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PPHA 39930  
Assignment 1  
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Q1. In class, we derived the Earth’s surface temperature using a simple energy balance model with a one-layer atmosphere. Now, you’ll derive the energy balance with a partly transparent atmosphere.

(a) Draw a diagram like the one on slide 36/120 in “Climate change crash course” lecture slides, but this time *include a term and arrows for a partially transparent atmosphere*

(b) Write out the energy balance equations for an atmosphere with an emissivity1, ϵ.

(c) Solve the equations for TS, the temperature of the Earth’s surface

(d) Assume the following values and calculate TS: S = 1370 Wm−2; ϵ = 0.78; A = 0.3

(e) One of our neighbours, Mars, has an average solar constant of SM = 589 Wm−2, an albedo of AM 0.24, and a surface temperature of -46◦C. What would its atmospheric emissivity, ϵM, need to be to achieve that surface temperature?

**Q1.** **a)** Added dotted lines to represent energy absorbed and radiated by a partially transparent atmosphere, with the emission represented by ϵ.

Diagram of a diagram of energy

Description automatically generated

**Q1. b)** Based on the slide, we know that:

Incoming solar radiation: S/4  
Reflected by Earth’s atmosphere: AS/4, where A represents albedo  
Absorbed by earth’s surface: (1-A)(S/4)  
Emitted by Earth’s surface: σTS­­4, where TS is Earth’s surface temperature  
Absorbed by the atmosphere: (1- ϵ)σTS4, where ϵ is the emissivity of the atmosphere  
Emitted by the atmosphere back to space: ϵσTe4  
Emitted by the atmosphere back to Earth’s surface: ϵσTe4

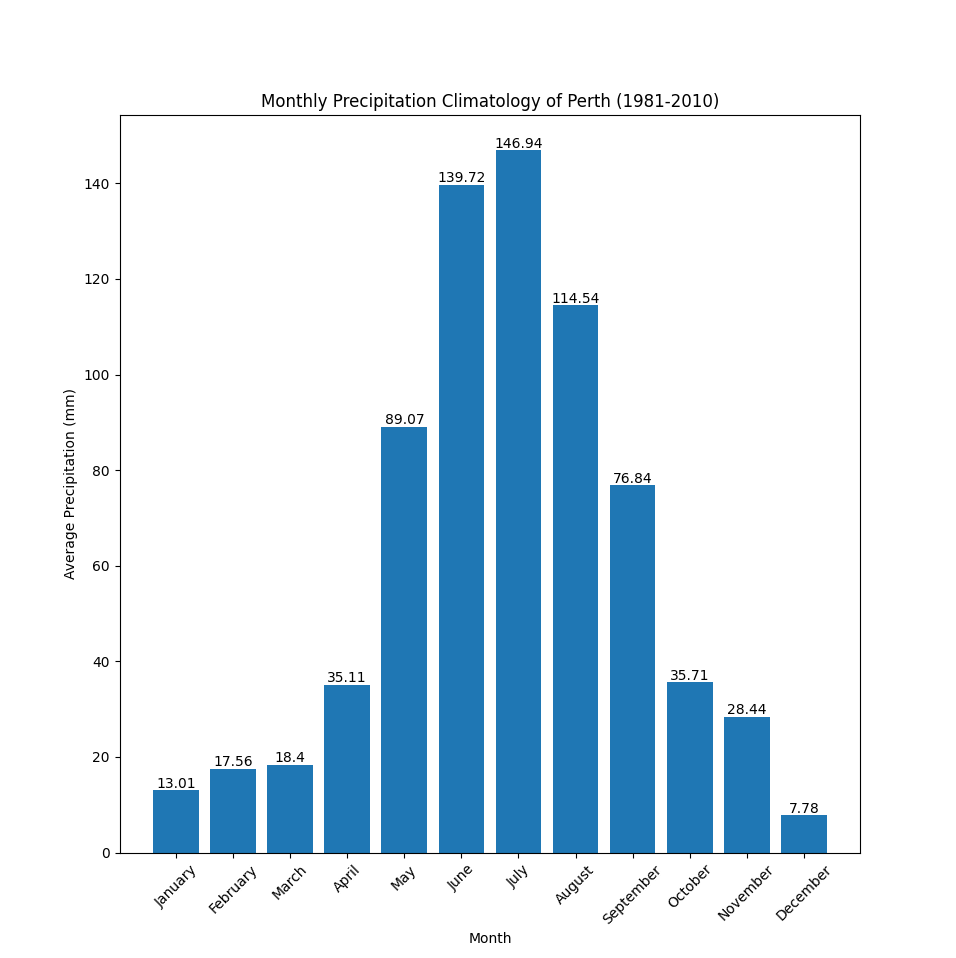
**Q1. c)** Energy balance equation for the Earth’s surface: (S/4)(1 – A) = ϵσTS4  
Solving for TS, we get:

**Q1. d)** Given S = 1370 Wm-2, ϵ = 0.78 and A = 0.3  
We know that the Stefan-Boltzmann constant σ = 5.67 x 10-8 Wm-2K-4  
Substituting this value in the above, we get

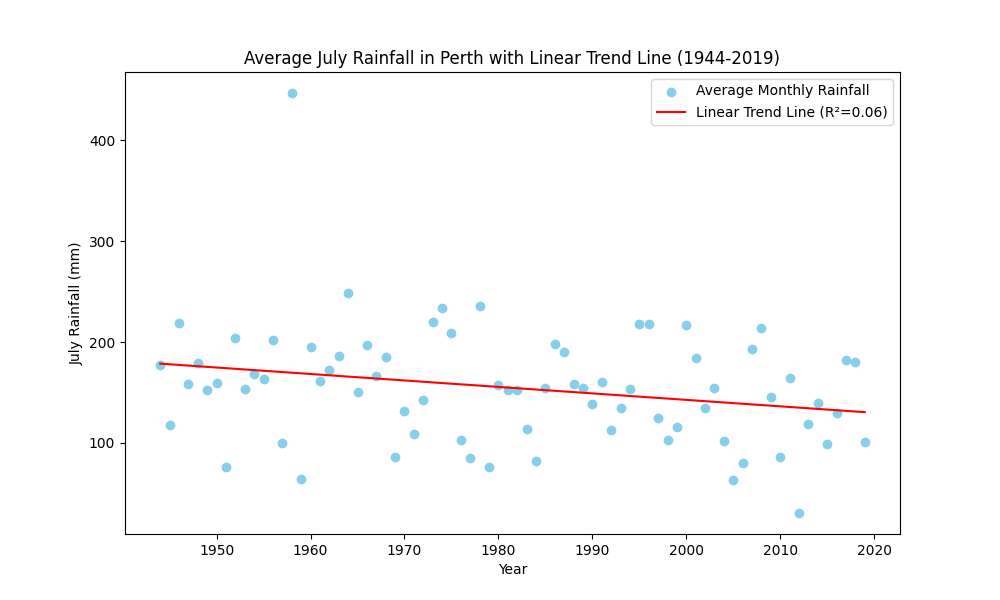
or TS = 271.344 K, or approximately -1.806 C

e)

**Q2.** **a)** The rainiest month on average across 1981 to 2010 is July, as evident from the below bar plot of the monthly climatology of precipitation.

