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**This is the author version of article published as:**

Tong, Shilu and Hu, Wenbiao and McMichael, Anthony J. (2004) Climate variability and Ross River virus transmission in Townsville region, Australia 1985 to 1996. *Tropical Medicine and International Health* 9(2):pp. 298-304.

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# **Climate Variability and Ross River Virus Transmission in Townsville Region, Australia, 1985 to 1996**

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## Contributors

Shilu Tong was the principal investigator and was responsible for the design of the study, collection of the data, development of analytical protocol, interpretation of the results and writing of the paper. Wenbiao Hu contributed to the data analyses, interpretation of the results and writing of the paper. A.J McMichael contributed to the design of the study, the interpretation of results and writing of the paper.

Word count: 224 for abstract, 2185 for text, 4 figures and 2 tables

## Abstract

**Background** How climate variability affects the transmission of infectious diseases at a regional level remains unclear. In this paper, we assessed the impact of climate variation on the Ross River virus (RRv) transmission in the Townsville region, Queensland, north-east Australia.

**Methods** Population-based information was obtained on monthly variations in RRv cases, climatic factors, sea level, and population growth between 1985 and 1996. Cross-correlations were computed for a series of associations between climate variables (rainfall, maximum temperature, minimum temperature, relative humidity and high tide) and the monthly incidence of RRv disease over a range of time lags. The impact of climate variability on RRv transmission was assessed using the seasonal auto-regressive integrated moving average (SARIMA) model.

**Results** There were significant correlations of the monthly incidence of RRv to rainfall, maximum temperature, minimum temperature and relative humidity, all at a lag of 2 months, and high tide in the current month. The results of SARIMA models show that monthly average rainfall ( $\beta=0.0012$ ,  $p=0.04$ ) and high tide ( $\beta=0.0262$ ,  $p=0.01$ ) were significantly associated with RRv transmission, although temperature and relative humidity did not seem to have played an important role in the Townsville region.

**Conclusions** Rainfall, and high tide were likely to be key determinants of RRv transmission in the Townsville region.

**Keywords** Climate change, cross-correlation function, Ross River virus, seasonal auto-regressive integrated moving average, time series

## Introduction

Ross River virus (RRv) disease is endemic in all states of Australia (Russell 1998). RRv causes a debilitating disease characterised by arthritis, rash, and constitutional symptoms such as fever, fatigue and myalgia (Curran *et al.* 1997). The natural vertebrate hosts for this arboviral disease include marsupial animals (e.g., kangaroos and wallabies, etc) and possibly other animals (e.g., dogs, cats and possums). RRv usually incubates for 7-9 days. Incubation may be as long as 21 days or as short as 3 days (Harley *et al.* 2001). Vectors that transmit this disease comprise *Aedes/Ochlerotatus* (17 species), *Culex* (5 species), *Anopheles* (2 species), *Coquillettidia* (2 species), *Mansonia* (1 species), *Triperoides* mosquitoes (1 species) and others (Russell 1998). The disease caused by RRv was first recognised in New South Wales in the late 1920s (Nimmol 1928), although the virus and its association with disease were not identified until the early 1960s (Nimmol 1928; Shope & Anderson 1960). RRv – an alphavirus – was first isolated by Doherty and colleagues from *Ochlerotatus vigilax* mosquitoes collected near the Ross River at Townsville region in northern Queensland in 1959 (Doherty *et al.* 1963). The single largest reported outbreak occurred in the South Pacific islands in 1979-1980, during which more than 50,000 people were affected (Aaskov *et al.* 1981).

RRv disease is the most prevalent vector-borne disease in Australia. For example, over the last eleven years (1991-2001) - a total of 47,059 laboratory confirmed cases of RRv infection was reported (Australian Department of Health and Aged Care 2001). Several studies have examined the relationship between climate variation and vector-borne diseases (McMichael *et al.* 1996; Tong *et al.* 1998; Hales *et al.* 2002), and models have been developed to assess the potential impact of future climatic change on the transmission of arboviral diseases (McMichael *et al.* 1996). Since the early 1970s, time series methods, in particular autoregressive integrated moving average (ARIMA) and seasonal autoregressive integrated moving average (SARIMA) models, which have the ability to cope with stochastic dependence of consecutive data, have become well established in the commercial and industrial fields (Helfenstein 1991; Helfenstein 1996). In ARIMA and SARIMA models, an important concept is that of stationarity, which implies that the probability structure of the series does not change with time. Many epidemiologic time series data are not stationary and they often exhibit trends. However, experience in economics and more recently in epidemiology has shown that the time series

