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SHORT COMMUNICATION

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Humidity is a consistent climatic factor contributing to SARS-CoV-2 transmission

Michael P. Ward[1] | **Shuang Xiao**[2] | **Zhijie Zhang**[2]

[1]Sydney School of Veterinary Science, The University of Sydney, Camden, NSW, Australia

[2]School of Public Health, Fudan University, Shanghai, China

Correspondence
Michael P. Ward, Sydney School of Veterinary Science, The University of Sydney, Private Mailbag 4003, Narellan, NSW 2567, Australia.
Email: michael.ward@sydney.edu.au

Zhijie Zhang, School of Public Health, Fudan University, Shanghai 200032, China.
Email: zhj_zhang@fudan.edu.cn

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Abstract

There is growing evidence that climatic factors could influence the evolution of the current COVID-19 pandemic. Here, we build on this evidence base, focusing on the southern hemisphere summer and autumn period. The relationship between climatic factors and COVID-19 cases in New South Wales, Australia was investigated during both the exponential and declining phases of the epidemic in 2020, and in different regions. Increased relative humidity was associated with decreased cases in both epidemic phases, and a consistent negative relationship was found between relative humidity and cases. Overall, a decrease in relative humidity of 1% was associated with an increase in cases of 7–8%. Overall, we found no relationship with between cases and temperature, rainfall or wind speed. Information generated in this study confirms humidity as a driver of SARS-CoV-2 transmission.

KEYWORDS
Australia, climate, COVID-19, humidity, meteorological factors, SARS-CoV-2, time series analysis

1 | INTRODUCTION

The global spread of severe acute respiratory coronavirus 2 (SARS-CoV-2), causing the novel coronavirus disease (COVID-19) pandemic, has been linked to climatic factors. This has a plausible biological basis. The spread of SARS-CoV-2 among people is predominantly via respiratory droplets and aerosols, as well as fomites (Cai et al., 2020) and possibly faecal–oral (Yeo, Kaushal, & Yeo, 2020). Temperature and relative humidity can affect coronavirus transmission (Casanova, Jeon, Rutala, Weber, & Sobsey, 2010) through virus survival (at lower temperatures coronaviruses survive longer) and the length of time infectious respiratory matter stays suspended in the air (at lower humidity more material stay suspended for longer) (Casanova et al., 2010; Chan et al., 2011; Guionie et al., 2013).

In previous observational research, a negative relationship between relative humidity and SARS cases has been found (Cai et al., 2007; Tan et al., 2005), and a similar negative relationship with Middle East respiratory syndrome coronavirus (MERS-CoV) cases has been described (Altamimi & Ahmed, 2020; Gardner, Kelton, Poljak, Van Kerkhove, & von Dobschuetz, 2019). However, the relationship with temperature is inconsistent: a positive relationship has been described for SARS (Gardner et al., 2019) and MERS-CoV (Altamimi & Ahmed, 2020), but a negative relationship has also been observed for MERS-CoV (Gardner et al., 2019). Specifically for SARS-CoV-2, a negative relationship between COVID-19 cases in China and temperature and humidity has recently been described (Qi et al., 2020), and more recently in the state of New South Wales (NSW), Australia we described a significant negative association between COVID-19 cases during the initial exponential phase of the epidemic and relative humidity (Ward, Xiao, & Zhang, 2020). In the current study, we extend this research to examine the effect of a greater number of climatic factors on the occurrence of COVID-19 cases during both exponential and descending phases of the epidemic and investigate whether there are regional and temporal differences in this relationship. This knowledge is needed to guide public health interventions to successfully control the spread of SARS-CoV-2.

Michael P. Ward and Zhijie Zhang contributed equally.

2 | METHODS

Case reports in NSW, Australia from the beginning of the epidemic in January to the end of May 2020 were accessed.[1] Those whose infection source was determined to be locally acquired, and whose postcode of residence was reported, were included. A daily time series of cases was created, from which separate series preceding and following the epidemic peak (31 March) and for individual NSW public health units (PHUs, see Figure 1a) were created. Based on the reported postcode the closest weather observation station was identified.[2] Daily observations of the following factors were downloaded: rainfall (mm) and temperature (°C), relative humidity (%) and wind speed (m/s) recorded at 9 a.m. and at 3 p.m.[2] The mean values for each day were estimated to create time series of weather data. Additional series of daily differences between 9 a.m. and 3 p.m. temperature, relative humidity and wind speed were created. Thus, 10 predictor time series were created for modelling.

