1 **Title: No Evidence for Temperature-Dependence of the COVID-19 Epidemic**

2 **Running Title:** Temperature-independence of COVID-19 Epidemic

3 **Keywords:** COVID-19, epidemic, temperature, exponential rate, R0

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12 **1. Abstract**

13 The pandemic of the COVID-19 disease extended from China across the north-temperate

14 zone, and more recently to the tropics and southern hemisphere. We find no evidence that

15 spread rates decline with temperatures above 20 ^{o}C, suggesting that the COVID-19 disease is

16 unlikely to behave as a seasonal respiratory virus.

17

18 **2. Introduction**

19   On 30th January the WHO declared the novel coronavirus (COVID-19) outbreak a

20 public health emergency of international concern (http://www.euro.who.int/en/home). The

21 epidemic spread gradually from Wuhan province in China, to other Asian nations, the middle

22 east and Europe. By early March the epidemic was mostly concentrated in territories

23 extending between 30° N and 50 ^{o}N (Sajadi et al., 2020), now in late winter, leading to the

24 suggestion, echoed by the global media, that the epidemic is likely to be temperature-

25 dependent. This supported speculation of possible decline in severity with the advent of

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26   warmer spring and summer temperatures in north-temperate latitudes (Sajadi et al.,

27   2020;Wang et al., 2020), comparable to many viruses affecting human respiratory systems,

28   including SARS (Tan et al., 2005; Gaunt et al., 2010).

29   However, recent (updated up to April 15, 2020; cf. Methods) data revealed the spread

30   of the epidemic across territories experiencing warm temperatures in the tropics (e.g.

31   Indonesia, Singapore, Brazil) and southern hemisphere as well (e.g. Australia, Argentina).

32   The current distribution of the epidemic challenges, therefore, the inference that SARS-CoV-

33   2 may behave as a seasonal respiratory virus based on previous statistical analyses from

34   earlier realized distributions.

35   Here we examine the relationship between the apparent exponential rate of SARS-

36   CoV-2 spread (γ) and the Effective Reproductive number (Rt) of infection and the average

37   daily temperature (T_{avg}) across nations and Chinese provinces where epidemics, with at least

38   100 case reported, have been reported (data updated up to 15th April, 2020).

39   **3. Methods**

40   *Novel Coronavirus (COVID-19) Cases Data*

41   The Novel Coronavirus (COVID-19) daily data are confirmed cases for affected

42   countries and provinces of China reported between 31st December 2019 to 15th April 2020.

43   The data was collected from the reports released by WHO, European Centre for Disease

44   Prevention and Control (ECDC), and John Hopkin CSSA. Data include confirmed and a

45   cumulative total of COVID-19 cases in affected countries/provinces.

46   *Average ambient temperature*

47   The average temperatures of all the affected countries were collected

48   from https://www.timeanddate.com/. The monthly mean temperature of February, March and

49   the two-weeks mean temperature of April of capital cities for the various nations were used

50   as reference temperatures for the country.

51

52 *Statistical Analysis*

53   The number of COVID-19 incidences follows the expected exponential growth,

54 although rates are only robust when cases exceed 100 persons for any country or province.

55 Hence, we fitted the exponential model to each country and each province of China. We

56 calculated exponential rate parameters for the countries where the COVID-19 incident has at

57 least a 10-day growth period, and the total number of cases was at least 100.

58 $N = ae^{\gamma} Days, \qquad \gamma > 0$

59 $logN = \alpha + \gamma\ Days.$

60 Where N is the cumulative number of diagnosed persons and Days is the number of days and

61 γ is the exponential rate (100 x γ = % increase per day).

62

63   To calculate the effect of temperature on the exponential rate parameter, we first

64 regressed the exponential rate parameters retrieved from the exponential model on $Temp$ and

65 $Temp^2$

$\gamma \sim Temp + Temp^2$

66 If the squared term is significant, it provides evidence of nonlinearity.

67 The thermal performance of COVID-19 was characterized by fitting spread rate estimate or

68 growth parameter (γ) and temperature to the Gaussian function;

$\gamma = ae^{\left[-0.5\left(\frac{(Temp-opt)}{tol}\right)^2\right]},$

69 $Temp$ is the average temperature (in °C) that best encompasses the growth period of COVID-

70 19 cases since its first incidence in a country/region of China. Where, a (amplitude) is the

71 coefficient related to maximum of spread rate of countries, the optimum (opt) on the

72 temperature gradient is where the maximum of spread rate is attained and the tolerance (tol)

73 gives the width of the response curve. This model has non-linear form, and the model

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74   parameters opt and tol occur nonlinearly in the model function. Parameter of thermal

75   performance curve was estimated by fitting Gaussian model to the growth rate and

76   temperature of infected countries. The initial values for the Gaussian parameters

77   opt, tol and a were obtained directly using maximum-likelihood polynomial regression for

78   the Gaussian function.

79   Estimated the Effective reproductive number (Rt), the average number of infections at

80   time t, per infected case over the course of their infection for COVID-19 for provinces of

81   China and other countries using a discrete γ distribution with a mean of 4.8 days and a

82   standard deviation of 3.5 days for the *serial interval* distribution.

