Weather-dependent SEIRVS framework to simulate the Austrian NPIs on a state level

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Abstract

To mathematically model the spread of infectious diseases so-called compartmental models are applied, i.e models in which the population is divided into certain compartments, e.g. into S-susceptible, E-exposed I-infected, R-recovered as in the case of the SEIR model, one of the most common of such models. We extended the simplistic SEIR model by a "Vaccination" compartment and, to be as close as possible to reality, allow reinfection of previously infected and vaccinated individuals. The goal of this project is to remodel the Covid19 outbreak Austria on a state level and to ultimately study which meteorological timeseries helps more in yielding a close-to-reality behaviour of the non-pharmaceutical interventions (NPI) out of the model.

1 Introduction

In order to not overwhelm their health systems, governments widely started to implement non-pharmaceutical interventions in order to mitigate and control the spread of the SARS-CoV-2 after the global outbreak in February 2020. The data in Desvars-Larrive et al. [2020] suggests that, compared to other European countries, Austria was rather fast in introducing compulsory policies. In this work we want to re-simulate the daily new infections separately for the nine Austrian federal states with different meteorological time-series as a model input, and calibrate them to the real infection numbers to obtain the modelled intensity of each contact restriction policy as an output. In order to study whether and to which extent the calibration process benefits from adding each of the corresponding timeseries we compare the output to the actual implemented policies and quantify the accuracy, in terms of reflecting an accurate policy behaviour, afterwards. We base our methodology on compartmental models, which were first introduced in the early 20th century by [W. O. Kermack, 1927] for mathematical modelling of epidemics. In this kind of model, the population under study is tracked throughout the time by being divided into mutually exclusive compartments based on each individual's infectious status at each timestep t. The rates of the epidemic model, e.g. the transmission-, latency- and the recovery rate of the disease move the individuals between the compartments through time. Even though compartment models are merely on a macroscopic level and thus face severe limitations, but due to their much simpler setup as opposed to microscopic approaches and their extensibility to different scenarios, they are still a widely-used tool for disease modelling.

2 The compartmental model

We base the modelling foundation on a SEIRVS framework, meaning that we extend the usual SEIR model by an additional compartment accounting for vaccinations, and thus at each time $t \in [0, T]$ each member of the population can be in one of the following possible and mutually exclusive states:

- S = susceptible
- E = exposed
- I = infected
- R = recovered
- V = vaccinated

As we have a SEIRVS model, the immunity after a recovered infection, as well as after vaccination are both of temporary nature, albeit waning with different rates.
We make the following simplified assumptions:

- There are no vital dynamics present in the population, i.e. no births and deaths occur during the modelling period of length T, hence it follows that the population stays constant throughout the whole modelling time, and that at each time step t^* the sum of the four compartments S, E, I, R, V always equals the population size denoted by N, meaning that $S(t^*) + E(t^*) + I(t^*) + R(t^*) + V(t^*) = N$, $\forall t^* \in [0, T]$.
- As opposed to the classic SIR model with vaccinations, we also have the additional "exposed" state, signifying that we take the incubation time of the disease into account. Individuals being in the exposed state can be regarded as pre-symptomatic. However note that even though an individual who is solely exposed, does not have symptoms yet himself, he still can transmit this respiratory disease to others in his proximity, thus acting as a host without even being aware. This dynamics of SARS-CoV-2 is what ultimately lead to the exponential chain transmission [Sil and Kumar, 2020]. For sake of simplicity, however, in our SEIRVS model only individuals in the "I" compartment count as infectious.
- The rate of latency, given by δ, respectively that of recovery, γ, remain fixed throughout the modelling horizon, even after the shift from the original SARS-CoV-2 wild-type to the new variants.

The system of differential equations for the SEIRVS model is given by

$$
\begin{aligned}
\frac{dS}{dt} &= \frac{-\beta(t)SI}{N} - 0.9 \cdot \upsilon(t) \cdot N \cdot \frac{S}{S+R} + \rho V + \theta R \\
\frac{dE}{dt} &= \frac{\beta(t)SI}{N} - \delta E \\
\frac{dI}{dt} &= \delta E - \gamma I \\
\frac{dR}{dt} &= \gamma I - 0.9 \cdot \upsilon(t) \cdot N \cdot \frac{R}{S+R} - \theta R \\
\frac{dV}{dt} &= 0.9 \cdot \upsilon(t) \cdot N - \rho V
\end{aligned} \tag{1}
$$

The ODE-system is executed with non-negative initial conditions:

$$S_0 = N - E_0 - I_0, \qquad E_0 = E_0 > 0, \qquad I_0 = I_0 \geq 0, \qquad R_0 = 0, \qquad V_0 = 0$$

with $S_0 + E_0 + I_0 + R_0 + V_0 = N$.

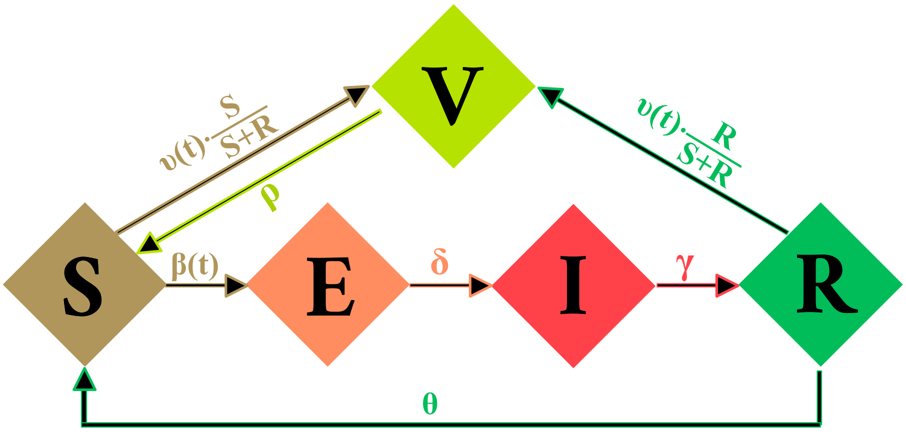

Figure 1: The state transitions in the SEIR model

As can be seen from the modelling equations in (1), the transmission rates $\beta(\mathrm{t})$ are time-dependent which will be further explained below, $\rho = \frac{1}{1000}$, respectively $\theta = \frac{1}{700}$ indicate the waning rate of immunity acquired through vaccination resp. convalescence. For sake of simplicity we allow vaccination only for people in either the S or the R compartment. Let $\upsilon(t)$ represent the additional daily percentage of the population who receive their second vaccination dose on day t, even though the different SARS-CoV-2 vaccines have a high efficacy they still can not provide an efficacy of 100%. Furthermore, the initially as a single-shot introduced vaccine Janssen, which was also widely inoculated in Austria, mainly during summer/beginning of fall 2021, has had a significantly decreased vaccine effectiveness in regards to preventing infections against both B.1.117 and B.1.617.2 ([Chalupka et al., 2021]). In addition, we wanted to also somehow reflect the reduced vaccine effectiveness of the AstraZeneca ([Bernal et al., 2021]) vaccine and Pfizer/BionTeach vaccine against infection with the B.1.617.2 (Delta) variant, thus, each day, of all additional people receiving either their second dose or the first shot with the J&J vaccine, we transfer only 90% of them directly from the S resp. R to the V compartment.

Since our modelling horizon ends on the November 08^{th}, 2021, we omitted the booster vaccination as its inoculated doses up to that very date could be regarded as negligible for our model.

We set the value of the mean recovery period to 10 days, due to the wide-consented approach that positive, but mild cases, should isolate for 10 days and thus are regarded as recovered after that very time period [ecd, 2022]. Linton et al. [2020] came to the conclusion that the incubation time of the wild-type version of SARS-CoV-2 ranges from 2 to 14 days with 95% confidence, Cheng et al. [2021] performed a meta-analysis of 53 studies in regards to the mean incubation period, the studies under their investigation indicated a mean incubation time between $t = 3$ days and $t = 11.14$ days. [Teles, 2020] modelled the initial disease spread of the wild-type in Portugal by using a SEIR model and achieved the best fit with an incubation time of 5.1 days, Grant et al. [2022] performed a case-control study in France and their calculations also lead to a incubation duration of 5.1 days for the wild-type. Grant et al. [2022] also calculated the incubation time for the subsequent lineages and their data yielded a mean incubation time of 5.0 (SD: 2.3) days for Alpha and 4.3 (SD: 2.4) days for the Delta variant. The approach we take in this study is to set the incubation period equal to 5.1 days for the entire modeling horizon, and instead model the excess infectiousness by an auxiliary factor var(t), which we will describe in detail in Section 3.1. We also include different meteorological time-series ω_k(t) (see Section 5), albeit one-at-a time, into the model, also by setting ω_k(t) as a multiplicative factor of the infection rates. The ultimate target of this study is to determine which ω_k(t) leads to a more accurate representation of the actual NPIs which were implemented in reality throughout our modeling horizon. Thus, for that matter, we define a policy vector τ(t), which is set to solely change values at the same dates as the implementation of the significant NPIs took place. In our framework we distinguish between two different modelling approaches in regards to τ(t). In the first case, denoted by τ_1(t), it represents a multiplicative factor. On the other hand, τ_2(t) is defined as a percentage change. The idea is, based on the results of the study of [Mossong et al., 2008], to define the pre-pandemic, daily average contact rate of the individuals as a constant value c_{const}, whose value, for the sake of simplicity, is equal in all age-classes. Our approach is to regard the usual, fixed contact rate c_{const} as a steadily changing value during the pandemic, whose rate is dependent on the stringency of the particular prevalent governmental health measures. Since each implemented or lifted NPI is set to be a change factor of the c_{const}, the mean number of contacts during the pandemics for each $t \in [0, T]$, $\tilde{c}_i$(t), are henceforth defined as

$$\tilde{c}_1(t) = \frac{c_{\text{const}}}{\tau_1(t)} \tag{2}$$

and

$$\tilde{c}_2(t) = c_{\text{const}} \cdot (1 - \tau_2(t)). \tag{3}$$

The value of c_{const} is not further defined in our model, due to it being merely a constant it is deemed as negligible for our study design and is therefore completely omitted from (2) and (3). Thus, the time-varying transmission rates β_i(t) are given by

Model 1
$$\beta_1(t) = \text{var}(t) \cdot \omega_k(t) \cdot \frac{1}{\tau_1(t)} \tag{4}$$

Model 2
$$\beta_2(t) = \text{var}(t) \cdot \omega_k(t) \cdot (1 - \tau_2(t)) \tag{5}$$

3 Emergence of SARS-CoV-2 variants

Since SARS-CoV-2 is a RNA virus [V'kovski et al., 2020] its replication process is highly error-prone [Robson et al., 2020], hence steadily mutating through this replication process, and even though the majority of these mutations will remain negligible, some of them might substantially increase the viral fitness due to enhanced transmissibility and also increased immune evasive properties [Cai et al., 2021], and ultimately causing new dominant variants to emerge. Burioni and Topol [2021] state that ultimately, the property of increased transmissibility is the most consequential in regards to a higher viral fitness and viability as opposed to immune evasion or even higher lethality. In the course of the SARS-CoV-2 pandemic, newly emerging variants which fulfill one or more of the below characteristics are classified as variants of concerns (VOCs) by the World Health Organization (WHO) [CDC, 2021]:

- increased transmissibility
- increased viral load
- decline of the efficacy of existing vaccines and therapeutics and/or damped effectiveness of previous health and social measures

Throughout or modelling timespan, March 6th, 2020 until November 8th, 2021 the following variants of concerns emerged:

- **B.1.1.7 (Alpha)**
- B.1.351 (Beta)
- P.1 (Gamma)
- **B.1.617.2 (Delta)**

The dynamics of the Covid19 pandemic in Austria in the year 2021 was shaped by its evolutionary more superior variants, B.1.1.7 (Alpha) and B.1.617.2 (Delta). Even though the data in 1 does not provide the total number of sequenced cases per week, one can still clearly see that the Alpha variant (B.1.1.7), gradually starting to establish dominance by the beginning of January 2021,and superseded the ancestral variant entirely by end of April 2021 (see Figure 2). Even though genomic surveillance also tracked B.1.351 and P.1 infections, those subtypes could not prevail against Alpha and thus did not play any role in the pandemic dynamics of Austria. Ultimately it was the highly infectious Delta variant (B.1.617.2) which could displace Alpha and henceforth became the sole dominant strain by end of June 2021 until the emergence of BA.1 (Omicron) in December 2021.

	calendar week	B.1.1.7 (Alpha)	B.1.351 (Beta)	P.1 (Gamma)	B.1.617.2 (Delta)	total cases
1	2021-W01	108	6	0	0	14637
2	2021-W02	352	59	0	0	1095
3	2021-W03	456	137	0	0	1016
4	2021-W04	1052	179	0	0	9513
5	2021-W05	1978	123	0	1	912
6	2021-W06	198	111	0	0	9461
7	2021-W07	3659	88	0	0	11632
8	2021-W08	7693	147	0	0	14189
9	2021-W09	9601	97	0	0	16315
10	2021-W10	11411	103	1	0	18225
11	2021-W11	13039	79	2	0	21091
12	2021-W12	12851	61	1	0	22323
13	2021-W13	12145	23	0	0	20795
14	2021-W14	943	23	1	5	17618
15	2021-W15	9626	36	2	4	16824
16	2021-W16	9912	32	6	6	15054
17	2021-W17	8803	24	12	3	12539
18	2021-W18	5827	3	24	3	9023
19	2021-W19	3798	0	10	9	5737
20	2021-W20	2667	7	9	8	4153
21	2021-W21	1957	5	27	25	3157
22	2021-W22	161	5	28	63	2425
23	2021-W23	1048	0	18	188	1687
24	2021-W24	441	0	1	289	1002
25	2021-W25	202	0	1	252	681
26	2021-W26	113	0	1	344	632
27	2021-W27	87	0	2	745	1089
28	2021-W28	72	1	1	1684	2198
29	2021-W29	30	0	1	1966	2526
30	2021-W30	14	0	3	2503	3248
31	2021-W31	22	0	1	2765	3673
32	2021-W32	4	1	1	4472	5896
33	2021-W33	5	0	0	5868	8064

Table 1: The number of sequenced cases of each variant and the total confirmed infections per week in Austria.[2]

3.1 Growth advantage of the VOCs

The variance surveillance strategy in Austria was based on specific PCR tests screened for the existence of the N501Y mutation of the spike protein, due to the fact that B.1.1.7 (Alpha) features this very receptor-binding domain mutation, but it is lacking in B.1.617.2 (Delta) ([Puligedda et al., 2021]). Thus the duration of the shifts of dominance from wild type to B.1.1.7 and B.1.1.7 to B.1.617.2, can be easily tracked through the percentage of sequenced positive PCR-tests showing the N501Y mutation. The weekly percentages of positive cases exhibiting the N501Y mutation starting from end of January 2021 until the beginning of August, 2021 are illustrated in Figure 2, the numbers are based on the publicly available weekly publications of the "Austrian Corona Kommission" [Österreichische Corona Kommission, 2021].

[2] from https://www.ages.at/mensch/krankheit/krankheitserreger-von-a-bis-z/coronavirus, accessed 2022-06-15

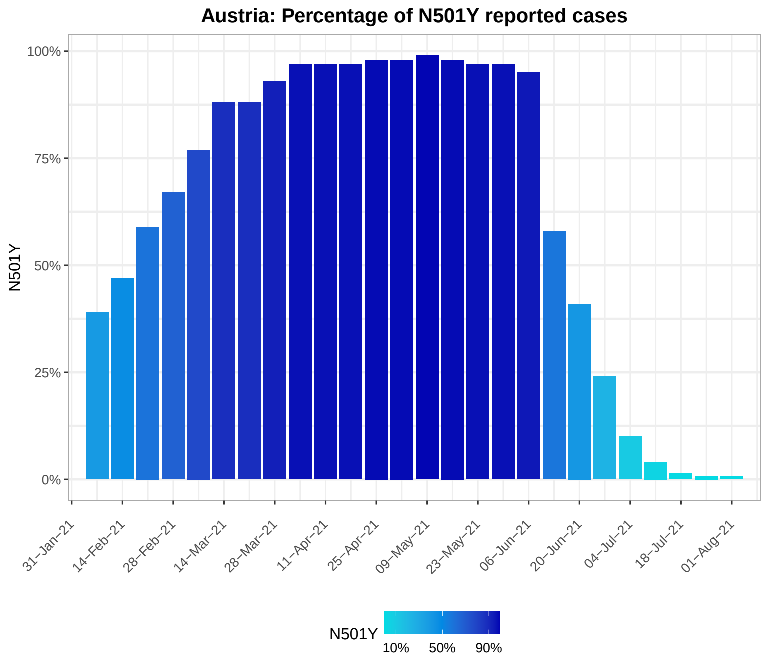

Figure 2: Percentage of screened positive PCR tests having the N501Y spike protein mutations.