The data was analysed based on the exponential and descending phases of the epidemic overall, and for 6 PHUs (those PHUs reporting <100 cases were excluded), to determine the effect of epidemic phases and locations on the association between climatic factors and case reports. Thus, 14 separate time series analyses were performed.

A PHU-average Spearman correlation coefficient matrix was first calculated to avoid multicollinearity among variables. Then, univariate quasi-Poisson generalized additive models (GAMs) were fit to the cases time series as the outcome and the climatic factors time series as the predictors. Climatic factors with *P* value <.1 in univariate analysis in all the PHUs were selected for multivariate analysis. A standard two-stage approach was then applied to evaluate the PHU-specific and NSW-average associations between short-term exposure to climate factors and cases. In the first stage, a quasi-Poisson GAM was used to estimate the association between PHU-specific climate factors and the daily count of cases. A 14-day exponential moving average (EMA) was used to represent the effects of climate factors on cases during the 14 days preceding case reporting. Natural splines of time were included to control short-term temporal trend; its optimal degrees of freedom (*df*) was chosen based on Quasi AIC (QAIC). In the second stage, a meta regression model with random effects were used to obtain NSW-average risk estimate of meteorological factors

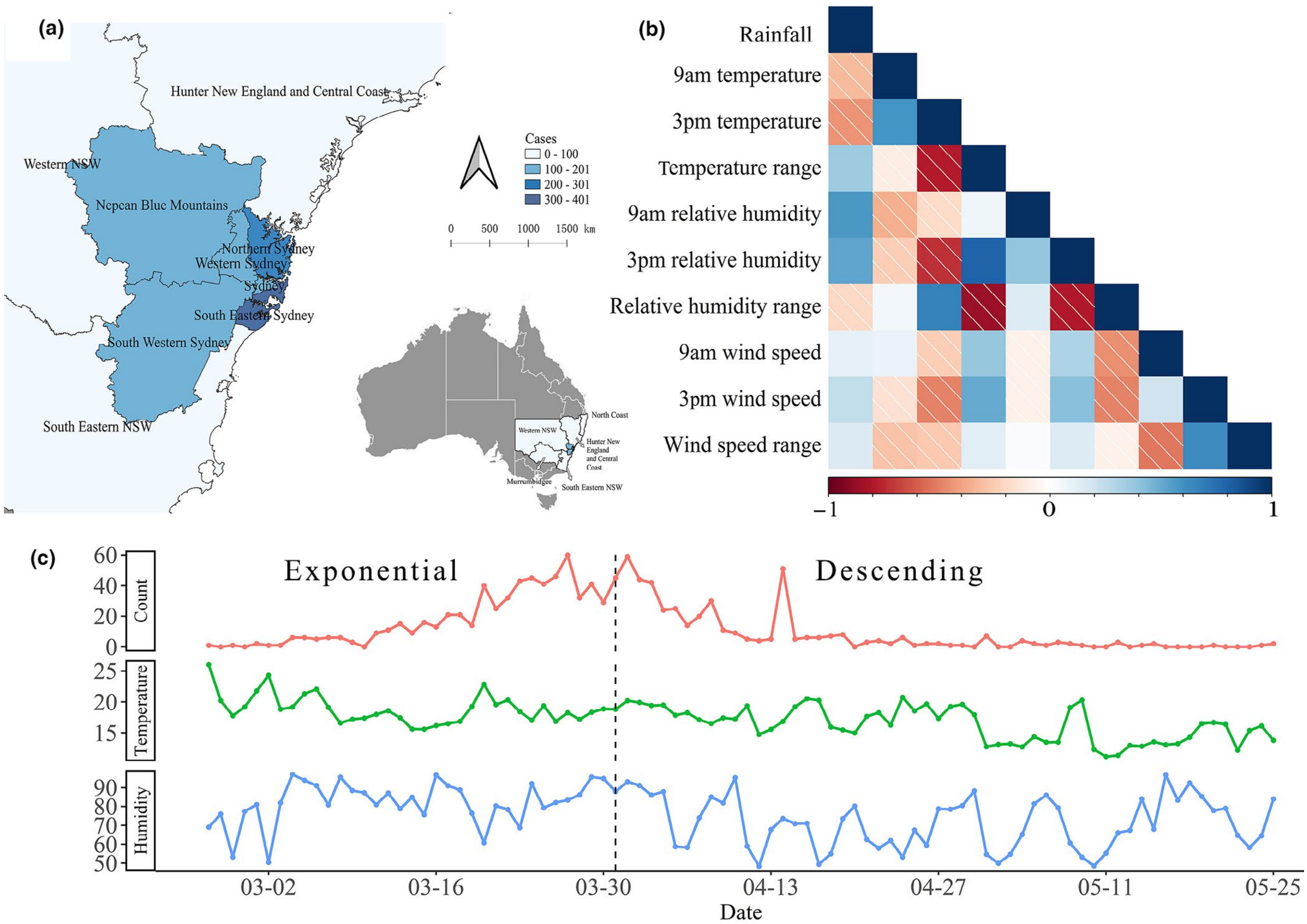

FIGURE 1 (a) The spatial distribution of cumulative notified cases of COVID-19 in New South Wales, Australia, in which infection was determined to be locally acquired and for which postcode of residence was reported. (b) Correlogram plot of climate factors recorded at the weather observation station closest to reported case postcode