

## COVID-19 and climatic factors: A global analysis

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## Abstract

### Background:

It is unknown if COVID-19 will exhibit seasonal pattern as other diseases e.g., seasonal influenza. Similarly, some environmental factors (e.g., temperature, humidity) have been shown to be associated with transmission of SARS-CoV and MERS-CoV, but global data on their association with COVID-19 are scarce.

**Objective:** To examine the association between climatic factors and COVID-19.

**Methods:** We used multilevel mixed-effects (two-level random-intercepts) negative binomial regression models to examine the association between 7- and 14-day-lagged temperature, humidity (relative and absolute), wind speed and UV index and COVID-19 cases, adjusting for Gross Domestic Products, Global Health Security Index, cloud cover (%), precipitation (mm), sea-level air-pressure (mb), and daytime length. The effects estimates are reported as adjusted rate ratio (aRR) and their corresponding 95% confidence interval (CI).

**Results:** Data from 206 countries with  $\geq 100$  reported cases each showed no association between COVID-19 cases and 7-day-lagged temperature, relative humidity, UV index, and wind speed, after adjusting for potential confounders, but a positive association with 14-day-lagged temperature and a negative association with 14-day-lagged wind speed. Compared to an absolute humidity  $< 5\text{g}/\text{m}^3$ , an absolute humidity of  $5\text{-}10\text{g}/\text{m}^3$  was associated with a 23% (95% CI:6-42%) higher rate of COVID-19 cases, while absolute humidity  $> 10\text{g}/\text{m}^3$  did not have a significant effect. These findings were robust in the 14-day-lagged analysis.

**Conclusion:** Our results of higher COVID-19 cases (through April 20) at absolute humidity of  $5\text{-}10\text{g}/\text{m}^3$  may be suggestive of a 'sweet point' for viral transmission, however only controlled laboratory experiments can decisively prove it.

*Key words:* COVID-19; SARS-CoV-2; Temperature; Humidity; Climatic factors; Meteorological factors

## Highlights

- A global study from 206 countries/regions to examine the effects of climatic factors on COVID-19.
- We adjusted for a range of climatic and structural factors in the analysis.
- No association with 7-day lagged climatic variables and COVID-19.
- Positive association between COVID-19 and 14-day lagged temperature.
- Negative association between COVID-19 and 14-day lagged wind speed.
- Consistently higher rate of COVID-19 cases in absolute humidity of 5-10g/m<sup>3</sup>

## 1 Introduction

Since its outbreak in late 2019 across China(1,2), the novel coronavirus SARS-CoV-2 rapidly spread across the continents owing to its high transmissibility(3) and increased global mobility with a potentially delayed travel ban in Wuhan, China.(4) With subsequent global spread, it was declared a pandemic by the World Health Organization on March 11, 2020.

SARS-CoV-2 belongs to the *Coronaviridae* family,(5) as are other “flu” viruses such as severe acute respiratory syndrome (SARS-CoV), and Middle East respiratory syndrome (MERS-CoV). Previous studies reported the association between SARS-CoV and MERS-CoV with climatic factors including temperature and humidity.(6–9) Since SARS-CoV-2 belongs to the same virus family, there has been widespread speculation and interest whether SARS-CoV-2 too will exhibit a similar pattern.(10) Some studies, mostly from China(11–13), also reported the association between COVID-19 and climatic factors, albeit with conflicting results. Most of these studies were from a specific country with limited range of climatic variabilities, and reported results without robustly adjusting for potential confounding factors. In this study, we aimed to undertake a global study to examine the association between COVID-19 cases and temperature, humidity, UV index, and wind speed adjusting for a range of climatic variables and country-level systemic factors.

