



Investigation of the maximum and minimum temperatures in the semi-arid region of northeastern Brazil¹

Investigação das temperaturas máximas e mínimas no semiárido cearense, nordeste do Brasil

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Abstract - Temperature records all over the world provide evidence that the earth's climate is changing. To investigate changes in the extreme temperatures of semi-arid regions, we analyzed 33 years (1975-2008) of monthly maximum and minimum air temperatures for three weather stations located in Quixeramobim, Crateús and Barbalha Cities, Ceará, Brazil. The data sets were provided by INMET (Instituto Nacional de Meteorologia), Brazil. Dataset of each station was shared in decades to better understand the temperature tendency as well as to identify the warmest one. The two most recent decades were the warmest at all three stations investigated, and the highest temperature values were observed for Barbalha station. The highest increases of maximum temperature occurred during the dry season (May/Dec), and the warmest month was October, during which temperature increases of up to 1.63 °C were observed in the 1980s. The minimum temperature increased substantially during the rainy season (Jan/Apr) and during the coldest months (Jun/Jul). The highest increase of minimum temperature (3.08 °C) was observed in July at the Barbalha station. The Quixeramobim station showed no significant increases in minimum temperature. The results indicate that temperature increases occur in an irregular pattern, suggesting that various regional agents affect changes in temperature.

Key words - Sensible Heat. Climate change. Weather.

Resumo - Registros de temperatura em todo o mundo fornecem evidências de que o clima da Terra está mudando. Neste estudo foram avaliadas as temperaturas máximas e mínimas mensais de uma série histórica de 33 anos para as estações meteorológicas das cidades de Quixeramobim, Crateús e Barbalha com o objetivo de se investigar mudanças nas temperaturas extremas em áreas localizadas no semiárido cearense. As séries históricas (1975-2008) foram cedidas pelo 3º Distrito do INMET (Instituto Nacional de Meteorologia). Os dados foram particionados em decênios para se investigar as tendências das temperaturas e identificar qual a década de maiores mudanças. Os resultados apontam para aumentos das temperaturas máximas e mínimas nos três decênios investigados, sendo os maiores incrementos registrados nos dois últimos, principalmente na estação de Barbalha. Para as temperaturas máximas, os maiores incrementos foram registrados no período seco (maio/dezembro), sendo o mês de outubro o que registrou os maiores incrementos, atingindo valores de 1,63 °C no segundo decênio. Já para as mínimas, os maiores acréscimos ocorreram durante o período chuvoso (janeiro/abril) e nos meses mais frios (maio/julho), sendo o maior valor (3,08 °C) observado no mês de julho para a estação de Barbalha. Os menores acréscimos das temperaturas mínimas foram constatados na estação de Quixeramobim, e os mesmos não apresentaram significância estatística ao nível de 5%. De acordo com os resultados conclui-se que os aumentos das temperaturas para as três estações ocorreram de forma irregular expressando o efeito de ações locais, as quais pode estar relacionadas às mudanças de uso da terra.

Palavras-chave - Calor sensível. Mudanças climáticas. Tempo.

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Introduction

For the last couple decades, research regarding temperature changes at the global and regional scales has been discussed not only by the scientific community but also by the general public. Although significant regional temperature variability has been observed, temperature changes mostly have been cited at the global scale (NASRALLAH *et al.*, 2004; PITMAN; PERKINS, 2009). Studies at the regional scale can supply not only more refined conclusions than large-scale studies but also more specific, localized information, which could be useful for local policy decisions.

Climate change is unambiguous and its effects are detected in many ecosystems of the Earth; however, the net increase in global temperature is not homogeneously distributed on the earth's surface (REIDSMA *et al.*, 2010). Climate change has significantly impacted many parts of the globe even while no significant changes have been observed in other parts (LIUBIMTSEVA *et al.*, 2005; BRYAN *et al.*, 2009).

Human action has been considered as the most important cause for these changes (IPCC, 2007) on a global scale (VOSE, 2005) or on a regional scale (PEREIRA; MORAIS, 2007; LOBELL; BONFILS, 2008). A number of possible sources of the climatic changes observed in the past two decades are under investigation. Temperature increases will induce levels of climate change that can affect the planet significantly, especially in regions of extreme temperatures, with greater impacts on tropical regions and developing countries (BRYAN *et al.*, 2009). Semi-arid regions of the globe may undergo desertification due to climate change and become unsuitable to human life (BRYAN *et al.*, 2009). Some research, such as Marengo (2008), have indicated that maximum temperatures have increased by 1.5 to 2.0 °C over the last 40 years in the Northeast Region of Brazil. As in other tropical arid and semi-arid regions, the Brazilian Northeast has a high amount of solar energy available. Its high levels of solar energy, along with an increase in sensible heat (air temperature) due to global warming, could cause increases in lake evaporation, evapotranspiration rates in plants, and demand for water by vegetation.

