



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



Short Communication

Correlation of ambient temperature and COVID-19 incidence in Canada

Teresa To^{a,b,*}, Kimball Zhang^a, Bryan Maguire^c, Emilie Terebessy^a, Ivy Fong^a, Supriya Parikh^c, Jingqin Zhu^a

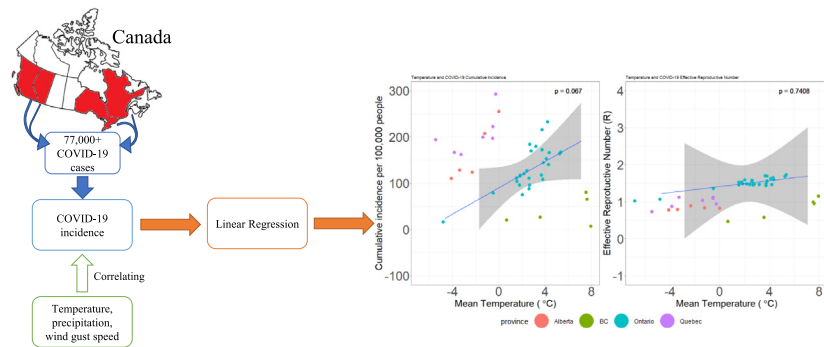
^a Child Health Evaluative Sciences, Research Institute, The Hospital for Sick Children, Toronto, ON, Canada
^b Dalla Lana School of Public Health, University of Toronto, Toronto, ON, Canada
^c Biostatistics, Design and Analysis, Research Institute, The Hospital for Sick Children, Toronto, ON, Canada



HIGHLIGHTS

- Studied effects of temperature on COVID-19 with daily meteorological data in Canada
- Used 99.6% of Canada's cases from January to May 2020 (77,700+) from four provinces
- No significant association between ambient temperature and COVID-19 incidence

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
 Received 19 June 2020
 Received in revised form 31 July 2020
 Accepted 3 August 2020
 Available online 4 August 2020

Editor: Jay Gan

Keywords:
 SARS-CoV-2
 COVID-19
 Temperature
 Reproductive number
 Canada

ABSTRACT

The SARS-CoV-2 is a novel coronavirus identified as the cause of COVID-19 and, as the pandemic evolves, many have made parallels to previous epidemics such as SARS-CoV (the cause of an outbreak of severe acute respiratory syndrome [SARS]) in 2003. Many have speculated that, like SARS, the activity of SARS-CoV-2 will subside when the climate becomes warmer. We sought to determine the relationship between ambient temperature and COVID-19 incidence in Canada. We analyzed over 77,700 COVID-19 cases from four Canadian provinces (Alberta, British Columbia, Ontario, and Quebec) from January to May 2020. After adjusting for precipitation, wind gust speed, and province in multiple linear regression models, we found a positive, but not statistically significant, association between cumulative incidence and ambient temperature (14.2 per 100,000 people; 95%CI: -0.60–29.0). We also did not find a statistically significant association between total cases or effective reproductive number of COVID-19 and ambient temperature. Our findings do not support the hypothesis that higher temperatures will reduce transmission of COVID-19 and warns the public not to lose vigilance and to continue practicing safety measures such as hand washing, social distancing, and use of facial masks despite the warming climates.

© 2020 Elsevier B.V. All rights reserved.

1. Background

The novel coronavirus disease (COVID-19) is caused by the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) (World Health Organization, 2020a). Coronaviruses are enveloped RNA viruses that cause respiratory illnesses of varying severity from the common cold to fatal pneumonia. The COVID-19 outbreak was declared a Public

* Corresponding author at: Child Health Evaluative Sciences, Peter Gilgan Centre for Research and Learning, The Hospital for Sick Children, 686 Bay St, Toronto, ON M5G 0A4, Canada.

E-mail address: teresa.to@sickkids.ca (T. To).

Health Emergency of International Concern by the World Health Organization (WHO) on 30 January 2020. Over a month later, with a 13-fold increase in the number of cases outside China and 3-fold increase in the number of countries with reported cases, the WHO declared the COVID-19 outbreak a global pandemic on March 11, 2020. Countries across the world began to launch various aggressive, but common, actions to contain the virus (e.g. national lockdown, closure of school and non-essential services, social/physical distancing, hand sanitizing, use of face mask coverings, self-isolation, etc.). While these actions have had strong disease control and some environmental benefits, it is coupled with rapidly increasing unemployment rates (Juni et al., 2020; Collivignarelli et al., 2020; Zambrano-Monserrate et al., 2020). As a result, the world population faces a significant health and economic burden from COVID-19. As of June 15, 2020, over 7.9 million individuals have been infected with COVID-19 and over 443,000 have died of it globally (Dong et al., 2020).

