# Will coronavirus pandemic diminish by summer?

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## Abstract

The novel coronavirus (2019-nCoV) has spread rapidly to multiple countries and has been declared a pandemic by the World Health Organization. While influenza virus has been shown to be affected by weather, it is unknown if COVID19 is similarly affected. In this work, we analyze the patterns in local weather of the regions effected by 2019-nCoV virus. Our results indicate that 90% of the 2019-nCoV transmissions have so far (March 22, 2020) occurred within a certain range of temperature (3 to 17C) and absolute humidity (4 to 9g/$m^3$) and the total number of cases in countries with mean Jan-Feb-March temperature >18C and and absolute humidity > 9 g/$m^3$ is less than 6%. The large difference in the number of cases between 0 and 30N and between 30 and 50N suggests that the transmission of 2019-nCoV virus might have been less efficient in warmer humid climate so far. Given previous associations between viral transmission and humidity and the small range of absolute humidity (4 - 9g/$m^3$) across which the majority of the 320,000 2019-nCoV cases have been observed, we believe that absolute humidity might play a role in determining the spread of 2019-nCoV, although the mechanistic understanding of the association between the spread of 2019-nCoV and absolute humidity is still missing.. For absolute humidity to be > 9 g/$m^3$, air temperature should be more than 15C. Between 15 and 25 C, the absolute humidity is > 9g/$m^3$ only when the relative humidity is >60%. Therefore, if humidity plays any role in the transmission of 2019-nCoV, its ability to limit the transmission might be negligible until June for regions above $35^0$N, that includes most of North America and Europe, since most of these regions might not have an absolute humidity >9g/$m^3$ as mean temperature would be less than 20C. On the other hand, Asian countries experiencing monsoon may see a slowdown in transmission as absolute humidity would be >10g/$m^3$. With more than 10,000 cases being reported in regions with mean temperature >18C after March 15, the role of

warmer temperature in slowing the spread of the 2019-nCoV as suggested previously, might only be observed, if at all, at much higher temperatures like 25 C, and therefore its implication will be limited at least for northern European countries and northern US which do not experience such warm temperatures until July and that too for a very short time window**. Our analysis shows that the chances of reduced spreading due to environmental factors would be limited across most of northern Europe and North America (USA and Canada) in summer**. Our conclusions are based on currently available data and its validity will automatically be tested in the next few weeks with reporting of new cases across the world. The relation between temperature and humidity and the spread of 2019-nCoV cases should be closely monitored and if a strong environmental dependence in the spread of 2019-nCOV emerges then it should be used to optimize the 2019-nCoV mitigation strategies. Our results in no way suggest that 2019-nCoV would not spread in warm humid regions and effective public health interventions should be implemented across the world to slow down the transmission of 2019-nCoV.

## Introduction

In the beginning of 2020, several cases of novel coronavirus, 2019-nCoV appeared across China [1,2]. The disease quickly spread to other regions, due to its highly transmissive nature [3] and increased global mobility, and was declared a pandemic by the World Health Organization on March 11, 2020 [4].

Human coronaviruses have been associated with a wide spectrum of respiratory diseases in different studies [5–9], and belong to the *Coronaviridae* family[10]. It has been suggested that flu viruses are not easily transmitted in hot and humid conditions [11,12] and similar comments about the 2019-nCoV have repeatedly been made by health officials as well as world leaders that the outbreak will slow down by summer, due to decreased transmissivity. It is also important to note that SARS-Cov, which is a type of coronavirus, loses its ability to survive in higher temperatures[13], which may be due to the breakdown of their lipid layer at higher temperatures [14]. However no seasonality has been established for coronaviruses.

The analysis presented in this paper provides a direct comparison between the spread of 2019-nCoV virus and local environemental conditions and is motivated by the significant differences in the growth rate of 2019-nCoV cases among different countries (figure 1) and different US states (figure 2). Countries and states experiencing high growth rates such as Italy, Iran, South Korea, New York and Washington (US) exhibit weather patterns similar to original hotspots of Hubei and Hunan with mean temperatures between 3 and 10C in February and March (figure 3). On the contrary, countries with warmer humid climates such as Singapore, Malaysia, Thailand and other South-East Asian countries (figure 3) exhibit a lower growth rate.

