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Review Article

Modeling COVID-19 in Different Countries as Sequences of SI Waves

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Abstract

The COVID-19 pandemic has been a huge task worldwide for many institutions, researchers, national health organizations, and the pharmaceutical industry. As natural scientists and engineers, we attempt to contribute by calculating models and analyzing data to keep track of the pandemic.

While a frequent goal is to predict the next pandemic wave by considering all influencing parameters, we examined methods to calculate a model course of the entire pandemic. This is done by reconstructing the course of infections into multiple model waves, that sum up into a pandemic model close to the real course. The model wave parameters are varied by an algorithm such as the Excel solver to minimize the difference between the real and the model course.

By reconstructing the course of infections by the commonly known SIR model, we found the calculated model parameters to be ambiguous and difficult to interpret. In contrast, we found sequenced SI model waves to provide an astonishing precise digital representation of the pandemic course. Until November 2022, we found between six and 16 waves (depending on the country) in each of the 14 countries investigated.

The calculated parameters are easy to interpret, comparable among each other and between countries. They wave parameters may be correlated to virus types and measures in each country by other researchers. New waves are detectable early, as they show a certain deviation from the actual model wave. After the maximum of the last real wave, the model indicates the further procedure of the pandemic course.

Introduction

Modeling epidemic courses started with differential equations and probability calculations by Ross [1] and Kermack and McKendrick [2]. They developed the SI model of infections which considers only infected (I) and susceptible (S) person, and later the SIR model, which also includes recovered (R) persons.

Since January 2020, Johns Hopkins University (JHU, [3]) has been publishing data on global COVID-19 infections. When the first data of the new epidemic in China were available on the Internet, we started to model the John's Hopkins data according to the SI model of epidemic growth, successfully.

Later on, we have started to use data by the organization Our World in Data (OWID, [4]) as international input data. For Germany, we use data by the Robert-Koch-Institute (RKI, [5]).

We are varying the SI model parameters to minimize the difference between the real and the model course. In the first wave this has been done manually, later on, the high number of parameters lead us to use the Excel solver tool with the GRG nonlinear method.

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The SI model

We have started to analyze the data using the simple SI infection model of a population N that contains susceptible S(t) and infected people I(t):

$$N = S(t) + I(t) \qquad (1)$$

The number of daily new infected people n(t) at time t depends on the infection rate (b),

$$n(t) = d\,I(t) / (d\,t) = b * I(t) * S(t) / N \qquad (2)$$

Eq. (2) may be solved by a closed mathematical term, the sum of all infected people I(t) at time t is

$$I(t) = N / [1 + (N / I(0) - 1) * \exp(- b * t)] \qquad (3)$$

I(0) is the number of all infected people in the beginning, t = 0. The solution (3) contains two unknown parameters: the total number of susceptible people N and the infection rate b. These constants are easily obtained from the logarithmic plot of infection data, see below in figure 1.

China was the first country that was hit by COVID-19 infections. Initially, the fit of the SI model was in good agreement to the COVID-19 data in China, as shown in figure 1. The two unknown constants b and N have been obtained from the slope and the maximum in the logarithmic plot in figure 1.

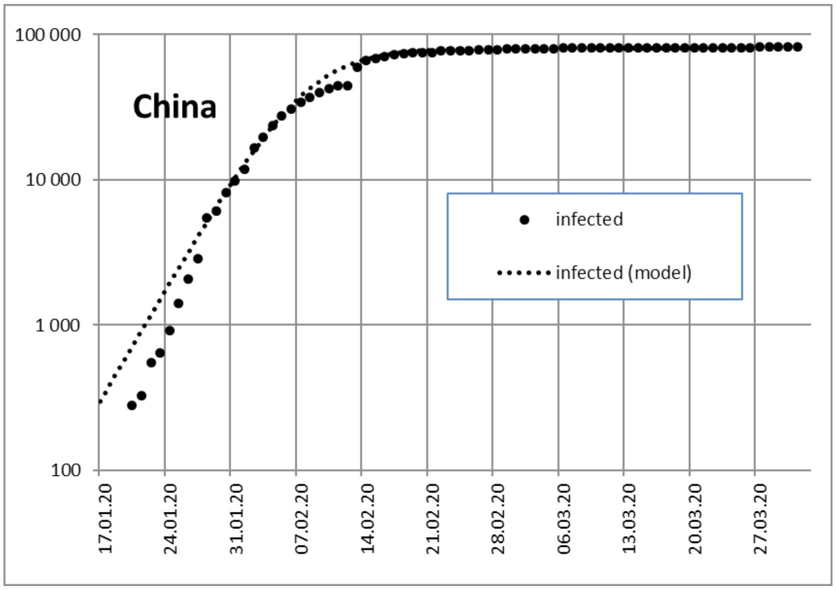

Figure 1: COVID-19 infection I(t) in China and SI model (logarithmic) [6]

In Europe, Italy was the first country that was hit by COVID-19 infections. When we modeled the course of infections in Italy after April, 2020, the simple SI model in figure 2 did not fit to the real course, as the SI model only allows for symmetrical model waves.

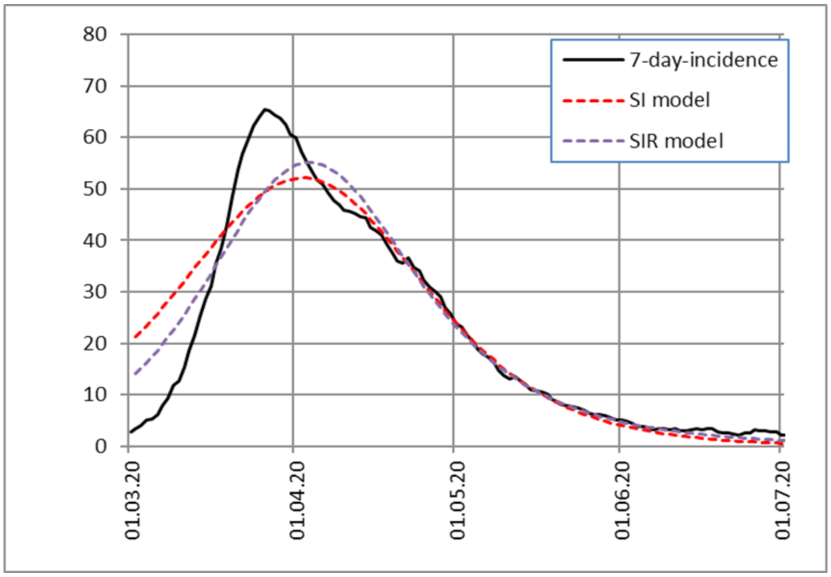

Figure 2: Asymmetrical wave of daily infected in Italy until the end of June 2020.

SIR model

To improve our modeling of COVID-19 data we started to implement the SIR model [2], which considers additionally the number of resistant, removed or recovered people R(t):

$$N = I(t) + S(t) + R(t) \quad (4)$$

A numerical iterative solution results in 3 equations,

$$\Delta S(t) = -b' * S(t-1) * I(t-1) \quad (5)$$

$$\Delta I(t) = b' * S(t-1) * I(t-1) - \gamma * I(t-1) \quad (6)$$

$$\Delta R(t) = \gamma * I(t-1) \quad (7)$$

where $b' = b/N$ is the infection rate, and γ (gamma) is the recovery rate.

If gamma equals zero, the model is equivalent to the SI model.

Figure 2 shows the data for new infections in Italy at the end of June 2020. The data have been approximated by the SI and the SIR model. As expected, the SI model does not agree very well with the data. The SIR model leads to an improvement, but still does not fit the data well. Only, when we added two SIR model waves, we obtained a very good approximation to the real course in figure 3, where we scaled the cases to “per million persons” (“pmp”):

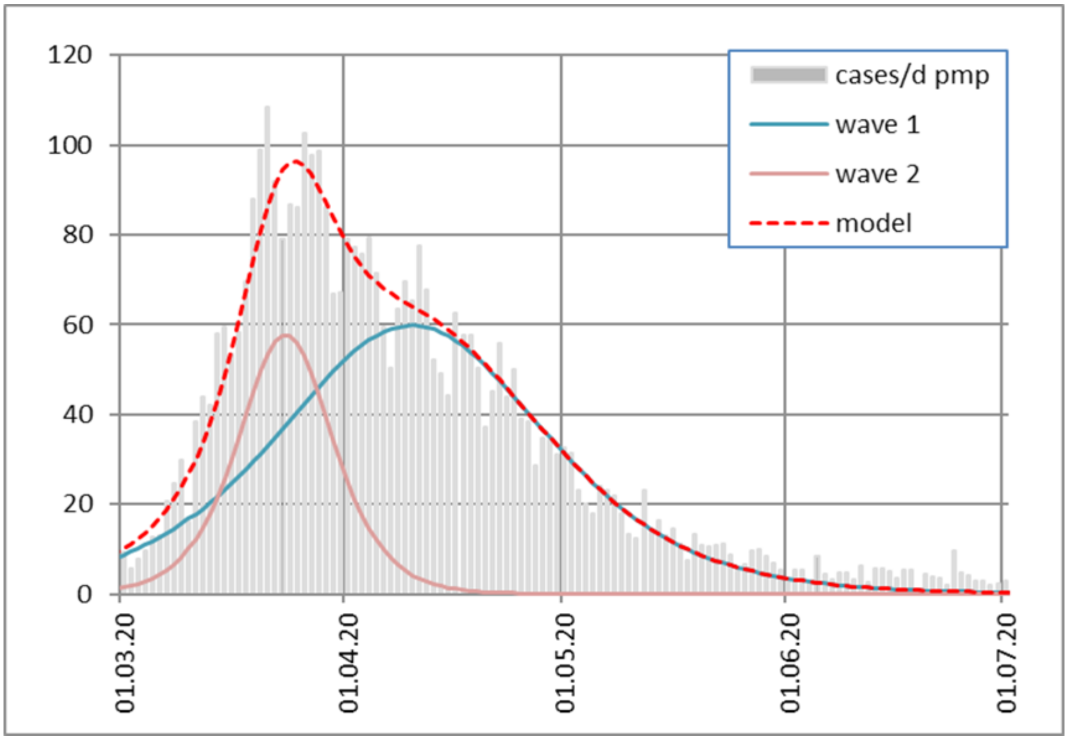

Figure 3: Daily infected in Italy with two model waves

The two different waves may be caused by

- local outbreaks in certain groups or regions
- different test measures
- different preventive measures
- another virus type etc.

Accordingly, we switched over to model with multiple SIR waves in the second wave of COVID-19 for obtaining better approximations.

