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Governmental Anti-Covid Measures Effectiveness Detection

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Abstract

We present a retrospective analysis of Czech anti-covid governmental measures' effectiveness for an unusually long three years of observation. Numerous Czech government restrictive measures illustrate this analysis applied to three years of COVID-19 data from the first three COVID-19 cases detected on 1st March 2020 till March 2023. It illustrates the course from the dramatic combat of unknown illness to resignation to country-wide measures and placing COVID-19 into a category of common nuisances. Our analysis uses the derived adaptive recursive Bayesian stochastic multidimensional Covid model-based prediction of nine essential publicly available COVID-19 data series. The COVID-19 model enables us to differentiate between effective measures and solely nuisance or antagonistic provisions and their correct or wrong timing. Our COVID model allows us to predict vital covid statistics such as the number of hospitalized, deaths, or symptomatic individuals, which can serve for daily control of anti-covid measures and the necessary precautions and formulate recommendations to control future pandemics.

Keywords: COVID-19, Recursive forecasting model, Machine learning method, Prediction, Anti-pandemic measures

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1. Introduction

Covid-19 was an unknown disease with an exponential spread that has affected over 178 countries around the world with over 6 million deaths, and no one knew anything about it, so it is not surprising that individual governments often reacted very chaotically. The change in recent lifestyles, such as increased global travel and urbanization, allows infectious diseases to quickly escalate into a global pandemic. The hastily introduced measures vary widely between countries and even within countries. The alternative applied measures, and their timing reflects different phases of the epidemic, as well as differences in resources, cultures, governments, and laws. School closings have sent more than half a billion children home, according to UNESCO [7]. Several studies or popular articles [8, 7, 12, 13, 14, 6, 11, 2, 15] tried to estimate the effectiveness of such governmental measures. However, the anti-covid influence of these measures, such as various closures, curfews, mask-wearing, and others, still needs to be better understood.

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The study [8] on 11 European countries found the efficient (the reproduction number *R* based) measures during the four months to be the lockdown, while school or university closure, case-based isolation, a ban on significant public events, social distancing, were less efficient. However, this conclusion is challenged in the [14] study. Similar study [6] tests eight mandatory non-pharmaceutical interventions implemented in 41 countries during a relatively short period of four months based on Data on confirmed COVID-19 cases and deaths from the Johns Hopkins CSSE COVID-19 Dataset. The effectiveness is measured as a percentage reduction in the reproduction number (Sec. 2.1) using the modified [8] Bayesian model. They found a considerable *R* reduction for closing all educational institutions, limiting gatherings to 10 people, and closing face-to-face businesses while having a negligible effect on stay-at-home orders. Paper [13] surveys significant statistical, analytical, mathematical, and medical parameters and the model's challenges to consider and suggests several recommendations. Past viral pandemics and the importance of preventive care measures are surveyed in [12]. A review [11] classifies 348 articles on covid-related subjects, including the effects of non-pharmaceutical measures on virus spreading, behavior, and medical practice. A survey of COVID-19 models, mostly some variants of the deterministic compartment differential equations model (SEIR), developed in India was presented in [3] with an observation of their hampered prediction due to lack of quality data.

A simple log-linear version of Poisson autoregression [1] is presented to understand the contagion dynamics of COVID-19 based on newly infected counts. A polynomial regression predictive model for positive covid cases [10] is validated on four countries' data. The model cannot detect new pandemic waves or the influence of external measures. The modified standard SEIR model [4] with approximate Bayesian solution studies possible alternative timing and non-pharmaceutical interventions in the first spring pandemic in the Czech Republic. The model uses some estimated sociological data to set up its parameters. The impact of non-pharmaceutical measures in the first half pandemic year in four Saudi Arabia regions using the SEPAIHR compartment model is illustrated in [2]. A framework to deploy a prospective real-time machine learning-based early warning system to anticipate or confirm COVID-19 outbreaks based on the effective reproductive number changes is presented in [15].

The objectives and novelty of the study are as follows:

- To study the effectiveness of anti-covid governmental measures and their correct or wrong timing by retrospectively analyzing observed time series data on Covid-19 epidemics.
- To propose an efficient adaptive recursive predictive Bayesian model that exploits the mutual correlation between various disease long-period time series.
- To predict vital covid statistics such as the number of hospitalized, deaths, or symptomatic individuals.

