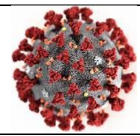
National COVID-19 Science Task Force (NCS-TF)



Type of document: Rapid review	
In response to a request from: Krisenstab, FOPH	**Date of request:** May 2020
Expert groups involved: Management group (Carole Dupont, Stefanie Hossmann, Matthias Egger), **PH group** (Antoine Flahault, Marcel Tanner), **Infection Prevetion and Control** (Sarah Tschudin-Sutter)	**Date of response:** 26/05/2020
Contact person: Matthias Egger	
Comment on planned updates : As soon as a significant amount of new evidence becomes available.	

The importance of seasonality and climate on the risk of COVID-19: rapid review

Summary of request/problem

There is an ongoing debate on the importance of seasonal/ climatic factors in the transmission of SARS-Cov-2. Specifically, there is debate on the extent to which the warmer temperatures during the summer may contribute to controlling the Covid-19 epidemic.

Executive summary

We conducted a rapid review of the literature to address the following two questions: (1) What is the role of the climate in the transmission of SARS-CoV-2? (2) To what extent could seasons in Switzerland affect the spread of the virus? We searched the living evidence database for COVID-19 of the Institute of Social and Preventive Medicine (ISPM) of the University of Bern for relevant studies. We screened 92 publications and included 7 modelling studies, 7 analyses of epidemiological data, 1 systematic review and 1 narrative review. There was broad agreement among studies that season and climatic factors play a role in the transmission of SARS-Cov-2 and the propagation of the COVID-19 epidemic. However, the mitigating effect of higher temperatures / the summer season will be modest and insufficient to control the epidemic.

Introduction

"Will COVID-19 go away on its own in warmer weather?" asked Marc Lipsitch in a recent blog, eloquently pointing out that there are four factors that may contribute to the winter-seasonal occurrence of respiratory viruses:[1]

The environment: In the winter, the outdoor air is colder, and the air is dryer. The drying and cooling of nasal mucous membranes may facilitate viral infections.[2] Humidity affects flu transmission, with drier conditions being more favourable.[3] For SARS-CoV-2 the relevance of these factors are unknown, but it is clear that transmission is possible in humid climates, for example, Singapore.

Human behavior: In the winter humans spend more time indoors with less ventilation and less personal space than outdoors in the summer.

The immune system: The immune system may be weaker in winter than summer, possibly due to lower vitamin D levels in winter. Of note, vitamin D supplementation reduces the incidence of acute respiratory infection.[4]

Depletion of susceptible hosts: Even without any seasonal variability, infectious disease epidemics rise exponentially, level off, and decline with the depletion of susceptible hosts. This process interacts with the seasonal factors to produce recurrent epidemics typically at the same time each year. New viruses, including pandemic influenza, can spread outside the typical season. For example in 2009, the pandemic started in April-May (well outside of flu season), quieted in the summer (perhaps because of the importance of children in the transmission of flu), and then rebounded in September-October, before the start of normal flu season.[1]

There is much interest in comparisons between COVID-19 and pandemic and **seasonal influenza**. A global review of latitudinal variations in seasonal activity of influenza found that in the temperate Northern hemisphere seasonal influenza typically peaks in January to late February and the temperate Southern hemisphere in June to July.[5] With increasing (absolute) latitude, epidemics peak later in the year. In tropical zones of the Northern and Southern hemispheres, the timing of influenza peaks was more diverse, partly due to semiannual influenza activity.[5] Unsurprisingly, pandemic influenza tends to appear earlier than normal seasonal influenza.[6]

There is also interest in comparisons with the **"Spanish flu" pandemic of 1918/19** and the most recent pandemic of "swine flu" in 2009. The Spanish flu affected Switzerland in two waves. The first one occurred in July 1918, the second, more severe one, in October–November 1918.[7] Unlike with COVID-19, the highest morbidity and mortality rates were observed in the adult population, in particular in the 20–49 years age group, with increased mortality in men.[7] For Switzerland (Geneva), the basic reproductive number was estimated at 1.49 for the first wave and at 3.75 for the second wave, in line with the greater risk of transmission in confined environments during the colder season.[8] The effect of seasonality was not formally assessed for the Spanish flu, but it was clearly important. Comparisons with the most recent **"swine flu" pandemic** are also of interest. The epidemic arrived in the United States from Mexico in spring 2009 and led to substantial excess mortality in the second half of the year.[6] The high mortality in children and young adults was a defining feature of the 2009 pandemic.[6,9] The basic reproductive rate was estimated at 1.75. The effect of seasonality was modeled by a factor that rescales the value of the basic reproductive number into a seasonally rescaled reproductive number, depending on time of the year.[10] The analysis showed that the rescaling factor was in the range 0.4 to 0.9. Such a relatively mild seasonality effect was consistent with the activity observed in June and July in Europe and the US: the number of cases kept increasing during the summer.

Rationale and review questions

It is reasonable to assume that, like other betacoronaviruses and other respiratory viruses, SARS-Cov-2 may transmit somewhat more efficiently in winter than summer. We performed a rapid review to examine two questions:

(1) What is the role of the climate in the transmission of SARS-CoV-2?
(2) To what extent could seasons in Switzerland affect the spread of the virus?

Methods

We searched the COVID-19 living evidence database of the Institute of Social and Preventive Medicine (ISPM) at the University of Bern.[11] The database includes daily updates of searches in four electronic databases: Medline-PubMed, Embase, bioRxiv and medRxiv, for articles with medical subject headings and keywords for SARS-CoV-2 infection and COVID-19. For our search, on May 18, we used the following keywords: "season* AND (incide* OR infec* OR transmi*)" in the title or abstract. We also examined articles suggested by experts or social media. We screened all titles for relevance for our questions using the following criteria:

1. Report on humans diagnosed with COVID-19;
2. Different climate or weather factors: humidity, temperature, wind speed, precipitation, etc. or seasonal development;
3. Transmission of SARS-CoV-2.

