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Discussion

On the usefulness of the bioclimatic correlative models of SARS-CoV-2

Oliver Gutiérrez-Hernández, a,*, Luis V. García

a Department of Geography, University of Málaga, Bulevar Louis Pasteur 27, 29010, Málaga, Spain
b Institute of Natural Resources and Agrobiology of Seville (IRNAs), Spanish National Research Council (CSIC), Av. Reina Mercedes 10, 41012, Seville, Spain

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ABSTRACT

This paper addresses the effects of atmospheric conditions on the spread of the SARS-CoV-2 coronavirus and its associated disease, COVID-19. For this purpose, we assess the limitations of bioclimatic correlative models to explain the geographic distribution of SARS-CoV-2 in the context of medical geography. Overall, there is a broad consensus that the global distribution of COVID-19 is not random but conditioned by environmental drivers. However, as the COVID-19 distribution becomes global, including tropical climates, the evidence reveals that atmospheric conditions explain, at most, only a limited amount of the space-time dynamics of SARS-CoV-2. Therefore, the usefulness of approaches based on bioclimatic envelopes is in question since the dominant route for the spread of COVID-19 seems to be the anthroposphere’s non-stationary environment. In this sense, there is a need to clarify further the role of different transmission routes at multiple scales and outdoor and indoor environments beyond bioclimatic envelopes. At this time, the possible influence of the weather in COVID-19 spread is not sufficient to be taken into account in public health policies. Hence, until reliable bioclimatic envelopes of SARS-CoV-2, if any, are found, caution should be exercised when reporting, as this could have unforeseen consequences.

1. Introduction

On March 11, 2020, the World Health Organization (WHO) declared the outbreak of the COVID-19 disease caused by the novel coronavirus SARS-CoV-2 to be a global pandemic (WHO, 2020). From the beginning, authors have highlighted the potential influence of atmospheric conditions on the distribution of SARS-CoV-2 and the spread of the COVID-19 disease. Most of the contributions concluded that there is some influence of weather and/or climate on the spread of COVID-19 (Al-Rousan and Al-Najjar, 2020; Bashir et al., 2020; Coccia, 2020a; Elami and Jalili, 2020; Holtmann et al., 2020; Ma et al., 2020; Rosario et al., 2020; Sajadi et al., 2020; Tobias and Molina, 2020; Xie and Zhu, 2020). Specifically, a cool and dry environment in a mesothermal climate seems to most favour the SARS-CoV-2 coronavirus spread. This perception became a mantra during the early stages of the COVID-19 pandemic. So, many research papers appeared based on the relationship between climate suitability of SARS-CoV-2 and the COVID-19 pandemic spread risk, some of which showed extrapolations in space-time (Araújo and Naimi, 2020; Coro, 2020; Scafetta, 2020).

However, other researchers questioned the effect of atmospheric conditions and the importance of these variables to explain the COVID-19 pandemic outbreaks across multiple scales (Bontempi, 2020a; Bontempi, 2020b; Briz-Redón and Serrano-Aroca, 2020a; Jüni et al., 2020; O’Reilly et al., 2020; Pacheco et al., 2020). Different epidemiological models suggest that direct transmission routes (i.e. from infected to non-infected individuals) account for most of the infections, and almost explain the epidemic growth alone (Ferretti et al., 2020). That is why control measures that limit direct transmissions at different scales (e.g. mobility restrictions) have a significant and predictable effect on COVID-19 spread (Wu et al., 2020a; Wu et al. 2020b; Zhou et al., 2020). In contrast, models based on genuine direct effects of atmospheric variables on environmentally mediated transmission routes have clearly failed to predict disease progression when projected in spatial-temporal contexts other than those in which they were fitted. Different review papers also questioned the evidence of significant genuine effects of atmospheric conditions on disease incidence (Brassey et al., 2020; Briz-Redón and Serrano-Aroca, 2020b; Gutiérrez-Hernández and García, 2020; Mecenas et al., 2020). Lack of control of relevant social variables closely related to weather and methodological inconsistencies are frequently cited as the primary sources of erroneous conclusions (Gutiérrez-Hernández and García, 2020).

