Respiratory viruses' epidemic dynamics – covid-19 case study and forecast for 2021 in the most affected countries

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Abstract

It was researched and adopted a method to introduce a seasonal behavior on SIR model to study the dynamics of covid-19. This method is based on the calculation of β for each week of the year based on observed previous seasonal behavior for several countries and regions, which are the most affected in the world. Was also included in the model the vaccination, which will be a factor of major effect on this dynamic in 2021. The model was used to build a simulator and was done the determination of β and the forecast of covid-19 cases for USA, Brazil and India. β was found to range seasonally from 0,15 to 0,40 or from 0,10 to 0,80 depending on the region. It was found that vaccination will be very effective in reducing the cases in 2021 and that the herd immunity will be reached when around 55% of the population be immune. The simulation took to some unexpected findings, like the effect of lockdown in later waves of the epidemic and about the epidemic dynamics. It was found a condition for exogenic respiratory viruses that triggers a major epidemic and a condition that explains why a respiratory virus for which part of the population is already immune has a seasonal behavior, with a small number of cases. This dynamic explains the evolution of covid-19 in 2020 and 2021 and even the Spanish flu in 1918 and 1919.

Introduction

To exercise the hypothesis raised in the previous work, was developed a simulator using SIR model for respiratory viruses. Then, were made simulations for places most affected by covid-19 and covering most type of climates, since one of the main objectives is to verify climate effects over epidemics. This way, the top three countries on the number of cases were selected to make a forecast of the evolution of covid-19 cases in 2021: USA, Brazil and India. Brazil has several types of climate as well as USA, so were selected the states of Amazonas with equatorial climate, Minas Gerais with tropical climate and Rio Grande do Sul with sub-tropical climate in Brazil, and Florida with subtropical climate and New York, with temperate climate in USA. India has a monsoon climate and completes the scenario. The objective is to have a very statistically significant database and a variety of climates that make it possible to extend the technique to other countries, climates and regions.

Next was selected a method to include in SIR model the seasonal climate effect desired. This took several tries of several different methods, but after that was developed a simulator based on a method that gave results in accordance with the observed data for 2020.

To make forecasts is highly risky but is a way to test hypothesis. Later, is just a case of verifying the deviation between the forecast and the observed data. There is an additional risk source in the forecast here proposed. The hypothesis tested is that human behavior, influenced by weather, is a key factor in the epidemic dynamics. Both are highly volatile, the human behavior and the weather. This makes the uncertainty of the simulation to be higher. Anyway, the premise taken is that the weather will not chance that much in 2021 compared to 2020 and that social experiments, like lockdown, will also not change the population behavior that much in 2021.

For the records, the forecasts done used the most updated data available at the time of simulation, which was up to week 8 of 2021.

Method to calculate Beta and for the forecast calculation

Model SIR has simple equations, listed below. β is called the effective contact rate, but a more adequate name would be effective transmission rate. γ is the removal rate, and $1/\gamma$ is the time of recovery.

$$\frac{dS}{dt} = -\frac{\beta SI}{N}$$

$$\frac{dI}{dt} = \frac{\beta SI}{N} - \gamma I$$

$$\frac{dR}{dt} = \gamma I$$

The solution of those equations is the logistic function. But this is valid for a constant β. When it is not constant it will be a distorted or noisy logistic function, as will be seen in the simulations ahead.

The parameter β is supposed to be a function of human contact to each other. What is effectively known is that it is a function of time, that is, it is not constant, it varies in time. It is presented by Bastos, from Fiocruz, that the behavior of an outbreak has a seasonal factor [1]. In fact, when the population is unaware of the risk of epidemic the transmission by contact might happen and might be the predominant mechanism. But since the population is informed and sensibilized about the risk, this might not be anymore the predominant way of transmission. It would be the airborne transmission, as presented in our previous work [2]. But the airborne transmission is a function of human behavior, modulated by the climate. So, one can say that β is:

$$\beta = f(HB(C, T, PI, GDP))$$

Where HB is Human Behavior, C is Contact, T is Temperature, PI is Pluviometric Index and GDP is Gross Domestic Product. So β is a function of the human behavior, which in its turn is a function of the rest of the variables listed. There might be other variables that influence, like UV index or Vitamin D rate on the population, but those listed seems to be enough to develop a model that fits on the observed data.

So, in the beginning of the outbreak β is function of C, contact, and strategies such as face masks and lockdown would be effective. The big issue is to know you are in this phase and might take those actions. Later in this paper we will discuss about the results of simulations on the effects of lockdown. After the initial outbreak, the effect of contact transmission would decrease and would increase the effect of airborne infection, becoming predominant. This way, β would be mostly a function of human behavior modulated by temperature and pluviometric index since a bigger proportion of people would enclose themselves in poorly ventilated indoor environments depending on the weather. The influence o GDP in this equation would be on the quantity of people that could afford heating or air conditioning, increasing the proportion enclosed indoors.

To calculate β was used the method presented by Tatiana Petrova of the Lomonosov Moscow State University [3]. For each location studied was calculated β for each week of 2020, which is the only historic reference for the coronavirus of covid-19. This $\beta(t)$ includes the effects of weather and GDP for each of these locations. This same function was used to forecast the quantity of cases in 2021. For a few weeks was necessary to estimate the value of β because this paper was done before the completion of one year of the pandemic. This estimation was done with linear or quadratic regression, depending on the case, and will be explicit for each one. Finally, was used a fixed value of γ as well as in the reference method. Was used a value of 1/30 days^{-1} or a γ of 7/30 weeks^{-1}.

A forecast was made for each location analyzed in our previous work. In those simulations was used the population in 2020 for each state or country, the seroprevalence published in January of 2021 or the most updated available, when available was used the SARS hospitalization cases, when not, was used simply the cases and was considered a vaccine time for effectivity of 4 weeks [4]. The use of SARS cases is supposed to be more precise because does not depend on testing policy, asymptomatic rate etc., because it is based on effective hospitalization registers. It is the methodology used by Fiocruz, which is the source of the data for the study of the Brazilian states [5]. The time interval dt used in the simulations was one week because this is the interval of the data available at Fiocruz data base.

In each forecast are solved the equations for S, I and R. It is also calculated the accumulated cases, C(t), and the SARS cases:

$$C(t) = I(t) + R(t)$$

$$C'(t) = SARS = \frac{dC(t)}{dt}$$

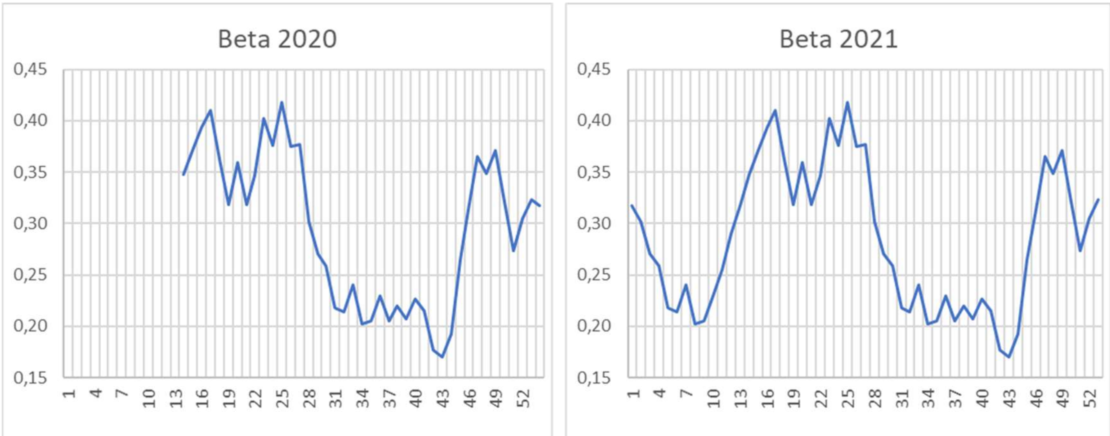
When is considered vaccination [6], the equation is:

$$C(t) = I(t) + R(t) - vac(t)$$

Where vac(t) is the quantity of vaccinated people in a determined week.