of residence. (c) Time series plot of cumulative cases, 9 a.m. temperature and 9 a.m. relative humidity, showing the division between the exponential (26 February to 31 March) and descending (1 April to 31 May) phases of the epidemic [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Summary of 1,203 notified cases of COVID-19 in New South Wales, Australia, in which infection was determined to be locally acquired and for which postcode of residence was reported, during the exponential (26 February to 31 March) and descending (1 April to 31 May) epidemic phases, and average temperature (°C) and relative humidity (%) recorded at the weather observation station closest to reported case postcode of residence

		Exponential epidemic phase			Descending epidemic phase		
Public health unit	Study period (days)	Temperature	Relative humidity	Cases	Temperature	Relative humidity	Cases
Nepean Blue Mountains	75	15.89 (2.37)*	86.73 (10.99)	28	13.81 (2.91)	75.96 (11.43)	72
Northern Sydney	85	19.61 (2.37)	84.86 (15.68)	137	17.05 (3.1)	74.46 (16.74)	64
South Eastern Sydney	86	20.37 (2.29)	77.42 (11.87)	237	17.83 (3.06)	64.13 (15.44)	120
South Western Sydney	69	17.42 (1.96)	85.37 (8.5)	63	15.86 (2.34)	74.49 (14.06)	57
Sydney	82	19.34 (1.77)	78.88 (10.37)	86	16.72 (3.12)	66.79 (15.56)	62
Western Sydney	72	18.99 (2.14)	88.15 (9.76)	95	17.63 (3.08)	69.43 (15.85)	52

*Mean (*SD*).

TABLE 2 Estimates (95% confidence interval) of association between notified cases of COVID-19 in New South Wales, Australia, in which infection was determined to be locally acquired and for which postcode of residence was reported, during the exponential (26 February to 31 March) and descending (1 April to 31 May) epidemic phases, and average temperature (°C) and relative humidity (%) recorded at the weather observation station closest to reported case postcode of residence

