CHANGES IN GLOBAL ANNUAL PRECIPITATION FROM THE 18TH CENTURY TO 2013

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1. INTRODUCTION

The global average temperature has increased by ~1 ^{o}C over the past century (IPPC 2013). The Clausius-Clapeyron equation shows the saturation water vapour pressure increases exponentially with temperature. Hence, atmospheric water vapour pressure should increase if relative humidity remains unchanged (Isaac & van Wijngaarden, 2012). It has been suggested that a higher water vapour pressure may increase precipitation (Wentz et al., 2007). The IPCC has reported that precipitation increased in some regions by as much as 1% in each decade of the 20th century (Dai et al., 2007). There has even been a claim of anthropogenic influence on 20th century precipitation trends (Zhang et al., 2007).

Three studies examined global precipitation records for decades in the last part of the 20th century (Li et al., 2014). The Climate Prediction Center produced 17 years of monthly analysis (Climate Merged Analysis of Precipitation or CMAP) based on observations using rain gauges, satellite estimates and numerical model outputs (Xie & Arkin, 1997). A second dataset was obtained by the Global Precipitation Climatology Project (GPCP) for the period 1979-2005 (Adler et al., 2003). A third data reanalysis was developed by the National Center for environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) (Kistler et al., 2001). For the period 1979-2008, the CMAP model shows a decreasing trend of -1 mm/year. In contrast, the GPCP trend shows a nearly flat trend of 0.1 mm/year while the NCEP/NCAR model shows an increasing trend of 3.5 mm/year. These differences are not surprising given that precipitation varies considerably over decadal time scales and the trends frequently are not statistically significant.

This study (van Wijngaarden & Syed, 2015) examined monthly precipitation measurements taken at nearly 1000 stations shown in Fig. 1, each having a record of at least 100 years. Data for some stations was recorded in the 1700s. This facilitates detection of a long term trend due to anthropogenic climate change as opposed to natural decadal variations.

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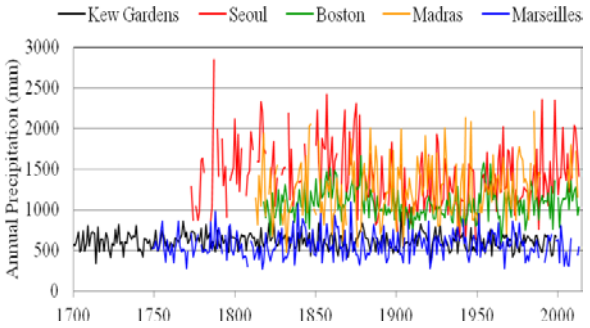
Fig. 1: Locations of stations examined.

2. DATA DESCRIPTION

Monthly precipitation totals were retrieved from the Royal Dutch Archive (KNMI, 2014). Most of the data was available beginning after 1850. Data was not available for many stations after 2000 when a number of stations closed or data was not forwarded to the KNMI archive. A disproportionate number of stations were located in Australia and the U.S. Therefore, the selection criteria for Australia and the U.S. were minimum observation periods of 115 and 125 years, respectively. The annual total precipitation was only computed for years in which no month had missing data.

The data was relatively free of inhomogeneities which occur most frequently during cold winter months (Groisman & Legates, 1994). Instrumental discontinuities can be large for high latitude stations but globally are not significant (Dai et al., 1997). Fig. 2 shows sample annual precipitation data. In general stations in the northern hemisphere had a longer data record than those located in the southern hemisphere.

a) Sample Northern Hemisphere Stations



b) Sample Northern Hemisphere Stations

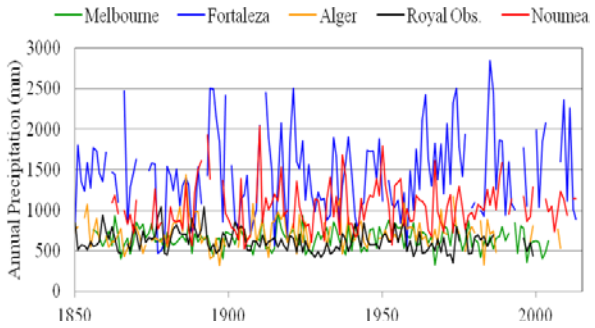


Fig. 2: Examples of annual precipitation for stations located in a) Northern and b) Southern Hemispheres. Stations are: Kew Gardens, U. K.; Seoul, South Korea; Boston, U.S.; Madras, India; Marseilles, France; Melbourne, Australia; Fortaleza, Brazil; Algiers, Algeria; Royal Observatory, South Africa and Noumea, New Caledonia.

