Spatial Changes in Climate across Mongolia

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ABSTRACT

Previous research using meteorological station data suggests that temperatures and precipitation have been changing more across the semi-arid and arid country of Mongolia than in many other locations across the globe. We used gridded monthly data to determine the annual and seasonal rate of change in total precipitation (P), maximum temperature (Tmax), and minimum temperature (Tmin), as computed from the non-parametric Thiel-Sen slope estimator method. The significance of those changes were computed from the Mann-Kendall test. The University of East Anglia Climatic Research Unit (CRU) dataset was used for the 50-year time period from 1963 through 2012 at a 0.5 degree (~55 km) resolution. For the first 30 years, 30 to 35 meteorological stations from across Mongolia were used to create the spatially distributed "*High Resolution Gridded Data of Month-by-Month Variation in Climate*" CRU product; 20 to 30 stations were used for the last 20 years due to a decrease in the number of operational stations. Results are presented as maps of 1) mean total annual P, and mean annual Tmax and Tmin, and ii) annual trends over the length of record (1963-2012) with significance overlain, for the three variables. Rates of change at annual and seasonal time scales varied spatially with more consistent increases in temperature; significant precipitation trends were observed over smaller areas than significant temperature trends.

Keywords: Mongolia, climate change, Mann-Kendall, Thiel-Sen, gridded climate variables, trend analyses

INTRODUCTION

The climate of Mongolia is characterized as semi-arid with cold winters, warm summers and strongly seasonal precipitation patterns. Over the last few decades, a myriad of sources of change have affected traditional nomadic pastoralist lifestyles. These include, but are not limited to, major socio-economic and political changes and an increasingly warming and potentially drying landscape with changes in the frequency and severity of extreme climatic events, such as winter disasters or *dzud* (Batima *et al*., 2005; Fernandez-Gimenez *et al*., 2015). Simultaneously, changes are occurring such as the promotion of more intensive agricultural land uses with trends toward less nomadic practices, and increasing urban, industrial, and mining development (Ojima and Chuluun, 2008; Yamamura *et al*., 2013). Herders have observed changes to their environment and many of these observations correlate well with available climatic data (Marin, 2010; Fassnacht *et al*., 2011; Venable *et al*., 2012; Lkhagvadorj *et al*., 2013).

Climate research in Mongolia as reported in the international literature is limited, but there is a general consensus regarding the occurrence of increasing trends in mean, warm, and cool season temperatures but a relative lack of countrywide patterns in precipitation change (e.g. Batima et al., 2005; Dagvadorj et al., 2010; Jamiyansharav, 2010). Longer-term climate research using climate proxies suggests that the most recent decade may be one of warming and drought unlike that seen over the last millennia (Pederson *et al*., 2014). Given the uncertainties inherent in station-based data due to sparse station availability and the amount of missing data, we chose to examine Mongolian climate trends using spatially and temporally coherent gridded datasets. Our work extends existing research by investigating climate variability seasonally and annually across the country at spatial resolutions beyond the station level.

METHODS

Monthly maximum and minimum temperature (Tmax and Tmin) and precipitation (P) grids from the Climatic Research Unit (CRU) Timeseries 3.21 were acquired from the British Atmospheric Data Centre (Harris *et al*., 2013). The 0.5 longitude by 0.5 latitude grids are interpolated from anomalies of station data (1961-1990 means) and then combined with existing climatologies to give absolute monthly grid values. The data were provided to CRU primarily by the World Meteorological Organization via the Mongolian Institute for Meteorology, Hydrology and the Environment. While the number of contributing stations varies depending on the presence or absence of recorded data, generally 30 to 35 stations contributed from 1963 up to 1990 with a slight decrease in stations (20-30) recording to 2012.

The gridded files of monthly P, Tmax, and Tmin were compiled annually and seasonally (winter is December through February, spring is March through May, summer is June through August, and fall is September through November) for the length of record (1963-2012). The Thiel-Sen estimator for slope and the Mann-Kendall test for significance of trend (Gilbert, 1987) were calculated for the aggregate (total for P, and mean for Tmax and Tmin) time series at each grid cell using R statistical software (R Core Team, 2014).

RESULTS

Climate Patterns

Mean annual total P, Tmax and Tmin are shown in Figure 1 for the 50-year length of record. Precipitation gradients are noticeable from north to south and in mountainous versus valley regions of the country (Fig 1a). Similar patterns are noticeable for Tmax and Tmin (Fig 1b and c), with cooler temperatures on average in the mountainous and more northerly portions of the country.

