



Optimal temperature zone for the dispersal of COVID-19

Zhongwei Huang, Jianping Huang*, Qianqing Gu, Pengyue Du, Hongbin Liang, Qing Dong

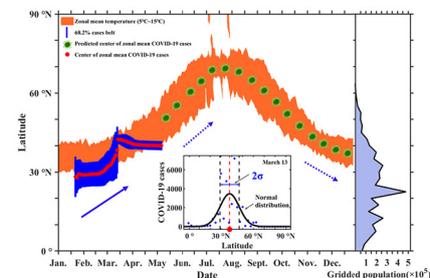
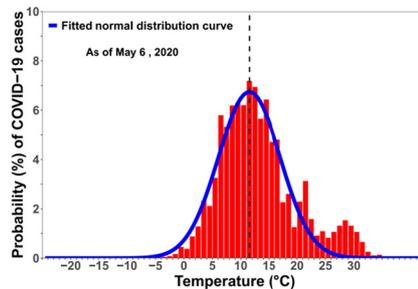
Collaborative Innovation Center for West Ecological Safety (CIWES), College of Atmospheric Sciences, Lanzhou University, Lanzhou 730000, China



HIGHLIGHTS

- We found that 60.0% of confirmed COVID-19 cases occurred in places where the air temperature ranged from 5°C to 15°C.
- Our results indicate that SARS-CoV-2 appears to be spreading toward higher latitudes.
- The COVID-19 pandemic may spread cyclically and outbreaks may recur in large cities in the mid-latitudes in autumn 2020.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 1 May 2020

Received in revised form 9 May 2020

Accepted 15 May 2020

Available online 16 May 2020

Keywords:

COVID-19
Temperature
SARS-CoV-2
Dispersal
Pandemic

ABSTRACT

It is essential to know the environmental parameters within which the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) can survive to understand its global dispersal pattern. We found that 60.0% of the confirmed cases of coronavirus disease 2019 (COVID-19) occurred in places where the air temperature ranged from 5 °C to 15 °C, with a peak in cases at 11.54 °C. Moreover, approximately 73.8% of the confirmed cases were concentrated in regions with absolute humidity of 3 g/m³ to 10 g/m³. SARS-CoV-2 appears to be spreading toward higher latitudes. Our findings suggest that there is an optimal climatic zone in which the concentration of SARS-CoV-2 markedly increases in the ambient environment (including the surfaces of objects). These results strongly imply that the COVID-19 pandemic may spread cyclically and outbreaks may recur in large cities in the mid-latitudes in autumn 2020.

© 2020 Elsevier B.V. All rights reserved.

1. Introduction

Recently, the coronavirus disease 2019 (COVID-19) outbreak has quickly spread globally and has shown significant impact on public health and economy (Chinazzi et al., 2020; Li et al., 2020; Rothe et al., 2020; Yan et al., 2020). Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the causative factor for the COVID-19 pandemic, can infect humans via several routes, such as inhalation of respiratory droplets or aerosols and contact with contaminated surfaces. Previous studies have indicated that SARS-CoV-2 can be detected in indoor as well as

outdoor air. Preliminary evidence clearly proved that the virus could cluster with outdoor particulate matter (PM) under certain circumstances (Jiang et al., 2020; Setti et al., 2020). Particularly, it is suggested that SARS-CoV-2 may have the potential to spread through aerosols, which can be produced by speaking at a normal volume (Anfinrud et al., 2020). In addition, it is found that SARS-CoV-2 can stay for a considerably long time in the air. The aerodynamic characteristics and propagation of SARS-CoV-2 in aerosols have been reported (Liu et al., 2020). It was reported that SARS-CoV-2 was still found in the Diamond Princess cruise ship 17 days after people disembarked.

Therefore, it is essential to understand the survival of SARS-CoV-2 in the ambient environment to prevent COVID-19. This information is very useful not only for the policymakers but also for the general population.

* Corresponding author.

