agrometeoros
REVISTA DA SOCIEDADE BRASILEIRA DE AGROMETEOROLOGIA

ISSN 2526-7043 www.sbagro.org.br DOI: http://dx.doi.org/10.31062/agrom.v28.e026770

Times of occurrence of daily maximum and minimum air temperatures and relative humidity in Santa Maria, RS, Brazil

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ARTICLE INFO

Article history:
Received 17 August 2020
Accepted 3 December2020

Index terms:
automatic weather station
frequency
daily variation

ABSTRACT

This study aimed to determine the most frequent occurrence times of daily extremes of air temperature and relative humidity in Santa Maria, RS, Brazil. Hourly data from 2002 to 2019 were obtained from an automatic weather station belonging to INMET. The relative frequencies of the times of occurrence of the daily minimum and maximum air temperatures were calculated for each month. The results allowed knowing the times of occurrence of the daily maximum and minimum air temperatures and relative humidity in Santa Maria , RS, Brazil. Thus, it is possible to obtain greater accuracy in the estimation of chill hours, duration of vernalization periods, and in the quantification of stresses caused by inadequate values of these variables in agriculture. The daily minimum air temperature is most frequently recorded at 7:00 a.m., varying from 6:00 a.m. to 8:00 a.m. throughout the year. The daily maximum air temperature occurs most frequently at 4:00 p.m., while in December and January, it is delayed to 5:00 p.m. The daily maximum relative air humidity occurs most frequently at 7:00 a.m., varying from 7:00 a.m. to 9:00 a.m. throughout the year. The daily minimum relative air humidity, on the other hand, occurs most frequently at 5:00 p.m., varying from 4:00 p.m. to 6:00 p.m. in the different months of the year.

Introduction

Climate and agriculture are intrinsically linked. Proof of this is the number of studies that show how the variability of meteorological elements influences regional biomass production. Air temperature is one of the most important meteorological elements in terms of plant development. Plants have an optimum temperature range in which they express their highest rate of development (Taiz et al., 2017).

Air temperatures below or above the optimum range are known to slow plant development. If the minimum or maximum temperatures (cardinal temperatures) are reached, plant development stagnates (Bergamaschi &

Bergonci, 2017). In addition to cardinal temperatures, there are also lethal temperatures at which plant death occurs. In southern Brazil, low air temperatures are ordinary in winter and eventually occur in spring, culminating in the occurrence of frost and cold damage in several crops, such as wheat, coffee, maize, oats, canola, sunflower, sugarcane, grape, potatoes, tobacco, beans, onion, banana, pastures, and garden vegetables (Alvares et al., 2018; Wrege et al., 2018; Perissato et al., 2013).

On the other hand, in spring and summer, high air temperatures may occur and damage some crops. Under these conditions, plants are subjected to a very high atmospheric demand, leading to stomatal closure due to dehydration. Thus, in addition to reducing the CO2 assimilation rate, the cooling capacity of plant tissues is impaired, resulting in heat stress damage (Taiz et al., 2017). According to Silva et al. (2007), depending on the sowing date, the probability of heat damage in common beans may be greater than 50% in the Central Region of Rio Grande do Sul. At temperatures above 30 °C, the potato crop induces shoot growth at the expense of root starch accumulation, negatively affecting crop yield (Bisognin et al., 2017).

The time during which the plant is exposed to stressful temperatures is also determinant for the negative effects of stress as well as the beneficial effects of cold below a certain thermal level, such as in overcoming dormancy in temperate climate fruits and the vernalization of winter cereals (Bergamaschi & Bergonci, 2017) by the quantitative regulation of flowering locus C expression (TAIZ et al., 2017) and plant acclimatization to cold (Dalmago et al., 2010). The time variable is not directly measured under a given thermal condition and is rarely made available by meteorological and agrometeorological services. Therefore, it has to be estimated by mathematical models based on analytical trigonometric functions, for which it is necessary to know the respective times of occurrence of daily Tmin and Tmax and their variation, which is usually associated with the season and, eventually, with the current weather condition, determining the shape of daily air temperature variation (Radons et. al, 2019).

Relative air humidity is another important meteorological element in agrometeorology. It can be used as an indicator of evaporative demand, an essential factor for calculating evapotranspiration, corresponding to both soil water evaporation and plant transpiration (Bergamaschi & Bergonci, 2017). Under high evaporative demand, plant transpiration increases as long as water is available in the soil and the roots can absorb it. Thus, the CO_2 assimilation rate is also increased as the stomatal exchange is intensified (Taiz et al., 2017).