Minas Gerais - Brazil

Minas Gerais had a population of 21.292.666 in 2020, a seroprevalence of 14,1% in January of 2021 [7] and reached a total of 43.251 cases of SARS on January 12^{th}, 2021 [5]. It was used the value of the seroprevalence in São Paulo, which was the only one publicly available as the average for the whole country. The β calculated is shown in Figure 1 (a). It was obtained in a simulation using the adopted method and the covid-19 SARS data for Minas Gerais in 2020. It was purged the initial surge on β due to the outbreak, from week 8 to 13 since it is supposed to be caused by contact transmission and not by airborne transmission. Notice its strong seasonal behavior, oscillating from around 0,15 in the spring in the southern hemisphere to around 0,40 in the winter and summer. As observed in our previous work, the summer and winter peaks are expected in tropical places, as Minas Gerais, and also in subtropical ones, when GDP is high enough to make people afford air conditioning in the summer. Otherwise, would only exist a winter peak when people are enclosed indoors to keep the warmth. β for 2020 was the base to estimate β for 2021, since it is the only reference available for covid-19. This way, the period from week 1 to 14 was estimated considering that the autumn would have the same behavior as the spring. That is, from weeks 2 to 10 were used the same values from week 27 to 35 (the value for week 1 was already available at the time of the study). Even though, would be missing the weeks 11 to 13. For them was used a linear adjustment between the values of weeks 10 and 14. The result obtained is presented in Figure 1 (b). One additional premise was considered for the estimation of β for 2021. Since it is supposed to be a function of the climate, it was considered that the climate in 2021 will not be substantially different from 2020.

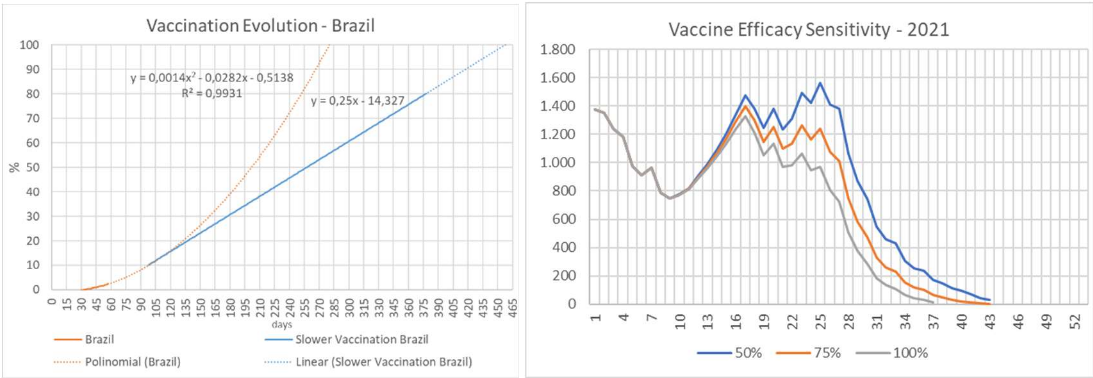


(a) (b)

Figure 1

For the simulation were used data from actual vaccination [8], which is in its very beginning, and done an extrapolation, considering two cases – one that it keeps its initial pace until the end and a second in which it reaches some infrastructure limit. In the case of slower vaccination presented in Figure 2 (a), it is supposed that the limit is 0,25% of the population per day, due to the capacity of the vaccination system. This represents 50 thousand doses per day in the case of Minas Gerais, which is a reasonable value. Other important premise in the vaccination simulation is that it takes roughly 4 weeks to have an immunizing effect [4].

Regarding vaccine efficiency, sensitivity tests done, presented in Figure 2 (b), showed that for the efficacy ranging from 100% to 50% makes the peak in week 25 ranges from around 1.000 to around 1.600 respectively, and the time to reach herd immunity from week 26 to 34. For the case of 50% of efficiency, this would take too long that the season would almost finish before the effect of the vaccine. Other factor that might affect the vaccination efficacy is the vaccination of asymptomatic already immune people. It is estimated that around 10% of people being vaccinated will be in this case. This would decrease the vaccination efficacy, for example, from 90% to 80%, within the sensitivity limits of Figure 2 (b) and will be considered in the calculation of the uncertainty of the simulations presented in this paper. The simulations in this work were done using an optimistic vaccine efficiency of 100%.



(a) (b)

Figure 2

The results of the simulation for 2021 without vaccination, with vaccination and with slower vaccination are presented in Figure 3. Without vaccination would have a peak in week 27, the beginning of July, with almost 2.500 cases in this week, around 60% more than the observed in 2020. This can be explained by the fact that there were more cases in the beginning of the period than in 2020. In 2020 it began with roughly zero cases, while in 2021 the starting point was above 750 cases per week. SIR equations are sensitive to the initial value. In the case of vaccination, the peak would be in week 18, the beginning of May, and would reach a value of around 1.200 cases. The result for slower vaccination is approximately the same because the herd immunity would be reached just after the vaccination infrastructure saturation. The herd immunity would be definitely reached at week 26, end of June, with an immune population of around 55%. This low value might be due to the also low value of β.

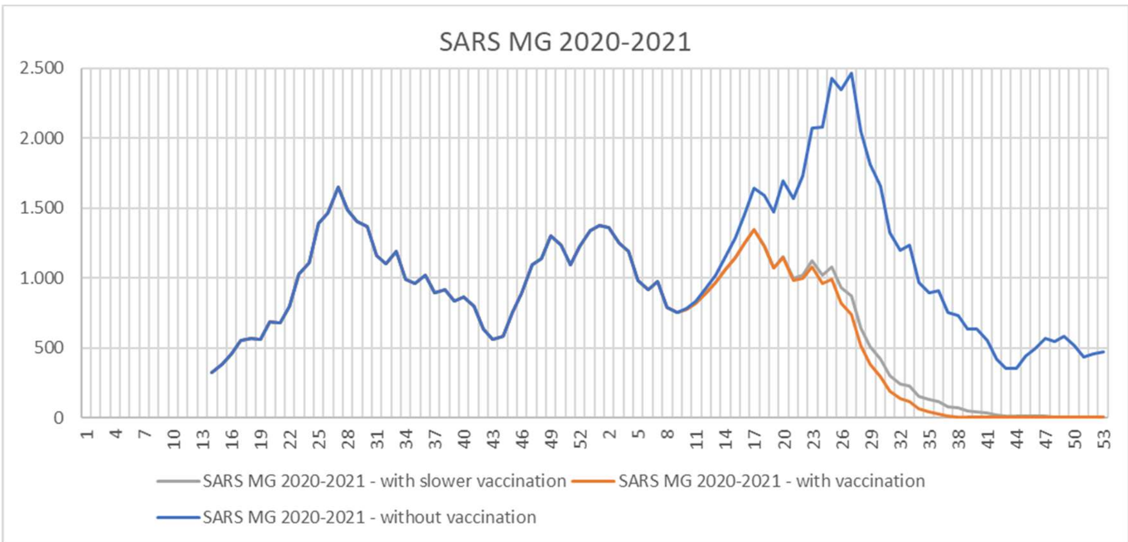
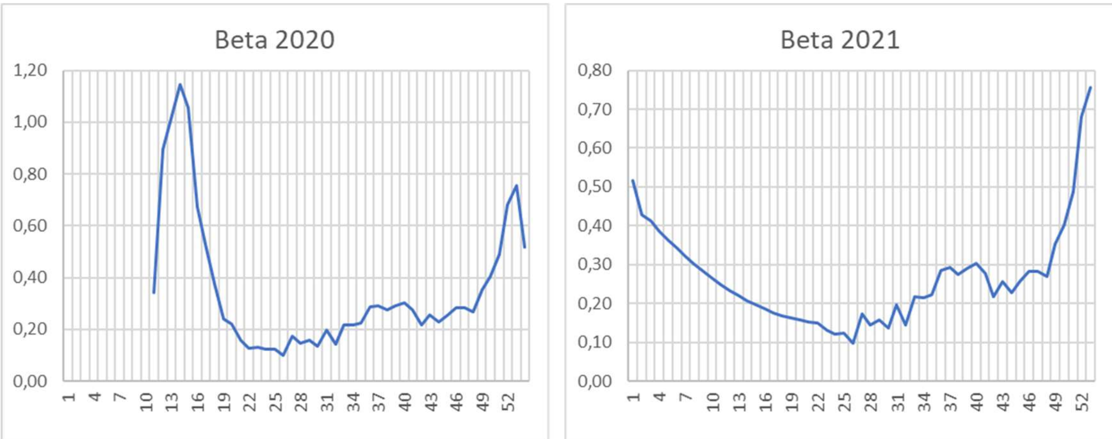


Figure 3

The uncertainty estimated for the vaccination index was 5%, CDC reports a seroprevalence uncertainty of +/-2% [9], we estimate an uncertainty of β of 20% and the vaccine efficacy uncertainty is estimated as 15%, as it seems to have an average value of 75% with a standard deviation of +/- 15%, including the efficacy lost due to vaccination of asymptomatic ones. This gives a total uncertainty of 25,57%. This is considered to be an uncertainty good enough for this type of estimate. This uncertainty is valid for all simulations forecasting SARS or cases in this paper.