We included both original research and reviews. We classified studies as follows:

Mathematical modelling study: Studies that use a mathematical framework representing variables and their interrelationships to describe observed phenomena or predict future events.[12]
Epidemiologic data analysis: statistical analyses of epidemiologic and other data to describe variation and associations between variables.[12]
Narrative review: Broad overview of a topic without clearly defined question, search strategy.[13]
Systematic review: "A study of studies" with a clearly defined question, eligibility criteria, pre-defined, structured search strategy, and an assessment of risk of bias / quality of studies.[14]

Two reviewers (CD, SH) assessed eligibility and extracted data on Objectives, Methods and data, Main findings and Interpretation. This was a rapid review, and no systematic assessment of the quality of studies was undertaken.

Results

We identified 92 potentially eligible studies; 16 publications were eligible (**Figure 1**).

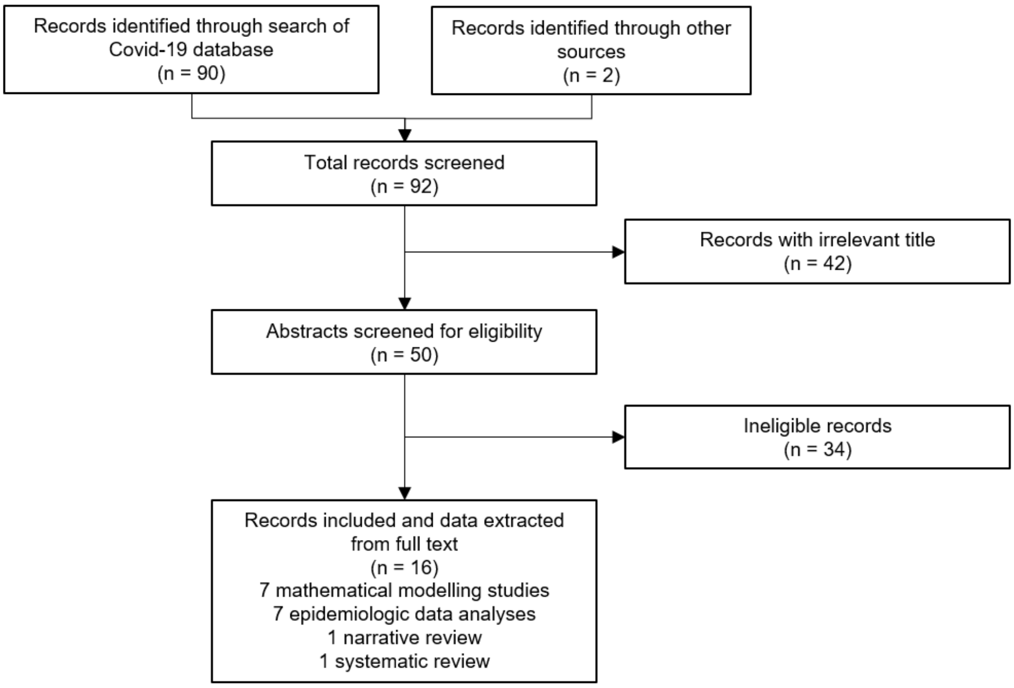


Figure 1: Flow chart of the inclusion process.

Table 1 provides an overview of the characteristics and conclusions from the 16 studies, including seven mathematical modelling studies[15–24], seven epidemiologic analyses[25–31] and one narrative[32,33] and systematic review each. More detailed summaries of the 16 studies are provided in the **Appendix**. Most studies covered seveal countries or were global in scope. Three studies focused on the USA and one on New York State.

In response to question 1 ("What is the role of the climate in the transmission of SARS-CoV-2?") there is broad agreement that climate is likely to play a role, with transmission lower in warm and wet climates. In the Northern hemisphere an increase in virus transmission iis expected in fall and winter. However, most studies stress that the influence of climate factors and seasonal changes will be moderate and not stop transmission of SARS-Cov-2. Several authors stress the need to reduce transmission of SARS-Cov-2 as much as possible in Northern countries using social distancing, hand hygiene and other measures, and to be prepared for an increase in the number of cases with the arrival of the colder season.

Table 1. Overview of the 16 included studies (modelling studies in blue, epidemiologic data analyses in green, reviews in yellow).

Author	Date	Type of study	Setting	Conclusions
Neher[15,16]	March 3	SEIR model, based on dynamics of other human coronaviruses	Northern Hemisphere	Reductions in the incidence rate might be due to a combination of seasonal variation and infection control efforts. Seasonality alone is unlikely to end transmission of SARS-CoV-2.

Kissler[17,18]	March 6	SEIR model, based on dynamics of other human coronaviruses	USA	In all modelled scenarios, SARS-CoV-2 was capable of producing a substantial outbreak regardless of establishment time/season.
Carleton & Meng[25]	March 26	Poisson regression model assessing the effects of climate and other potentially correlated factors.	Global (134 countries)	During summer, Northern countries can maintain low case rates by implementing large-scale public health interventions that limit contact amongst individuals. If transmission persists through summer, cooler fall and winter months could lead to a resurgence of new cases.
Baker[19]	April 7	SIRS model fitted to data of seasonal coronaviruses.	USA	The results imply that both tropical and temperate locations should prepare for severe outbreaks of the disease and that summertime temperatures will not effectively limit the spread of the infection. However, this does not mean the climate is not important in the longer term.
Harbert[20]	April 10	SDMs applied to SARS-CoV-2 county-level data.	USA	Climate's role on SARS-CoV-2 should continue to be cautiously examined, but at this time, we should assume that SARS-CoV-2 can spread anywhere in the US.
Triplett[26]	April 12	Multiple linear and nonlinear regression of daily COVID-19 situation reports from WHO.	Global	Climate has an impact on the transmissibility on a global level but does not explain the variance at the local level. COVID-19 can survive and transmit in warm and humid temperatures.
Chiyomaru[34]	April 14	OLS regression and spatial analyses were used to analyze the growth rate	Global	The contribution of climate to the growth rate of COVID-19 cases were moderate, while those of national emergency responses (i.e., travel restrictions) were more significant.
Australian Academy of Science[32]	April 15	Rapid, narrative review	Literature review, mainly China	We may expect an increase in virus transmission in the winter because of cooler, less humid climate. Climate may be a less important factor for transmission than containment measures and human behaviour (hygiene, physical distancing).
Mecenas[33]	April 17	Systematic review of empirical studies	17 studies of data from China and other countries	The spread of COVID-19 seems to be lower in warm and wet climates. However, temperature and humidity alone do not explain most of the variability of the COVID-19 outbreak.
Ficetola[28]	April 20	Linear mixed models	Global	The highest growth rates were in temperate regions of the Northern Hemisphere. Fast growth also occurred in warm climates, for example in Brazil, suggesting that no area of the world is exempt from SARS-Cov-2 infection risk.
Merow[29]	April 22	Hierarchical Bayesian Gaussian regression model	Global	Projections suggest that, in the absence of intervention, COVID-19 will decrease temporarily during summer, rebound by autumn, and peak next winter.
Notari[30]	April 24	Exponential curve fitting, linear and	Three datasets of	The decrease in the growth rate at high temperatures is in line with what is observed with other coronaviruses.