3. DATA ANALYSIS AND RESULTS

The percentage precipitation change relative to the average annual precipitation occurring during 1961-90 was computed for each station. Fig. 3 shows the location of stations experiencing either increasing or decreasing precipitation. Trends were only found for stations having observations for at least 80% of the years for the period in question. The fraction of stations experiencing increasing precipitation trends was 61%, 64% and 54% for the periods 1850-2000, 1900-2000 and 1950-2000, respectively. Many stations experienced increased precipitation during one period but decreasing precipitation during another time period. Half of the 256 stations for which trends were found for all 3 intervals, experienced trends that either all increased or all decreased. About one third of the 684 stations had opposite trends during 1900-2000 and 1950-2000. The average trends in units of % per century were 2.3 ± 1.3, 3.6 ± 1.1 and -1.9 ± 3.3 during 1850-2000, 1900-2000 and 1950-2000, respectively. The trend uncertainty is the 95% confidence interval resulting from applying a statistical t-test.

The percentage precipitation change was averaged over all stations in a given country or region as shown in Fig. 4. The data do not show dramatic long term precipitation changes but large fluctuations on time scales of years to decades are evident. Notably, countries such as India/Pakistan and Africa north of the equator experience greater interannual variability than do countries such as the United Kingdom. There are notable outlier points. For example, 1900 was an exceptionally

a) 1850-2000

b) 1900-2000

c) 1950-2000

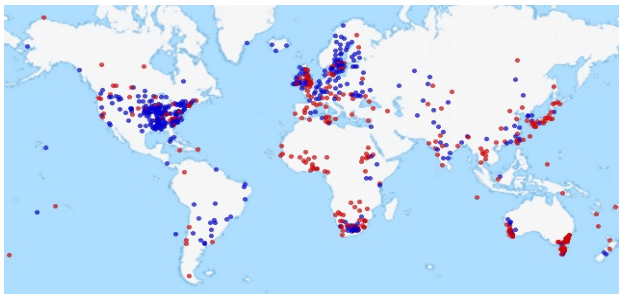
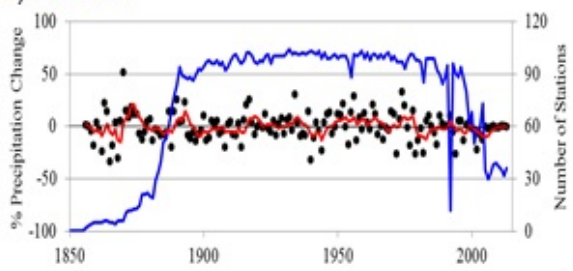


Fig. 3: Maps of Station Precipitation Trends. Blue (red) indicates precipitation is increasing (decreasing) during the time period indicated.

dry year in India/Pakistan. The monsoons failed to arrive causing widespread starvation.

The trends shown in Fig. 4 were computed for the years in which there were at least 5 stations reporting data. Most of the resulting trends are consistent with little precipitation change.

a) Australia



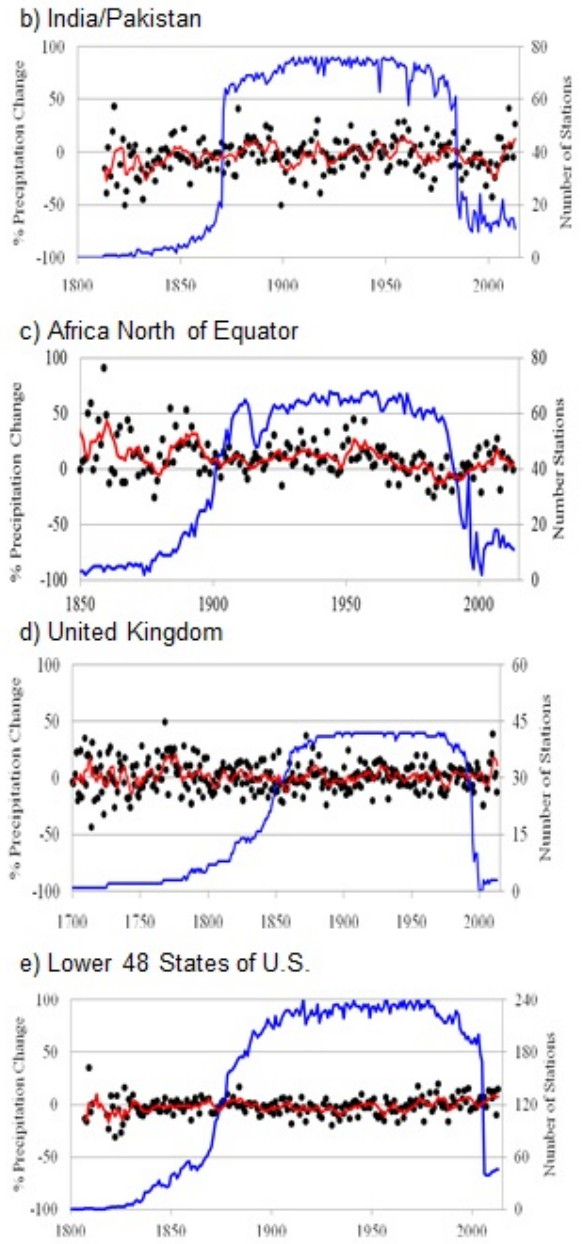


Fig. 4: Percentage Precipitation Change relative to 1961-90 for various countries. The red curve is the moving 5 year average while the blue curve shows the number of stations. Considering only years having at least 5 stations reporting data, the trends in units of % per century are: a) Australia -1.0 ± 4.8, b) India/Pakistan 0.5 ± 5.3, c) Africa North of Equator -10 ± 5.2, d) U.K. 0.6 ± 2.4 and e) Lower 48 States of U.S. 2.2 ± 2.0.

