubei, the peak outbreak time is later, the increase in the number of sick people is greater, the mortality rate is higher, and the necessary period of suppression is longer.
4. China provides compelling evidence that suppression of SARS-CoV-2 transmission can be achieved within 60 days, even following widespread community transmission. It is the opinion of the authors that addressing the widespread SARS-CoV-2 transmission in other countries with unproven mitigation strategies may subject a large part of their populations unnecessarily to the adverse health risks associated with COVID-19[7,24].

Methods

All data were extracted from official reports from the National Health Commission of China[25]. We obtained time series data of total confirmed, total recovered, and total death cases for each provinces of China. We used the data starting on 21 January when reporting daily infected cases started at the national level, and up to 10 March 2020 when almost no new confirmed case in China[25]. We did not use data after 10 March to minimize the influence of cases introduced from outside of China.

We used three-parameter logistic models to fit the time series of the total confirmed and of the total recovered cases. Parameters refer to the asymptotic value (a; number of cases), the inflection point of the curve (b; date) and a scale parameter (c; days).

$$T_t = \frac{a}{1 + \exp\left(\frac{b - t}{c}\right)}$$

$$C_t = \frac{a_2}{1 + \exp\left(\frac{b_2 - t}{c_2}\right)}$$

where T_t and C_t are total infected and recovered cases at day t.

In addition, we assume a constant daily death rate k, which was calculated as the average of number of deceased each day divided by the infected cases at that day:

$$k = \frac{1}{n}\sum_{i=1}^{n}\frac{D_i}{I_i}$$

Where D_t and I_t are the number of daily death cases and active infected cases at day t. We excluded data before 25 January and data where $I_t < 50$ in this calculation, as values may be over-estimated at that early stage of the outbreak (under-estimated denominator) and at low I_t (high variability in the outcome).

We then calculated the active infected cases, which can be expressed as

$$I_t = T_t - TD_t - C_t$$

Of which TD_t is the number of total death at day t, which equals

$$TD_t = \sum_{i=1}^{t} k\, I_i$$

And therefore (see Appendix 1 for inference)

239 $$I_t = \frac{(T_t - T_{t-1}) - (C_t - C_{t-1}) + I_{t-1}}{1 + k}$$

240

241 where $T_t - T_{t\text{-}1}$ is the daily change in the number of infected cases, and $C_t - C_{t\text{-}1}$ is the daily

242 change in the number of recovered cases.

243

244 Based on the fitted model, we then calculated the peak date of 1) active sick people, which is

245 also the date of peak number of daily death, 2) number of sick cases during the peak, 3) the

246 date of maximum increase in the number of infected cases and 4) the daily rate of increase on

247 this date, 5) total infected cases on this date, 6) the relative rate on this date, 7) the end date of

248 daily increase (<1) case (operationally the end of the epidemic), and 8) time from maximum

249 increase till sick peak. Taking the date of public health emergency action as the

250 implementation of suppression measures[26], which varied between 23 January to 25 January

251 across provinces (we set the median date, 24 January as the date for entire China), we then

252 calculated 9) the delay from the action date until the sick peak, 10) the delay from the action

253 date until the date at which the rate of increase peaked, 11) the time from suppression measure

254 till the end date of daily increase in number of reported infections, 12) the ratio between sick

255 cases at peak and total infected case at the action date, as well as 13) the same ratio

256 considering a reporting delay of 6 days[9], i.e. by taking the ratio of sick(t_{peak})/sick(t_{action}+6).

257

258 Calculations were made for 20 Chinese provinces with more than 150 infected cases, and also

259 for China excluding Hubei, by far the worst affected province. . The built-in function

260 "SSlogis" in R[27] was used to fit logistic growth curves. Data were obtained using package

261 "nCov2019" [28,29].

