Homework #3

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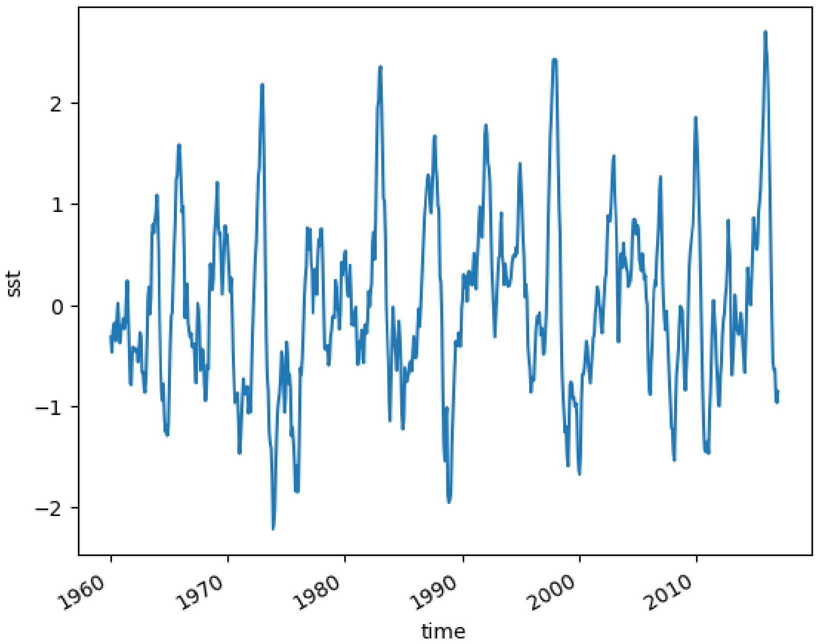
Problem 1: The Niño 3.4 anomalies may be thought of as representing the average equatorial sea surface temperatures (SSTs) across the Pacific from about the dateline to the South American coast (5N-5S, 170W-120W). The Niño 3.4 index typically uses a 3-month running mean, and El Niño or La Niña events are defined when the Niño 3.4 SSTs exceed +/- 0.5°C for a period of 5 months or more. Check Equatorial Pacific Sea Surface Temperatures for more about the Niño 3.4 index.

1.1 [10 points] Compute monthly climatology for SST from Niño 3.4 region, and subtract climatology from SST time series to obtain anomalies.

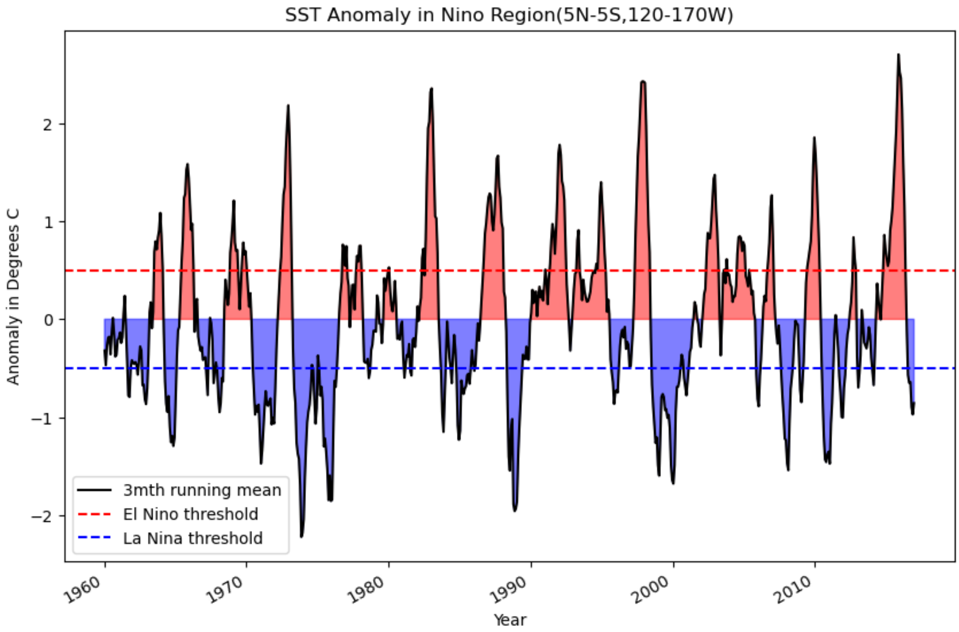
Answer: First, the data file for sea surface temperature is read to obtain the dataset and is stored in variable **ds**. The sel function is used to select the data in the El Niño 3.4 region. Then, in combination with the groupby function, the monthly average of sea surface temperature is calculated to obtain the climatology. Subsequently, the data grouped by month is subtracted from the climatology to obtain the anomalies. Finally, the global average anomalies of sea surface temperature are plotted.The final graph is as follows:



1.2 [10 points] Visualize the computed Niño 3.4. Your plot should look similar to this one.

