CLIMATE CHANGE HAZARDS: EXTREME PRECIPITATION EVENTS & FLOODING IN OKLAHOMA'S TRIBAL NATIONS

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ABSTRACT

Extreme weather hazards are important because they can result in the loss of life, destruction of property, and damage to the environment. It is therefore important to understand how the frequency and intensity of these hazards may change in the future due to climate change. For this study, we address extreme precipitation across Oklahoma, specifically the area which the Citizen Potawatomi Nation, Choctaw Nation of Oklahoma, and Chickasaw Nation encompass. Based on interviews with tribal emergency managers of these three nations, flooding was indicted as a particularly impactful hazard. As a result, this project develops nation-specific projections in heavy precipitation, using various metrics to quantify extremes. High-resolution (~6 km) statistically-downscaled climate model projections, from the Multivariate Adaptive Constructed Analogues (MACA) project were used to assess future changes in heavy precipitation. The results of the future projections show that the average daily precipitation rate does not change in the mid-century (2021-2051) or late-century future (2060-2090); however, heavy precipitation at higher thresholds are likely to increase over these tribal nations in Oklahoma for the same time periods. This was evident by the trends identified in frequencies of 2 inches and 4 inches per day, and 5-day accumulations exceeding 8 inches. Overall, this research will assist tribal emergency mangers in planning for and mitigating potential impacts of floods.

1. INTRODUCTION

Climate variability and change can influence the characteristics of extreme weather events such as the intensity, frequency, timing, and duration (Greenough et al., 2001). An extreme event is one that deviates from the norm and stresses populations beyond adaptation limits. From the start of the 20th century, the global mean temperature increased about 0.6°C (Easterling et al., 2000; McMichael et al., 2006). This increase in temperature can be attributed to the anthropogenic rise in greenhouse gases. Not only does the rise in greenhouse gases affect the temperature of the atmosphere, it also has an effect on the hydrologic cycle (Pielke & Downtown, 2000). In this case, it is predicted that the hydrologic cycle will intensify, resulting in more heavy rain events, which in turn can exacerbate flooding.

According to the National Climate Assessment, the Great Plains region of the United States can expect increasing intensity and frequency of floods, droughts, and heat waves (NCA, 2014). Recently, there have been historic rainfall amounts in Oklahoma specifically in May 2015 when many precipitation records were broken (Kloesel, 2015). The state received the most rainfall on record for any month (14.40 in.), and many climate divisions recorded their wettest month ever. Extreme 24-hour precipitation totals occurred throughout Oklahoma, especially in the central, south central and southeast climate divisions. These extreme daily precipitation totals ranged from about 2-6 inches while Oklahoma's statewide total average precipitation for the month of May is 4.72 inches (US Climate Data). Therefore, some locations surpassed the May average rainfall total in one day. With the extreme precipitation totals, significant flooding occurred resulting in ten fatalities.

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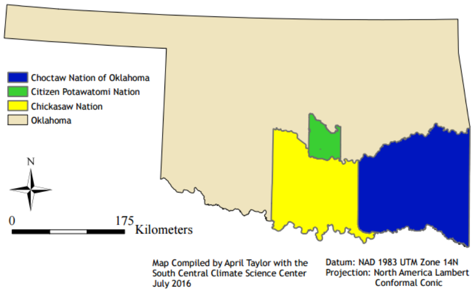

Figure 1: Map of Oklahoma outlining the jurisdictions of the three tribal nations.

With the likelihood of more extreme events like this occurring, it is important to be prepared and mitigate the effects of these events by planning ahead. This study specifically focuses on three tribal nations, Citizen Potawatomi Nation, Choctaw Nation of Oklahoma, and Chickasaw Nation within the state of Oklahoma (Fig. 1), since these nations already have hazard mitigation plans outlining possible hazards their nations are prone to. These nations are particularly vulnerable to floods, because of convective thunderstorms that can produce a large amount of rain (CPN staff and Leadership, 2010, Nutter-Klepper & Hansen, 2014, Chickasaw Nation Hazard Mitigation Planning Team, 2016). In these regions, although flooding can occur at any point during the year, it is most common in the late spring, summer, and early fall. Floods can cause many fatalities, as wells as destruction to homes, businesses, and roadways. They can make roadways impassible which can result in hospitals and urgent care centers becoming inaccessible. Additionally, the inaccessibility of facilitates during the time of flooding puts a financial strain on the nations. Although all tribes have outlined their hazards with mitigation plans, and noted historical weather events, the impacts of climate change are not included in their plans (Zientek, Hansen & Jones, 2016). It would be helpful for the tribes to plan ahead for climate change that can result in more extreme precipitation events. Therefore, this study seeks to assess whether extreme weather events can be expected to change in the future.

2. DATA AND METHODS

2.1 Tribal Emergency Manager Interviews

Based on interviews with tribal emergency managers, this study focuses on extreme precipitation events that can potentially result in dangerous flooding. The emergency managers interviewed were, Tim Zientek from Citizen Potawatomi Nation, Jeff Hansen from Choctaw Nation of Oklahoma, and Sara Jones from Chickasaw Nation. Questions asked during these meetings included what top hazards are currently affecting your area, and what kind of future climate projections would be useful to you in order to prepare for climate change? The top hazards that were discussed included flooding, winter weather events, extreme heat events and drought. All tribes rated flooding caused by extreme precipitation events as either their first or second hazard of most concern. Also, the emergency managers noted that spatial maps showing future projections of extreme precipitation would be of most use to them (Zientek, Hansen & Jones, personal comm).