## 2 Methods

### 2.1 Data sources:

**2.1.1 Weather Data:** We obtained weather data from 'World Weather Online' using a Python based API from January 8, 2020 to April 20, 2020. Weather data included temperature, relative humidity, UV index, wind speed, cloud cover, precipitation, sea-level air-pressure, and daytime length. We obtained these data 7- and 14-day prior to the reported cases since the climatic variables are not expected to have an immediate effect on COVID-19 cases (more below).(14)

We also calculated absolute humidity using Clausius Clapeyron equation(15) as follows:

$$AH = \frac{6.112 * e^{\left(\frac{17.67 * T}{T + 243.5}\right)} * RH * 2.1674}{273.15 + T} \quad (1)$$

where AH is the absolute humidity, RH is the relative humidity, and T is the temperature in °C.

For Australia, China, Canada and US, weather data were obtained at provincial/state level and for the remaining countries, the data were obtained at country level.

**2.1.2 COVID-19 cases:** COVID-19 cases (up to April 20, 2020), estimating approximately 2.5 million cases worldwide, were obtained from the database developed by Johns Hopkins University (data available at <https://github.com/CSSEGISandData/COVID-19>).

**2.1.3 Other variables:** GDP per capita (2018 estimates) were obtained from the International Monetary Fund.(16) The 2019 Global Health Security Index, a measure of country's emergency

pandemic preparedness status developed by the Johns Hopkins University, was obtained from the official report.(17) These two variables were adjusted in all the analyses to address the issue of potential country-level factors (such as variability in testing rates, health systems financing, healthcare resource mobilization during emergency situations such as pandemics) that may confound the reported effects estimates.

**2.2 Statistical analysis:** Our analysis included the regions/countries that reported  $\geq 100$  COVID-19 cases by April 20, 2020. Since the COVID-19 cases were nested within time (starting at the day the first case was reported by the respective country/region), which in turn is nested within the countries/regions, we used multilevel mixed-effects negative binomial regression model(18) to examine the association between daily weather variables and the daily number of new COVID-19 cases using a two-level random intercepts nested within the regions (countries, or states/provinces for larger countries). The number of newly reported COVID-19 cases each day were regressed on the historical weather (preceding 1- and 2-week to coincide with the SARS-CoV-2 incubation period).(19) Population of the respective region/country was added as an offset term in the model.

Our primary weather variables of interest were daily maximum temperature (Celsius), humidity ( $\text{g}/\text{m}^3$ ), UV index, and wind speed (kmph) since these have been reported to be associated with other coronaviruses in previous studies.(6–9) . All the models were adjusted for GDP per capita, Global Health Security Index, and other (standardized) climatic factors including cloud cover (%), precipitation (mm), sea-level air-pressure (mb), and length of daytime with the following exception: since temperature and UV index were highly correlated (Pearson's correlation

coefficient: 0.95), we did not use them together in the same model. Instead, two separate models were fit for the temperature and the UV index keeping all the other variables identical. For example, the model for temperature would have the number of cases regressed on temperature, humidity, wind speed, cloud cover, precipitation, sea-level air pressure and the length of daytime. The model for UV index will have all the variables stated above except temperature, which would be replaced by UV index.

From exploratory analysis, we observed an excess number of new daily cases in the range of absolute humidity between 5 and 10 g/m<sup>3</sup>. Therefore, we also tested the hypothesis whether this observed association holds when we adjust for the potential confounders stated above. Specifically, we reported the association between absolute daily humidity (<5 g/m<sup>3</sup>, 5-10 g/m<sup>3</sup>, and >10 g/m<sup>3</sup>) and daily number of new COVID-19 cases adjusting for the variables listed above. The theoretical relationship between the temperature, relative humidity, and absolute humidity is shown in Figure 1.

The effects estimates are reported as adjusted rate ratio (aRR) and their corresponding 95% confidence interval (CI). Data analysis was conducted in Stata/SE v.14.2.(20) P-values are two-sided and are considered statistically significant at the 0.05 level of significance.

### 3 Results

Two-hundred-six (206) regions/countries were included in the analysis that reported  $\geq 100$  cases each by April 20, 2020. Data from France were dropped from the analysis due to changes in their reporting that resulted in an anomalous increase on April 4, 2020.

