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COVID-19 Pandemic in Brazil: Institute for Health Metrics and Evaluation Projections and the Ensuing Evolution

Brief Title: IHME Projections

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IHME Projections

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Abstract

Objective: To describe IHME projections for the COVID-19 pandemic in Brazil and its states and discuss their accuracy and implications for different scenarios. **Methods:** We describe and estimate the accuracy of these predictions for Brazil by comparing them with the ensuing reported cumulative deaths. **Results:** The pandemic is projected to cause 192,511 deaths by December 1, 2020. Continued relaxation of mandated physical isolation despite rising deaths could cause >63,000 additional deaths, while rapid increase in mask use could reduce the projected death toll by ~25,000. Several states will likely be obliged to reinstitute mandated restrictions. Differences between IHME projections up to 6 weeks and recorded deaths ranged from -11% to 48% for Brazil. **Conclusion:** IHME short to medium term projections of deaths provide sufficiently accurate information to inform health planners, elected officials, and society. They suggest a prolonged pandemic course, with major mortality and probable necessity of renewed restrictions.

Keywords: COVID-19, transmission, forecasting, pandemics, Brazil

Introduction

The first known case of COVID-19 in Brazil, a disease caused by the SARS-CoV-2 virus, was reported on February 26, 2020, with the first death being announced on March 17 [1]. As of August 10, Brazil has presented the world´s second greatest total number of deaths and cases [2].

Continuously generated data and meaningful projections regarding the course of the pandemic under different control scenarios are fundamental to inform policy planning to contain the pandemic.

The Institute for Health Metrics and Evaluation (IHME), at the University of Washington, began publishing projections for COVID-19 on March 26, 2020, initial projections focusing on the United States. In May they expanded to include Brazil. Their estimate of projections consist of daily and accumulated deaths due to COVID-19; number of infections and tests performed; hospital capacity and hospital resource needs; and summaries on social mobility for the upcoming months [3].

Considering the potential usefulness of these IHME projections, our goal is to describe the methods and the content of the projections made so far. In addition, we aim to analyze the accuracy of the IHME projections by comparing them against statistics of ensuing cumulative deaths due to COVID-19 in Brazil as provided by the Ministry of Health.

Methods

The IHME starting on May 12, has now released several iterations its COVID-19 Projections (https://covid19.healthdata.org/brazil) for Brazil and its states [4,5].

The models use population size estimates obtained from WorldPop 2020 [6,7]. The numbers of daily and cumulative deaths are obtained from the Brazilian Ministry of

Health´s website (https://covid.saude.gov.br/) [1,4]. The numbers of cases and tests performed are obtained from national and state government websites, always being expressed as the average of the last 3 days to avoid fluctuations due to delays in reporting occurring on weekends and holidays [4]. Hospital capacity data are obtained from Brazilian government websites, Organization for Economic Co-operation and Development, WHO, and published studies [4,5].

The GBD Brazil Network, which is composed of Brazilian researchers affiliated with the IHME, and the central IHME team have sought measures of social distancing published by the state governments, focusing on decrees and ordinances published on state websites on a weekly basis [4]. These measures are classified using an adaptation of the New Zealand 4-Level Alert System [8]. Among the mandates evaluated are educational facilities ordered to close, non-essential companies ordered to close, people ordered to stay at home, and severe travel restrictions [8]. More recently, orders of partial restriction have also been included: mandates restricting any degree of agglomeration and any degree of business closure. Currently, only measures which apply to the entire population of the state are considered.

Mobility measures based upon anonymous data from cell phones, are obtained from Facebook and Google mobility for all states, and Apple mobility for some states [4]. Mask use is estimated based on periodic surveys of self-reported mask use outside the home based on the Facebook Global Symptom Survey [9].

The current model used by the IHME is a hybrid one that combines statistical modeling of the curves of cases and deaths with disease transmission modelling based on estimates of fractions of the population – in each location - who are susceptible to, exposed to, infected by and recovered from SARS-CoV-2 (SEIR model) [9].

For the projections of deaths, historical trends in the number of deaths are initially modeled. Correlations between increases in mobility and the use of masks with the disease transmission rate are then applied to adjust death projections, allowing variability in future transmission according to the degree of implementation of these measures [4]. Additional covariates in this modeling are population density, smoking prevalence, environmental pollution, altitude, and the annual pneumonia mortality rate, the latter used as an estimate of transmission seasonality [4,5,9].

To minimize the impact of inconsistent reporting on the number of deaths, published forecasts are based on the average of several iterations of projections and published with uncertainty intervals [4,5].

The current number of COVID-19 cases is then estimated backwards from mortality rates based on estimates of case fatality proportion. The case number is then applied in the disease transmission component of the hybrid model to generate projections of deaths and cases [4,5]. The projection of numbers of cases also takes into account the expected increase in scale of the tests, which is estimated based on the trends observed in the test data [4].

The need for hospital resources is estimated based on the resources available only to patients with COVID-19 [4,5].

Over the months, IHME has developed progressively sophisticated models. The first and second projection, released on May 12 and May 25 were based on the May 4 model and included eight and 19 Brazilian states, respectively. The third, of June 5, based on a new model of May 29, included all 26 states and the Federal District [9]. The fourth, on June 24, added sensitivity analyses in the projections.

The May 4 model was multi-stage and hybrid, and additionally allowed for the inclusion of data on the easing of social distance measures, increasing mobility, and

increased testing. The June 24 model added to the base projection alternative scenarios [4,9]. The base projection assumed the use of masks at rates reported at that date, the easing of social distancing mandates based on recent trends, and the reimplementation of restrictive decrees if the daily mortality rates reached 8 deaths/million. The first alternative scenario assumed no reimplementation of decrees. The second alternative scenario added to the base projection the universal use of masks when in public, with an increase in the percentage of use to 95% in 7 days [4,9].