2.2 Climate Model Output

Our data for this project includes Multivariate Adaptive Constructed Analogs (MACA; Abatzoglou & Brown, 2012), a statistically-downscaled set of climate projections, based on the Coupled Model Intercomparison Project Phase 5 (CMIP5; Karl, 2012). MACA uses Global Climate Model (GCM) output along with observational data, which is interpolated to a 1 degree latitude and longitude grid. Constructed analogs are then used to compare GCM output to observational data looking for similar or analogous spatial patterns for a suite of variables. The observational dataset that the projections are trained against is that of Livneh (2013), which has a spatial resolution of 1/16 degree ~6km. While MACA includes data for 21 models, a subset of 15 (Table 1) were selected for this work that better represent the regional temperature and precipitation climatology, based on work by D. Rupp, and D. Rosendahl (personal comm.). For this study downscaled precipitation accumulation was investigated for historical (1950-2005) and future (2006-2099) conditions. The dataset includes two representative concentration pathways, RCP4.5 and RCP8.5, which are radiative forcing trajectories (Van Vuuren et al., 2001). RCP4.5 is an intermediate mitigation scenario, while RCP8.5 is a high emission scenario. By using the MACA method, future projections of the average daily precipitation rate, the amount of days exceeding 2 and 4 inches, and 5-day total accumulations above 8 inches were calculated over the three tribal regions. These precipitation rates and extremes were compiled by Dr. Esther Mullens, South Central Climate Science Center.

BNU-ESM	inmcm4
CanESM2	IPSL-CM5A-LR
CCSM4	IPSL-CM5A-MR
CNRM-CM5	MIROC5
CSIRO-mk3-6-0	MIROC-ESM-CHEM
GFDL-ESM2G	MIROC-ESM
HadGEM2-CC365	NorESM1-M
HadGEM2-ES365	

Table 1: 15 CMIP5 Models Used

Spatial maps using the thresholds listed above were created for the multi-model mean. Three time periods were averaged together which included a historical period (1970-2000), a mid-century future period (2021-2051) and a late-century future period (2060-2090). The multi-model mean was used in these results to show general differences across time periods, and to remove potential biases in individual models (Esther Mullens, personal comm). The thresholds of 2 and 4 inches were chosen, because the May 2015 event had 24 hour high precipitation totals predominantly ranging between 2 and 6 inches of rain in the southeast, southcentral and central climate divisions the three climate divisions the tribes mainly encompass. The 5-day total accumulation above 8 inches was chosen, because it describes a period of excessive rainfall that could potentially occur in this region. Thresholds beyond 4 inches in one day were not calculated due to the few occurrences observed in the number of 4 inch rainfall days per year. Also, if certain thresholds in the past were not observed, they cannot be projected in future, since the projections are based off what was observed in the past. The average daily precipitation rate was calculated by taking the amount of rain that fell during one month, and dividing it by the number of days precipitation occurred.

3. RESULTS AND ANALYSIS

We now describe the results of the different thresholds in detail, and the multi-model mean projections produced for historical (1970-2000), mid-century future (2021-2051) and late-century future (2060-2090) time periods.

3.1 Average Daily Precipitation Rate

The first variable assessed was the average daily precipitation rate for all the nations. The historical and future projections for Choctaw Nation are shown in Fig. 2. There is little to no change in the average daily precipitation rate for future time periods in either the RCP4.5 or RCP8.5 scenarios. For Chickasaw Nation, and Citizen Potawatomi Nation, the same is true (not shown). Although the average daily precipitation rate does not appear to vary within each nation, the nations experience slightly different precipitation rates. For instance, Choctaw Nation has values ranging from 0.25 to 0.35 inches, with greater values occurring in the southeast. However, Chickasaw Nation has a daily precipitation rate ranging from 0.25 to 0.30 inches, while Citizen Potawatomi experiences about 0.25 inches for all three time period projections. The lower daily precipitation rates observed in Chickasaw and Citizen Potawatomi Nations is most likely caused by the precipitation climatology in Oklahoma, where the west is drier than the east.

3.2 Average Number of 2-inch Rainfall Days per Year

Next, the average number of 2-inch rain days per year was evaluated (Fig. 3-5). The unis calculated are in number of days, which are not necessarily whole numbers, since they are averaged over a 30 year period; therefore, if the graph displays .5 days, that would represent an event occurring every two years. The observational 30 year average (1970-2000) was included to compare the historical multi-model mean for this same time period.

Unlike the average daily precipitation rate, we now see an increase in the number of 2-inch rain days per year in all the nations throughout the three different time periods. Choctaw Nation (Fig. 3) has a historical multi-model mean average of about 1.5, 2-inch rain days per year in the west, and about 2 days in the east. This increases to about 2 days for most of the nation in the mid-century time period for both RCP4.5 and RCP8.5. However, there is not much of a change from the mid-century to late-century time periods for Choctaw Nation, where the late-century multi-mean model projections remain at two, 2-inch rain days per year with the southeast region receiving between 2.5 and 2.75, 2-inch rain days per year. For Chickasaw Nation (Fig. 4), there is about one, 2-inch rainfall event per year increasing to about 1.5 for the eastern half of the nation in the mid-century future. Looking at the late-century future, the region experiencing 1.5, 2-inch rainfall events per year expands westward encompassing more of the nation. With Citizen Potawatomi Nation (Fig. 5), about the same number of 2-inch rainfall days, over the three time periods are observed as Chickasaw Nation.

3.3 Average Number of 4-inch Rainfall Days per Year

There is also an increase in the number of 4-inch rainfall days per year. Starting with Choctaw Nation's historical time period, there was about 0-0.1 days of this event (Fig. 6), meaning that within this dataset, an event of this magnitude occurred roughly once every 10-years or less on average. That increased to about 0.2-0.25 days in the mid-century, which would mean every 4 years, a 4-inch rainfall event could occur. In the late century future the southeast region of Choctaw Nation could experience up to 0.35 days per year of 4-inch rainfall days. Less of these 4-inch rain events are likely in Chickasaw Nation (note shown). In the historical time period there was 0-0.1 days, which increases to about 0.2-0.25 in the mid-century future for the southeast. In the late-century future more of Chickasaw Nation would be expected to receive 0.25, 4-inch rainfall events per year. Once again for this threshold, Citizen Potawatomi Nation's results closely resemble that of Chickasaw Nation (not shown).