India as an example of multiple model waves

When we took India as an example for approximating the real course by multiple SIR waves, we also got a very good approximation result (figure 4):

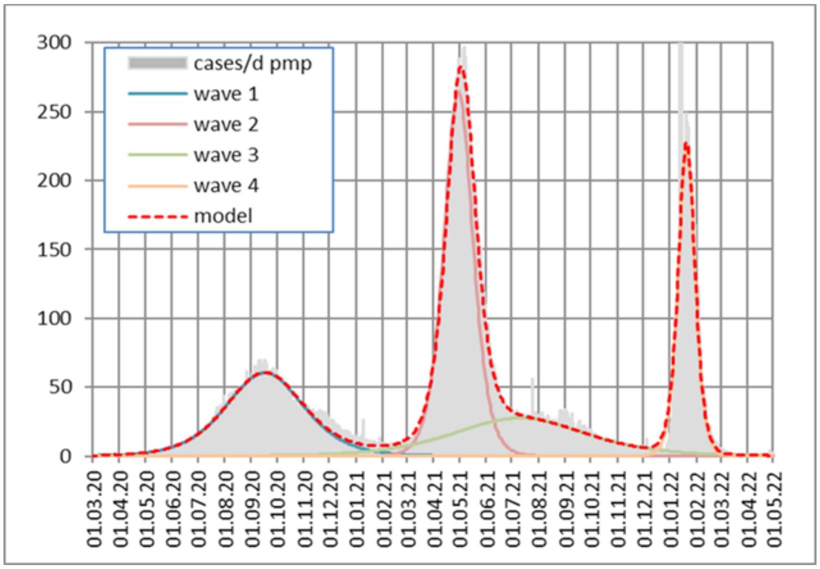

Figure 4: Daily infected in India

But when we look to the parameters of the iteratively calculated SIR model waves, the SIR parameters are not plausible (table I):

wave #	**infection rate b‘**	**infected persons pmp per wave, N**	**start day of next wave**	**gamma**
1	6 %	9 383	0	0.02
2	13 %	22 034	345	0.20
3	14 %	**53 063**	357	**0.73**
4	60 %	**6 566**	656	**0.19**

Table I**:** Modeled SIR waves in India (start day 0 is February 21, 2020).

The start day of a wave has been defined by us by one infected person per one million people.

The 3rd flat wave in India obviously does not have an 8 times higher value of infected persons than the 4th wave. This contradiction may be due to the fact, that SIR parameters are nonlinearly interconnected and cannot be separated unambiguously during the iteration process.

As approximated SIR parameters apparently do not give an insight into a wave, we switched back to SI models.

When we applied SI model waves to India instead of SIR waves, we got reasonable results. The 3rd and the 4th wave now have similar values, and all infection rates appear realistic for each wave (table II).

wave #	**infection rate b‘**	**infected persons pmp per wave, N**	**start day of next wave**	**gamma**
1	3 %	7 319	0	0
2	9 %	11 686	333	0
3	2 %	**5 826**	34	0
4	15 %	**5 821**	642	0

Table II**:** Modeled SI waves in India (start day 0 is February 20, 2020)

Spain as an example of multiple SI waves

Also, for more complicated courses, using SI model waves shows a low deviation between course and model (figure 5, figure A12). Figure 6 shows 10 modeled SI waves. The incidence scale in figure 5 is 0.7 times lower than the cases per day pmp scale in figure 6, because the incidence relates to a sum of 7 days and 100 000 people, while the cases per day relate to one day and 1 000 000 people.

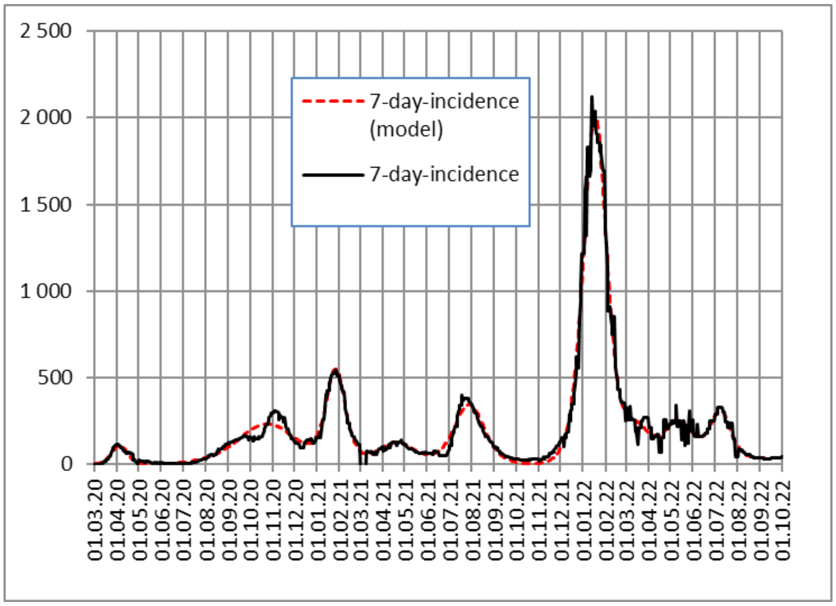

Figure 5: Daily infected in Spain

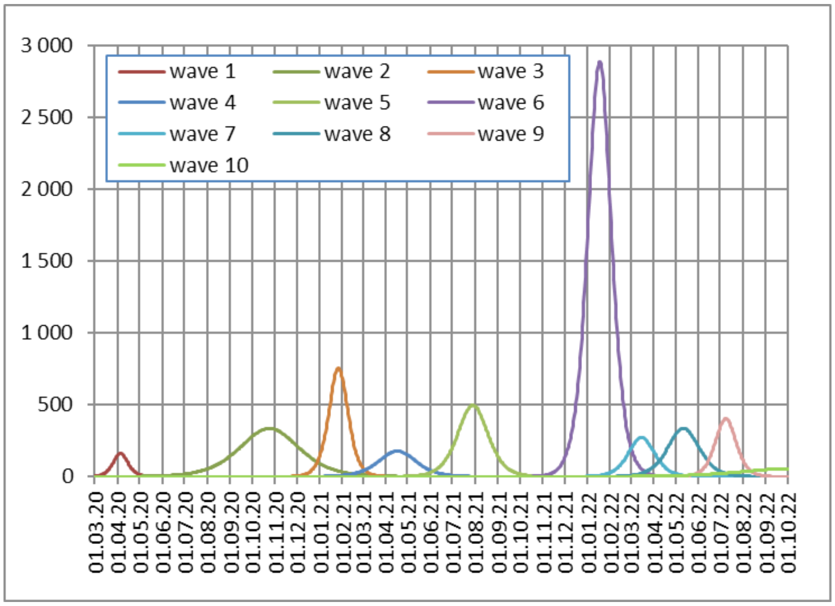

Figure 6: Daily infected in Spain, broken into SI model waves (cases/d pmp)

A new wave is modeled, if the total course approximation is improved.

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Approximation error

Table III shows the relative error of our model for different countries. The mean daily deviation of our model is given in relation to the mean value of daily cases.

Country	Mean approximation error 2022
AUT Austria	3.6 %
BRA Brazil	8.3 %
ESP Spain	8.3 %
DEU Germany	2.9 %
FRA France	5.9 %
GBR Great Britain	6.1 %
GRC Greece	3.9 %
IND India	6.7 %
ITA Italy	3.8 %
ISR Israel	7.6 %
JPN Japan	3.1 %
NLD Netherlands	7.4 %
SWE Sweden	11.0 %
USA	4.8 %
World	2.7 %

Table III: Approximation error per country.

The mean relative error of the investigated countries in table III is about 5.8 %. During 2022, some countries have begun to report only once a week. Therefore, the mean approximation error will increase.

SI waves and virus types

In Germany, the predominant virus types at each time are published by RKI [6], and we have assigned them to the SI waves. For some virus types apparently more than one wave occurred, indicated by roman numbers in figure 7, figure A04, and in table A04:

wave no.	day of maximum	main virus type
1	20-04-05	
2	20-12-16	
3	21-04-17	Alpha
4	21-09-11	Delta I
5	21-11-30	Delta II
6	22-02-08	Omicron BA.1
7	22-03-22	Omicron BA.2 I
8	22-04-28	Omicron BA.2 II
9	22-06-25	Omicron BA.5 I
10	22-07-19	Omicron BA.5 II
11	22-08-20	Omicron BA.5 III
12	22-10-14	Omicron BA.5 IV

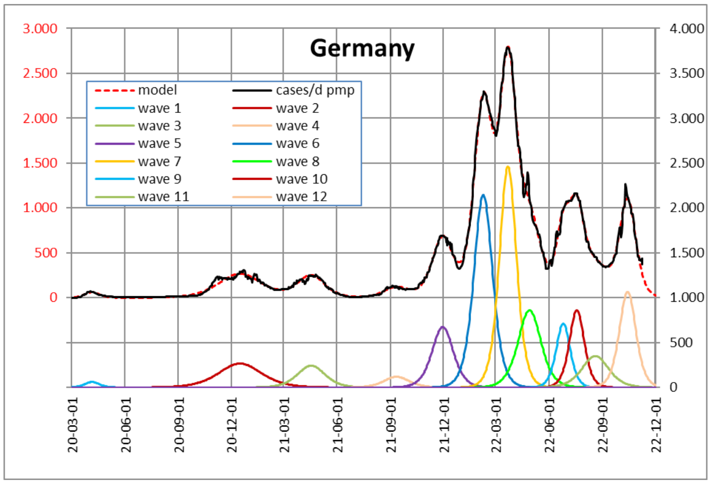

Figure 7: Daily infected in Germany (Updated. Left axis: real course and model. Right axis: model waves)

Even when there are no virus type data available, it may be possible to assign the virus types by comparison between waves of different countries during the same time interval.

SI waves for prediction

The last model wave of a real course may appear as suited to predict the further progression of infections. This may be possible once the wave in reality has reached its maximum. But at the start of a wave, the slope of an SI function is nearly independent of the later maximum (figure 8). That means that slight variations of the real data result in strong variations of the time point and height of the model's maximum.