The significance of this study is illustrated by the enormous number of COVID-19 deaths in the country in Fig. 1.

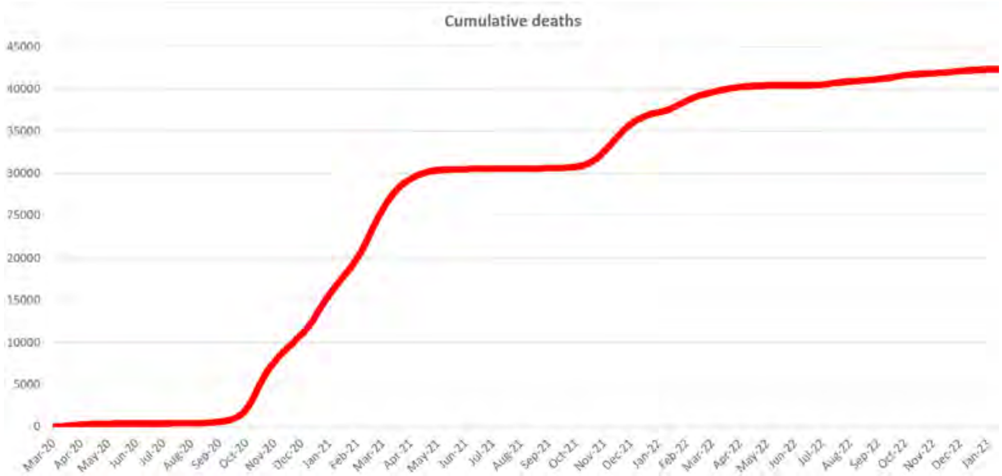

Fig. 1. The cumulative deaths in Czechia from the spring of 2020 to the spring 2023.

2. Covid Model

Modeling general multi-time-series data require two-dimensional random vector models to allow unrestricted time-series correlation representation. The advantage of 2D VCAR models (1) is that it can be solved analytically under several additional and acceptable assumptions. Multi-time-series are modeled by their dedicated Gaussian noise-driven VCAR random vector model. Let the digitized time-series Y is indexed on a finite rectangular two-dimensional $N \times d$ underlying lattice I, where N is the overall time interval and d is the number of time series simultaneously modeled. Let us denote a time index r. The (VCAR) random vector is a family of random variables with a joint probability density on the set of all possible realisations Y of the $N \times d$ lattice I, subject to the following condition:

$$p(Y \,|\, \gamma, \Sigma^{-1}) = (2\pi)^{-\frac{d(N-1)}{2}} |\Sigma^{-1}|^{\frac{(N-1)}{2}} \exp\left\{ -\frac{1}{2} tr\{\Sigma^{-1} \begin{pmatrix} -I \\ \gamma^T \end{pmatrix}^T \tilde{V}_{T-1} \begin{pmatrix} -I \\ \gamma^T \end{pmatrix}\} \right\} \quad , \tag{1}$$

$$\tilde{V}_{r-1} = \begin{pmatrix} \tilde{V}_{yy(r-1)} & \tilde{V}^T_{xy(r-1)} \\ \tilde{V}_{xy(r-1)} & \tilde{V}_{xx(r-1)} \end{pmatrix} \quad , \tag{2}$$

where the used notion is: $\tilde{V}_{uz(r-1)} = \sum_{k=1}^{r-1} U_k Z_k^T$. The 2D VCAR model can be expressed as a stationary causal uncorrelated noise driven 2D autoregressive process:

$$Y_r = \gamma X_r + e_r \quad , \tag{3}$$

where γ is the $d \times d\eta$ parameter matrix $\gamma = [A_1, \ldots, A_\eta]$, $\eta = card(I_r^c)$, I_r^c is a causal neighbourhood, e_r is a Gaussian white noise vector with zero mean and a constant but unknown covariance matrix Σ and X_r is a corresponding vector of Y_{r-s} (design vector).