3.4 5-Day Total Accumulations above 8 Inches

Lastly, an increase in the 5-day total accumulations above 8 inches per year were observed in our results (Fig. 7). These occur more frequently than the 4-inch rain day events, but less frequently than the 2-inch rain day events. Choctaw Nation's historical multi-model mean projected about 0.3-0.4 events. In the southeast, that increases to about 0.6 days in mid-century future, and later increases to about 0.8 events in the RCP4.5 scenario or 1 day in the RCP8.5 scenario for the late-century future. This suggests an event that previously might have occurred once every 2-3 years is likely to occur nearly every year in the future projection. Chickasaw Nation had about 0-0.2, 5-day total accumulations above 8 inches per year for the historical projection, increasing to about 0.3-0.4 events in the mid-century future, and then to about 0.6-0.8 events in the late-century future, especially in the southeast region of the nation. Citizen Potawatomi Nation (not shown) had the same historical projection as Chickasaw Nation for this event (not shown). However, there was not as big of an increase in the mid and late-century future as observed for Chickasaw Nation. For the mid-century projection of Citizen Potawatomi Nation, they are likely to receive 0.3 days of this precipitation accumulation, and then some parts of the nation, in the late-century future are likely to receive 0.4 days of this event (not shown).

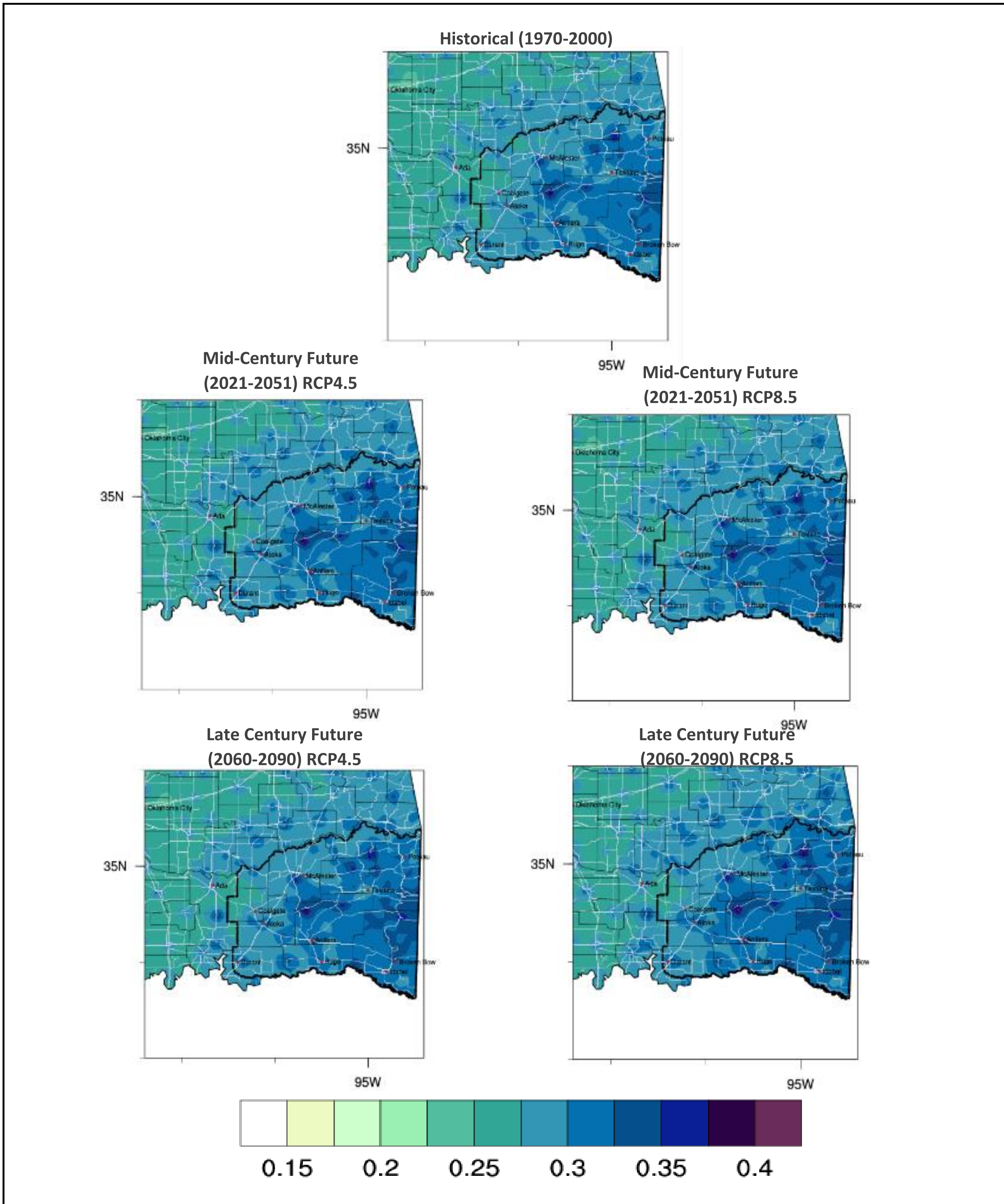

Figure 2: Choctaw Nation of Oklahoma average daily precipitation rates for historical, mid-century future and late century future time periods. (Both RCP4.5 & RCP8.5 used for future projections).

