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Original Empirical Research

Update of the COVID-19 Incidence Forecast with the Overlap of Seasonal Flu Outbreaks

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Abstract

Introduction. The emergence of new vector-borne diseases necessitates the development of adequate medical regulations, prevention measures, rehabilitation programs, etc. Among all these measures, timeliness is the most crucial element, which cannot be achieved without reliable forecasting of the epidemic situation. In fact, the situation can deteriorate when two epidemics occur simultaneously, emphasizing the need for predicting the corresponding time intervals accurately. The aim of this study is to scientifically predict the periods when traditional influenza and COVID-19 epidemics may overlap.

Materials and Methods. The scientific research was based on the analysis of statistical data, which was processed using Fourier decomposition and autoregression techniques to study and predict various processes. The original mathematical model of COVID-19 dynamics was adjusted with new statistical data. The resulting scale-time and random characteristics of COVID-19 within the model were compared with known parameters of traditional influenza.

Results. It was established that the dynamics of the COVID-19 epidemic had a pronounced seasonal character with a frequency of three times a year. It was found that the method of forecasting COVID-19 incidence using Fourier decomposition was not reliable, but it allowed for a good description of the observed dynamics of the epidemic. Autoregressive analysis, on the other hand, was only suitable for short-term forecasting of coronavirus epidemics. The features of the two seasonal diseases, COVID-19 and influenza, have been compared, and the moments when their combined effects on a person would be particularly harmful have been predicted.

Discussion and Conclusion. All methods of mathematical analysis have convincingly demonstrated that the frequency of COVID-19 outbreaks occurs three times per year, while influenza occurs annually. During times when the activities of both viruses (coronavirus and influenza) coincide, special attention should be paid and measures taken to reduce the risk of contracting a seasonal viral infection, including through regular vaccination.

Keywords: epidemic, pandemic, COVID-19, epidemiological characteristics of the virus, counteracting the spread of COVID-19, mathematical model of epidemic process, omicron

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Оригинальное эмпирическое исследование

Уточнение прогноза заболеваемости COVID-19 с наложением на сезонные вспышки гриппа

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Аннотация
Введение. Появление новых трансмиссивных заболеваний требует разработки соответствующих лечебных регламентов, мер предупреждения болезни, схем реабилитации и т. д. Важнейшим элементом всех обозначенных выше мероприятий является своевременность, которая невозможна без надёжного прогнозирования эпидемической обстановки. Фактически эпидемическая ситуация может обостриться при наложении двух эпидемий, что актуализует прогнозирование соответствующих временных интервалов. Цель данной работы — научно обоснованное предсказание периодов, отвечающих наложению эпидемий традиционного гриппа и вновь появившегося COVID-19.
Материалы и методы. Научные изыскания основываются на анализе статистических данных. Для изучения и прогнозирования процессов использованы техники Фурье-разложения и авторегрессии. Скорректирована оригинальная математическая модель динамики COVID-19 с учетом новых статистических данных. Сопоставлены результирующие масштабно-временные и случайные характеристики COVID-19 в рамках модели с известными параметрами традиционного гриппа.
Результаты исследования. Установлено, что динамика эпидемии COVID-19 имеет ярко выраженный сезонный характер с периодичностью три раза в год. Выявлено, что алгоритм прогноза заболеваемости COVID-19 методом Фурье-разложения не является надежным, однако позволяет хорошо описать наблюдаемую динамику развития эпидемии. Авторегрессионный анализ подходит лишь для краткосрочного прогнозирования коронавирусной эпидемии. Сопоставлены особенности течения двух заболеваний сезонного характера — COVID-19 и гриппа. Спрогнозированы моменты, когда их совместное действие на человека окажется особенно пагубным.
Обсуждение и заключения. Все методы математического анализа убедительно доказали, что периодичность вспышек COVID-19 — трижды в год, а гриппа — ежегодно. В периоды, когда действия двух вирусов (коронавируса и гриппа) накладываются, следует быть особо осторожными и соблюдать меры, направленные на снижение риска заболеть сезонной вирусной инфекцией, в том числе проводить регулярную вакцинацию.

Ключевые слова: эпидемия, пандемия, COVID-19, эпидемиологические характеристики вируса, противодействие распространению COVID-19, математическая модель эпидемического процесса, омикрон

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Introduction. Harmful effects of epidemics on humans and their livelihoods as a whole are prevented through the constant improvement of preventive measures. These measures aim to break the chain of disease transmission, reduce its severity, and reduce the risk of infection. These elements have been carefully developed for seasonal viral diseases, such as SARS and influenza, in particular. The emergence of new vector-borne diseases requires the development of new measures, such as medical regulations, prevention strategies, rehabilitation plans, medications, and specialized medical facilities. An example of this is the recent COVID-19 pandemic and the response from global governments and healthcare systems [1]. The most important aspect of these measures is their timeliness, which requires reliable forecasting of epidemic situations.