The selection of an appropriate VCAR model support is important to obtain good modelling results. Too small contextual neighbourhood can not capture all details while inclusion of surplus neighbours add to the computational burden and can potentially degrade the performance of the model as an additional source of noise. The optimal neighbourhood can be found using the Bayesian decision rule for minimizing the average probability of decision error. The most probable VCAR model given past data, the normal-Wishart parameter prior and the uniform model prior is the model which maximise the statistics (see [9] for details):

$$D_{j(r-1)} = \frac{-d}{2} \ln |V_{xx(r-1)}| - \frac{\beta(r)}{2} \ln |\lambda_{(r-1)}| + \frac{d^2\eta}{2} \ln \pi \sum_{i=1}^{d} \left[\ln \frac{\Gamma(\frac{\beta(r)+1-i}{2})}{\Gamma(\frac{\beta(0)-d\eta+d+2-i}{2})} \right] \tag{4}$$

where $\beta(r) = \beta(0) + r - d\eta + d$, $\beta(0) > 1$, and

$$\lambda_{(r)} = V_{yy(r)} - V^T_{xy(r)} V^{-1}_{xx(r)} V_{xy(r)} \quad . \tag{5}$$

Parameter estimations (5),(6) of the VCAR model using the Bayesian method and the normal-Wishart parameter prior can be found analytically:

$$\hat{\gamma}_{r-1}^{T} = V_{xx(r-1)}^{-1} V_{xy(r-1)} \ , \tag{6}$$

where $V_{uz(r-1)} = \tilde{V}_{uz(r-1)} + V_{uz(0)}$ and matrices $V_{uz(0)}$ are the corresponding matrices from the normal-Wishart parameter prior.