As the COVID-19 pandemic evolves globally over several seasons, the role of the climate and environment are important factors to consider in transmission. For example, previous studies in California and Italy have shown that air pollutants are associated with increased COVID-19 incidence (Bashir et al., 2020a; Fattorini and Regoli, 2020). In terms of temperature, many have drawn parallels between the COVID-19 pandemic with previous epidemics such as SARS-CoV (the cause of an outbreak of severe acute respiratory syndrome [SARS]) in 2003. Many speculated that, like SARS, the activity of SARS-CoV-2 would subside when the climate becomes warmer. This speculation is drawn from the inverse relationship between warm temperatures and viral infections, including influenza and other coronaviruses like MERS-CoV (Fagbo et al., 2017; Lowen et al., 2007). Likeness of viral activity between SARS-CoV-2 and SARS-CoV is especially emphasized given their similarities in genetics (~79%) (Lu et al., 2020) and their hypothesized primary reservoir of bats (Wang et al., 2006; Lai et al., 2020). However, the widespread cases in warmer climate countries such as India, Iran, and Brazil have contradicted the aforementioned speculation. Nevertheless, this speculation was so widespread that the WHO issued a statement on its web page of COVID-19 myth busters to caution the public that “Exposing yourself to the sun or to temperatures higher than 25 °C degrees DOES NOT prevent the coronavirus disease (COVID-19)” (World Health Organization, 2020b).

Given its novelty, there is a limited but rapidly growing body of literature on SARS-CoV-2 and meteorological conditions. To date, there have been a limited number of peer-reviewed publications with a major focus on studying the effect of ambient temperature on the transmission of COVID-19. Table 1 provides a literature review of the findings of these studies. Seven of these studies used data from China and the rest were from various parts of the world. All but one of the studies with data from China showed a negative correlation between temperature and COVID-19 incidence (i.e. every unit increase in temperature was associated with decreasing COVID-19 cases). Similarly, among the 10 studies that excluded China, six reported negative correlations, three showed no significant association, and another suggested a questionable association. The mixed and contrasting evidence among observational studies still warrant the need for further investigation. Thus, in the face of inconsistent findings in the literature and an increased urgency to understand this new disease, this study aims to examine the association between temperature and COVID-19 incidence in Canada.

2. Methods

2.1. Data sources

Our study used Canadian data to study the potential correlation between ambient temperature and the incidence of COVID-19. Four Canadian provinces (Alberta, British Columbia, Ontario, and Quebec) were included in this study, where the cumulative number of COVID-19 cases was above 77,700. Individual-level epidemiologic data of positive

COVID-19 cases from January to May 2020 were obtained from open access datasets. Ontario case data were obtained from a dataset compiled by the Ontario Ministry of Health and Long-Term Care based on information reported by local public health agencies (Ontario Ministry of Health, 2020). Case data for the other three provinces were obtained from a dataset with individual-level data which were collected and updated from publicly available sources including government reports, government websites, and news media by the COVID-19 Canada Open Data Working Group, a team at the University of Toronto (Berry et al., 2020).

2.2. Statistical analysis

We aggregated the COVID-19 incidence data by report date and Canadian health regions. Canadian health regions are administrative geographical units defined by provincial health ministries to facilitate the delivery of health care to communities within the regions. Daily data on mean, minimum, and maximum ambient temperature (°C), total precipitation (mm), and maximum wind gust speed (km/h) were obtained from January to May 2020 from Environment and Climate Change Canada (Environment Canada, 2019); they were averaged across Canadian health regions. Time-varying effective reproductive number (R_t) was calculated from daily case data (Thompson et al., 2019). Cumulative incidence rate per 100,000 was calculated from the total case count divided by the regional population count in 2016 from Statistics Canada (Statistics Canada, 2019). Regions with less than 50 COVID-19 incident cases were excluded from the study.

All province data provided a report date for each case. To estimate the climate around time of infection, climate data was averaged 2 weeks prior to the report date. Linear regression models were used to generate point estimates and 95% confidence intervals (CIs) for associations between temperature and the R_t , total cumulative incident cases, and cumulative incidence rate. Models were made using the latest data available, up to 18 May 2020. Covariates for models were selected a priori. All models were adjusted for wind gust speed, precipitation, and province. Regression models were adjusted for the province where the health region was located to control for different social distancing and public health policies that may have been in place. Statistical significance was defined where p -values were < 0.05 . All analyses were performed in R software (version 4.0.0) with the rms (v6.0.0) and tidyverse (v1.3.0) packages (R Foundation, 2020; Harrell Jr, 2020; Wickham et al., 2019).