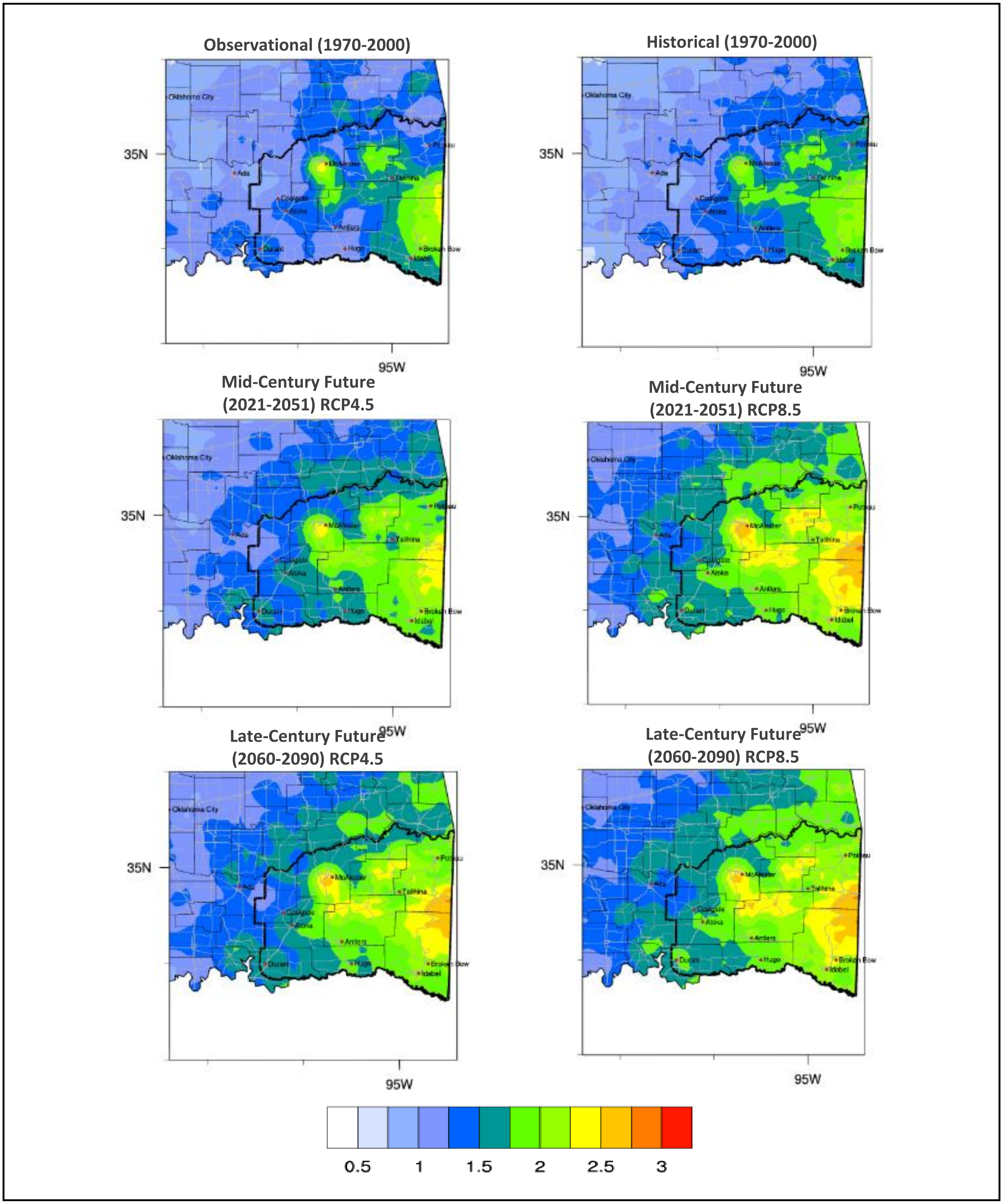

Figure 3: Choctaw Nation of Oklahoma average number of 2 in. rainfall days for historical, mid-century future and late century future time periods. (Both RCP4.5 & RCP8.5 used for future projections).