of differences (ie, each value in the series is replaced by the difference between that value and the preceding value) is often stationary (Helfenstein 1991). Box and Jenkins have extended the concepts to cope with time series that contain seasonal variations. In particular, a time series with seasonal non-stationarity may be transformed to stationary data by taking seasonal differences into account (Bowie & Prothero 1981; Helfenstein 1991).

Time series analyses have been increasingly used in epidemiological research (Bowie & Prothero 1981; Helfenstein 1986; Catalano & Serxner 1987; Helfenstein 1991; Helfenstein 1996; Allard 1998; Checkley *et al.* 2000; Nobre *et al.* 2001; Abeku *et al.* 2002; Borghi *et al.* 2002; Clancy *et al.* 2002; Dominici *et al.* 2002; Hajat & Haines 2002; Pope *et al.* 2002). In this paper, we used a time series model to examine the association between climate variation and RRv transmission in the Townsville region, Australia.

## Methods

The Townsville region is situated in the tropics of north Queensland and located approximately 1,380 km north of Brisbane (the state's capital). The Townsville region, comprising Townsville and Thuringowa with a population exceeding 130,000 in 2001, is the largest regional centre in Queensland (Australian Bureau of Statistics, 2001), in which RRv transmission has been highly active over recent years.

[Figure 1 about here]

The computerised data set on monthly notified RRv cases in Queensland for the period of 1985 to 1996 and information on notification (including place and time of onset) were obtained from the Queensland Department of Health. The data on RRv cases had been collected for the National Notifiable Diseases Surveillance System which is conducted under the auspices of the Communicable Diseases Network Australia New Zealand. The quality of routinely collected RRv data, assuming constancy over time, is generally regarded as valid information for a large-scale assessment of the impact of climatic variations (McMichael *et al.* 1996). Climate, sea level and population data were obtained from the Australian

Bureau of Meteorology, Queensland Transport Department, and the Australian Bureau of Statistics, respectively. Climate data consisted of monthly average maximum and minimum temperature, monthly total rainfall, monthly mean relative humidity at 9am and monthly mean high tides.

To examine whether climate variation was associated with the RRv transmission, cross-correlations were used to compute a series of correlations between climate variables and the incidence of RRv disease over a range of time lags (a time lag was defined as the time span between a climatic observations and the incidence of RRv) (Chatfield 1975). The SARIMA model was used to estimate the independent contribution of each climate variable in this study as it was assumed that there was a dose-response relationship between the dependent variable and independent variables. Three steps were undertaken in the modelling of the relationship between climate variation and the RRv transmission in Townsville region. Firstly, SARIMA models were developed using the monthly incidence of RRv as dependent variable and the monthly averages of climate variables and high tides as independent variables after seasonal difference was smoothed to make a drifting series stationary. Secondly, the goodness-of-fit of the models was checked for adequacy, using both time series (ie, auto-correlation functions of residuals which are defined as the differences between the actual values and the forecasted values) and classical tools (ie, to check the normality of residuals) (Tabachnick & Fidell 2001). Finally, the model developed was verified by dividing the data file into two data sets: the data between January 1985-December 1994 were used to construct a SARIMA model and those data between January 1995-December 1996 were then used to verify that particular model.

## **Results**

Figure 2 shows the associations between monthly incidence rates of RRv infection and rainfall, maximum temperature, minimum temperature, relative humidity and high tide in the Townsville region between 1985 and 1996. Climate variability (eg, rainfall, maximum temperature, minimum temperature, relative humidity) was positively associated with the RRv, as also was high tide.

