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Long-term trends and extremes in observed daily precipitation and near surface air temperature in the Philippines for the period 1951–2010

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ABSTRACT

Observed daily precipitation and near surface air temperature data from 34 synoptic weather stations in the Philippines for the period 1951–2010 were subjected to trend analysis which revealed an overall warming tendency compared to the normal mean values for the period 1961–1990. This warming trend can be observed in the annual mean temperatures, daily minimum mean temperatures and to a lesser extent, daily maximum mean temperatures. Precipitation and temperature extremes for the period 1951–2010 were also analysed relative to the mean 1961–1990 baseline values. Some stations (Cotabato, Iloilo, Laoag and Tacloban,) show increases in both frequency and intensity of extreme daily rainfall events which are significant at the 95% level with none of the stations showing decreasing trends. The frequency of daily temperature maximum above the 99th percentile (hot days) and nights at the 1st percentile (cold nights) suggests that both days and nights in particular are becoming warmer. Such indicators of a warming trend and increase in extreme events in the Philippines are discussed in the context of similar national, regional (Asia Pacific) and global studies. The relevance of such empirically based climatology studies, particularly for nations such as the Philippines which are increasingly vulnerable to the multiple impacts of global climate change, is also considered.

1. Introduction

Climate trends and climatic extreme indices derived from empirical, observed data indicate that global average surface temperatures have been increasing since the mid-19th century with the greatest rate of change observable since the mid-1970s (Alexander et al., 2006; Frich et al., 2002; IPCC, 2007, 2013a; Quirk, 2012). Correspondingly, in East and Southeast Asia, a number of studies reveal a warming trend with increased mean surface temperatures for both inter-seasonal and inter-annual means at the national and regional scale (Cruz et al., 2007; Su et al., 2005; Yue and Hashino, 2003). The most recent Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) provides the strongest indication to date that climate change is “unequivocal”, that changes since the mid-20th century are “unprecedented” and that this is very likely due to an increase in the atmospheric concentration of anthropogenic greenhouse gases (IPCC, 2013a). Continued increases in greenhouse gas (GHG) emissions and atmospheric concentrations may see global average surface warming reach as

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high as 4.8 °C before century end (relative to 1986–2005) under the most extreme IPCC representative concentration pathway (RCP 8.5) and seem likely to reach 1.8 °C (RCP 4.5) without a significant and continuous reduction in GHGs (IPCC, 2013a; May, 2011). Indeed, one of the longest running continuous time series monitoring stations, Mauna Loa in the mid-Pacific (Quirk, 2012) has recorded CO_2 concentrations in excess of 400 ppm for the first time in 2013 (NOAA, 2013) and the IPCC's latest estimate is that concentrations for 2011 were 391 ppm. Perhaps of most concern is that this is a stock, not simply a flow problem in that these concentrations of GHGs will remain in the atmosphere for a significant period, seemingly committing us to further future warming. This will create significant challenges for those nations most at risk from the effects of extreme climate change. Developing nations least able to cope with climate change related impacts including rising sea levels due to thermal expansion and the melting of polar ice caps, changes in the frequency and intensity of flood and drought will be disproportionately affected (ADB, 2009; Cruz et al., 2007; IPCC, 2012).

IPCC projections and regional level studies suggest that a changing climate is likely to impact agricultural production, adversely affect human health through climate induced heat stresses and diseases as well as altering the hydrological cycle in East and Southeast Asia (Cruz et al., 2007; IPCC, 2012; Su et al., 2005; Webster et al., 2005; Yue and Hashino, 2003). In the Philippines in particular, observed data already points to a decreasing trend in mean annual rainfall (Cruz et al., 2013). Regional level studies have noted an increase in frequency and intensity of El Niño–Southern Oscillation (ENSO) events and tropical cyclones originating in the Pacific (Trenberth et al., 2007; Lyon and Camargo, 2008) and that these events are causing more damage than before (ADB, 2009; Yumul et al., 2013). Furthermore, there is evidence of an increase in rain induced land slides and flooding in the Philippines with significant loss of life, disruption to livelihoods and economic activity (Evans et al., 2007; PAGASA, 2011; Yumul et al., 2012, 2013). Conversely, during El Niño episodes widespread drought and water shortages have been observed. During the strong El Niño event recorded in 1997–1998 late onset of the southwest monsoon (wet season) led to water shortages, crop failures and forest fires in some areas of the Philippines (Cruz et al., 2007, 2013; Moya and Malayang, 2004). More recently however, there appears to have been an alteration in the sub-national effects of ENSO events making such episodes more unpredictable, in turn demonstrating the complexity of the regional climate system (Lyon et al., 2006; Yumul et al., 2013).

Such a compelling body of evidence highlights the need for generating and gathering reliable, country level climate data to provide a scientific basis for an appropriate response to these multiple challenges. In order to increase levels of certainty for modelled and predicted changes in temperature, precipitation and extreme events including the frequency and intensity of tropical cyclones, empirical data based on direct observations is of vital importance. Consistent, high quality, daily time-series data for precipitation and temperature allows for the identification and quantification of longer term climatic trends. Furthermore, accurate data on climatic variables can be used to develop, test and validate algorithms for satellite derived data and for modelling predictions of future climate (Cruz et al., 2013; Jamandre and Narisma, 2013).

However, long term climatic data for the Southeast Asia and Asia-Pacific region is limited, particularly at the country level. Two authoritative early studies offer regional level trend analysis for temperature, precipitation and climatic extremes covering the period 1961–1998 (Manton et al., 2001) and 1961–2003 (Griffiths et al., 2005). They demonstrate largely coherent inter-country data which reveal an overall warming trend within the region, including an increase in the occurrence of hot days and warm nights and a decrease in cool days and cold nights.

These studies used observed data gathered from synoptic stations from across Asia-Pacific countries. In the case of the Philippines, Manton et al. (2001) selected 5 weather stations and Griffiths et al. (2005) just 3 stations which met their selection criteria in terms of data quality. Such collaborative efforts produced for the first time a robust data set for the region, contributing to global efforts to record, detect and monitor climate trends. Such studies have also encouraged relevant authorities in participating nations to improve the quality of their data, continue national level studies to identify climate trends and share this data more widely. This paper is the result of such efforts and has the following specific objectives: (1) to analyse and quantify near surface temperature trends; (2) to identify trends in extreme temperature and rainfall events (climate extremes); and (3) to discuss the results and their significance in a national, regional and global context.

2. The Philippines: location and climate in context

The Philippines is located in the western north Pacific between 4°40′N to 21°10′N, 116°40′E to 126°34′E, and consists of more than 7,000 islands totalling some 30 M hectares. The climate is influenced by both mesoscale and synoptic systems including monsoon and tropical cyclones as well as ENSO events (Chang et al., 2005; Jamandre and Narisma, 2013; Villafuerte et al., 2014). Whilst there are four climate types based on mean annual rainfall using the Modified Coronas Classification which is influenced by land–sea interactions as well as orography, the two major monsoons seasons, the northeast monsoon (NEM) from November to April and the southwest monsoon (SWM) from May to October, have the greatest influence on recorded precipitation at the national level.

The Philippines receives roughly 2000 mm of rainfall annually on average although there is significant sub-national and inter-island variation depending on the location of the weather station, with the north and Pacific (east) coasts receiving almost double the national mean in some years (Jamandre and Narisma, 2013). Spatial variation of rainfall relating to orographic effects are generally confined to the mountainous areas of north-western and far south of the Philippines which influence the inter-seasonal effects of the SWM bringing a later wet season to the north eastern Philippines (Chang et al., 2005). The predictability of rainfall quantity and timing is extremely important for a country in which agriculture plays a significant role in the economy and livelihoods of millions of people (ADB, 2009). However the timing of the onset of monsoon rains has become less predictable in recent years and the effects of extreme climatic events such as flood, drought and tropical cyclones have all combined to create significant negative impacts for a developing country with a growing population (Yumul et al., 2011, 2013).

Indeed, the Philippines has been identified as one of the most vulnerable nations to the impacts of climate change; a function of the density of populations living near to the coast and in marginal upland settings and the frequency and intensity of extreme events including tropical cyclones, associated flooding and rain triggered landslides (Yumul et al., 2011; Yusuf and Francisco, 2009). Identifying, quantifying and understanding the threats and associated risks are therefore of the utmost importance for decision makers in a range of sectors to provide accurate and timely information to those communities at risk. Recent efforts to predict the impacts of a changing climate across a range of sectors including agriculture, have led to the integration of climate change oriented policies and the creation of new institutions and bodies to ensure that social and economic interests are protected (PAGASA, 2011; Republic of the Philippines, 2009, 2010, 2011). Such institutional tools designed to improve the Philippines' resilience and adaptive capacities are only effective if they are guided robust scientific data.