The aim of this study is to identify the periods of overlap between traditional influenza epidemics and the recently emerged COVID-19 pandemic. This information will help us prepare for future outbreaks, minimizing the severity and impact of the diseases.

Materials and Methods. The emergence of new epidemiological data for the period from September 23, 2021, to March 3, 2023, requires a radical revision of the previous scenario for the development of the disease. Specifically, the previous scenario assumed that the pandemic would continue indefinitely, with an average daily incidence of 600,000 people, fluctuating three times per year with an amplitude of ±300,000. This corresponded to what was referred to as the "pessimistic" scenario. However, the emergence of new viral strains has led to an increased fitness between the virus and human hosts, redirecting the dynamics of COVID-19 towards an “optimistic” trajectory. This development necessitates adjusting the mathematical model in order to accurately predict the timing and magnitude of disease outbreaks [2, 3]. To accomplish this, the following objectives should be addressed:

1. to clarify the results of parametric identification of the external model based on new data [4];
2. to assess the impact of the regular component and random factors on the dynamics of the pandemic;
3. to make a forecast of the epidemic situation using both a stochastic model (adjusted based on new data) and new algorithms — Fourier analysis and autoregression;
4. to compare the resulting time-scale and random characteristics of COVID-19 within the framework of the model with the known parameters of traditional influenza.

As a template function describing the dynamics of COVID-19, we take

$$\Phi(t,A,B,C,D,E,F,\alpha,\beta,\gamma,\delta,\varepsilon)=\frac{A\left[\alpha+cos(\beta t+\gamma)\right]}{ch^2(Bt+C)}+D\left[1+th(Et+F)\right]\left(\delta+cos(\delta t+\varepsilon)\right). \quad (1)$$

The first term of this function corresponds to a high peak caused by the Omicron strain. The second term represents the scenario where morbidity exits to an average level of 500,000 people, oscillating around this value with a frequency of β/(2π). The parameters included in equation (1) have an obvious meaning of duration, frequency, amplitude and initial phase of individual disease modes.

To find all the parameters of model (1), according to the updated WHO data for the period from 01.04.2022 to 03.03.2023, we solved a significantly nonlinear mathematical programming problem:

$$ЦФ=\Sigma_i\left(lg\,\Phi(t_i,A,B,C,D,E,F,\alpha,\beta,\gamma,\delta,\varepsilon)-lg\,\Phi_i\right)^2\rightarrow min. \quad (2)$$

The results of parametric identification (1) are shown in Table 1 and in Figure 1.

Table 1

Numerical characteristics of the COVID-19 template morbidity model

A	B	C	D	E	F	α	β	γ	δ	ε	ЦФ
4381.458	0.036	–25.085	58.159	0.009	–1.280	1.233	0.043	–1.827	4.346	1.767	23.64

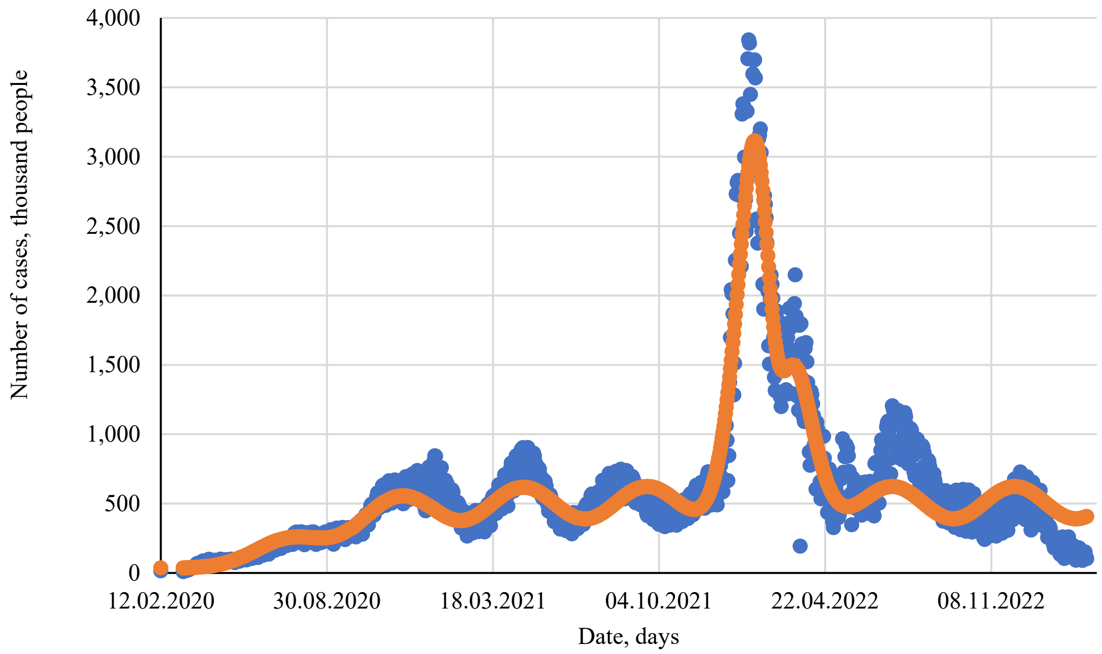


Fig. 1. Results of calculating the number of cases by date

According to the calculations performed, formula (1) takes the form:

$$\Phi(t)=\left(\frac{4,381.458\left[1,233+cos(0.043t-1.827)\right]}{ch^2\,0.036t-25.085}\right)58.159\left[1+th(0.009t-1.280)\right]\left(4.346+cos(0.043t+1.767)\right). \quad (3)$$