		quadratic regression models	42, 88, 125 countries	
Li[34]	May 5	Linear equation models	China, international	Warmer weather will help slow down the outbreak but not stop Covid-19 from spreading. Public health interventions are needed to overcome the outbreak.
Jüni[31]	May 8	Weighted random-effects regression	Worldwide without China, South Korea, Iran and Italy	Seasonality plays only a minor role in the epidemiology of COVID-19, while public health interventions appear to have a major impact.
Hoffman[22]	May 14	ODEs describing an 11-compartment SEIRS model	New York State	In the absence of immunity, the virus will become endemic with seasonal variation. The model predicts a significant second outbreak in early 2021 that can be mitigated, but not avoided entirely, through the resumption of strong social distancing measures.
Xu[24]	May 23	Stochastic simulation model, individual-based transmission model	Global	Weather plays a secondary role in the control of the pandemic, and will not be enough to control the epidemic in most locations on its own.

In response to question 2 ("To what extent could seasons in Switzerland affect the spread of the virus?"), only one study[23,24] provided estimates specifically for Switzerland.

Xu et al. studied the relative risk of COVID-19 due to weather and ambient air pollution and predicted the relative risk of COVID-19 transmission due to environmental factors in different countries and cities. The authors compiled a comprehensive datasets of the global spread of COVID-19, including infection data for 3,739 distinct locations, spanning the beginning of the epidemic (December 12, 2019) to April 22, 2020. The authors estimated *Re* taking into account asymptomatic cases, under-reporting and reporting delays, and changing test coverage. A stochastic simulation model and individual-based transmission model were developed and validated for this purpose.
The authors defined "Relative COVID-19 Risk Due to Weather and air pollution" (CRW) as the relative predicted risk of each weather and air pollution vector relative to the 95th percentile of predicted risk. A CRW of 0.5 reflects a 50% reduction in the estimated reproduction number compared to this (high-risk) reference. An interactive online platform at https://projects.iq.harvard.edu/covid19 offers comprehensive projections for different countries, including Switzerland.

The authors conclude that summer may offer partial relief to some regions of the world. However, given a highly susceptible population, the estimated impact of summer weather on transmission risk is not large enough in most places to quell the epidemic in 2020, indicating that policymakers and the public should remain vigilant in their responses to the pandemic. Weather plays a secondary role in the control of the pandemic, and will not be enough to control the epidemic in most locations on its own.

Figure 2 shows the CRWs over time worldwide and for Switzerland. The estimates for Switzerland stipulate a 10-15% reduction in the risk of COVID-19 during the summer 2020 followed by a 10-15% increase in the risk in winter 2020/21.