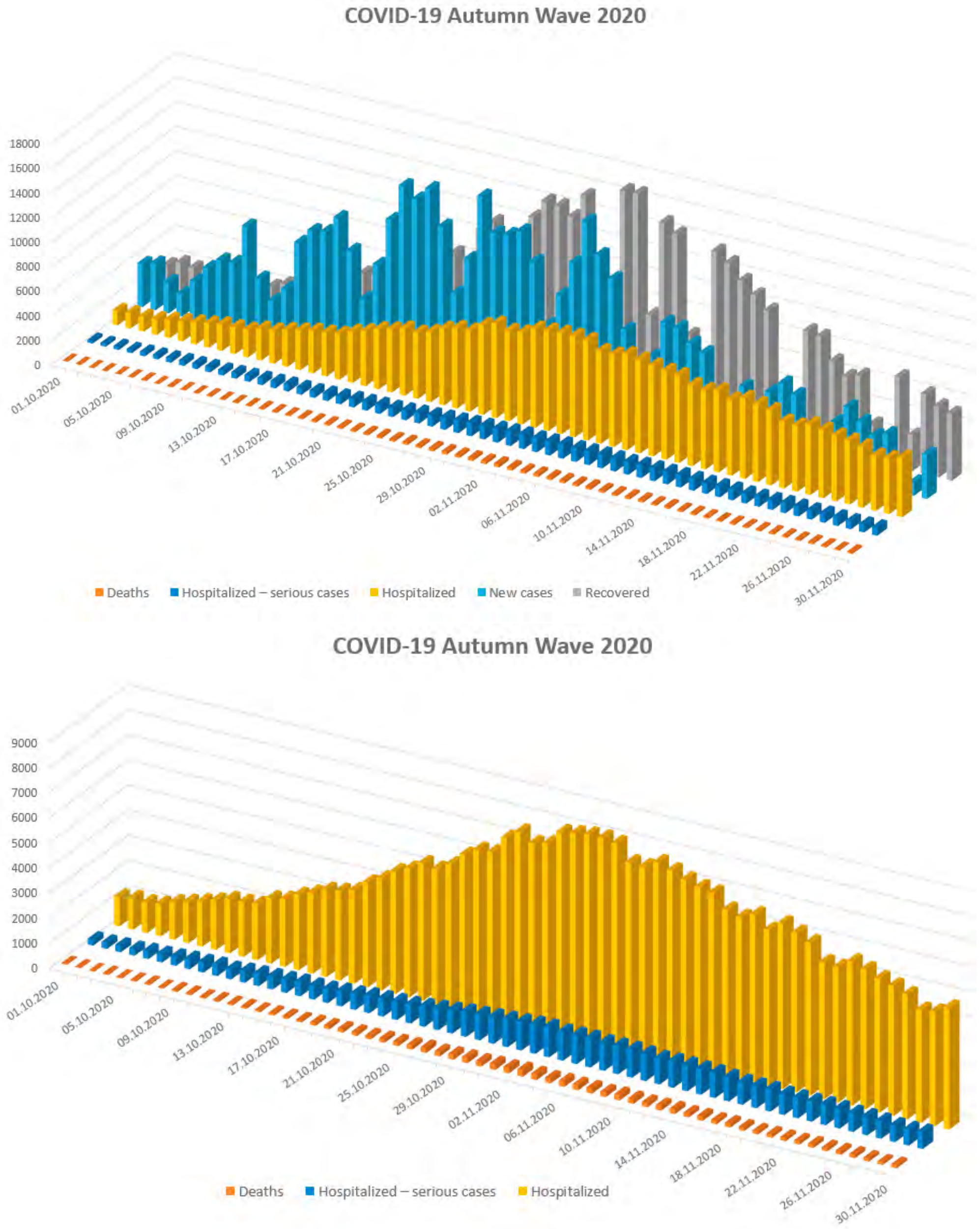

Fig. 2. The selected data from the autumn 2020 wave of COVID-19 (upper) and deaths and hospitalized (bottom).

The one-step-ahead predictor for the normal-Wishart parameter prior is

$$E\left\{Y_r \,|\, Y^{(r-1)}\right\} = \hat{\gamma}_{r-1} X_r \quad , \tag{7}$$

and the corresponding prediction error

$$\epsilon_r = Y_r - E\left\{Y_r \,|\, Y^{(r-1)}\right\} = Y_r - \hat{\gamma}_{r-1} X_r \quad . \tag{8}$$

The measure influence Δ is detected from the prediction error:

$$\Delta \begin{cases} > \frac{2.5|\epsilon_{r,i}|card\{r\}}{\sum_{\forall r}|\epsilon_{r,i}|}, & \text{strong effect;} \\ \in \left\langle \frac{1.6|\epsilon_{r,i}|card\{r\}}{\sum_{\forall r}|\epsilon_{r,i}|}; \frac{2.5|\epsilon_{r,i}|card\{r\}}{\sum_{\forall r}|\epsilon_{r,i}|} \right\rangle, & \text{medium effect;} \\ \in \left\langle \frac{0.6|\epsilon_{r,i}|card\{r\}}{\sum_{\forall r}|\epsilon_{r,i}|}; \frac{1.6|\epsilon_{r,i}|card\{r\}}{\sum_{\forall r}|\epsilon_{r,i}|} \right\rangle, & \text{small effect,} \end{cases} \tag{9}$$

where i is a corresponding element from the prediction error vector. The estimates (5) - (8) are evaluated recursively (see [9] for details).

2.1. Reproduction Number Estimation

The effective reproduction number (R number) is a crucial statistic allowing to estimate further pandemic progress, possibly modified by external measures, while the basic reproduction number is without external disease-influencing measures. The R number is the expected number of cases directly generated by one typical infectious case in a population where all individuals are susceptible to infection. There are numerous methods to estimate the R number [5, 6]. For a systematic literature review, see, e.g., [5]. We are using in the VCAR model a simple but reliable algorithm for R number calculation:

$$R_t = \frac{\sum_{i=1}^{7} \tilde{n}_{t-7+i}}{\sum_{i=1}^{7} \tilde{n}_{t-12+i}} \tag{10}$$

where t is the current date, $\tilde{n}_j$ is the number of newly infected people in the j-th day.

$$R_t \begin{cases} > 1, \text{ infection propagation } (\nearrow); \\ = 1, \text{ sharp threshold between the disease } \nearrow \text{ and } \searrow; \\ < 1, \text{ the number of infectious individuals } \searrow 0. \end{cases} \tag{11}$$

The R number speeds up new cases part model adaptation and corrects the number new cases.