Infection conditions by phytopathogenic agents are greatly influenced by relative air humidity. In soybean, Juliatti et al. (2004) reported that the optimum conditions for Asian rust development are average air temperatures from 15 to 28 °C and relative humidity from 75% to 80%, with prolonged dew periods. Melching et al. (1989), on the other hand, state that the ideal conditions for soybean rust development are temperatures from 18 to 26.5 ºC and abundant dew. Relative air humidity is another important parameter in disease forecasting systems (El Jarroudi et al., 2017; Marcuzzo & Haveroth, 2016; Small et al., 2015).

In this context, knowing the moments when the daily maximum and minimum air temperatures and relative humidity most frequently occur constitutes an important tool for adopting practices to minimize their damage in agriculture. This study aimed to determine, in each month of the year, the time of the day corresponding to the most frequent occurrence of daily extremes of temperature and relative humidity in Santa Maria, RS.

Material and Methods

The hourly meteorological data of air temperature and relative air humidity from January 2002 to December 2019, totaling eighteen years, were obtained from an automatic weather station belonging to the Brazilian National Institute of Meteorology (INMET). This station is located in the experimental field of the Phytotechnics Department of the Federal University of Santa Maria (29° 43'23'' S, 53 ° 43' 15'' W; 95 m), in the municipality of Santa Maria, RS, Brazil. The climate of the region is classified as Cfa, humid subtropical, with hot summers and without a defined dry season (Alvares et al., 2013). The local time zone is the same as in Brasília (UTC - 3h).

The database was manually analyzed by eliminating the days with entry failures. After the screening, the relative frequencies of occurrence of daily minimum air temperature (Tmin), daily maximum air temperature (Tmax), daily minimum relative air humidity (RHmin), and daily maximum relative air humidity (RHmax) were calculated for each hour, also determining the times when they most frequently occurred. It is worth noting that the data provided by the automatic weather station of Santa Maria are recorded based on the previous one-hour history; therefore, the extreme records for 5:00 p.m., for example, correspond to the period from 4:00 to 5:00 p.m.

