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Short Communication

Correlation of ambient temperature and COVID-19 incidence in Canada

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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

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.

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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 Health Emergency of International Concern by the World Health Organization on January 30, 2020.
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). Table 1 provides a literature review of the associations between temperature and cumulative incidence rates tended to be highest in and around urban centres. 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 (Rt) 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 Rt. To account 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 ± standard deviation and range (min-max) for temperature was (1.48 ± 3.46, −6.83–7.94), wind gust speed was (43.5 ± 2.45, 29.9–49.5), and precipitation was (2.03 ± 0.78, 0.44–3.72). Mean temperature and total precipitation tended to decrease at higher latitudes. The mean ± standard deviation and range for Rt and cumulative incidence were (1.27 ± 1.25, 0.27–8.85) and (133.7 ± 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 Rt (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 |
|-------|---------|----------|---------|----------|
| Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China | Ma Y et al | China | Sci Total Environ | ↑↑ |
| Association between ambient temperature and COVID-19 infection in 122 cities from China | Xie J et al | China | Sci Total Environ | ↑ ↓ |
| Eco-epidemiological assessment of the COVID-19 epidemic in China, January-February 2020 | Byass P | China | Glob Health Action | ↑ ↓ |
| Effect of ambient air pollutants and meteorological variables on COVID-19 incidence | Jiang Y et al | China | Infect Control Hosp Epidemiol | ↑ ↓ |
| 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 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 | ↑ |
| Impact of meteorological factors on the COVID-19 transmission: A multi-city study in China | Liu J et al | China | Sci Total Environ | ↑ |
| Association between climate variables and global transmission of SARS-CoV-2 | Sobral MFF et al | Global | Sci Total Environ | ↑ |
| Correlation between weather and Covid-19 pandemic in Jakarta, Indonesia | Tosepu R et al | Indonesia | Sci Total Environ | ↑ |
| The role of environmental factors to transmission of SARS-CoV-2 (COVID-19) | Eslami H et al | Iran | AMB Express | ↑ |
| Correlation between climate indicators and COVID-19 pandemic in New York City, US | Bashir MF et al | New York City, US | Sci Total Environ | ↑ |
| Impact of climate and public health interventions on the COVID-19 pandemic: A prospective cohort study | Juní P et al | 144 geopolitical areas except China, S Korea, Iran and Italy | CMAJ | No association |
| 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 | ↑ |
| Temperature Decreases Spread Parameters of the New Covid-19 Case Dynamics | Demongeot J et al | 21 countries in the French administrative regions | Biology | Questionable |
| Temperature significantly changes COVID-19 transmission in (sub)tropical cities of Brazil | Prata Dhi et al | Brazil | Sci Total Environ | ↑ |
| Investigation of effective climatology parameters on COVID-19 outbreak in Iran | Ahmad M et al | Iran | Sci Total Environ | No association |
| 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 association |
| Correlation of ambient temperature and COVID-19 incidence in Canada | To T et al (current study) | Canada | Sci Total Environ | No association |

Note: ↑ indicates a significant increase, ↓ indicates a significant decrease, No association indicates no significant association.
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 \( R_0 \), 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.](image)

| 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 | British Columbia | Ontario | Quebec |
|----------|---------|------------------|---------|--------|
| Ref      | −0.57   | −2.67            | 1.54    | 0.60   |
| p-value  |         |                  |         |        |

| 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 | British Columbia | Ontario | Quebec |
|----------|---------|------------------|---------|--------|
| Ref      | −182.2  | −314.4           | −50.0   | 0.01   |
| p-value  |         |                  |         |        |

| Cumulative Incidence (per 100,000) | Precipitation | −27.1 | −86.9 | 32.6  | 0.38  |
|-----------------------------------|---------------|-------|-------|-------|-------|
| Wind Gust Speed                   | 12.6          | 1.40  | 23.8  | 0.034 |

| Province | Alberta | British Columbia | Ontario | Quebec |
|----------|---------|------------------|---------|--------|
| Ref      | −60.9   | −163.2           | 41.4    | 0.25   |
| p-value  |         |                  |         |        |

| Cumulative Incidence (per 100,000) | Precipitation | −27.1 | −86.9 | 32.6  | 0.38  |
|-----------------------------------|---------------|-------|-------|-------|-------|
| Wind Gust Speed                   | 12.6          | 1.40  | 23.8  | 0.034 |

| Province | Alberta | British Columbia | Ontario | Quebec |
|----------|---------|------------------|---------|--------|
| Ref      | 102.1   | −44.4            | 248.6   | 0.18   |
| p-value  |         |                  |         |        |
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, 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 our 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. Emille Terebessy: Project administration, Data curation, Writing - review & editing. Ivy Fong: Data curation, Writing - review & editing. Supriya Parikh: Data curation, Writing - review & editing. Jingjin 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.

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