We describe, using publicly available data, the evolution of IHME projections [9] of deaths per day and accumulated deaths due to COVID-19 for Brazil and four of its states. We present one state from each of the four Brazilian regions – North, Northeast, Southeast and South – which were evaluated in the first prediction. The states were chosen for having, among those present in the earliest predictions, the greatest number of estimated deaths among the reported states of their region. All projections are shown, except those of July 30, as they are quite similar to projections made immediately before (July 22) and soon afterwards (August 6).

To estimate the accuracy of IHME projections, we contrast graphically the estimates of deaths from projections against the ensuing number reported by the Ministry of Health (MS). We then produce error rates of the projections, for Brazil and the four states, comparing the estimated cumulative number of deaths two, four and six weeks beyond release with the ensuing cumulative death count reported by the Ministry of Health for the same periods.

Results

As of August 06, 2020, IHME has published nine projections for Brazil and its states. The May 12th projections estimated a total of 88,305 deaths in 8 states, and those

of May 25th a total of 125,833 deaths in 19 states through August 4th. Those of June 5th projected a total of 165,960 deaths for all states in Brazil through that date. The estimates of June 24th extended the estimates through to October 1st, projecting a total of 166,362 deaths. The July 7th, 14th and 22th projections extended the estimates to November 1st. The August 6 projection was extended to December 1, estimating a total of 192,511 deaths. The projected numbers of accumulated deaths by states and for Brazil are shown in the Supplementary Table.

The brown line in Figure 1 shows the base projection of August 6th of a total of 192,511 [Uncertainty interval (UI) 159,152- – 229,370] deaths. The rising red line demonstrates the increased deaths estimated to occur if social distancing measures are not reimplemented in the face of unfavorable trends, with a resultant total of 256,289 (UI 195,116 – 323,726) deaths. The green line shows the delay in deaths given a rapid increase in the use of masks. With mask use, the final total, 167,643 (UI 141,986 – 197,687) deaths, is reduced by 24,868 deaths.

Figure 2 shows the evolution of the mortality projections, by date, of the IHME accompanied by the official death numbers, in green, from the Ministry of Health. The top panel shows daily deaths, the bottom one, accumulated deaths. They both show good alignment of the projections with the ensuing reported deaths over the first month, most also showing good accuracy over a longer period. Note that the projections for more distant dates of the June 5th projection were revised downward in later projections.

The following figures similarly show the evolution of projections and deaths in four states. For the state of Amazonas (Figure 3), the initial projection of daily deaths (top panel) was quite accurate for two weeks, then overshot, that of June 5th also

overshot, and the remainder have followed well the curves of deaths reported the Ministry of Health.

The state of Paraná (Supplementary Figure 1), initially minimally affected by the pandemic, had an important uptick beginning in June. Initial projections were reasonably accurate over the first month, but later undershot. Later ones have tracked the ensuing curve of Ministry of Health data well, and have progressively decreased in total deaths predicted. That of August 6 predicts the peak of deaths in October.

For the state of Pernambuco (Supplementary Figure 2), initial predictions, especially the second, after tracking well initially, overshot ensuing Ministry of Health data. Most recent projections have tracked well over initial weeks, and then diverge. The most recent projection predicts a decrease until October, with a stable number, far from zero, thereafter.

São Paulo, Brazil´s most populous state, as shown in the Supplementary Table, has had the largest outbreak, in absolute numbers, to date. Figure 4 shows that almost all IHME estimates for São Paulo have overshot ensuing reality. The peak of daily deaths is now estimated to occur toward the end of August following new implementation of social distancing mandates.

Figure 5 shows the error of estimates at two, four and six weeks following their publication of IHME predictions of cumulative deaths. At 4 weeks, for Brazil, estimates varied across projections from 9% below to 32% above ensuing reported deaths; at 6 weeks from 6% below to 48% above. Projections for individual states are considerably less accurate. As can be seen qualitatively by the lesser degree of shading to the right, the accuracy of projections has generally improved over time.

Discussion

Among predictions of the pandemic´s future course with a focus on Brazil, the projections of the IHME stand out for their sophistication and detail. Following several iterations in methodology, the IHME currently offers multiple estimates for use. Their methodology goes beyond the more simple, traditional approaches describing infectious spread to include many additional factors. Among these are recent trends in deaths, multiple environmental factors which influence SARS-CoV-2 spread, and society´s responses to the pandemic threat. In comparisons with the ensuing reality for Brazil and its states, recent IHME models have performed reasonably well, and sufficiently so to guide short- and medium-term public policy. Particularly interesting to health officials are estimates of hospital bed needs and the three predicted paths to the future the models currently produce – the base estimate, the alternative estimate showing what would happen with continued relaxation of mandates and the additional one showing the benefit of rapidly increasing mask use.

Aside from the IHME, other national and international sources produce predictions of the pandemic´s future course in Brazil. Sites hosted at the Federal University of Minas Gerais (UFMG) (https://dest-ufmg.shinyapps.io/app_COVID19//), and the Federal University of Rio Grande do Sul (https://covid19.ufrgs.dev/tools/predictions) present short and long term forecasts. One hosted at the University of São Paulo (USP) applies a SEIR model to predict pressure on hospital resources for Brazil and its states (https://ciis.fmrp.usp.br/covid19/) [10–12]. Interestingly, the UFMG model available on August 10 predicts the epidemic extending well into 2021, with ~700 deaths/day at the beginning of 2021 and over 100 deaths/day continuing through July, 2021.

IHME Projections

In terms of international groups, of the Imperial College of London (https://covidsim.org/v2.20200806/?place=Brazil) predicts an important second wave for Brazil and other countries [13]. Youyang Gu (https://covid19-projections.com/brazil), using a machine learning approach, suggests that the daily peak of somewhat more than 1000 deaths/day in Brazil will continue through September, and slowly decline thereafter, with a total of 179,066 deaths having occurred by November 1st, quite similar to the approximately 180,368 deaths predicted to that date by the IHME [3,14]. The Los Alamos National Laboratory (https://covid-19.bsvgateway.org/), another group making projections for Brazil, has consistently undershot ensuing reality. It currently projects ~139,000 deaths to September 16, vs. ~154,000 of the IHME [15].