From Figure 2 and Table 1, one can see that, compared to Alpha, Delta evolved at a much faster pace in becoming the dominant strain; while first being sequenced in the beginning of January 2021, it took the Alpha strain around seven weeks to displace the wild-type and account for the majority of the cases. On the other hand, the shift from Alpha to Delta happened at a much higher speed, since it took the Delta variant only around four weeks to being responsible for the majority of infections. As a comparison, the data in Denmark also draws a very similar picture; in Denmark, the Alpha variant needed 8 weeks but the Delta variant only 4 weeks for asserting sole dominance [Hansen, 2022]. Campbell et al. [2021] study the relative transmission rates and come to the conclusion that B.1.617.2 has a 55% (95% CI: 43%-68%) higher effective reproduction number R_{eff}. However one must note though that their ([Campbell et al., 2021]) calculated R_{eff} estimate does not reflect the genuine excess transmissibility of B.1.617.2 compared to B.1.1.7 , since the higher ability of the B.1.617.2 lineage to evade immunity ([Mlcochova et al., 2021]), also accounts for an increase of the R_{eff}. According to [Hansen, 2022] the reason for the different evolving speeds might not only be due to the increased infectivity of B.1.617.2 but could also partly be attributed to the fact that Alpha started to emerge during a time period where still major confinements policies were in place and thus its transmissibility was artificially damped [Trobajo-Sanmartín et al., 2022].In fact, right before Delta started to control the pandemics trajectory in June 2021, the pandemic was on the wane due to the seasonal effects and especially the wide vaccine roll-out, thus Delta first emerged after most restrictions were already lifted, and thus its initial spread was not impeded by any NPIs. This in combination with the substantially increased viral load when infected with B.1.617.2 (see e.g. [Puhach et al., 2022]), and furthermore a diminished vaccine efficacy ([Eyre et al., 2022], [Kislaya et al., 2022]) was what made it possible for Delta to spread at this fast pace.

3.1.1 Relative contagiousness of the variants

For the variants of concerns, Alpha B.1.1.7 and Delta B.1.167.2, exhibit a significantly higher transmissibility (see e.g. [Xia et al., 2021], [Liu and Rocklöv, 2021], [Trobajo-Sanmartín et al., 2022], [Campbell et al., 2021]), a key measure of interest in our model in (1) is the factor of excess infectiousness var(t) of each variant as compared to its predecessor. Furthermore, due to our model assumption, the latency rate δ of the SEIRVS model given in (1) remains fixed throughout the end, therefore we offset the considerably shorter generation time of the B.1.167.2 variant (see e.g. [Hart et al., 2022]) also by an appropriate increase of the factor var(t) after the emergence of B.1.167.2. Based on the notation of [Hansen, 2022], let ν^0 represent the current prevalent variant of a virus and ν^1 the newly appeared variant, with ${R_0}^{\nu^0}$ and ${R_0}^{\nu_1}$ denoting their respective basic reproduction numbers. Hansen [2022] define the relative contagiousness ΔR, as $\Delta R = {R_0}^{\nu^1}/{R_0}^{\nu^0}$. Further let the growth rate for the two competing variants be defined by $r_t^0 = \nu_t^0/\nu_{t-1}^0$ and $r_t^1 = \nu_t^1/\nu_{t-1}^1$. The approach of [Hansen, 2022] is based on the theory that each variant, in terms of quantity, has equal opportunities to infect individuals, i.e. that the transmission rates of both variants are affected by the exact same level of any prevalent dampening factors such as e.g. NPIs and seasonality. Thus, the only difference between variant ν^0 and ν^1 is in respect to the level of their contagiousness, following this assumption leads to the simplified outcome that the ratios of their effective reproduction rates is constant and given by

$$ {R_{eff}}^{\nu^1}/{R_{eff}}^{\nu^0} = {R_0}^{\nu^1}/{R_0}^{\nu^0} = \Delta R = \beta^{\nu^1}(t)/\beta^{\nu^0}(t) \tag{6} $$

In (6) the β(t) denote the transmission rates of the respective virus strain at time t. Moreover, it immediately follows that the growth rate of the newly emerged variant, r_t^1, is proportional to r_t^0 and given by $r_t^1 = \nu_t^1/\nu_{t-1}^1 = \Delta R \cdot r_t^0$. Bicher et al. [2021 (In print)], who modelled the excess contagiousness for the Alpha and Delta variant in Austria, also assume the time independence of ΔR during the displacement phase of the wild-type by B.1.1.7, due to the negligible difference between the generation time of the ancestral type and Alpha variant ([Grant et al., 2022]). The modelling framework of [Bicher et al., 2021 (In print)] is based on a SIIR model, i.e. a SIR compartmental model with two different "Infectious" compartments, for the distinction between infections with the current prevalent virus strain and the ones caused by the newly emerging variant. By using the actual Austrian surveillance data the model fitting process of [Bicher et al., 2021 (In print)] lead to $\Delta R_{B.1.1.7} = 1.36$ (95% CI: 1.33 - 1.39). The approach in [Bicher et al., 2021 (In print)] to calibrate excess infectiousness in Austria for the Delta variant was more complex, as here, due to the significant shorter generation time, the ratio of the infection rates could not be supposed to be equal anymore, and further, since Delta ascended to the dominant strain during the summer months, a considerable number of cases traced back to tourism. Thus, Bicher et al. [2021 (In print)] extended their model to distinguish between new infections brought in by tourism and new infections caused by the domestic population and ultimately, obtained $\Delta R_{B.1.617.2} = 2.11$ (95% CI: 2.00 - 2.21). The results of [Bicher et al., 2021 (In print)] are in line with the study of [Campbell et al., 2021], who made a global analysis of the increased transmission rates and estimated the excess transmissibility of B.1.1.7 by 29 % (95% CI: 24–33) and that of B.1.617.2 by 97% (95% CI: 76–117). In Figure 3 the function representing the excess infectivity of SARS-CoV-2 over time due to the evolution of the corresponding variants is illustrated.

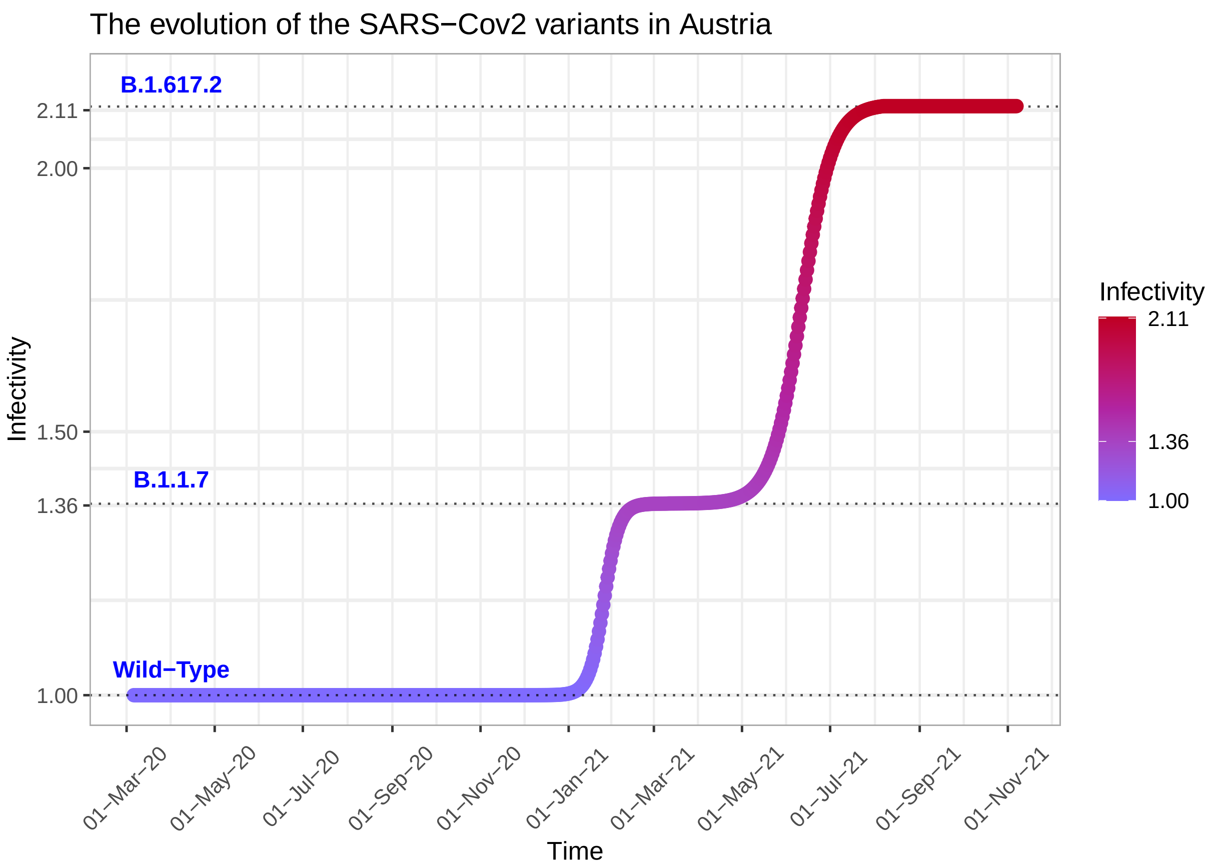

Figure 3: Graphic illustration of the excess infectivity function.

4 Non pharmacological interventions (NPI) in Austria

Non-pharmaceutical interventions are a very powerful mechanism in controlling the transmission dynamics, especially in the beginning phase of the SARS-CoV-2 pandemic where vaccinations were not available yet, social distancing measures were the only possible countermeasure in controlling the spread of the disease. Thus as a response to the Covid19 outbreak in February/March 2020, governments across the globe started to unprecedentedly implement various wide-reaching non-pharmaceutical interventions [Desvars-Larrive et al., 2020]. For a better comparison of the governmental response policies across all countries, the University of Oxford started to publish "The Oxford COVID-19 Government Response Tracker (OxCGRT)" [Hale et al., 2021] which also, among other indices, includes calculating the so-called stringency-index, a normalized index based on the pre-defined scales of [Hale et al., 2021]

- School closing
- Workplace closing
- Cancellation of public events
- Restrictions on gathering size
- Close public transport
- Stay-at-home requirements
- Restrictions on internal movement
- Restrictions on international travel
- Public Covid-19 information campaign

The value of the stringency index ranges from 0-100, whereas the tighter the governmental containment policies are, the higher the index, e.g. a stringency index of 100 indicates the strictest possible policy. Conversely, the inverse stringency index, which is simply the difference between 100 and the actual stringency index, would increase whenever NPIs are easened and decrease whenever stricter measures are implemented. It is important to note that the stringency index is calculated on a country level, hence not being able to distinguish between measures on a state level, at least not to a full extent, since one might notice that some of the more important regional measures in the federal states are still somewhat reflected in Austrian's stringency index, e.g. after the restaurants were allowed to reopen in Vorarlberg in March 2021, the stringency slightly decreased and after the lockdown in the three eastern federal states in April 2021, the index experienced an increase. In Figure 4 the stringency curve of Austria from March 6th, 2020 until November 8th, 2020 and the daily new infections in Vienna are depicted, the vertical red lines indicate the implementation days of the restriction measures in Vienna and the green ones represent the easing of the policies. Unfortunately it is to note that due to the stiff predefined scales [Hale et al., 2021] some significant country-wide policies are completely neglected as they do not fall into any of those categories, for example the national FFP2 mask mandate introduced on Jan 25th, 2021. Some further reasons why we can not use the stringency index as "anchor-values" for the policies would be that the increase and decrease of the stringency index is often a few days off as compared to the real governmental NPIs and the bigger problem, however, would be that the stringency curve occasionally exhibits an increase which can not be explained by the actual compulsory policies around the same time period, see e.g. the rise at the beginning of October 2021 which can be seen in Figure 4.

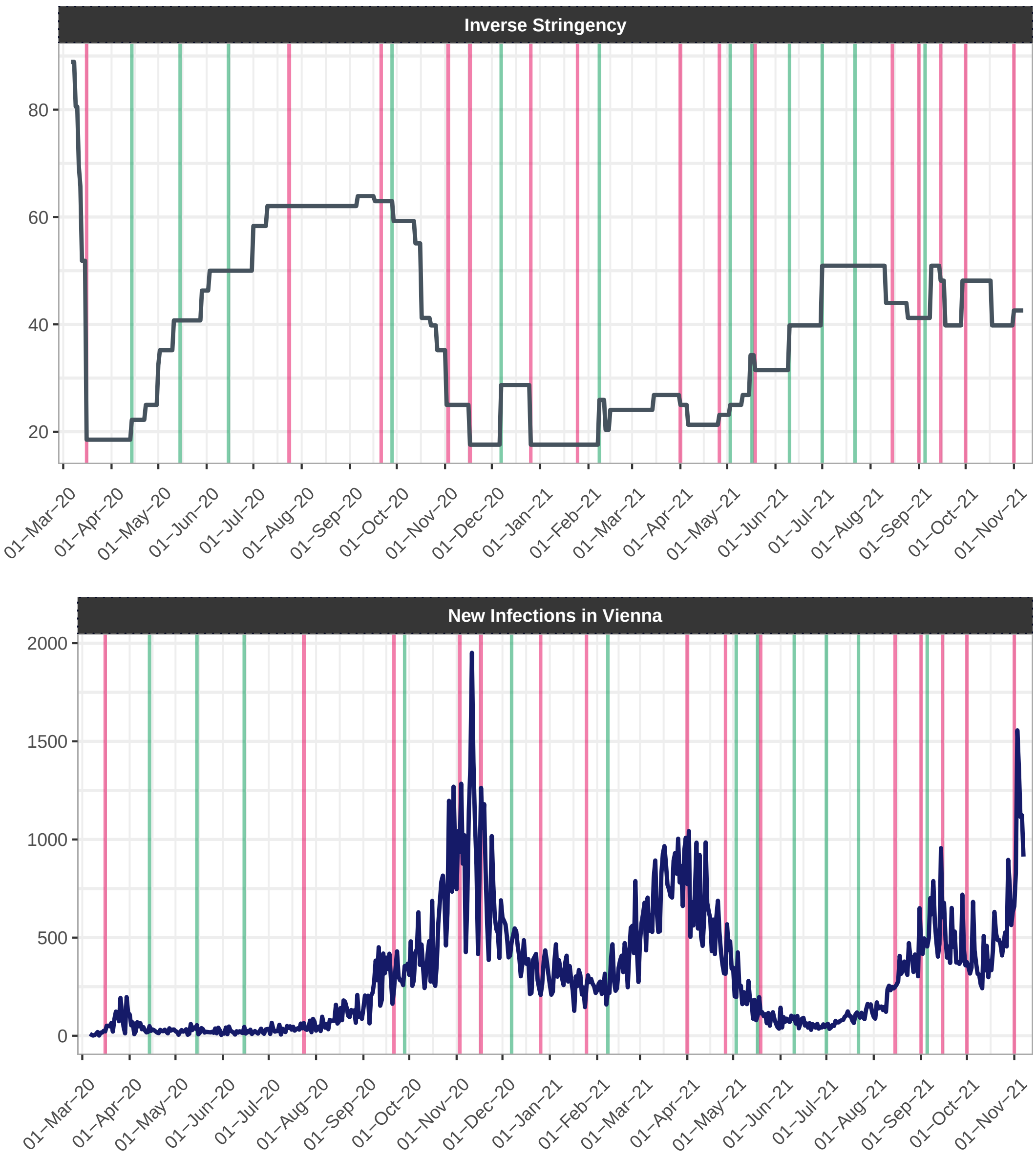

Figure 4: The inverse stringency index and the daily new infections in Vienna and the restriction (red) policies and easing (green) of the NPIs implemented in Vienna.

The breaks which are included for each federal state are listed in the Appendix in Figure 27 - Figure 35. Due to the aforementioned inconsistencies of the real stringency index, we have to manually determine for each included policy whether it can be regarded as an "opening" or "confinement" as compared to its predecessor. Our goal is to examine how consistent, in terms of increase and decrease, the behaviour of the modelled policies is with real governmental policies, in order to reach this objective we define a quantification measure to measure the accuracy between the modelled policies at the respective actual policy at each break. Let the real policies be given by $\overrightarrow{\boldsymbol{r_k}} = (r_{1_k}, r_{2_k}, \dots, r_{n_k})$ and the modelled ones given by $\overrightarrow{\boldsymbol{m_k}} = (m_{1_k}, m_{2_k}, \dots, m_{n_k})$, whereby $k = \{1, 2, \dots, 9\}$, indicates the state code of the corresponding federal state.
Let

$$\delta_{r_{i_k}, m_{i_k}} = \begin{cases} 1 & \operatorname{sgn}(r_{i_k} - r_{i_k - 1}) = \operatorname{sgn}(m_{i_k} - m_{i_k - 1}) \\ 0 & \text{else} \end{cases}$$

Whereas $\text{sgn}(r_{i_k} - r_{i_k - 1})$ is manually determined beforehand for each pair of consecutive measures. Furthermore, let T indicate the duration of the modelling time, and let the duration of each policy m_{i_k} be given by t_{ik}, whereas t_{ik} is defined as the difference (in days) between the implementation day of m_{i_k+1} and m_{i_k}.

Thus, to quantify the accuracy of our calibration results, we use

$$C_k = \sum_{i_k=2}^{n_k} \delta_{r_{i_k}, m_{i_k}} \cdot \frac{t_{ik}}{T_k}$$

The higher C_k, the closer the model reflects the actual behaviour of the measures, with $\frac{t_{ik}}{T}$ being the weighting factor for each policy.

5 The meteorological parameters

Our goal was to determine the impact of meteorological conditions on the calibration process of our compartment model to the SARS-CoV-2 cases in Austria. The seasonal impact on the Covid19 incidences has been a very hot research topic since right from the start of the SARS-CoV-2 pandemic. In general, it is a common phenomena for respiratory tract diseases, which Covid19 also is a representative of, that the peaks of the daily new confirmed cases (DNCC) almost always occur during winter months when the temperatures are low [Mecenas et al., 2020]. In laboratory testing, evidence has been found for the fact, that the infectivity of SARS-CoV-2 completely disappeared after being heated at 56°C for several minutes [Chan et al., 2011]. In [Chan et al., 2011] it is further shown, that, when examining contaminated surfaces, high temperature combined with high humidity has a synergistic effect on the elimination of the virus activity, while, on the other hand lower temperatures mixed with low humidity enable a prolonged viability of the virus. Studies which exclusively have focused on the seasonal effect of SARS-CoV-2 have applied different methods to further examine the meteorological effects, for example, Wu et al. [2020] and Qi et al. [2020] use generalized additive models and both come to the same conclusion that temperature and humidity correlate negatively with the incidences. In this project however, we do not want to dive into regression- and time series analysis, but rather want to study whether the addition of a meteorological data on a state level aids in yielding more consistent behaviour of the policies, as compared to the actual NPIs, out of the model after the calibration process.
For each federal state, the following weather data in the respective time horizon were available, whereas all values are daily averages over all daylight hours and median weighted by the number of inhabitants in each region:

- humidity in % (2020/01/01-2021/06/23)
- cloudiness in % (2020/01/01-2021/06/23)
- aerosol concentration rate (CR)(2020/01/06-2021/06/23)

Whereby the concentration rate is yield as a function of temperature T, wind speed U and relative humidity RH, see [Dbouk and Drikakis, 2021]. Furthermore, Dbouk and Drikakis [2021] came to the conclusion that the aerosol concentration rate correlates negatively with the temperature T and, additionally, it increases whenever both wind speed and relative humidity raise.