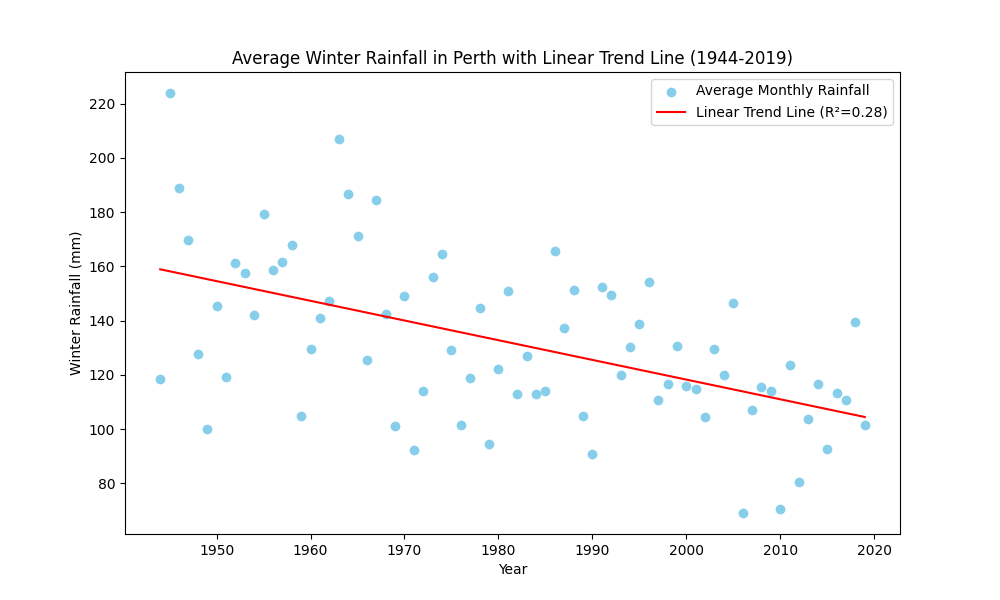


**Q2. b)** The trend line for the rainfall in July over the years 1944-2019 in Perth shows a slight downward trajectory, indicating a decrease in rainfall in the month of July over the years.



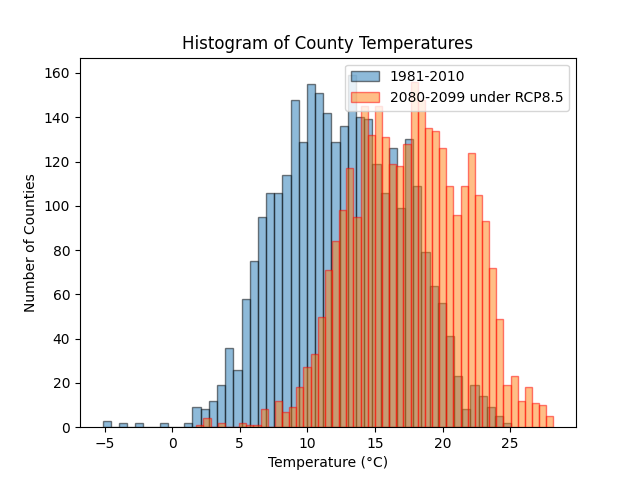
Based on the two-sample t-test performed using the scipy library in Python (see attached file), we see that the difference between the two periods is not statistically significant (fail to reject H0). This means that there is insufficient evidence to conclude that there is a significant difference in July rainfall between the earlier period (1951-1980) and the later period (1981-2010). Based on the available data and the statistical test performed, the variation in July rainfall observed between the two periods could be due to random chance rather than a systematic, significant change.

**Q2. c)** The trend line for rainfall during winter months in Perth over 1944 to 2019 shows a clear downward trajectory over time, indicating a steady decline in rainfall over the years. While there are outliers, the R-squared value of 0.28 shows a weak but present correlation between years and decrease in rainfall.



The result of the two-sample t-test shows that the difference in average winter rainfall trend is statistically significant since the p-value of 0.005178 is smaller than significance level of 0.05, contrary to the same test performed for just a single month. Since the p-value is less than the significance level, we reject the null hypothesis (H0) which states that there is no effect or no difference.   
Hence, it is safe to say that there is indeed a statistically significant difference in the average winter rainfall trend between the two periods being compared. The positive t-statistic of 2.906 indicates that the average winter rainfall in the later period is higher than in the earlier period.

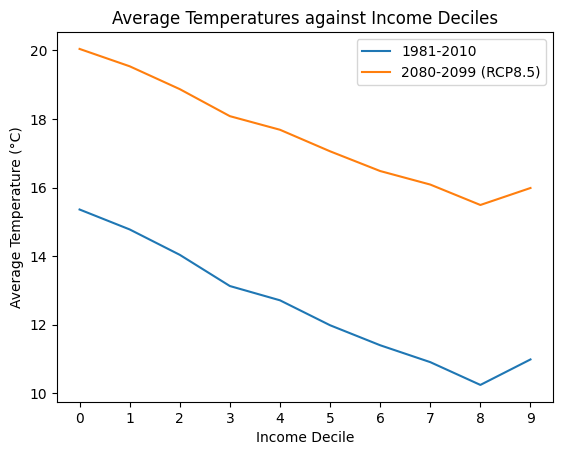
**Q3. a)** Based on the graph as shown below, we see that most counties’ temperatures will increase by around 5°C compared to historical climate as per the RCP8.5 emissions.



