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Characterisation of Hot Days and Heatwaves: A Case Study for Queensland State in Australia

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Abstract: Due to climate change, the temperature is increasing; however, its spatial and temporal distribution and trend are less understood. To fill this research gap, this study examines the nature of temperature rise in the Queensland State of Australia. Based on the daily maximum and minimum temperature data of 17 weather stations covering 1969-2018, the geographical patterns as well as the temporal variations of hot days and heatwaves over the state are examined. The Mann-Kendall trend test and simple regression methods are employed for detecting trends. The majority of the stations show a significant increase in temperature indices, indicating the warming of the state. Out of 17 stations, 12/14 display a significant increase in the annual frequency of warm days/nights, and 2/11 reveal a significant decrease in the frequency of cool days/nights. The rest of the stations show no change, except two stations showing an upward trend for cold nights. The Excess Heat Factor (EHF) index is used to identify the heat waves. Over Southern Queensland, frequency, total duration, and maximum duration of heatwaves are found to have increased significantly with a greater magnitude compared to other parts of the state. These findings will be useful for climate adaption and mitigation measures in Queensland is compulsory.

Keywords: Climate change, extreme temperature, excess heat factor (EHF), heatwaves, Mann-Kendall (MK), linear regression

1. Introduction

Australia's weather and climate have been changing similar to other parts of the globe. Human effects associated with emissions of greenhouse gases are mainly responsible for this change [1]. Hot days and heat waves have been occurring more frequently and become more intense due to climate change. Since 1910, Australia has warmed by an average of 0.8°C [2], with the most warming being observed since 1950 [3]. Since 1950, every decade has been found to be warmer than the previous ones.

The warmest year (annual mean temperature being 1.52°C above the average) in Australia was 2019, with the hottest temperature of 49.9°C, recorded at Nullarbor in South Australia. Temperatures have been rising both during the day and at night across Australia [4]. Most parts of the country, notably Queensland and the southern half of Western Australia, have seen the greatest warming since 1910. The rise of mean temperatures has been greater than 0.1°C per decade during this period [2].

Heatwaves have been attributed to the deaths of more people in Australia than any other natural hazard in the last century, with almost 500 deaths recorded by 2009 Australian heatwaves [5]. In addition, heatwaves increase risk of drought and bushfire [6,7] and badly affect biodiversity [8,9]. To reduce global warming, the Paris Agreement sets a goal to keep it less than 2°C compared to pre-industrial levels, and below 1.5°C by the end of the century [10]. A rise in global temperature of 1.5°C to 2°C would affect approximately 30% of the world's population [11,12].

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In Australia, few studies have analysed the changes in heatwave attributes in greater depth [13,14]. To fill this knowledge gap, in this study extreme days and nights, defined by comparing daily maximum and minimum temperatures with threshold values, and Excess Heat Factor (EHF) are examined using data from Queensland State in Australia.

2. Study Area and Data Preparation

In this study, Queensland State of Australia, is selected as the study area. A total of 341 weather stations are located in Queensland. There are gaps in daily maximum (T_{max}) and minimum temperature (T_{min}) data, and all these stations have not been in operation since their installation. Therefore, only stations with missing values of less than five per cent and covering at least the last five decades, e.g., 1969 to 2018, have been selected for this study. These criteria have been applied to have consistent temperature data over a 50-year timespan. Applying these criteria, 17 weather stations from Queensland have been selected as shown in Fig. 1. Spatial interpolation technique has been employed to fill the missing T_{max} and T_{min} data at a given station.