Within the US, the outbreak also shows a north-south divide. Northern (cooler) states have much higher growth rates compared to southern (warmer) states (figure 2). The spread of 2019-nCoV has been limited in Texas, New Mexico and Arizona. Even in California, which spans a large climatic zone, the number of cases in northern California is double than Southern California. Within the US, Oregon and Louisiana are two outliers, with Oregon having < 200 cases even though it is stradelled between the hotspots of California and Washington and Louisiana having approximately 1000 cases by March 22nd 2020, even though it is relatively warm and humid. None of the Asia, Middle eastern and South American countries have implemented drastic quarantine measures such as those in China, Europe and some US states, however their overall growth rate is lower (figure 1). It could be argued that it may be due to lower number of testings such as in India, Pakistan, Indonesia and African countries but many countries such as Singapore, UAE, Saudi Arabia, Australia, Qatar, Taiwan and Hong Kong have performed more 2019-nCoV tests per million people than US, Italy, and several European countries [15] suggesting that non-testing is not an issue at least for the countries listed above. Many of these countries such as UAE, Singapore and Qatar are also global travel hubs with thousands of people entering and exiting the country everyday. Saudi Arabia is visited by hundreds of thousands of pilgrims from around the world on a regular basis. Therefore, factors other than mobility and quarantining might play an important role in slowing the transmission of the virus. Since climate appears to be one of the major differences between the countries/regions experiencing high and low growth rates, we explored the role (if any) of weather in the transmission of coronavirus.

## Data and Methods

1. Weather Data: We obtained weather data using the 'worldmet' library in R from January 20, 2020 to March 19, 2020. We downloaded temperature, relative and humidity and wind speed at a time step of 15 minutes and used the daily mean values for our analysis. We also calculated absolute humidity using Clausius Clapeyron equation [16,17] as follows:

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

where AH is the absolute humidity and T is the temperature in degrees C.

For Australia, China, Canada and US weather data was obtained at provincial/state level and for the remaining countries, the data was obtained at country level. For each country/state, we downloaded the weather data from the busiest airport to approximate the weather of that state/country (for example, Logan Airport for Massachusetts, USA and Icheon of South Korea).

We assumed that most of the cases would occur in large cities and the largest airport in the state/country generally lies close to its biggest city.

2. Covid-19 cases: The data on confirmed Covid-19 cases for each country and state (where available) was downloaded from John Hopkins University Coronavirus Resource Center repository on March 19, 2020.

3. Relation between Covid-19 cases and weather: For visualizing, we divided the entire data in 6 groups (group1 - Jan 20, 2020 to Jan 31, 2020, group 2 - Feb 1, 2020 to Feb 10, 2020, group 3 - Feb 10, 2020 to Feb 20, 2020, group 4 - Feb 21, 2020 to Feb 29, 2020, group 5 - March 1, 2020 to March 10, 2020 and group 6 - March 11, 2020 to March 21, 2020). For each week, we obtained the number of new confirmed Covid-19 cases and analyzed the weather data of all the countries/states in which new cases were observed to uncover any pattern and relationship between 2019-nCoV outbreak and weather.

## Results and Discussion

Our analysis shows that for each 10 day period between January 22, 2020 to March 21, 2020 the maximum number of new cases developed in regions with mean temperature between 4 to 10C and absolute humidity between 3 and 9 $g/m^3$. The data so far clearly shows that the number of cases for temperature > 17C and absolute humidity > 9 $g/m^3$ is low. Except for the new cases between March 11 to March 21, 2020 (figure 4), the number of cases above 11C and below 0C is less than 5% and the total number of cases in regions with absolute humidity > 9 $g/m^3$ is less than 10% (figure 4). Between March 11 and 19, 2020 we observed a surge in the number of cases in regions with temperature >18C, however it is still many times lower than the surge in cases between 8 and 12C (figure 4). The sudden increase in the number of cases in regions with temperature >18C could be due to several reasons including recent initiation of large-scale 2019-nCoV testing in India, Brazil, Indonesia and Pakistan or analysis of backdated samples (Florida, US) [18,19]. We believe that the 10,000 cases in regions above 18C in the last week is unlikely due to rapid transmission of the virus in the last few days (discussed subsequently).

The number of 2019-nCoV cases detected in a country/state depends on multiple factors including testing, population (density), community structure, social dynamics, governmental policies, global connectivity, air and surface life [20], reproduction number and serial interval of the virus. Many of these information regarding 2019-nCoV are still emerging such as the virus being airborne for more than 3 hours and having very different survival times on metals, cardboards and plastics [20] which was published on March 17, 2020. Previous works have shown that the spread of viruses also depends upon environmental factors, with many respiratory pathogens showing seasonality and decreased transmission rates in warmer humid climates, however, the behavior of 2019-nCoV is still under investigation and also the subject of this paper .