A combination of factors associated with climate change, such as low rainfall, high temperatures and high evaporation rates, could pose difficulties for small farmers in rural northeastern Brazil. Within this context, detailed studies of regional indicators of climatic change are relevant. In this work, the trends of the maximum and minimum temperatures over 33 years were calculated using data sets from three stations located in semi-arid regions of northeastern Brazil.

Materials and methods

To investigate trends in extreme temperatures changes at our study sites, we used data sets of absolute maximum and minimum temperatures, measured two meters above the ground at each site. The data sets encompass a period of 33 years (1975-2008) of monthly maximum and minimum temperatures for three stations located in the cities of Quixeramobim (05°10' S, 39°17' W, 179 m), Crateús (05°10' S, 40°40' W, 297 m) and Barbalha (07°19' S, 39°18' W, 409 m), Ceará, Brazil. The climate of the studied region is classified as hot semi-arid. The region has an average evaporation of 2,527.6 mm year⁻¹ with an insolation of 2,776.4 hours year⁻¹ and average global irradiance of 23 MJ m⁻² day⁻¹. Average annual rainfall is 750 mm; the wet (Jan/April) and dry (May/Dec) seasons are well defined.

The data for monthly maximum and minimum temperatures were collected from three stations situated inland in the State of Ceará and were supplied by the third INMET (Instituto Nacional de Meteorologia) district. The years in the data sets that contained missing values were not used in the analysis. To explore changes in the absolute maximum and minimum temperatures of the three available stations, we pooled data into decades to compare the decade means among stations (Table 1), applying the Student's t test at a significant level of 5%.

Table 1 - Data sets of monthly maximum and minimum temperatures from Barbalha, Crateús and Quixeramobim stations were pooled by decade

Decade	Period	Combination	Algorithm
1	1975/1984	(1975/1984) – (1994/1998)	1-2
2	1994/1998*	(1975/1984) – (1999/2008)	1-3
3	1999/2008	(1994/1998) – (1999/2008)	2-3

* Only five years were considered in the second decade due to missing values in the data sets.

Results and discussion

Maximum temperature

The stations studied are located near the equator (latitude < 6° S), and the temperature during the year ranges between 14 °C and 38 °C. During the three decades analyzed here, maximum temperatures exceeded 32 °C. The “Decade means” (average monthly temperatures for each decade) showed clear increases in maximum temperatures during Decades 1, 2 and 3, regardless of

where the measurements were taken (Figure 1). The two most recent decades investigated showed the highest values of maximum temperature. This observation is in accordance with an analysis by the IPCC (2007), which stated that an increase of 0.65 °C in average global temperature was detectable beginning in the 1990s.

The Barbalha station showed the highest values of monthly maximum temperature. At the station in Crateús, the highest maximum temperatures were recorded in Decade 2 (1994-1998) for seven months of the year, while the highest temperatures during the beginning of the dry season (May/August) occurred in Decade 3 (1999-2008). At the Quixeramobim station, Decade 3 contained nine months with the highest maximum temperatures, while Decade 2 contained only three instances of highest maximum temperatures (March, June and October). The temperature data taken at the three stations corroborate the high regional temperature variability observed in many different parts of the globe (HOMAR *et al.*, 2010; HERTIG; JACOBET, 2008).

One important question regarding these events is their tendency to increase or to decrease over the time,

as well as whether or not they are statistically significant. In this study, the increase rates of decadal average of maximum temperatures were investigated. When “decade means” were compared within stations, the temperature increased between decades for some months (Table 2). For the pooled data (Table 2), 89% (97 events) of total observations showed an increase in maximum temperature. Most of these increases were observed in the dry season (May/Dec).

Increases were observed most often between Decades 1 and 3, and the highest increases occurred at the Barbalha and Quixeramobim stations. The opposite trend was observed at the Crateús station. At this station, seven of twelve months showed a trend of decreasing “decade means” in Decade 3, (Table 2). Monthly variation in maximum temperature was observed.