3. Methods

3.1. Data gathering

The Philippines Atmospheric Geophysical Astronomical Services Administration (PAGASA) under the Department of Science and Technology (DOST) is responsible for managing a countrywide network of over 50 synoptic weather stations which have captured daily rainfall and temperature data since the 1950s and as early as 1911 in some cases, and from which the observed data discussed here is retrieved.

The records gathered from the selected stations have been compiled to form a time series data set for daily near surface temperature and precipitation. Data observed and collected between 1951 and 2010 was used and the baseline or reference period against which anomalies or departures from this norm are measured is 1961 to 1990 for mean, minimum and maximum temperatures and extreme temperature and precipitation events.

In order for the synoptic station to be included in the sample, certain criteria relating to the quality of the data produced had to be met including; records were for as long as possible including the reference period 1961–1990; less than 20% of the daily values were missing in each year (i.e. ≥293 days data available); the stations were of high quality and well-maintained; and the station had been located at a single site during the period of record. Fig. 1 shows the location of the stations from which data was retrieved, in their topographic context. Most of the stations are located in the coastal areas of the Philippines which is where many of the population centres are situated. However, two of the stations – those at Baguio and Malaybalay – are located in upland areas of Luzon and Mindanao, respectively, which is important to note when considering the results, particularly for rainfall extremes. Appendix A provides available metadata relating to the location of the stations used in this study.

3.2. Data quality and inhomogeneities

Whilst every effort was taken to select the synoptic weather stations with the highest quality, most complete data, some discontinuities in the data are inevitable and were therefore statistically treated to remove inhomogeneities which can affect the mean climatic values and in turn the anomalies and extremes (Manton et al., 2001). Common causes of data discontinuities include the relocation of synoptic stations, any change in the measurement or data gathering techniques used as well as mechanical damage to the station (De Lima et al., 2013; Griffiths et al., 2005; Shahid et al., 2012). In the Philippines, there has been a rapid increase in population since the middle of the 20th century which has led to a commensurate increase in population density (from 68 capita km^{-2} in 1950 to 303 capita km^{-2} in 2010) and growing urbanisation. Unfortunately, this means that many of the stations included here are now situated in urban locations and subject to the heat island effect, a fact which should be considered when assessing the results.

An initial visual inspection of the complete datasets was conducted in order to identify and eliminate any obvious outliers which were outside three standard deviations from the daily mean values, although this form of initial subjective treatment may mean that some genuine trends have been excluded. To identify and eliminate discontinuities, the data was subsequently arranged in series, creating mean, minimum and maximum daily temperatures and annual precipitation for each station. This data was then subjected to a form of nearest neighbour statistical analysis using the Multiple Analysis of Series for Homogenization (MASH) software following Manton et al. (2001) which compares the target station data with that of climatically similar stations to identify significant changes in the target station. MASH was originally developed by the Hungarian Meteorological Service and has become widely used as an acceptably accurate means of conducting homogeneity tests and for smoothing time series data (Lakatos et al., 2013; Szentimrey, 2011; Zhen and Zhongwei, 2010). Once discontinuities were identified, if they could be linked to changes in the weather station or data management technique, then they were excluded otherwise they were included in the final dataset. However, overall this technique may still allow for the inclusion of undetected inhomogeneities and this should be considered when reviewing the results. The overall mean annual temperature used data from all 34 synoptic stations but for the extreme rainfall events a number of stations were discounted on the basis that some of the daily data was not wholly reliable.

3.3. Data analysis and trend identification

Remaining data from the identified highest quality synoptic stations was further analysed to identify climatic trends for both rainfall and temperature.

3.3.1. Mean temperature trends

The first step was to arrange the observed annual mean of daily temperature for each of the selected synoptic stations to create a time series 1951–2010. National values were calculated by taking the arithmetic mean from all the stations included in the study. Using this data the mean annual

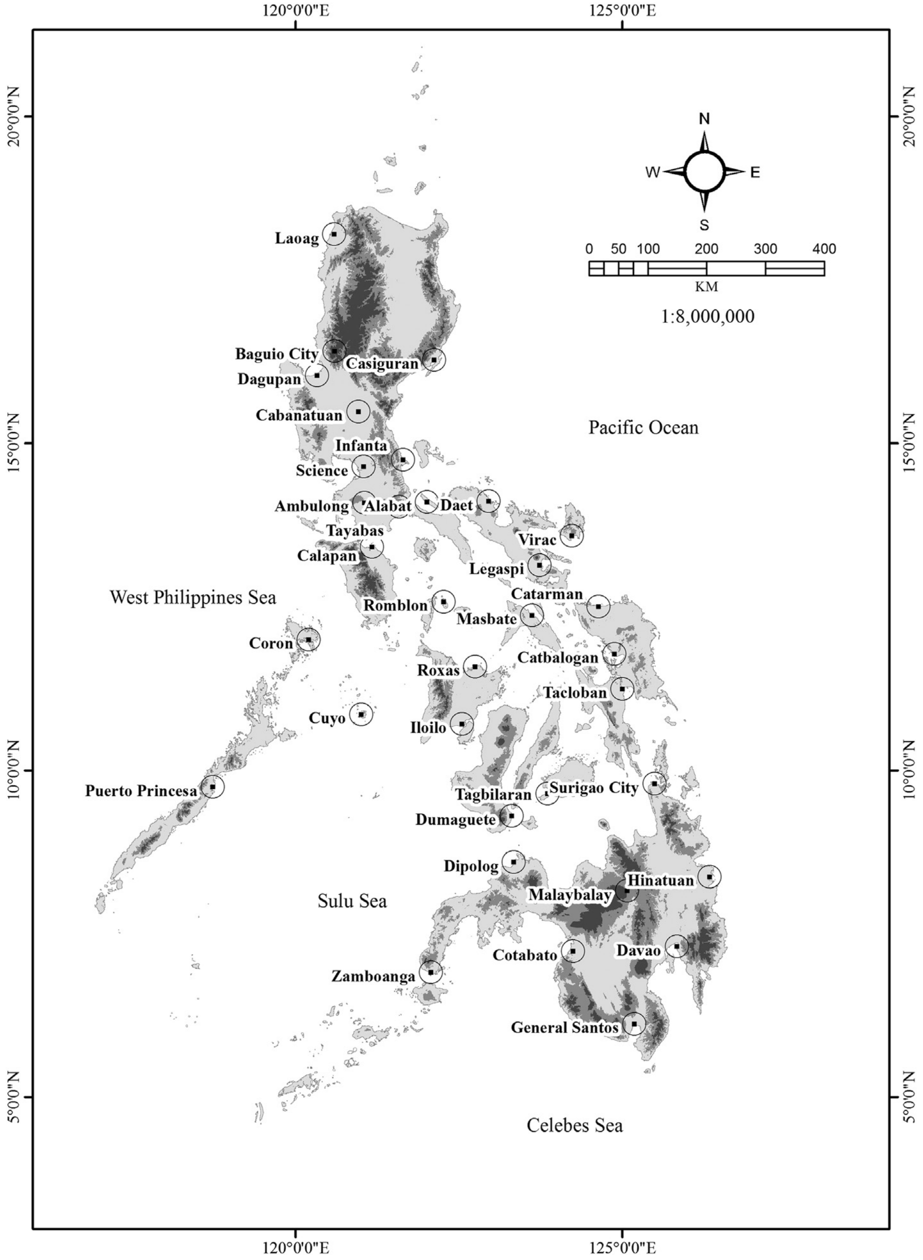

Fig. 1. Topographic map of the Philippines showing the location of synoptic stations, data from which was used in this study. Note the location of stations at Baguio (north west) and Malaybalay (south east) in the uplands (dark shaded areas).

temperature (T_{mean}) was calculated for the baseline period of 1961–1990 for each of the stations against which subsequent annual anomalies are calculated. The anomalies were calculated by taking the mean temperature in each year and subtracting the mean for the period 1961–1990. In addition the five-year running mean was calculated and plotted.