Since most of the cases have been reported between 3 and 17C (figure 4, cold climate), the number of 2019-nCoV cases between 0 and 30N latitude are several times lower than the number of cases between 30 and 50 N. We can hypothesize several reasons for the lower number of cases detected in the tropics. First, it could solely be due to less testing as many of the countries lack good health care facilities and may have not done enough testing to detect the actual spread of 2019-nCoV. While it may be partially true, if the spread was really rampant then local media would have reported overcrowded hospitals and health centers. In fact, in Italy, pro-active testing on 2019-nCoV was limited until the healthcare system was overwhelmed with a large number of people showing up with symptoms associated with 2019-nCoV, thus forcing the government to take heed into the matter. Additionally many countries have the capacity and have indeed performed extensive 2019-nCoV testing such as UAE, Qatar and Singapore.

Second, it could be argued that human mobility between China and Europe and between China and the US is high, therefore the number of cases in these regions are high. However, as China is a global manufacturing hub, human mobility between China and South-East Asia is also high and therefore the lower growth rate in these countries is perplexing (figure 1). Robust health infrastructure and quarantine measures developed after the 2003 SARS epidemic in Hong Kong, Singapore and Taiwan could have helped in containing the spread of the virus in these countries. However such sophisticated infrastructure does not exist in Malaysia, Thailand, Philippines, Cambodia and the lower growth rate in South-East Asia[4] cannot be explained by lower human mobility with China or robust health infrastructure.

Third, it could also be argued that the government in these countries is taking exceptional measures to stop the spread of the virus which we also know is not true. Until March 19, 2020 many south Asian and African countries were working in normal mode. Therefore, the significantly lower number of cases until now, in the densely populated countries between 0N and 30N (combined population of almost 3 billion people) may be due to natural factors that are limiting the spread of the virus. As mentioned earlier, viral transmission can be lower at higher humidity and temperature and most of the countries between 0 and 30N are warm and humid. Therefore, it appears that the spread of 2019-nCov might be influenced by environmental factors. **Based on the current data on the spread of 2019-nCoV, we hypothesize that the lower number of cases in tropical countries might be due to warm humid conditions, under which the spread of the virus might be slower as has been observed for other viruses.**

The relation between the number of 2019-nCoV cases and temperature and absolute humidity observed here is strong however, the underlying reasoning behind this relationship is still not clear. Similarly, we do not know which environmental factor is more important. It could be that either temperature or absolute humidity is more important, or both may be equally or not important at all in the transmission of 2019-nCoV. The temperature dependency of 2019-nCoV may be similar to that of SARS-Cov which loses its ability to survive in higher temperatures[13], due to the breakdown of their lipid layer at higher temperatures[14]. With approaching summer, it may also be that the temperature ranges we have seen so far for most of the cases (3 C to 17C) may be further broadened in the coming weeks, and any effect, if at all, may only happen at temperatures above 25C similar to that found in SARS-Cov[13]. The humidity dependency may be due to the less effective airborne nature of the viruses at higher absolute humidity, thus reducing the overall indirect transmission of 2019-nCoV at higher levels of humidity [21]. Although higher humidity may increase the amount of virus deposited on surfaces, and virus survival time in droplets on surfaces[21], the reduction of the virus spread by indirect (through air) transmission may be the factor behind the reduced 2019-nCoV spread in humid climate. These explanations are speculative and based on patterns observed for other coronaviruses. Urgent study/experiments on the association between coronavirus transmission against temperature and humidity in laboratories are needed to understand these associations.

**Implications for future transmission of 2019-nCoV:** Before March 11, 2020, 90% of the 2019-nCOV cases were recorded in places with temperature less than 11C and it appeared that temperature might play an important role in spread of the virus with higher temperature limiting the spread of the virus. However, almost 10,000 new cases were recorded in regions with temperature between 16 and 18C during March 10, 2020 to March 21, 2020, thereby challenging the hypothesis that rise in temperature would minimize the spread of the 2019-nCoV. Given that the northern hemisphere is approaching summer, it is expected to see a shift in the number of cases at slightly higher temperature due to warming, and the slight surge in the number of cases recorded at temperature between 16 and 18C should not force us to disregard exploring the association between temperature and the spread of 2019-nCoV (until there is enough evidence to show that 2019-nCoV spreads at warmer temperatures). Nonetheless the observation of more than 10,000 cases in the last 1 week makes it clear that the immediate effect of rising summer temperature would be limited in the current hotspot of Europe, and northern US, as the mean temperature for most of the major cities in these regions is below 20C for most of April and May.