262

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Supplementary information

Table A1. Estimated model parameters per province and for China (excluding Hubei) and other 20 provinces with at least 150 cases of SARS-CoV2

Region	Daily fatality rate (%)	a	b	c	R-squared	a2	b2	c2	R-squared2
China (excluding Hubei)	0.05 ± 0.01	12882 ± 42	14.7 ± 0.1	3.91 ± 0.07	0.999	12558 ± 83	31.9 ± 0.1	5.43 ± 0.09	0.999
Hubei	0.34 ± 0.05	67622 ± 463	21.3 ± 0.2	4.13 ± 0.13	0.996	55387 ± 556	39.6 ± 0.2	5.73 ± 0.08	0.999
Guangdong	0.05 ± 0.03	1344 ± 3	14 ± 0.1	3.52 ± 0.05	0.999	1304 ± 24	32.4 ± 0.4	6.19 ± 0.24	0.995
Henan	0.17 ± 0.06	1270 ± 4	13.7 ± 0.1	3.47 ± 0.06	0.999	1288 ± 8	29.8 ± 0.1	4.62 ± 0.09	0.999
Zhejiang	0.00 ± 0.00	1196 ± 5	12.5 ± 0.1	3.13 ± 0.09	0.997	1245 ± 16	31.6 ± 0.3	6.30 ± 0.18	0.997
Hunan	0.02 ± 0.01	1018 ± 3	12.9 ± 0.1	3.50 ± 0.07	0.999	972 ± 11	27.8 ± 0.2	5.30 ± 0.17	0.997
Anhui	0.02 ± 0.01	993 ± 2	15.3 ± 0.1	3.54 ± 0.04	0.999	1003 ± 5	32.4 ± 0.1	4.43 ± 0.06	0.999
Jiangxi	0.00 ± 0.00	936 ± 3	15.1 ± 0.1	3.32 ± 0.06	0.999	938 ± 5	31.6 ± 0.1	4.61 ± 0.07	0.999
Shandong	0.04 ± 0.02	774 ± 13	19.6 ± 0.5	6.39 ± 0.40	0.979	854 ± 39	39.6 ± 0.9	7.81 ± 0.37	0.993
Jiangsu	0.00 ± 0.00	635 ± 2	13.5 ± 0.1	3.89 ± 0.09	0.998	616 ± 5	28.9 ± 0.1	4.89 ± 0.12	0.998
Chongqing	0.05 ± 0.02	575 ± 2	12.9 ± 0.1	4.40 ± 0.09	0.998	543 ± 9	30.8 ± 0.3	5.57 ± 0.22	0.995
Sichuan	0.03 ± 0.02	536 ± 3	15.2 ± 0.2	4.72 ± 0.14	0.996	515 ± 9	34.7 ± 0.3	6.89 ± 0.19	0.997
Beijing	0.11 ± 0.05	411 ± 2	14.2 ± 0.1	4.35 ± 0.12	0.996	330 ± 3	31.9 ± 0.2	5.92 ± 0.11	0.999
Heilongjiang	0.15 ± 0.05	482 ± 2	16.8 ± 0.1	3.66 ± 0.06	0.999	445 ± 6	34.7 ± 0.2	5.03 ± 0.15	0.997
Shanghai	0.04 ± 0.03	337 ± 1	13 ± 0.1	3.67 ± 0.06	0.999	311 ± 2	29.4 ± 0.1	4.35 ± 0.11	0.998
Hebei	0.11 ± 0.05	319 ± 2	14.9 ± 0.1	4.42 ± 0.12	0.997	315 ± 2	29 ± 0.1	4.56 ± 0.07	0.999
Fujian	0.02 ± 0.02	294 ± 2	10.9 ± 0.1	3.57 ± 0.12	0.995	307 ± 3	31.4 ± 0.2	5.45 ± 0.13	0.998
Guangxi	0.03 ± 0.02	251 ± 1	14.2 ± 0.1	4.38 ± 0.10	0.998	255 ± 3	35.7 ± 0.2	5.96 ± 0.14	0.998
Shaanxi	0.03 ± 0.03	244 ± 1	11.8 ± 0.1	3.89 ± 0.09	0.997	233 ± 2	30.1 ± 0.1	4.32 ± 0.11	0.998
Yunnan	0.07 ± 0.05	172 ± 1	12.6 ± 0.2	3.77 ± 0.19	0.988	177 ± 2	32.5 ± 0.2	4.20 ± 0.13	0.997
Hainan	0.18 ± 0.09	170 ± 1	15 ± 0.1	4.41 ± 0.12	0.996	163 ± 1	31.4 ± 0.1	4.64 ± 0.11	0.998