3.3.2. Daily maximum and minimum temperatures (T_{max} and T_{min})

The temperature extremes were considered and subjected to the same analysis as the annual mean temperatures described above (3.3.1). The observed mean annual maximum temperatures (T_{max}) were gathered and plotted in time series. The mean of annual temperatures for the period 1961–1990 normal was calculated in the same manner and is considered the baseline for detecting anomalies. The five-year running mean as well as linear regression analysis were also plotted to demonstrate the relationship between the changes in temperature over time and to illustrate the overall trend. This same process was repeated for the observed mean annual minimum temperature (T_{min}).

3.3.3. Extreme daily events: temperature and precipitation

In order to identify trends in climatic extremes based on daily data, indices consistent with those used by Manton et al. (2001) were selected (Table 1). The data used for the extreme events is from the period 1951–2010 with the normal value based on the period 1961–1990. Percentiles were computed using all non-missing days where the 1st percentile is the 4th lowest value, and the 99th percentile is the 4th highest value.

The statistical significance of the trends was calculated using the Kendall-tau test with trends noted as significant at the 95% confidence level. A statistically significant positive trend for the precipitation indices indicates an increase in either frequency or intensity based on values above the 99th percentile. The hot day index calculates the frequency of days above the 99th percentile based on the mean values for 1961–1990 whereas the cold nights index represents the frequency of daytime temperatures below the 1st percentile for the same period. For the temperature indices a significant positive trend represents an increase in the frequency of hot days and cold nights. If, as the wider regional level data suggests, there is a warming trend we would expect to see significant increases for the hot days and significant decreases (negative values) for the cold nights.

Neither the temperature nor the rainfall indices are deseasonalised and although, for temperature at least, the effect of this is minimal in a tropical country such as the Philippines this fact should be considered when reviewing the results, especially those for rainfall.

4. Results and discussion

4.1. Temperature trends

Fig. 2 shows temperature anomalies versus the normal value for the period 1961–1990. Mean temperatures in the Philippines begin to rise consistently from 1978 and become consistently positively anomalous in 1983 which approximately matches global trends in the second half of the 20th century (Alexander et al., 2006; Frich et al., 2002). The overall trend of temperature anomalies increases throughout the latter half of the observed period ranging from a minimum of +0.1 °C (1993) to a maximum of +1.0 °C (1998). 1998 thus represents the largest positive anomaly of the entire observed period which also corresponds with the declining phase of one of the most significant El Niño events with the central and equatorial Pacific. The Philippines and Indonesia in particular, suffered from widespread drought and forest fires relating to lower than average rainfall during 1997–1998 (Moya and Malayang, 2004).

Despite this overall upward trend, there remains variability within the latter half of the last century and the first decade of this. In particular, 1992 to 1995 shows a decreasing trend also detectable in global data for the same period (HadCRUT3 and GISSTemp) and which could be associated with the 1991 eruption of Mount Pinatubo in central Luzon, Philippines. This reduction of global temperatures has been linked to the ejection of sulphur dioxide into the stratosphere from Mount Pinatubo, creating stratospheric aerosols which reflected solar radiation and produced a negative radiative forcing of $-3.7\ \mathrm{W\ m^{-2}}$ (IPCC, 2013b).

Fig. 3 shows the mean maximum temperatures during the period 1951–2010 based on the normal values from 1961 to 1990. As with the mean values discussed earlier, 1998 sees the largest anomaly reaching a maximum of +0.9 °C versus the normal value. Over the entire period, the data shows that the anomalies are more variable, moving between positive and negative from 1951 to 2010 and the shallow line of best fit illustrates a slower rate of warming than the overall mean values. Unlike the T_{mean} and T_{min} values (discussed below), negative anomalies continue to be observed after 1978.

Fig. 4 shows the minimum temperature anomalies for the period 1951–2010 against the baseline period of 1961–1990 and demonstrates an overall increasing trend with values becoming positive in 1977 and ‘peaking’ in 1998 with a +1.0 °C anomaly. From 1996 to 2010, the end of the observed period, positive anomalies are consistently greater than 0.5 °C with 2005 and 2006 marking the peak warm years of the first decade of the 21st century.

We have observed that T_{mean} and T_{min} anomalies for the period 1951–2010 show a consistently positive trend with T_{max} anomalies showing slightly less consistency but a warming trend nonetheless. The larger increase found in the minimum temperatures over the observed period suggests that overall nights (often the minimum daily temperature) are becoming warmer in the Philippines, demonstrating reduced variability and increased convergence between diurnal (normally the T_{max}) and nocturnal temperatures. However, it should be noted that this could possibly be attributed to the ‘noise’ associated with urbanisation and the heat island effect discussed in Section 3.2. $T_{mean,}$ T_{max} and T_{min} all show 1998 to be the year with the highest positive anomaly which also coincides a period of severe drought in the Philippines, often associated with a strong El Niño event.

When referring to El Niño, we use the Niño 3.4 index and definition of ENSO variability offered by Trenberth (1997) in which the average sea surface temperature (SST) anomalies in the 5°N–5°S, 120°W–170°W region of the Central Pacific are used as an indicator, with positive (negative) values of ± 0.5 °C for six consecutive overlapping phases (3 month periods) beginning in the period June–August suggesting an El Niño (La Niña) phase (Trenberth, 1997). Using this definition and according to National Oceanic and Atmospheric Administration's (NOAA) (NOAA, n.d.) historic records for the 1951–2010 period under study here, the following years are considered as El Niño (La Niña) years: 1951, 1953, 1963,

Table 1
Description of the extreme weather event indices used when analysing the time series data following Manton et al. (2001).

Index	Description
Hot days index	Frequency of days with maximum temperature above the 1961–1990 mean 99th percentile
Cold nights index	Frequency of days with minimum temperature below the 1961–1990 mean 1st percentile.
Extreme precipitation intensity	Mean intensity of events greater than or equal to the 99th percentile each year.
Extreme precipitation frequency	Mean frequency of events greater than or equal to the 99th percentile each year.

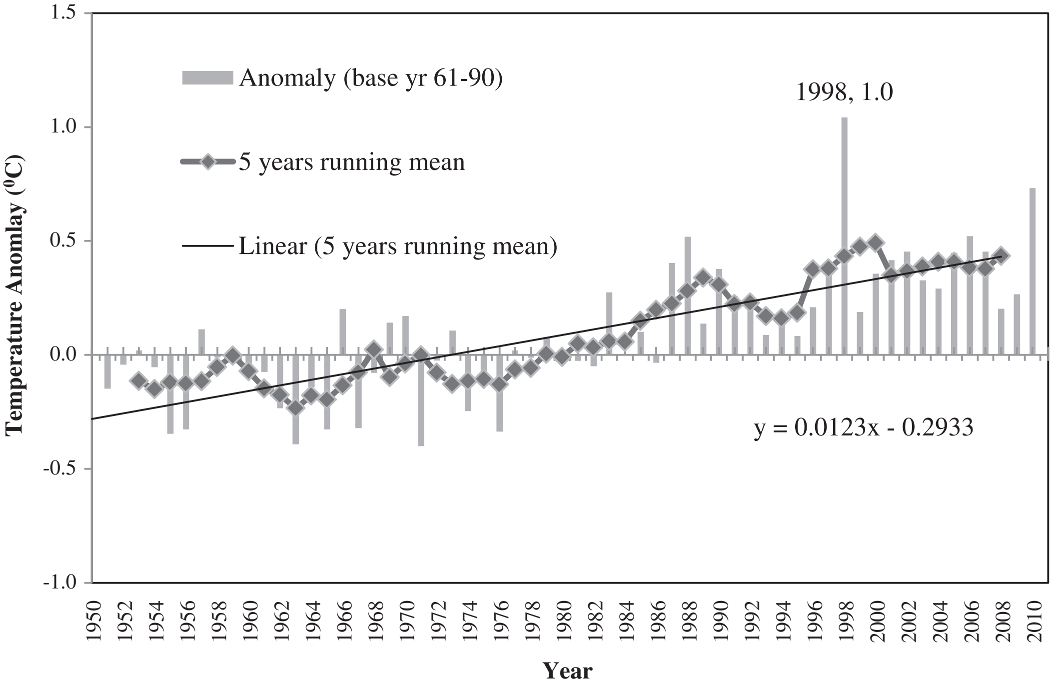

Fig. 2. Observed annual mean temperature anomalies in the Philippines during the period 1951–2010 compared with the 1961–1990 normal values.

1965, 1972, 1982, 1987, 1991, 1994, 1997, 2002, 2004, 2009 (1964, 1970, 1971, 1973, 1974, 1975, 1988, 1998, 1999, 2010).

