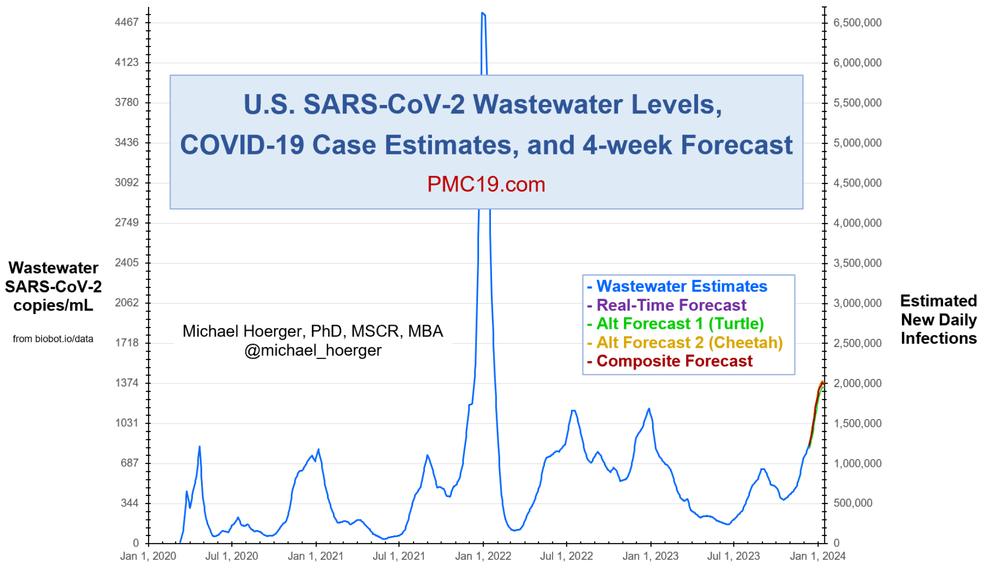
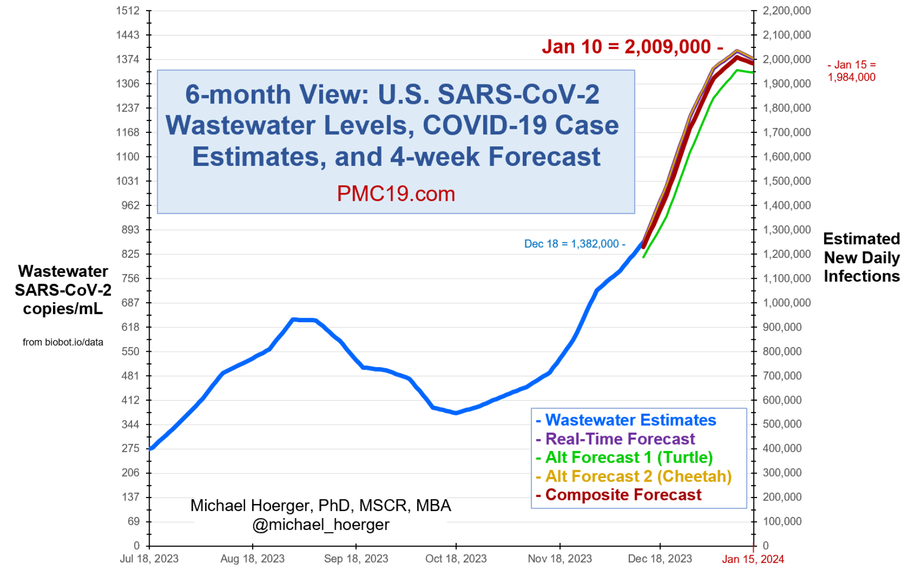
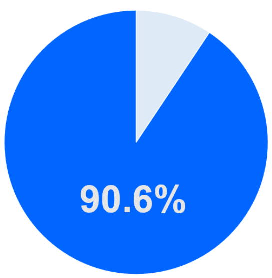
Michael Hoerger, PhD, MSCR, MBA, Pandemic Mitigation Collaborative

U.S. SARS-CoV-2 Wastewater Levels, COVID-19 Case Estimates, and 4-Week Forecast: Report for December 18, 2023, pmc19.com/data







There is more COVID-19 transmission today than during 90.6% of the pandemic.