Amazonas - Brazil

Amazonas had a population of 4.207.714 in 2020, a seroprevalence of 14,1% in January of 2021, the average for Brazil, and reached a total of 17.475 cases of SARS on January 12th, 2021 [5]. The β calculated is shown in Figure 4 (a). It was obtained in a simulation using the adopted method and the covid-19 SARS data for Amazonas in 2020. It was not done any filtering in this case because the behavior of β in 2020 was smooth. To estimate β for 2021 was made a parabolic interpolation between weeks 3 and 22, which was when there was the outbreak of 2020 and β has not its seasonal behavior. The result obtained is presented in Figure 4 (b). Again, notice its strong seasonal behavior, oscillating from around 0,8 in the summer in the southern hemisphere to around 0,10 in the winter. This is consistent with the data observed in previous years in Amazonas [5] and with the observed in our previous work that raised the hypothesis that in the raining season, which is in the summer down there, people is likely to be more indoors [2].



(a) (b)

Figure 4

For the simulation of the vaccination was used the same data from Brazil used for Minas Gerais, since specific data for each state is not easily available. In the case of slower vaccination presented in Figure 2, it is supposed that the limit is 0,25% of the population per day, due to the capacity of the vaccination system. This represents 10 thousand doses per day in the case of Amazonas.

The results of the simulation for 2021 without vaccination, with vaccination and with slower vaccination are presented in Figure 5. They were not much different from each other because when the vaccination reaches a representative level the outbreak would already be gone. What is seen is that in the end of 2021 would start a new outbreak on the summer or raining season and with vaccination this would not happen. Because of this type of seasonal pattern coincident with the vaccination was not possible to determine the level for herd immunity.

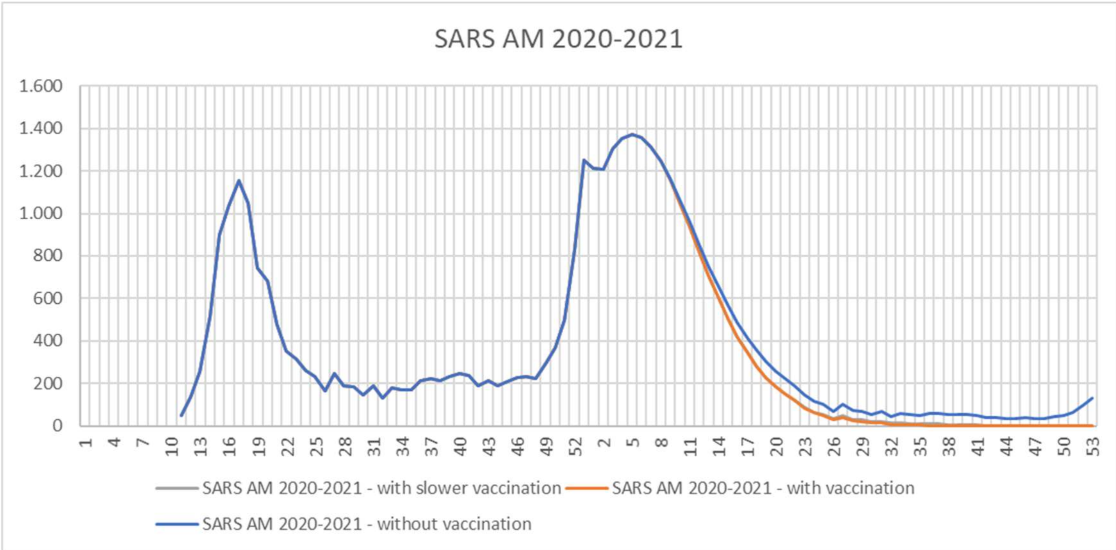
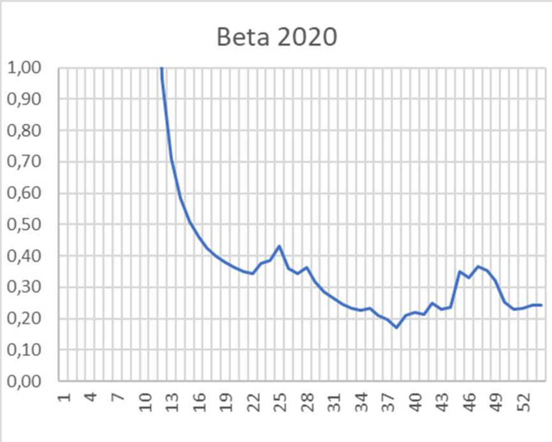


Figure 5

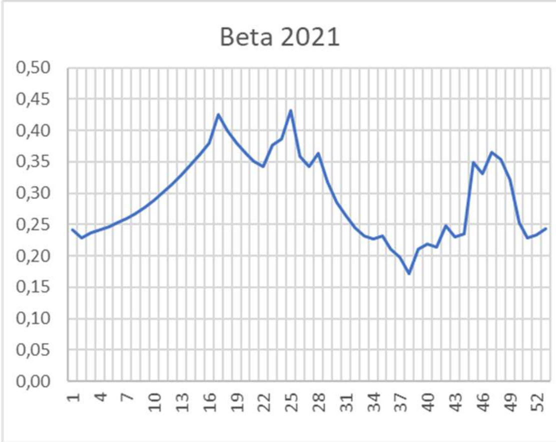
Rio Grande do Sul - Brazil

Rio Grande do Sul had a population of 11.422.973 in 2020, a seroprevalence of 14,1% in January of 2021, the average for Brazil as in the previous cases, and reached a total of 22.751 cases of SARS on January 12th, 2021 [5]. The β calculated is shown in Figure 4 (a). It was obtained in a simulation using the adopted method and the covid-19 SARS data for Rio Grande do Sul in 2020. This SARS data used to calculate β for 2020 had the initial outbreak, from week 10 to 21, purged and substituted by a linear interpolation since it is supposed to be caused by contact transmission and not by airborne transmission, as for Minas Gerais case. To estimate β for 2021 was made a parabolic interpolation between weeks 3 and 16, which was when there was the outbreak of 2020 and β has not its seasonal behavior. The result obtained is presented in Figure 6 (b). Again, notice its seasonal behavior, oscillating from around 0,45 in the winter in the southern hemisphere to around 0,20 in the summer. This is consistent with the data observed in previous years in Rio Grande do Sul, but the summer peak from week 45 to 50 [5]. One possible cause for that is that now the GDP in the state is big enough for the people, in average, to afford air conditioning. Other possible explanation is that lockdown kept people in poorly ventilated indoors environment. After all, this summer outbreak was never observed before in available data in this state, as well as in Minas Gerais [5].

For the simulation of the vaccination was used the same data from Brazil used before. In the case of slower vaccination presented in Figure 2, it is supposed that the limit is 0,25% of the population per day, due to the capacity of the vaccination system. This represents 30 thousand doses per day in the case of Rio Grande do Sul.



(a)



(b)

Figure 6

The results of the simulation for 2021 without vaccination, with vaccination and with slower vaccination are presented in Figure 7. Without vaccination would have a peak in week 25, the middle of June, with almost 1.600 cases in this week, around twice the observed in 2020. The explanation for that is again the SIR equations sensitivity to the initial value. In the case of vaccination, the peak would be in week 17, the end of April, and would reach a value of around 800 cases. The result for slower vaccination is approximately the same because the herd immunity would be reached just after the vaccination infrastructure saturation. The herd immunity would be definitely reached at week 26, end of June, with an immune population again of around 55%. This might be because the value of β is around the same for those two states.