However, the temperature signal is often noted in the year following the onset of a warming phase and on this basis it would appear that 1972–1973, 1982–1983, 1986–1987, 1997–1998 and 2009–2010 are El Niño events detectable in the Philippines' temperature record. This suggests that not all recorded El Niño events produce a noticeable response in the Philippines' temperature records. According to the records,

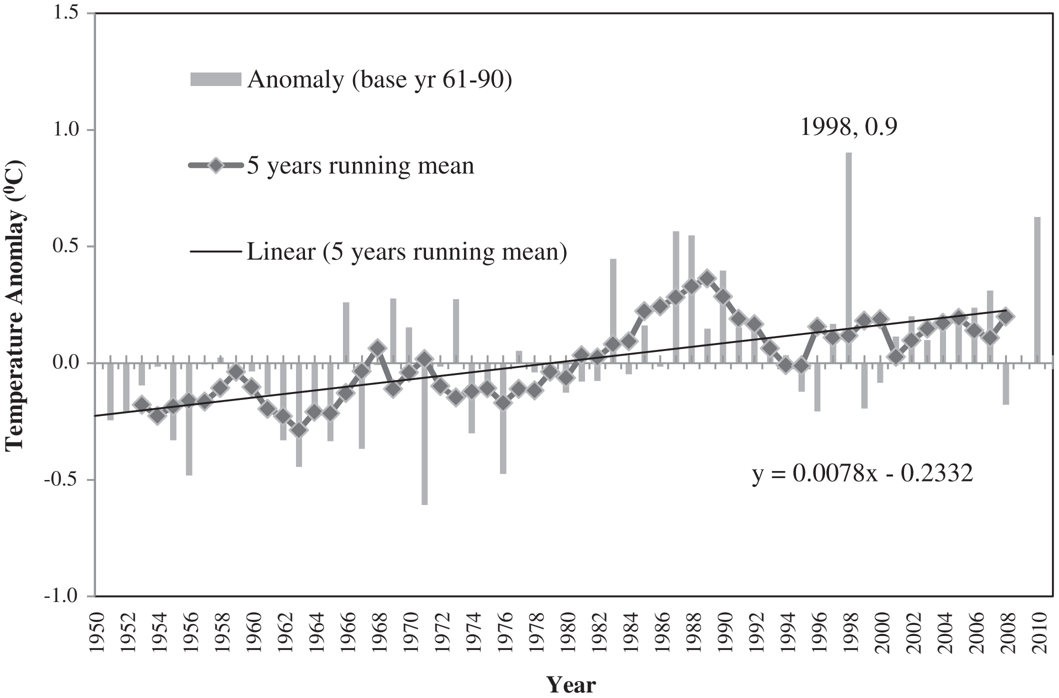

Fig. 3. Observed mean annual maximum temperature anomalies in the Philippines during the period 1951–2010 compared with the 1961–1990 normal values.

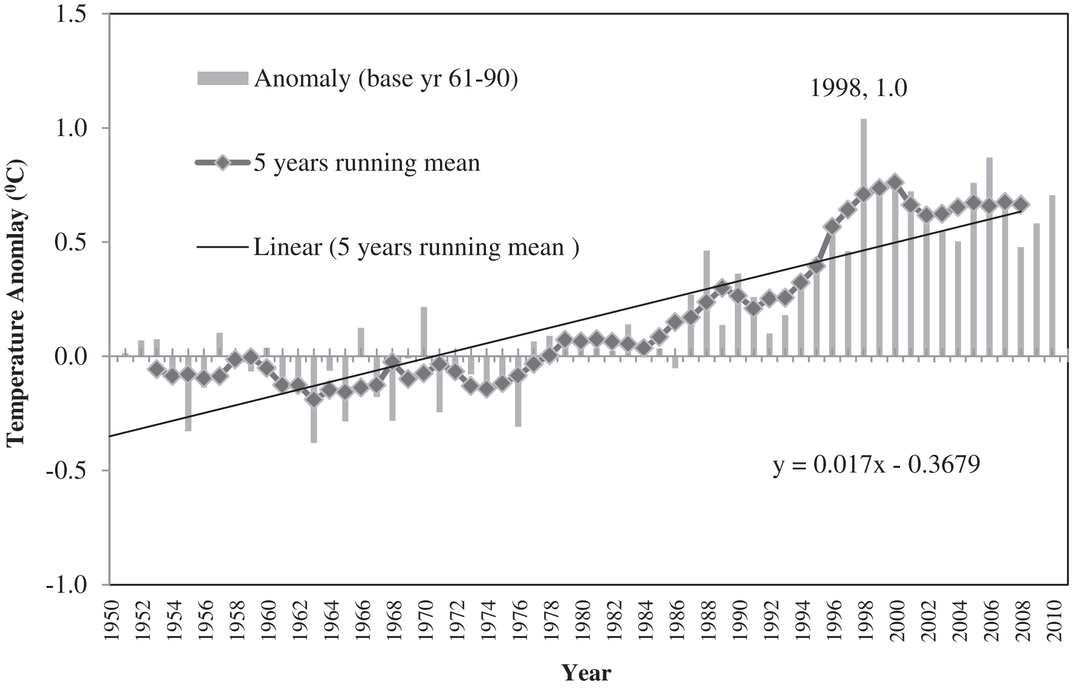

Fig. 4. Observed mean annual minimum temperature anomalies in the Philippines during the 1951–2010 period (compared with 1961–1990 normal values).

the 1997 El Niño event peaked during the period October–December (OND) and thereafter began to decay, finishing in the period March–May (MAM) of 1998. In the Philippines, an El Niño (La Niña) event is normally associated with drier (wetter) than normal conditions with the most severe events resulting in droughts (floods). However, more recent studies have shown that there is sub-national variability within this generalisation with the reverse (i.e. wetter conditions) occurring during some events (Lyon et al., 2006; Villafuerte et al., 2014).

The large 1998 anomaly could also be associated with a global maximum in the same year which is considered one of the warmest in the last century based on instrumental records of global surface temperatures from three major climatic monitoring organisations around the world. Zonal data for the equator to 24°N from NASA's GISS Surface Temperature Analysis (GISSTemp), clearly shows 1998 and 2010 (which is the second warmest year since 1951 in the Philippines according to the T_{mean} indicator) as the hottest years since 1880 although the base period for this is 1951–1980, not 1961–1990 as in this study. This is also reflected in the UK Met Office's HadCRUT3 dataset which shows a clear peak in 1998 for global temperatures and a downturn in the early 1990's (Brohan et al., 2005). This provides an indicator that this aspect of the observed data in the Philippines is consistent with global data (IPCC, 2007, 2013a).

4.2. Extreme daily events

Analysis of trends in extreme daily maximum and minimum temperatures (hot-days index and cold-nights index, respectively) show that there are a statistically significant increasing number of hot days and decreasing number of cold nights. Fig. 5 shows the trends in the frequency of days with minimum temperature below the 1st percentile (cold nights) and Fig. 6 the trends in frequency of days with maximum temperature above the 99th percentile (hot days). In each figure an increase is represented by a (+) sign, a significant increase with (▲); decreases are shown using a (−) symbol and significant decreases with a (▼) symbol.

Table 2 shows in detail the calculated values used to determine the direction and significance of the trends for the figures above for each of the 30 synoptic stations at which the trend was observed. Those stations which showed a statistically significant trend are highlighted in grey. This demonstrates that there is a statistically significant increase in the occurrence of hot days and decrease in cold nights across much of the Philippines during the period 1951–2010. In fact none of the stations shows a statistically significant increase in cold nights throughout the Philippines with only five of the thirty stations showing any observed decrease (statistically insignificant). Those stations which show significant decreases in cold nights are dispersed throughout the Philippines on all major island groups although the station at General Santos, the southernmost station considered here, shows a particularly large statistically significant decrease.