It is highly plausible that we may see a rise in the number of cases in regions with temperature >20C in the next few weeks, and similar to SARS-CoV the temperature at which slow down of the transmission might happen (if any) may only be at above 25C. Indeed, laboratory experiments performed between 21-23C at a relative humidity of 40%, showed that the virus survived for several days on plastics and metals [20]. Therefore while we do think that temperature may have an effect based on the currently available data and there is evidence of previous relationship observed between SARS-CoV and temperature [13], we do not say at what temperature and to what extent it would reduce the spread of 2019-nCoV. Under any circumstances we believe that large gatherings (both indoor and outdoor) should be avoided across the world.

In comparison to temperature, absolute humidity is tightly bound throughout (figure 4) with >90% of cases occurring between 4 and 9 $g/m^3$. It has been suggested that absolute humidity plays an important role in the transmission of viruses [21–23] and its role in the transmission of 2019-nCoV should be thoroughly investigated. We calculated the theoretical absolute humidity for temperatures between -5 and 40C and RH between 0 and 100% (see equation 1). The absolute humidity is <9 $g/m^3$ for temperature below 15C (figure 5). For temperatures between 15 and 25 C, the relative humidity has to be higher than 60% for absolute humidity to be less than 9$g/m^3$ (figure 5). Based on currently available data, 2019-nCoV is spreading easily in regions with absolute humidity <10$g/m^3$. This has serious implications on the assumption that the 2019-nCoV spread would slow down during summer in the current hotspot of US and Europe as in many regions the absolute humidity might be above 10$g/m^3$ (figure 5) only for a brief period in July and August. On the other hand, Asian countries especially those experiencing monsoon have absolute humidity >10$g/m^3$ between June and September and may experience some relief in outdoor/indirect transmission of the virus.

**Recent spike in 2019-nCoV cases in warmer and humid regions:** In the last one week (March 13 - 21,2020), several countries in Asia, South America and Africa started showing an increase in the number of 2019-nCoV cases. It has been speculated that many countries will show an exponential increase in the number of 2019-nCoV cases, however we believe that this speculation is incorrect. Many of these countries were not testing for 2019-nCoV cases until recently and therefore a spike was expected once they start testing. We should also account for the difference between local transmission and exported cases (where the people got the infection elsewhere but tested in another region). Unlike the stringent lockdown imposed by the European and the US authorities, movement within and outside the country in the Middle East, Africa, South America and South Asia is reasonably fluid (as of March 20, 2020). In Pakistan [24] and Qatar [25] most of the cases are imported from Iran [24,25]. Malaysia recently confirmed 77 cases from a single event [26] and 2/3rd of the total cases have already been linked to that event as of March 17, 2020. We also believe that there might be a big surge in the cases in Indian subcontinent as the respective governments catch up on testing. The growth trajectory in the next one month in these relatively warm and humid countries (India, Pakistan and Bangladesh - together they account for 22% of global population) would be critical in understanding the dependency of 2019-nCoV cases on temperature and humidity.

**Limitations:** There may be several caveats to our work. Even though the number of reported cases has been taken directly from the WHO reports, several countries are underreporting the cases and have adopted different public health strategies[27]. For example, while Korea did widespread testing to identify potential 2019-nCoV positive subjects, including asymptomatic ones, to reduce the transmission, the US and several other countries, including UK, Japan etc decided to only test individuals with symptoms or in contact with 2019-nCoV positives. This may in turn lead to undetected cases and therefore even though the population may have a larger number of 2019-nCoV positives, they may go undetected until transmitting it to the most vulnerable in the population. Further, the rate of outdoor transmission versus indoor and direct versus indirect transmission are also not well understood and environmental related impacts are mostly applicable to outdoor transmissions.

**Recommendations:** There are significant implications of weather-related behavior observed in 2019-nCoV. Several governments have adopted the 'flatten the curve' strategy to mitigate the burden on healthcare instantly, spreading the number of patients requiring treatment over time to properly manage the medical needs of the patients and eventually slowing the spread of the pandemic in summer. While proper quarantine measures help in 'spreading the curve', we believe that warm humid conditions in the coming days will be of limited use (if any) to Europe and North America.

While we identified weather-related effects, we highly stress on using the proper quarantine measures even in warmer humid regions, to effectively reduce the transmission of 2019-nCoV and protect the vulnerables against it. Besides weather there are several other factors that may play roles in the number of affected cases in any region including population density, public health policies, political and social structures, healthcare quality, healthcare intervention, global connectedness etc. Future work should include using these factors, to predict the spread using time series modelling via Deep Learning e.g. LSTM (Long Short Term Modeling) [28,29] which is a recurrent artificial neural network and is considered state of the art for prediction of events in time series data.