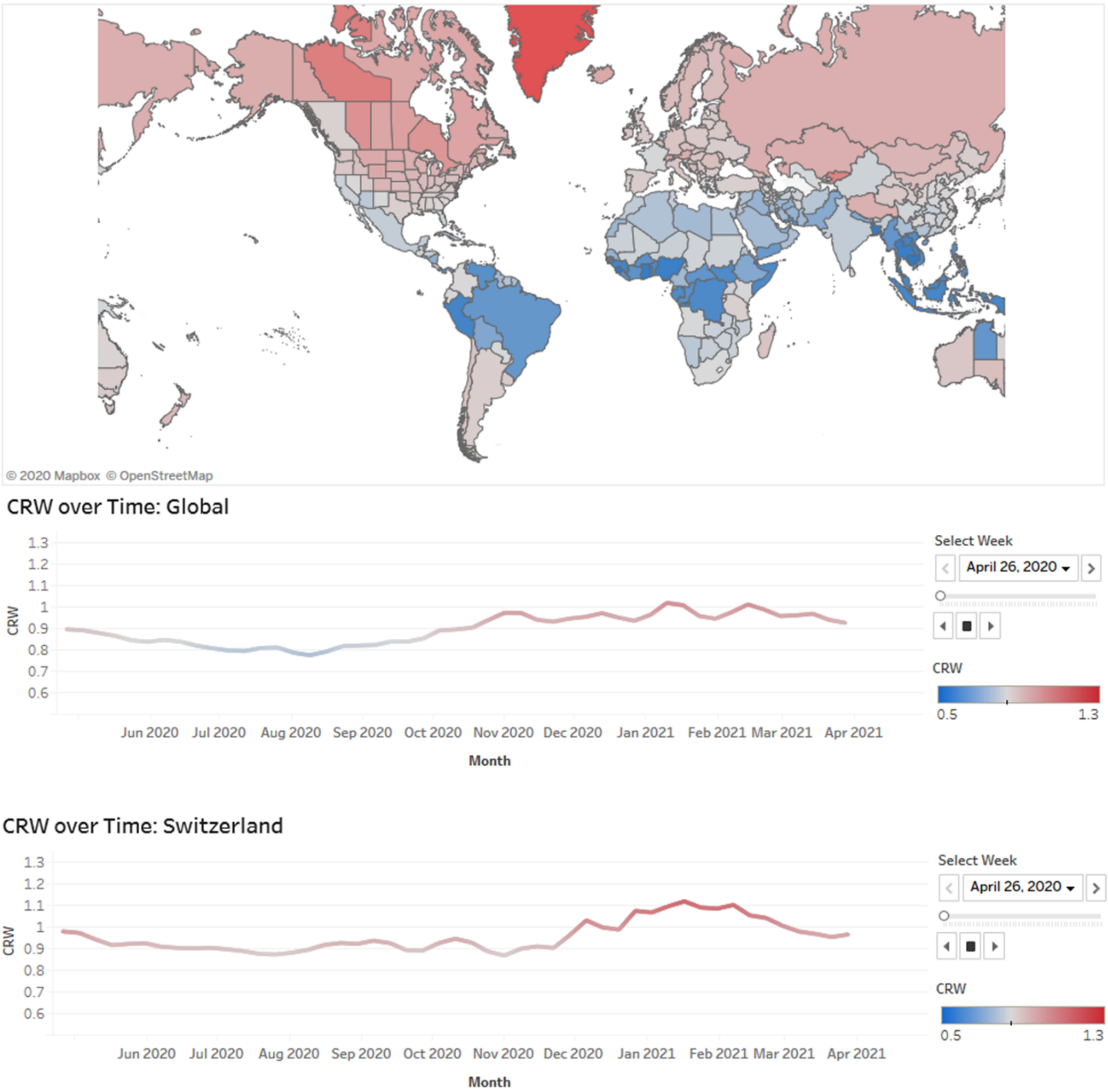


Figure 2: Relative COVID-19 Risk Due to Weather and air pollution (CRW) globally and for Switzerland.

Conclusion

Climate factors only explain a small part of the differences in the transmission rates of the current outbreak, in the different regions of the planet. Public health interventions are influencing the epidemic curve in a stronger way than do environmental factors. However, when climate factors like humidity and temperature have a certain range, like in Switzerland, they can still affect the epidemic growth. This leads to the recommendation that the public health interventions should not abandoned during the warmer months. Rather the emphasis should be on maintaining a low case rate until the arrival of the winter.

Unresolved issues

The evidence from many studies of the studies is imprecise and association may not be causal. Most of the included papers were pre-prints and not peer-reviewed.

References

1. Lipsitch M. Seasonality of SARS-CoV-2: Will COVID-19 go away on its own in warmer weather? Center for Communicable Disease Dynamics. Published February 26, 2020. Accessed May 23, 2020. https://ccdd.hsph.harvard.edu/will-covid-19-go-away-on-its-own-in-warmer-weather/

2. Eccles R. An Explanation for the Seasonality of Acute Upper Respiratory Tract Viral Infections. *Acta Otolaryngol (Stockh)*. 2002;122(2):183-191. doi:10.1080/00016480252814207

3. Lowen AC, Steel J. Roles of Humidity and Temperature in Shaping Influenza Seasonality. *J Virol*. 2014;88(14):7692-7695. doi:10.1128/JVI.03544-13

4. Martineau AR, Jolliffe DA, Hooper RL, et al. Vitamin D supplementation to prevent acute respiratory tract infections: systematic review and meta-analysis of individual participant data. *BMJ*. 2017;356:i6583. doi:10.1136/bmj.i6583

5. Bloom-Feshbach K, Alonso WJ, Charu V, et al. Latitudinal variations in seasonal activity of influenza and respiratory syncytial virus (RSV): a global comparative review. *PloS One*. 2013;8(2):e54445. doi:10.1371/journal.pone.0054445

6. Cliff A, Smallman-Raynor M. *Oxford Textbook of Infectious Disease Control: A Geographical Analysis from Medieval Quarantine to Global Eradication*. Oxford University Press; 2013. Accessed June 1, 2020. https://oxfordmedicine.com/view/10.1093/med/9780199596614.001.0001/med-9780199596614

7. Ammon CE. Spanish flu epidemic in 1918 in Geneva, Switzerland. *Euro Surveill Bull Eur Sur Mal Transm Eur Commun Dis Bull*. 2002;7(12):190-192. doi:10.2807/esm.07.12.00391-en

8. Chowell G, Ammon CE, Hengartner NW, Hyman JM. Estimation of the reproductive number of the Spanish flu epidemic in Geneva, Switzerland. *Vaccine*. 2006;24(44-46):6747-6750. doi:10.1016/j.vaccine.2006.05.055

9. Lemaitre M, Carrat F. Comparative age distribution of influenza morbidity and mortality during seasonal influenza epidemics and the 2009 H1N1 pandemic. *BMC Infect Dis*. 2010;10:162. doi:10.1186/1471-2334-10-162

10. Balcan D, Hu H, Goncalves B, et al. Seasonal transmission potential and activity peaks of the new influenza A(H1N1): a Monte Carlo likelihood analysis based on human mobility. *BMC Med*. 2009;7:45. doi:10.1186/1741-7015-7-45

11. Living Evidence on COVID-19. Accessed May 26, 2020. https://zika.ispm.unibe.ch/assets/data/pub/search_beta/

12. Egger M, Johnson L, Althaus C, et al. Developing WHO guidelines: Time to formally include evidence from mathematical modelling studies. *F1000Research*. 2017;6:1584. doi:10.12688/f1000research.12367.1

13. Pae C-U. Why Systematic Review rather than Narrative Review? *Psychiatry Investig*. 2015;12(3):417-419. doi:10.4306/pi.2015.12.3.417

14. Egger M, Smith GD, Altman DG. *Systematic Reviews in Health Care: Meta-Analysis in Context*. Vol 2. (Egger M, Smith DG, Altman DG, eds.). BMJ Books; 2001.