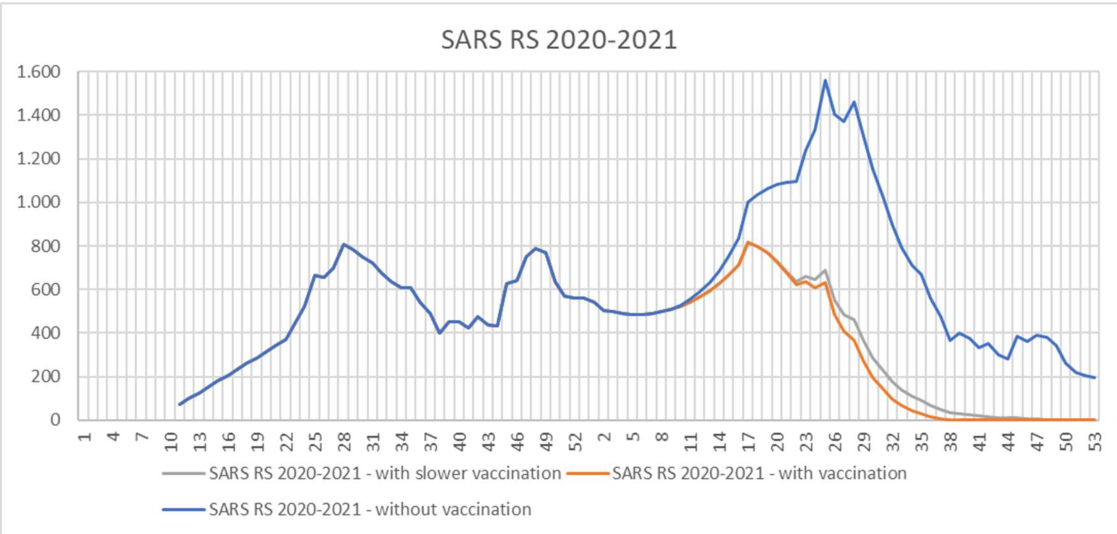
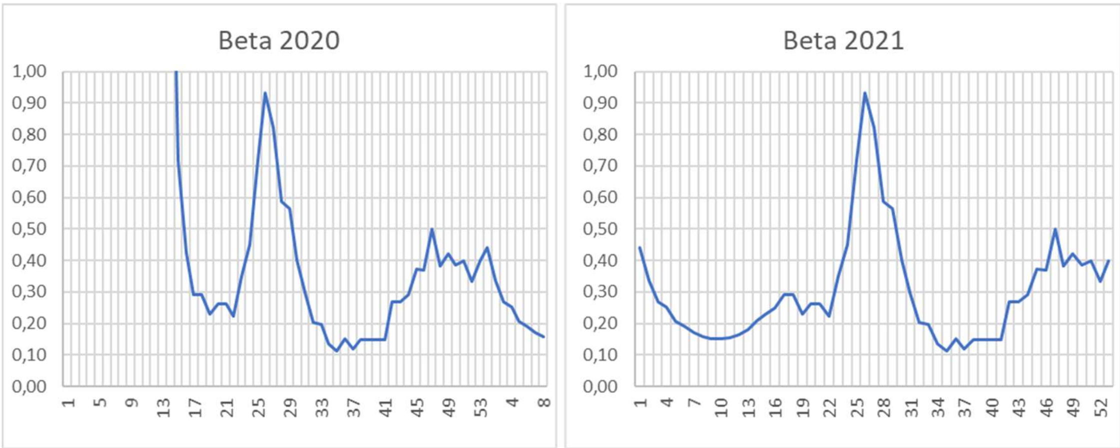


Figure 7

Florida - USA

Florida had a population of 21.733.312 in 2020, a seroprevalence of 13,0% in December of 2020, the last available at the time of this work [9] and reached a total of 1.332.172 cases of covid-19 on January 12th, 2021 [10]. The β calculated for 2020 is shown in Figure 8 (a), and it covers the values already available for 2021 until week 8. It was obtained in a simulation using the adopted method and the covid-19 cases data for Florida in 2020. β for 2021 is supposed to be the same as in 2020, unless for weeks 9 to 16 since they fall in the period of the initial outbreak of 2020. As said before, this period is believed to be caused mainly by contact transmission and not by airborne transmission. The result obtained is presented in Figure 8 (b). Notice one more time its seasonal behavior, oscillating from around 0,90 in the summer in the northern hemisphere to around 0,10 in the autumn, raising to around 0,50 in the winter and to fall again to around 0,15 in the spring.



(a) (b)

Figure 8

For the simulation were used data from the actual vaccination [8], which is in a more advanced stage for USA, and done an extrapolation, considering two cases – one that it keeps its initial pace until the end and a second in which it reaches some infrastructure limit. In the case of slower vaccination presented in Figure 9, it is supposed that the limit is 0,73% of the population per day, due to the capacity of the vaccination system. This represents 150 thousand doses per day in the case of Florida, which is a reasonable value.

The results of the simulation for 2021 without vaccination, with vaccination and with slower vaccination are presented in Figure 10. Without vaccination would have a peak in week 29, the middle of July, with almost 160.000 cases in this week, around twice the observed in the summer of 2020. This can be explained by the fact that there were more cases in the beginning of the period than in 2020 and, again, SIR equations are sensitive to the initial value. In the case of vaccination, the epidemic would relief and vanish without another peak. The result for slower vaccination is quite the same.

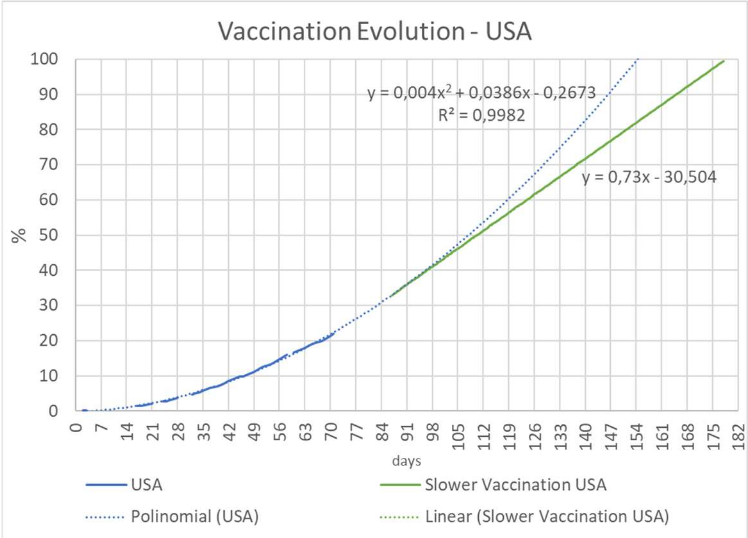


Figure 9

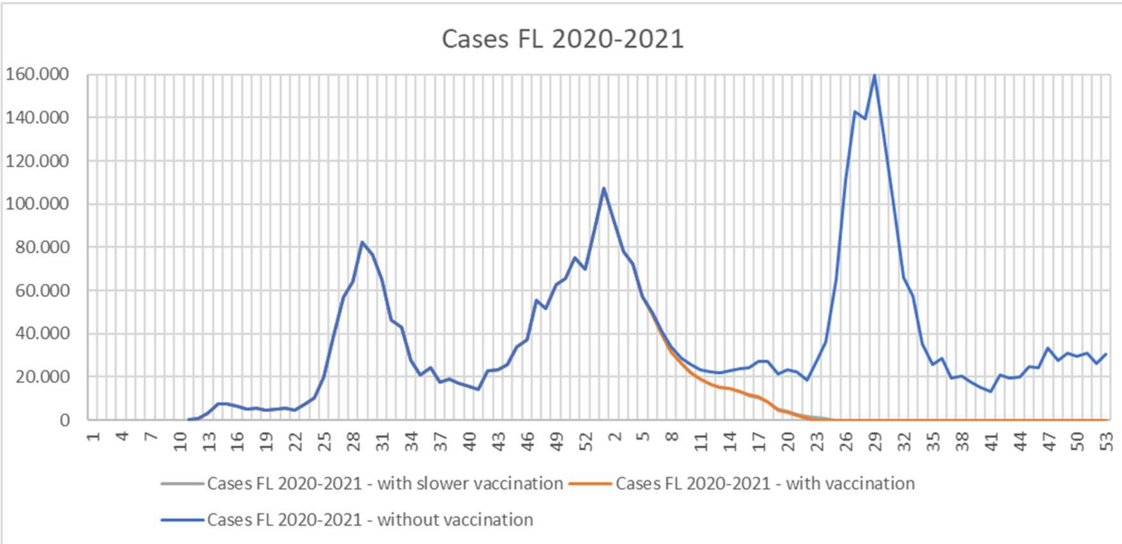
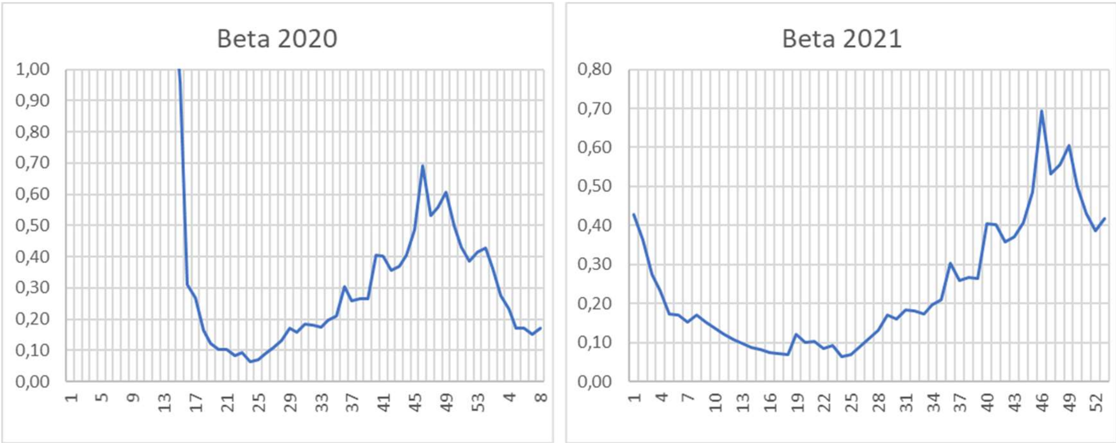