There is greater variation between stations when we consider the hot days index with five of the 30 stations exhibiting a statistically significant decrease in the occurrence of hot days. Stations in the northern part of the Philippines (Baguio, Cabanatuan, Infanta and Laoag) show mainly an increase in hot days, four of them at a statistically significant level. Zamboanga station shows strong, statistically significant

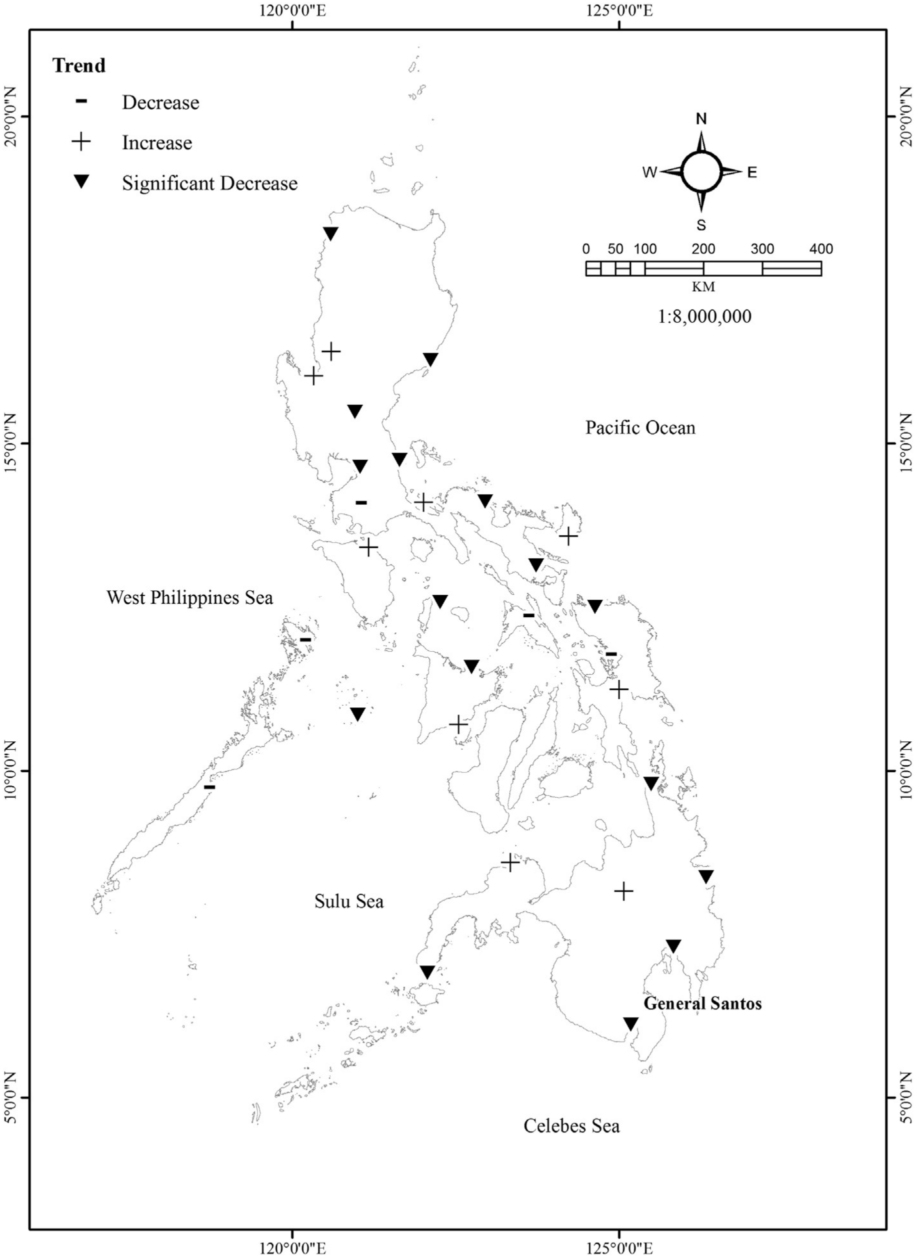

Fig. 5. Trends in the frequency of days with minimum temperature in the Philippines (1951–2010) below the 1961–1990 mean 1st percentile (cold nights).

trends for both an increase in hot days and decrease in cold nights. The stations at Alabat, Virac and Legaspi which are located on the Pacific coast within 200 km of one another, in an area known as the Bicol region, show a significant decrease in hot days which could be considered as a small cooling trend cluster. From approximately 8°N to 13°N there is a line of five stations on the Pacific coast (Catamaran, Hinatuan, Surigao, Catbalogan and Tacloban) which all exhibit statistically significant increase in hot days with the station at Tacloban showing a particularly high increase. Other than this, there does not appear to be a discernible national level spatial pattern for either cold day or hot night indices.

A significant increase in hot days is also found at the station in Baguio and this was also the case in both the other reference studies which used data from this station in earlier observations of the same indicator (Griffiths et al., 2005; Manton et al., 2001). This station is also one of two stations (the other is Malaybalay) located in an upland area, both of which show large significant trend increases which perhaps provides an indication that elevation does not play an influential constraining role in temperature extreme indices. However, the recent urbanisation of most of the cities in which the stations used in this study are located means we must use caution when considering these results as definitive.

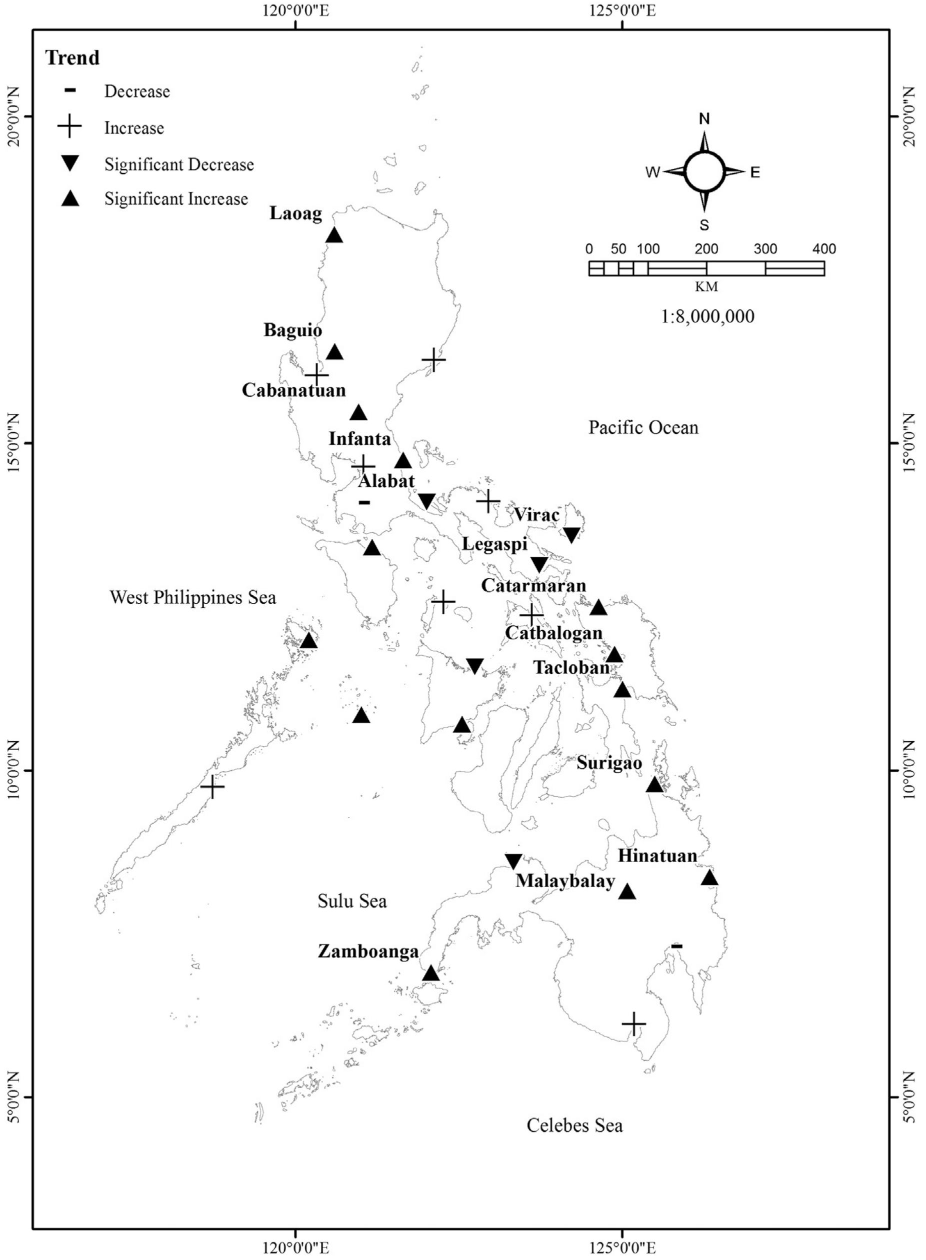

Fig. 6. Trends in the frequency of days with maximum temperature in the Philippines (1951–2010) above the 1961–1990 mean 99th percentile (hot days).