E-mail address: hjp@lzu.edu.cn (J. Huang).

Many previous investigations have shown that the viability of viruses is strongly dependent on temperature (Tang, 2009; Huang et al., 2018). Transmission of influenza can be reduced under high temperature conditions (Lowen et al., 2008). It has been proven that high temperatures can effectively deactivate viruses, resulting in a large reduction in the amount of active viruses (Park et al., 2020). Recent studies have shown that the rate of confirmed COVID-19 cases is closely related to temperature (Triplett, 2020; Luo et al., 2020; Xie and Zhu, 2020). It is of great importance to determine the preferred temperature range of SARS-CoV-2 in order to help us prevent the COVID-19 outbreak. Particularly, hospitals and densely populated areas can be informed about optimal temperature ranges to reduce the probability of cross-infection. However, such knowledge is not currently available for SARS-CoV-2, which is a novel virus. Therefore, it cannot be utilized yet to prevent the spread of the COVID-19 pandemic.

To address these knowledge gaps, we investigated the impact of ambient temperature on global dispersal of COVID-19. The relationship between daily confirmed cases of COVID-19 and meteorological conditions (temperature and humidity) was studied using the data of approximately 3,750,000 global confirmed COVID-19 cases. Section 2 briefly introduces the data and the methods used in this paper. The results and the discussion are presented in Section 3 and the conclusion is presented in Section 4.

2. Data and methods

In this study, global COVID-19 case datasets were downloaded from the Center for Systems Science and Engineering at Johns Hopkins University. Data of more than 3,750,000 confirmed COVID-19 cases from 185 countries/regions from January 21, 2020 to May 6, 2020 were included in this paper. The daily numbers of COVID-19 cases are being reported for each province or state in several large countries such as China and the United States. Zonal mean COVID-19 cases on each day were

calculated and fitted using normal distribution. The center and the standard deviation of the fitted curve were used to show the most serious dispersal regions.

Corresponding observational data of daily air temperature and dew-point temperature were obtained from the Weather Underground website (<https://www.wunderground.com/>). The relative humidity and the absolute humidity were calculated using daily air temperature and dew-point temperature. Maximum/minimum temperatures and temperature difference on each day were also calculated for each state/country. Furthermore, time-series of zonal mean temperature at 1000 mb in 2019 was calculated from National Centers for Environmental Prediction reanalysis data to study the trend of approximate global COVID-19 dispersal.

In addition, the Gridded Population of the World from 1980 to 2010 was developed by the Center for Global Environmental Research at the National Institute for Environmental Studies, Japan (Murakami and Yamagata, 2019). We calculated zonal means of gridded populations to show the locations with high population density.

3. Results and discussion

The global probability distribution of COVID-19 cases with respect to the ambient temperature is shown in Fig. 1. The temperature interval at each panel is 1 °C. The results clearly illustrate that 60.0% of the confirmed COVID-19 cases were found in places where the air temperature ranged from 5 °C to 15 °C, with a peak at 11 °C. However, there were few confirmed cases located at cold (lower than 0 °C) and hot (greater than 30 °C) regions. Fitting the results using normal distribution, we found that the mean and the standard deviation of the fitted normal distribution curve were 11.54 °C and 5.47 °C, respectively. A previous study analyzed the relationship between daily confirmed COVID-19 cases and air temperature from 122 cities in China (Xie and Zhu, 2020) and pointed out that confirmed COVID-19 cases increased by 4.861%/°C for ambient