Figure 10

New York - USA

The state of New York, excluding New York City, had a population of 11.411.400 in 2020, a seroprevalence of 9,7% in December of 2020, the last available at the time of this work [9] and reached a total of 579.631 cases of covid-19 on January 12th, 2021 [10]. β calculated for 2020 is shown in Figure 11 (a), and it covers the values already available for 2021 until week 8. It was obtained in a simulation using the adopted method and the covid-19 cases data for New York, excluding New York City in 2020. β for 2021 is supposed to be the same as in 2020, unless for weeks 9 to 18 since they fall in the period of the initial outbreak of 2020. Again, this period is believed to be caused mainly by contact transmission and not by airborne transmission. The result obtained is presented in Figure 11 (b). Notice one more time its seasonal behavior, oscillating from around 0,10 in the summer in the northern hemisphere to around 0,70 in the end of autumn. As discussed in our previous work [2], New York has a temperate climate and

Florida a subtropical climate. It is expected to have a peak of cases in the summer in subtropical and tropical climates when the GDP is high enough to make people afford for air conditioning. This is not the case in the temperate climate, in which there is only the winter peak.



(a) (b)

Figure 11

In the case of slower vaccination presented in Figure 9, it is supposed that the limit is 0,73% of the population per day, due to the capacity of the vaccination system. This represents 80 thousand doses per day in the case of New York, which is a reasonable value.

The results of the simulation for 2021 without vaccination, with vaccination and with slower vaccination are presented in Figure 12. In any case the peak was already observed in week 1, with almost 70.000 cases in this week, almost twice the observed in the initial outbreak in the spring of 2020. This can be explained by the seasonal behavior of β, and another wave would happen only in the winter of 2021. In the case of vaccination, it will guarantee that there will not have a summer wave. The result for slower vaccination is approximately the same.

India

India had a population of 1.380.004.385 in 2020, a seroprevalence of 21,0% in January of 2020, the last available at the time of this work [11] and reached a total of 10.323.964 cases of covid-19 on January 12th, 2021 [12]. β calculated for 2020 is shown in Figure 13 (a), and it covers the values already available for 2021 until week 8. It was obtained in a simulation using the adopted method and the covid-19 cases data for India in 2020. β for 2021 is the supposed to be the same as in 2020, unless for weeks 9 to 17 since they fall in the period of the initial outbreak of 2020, which is believed to be caused mainly by contact transmission and not by airborne transmission. The result obtained is presented in Figure 13 (b). Notice one more time its seasonal behavior, oscillating from around 0,80 in the end of the spring in the northern hemisphere to around 0,15 in the winter. One shall notice that it is quite similar to Amazonas β (Figure 4), but with a phase difference, or delay, of roughly 6 months.

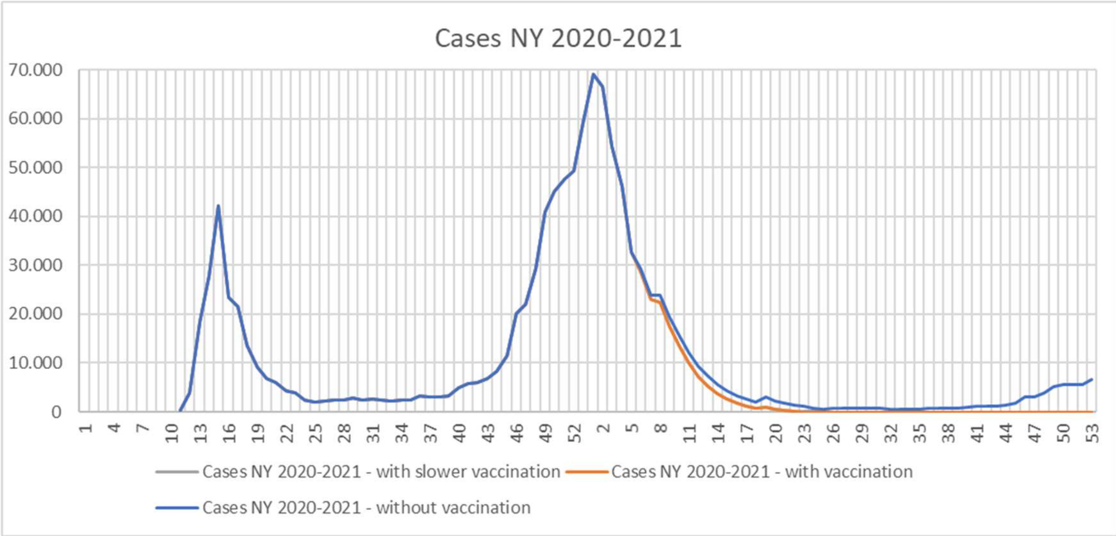
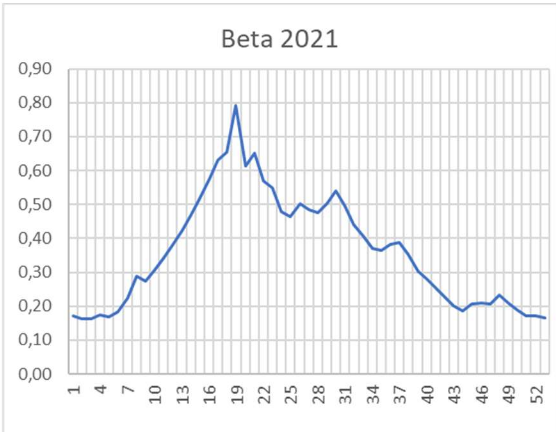


Figure 12

(a)



(b)

Figure 13

For the simulation were used data from the actual vaccination [8], which is in a slower rate at India in face of the challenge of the size of the population, and done an extrapolation, considering two cases – one that it keeps its initial pace until the end and a second in which it reaches some infrastructure limit. In the case of slower vaccination presented in Figure 14, it is supposed that the limit is 0,05% of the population per day, due to the capacity of the vaccination system. This represents 700 thousand doses per day in the case of India, which is an outstanding value, but that might be possible for the scale of the population of India.

The results of the simulation for 2021 without vaccination, with vaccination and with slower vaccination are presented in Figure 15. Without vaccination would have a peak in week 30, the middle of July, with around 1.200.000 cases in this week, around twice the observed in the summer of 2020. This can be explained by the fact that there were more cases in the beginning of the period than in 2020 and, again, SIR equations are sensitive to the initial value. In the case of vaccination, the peak would be smaller, reaching slightly above 800.000 cases per week in week 23, beginning of june. The result for slower vaccination is approximately the same, but the peak would be in week 30. In all the three cases of Figure 15, the herd immunity seems to be reached around week 29 to 30, and also when the immune population is around 55%.