Oscillation period is 147 days versus 120–125 in the previous version of model [2]. However, this increase appears to be an artifact (Fig. 1) and is the result of a failure of the morbidity phase in an outbreak of omicron. Value (γ – ε) characterizes the phase shift between the incidence of traditional COVID-19 and omicron modification.

The removal of the trend and oscillatory components from the data prevented us from obtaining a purely noise background (Fig. 2) [5]. This is due to the presence of some non-linear interaction in reality that does not fit within the framework of our model (3).

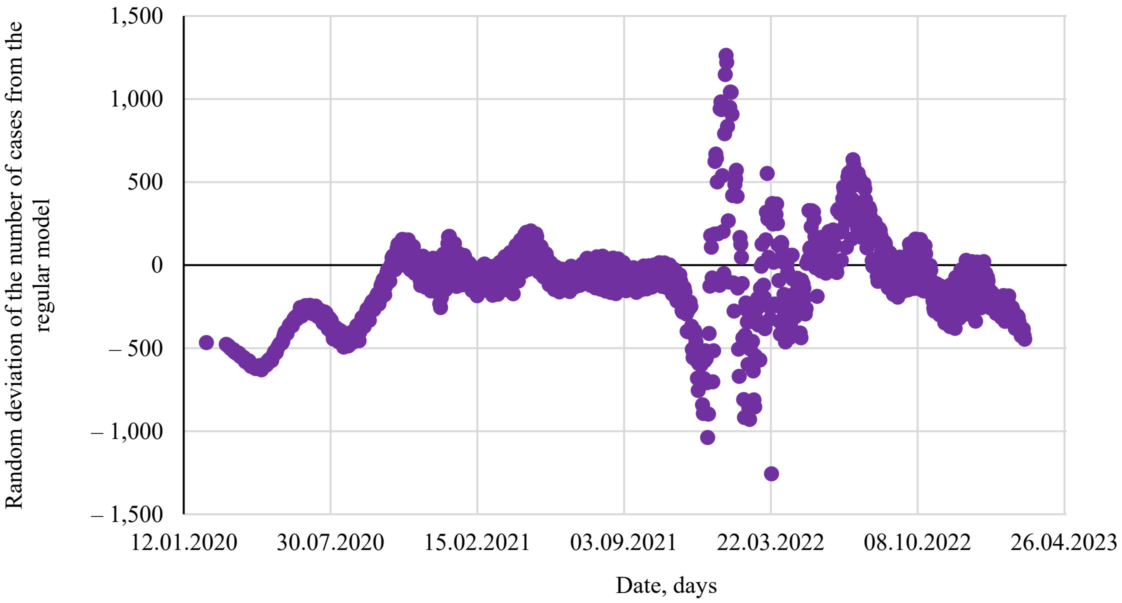


Fig. 2. Error in the approximation of WHO data by model (3)

The inability to accurately describe the dynamics of COVID-19 with 11-parametric function (1) encourages the use of alternative approaches for this purpose.

The results of representing the observed dynamics of the epidemic using Fourier decomposition with 40 and 100 harmonics are shown in Fig. 3.