The original entries of all the weather time series x are made dimensionless by standardizing them to the [0,1] range using the following formula [Dbouk and Drikakis, 2021]:

$$x_{new} = \frac{x_{org} - min(x)}{max(x) - min(x)}$$

Before plugging the [0,1]-standardized timeseries into (1), we first smoothed them by finding curve fits through sinusoidal linear regression, because our modelling horizon extends the time span for which the meteorological data was available and thus we needed appropriate underlying periodic functions with a period of 365 days, such that they can easily be extended to the desired length. The timeseries and their periodical curve fits are displayed in the Appendix in Figure 6 - 8.

Since many studies, such as e.g. Bochenek et al. [2021], suggest that weather conditions have a delayed impact of few days on the number of new infections, the timeseries were shifted five days backwards before being plugged into the SEIRVS model, such that in (1) for any given date x during our modelling time, the corresponding value of the timeseries is that of day $x-5$. In order to analyze the added value of the corresponding timeseries, we also set up a model in which the transmission rate β(t) does not depend on any weather inputs, henceforth, this model is referred to as "Constant".

6 Implementation and calibration

The SEIRVS model was implemented in the program `R` with the use of the `deSolve` package [Soetaert et al., 2010]. The specific solver which we applied to our equations was the `ode45` which is also the standard solver of `MATLAB` [Zhang, 2015]. The ode45 solver is based on an explicit Runge-Kutta (4, 5) formula, in order to numerically solve the system of differential equations.

6.1 The optimization algorithm L-BFGS-B

The optimization algorithm which was applied to fit our models, was a modified version of the original BFGS algorithm, named after its four originators ([Fletcher, 1970], [Goldfarb, 1970], [Shanno, 1970], [Broyden, 1970]), which were working and publishing independently from each other. The `BFGS`, as all the other quasi Newton does not calculate the computationally expensive inverse of the Hessian directly, but only uses approximations at each step. Each iteration exhibits a computation cost of $\mathcal{O}(n^2)$ arithmetic operations [Mokhtari and Ribeiro, 2014], in comparison, the Newton method itself would cost $\mathcal{O}(n^3)$ arithmetic operations. However, for large scale problems it is required to further reduce the cost of the minimization, thus the L-BFGS algorithm was introduced [Liu and Nocedal, 1989]. The big advantage which the `L-BFGS` algorithm has, is, that it only uses a limited amount of memory to approximate the inverse of the Hessian, since only the last k iterations are used at each step, hence reducing the cost to $\mathcal{O}(kn)$ [Mokhtari and Ribeiro, 2014]. The `L-BFGS-B` algorithm is a slight extension of `L-BFGS`, the only difference being that the cost-function $f(x_i)$ is minimized subject to the bound constraints $l_i \leq x_i \leq b_i$ for the parameters x_i. In general, quasi Newton methods are intended only for smooth functions, here, due to the set up of our spline function, $\beta(t)$ is only piece-wise continuous. However Lewis and Overton [2012] came to the conclusion that the BFGS algorithm can also handle non-smooth functions surprisingly well.

6.2 The calibration process

The outcome of our work relies on the calibration of the values of τ_j(t), which is done by the application of the L-BFGS-B algorithm, whereby we minimize the residual sum of squares between the actual daily new confirmed cases (DNCC), and the modelled ones out of our SEIRVS given in (1). Hence our target function to minimize is given by

$$\text{RSS} = \sum_{t=1}^{T} (DNCC(t)_{\text{real}} - DNCC(t)_{\text{model}})^2 \tag{7}$$

Since we employed the L-BFGS-B algorithm, we were also able to provide upper and lower bounds for every single parameter ensuring that the values stay between certain intervals. From a mathematical point of view, our sole real constraint for the bounds was that the values of β(t) do not become negative, hence

- in Model 1, the parameters definitely needed to be bounded by below and
- in Model 2, the parameters definitely needed to be bounded by above.

Even though we could have set different and tighter bounds for each parameter, ensuring that it generates a suitable curve fit fast, one needs to remember that the best fit was only a by-product here, and our main outcome were the actual values of those very parameters, thus we did not want to interfere with the outcome. Therefore in order not to constrain the parameter space and letting the algorithm truly search freely we decided to only set the value of the first parameter (pre-pandemic era) between tighter bounds, which helped both in specifying somehow a "direction" for the other parameter values as well as fitting the small infection peak in March/April 2020 of the curve. For parameter 2 (first full lockdown) and parameter 3 (added mask mandate during full lockdown) slightly higher lower bounds were chosen as compared to the successive parameters. For all the others the exact same lower and upper values were set, whereby the interval width for all parameters except for the first one was chosen very generously such that the optimization algorithm is faced with as little limitations as possible.

6.2.1 Model comparisons

Even though, as mentioned before, the best curve fit was only secondary to us, the set of parameter values for the measures was only accepted if the fit could not be further improved anymore. It is interesting to note that the calibration process differed vastly between Model 1 and Model 2, in Model 2 the calibration results were not that dependent from the starting values and it yielded a very suitable curve fit pretty fast. Conversely, it was the exact opposite in case of Model 1, the calibration process heavily relied on the starting values as it tried to select the optimal values as close as possible to the provided initial values. This also had as a consequence that it needed many runs for finding a good fit, since due it trying to always stay near the starting values in each run, the fit was always only improving in small steps from run to run. In general, the curve fit provided by Model 2 was far superior to that of Model 1, a small comparison is given between the two "Humidity" models of Vienna in Figure 5. Since especially in Model 1 but also partly in Model 2, we were faced with a certain trade-off between "goodness of curve fit" and "accuracy of measures", a recalibration resulting in more accurate values for the measures was only accepted if it either improved the fit or at least did not deteriorate it in any way. The calibration results are attached in the Appendix in Figure 9 - Figure 17. Out of the calibration results, the C_k values, as described in Section 4 were calculated, which are printed in the Appendix in Table 2-Table 10.

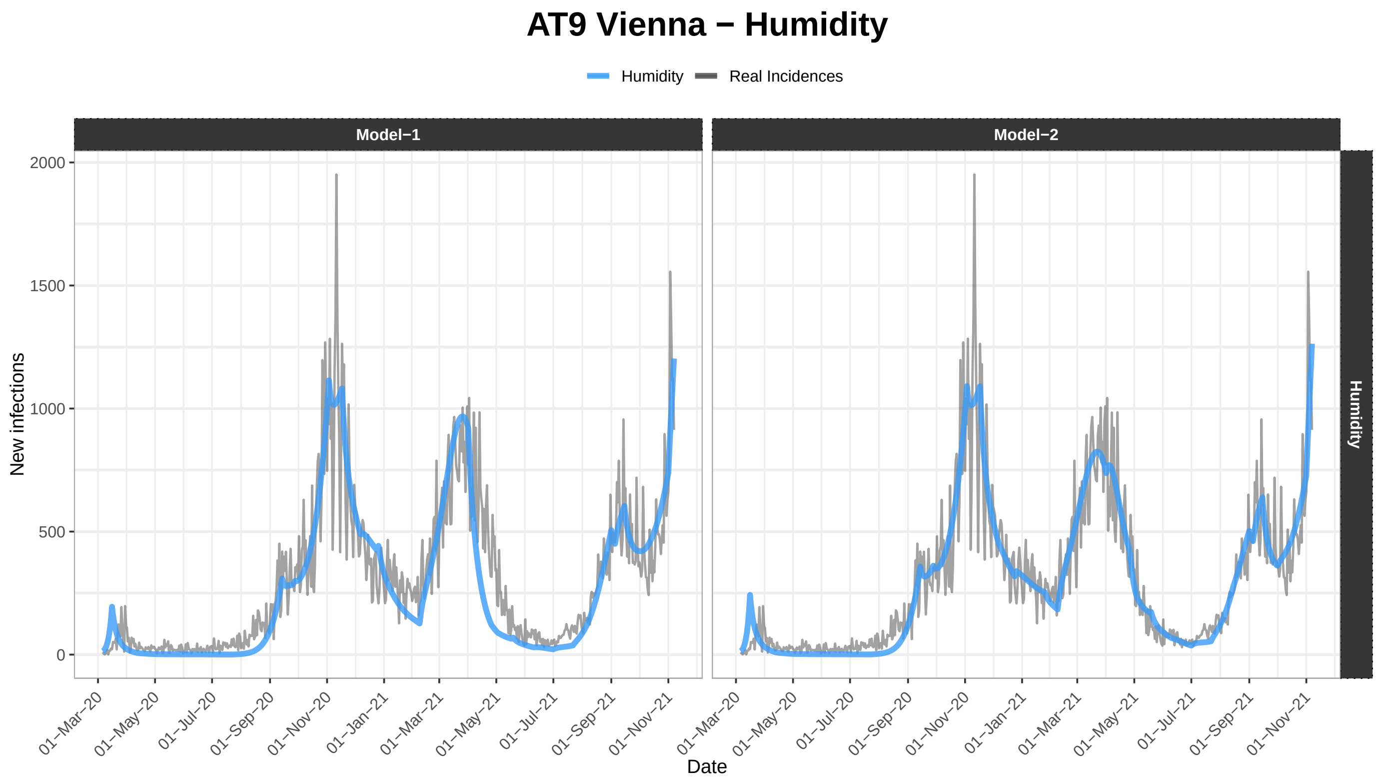

Figure 5: Comparison between the calibration result for the curve fits in the "Humidity" models of Vienna.

7 Conclusion

Since the timeseries "Aerosol Concentration Rate" is a composed variable based on multiple factors, it incorporates the highest amount of information, thus unsurprisingly, this timeseries was the one which not only reflected the measures most accurately but also provided the best fit at the same time throughout both models and all federal states. When comparing Model 1 to Model 2, one can see that Model 2 is significantly better when solely considering the curve fits, but regarding our main outcome, the resulting accuracy of the modelled policies, no model clearly outperforms the outer one. While "Aerosol concentration rate" is undisputed in the first place in both models, both in terms of goodness of fit as well as regarding the C_k quantification measure, "Humidity" and "Cloud" can not be ranked clearly, neither in case of accuracy of the measures nor in terms of added benefit for the curve fits, as their positions vary across the different models and are sometimes even overtaken by the constant model. However, one might argue that the sinusoidal smoothing of the timeseries beforehand lead to a non negligible information loss of the original weather data and therefore kind of distorted the outcome, thus one could further study how the results would differ if the actual values of the timeseries were plugged into the model instead of the sinusoidal curve fits.

A Appendix

A.1 Meterological parameters

A.1.1 Aerosol concentration rate

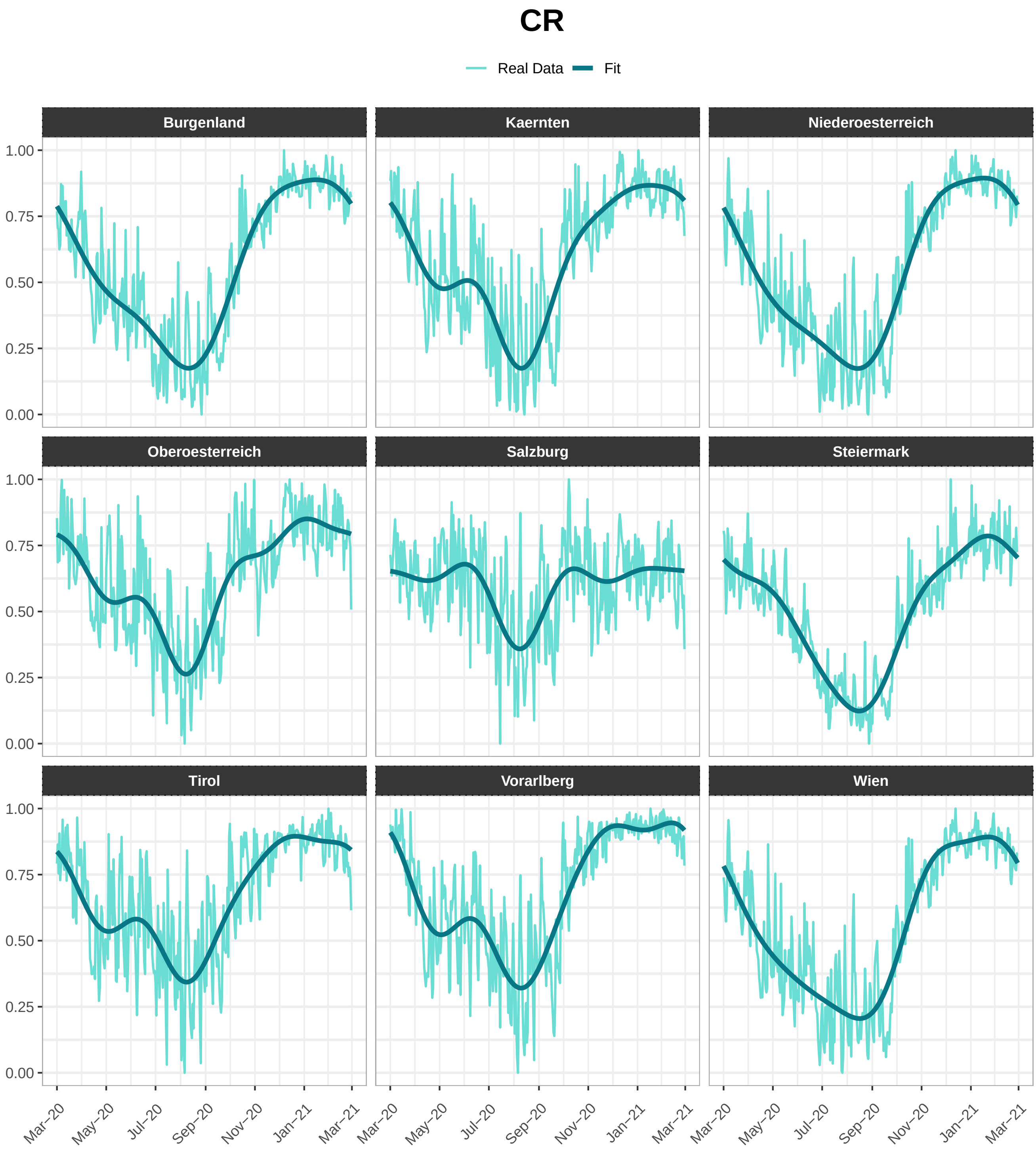

Figure 6: The [0,1]-standardized concentration rate data and its sinusoidal curve fit