[Figure 2 about here]

The results of the cross-correlations show that climate variables (including tidal level) were significantly associated with the incidence of RRv. The significant associations were found for rainfall ( $r=0.43$ ,  $p<0.05$ ), maximum temperature ( $r=0.16$ ,  $p<0.05$ ), minimum temperature ( $r=0.23$ ,  $p<0.05$ ), and relative humidity ( $r=0.24$ ,  $p<0.05$ ) at a lag of 2 months, and high tide ( $r=0.31$ ,  $p<0.05$ ) in the current month in Townsville region (Table 1). The results of SARIMA models show that the incidence of RRv disease was significantly associated with rainfall ( $\beta=0.0012$ ,  $p=0.04$ ) and high tide ( $\beta=0.0262$ ,  $p=0.01$ ) in the Townsville region after adjustment for other covariates (Table 2). However, there was no significant association between temperature or relative humidity were and the monthly incidence of RRv.

[Tables 1 and 2 about here]

Figure 3 shows that there was no significant auto-correlation between residuals at different lag times in the SARIMA model. The graphic analysis of residuals shows that the residuals in the model appeared to fluctuate randomly around zero with no obvious trend in variation as the predicted incidence values increased. Thus no violation of assumptions was apparent.

[Figure 3 about here]

The SARIMA models were also verified using the data over the period of January 1995 to December 1996 after the models had been constructed with the data compiled between January 1985 and December 1994. Figure 4 indicates that the predicted values and the actual incidence rates of RRv matched well.

[Figure 4 about here]

## Discussion

Although global climate change may pose a significant threat to the control and prevention of infectious disease, little empirical research has been conducted in this field. Some recent studies suggest that climate variation is associated with changes in the occurrence of various vector-borne and waterborne diseases (Lindsay & Mackenzie 1996; Tong *et al.* 1998; Curriero *et al.* 2001; Tong & Hu 2002; Woodruff *et al.* 2002). In this study, we found that rainfall and high tides are among the major determinants in the transmission of RRv infection in Townsville region, Australia.

The incidence of RRv infection fluctuates with the seasons and is usually associated with warmer and more humid weather. In general, epidemic activity is more often observed in temperate areas with heavy rainfall or flooding, whereas in tropical Australia transmission occurs throughout the year (Mackenzie *et al.* 1998). Nevertheless, distinct epidemics do occur in northern Australia, especially associated with heavy monsoonal rainfalls.

Clearly, precipitation is one of the important elements for the breeding and development of mosquitos (Hennessy & Whetton 1997). All mosquitos have aquatic larval and pupal stages and therefore require water for breeding (Lindsay & Mackenzie 1996; McMichael *et al.* 1996). Considerable evidence has accrued to show that heavy rainfall and flooding can lead to increased mosquito breeding and outbreaks of arboviral disease in Australia (McMichael *et al.* 1996; Liehne 1998). Examples are readily available for RRv outbreaks in various parts of Australia (Liehne 1998). Our study corroborated previous observations and indicated that rainfall is one of the key predictors of RRv transmission. However, climate models predict that, under likely scenarios of climate change, little rainfall change will occur in the Townsville area, with a range of annual rainfall change of  $-4$  to  $+4\%$  by 2030 and  $-12$  to  $+12\%$  by 2070 (Whetton 2001). Therefore, there may be no increase of RRv cases resulting from rainfall change in that particular region. However, the possible future impact of rainfall on the transmission of RRv disease should be estimated cautiously, as many socio-ecological factors can also influence the balance of RRv transmission cycles. Future, climate changes in adjoining regions of Australia may affect the transmissibility of RRv in those regions.



High tides and rise in sea-level have been implicated as important precursors of outbreaks of RRv (McManus *et al.* 1992; Lindsay *et al.* 1993; Weinstein 1997). Tidal inundation of saltmarshes is a major source of water for breeding of the important arbovirus vectors *Ochlerotatus vigilax* and *Ochlerotatus camptorhynchus*. Adult females of both species lay their eggs on soil, mud substrate and the plants around the margins of their breeding sites. The eggs hatch when high tides subsequently inundate sites. Large populations of adult mosquitos can emerge in as little as eight days after a series of spring tides (Lindsay & Mackenzie 1996). There is good evidence that a rise in sea-level may contribute to a major outbreak of RRv. The results of this present study corroborate the previous findings, indicating that sea-level is an important factor in the transmission of RRv in Townsville region.