Fig. A1

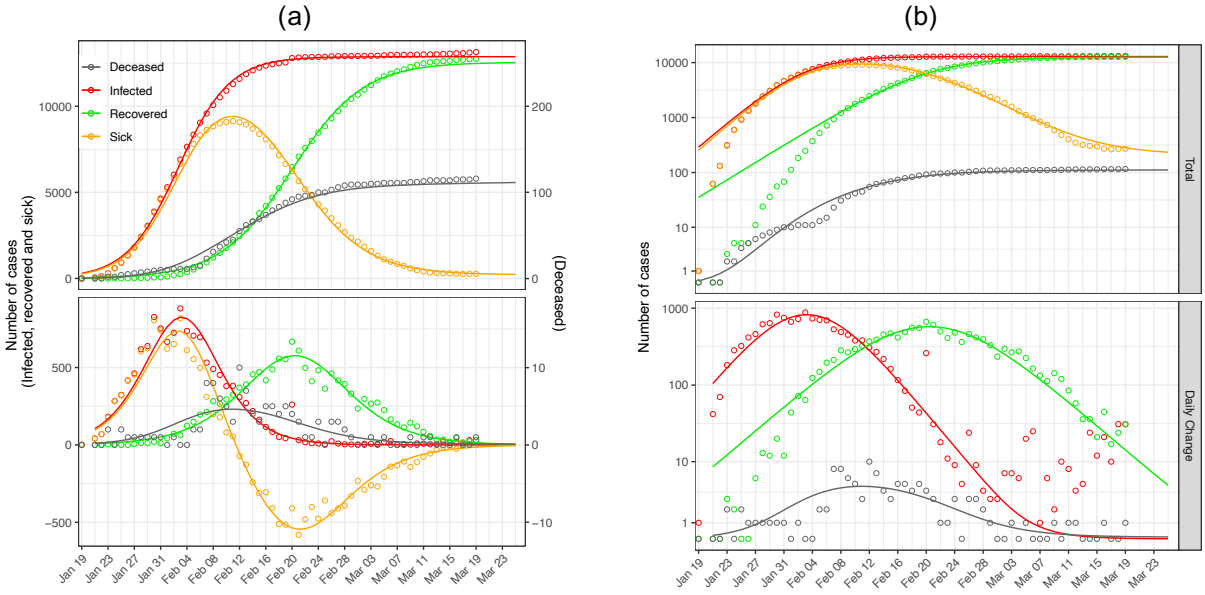

Fig. A1 Observed and fitted epidemics of SARS-CoV2 in mainland China excluding Hubei province for normal- (a) and log-scale (b) y-axis. Dots are observed cases and lines are model fits. Top panel refers total cases and bottom panel refers to daily changes. For the normal scale (A), the left y-axis is for infected, recovered and sick cases and the right y-axis for deceased cases. Red colour indicates the total number of infected cases (confirmed and suspected) (top panel) or the daily rate of increase in the number of cases (bottom panel). Green colour indicate the recovered cases in both panels. Grey colour indicates cumulative deaths in the upper graph and daily death cases in the lower panel. Orange colour indicates the number of "active" cases (top panel), i.e. infected and not yet recovered or deceased, and the daily change in the number of active cases (bottom panel). Negative values (in normal scale) in the lower panel mean that the number of active cases is decreasing.