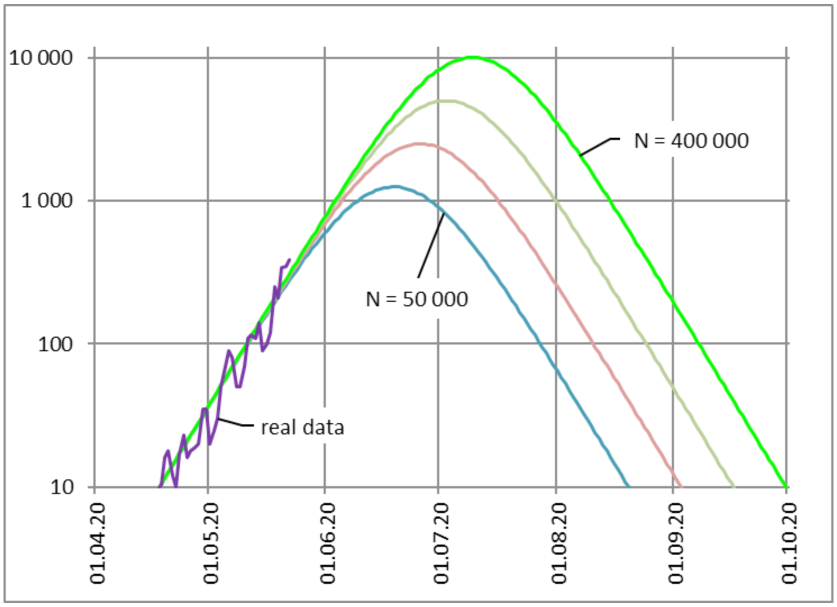

Figure 8: SI waves with different peaks but similar positive slope (logarithmic scale)

We have to wait until the slope of the real wave becomes negative to be sure that the maximum has really been reached. At least, the positive slope indicates the minimum number of persons who will be infected until the end of that wave. On the other hand, if the negative slope of the real data deviates strongly from the modeled waves, it indicates a new wave. After June 2020, that happened almost every time in all investigated countries during a negative slope (figure A01 to figure A14).

Using SI parameters

SI waves are comparable or sortable by each parameter, including the start day, the calculated maximum day, or the duration of a wave. Table IV shows an example where the Omicron BA.1 I waves are sorted by the number N of infected persons.

Country	**day of maximum**	**Infection rate**	**infected in wave BA.1 I (pmp)**
FRA	22-01-24	10,7%	196.562
NLD	22-02-05	10,4%	174.105
ISR	22-01-26	17,0%	168.968
AUT	22-02-06	9,8%	154.388
ESP	22-01-17	9,3%	121.113
ITA	22-01-19	10,1%	119.733
SWE	22-01-28	14,8%	94.485
DEU	22-02-08	9,3%	91.956
USA	22-01-17	11,7%	76.324
GBR	22-01-05	15,8%	52.371
GRC	22-01-03	29,2%	39.021
BRA	22-01-30	14,8%	18.238
JPN	22-02-06	13,9%	17.257
IND	22-01-24	15,2%	5.808

Table IV: Waves of Omicron BA.1 I, sorted by the number N of infected persons.

Special observations

In Great Britain (figure 9, figure A05) and in the world data (figure 10, figure A15), we detected also very long waves, lasting more than 18 months.

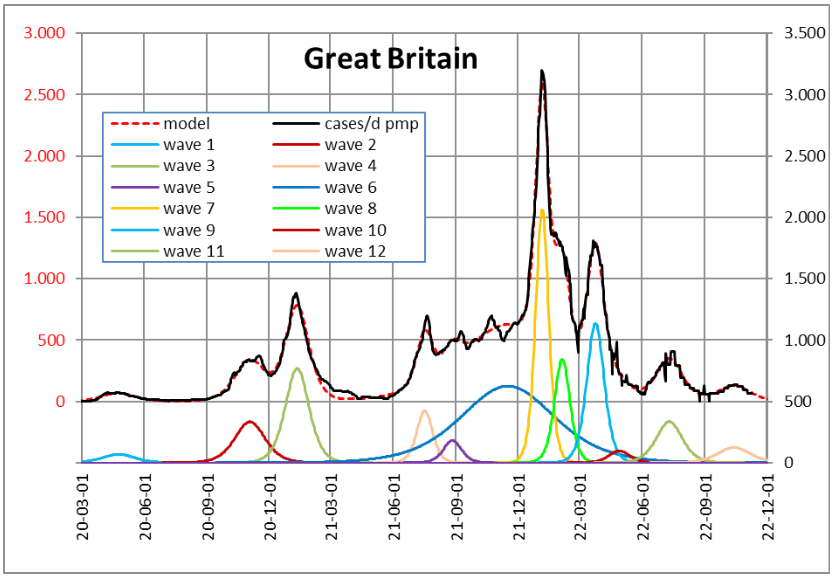

Figure 9: Daily infected in Great Britain, long wave 6 (blue)

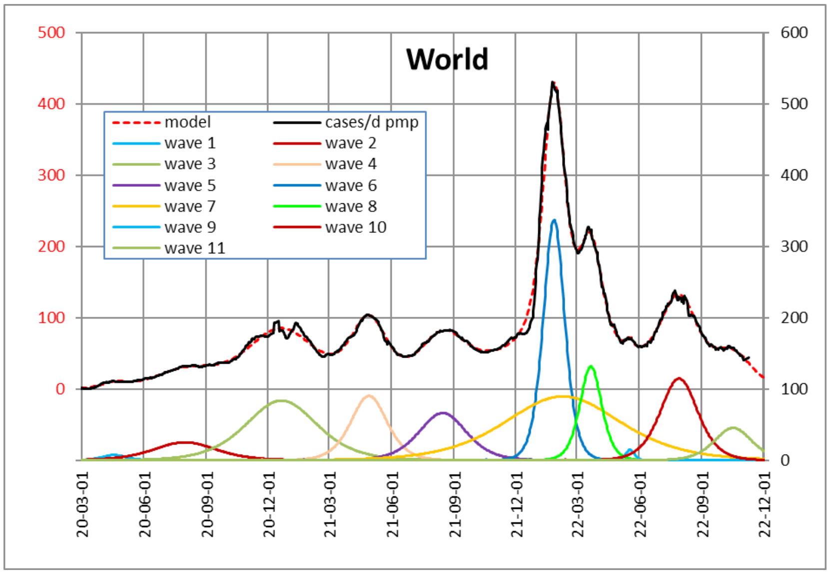

Figure 10: Daily infected in the World, long wave 7.

Another interesting effect is that despite of lock downs, vaccinations or other measures, the total course of the pandemic may be modeled very well by simple symmetrical SI waves. This is obviously due to the fact that lock downs and other measures only affect the height of a wave, not the shape.

Publication of the modeling results

Our results are used by a local medical COVID-19 committee in our city of Paderborn/Germany. Link: praxisnetz-pb.de/aktuelles-2/

We used the Excel solver for iteration of parameters allowing for an easy use for everyone. The Excel sheets also do not contain macros. The complete Excel sheets are available for free download and free use. Each of about 190 countries reported by "Our World in Data" is available by changing the country code within a sheet. Link: www.janssenplan.de („ activities ")

Conclusions

The complete COVID-19 course of 14 countries has been modeled well by about six to 16 SI waves until November 2022. Asymmetrical waves of cases per day have been modeled by two or more symmetrical waves. While SIR wave parameters are ambiguous and give no insight into a wave, we use SI wave parameters, that are unambiguous and easy to assign. They are well comparable among each other and between countries. The parameters may be correlated to virus types and also to preventive measures if known in each country. New waves are early detectable, as they show an early deviation from the actual model wave. The last wave of the wave sequence gives an indication how the pandemic will proceed.

All wave data and the underlying Excel file including a help sheet are published and are free for public use.

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Annex

In each figure A01 to A15 in this annex, the course of infections, the model of the course and the model waves are shown in a common figure. For a better visibility, the waves are shown there with a small distance to the course and the model course. In addition, the wave parameters are given in table A01 to table A15. The start day is omitted if it lies outside of the range the figure.

If input data have been extremely implausible, they have been replaced by the mean of the neighbored values.

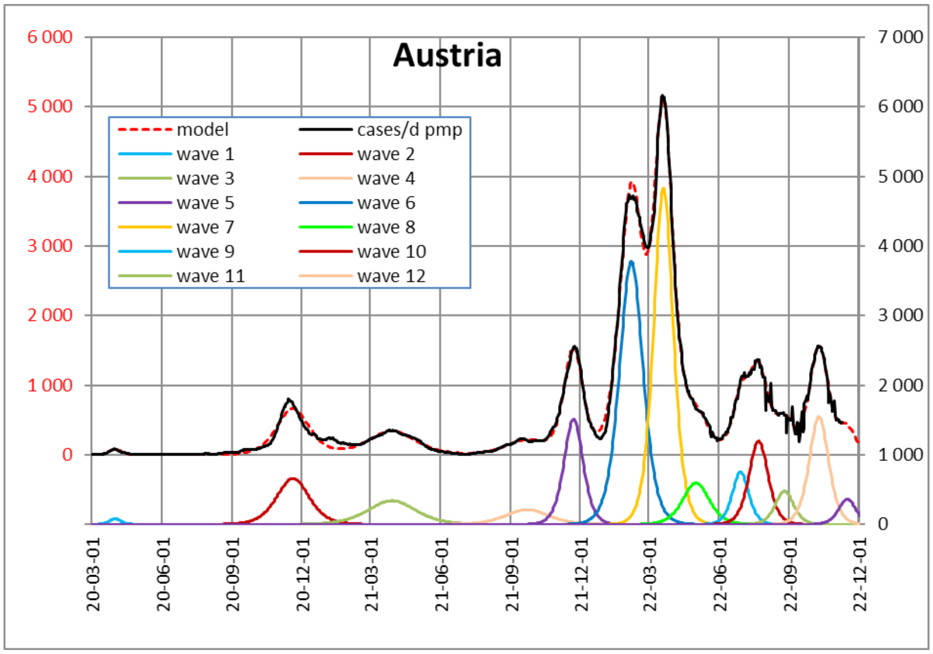

Figure A01: Austria, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-01	**19.4%**	**1 689**		**0.9**	
2	20-11-20	**7.0%**	**37 828**	**121**	**1.0**	
3	21-03-29	**4.8%**	**28 667**	**186**	**1.0**	
4	21-09-23	**5.4%**	**15 973**	**399**	**1.0**	
5	21-11-22	**12.0%**	**50 265**	**550**	**1.0**	
6	22-02-06	**9.8%**	**154 388**	**594**	**1.0**	Omicron BA.1
7	22-03-20	**11.8%**	**163 893**	**656**	**1.0**	
8	22-05-02	**8.6%**	**27 732**	**681**	**1.0**	
9	22-06-29	**13.9%**	**21 669**	**787**	**1.0**	
10	22-07-23	**12.0%**	**39 922**	**794**	**1.0**	
11	22-08-26	**12.5%**	**15 378**	**839**	**1.0**	
12	22-10-10	**11.9%**	**52 225**	**870**	**1.0**	
13	22-11-16	**13.1%**	**11 116**	**927**	**1.0**	

Table A01: Austria, SI parameters.