Temperature changes affect RRv transmission and epidemic potential by altering the vector's reproduction or biting rate; by shifting a vector's geographic range or distribution; by altering the extrinsic incubation periods (EIPs) of the pathogen; and by increasing or decreasing vector-pathogen-host interaction and thereby affecting host susceptibility (McManus *et al.* 1992). In this study, temperature was not significantly associated with the incidence of RRv. This may be because the Townsville region is located in the tropical zone and the monthly average temperature is usually high (more than 20<sup>0</sup>C). Hence, temperature does not play the same important role as do rainfall and sea-level. Additionally, in a recent study, it was found that rearing temperature seemed unimportant to vector competence for mosquito species *Oc. vigilax* found in Townsville (Kay & Jennings 2002). Our epidemiological finding appeared to provide compelling support to the laboratory data.

Relative humidity influences longevity, mating, dispersal, feeding behaviour and oviposition of mosquitoes (McMichael *et al.* 1996). At high humidity, mosquitoes generally survive for longer and disperse further. Therefore, they have a greater chance of feeding on an infecting animal and surviving to transmit a virus to humans or other animals. Relative humidity also directly affects evaporation rates from vector breeding sites. Clearly, humidity is another factor contributing to outbreaks of RRv disease, particularly in normally arid regions (Lindsay & Mackenzie 1996). In this study, however, relative humidity did not appear to have played a major role in the RRv transmission. It might be because the Townsville region is on the coast and it is usually not dry.

RRv disease epidemics are driven by environmental conditions such as heavy rainfall events, flooding and tidal inundation of marshes (and probably levels of host immunity as well) (Lindsay & Mackenzie, 1996; Harley et al., 2001). The fact that RRv outbreaks often occur suddenly after such events has led researchers to investigate the mechanism of RRv transmission more closely. For example, Lindsay et al (1993) have indicated that there is a strong evidence that the virus can persist in the environment during adverse conditions (dry season) by vertical transmission in desiccation-resistant mosquito (*Aedes/Ochlerotatus*) eggs. They isolated the virus from male mosquitoes prior to an outbreak implying that vertical transmission is a likely explanation for the sudden recurrence of virus activity after tidal inundation of marshes or heavy rainfall. The incubation period in humans ranges from 5-21 days but is usually 7-9 days (Harley *et al.* 2001), which also helps rapid transmission once the outbreak starts.

Research outcomes from this study may be used to assist public health decision-making and environmental health risk management. It is anticipated that early warning based on forecasts can assist in improving vector control, community intervention and personal protection. A practical model for estimating the probability of epidemic occurrence in relation to socio-ecological change can help decision-makers to determine where and when RRv disease is likely to occur so that response can be made promptly and limited resources can be mobilised and allocated more effectively and efficiently.

## **ACKNOWLEDGEMENTS**

The authors thank three anonymous reviewers for their thoughtful comments; the Queensland Department of Health, Australian Bureau of Meteorology, Queensland transport and the Australian Bureau of Statistics for providing the data on notified Ross River virus cases, climate, sea level and population growth between 1985 and 1996, respectively. This study was partly funded by the National Health and Medical Research Council, Queensland Health and Queensland University of Technology.

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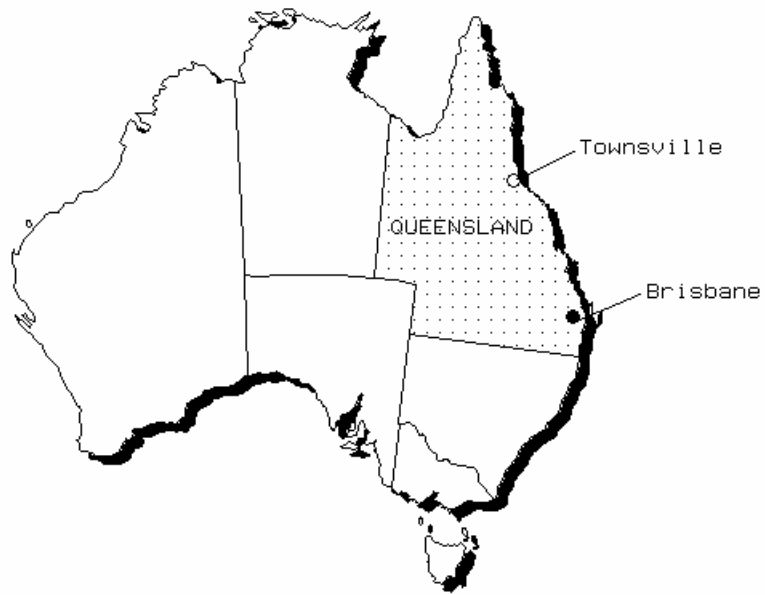
### **Legends for Figures 1, 2, 3 & 4**