3. Results

We observed 49 health regions across four Canadian provinces that collectively made up 99.6% (77,773) of Canada's COVID-19 cases from January 25 to May 18, 2020. The mean \pm standard deviation and range (min-max) for temperature was (1.48 \pm 3.46, -6.83-7.94), wind gust speed was (43.5 \pm 2.45, 29.9-49.5), and precipitation was (2.03 \pm 0.78, 0.44-3.72). Mean temperature and total precipitation tended to decrease at higher latitudes. The mean \pm standard deviation and range for R_t and cumulative incidence were (1.27 \pm 1.25, 0.27-8.85) and (133.7 \pm 100.4, 15.8-415.7), respectively. Total cumulative cases and cumulative incidence rates tended to be highest in and around urban centres.

After adjusting for wind gust speed, precipitation, and province, our results did not find a statistically significant association between temperature and R_t ($p=0.74$) (see Table 2). The multiple regression model, adjusted for wind gust speed, precipitation, and province, showed that per unit increase in temperature, there was an associated increase in COVID-19 incidence cases of 14.3 per 100,000 people (95% CI: -0.20-29.0; $p=0.07$), as shown in Table 2 and Fig. 1. However, this association was statistically nonsignificant. The association between temperature and cumulative incidence rate was further analyzed by province while adjusting for wind gust speed and precipitation. None

Table 1

Literature review of 17 peer-reviewed papers on temperature and COVID-19 (Juni et al., 2020; Demongeot et al., 2020; Ahmadi et al., 2020; Briz-Redon and Serrano-Aroca, 2020; Ma et al., 2020; Xie and Zhu, 2020; Byass, 2020; Jiang et al., 2020; Iqbal et al., 2020; Al-Rousan and Al-Najjar, 2020; Liu et al., 2020; Sobral et al., 2020; Tosepu et al., 2020; Eslami and Jalili, 2020; Bashir et al., 2020b; Wu et al., 2020; Prata et al., 2020).