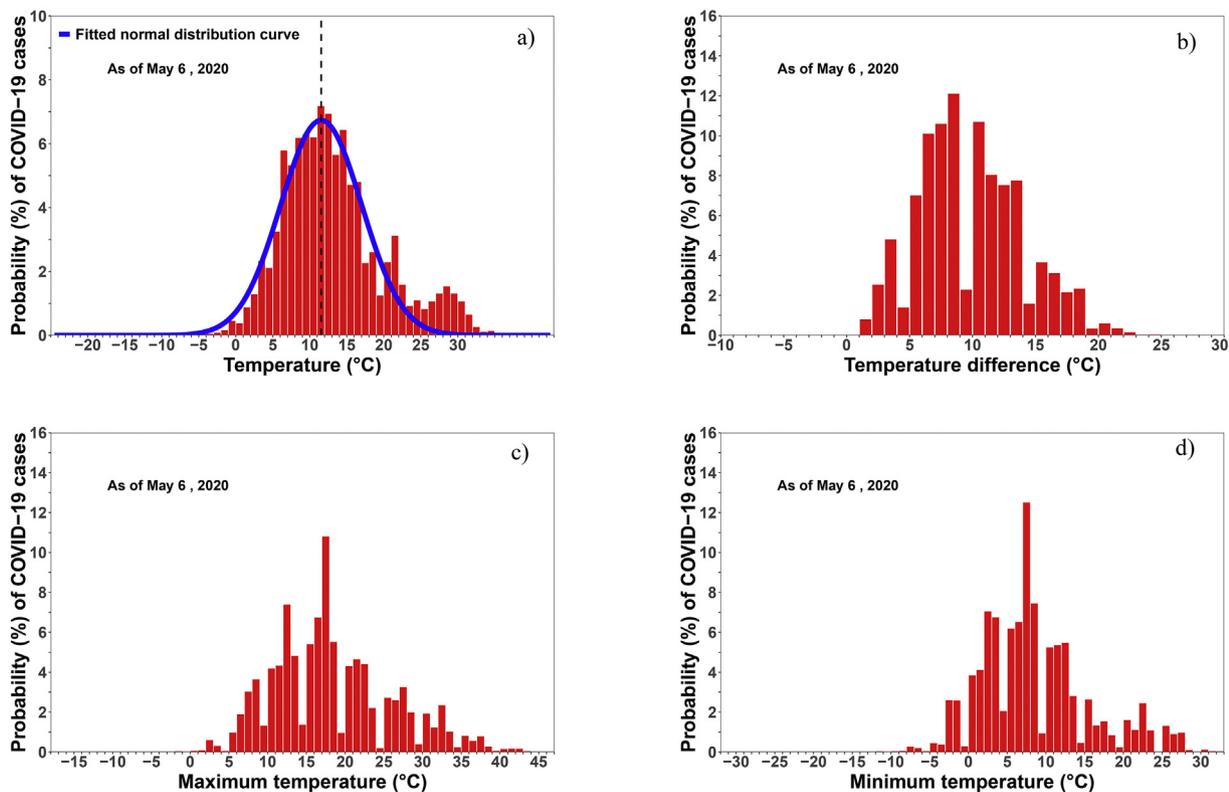


Fig. 1. Relationship of daily confirmed cases of coronavirus disease 2019 with (a) corresponding temperatures, (b) daily temperature difference, (c) maximum temperature, and (d) minimum temperature globally from January 22, 2020 to May 6, 2020. The blue line represents the fitted normal distribution curve.

temperature lower than 3 °C. Based on the analysis of global COVID-19 cases, our results demonstrated that confirmed COVID-19 cases increased by 27,536 cases/°C for ambient temperature lower than 10 °C. Thus, the rate of increase in COVID-19 cases induced by temperature may have been underestimated by the previous study.

To understand the impact of ambient temperature on dispersal of global COVID-19 pandemic in a better way, we investigated the relationship between daily confirmed cases and maximum/minimum temperatures. It was observed that most of the daily COVID-19 cases were located in regions with maximum temperature range of 5 °C to 30 °C. A similar study by Triplett (2020) indicated that the rate of confirmed COVID-19 cases will be significantly reduced when maximum temperature reaches above 22.5 °C. Moreover, the cases were mainly concentrated in regions with minimum temperature range of 0 °C to 15 °C. It is well known that large daily temperature difference may easily trigger influenza. Therefore, we investigated the relationship between daily confirmed cases and temperature difference. The results showed that rapid increase in the number of COVID-19 cases was associated with a daily temperature difference threshold of 8 °C and the number of

cases decreased when daily temperature difference was greater than 8 °C. These results indicated that there was a nonlinear association between confirmed cases of COVID-19 and daily temperature difference.