CURRENT ESTIMATES FOR December 18, 2023
Wastewater Levels (copies/mL)
950
New Daily Cases
1,382,000
% of Population Infectious
2.89% (1 in 35 people)
New Daily Long COVID Cases
69,000 to 276,000

WEEKLY ESTIMATES FOR December 18, 2023
New Weekly Cases
9,700,000
New Weekly Long COVID Cases
484,000 to 1,935,000

2023 CUMULATIVE ESTIMATES AS OF December 18, 2023
Total 2023 Cases To Date
230,778,870
Total 2023 Long COVID Cases To Date
11,539,000 to 46,156,000

4-WEEK FORECAST FOR January 15, 2024
Wastewater Levels (copies/mL)
1,363 (44% higher)
New Daily Cases
1,984,000
% of Population Infectious
4.15% (1 in 24 people)
New Daily Long COVID Cases
99,000 to 397,000

How Does Risk Increase with More Social Contacts?

Number of People	Chances Anyone is Infectious	Number of People	Chances Anyone is Infectious
1	2.9%	25	52.0%
2	5.7%	30	58.5%
3	8.4%	35	64.2%
4	11.1%	40	69.1%
5	13.6%	50	76.9%
6	16.1%	75	88.9%
7	18.6%	100	94.7%
8	20.9%	150	98.8%
9	23.2%	200	99.7%
10	25.4%	300	>99.9%
15	35.6%	400	>99.9%
20	44.4%	500	>99.9%

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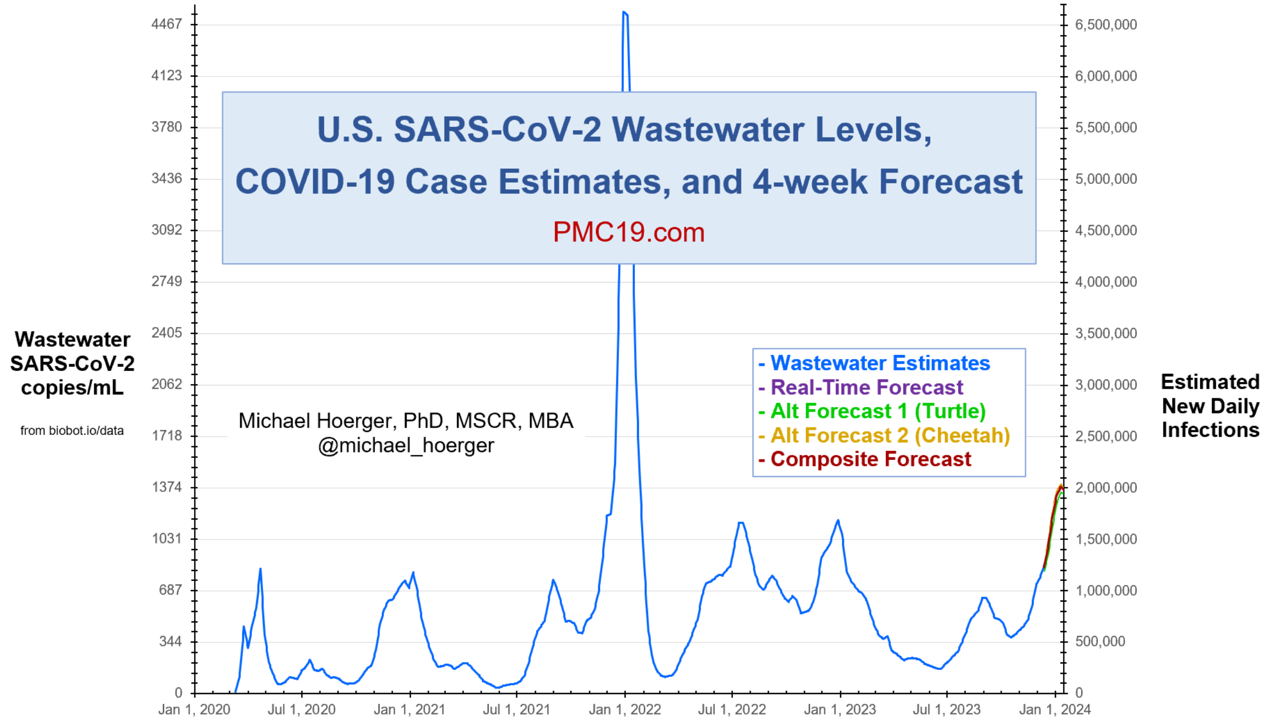
General Commentary

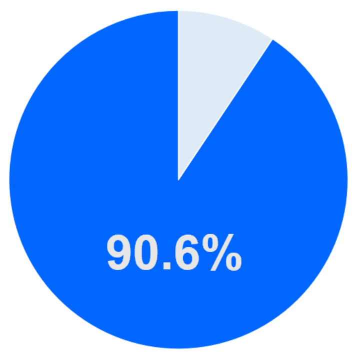
We are in the 8th U.S. COVID wave. The wave has surpassed the 7th wave we saw in the late summer. We are potentially heading toward the 2nd to 4th largest COVID wave of all time, rivaling that of last winter, potentially larger.