| Title | Authors | Location | Journal | Findings | | URL |
|---|--------------------------------|--|-------------------------------|---|-------------------------------|--|
| Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China | Ma Y et al | China | Sci Total Environ | 1 unit increase of temperature and absolute humidity were related to the decreased COVID-19 death in lag 3 and lag 5, with the greatest decrease both in lag 3 [-7.50% (95% CI: -10.99%, -3.88%) and -11.41% (95% CI: -19.68%, -2.29%)]. | ↑T ↓ | Sci Total Environ. 2020 Jul 1;724:138226. doi: 10.1016/j.scitotenv.2020.138226. Epub 2020 Mar 26. |
| Association between ambient temperature and COVID-19 infection in 122 cities from China | Xie J et al | China | Sci Total Environ | When mean temperature (lag0-14) was below 3 °C, each 1 °C rise was associated with a 4.861% (95% CI: 3.209-6.513) increase in the daily number of COVID-19 confirmed cases | only at the threshold of 3 °C | Sci Total Environ. 2020 Jul 1;724:138201. doi: 10.1016/j.scitotenv.2020.138201. Epub 2020 Mar 30. |
| Eco-epidemiological assessment of the COVID-19 epidemic in China, January-February 2020 | Byass P | China | Glob Health Action | Adjusted incidence rate ratios suggested brighter, warmer and drier conditions were associated with lower incidence | ↑T ↓ | Glob Health Action. 2020 Dec 31;13(1):1760490. doi:10.1080/16549716.2020.1760490. |
| Effect of ambient air pollutants and meteorological variables on COVID-19 incidence | Jiang Y et al | China | Infect Control Hosp Epidemiol | The relative risk of temperature and COVID19 cases was 0.738 (95% CL, 0.717 - 0.759) to 0.969 (95% CL, 0.966 - 0.973); but may not be independent of PM10. | ↑T ↓ | Infect Control Hosp Epidemiol. 2020 May 11:1-11. doi: 10.1017/ice.2020.222. [Epub ahead of print] |
| The nexus between COVID-19, temperature and exchange rate in Wuhan city: New findings from partial and multiple wavelet coherence | Iqbal N et al | China | Sci Total Environ | The overall results suggest the insignificance of an increase in temperature to contain or slow down the new COVID-19 infections | No association | Sci Total Environ. 2020 Apr 22;729:138916. doi: 10.1016/j.scitotenv.2020.138916. [Epub ahead of print] |
| The correlation between the spread of COVID-19 infections and weather variables in 30 Chinese provinces and the impact of Chinese government mitigation plans | Al-Rousan N et al | China | Eur Rev Med Pharmacol Sci | This study predicted the spread of CoVID-19 before and after applying the Chinese rules and regulations on COVID-19 infections. These findings indicate that weather conditions, particularly higher temperatures and short-wave radiation, increase the number of confirmed, fatal, and recovered cases in most of the Chinese provinces | ↑T ↑ | Eur Rev Med Pharmacol Sci. 2020 Apr;24(8):4565-4571. doi:10.26355/eurrev_202004_21042 |
| Impact of meteorological factors on the COVID-19 transmission: A multi-city study in China | Liu J et al | China | Sci Total Environ | Each 1 °C increase in ambient temperature and diurnal temperature range was related to the decline of daily confirmed case counts, and the corresponding pooled RRs were 0.80 (95% CI: 0.75, 0.85) and 0.90 (95% CI: 0.86, 0.95), respectively. | ↑T ↓ | Sci Total Environ. 2020 Apr 9;726:138513. doi: 10.1016/j.scitotenv.2020.138513.[Epub ahead of print] |
| Association between climate variables and global transmission of SARS-CoV-2 | Sobral MFF et al | Global | Sci Total Environ | An increase in the average daily temperature by one degree Fahrenheit reduced the number of cases by approximately 6.4 cases/day. | ↑T ↓ | Sci Total Environ. 2020 Apr 27;729:138997. doi: 10.1016/j.scitotenv.2020.138997. [Epub ahead of print] |
| Correlation between weather and Covid-19 pandemic in Jakarta, Indonesia | Tosepu R et al | Indonesia | Sci Total Environ | Among the components of the weather, only temperature average (°C) was significantly correlated with covid-19 pandemic (r = 0.392; p < .01). | ↑T ↓ | Sci Total Environ. 2020 Apr 4;725:138436. doi: 10.1016/j.scitotenv.2020.138436. [Epub ahead of print] |
| The role of environmental factors to transmission of SARS-CoV-2 (COVID-19) | Eslami H et al | Iran | AMB Express | Minimum ambient air temperature increases by 1 °C, the cumulative number of cases decreases by 0.86%. | ↑T ↓ | AMB Express. 2020 May 15;10(1):92. doi: 10.1186/s13568-020-01028-0 |
| Correlation between climate indicators and COVID-19 pandemic in New York, USA | Bashir MF et al | New York City, US | Sci Total Environ | average temperature, minimum temperature, and air quality were significantly associated with the COVID-19 pandemic. | ↑T ↓ | Sci Total Environ. 2020 Apr 20;728:138835. doi: 10.1016/j.scitotenv.2020.138835. [Epub ahead of print] |
| Impact of climate and public health interventions on the COVID-19 pandemic: A prospective cohort study | Jüni P et al | 144 geopolitical areas except China, S Korea, Iran and Italy | CMAJ | Epidemic growth of COVID-19 was not associated with latitude and temperature | No association | CMAJ. 2020 May 8. pii: cmaj.200920. doi: 10.1503/cmaj.200920. [Epub ahead of print] |
| Effects of temperature and humidity on the daily new cases and new deaths of COVID-19 in 166 countries | Wu Y et al | 166 countries except China | Sci Total Environ | 1 °C increase in temperature was associated with a 3.08% (95% CI: 1.53%, 4.63%) reduction in daily new cases and a 1.19% (95% CI:0.44%, 1.95%) reduction in daily new deaths | ↑T ↓ | Sci Total Environ. 2020 Apr 28;729:139051. doi: 10.1016/j.scitotenv.2020.139051. [Epub ahead of print] |
| Temperature Decreases Spread Parameters of the New Covid-19 Case Dynamics | Demongeot J et al | 21 countries in the French administrative regions | Biology | high temperatures diminish initial contagion rates, but seasonal temperature effects at later stages of the epidemy remain questionable | Questionable | Biology (Basel). 2020 May 3;9(5). pii: E94. doi: 10.3390/biology9050094. |
| Temperature significantly changes COVID-19 transmission in (sub)tropical cities of Brazil | Prata DN et al | Brazil | Sci Total Environ | Each 1 °C rise of temperature was associated with a -4.8951% (t = -2.29, p = 0.0226) decrease in the number of daily cumulative confirmed cases of COVID-19. The curve flattened at a threshold of 25.8 °C. There is no evidence supporting that the curve declined for temperatures above 25.8 °C | ↑T ↓ | Sci Total Environ. 2020 Apr 25;729:138862. doi: 10.1016/j.scitotenv.2020.138862. [Epub ahead of print] |
| Investigation of effective climatology parameters on COVID-19 outbreak in Iran | Ahmadi M et al | Iran | Sci Total Environ | Air temperature in the study were not significantly correlated with the COVID-19 outbreak. | No association | Sci Total Environ. 2020 Apr 17;729:138705. doi: 10.1016/j.scitotenv.2020.138705 [Epub ahead of print] |
| A spatio-temporal analysis for exploring the effect of temperature on COVID-19 early evolution in Spain | Briz-Redon A & Serrano-Aroca A | Spain | Sci Total Environ | No evidence of a relationship between COVID-19 cases and temperature was found. | No association | Sci Total Environ. 2020 Apr 17;729:138811. doi: 10.1016/j.scitotenv.2020.138811 [Epub ahead of print] |
| Correlation of ambient temperature and COVID-19 incidence in Canada | To T et al (current study) | Canada | Sci Total Environ | Temperature is not significantly associated with COVID-19 outbreak after adjusted for precipitation, gust speed, and province. | No association | TBA |