There was an obvious relationship between the number of confirmed cases and relative humidity, with a peak at 65% (Fig. 2). The distribution was much broader (30% to 100%) when compared with distribution of COVID-19 cases according to temperature. Additionally, we analyzed the variation in the number of confirmed COVID-19 cases according to absolute humidity. Approximately 73.8% of the cases were concentrated in regions with absolute humidity ranging from 3 g/m³ to 10 g/m³, with a peak at 5 g/m³. This result suggests that humid conditions were conducive for the spread of the COVID-19 pandemic.

Fig. 3 presents the time-series zonal distribution of daily COVID-19 cases and their dispersal trend. As shown in Fig. 3(a), the temperature zone (5 °C–15 °C) and the center of the fitted normal distribution curve of the zonal mean daily cumulative COVID-19 cases were coincident. The center of the zone denoting COVID-19 cases moved toward higher latitude along with the temperature zone. Notably, there was a

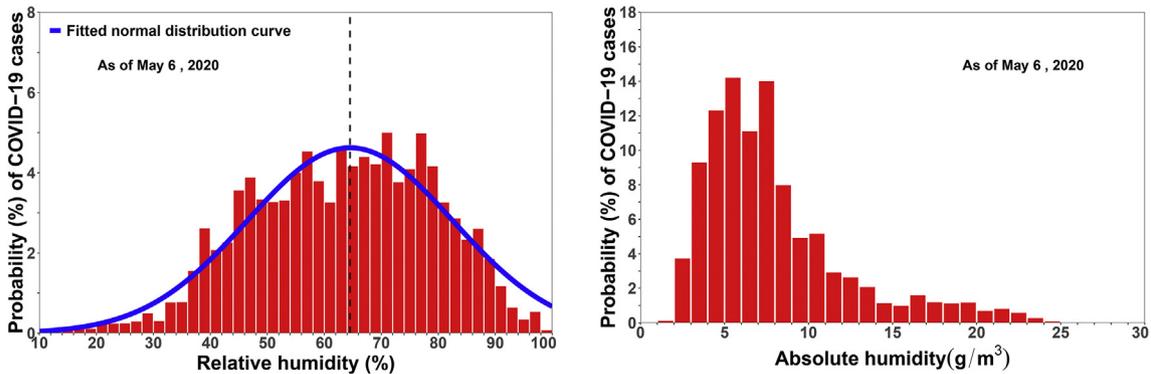


Fig. 2. Relationship of daily confirmed cases of coronavirus disease 2019 with (left) daily relative humidity and (right) absolute humidity. The blue line represents the fitted normal distribution curve.