A.1.2 Humidity

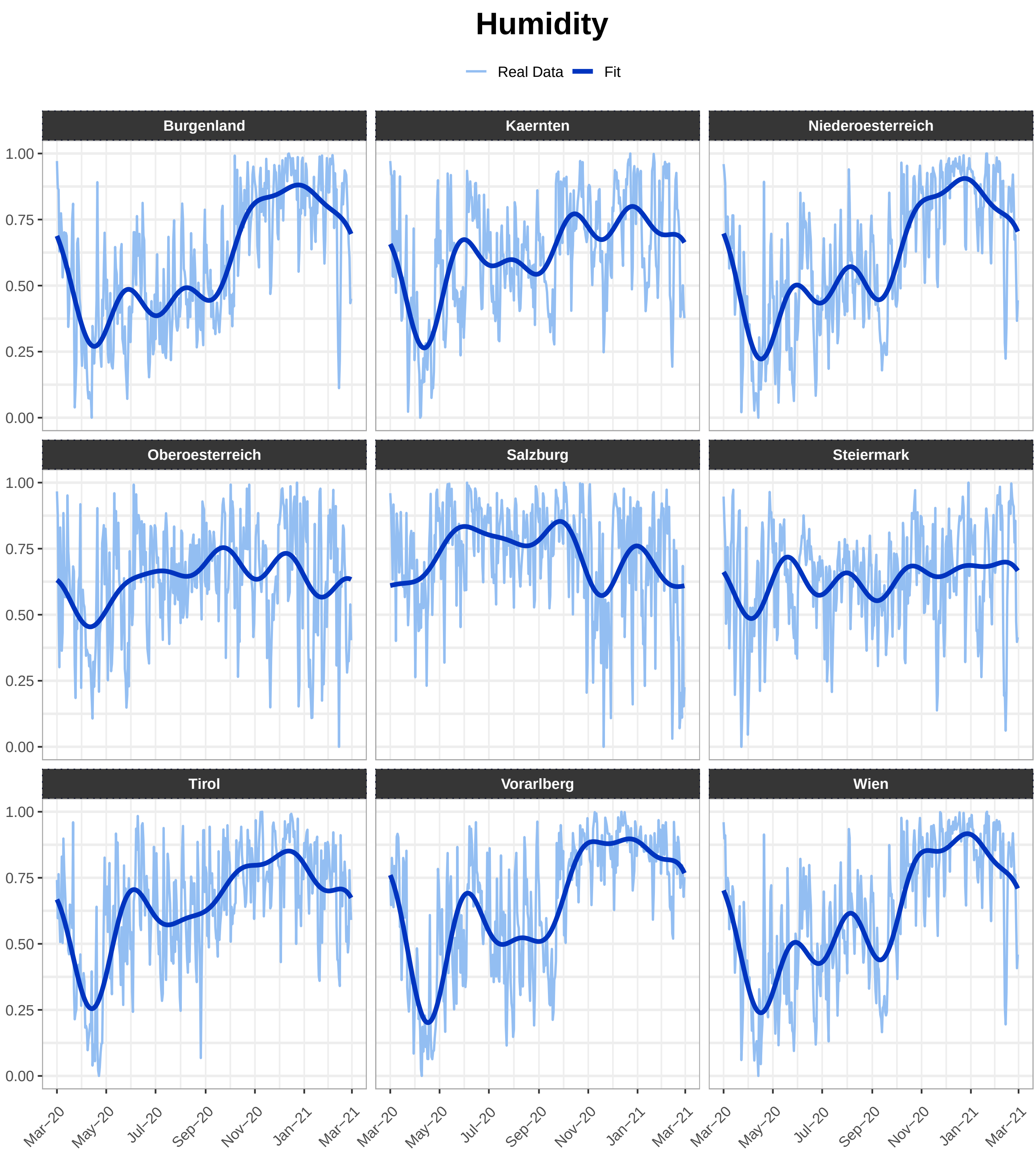

Figure 7: The [0,1]-standardized humidity data and its sinusoidal curve fit

A.1.3 Cloud

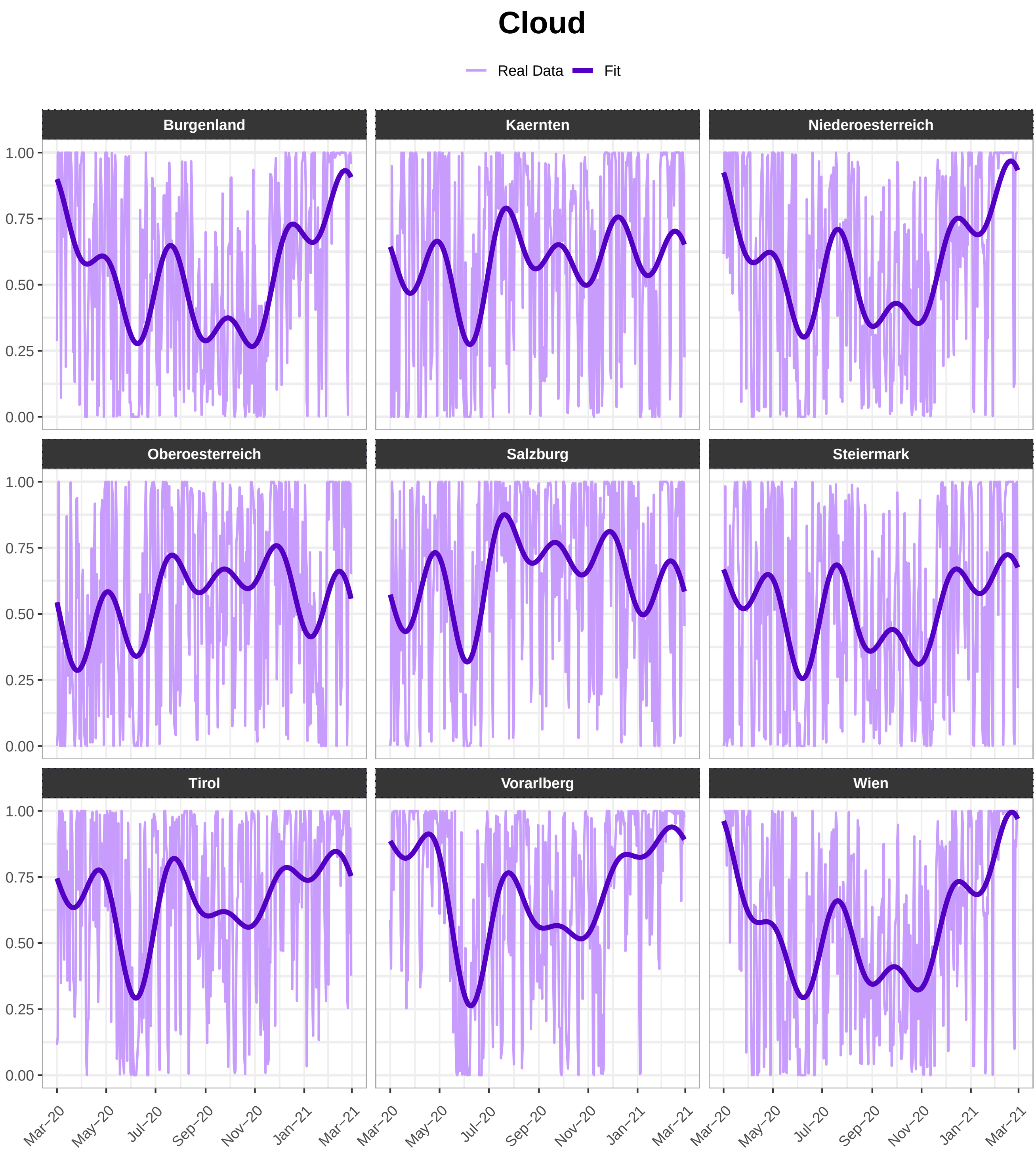

Figure 8: The [0,1]-standardized cloud data and its sinusoidal curve fit

A.2 Model calibrations

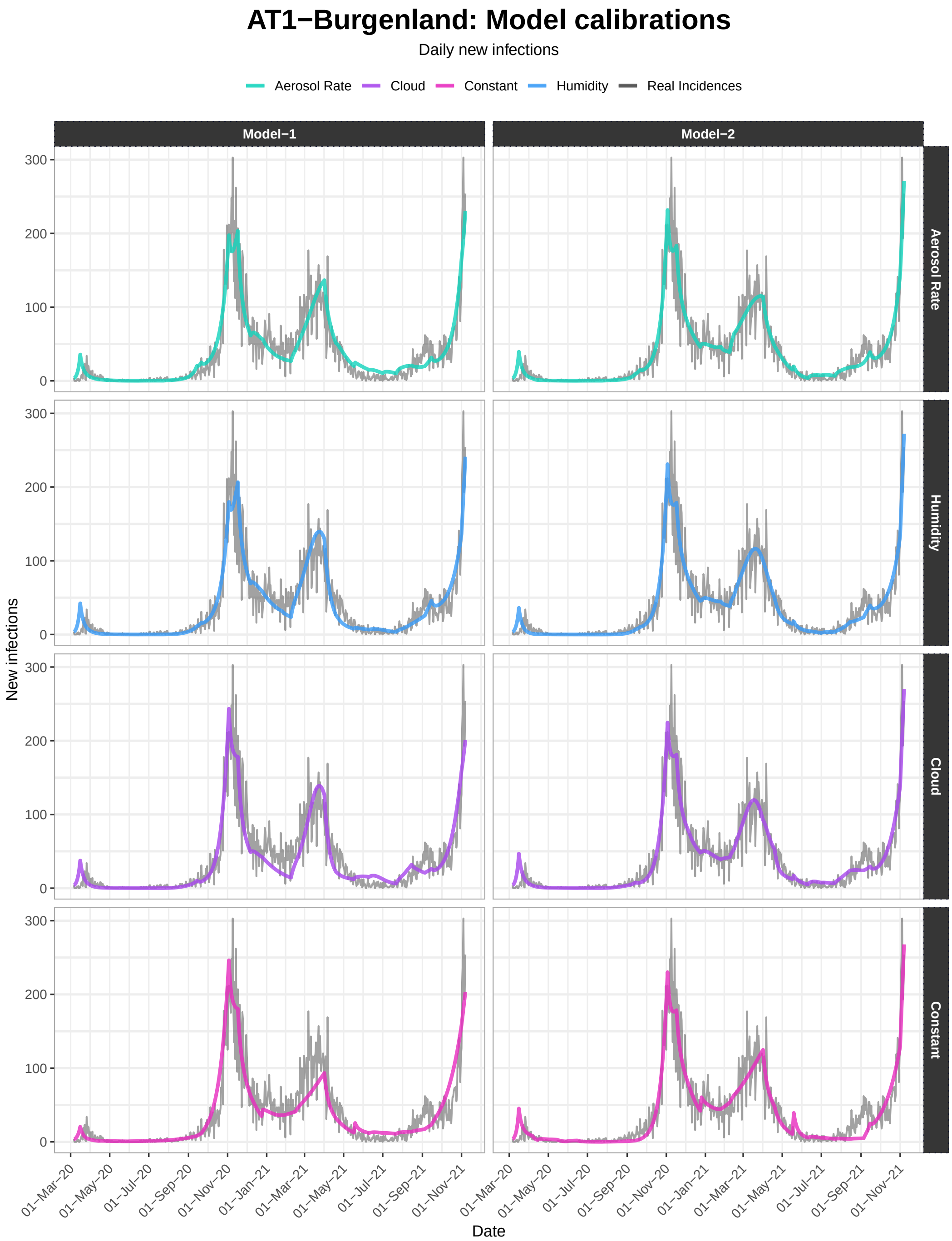

Figure 9: Burgenland: The curve fits across all models

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT1	260025.56	260847.93	303127.41	343308.95	Model-1
2	AT1	214027.08	213504.00	217154.49	251713.75	Model-2

Table 2: Burgenland: The values of the target function (residual sum of squares) whereas the lowest in each model is highlighted in pink.

Due to the very small and negligible difference between the values of the residual sum of squares for "Aerosol Rate" and "Humidity" in Model 2, both were highlighted.

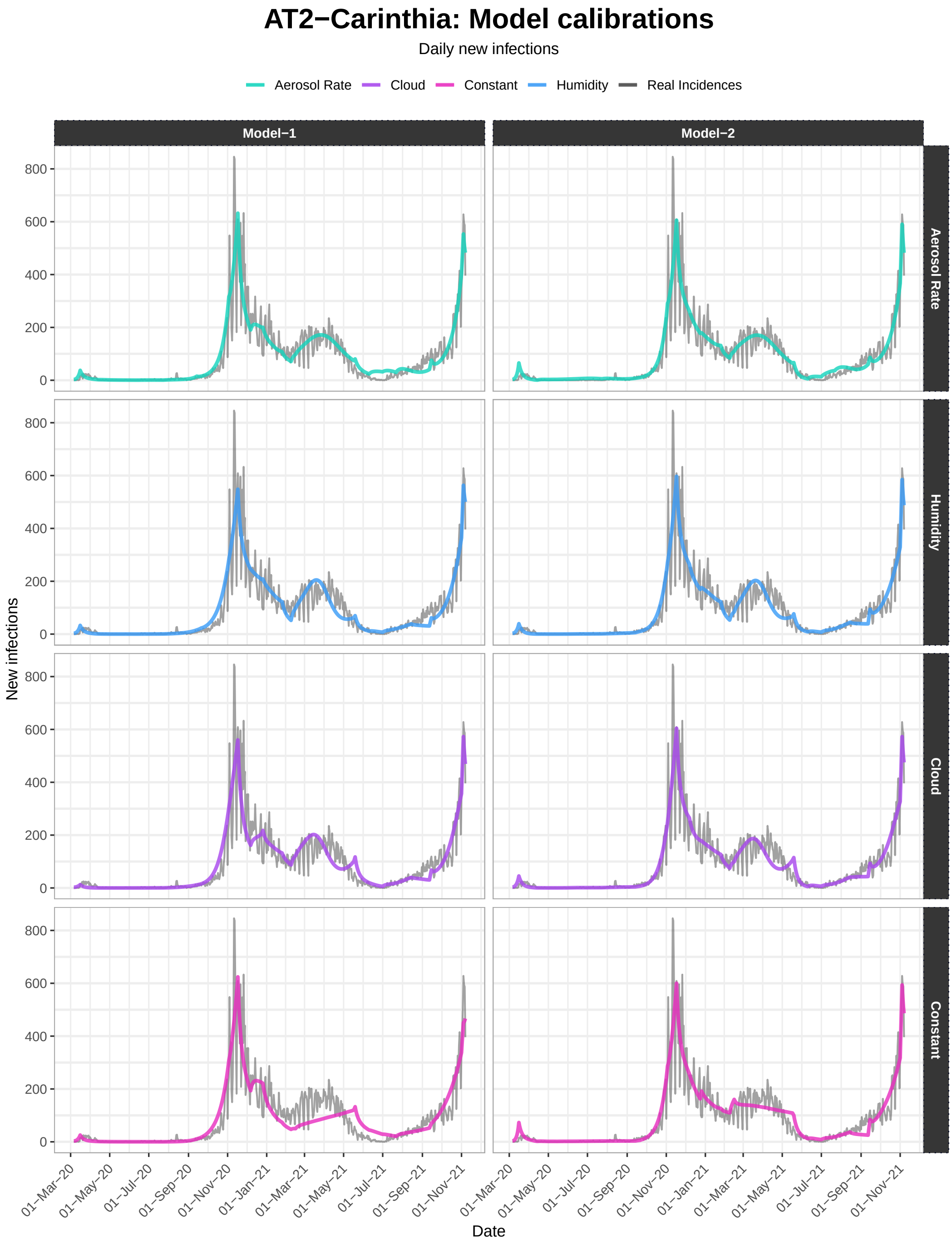

Figure 10: Carinthia: The curve fits across all models

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT2	1563041.11	1630623.00	1814088.81	2175384.11	Model-1
2	AT2	1400634.78	1519018.45	1529771.30	1517370.85	Model-2

Table 3: Carinthia: The values of the target function (residual sum of squares).

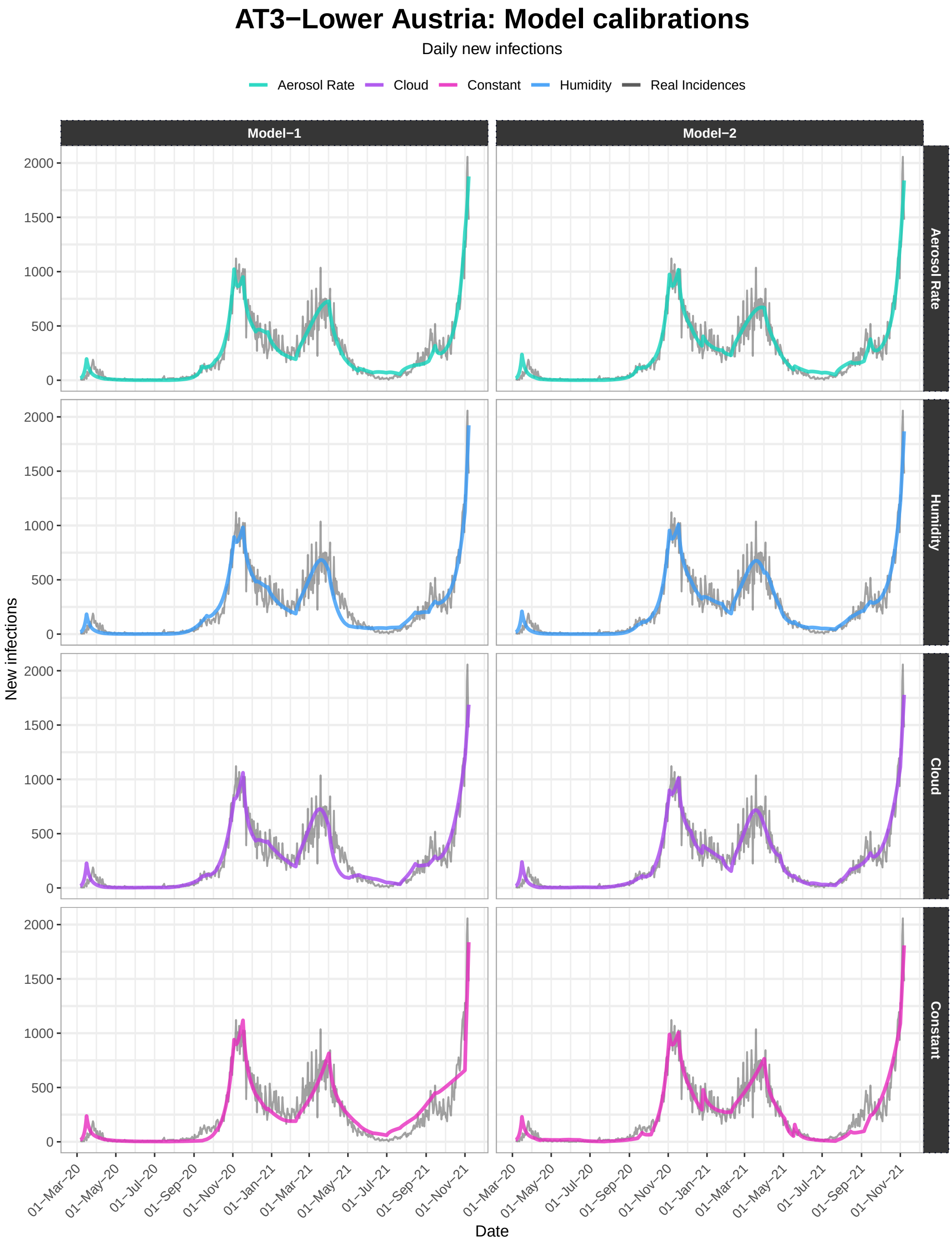

Figure 11: Lower Austria: The curve fits across all models

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT3	3992315.67	4779461.32	5309125.47	7900959.94	Model-1
2	AT3	3569259.88	3586937.96	3898047.26	4708475.87	Model-2

Table 4: Lower Austria: The values of the target function (residual sum of squares).