U.S. wastewater levels indicate that COVID transmission is higher than during 90% of the days of the pandemic and lower than during 10% of the days of the pandemic.

- 2.89% (1 in 35) are infectious
- >1.3 million COVID cases/day
- >69,000 #LongCovid cases/day

Weekly new cases stand at 9.7 million. Weekly long COVID cases resulting from these infections stand at >400,000.





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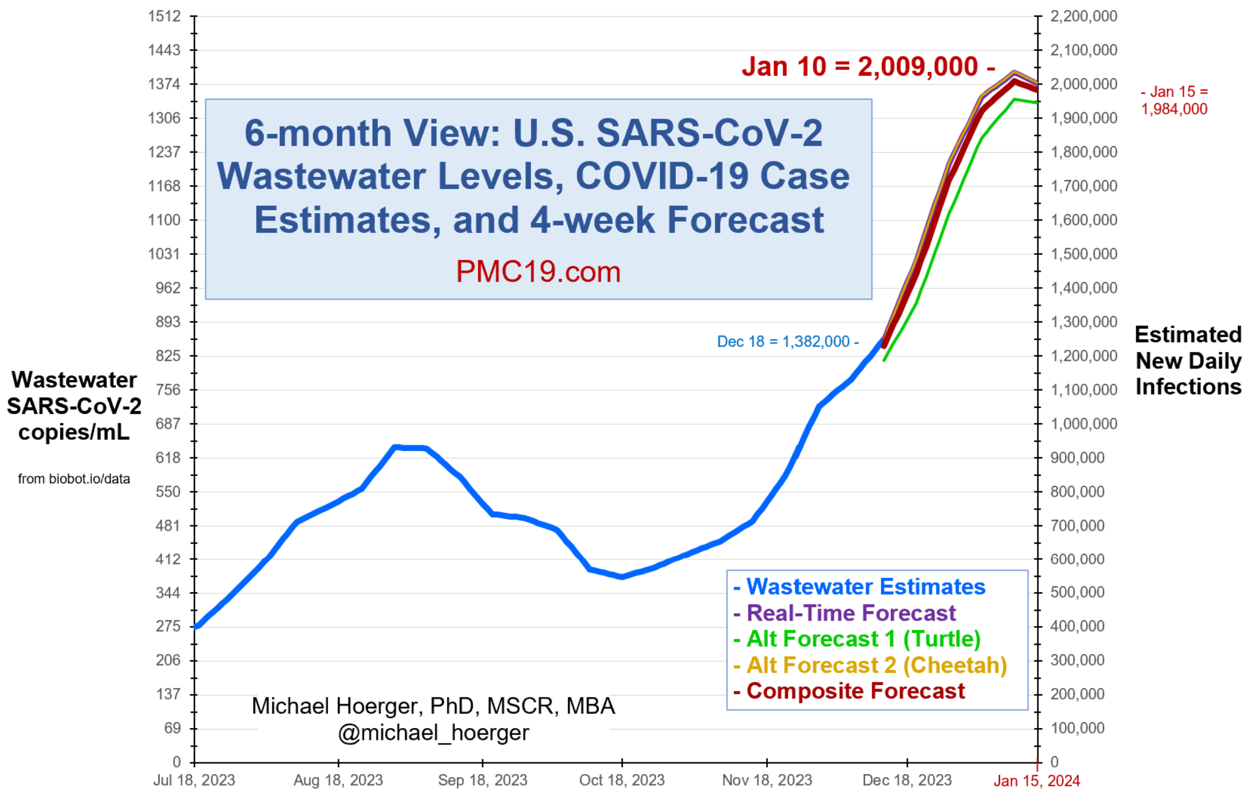
Forecast for the Next Month

The forecast indicates that we are continuing toward the peak of a surge that may be the 4th to 2nd largest all-time. The different forecasting models now show a high level of convergence. At peak, we may see 2 million U.S. infections/day with 4.2% of the population (1 in 24 people) actively infectious around January 10. The specific day of the peak will be unknowable even in hindsight (different data sources, some with weekly versus more frequent reporting), but a reasonable approximation would be around January 10th.