	Exponential epidemic phase		Descending epidemic phase	
Public health unit	Temperature	Relative humidity	Temperature	Relative humidity
Nepean Blue Mountains	−0.40 (−2.83, 2.03)	−0.09 (−0.67, 0.49)	−2.66 (−5.44, 0.12)	−0.23 (−0.72, 0.26)
Northern Sydney	0.24 (−0.52, 1.01)	−0.07 (−0.23, 0.08)	−0.316 (−1.037, 0.4)	−0.12 (−0.26, 0.02)
South Eastern Sydney	0.10 (−0.84, 1.04)	−0.01 (−0.2, 0.18)	**0.72 (0.15, 1.298)**	−0.08 (−0.18, 0.01)
South Western Sydney	0.07 (−1.11, 1.26)	0.06 (−0.21, 0.33)	−0.75 (−2.42, 0.93)	−0.04 (−0.25, 0.16)
Sydney	−0.0002 (−0.87, 0.87)	**−0.15 (−0.29, −0.02)**	−0.19 (−1.51, 1.13)	−0.017 (−0.25, 0.21)
Western Sydney	−0.47 (−1.43, 0.49)	−0.104 (−0.37, 0.16)	0.07 (−0.88, 1.01)	0.008 (−0.13, 0.15)
New South Wales	0.0002 (−0.4, 0.4)	**−0.08 (−0.16, −0.0004)**	−0.02 (−0.54, 0.51)	**−0.07 (−0.13, −0.004)**

Public health unit-specific associations are shown, and bold indicates significant ($p < .05$) associations

on cases. To estimate the overall relationship, exposure-response curves were plotted using the GAM with natural spline's knot setting at its median (*df* = 2). A sensitivity analysis was performed by modifying the EMA (14 days to 13 or 15 days), and changing *df* for natural splines of time (3 to 2 or 4). R4.0.1 software (R Foundation for Statistical Computing) was used to perform all analyses.

3 | RESULTS

The first COVID-19 case in which infection was locally acquired was notified on 26 February 2020.[1] Between 26 February and 31 May, 1,203 locally acquired cases with a residence postcode were notified. Cases were reported from 11 PHUs (range 3–357; Figure 1a); 6 of these reported >100 cases, and climatic data were acquired from 27 weather observation stations within these PHUs.[2]

Based on correlation coefficients, 3 p.m. temperature and relative humidity, and temperature and relative humidity range were excluded from univariate modelling (Figure 1b). Overall, only 9 a.m. temperature (range 8.05–26.6°C) and 9 a.m. relative humidity (35–100%) entered the final model (Figure 1c). Mean temperature range was higher during the exponential epidemic phase than the descending epidemic phase, whereas the reverse occurred for relative humidity range (Table 1).

Overall, we observed a negative association between COVID-19 cases and relative humidity in both epidemic phases (Table 2), but no association with temperature. A 1% decrease in relative humidity was associated with a 7.7% (95% CI: 0.04–14.8%) and 6.8% (95% CI: 0.4%–12.2%) increase in the pooled estimate of daily counts of COVID-19 in the two epidemic phases, respectively. Heterogeneous effects across PHUs were obvious: a significant positive association between temperature and cases in South Eastern Sydney PHU during the descending epidemic phase (Figure 2a,c), whereas a significant negative association between humidity and cases in Sydney PHU during the exponential epidemic phase (Figure 2b,d), were noted. However, the association between humidity and cases was consistently negative in the epidemic phase- and location-specific analyses (Table 2 and Figure 2).