A comparison of errors in estimation of deaths due to COVID- 19 in Brazil made by IHME, Imperial College of London (ICL), Youyang Gu, Los Alamos National Lab, and Delphi, finding similar error among estimations, except for the ICL which presented major overestimations [9,16]. Comparison of the predictive validity of cumulative mortality of different international institutions indicated that IHME presented the smallest error for the Latin America and Caribbean super region [9,16]. One of main advantages of the IHME projections is their availability for Brazilian states.

The IHME approach is limited by the fact that their estimations of social distancing are done at the state level, when in fact, in many Brazilian states, different recommendations for different municipalities or regions are in place [17,18]. Another problem is that heterogeneity in underreporting of cases and deaths due to COVID-19 at the state level may introduce uncertainty into the projections [19]. A further one is that estimates of available hospital resources have frequently become outdated, not considering increases created in response to the pandemic, for example, through the establishment of temporary field hospitals. Additionally, models may not adequately

consider the impact of social determinants – the extensive inequality in Brazilian society and the impossibility of many Brazilians, given living conditions, to apply social distancing [20,21].

As shown by the figures we present, predictions were more accurate for Brazil as a nation than for individual states. The quality of projections has varied, the projections of June 5th being notable overestimates, particularly for Paraná and São Paulo. Shortly after these projections, IHME implemented a new model which considered several additional factors, including predicted changes in social distancing and mask use. This new model produced a considerable decrease in base projection estimates. However, as seen in Figure 5, predictions of deaths have very frequently been overestimates, with some states being considerably overestimated at times.

The utility of IHME findings is facilitated by the ready availability of easily interpretable charts and the continued updating of methods which both incorporate changes in estimated social mobility and new findings of the underlying causes of the rate of propagation. An example of the latter was the rapid incorporation of estimates of seasonality into estimates, leading, for example, to predictions, so far accurate, of greater propagation and rising numbers of events during winter in Brazil´s southern states.

When interpreting estimated deaths due to COVID-19 epidemic, one needs to consider that these death rates in Brazil, as in countries around the world, have been underestimated, as testing has been far from universal, especially for non-hospital deaths [19,22]. Brazil stands out, among the world´s countries, in terms of the low rate of testing done to date. Underreporting can be estimated comparing the number of deaths reported through civil registration during the pandemic with the expected number based on the average of the previous five years. By this comparison, reported deaths attributed

to COVID-19 up to June 20, 2020 represent only two-thirds of the estimated 74,172 excess deaths to that date [23].

As IHME projected deaths aim to track official death counts, to the extent these underreport deaths, IHME predictions of deaths in Brazil will also be underestimated. Confirmed case rates in official statistics, given not only limited testing but also the fact that many asymptomatic or very mild cases never come to medical attention, grossly underestimate true cases. The most recent nationally representative seroprevalence study suggests that for every case officially reported through testing, five go undetected [24,25]. IHME estimates of prevalent cases, however, are less affected by this problem as they are calculated indirectly based on deaths and case fatality ratios.

Important findings arise from the projections. One involves mask use. Initially, the World Health Organization did not recommend mask use, based on a lack of data showing airborne coronavirus transmission outside of health care settings and on the concern that the limited surgical mask and respirator supply was best reserved for health care professionals, who were clearly at risk. However, over the ensuing months, evidence has come forth that mask use is particularly important [26,27], and that cloth masks, as used extensively in Asian countries having success in containing their epidemics, may play a large role by avoiding greater transmission, especially from those without symptoms [28]. The IHME projections, which suggest that mask use by 95% of the population could prevent over 25,000 pandemic deaths in Brazil by December 1st, permit an estimate of the magnitude of the benefit of greater mask use. Additionally, according to an IHME summary of mask use around the world, mask use in Brazil, and Latin America in general, has been high vis-à-vis its use in the United States and many European countries [9].

A second finding of the IHME projections is the predicted difficulty in controlling the pandemic and the resultant probable need for reimplementation of restrictions in several states in coming months. Though this reimplementation is not shown at the national level (Figure 1), it can be seen for Brazilian states in IHME website predictions (http://covid19.healthdata.org) by the sudden departure in base projection daily death and case rates from those of the alternative scenario of no new mandates [3]. These points represent the effect of newly reinstated restrictions resulting from the expanding pandemic and imminent risk of health system collapse.

A third finding is derived from IHME´s and others´ predictions over the longer range. Though considerably less reliable longer term estimates of multiple institutions, taken as a whole, are sobering. They suggest that the pandemic will follow a prolonged course in Brazil. Most recent IHME estimates suggest that through to the beginning of December, a total of nearly 193,000 deaths will have accumulated in Brazil, nearly double the total in early August. Approximately 350 deaths/day will still be occurring, compared to the rate of somewhat more than 1,000 deaths/day in early August. Additionally, many of the hardest hit Brazilian states will still have hospitals full of patients with severe complications. Game-changing events be they positive – rapid dissemination of proven effective therapy or a vaccine – or negative – viral mutations leading to a new strain with greater infectivity or virulence – are possible. Yet, barring unforeseen positive changes, the implication of current projections is that Brazil will face a long struggle to overcome the pandemic.

Finally, the false dichotomy between protecting health and protecting the economy is highlighted by the projections. Comparison of the economic perspective of Brazil vis-a-vis that of other societies, including Canada, many in Western Europe, and especially New Zealand and several Asian countries which have been better able to

control the virus [3] demonstrates that, given current options, actions which have produced major economic harm in the short term have been essential for longer term economic health. To the extent that Brazilian leaders and society can come to grasp with the necessity at times of strong social measures to contain the virus, both health and the economy will benefit not only over the short term, but also over the medium and long term.