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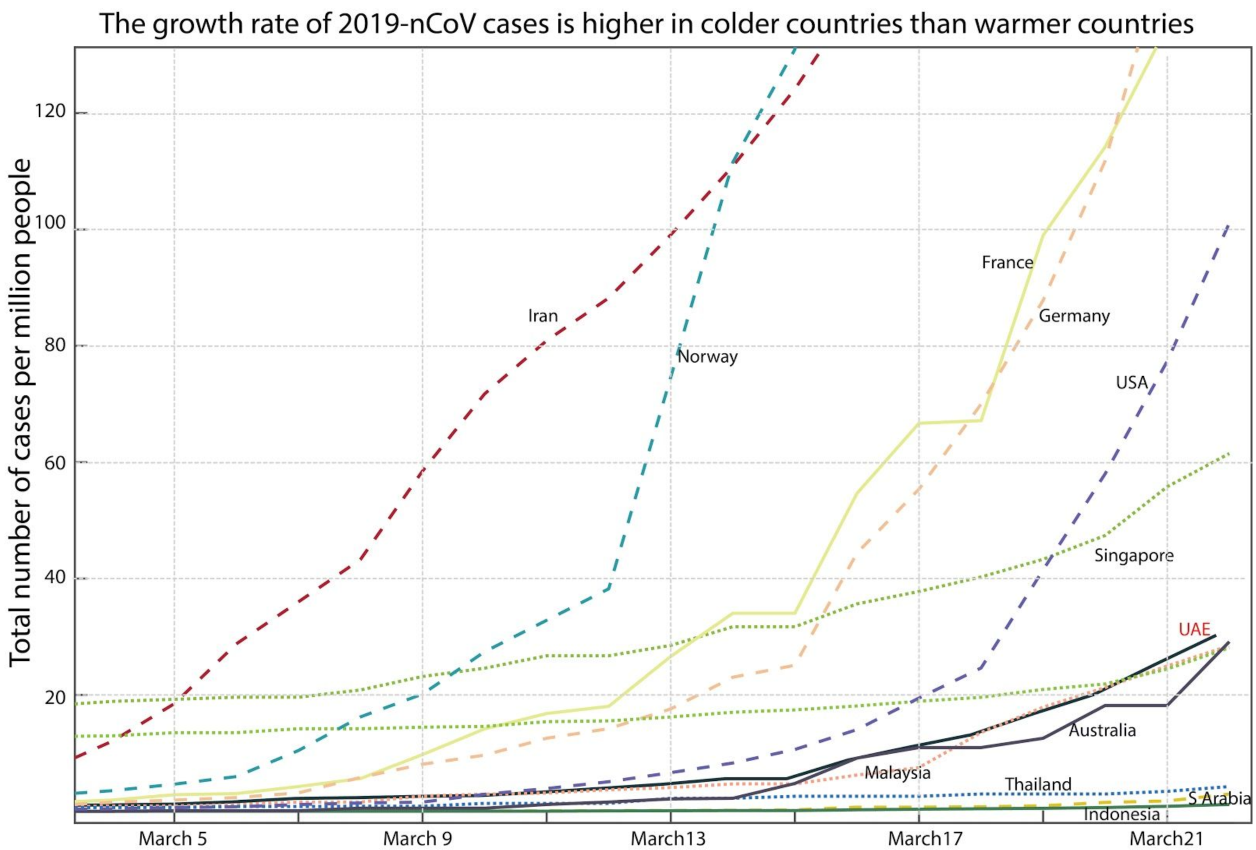


***Figure 1: Growth curve of 2019-nCoV cases for different countries (until March 19,2020).*** *The figure shows the total number of cases (normalized by the population of the country) between March 5 and March 22, 2020.. Different regions and states clearly follow different growth curves. The y-axis has been capped at 140 cases.*