Figure 1. Location of Townsville region, Queensland, Australia

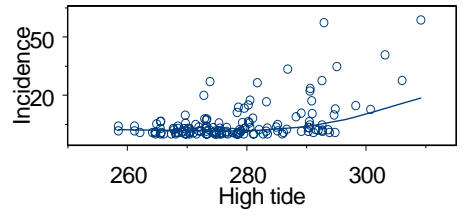
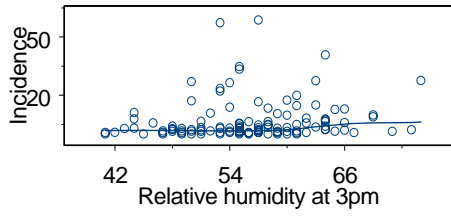
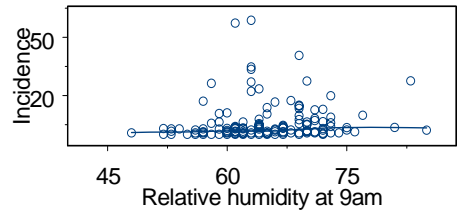
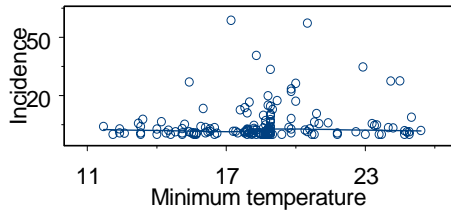
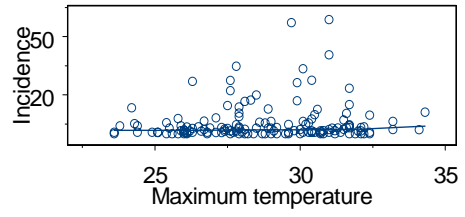
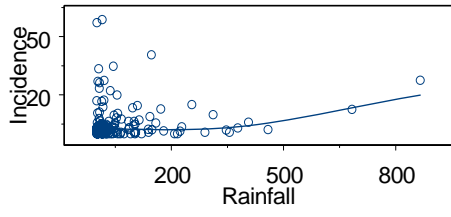
Figure 2. The relationships between monthly incidence of Ross River virus and climate variables in Townsville region between 1985 and 1996

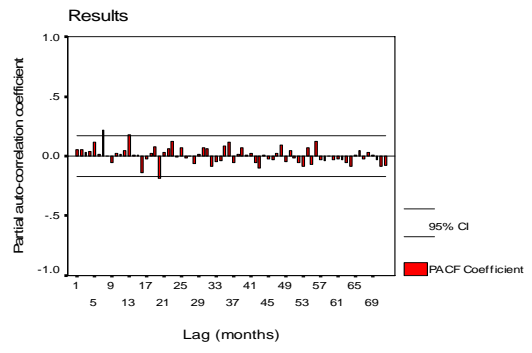
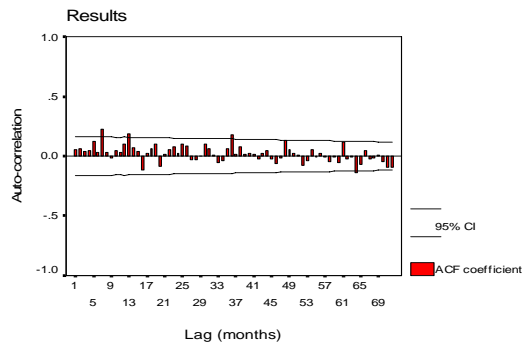
Figure 3. Auto-correlation and partial auto-correlation of residuals (ACF: auto-correlation function; PACF: partial auto-correlation function)