Fig. 7 shows the trend in the mean number of daily rainfall events which exceed the 99th percentile of rainfall intensity, whilst Fig. 8 shows the trend in the frequency of daily rainfall in excess of the 99th percentile. Again, in each figure an increase is represented by a (+) sign, a significant increase with a (▲) symbol; decreases are shown using a (−) symbol and significant decreases with a (▼) symbol.

Table 3 below provides a detailed summary of the data used in the maps including the frequency, significance at the 5% level (p), direction and magnitude of the trend at each synoptic station. Figures highlighted in grey are those showing high significance at the 95% confidence level and show an overall low level of statistically significant results. The results of this analysis show that although the period 1951 to 2010 has seen increases in both the frequency and intensity of extreme daily rainfall events at most stations throughout the Philippines, unlike temperature extremes, the majority do not show a high level of statistical significance at the 95% confidence level.

Six of the 30 stations showed significantly increasing trends in the intensity of extreme rainfall events. Stations from Laoag, in the far north of the Philippines to Cotabato in the far south exhibited a significant increase in rainfall intensity and there is no identifiable spatial pattern to the distribution of rainfall intensity within the country. The influence of elevation appears also to be minimal with the

Table 2
Extreme temperature trend values for hot days and cold nights from synoptic weather stations in the Philippines.

	Hot days			Cold nights		
Stations	Freq.	*p* (95%)	Trend	Freq.	*p* (95%)	Trend
Alabat	-0.2004	0.0016	<	0.0655	0.3450	>
Ambulong	-0.0097	0.1379	<	-0.0186	0.1702	<
Baguio city	0.2202	0.0000	>	0.0140	0.3695	>
Cabanatuan	0.2044	0.0040	>	-0.0499	0.0163	<
Calapan	0.1116	0.0012	>	0.0171	0.8276	>
Casiguran	0.0702	0.6896	>	-0.0862	0.0025	<
Catarman	0.2837	0.0000	>	-0.1465	0.0000	<
Catbalogan	0.3923	0.0000	>	-0.0286	0.0613	<
Coron	0.2142	0.0002	>	-0.2330	0.0639	<
Cuyo	0.5355	0.0000	>	-0.1876	0.0000	<
Daet	0.0067	0.8859	>	-0.1173	0.0000	<
Dagupan	0.0406	0.2520	>	0.0820	0.0121	>
Davao	-0.0218	0.4359	<	-0.1428	0.0000	<
Dipolog	-0.1106	0.0014	<	0.6713	0.4828	>
General Santos	0.1119	0.0628	>	-0.3286	0.0000	<
Hinatuan	0.1263	0.0102	>	-0.0956	0.0000	<
Iloilo	0.2537	0.0000	>	0.0155	0.6674	>
Infanta	0.3102	0.0000	>	-0.0569	0.0112	<
Laoag	0.0959	0.0059	>	-0.0481	0.0093	<
Legaspi	-0.0691	0.0200	<	-0.0038	0.0318	<
Malaybalay	0.4663	0.0000	>	0.0302	0.8044	>
Masbate	0.1163	0.3397	>	-0.0183	0.2264	<
Puerto Princesa	0.1068	0.0889	>	-0.0013	0.7771	<
Romblon	0.0014	0.6589	>	-0.1047	0.0000	<
Roxas	-0.2455	0.0042	<	-0.0284	0.0061	<
Science Garden Q.C)	0.0449	0.6876	>	-0.1488	0.0000	<
Surigao	0.2064	0.0000	>	-0.1064	0.0000	<
Tacloban	0.5685	0.0000	>	0.0114	0.4545	>
Virac (synoptic)	-0.2471	0.0027	<	0.0028	0.6815	>
Zamboanga	0.6163	0.0000	>	-0.1548	0.0000	<

station at Baguio located in a mountainous area of the north western Philippines, exhibiting a significant increase in rainfall intensity similar to other lowland stations in the region (Laoag and Infanta). Overall, only six of the stations produced negative trends in rainfall intensity, all of which were statistically insignificant with the remainder showing positive but similarly insignificant trends.

The majority of the stations showed positive trends in the frequency of severe rainfall events with only four stations showing negative trends all of which are statistically insignificant. The seven stations showing significant increases are again distributed throughout the islands of the Philippines from the far north to the far south and from east to west. Stations at Calapan and Casiguran showed significant increases in frequency whilst those at Iloilo, Tacloban (both within the central island group of the Philippines and recently affected by typhoon Haiyan), Laoag, Infanta and Cotabato all showed a significant increase in both intensity and frequency.

The persistent level of variability between stations and the lack of a discernible, coherent trend in the data may, in part be due to the analysis not being sensitive to the inter seasonal variation, different orographic conditions and because there are complex, localised oceanic–atmospheric interactions at play in an archipelagic nation such as the Philippines. Indeed, this is consistent with the reference studies which have found little evidence of spatial coherence when considering extreme rainfall (Griffiths et al., 2005; Manton et al., 2001). A weaker signal for rainfall variables could also be associated with the higher inter-annual variability of extreme rainfall events as well as the comparatively shorter timescale over which change occurs when compared to that of temperature variables.

4.3. Results in a national and regional context

Rainfall trends for both intensity and frequency of extreme events for the whole of the Philippines based on observed data are in the majority not statistically significant. However, some stations do show a significant increase in both intensity and frequency and some of these frequently experience the effects of tropical cyclones including typhoons. More coherent at the national level are the extreme daily temperature trends for cold nights and hot days. The statistically significant trends in extreme events when considered in conjunction with the observed warming trends described earlier combine to reveal a warming climate over the last 30 years.

These findings at a national level appear to be broadly consistent with both previous regional studies for similar temperature indicators for the Asia-Pacific region and with global studies. One of the earliest and most comprehensive studies to which the findings of this study can be compared is that of Manton et al. (2001) which used data from five stations in the Philippines (Basco, Baguio, Daet, Dumaguete and Tuguegarao) considered to have the highest quality time series data for the period 1961–1998. The data common to both that study and this is from the stations at Baguio and Dumaguete. Analysis of the data from the other stations used by Manton et al. (2001) available for the period 1951–2010 was deemed unreliable. This makes a direct comparison of results from those studies and this one difficult, not least because station level information is not presented in detail in earlier studies (although Manton et al. (2001) noted that there was a significant increase in hot days at the Baguio station which is consistent with this study). Indeed, the aim of this study was not to conduct a direct comparison of national level data with that of Manton et al. (2001). Instead this study uses the same methodology employed by Manton et al. (2001) to provide an updated, contemporary insight into the temperature and precipitation trends within the Philippines, providing a more detailed analysis from a greater number of stations and presenting the results in a regional and global context.

At the regional level in Southeast Asia, the findings here are broadly consistent with other earlier studies demonstrating a largely coherent warming trend over much of the region with a few exceptions found in Australia and the southern Pacific (Griffiths et al., 2005). Sub-nationally, the station at Baguio was found to have a large, statistically significant increase in hot days, which is in agreement with this study. Griffiths et al. (2005) also established a link between mean temperature trends and extreme events, particularly in the tropical Pacific region, including the Philippines, suggesting that even small increases in mean temperatures may lead to an increased probability of extreme events. Given that this study has highlighted the increasing trends of mean, minimum and maximum temperatures observed at a national level, the link between extreme events and these indicators for a nation vulnerable to the impacts of climate change is notable.