Fig. A2-A

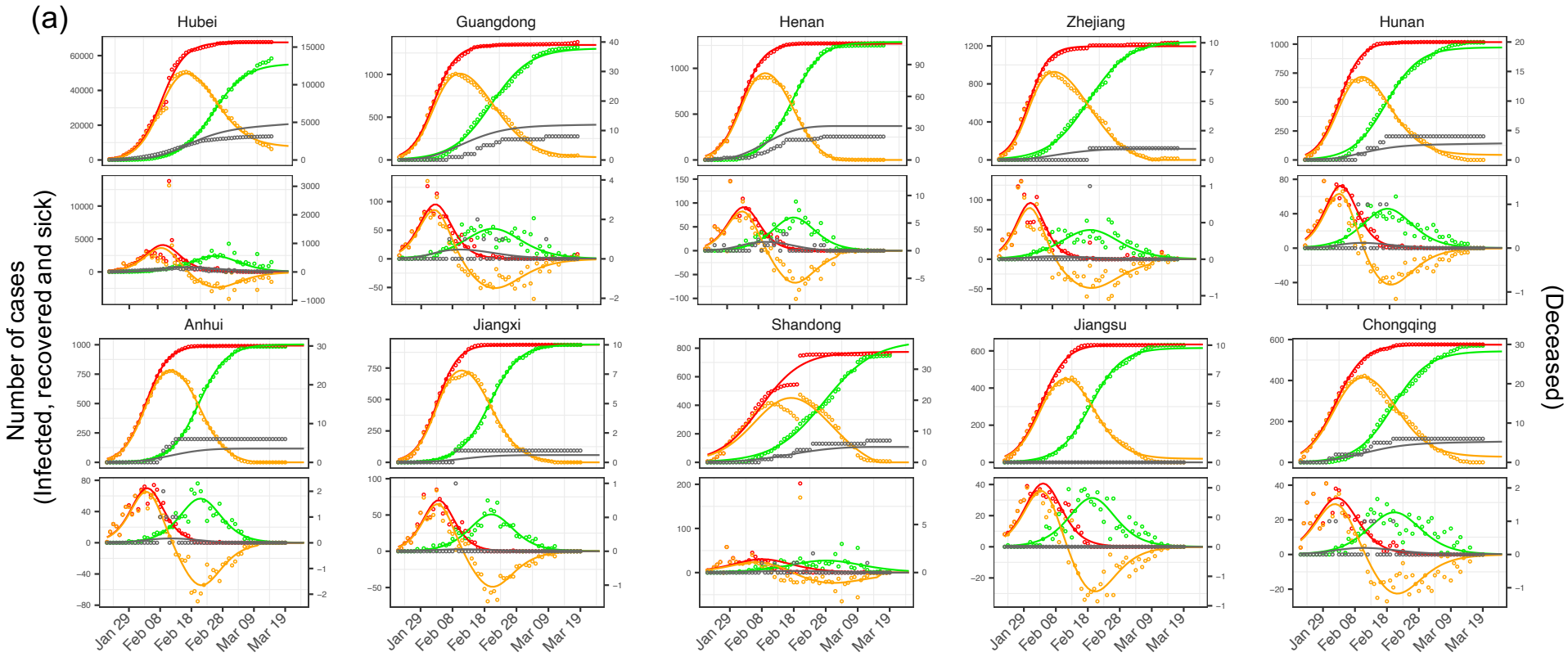
(a)
Hubei
Guangdong
Henan
Zhejiang
Hunan
Anhui
Jiangxi
Shandong
Jiangsu
Chongqing
Number of cases
(Infected, recovered and sick)
(Deceased)
Jan 29
Feb 08
Feb 18
Feb 28
Mar 09
Mar 19

Fig. A2-a (continue)