Annual Trends

On an annual basis, significantly decreasing precipitation trends occur in the eastern and central parts of the country (ranging from about -8 to -21 mm/decade), with slight decreases in parts of the far south-central Gobi region (from -7 and -9 mm/decade) and the northwestern part of the country near Zavkhan *aimag* (province), (between -12 and -14 mm/decade) (Fig 2a). Changes in annual mean maximum temperature through time were found to be significant across most of the country (ranging from 0.2 to 0.6 deg C/decade) (Fig 2b). Trends in annual mean minimum temperature were significant across the entire country (ranging from 0.2 to 0.7 deg C/decade) with the greatest rates of change occurring in the north central part of the nation near Lake Khovsgol (0.7 deg C/decade), across parts of the western Altai Mountains and Great Lakes region (up to 0.6 deg C/decade), and in the far eastern steppe (from 0.5 to 0.6 deg C/decade). Increasing mean minimum temperature trends were also greater in the central Gobi region (up to 0.5 deg C/decade) (Fig 2c).

Seasonal Trends

Seasonal trends (not shown) are more spatially diverse than the annual trends. Changes in precipitation are generally not significant across a majority of the country particularly in the winter and spring months. In summer however, significant decreases in precipitation are seen from the central northwest across the central forest steppe to the eastern steppe, similar in magnitude and location to and of somewhat greater extent than those patterns illustrated in the annual trend (Fig 2a). Decreasing trends in fall precipitation are centered in a region extending east from near the eastern edge of Khovsgol *aimag* across the central forest steppe and steppe to the area west of Ulaanbaatar (from -2 to -7 mm/decade).

Trends in mean maximum winter temperatures are not significant over a majority of Mongolia. Fall mean maximum temperature changes over the period of record are also generally non-significant with the exception of the northwestern part of the country (up to 0.6 deg C/decade), the south central Gobi region (up to 0.3 deg C/decade) and areas south of the Khangai Mountains (from 0.3 to 0.4 deg C/decade). Increases in mean maximum fall temperatures are also seen north and west of Ulaanbaatar (up to 0.4 deg C/decade). Significant increases in spring and summer mean maximum temperatures are observed across most areas of the country (up to 0.4 deg C/decade in the summer), except for in the central Gobi (not significant in springtime) and parts of the eastern steppe.

Minimum mean temperature has been warming the most and has the largest extent of significant change throughout the seasons. While minimum winter and fall temperatures have increased significantly mainly over the western, central-southern and eastern portions of the country (overall ranges from 0.3 to 0.8 deg C/ decade in winter, and 0.2 to 0.7 deg C/decade increase in fall), minimum spring and summer temperatures have increased significantly across the entire nation. Only one small area of the far western Khangai Mountain region has not seen a significant warming of minimum spring temperatures over the last 50 years. Similar rates of change are seen in both spring and summer seasons (from 0.3 to 0.7 deg C/decade spring, 0.2 to 0.5 deg C/decade summer).

DISCUSSION AND CONCLUSIONS

The results of previous climate trend analyses by other authors often parallel the gridded results presented here. There are however, key differences. For example, when studying mean seasonal temperatures, Batima *et al*., (2005) concluded that primarily winter temperatures were increasing with increases also in spring and fall. They did not find clear increasing or decreasing trends in summer, though they found evidence of longer durations of periods with hot days. They did not find significant changes in seasonal precipitation, though they did acknowledge strong spatial variability in the precipitation results. Our analyses of these gridded datasets reveal clear temperature increases in summer, particularly for minimum temperatures and significant changes (decreasing) in precipitation in the summer and fall for nearly a quarter to a third of the country, depending on the season.

Other analyses of climate are more difficult to compare to our results due to the use of climate indices rather than explicit values of P, Tmax, and Tmin. In the *Mongolia Second National Communication* document (Dagvadorj, 2010), results are presented as an increase in the frequency of extreme high temperatures and a drop in the occurrence of extreme low temperatures. Increases in winter precipitation are also mentioned with decreases in summer precipitation across the country. These results are somewhat correlative to the increasing mean maximum and minimum temperatures, as well as the significant decreases in summer precipitation shown herein.