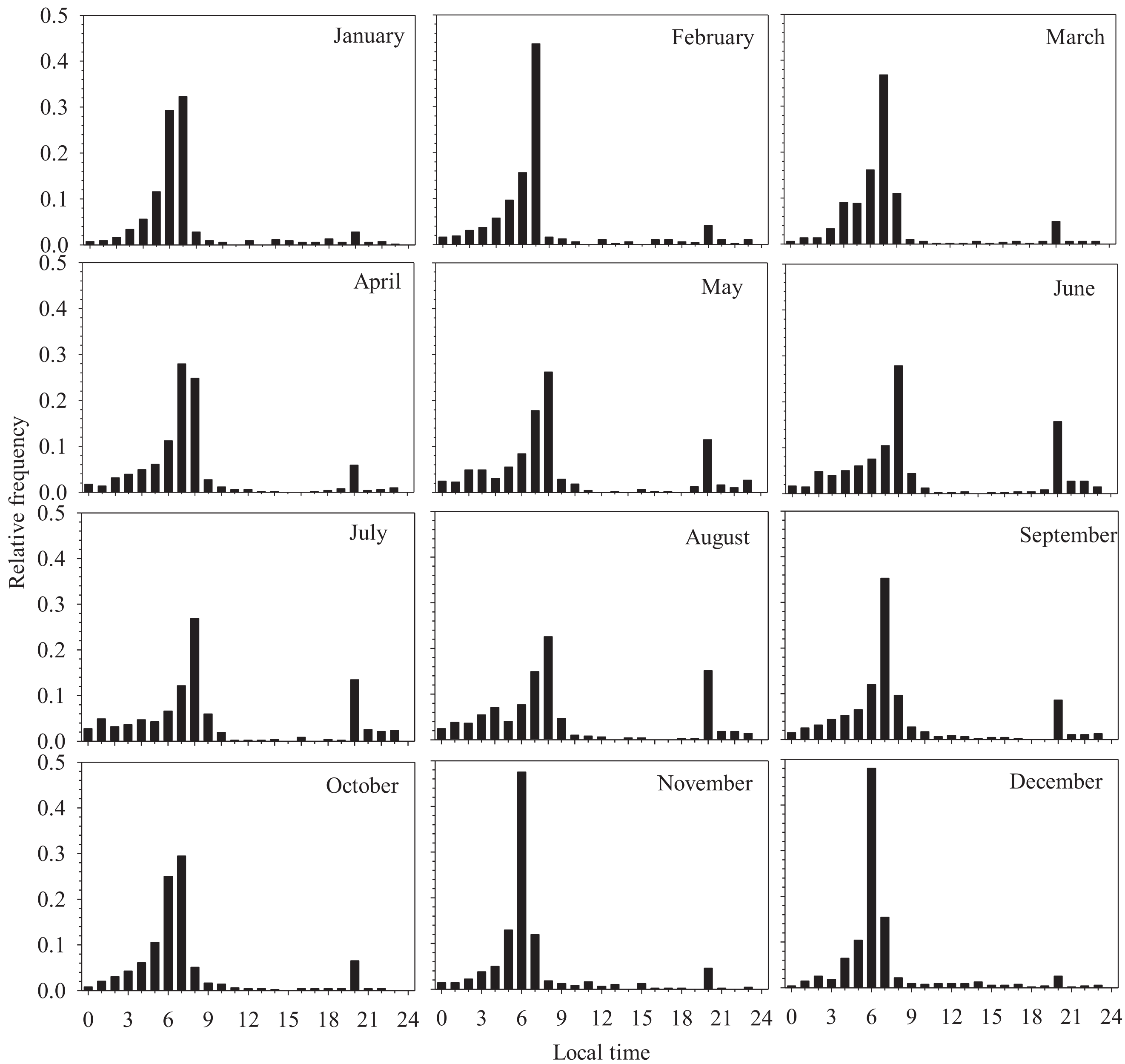
Data analysis was performed in Microsoft Excel sheets by analyzing the relative frequency of occurrence at each time in different months. The relative frequency was calculated as the ratio between the number of days in which the extremes of temperature and relative humidity occurred at a particular time and the total number of days. The graphs were created with the SigmaPlot software.

Results and Discussion

Tmin occurs earlier in November and December than in other months, more frequently at 6:00 am (Figure 1). On the other hand, from May to August, Tmin occurs later, at 8:00 am. This delay is probably due to the decrease in day length with the coming of the winter solstice in the Southern Hemisphere, which takes place on June 21. With this decrease, dawn occurs later, allowing air temperature to decrease for a longer time before heating begins. Bergamaschi and Bergonci (2017) highlight that the minimum daily air temperature usually occurs just after dawn, when the radiation balance is no longer negative. In Capão do Leão, RS (31 º 52' S; 52º 21' W; 13 m), Strassburger et al. (2011) determined that the highest annual frequency of Tmin occurs at 6:00 am, in agreement with the present study. However, the authors did not detail the monthly times with a higher frequency of occurrence. In the remaining months, Tmin occurred more frequently at 7:00 am.

In some months, the peaks of minimum daily air temperatures were identified at 8:00 p.m. These days represent 7% of cases in the annual average, varying from 3.4% in January to 13% in June (Figure 1). This behavior can be explained by the prefrontal condition in the state of Rio Grande do Sul, in which the remaining cold air from the east wind is gradually removed by advection due to the warm north wind, raising the temperature, even at night, in the period from May to September (Sartori, 2015). This is followed by the arrival of a new cold front, and later, in the postfrontal condition, the polar air mass predominates over the region (Sartori, 2015). In this scenario, air

Figure 1. Relative frequency of occurrence of daily minimum air temperatures at different times of the day throughout the year in Santa Maria, RS, from January 2002 to December 2019.