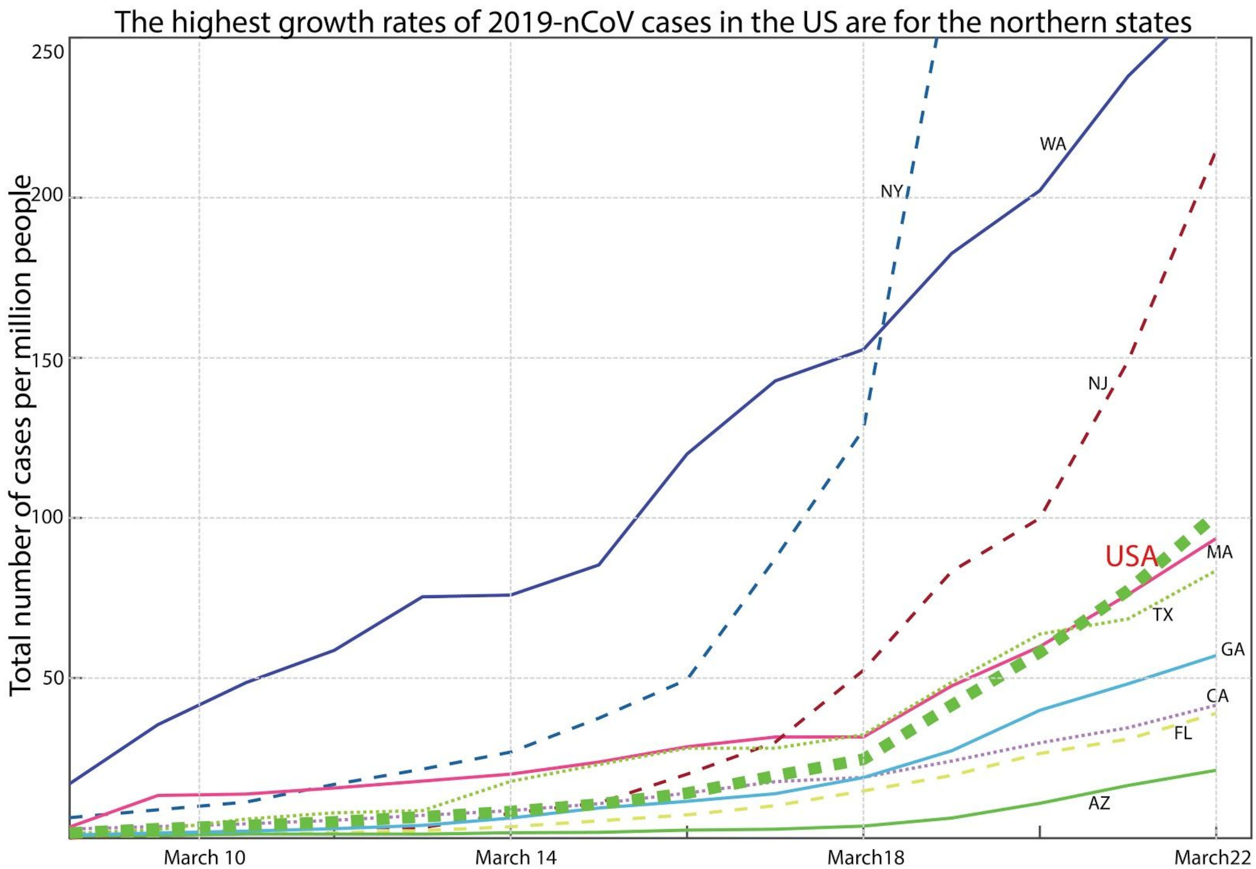


***Figure 2: Growth curve of 2019-nCoV cases for different US states (until March 19,2020).*** *The figure shows the total number of cases (normalized by the population of the state)) between March 7 and March 22, 2020.. Different states clearly follow different growth curves. The y-axis has been capped at 250 cases. NY: New York, WA: Washington, NJ: New Jersey, MA: MAssachusetts, TX: Texas, GA: Georgia, CA: California, FL: Florida and AZ: Arizona.*