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U.S. Winter 2023-24 COVID Surge

	Best Estimate	Range	
Rank among COVID waves	2nd	2nd	4th
Date of peak	Jan 10	Jan 3	Jan 17
Daily infections at peak	2.0 million/day	1.7 million/day	2.2 million/day
Percentage of population infectious at peak	4.2% (1 in 24)	3.7% (1 in 27)	4.6% (1 in 22)

The differences across the four forecasting models are marginal. The real-time forecast (barely visible purple line behind orange line) anticipates a peak at >2 million daily infections. The cheetah model (orange) corrects the real-time model for over/under-reporting in last week's real-time Biobot data, but there was almost no error, so the model is virtually identical to the real-time model. The turtle model (green) ignores the most recent week's real-time data as a potential aberration and is a bit more conservative than the other models because transmission is accelerating marginally faster than anticipated. The composite model (red) is the average of all three. These differences are not particularly important.

More importantly, consider optimistic and pessimistic scenarios not captured by these models. A rosy scenario would be that the peak occurs a week earlier at a slightly lower level (1.6-1.7 infections/day like last winter or the preceding summer). The level of acceleration in transmission argues against that, in favor of a higher peak, but Biobot is reporting some unusual regional variation (much lower transmission in the U.S. South and West). Moreover, historical patterns of how transmission should or should not accelerate cannot account for existing variation on population-level immunity due to variation in prior exposure history, recency of vaccination, and how well the current vaccine matches disseminating subvariants relative to prior vaccines. Finally, Biobot wastewater sites could be overreporting, and levels could get corrected downward. Each of these factors is highly plausible, but the "rosy" scenario remains quite bleak and suggests the pandemic remains far from "over."

Also, consider more pessimistic scenarios. Current vaccination rates remain extremely low, and several other countries are reporting atypically high acceleration via wastewater data. Placing plausible hypothetical values in the model, it is difficult to imagine a scenario where the U.S. reaches 2.5 million infections/day. Sometimes, people draw graphs showing a continued acceleration like BA.1, but such models seem to reflect imagination rather than data. The data do not suggest an evidence for a BA.1-level surge.

Current Risk Based on Number of Social Contacts

The office and classroom risks remain quite bad. In a group of 10 people (daycare, team meeting, etc.), there's a 25% chance someone will have infectious COVID. In a group of 20-30 people (e.g., K-12 classroom, department meeting, busy hospital waiting room, etc.), there's about a 50% chance someone has infectious COVID. This is quite troubling for people who spend time with multiple large groups each week.

How Does Risk Increase with More Social Contacts?

Number of People	Chances Anyone is Infectious	Number of People	Chances Anyone is Infectious
1	2.9%	25	52.0%
2	5.7%	30	58.5%
3	8.4%	35	64.2%
4	11.1%	40	69.1%
5	13.6%	50	76.9%
6	16.1%	75	88.9%
7	18.6%	100	94.7%
8	20.9%	150	98.8%
9	23.2%	200	99.7%
10	25.4%	300	>99.9%
15	35.6%	400	>99.9%
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Not all meetings are the same. Virtual meetings reduce risk close to zero. Outdoor meetings are often safer than indoors. Testing reduces risk, as do policies that encourage people to stay home when symptomatic. High-quality, well-fitting masks greatly reduce risk. Air quality monitoring and improved air cleaning reduce risk. Recent boosters reduce risk. It remains troubling that elected leaders and public health officials choose to model poor mitigation when ongoing risk is so high.

It should be noted that transmission will be high the next month because a lot of the places that are inherently most risky based on the density of occupants (schools, transportation, homes, restaurants) often have the poorest indoor air cleaning. As an example, take schools. Most schools clean the air at 0.8 to 3.0 air changes per hour, substantially lower than ASHRAE 2023 Standard 241. Most school settings should have 6.7 to 9.3 air changes per hour, and sometimes much higher in large densely packed settings. We will see a lot of "mixing" of people across these different high-risk settings who then come together for holiday gatherings, seed the spread of infection, and then mix among each other again in early to mid January.

The CDC has recently approved an updated booster, available to anyone in the U.S. older than 6 months. It is becoming widely available for adults, and now increasingly available for children. Utilization rates remain abysmally low. Use the PMC data and local vaccination location information to help people get vaccinated.