**Q3. b)** The below table contains all calculations as required:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Income  Decile | 1981-2010  (Normal) | 2020-2039  (RCP8.5) | 2040-2059  (RCP8.5) | 2080-2099  (RCP8.5) |
| 0 | 15.358 | 16.634 | 17.692 | 20.046 |
| 1 | 14.776 | 16.072 | 17.147 | 19.539 |
| 2 | 14.035 | 15.345 | 16.438 | 18.872 |
| 3 | 13.124 | 14.474 | 15.595 | 18.083 |
| 4 | 12.707 | 14.067 | 15.18 | 17.686 |
| 5 | 11.979 | 13.351 | 14.497 | 17.057 |
| 6 | 11.395 | 12.767 | 13.908 | 16.481 |
| 7 | 10.902 | 12.292 | 13.458 | 16.086 |
| 8 | 10.237 | 11.644 | 12.826 | 15.49 |
| 9 | 10.981 | 12.333 | 13.455 | 15.986 |
|  | *All figures (except Income Decile) are in °C* | | | |

**Q3. c)** Graph plotted using Python as specified below:



**Q3. d)** Based on the above plots, it is evident that the higher income deciles’ average temperature is much lower than those from lower income deciles. This implies that the population present in the lower income deciles will feel the highest impact of climate change, since the climate was already warmer for them compared to higher deciles, and it only worsens as per the RCP8.5 estimates.

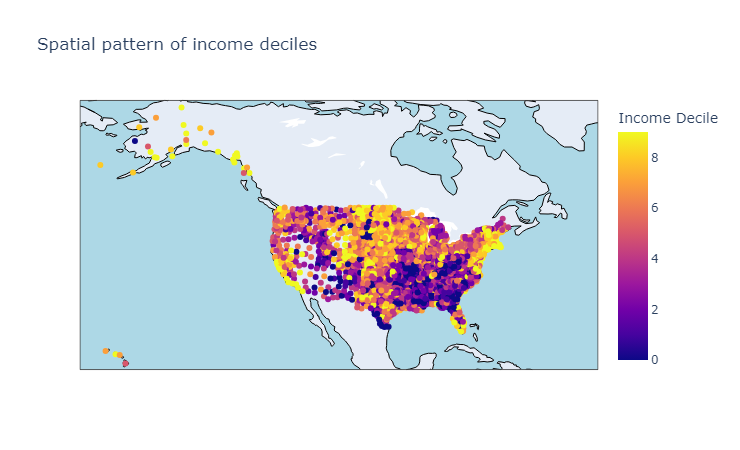
**Q3. e)** The variable created was “temp\_change” for the required purpose. Income decile 8 will experience the most change. Below is a table representing the various statistics associated with this income decile:

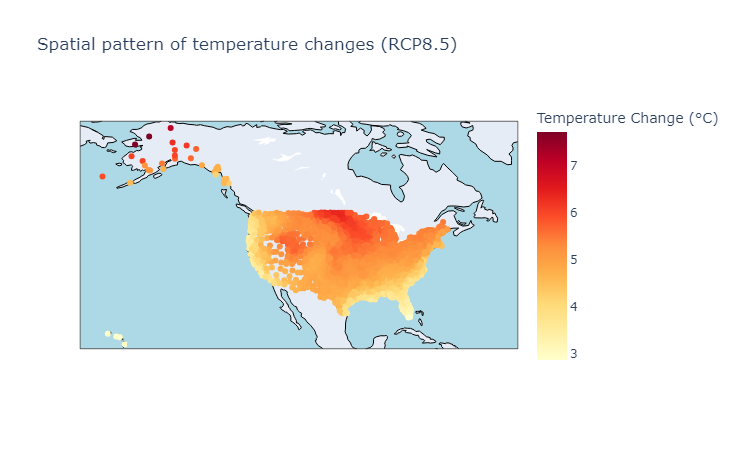
|  |  |  |  |
| --- | --- | --- | --- |
| Statistic | lat | lon | temp\_change |
| count | 311 | 311 | 311 |
| mean | 41.423 | -94.289 | 5.252 |
| std | 5.196 | 15.203 | 0.624 |
| min | 26.576 | -170.28 | 3.256 |
| 25% | 38.767 | -99.708 | 4.919 |
| 50% | 41.772 | -95.310 | 5.322 |
| 75% | 44.309 | -84.687 | 5.667 |
| max | 65.018 | -68.345 | 7.722 |