For visualization, we divided the data in five time periods (period 1 - Jan 22, 2020 to Feb 15, 2020, period 2 - Feb 16, 2020 to Feb 29, 2020, period 3 - March 1, 2020 to March 15, 2020, period 4 - March 16, 2020 to March 31, 2020 and period 5 - April 1, 2020 to April 20, 2020) and plotted the number of COVID-19 cases against daily maximum temperature (Celsius), humidity ( $\text{g}/\text{m}^3$ ), UV index for each of those time periods (Figure 2). Majority of the cases between January 22, 2020 and 20, April 2020 occurred at temperatures ranging between 0 and  $17.5^\circ\text{C}$ , absolute humidity between 5 and  $10 \text{ g}/\text{m}^3$  and UV index between 0 and 5. In March, the number of COVID-19 cases was similar for temperatures between  $2.5$  and  $17.5^\circ\text{C}$ ; with low cases in the temperature range between  $17.5$  and  $20^\circ\text{C}$ . However, for April, the cases per million people between  $17.5$  and  $20^\circ\text{C}$  increased likely due to natural warming up of the northern Hemisphere as summer approaches. Unlike, temperature, where the observed trend of COVID-19 cases was observed across a wide range of temperature, approximately 75% of the cases through 20 April 2020 occurred between an absolute humidity between 5 and  $10 \text{ g}/\text{m}^3$  suggesting a much stronger influence of AH on COVID-19 incidence (Figure 2).

After adjusting for cloud cover, precipitation, sea-level air-pressure, length of daytime, GDP and Global Health Security Index, no climatic factor was associated with COVID-19 cases in the 7-day-



lagged analysis. There was an indication of a negative association between wind speed and COVID-19 cases, but the effect estimates included the null value (Table 1).

In the 14-day-lagged analysis, daily maximum temperature was positively associated with COVID-19 cases showing a 7% increase (95% CI: 2-12%) for every 5°C in daily maximum temperature, after adjusting for the same variables mentioned above. In the same analysis, a 5 kmph increase in wind speed was associated with a 6% (95% CI: 2-9%) decrease in COVID-19 cases; the association between COVID-19 and 14-day-lagged relative humidity and UV index was inconclusive (Table 1).

**Table 2** shows the association between absolute humidity and number of new COVID-19 cases. In the adjusted model, an absolute humidity between 5 and 10 g/m<sup>3</sup>, inclusive, was associated with a 23% (95% CI: 6-42%) higher number of new COVID-19 cases, compared to an absolute humidity <5 g/m<sup>3</sup>, while the effect of an absolute humidity above 10 g/m<sup>3</sup> was not different compared with absolute humidity <5 g/m<sup>3</sup> (aRR: 1.03, 95% CI: 0.88-1.39). These results were robust and consistent in the analyses using 14-day-lagged data (Table 2).

## 4 Discussion

To our knowledge, this is one of the largest studies to date that examines the association between the incidence of COVID-19 and a range of climatic factors spanning across 206 regions of the world with approximately 2.5 million cases reported through April 20, 2020. We used robust statistical methods adjusted for a range of potential systems-related and climatic confounding factors to assess the relationship of COVID-19 cases and climatic factors. Our results show that the hypothesized associations between many of the climatic variables and COVID-19 do not hold when adjusted for a range of potential confounding variables. In fact, a positive association between 14-day-lagged temperature and COVID-19 cases may suggest that warm environment may provide a more favorable condition for SARS-CoV-2 survival, which is conflicting with the pattern proposed for other coronavirus such as SARS-CoV and MERS-CoV.(6–9) An inverse association with wind speed may indicate a shorter suspending time in the air due to dilution and removal of SARS-CoV-2.<sup>3</sup>

Several recent studies have reported, albeit conflicting results, on the associations between climatic factors and COVID-19 cases.(11–13,21,22) While, an inverse relationship between temperature and COVID-19 cases was reported,(11,23); studies also reported a higher rate of COVID-19 with increasing temperature.(12,22) Most of these studies, however, have analyzed data when COVID-19 cases were still less than 1 million. The rapid growth in the number of cases in April 2020 warrants an updated analysis to understand the association between COVID-19 and weather variables.