Simplified Recommendations for Classroom Air Cleaning to Reduce the Risk of Far-Field Airborne Infectious Disease Transmission, Derived from ASHRAE Standards 241 & 62.1

- Mike Hoerger, PhD, MSCR, MBA (Aug 1, 2023)

Educational Facilities	cfm/person (ft^3 / minute per person)	ACH (air changes per hour) for Full-Capacity Rooms
Libraries	40	2.7
Art classroom	40	5.3
Wood and metal shop	40	5.3
Computer lab	40	6.7
Media center	40	6.7
Science labs	40	6.7
University and college labs	40	6.7
Daycare, ages 4 and under	40	6.7
Classroom, ages 5-8	40	6.7
Classroom, ages 9+	40	9.3
Music, theater, and dance	40	9.3
Lecture classroom	40	17.3
Multiuse assembly	40	26.7
Lecture hall, fixed seats	50	50.0

Note. cfm/person based on ASHRAE Standard 241. ACH derived from typical full-capacity person density estimates from ASHRAE Standard 62.1. Use the most comparable educational facility. If half or one-quarter capacity, prorate the ACH estimate accordingly. Calculations focus on reducing risk primarily of far-field transmission in rooms with well-mixed air, and masks remain needed to avoid near-field transmission.

Forecast for Christmas

With Christmas Day a week out, the model has precise estimates for the holiday. Based on forecasted transmission on Christmas day, this figure shows the chance anyone would be infectious in a group based on group size. If seeing 10 people for Christmas, there's a 30% chance anyone would be infectious. In a group of 20 (or two family gatherings totaling 20), it's a coin toss whether someone will be infectious. If going to a packed restaurant or traveling on a plane with 100 other people, assume 97% chance someone there may be infectious. These estimates are similar to those suggested over the past several weeks, so hopefully they have been helpful in planning.

In the U.S., What's the COVID Risk for Christmas Day?

Number of People	Chances Anyone is Infectious	Number of People	Chances Anyone is Infectious
1	3.4%	25	58.2%
2	6.7%	30	64.9%
3	9.9%	35	70.5%
4	13.0%	40	75.3%
5	16.0%	50	82.6%
6	18.9%	75	92.7%
7	21.7%	100	97.0%
8	24.4%	150	99.5%
9	27.0%	200	99.9%
10	29.5%	300	>99.9%
15	40.8%	400	>99.9%
20	50.3%	500	>99.9%