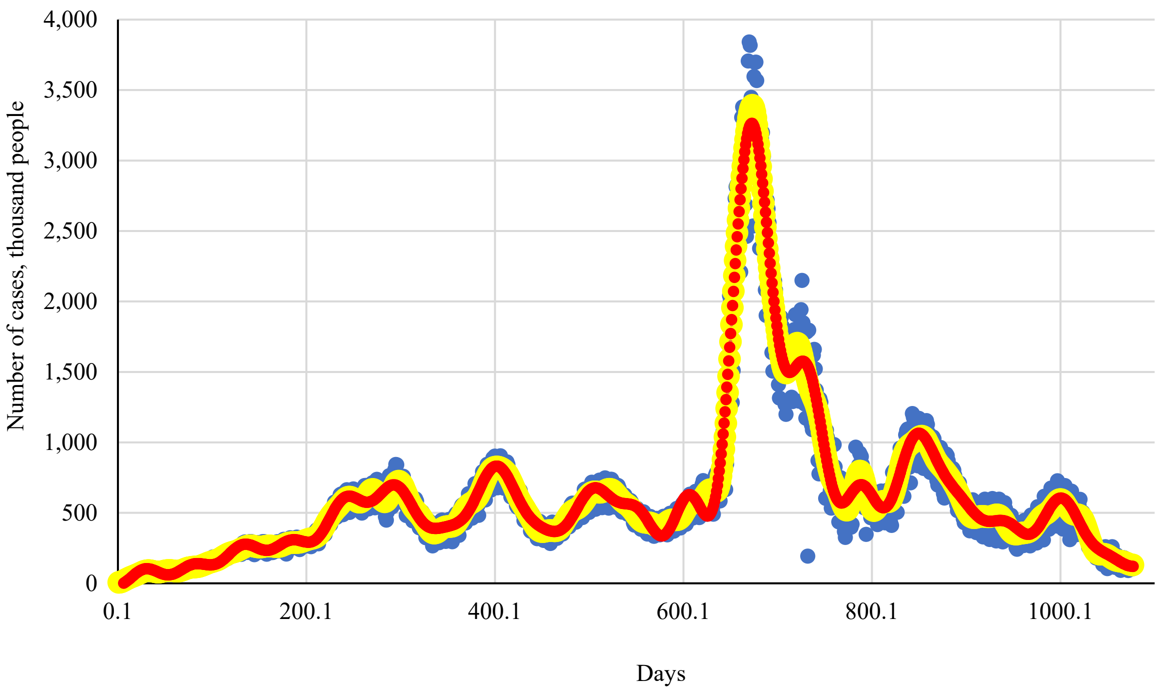


Fig. 3. The initial dynamics of the epidemic and its Fourier approximation. The initial data is shown in blue. The Fourier decomposition with 100 harmonics is shown in yellow, and the decomposition with 40 harmonics is in red

Comparison of the data in Figures 1 and 3 shows that considering a larger number of modes allows for a better description of the real dynamics of the epidemic. This is supported by both the slower decrease of a_i coefficients in the decomposition (Fig. 4) and the more dispersed nature of the residual random component (Fig. 5).

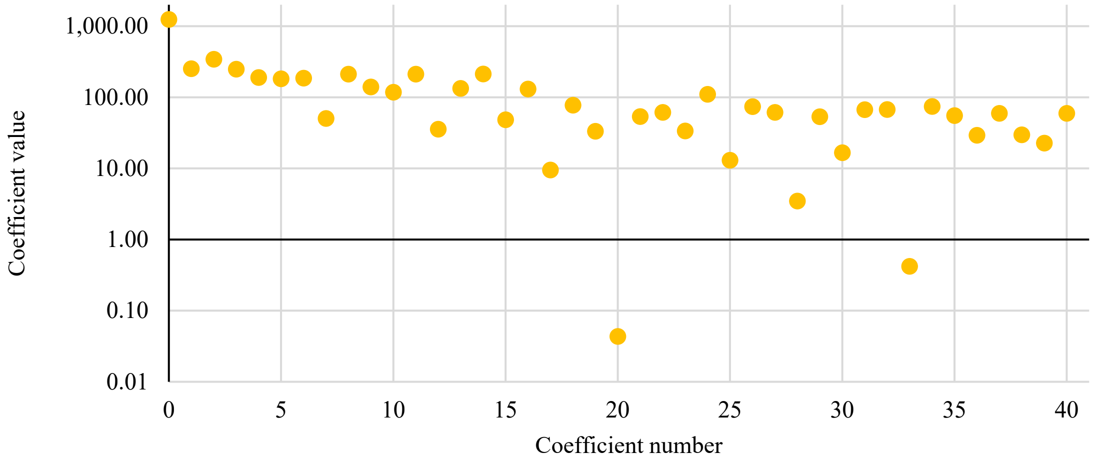
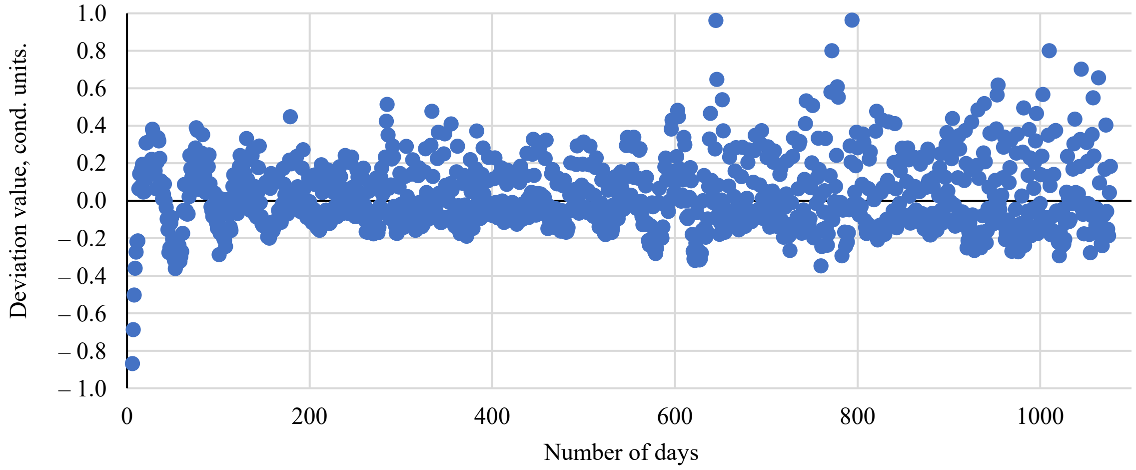
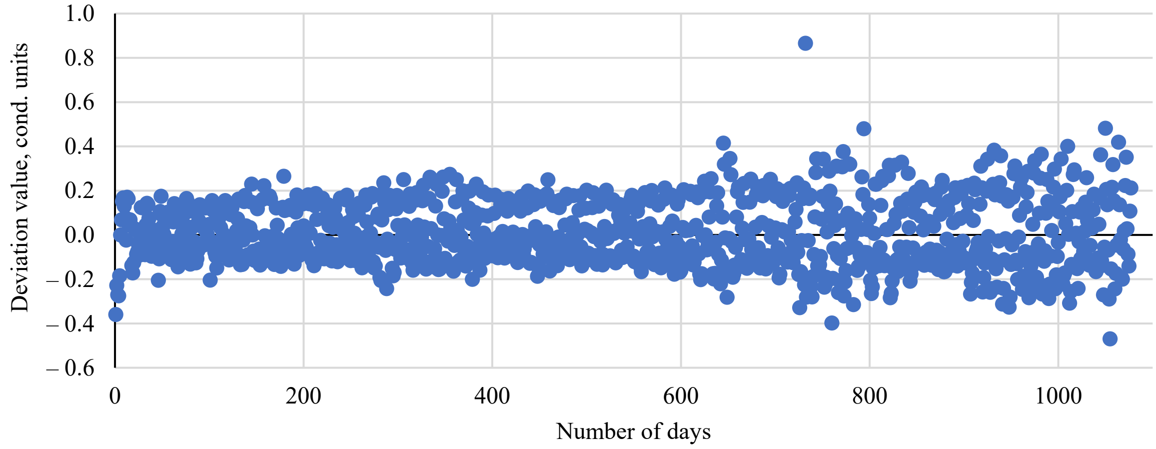