Limitations of our evaluation merit note. As mentioned above, problems in underlying official data on cases and deaths limit our ability to compare IHME predictions with the ensuing reality. Additionally, we cannot compare the accuracy of IHME projections with those done by Brazilian institutions, as the latter do not include a publicly available backlog of previous estimates.

In conclusion, we have presented the underlying methodology of IHME COVID-19 projections and resultant major predictions for Brazil. Evaluation of the accuracy of these predictions over a span of 2 to 6 weeks demonstrates the validity of the robust methodology that the IHME has brought to this task. The greater error rates over longer periods show the necessity of frequent updates in predictions. We hope that greater awareness of these projections of COVID-19 deaths and cases will lead to greater use of this tool among Brazilian decision makers and society in general.

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Author Contributions

CS and BBD designed the study and drafted the manuscript. CS and EC performed the analyses. All authors reviewed and approved the manuscript.

Conflict of interest

None of the authors have conflicting interests with regard to this manuscript.

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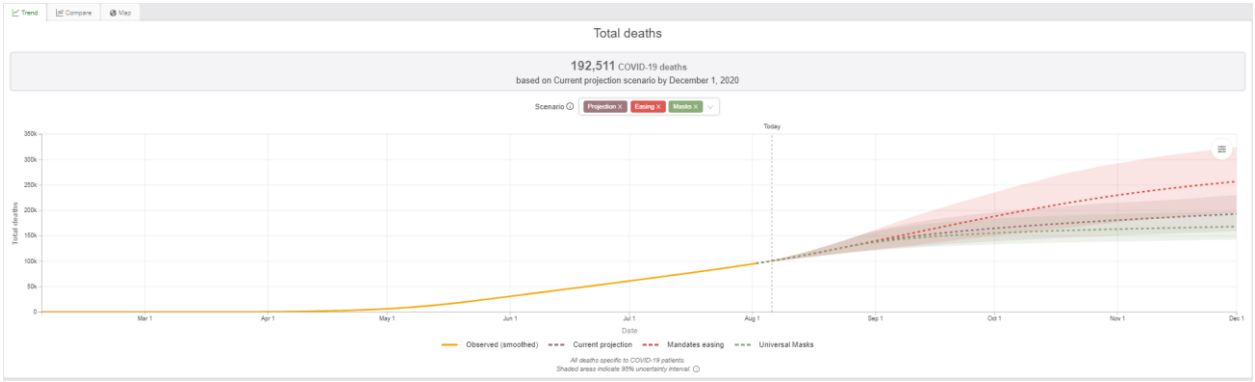


Figure 1. Current IHME projection (08/06/20), considering three scenarios, the base projection, the projection without reimplantation of social distancing measures and the projection considering universal use of masks.

IHME Projections

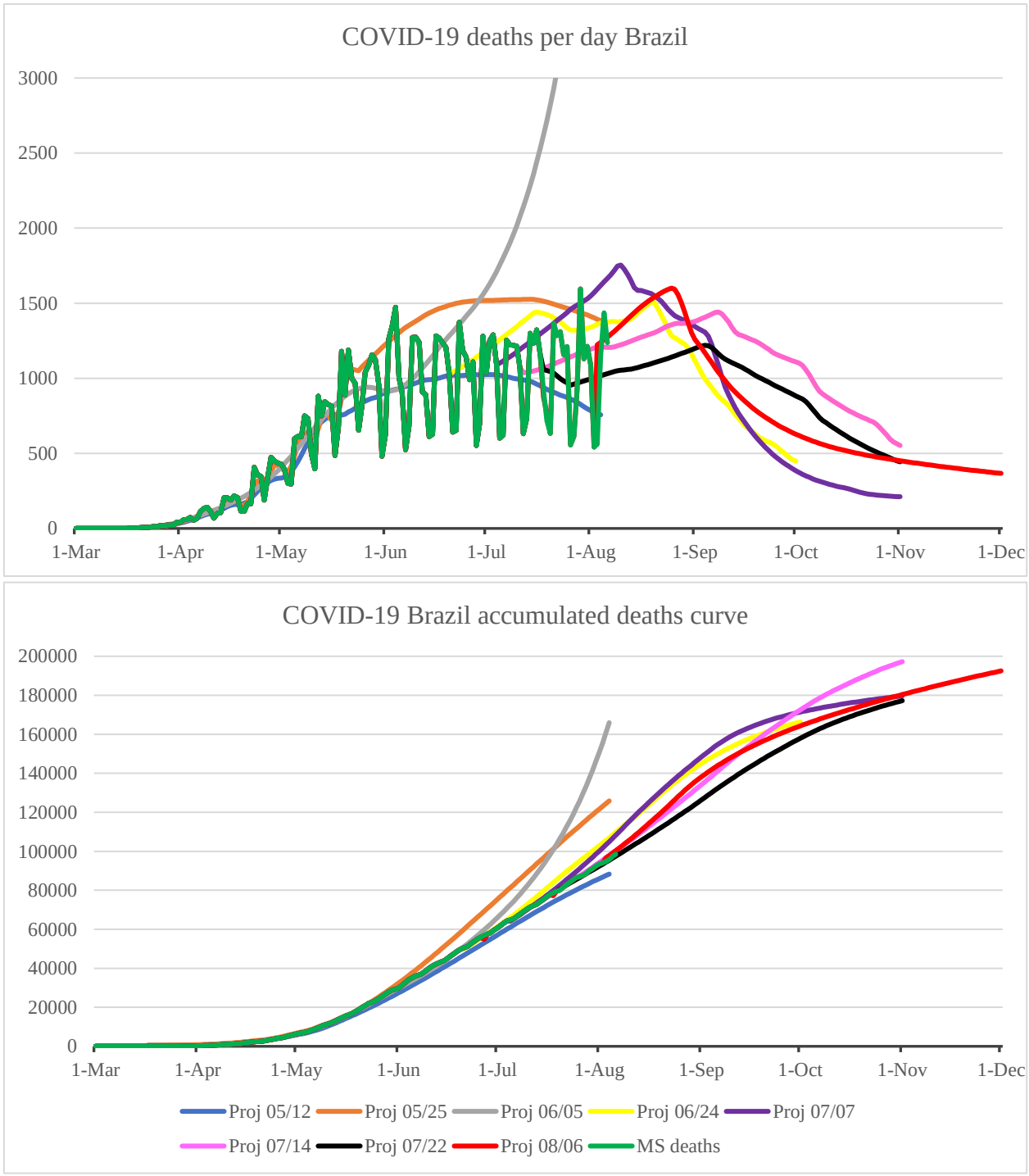


Figure 2. IHME projections and data from the Ministry of Health (MS) for daily (top) and accumulated (bottom) deaths due to COVID-19 in Brazil.