@michael_hoerger Estimated December 18, 2023

Forecast for New Year's Day

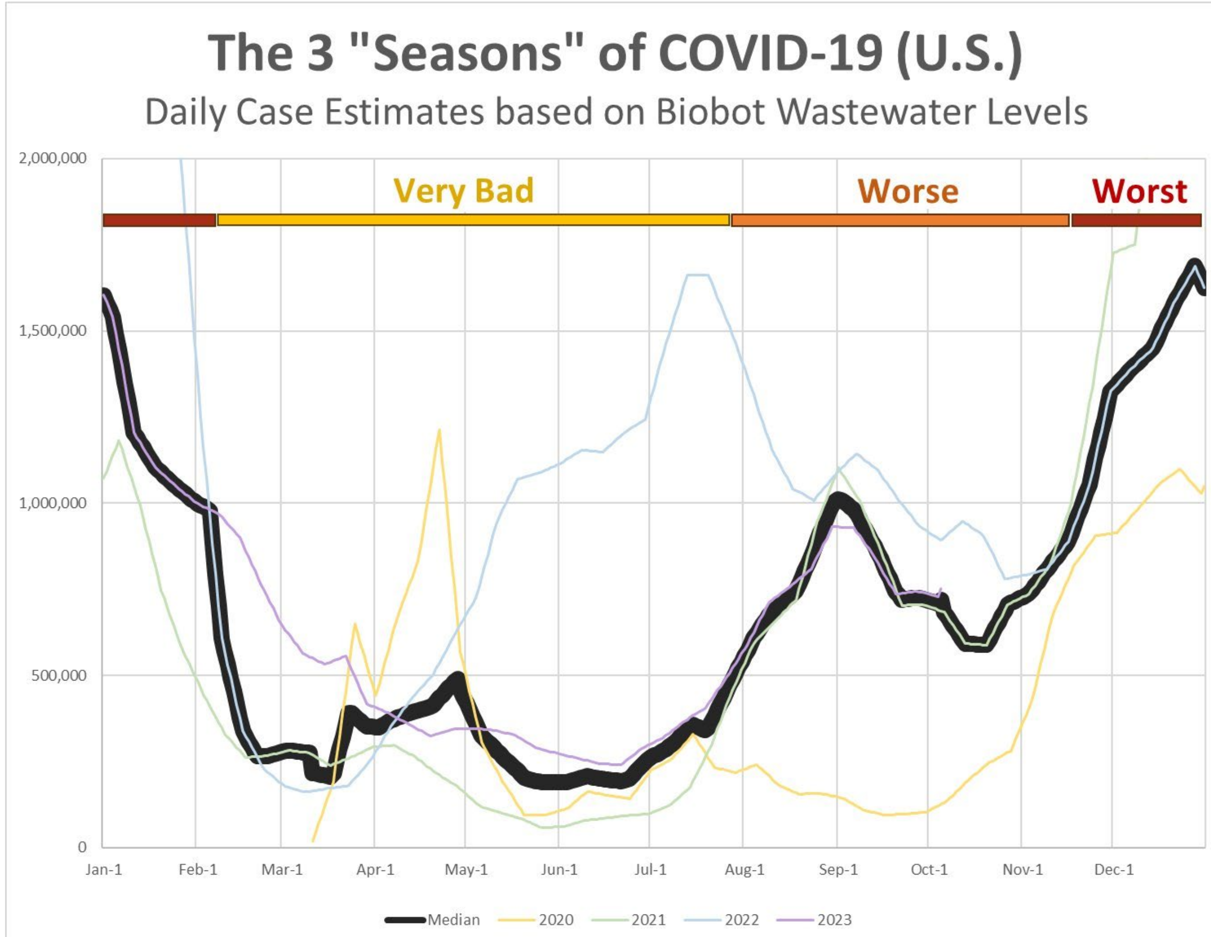
Our forecasting model also yields high-quality inferences at the 2-week mark, which takes us to New Year's Day. This figure shows the chance anyone would be infectious in a group based on group size. Transmission will hopefully peak around New Year's Day if we are lucky, though likely 1-2 weeks later. Expect transmission to be exceedingly bad. If seeing 10 people on New Year's Eve or for a New Year's Day brunch, there's likely about a 33% chance anyone would be infectious. In a group of 15-20, it's a coin toss whether someone will be infectious. If going to a packed restaurant or traveling on a plane with 100 other people, assume there's a 98% chance someone there may be infectious.

In the U.S., What's the COVID Risk for New Year's Day?

Number of People	Chances Anyone is Infectious	Number of People	Chances Anyone is Infectious
1	3.9%	25	63.0%
2	7.7%	30	69.7%
3	11.3%	35	75.2%
4	14.7%	40	79.7%
5	18.1%	50	86.3%
6	21.2%	75	95.0%
7	24.3%	100	98.1%
8	27.3%	150	99.7%
9	30.1%	200	>99.9%
10	32.8%	300	>99.9%
15	45.0%	400	>99.9%
20	54.9%	500	>99.9%

@michael_hoerger Estimated December 18, 2023

Forecast for the Longer-Term – Annual Trends



*This section is being reshared from a prior report, as some people may need to make decisions about travel, surgery, and other important events several months out.

Is C0VID-19 "seasonal"? Not in any meaningful sense of the word. The following graph uses historical Biobot #wastewater data to estimate daily case rates using the PMC model. Thin lines show 2020 (yellow), 2021 (green), 2022 (blue) and 2023 (purple). The black line is the median. It is not really a forecast, but merely a summary of historical data. To the extent the median provides a reasonable approximation of the future, it is a useful starting point for a gift-level forecast.

Season 1: "Very Bad Transmission." Focusing on the median, you'll see that case rates tend to be lower (but still in the 250-500K/day range) from mid-Feb through the end of July. These are valuable data. If I needed to schedule a non-urgent surgery, when would I do it? Late February, when transmission has often dropped, but before the general public not monitoring wastewater has realized so, perhaps meaning some people are still using airborne precautions. You're basically hopefully beating the transmission "market." I'd also be prepared to cancel an appointment or push back 6 weeks if needed.