Inherent in the use of climatic datasets are uncertainties introduced due to data collection, processing, and in the case of gridded datasets, the interpolation of climate data. Jamiyasharav (2010) documented biases that may be present in the Mongolian climate records due to station siting, movements of station locations, and changes to instrumentation. Whether the differences between existing studies and our results are artifacts of the original station data, the interpolation processes used in gridding the climate variables, or differences in trend analyses methodology, or all of these, it is clear that the historical climate record exhibits significant change over a 50-year period from 1963 through 2012.

Spatial trend analyses at annual and seasonal time steps using gridded datasets (e.g. Hendricks and Fassnacht, *in prep*) provide a strong visual tool for examining significant climate change across Mongolia. These results suggest that significant warming trends and some drying trends are present in areas of the country that support much of the population. Mitigating adverse impacts from these changes will be particularly challenging under increasing agricultural and water-resource intensive mining development in these regions.

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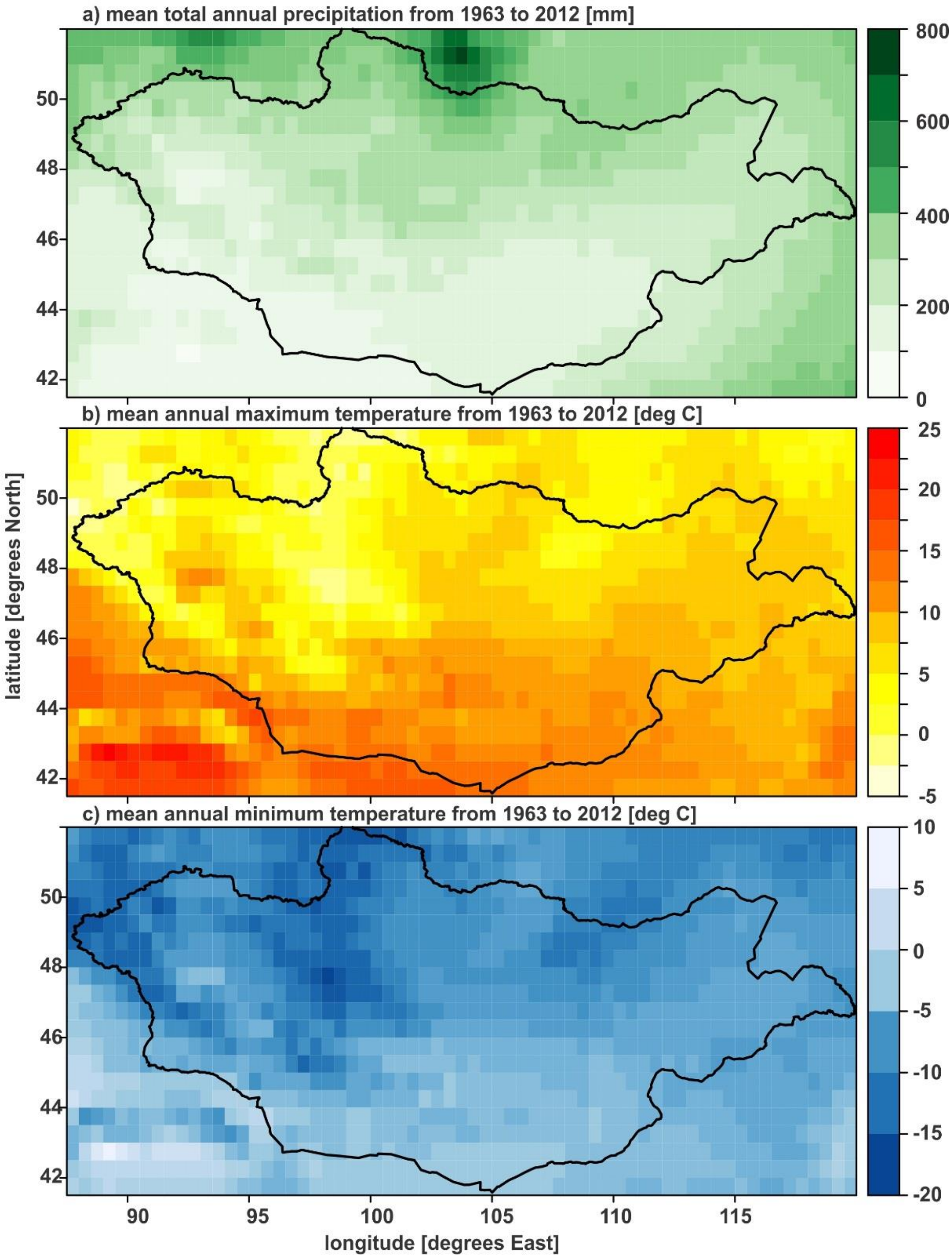

Figure 1. Mongolia mean annual (1963-2012) a) total precipitation in millimeters, b) maximum temperature in degrees Celsius, c) minimum temperature in degrees Celsius.