In this discussion paper, we address the uncertainties about the
spread of the COVID-19 disease and the limitations of the correlative bioclimatic models. Concerning the influence of atmospheric conditions (and other candidate drivers) on the disease distribution, we hypothesise that extrapolations in space-time do not add explanatory power to future scenarios of the COVID-19 pandemic.

Ultimately, the research question that we pose is whether in the current circumstances these correlational models can provide useful information to combat the disease or can instead be a source of confusion that can even weaken the control measures supported by scientific evidence. For this purpose, we discuss some key points paramount to understanding the research problem posed to the geographical distribution and spread of the COVID-19 pandemic: 1) SARS-CoV-2 stability vs COVID-19 spread; 2) Weather vs climate; 3) Atmosphere vs anthroposphere; 4) Scientific evidence vs statistical significance.

2. Discussion

2.1. SARS-CoV-2 stability vs COVID-19 spread

SARS-CoV-2 is the name of the virus (severe acute respiratory syndrome coronavirus 2), and COVID-19 refers to the coronavirus disease (Guan et al., 2020; Hu et al., 2020; Wu et al., 2020a). It is crucial to distinguish between the virus and the disease because research mistakes derive from this misperception. According to experimental studies, the stability of SARS-CoV-2 depends on temperature and humidity: the virus is highly stable at 4 °C, but sensitive to heat (Chin et al., 2020). Aerosol and fomite transmission of SARS-CoV-2 is plausible since the virus can remain viable and infectious in aerosols for hours and on surfaces for up to days (van Doremalen et al., 2020). Sarkodie and Owusu (2020) reported that high temperature and high relative humidity reduce the viability, stability, survival and transmission of COVID-19 whereas low temperature, wind speed, dew/frost point, precipitation and surface pressure prolong the activation and infectivity of the virus.

Experimental evidence shows that SARS-CoV-2 is environmentally sensitive. However, knowledge about the spread of SARS-CoV-2 in controlled environments on the human transmission of COVID-19 is still insufficient, and other factors may also determine the incidence of COVID-19. Huang et al. (2020) investigated the associations between several built-environment variables (e.g. accessibility and green space density) and COVID-19 risk using global Poisson regression and geographically weighted Poisson regression models. They found that relevant built-environment features can explain the observed incidence of COVID-19. Kwon et al. (2020) found evidence of long-distance droplet transmission of SARS-CoV-2, and they suggest that droplet transmission can occur at a distance greater than 2 m if there is direct airflow from an infected person. Hwang et al. (2020) suggest that aerosols’ indoor infection risks are underappreciated and urgently need attention. Based on mobility network models, Chang et al. (2020) found that a small minority of ‘super-spreader’ points of interest account for a large majority of the infections and restricting maximum occupancy at each point of interest is more effective than uniformly reducing mobility.

Conceptually, it is not realistic to consider only outdoor temperature and relative humidity as the significant driving factors of the COVID-19 incidence (Passeri et al., 2020). Most of the research that related weather variables with the spread of COVID-19 were retrospective observational studies. Based on a systematic review, Mecenas et al. (2020) observed a remarkable homogeneity in the findings regarding the influence of temperature and humidity on the seasonal viability and transmissibility of COVID-19. They reviewed seventeen studies and performed a quality assessment. They found four studies with a high risk of bias and another thirteen with moderate risk. The certainty of the overall evidence was rated low for both temperature and humidity.