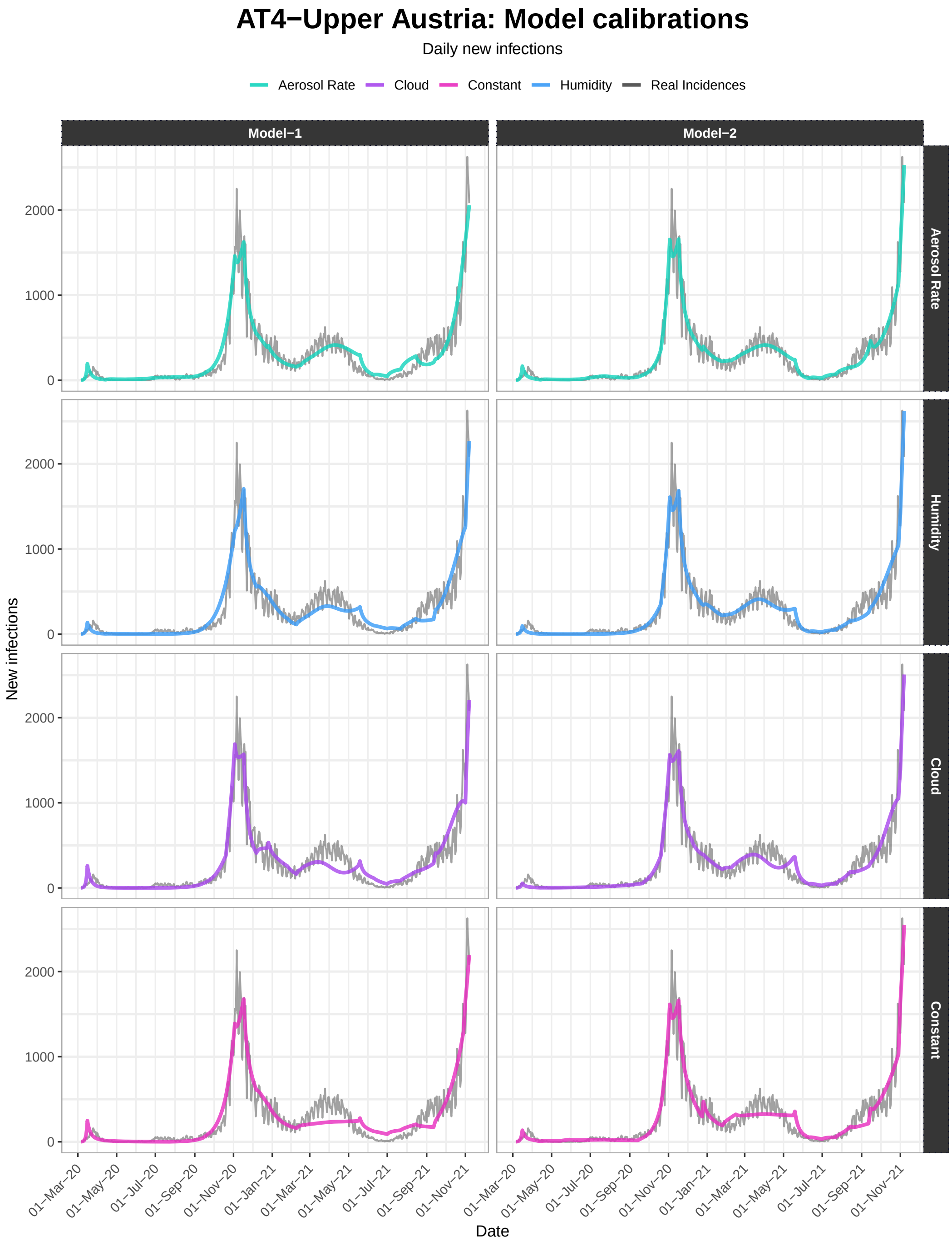

Figure 12: Upper Austria: The curve fits across all models

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT4	10782931.16	12603938.35	13438188.48	12588484.40	Model-1
2	AT4	7694875.68	8902717.04	9810873.71	9435789.71	Model-2

Table 5: Upper Austria: The values of the target function (residual sum of squares).

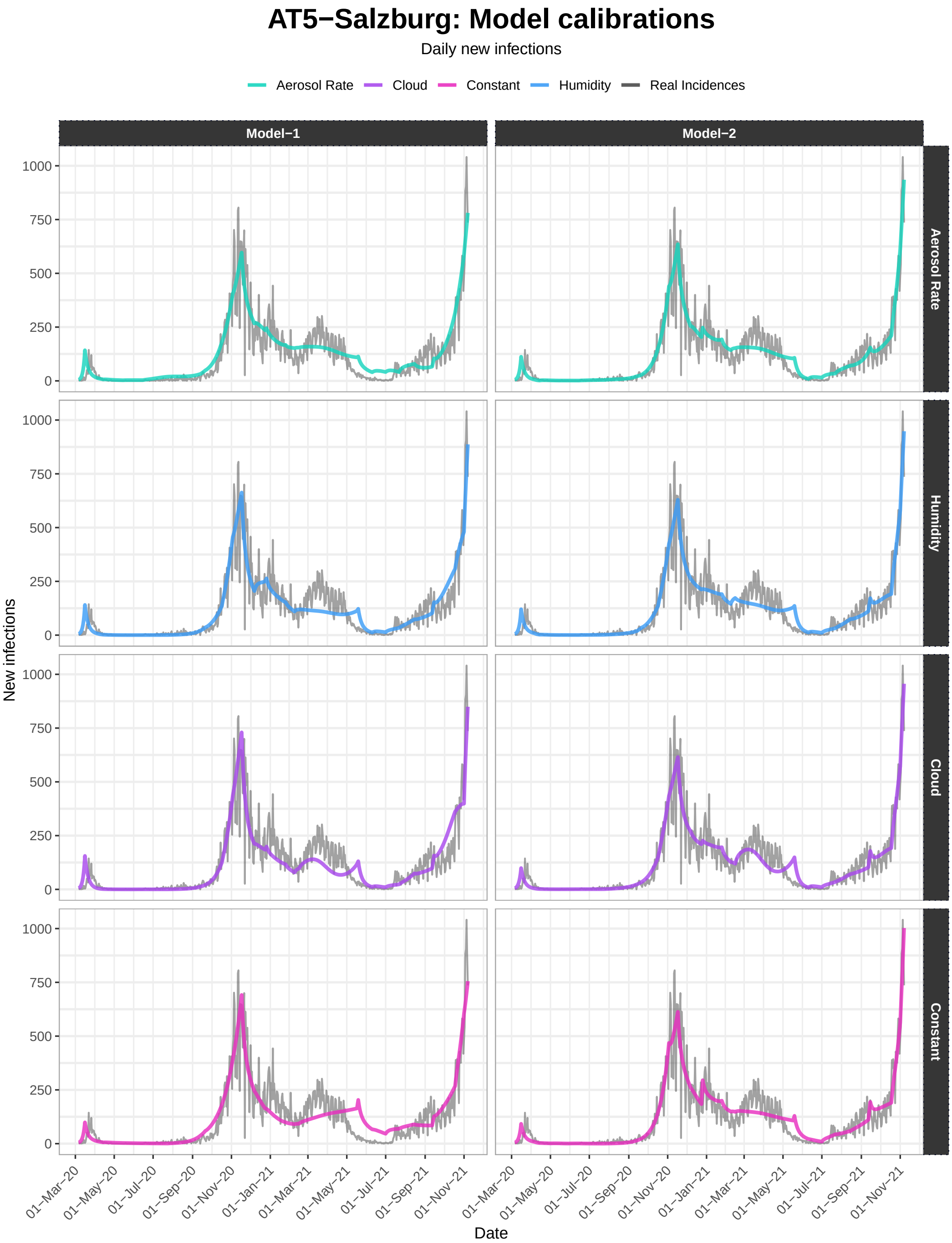

Figure 13: Salzburg: The curve fits across all models

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT5	2609645.33	2744931.01	3181282.15	3240347.31	Model-1
2	AT5	2194771.88	2353615.18	2313292.11	2298662.01	Model-2

Table 6: Salzburg: The values of the target function (residual sum of squares).

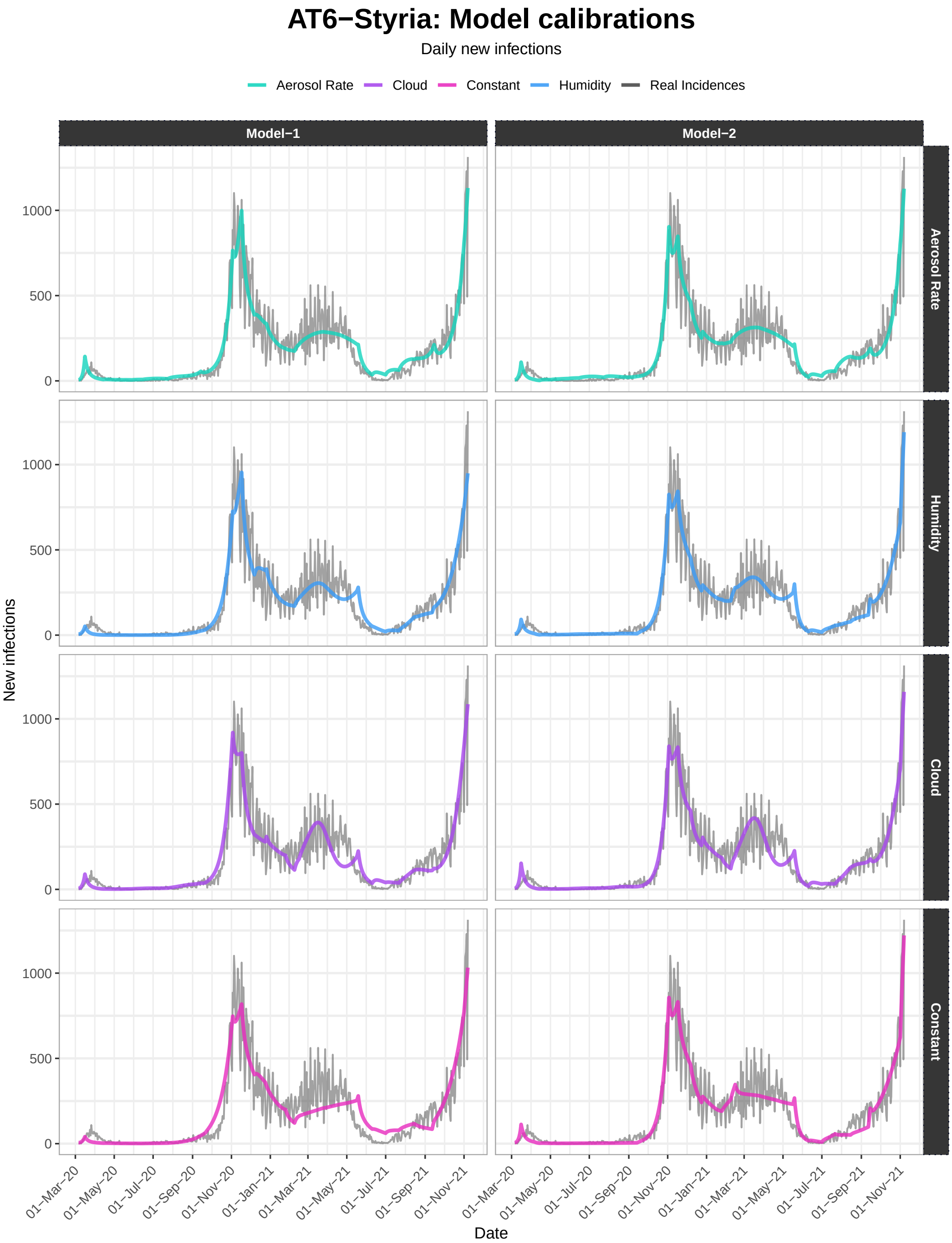

Figure 14: Styria: The curve fits across all models

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT6	4449493.08	4872753.94	5365581.84	6086521.50	Model-1
2	AT6	4080992.39	4242428.44	4584251.83	4388307.98	Model-2

Table 7: Styria: The values of the target function (residual sum of squares).

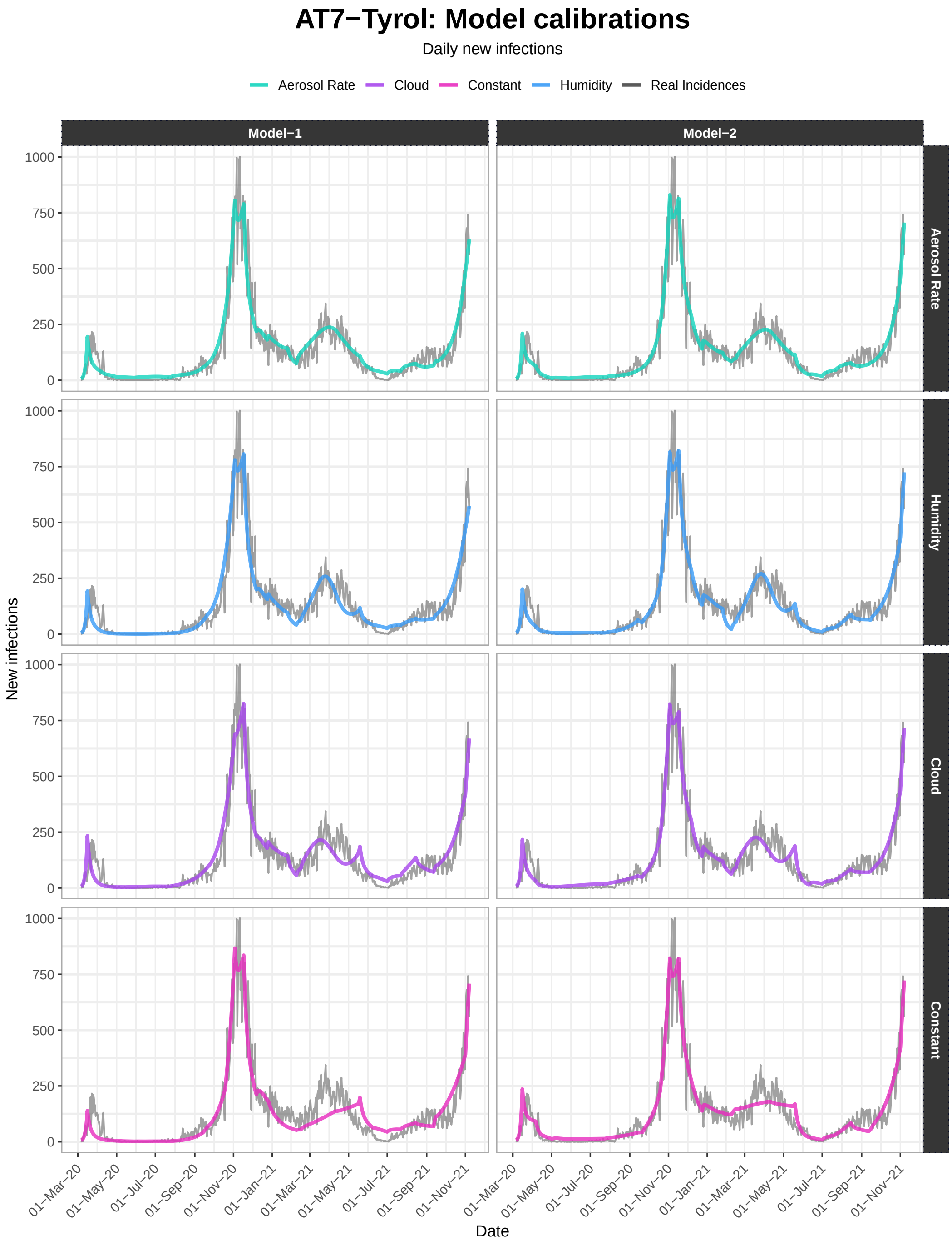

Figure 15: Tyrol: The curve fits across all models

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT7	1867266.40	2272202.14	2366794.82	2735061.13	Model-1
2	AT7	1582452.44	1762372.89	1889780.27	1844244.61	Model-2

Table 8: Tyrol: The values of the target function (residual sum of squares).

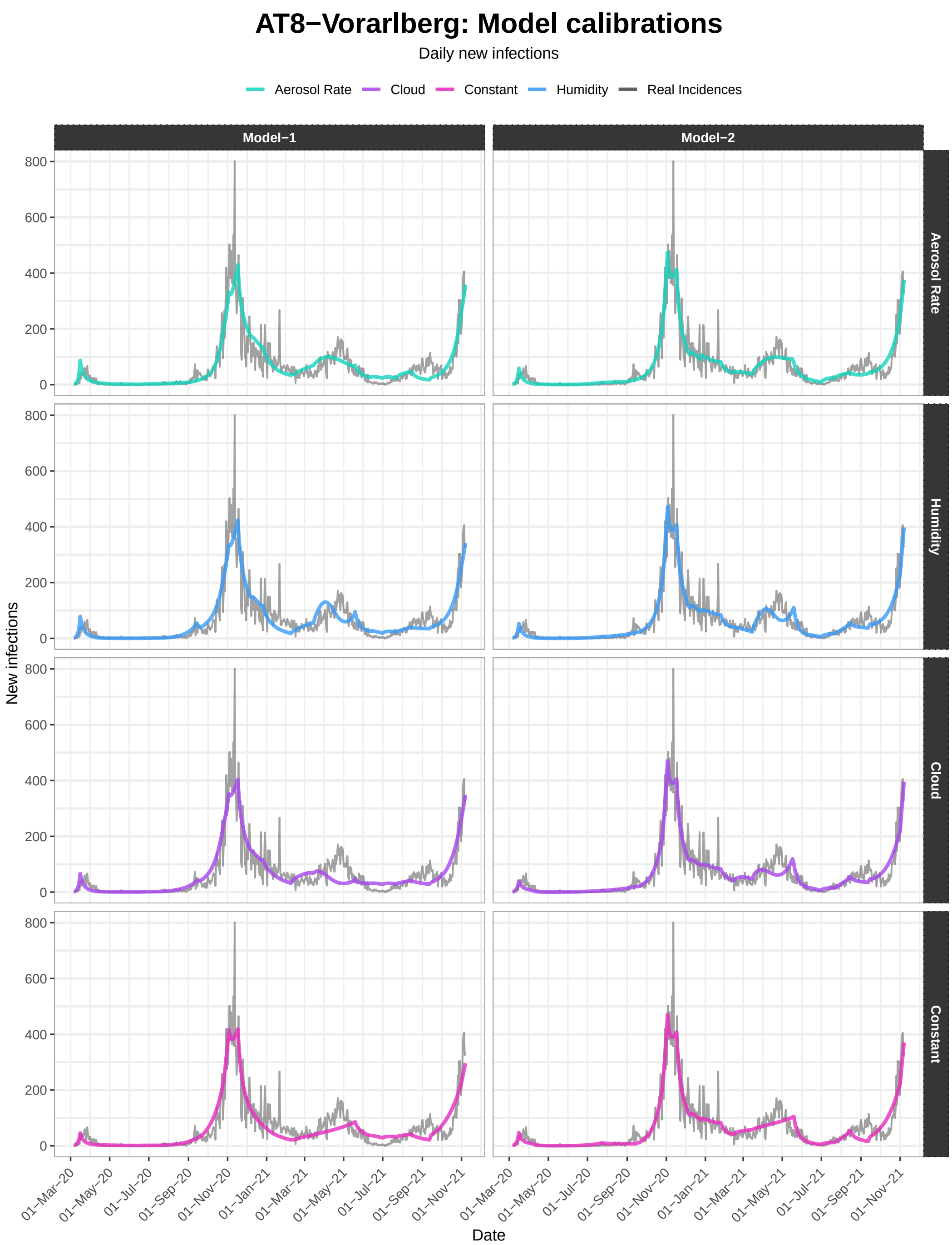

Figure 16: Vorarlberg: The curve fits across all models

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT8	1097334.15	1122001.16	1186230.20	1123158.20	Model-1
2	AT8	808482.75	854024.94	881382.66	889470.62	Model-2

Table 9: Vorarlberg: The values of the target function (residual sum of squares).