Season 2: "Worse Transmission." Again, focusing on the median, you see a late summer wave from August through mid-October. This is the clearest indication that C19 is not "seasonal," if people are using that term to mean an annual event. If we were doing two boosters a year, it seems like booster 1 would roll out in July. Why do we have this wave? Schools have very little mitigation (poor air quality, little/no testing, little/no masking, low vax rates). Also, the fleeting immunity from winter boosters and infections has waned. If I had an urgent maskless medical/dental visit, I'd schedule mid-October through early November and cross my fingers (around my HEPA). It's still high transmission but about to get worse. This is also a good time to stock up on N95s, rapid tests, and HEPA filters before the prices may increase, scarcity may become a problem, or one has an infection in the home. Travel insurance is wise.

Season 3: "Worst Transmission." From mid-November to mid-Feb, transmission is extremely problematic, according to the median line. Everybody should be wearing high-quality masks, testing as frequently as possible, improving indoor air quality, and moving activities outdoors and remote.

A Couple Caveats. *Seasonality*. Some people use the word "seasonal" to mean predictable, rather than merely a discrete 2-3 month season of transmission. In some ways, transmission is predictable. You'll see the 2023 purple line has followed the median very closely. However, we're talking about a very small sample size of years, so one would expect one of the years to mostly follow the median. Also, there are clear discrepant cases. BA.1 goes off the chart (winter 2021 to early 2022). The 2022 summer wave was also sizable. My approach is to make longer-term plans based on the median line and then be prepared to shift plans toward more remote activities if a large wave picks up. Hopefully, transmission becomes more predictable as years go by, but I'm not betting on it yet.

Case estimates. If you have followed the PMC dashboard, you'll know these are estimated by linking Biobot wastewater levels to IHME true case estimates. I would find case estimates 15% higher or 30% lower also reasonable and discuss these estimates with many modeling experts. There are also some more sophisticated models, where I believe an argument can be made that waves are actually marginally more leptokurtic (spikier mountains and deeper valleys than shown here).

General Technical Notes, Not Specific to the Current Week's Report

Status of Biobot wastewater reporting. The estimates and forecast described here use wastewater data reported by Biobot. Biobot is now updating their data on Fridays or Mondays, and the CDC has awarded several prior Biobot sites to a company called Verily. The transitionary phase at Biobot seems mostly through, though Biobot is contesting the contract reassignment in court. As long as national wastewater data are being reported, the PMC reports will continue.

Case estimates. Case estimates were used by evaluating various potential multipliers to go from wastewater levels to cases. To identify true cases, not merely just reported cases, I used the IHME's case estimates for January 1, 2021 through April 1, 2023 (https://covid19.healthdata.org/united-states-of-america?view=cumulative-deaths&tab=trend). I compared wastewater with their case estimates on the 1st of each month. The correlation was r=.94. The maximum possible correlation is 1.00, so that is freakishly high, higher than just about any of the 10,000 or so correlations I've ever run. I was hoping for a correlation of r=.70 or higher, which still would have been great. Basically, wastewater is a supreme indicator of case rates. Next, I examined multipliers. Are cases 10x the arbitrary wastewater metric? 10,000x? Something else? Take cases and divide by wastewater at each data point, then find a summary metric (mean, median, trimmed mean, etc.). The metric I found most defensible was to use a +/-10% trimmed mean (average that excludes extreme data points, where case estimates are more error-prone), where each unit of wastewater translated into 1455 cases. I would find multipliers of 1000 to 1700 (31% lower to 17% higher) also reasonable. Arguably, case rates are magnitudes (10-100 times) higher than many people expect, so these details have minimal practical significance for everyday decision making. There are also more sophisticated strategies, such as regression models, but I found those results to be counter-intuitive (e.g., positive intercept, where I would have expected zero or negative). One can set the intercept to zero, use various heteroscedasticity-related techniques, and correct for the lack of imperfect reliability, but most of that is over the heads of people using this model and would accomplish little more than the trimmed multiplier method. The multiplier method has also led to techniques (only posted on Twitter thus far) for making regional estimates using very simple multipliers. Elegant is good.