IHME Projections

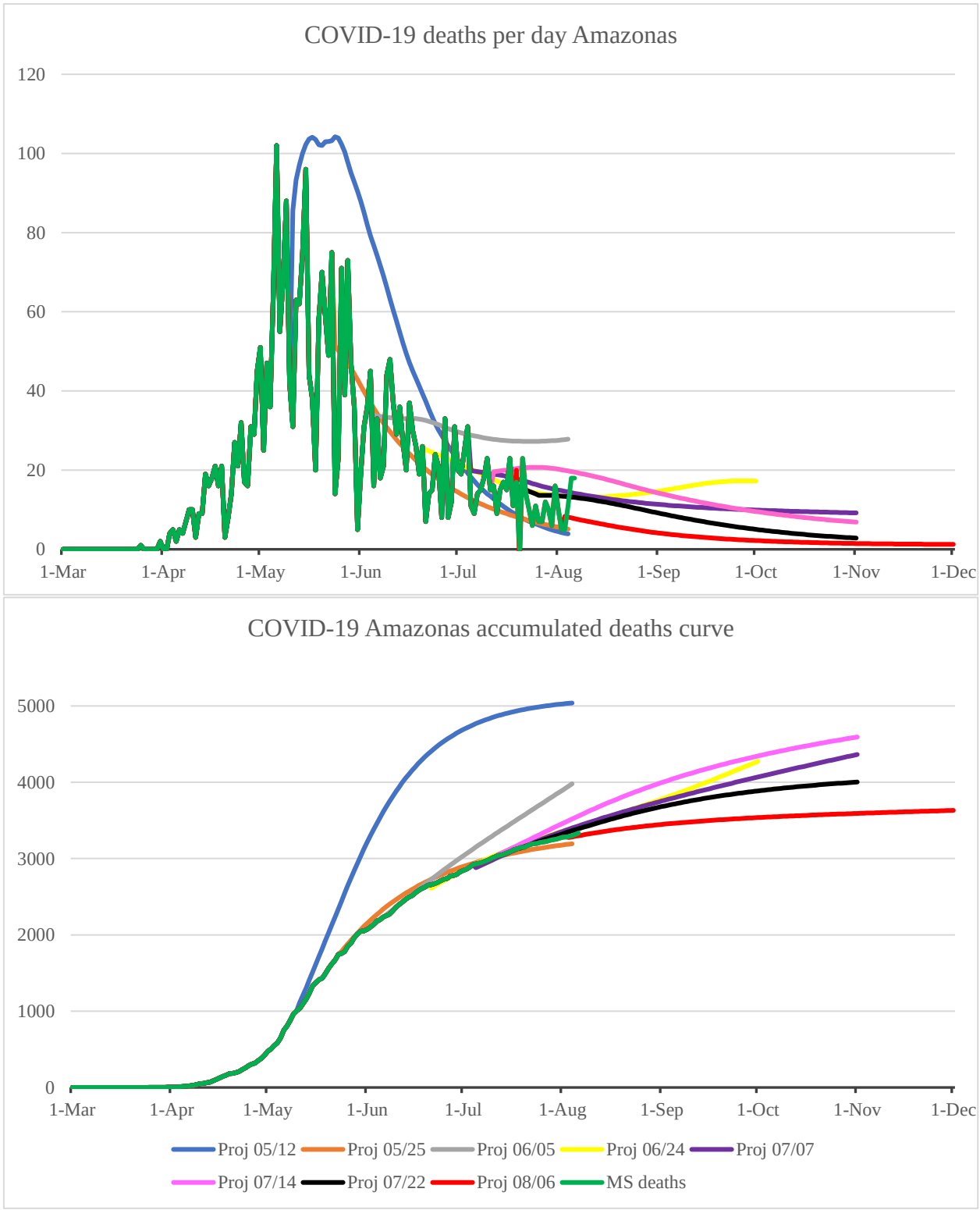


Figure 3. IHME projections and data from the Ministry of Health for daily (top) and accumulated (bottom) deaths due to COVID-19 in Amazonas.