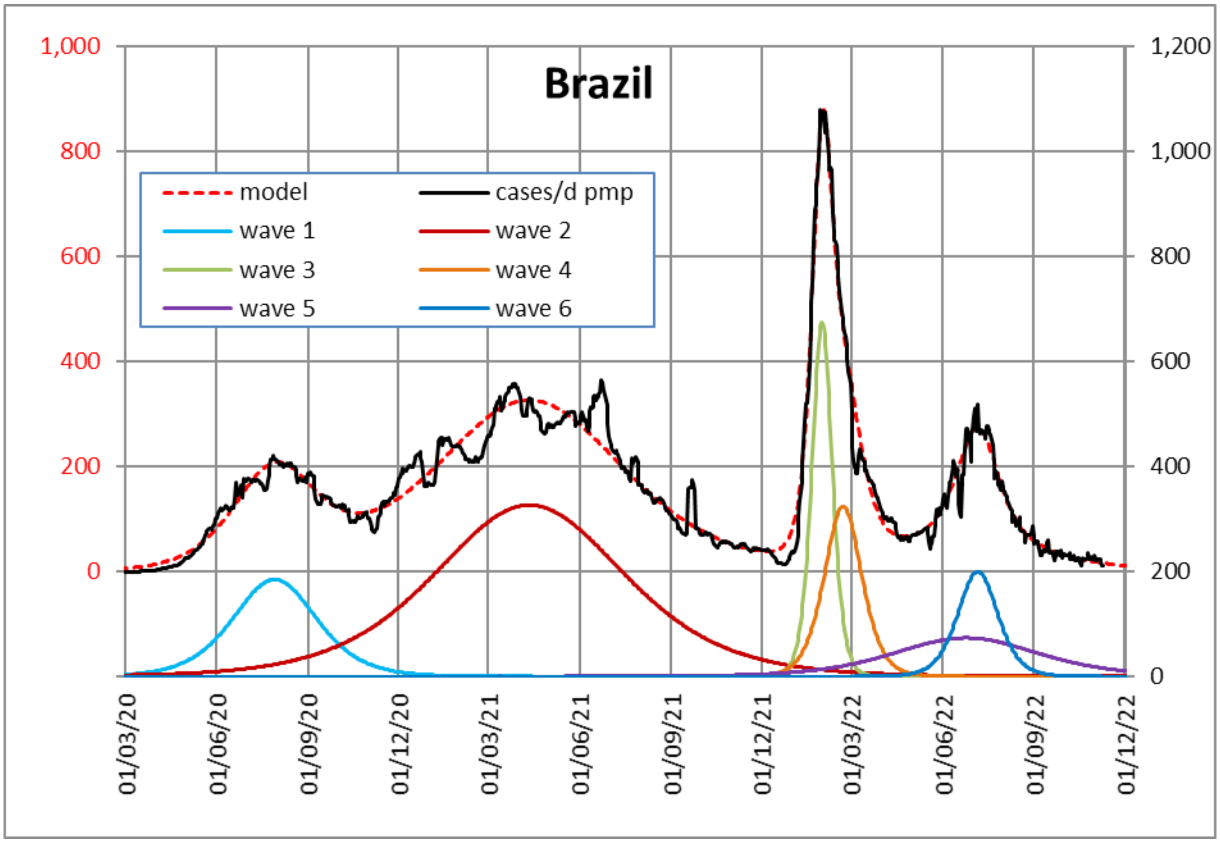

Figure A02: Brazil, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-07-29	**3.6%**	**20 811**		**74.7**	
2	21-04-11	**1.6%**	**83 378**		**126.6**	
3	22-01-30	**14.8%**	**18 238**	**643**	**1.0**	Omicron BA.1
4	22-02-21	**7.9%**	**16 303**	**608**	**1.0**	
5	22-06-24	**2.0%**	**14 367**	**385**	**1.0**	
6	22-07-06	**7.5%**	**10 693**	**741**	**1.0**	

Table A02: Brazil, SI parameters.

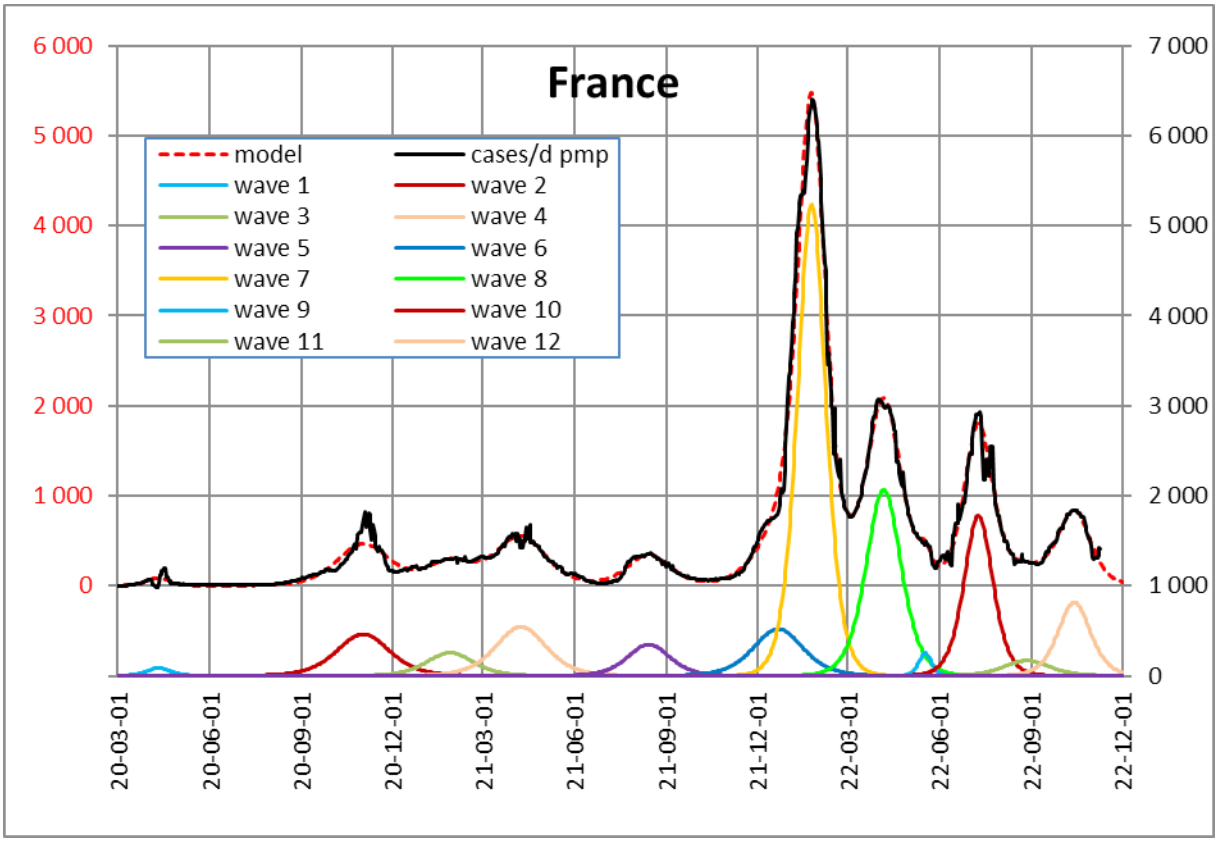

Figure A03: France, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-11	12.8%	2 706	-	4.8	
2	20-11-01	5.6%	32 805	-	0.0	
3	21-01-27	6.4%	15 980	190	1.0	
4	21-04-08	5.9%	36 771	234	1.0	
5	21-08-14	7.1%	19 690	400	1.0	
6	21-12-22	6.0%	34 509	496	1.0	
7	22-01-24	10.7%	196 562	588	1.0	Omicron BA.1
8	22-04-06	8.6%	96 573	641	1.0	
9	22-05-18	23.9%	4 221	781	1.0	
10	22-07-10	10.4%	68 130	763	1.0	
11	22-08-27	6.5%	10 329	776	1.0	
12	22-10-14	9.2%	35 533	851	1.0	

Table A03: France, SI parameters.