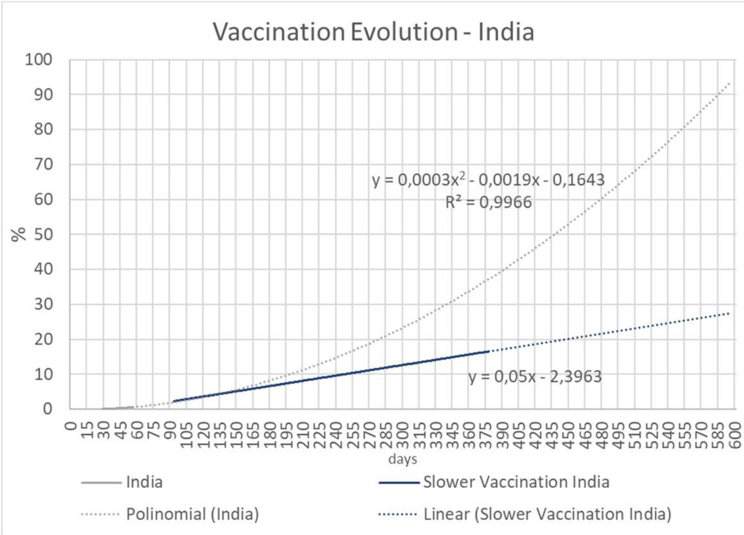


Figure 14

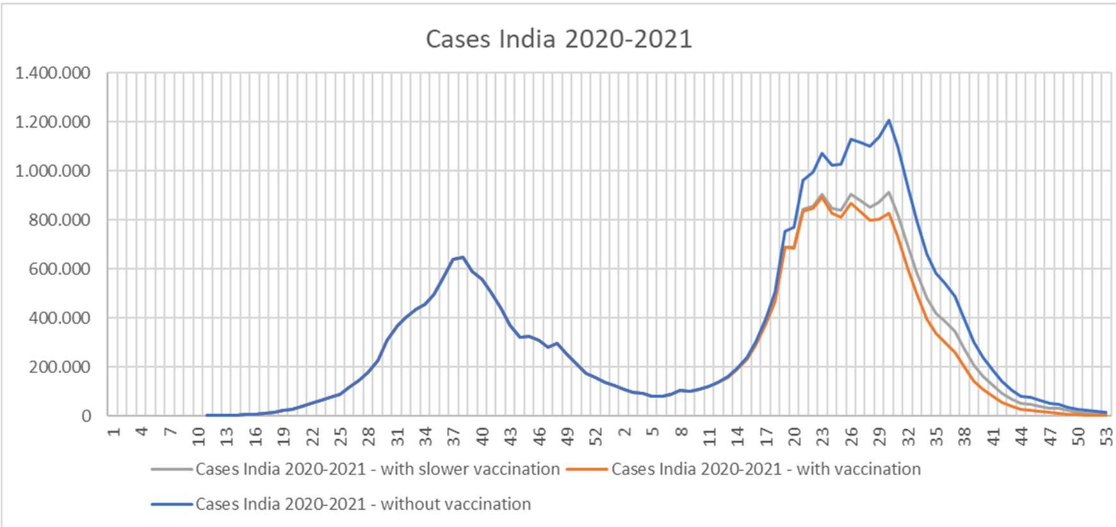


Figure 15

Study of lockdown

To evaluate the effects of lockdown, the first step will be to compare the behavior of β in 2020 with previous flu seasons. I our previous work we found that in Minas Gerais in 2013 the number of cases for the epidemiological weeks had a similar profile to 2020 [2]. Using the method adopted in this work we calculated β for 2013 and compared to 2020 in Figure 16. We can observe two major differences: before week 15 the value for 2020 is too high due to the initial outbreak and after week 45 there was an unexpected outbreak in the summer. Before week 15 in 2013 β has a noisy behavior due to the small quantities of cases involved. But between weeks 15 and 45 the behavior in these two years is very similar, reaching a correlation of 0,88.

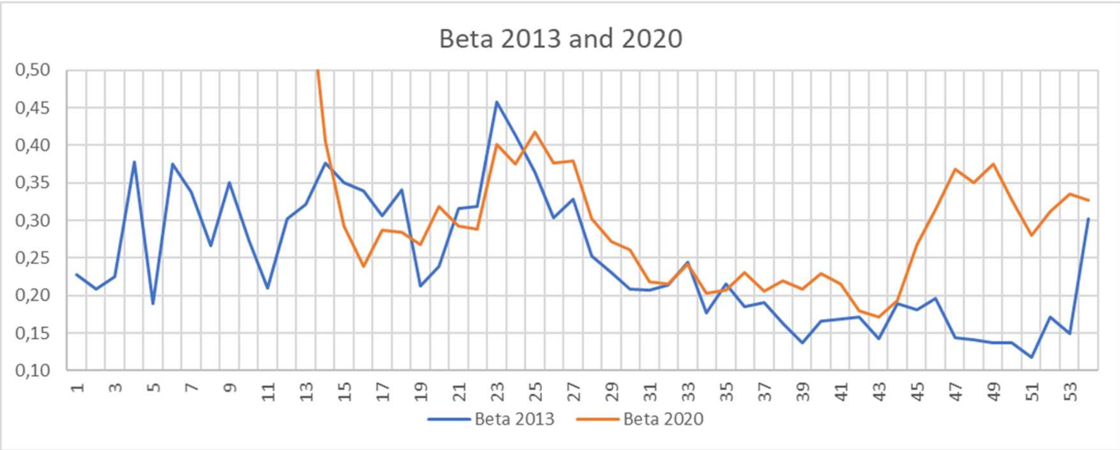


Figure 16

As explained for Figure 1, the value of β for 2021 is the same of 2020, with an estimation for weeks 2 to 14, which was the period of the initial covid-19 outbreak and is not seasonal. So, in Figure 17 is presented the difference between β for 2021 and 2013. Observe that in the period of interest, between weeks 15 and 45 the value of β for 2020 is consistently bigger than for 2013.

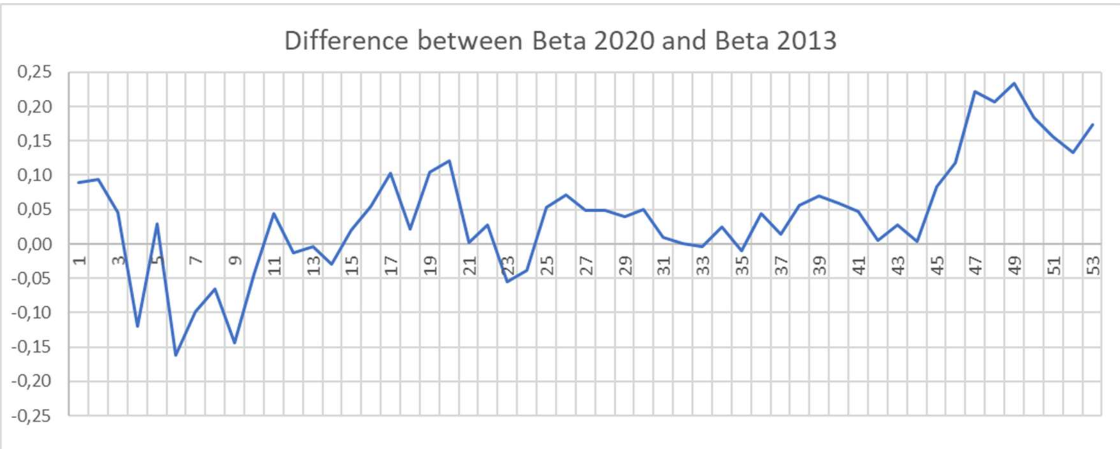


Figure 17

We shall observe that in 2020 there was effectively a Lockdown in the state from weeks 13 to 22. The evidence is that during this period, the energy consumption was up to 10% smaller than in 2019 [13]. That is, people really did a lockdown, as can be seen in Figure 18, that shows the start of week 13, the end of week 22 and can be seen the smaller consumption of 2020 in the series in brown. But from weeks 13 to 22 is not observed any reduction in β in Figure 17. On the contrary, it is observed an increase of up to 0,10, or around 30% of increase.