IHME Projections

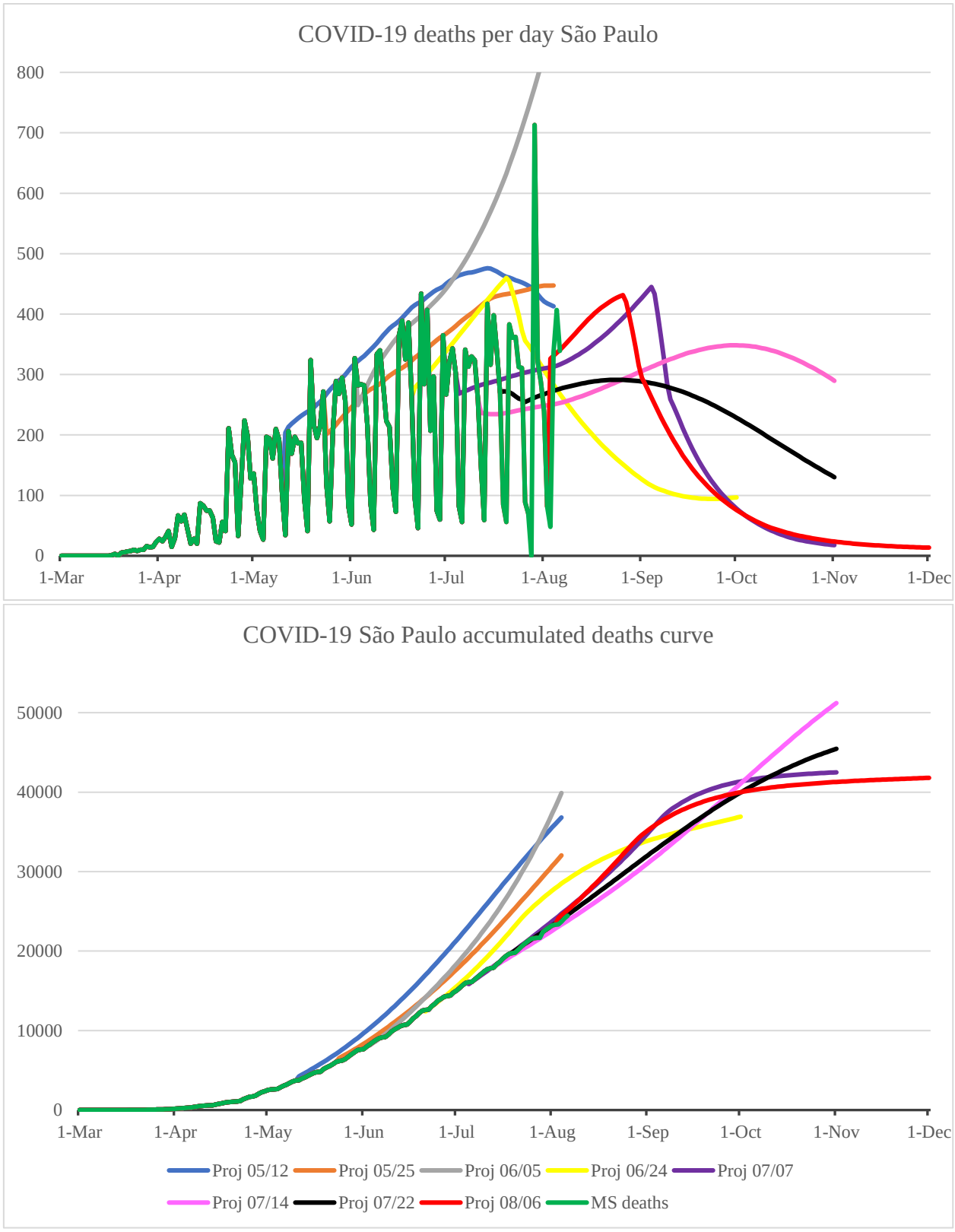


Figure 4. IHME projections and data from the Ministry of Health for daily (top) and accumulated (bottom) deaths due to COVID-19 in São Paulo state.

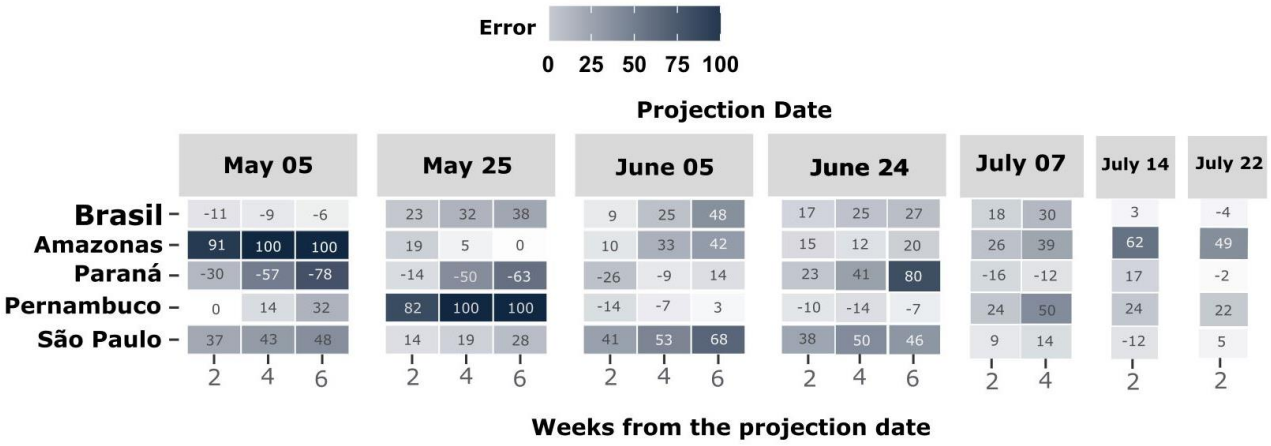


Figure 5. Percent error in estimation comparing IHME estimated cumulative deaths at two, four and six weeks beyond the date of the projection with the cumulative number of deaths reported by the Ministry of Health over the same period. A darker color indicates a greater degree of error.

IHME Projections

Supplementary Materials

Supplementary Table.

Table 1. Progressive projections of accumulated deaths due to COVID-19 for Brazil and its states, as estimated by IHME from May 12 to August 06, 2020.