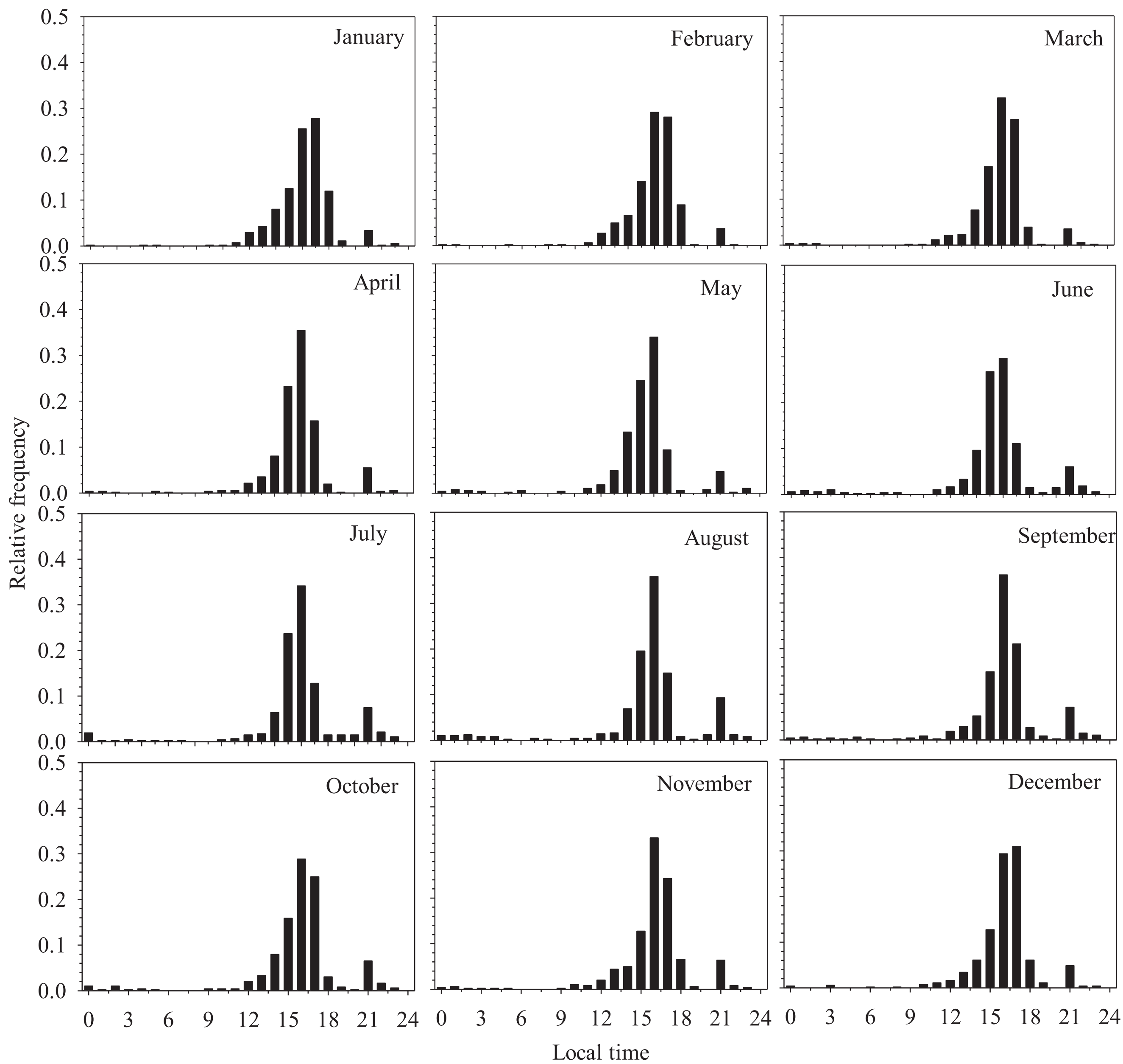


temperature decreases throughout the day, with the minimum value being recorded in the last hour of record of the day, at 8:00 p.m. (11:00 p.m. UTC). Under these conditions, the analytical models used to estimate the times of the day with temperatures either above or below a certain level, such as in the estimation of chill hours in order to evaluate vernalization, dormancy breaking, or plant acclimation to cold, as in the case of canola (Dalmago et al., 2010), should include other equations than those used only on normal days, when Tmin occurs in the early morning and Tmax occurs in mid-afternoon.

The months with the most uniform records of daily minimum air temperature at a given time were November, December, and February, when the frequencies were 0.48, 0.48, and 0.44, respectively. From May to August, the frequency difference between the times of record of daily minimum air temperatures throughout the day was smaller, indicating greater variation in the times of record. This trend was expected since, in the colder nights, wind gusts can promote air heating, increasing air temperature due to the energy flow caused by advection (Heldwein, 1993). The uncertainty regarding the exact time of occurrence of Tmin can be a deviation source in hourly estimates of meteorological elements (Radons et al., 2019).