Manton et al. (2001) observed an increased frequency in hot extremes (hot days) and decrease in cold extremes (cold days) across the Asia Pacific region as well as the notable

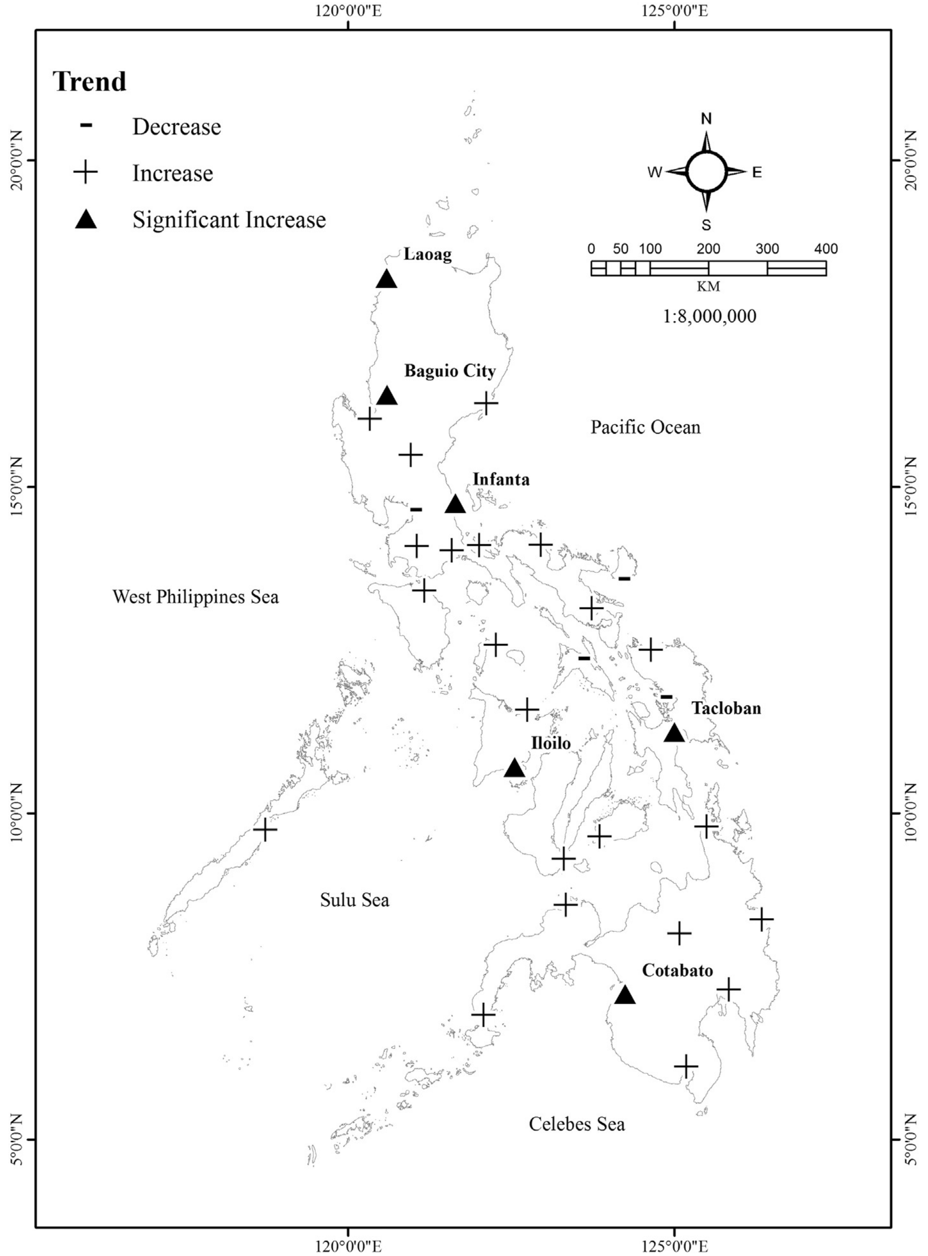

Fig. 7. Trends in extreme daily rainfall intensity in the Philippines (1951–2010) compared with the 1961–1990 mean values.

peak in temperatures in 1998 all of which are consistent with the results of analysis presented here. Furthermore, the lack of sub-national spatial consistency and a lower occurrence of statistically significant results for rainfall related indices (extreme frequency and intensity) observed in this study are also consistent with the regional findings in the Manton et al. (2001) study. In the same study, all five stations in the Philippines showed an insignificant decrease in extreme frequency of rainfall events with stations at Baguio and Tuguegarao (not considered here) showing an insignificant increase in extreme rainfall intensity, somewhat inconsistent with the results described here. Such inconsistency could be associated with the fact that this study used an additional 12 years of data spanning what is widely considered one of the warmest periods in the last two hundred years (IPCC, 2013a) presenting results which are broadly consistent with global data (e.g. HadCRUT3 and GISSTemp). Building on earlier research, this study has allowed for the identification of spatial variations between stations across a number of indicators and highlighted the geographic heterogeneity of the climate in the Philippines.

More recent national level literature using data from the same stations as those in this study have revealed an overall decreasing trend in seasonal rainfall associated with the southwest monsoon (SWM) which is normally responsible for up to 43% of annual rainfall in the Philippines (Cruz

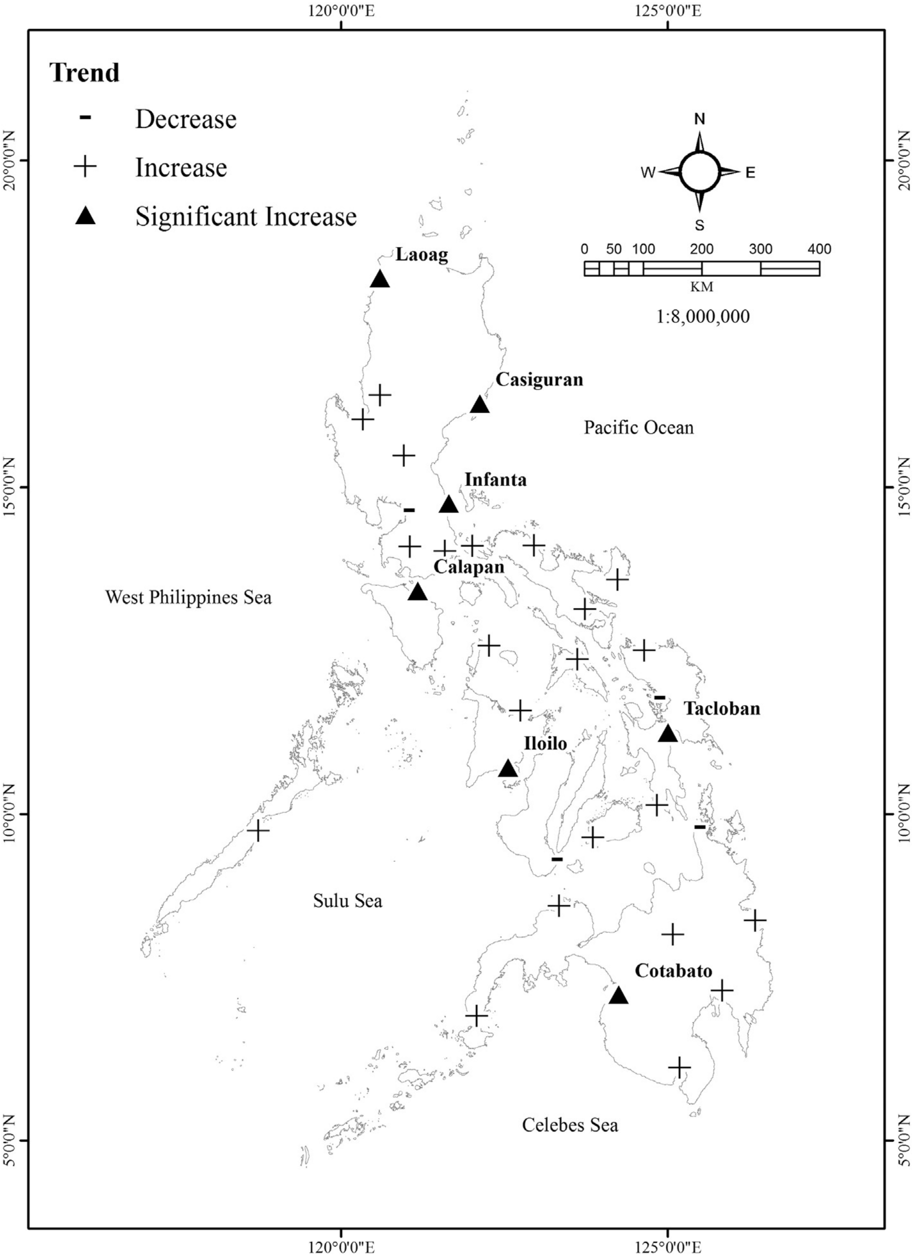

Fig. 8. Trends of extreme daily rainfall frequency in the Philippines (1951–2010) compared with the 1961–1990 mean value.

et al., 2013). The station at Baguio shows a decreasing trend in SWM rainfall, a significant increase in no rain days as well as an inter-decadal reduction in heavy rainfall days above the 95th percentile. Conversely, our results show a significant increase in rainfall intensity and an insignificant increase in frequency of extreme rainfall. Baguio is situated in a mountainous region of the Philippines and in addition to orographic influences, is subject to visiting tropical cyclones. It is also located in a region which was found to exhibit anomalous rainfall signals associated with early development (JAS) El Niño (La Niña) phases which normally bring drier (wetter) conditions (Lyon and Camargo, 2008; Villafuerte et al., 2014) to the north central Philippines. The station at Iloilo shows an increase in SWM rainfall, albeit minimally, as well as a slight increase in inter-decadal heavy rainfall. There was also a significantly increasing trend in 5 day maximum rainfall found at this station for the same period (1951–2010) in a recent study by Villafuerte et al. (2014). This study also confirmed the influence of ENSO events on the seasonal rainfall patterns of the Philippines and provides perhaps the strongest evidence yet at a national level, of its influence on extreme rainfall indicators. Taken together this would

Table 3
Extreme rainfall event frequency and intensity values for synoptic weather stations in the Philippines.