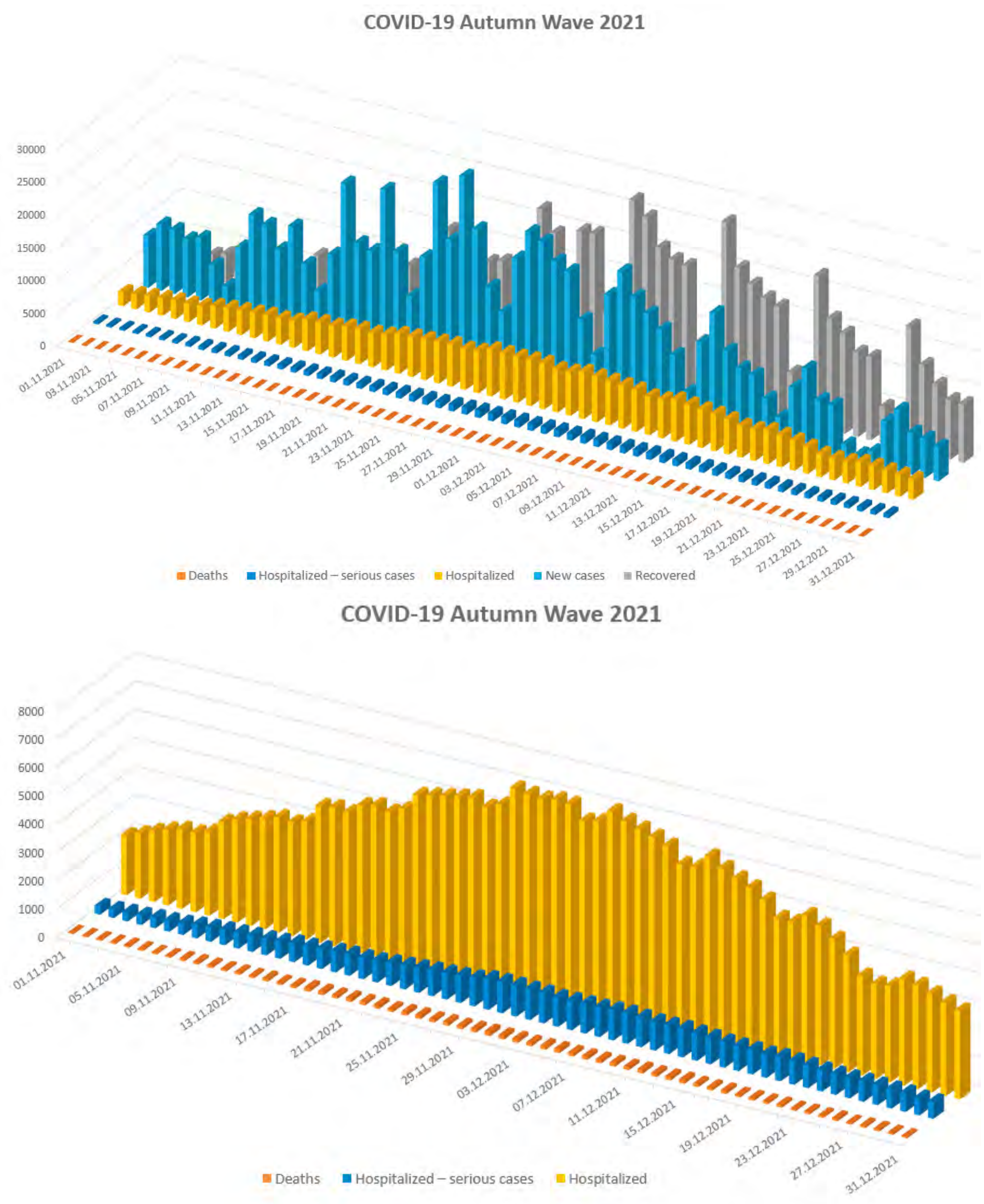

Fig. 3. The selected data from the autumn 2021 wave of COVID-19 (upper) and deaths and hospitalized (bottom).

3. Covid Data

The Czech covid-19 data are publicly available on the webpage `https://onemocneni-aktualne.mzcr.cz/api/v2/covid-19` of the Ministry of Health of the Czech Republic. They have been available since December 31st, 2019 till now. These data contain daily new sick, PCR tests, AG tests, deaths, cumulative deaths, cumulative sick, number of recovered, the cumulative number of recovered, the number of sick, the number of hospitalized, number of hospitalized in serious condition, 1. vaccinations, cumulative 1. vaccinations, 2. vaccinations, cumulative 2. vaccinations, 3. vaccinations, cumulative 3. vaccinations, 4. vaccinations, and cumulative 4. vaccinations and some other. Some data series (e.g., vaccinations) are not available during full-time intervals N.