We did, however, find that an absolute humidity between 5 and 10 g/m<sup>3</sup>, inclusive, was associated with a higher rate of COVID-19 cases. These results were robust and consistent with the analysis using historical data (preceding 7-and 14-days). The greater rate of COVID-19 may suggest a potential 'sweet spot' for viral transmission and warrants laboratory experiments to establish the relationship between SARS-CoV-2 and absolute humidity. Our finding of a consistent association between absolute humidity, as opposed to relative humidity, emphasizes that it is not just one factor that affects, rather a combination of temperature and humidity. Previous studies showed that SARS-CoV can survive for up to 14 days after drying, and remains viable for up to 5 days at temperatures of between 22 and 25°C and between 40 and 50% relative humidity.(24) The infectivity, however, declines after 24-hours at 38°C and 80-90% relative humidity.(24) MERS-CoV, on the other hand, is viable in conditions with low temperature and low humidity. The virus was found to be viable on different surfaces for 48 hours at 20°C temperature and 40% relative humidity. The viability, however, decreased to 8 hours at 30°C temperature and 80% relative humidity.(25) Similar viability data are SARS-CoV-2 yet to be available.(26)

Our results have several limitations. First, our analysis solely depends on the number of COVID-19 cases as reported by the respective countries and the definition of 'confirmed' cases is not consistent across and even within countries. COVID-19 testing rates also vary significantly across countries, and within countries over time, which may influence the results reported in our analysis. Even though we adjusted for country-level Global Health Security Index, it was not possible to adjust for temporal trend of testing rates, and therefore residual, and potentially unknown, confounding cannot be ruled out with certainty. Additionally, the actual daily

incidence might be different from the reported values due to lack of testing in the initial days resulting in a backlog of samples. Our results also do not report causal association between the climatic factors and COVID-19. While there may be a causal link between these climatic factors and the reproduction and transmission of SARS-CoV-2, our data does not provide any evidence for or against these potentially important hypotheses. Controlled laboratory experiments will be required to answer these questions.

## 5 Conclusions

In conclusion, our study finds conflicting results on the association between temperature and COVID-19 cases. The association between COVID-19 and humidity, and UV index were inconclusive. We found a negative association between wind speed and COVID-19 cases. A higher rate of COVID-19 was found between an absolute humidity between 5 and 10 g/m<sup>3</sup>. However, our results do not infer causality, and these reported findings may provide baseline data for experimental studies to provide a confirmatory result. Any pandemic, and therefore COVID-19, requires a multifaceted expertise and approaches to handle it properly. We need more data to understand the clinical and epidemiological nature of SARS-CoV-2 while we continue to improve our understanding of other closely related areas such as public health interventions,(27) socioeconomic implications,(28) ethical ramifications, environmental insights to name a few. We hope our findings add to the existing literature on the association of climatic factors and COVID-19.

**Conflict of Interests:** Authors declare no conflict of interest.

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Table 1. Association between climatic factors and COVID-19

Weather factors	7-day lagged		14-day lagged		
	aRR (95% CI)	P-value	aRR (95% CI)	P-value	
Model -1	Daily maximum temperature (°C)*	1.00 (0.95-1.04)	0.904	1.07 (1.02-1.12)	0.003
	Relative humidity (%)*	0.99 (0.97-1.01)	0.215	1.02 (1.00-1.04)	0.076
	Wind speed (kmph)*	0.97 (0.94-1.00)	0.071	0.94 (0.91-0.98)	0.001
Model -2	UV index**	1.00 (0.95-1.04)	0.874	1.03 (0.99-1.08)	0.180
	Relative humidity (%)*	0.99 (0.97-1.01)	0.213	1.01 (0.99-1.03)	0.201
	Wind speed (kmph)*	0.97 (0.94-1.00)	0.069	0.94 (0.91-0.97)	<0.001

-The models were additionally adjusted for cloud cover (%), precipitation (mm), sea-level air-pressure (mb), length of daytime, GDP per capita, and Global Health Security Index; aRR: Adjusted rate ratio; CI: confidence interval.