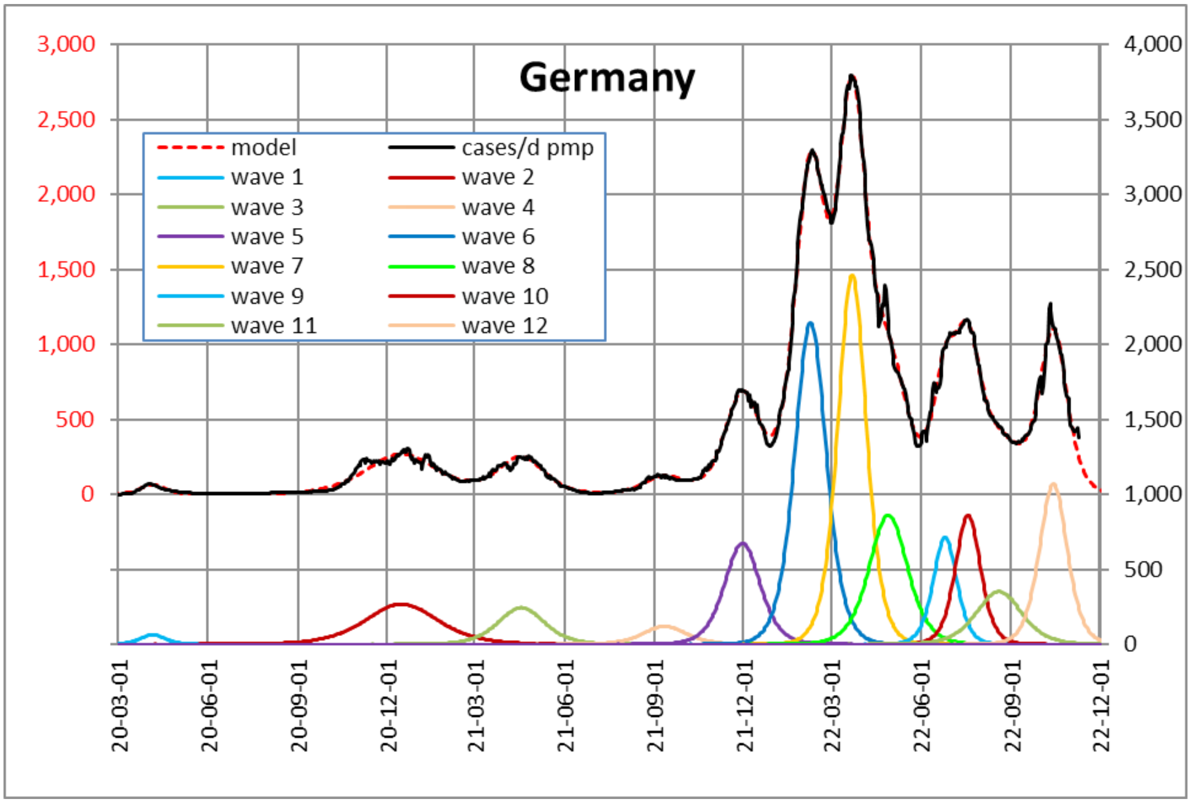

Figure A04: Germany, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-05	11.8%	2 124	-	12.6	
2	20-12-16	4.0%	26 582	45	1.0	
3	21-04-17	6.3%	15 473	268	1.0	Alpha
4	21-09-11	6.8%	7 067	437	1.0	Delta I
5	21-11-30	8.2%	32 900	520	1.0	Delta II
6	22-02-08	9.3%	91 956	595	1.0	Omicron BA.1
7	22-03-22	10.3%	95 695	648	1.0	Omicron BA.2 I
8	22-04-28	7.6%	45 116	657	1.0	Omicron BA.2 II
9	22-06-25	12.4%	23 067	774	1.0	Omicron BA.5 I
10	22-07-19	11.7%	29 380	791	1.0	Omicron BA.5 II
11	22-08-20	6.5%	21 712	756	1.0	Omicron BA.5 III
12	22-10-14	10.5%	40 537	865	1.0	Omicron BA.5 IV

Table A04: Germany, SI parameters.

Input data are taken from RKI [5], as they are continuously updated also retroactiv. Main virus types are assigned on base of RKI [7].

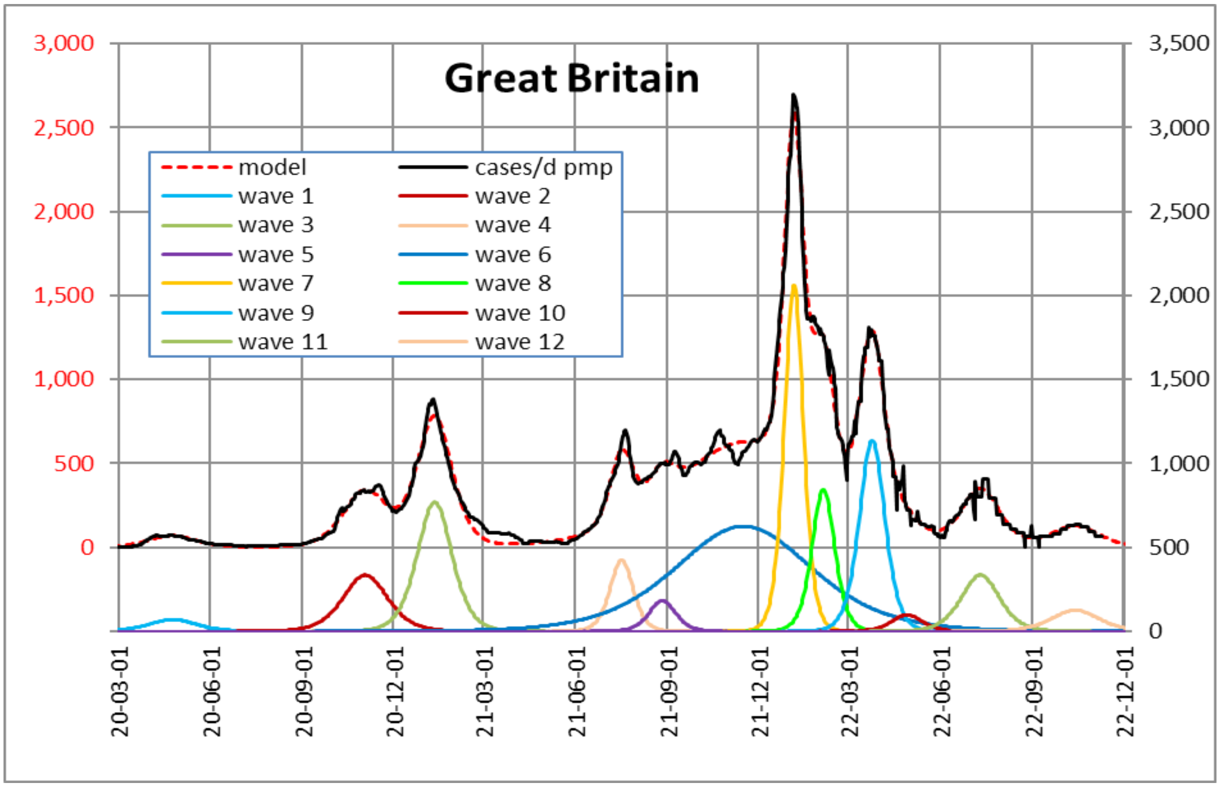

Figure A05: Great Britain, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-24	6.2%	4 482	-	89.9	
2	20-11-03	6.7%	19 902	-	0.0	
3	21-01-11	8.6%	35 736	203	1.0	
4	21-07-17	12.9%	13 113	438	1.0	
5	21-08-27	11.2%	6 518	474	1.0	
6	21-11-16	2.2%	115 164	97	1.0	
7	22-01-05	15.8%	52 371	615	1.0	Omicron BA.1
8	22-02-04	13.2%	25 577	637	1.0	
9	22-03-25	11.7%	38 721	672	1.0	
10	22-04-29	9.6%	4 093	711	1.0	
11	22-07-11	7.8%	17 156	746	1.0	
12	22-10-14	6.3%	8 063	821	1.0	

Table A05: Great Britain, SI parameters.

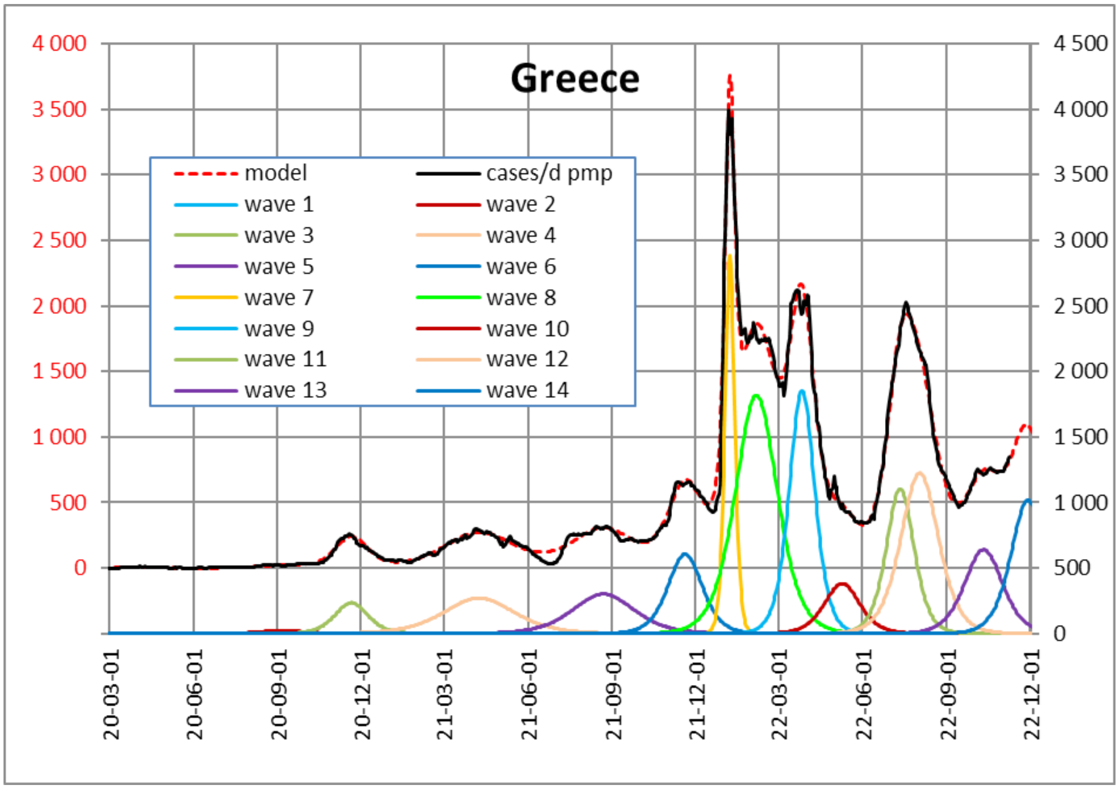

Figure A06: Greece, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-04	9.7%	267		4.2	
2	20-09-06	6.1%	1 512	77	1.0	
3	20-11-20	8.3%	11 356	160	1.0	
4	21-04-08	3.9%	28 016	147	1.0	
5	21-08-22	4.4%	27 219	317	1.0	
6	21-11-19	8.0%	30 257	508	1.0	
7	22-01-07	29.0%	39 838	649	1.0	Omicron BA.1
8	22-02-05	6.6%	110 781	537	1.0	
9	22-03-27	10.8%	68 690	661	1.0	
10	22-05-09	7.7%	19 760	680	1.0	
11	22-07-12	9.9%	44 695	763	1.0	
12	22-08-02	7.3%	67 217	740	1.0	
13	22-10-11	7.2%	35 470	817	1.0	
14	22-11-28	8.1%	50 323	877	1.0	

Table A06: Greece, SI parameters.