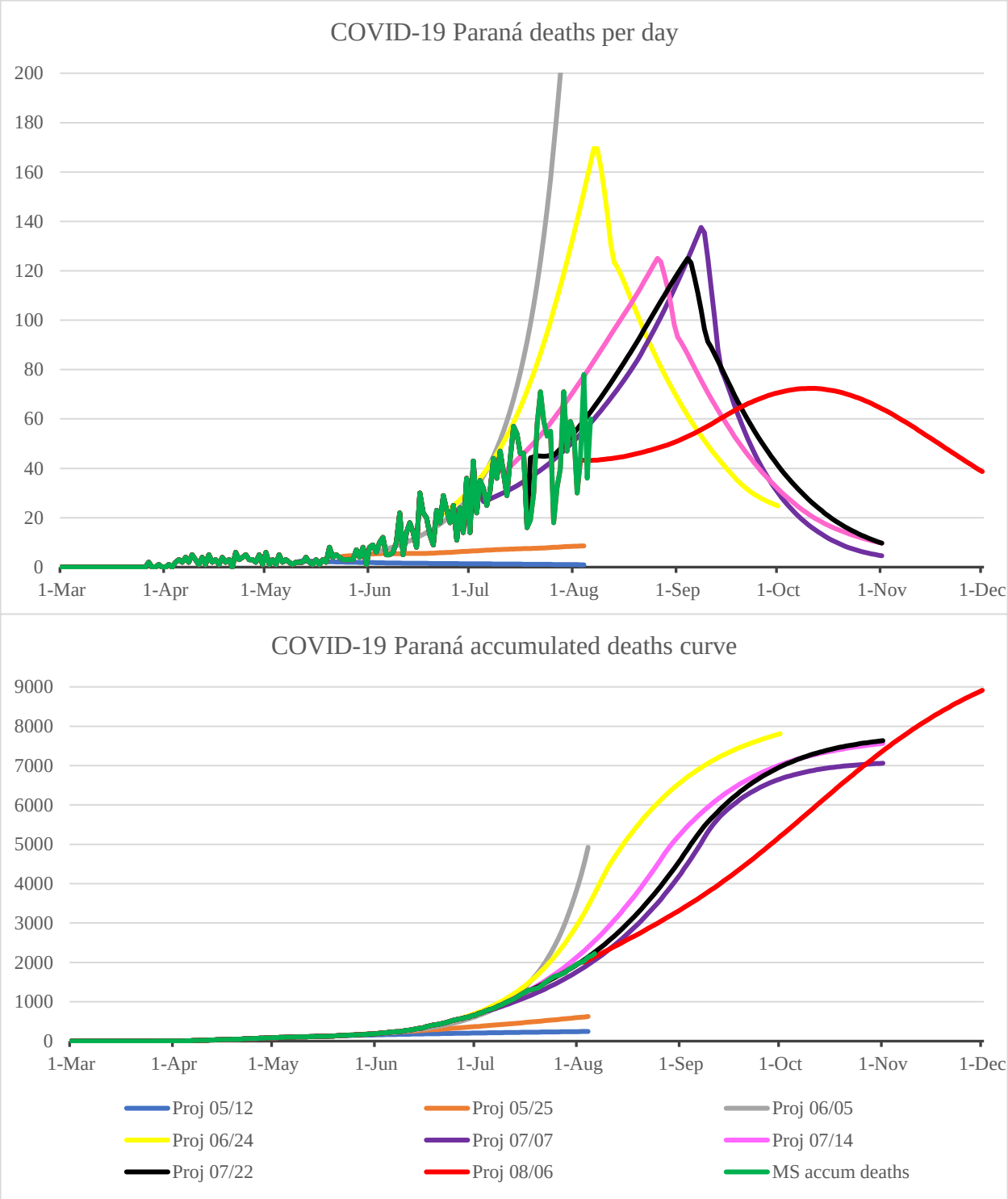
State	Projection 1 (May 12) Up to August 4	Projection 3 (June 5) Up to August 4	Projection 5 (July 7) Up to Nov 1	Projection 7 (July 22) Up to Nov 1	Projection 9 (August 06) Up to Dec 1
Brazil	88305 (30302 - 193786)	165960 (113673 - 253131)	179703 (155069 - 208623)	177235(81623 - 233449)	192511(159153 - 229371)
Acre	-	585 (329 - 1204)	1070 (808 - 1386)	808(468 - 1130)	1045(745 - 1378)
Alagoas	-	5704 (2984 - 9515)	3678 (3035 - 4669)	2497(1430 - 3168)	3040(2331 - 3905)
Amapá	-	804 (599 - 1125)	938 (661 - 1273)	770(511 - 977)	783(630 - 1091)
Amazonas	5039 (1859 - 9383)	3980 (3445 - 4778)	4364 (3723 - 5334)	4003(3160 - 4939)	3631(3460 - 3875)
Bahia	2443 (529 - 8429)	12076 (5049 - 28561)	9675 (5793 - 16449)	8852(2930 - 14463)	13551(9005 - 20809)
Ceará	8679 (2894 - 18593)	12931 (8763 - 19338)	9467 (7543 - 13510)	9879(7362 - 13595)	10710(8711 - 15474)
Distrito Federal	-	2479 (1119 - 5403)	2038 (1479 - 2777)	2452(1161 - 3391)	3187(2529 - 4083)
Espírito Santo	-	7489 (4084 - 12573)	3490 (2831 - 4293)	4261(2242 - 5777)	4617(3630 - 5645)
Goiás	-	3840 (1025 - 11942)	4460 (2148 - 8251)	5132(1086 - 11055)	7406(3088 - 17006)
Maranhão	4613 (868 - 12661)	5544 (3369 - 10106)	4874 (4132 - 5830)	4233(2732 - 5422)	4024(3568 - 4623)
Mato Grosso	-	1702 (442 - 5162)	2213 (1706 - 2865)	2937(1388 - 4300)	3417(2795 - 4319)
Mato Grosso do Sul	-	120 (33 - 595)	1770 (477 - 4554)	1617(235 - 3942)	1563(863 - 3422)
Minas Gerais	-	5968 (2155 - 16757)	16439 (8837 - 29040)	13326(2058 - 32366)	14201(6916 - 26461)
Pará	-	6762 (5002 - 9310)	6927 (5990 - 8275)	6984(5491 - 8583)	6748(5968 - 8764)
Paraíba	-	4818 (1885 - 12579)	3314 (2234 - 4997)	4255(1529 - 6878)	4763(2852 - 7645)
Paraná	245 (170 - 397)	4923 (1817 - 12565)	7060 (3323 - 12959)	7634(1409 - 14762)	8912(4234 - 15159)
Pernambuco	9401 (2468 - 23027)	8025 (5965 - 11609)	9028 (7538 - 11313)	10545(6135 - 14198)	11536(9402 - 14751)
Piauí	-	898 (522 - 1748)	2245 (1771 - 2851)	2792(1140 - 4840)	2349(1892 - 2950)
Rio Grande do Norte	-	1570 (941 - 2856)	4648 (1593 - 11432)	2136(1544 - 3171)	3056(2056 - 6074)
Rio Grande do Sul	-	3990 (1372 - 11101)	8877 (4440 - 15795)	8395(1297 - 17135)	8764(3855 - 23193)
Rio de Janeiro	21073 (5966 - 51901)	20791 (13541 - 33143)	21134 (15600 - 29928)	18479(12168 - 25425)	22314(16565 - 36585)
Rondônia	-	1807 (925 - 3134)	966 (749 - 1288)	1568(732 - 2706)	1736(1070 - 3270)
Roraima	-	952 (575 - 1356)	910 (556 - 1328)	502(417 - 710)	834(664 - 1068)
Santa Catarina	-	6140 (1794 - 16108)	4634 (1724 - 9688)	4769(676 - 10982)	4891(2839 - 7762)