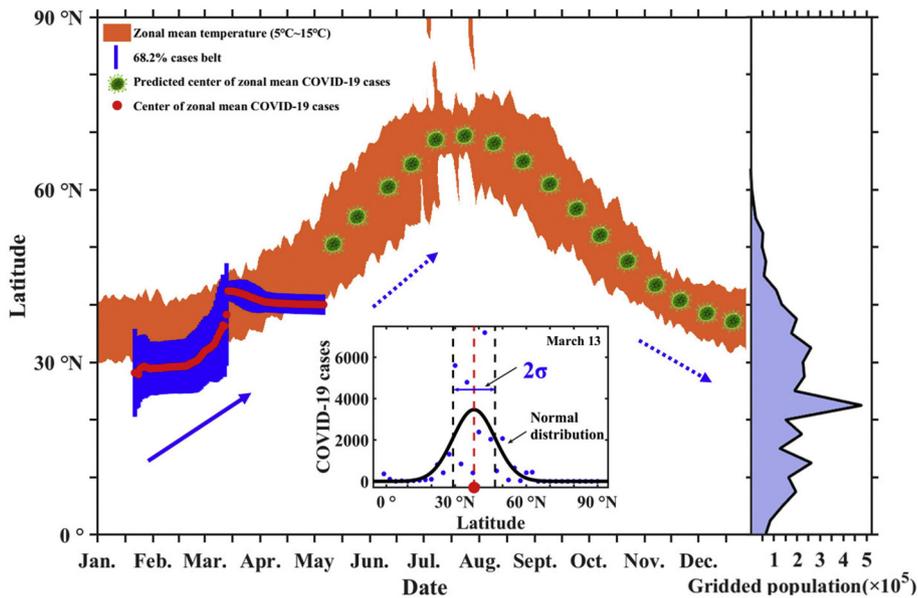


Fig. 3. (a) Relationship between cumulative cases of coronavirus disease 2019 (COVID-19) and temperatures from January 22, 2020 to May 6, 2020. The orange zone represents the latitudinal zone with a mean surface temperature between 5 °C and 15 °C in 2019 according to a reanalysis of the National Centers for Environmental Prediction data. Blue lines (red points) represent the standard derivation (center) of the fitted normal distribution curve of zonal mean cumulative COVID-19 cases each day. The illustration is an example of the normal distribution fitted on March 13, 2020. Notably, daily COVID-19 cases in several countries such as China, the United States, and Canada were counted separately for each province. (b) Zonal mean of the gridded populations from 1980 to 2010 developed by the Center for Global Environmental Research at the National Institute for Environmental Studies, Japan.

breakpoint on March 14, 2020 due to the outbreak of COVID-19 in Europe. As a result, the center of the zone denoting COVID-19 cases switched to 42.39°N and its standard deviation became much smaller. Clearly, most of the cases (68.2%) of COVID-19 occurred at higher latitudes, spreading along a path where the temperature ranged from 5 °C to 15 °C. This finding confirms that air temperature truly affects the distribution of COVID-19. It is noteworthy that the COVID-19 pandemic has not spread to areas with high population densities. Hence, we predict that the center of the fitted normal distribution curve of zonal mean COVID-19 cases will continually move to higher latitudes along the temperature zone between 5 °C to 15 °C over time. Therefore, the scale of the COVID-19 pandemic will be substantially reduced in early May and might recur in large mid-latitude cities in autumn 2020. It is very important to pay more attention to places at higher latitudes. In addition, mid-latitude locations with higher population densities will also face the possibility of another COVID-19 outbreak in the autumn.

Our findings suggest that there is an optimal climatic zone in which the concentration of SARS-CoV-2 markedly increases in the ambient environment (including the surfaces of objects). Even though the dispersal of the COVID-19 outbreak is affected by many countermeasures and medical conditions, our results confirm that there is an optimal temperature zone for the survival of SARS-CoV-2. The concentration of SARS-CoV-2 can markedly increase in the ambient environment including the surfaces of objects in this temperature range. It is worth recognizing that the spread of the COVID-19 outbreak is affected by several factors. In the present study, we investigated the natural factors affecting the COVID-19 pandemic. The analysis of large datasets (samples) yielded significant results with a high degree of confidence in the findings. These findings are important for the prediction of COVID-19 transmission in the near future. We cannot rely on the conjecture that COVID-19 outbreak will stop with increase in the temperature in summer. Undoubtedly, control strategies including school closure and social distancing have reduced the number of total cases considerably (Prem et al., 2020; Luo et al., 2020; Kissler et al., 2020).