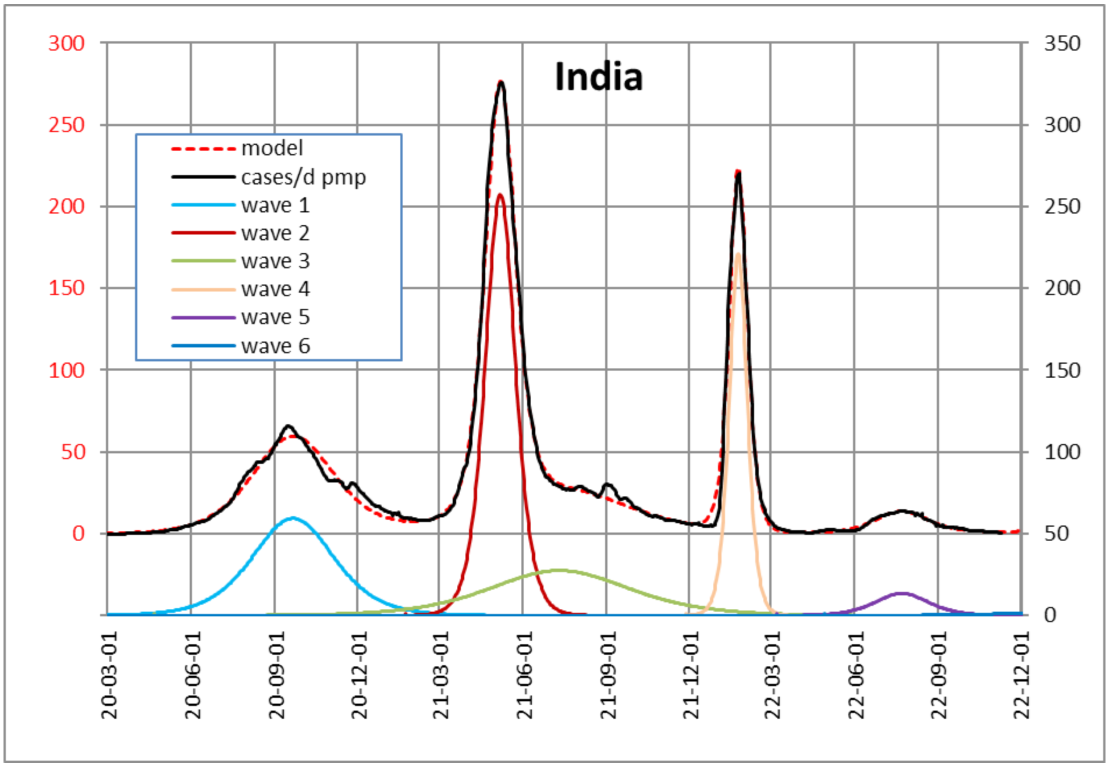

Figure A07: India, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-09-21	**3.3%**	**7 176**	**-**	**6.4**	
2	21-05-07	**9.0%**	**11 467**	**336**	**1.0**	
3	21-07-11	**1.9%**	**5 674**	**59**	**1.0**	
4	22-01-24	**15.2%**	**5 808**	**646**	**1.0**	Omicron BA.1
5	22-07-23	**5.1%**	**1 067**	**745**	**1.0**	
6	23-01-26	**2.2%**	**370**	**797**	**1.0**	

Table A07: India, SI parameters.

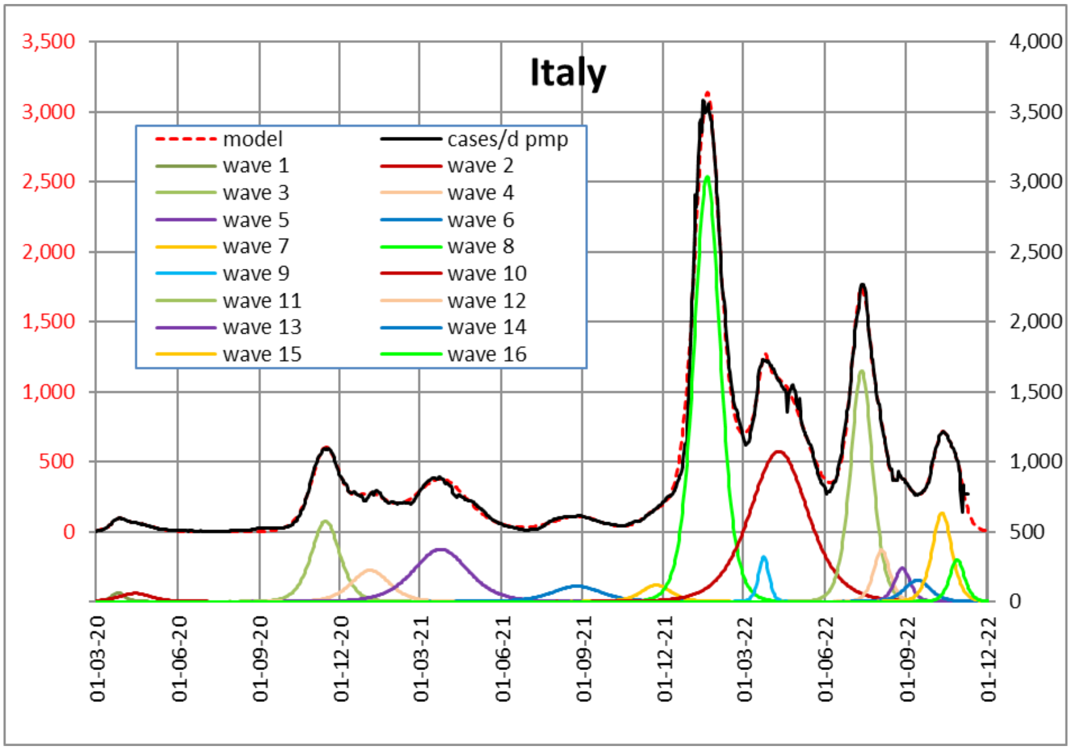

Figure A08: Italy, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-03-26	20.1%	1 240		1.6	
2	20-04-14	8.3%	2 809		36.0	
3	20-11-14	9.4%	24 538	159	1.0	
4	21-01-04	7.1%	12 667	184	1.0	
5	21-03-24	4.9%	30 674	185	1.0	
6	21-08-25	5.4%	8 082	385	1.0	Omicron BA.1
7	21-11-23	9.0%	5 265	545	1.0	
8	22-01-19	10.1%	119 733	582	1.0	
9	22-03-24	25.9%	4 923	729	1.0	
10	22-04-10	4.6%	93 555	529	1.0	
11	22-07-12	12.2%	53 933	783	1.0	
12	22-08-04	16.8%	8 803	840	1.0	
13	22-08-27	17.1%	5 582	867	1.0	
14	22-09-13	10.5%	5 858	852	1.0	
15	22-10-11	13.6%	18 582	890	1.0	
16	22-10-28	18.1%	6 661	931	1.0	

Table A08: Italy, SI parameters

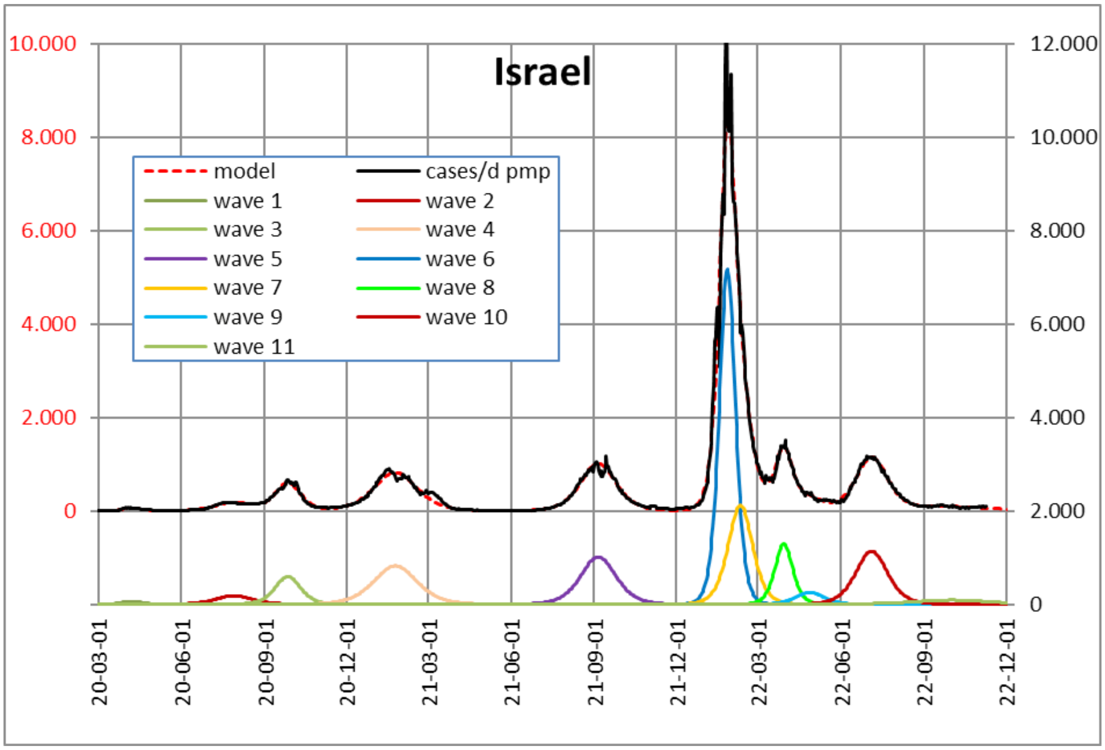

Figure A09: Israel, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-07	14.0%	1 826	-	3.0	
2	20-07-29	7.4%	9 755	35	1.0	
3	20-09-27	10.7%	22 323	125	1.0	
4	21-01-24	6.3%	52 465	164	1.0	
5	21-09-05	7.7%	52 750	420	1.0	
6	22-01-26	17.0%	168 968	634	1.0	Omicron BA.1
7	22-02-10	11.1%	76 228	618	1.0	
8	22-03-30	15.2%	33 932	698	1.0	
9	22-04-27	9.9%	10 510	702	1.0	
10	22-07-05	8.5%	53 237	737	1.0	
11	22-10-02	3.5%	10 124	691	1.0	

Table A09: Israel, SI parameters.