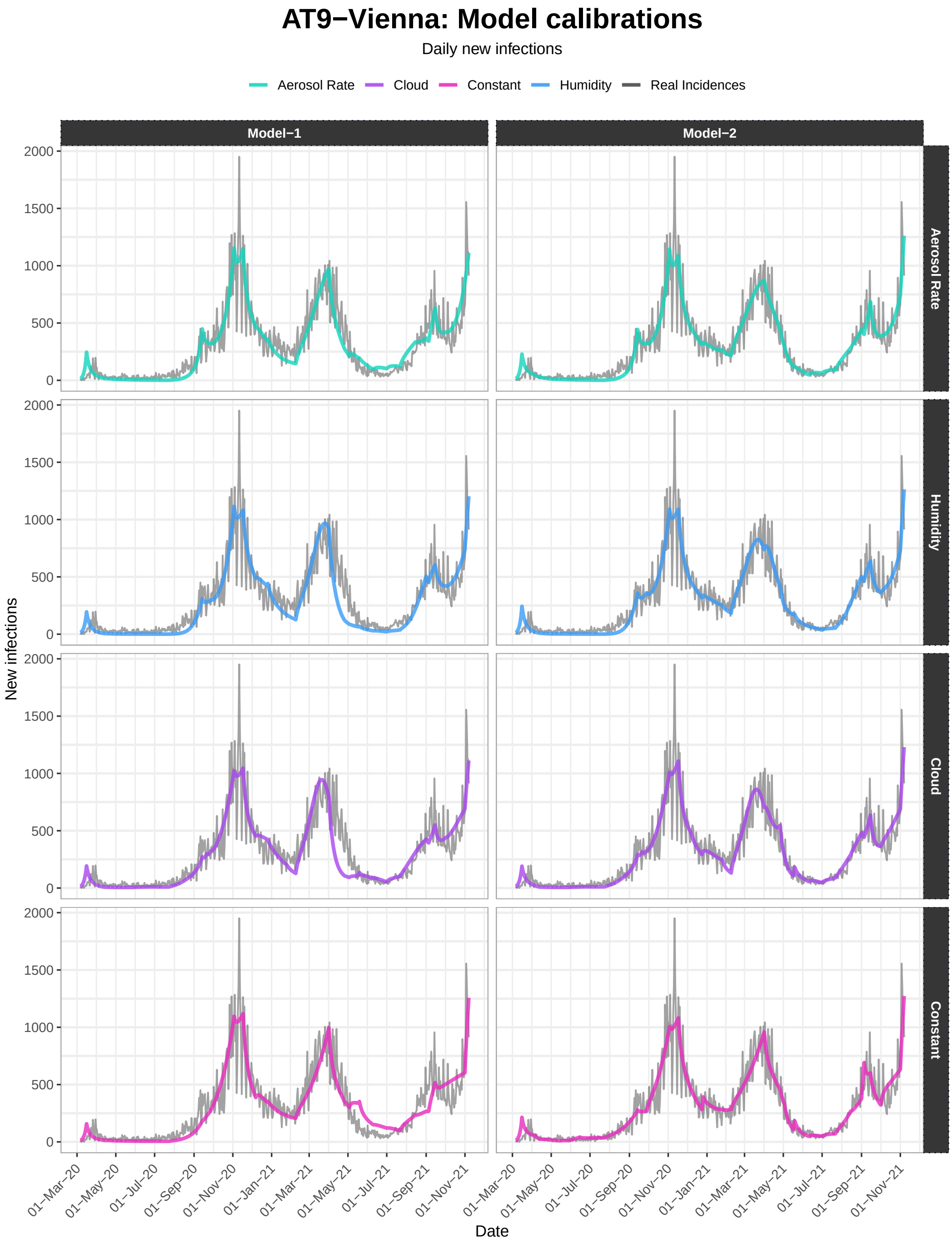

Figure 17: Vienna: The curve fits across all models

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT9	9870008.22	11672546.43	12784443.70	11241830.96	Model-1
2	AT9	8056754.15	8141207.35	8475616.80	8415550.19	Model-2

Table 10: Vienna: The values of the target function (residual sum of squares).

A.3 Correctness of measures/Quantification

A.3.1 Burgenland

Fed	CR_1	CR_2	HUM_1	HUM_2	Reality	CL_1	CL_2	CONST_1	CONST_2	Duration	Break
AT1	-	-	-	-	-	-	-	-	-	21	B.2
AT1	-	-	-	-	-	-	-	-	-	8	B.3
AT1	+	+	+	+	+	+	+	+	+	18	B.4
AT1	+	+	+	+	+	+	+	+	+	13	B.5
AT1	+	+	+	+	+	+	-	+	-	14	B.6
AT1	+	+	-	+	+	+	+	+	+	17	B.7
AT1	+	+	+	+	+	+	+	+	-	39	B.8
AT1	+	+	+	+	-	+	+	+	+	52	B.9
AT1	-	-	-	-	-	-	-	+	+	7	B.10
AT1	-	-	-	-	-	+	+	+	+	43	B.11
AT1	-	-	-	-	-	-	-	-	-	14	B.12
AT1	-	-	-	-	-	-	-	-	-	20	B.13
AT1	+	+	+	+	+	+	-	+	-	17	B.14
AT1	+	+	-	+	+	+	+	+	+	2	B.15
AT1	-	-	-	+	-	-	+	-	-	30	B.16
AT1	-	-	-	-	-	-	-	-	+	14	B.17
AT1	+	+	+	+	+	+	+	+	+	7	B.18
AT1	+	-	-	+	+	-	+	+	-	45	B.19
AT1	-	-	-	-	-	-	+	-	-	18	B.20
AT1	+	+	+	-	+	+	-	+	-	28	B.21
AT1	+	+	+	+	+	+	+	+	+	2	B.22
AT1	-	-	-	-	-	-	-	-	-	22	B.23
AT1	+	+	+	+	+	+	+	+	+	21	B.24
AT1	+	+	-	+	+	-	+	+	+	21	B.25
AT1	+	+	+	+	+	+	+	+	+	24	B.26
AT1	-	-	-	-	-	-	-	+	+	21	B.27
AT1	+	+	+	+	+	+	+	+	+	10	B.28
AT1	-	-	-	-	-	-	-	+	-	47	B.29
AT1	-	+	+	+	-	-	+	+	+	7	B.30

Figure 18: Burgenland: Comparison between the signs of the modelled measures and the real events.

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT1	0.90	0.75	0.72	0.69	Model-1
2	AT1	0.81	0.79	0.64	0.51	Model-2

Table 11: Burgenland: The calculated C_k values whereas the highest in each model is highlighted in blue.

A.3.2 Carinthia

Fed	CR_1	CR_2	HUM_1	HUM_2	Reality	CL_1	CL_2	CONST_1	CONST_2	Duration	Break
AT2	-	-	-	-	-	-	-	-	-	21	B.2
AT2	-	-	-	-	-	-	-	-	-	8	B.3
AT2	+	+	+	+	+	+	+	+	+	18	B.4
AT2	+	+	+	+	+	+	+	+	+	13	B.5
AT2	+	+	+	+	+	+	+	+	+	14	B.6
AT2	+	+	+	+	+	+	+	+	+	17	B.7
AT2	+	+	+	-	+	+	-	+	+	39	B.8
AT2	+	+	+	+	-	+	+	+	-	52	B.9
AT2	-	-	-	+	-	-	+	-	+	7	B.10
AT2	-	-	-	-	-	+	+	-	+	43	B.11
AT2	-	-	-	-	-	-	+	-	-	14	B.12
AT2	-	-	-	-	-	-	-	-	-	20	B.13
AT2	+	-	+	-	+	+	-	+	-	17	B.14
AT2	+	+	+	+	+	+	+	-	+	2	B.15
AT2	-	-	-	-	-	-	-	-	-	30	B.16
AT2	-	-	-	-	-	-	-	-	-	14	B.17
AT2	+	+	+	+	+	+	+	+	+	7	B.18
AT2	+	+	+	+	+	+	+	+	-	91	B.19
AT2	+	+	+	+	+	+	+	+	-	2	B.20
AT2	-	-	-	-	-	-	-	-	-	22	B.21
AT2	+	+	+	+	+	+	+	+	+	21	B.22
AT2	+	+	+	+	+	+	+	+	+	21	B.23
AT2	+	+	+	+	+	+	+	+	+	24	B.24
AT2	-	-	-	-	-	-	-	+	-	28	B.25
AT2	+	+	+	+	+	+	+	+	+	3	B.26
AT2	-	-	-	-	-	-	-	-	-	47	B.27
AT2	+	+	+	+	-	+	+	+	+	3	B.28
AT2	-	-	-	-	-	-	-	-	-	4	B.29

Figure 19: Carinthia: Comparison between the signs of the modelled measures and the real events.

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT2	0.89	0.89	0.82	0.84	Model-1
2	AT2	0.87	0.79	0.70	0.72	Model-2

Table 12: Carinthia: The calculated C_k values.

A.3.3 Lower Austria

Fed	CR_1	CR_2	HUM_1	HUM_2	Reality	CL_1	CL_2	CONST_1	CONST_2	Duration	Break
AT3	-	-	-	-	-	-	-	-	-	21	B.2
AT3	-	-	-	-	-	-	-	-	-	8	B.3
AT3	+	+	+	+	+	+	+	+	+	18	B.4
AT3	+	+	+	+	+	+	+	+	+	13	B.5
AT3	+	+	+	+	+	+	+	+	+	14	B.6
AT3	+	+	+	+	+	+	+	+	-	17	B.7
AT3	+	+	+	+	+	+	+	+	-	39	B.8
AT3	+	+	+	+	-	+	+	+	+	52	B.9
AT3	-	-	-	-	-	-	-	+	+	7	B.10
AT3	-	-	-	-	-	-	-	+	-	14	B.11
AT3	-	-	-	-	-	+	+	-	+	29	B.12
AT3	-	-	-	-	-	-	-	-	-	14	B.13
AT3	-	-	-	-	-	-	-	-	-	20	B.14
AT3	+	-	+	-	+	+	-	+	-	17	B.15
AT3	+	+	+	+	+	+	+	+	+	2	B.16
AT3	-	-	-	-	-	-	-	-	-	30	B.17
AT3	-	-	-	-	-	-	-	-	-	14	B.18
AT3	+	+	+	+	+	+	+	+	+	52	B.19
AT3	-	-	-	+	-	-	+	-	-	25	B.20
AT3	+	-	+	-	+	+	-	+	-	7	B.21
AT3	+	+	+	-	+	+	+	+	-	14	B.22
AT3	+	+	+	+	+	-	+	-	+	2	B.23
AT3	-	-	-	-	-	-	-	-	-	22	B.24
AT3	+	+	+	+	+	+	+	+	+	21	B.25
AT3	+	+	+	+	+	+	+	+	+	21	B.26
AT3	+	+	+	+	+	+	+	+	+	24	B.27
AT3	-	-	-	-	-	-	-	+	-	21	B.28
AT3	+	+	+	+	+	+	+	-	+	10	B.29
AT3	-	-	-	-	-	-	-	-	-	47	B.30
AT3	-	-	+	+	-	+	+	+	+	7	B.31

Figure 20: Lower Austria: Comparison between the signs of the modelled measures and the real events.

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT3	0.90	0.89	0.84	0.80	Model-1
2	AT3	0.86	0.78	0.76	0.67	Model-2

Table 13: Lower Austria: The calculated C_k values.

A.3.4 Upper Austria

Fed	CR_1	CR_2	HUM_1	HUM_2	Reality	CL_1	CL_2	CONST_1	CONST_2	Duration	Break
AT4	-	-	-	-	-	-	-	-	-	21	B.2
AT4	-	-	-	-	-	-	-	-	-	8	B.3
AT4	+	+	+	+	+	+	+	+	+	18	B.4
AT4	+	+	+	+	+	+	+	+	+	13	B.5
AT4	+	+	-	+	+	+	+	+	+	14	B.6
AT4	+	+	+	+	+	+	-	+	-	17	B.7
AT4	+	+	+	+	+	+	+	+	+	39	B.8
AT4	+	-	+	+	-	+	-	+	-	52	B.9
AT4	-	+	-	-	-	-	-	+	+	7	B.10
AT4	-	-	-	-	-	-	+	-	-	29	B.11
AT4	-	+	+	+	-	+	+	+	+	14	B.12
AT4	-	-	-	-	-	-	-	-	-	14	B.13
AT4	-	-	-	-	-	-	-	-	-	20	B.14
AT4	+	+	+	+	+	+	-	+	+	17	B.15
AT4	+	+	+	+	+	+	+	+	+	2	B.16
AT4	-	-	-	+	-	-	-	-	-	30	B.17
AT4	-	+	-	+	-	-	+	-	+	14	B.18
AT4	+	+	+	+	+	+	+	+	-	7	B.19
AT4	+	+	+	+	+	+	+	-	-	91	B.20
AT4	+	+	+	-	+	+	-	+	+	2	B.21
AT4	-	-	-	-	-	-	-	-	-	22	B.22
AT4	+	+	+	+	+	-	+	+	+	21	B.23
AT4	+	+	+	+	+	+	+	+	+	21	B.24
AT4	+	+	+	+	+	+	+	+	+	24	B.25
AT4	-	-	-	-	-	-	-	-	-	28	B.26
AT4	+	+	+	+	+	+	+	+	+	3	B.27
AT4	-	-	-	-	-	-	-	-	-	44	B.28
AT4	-	+	-	+	-	-	+	+	+	3	B.29
AT4	-	-	+	+	-	+	+	-	-	7	B.30

Figure 21: Upper Austria: Comparison between the signs of the modelled measures and the real events.

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT4	0.90	0.84	0.83	0.71	Model-1
2	AT4	0.92	0.78	0.82	0.73	Model-2

Table 14: Upper Austria: The calculated C_k values.

A.3.5 Salzburg

Fed	CR_1	CR_2	HUM_1	HUM_2	Reality	CL_1	CL_2	CONST_1	CONST_2	Duration	Break
AT5	-	-	-	-	-	-	-	-	-	21	B.2
AT5	-	-	-	-	-	-	-	-	-	8	B.3
AT5	+	+	+	+	+	+	+	+	+	18	B.4
AT5	+	+	+	+	+	+	+	+	+	13	B.5
AT5	+	+	+	+	+	+	+	+	-	14	B.6
AT5	+	+	+	+	+	+	+	-	+	17	B.7
AT5	+	+	+	+	+	+	+	+	-	39	B.8
AT5	-	+	+	+	-	+	+	+	+	52	B.9
AT5	+	-	-	+	-	-	-	-	-	7	B.10
AT5	-	+	-	-	-	-	-	-	+	26	B.11
AT5	-	-	+	+	-	+	+	+	-	17	B.12
AT5	-	-	-	-	-	-	-	-	-	14	B.13
AT5	-	-	-	-	-	-	-	-	-	20	B.14
AT5	+	+	+	+	+	+	-	+	+	17	B.15
AT5	+	+	+	+	+	+	+	+	+	2	B.16
AT5	-	-	-	-	-	-	-	-	-	30	B.17
AT5	-	-	-	-	-	-	-	-	-	14	B.18
AT5	+	+	+	+	+	+	+	+	+	7	B.19
AT5	+	+	+	-	+	+	+	+	+	91	B.20
AT5	+	+	+	+	+	+	+	+	+	2	B.21
AT5	-	-	-	-	-	-	-	-	-	22	B.22
AT5	+	+	+	+	+	+	+	+	+	21	B.23
AT5	+	+	+	+	+	+	+	+	+	21	B.24
AT5	+	+	+	+	+	+	+	+	-	24	B.25
AT5	-	-	-	-	-	-	-	-	+	28	B.26
AT5	+	+	+	+	+	+	+	+	+	3	B.27
AT5	-	-	-	-	-	-	-	-	-	33	B.28
AT5	+	+	+	+	-	-	+	+	+	14	B.29
AT5	+	+	+	+	-	+	+	-	+	7	B.30

Figure 22: Salzburg: Comparison between the signs of the modelled measures and the real events.