4. Conclusion

We investigated the global dispersal of COVID-19 according to ambient temperature using data of approximately 3,750,000 global confirmed COVID-19 cases from January 21, 2020 to May 6, 2020. The results revealed that SARS-CoV-2 has a greater chance of survival in the ambient environment within the optimal temperature zone, suggesting that more attention should be paid to preventive measures when the air temperatures are between 5 °C and 15 °C. Moreover, about 73.8% of the confirmed cases were concentrated in the absolute humidity range of 3 g/m³ to 10 g/m³, with a peak at 5 g/m³. The present study provides information about the survival of SARS-CoV-2, the transportation of the virus in the atmosphere on a global scale, and the modeling of the dispersal of viral diseases. Our findings are important for public health and suggest that air temperatures in hospitals and at home should be set outside the range of 5 °C to 15 °C. Furthermore, measures to prevent the disease should be implemented in areas within the optimal climatic zone, where the survival of SARS-CoV-2 may be enhanced. Policy makers need to establish an early warning system for pandemics by considering bioaerosol transport on a transcontinental or even a global scale. Such system should include weather forecasting and climatological analysis.

Author's contribution

J. H. contributed to the conceptualization, funding acquisition and writing. Z. H. contributed to the data curation, methodology and writing. Q. G., P. D., H. L., and Q. D. contributed to the data curation and writing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Surface air temperature was provided by the Weather Underground Organization (WUO). Global COVID-19 cases data were provided by the Center for systems science and engineering at Johns Hopkins University. Zonal mean temperature at 1000 mb was provided from NCEP reanalysis data. Gridded populations during 1980-2010 was provided from the Center for Global Environmental Research (CGER) at National Institute for Environmental Studies, Japan.

Funding

This work was jointly supported by the National Science Foundation of China (41521004, 41705077, and 41875029), and Gansu Provincial Special Fund Project for Guiding Scientific and Technological Innovation and Development (2019ZX-06).