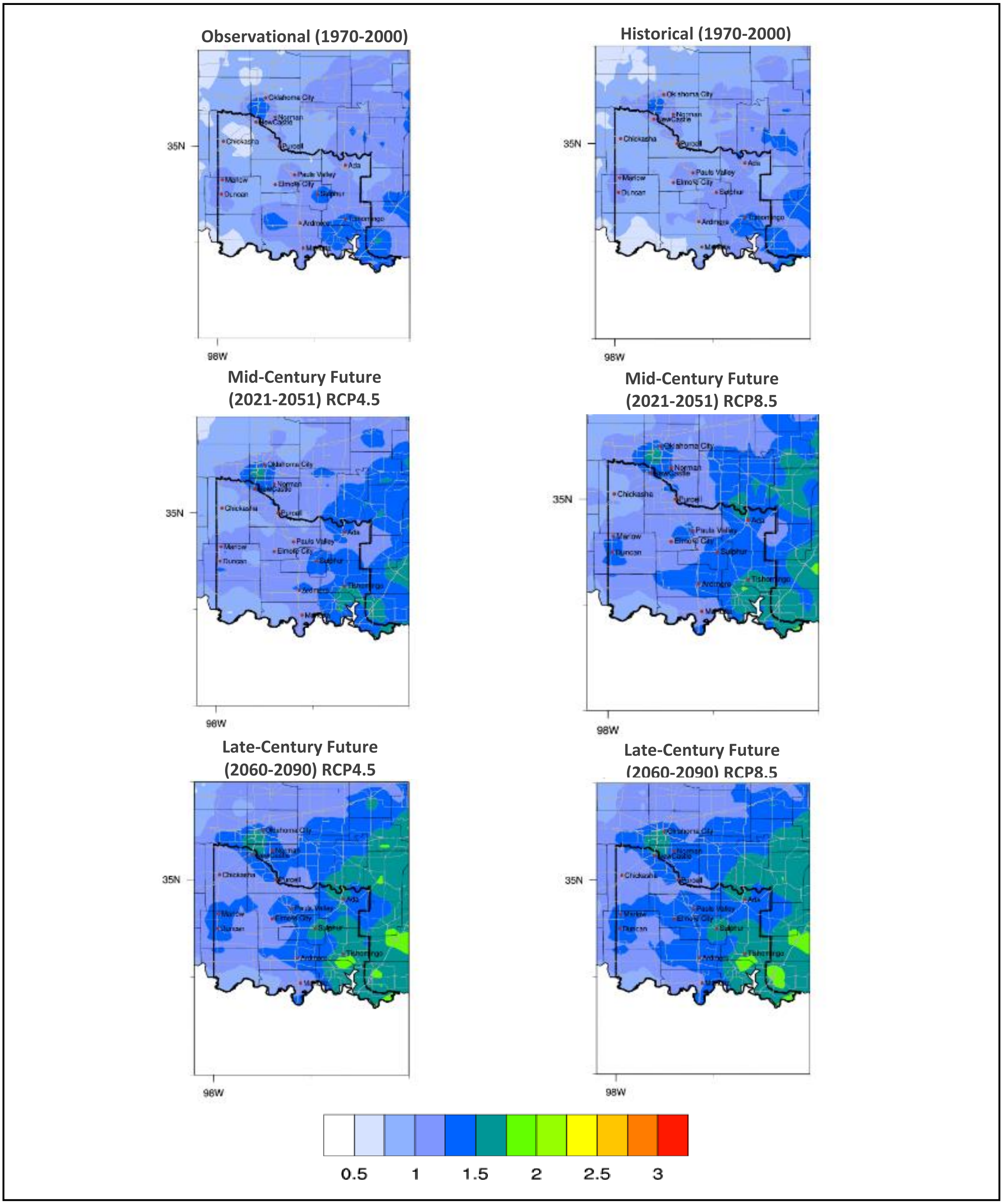

Figure 4: Chickasaw Nation average number of 2 in. rainfall days for historical, mid-century future and late century future time periods. (Both RCP4.5 & RCP8.5 used for future projections).

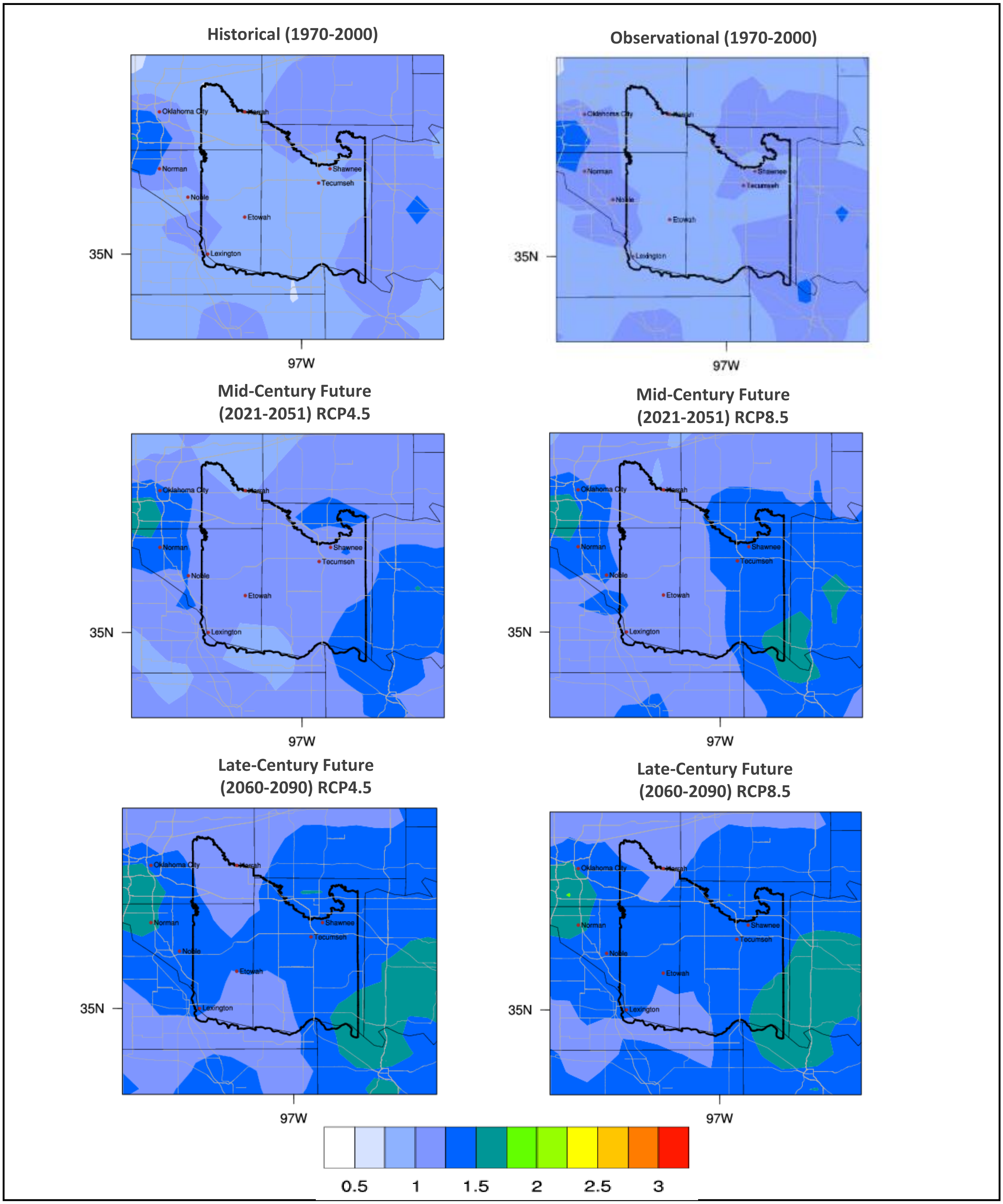

Figure 5: Citizen Potawatomi Nation average number of 2 in. rainfall days for historical, mid-century future and late century future time periods. (Both RCP4.5 & RCP8.5 used for future projections).