2.2. Weather vs climate

Weather is the state of the atmosphere and its short-term variation in minutes to weeks. Climate is the weather of a region over a long time: 30 years have been established by convention (Barry and Chorley, 1968). Climate information includes statistical analyses about the usual weather and the range of weather extremes for a location or region. Here, it is also crucial to distinguish between the scales of weather and climate. Many researchers have suggested that the optimal conditions for increasing the transmission of SARS-CoV-2 are a cool and dry environment in a mesothermal climate, which could confer a seasonal component to the pandemic (Baker et al., 2020; Sajadi et al., 2020). Araújo and Naimi (2020) suggested that the average long-term conditions significantly influence the human-to-human transmission of SARS-CoV-2 and that unsuitable climates can cause the virus to destabilise rapidly, hence reducing its capacity to become epidemic. According to Baker et al. (2020), atmospheric conditions variations may be significant for endemic infections, but the climate drives only modest changes through the pandemic stage of an emerging pathogen. In this sense, they suggest that, after the initial pandemic phase, endemic cycles of the disease will probably be linked to climate drivers. However, at present, SARS-CoV-2 is in an active propagation phase; therefore, it is incorrect to assume that its current distribution is in equilibrium with climate.

Bioclimatic envelope models are correlative models exploring the relationship between species occurrences and environmental predictors (Araújo and Peterson, 2012). The most straightforward approach to model ecological niches is by fitting bioclimatic envelopes and identifying shapes in multidimensional environmental space that enclose environments associated with known occurrence localities (Peterson et al., 2011). One of the most controversial assumptions of the bioclimatic envelope models is that species distributions will be at equilibrium with the climate; this means that species inhabit the entire spatial footprint of their habitable conditions (Václavik and Meentemeyer, 2012). When applying the bioclimatic envelopes in static species distribution modelling, without including dynamic elements, the underlying assumption is that species are in quasi-equilibrium with current environmental conditions (Franklin, 2009). However, the distribution of SARS-CoV-2 is not in equilibrium with climate, and correlative models are inappropriate for explaining and predicting the spread of COVID-19 (Carlson et al., 2020a, 2020b; Chipperfield et al., 2020).

According to Araújo et al. (2020), correlative models can provide insight concerning the environmental persistence of SARS-CoV-2; they propose that this insight may explain the spread of the disease. However, their models have changed over time (Araújo and Naimi, 2020), and no bioclimatic niche has been found. COVID-19 seems to have spread globally, unencumbered by climate, but correlative modelling efforts continue to search for a climate signal (Carlson et al., 2020c). At present (January 25, 2021), according to the real-time data from Johns Hopkins University (Dong et al., 2020), the COVID-19 pandemic projects a big global wave or several waves in many parts of the world. However, the COVID-19 seasonal behaviour due to weather variations is still unknown and unpredictable, at least in this stage of the pandemic wave.

2.3. Atmosphere vs anthroposphere

In order to model the space-time dynamics of COVID-19, it is crucial to consider the non-stationary nature of the anthroposphere.

Most of the bioclimatic studies about COVID-19 are based on correlational models, in which they interpret (implicit or explicitly) the resulting correlations as evidence of causal links (Currie et al., 2019). Correlational models (similar to bioclimatic envelope models) transfer the suitability of human transmissions of SARS-CoV-2, assuming an inadequate space-for-time substitution assumption (Damgaard, 2019). They use static models in non-stationary environments, and the results can lead to erroneous conclusions because epidemiological processes occur
in time.

We relate another limitation to the data. Omori et al. (2020) illustrate how reported cases’ epidemic curves may not always reflect the real epidemic growth rate because of changes in testing rates. The limited diagnostic testing capacity could have been influencing data during the early epidemic phase. This limited capacity generates unknowns related to the prevalence of COVID-19 over time. In this sense, serological surveys are a valuable tool to assess the extent of the epidemic, given the existence of asymptomatic cases and low access to diagnostic tests (Pollán et al., 2020). However, testing and reporting of COVID-19 differ across reporting units and is constantly changing; this makes a comparison between different periods and space units problematic (Malanson, 2020).