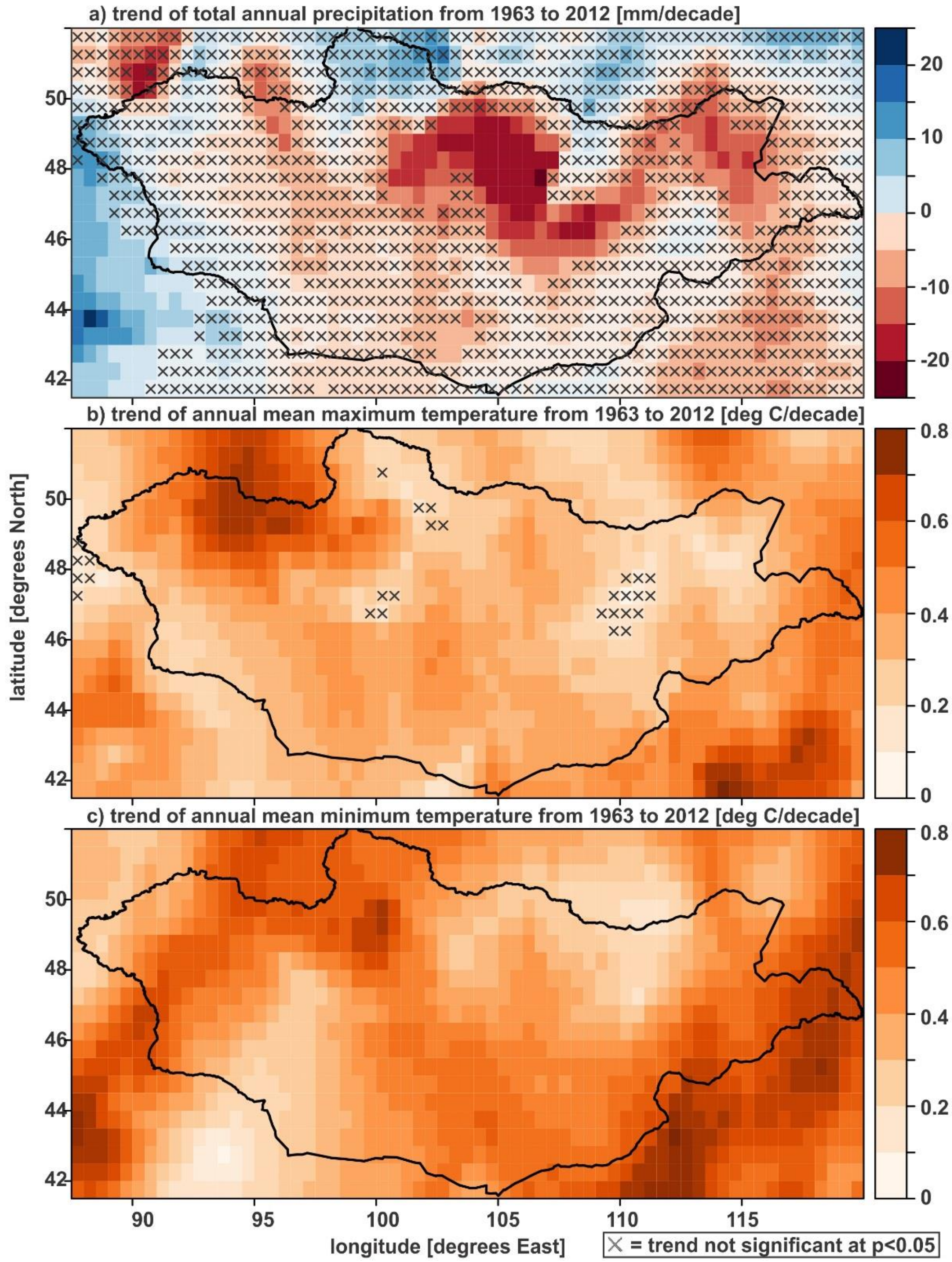

Figure 2. Trends per decade in the annual mean a) total precipitation trend in millimeters, b) maximum temperature in degrees Celsius, and c) minimum temperature in degrees Celsius. Note that the X's in the figure denote areas where the trend was not significant at the p<0.05 level.