Significant temperature increases of up to 1 °C occurred at Barbalha station, and October brought the highest increases at all three stations, suggesting a gradual increase in the diurnal temperatures. Temperature variation depends on the amount of energy present in the air in the form of sensible heat. Increasing temperatures might

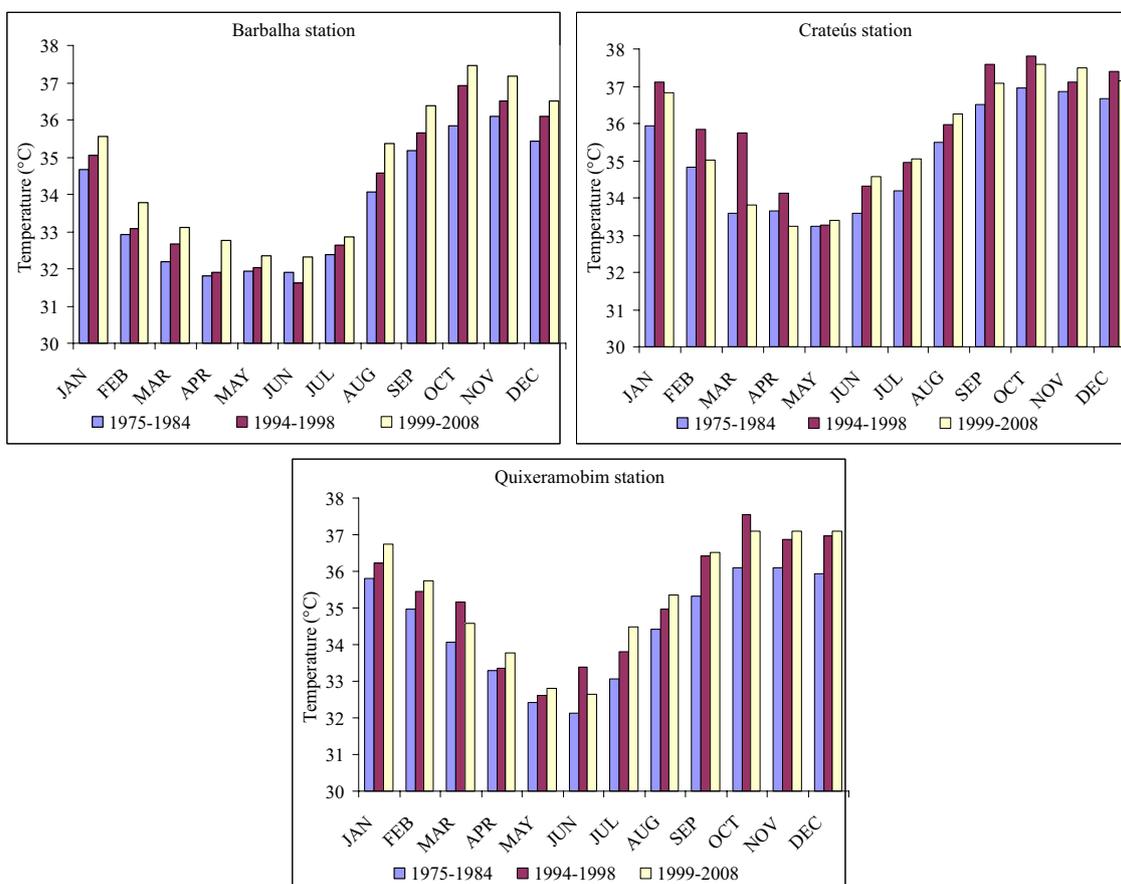


Figure 1 – Pooled data for monthly average maximum temperature changes recorded at stations in Barbalha, Crateús and Quixeramobim for Decades 1, 2 and 3.

Table 2 – Differences between decades of the “decade means” of monthly maximum temperature for three locations in the semi-arid region of the State of Ceará, Brazil

Month	Barbalha			Crateús			Quixeramobim		
	2-11	3-12	3-23	2-1	3-1	3-2	2-1	3-1	3-2
Jan	0.41	0.89	0.48	1.16	0.89*	-0.27	0.43	0.92*	0.49
Feb	-0.05	0.84	0.89	1.01	0.19	-0.82	0.47	0.77	0.30
Mar	0.57	0.94	0.36	2.16	0.21	-1.95	1.09	0.52	-0.57
Apr	0.16	0.94	0.78	0.47	-0.42	-0.89	0.08	0.49	0.41
May	0.25	0.42	0.16	0.05	0.17	0.13	0.20	0.38	0.18
Jun	0.33	0.42	0.75	0.74	0.97*	0.23	1.24	0.48	-0.75
Jul	0.28	0.48	0.19	0.76	0.86*	0.10	0.75	1.41*	0.66
Aug	0.61	1.33*	0.72	0.50	0.77*	0.23	0.53	0.91*	0.38
Sept	0.44	1.20*	0.75	1.08*	0.59	-0.49	1.10*	1.12*	0.10
Oct	1.39*	1.63*	0.24	0.89*	0.65*	-0.24	1.44*	0.99*	-0.45
Nov	0.47	1.09*	0.60	0.25	0.64*	0.39	0.75*	0.99*	0.24
Dec	0.64	1.09*	0.45	0.71	0.47	-0.26	1.02*	1.17*	0.15