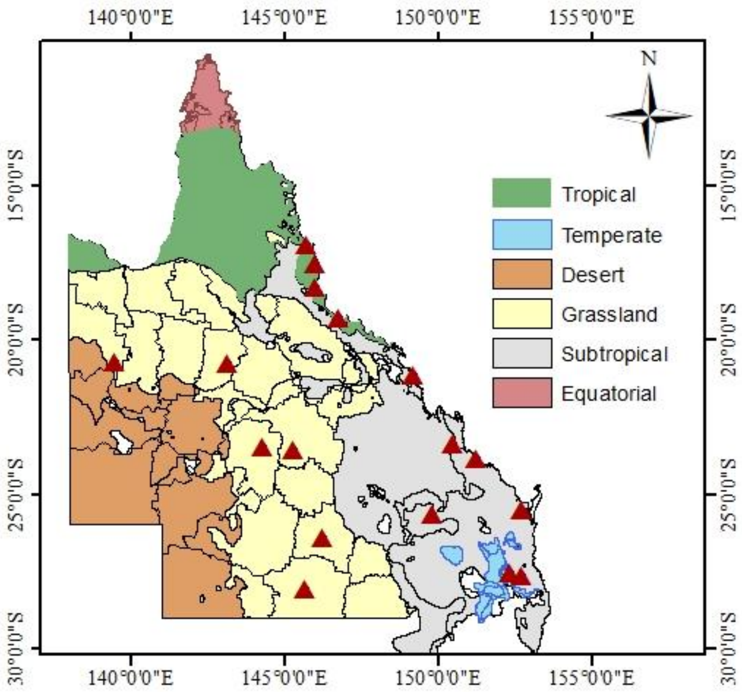


Fig. 1 - Location of selected weather stations in Queensland, Australia

3. Methodology

The statistical tests of trends in extreme days and heat waves have been carried out based on the linear regression technique and Sen's slope estimator [15,16] and Mann-Kendall test [17]. Four indices have been adopted to characterise the trends in extreme temperature data using Australian Bureau of Meteorology recommended criteria:

- TXx = Annual count of days when TX (daily maximum temperature) > 35°C
- TNx = Annual count of days when TN (daily minimum temperature) > 20°C
- TXn = Annual count of days when TX (daily maximum temperature) < 15°C
- TNn = Annual count of days when TN (daily minimum temperature) < 5°C

Four different characteristics of heatwaves have been adopted to assess heatwave changes based on the Excess Heat Factor (EHF) criterion [16] . EHF is defined by two excessive heat indices, Excess Heat and Heat Stress, where a positive value of EHF suggests a heatwave condition. Heatwaves attributes are defined according to Fischer and Schär [18], as follows:

- Heatwave amplitude (HWA), the hottest day (amplitude) of the hottest event,
- Heatwave number (HWN), the number of heatwave events per austral summer,
- Heatwave frequency (HWF), the number of heatwave days per austral summer, and
- Heatwave duration (HWD), the length of the longest summer heatwave event.

Heatwave attributes have been calculated only for summer season in Queensland (November to March).

4. Results

4.1 Trends In Extreme Days and Nights

The slopes of all the four temperature indices of extreme days have been calculated for each station and presented in Fig. 2 and Table 1 based on the linear regression technique and Sen's slope estimator, following the Mann-Kendall test.