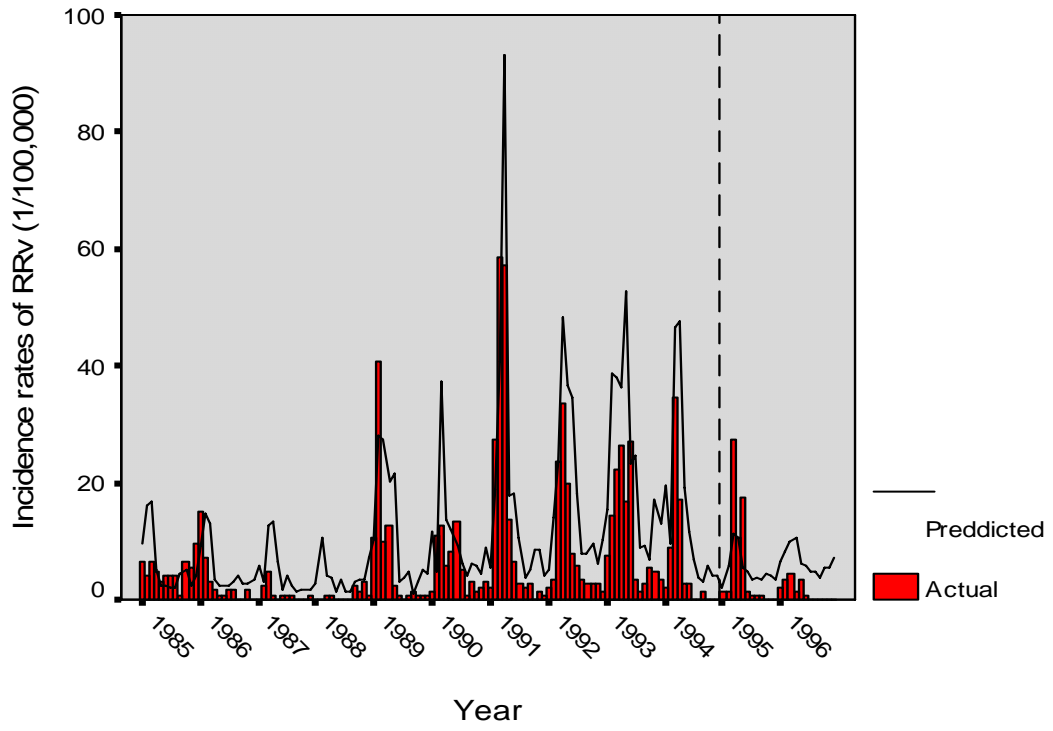
Figure 4. The validated SARIMA model of climate variation in Townsville region (validation period: 1.1995 - 12. 1996 ie., to the right of the vertical dotted line).











**Table 1. Cross-correlation coefficients between climate variables and incidence of RRv in Townsville region, Australia\***

| <b>Lag (months)</b> | <b>MaxT</b> | <b>MinT</b> | <b>Rainfall</b> | <b>Rh9am</b> | <b>HT</b> |
|---------------------|-------------|-------------|-----------------|--------------|-----------|
| 0                   | 0.070       | 0.050       | -0.174†         | -0.219†      | 0.306†    |
| 1                   | -0.023      | 0.106       | 0.076           | 0.129        | 0.224†    |
| 2                   | 0.161†      | 0.227†      | 0.427†          | 0.244†       | 0.134     |
| 3                   | 0.071       | -0.093      | 0.033           | 0.088        | -0.015    |
| 4                   | 0.126       | 0.035       | -0.033          | -0.016       | -0.159†   |

\* MaxT: Maximum temperature; MinT: Minimum temperature; Rh9am: Relative humidity at 9am; HT: High tide

† Significant at the 0.05 level (2-tailed)

**Table 2. Regression coefficients of climate variables on the monthly incidence of RRv disease in Townsville region, Queensland**

| <b>Variable</b>            | <b><math>\beta</math></b> | <b>SE</b> | <b>p</b> |
|----------------------------|---------------------------|-----------|----------|
| <i>Intercept</i>           | -8.2072                   | 2.6866    | 0.00     |
| <i>High tide</i>           | 0.0262                    | 0.0093    | 0.01     |
| <i>Rainfall</i>            | 0.0012                    | 0.0006    | 0.04     |
| <i>Maximum temperature</i> | 0.0744                    | 0.0531    | 0.16     |
| <i>Minimum temperature</i> | 0.0274                    | 0.0419    | 0.51     |
| <i>Relative humidity</i>   | 0.0012                    | 0.0128    | 0.92     |