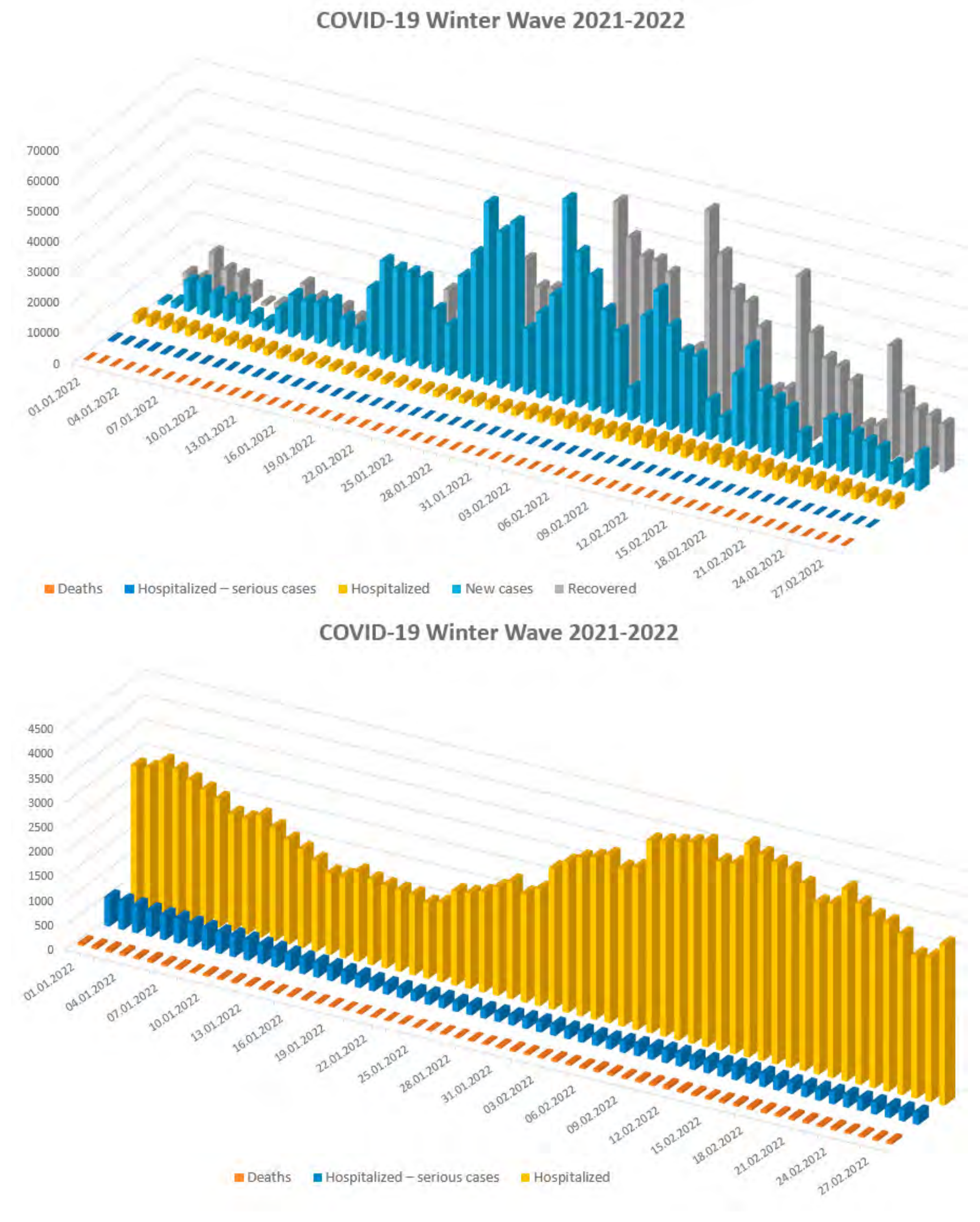

Fig. 4. The selected data from the winter 2021-2022 wave of COVID-19 (upper) and deaths and hospitalized (bottom).