Fig. 4. The change in coefficients of decomposition a_i as the number increases



a)



b)

Fig. 5. The result of the elimination of the Fourier image from the source data:
a — Fourier decomposition into 40 harmonics; *b* — Fourier decomposition into 100 harmonics

According to the data in Figure 5, the residual relative noise is random. In practice, knowledge of the Fourier expansion coefficients a_i [6] makes it possible to synthesize a regularly random function for forecasting [7]. To make the result more transparent, only the trend is included in the forecast line (brown in Fig. 6) and compared with new statistical data [8]. The comparison suggests that the proposed algorithm does not provide long-term forecasts [9].

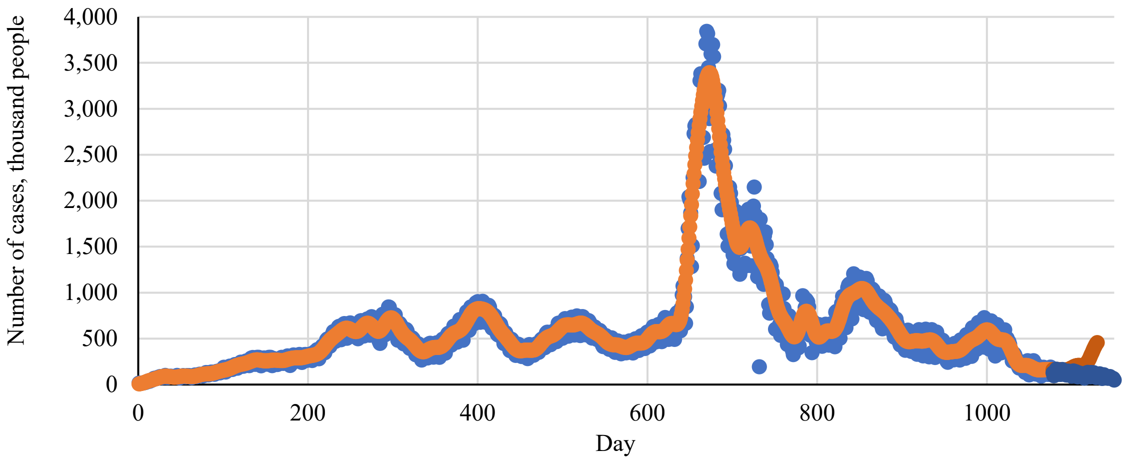


Fig. 6. Forecast of epidemic situation based on Fourier decomposition in comparison with new WHO data. Orange indicates a model based on the Fourier decomposition of a time series; brown indicates the predicted development of the coronavirus; blue indicates the initial data; dark blue indicates the real data compared to the predicted values

In this regard, the possibility of improving the quality of forecasting based on the autoregressive approach is investigated. The autoregression procedure is regulated by the following algorithm: 1) initialization of the initial data; 2) a suitable model is selected, depending on the characteristics of the time series and the requirements of the forecast; 3) training the model on a training sample; 4) validation of the model (checking the quality of the forecast on a test sample); 5) forecasting.