\* Estimated effects with every 5 unit increase in the respective variables (e.g., 5°C increase in temperature).

\*\*Estimated effects per one unit increase in UV index.



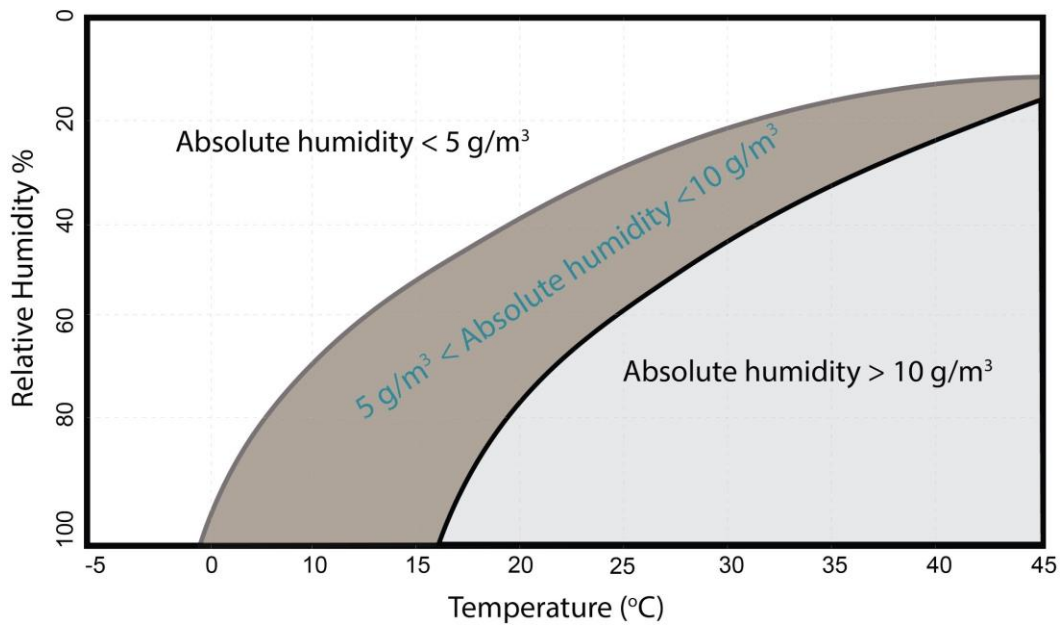
Table 2. Association between absolute humidity and COVID-19

	7-day lagged		14-day lagged	
	aRR (95% CI)	P-value	aRR (95% CI)	P-value
Absolute humidity				
<5 g/m <sup>3</sup>	<i>Ref</i>		<i>Ref</i>	
5-10 g/m <sup>3</sup>	1.23 (1.06-1.42)	0.005	1.25 (1.08-1.44)	0.003
>10 g/m <sup>3</sup>	1.03 (0.81-1.3)	0.815	1.13 (0.89-1.42)	0.325

-The models were additionally adjusted for daily maximum temperature, relative humidity, cloud cover (%), precipitation (mm), sea-level air-pressure (mb), length of daytime, GDP per capita, and Global Health Security Index; aRR: Adjusted rate ratio; CI: confidence interval.

**Figure 1:** Variation of absolute humidity as a function of temperature and relative humidity.

More than 75% of the COVID-19 cases (so far) have occurred in the area shown in light brown ( $5 \text{ g/m}^3 \leq \text{AH} \leq 10 \text{ g/m}^3$ ). Less than 25% of the cases have been reported in areas where absolute humidity is  $>10 \text{ g/m}^3$  or  $<5 \text{ g/m}^3$ .



**Figure 2:** COVID-19 cases across the world versus temperature, absolute humidity, and UV.

Temperature absolute humidity and UV ranges with the majority of COVID-19 cases (>75%) are highlighted with light blue color, and is consistently between 3 and 17°C for temperature, between 5 and 10 g/m<sup>3</sup> for absolute humidity and 0-5 for UV for each time period.