Answer: As described in Section 1.1, the first step involved the computation of anomalies in sea surface temperatures, which refers to the deviation of sea surface temperatures from their climatological mean. The anomalies were calculated by taking the average over both longitude and latitude dimensions, resulting in the global mean sea surface temperature anomaly. A three-month rolling average was then applied using the rolling function to obtain the El Niño 3.4 index.

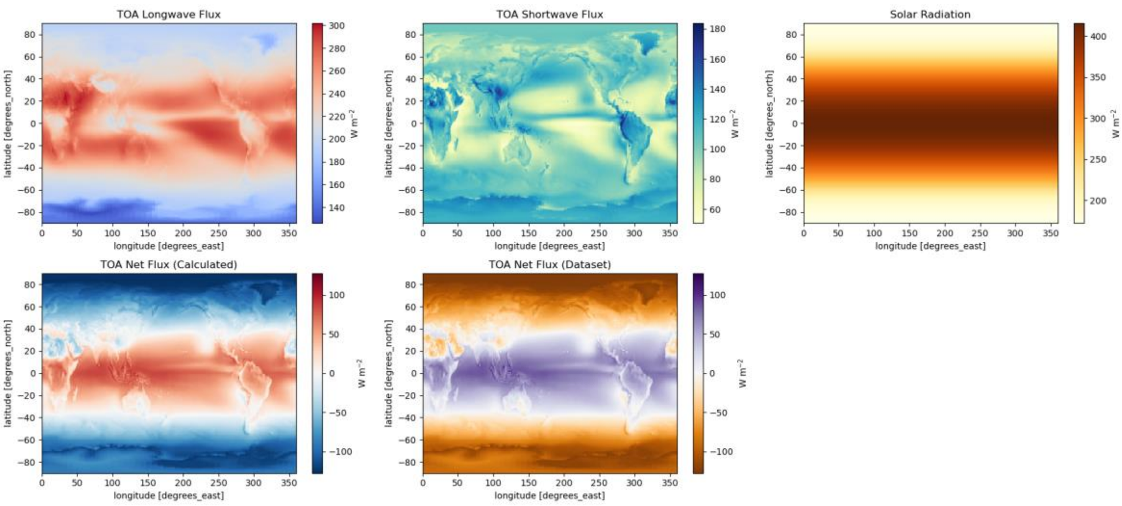
A canvas and graphical representation were created to illustrate the variation of the El Niño 3.4 index. The graph was generated with different colors filling the areas corresponding to positive and negative anomalies, where the positive values were represented in red and negative values in blue. El Niño and La Niña thresholds were delineated based on the definition of El Niño and La Niña events. The final result, the SST Anomaly in the Nino Region, is displayed in the figure below：



Problem 2: In this problem set, you will analyze top-of-atmosphere (TOA) radiation data from NASA's CERES project. Read this post for more about Earth's energy budget. Download the data (CERES_EBAF-TOA_200003-201701.nc) [here](). The size of the data file is 702.5 MB. It will take a minute or two to download. Start by importing xarray, numpy, and matplotlib.

2.1 [5 points] Make a 2D plot of the time-mean TOA longwave, shortwave, and solar radiation for all-sky conditions. Add up the three variables above and verify (visually) that they are equivalent to the TOA net flux.

Answer: Firstly, the dataset was read using the xr.open_dataset() method from the xarray library. Subsequently, the mean(dim='time') method was employed to calculate the temporal averages of Top of Atmosphere Longwave Radiation (toa_lw_mean), Top of Atmosphere Shortwave Radiation (toa_sw_mean), and Solar Radiation (solar_mean). Following this, the Top of Atmosphere Net Radiation (toa_net_calc) was computed using these mean values, defined as the difference between Solar Radiation and the sum of Top of Atmosphere Longwave and Shortwave Radiation. Afterwards, an irregular subplot grid (GridSpec) consisting of 2 rows and 3 columns of images was created using the Matplotlib library. Subsequently, Top of Atmosphere Longwave Radiation, Top of Atmosphere Shortwave Radiation, Solar Radiation, the calculated Top of Atmosphere Net Radiation, and the provided Top of Atmosphere Net Radiation from this dataset were individually plotted on this subplot grid. Finally, the layout of the images was ensured to be compact using plt.tight_layout(), and the resulting plot was displayed using plt.show() as shown below:



Upon visual inspection, the calculated result equals the TOA net flux.