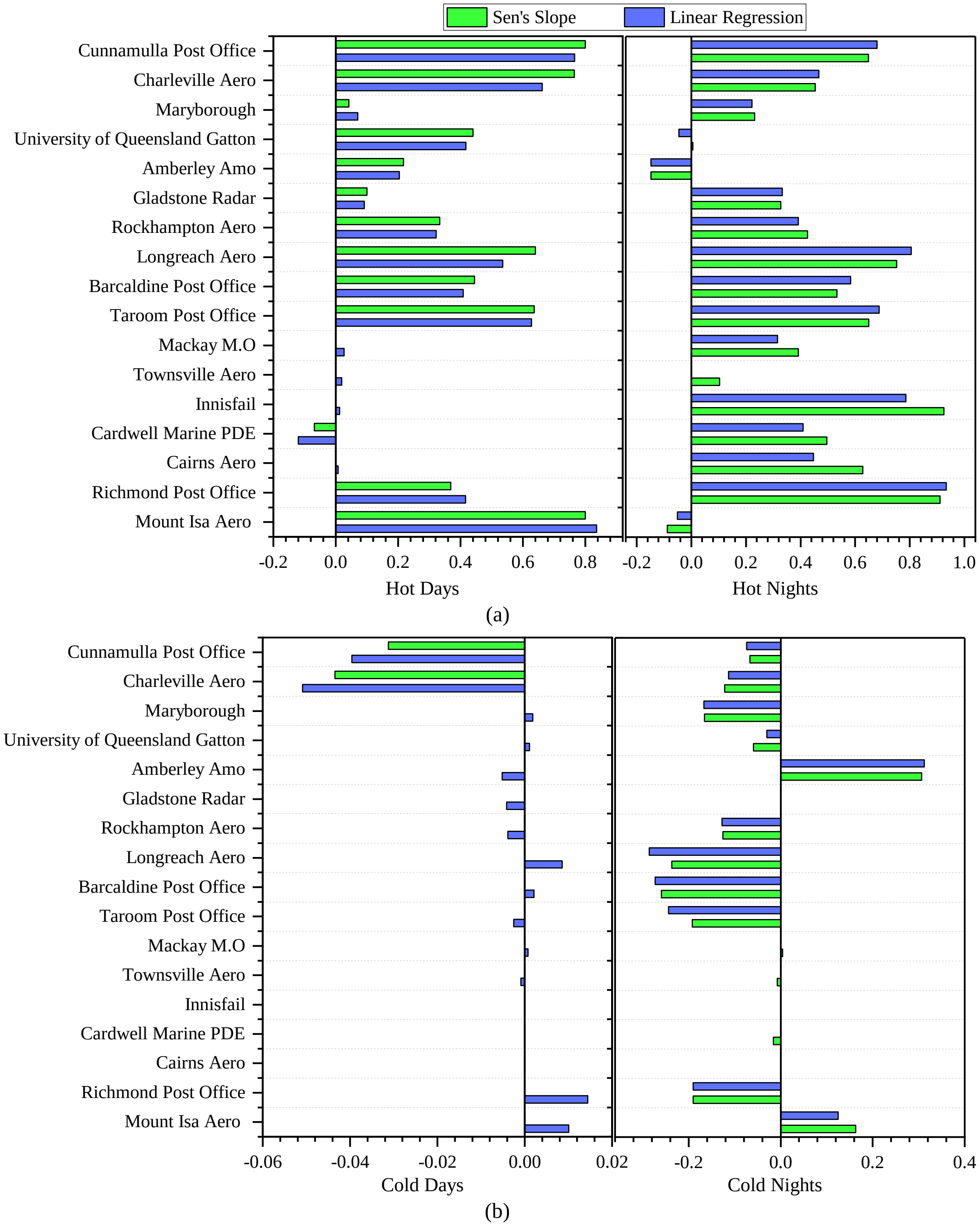


Fig. 2 - Annual trend slopes for (a) TXx, TNx and; (b) TXn, TNn considering linear regression and Sen's slope estimator for each selected station

Mostly similar slopes are found utilising both Sen's slope and linear regression, as shown in Fig. 2. For hot days, 12 out of 17 stations show warming trends, as illustrated in Fig. 2(a), and ten stations show statistically significant upward trends at 5% level of significance (Table 1). The only significant downward trend is found for Cardwell Marine PDE station in Northeast Queensland (Tropical). However, in Mount Isa Aero and Cunnamulla Post Office stations, the highest increase in hot days is observed with the increasing trend of 8 days/decade, as shown in Fig. 2(a). These stations are situated in the Northwest and Southern region of Queensland (Grassland) (Fig. 1).

Higher increasing trends in hot nights compared to hot days are observed for most of the stations, with the exception of Mount Isa Aero, Amberley AMO and University of Queensland Gatton stations showing negative trends of 0.5, 1.47 and 0.45 days/decade, respectively, and are not statistically significant at 5% significance level. However, while considering hot nights, in total 11 stations have shown significantly upward trends, and the Richmond Post Office has been the highest amongst them, located in the North (Grassland) with the slope value of 9.3 days/decade (Fig. 2(a) and Table 1).

The decadal variations in the cold days and cold nights are also investigated. The results indicate that changes in cold nights are more apparent than cold days, which is consistent with the study reported by Wang et al. [19]. Large number of stations (11 out of 17) in the study area have exhibited a downward trend in cold nights. However, Amberley Amo and Mount Isa Aero stations have shown an upward trend of approximately 3.1 and 1.3 days/decade, respectively (Fig. 2(b)). Seven out of 17 stations have exhibited statistically significant downward trend at 5% level of significance (Table 1). However, Charleville Aero and Cunnamulla Post Office stations have shown a decreasing trend in Cold Days with a non-significant decrease of 0.4 and 0.3 days/decade. Other stations have not shown any significant change over time.