83   All analyses were performed using R statistical computing software.

84

85   **4. Results**

86   Our results show that evidence for a temperature-dependence of the transmission

87   reported in previous papers was likely to be an artifact, reflecting the pathways of spread, and

88   that there is no evidence for thermal dependence of the transmission across the -1 to 36°C

89   T_{avg} range across the affected regions. This suggests little basis to expect evidence for the

90   virus to behave as a seasonal respiratory virus.

91   Epidemiological data consisting in the rate of increase in accumulated diagnosed

92   cases among nations (global) shows γ ranging from 1% day^{-1} to 23.8 % day^{-1} (Figure S1),

93   with an average of 9.82$\pm$ 0.39 % day^{-1} (Figure 1, Figure S1A), and apparent Rt of 1.27 $\pm$ 0.02

94   (Figure 1, Figure S1A). Surprisingly, γ and Rt across Chinese provinces (mean $\pm$ SE = 1.3 $\pm$

95   0.28 % day^{-1} and 0.96 $\pm$ 0.02) (Figure S1B)were well below those of other nations (mean $\pm$

96   SE = 19.82$\pm$ 0.39 % day^{-1} and 1.27 $\pm$ 0.02), possibly because much faster confinement of the

97   Chinese population did not allow for the potential exponential rates under uncontrolled

98   conditions to be realized. The broad variability in realized γ and Rt between nations (global)

99   and provinces (China) largely reflects differences in detection likelihood along with the

100   timing and rigour of adoption of confinement measures.

101   The relationship between γ and Rt and T_{avg} shows no evidence for a reduced spread

102   rate with warming (Figure 1), unlike analyses based on previous data. A number of nations

103   with $T_{avg} > 20$ ^{o}C, including subtropical and tropical (Brazil, Cuba, UAE, Saudi Arabia, India

104   and Panama), and southern-hemisphere (Peru, Argentina, Indonesia) nations (Figure 2),

105   support γ and Rt above the median values of 9.6% day^{-1} and 1.23, respectively (Figure 1).

106   However, the same analysis conducted one weeks ago (15th March), did provide some

107   evidence for low γ and Rt for $T_{avg} > 20$ ^{o}C (Figure S2). Our updated results (Figure 1) show,

108   however, that this apparent temperature-dependence was confounded with a prevailing zonal

109   pattern of spread across the north-temperate zone, possibly reflecting the main patterns of

110   human mobility, which delayed arrival of the epidemics to the southern hemisphere and the

111   tropics.

112   **5. Discussion**

113   These results suggest that, contrary to prior assessments, the spread rate of the

114   COVID-19 pandemic is temperature-independent, it is transmitting in countries with warm

115   weather. This signifying that there is little hope for relief as temperatures in the northern

116   hemisphere increase, and that poor nations with weak health systems in tropical regions, such

117   as African, are at great risk. Therefore, in order to reduce transmission, it's important to

118   employ strong lockdown, social distancing and testing and tracking polices.

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120   Data sources: The data on COVID-19 is available publicly across many sources; where

121   downloadable data files are updated daily few are listed below;

122   World health organization (https://www.who.int/emergencies/diseases/novel-coronavirus-
123   2019/situation-reports/)

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125   Johns Hopkins CSSE (https://data.humdata.org/dataset/novel-coronavirus-2019-ncov-cases)

126   [Accessed April 15, 2020]
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128   European Centre for Disease Prevention and Control
129   (https://www.ecdc.europa.eu/en/publications-data/download-todays-data-geographic-
130   distribution-covid-19-cases-worldwide) [Accessed April 15, 2020].
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132   **Author Contribution**
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134   CMD and TJ conceived and designed the research, TJ conducted the analysis, TJ and CMD

135   wrote the first draft and all co-authors contributed to improving the paper and approved the

136   submission.

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168   **Figure legends**

169   **Figure 1.** The relationship between the apparent exponential rate of SARS-CoV-2 spread (B)

170   and the Effective Reproductive number of infection (Rt) and the average daily temperature

171   (T_{avg}) across nations and Chinese provinces where > 100 cases of COVID-19 have been

172   reported (data last accessed April 15, 2020, Figure S1). Green symbols represent provinces in

173   China while red symbols represent other nations. Neither the double exponential function

174   with temperature nor the Gaussian function provided a significant ($p < 0.05$) fir for either γ or

175   Rt with temperature.

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177   **Figure 2.** Distribution of the apparent exponential rate of SARS-CoV-2 spread (γ) and the

178   Effective Reproductive number of infection (Rt) and the average daily temperature (T_{avg})

179   across nations where > 100 cases of COVID-19 have been reported (data last accessed April

180   15, 2020).

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182   **Appendix Figure S1.** The apparent average ($\pm$ SE) exponential rate of SARS-CoV-2 spread

183   (γ), the average (and 95% confidence limits) of Effective Reproductive number of infection

184   (Rt) and the average daily temperature (T_{avg}), total case and number of days since the first

185   case reported across nations and Chinese provinces where epidemics, with at least 100 case

186   reported, have been reported (data updated through April 15, 2020).

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188   **Appendix Figure S2**. The relationship between the apparent exponential rate of SARS-CoV-

189   2 spread (γ) and the Effective Reproductive number (Rt) of infection and the average daily

190   temperature (T_{avg}) across nations and Chinese provinces where > 100 cases of COVID-19

191   have been reported, as of Figure 1, but with data updated only until 15th March. The Gaussian

192   function with temperature provided a significant fit for γ with temperature.