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT5	0.94	0.84	0.86	0.82	Model-1
2	AT5	0.82	0.68	0.81	0.65	Model-2

Table 15: Salzburg: The calculated C_k values.

A.3.6 Styria

Fed	CR_1	CR_2	HUM_1	HUM_2	Reality	CL_1	CL_2	CONST_1	CONST_2	Duration	Break
AT6	-	-	-	-	-	-	-	-	-	21	B.2
AT6	-	-	-	-	-	-	-	-	-	8	B.3
AT6	+	+	+	+	+	+	+	+	+	18	B.4
AT6	+	+	+	+	+	+	+	+	+	13	B.5
AT6	+	+	+	+	+	+	+	+	+	14	B.6
AT6	+	+	+	+	+	+	+	+	+	17	B.7
AT6	+	+	+	-	+	+	+	+	-	39	B.8
AT6	+	+	+	-	-	+	+	+	+	52	B.9
AT6	-	-	-	+	-	-	+	-	+	7	B.10
AT6	-	-	+	-	-	+	+	+	-	43	B.11
AT6	-	-	-	-	-	-	-	-	-	14	B.12
AT6	-	-	-	-	-	-	-	-	-	20	B.13
AT6	+	-	+	-	+	+	-	+	-	17	B.14
AT6	+	+	+	+	+	+	+	-	+	2	B.15
AT6	-	-	-	-	-	-	-	-	-	30	B.16
AT6	-	-	-	-	-	-	-	-	+	14	B.17
AT6	+	+	+	+	+	+	+	+	+	7	B.18
AT6	+	+	+	-	+	+	+	-	-	91	B.19
AT6	+	+	+	+	+	+	+	+	+	2	B.20
AT6	-	-	-	-	-	-	-	-	-	22	B.21
AT6	+	+	+	+	+	+	+	+	+	21	B.22
AT6	+	+	+	+	+	+	+	+	+	21	B.23
AT6	+	+	+	-	+	+	+	+	-	24	B.24
AT6	+	-	-	+	-	-	-	-	+	28	B.25
AT6	+	+	+	+	+	+	+	+	+	3	B.26
AT6	-	-	-	-	-	-	-	-	-	47	B.27
AT6	-	-	+	+	-	+	+	+	+	7	B.28

Figure 23: Styria: Comparison between the signs of the modelled measures and the real events.

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT6	0.85	0.82	0.82	0.67	Model-1
2	AT6	0.87	0.64	0.78	0.53	Model-2

Table 16: Styria: The calculated C_k values.

A.3.7 Tyrol

Fed	CR_1	CR_2	HUM_1	HUM_2	Reality	CL_1	CL_2	CONST_1	CONST_2	Duration	Break
AT7	-	-	-	-	-	-	-	-	-	21	B.2
AT7	-	-	-	-	-	-	-	-	-	8	B.3
AT7	+	+	+	+	+	+	+	+	+	18	B.4
AT7	+	+	+	+	+	+	+	+	+	13	B.5
AT7	+	+	+	+	+	+	+	+	+	14	B.6
AT7	+	+	+	+	+	+	+	+	+	17	B.7
AT7	+	+	+	+	+	+	+	+	+	39	B.8
AT7	+	+	+	+	-	+	+	+	+	52	B.9
AT7	-	-	-	-	-	-	-	+	-	7	B.10
AT7	-	-	-	+	-	-	+	-	+	28	B.11
AT7	-	+	-	+	-	-	+	+	+	15	B.12
AT7	-	-	-	-	-	-	-	-	-	14	B.13
AT7	-	-	-	-	-	-	-	-	-	20	B.14
AT7	+	-	+	-	+	+	-	+	-	17	B.15
AT7	+	+	+	+	+	+	+	+	+	2	B.16
AT7	-	-	-	-	-	-	-	-	-	30	B.17
AT7	-	-	-	-	-	-	-	-	-	14	B.18
AT7	+	+	+	+	+	+	+	+	+	7	B.19
AT7	+	+	+	+	+	+	+	+	-	91	B.20
AT7	+	+	+	+	+	+	-	+	+	2	B.21
AT7	-	-	-	-	-	-	-	-	-	22	B.22
AT7	+	+	+	+	+	+	+	+	+	21	B.23
AT7	+	+	+	+	+	+	+	+	+	21	B.24
AT7	+	+	+	+	+	+	+	+	+	24	B.25
AT7	-	-	-	-	-	-	-	-	-	28	B.26
AT7	+	+	+	-	+	+	+	+	+	3	B.27
AT7	-	-	-	+	-	-	+	-	+	47	B.28
AT7	-	+	-	+	-	+	+	+	+	7	B.29

Figure 24: Tyrol: Comparison between the signs of the modelled measures and the real events.

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT7	0.90	0.90	0.89	0.85	Model-1
2	AT7	0.83	0.71	0.71	0.56	Model-2

Table 17: Tyrol: The calculated C_k values.

A.3.8 Vorarlberg

Fed	CR_1	CR_2	HUM_1	HUM_2	Reality	CL_1	CL_2	CONST_1	CONST_2	Duration	Break
AT8	-	-	-	-	-	-	-	-	-	21	B.2
AT8	-	-	-	-	-	-	-	+	-	8	B.3
AT8	+	+	+	+	+	+	+	+	+	18	B.4
AT8	+	+	+	+	+	+	+	+	+	13	B.5
AT8	+	+	+	+	+	+	+	+	+	14	B.6
AT8	+	+	+	+	+	+	+	+	+	17	B.7
AT8	+	+	+	+	+	+	+	+	+	39	B.8
AT8	+	-	+	-	-	+	-	+	-	52	B.9
AT8	-	-	-	-	-	-	-	-	+	7	B.10
AT8	-	-	+	+	-	+	+	+	+	35	B.11
AT8	-	+	-	+	-	-	+	+	+	8	B.12
AT8	-	-	-	-	-	-	-	-	-	14	B.13
AT8	-	-	-	-	-	-	-	-	-	20	B.14
AT8	+	+	+	+	+	+	+	+	+	17	B.15
AT8	+	+	+	+	+	+	+	+	+	2	B.16
AT8	-	-	-	-	-	-	-	-	-	30	B.17
AT8	-	-	-	-	-	-	-	-	-	14	B.18
AT8	+	+	+	+	+	+	+	+	+	7	B.19
AT8	+	+	+	+	+	+	+	+	+	28	B.20
AT8	+	+	+	+	+	+	+	+	+	63	B.21
AT8	+	-	+	-	+	+	-	+	+	2	B.22
AT8	-	-	-	-	-	-	-	-	-	22	B.23
AT8	+	+	+	+	+	+	+	+	+	21	B.24
AT8	+	+	+	+	+	+	+	+	+	21	B.25
AT8	+	+	+	+	+	+	+	+	+	24	B.26
AT8	-	-	-	-	-	-	-	-	-	28	B.27
AT8	+	+	+	+	+	+	+	+	+	3	B.28
AT8	-	-	-	-	-	-	-	-	-	47	B.29
AT8	-	+	-	+	-	-	+	+	+	7	B.30

Figure 25: Vorarlberg: Comparison between the signs of the modelled measures and the real events.

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT8	0.90	0.84	0.84	0.80	Model-1
2	AT8	0.96	0.90	0.90	0.89	Model-2

Table 18: Vorarlberg: The calculated C_k values.

A.3.9 Vienna

Fed	CR_1	CR_2	HUM_1	HUM_2	Reality	CL_1	CL_2	CONST_1	CONST_2	Duration	Break
AT9	-	-	-	-	-	-	-	-	-	21	B.2
AT9	-	-	-	-	-	-	-	-	-	8	B.3
AT9	+	+	+	+	+	+	+	+	+	18	B.4
AT9	+	+	+	+	+	+	+	+	+	13	B.5
AT9	+	+	+	+	+	+	+	+	+	14	B.6
AT9	+	+	+	+	+	+	+	+	+	17	B.7
AT9	+	+	+	+	+	+	+	+	-	39	B.8
AT9	+	+	+	+	-	+	+	+	+	52	B.9
AT9	-	-	-	-	-	-	-	-	-	7	B.10
AT9	-	-	-	-	-	-	-	-	-	7	B.11
AT9	-	-	-	-	-	-	-	+	+	36	B.12
AT9	-	-	-	-	-	-	-	-	-	14	B.13
AT9	-	-	-	-	-	-	-	-	-	20	B.14
AT9	+	+	+	+	+	+	-	+	+	17	B.15
AT9	+	+	+	+	+	-	+	+	+	2	B.16
AT9	-	-	-	-	-	-	-	-	-	30	B.17
AT9	-	-	-	-	-	-	-	-	-	14	B.18
AT9	+	+	+	+	+	+	+	+	+	52	B.19
AT9	-	-	-	+	-	-	+	-	-	25	B.20
AT9	+	-	+	-	+	+	-	+	-	7	B.21
AT9	+	-	+	+	+	+	-	+	-	14	B.22
AT9	+	+	+	+	+	+	+	+	+	2	B.23
AT9	-	-	-	-	-	-	-	-	-	22	B.24
AT9	+	+	+	+	+	+	+	+	+	21	B.25
AT9	+	+	+	+	+	+	+	+	+	21	B.26
AT9	+	+	+	+	+	+	+	+	+	24	B.27
AT9	-	+	-	-	-	+	+	-	-	17	B.28
AT9	-	-	-	-	-	-	-	-	+	4	B.29
AT9	+	+	+	+	+	+	+	+	-	10	B.30
AT9	-	-	-	-	-	-	-	-	-	16	B.31
AT9	-	-	-	+	-	-	+	-	+	31	B.32
AT9	-	+	+	+	-	+	+	+	+	7	B.33

Figure 26: Vienna: Comparison between the signs of the modelled measures and the real events.

	Fed	Aerosol Rate	Humidity	Cloud	Constant	Model
1	AT9	0.90	0.89	0.86	0.83	Model-1
2	AT9	0.83	0.78	0.71	0.66	Model-2

Table 19: Vienna: The calculated C_k values.

A.4 Measures

Measures in Burgenland

Date	What happened?	Overall Classification	Comment
2020/03/16	Full Lockdown	🔴	
2020/04/06	Implementation of mask mandate in stores.	🔴	
2020/04/14	Opening of smaller and DIY stores, extension of mask mandate to public transport.	🟢	Opening outweighed the mask mandate
2020/05/01	End of curfew rules.	○	Merged with 2020/05/02
2020/05/02	Full reopening of all stores and services like hairstylists etc..	🟢	
2020/05/04	Reopening of schools for high school seniors	○	Merged with 2020/05/04
2020/05/15	Reopening of restaurants	🟢	
2020/05/29	Full reopening of all schools	🟢	
2020/06/15	End of mask mandate	🟢	
2020/07/24	Partial return of the mask mandate	🔴	
2020/09/14	First tightening of mask mandate	🔴	
2020/09/21	Second tightening of mask mandate	🔴	
2020/09/28	Registration requirement in restaurants	🔴	
2020/11/03	Lockdown light (curfew rules, distance learning in senior highs and universities, closure of restaurants)	🔴	
2020/11/17	Full lockdown	🔴	
2020/12/07	Softening of some lockdown rules	🟢	
2020/12/24 2020/12/25	Christmas exception: Private gatherings with <10 ppl allowed w.o. any distance rules	🟢	
2020/12/26	Full lockdown	🔴	
2021/01/25	Nationwide FFP2 mask mandate	🔴	
2021/02/08	Softening of curfew rules, reopening of stores.	🟢	
2021/02/15	Reopening of elementary schools, shift operation for junior- and senior highs.	🟢	
2021/04/01	Full lockdown	🔴	
2021/04/19	reopening of elementary schools, shift operation for junior- and senior highs, softening of curfew rules, reopening of stores	🟢	
2021/05/16	Complete lifting of curfew rules	○	Merged with 2021/05/17
2021/05/17	Reopening of all schools.	🟢	
2021/05/19	Requirement of the “3G”-rule for many activities Reopening of restaurants.	🔴	Implementation of 3G rule outweighed the reopening
2021/06/10	Loosening of the person/m² rule in stores, later closing hour in gastronomy allowed.	🟢	
2021/07/01	Lifting of any closing hour limitation for gastronomy. In restaurants no mask mandate anymore for guests offside the tables.	🟢	
2021/07/22	Reopening of the clubbing scene (entrance either with a PCR test or after vaccination).	🟢	
2021/08/15	For vaccines which required 2 doses at that time: “Green Pass” only available after the second dose of that vaccine or after a confirmed convalescence + 1 vaccine.	🔴	
2021/09/05	Normal school reopening despite of the B.1.617.2 infection wave.	🟢	
2021/09/15	FFP2 mask mandate for all in stores of daily needs, In other stores: FFP2 mask mandate for unvaccinated.	🔴	
2021/11/01	Implementation of the 3G rule in workplaces.	🔴	

Figure 27: The dates of the breaks and anchor signs in the models for Burgenland.

Measures in Carinthia

Date	What happened?	Overall Classification	Comment
2020/03/16	Full Lockdown	🔴	
2020/04/06	Implementation of mask mandate in stores.	🔴	
2020/04/14	Opening of smaller and DIY stores, extension of mask mandate to public transport.	🟢	Opening outweighed the mask mandate
2020/05/01	End of curfew rules.	○	Merged with 2020/05/02
2020/05/02	Full reopening of all stores and services like hairstylists etc..	🟢	
2020/05/04	Reopening of schools for high school seniors	○	Merged with 2020/05/04
2020/05/15	Reopening of restaurants	🟢	
2020/05/29	Full reopening of all schools	🟢	
2020/06/15	End of mask mandate	🟢	
2020/07/24	Partial return of the mask mandate	🔴	
2020/09/14	First tightening of mask mandate	🔴	
2020/09/21	Second tightening of mask mandate	🔴	
2020/11/03	Lockdown light (curfew rules, distance learning in senior highs and universities, closure of restaurants)	🔴	
2020/11/17	Full lockdown	🔴	
2020/12/07	Softening of some lockdown rules	🟢	
2020/12/24 2020/12/25	Christmas exception: Private gatherings with <10 ppl allowed w.o. any distance rules	🟢	
2020/12/26	Full Lockdown	🔴	
2021/01/25	Nationwide FFP2 mask mandate	🔴	
2021/02/08	Softening of curfew rules, reopening of stores	🟢	
2021/02/15	Reopening of elementary schools, shift operation for junior- and senior highs	🟢	
2021/05/16	Complete lifting of curfew rules	○	Merged with 2021/05/17
2021/05/17	Reopening of all schools.	🟢	
2021/05/19	Requirement of the “3G”-rule for many activities Reopening of restaurants.	🔴	Implementation of 3G rule outweighed the reopening
2021/06/10	Loosening of the person/m² rule in stores, later closing hour in gastronomy allowed.	🟢	
2021/07/01	Lifting of any closing hour limitation for gastronomy. In restaurants no mask mandate anymore for guests offside the tables.	🟢	
2021/07/22	Reopening of the clubbing scene (entrance either with a PCR test or after vaccination).	🟢	
2021/08/15	For vaccines which required 2 doses at that time: “Green Pass” only available after the second dose of that vaccine or after a confirmed convalescence + 1 vaccine.	🔴	
2021/09/12	Normal school reopening despite of the B.1.617.2 infection wave.	🟢	
2021/09/15	FFP2 mask mandate for all in stores of daily needs, In other stores: FFP2 mask mandate for unvaccinated. Validity of antigen tests reduced to 24hours.	🔴	
2021/11/01	Implementation of the 3G rule in workplaces.	🔴	

Figure 28: The dates of the breaks and anchor signs in the models for Carinthia.

Measures in Lower Austria

Date	What happened?	Overall Classification	Comment
2020/03/16	Full Lockdown	🔴	
2020/04/06	Implementation of mask mandate in stores.	🔴	
2020/04/14	Opening of smaller and DIY stores, extension of mask mandate to public transport.	🟢	Opening outweighed the mask mandate
2020/05/01	End of curfew rules.	○	Merged with 2020/05/02
2020/05/02	Full reopening of all stores and services like hairstylists etc..	🟢	
2020/05/04	Reopening of schools for high school seniors	○	Merged with 2020/05/04
2020/05/15	Reopening of restaurants	🟢	
2020/05/29	Full reopening of all schools	🟢	
2020/06/15	End of mask mandate	🟢	
2020/07/24	Partial return of the mask mandate	🔴	
2020/09/14	First tightening of mask mandate	🔴	
2020/09/21	Second tightening of mask mandate	🔴	
2020/09/28	Registration requirement in restaurants	🔴	
2020/11/03	Lockdown light (curfew rules, distance learning in senior highs and universities, closure of restaurants)	🔴	
2020/11/17	Full lockdown	🔴	
2020/12/07	Softening of some lockdown rules	🟢	
2020/12/24 2020/12/25	Christmas exception: Private gatherings with <10 ppl allowed w.o. any distance rules	🟢	
2020/12/26	Full lockdown	🔴	
2021/01/25	Nationwide FFP2 mask mandate	🔴	
2021/02/08	Softening of curfew rules, reopening of stores and elementary schools, shift operation for junior- and senior highs	🟢	
2021/04/01	Full lockdown	🔴	
2021/04/26	reopening of elementary schools, shift operation for junior- and senior highs	🟢	
2021/05/03	Softening of curfew rules, reopening of stores (with the limitation of 1 person per 20 m^2)	🟢	
2021/05/16	Complete lifting of curfew rules	○	Merged with 2021/05/17
2021/05/17	Reopening of all schools.	🟢	
2021/05/19	Requirement of the "3G"-rule for many activities Reopening of restaurants.	🔴	Implementation of 3G rule outweighed the reopening
2021/06/10	Loosening of the person/m^2 rule in stores, later closing hour in gastronomy allowed.	🟢	
2021/07/01	Lifting of any closing hour limitation for gastronomy. In restaurants no mask mandate anymore for guests offside the tables.	🟢	
2021/07/22	Reopening of the clubbing scene (entrance either with a PCR test or after vaccination).	🟢	
2021/08/15	For vaccines which required 2 doses at that time: "Green Pass" only available after the second dose of that vaccine or after a confirmed convalescence + 1 vaccine.	🔴	
2021/09/05	Normal school reopening despite of the B.1.617.2 infection wave.	🟢	
2021/09/15	FFP2 mask mandate for all in stores of daily needs, In other stores: FFP2 mask mandate for unvaccinated, Validity of antigen tests reduced to 24 hours.	🔴	
2021/11/01	Implementation of the 3G rule in workplaces	🔴	

Figure 29: The dates of the breaks and anchor signs in the models for Lower Austria.