The Central Depression of Rio Grande do Sul is one of the regions with the highest fog frequencies in the state (Sartori, 2015), a phenomenon that usually influences daily air temperature variation, especially during the early morning. The period with higher fog occurrence extends from March to July, with the highest frequency in April,

Figure 2. Relative frequency of occurrence of daily maximum air temperatures at different times of the day throughout the year in Santa Maria, RS, from January 2002 to December 2019.



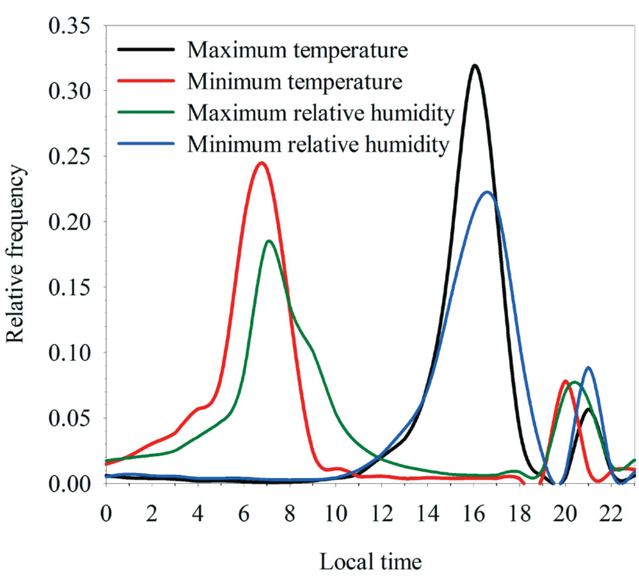
June, and May, corresponding to 31, 27, and 21% of the days with fog, respectively (Radons, 2012). The different temperature distribution in these months is probably associated with fog occurrence since, in this period, the frequency of this phenomenon is still high, with 27, 17, and 12% of foggy days in June, July, and September, respectively (Radons, 2012).

In December and January, the daily maximum air temperatures (Tmax) occurred predominantly at 5:00 p.m. (Figure 2). In all other months, Tmax occurred more frequently at 4:00 p.m. These results disagree with those obtained by Strassburger et al. (2011), measured with a conventional weather station, in which the daily maximum air temperatures throughout the year occurred more frequently at times closer to 3:00 p.m. in Capão do Leão, RS. The authors reported that the times showed greater variation in the automatic weather station measurements than in the conventional station and that the measurement sensitivity of the equipment may be the explanation for this difference.

On an annual average, Tmin and RHmax are more frequent at 7:00 a.m., while Tmax and RHmin are more frequent at 4:00 and 5:00 p.m., respectively (Figure 3). This trend was expected as Tubelis and Nascimento (1980) found that the relative air humidity shows a daily variation that is inverse to air temperature, with lower values during the day and higher values at night, reaching the minimum value when the air temperature is maximum, and the maximum value when the air temperature is minimum.

In Imporá, GO (16º 26’ S and 51°07’W, 584 m), Alves & Mariano (2015), studying different city locations, verified that the absolute minimum temperature values occurred more frequently at 5:30 a.m., with the lowest value recorded at 7:00 a.m. Moreira et al. (2015) determined that the lowest air temperature occurred at 6:00 a.m. in five cities of the state of Mato Grosso, while Oliveira et al. (2010), for September and October, in Cuiabá, MT (15º 35’ S and 56º 5’ W, 165 m), verified that the mean Tmin and RHmax occurred at 6:00 a.m., while the mean Tmax occurred at 3:00 p.m.

Figure 3. Relative frequency of occurrence of daily extremes of air temperature and relative humidity at different times of the day in Santa Maria, RS, from January 2002 to December 2019.



The RHmin occurs most frequently from 4:00 p.m. to 6:00 p.m., depending on the month (Figure 4). From May to August, the RHmin occurs most frequently at 4:00 p.m., while in February and December, the RHmin prevails at 6:00 p.m. In the other months, the highest occurrence was verified at 5:00 p.m. For September, Alves & Mariano (2015) found absolute minimum RH values occurring more frequently at 1:30 p.m., with the absolute minimum occurring at 2:30 p.m., a time close to that found by Oliveira et al. (2010), at 2:00 p.m., for the mean RHmin in Cuiabá, MT.