Table 2
Point estimates, 95% confidence intervals, and *p*-values of associations for linear regression models. Effective reproductive number and cumulative incidence rate hold no significant associations with mean temperature. Models were adjusted for precipitation, gust speed, and province.

| | | Estimate | 95% LCI | 95% UCI | <i>p</i> -value |
|------------------------------------|------------------|----------|---------|---------|-----------------|
| Effective R | Temperature | 0.04 | -0.20 | 0.28 | 0.74 |
| | Precipitation | 0.15 | -0.80 | 1.10 | 0.75 |
| | Wind Gust Speed | -0.016 | -0.19 | 0.16 | 0.86 |
| | Province | | | | |
| | Alberta | Ref | Ref | Ref | Ref |
| | British Columbia | -0.57 | -2.67 | 1.54 | 0.60 |
| | Ontario | 0.26 | -1.37 | 1.89 | 0.75 |
| Cumulative Incidence (per 100,000) | Temperature | 14.2 | -0.6 | 29.0 | 0.067 |
| | Precipitation | -27.1 | -86.9 | 32.6 | 0.38 |
| | Wind Gust Speed | 12.6 | 1.40 | 23.8 | 0.034 |
| | Province | | | | |
| | Alberta | Ref | Ref | Ref | Ref |
| | British Columbia | -182.2 | -314.4 | -50.0 | 0.01 |
| | Quebec | -60.9 | -163.2 | 41.4 | 0.25 |
| | Quebec | 102.1 | -44.4 | 248.6 | 0.18 |

of the province-specific regression coefficients for temperature reached statistical significance.

4. Discussion

This study is the first Canadian study that used daily meteorological data from four major provinces to investigate the association between ambient temperature and COVID-19 from January to May 2020. Our study found no statistically significant associations between *R_t*, total cumulative cases, or cumulative incidence rates and ambient temperature using multiple regression analyses.

To date, several COVID-19 studies have suggested an inverse relationship between temperature and COVID-19 case incidence. However, our study results are in keeping with those reported by a few recent studies. A study in Wuhan, China and a Canadian study of 144 geopolitical areas found no association (Juni et al., 2020; Yao et al., 2020). Similarly, in a study of 21 countries and French administrative regions, Demongeot et al. found an inverse association at high temperatures but questioned the association at lower, seasonal temperatures (Demongeot et al., 2020). At the time of this study, it is likely that Canada experienced these lower seasonal temperatures rather than high temperatures sufficiently needed to affect COVID-19, as seen in Demongeot et al.'s study. Moreover, neither the study in Iran that looked at various climate variables nor the spatio-temporal analysis of Spain during its early wave of COVID-19 found an association between temperature and COVID-19 (Ahmadi et al., 2020; Briz-Redon and Serrano-Aroca, 2020). A pre-print study in Nigeria did not find an association either (Taiwo and Adebayo, 2020). While our study reported a statistically nonsignificant association between temperature and COVID-19 cases, its positive regression coefficient indicated that COVID-19 incidence increased as temperature increased. However, our findings should be interpreted with caution. During our study period, spikes in COVID-19 incidence were noted in April and May, when outbreaks occurred in meat processing plants in Alberta and a number of long-term care homes in Ontario and Quebec (Public Health Agency of Canada, 2020). These outbreaks might have skewed the association away from the null independent of increasing temperatures in these provinces.