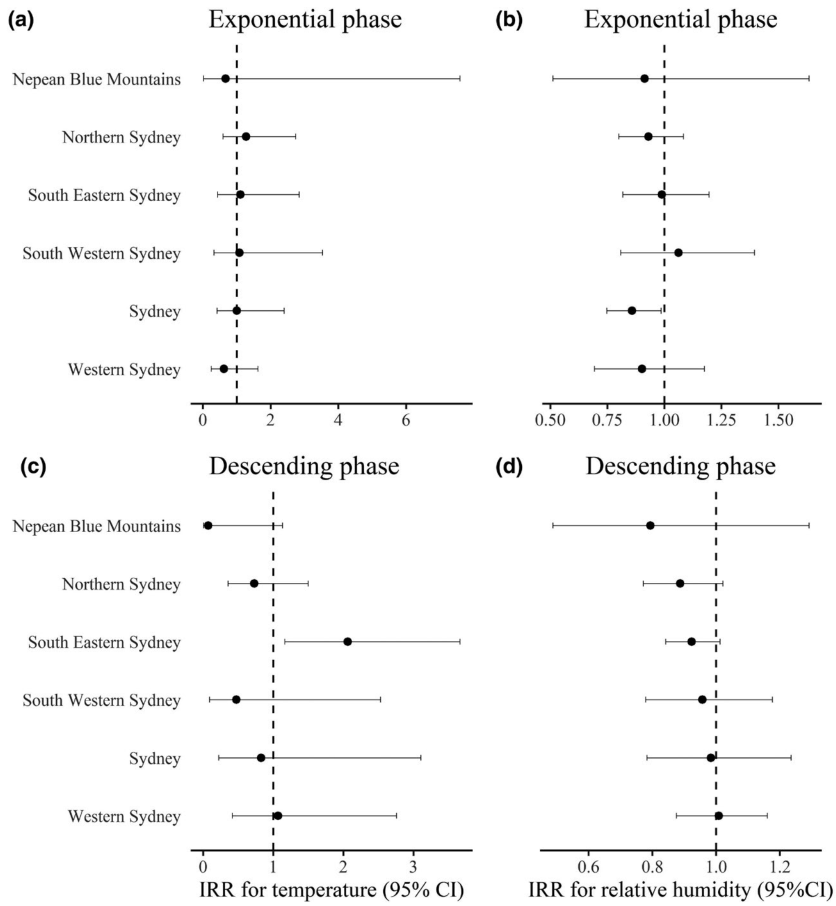

FIGURE 2 Forest plots of the associations between notified cases of COVID-19 in New South Wales, Australia, in which infection was determined to be locally acquired and for which postcode of residence was reported and 9 a.m. temperature and 9 a.m. relative humidity recorded at the weather observation station closest to reported case postcode of residence, for public health units both during the exponential (26 February to 31 March) and descending (1 April to 31 May) phases of the epidemic. (a) incidence rate ratio (IRR) for temperature (95% CI) in Phase I; (b) IRR for relative humidity (95% CI) in Phase II; (c) IRR for temperature (95% CI) in Phase I; (d) IRR for relative humidity (95% CI) in Phase II

The overall exposure-response curves showed that the negative association between cases and relative humidity was more pronounced above 79% and 75% relative humidity in the exponential and descending epidemic phases, respectively (Figure 3). The sensitivity analysis indicated that the associations between cases and relative humidity were robust (Table 3).

4 | DISCUSSION

We found that throughout the epidemic of COVID-19 in NSW, Australia—both during the exponential and descending phases of the epidemic—there was a consistent negative relationship between relative humidity and case occurrence: a 1% decrease in relative

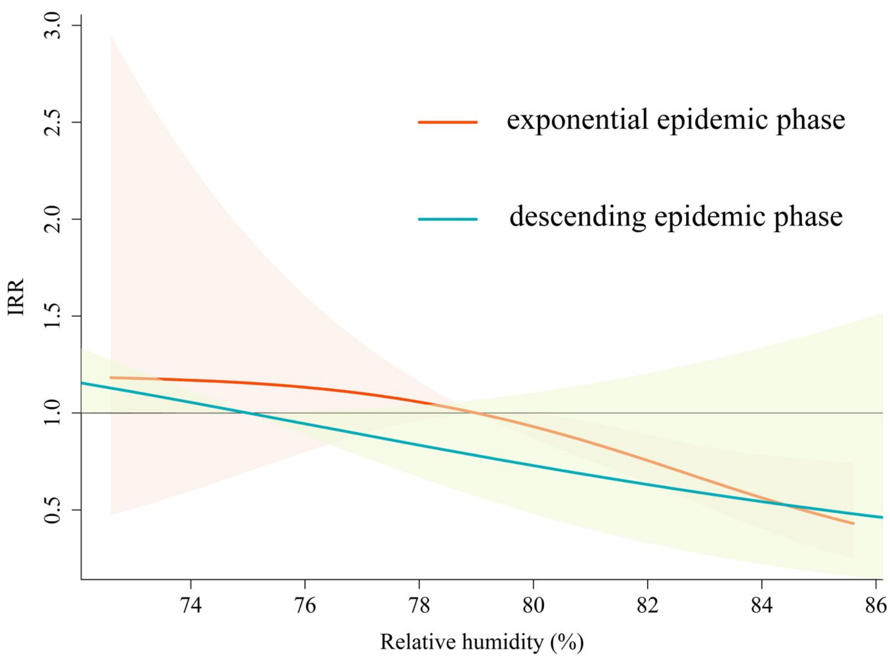

FIGURE 3 The exposure response curves for relative humidity associations with notified cases of COVID-19 in New South Wales, Australia during exponential and descending epidemic phases. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Sensitivity analysis of pooled estimates (95% confidence interval) of models of COVID-19 cases in New South Wales, Australia, during the exponential and descending epidemic phases