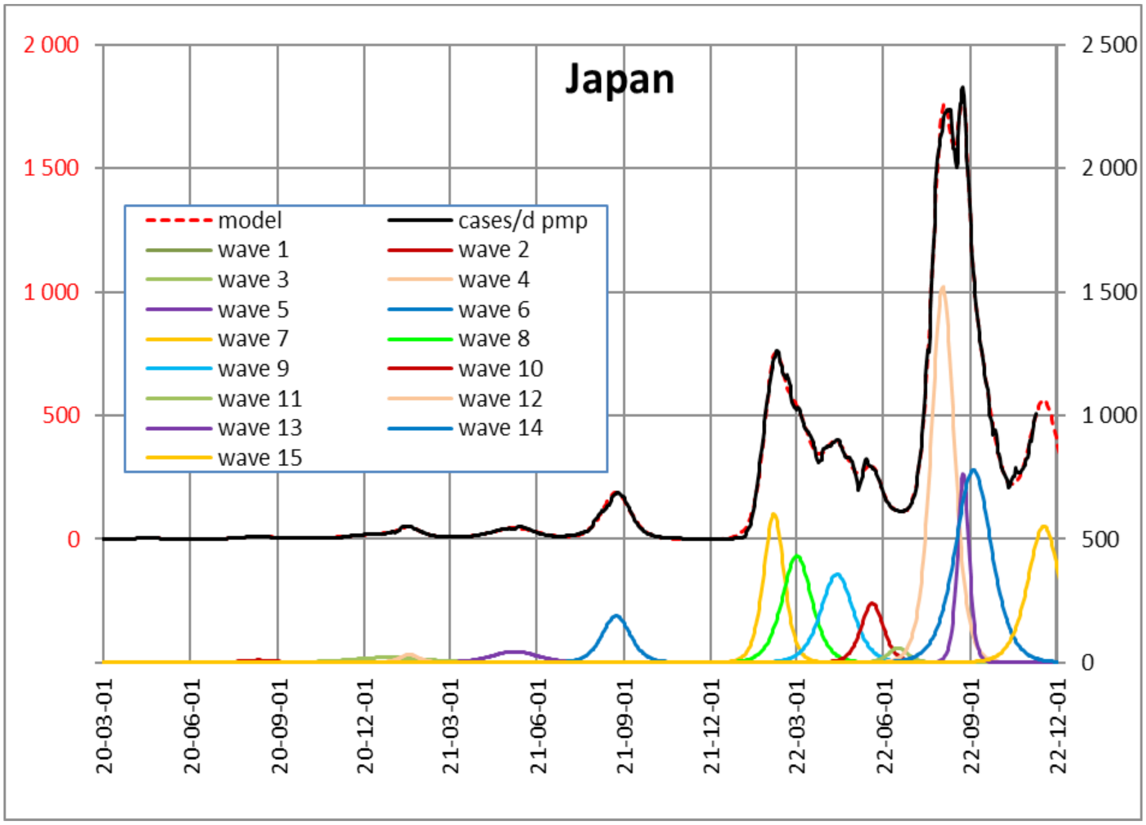

Figure A10: Japan, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-18	12.1%	132		0.1	
2	20-08-12	8.4%	439	100	1.0	
3	20-12-26	3.9%	2 127	112	1.0	
4	21-01-17	14.9%	875	286	1.0	
5	21-05-08	6.2%	2 875	313	1.0	
6	21-08-23	10.1%	7 486	460	1.0	
7	22-02-06	13.9%	17 257	645	1.0	Omicron BA.1
8	22-03-02	9.6%	17 963	638	1.0	
9	22-04-13	8.9%	16 104	673	1.0	
10	22-05-20	12.8%	7 523	749	1.0	
11	22-06-17	14.4%	1 633	795	1.0	
12	22-08-03	12.4%	49 048	806	1.0	
13	22-08-24	24.9%	12 257	877	1.0	
14	22-09-04	7.9%	39 620	791	1.0	
15	22-11-17	8.8%	25 013	885	1.0	

Table A10: Japan, SI parameters.

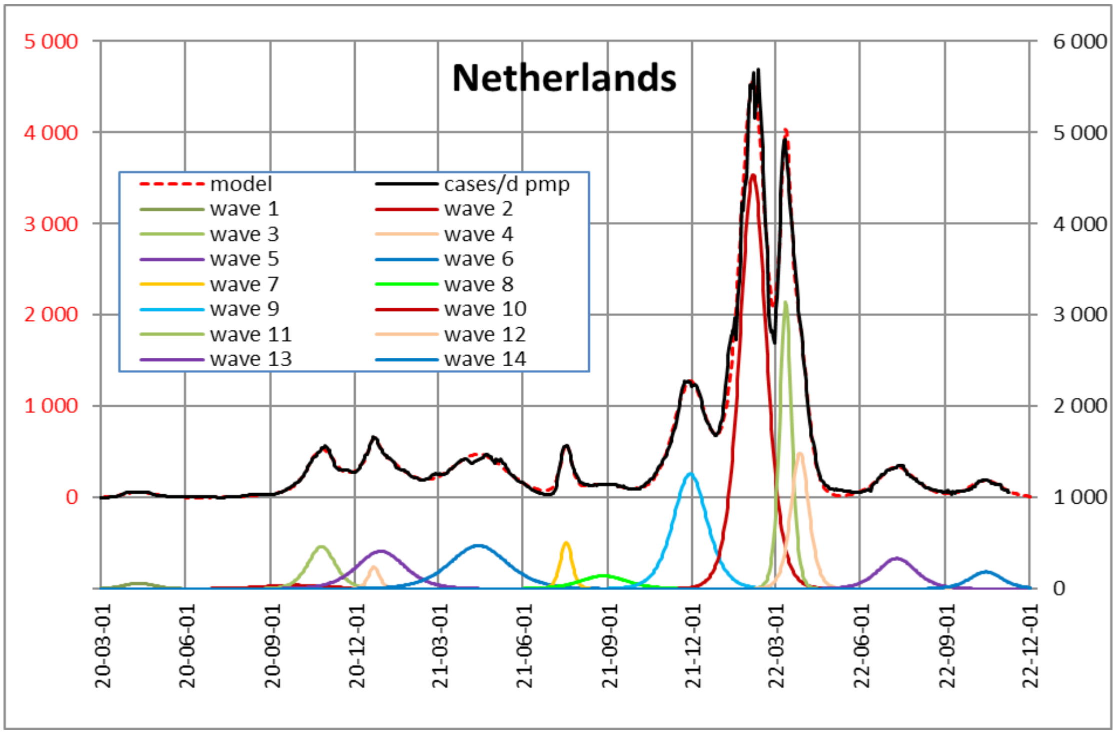

Figure A11: Netherlands, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-11	9.1%	2 759	0	29.6	
2	20-09-27	4.1%	3 934	18	1.0	
3	20-10-26	10.2%	18 239	151	1.0	
4	20-12-21	24.9%	3 881	271	1.0	
5	20-12-29	5.8%	28 740	133	1.0	
6	21-04-14	4.8%	39 718	195	1.0	
7	21-07-17	24.1%	8 542	474	1.0	
8	21-08-27	5.8%	9 831	395	1.0	
9	21-11-29	8.1%	61 992	511	1.0	
10	22-02-05	10.4%	174 105	599	1.0	Omicron BA.1
11	22-03-12	23.6%	53 458	703	1.0	
12	22-03-28	15.5%	38 547	697	1.0	
13	22-07-10	7.3%	18 369	735	1.0	
14	22-10-15	8.4%	8 904	858	1.0	

Table A11: Netherlands, SI parameters.

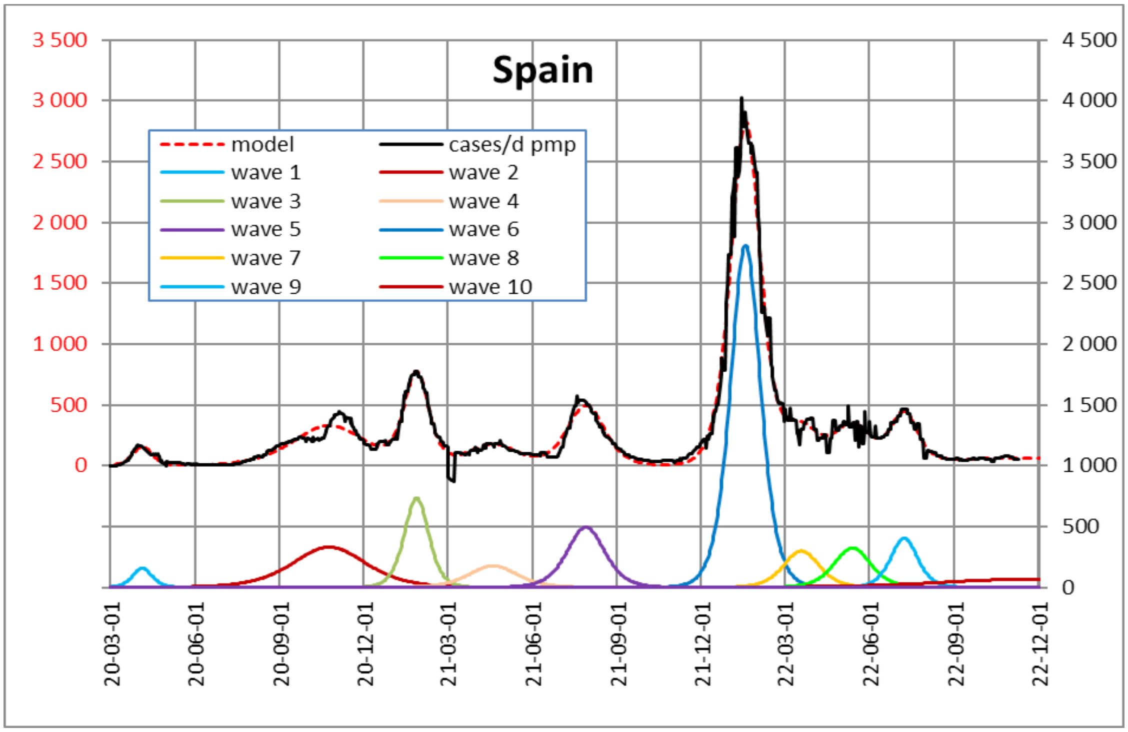

Figure A12: Spain, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-05	**14.4%**	**4 395**		**8.7**	
2	20-10-24	**3.8%**	**35 154**		**3.5**	
3	21-01-26	**11.3%**	**25 884**	**250**	**1.0**	
4	21-04-19	**5.7%**	**12 347**	**258**	**1.0**	
5	21-07-29	**7.3%**	**26 858**	**384**	**1.0**	
6	22-01-17	**9.3%**	**121 113**	**570**	**1.0**	Omicron BA.1
7	22-03-19	**7.7%**	**15 459**	**632**	**1.0**	
8	22-05-13	**7.6%**	**17 054**	**683**	**1.0**	
9	22-07-08	**10.3%**	**15 775**	**773**	**1.0**	
10	22-11-08	**1.7%**	**15 007**	**425**	**1.0**	

Table A12: Spain, SI parameters.