15. Neher RA, Dyrdak R, Druelle V, Hodcroft EB, Albert J. Potential impact of seasonal forcing on a SARS-CoV-2 pandemic. *medRxiv*. Published online March 3, 2020:2020.02.13.20022806. doi:10.1101/2020.02.13.20022806

16. Neher RA, Dyrdak R, Druelle V, Hodcroft EB, Albert J. Potential impact of seasonal forcing on a SARS-CoV-2 pandemic. *Swiss Med Wkly*. 2020;150:w20224. doi:10.4414/smw.2020.20224

17. Kissler SM, Tedijanto C, Goldstein E, Grad YH, Lipsitch M. Projecting the transmission dynamics of SARS-CoV-2 through the post-pandemic period. *medRxiv*. Published online March 6, 2020:2020.03.04.20031112. doi:10.1101/2020.03.04.20031112

18. Kissler SM, Tedijanto C, Goldstein E, Grad YH, Lipsitch M. Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. *Science*. Published online April 14, 2020. doi:10.1126/science.abb5793

19. Baker RE, Yang W, Vecchi GA, Metcalf CJE, Grenfell BT. Susceptible supply limits the role of climate in the COVID-19 pandemic. *medRxiv*. Published online April 7, 2020:2020.04.03.20052787. doi:10.1101/2020.04.03.20052787

20. Harbert RS, Cunningham SW, Tessler M. Spatial modeling cannot currently differentiate SARS-CoV-2 coronavirus and human distributions on the basis of climate in the United States. *medRxiv*. Published online April 10, 2020:2020.04.08.20057281. doi:10.1101/2020.04.08.20057281

21. Li H, Xiao H, Zhu R, Sun C, Liu C, Xiao H. Warmer weather and global trends in the coronavirus COVID-19. *medRxiv*. Published online May 5, 2020:2020.04.28.20084004. doi:10.1101/2020.04.28.20084004

22. Hoffman BU. Significant Relaxation of SARS-CoV-2-Targeted Non-Pharmaceutical Interventions Will Result in Profound Mortality: A New York State Modelling Study. *medRxiv*. Published online May 14, 2020:2020.05.08.20095505. doi:10.1101/2020.05.08.20095505

23. Xu R, Rahmandad H, Gupta M, DiGennaro C, Amini H, Jalali MS. The Modest Impact of Weather and Air Pollution on COVID-19 Transmission. https://projects.iq.harvard.edu/files/covid19/files/weather_and_covid-19_preprint.pdf

24. Xu R, Rahmandad H, Gupta M, DiGennaro C, Ghaffarzadegan N, Jalali MS. Weather Conditions and COVID-19 Transmission: Estimates and Projections. *medRxiv*. Published online 2020. doi:10.1101/2020.05.05.20092627

25. Carleton T, Meng KC. Causal empirical estimates suggest COVID-19 transmission rates are highly seasonal. *medRxiv*. Published online March 30, 2020:2020.03.26.20044420. doi:10.1101/2020.03.26.20044420

26. Triplett M. Evidence that higher temperatures are associated with lower incidence of COVID-19 in pandemic state, cumulative cases reported up to March 27, 2020. *medRxiv*. Published online April 12, 2020:2020.04.02.20051524. doi:10.1101/2020.04.02.20051524

27. Chiyomaru K, Takemoto K. *Global COVID-19 Transmission Rate Is Influenced by Precipitation Seasonality and the Speed of Climate Temperature Warming*.; 2020. doi:10.1101/2020.04.10.20060459

28. Ficetola GF, Rubolini D. Climate affects global patterns of COVID-19 early outbreak dynamics. *medRxiv*. Published online April 20, 2020:2020.03.23.20040501. doi:10.1101/2020.03.23.20040501

29. Merow C, Urban MC. Seasonality and uncertainty in COVID-19 growth rates. *medRxiv*. Published online April 22, 2020:2020.04.19.20071951. doi:10.1101/2020.04.19.20071951

30. Notari A. Temperature dependence of COVID-19 transmission. *medRxiv*. Published online April 24, 2020:2020.03.26.20044529. doi:10.1101/2020.03.26.20044529

31. Jüni P, Rothenbühler M, Bobos P, et al. Impact of climate and public health interventions on the COVID-19 pandemic: A prospective cohort study. *CMAJ Can Med Assoc J J Assoc Medicale Can*. Published online May 8, 2020. doi:10.1503/cmaj.200920

32. Australian Academy of Science. Seasonality of COVID-19: Impact on the spread and severity. Accessed May 24, 2020. https://www.science.org.au/covid19/seasonality-covid-19

33. Mecenas P, Bastos R, Vallinoto A, Normando D. Effects of temperature and humidity on the spread of COVID-19: A systematic review. *medRxiv*. Published online April 17, 2020:2020.04.14.20064923. doi:10.1101/2020.04.14.20064923

34. Chiyomaru K, Takemoto K. Global COVID-19 transmission rate is influenced by precipitation seasonality and the speed of climate temperature warming. *medRxiv*. Published online April 14, 2020:2020.04.10.20060459. doi:10.1101/2020.04.10.20060459

Appendix: Structured summaries of included studies

The studies are listed by date of publication.

Neher et al., March 3, 2020 – mathematical modelling study[15]

Objectives: To explore how seasonal variation in transmissibility could modulate the SARS-CoV-2 pandemic in the temperate zone of Northern Hemisphere.

Data: Seasonal prevalence data from seasonal coronaviruses (sCoVs: 229E, HKU1, NL63, OC43) in Sweden from 2010-2019.

Methods: Use of the data on sCoVs to parameterize a SEIR (susceptible, exposed, infected, recovered model for SARS-CoV-2.

Main findings:

- Plausible parameters result in a small peak in early 2020 in temperate regions of the Northern Hemisphere and a larger peak in winter 2020/2021.
- Variation in transmission and migration rates can result in substantial variation in prevalence between regions.

Interpretation:
Reductions in the incidence rate might be due to a combination of seasonal variation and infection control efforts but do not necessarily mean the epidemic is contained. Seasonality alone is unlikely to end transmission of SARS-CoV-2. The dynamics can differ significantly between countries. Trajectories in one country should be used cautiously to inform projections in a second country, even in the same climate zone.

Kissler et al., March 6, 2020 – mathematical modelling study[17,18]

Objectives: To project transmission of SARS-CoV-2 through year 2025 in the USA.

Data: Data on the dynamics of other human coronaviruses (HCoV-OC43 and HCoV-HKU1), including transmissibility, immunity, cross-immunity and impact of seasonal variation in the USA 2014 to 2019.