¹Average temperature difference between Decades 1 and 2

²Average temperature difference between Decades 1 and 3

³Average temperature difference between Decades 2 and 3

*Average temperature increases between decades are statistically different at a 5% significance level ($p < 0.05$)

indicate changes in land use, whereby surfaces of higher albedo are replaced by surfaces with higher capacities for absorption. Another possible cause of these observed temperature increases is a reduction in the vegetated area, i.e., a decreased latent heat of evapotranspiration. Similar trends have been observed in different parts of the globe (LINKOSALO *et al.*, 2009; BRYAN *et al.*, 2009).

Minimum temperature

The tendency of average monthly minimum temperature can be analyzed in Figure 2. The highest minimum temperatures recorded in the data sets were observed in the two most recent decades. At the Crateús station, the highest minimum temperatures were recorded in Decade 3 (1999-2008) except for May, for which the highest minimum temperature occurred in Decade 2 (1995-1998). A similar pattern was found at the Barbalha station, which recorded the highest values of minimum temperature in Decade 2, except during the months of March, April and July. The Quixeramobim station also recorded the highest values of monthly minimum temperature during Decade 2. Similar observations have been made in other studies (NASRALLAH *et al.*, 2004; BRYAN *et al.*, 2009), indicating that although high regional variability in temperature data exists, a general increase of minimum temperature appears to be a global trend.

The Student's *t* test was applied to evaluate increases in “decade means” of minimum temperatures between decades (Table 3); we used a significance level

of 5%. Overall, 79 events (73%) of the highest minimum temperatures occurred in Decades 2 and 3. Because energy loss from the earth to the atmosphere as sensible heat causes minimum temperatures, an increase in minimum temperature indicates that the heat exchange between the earth and the atmosphere has been reduced. Such changes result in an increasing number of “hot” nights. Our analysis corroborates other observations at the global and regional scales (VOSE *et al.*, 2005; PEREIRA; MORAIS, 2007).

For minimum temperature, significant differences between decades were detected during the wet season (Jan/Apr) and the coldest months (Jun/Jul). At Barbalha station, differences in monthly minimum temperature increases were significant between Decades 1 and 2 and between Decades 1 and 3 from January to July. Although only four events recorded at the Crateús station showed statistical differences among decades, 80% of observations showed trends of increased monthly minimum temperatures. The Quixeramobim site was different from the other two stations with regard to minimum temperature. No observations at this station showed statistically significant differences across decades, and more than 50% of the data collected indicated a decreasing trend in minimum temperature over time. The differences among the three stations might be related to the differences in land use around the stations.

Our results from three stations in northeastern Brazil indicate that temperature increases occur in an irregular pattern, suggesting that different variables influence