IHME Projections

São Paulo	36811 (11097 - 81774)	39888 (26995 - 61309)	42488 (29182 - 62655)	45454(20256 - 69224)	41797(30284 - 57837)
Sergipe	-	1309 (530 - 3682)	2177 (1483 - 3087)	1915(1201 - 2443)	2362(2008 - 2963)
Tocantins	-	864 (319 - 2190)	818 (409 - 1597)	1043(305 - 1915)	1275(793 - 1883)

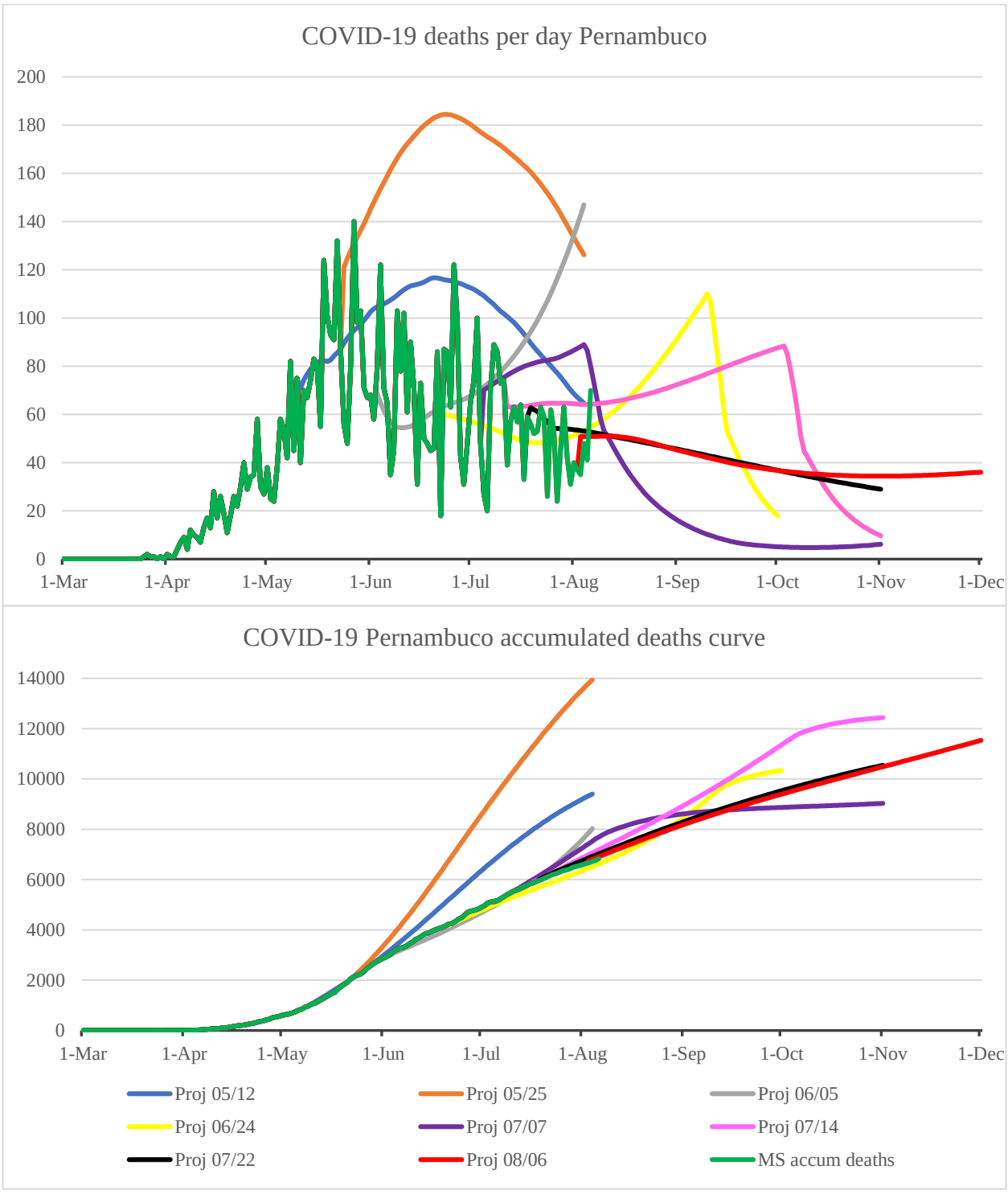
IHME Projections

Supplementary Figure



Supplementary Figure 1. IHME projections and data from the Ministry of Health for daily (top) and accumulated (bottom) deaths due to COVID-19 in Paraná.

IHME Projections



Supplementary Figure 2. IHME projections and data from the Ministry of Health for daily (top) and accumulated (bottom) deaths due to COVID-19 in Pernambuco.