	Intensity			Frequency		
Stations	Freq.	*p* (95%)	Trend	Freq.	*p* (95%)	Trend
Alabat	0.0186	0.6109	>	0.0128	0.2126	>
Ambulong	0.0133	0.5358	>	0.0087	0.4321	>
Baguio City	0.1974	0.0148	>	0.0269	0.0634	>
Cabanatuan	0.0224	0.1929	>	0.0163	0.1595	>
Calapan	0.0354	0.1995	>	0.0335	0.0429	>
Casiguran	0.0363	0.2042	>	0.0425	0.0513	>
Catarman	0.0121	0.7583	>	0.0116	0.4991	>
Catbalogan	-0.0025	0.6872	<	-0.0057	0.6389	<
Cotabato	0.1698	0.0420	>	0.2453	0.0279	>
Daet	0.0153	0.6275	>	0.0150	0.3709	>
Dagupan	0.0787	0.0782	>	0.0140	0.2790	>
Davao	0.0126	0.2560	>	0.0078	0.6268	>
Dipolog	-0.0135	0.3195	<	0.0033	0.9345	>
Dumaguete	0.0091	0.9426	>	-0.0018	0.6504	<
General santos	0.0043	0.6439	>	0.0066	0.5697	>
Hinatuan	0.0238	0.5742	>	0.0247	0.1482	>
Iloilo	0.0463	0.0223	>	0.0268	0.0304	>
Infanta	0.0575	0.0533	>	0.0293	0.0551	>
Laoag	0.1443	0.0131	>	0.0307	0.0280	>
Legaspi	0.0250	0.7304	>	0.0161	0.2148	>
Maasin	-0.0157	0.3396	<	0.0246	0.4046	>
Malaybalay	0.0098	0.4591	>	0.0045	0.9943	>
Masbate	-0.0142	0.4866	<	0.0204	0.1749	>
Puerto Princesa	0.0012	0.7640	>	0.0079	0.6507	>
Romblon	0.0344	0.4556	>	0.0333	0.2242	>
Roxas	0.0098	0.7740	>	0.0161	0.4786	>
Science	-0.0008	0.5634	<	-0.0118	0.7427	<
Surigao City	0.0296	0.8105	>	-0.0044	0.9067	<
Tacloban	0.0531	0.0023	>	0.0618	0.0008	>
Tagbilaran	0.0206	0.3692	>	0.0394	0.1646	>
Tayabas	0.0007	0.5446	>	0.0064	0.9004	>
Virac	-0.0220	0.8482	<	0.0041	0.7530	>
Zamboanga	0.0102	0.7471	>	0.0109	0.6598	>

indicate, as our results have, that Baguio is likely becoming wetter.

Interestingly Iloilo and Tacloban are two of the few stations to show a significant increase in both intensity and frequency of extreme rainfall events in this study and both these stations were also found by Lyon and Camargo (2008) to have above average seasonal rainfall signals during El Niño development phases, maintaining higher levels of precipitation at a time of generally decreasing trends. Another station is at Infanta and similarly to Tacloban this is located on the eastern seaboard of the Philippines which Chang et al. (2005) found to be affected by heavy rain brought by strong onshore winds of the northeast monsoon, perhaps explaining this observation.

It is worth noting however that the earlier studies discussed above use slightly different datasets to those used in this study and investigate seasonal variations as opposed to long term trends so direct comparisons are not wholly appropriate but this does provide some indication of the level of national and sub-national consistency of the results of this study.

5. Conclusion

This paper has presented temperature indicators which suggest that the climate in the Philippines, like much of the rest of the region and the globe, is warming. Across a range of climatic indicators presented and discussed here (e.g. T_{mean}, T_{max} and T_{min}), an increasing trend of anomalous temperatures versus the 30 year normal period of 1961–1990 can be observed. In addition, daily temperature extremes reveal more hot days and fewer cooler nights versus the mean from the normal period of 1961–1990 for much of the Philippines, with the majority of these results statistically significant. These trends, derived from directly observed data, contribute to a body of evidence which is consistent with a global climate which is warming above any normal variation we might expect to see since the mid-20th century. Less clear-cut is the apparent trend in extreme rainfall events across the country with only a handful of synoptic stations recording a statistically significant increase in intensity and frequency of extreme rainfall events.

Little discernible spatial coherence at the sub national level for any of the temperature or rainfall indicators was found which points to the heterogeneous nature of the climate system in the Philippines. Whilst orographic effects appear to be minimal (see stations at Baguio and Malaybalay), the effects of monsoon moisture laden winds may account for extreme rainfall indicators on the Pacific coast showing as significantly positive, and the effects of passing tropical cyclones cannot be ruled out. Stations which showed an increase in both frequency and intensity of rainfall extremes are located in the typhoon belt of the Philippines and the investigation of any correlation between extreme indices and tropical cyclone activity could be a useful future research direction.

If the temperature in the Philippines continues with the upward trend seen here, notwithstanding continued inter annual variability, there may be serious implications for the economic and social development of this archipelagic nation. If, according to Griffiths et al. (2005) increasing temperature trends can be an indicator of the probability of more frequent extreme weather events, then this could suggest that the Philippines should be prepared for additional climate change impacts. Continued and increased exposure to the effects of a warming climate – disrupted growing seasons, changes in the occurrence of vector borne diseases and the threat of severe weather events (the impacts of which were painfully revealed following Typhoon Haiyan) – continues to pose a real development challenge in the Philippines. It is hoped that this study and others like it can form an evidence base for appropriate action to address and prepare for some of these impacts so as to avoid the worst of the damage to its emerging economy and the communities who will bear the brunt. This study builds on earlier efforts to provide a basis for the on-going monitoring of climatic trends and extremes and should be considered a reference point for future analysis of precipitation and temperature trends in the Philippines.

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Appendix A

Table A.1
Philippines synoptic weather stations including available meta-data.

Name	Province	Lat.	Long.
Alabat	Quezon	14.103	122.010
Ambulong	Batangas	14.092	121.055
Baguio City	Benguet	16.410	120.600
Cabanatuan City	Nueva Ecija	15.488	120.962
Calapan	Mindoro	13.413	121.170
Casiguran	Quezon	16.280	122.123
Catarman	Samar	12.500	124.638
Catbalogan	Samar	11.778	124.880
Coron Island	Palawan	11.998	120.203
Cotabato City	Maguindanao	7.228	124.247
Cuyo Island	Palawan	10.853	121.007
Daet	Camarines Norte	14.113	122.953
Dagupan City	Pangasinan	16.043	120.333
Davao City	Davao	7.300	125.833
Dipolog City	Zamboanga Del Norte	8.592	123.338
Dumaguete City	Negros Oriental	9.302	123.307
Gen Santos City	South Cotabato	6.117	125.183
Hinatuan City	Surigao Del Sur	8.370	126.337
Iloilo City	Iloilo	10.708	122.550
Infanta	Quezon	14.750	121.647
Laoag City	Ilocos Norte	18.200	120.592
Legaspi City	Albay	13.138	123.733
Malaybalay	Bukidnon	8.153	125.077
Masbate	Masbate	12.370	123.618
Puerto Princesa City	Palawan	9.742	118.733
Romblon Island	Romblon	12.577	122.268
Roxas City	Aklan	11.583	122.750
Science Garden	NCR	14.645	121.042
Surigao City	Surigao Del Norte	9.792	125.492
Tacloban City	Leyte	11.245	125.000
Tagbilaran City	Bohol	9.643	123.855
Tayabas	Quezon	14.028	121.588
Virac Synop	Catanduanes	13.585	124.230
Zamboanga City	Zamboanga Del Sur	6.905	122.075

Appendix B. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.atmosres.2014.03.025.

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