The dynamics of the epidemic have been predicted from March 4, 2023 until the present, comparing the results with current WHO data [6–8]. The results of this comparison are shown in Figure 7. As it can be seen, the autoregression technique is only suitable as a tool for short-term forecasting.

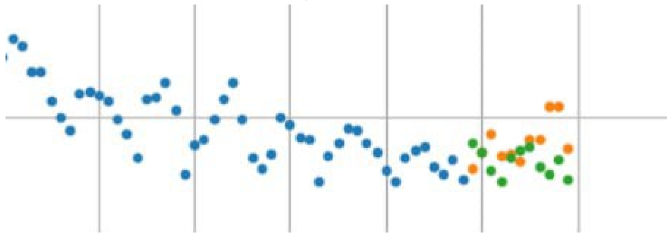


Fig. 7. Forecast of epidemic situation based on the autoregression method in comparison with new WHO data. The blue dots indicate the source data; orange — predicted values; green — real data compared to predicted values

Due to the fact that COVID-19 has rapidly evolved into a seasonal viral disease, it is interesting to compare its epidemic characteristics with those of influenza, as well as to analyze the combined effects of two virulent diseases on the human population.

To successfully compare the characteristics of the COVID-19 and influenza epidemics, statistical data on the incidence of influenza on a global scale from 03.01.2000 to 03.20.2023 were used, which can be found on the resource and shown in Figure 8.

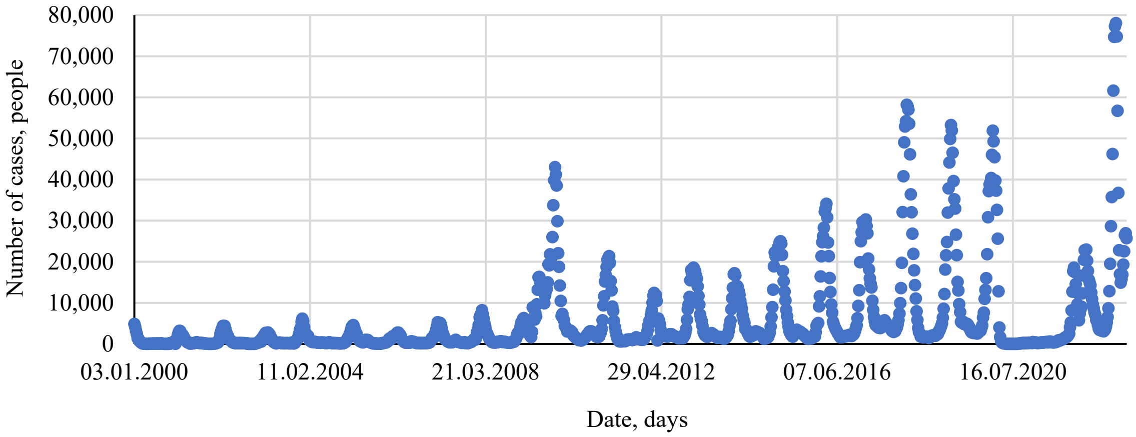


Fig. 8. Actual data on the influenza incidence according to WHO data

The logistic dependence was used as a trend model for the influenza epidemic [10] (Fig. 9):

$$N(t)=\frac{\mu\cdot e^{\eta(t-\chi)}}{1+e^{\eta(t-\chi)}}. \quad (4)$$

Initialization of the model using mathematical programming methods gives the following parameter values: μ = 6,847 thousand people/day (the maximum average incidence of influenza); η = 0.29 years^{-1} (the rate of increase in the coverage of patients with the global morbidity control system); χ = 2,013.9 year (the moment of half coverage of patients with the accounting system). Within the framework of this trend model, the incidence of influenza is reaching a historical plateau, and its recorded growth is associated exclusively with informatization in healthcare.

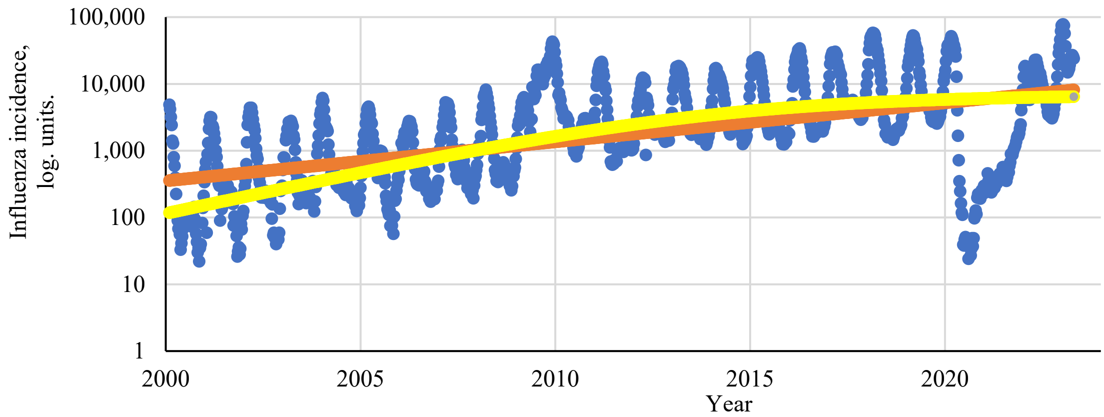


Fig. 9. Initialization of the influenza incidence trend. The blue color represents the incidence of influenza on a logarithmic scale; the orange line shows the assumed exponential trend; the yellow one shows trend model (4)