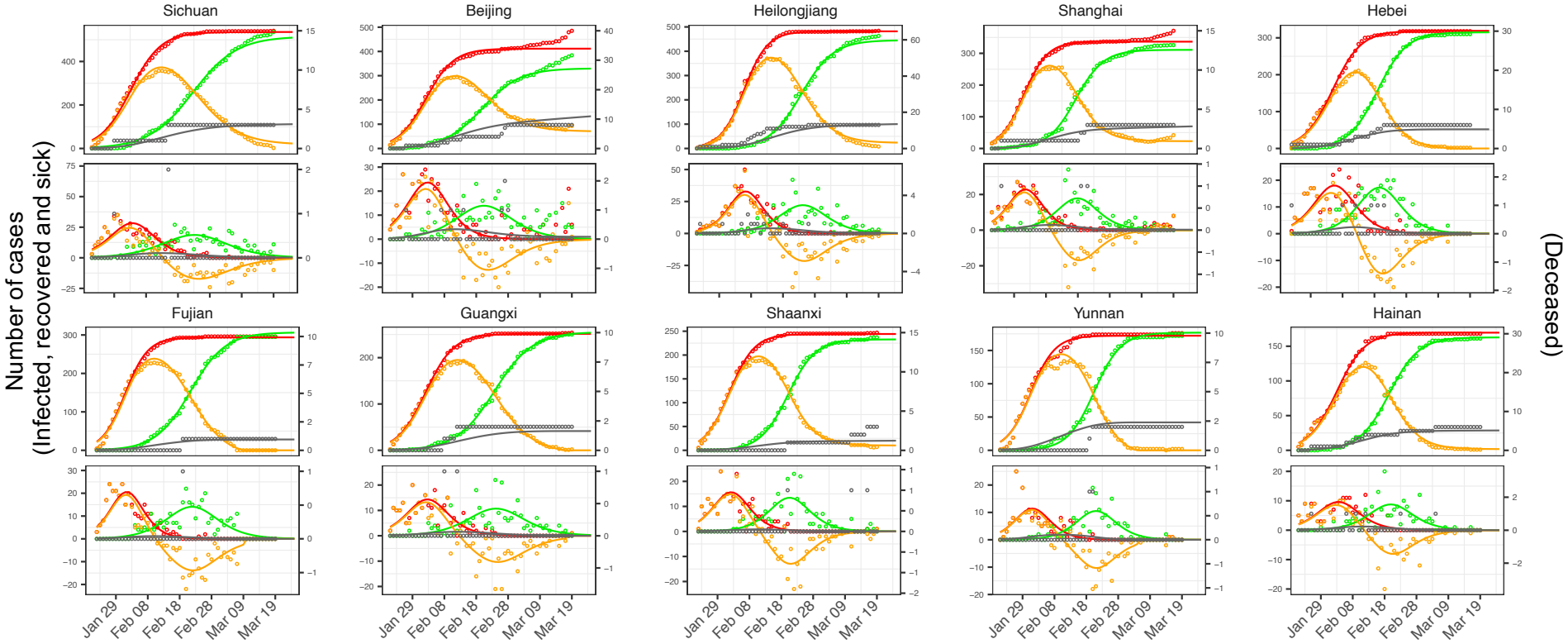

Fig. A2-b

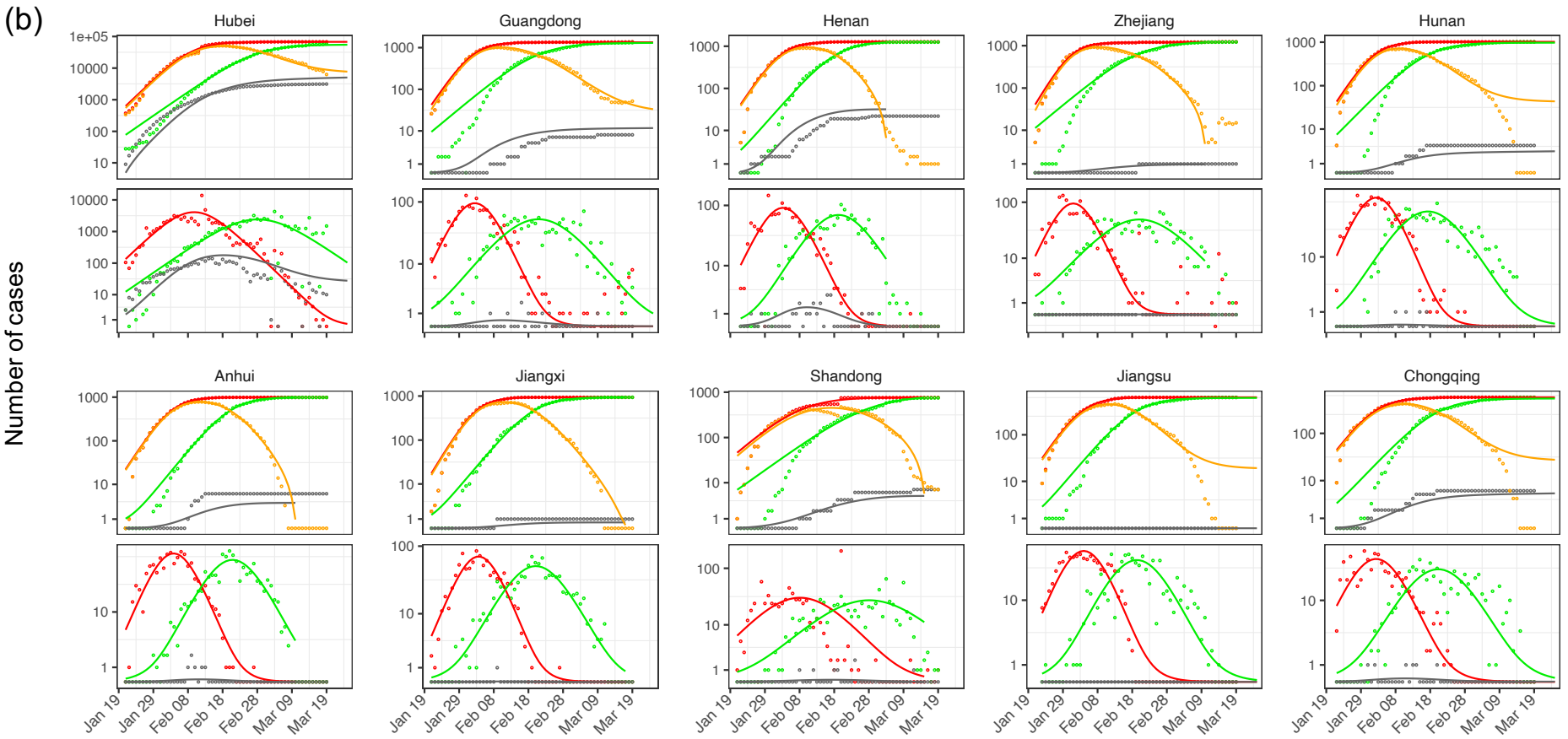
(b)
Number of cases
Hubei
Guangdong
Henan
Zhejiang
Hunan
Anhui
Jiangxi
Shandong
Jiangsu
Chongqing
Jan 19
Jan 29
Feb 08
Feb 18
Feb 28
Mar 09
Mar 19

Fig. A2-b (continue)