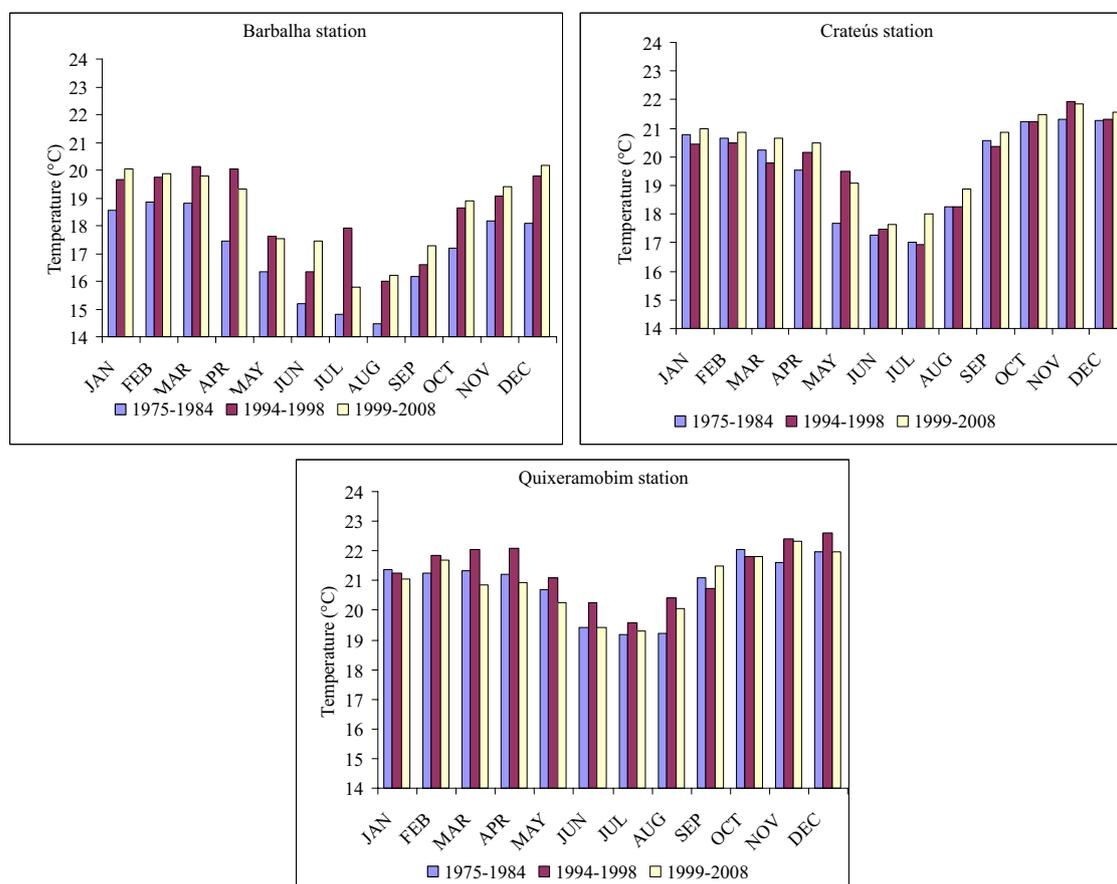


Figure 2 - Pooled data for monthly average minimum temperature changes recorded at stations in Barbalha, Crateús and Quixeramobim for Decades 1, 2 and 3

Table 3 – Differences between the “decade means” of monthly minimum temperatures for three locations in the semi-arid region of the State of Ceará, Brazil

Month	Barbalha			Crateús			Quixeramobim		
	2-11	3-12	3-23	2-1	3-1	3-2	2-1	3-1	3-2
Jan	1.12*	1.49*	0.37	-0.31	0.24	0.55	-0.12	-0.34	-0.22
Feb	0.90	1.03*	0.13	-0.17	0.20	0.37	0.61	0.43	-0.18
Mar	1.30*	0.96*	-0.32	-0.47	0.41	0.87	0.73	-0.47	-1.20
Apr	2.61*	1.87*	-0.74	0.64	0.96	0.33	0.90	-0.27	-1.17
May	1.24*	1.19*	-0.05	1.82*	1.40*	0.81	0.40	-0.41	-0.81
Jun	1.11	2.24*	1.13	0.20	0.35	0.16	0.86	0.01	-0.85
Jul	3.08*	0.96*	-2.12	-0.06	1.01*	1.07*	0.41	0.12	-0.29
Aug	1.53	1.75	0.22	0.01	0.63	0.62	1.20	0.87	-0.33
Sept	0.43	1.11	0.68	-0.22	0.26	0.48	-0.36	0.43	0.78
Oct	1.44	1.71*	0.27	-0.02	0.25	0.27	-0.22	-0.24	-0.02
Nov	0.87	1.21	0.34	0.63	0.55	-0.08	0.79	0.72	-0.07
Dec	1.70	2.08	0.38	0.02	0.28	0.26	0.61	-0.03	-0.64

¹Average temperature difference between Decades 1 and 2

²Average temperature difference between Decades 1 and 3

³Average temperature difference between Decades 2 and 3

*Average temperature increases between decades are statistically different at a 5% significance level ($p < 0.05$)

temperature changes at the regional scale. Climate change has considerably impacted many regions of the globe (PITMAN; PERKINS, 2009), though some regions appear to be relatively unaffected (LIOUBIMTSEVA *et al.*, 2005; BRYAN *et al.*, 2009).

Conclusions

The highest observed maximum and minimum temperatures at our study sites occurred during the two most recent decades.

Independent of regional temperature variation, all three stations showed similar trends of increasing monthly maximum temperatures.

Increases in maximum temperatures were greater in magnitude than increases in minimum temperatures, indicating a higher quantity of sensible heat during the day.

The highest increases of both maximum and minimum temperatures were observed at the Barbalha station.

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