Table 1 - Trends evaluated by non-parametric Kendall slope estimator

Station	Hot Days	Hot Night	Cold Days	Cold Night
Mount Isa Aero	**2.85**	-0.31	1.23	1.61
Richmond Post Office	1.46	**4.75**	**2.38**	**-2.77**
Cairns Aero	0.30	**2.21**	0.00	0.00
Cardwell Marine PDE	**-2.35**	1.88	0.00	**-2.93**
Innisfail	0.50	**3.51**	0.00	0.00
Townsville Aero	0.54	-0.03	-0.42	**-2.09**
Mackay M.O.	**2.19**	**2.99**	-0.16	1.52
Taroom Post Office	**3.43**	**4.73**	0.23	-1.61
Barcaldine Post Office	1.72	**3.59**	0.46	**-3.30**
Longreach Aero	**2.56**	**3.70**	0.68	**-2.23**
Rockhampton Aero	**2.83**	**2.72**	-1.08	**-2.47**
Gladstone Radar	**2.96**	**2.45**	-1.21	0.07
Amberley AMO	**3.07**	-1.20	-0.71	**1.97**
University of Queensland Gatton	**4.20**	-0.44	-0.37	-0.40
Maryborough	1.76	1.68	0.20	-1.89
Charleville Aero	**3.11**	**2.58**	-1.48	-0.96
Cunnamulla Post Office	**3.07**	**4.24**	-1.14	-0.59

Note: The boldface highlights statistically significant trends.

Table 2 presents the summary of the average, maximum and minimum numbers of hot days and nights, and cold days and nights of each station. In the case of hot days, Richmond Post Office station has shown the highest number (203 days) (Table 2). It should also be noted that for every station, the average number of hot nights is greater than the hot days.

Based on Koppean major climatic zone, Queensland is divided into tropical, subtropical, desert and grassland. Stations with a higher number of hot days have been found to be mainly located in grassland areas. Similarly, the stations with a higher number of hot nights have been found in the tropical regions. For example, the highest hot nights have been seen in Cairns Aero stations (more than 236 days), whereas the lowest has been found in the University of Queensland Gatton station (40.72 days).

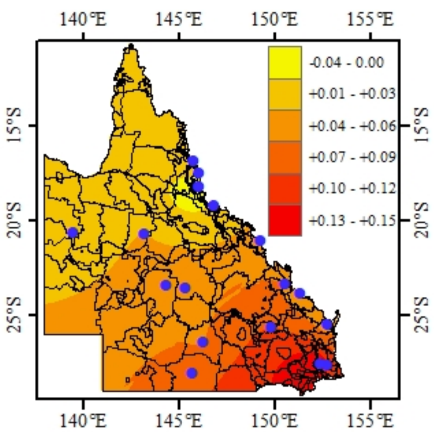
The use of the absolute criterion (<15°C) for cold days has revealed limited occurrences in tropical and subtropical regions but a higher number (about 5 days) in Cunnamulla Post Office station in the grassland region. For cold nights, a high number (more than 57 days) has occurred in Charleville Aero station, which is also located in the grassland region. Compared to cold days, a greater number of cold nights has been observed for each station, and the highest has been observed in Charleville Aero station located in the grassland region.

Table 2 - Mean, minimum and maximum number of extreme days and nights at 17 stations located in different environments