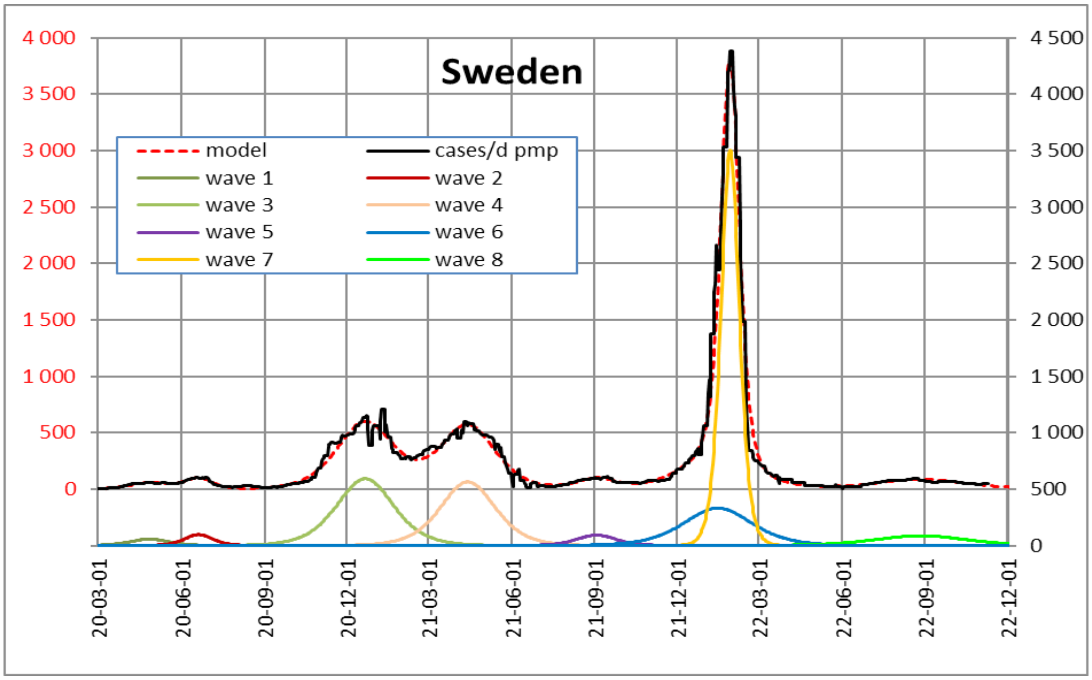

Figure A13: Sweden, real course and models.

1	20-04-26	**7,0%**	**3.210**	**-**	**33,7**	
2	20-06-20	**9,6%**	**4.015**	**-**	**0,0**	
3	20-12-21	**4,7%**	**49.953**	**75**	**1,0**	
4	21-04-13	**4,9%**	**45.740**	**199**	**1,0**	
5	21-09-02	**6,8%**	**5.347**	**433**	**1,0**	
6	22-01-15	**4,0%**	**33.360**	**431**	**1,0**	
7	22-01-28	**14,8%**	**94.485**	**629**	**1,0**	Omicron BA.1
8	22-08-27	**3,0%**	**11.633**	**602**	**1,0**	

Table A13: Sweden, SI parameters.

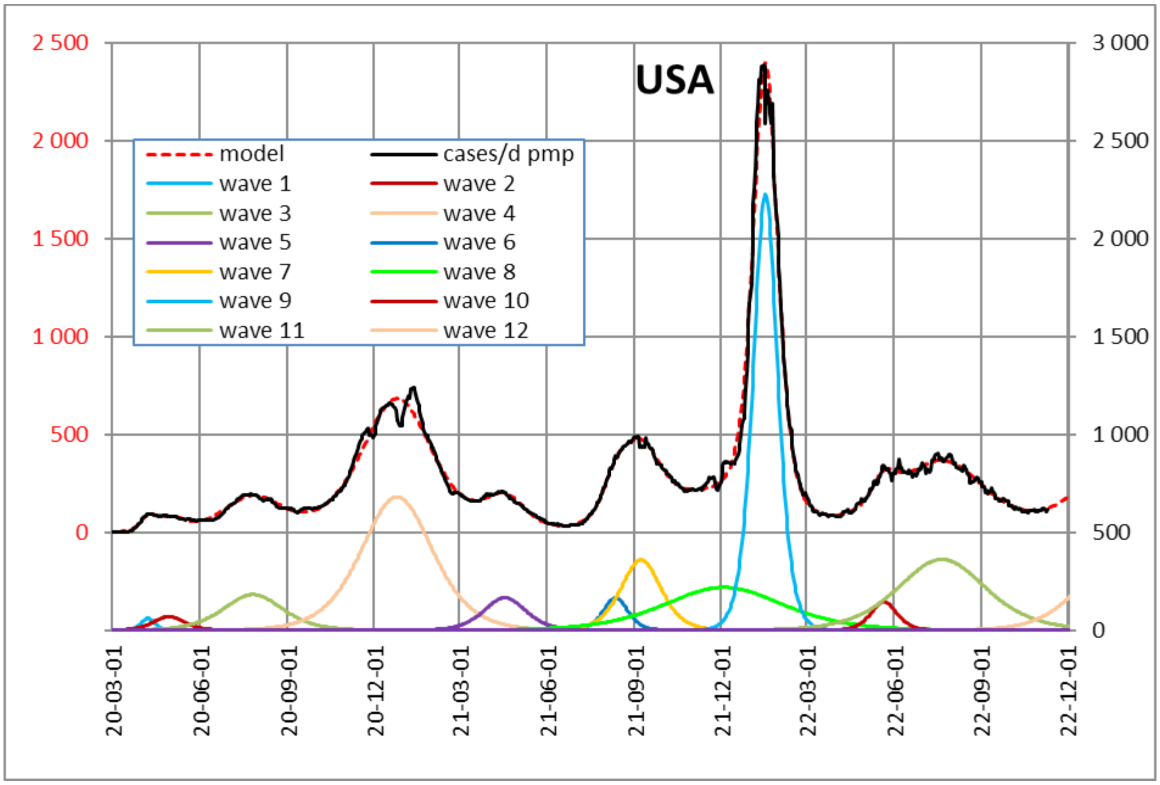

Figure A14: USA, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-07	**20.4%**	**1 201**	**-**	**0.1**	
2	20-04-29	**9.1%**	**3 099**	**-**	**6.6**	
3	20-07-27	**4.8%**	**15 328**	**-**	**9.1**	
4	20-12-25	**4.0%**	**68 675**	**27**	**1.0**	
5	21-04-18	**6.8%**	**9 884**	**285**	**1.0**	
6	21-08-12	**11.4%**	**5 788**	**462**	**1.0**	
7	21-09-08	**7.1%**	**20 245**	**425**	**1.0**	
8	21-12-04	**2.4%**	**36 797**	**210**	**1.0**	
9	22-01-17	**11.7%**	**76 324**	**599**	**1.0**	Omicron BA.1
10	22-05-21	**10.8%**	**5 384**	**741**	**1.0**	
11	22-07-21	**3.2%**	**44 862**	**549**	**1.0**	
12	23-01-09	**4.0%**	**28 627**	**798**	**1.0**	

Table A14: USA, SI parameters.

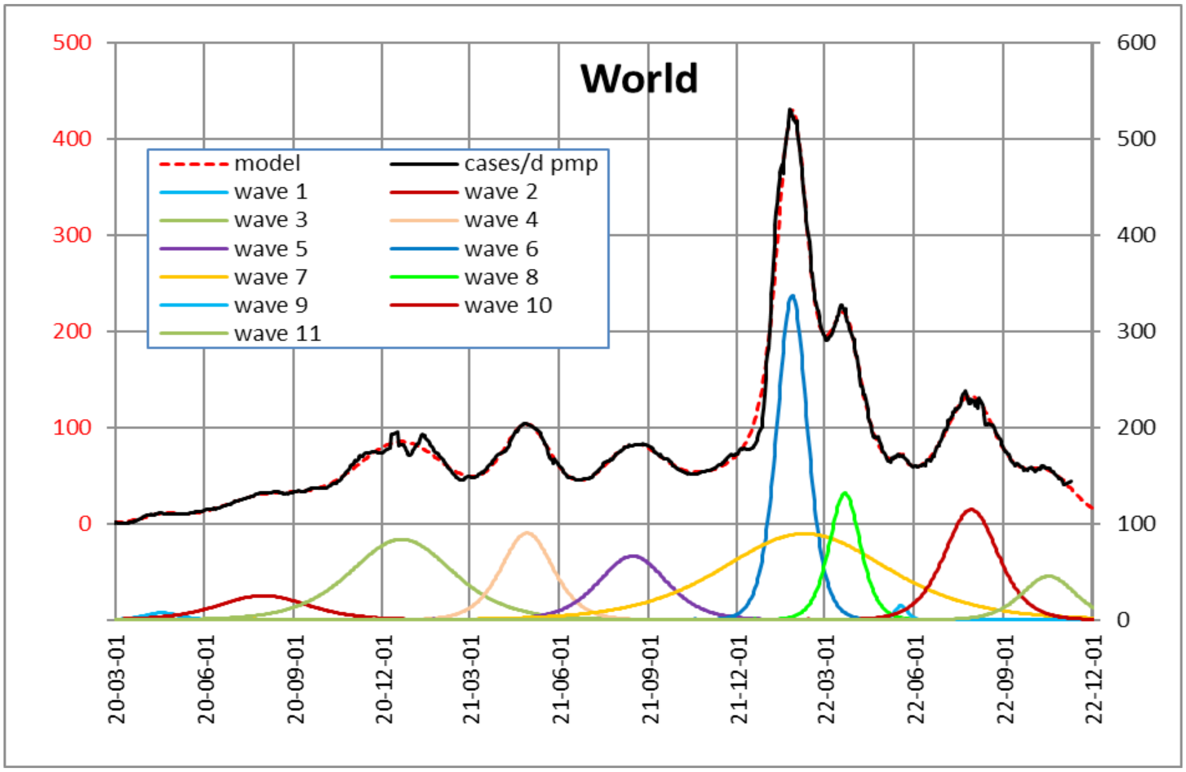

Figure A15: World, real course and models.

wave no.	day of maximum	infection rate, b´	infected per wave pmp, N	start day of wave, t0	infected at wave start	main virus type
1	20-04-17	8.2%	359	-	3.6	
2	20-07-31	3.2%	3 139	-	18.0	
3	20-12-21	2.8%	11 813	-	2.2	
4	21-04-28	5.6%	6 470	275	1.0	
5	21-08-15	4.3%	6 222	336	1.0	
6	22-01-26	9.6%	14 111	605	1.0	Omicron BA.1
7	22-02-08	1.8%	20 455	151	1.0	
8	22-03-21	9.3%	5 651	666	1.0	
9	22-05-18	23.4%	254	793	1.0	
10	22-07-30	5.4%	8 476	722	1.0	
11	22-10-17	5.4%	3 371	818	1.0	

Table A15: World, SI parameters.