Many studies suffer from inadequate research designs that do not address critical issues such as brief time series, serial and spatial auto-correlation, clustering, spurious correlations, problems of multicollinearity and inadequate analysis scales (Carlson et al., 2020a; Chipperfield et al., 2020; Malanson, 2020; Mecenas et al., 2020). These issues make it difficult to isolate a genuine effect of atmospheric conditions on disease spread from any other effects, including potential artefacts derived from observed prevalence, spatial dependence, temporal dependence and human geography (Gutiérrez-Hernández and García, 2020). Clearly, more research is necessary to clarify the modes of virus transmission, evolution, mutation, and direct and indirect contagion mechanisms (Eslami and Jalili, 2020).

The anthroposphere can be defined as the portion of the environment where human activities make up a significant change source (Kuhn and Heckelet, 2010). Cultural habits, epidemiological knowledge, and public health interventions will decisively determine the state and change of the COVID-19 pandemic. Therefore, the anthroposphere is a non-stationary environment. According to Brunsdon et al. (1996), spatial non-stationary is a condition in which a simple global model cannot explain the relationships between some sets of variables, and the nature of the model must alter over space to reflect the structure within the data. In this sense, one of the most effective tools for examining localised effects is Geographically Weighted Regression (Fotheringham et al., 2003). This technique attempts to capture this variation by calibrating a multiple regression model that allows unique relationships to exist at different spatial locations.

According to Coccia (2020b), one of the fundamental problems in environmental research and public health is the evaluation of environmental and social weaknesses of cities/regions to the exposure of infectious diseases for preventing and/or containing new COVID-19 outbreaks, and the diffusion of other viral agents that generate a negative impact on public health and economy of countries. He proposed the Index c (as contagions) that quantifies, ex-ante, the environmental risk of exposure of cities/regions to future epidemics of the COVID-19 and similar vital agents. This index synthesises environmental, demographic, climatological and health risk factors that show infectious diseases exposure. In this sense, SARS virus and other respiratory diseases find a spreading factor in atmospheric stability, wind speed and air pollution (Coccia, 2020c, 2020d); they survive longer and become more aggressive in an immune system already aggravated by these harmful substances (Marteletti and Martelletti, 2020; Srivastava, 2021; Sterpetti, 2020). Paradoxically, the lockdown of the COVID-19 pandemic caused the air quality in many cities to improve, at least temporarily, and drop in water pollution in some parts of the world (Saadat et al., 2020).

Although several authors have suggested that seasonal forcing on SARS-CoV-2 should be considered to monitor global transmission (Noher et al., 2020), we think the COVID-19 pandemic overflows the climate determinism. It is not that climate drivers may not be relevant to aerosol transmission processes, but rather that their influence may be partial and confused by human behaviour and the microclimate of built environments (Carlson et al., 2020a; Carlson et al., 2020b). Early healthcare measures (e.g. social distancing, wearing masks) are more effective than the later ones (Ortega-Garcia et al., 2020), so it is possible to mitigate the potential seasonal climate effects. Public health interventions are crucial to reducing epidemic growth over climate drivers (Jüni et al., 2020).

Recent evidence shows more and more complexity in the nature, variability and interactions between the factors that determine the spread of the COVID-19 disease (Buss et al., 2021). Besides complex socioeconomic factors, there are relevant changes in biological factors and their interactions. These biological factors include both variations in the host’s defences, as well as the appearance of new variants of the virus with different contagion capacities (Faria et al., 2021; Kraemer et al., 2021; Kupferschmidt, 2021) which, eventually, may present different lethality and/or interact in different ways with the host’s defences (Wibmer et al., 2021).

Additionally, intensity and distribution in space and time of vaccination will also affect the disease patterns. All of this configures exceptionally complex scenarios that are very difficult to model, if possible.

2.4. Scientific evidence vs statistical significance

Finally, we must highlight the worrying confusion seen in the recent literature on the subject between a causal relationship, supported by scientific evidence, and a statistically significant relationship or association between variables derived from observational studies. Scientific evidence supporting the existence of causal relationships to explain the spread of SARS-CoV-2 based on environments conditions derives from measurements under controlled conditions.