Methods: After building a SEIR model based on the dynamics of HCoV-OC43 and HCoV-HKU1, Kissler et al. incorporated SARS-CoV-2 as a third virus using the available parameters (incubation and infection period) and allowing variation of the unknown SARS-CoV-2 parameters (the duration of immunity, cross-immunity, degree of seasonal variation in transmissibility and establishment time of sustained transmission). Outcomes were the annual incidence of SARS-CoV-2 and the outbreak size for the next five years.

Main findings:

- If immunity to SARS-CoV-2 is not permanent, it will enter into seasonal circulation.
- If immunity to SARS-CoV-2 is permanent, the virus could disappear for five or more years.
- Low levels of cross-immunity from the other betacoronaviruses against SARS-CoV-2 could make SARS-CoV-2 appear to die out, only to resurge after a few years.
- The dynamics of coronavirus outbreaks in temperate regions over the next five years could depend on when SARS-CoV-2 became established.

Interpretation:
Recurrent wintertime outbreaks will probably occur after the initial pandemic wave. The cumulative incidence of COVID-19 illness over the next five years will depend critically upon whether or not it enters into regular circulation after the initial pandemic wave. This depends primarily upon the duration of immunity that SARS-CoV-2 infection imparts. The intensity and timing of pandemic and post-pandemic outbreaks will depend on the time of year when widespread SARS-CoV-2 infection happens and the seasonal variation in transmissibility.

Carleton and Meng, March 26, 2020 – epidemiologic data analysis[25]

Objectives: To provide an estimates of the relationship between new COVID-19 cases and local temperature.

Data: Sample of 166,686 confirmed new COVID-19 cases from 134 countries from January 22, 2020 to March 15, 2020.

Methods: Poisson regression model separating effects of climate variation on COVID-19 transmission from other potentially correlated factors (e.g. public health response, heterogeneous population densities).

Main findings:

- 1°C increase in local temperature reduces new COVID-19 cases per 1 million people by 13% (95% CI -21% to -4%). There was no significant effect of precipitation and humidity.
- Changing temperature between March 2020 and July 2020 will cause COVID-19 transmission to fall by 43% on average for Northern Hemisphere countries and to rise by 71% on average for Southern Hemisphere countries.

- Inverse pattern with the boreal winter approaching: in January 2021 increasing of transmission by 59% relative to March 2020 in the North and lowering of 2% in the South.

Interpretation:
With the fall of transmission during summer in the Northern Hemisphere, Northern countries have a window of opportunity to eliminate COVID-19 from their populations. Keeping in place or implementing large-scale public health interventions that limit contact amongst individuals will achieve or maintain low overall case rates. If transmission persists through summer, cooler fall and winter months could lead to a substantial resurgence of new cases.

Baker et al., April 07, 2020 – mathematical modelling study[19]

Objectives: To assess whether seasonal and geographic variations in climate can substantially alter the pandemic trajectory in the USA, given the high level of susceptibility to SARS-Cov-2 is a core driver in the population.

Method: Susceptible-Infected-Recovered-Susceptible(SIRS) fitted to US case data of HCoV-HKU1 and HCoV-OC43, with all other parameters taken from Kissler et al. 2020.[17,18]

Main findings:

- The initial pandemic trajectory is relatively independent of seasonal forcing.
- After that, the trajectory gives way to the endemic attractor, which oscillates around the equilibrium of the unforced model. These longer-term dynamics show a much stronger signature of seasonal forcing than the pandemic phase.

Interpretation:
The results imply that both tropical and temperate locations should prepare for severe outbreaks of the disease and that summertime temperatures will not effectively limit the spread of the infection. However, this does not mean the climate is not important in the longer term.

Harbert et al., April 10, 2020 – mathematical modelling study[20]

Objectives: To examine whether climate is important for predicting the future distribution of SARS-CoV-2 in the USA.

Method: Species distribution models (SDMs) applied to raw cases and population scaled cases from SARS-CoV-2 county-level data from the USA.

Main findings:

- When taking into account the size of the population, results show that the climate may not play a central role in current US viral distribution and that human population density is likely a primary driver. Still, the authors find slightly more cases in colder areas.

Interpretation:
Climate's role on SARS-CoV-2 should continue to be cautiously examined, but at this time, we should assume that SARS-CoV-2 can spread anywhere in the US.

Triplett, April 12, 2020 – epidemiologic data analysis[26]

Objectives: To examine the impact of seasonal temperature variation on the trajectories of COVID-19 in different global regions.

Methods: Multiple linear and nonlinear regression of daily COVID-19 situation reports provided by the World Health Organization (WHO) from March 14 to March 27. Global gridded daily maximum surface temperature data, with 0.5° spatial resolution, for the dates from February 29 to March 14, 2020, from the US National Oceanic and Atmospheric Administration (NOAA website were used.

Main findings:

- Case rates appeared to be increasing south of -30° latitude, where temperatures fall first with the transition to the fall season.
- Nonlinear regression of case rates on temperature showed the best fit, with highest case rates at 7.5°C, and case rates uniformly distributed near zero at temperatures above 22.5°C.

Interpretation:

These results imply that climate has an impact on the transmissibility on a global level. However, geography and temperature do not explain the variance at the local level. These results should not be interpreted as showing that COVID-19 cannot survive or transmit in warm and humid temperatures, or establish a causal connection between temperature and transmission. The Southern hemisphere should also expect increased case rates as that region moves from summer into fall and winter

Chiyomaru et al., April 14, 2020 – epidemiologic data analysis[34]

Objectives: To investigate the contribution of climate parameters to the growth rate of COVID-19 cases.

Methods: Ordinary least-squares (OLS) regression and spatial analyses were used to analyze the growth rate in the number of confirmed cases of COVID-19 as reported by the Johns Hopkins University. Several global databases were used for climate and other parameters, including the WorldClim database.

Main findings:

- The growth rate in new COVID-19 cases decreased with increasing temperature and was also affected by precipitation seasonality and warming velocity. Lower growth rates were observed for higher precipitation and lower warming velocity. These effects were independent of population density, human life quality, and travel restrictions. The humidity did not contribute to growth rates.