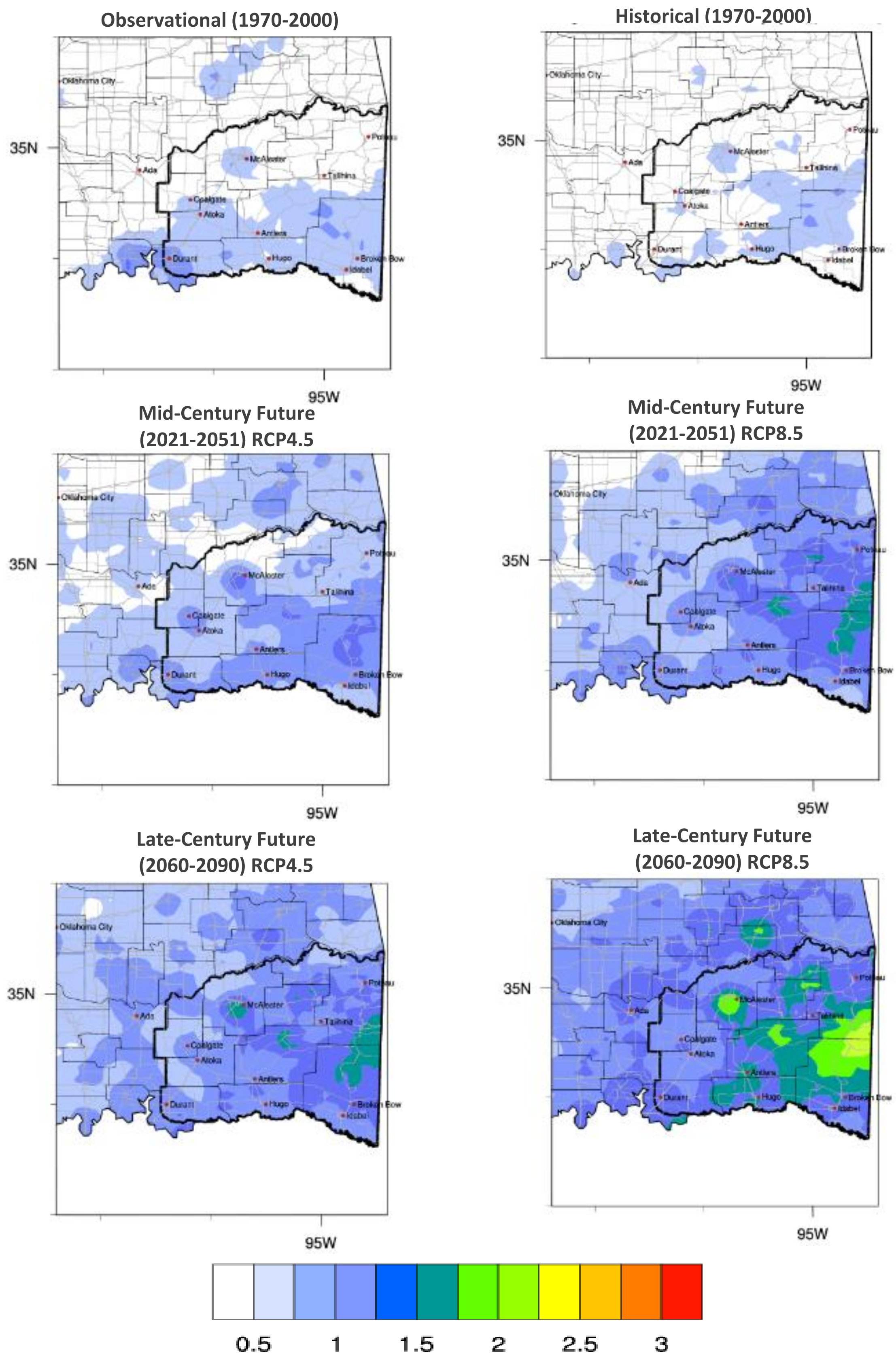

Figure 6: Choctaw Nation of Oklahoma average number of 4 in. rainfall days for historical, mid-century future and late century future time periods. (Both RCP4.5 & RCP8.5 used for future projections).