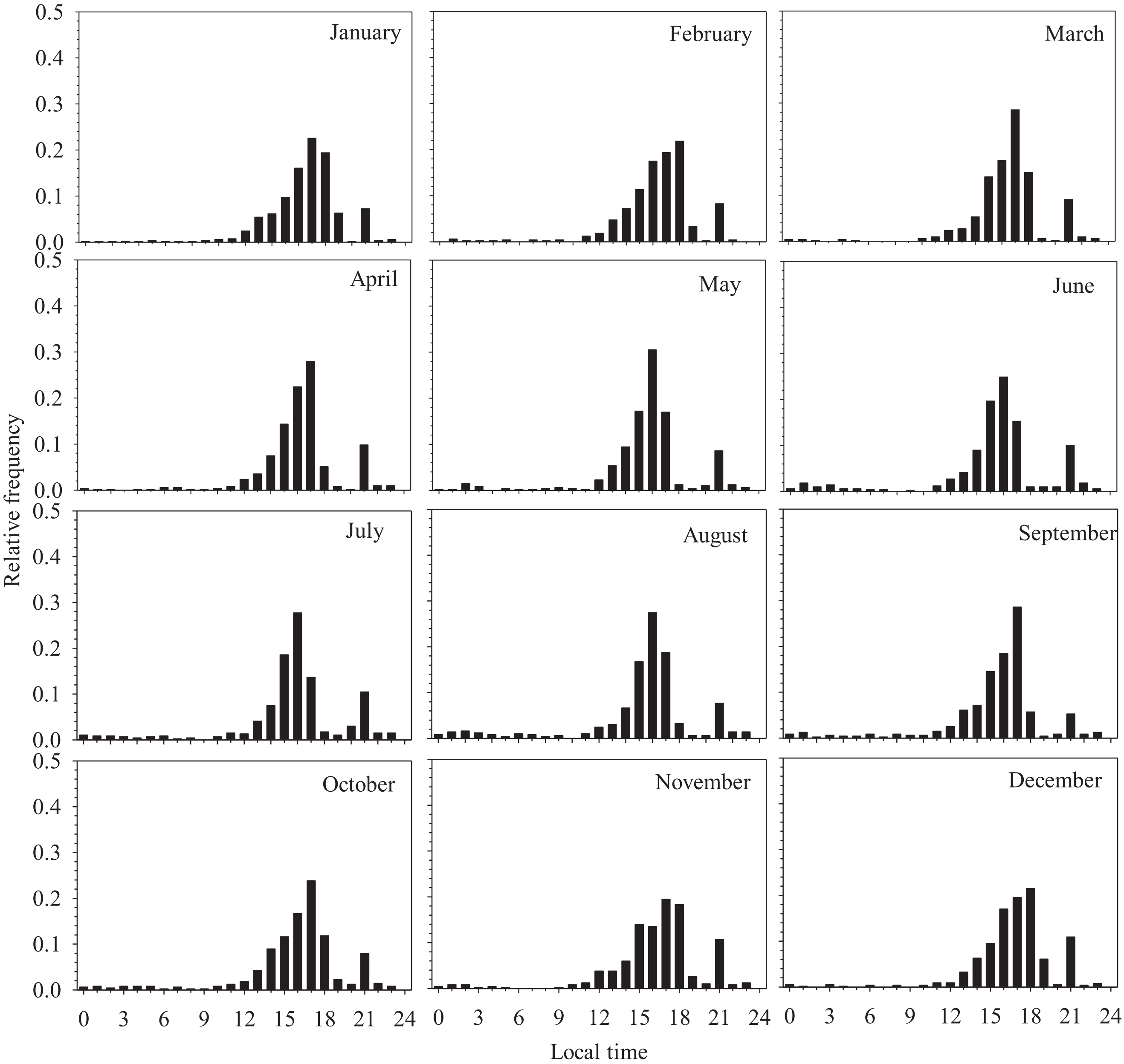
From October to February, the RHmax occurred at 7:00 a.m., being delayed to 8:00 a.m. in March, April, August, and September. From May to July, the RHmax took place at an even later time, at 9:00 a.m., as shown in Figure 5. Moreira et al. (2015) verified that the RHmax occurred at 6:00 a.m. for the general, January, and August averages measured by three of five stations studied in Mato Grosso. For the RHmin, in the January and August averages, the times of occurrence in the different locations varied from 1:00 p.m. to 3:00 p.m.