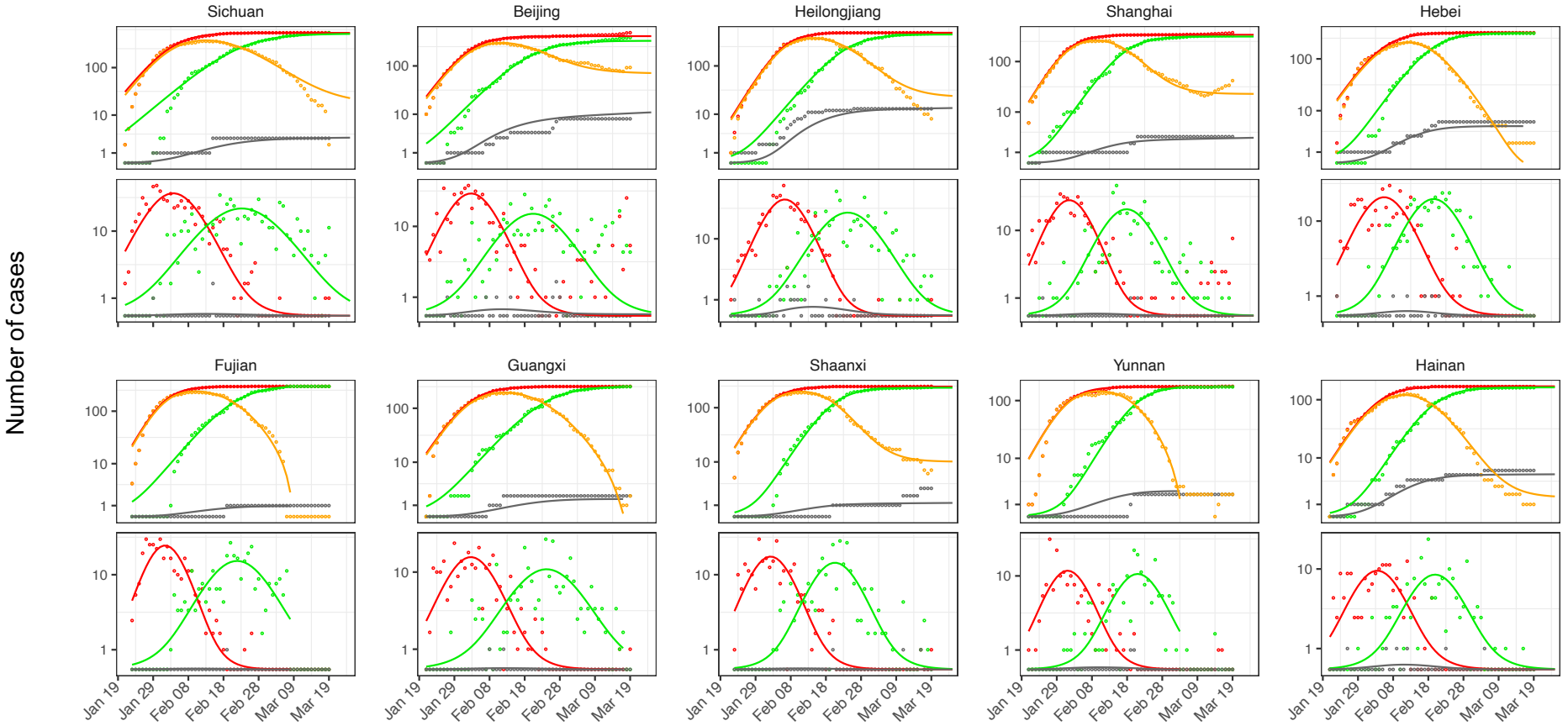

Fig. A2. Epidemics of SARS-CoV2 in 20 Chinese provinces with a minimum of 150 cases for normal- (a) and log-scale (b) y-axis. Dots are observed cases and lines are model fits. Red, green and grey colors indicate confirmed, recovered and deceased cases. For the normal scale (a), the left y-axis is for infected, recovered and sick cases and the right y-axis for deceased cases. Orange color indicates the number of "active" sick cases (relative to total infected, top panel), i.e. infected and not yet recovered or deceased, and the daily changes (bottom panel), with negative values (in normal scale) in the lower panel indicating that the number of active cases is decreasing. The upper panel for each province refers to the total number of cases while the lower panel refers to the daily change in the number of cases.

Appendix 1. Formula inference

$$I_t = T_t - \sum_{i=1}^{t} k\, I_i - C_t \quad (1)$$

$$I_{t-1} = T_{t-1} - \sum_{i=1}^{t-1} k\, I_i - C_{t-1} \quad (2)$$

Equation (1) - Equation (2)

$$I_t - I_{t-1} = (T_t - T_{t-1}) - (C_t - C_{t-1}) - k\, I_t$$

$$I_t - I_{t-1} + k\, I_t = (T_t - T_{t-1}) - (C_t - C_{t-1})$$

$$I_t + k\, I_t = (T_t - T_{t-1}) - (C_t - C_{t-1}) + I_{t-1}$$

$$I_t\,(1 + k) = (T_t - T_{t-1}) - (C_t - C_{t-1}) + I_{t-1}$$

Therefore,

$$I_t = \frac{(T_t - T_{t-1}) - (C_{t-1} - C_{t-1}) + I_{t-1}}{1 + k}$$