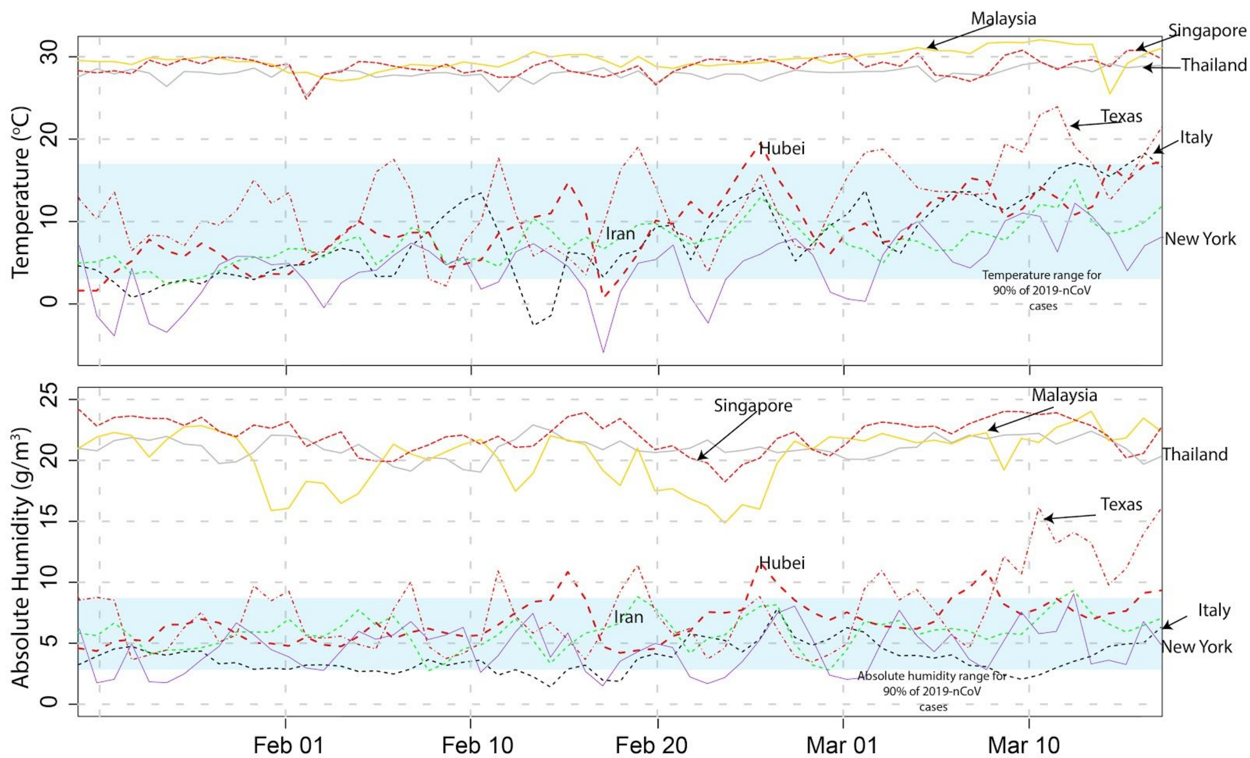


***Figure 3: Time series of temperature and absolute humidity across several 2019-nCoV impacted regions.*** *The regions with higher temperature and absolute humidity (Singapore and Thailand) have reported lesser 2019-nCoV cases. Hubei, the epicenter of the pandemic is shown as a red-dotted line. Temperature and absolute humidity range with the majority of 2019-nCoV cases (>90%) is highlighted with light blue color, and is consistently between 3 and 17 degree C for temperature and between 4 and 8 g/m$^3$ for absolute humidity.*