4. Governmental Anti-Covid Measures

The first 3 cases in the Czech Republic were detected on March 1st, 2020. From March 2nd, 2020, till April 14th, 2022, i.e., 1035 days, the Czech government issued over 70 various anti-covid measures. This means, on average, one measure approximately every two weeks. Apart from these country-wide measures, there were also some additional local authorities measures that we neglect here. These measures included schools, businesses, border closures, curfews, lockdowns, mandatory respirators, five vaccination doses, and others.

01.03.2020 The first 3 cases in the Czech Republic

11.03.2020 Schools are closed, except for kindergartens

12.03.2020 State of emergency for 30 days, Events with more than 30 people are prohibited, restaurants

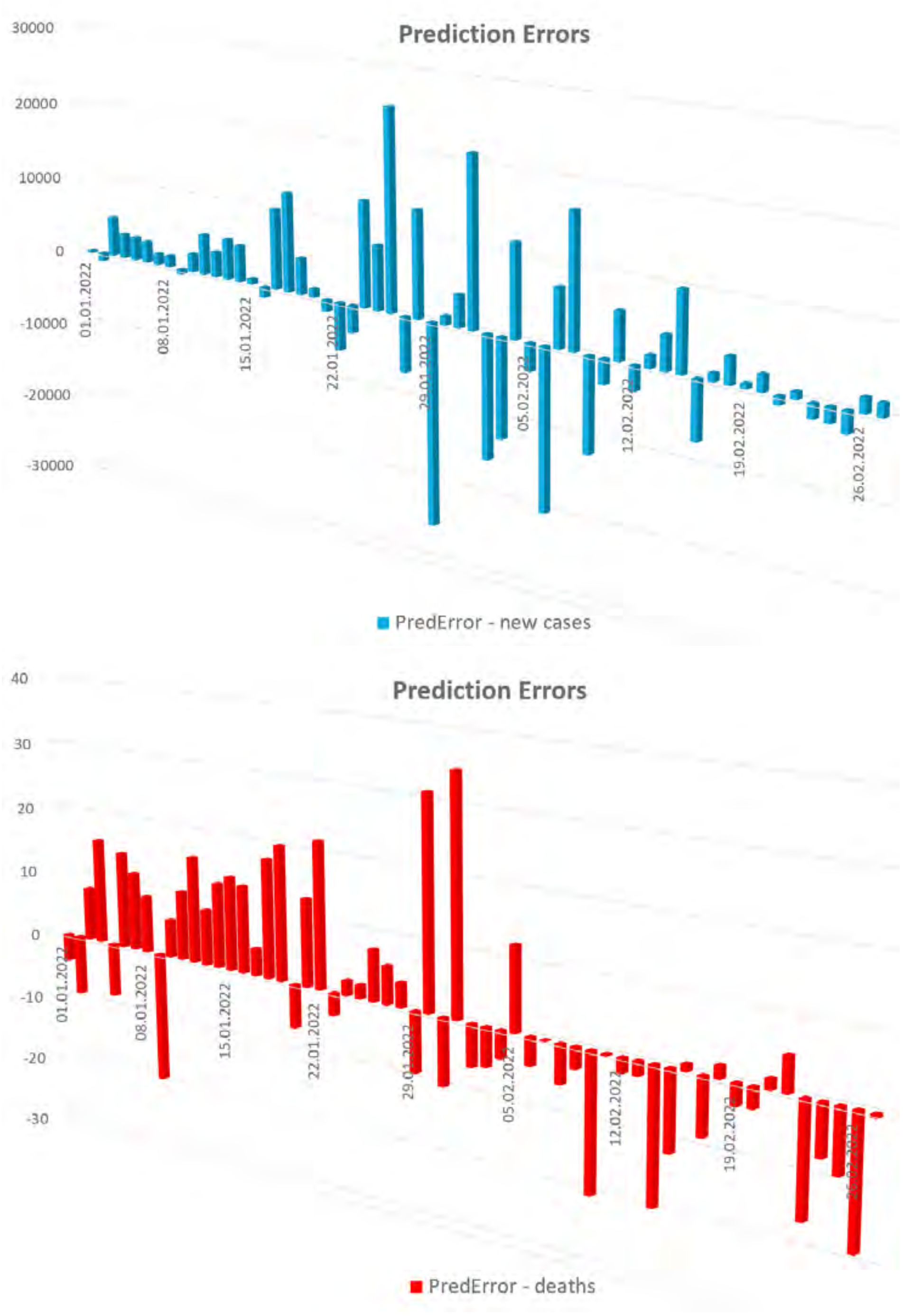

Fig. 5. The selected prediction errors from the winter 2021-2022 wave of COVID-19 (new cases upper) and deaths (bottom).