A reasonable conviction of the possible existence of causal relationships in complex multifactorial systems can be gained through statistical integration of the multidisciplinary knowledge available. This conviction is achieved using techniques that allow a reasonable statistical control of the influence of all known variables of different nature that could confound in the relationship of interest (e.g. causal modelling), provided there is prior in-depth knowledge of the studied system.

If there is no convincing conceptual model based on expert and multidisciplinary knowledge of the phenomenon and all the factors involved are considered, causality cannot be reasonably concluded. It does not matter the statistical complexity of the model used or the fulfilment of all the starting assumptions or the calculated parameters’ statistical significance. Even an observational model with good predictions can only give indications, plausible working hypotheses for further planned research, but the conclusions drawn regarding causality may be spurious (Garcia, 2004).

In this sense, Briz-Redón and Serrano-Aroca (2020b) provide an exciting systematic review of the literature on the effects of climate on COVID-19’s global expansion. The review focuses on both the findings and the statistical and modelling techniques used. Many of the papers reviewed by these authors are based on the correlative bioclimatic models. They point out the following problems: 1) Computing correlation coefficients between two-time series do not account for the possible presence of temporal trends in the data which can strongly affect the correlation value and yield artefactual associations. 2) Accounting for the effect of multiple variables simultaneously entails ensuring that multicollinearity issues, namely strong correlations between the variables, are not present in the data being analysed. 3) The classical regression model does not account for specific data characteristics that are very possibly present when one conducts an ecological analysis of the evolution of an infectious disease.

SARS-CoV-2 and other viruses with a lipid envelope are probably sensitive to weather (temperature, humidity, and solar radiation). The weather probably influences COVID-19 transmission, but not at a scale sufficient to outweigh the effects of lockdowns or reopenings in populations. However, microbiology’s more refined details are often lost, leading to false confidence in how lab studies could scale up to the real world (Carlson et al., 2020c).

According to Susswein and Bansal (2020), we also highlight the
intrinsic complexity of modelling the epidemic dynamics and the need for a robust theory to guide public health intervention. In this sense, as suggested by Eggo et al. (2021), it is crucial to adapt models to local contexts to provide more accurate and relevant estimates, both for the COVID-19 pandemic (and their pandemic waves) and for future pandemics.

3. Conclusions

Most of the studies are based on correlative models with weak statistical and theoretical foundations. In particular, bioclimatic envelope models are not adequate to explain the anthroposphere’s non-stationary context, at least in the early stages of the COVID-19 pandemic. In any case, their results should be interpreted with caution, avoiding extrapolation. Further studies are needed to clarify the relative importance of different transmission routes at multiple scales and outdoor and indoor environments. Atmospheric conditions may influence the spread of COVID-19, directly or indirectly, but the dominant route is the anthroposphere’s non-stationary environment. Regardless, we suggest incorporating Geographically Weighted Regressions to locally examine spatial non-stationarity, and provide useful insights to policymakers for targeted interventions at the regional level.

It seems clear that atmospheric conditions may only explain a minimal amount of the space-time dynamics of SARS-CoV-2. Until reliable bioclimatic envelopes of SARS-CoV-2, if any, are found, care should be taken when reporting, as this could have dangerous and unforeseen consequences. It is essential to realise the amount of risk we take when we report interim results that have not been subjected to peer review.

This discussion paper has highlighted some blind spots in research on the relationship between SARS-CoV-2 and weather conditions. However, more systematic studies on these blind spots are needed and rigorous meta-analyses of the many experimental and observational studies available to date. The COVID-19 pandemic spread should be interpreted based on an ensemble of multi-criteria and multi-scale analyses. Science is not a heuristic game. Incorrect extrapolations can have pernicious consequences for the credibility of science and public health, particularly if the media and official institutions echo them.

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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