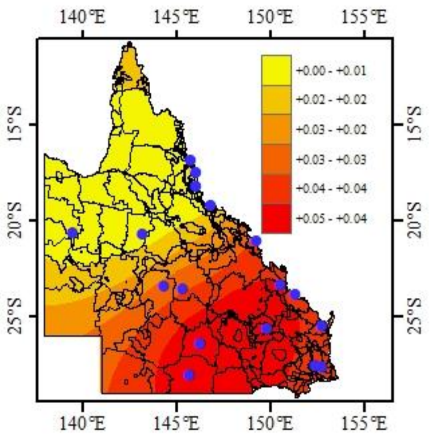
Station	Hot Days (> 35°C)	Hot Night (> 20°C)	Cold Days (< 15°C)	Cold Night (< 5°C)	Environment
Mount Isa Aero	123.88 [57 – 190]	151.58 [121 – 192]	0.28 [0 – 4]	14.34 [0 – 40]	Grassland
Richmond Post Office	145.28 [95 – 203]	147.28 [107 – 187]	0.24 [0 – 3]	10.80 [0 – 33]	Grassland
Cairns Aero	3.24 [0 – 14]	236.6 [174 – 321]	0.00 [0 – 0]	0.00 [0 – 0]	Tropical
Cardwell Marine PDE	3.90 [0 – 22]	204.38 [166 – 269]	0.00 [0 – 0]	0.22 [0 – 3]	Tropical
Innisfail	2.36 [0 – 9]	202.64 [146 – 286]	0.00 [0 – 0]	0.00 [0 – 0]	Tropical
Townsville Aero	3.70 [0 – 15]	213.38 [175 – 263]	0.04 [0 – 1]	0.14 [0 – 2]	Tropical
Mackay M.O.	0.72 [0 – 7]	182.94 [147 – 220]	0.12 [0 – 2]	0.04 [0 – 2]	Subtropical
Taroom Post Office	43.26 [11 – 84]	71.94 [34 – 112]	1.64 [0 – 10]	45.66 [20 – 74]	Subtropical
Barcaldine Post Office	87.14 [14 – 133]	141.14 [102 – 174]	0.72 [0 – 6]	13.30 [1 – 35]	Grassland
Longreach Aero	120.16 [32 – 175]	122.82 [81 – 163]	0.48 [0 – 4]	26.44 [4 – 54]	Grassland
Rockhampton Aero	18.74 [2 – 45]	131.2 [96 – 165]	0.22 [0 – 2]	7.00 [0 – 20]	Subtropical
Gladstone Radar	4.46 [0 – 19]	153.66 [122 – 187]	0.22 [0 – 2]	0.02 [0 – 1]	Subtropical
Amberley Amo	13.32 [3 – 26]	46.42 [24 – 70]	0.42 [0 – 3]	47.62 [8 – 83]	Subtropical
University of Queensland Gatton	17.54 [1 – 40]	40.72 [16 – 59]	0.80 [0 – 5]	30.62 [6 – 65]	Subtropical
Maryborough	3.84 [0 – 23]	77.00 [54 – 111]	0.16 [0 – 2]	14.82 [2 – 34]	Subtropical
Charleville Aero	68.76 [17 – 114]	91.24 [60 – 124]	4.84 [0 – 21]	57.38 [25 – 87]	Grassland
Cunnamulla Post Office	75.50 [23 – 119]	95.38 [43 – 127]	5.14 [0 – 21]	32.20 [11 – 55]	Grassland

4.2 Trends in Heatwave Attributes

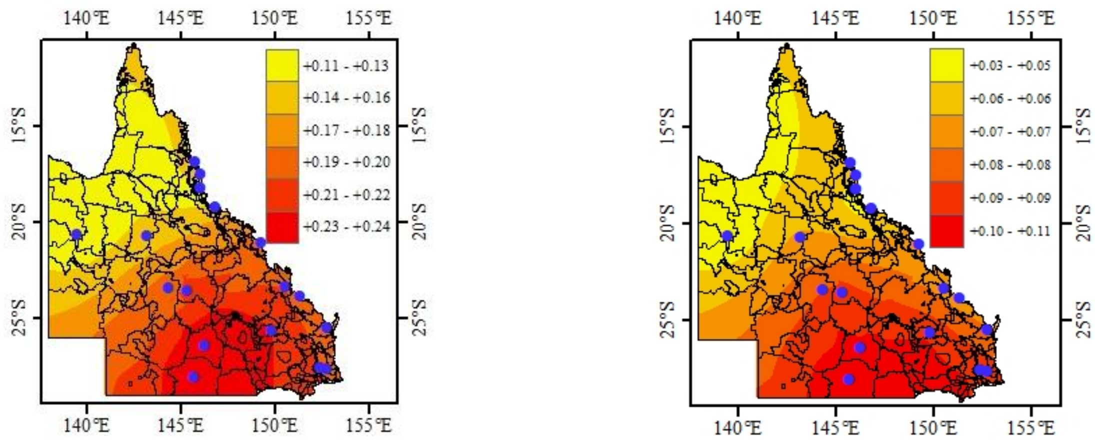
Trends of four different characteristics of heatwaves, namely HWA, HWN, HWF and HWD, based on the Excess Heat Factor (EHF) criterion for each year for the summer months have been calculated. The regional variation of trends in heatwave attributes is presented in Fig. 3.