If you know the trend you can exclude it from the observed statistics and thereby highlight the oscillatory component:

$$P(t)=A\cdot sin^{6}(Bt+\varphi). \quad (5)$$

The degree of sine chosen here equal to 6 is responsible for the "blurring" of the outbreak of the disease over time. To find the coefficients of the model, optimization problem should be solved

$$\Sigma_i (F_i-P_i)^2 \rightarrow min, \quad (6)$$

where F_i — incidence; P_i — model value; $i \in [1,1212]$.

The results of the calculations are shown in Figure 10 and can be calculated using the following formula:

$$P(t)=5.03\cdot sin^{6}(3.2\cdot t-0.29). \quad (7)$$

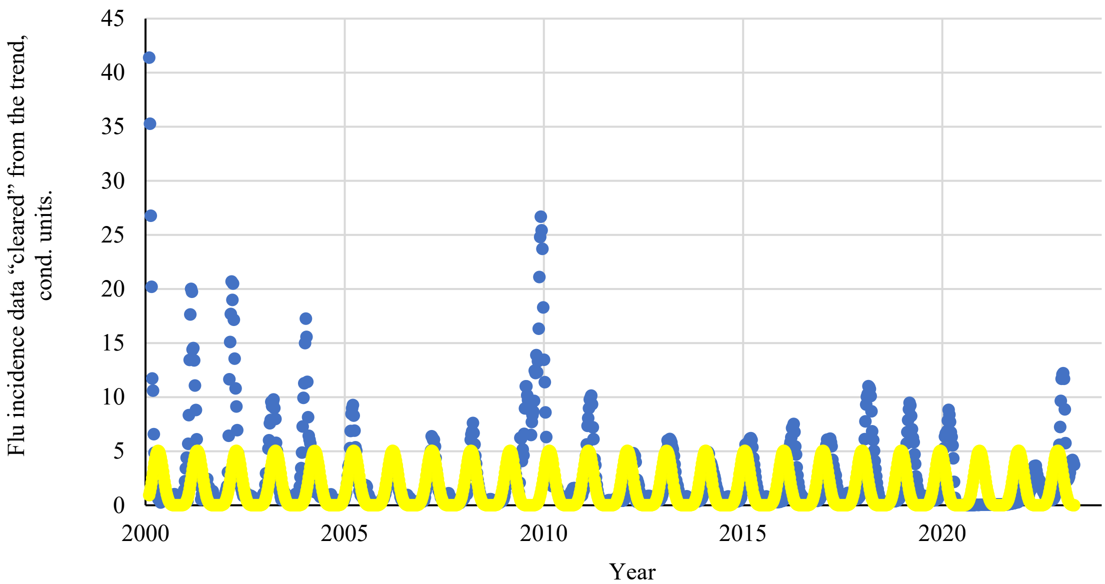


Fig. 10. The result of solving the optimization problem for the improved trend. The blue color shows the initial data cleared from the trend; the yellow color shows the curve corresponding to the random component

The presented data indicate that the influenza epidemic is a seasonal process that occurs annually [11, 12]. This means that, depending on the timing of the initial stages of epidemics, overlapping periods of high morbidity can occur. To determine these moments, the dynamics of influenza and COVID-19 incidence is presented in parametric form based on the results of [2]:

$$G(t) = 5.03 \cdot sin^6\left(3.15 \cdot \left(2{,}022.48 + \frac{t}{365}\right) - 0.18\right) \text{ — для гриппа;} \quad (8)$$

$$K(t) = 1 + 0.2 \cdot sin\left(0.043 \cdot t - \frac{\pi}{2}\right) \text{ — для COVID-19.} \quad (9)$$

In formulas (8, 9), time t is counted from moment t_0 = {03.01.2000} in units of one day. The standard representation of these data in Figure 11 is not informative, which prompts them to be converted into a parametric form (Fig. 12).