The times of occurrence of the daily extremes of temperature and relative humidity in this study show an inversely proportional relationship with the increase in air temperature and the decrease in relative humidity. This phenomenon occurs due to the progressive air temperature increase with the increase in solar energy availability on the soil surface. In contrast, the relative humidity decreases as a function of air heating (Costa et al., 2004).

The hourly air temperature distribution trend as a function of solar radiation and surface radiation balance was also verified in this study. Daily maximum air temperature values tends to occur two to three hours after noon while minimum values tend to occur at dawn and just before sunrise and may be influenced by cold fronts, fog, and cloudiness (Ometto, 1981; Varejão-Silva, 2006). Also, daily peaks of temperature and relative humidity outside daily patterns are usually associated with changes in wind speed and direction caused by secondary circulation changes in the lower troposphere.

The results of this study provided information on the times of occurrence of daily maximum and minimum air temperatures and relative humidity in Santa Maria, RS, allowing greater accuracy in the estimation of chill hours,

Figure 4. Relative frequency of occurrence of daily minimum relative air humidity values at different times of the day throughout the year in Santa Maria, RS, from January 2002 to December 2019.



duration of vernalization periods, and in the quantification of stresses caused by inadequate values of these variables in agriculture. The authors encourage similar studies in other places in order to verify this information in different climate types.

Conclusions

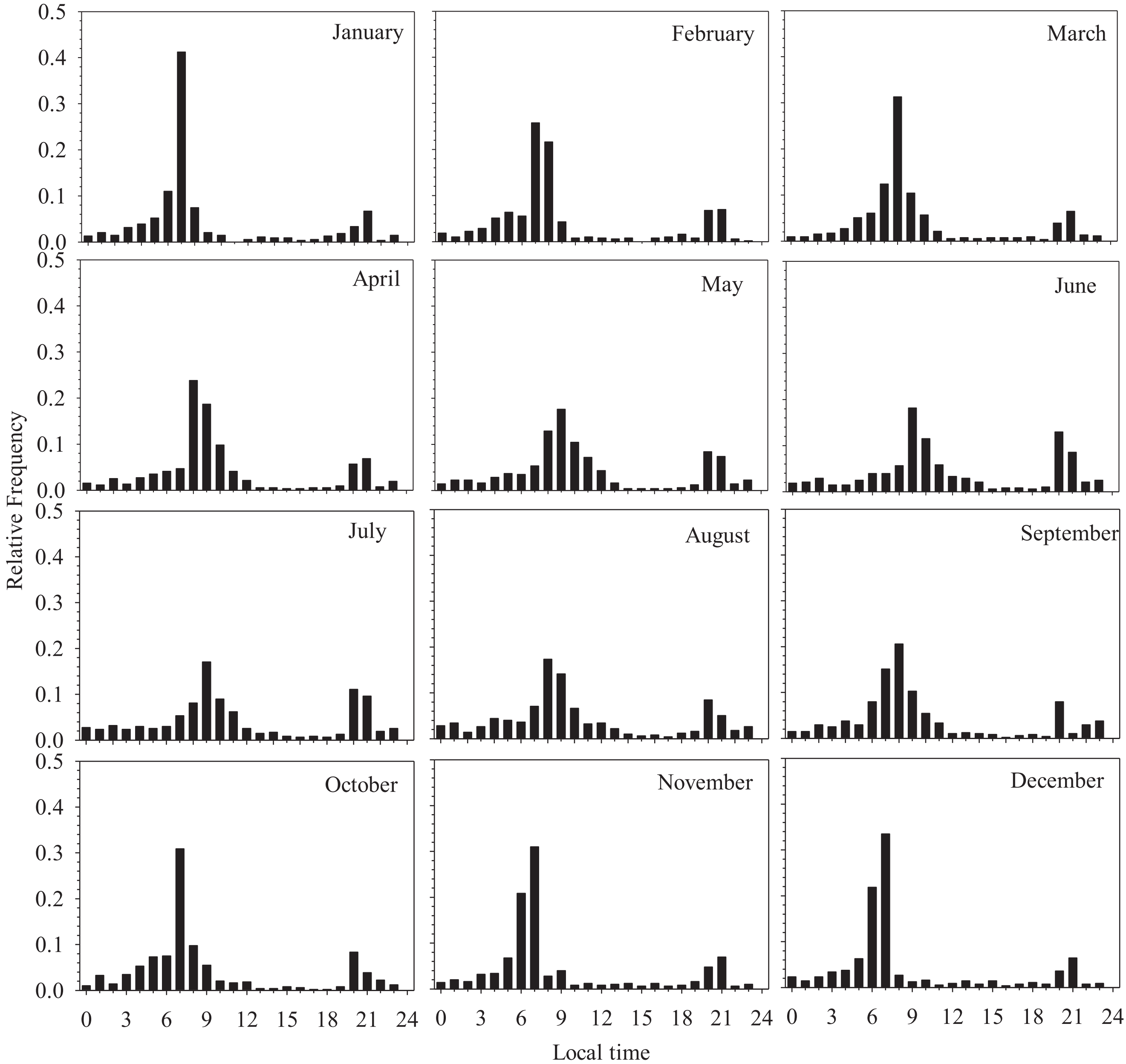
The daily minimum air temperature is most frequently recorded at 7:00 a.m. in Santa Maria, RS, varying from 6:00 a.m. to 8:00 a.m. throughout the year. The daily maximum air temperature occurs most frequently at 4:00 p.m., while in December and January, it is delayed to 5:00 p.m.