2.2 [10 points] Calculate and verify that the TOA incoming solar, outgoing longwave, and outgoing shortwave approximately match up with the cartoon above.

Answer: Firstly, the radius of the Earth (in meters) is defined as the constant earth_radius. The latitude difference (dlat_rad) and longitude difference (dlon_rad) are calculated by converting the differences in latitude and longitude to radians. To match the size of the grid cells, additional differences are added to dlat_rad and dlon_rad. The weights and grid area for each latitude band are calculated based on the latitude edges. The code uses the sine function to compute weights, which are then multiplied by the square of the Earth's radius, latitude difference, and weight difference. Using the calculated latitude weights and longitude difference, the total grid area for each grid cell is determined. Next, the time averages of three variables (toa_lw_all_mon, toa_sw_all_mon, and solar_mon) are calculated separately. Using xr.DataArray, grid_area_da is created for weighted averaging of the three variables. Finally, the calculated incoming solar radiation flux, outgoing longwave radiation flux, and outgoing shortwave radiation flux are printed.The result is as follows:

TOA Incoming Solar Flux: 340.28513

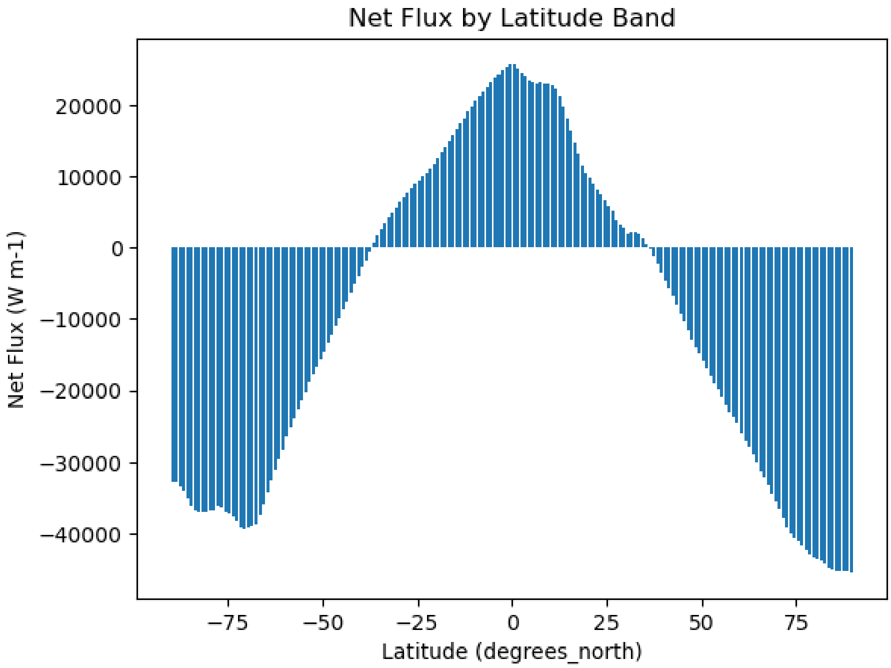
TOA Outgoing Longwave Flux: 240.268

TOA Outgoing Shortwave Flux: 99.139046

Upon examination, the calculated results are consistent with the diagram provided in the question.