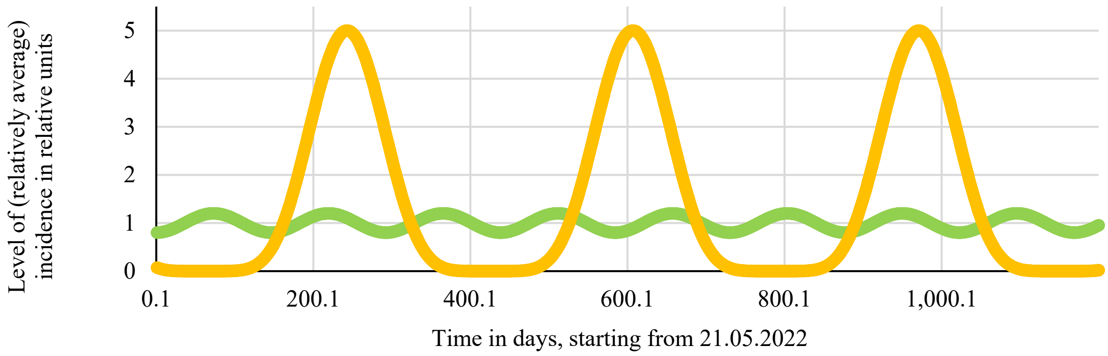


Fig. 11. Comparison of the dynamics of incidence of COVID-19 and influenza in relative units. The curve corresponding to the incidence of COVID-19 is shown in green, and the incidence of influenza is shown in orange

Since all methods of mathematical analysis have convincingly proved that COVID-19 outbreaks occur three times a year and influenza occurs annually, we will plot the data in Figure 11 in a parametric form (Fig. 12)

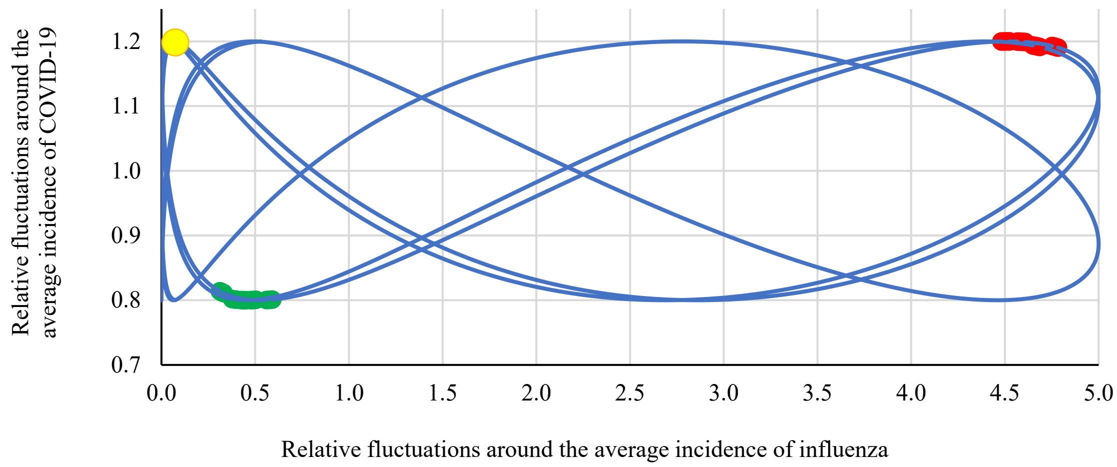


Fig. 12. Comparison of the dynamics of incidence of COVID-19 and influenza in parametric form

The joint display of the incidence of influenza and COVID-19, as shown in Figure 12, allows us to identify the most challenging moments when the effects of these two viruses overlap. During these periods, it is especially important to be cautious and follow all regulations for sanitary and epidemic control [13–15]. Currently, we are in a situation indicated by a yellow dot on the graph. From the most severe moment in terms of the epidemic (the red area), we are separated by approximately 580 days.

Results. As a result of our research, we have reached the following conclusions:

1. We have made significant adjustments to align the existing model with new data.
2. Previous estimates of the severity of COVID-19 were overly pessimistic.
3. We used new methods, such as Fourier analysis and autoregressive techniques, to increase the information content and reliability of our analysis and epidemic forecasting.
4. Even with the combined use of these methods, we can only make a short-term forecast.
5. We compared the features of two seasonal diseases, COVID-19 and influenza.
6. We predicted the moments when the combined effect of these diseases will be most harmful to humans.

Discussion and Conclusion. The authors substantiate the need to reliably predict the coincidence of peaks in the incidence of influenza and COVID-19. It is shown that the visibility of the coincidence is achieved by presenting the dynamics of both diseases in a parametric form. It has been established that due to the multiplicity of the period of both epidemics, the maximum and minimum danger of their imposition is also periodic. Numerical indicators of the cyclical nature of epidemics were revealed according to experimental data by direct approximation, Fourier decomposition and autoregressive algorithm. A computer experiment has shown that even the combined use of these methods allows only a short-term forecast of the epidemic situation. The authors predicted the moments when the peaks of the incidence of influenza and COVID-19 will coincide.

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DKh Zairova: selection and verification of new statistical data, comparison of the results of experiments on forecasting the epidemic dynamics with the real data.

AS Ermakov: comparative characteristics of the COVID-19 and influenza epidemics, performing experiments to predict the dynamics of the epidemic, preparing the text of the article.

EN Ladosha: formulation of meaningful conclusions and recommendations, revision of the text.

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