21.10.2020 Obligation to wear a mask at a distance of less than 2m or in a car, except from family members

28.10.2020 Curfew at night

25.11.2020 Opening of the last years of secondary schools

30.11.2020 Opening of the 2nd grade of primary schools

25.11.2021 State of emergency for 30 days, restaurants closed between 22:00 and 05:00, cultural and sports events up to 1,000 people, condition free of infection

22.12.2021 Specific measures for Christmas and New Year's Eve: A maximum of one thousand seated people can participate in cultural or other events, and a maximum of one hundred people in events where the participants are not seated at the table. From December 29 to January 2, special contact restrictions will apply during New Year's Eve. The number of people sitting at a table in restaurants is reduced from six to four. A maximum of fifty people will be allowed to participate in the parties.

11.01.2022 The period of quarantine and isolation was reduced to five days.

17.01.2022 Employees in all companies to be tested twice a week, pupils and teachers in schools only once a week, this also applies to vaccinated people and people who have experienced covid.

19.02.2022 The period of isolation has been extended from five to seven days. On the contrary, a person after contact with a positive test is not sent to quarantine.

14.04.2022 The obligation to wear a respirator in public transport and trains has ceased to apply. They remain mandatory only in hospitals and social service facilities.

5. Results

Our model reliably detects COVID-19 pandemic changes and consequences of accepted anti-covid measures, either positive or negative, as well as the strength of their influence. The polymerase chain reaction (PCR) COVID-19 test results are typically delayed by multiple days and thus negatively affect the number of detected positive cases and the modeling precision. The quality of the reported COVID-19 data, their reliability, and consistency often need to be improved. Fig. 2 shows the second autumn 2020 COVID-19 wave. The upper image shows local, new cases maxima in 7 days cycles, mostly on Fridays, and recoveries maxima shifted by 3-5 days. The bottom figure shows the first three rows from the upper image with their appropriate measure. This bottom image demonstrates a strong correlation between hospitalized patients in serious condition and deaths and three-day shifts between hospitalized and seriously hospitalized curves. Fig. 3 illustrates the detected effect of the mandatory mask-wearing decree from the 21st of October 2021, which results in an apparent decline in new disease cases and the number of hospitalized and dead people. Winter 2021-2022 COVID-19 wave graph Fig. 4 shows the negative influence of reducing quarantine and isolation to five days and removing vaccinated people on January 11th, 2022. The graph Fig. 4-bottom illustrates this negative effect on the daily death numbers, which decreases when the government returns to the original seven-day isolation interval. The upper graph shows the rapid increase of new cases detected due to mandatory tests twice a week for employees in all companies and similarly in schools (January 17th, 2022). The new cases numbers returned to previous levels in a fortnight when previously undetected cases were caught. The selected two single prediction errors are illustrated in Fig. 5.

6. Conclusions

The presented VCAR model allows estimating the level of efficiency of country-wide governmental anti-covid decrees detected in the long observation time intervals between the 1st of March 2020 till March 2023, the course from the dramatic combat of unknown illness to resignation to country-wide measures and placing COVID-19 into a category of common inconveniences. Simultaneously our model suggests their appropriate timing based on analysis of Bayesian adaptive prediction error estimations from nine publicly available COVID-19 data series. The retrospective analysis of Czech anti-covid of a few selected governmental measures automatically detected illustrates some measures' correct and wrong timing. The COVID-19 model allows us to differentiate between genuinely effective measures and measures which were useless or with negligible positive or adverse effects. Our COVID model allows us to predict vital covid statistics such as the number of hospitalized, deaths, or symptomatic individuals, which can serve for daily control of anti-covid measures and the necessary precautions and formulate recommendations to control future pandemics.

Acknowledgments

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