By comparing results between provinces, this study takes advantage of the strongly heterogeneous climate that occurs across Canada. Compared to other countries with large outbreaks, Canada had a greater variation in temperature across the country that allowed for a more robust study and a better identification of the association between temperature and COVID-19 incidence in the findings. Additionally, by using a health region level of analysis, this study was able to accurately represent area-wide climate patterns. Despite this advantage, using health regions as a geographical unit was also a study limitation as the regions

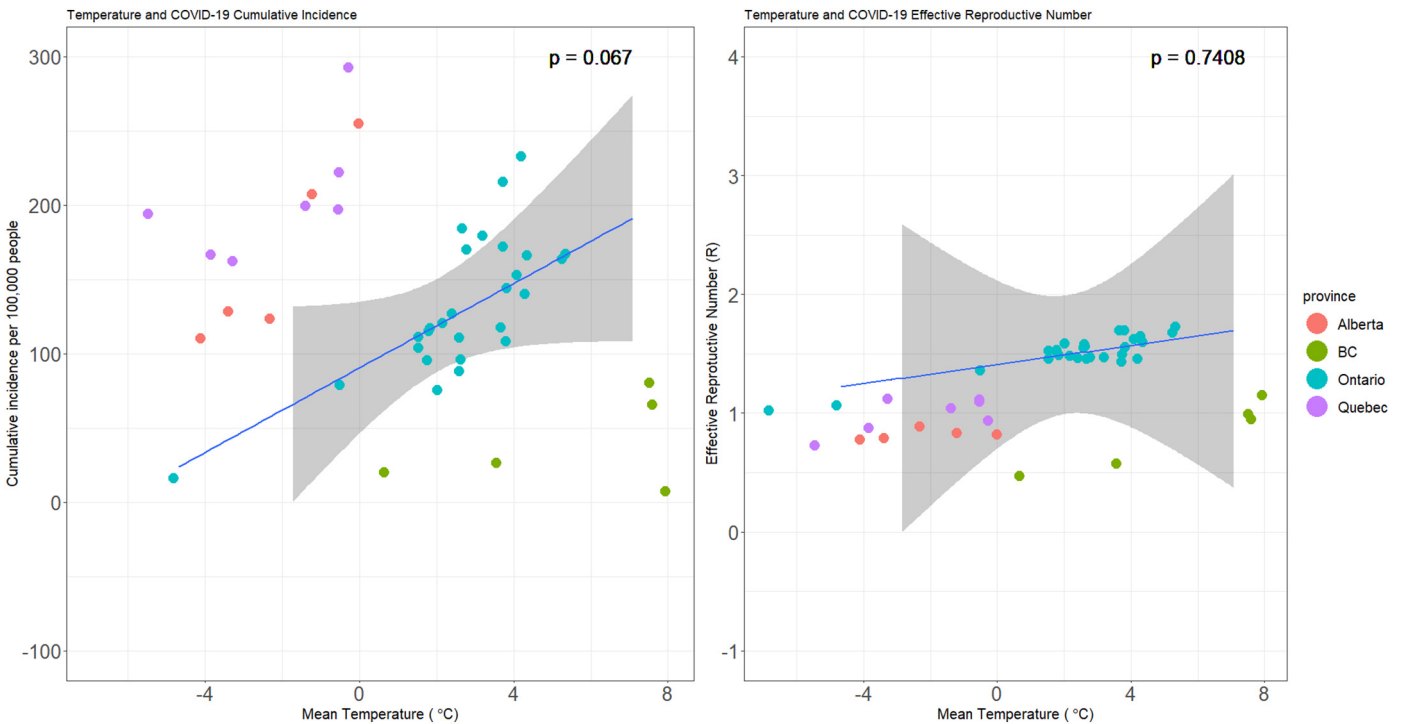


Fig. 1. Temperature, COVID-19 Cumulative Incidence, and Effective R. Cumulative incidence rate (left) and effective reproductive number (right) hold no significant association with mean temperature. Models are adjusted for precipitation, gust speed, and province. Solid lines and grey areas refer to the linear trend and 95% confidence interval, respectively, of the correlation between cumulative incidence rate or effective reproductive number and mean temperature.

could not be further disaggregated at a more granular level like cities. As such, the ecological nature of this study may be confounded by other factors like local public health policies, testing rates, and urbanization. Furthermore, this study could not encompass the summer season and largely occurred in the winter and spring seasons. It is possible that this study did not reach a threshold in which the effects of temperature on viral activity would be more pronounced.

This is an unprecedented situation whereby a new disease is evolving in front of us. Unlike a controlled clinical trial, we are in a natural experiment, observing what is being unfolded as opposed to applying controlled parameters. As we learn how the disease is being transmitted, how it manifests in different patient groups, and how the environment may or may not influence its activity, we must be cautious in making causal inference. Globally, many clinical interventions are being implemented over time, such as new treatment options, novel tests, case finding, contact tracing, together with community-based strategies, that collectively impact the curbing of COVID-19 transmission independent of the climate. The attribution of the observed difference in the pandemic outcome (decrease in cases and deaths) to changing climates may be subject to a potential ecological fallacy because the climate is changing regardless of the pandemic, and the pandemic is slowing down with implementations of collective actions. Nonetheless, it is important to monitor how changes in the environment may contribute to improving or impairing immunity, which may put the population at risk for infection.