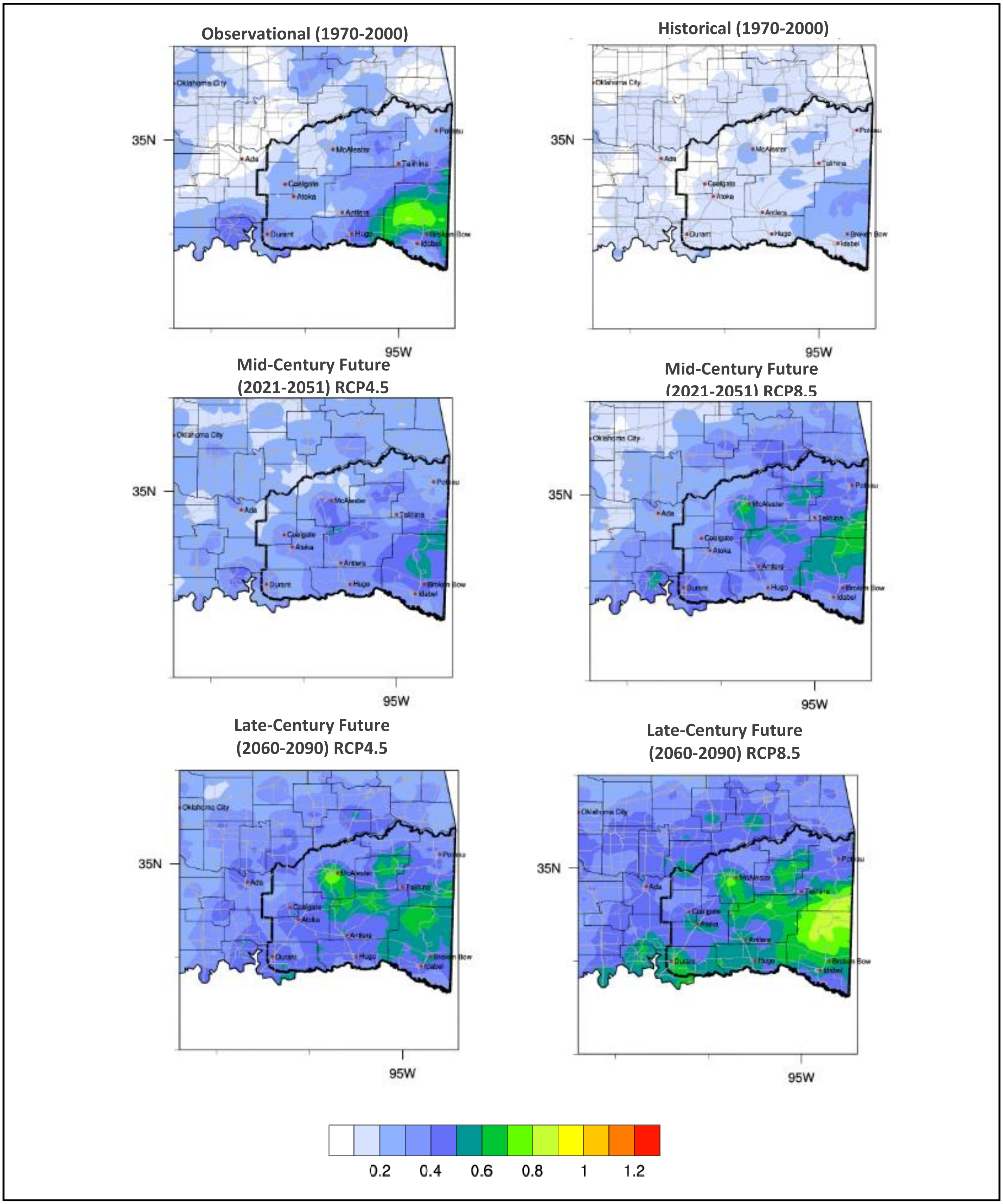

Figure 7: Choctaw Nation of Oklahoma average 5-day total accumulations above 8 inches for historical, mid-century future and late century future time periods. (Both RCP4.5 & RCP8.5 used for future projections).

3.5 Percent Change Increases

We also estimated the percent change increases for the number of 2-inch and 4-inch rain days per year using RCP8.5 (table 2 & 3). These estimated calculations, based on the spatial maps were computed by taking the historical multi-model mean number of rain days, subtracting it from the future projected number of rain days, and then dividing that quantity by the historical projected number of days. This was then multiplied by one hundred to get the percent. There is a wide range of percent changes due to different locations within each nation where the values were calculated. In addition, there are much higher percent change increases with the number of 4-inch rain days, since there are significantly fewer days per year that this event can likely occur.

Tribal Nation	% change from (1970-2000) to (2021-2051)	% change from (1970-2000) to (2060-2090)
Choctaw Nation	15%-40%	15%-40%
Chickasaw Nation	20%-25%	25%-50%
Citizen Potawatomi	20%-25%	40%-50%

Table 2: Estimated percent change in the number of 2 in. rain days (RCP8.5) for each tribal nation

Tribal Nation	% change from (1970-2000) to (2021-2051)	% change from (1970-2000) to (2060-2090)
Choctaw Nation	60%-150%	100%-130%
Chickasaw Nation	50%-100%	100%-150%
Citizen Potawatomi	50%-100%	100%-150%

Table 3: Estimated percent change in the number of 4 in. rain days (RCP8.5) for each tribal nation

3.6 Comparison of Observational Data vs. Multi-Model Mean Projections

Looking at Fig. 3-7 the multi-mean model projections for the historical period (1970-2000) are slightly underestimating the observational data for this same time period, with the exception of the 5-day total accumulations above 8 inches. Here we see the greatest underestimation to what was observed in the multi-model mean projections for the southeast of Choctaw Nation. With the historical multi-model mean slightly underestimating the historical observational data, it should be noted that the multi-model mean projections for the future time periods may also be slightly underestimated.

Region	North Latitude	South Latitude	West Longitude	East Longitude
Citizen Potawatomi	34.8°N	35.6°N	97.4°W	96.6°W
Choctaw	33.6°N	35.4°N	96.5°W	94.5°W
Chickasaw	33.6°N	35.4°N	98.0°W	96.4°W

Table 4: Boxed latitudes and longitudes of the three tribal nations

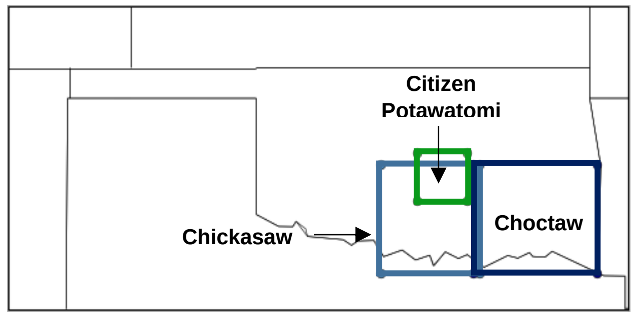

Figure 8: Boxed regions of the tribes

To get a better understanding of how the models compare to each other, and to the observational data, box and whisker plots were created for all the nation's number of rain days above 2 inches; however, only Choctaw Nation of Oklahoma plots are displayed in this paper. Here the number of rain days above 2 inches were calculated over defined boxed regions representing each tribal nation. The latitudes and longitudes used to represent each nation are displayed in table 4 with a map shown in Fig. 8. For the historical period (1970-2000) 2-inch precipitation days over the Choctaw Nation of Oklahoma (Fig. 9), 14 of the 15 models slightly underestimate the median of the observational data, of about 1.5 days. Although they underestimate the median, their medians are fairly close to that of the observational data ranging from about 1.1-1.6 days. Now when looking at the mid-century future, and late-century future box plots (Fig. 10 & Fig. 11) for the same nation and threshold, there are a greater number of days above 2 inches. Some models project up to six, 2-inch rainfall days over this period; however, the median of the 15 models ranges between 1.2-2.2 days. This is greater than the historical projections.