Interpretation:

The contributions of climate parameters to the growth rate of COVID-19 cases were moderate, while those of national emergency responses (i.e., travel restrictions) were more significant. Thus, the arrival of the summer season may not slow the spread of COVID-19. Instead, global collaborative interventions might be necessary to halt the epidemic outbreak.

Australian Academy of Science, April 15, 2020 – rapid, narrative review[32]

Objectives: To provide a rapid review of the literature, including of publications that may not have been peer-reviewed yet.

Methods: Rapid, narrative review. No description of the literature search or eligibility criteria.

Main findings:

- Research suggests there will be some influence of winter on spread of COVID-19. Lower temperature and humidity increase the stability of the virus. Cold and dry air makes the respiratory epithelium more prone to damage. Less vitamin D decreases innate immunity. People spend more time indoors (physical distance more difficult). Infections with other viruses increase the burden on the public health system. The onset of winter may further exacerbate the psychological effects of COVID-19 if quarantining measures are extended.

Interpretation:

Although there is no compelling data that clearly demonstrate a link between winter and increased occurrence of COVID-19, collectively these studies suggest that we may expect an increase in virus transmission in the winter because of cooler, less humid climate. Nevertheless, climate may be a less important factor forSARS-CoV-2transmission than active containment measures and human behaviour, such as good hygiene and physical distancing.

Mecenas et al. April 17, 2020 – systematic review[33]

Objectives: To describe the evidence on the emergence and replicability of the virus and its correlation with temperature and relative humidity.

Methods: The review was registered with the PROSPERO database (CRD42020176909). PubMed, Scopus, Web of Science, Cochrane Library, LILACS, OpenGrey and Google Scholar were searched. Risk of bias was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist tool. The GRADE tool was used to assess the quality of the evidence.

Data: 17 studies met the review's eligibility criteria.

Main findings:

- Four studies were at high risk of bias, 13 had a moderate risk of bias. Sixteen articles selected were unanimous in stating that cool and dry conditions were potentiating factors for the spread of COVID-19, with the spread being largely absent under extremely cold and very hot and wet conditions. Only one article reported no strong effect of temperature and humidity on the spread of the virus.
- The certainty of the evidence was graded as low for both outcomes (temperature and relative humidity).

Interpretation:

The spread of COVID-19 seems to be lower in warm and wet climates. However, the certainty of the evidence generated was graded as low. Temperature and humidity alone do not explain most of the variability of the COVID-19 outbreak. Public isolation policies, herd immunity, migration patterns, population density, and cultural aspects might influence how the spread of this disease occurs.

Ficetola et al., April 20, 2020 – epidemiologic data analysis[28]

Objectives: To assess the impact of temperature and humidity on the global patterns of Covid-19 early outbreak dynamics during January-March 2020.

Methods: Linear mixed models were used to relate the global variation of Covid-19 growth rates to five predictors (temperature and humidity of outbreak month; population size; population density; health expenditure; PM2.5; population 65+). Country was included as a random factor. Several databases were used, including the Johns Hopkins University database.

Main findings:

- Covid-19 growth rates peaked in temperate regions of the Northern Hemisphere with a mean temperature of ~5°C, and specific humidity of 4-6 g/m3 during the outbreak period
- They were lower both in warmer/wetter and colder/dryer regions
- Relationships between Covid-19 and climate were robust to the potential confounding effects of air pollution and socio-economic variables, including population size, density and health expenditure.

Interpretation:

The highest growth rates were observed in temperate regions of the Northern Hemisphere. However, fast growth also occurred in some warm climates, notably in Brazil, Indonesia and the Philippines, suggesting that no area of the world is exempt from SARS-Cov-2 infection risk.

Merow et al., April 22, 2020 – epidemiologic data analysis[29]

Objectives: To assess if summer weather will reduce COVID-19's continued spread, and thereby alleviating strains on hospitals and providing time for vaccine development.

Methods: The authors used a hierarchical Bayesian Gaussian regression model, which included 14 days lagged temperature, relative humidity, absolute humidity, UV light, population density and proportion of the population over 60. Data sources included the Johns Hopkins database on Covid-19 cases as well as global wheater and population databases. Data from 128 countries and 98 states or provinces were included. Human behaviour and control measures were not considered.

Main findings:

- The model that explained 36% of the variation in early growth rates before public health interventions, with 17% based on weather or demography and 19% based on country-specific effects. UV light was most strongly associated with lower COVID-19 growth rates.
- The model was characterized by equally strong random effects associated with country. For instance, Turkey, Brazil, Iran, the U.S., and Spain had the highest growth rates independent of modeled factors, whereas China, Iceland, Burkina Faso, Sweden, and Cambodia had the lowest.

Interpretation:

Projections suggest that, in the absence of intervention, COVID-19 will decrease temporarily during summer, rebound by autumn, and peak next winter.

Notari et al., April 24, 2020 – epidemiologic data analysis[30]

Objectives: To assess whether the growth rate of confirmed Covid-19 cases decreases with increasing temperature, and to examine the relationship with the GDP of countries.

Methods: The data on Covid-19 cases in different countries were obtained from the European Centre for Disease Prevention and Control (ECDC). Three datasets were analyzed: a base set of 42 countries, which developed the epidemic at an earlier stage, an intermediate set of 88 countries and an extended set of 125 countries, which developed the epidemic more recently. Temperature data were obtained from Wikipedia. The author first fit the data for each country with a simple exponential model and extracted the exponents for each country. He then analyzed exponents as a function of the temperature, using linear and quadratic models.

Main findings:

- Analyses of all three datasets showed that the growth rate of Covid-19 cases decreased with decreasing temperature.
- Using a quadratic fit for the base set of countries, a peak of maximal transmission was evident at around 7.7 °C.

Interpretation:
The decrease in the growth rate at high temperatures is in line with what is observed with other coronaviruses. A large scatter in the residual data is present, clearly due to many other factors, such as variations in the methods and resources used for collecting data and variations in the amount of social interactions, due to cultural reasons. In general, it is important to fully stop the propagation, using lockdown, testing and tracking policies, taking advantage of the warmer season, and before the arrival of the next cold season.