Measures in Upper Austria

Date	What happened?	Overall Classification	Comment
2020/03/16	Full Lockdown	🔴	
2020/04/06	Implementation of mask mandate in stores.	🔴	
2020/04/14	Opening of smaller and DIY stores, extension of mask mandate to public transport.	🟢	Opening outweighed the mask mandate
2020/05/01	End of curfew rules.	○	Merged with 2020/05/02
2020/05/02	Full reopening of all stores and services like hairstylists etc..	🟢	
2020/05/04	Reopening of schools for high school seniors	○	Merged with 2020/05/04
2020/05/15	Reopening of restaurants	🟢	
2020/05/29	Full reopening of all schools	🟢	
2020/06/15	End of mask mandate	🟢	
2020/07/24	Partial return of the mask mandate	🔴	
2020/09/14	First tightening of mask mandate	🔴	
2020/09/21	Second tightening of mask mandate	🔴	
2020/10/20	Registration requirement in restaurants	🔴	
2020/11/03	Lockdown light (curfew rules, distance learning in senior highs and universities, closure of restaurants)	🔴	
2020/11/17	Full lockdown	🔴	
2020/12/07	Softening of some lockdown rules	🟢	
2020/12/24 2020/12/25	Christmas exception: Private gatherings with <10 ppl allowed w.o. any distance rules	🟢	
2020/12/26	Full lockdown	🔴	
2021/01/25	Nationwide FFP2 mask mandate	🔴	
2021/02/08	Softening of curfew rules, reopening of stores	🟢	
2021/02/15	Reopening of elementary schools, shift operation for junior- and senior highs	🟢	
2021/05/16	Complete lifting of curfew rules	○	Merged with 2021/05/17
2021/05/17	Reopening of all schools.	🟢	
2021/05/19	Requirement of the "3G"-rule for many activities Reopening of restaurants.	🔴	Implementation of 3G rule outweighed the reopening
2021/06/10	Loosening of the person/m² rule in stores, later closing hour in gastronomy allowed.	🟢	
2021/07/01	Lifting of any closing hour limitation for gastronomy. In restaurants no mask mandate anymore for guests offside the tables.	🟢	
2021/07/22	Reopening of the clubbing scene (entrance either with a PCR test or after vaccination).	🟢	
2021/08/15	For vaccines which required 2 doses at that time: "Green Pass" only available after the second dose of that vaccine or after a confirmed convalescence + 1 vaccine.	🔴	
2021/09/12	Normal school reopening despite of the B.1.617.2 infection wave.	🟢	
2021/09/15	FFP2 mask mandate for all in stores of daily needs, In other stores: FFP2 mask mandate for unvaccinated. Validity of antigen tests reduced to 24hours.	🔴	
2021/10/29	Extension of the FFP2 mask mandate	🔴	
2021/11/01	Implementation of the 3G rule in workplaces.	🔴	

Figure 30: The dates of the breaks and anchor signs in the models for Upper Austria.

Measures in Salzburg

Date	What happened?	Overall Classification	Comment
2020/03/16	Full Lockdown	🔴	
2020/04/06	Implementation of mask mandate in stores.	🔴	
2020/04/14	Opening of smaller and DIY stores, extension of mask mandate to public transport.	🟢	Opening outweighed the mask mandate
2020/05/01	End of curfew rules.	○	Merged with 2020/05/02
2020/05/02	Full reopening of all stores and services like hairstylists etc..	🟢	
2020/05/04	Reopening of schools for high school seniors	○	Merged with 2020/05/04
2020/05/15	Reopening of restaurants	🟢	
2020/05/29	Full reopening of all schools	🟢	
2020/06/15	End of mask mandate	🟢	
2020/07/24	Partial return of the mask mandate	🔴	
2020/09/14	First tightening of mask mandate	🔴	
2020/09/21	Second tightening of mask mandate	🔴	
2020/10/17	Registration requirement in restaurants	🔴	
2020/11/03	Lockdown light (curfew rules, distance learning in senior highs and universities, closure of restaurants)	🔴	
2020/11/17	Full lockdown	🔴	
2020/12/07	Softening of some lockdown rules	🟢	
2020/12/24 2020/12/25	Christmas exception: Private gatherings with <10 ppl allowed w.o. any distance rules	🟢	
2020/12/26	Full lockdown	🔴	
2021/01/25	Nationwide FFP2 mask mandate	🔴	
2021/02/08	Softening of curfew rules, reopening of stores	🟢	
2021/02/15	Reopening of elementary schools, shift operation for junior- and senior highs	🟢	
2021/05/16	Complete lifting of curfew rules	○	Merged with 2021/05/17
2021/05/17	Reopening of all schools.	🟢	
2021/05/19	Requirement of the "3G"-rule for many activities Reopening of restaurants.	🔴	Implementation of 3G rule outweighed the reopening
2021/06/10	Loosening of the person/m² rule in stores, later closing hour in gastronomy allowed.	🟢	
2021/07/01	Lifting of any closing hour limitation for gastronomy. In restaurants no mask mandate anymore for guests offside the tables.	🟢	
2021/07/22	Reopening of the clubbing scene (entrance either with a PCR test or after vaccination).	🟢	
2021/08/15	For vaccines which required 2 doses at that time: "Green Pass" only available after the second dose of that vaccine or after a confirmed convalescence + 1 vaccine.	🔴	
2021/09/12	Normal school reopening despite of the B.1.617.2 infection wave.	🟢	
2021/09/15	FFP2 mask mandate for all in stores of daily needs, In other stores: FFP2 mask mandate for unvaccinated. Validity of antigen tests reduced to 24hours.	🔴	
2021/10/18	Extension of the FFP2 mask mandate	🔴	
2021/11/01	Implementation of the 3G rule in workplaces.	🔴	

Figure 31: The dates of the breaks and anchor signs in the models for Salzburg.

Measures in Styria

Date	What happened?	Overall Classification	Comment
2020/03/16	Full Lockdown		
2020/04/06	Implementation of mask mandate in stores.		
2020/04/14	Opening of smaller and DIY stores, extension of mask mandate to public transport.		Opening outweighed the mask mandate
2020/05/01	End of curfew rules.		Merged with 2020/05/02
2020/05/02	Full reopening of all stores and services like hairstylists etc..		
2020/05/04	Reopening of schools for high school seniors		Merged with 2020/05/04
2020/05/15	Reopening of restaurants		
2020/05/29	Full reopening of all schools		
2020/06/15	End of mask mandate		
2020/07/24	Partial return of the mask mandate		
2020/09/14	First tightening of mask mandate		
2020/09/21	Second tightening of mask mandate		
2020/11/03	Lockdown light (curfew rules, distance learning in senior highs and universities, closure of restaurants)		
2020/11/17	Full lockdown		
2020/12/07	Softening of some lockdown rules		
2020/12/24 2020/12/25	Christmas exception: Private gatherings with <10 ppl allowed w.o. any distance rules		
2020/12/26	Full lockdown		
2021/01/25	Nationwide FFP2 mask mandate		
2021/02/08	Softening of curfew rules, reopening of stores		
2021/02/15	Reopening of elementary schools, shift operation for junior- and senior highs		
2021/05/16	Complete lifting of curfew rules		Merged with 2021/05/17
2021/05/17	Reopening of all schools.		
2021/05/19	Requirement of the "3G"-rule for many activities Reopening of restaurants.		Implementation of 3G rule outweighed the reopening
2021/06/10	Loosening of the person/m² rule in stores, later closing hour in gastronomy allowed.		
2021/07/01	Lifting of any closing hour limitation for gastronomy. In restaurants no mask mandate anymore for guests offside the tables.		
2021/07/22	Reopening of the clubbing scene (entrance either with a PCR test or after vaccination).		
2021/08/15	For vaccines which required 2 doses at that time: "Green Pass" only available after the second dose of that vaccine or after a confirmed convalescence + 1 vaccine.		
2021/09/12	Normal school reopening despite of the B.1.617.2 infection wave.		
2021/09/15	FFP2 mask mandate for all in stores of daily needs, In other stores: FFP2 mask mandate for unvaccinated. Validity of antigen tests reduced to 24hours		
2021/11/01	Implementation of the 3G rule in workplaces		

Figure 32: The dates of the breaks and anchor signs in the models for Styria

Measures in Tyrol

Date	What happened?	Overall Classification	Comment
2020/03/16	Full Lockdown		
2020/04/06	Implementation of mask mandate in stores.		
2020/04/14	Opening of smaller and DIY stores, extension of mask mandate to public transport.		Opening outweighed the mask mandate
2020/05/01	End of curfew rules.		Merged with 2020/05/02
2020/05/02	Full reopening of all stores and services like hairstylists etc..		
2020/05/04	Reopening of schools for high school seniors		Merged with 2020/05/04
2020/05/15	Reopening of restaurants		
2020/05/29	Full reopening of all schools		
2020/06/15	End of mask mandate		
2020/07/24	Partial return of the mask mandate		
2020/09/14	First tightening of mask mandate		
2020/09/21	Second tightening of mask mandate		
2020/10/19	Registration requirement in restaurants		
2020/11/03	Lockdown light (curfew rules, distance learning in senior highs and universities, closure of restaurants)		
2020/11/17	Full lockdown		
2020/12/07	Softening of some lockdown rules		
2020/12/24 2020/12/25	Christmas exception: Private gatherings with <10 ppl allowed w.o. any distance rules		
2020/12/26	Full lockdown		
2021/01/25	Nationwide FFP2 mask mandate		
2021/02/08	Softening of curfew rules, reopening of stores		
2021/02/15	Reopening of elementary schools, shift operation for junior- and senior highs		
2021/05/16	Complete lifting of curfew rules		Merged with 2021/05/17
2021/05/17	Reopening of all schools.		
2021/05/19	Requirement of the "3G"-rule for many activities Reopening of restaurants.		Implementation of 3G rule outweighed the reopening
2021/06/10	Loosening of the person/m² rule in stores, later closing hour in gastronomy allowed.		
2021/07/01	Lifting of any closing hour limitation for gastronomy. In restaurants no mask mandate anymore for guests offside the tables.		
2021/07/22	Reopening of the clubbing scene (entrance either with a PCR test or after vaccination).		
2021/08/15	For vaccines which required 2 doses at that time: "Green Pass" only available after the second dose of that vaccine or after a confirmed convalescence + 1 vaccine.		
2021/09/12	Normal school reopening despite of the B.1.617.2 infection wave.		
2021/09/15	FFP2 mask mandate for all in stores of daily needs, In other stores: FFP2 mask mandate for unvaccinated. Validity of antigen tests reduced to 24hours		
2021/11/01	Implementation of the 3G rule in workplaces		

Figure 33: The dates of the breaks and anchor signs in the models for Tyrol.

Measures in Vorarlberg

Date	What happened?	Overall Classification	Comment
2020/03/16	Full Lockdown	🔴	
2020/04/06	Implementation of mask mandate in stores.	🔴	
2020/04/14	Opening of smaller and DIY stores, extension of mask mandate to public transport.	🟢	Opening outweighed the mask mandate
2020/05/01	End of curfew rules.	○	Merged with 2020/05/02
2020/05/02	Full reopening of all stores and services like hairstylists etc..	🟢	
2020/05/04	Reopening of schools for high school seniors	○	Merged with 2020/05/04
2020/05/15	Reopening of restaurants	🟢	
2020/05/29	Full reopening of all schools	🟢	
2020/06/15	End of mask mandate	🟢	
2020/07/24	Partial return of the mask mandate	🔴	
2020/09/14	First tightening of mask mandate	🔴	
2020/09/21	Second tightening of mask mandate	🔴	
2020/10/26	Registration requirement in restaurants	🔴	
2020/11/03	Lockdown light (curfew rules, distance learning in senior highs and universities, closure of restaurants)	🔴	
2020/11/17	Full lockdown	🔴	
2020/12/07	Softening of some lockdown rules	🟢	
2020/12/24 2020/12/25	Christmas exception: Private gatherings with <10 ppl allowed w.o. any distance rules	🟢	
2020/12/26	Full lockdown	🔴	
2021/01/25	Nationwide FFP2 mask mandate	🔴	
2021/02/08	Softening of curfew rules, reopening of stores	🟢	
2021/02/15	Reopening of elementary schools, shift operation for junior- and senior highs.	🟢	
2021/03/15	Reopening of restaurants, loosening of curfew rules.	🟢	
2021/05/16	Complete lifting of curfew rules	○	Merged with 2021/05/17
2021/05/17	Reopening of all schools.	🟢	
2021/05/19	Requirement of the “3G”-rule for many activities Reopening of hotels. Big events allowed again.	🔴	Implementation of 3G rule outweighed the reopening
2021/06/10	Loosening of the person/m² rule in stores, later closing hour in gastronomy allowed.	🟢	
2021/07/01	Lifting of any closing hour limitation for gastronomy. In restaurants no mask mandate anymore for guests offside the tables.	🟢	
2021/07/22	Reopening of the clubbing scene (entrance either with a PCR test or after vaccination).	🟢	
2021/08/15	For vaccines which required 2 doses at that time: “Green Pass” only available after the second dose of that vaccine or after a confirmed convalescence + 1 vaccine.	🔴	
2021/09/12	Normal school reopening despite of the B.1.617.2 infection wave.	🟢	
2021/09/15	FFP2 mask mandate for all in stores of daily needs, In other stores: FFP2 mask mandate for unvaccinated. Validity of antigen tests reduced to 24hours.	🔴	
2021/11/01	Implementation of the 3G rule in workplaces.	🔴	

Figure 34: The dates of the breaks and anchor signs in the models for Vorarlberg.

Measures in Vienna

Date	What happened?	Overall Classification	Comment
2020/03/16	Full Lockdown	🔴	
2020/04/06	Implementation of mask mandate in stores.	🔴	
2020/04/14	Opening of smaller and DIY stores, extension of mask mandate to public transport.	🟢	Opening outweighed the mask mandate
2020/05/01	End of curfew rules.	○	Merged with 2020/05/02
2020/05/02	Full reopening of all stores and services like hairstylists etc..	🟢	
2020/05/04	Reopening of schools for high school seniors	○	Merged with 2020/05/04
2020/05/15	Reopening of restaurants	🟢	
2020/05/29	Full reopening of all schools	🟢	
2020/06/15	End of mask mandate	🟢	
2020/07/24	Partial return of the mask mandate	🔴	
2020/09/14	First tightening of mask mandate	🔴	
2020/09/21	Second tightening of mask mandate	🔴	
2020/09/28	Registration requirement in restaurants	🔴	
2020/11/03	Lockdown light (curfew rules, distance learning in senior highs and universities, closure of restaurants)	🔴	
2020/11/17	Full lockdown	🔴	
2020/12/07	Softening of some lockdown rules	🟢	
2020/12/24 2020/12/25	Christmas exception: Private gatherings with <10 ppl allowed w.o. any distance rules	🟢	
2020/12/26	Full lockdown	🔴	
2021/01/25	Nationwide FFP2 mask mandate	🔴	
2021/02/08	Softening of curfew rules, reopening of stores and elementary schools, shift operation for junior- and senior highs	🟢	
2021/04/01	Full lockdown	🔴	
2021/04/26	reopening of elementary schools, shift operation for junior- and senior highs	🟢	
2021/05/03	Softening of curfew rules, reopening of stores (with the limitation of 1 person per 20 m²)	🟢	
2021/05/16	Complete lifting of curfew rules	○	Merged with 2021/05/17
2021/05/17	Reopening of all schools.	🟢	
2021/05/19	Requirement of the "3G"-rule for many activities Reopening of restaurants.	🔴	Implementation of 3G rule outweighed the reopening
2021/06/10	Loosening of the person/m² rule in stores, later closing hour in gastronomy allowed.	🟢	
2021/07/01	3G rule also implemented for children ≥ 6a, no self-tests allowed anymore for proof of "3G". Lifting of any closing hour limitation for gastronomy. In restaurants no mask mandate anymore for guests offside the tables.	🟢	The loosening of rules in the restaurant business outweighed the new rules regarding 3G.
2021/07/22	Reopening of the clubbing scene (entrance either with a PCR test or after vaccination).	🟢	
2021/08/15	For vaccines which required 2 doses at that time: "Green Pass" only available after the second dose of that vaccine or after a confirmed convalescence + 1 vaccine.	🔴	
2021/09/01	For everyone older than 12 years: shortening the timeframe of the validation of the test results from 72h to 48h (PCR) and 48h to 24h (antigen).	🔴	
2021/09/05	Normal school reopening despite of the B.1.617.2 infection wave.	🟢	
2021/09/15	FFP2 mask mandate for all in stores of daily needs, In other stores: FFP2 mask mandate for unvaccinated.	🔴	
2021/10/01	FFP2 mask mandate for everyone in all kinds of stores, no validity of antigen tests anymore, "2G" rule for clubbing scene.	🔴	
2021/11/01	Implementation of the 3G rule in workplaces.	🔴	

Figure 35: The dates of the breaks and anchor signs in the models for Vienna.

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