References

- Anfinrud, P., Stadnytskyi, V., Bax, C.E., Bax, A., 2020. Visualizing speech-generated oral fluid droplets with laser light scattering. *N. Engl. J. Med.*, 1–2 <https://doi.org/10.1056/nejmc2007800>.
- Chinazzi, M., Davis, J.T., Ajelli, M., Gioannini, C., Litvinova, M., Merler, S., Pastore Y Piontti, A., Mu, K., Rossi, L., Sun, K., Viboud, C., Xiong, X., Yu, H., Halloran, M.E., Longini, I.M., Vespignani, A., 2020. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. *Science (New York, N.Y.)* 9757 (March), 1–12. <https://doi.org/10.1126/science.aba9757>.
- Huang, J., Liu, X., Li, C., Ding, L., Yu, H., 2018. The global oxygen budget and its future projection. *Sci. Bull.* 63, 1180–1186. <https://doi.org/10.1016/j.scib.2018.07.023>.
- Jiang, Y., Wang, H., Chen, Y., He, J., Chen, L., Liu, Y., Hu, X., Li, A., Liu, S., Zhang, P., Zou, H., Hua, S., 2020. Clinical Data on Hospital Environmental Hygiene Monitoring and Medical Staffs Protection during the Coronavirus Disease 2019 Outbreak. <https://doi.org/10.1101/2020.02.25.20028043>.
- Kissler, S., Tedijanto, C., Goldstein, E., Grad, Y., Lipsitch, M., 2020. Projecting the Transmission Dynamics of SARS-CoV-2 Through the Post-Pandemic Period. <https://doi.org/10.1101/2020.03.04.20031112>.
- Li, R., Pei, S., Chen, B., Song, Y., Zhang, T., Yang, W., Shaman, J., 2020. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV2). *Science (New York, N.Y.)* 3221 (January), 1–9. <https://doi.org/10.1126/science.abb3221>.
- Liu, Y., Ning, Z., Chen, Y., Guo, M., Liu, Y., Gali, N.K., Sun, L., Duan, Y., Cai, J., Westerdahl, D., Liu, X., Xu, K., Ho, K., Kan, H., Fu, Q., Lan, K., 2020. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. *Nature* <https://doi.org/10.1038/s41586-020-2271-3>.
- Lowen, A.C., Steel, J., Mubareka, S., Palese, P., 2008. High temperature (30°C) blocks aerosol but not contact transmission of influenza virus. *J. Virol.* 82 (11), 5650–5652. <https://doi.org/10.1128/jvi.00325-08>.
- Luo, W., Majumder, M.S., Liu, D., Poirier, C., Mandl, K.D., Lipsitch, M., Santillana, M., 2020. The role of absolute humidity on transmission rates of the COVID-19 outbreak. *MedRxiv* <https://doi.org/10.1101/2020.02.12.20022467> 2020.02.12.20022467.
- Murakami, D., Yamagata, Y., 2019. Estimation of gridded population and GDP scenarios with spatially explicit statistical downscaling. *Sustainability (Switzerland)* 11 (7), 1–18. <https://doi.org/10.3390/su11072106>.
- Park, J.E., Son, W.S., Ryu, Y., Choi, S.B., Kwon, O., Ahn, I., 2020. Effects of temperature, humidity, and diurnal temperature range on influenza incidence in a temperate region. *Influenza Other Respir. Viruses* 14 (1), 11–18. <https://doi.org/10.1111/irv.12682>.
- Prem, K., Liu, Y., Russell, T.W., Kucharski, A.J., Eggo, R.M., Davies, N., Flasche, S., Clifford, S., Pearson, C.A.B., Munday, J.D., Abbott, S., Gibbs, H., Rosello, A., Quilty, B.J., Jombart, T., Sun, F., Diamond, C., Gimma, A., van Zandvoort, K., ... Klepac, P., 2020. The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: a modelling study. *The Lancet Public Health* 2667 (20), 1–10. [https://doi.org/10.1016/S2468-2667\(20\)30073-6](https://doi.org/10.1016/S2468-2667(20)30073-6).
- Rothe, C., Schunk, M., Sothmann, P., Bretzel, G., Froeschl, G., Wallrauch, C., Zimmer, T., Thiel, V., Janke, C., Guggemos, W., Seilmaier, M., Drosten, C., Vollmar, P., Zwirgmaier, K., Zange, S., Wölfel, R., Hoelscher, M., 2020. Transmission of 2019-NCoV infection from an asymptomatic contact in Germany. *N. Engl. J. Med.* 382 (10), 970–971. <https://doi.org/10.1056/NEJMc2001468>.
- Setti, L., Passarini, F., de gennaro, G., Baribieri, P., Perrone, M., Borelli, M., Palmisani, J., Gilio, A., Torboli, V., Pallavicini, A., Ruscio, M., PISCITELLI, P., Miani, A., 2020. SARS-Cov-2 RNA Found on Particulate Matter of Bergamo in Northern Italy: First Preliminary Evidence. <https://doi.org/10.1101/2020.04.15.20065995>.
- Tang, J.W., 2009. The effect of environmental parameters on the survival of airborne infectious agents. *J. R. Soc. Interface* 6 (Suppl. 6). <https://doi.org/10.1098/rsif.2009.0227>.

- Triplett, M., 2020. Evidence that Higher Temperatures Are Associated with Lower Incidence of COVID-19 in Pandemic State, Cumulative Cases Reported up to March 27, 2020. MedRxiv, 2020.04.02.20051524. <https://doi.org/10.1101/2020.04.02.20051524>.
- Xie, J., Zhu, Y., 2020. Association between ambient temperature and COVID-19 infection in 122 cities from China. Sci. Total Environ. 724, 138201. <https://doi.org/10.1016/j.scitotenv.2020.138201>.
- Yan, R., Yan, R., Zhang, Y., Li, Y., Xia, L., Guo, Y., Zhou, Q., 2020. Structural basis for the recognition of the SARS-CoV-2 by. Science 367 (6485), 1444–1448. <https://doi.org/10.1126/science.abb2762>.