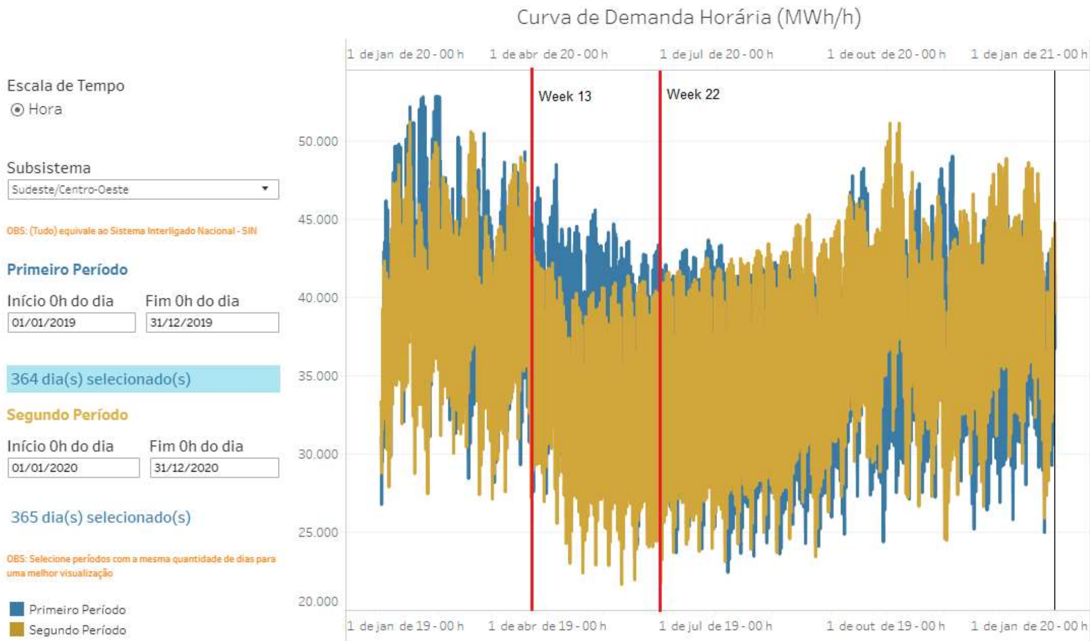


Figure 18

This way, SARS cases in the state in 2020 and the simulation for 2021 presents no effects of lockdown on them. Anyway, let us make a simulation of lockdown effects, using as basis the simulation for Minas Gerais without vaccination (Figure 3). We considered an effectiveness of 25% for lockdown during weeks 13 to 22 of 2020. That is, during this period β would be reduced 25%. Figure 19 presents the result. Observe that the reduction during weeks 13 to 22 would reflect a sensitive reduction in SARS cases during 2020. But after week 20 of 2021 paradoxically the cases with lockdown would become bigger than the cases without lockdown. This can be explained that in the next season, with a bigger initial value and a bigger susceptible population, the peak would be even bigger. One conclusion is that lockdown, if it would be effective, makes time to provide some solution for an epidemic, such as hospitals or vaccines, but delays a bigger peak for a later moment.

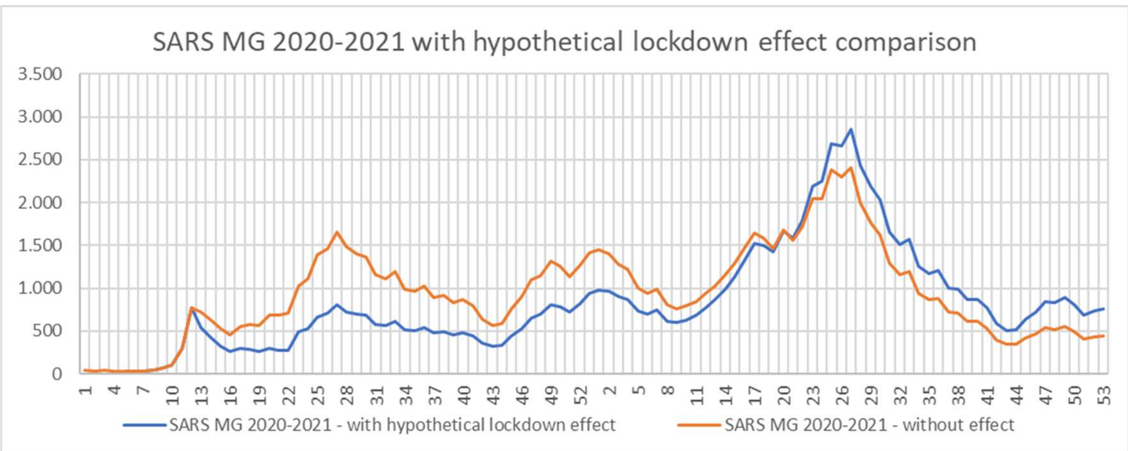


Figure 19

Epidemic Dynamics

This paper discussed the hypothesis of a β variable in time. Let us give a step back and consider a constant β. It was done some simulations to check the dynamics of the epidemic with the range of values found in this work for β. This way, Figure 20 presents the β needed to start and maintain an epidemic. It was found that is needed an initial pulse of around 1 that would decay in a few weeks to the steady state value, just like some cases presented in this paper, such as Amazonas, Florida and India. The steady state value found was around 0,3, which is the average of the cases studied in this work. With these conditions, an epidemic would last approximately 3 years, as can be seen in the bottom of Figure 20.

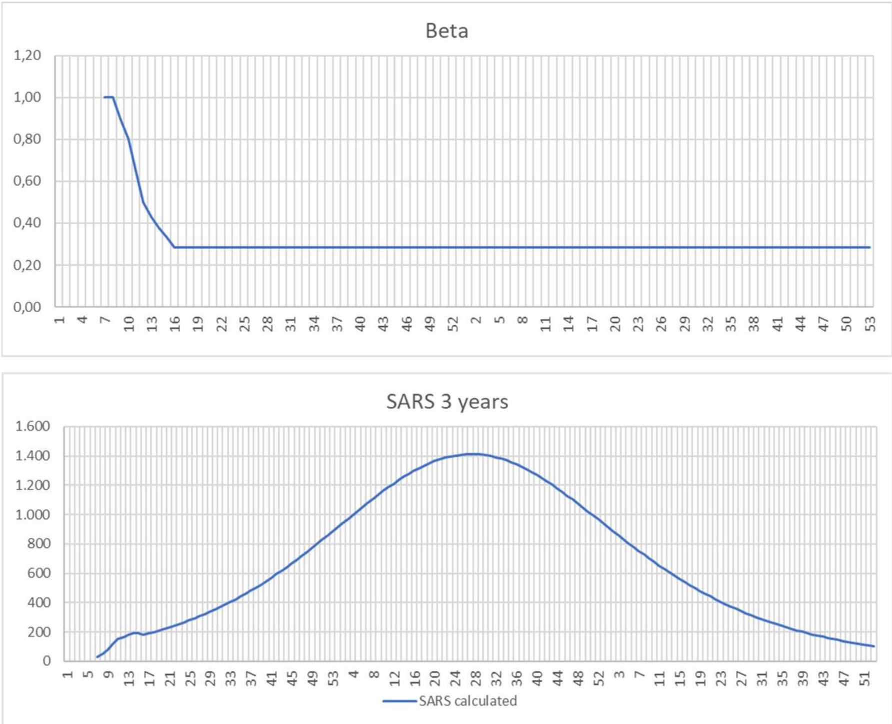
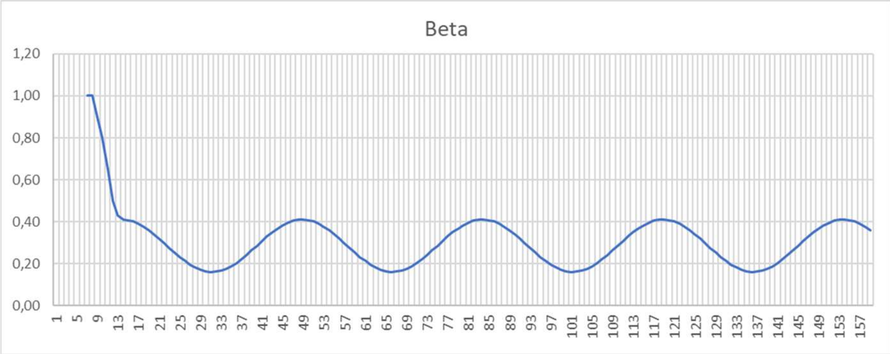


Figure 20

Figure 21 presents the very same simulation, but instead of a fixed value of β after the initial pulse, it has a sinusoidal variation, with the same average value of 0,3 and a period of 35 weeks. This is consistent with the seasonal behavior observed in some of the cases studied, as Minas Gerais, Rio Grande do Sul and Florida. It is observed a pattern with several "waves" of the epidemic, one bigger than another, until the herd immunity is reached on the fourth wave in this example. This can be explained by the periodic or seasonal behavior of β and the characteristic of SIR equations to be sensitive to the initial value. In each season the initial value is bigger and so is bigger the peak. This is consistent with the covid-19 data observed in the mentioned cases studied in this paper.