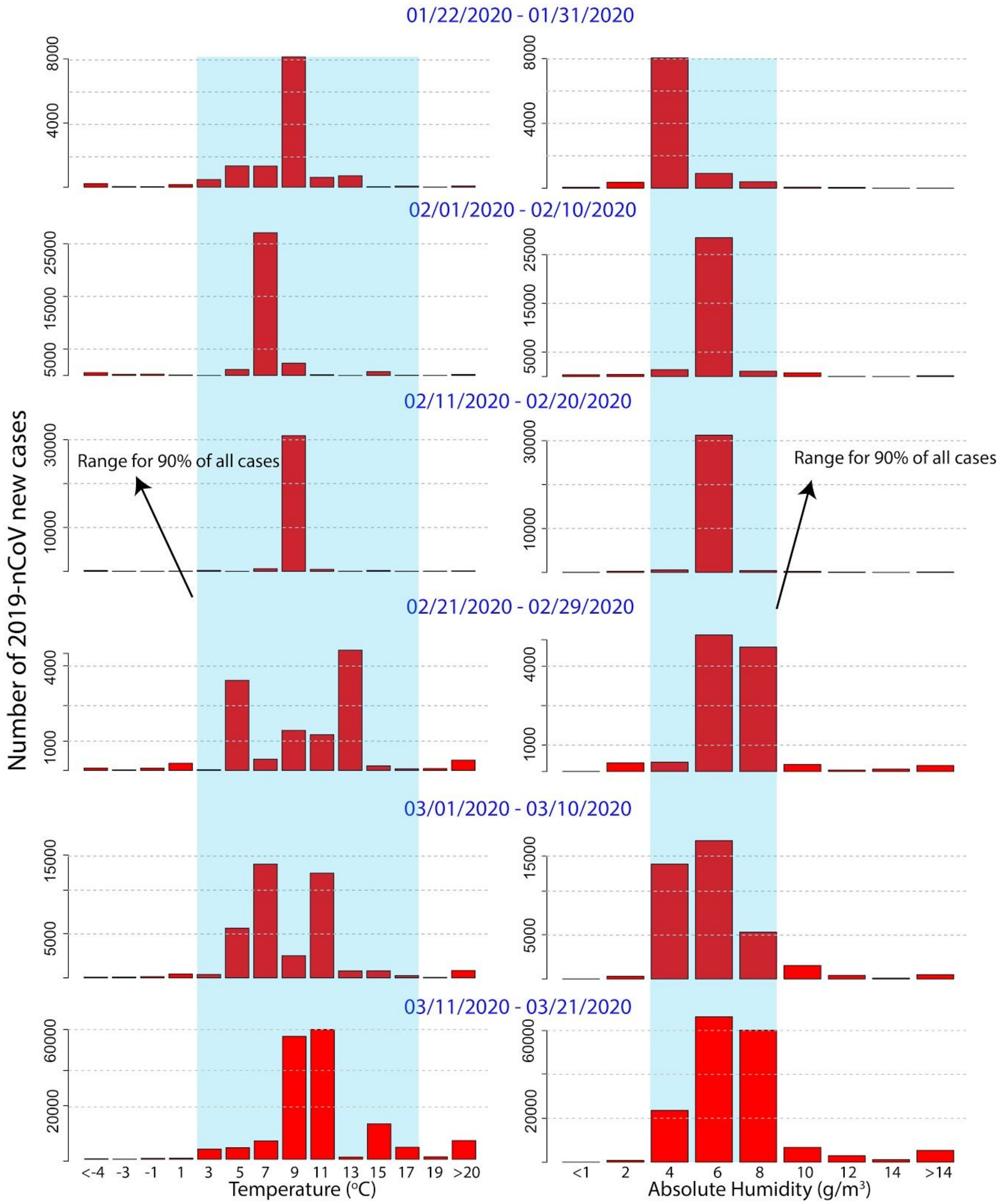


***Figure 4: Number of 2019-nCoV cases across the world as a function of temperature and absolute-humidity.*** *The figure shows the number of cases reported 2019-nCoV cases per 10 day period for different temperature and absolute humidity values. Temperature and absolute humidity range with the majority of 2019-nCoV cases (>90%) is highlighted with light blue color, and is consistently between 3 and 17 degree C for temperature and between 4 and 8 g/m*$^3$ *for absolute humidity every week.*

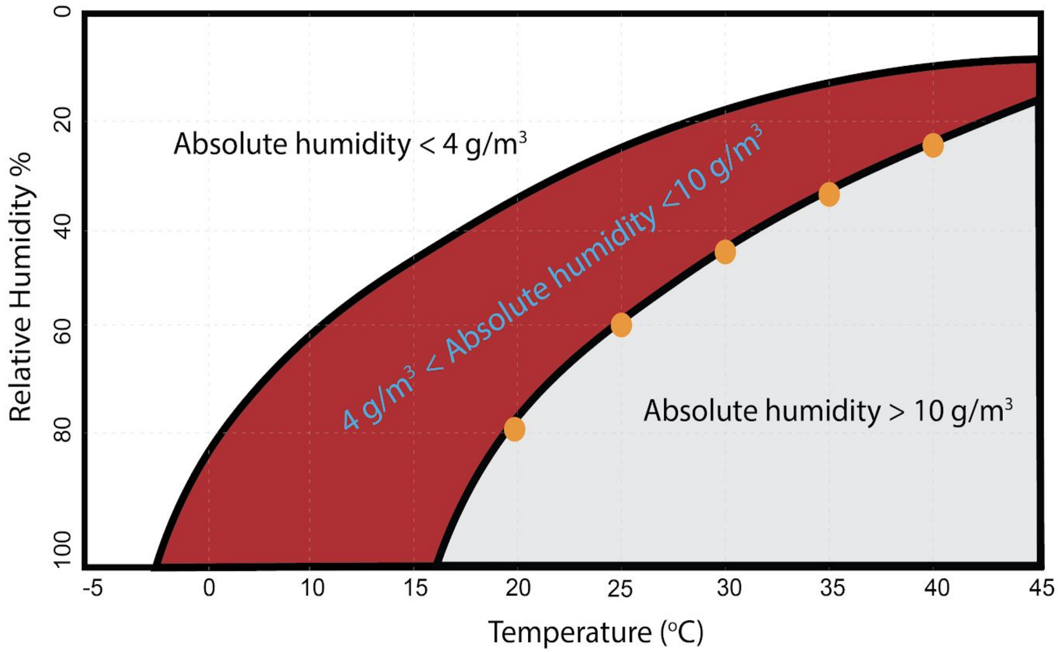


***Figure 5: Variation of absolute humidity with temperature and relative-humidity .*** *The figure shows the variation of absolute humidity as a function of relative humidity and temperature. More than 90% of the 2019-nCoV cases (so far) have occured in the area shown in red. Less than 10% of the cases have been reported in areas where absolute humidity is greater than 10 g/m$^3$ or less than 4g/m$^3$. The orange circles are the temperature-relative humidity pair above which the absolute humidity is >10 g/m$^3$.*