Li et al., May 5, 2020 – mathematical modelling study[21]

Objectives: To propose a new concept of environmental infection rate (RE), based on floating time of respiratory droplets in the air and inactivation rate of virus.

Methods: RE is estimated using linear equations, based on the effective floating time of respiratory droplets in the air, which in turn is influenced by temperature and relative humidity, and the infection period. Different datasets with information on the outbreak in China and internationally are used.

Main findings:

- The modelled environmental reproduction rate value of COVID-19 worldwide ranged between 2.15 and 4.25
- In the Northern hemisphere, the areas with high modelled environmental reproduction rate values (>3.5) are largest in April but shrink to the North after that.
- In the Southern hemisphere, regions with high global environmental reproduction rate values (>3.3) also expand northward as air temperature rises.

Interpretation:
The model estimations show that warmer weather after April will help slow down the outbreak in the 30°-60°N zone The high modelled RE values up to July suggest that warmer weather will not stop Covid-19 from spreading. Public health interventions are needed to overcome the outbreak.

Jüni et al. May 8, 2020 – epidemiologic data analysis[31]

Objectives: To determine whether epidemic growth is globally associated with climate or public health interventions intended to reduce transmission of SARS-CoV-2.

Methods: Using univariable and multivariable weighted random-effects regression, the authors determined the association between epidemic growth and latitude, temperature, humidity, school closures, restrictions of mass gatherings, and measures of social distancing during an exposure period 14 days in early March 2020. The follow-up period started 2 weeks later. The study included 144 geopolitical areas worldwide without China, South Korea, Iran and Italy. Data sources included the John Hopkins University databases and publicly available data on meterological data and public health measures, including Wikipedia. Results were expressed as ratios of rate ratios (RRRs).

Main findings:

- Univariate analyses:
    - few or no associations of epidemic growth of the current outbreak with latitude and temperature.
    - weak negative associations with relative humidity (RRR per 10% 0.91, 95% confidence interval [CI] 0.85-0.96) and absolute humidity (RRR per 5 g/m3 0.92, 95% CI 0.85-0.99).
    - strong association with public health interventions.
- Multivariable analysis:
    - public health interventions still show a strong negative association
    - humidity was no longer statistically significant.

Interpretation:

Epidemic growth of COVID-19 was not associated with geographic latitude, nor with temperature during the exposure period, in our global analysis. Only area-wide public health interventions were consistently associated with reduced epidemic growth, and the greater the number of co-occurring public health interventions, the larger the reduction in growth. Taken together, these findings suggest that seasonality is likely to play only a minor role in the epidemiology of COVID-19, while public health interventions (schoolclosures, restricting mass gatherings, social distancing) appear to have a major impact.

Hoffmann et al., May 14, 2020 – mathematical modelling study[22]

Objectives: To estimate the effect of undocumented infections, seasonal infectivity, immunity, and non-pharmaceutical interventions, such as social distancing, on the transmission, morbidity, and mortality of SARS-CoV-2 in New York State (NYS).

Methods: SARS-CoV-2 case data for NYS were extracted from publicly reported clinical statistics by the NYS Department of Health. Non-SARS-CoV-2 human coronavirus (HCoV) data was obtained from the CDC National Respiratory and Enteric Virus Surveillance System (NRVESS). The transmission dynamics of SARS-CoV-2 were modelled with a system of ordinary differential equations (ODEs) describing an eleven-compartment susceptible-exposed-infected-recovered-susceptible (SEIRS) model. The seasonal variability SARS-CoV-2transmission was modelled afternon-SARS-CoV-2 HCoV seasonal variability.

Main findings:

- Undocumented infections driveSARS-CoV-2 transmission.
- Reduction of social distancing by >50% will result in a substantial increase in mortality.
- A recurrent outbreak of SARS-CoV-2 in NYS is likely in early 2021.
- The seasonal variability of infectivity and incomplete sustained immunity means that Covid-19 will likely become endemic.

Interpretation:

This study revealsthat dynamic social distancing measures are essential and critical to controlling the spread of SARS-CoV-2, and that in the absence of development of profound immunity caused by infection or the development of an efficacious vaccine, the virus is very likely to become endemic with seasonal variation. The model predicts a significant second outbreak in early 2021 that can be mitigated, but not avoided entirely, through the resumption of strong social distancing measures.

Xu et al., May 23, 2020 – mathematical modelling study[23]

Objectives: To study the relative risk of COVID-19 due to weather and ambient air pollution and to predict the relative risk of COVID-19 transmission due to environmental factors in different countries and cities.

Methods: The authors compiled a comprehensive datasets of the global spread of COVID-19, including infection data for 3,739 distinct locations, spanning the beginning of the epidemic (December 12, 2019) to April 22, 2020. The Johns Hopkins University data were augmented with data reported by the Chinese Center for Disease Control and Prevention, Provincial Health Commissions in China, and Iran's state-level reports. Weather and population data were obtained from various sources. The authors estimated *Re* taking into account asymptomatic cases, under-reporting and reporting delays, and changing test coverage. A stochastic simulation model and individual-based transmission model were developed and validated for this purpose.

The authors defined "Relative COVID-19 Risk Due to Weather and air pollution" (CRW) as the relative predicted risk of each weather and air pollution vector relative to the 95th percentile of predicted risk. A CRW of 0.5 reflects a 50% reduction in the estimated reproduction number compared to this (high-risk) reference.

Main findings:

- Mean temperature, Ultraviolet index, diurnal temperature, air pressure, wind speed, precipitation, and air pollution levels were all significantly associated with transmission.
- Temperatures higher than than 25°C were strongly associated with lower transmission rates while those below that threshold had a smaller effect.
- An interactive online platform at https://projects.iq.harvard.edu/covid19 offers comprehensive projections for countries, most populous cities and US counties.

Interpretation:

The authors conclude that summer may offer partial relief to some regions of the world. However, given a highly susceptible population, the estimated impact of summer weather on transmission risk is not large enough in most places to quell the epidemic in 2020, indicating that policymakers and the public should remain vigilant in their responses to the pandemic. Weather plays a secondary role in the control of the pandemic, and will not be enough to control the epidemic in most locations on its own.