In summary, our study did not find any evidence to support the hypothesis that higher temperatures will reduce transmission of COVID-19. While this knowledge may not help curtail the current pandemic, it warns the public not to lose vigilance and to continue practicing safety measures such as hand washing, social distancing, and use of facial masks despite the warming of climates. Our findings may also shed light in preparing for future potential resurgences of COVID-19. Future studies, which will be able to encompass more climate and case data as cases substantially increase globally into the summer months, should continue to look at meteorological factors to further elucidate the relationship between COVID-19 and the climate.

CRedit authorship contribution statement

Teresa To: Conceptualization, Supervision, Writing - original draft. **Kimball Zhang:** Formal analysis, Writing - original draft, Visualization, Project administration. **Bryan Maguire:** Formal analysis, Methodology, Writing - review & editing. **Emilie Terebessy:** Project administration, Data curation, Writing - review & editing. **Ivy Fong:** Data curation, Writing - review & editing. **Supriya Parikh:** Data curation, Writing - review & editing. **Jingqin Zhu:** Writing - review & editing.

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.

Acknowledgement

This study used data compiled and provided by the Ontario Ministry of Health, COVID-19 Canada Open Data Working Group, Environment and Climate Change Canada, and Statistics Canada. The results, conclusions, opinions, and statements expressed herein are solely those of the authors and do not reflect those of the data sources.

References

Ahmadi, M., Sharifi, A., Dorosti, S., Jafarzadeh Ghouschi, S., Ghanbari, N., 2020. Investigation of effective climatology parameters on COVID-19 outbreak in Iran. *Sci. Total Environ.* 729, 138705.

Al-Rousan, N., Al-Najjar, H., 2020. The correlation between the spread of COVID-19 infections and weather variables in 30 Chinese provinces and the impact of Chinese government mitigation plans. *Eur. Rev. Med. Pharmacol. Sci.* 24 (8), 4565–4571.

Bashir, M.F., Ma, B.J., Bilal, et al., 2020a. Correlation between environmental pollution indicators and COVID-19 pandemic: a brief study in Californian context. *Environ. Res.* 187.

Bashir, M.F., Ma, B., Bilal, et al., 2020b. Correlation between climate indicators and COVID-19 pandemic in New York, USA. *Sci. Total Environ.* 728, 138835.

Berry, I., Soucy, J.-P.R., Tuite, A., Fisman, D., 2020. Open access epidemiologic data and an interactive dashboard to monitor the COVID-19 outbreak in Canada. *Can. Med. Assoc. J.* 192 (15), E420.

Briz-Redon, A., Serrano-Aroca, A., 2020. A spatio-temporal analysis for exploring the effect of temperature on COVID-19 early evolution in Spain. *Sci. Total Environ.* 728, 138811.

Byass, P., 2020. Eco-epidemiological assessment of the COVID-19 epidemic in China, January–February 2020. *Glob. Health Action* 13 (1), 1760490.

Collivignarelli, M.C., Abba, A., Bertanza, G., Pedrazzani, R., Ricciardi, P., Carnevale Miino, M., 2020. Lockdown for CoViD-2019 in Milan: what are the effects on air quality? *Sci. Total Environ.* 732, 139280.

Demongeot, J., Flet-Berliac, Y., Seligmann, H., 2020. Temperature decreases spread parameters of the new Covid-19 case dynamics. *Biology (Basel)* 9 (5).

Dong, E., Du, H., Gardner, L., 2020. An interactive web-based dashboard to track COVID-19 in real time. *Lancet Infect. Dis.* 20 (5), 533–534.

Environment Canada, 2019. Historical data. https://climate.weather.gc.ca/historical_data/search_historic_data_e.html.

Eslami, H., Jalili, M., 2020. The role of environmental factors to transmission of SARS-CoV-2 (COVID-19). *AMB Express* 10 (1), 92.

Fagbo, S.F., Garbati, M.A., Hasan, R., et al., 2017. Acute viral respiratory infections among children in MERS-endemic Riyadh, Saudi Arabia, 2012–2013. *J. Med. Virol.* 89 (2), 195–201.

Fattorini, D., Regoli, F., 2020. Role of the chronic air pollution levels in the Covid-19 outbreak risk in Italy. *Environ. Pollut.* 264.

Harrell Jr., F.E., 2020. rms: Regression Modeling Strategies. R package version 6.0-0 <https://CRAN.R-project.org/package=rms>.