In Santa Maria, RS, the daily maximum relative air humidity occurs most frequently at 7:00 a.m., varying from 7:00 a.m. to 9:00 a.m. throughout the year. The daily minimum relative air humidity, on the other hand, occurs most frequently at 5:00 p.m., varying from 4:00 p.m. to 6:00 p.m. in the different months of the year.

Author contributions

S. Z. RADONS designed the experiments, analyzed the data, and wrote the manuscript. A. B. HELDWEIN designed the experiments and wrote the manuscript. L. H. LOOSE analyzed the data and wrote the manuscript. A. J. PUHL wrote the manuscript. H. K. POSSER wrote the manuscript. A. H. NIED analyzed the data and wrote the manuscript.

Figure 5. Relative frequency of occurrence of daily maximum relative air humidity values at different times of the day throughout the year in Santa Maria, RS, from January 2002 to December 2019.



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CITATION

RADONS, S. Z.; HELDWEIN, A. B.; LOOSE, L. H.; PUHL, A. J.; POSSER, H. K.; NIED, A. H. Times of occurrence of daily maximum and minimum air temperatures and relative humidity in Santa Maria, RS, Brazil. **Agrometeoros**, Passo Fundo, v.28, e026770, 2020.

agrometeoros
REVISTA DA SOCIEDADE BRASILEIRA DE AGROMETEOROLOGIA

ISSN 2526-7043 www.sbagro.org.br DOI: http://dx.doi.org/10.31062/agrom.v28.e026770

Horários de ocorrência dos máximos e mínimos diários de temperatura e umidade relativa do ar em Santa Maria, RS

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INFORMAÇÕES

História do artigo:
Recebido em 17 de agosto de 2020
Aceito em 3 de dezembro de 2020

Termos para indexação:
estação meteorológica automática
frequência
variação diária

RESUMO

O objetivo deste estudo foi determinar os horários de maior frequência de ocorrência dos extremos diários de temperatura e umidade relativa do ar em Santa Maria. Os dados horários foram obtidos da estação meteorológica automática do INMET, na série 2002 a 2019. Foram calculadas as frequências relativas dos horários de ocorrência diária das temperaturas mínimas e máximas do ar para cada mês. Os resultados permitiram conhecer os horários de ocorrência das temperaturas máximas e mínimas diárias do ar e da umidade relativa do ar em Santa Maria, RS. Desta forma, pode ser possível maior precisão na estimativa das horas de frio, duração dos períodos de vernalizacão e na quantificação dos estresses causados por valores inadequados dessas variáveis na agricultura. A temperatura mínima diária do ar é registrada com maior frequência às 7 h, com variações entre 6 h (novembro e dezembro) e 8 h (maio a agosto). A temperatura máxima diária do ar ocorre com maior frequência às 16 h, sendo que, em dezembro e janeiro, seu horário predominante é atrasado para às 17 h. A umidade relativa máxima diária do ar ocorre com maior frequência às 7 h, variando entre às 7 e as 9 h ao longo do ano. A umidade relativa mínima diária do ar ocorre mais frequentemente às 17 h, variando entre às 16 e às 18 h nos diferentes meses.

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