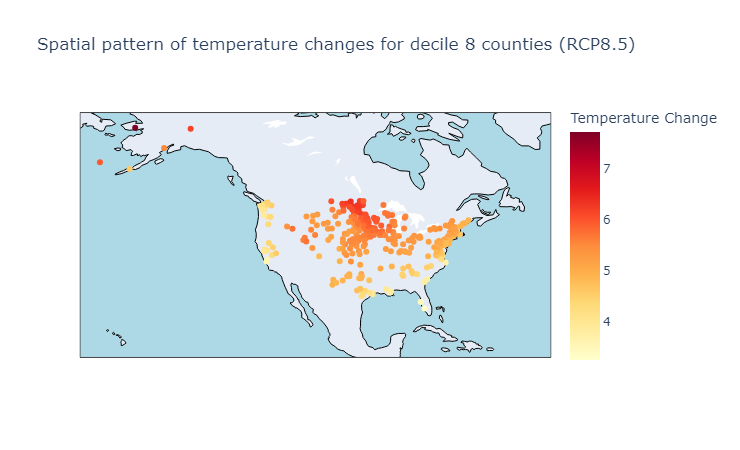
For comparison, here is a similar table comprising all deciles:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Statistic | lat | lon | temp\_change | Income Decile |
| count | 3112 | 3112 | 3112 | 3112 |
| mean | 38.471 | -92.390 | 4.983 | 4.500 |
| std | 5.329 | 12.877 | 0.595 | 2.874 |
| min | 19.598 | -170.28 | 2.878 | 0.000 |
| 25% | 34.659 | -98.348 | 4.678 | 2.000 |
| 50% | 38.418 | -90.495 | 5.072 | 4.500 |
| 75% | 41.852 | -83.602 | 5.361 | 7.000 |
| max | 69.306 | -67.638 | 7.722 | 9.000 |

Below are cartographical representations of these spatial patterns:

*Map 1*

*Map 2*

*Map 3*

In *Map 2*, we see that the temperature change is disproportionate. Counties farther north from the equator are heating much more than those closer to it. In other words, a higher latitude correlates to a higher temperature change. At the same time, the *Map 2* shows us that counties with higher income deciles are concentrated more around central USA, similar to the map showing decile 8 counties.

It seems that there may be some correlation between the counties having a higher income decile and temperature changes, as temperature changes seem to be the highest in those areas (*Map 3* and *Map 2* in combination with *Map 1*), as seen from the above maps. The latitudes that they occupy are higher up on the globe, ie, farther away from the equator as noted previously, and it may be the case that the higher temperature changes in these latitudes are due to a higher concentration of wealthier deciles (*Map 1*).

**Q3. f)** Seeing as to how climate change disproportionately affects poorer counties compared to wealthier ones, along with the fact that the temperature changes are the most pronounced in the wealthier counties (which will eventually influence neighboring and global climate; rich and poor alike – the latter for no fault of their own, without any of the benefits reaped by the wealthier counties from likely higher emissions) it would be appropriate that equitable climate adaptation includes a component of wealth transfer. This can be achieved in several ways, one of which could be taxing richer people and corporations higher and using that as a kickback for better resources, infrastructure and development of more sustainable consumption, majorly benefitting the poorer counties. Regulations are another way to achieve higher equity, where there may be limits or caps on how much carbon emissions are allowed per unit (per capita, per county, or others).

Q4.