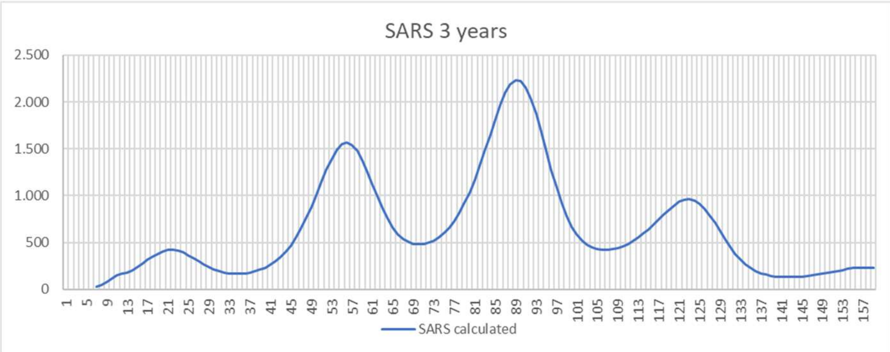


Figure 21

Last, let us consider a partial susceptible population, the S of SIR equations, and not all the population as done so far. Let us make it 80% of the total population and all the other input parameters are kept the same. So, the result of the simulation obtained is presented in Figure 22. It is consistent with the pattern observed for previous years in the historic of Fiocruz or CDC database [5, 14], in frequency and amplitude. Notice that only 20% of previously immune people is enough to avoid a large-scale spread.

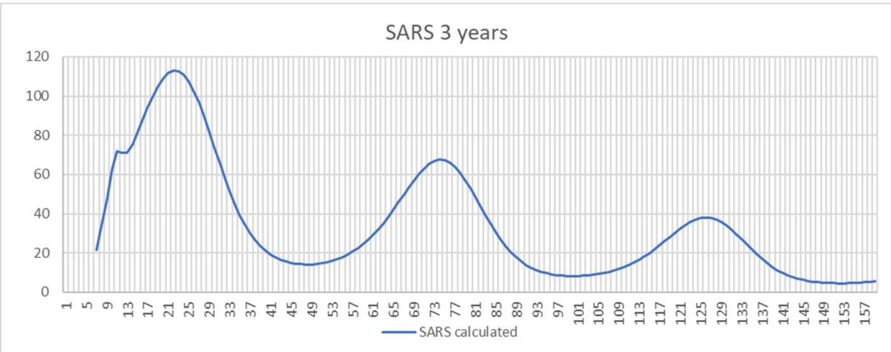


Figure 22

Some additional interesting discussion can be done on those results. First, seems to be valid the hypothesis that when emerge a new virus, an exogenic respiratory virus, all the population is susceptible and is probable to rise an epidemic of major proportions. On the other hand, when it is the case of a virus already circulating in a region, people will have some immunity, acquired by having the disease itself or by vaccine, just like H1N1, for example. This way, the susceptible population will be smaller and the behavior of the epidemic in each season will be closer to endemic. This is consistent with the observed for seasonal flu and other respiratory viruses' diseases.

This seems to be caused by the value of β and its seasonal behavior. With these parameters a pandemic or an exogenic respiratory virus epidemic seems to take around 100 weeks or 2 years to vanish, as can be observed in Figure 22.

Not surprisingly, the described behavior was also observed at Spanish flu pandemic of 1918, as can be observed at Figure 23 [15]. Notice that the peaks occurred at the winter of 1918 and summer and winter of 1919, presenting approximately a period of 20 weeks. Not different from the observed in the case studies presented and from the dynamics proposed.

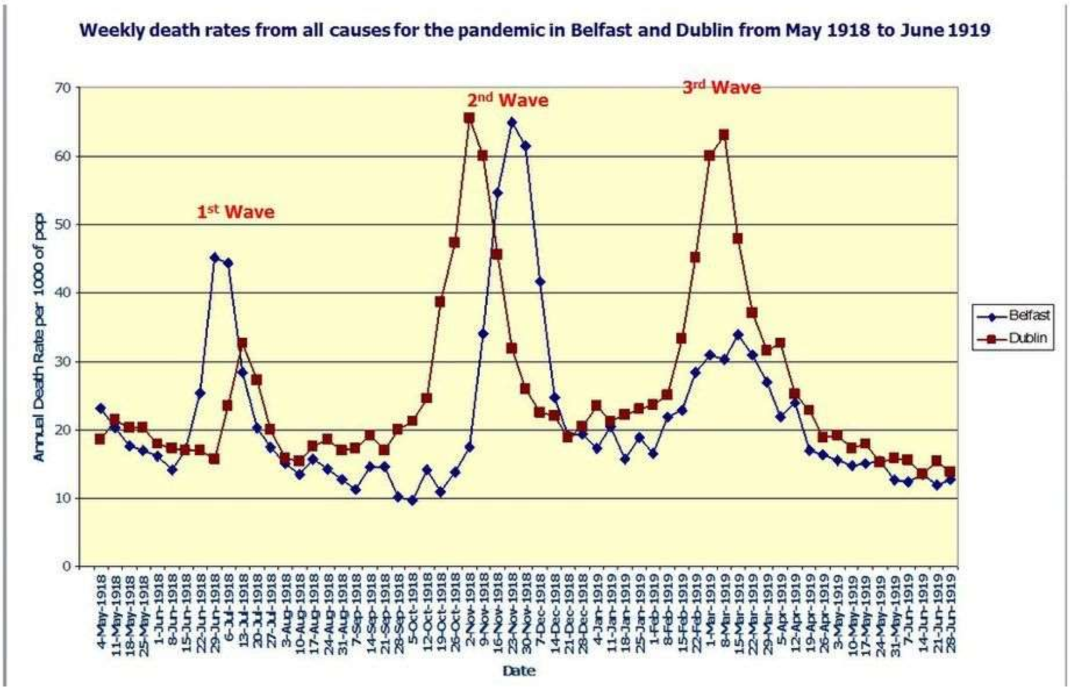


Figure 23

Conclusions

Several important findings were done in this paper and they deserve a summary:

It was raised the hypothesis that β is a function of human behavior, which is function of the climate, and because of that it is seasonal.

It was made the forecast for 2021 using this seasonal hypothesis and data from 2020 for places with different climates: Amazon for equatorial climate, Minas Gerais for tropical, Rio Grande do Sul and Florida for sub-tropical, New York for temperate and India for monsoon.

β ranges from 0,15 to 0,40 for Minas Gerais, Rio Grande do Sul and from 0,10 to 0,80 for Amazonas, Florida, New York and India. It was not found effect of the lockdown from March to

May of 2020 in Minas Gerais in reducing β. In fact, β increased around 30% during lockdown period.

Up to around week 30 of 2021 the vaccination will relief the pandemic in the studied regions if its pace is kept.

The quantity of people immune to provide herd immunity for covid-19 is around 55%. This is believed to be explained by the value observed for β, which is relatively low.

If lockdown would have some effect, it was shown by the simulation that there would be a bigger peak in a latter season because of a bigger quantity of susceptible people with a bigger initial quantity of infected in the beginning of this season.

The seasonal average value for β was used in a simulation for an exogenic respiratory virus to demonstrate the epidemic dynamics, which shown that there would have several waves for around two years, one bigger than another, until the herd immunity would be reached. This was shown to be consistent even with the 1918 pandemic. In the other hand, it was shown that if the respiratory virus is not exogenic, only 20% of immune people is enough to keep the epidemic in an endemic level.

The uncertainty of this forecast is estimated to be around 25%.

Next Steps

In the next paper will be presented the comparison of the forecast and the observed data and will be checked if it is within the uncertainty estimated. This might be available by the end of 2021. All the data and simulations used in this work were made public to allow verification and further works.

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