The global percentage precipitation change is shown in Fig. 5. This was computed in two ways. First an average of the station data was taken. This preferentially weights North America and

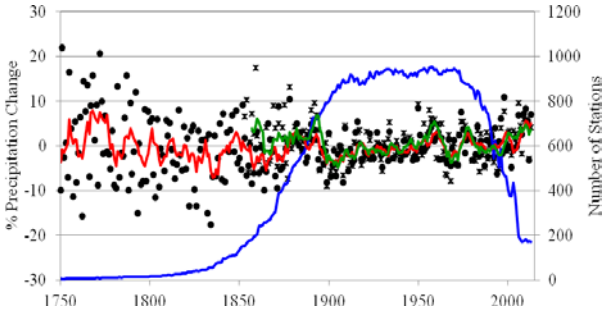


Fig. 5: Percentage Precipitation change relative to 1961-90. The black dots represent data found by averaging data over all stations while the crosses were found by weighting the various continental time series by the continental areas. The red (green) curves are the 5 year moving averages while the blue curve indicates the number of stations. The green curve was only found for years where data exists for the 6 continents.

Europe where about half of the stations are located. An alternative was to combine the time series for the 6 continents excluding Antarctica using weighting factors proportional to the continental areas. The resulting two curves do not differ significantly. Table 1 shows the trends depend strongly on the time period considered illustrating the effect of decadal variations. Most trends to not exceed the 95% confidence intervals.

Period	Trend % / Century	
	Station Average	Continental Average
1700-2000	-0.2 ± 1.1	
1750-2000	-0.3 ± 1.0	
1800-2000	1.2 ± 1.1	
1850-2000	1.7 ± 1.4	-1.2 ± 1.7
1900-2000	3.1 ± 2.2	2.6 ± 2.5
1950-2000	-1.1 ± 6.8	-5.4 ± 8.1
1700-2013	0.01 ± 1.1	
1750-2013	0.02 ± 1.0	
1800-2013	1.5 ± 1.0	
1850-2013	2.1 ± 1.2	-0.3 ± 1.5
1900-2013	3.5 ± 1.8	3.9 ± 2.1
1950-2013	2.2 ± 4.8	2.0 ± 5.8

Table I. Global Trends of Precipitation Change.

The percentage precipitation change was also examined for stations located north of 20^{o} N latitude, within ±20^{o} of the equator and south of 20 ^{o}S latitude. No substantial trend differences were found. Similarly, the percentage precipitation change was studied for dry stations (total precipitation <500 mm), stations experiencing moderate rainfall (500 - 1000 mm) and wet stations (>1000 mm). No dramatic trend differences were observed. Hence, one cannot conclude that dry areas are becoming drier nor wet areas wetter.

4. CONCLUSIONS

This study examined the precipitation at nearly 1,000 stations each having monthly totals of daily precipitation measurements for over a century. The data extended from 1700-2013, although most stations only had observations available after 1850. The percentage change in precipitation relative to that occurring during 1961-90 was plotted for various countries as well as the continents excluding Antarctica. There are year to year as well as decadal fluctuations. However, most trends over a prolonged period of a century or longer are consistent with little precipitation change. Similarly, data plotted for a number of countries and or regions thereof that each have a substantial number of stations, show few statistically significant trends. The annual precipitation averaged over all stations was 850 mm. Therefore a change of 1% per century corresponds to a change of 0.09 mm per year. This is consistent with the results obtained by the GPCP for the period 1979-2005.

There have been claims of a possible shift of global precipitation patterns (Zhang et al., 2007). Precipitation during the 20th century appeared to have decreased in regions near the equator while a small increase was found in the Northern Hemisphere mid-latitudes as well as in the Southern Hemisphere. This study found precipitation has decreased in Northern Africa since 1850 but there is no clear change in places such as the Indian subcontinent. Northern Africa contains the Sahara desert which experiences very low rainfall and very few rainfall events in a year can strongly affect the percentage precipitation change causing relatively large year to year fluctuations. This study also found some indications that precipitation increased slightly in regions of the Northern Hemisphere such as the U.S. and in parts of Europe such as Sweden. Fig. 3 also shows indications of increased precipitation at a number of stations in South America. However, many of the trends are small and most of the confidence intervals overlap with zero precipitation change.

Stations experiencing low, moderate and heavy annual precipitation did not show markedly different trends. This indicates deserts/jungles are neither expanding nor shrinking. It is therefore reasonable to conclude some caution is warranted about claiming large changes to global precipitation have occurred during the last 150 years.

5. Acknowledgements

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