Percentage infectious. After estimating the current number of new infections, it is relatively straightforward to estimate the percentage of the U.S. population actively infectious with COVID-19, but there are several caveats worth noting. One, the U.S. population is assumed to be 334,565,848. This was the CDC-estimated U.S. population on the final day of the IHME case estimation model. The number of new daily cases divided by the population tells one the percentage of the population newly infected today, often small at around 0.3% or less. Two, consider the infectious window. The percentage of the population infectious depends on the percentage of new people infected but also the duration people stay infectious. The model assumes people stay infectious for 7 days. Low estimates are that people are infectious for an average of 5 days (this defies the preponderance of the evidence, in my view), and high estimates are more like 10 days (too high in my view, based on a preference for round numbers). Other compelling estimates are more like 8-8.5 days. This duration may change over time, based on new variants, new vaccines, vaccine utilization rates, and treatments. If assuming the infectiousness duration is 10% longer, multiply by 1.10. If assuming 20% shorter, multiply by 0.80. New cases divided by the population equals new daily infections. Note also, these are merely averages and do not reflect individual variation, as some get infected and are not contagious, whereas others get infected and remain infectious likely for months (extremely rare). New daily infections multiplied by the number of days infectious indicates the percentage of the population actively infectious.

Long COVID. Long COVID case estimation. The lower and upper bounds for Long COVID case estimates assume that 5-20% of people infected with SARS-CoV-2 will develop Long COVID as a result of that infection. Some published reports and analysts have suggested lower (1%) or higher (40%) values. A useful framework for thinking about these estimates is that the low value is more indicative of people experiencing serious, enduring, known harms, whereas the upper estimates are closer to the number experiencing disruptive symptoms for at least several months, perhaps with full or partial recovery. These estimates do not indicate unknown long-term harms. For example, if infections increase the risk of cancer or cardiovascular disease substantially and with increasing risk over 10-30 years, that is not captured well by these metrics. The metrics also do not encompass the 1.2 to 1.8 million Americans who have died of COVID-19. Future models may incorporate estimates of mortality. Finally, the estimates project the number who will ultimately experience Long COVID from a new infection, but that is several months down the line. The estimates reflect future implications. For simplicity of interpretation, they are not modeling the number of new Long COVID cases today that resulted from infections three months ago.

General forecasting model specification. The forecasting models are elegant, meaning simple and effective. In regression analyses using historical pandemic wastewater data, the model explains 96% of the variance in the following week's forecast. The model is simple. It includes the year (2020, 2021, 2022, or 2023). It includes the historical median (switched from average on 12/11/23) for the current half month; imagine the year sliced into 26 pieces, and it incorporates data on the historical median for that half month (e.g., second half of September). The model also incorporates four lagged variables, the wastewater levels 1, 2, 3, and 4 weeks ago. Overall, you can think of the model as having two main processes. One incorporates what we know historically. The other incorporates what has been happening the past several weeks. The historical data are useful because transmission mostly, but not always, follows a particular monthly pattern. It is not seasonal in that there are not just three bad months a year, but there is month-to-month variation, and sometimes even useful differences between the first versus second half of the month. The use of recent wastewater estimates helps in several ways. It lets the model know if something about the current point in time differs dramatically from the historical data, and it quickly adapts the model to changes, such as if a wave is starting or ending,

Real-time model (purple line). This model assumes that real-time data reports of wastewater levels are accurate. However, real-time data often get corrected. Some sites may be slow reporting, and if there is a bias built in, such as places with high transmission being late to report, that would be a problem. Often, the real-time reports are quite accurate, but occasionally they have been corrected substantially a week later. The general model places a lot of weight on the most recent data, so any errors here can lead the model to assume a wave is picking up that really is not (false alarm) or that things are improving better than expected (false hope).

Alt model #1, turtle (green line). The turtle model moves slow and steady. It completely ignores the most recent week's worth of data from Biobot, treating it as unreliable. It will ignore false fluctuations inferred from inaccurate real-time reporting. However, it will be slower to respond to real changes, such as the onset in a new wave or the decline in a wave that has peaked.

Alt model #2, cheetah (orange line). The cheetah model moves fast. It aims to correct for biases in real-time data reports. If last week's real-time report overestimated levels by 10% upon correction, it assumes this week's real-time report suffers the same bias. If last week's real-time report underestimated true levels, it assumes the same for this week. If last week's real-time report was accurate, it will look similar to the real-time model. This model is very good if there is a bias, such as if areas with high transmission experience delays in reporting. However, it can also be overreactive. If there was some error in a real-time report that was just "random" rather than biased in a particular correction, it will tend to overcorrect the next week's model.

Composite Model (red line). This is the arithmetic average of the three models. It's what's used for deriving all of the statistics reported. When all of the individual models are very close to the average, that suggests high confidence. When the models make vastly different predictions, that suggests more uncertainty in the data, largely based on perceptions of the accuracy of real-time wastewater reporting.