(a)



(b)



(c) (d)

Fig. 3 - Spatial patterns of trends computed by Sen's Kendall slope estimator for (a) HWA; (b) HWN; (c) HWF and; (d) HWD

The results reveal that the increase in all the four heat waves attributes is more intense in the southern part of Queensland. The heatwave peak temperature (HWA) has increased by up to 1.5°C/ decade over a 50-year period (Fig. 3(a)). Similarly, heatwave number (HWN) has also increased at a rate of up to 0.5 days/decade (Fig. 3(b)), and the highest frequency of heatwave (HWF) increase is found to be 2.4 days/decade (Fig. 3(c)). The maximum rising of heatwave duration (HWD) is found to be 1 day/decade (Fig. 3(d)). This result provides strong evidence of the acceleration of heatwaves in Queensland. In north and western parts of Queensland, heatwaves have been found to be relatively less in frequency (1.3 days/decade), number (0.1 days/decade), duration (0.5 days/decade), and peak temperature (0.3°C/decade) (Fig. 3).

Fig. 4 presents the average time series of the hottest amplitude of HWA, trends for HWD, HWN and HWF. All the heatwave features have shown an increasing trend (2.5°C/decade, 0.9 days/decade, 0.3/decade and 2.6 days/decade for HWA, HWD, HWN and HWF, respectively).

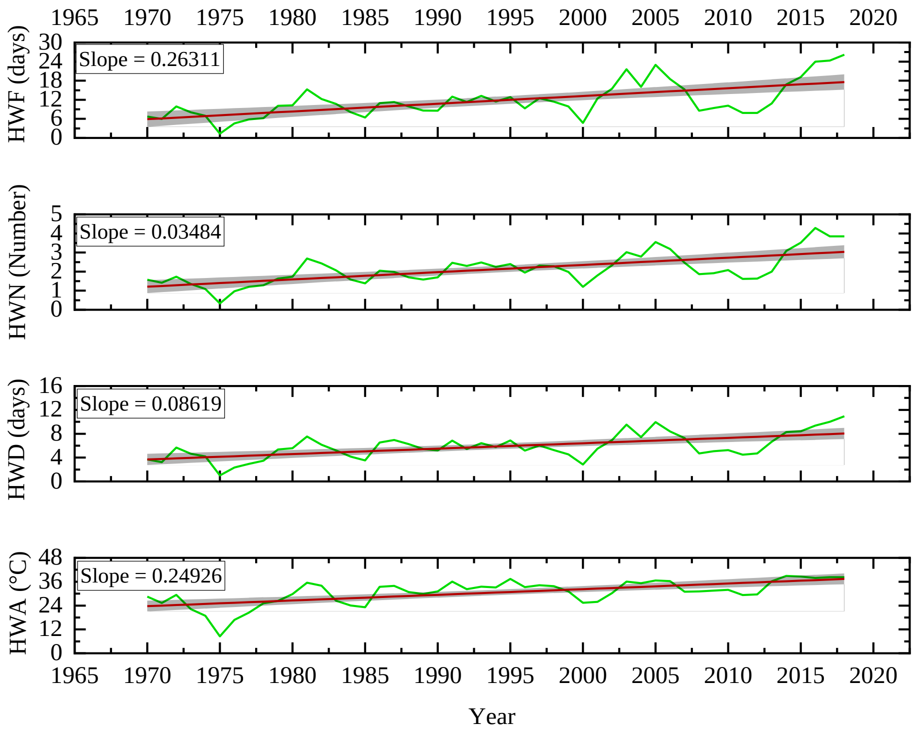


Fig. 4 - Linear regression slope for heatwave attributes

5. Conclusion

This paper presents a study on the variability in extreme temperature and heatwave indices in Queensland considering data for 1969–2018. Trends in the four extreme temperature indices selected in this study show an agreement with the general global warming trend. The increases in trends in hot nights are found to be higher than those of hot days for most of the selected stations. In addition, the decreases in cold nights are also more obvious than those of cold days. The heatwave frequency, duration and magnitude show a significant positive trend, particularly in southern Queensland.

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