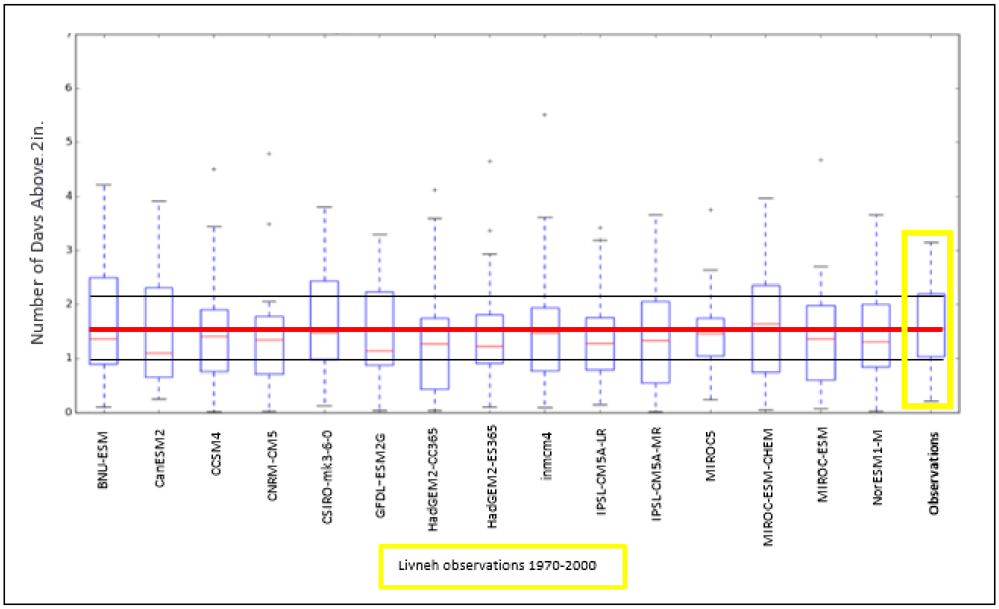

Figure 8: Choctaw Nation of Oklahoma (1970-2000) number of rain days above 2 in. for 15 models box and whisker plot

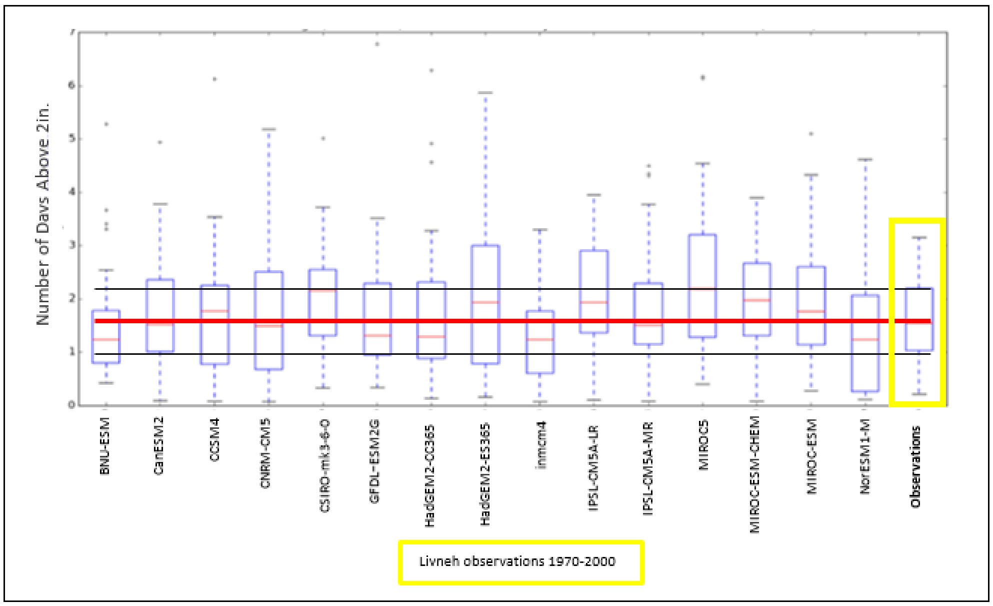

Figure 9: Choctaw Nation of Oklahoma (2021-2051) number of rain days above 2 in. for 15 models box and whisker plot

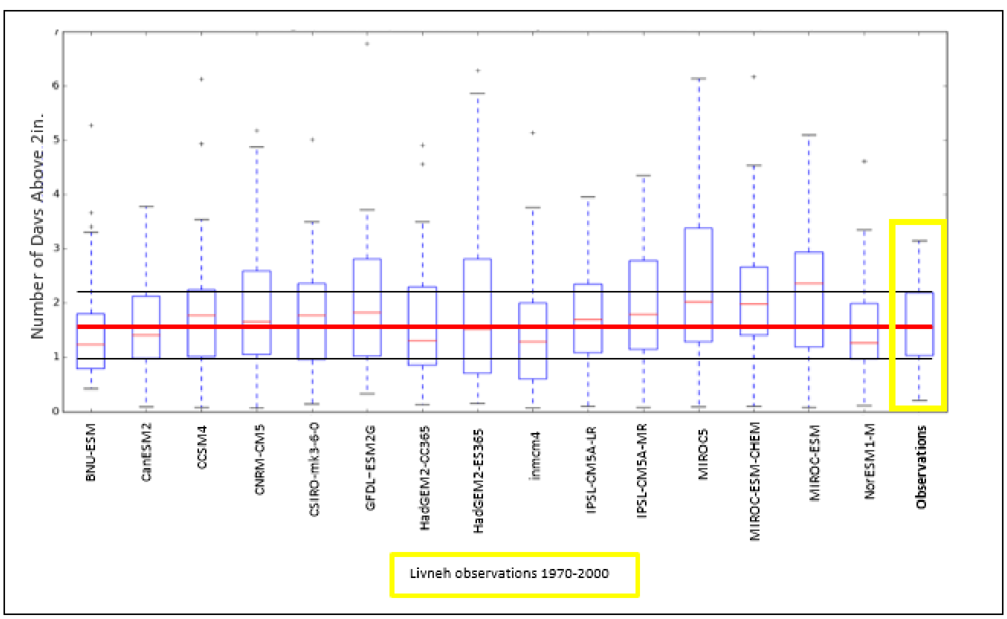

Figure 10: Choctaw Nation of Oklahoma (2060-2090) number of rain days above 2 in. for 15 models box and whisker plot

4. CONCLUSION

Our research shows that over the regions of Citizen Potawatomi Nation, Choctaw Nation of Oklahoma, and Chickasaw Nation the average daily precipitation rate does not appear to change throughout the three historical periods studied; however, the number of rain days above 2 and 4 inches, and 5-day total accumulations above 8 inches are likely to increase in the future, according to the spatial map projections produced. There is reasonable confidence in extreme precipitation changes across these regions according to the multi-model mean projections.

Overall, climate change can have an impact on increasing extreme precipitation events, which can result in more flooding. Emergency tribal managers of the Citizen Potawatomi Nation, Choctaw Nation of Oklahoma, and Chickasaw Nation should expect an increase in the number of more extreme rainfall events in the future, not necessarily more rain. They should plan accordingly to reduce the damaging effects these events could produce.

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