Iqbal, N., Fareed, Z., Shahzad, F., He, X., Shahzad, U., Lina, M., 2020. The nexus between COVID-19, temperature and exchange rate in Wuhan city: new findings from partial and multiple wavelet coherence. *Sci. Total Environ.* 729, 138916.

Jiang, Y., Wu, X.J., Guan, Y.J., 2020. Effect of ambient air pollutants and meteorological variables on COVID-19 incidence. *Infect. Control Hosp. Epidemiol.* 1–11.

Juni, P., Rothenbuhler, M., Bobos, P., et al., 2020. Impact of climate and public health interventions on the COVID-19 pandemic: a prospective cohort study. *CMAJ : Canadian Medical Association journal = journal de l'Association medicale canadienne* 192 (21), E566–E573.

Lai, C.C., Shih, T.P., Ko, W.C., Tang, H.J., Hsueh, P.R., 2020. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): the epidemic and the challenges. *Int J Antimicrob Ag* 55 (3).

Liu, J., Zhou, J., Yao, J., et al., 2020. Impact of meteorological factors on the COVID-19 transmission: a multi-city study in China. *Sci. Total Environ.* 726, 138513.

Lowen, A.C., Mubareka, S., Steel, J., Palese, P., 2007. Influenza virus transmission is dependent on relative humidity and temperature. *PLoS Pathog.* 3 (10), 1470–1476.

Lu, R.J., Zhao, X., Li, J., et al., 2020. Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. *Lancet* 395 (10224), 565–574.

Ma, Y., Zhao, Y., Liu, J., et al., 2020. Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China. *Sci. Total Environ.* 724, 138226.

Ontario Ministry of Health, 2020. Confirmed positive cases of COVID-19 in Ontario. <https://data.ontario.ca/dataset/confirmed-positive-cases-of-covid-19-in-ontario>.

Prata, D.N., Rodrigues, W., Bermejo, P.H., 2020. Temperature significantly changes COVID-19 transmission in (sub)tropical cities of Brazil. *Sci. Total Environ.* 729, 138862.

Public Health Agency of Canada, 2020. Update on COVID-19 in Canada: Epidemiology and Modelling. Canada PHA ed.

R Foundation, 2020. The R project for statistical computing. <https://www.r-project.org/>.

Sobral, M.F.F., Duarte, G.B., da Penha Sobral, A.I.G., Marinho, M.L.M., de Souza Melo, A., 2020. Association between climate variables and global transmission of SARS-CoV-2. *Sci. Total Environ.* 729, 138997.

Statistics Canada, 2019. Census Profile, 2016 Census. In: 98-316-X2016001, ed.

Taiwo, I.F., Adebayo, 2020. COVID-19 Spread and Average Temperature Distribution in Nigeria.

Thompson, R.N., Stockwin, J.E., van Gaalen, R.D., et al., 2019. Improved inference of time-varying reproduction numbers during infectious disease outbreaks. *Epidemics* 29, 100356.

Tosepu, R., Gunawan, J., Effendy, D.S., et al., 2020. Correlation between weather and Covid-19 pandemic in Jakarta, Indonesia. *Sci. Total Environ.* 725, 138436.

Wang, L.F., Shi, Z.L., Zhang, S.Y., Field, H., Daszak, P., Eaton, B.T., 2006. Review of bats and SARS. *Emerg. Infect. Dis.* 12 (12), 1834–1840.

Wickham, H., Averick, M., Bryan, J., et al., 2019. Welcome to the Tidyverse. *Journal of Open Source Software* 4 (43), 1686.

World Health Organization, 2020a. WHO Director-General's remarks at the media briefing on 2019-nCoV on 11 February 2020. <https://www.who.int/dg/speeches/detail/who-director-general-s-remarks-at-the-media-briefing-on-2019-ncov-on-11-february-2020>.

World Health Organization, 2020b. Coronavirus disease (COVID-19) advice for the public: myth busters. <https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public/myth-busters>. (Accessed 11 June 2020).

Wu, Y., Jing, W., Liu, J., et al., 2020. Effects of temperature and humidity on the daily new cases and new deaths of COVID-19 in 166 countries. *Sci. Total Environ.* 729, 139051.

Xie, J., Zhu, Y., 2020. Association between ambient temperature and COVID-19 infection in 122 cities from China. *Sci. Total Environ.* 724, 138201.

Yao, Y., Pan, J., Liu, Z., et al., 2020. No association of COVID-19 transmission with temperature or UV radiation in Chinese cities. *Eur. Respir. J.* 55, 2000517.

Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. *Sci. Total Environ.* 728, 138813.