	Exponential phase		Descending phase	
Variables	Temperature	Relative humidity	Temperature	Relative humidity
Degrees of freedom of time				
2	0.04 (−0.28, 0.37)	**−0.096 (−0.15, −0.04)**	−0.22 (−0.88, 0.43)	−0.05 (−0.10, 0.007)
4	−0.02 (−0.46, 0.43)	−0.07 (−0.16, 0.02)	−0.09 (−0.78, 0.6)	−0.06 (−0.12, 0.003)
Exponential moving average				
13	0.01 (−0.37, 0.39)	**−0.08 (−0.15, −0.000004)**	−0.02 (−0.51, 0.47)	**−0.06 (−0.12, −0.003)**
15	−0.009 (−0.44, 0.42)	**−0.09 (−0.18, −0.001)**	−0.01 (−0.6, 0.55)	**−0.07 (−0.14, −0.005)**

Bold indicates significant (p <.05) associations.

humidity was predicted to increase cases about 7–8%, with a more pronounced effect at a relative humidity <75–79%. In almost all PHUs this negative relationship between relative humidity and cases was found.

Given that SARS-CoV-2 transmission is thought to be primarily via the respiratory route (Cai et al., 2020), and that coronaviruses are known to be susceptible in the environment (Casanova et al., 2010), the finding of an association with relative humidity is expected. This association might occur via the effect on respiratory aerosols and therefore infectious material remaining airborne for longer; or it could be a more direct effect on the survivability of the virus in the environment. The lack of a consistent association between temperature and COVID-19 cases in this and other studies (Qi et al., 2020)—as well as for SARS-CoV-1 and MERS-CoV cases (Altamimi & Ahmed, 2020; Gardner et al., 2019; Tan et al., 2005)—suggests that it is the former that influences SARS-CoV-2 transmission. This raises an interesting question, and one with potentially profound importance for public health: could increasing relative humidity contribute to a reduction in SARS-CoV-2 infections when infectious individuals mix with susceptible individuals? In the current study—as with other studies conducted to date on SARS-CoV-1, SARS-CoV-2 and MERS-CoV—we used data collected from meteorological recording stations under the assumption that either cases were infected in an outdoors setting, or that ambient outdoors weather conditions are a proxy for the indoors environment (if that is where most infections occur). Measuring the indoors environment is not possible when retrospectively analysing hundreds of disease cases that have occurred in an epidemic across an entire country or state. The conduct of controlled studies of the relationship between COVID-19 cases and factors such as relative humidity is challenging.

It is important to highlight that COVID-19 cases used in this study occurred predominantly during the autumn season in southern hemisphere. In contrast, most COVID-19 cases in northern hemisphere have been reported during the winter and spring seasons. Despite the seasons being diametrically opposed, the negative relationship between humidity and cases we observed in the Australian autumn is consistent with that observed in the Chinese winter (Qi et al., 2020). Combined with evidence from studies in the northern hemisphere, the influence of relative humidity on COVID-19 incidence was found to be always negative in different regions, suggesting that the relationship could be universal: COVID-19 is more sensitive to humidity and periods of lower humidity might forecast spikes in SARS-CoV-2 transmission. In the absence of a vaccine, such observations allow the more timely, efficient and effective deployment of public health interventions.

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CONFLICT OF INTEREST

Not applicable.

ETHICAL APPROVAL

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. No ethical approval was required as the case notification data was accessed from the public (NSW Government) domain.

ORCID

Michael P. Ward https://orcid.org/0000-0002-9921-4986
Zhijie Zhang https://orcid.org/0000-0002-1276-787X

ENDNOTES

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