Long-term changes in extreme air temperature in Nuwara Eliya: a case study from Sri Lanka

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Introduction

There is evidence to suggest that urbanisation and land use change the natural variability in mean surface air temperature, exhibiting variability on both the temporal and spatial scales. An assessment of the effects of urbanisation on surface air temperature based on a set of rural station data, carried out by Jones *et al*. (1990), revealed that urbanisation is at least an order of magnitude less influential than the warming of 0.5 degC seen over land areas on a century scale. Recent studies carried out in large cities report much higher values (Fujibe, 2011; Jeganathan and Andimuthu, 2013).

Although it is difficult to isolate changes due to natural climate variability from changes due to human activities and anthropogenic greenhouse gases in the atmosphere, existing data on surface air temperature indicate increases in daily minimum temperature leading to a decrease in diurnal temperature range (DTR) in many regions of the world (Karl *et al*., 1993). Karl *et al*. (1993) reported that the rise in the minimum air temperature is up to three times greater than the maximum temperature (+0.84 degC compared to +0.28 degC). Easterling *et al*. (1997) and Jones *et al*. (1999) also reported a decrease in DTR over many parts of the world. The DTR is generally considered an important proxy for climate change.

There is also a growing concern that climate change will adversely affect the mountainous regions of the world (Diaz and Brandley, 1997). Changes in climate can have an impact on ecology, including animals and plant species living in higher-elevation areas (Schneider, 1990). The published literature shows that temperatures in high-elevation mountain areas have increased by 1–2 degC over the last century, with lower temperatures rising faster than the higher temperatures (Beniston *et al*., 1997; Weber *et al*., 1997). A study carried out by Diaz and Graham (1997) on decadal changes in temperature in the tropical regions concluded that there were regional differences in temperature trends, both spatially and with respect to elevation in the middle latitudes.

Findings in the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5) confirmed that the globally averaged land surface temperature has risen since the 1900s and that there has been a marked increase in warming since the 1970s (IPCC, 2013). For example, the trend (at 90% confidence interval) from 1901 to 2012 is approximately +0.1 degC per decade, while the trend for the period 1979–2012 is over +0.25 degC per decade. However, AR5 also highlights a possible trend reversal in DTR. Rohde *et al*. (2013) and Wild *et al*. (2007) have noted that, globally, DTR decreased until the mid-1980s, then levelled off and increased thereafter. At the regional level, in India, which is geographically close to Sri Lanka, little change in DTR has been reported over the period 1931–2002 (Sen and Balling, 2005).

In relation to Sri Lanka, which is located in the tropics, a time series analysis of long-term annual mean air temperature revealed significant warming trends in all regions (Chandrapala, 1996). Statistically significant warming trends between +0.08 and +0.25 degC per decade were reported for annual temperature records from 1961 to 1990. In addition, a study carried out to find the impact of climate change on selected areas of the hill regions reported a significant rise in the annual temperature series over the last 100 years (Bandara and Wickremagamage, 2004). The observed trend has been steeper during the latter half of the last century. A study carried out to find the effect of deforestation on plantation areas in the central highlands of Sri Lanka indicated that this increasing trend is confined to the higher elevation areas. However, due to meteorological observations starting many years after deforestation for coffee plantation, the cause of the temperature rise in the hill regions is difficult to isolate (Wickramagamage, 1998).

To our knowledge, information on the variation of DTR over Sri Lanka is almost non-existent. Thus, the objective of the present study is to investigate trends in DTR and the minimum and maximum temperatures in Nuwara Eliya over annual, seasonal and monthly time scales, where the highest warming trends were observed.

Methodology

The present study focuses on Nuwara Eliya, which is located on the western slopes of the central mountainous region at an altitude of 1895m asl (see Figure 1). A detailed description of the study area has been given in an earlier related study (De Silva and Sonnadara, 2016). For our study, daily maximum and minimum air temperature records from 1926 to 2015 were obtained from the Department of Meteorology, Sri Lanka. The daily data have been further categorised according to the onset and withdrawal of monsoons, that is, from May to September for the southwest monsoon, December to February for the northeast monsoon, October to November for the first inter-monsoon and March to April for the second inter-monsoons. Initial screening showed that there was about 1% missing data in the daily maximum air temperature series but less than 0.3% for the minimum air temperature series. The missing data were filled simply by using data available for the adjacent days.

First, maximum and minimum air temperature time series were prepared for different time scales, namely: annually, seasonally, monthly and daily. Then, the linear trends were estimated for each series using a least-squares regression analysis. The statistical significance of the observed linear trends were confirmed using a Mann-Kendall test (see Appendix 1).

Results and discussion

Annual variability

The variations in the annual maximum and minimum air temperatures fitted with the least-squares regression lines are shown in Figure 2(a). There are no warm or cold periods which deviate substantially from the linear trend during the period 1926–2015. The average maximum and minimum air temperatures are 20.1 and 11.4°C, respectively. The average DTR is 8.7°C. The inter-annual variability of the annual maximum and

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