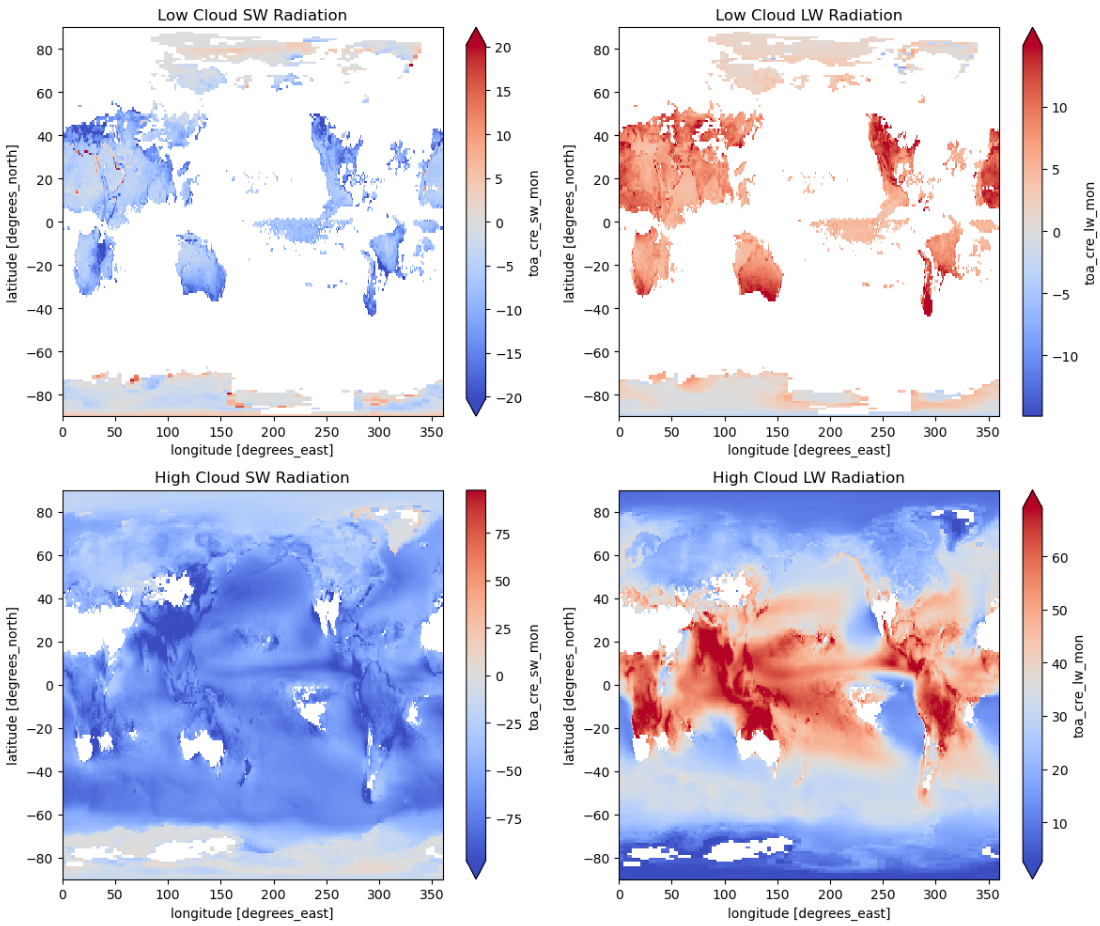
2.3 [5 points] Calculate and plot the total amount of net radiation in each 1-degree latitude band. Label with correct units.

Answer: Calculate the total net radiation sum along the latitude using .sum(dim='lon') and plot the resulting bar graph：



2.4 [5 points] Calculate and plot composites of time-mean outgoing shortwave and longwave radiation for low and high cloud area regions. Here we define low cloud area as ≤25% and high cloud area as ≥75%. Your results should be 2D maps.

Answer: Firstly, create masks for low clouds and high clouds using the data from da['cldarea_total_daynight_mon']. Obtain the low cloud mask low_cloud_mask by using <= 25 and the high cloud mask high_cloud_mask by using >= 75. Next, calculate the time-averaged output of shortwave and longwave radiation for the low cloud region using the data from da['toa_cre_sw_mon'] and da['toa_cre_lw_mon']. Apply the masks for low and high clouds (low_cloud_mask and high_cloud_mask) using the .where() method, and calculate the time average using .mean(dim='time') to obtain toa_cre_sw_low/high_cloud and toa_cre_lw_low/high_cloud. Finally, plot the corresponding images, showing the output of shortwave radiation for the low cloud region, the output of longwave radiation for the low cloud region, the output of shortwave radiation for the high cloud region, and the output of longwave radiation for the high cloud region.



2.5 [5 points] Calculate the global mean values of shortwave and longwave radiation, composited in high and low cloud regions. What is the overall effect of clouds on shortwave and longwave radiation?

Answer: Firstly, based on the threshold of cloud coverage, masks for low-cloud and high-cloud areas are defined. The cloud coverage in the low-cloud area is less than or equal to 25%, while in the high-cloud area, it is greater than or equal to 75%. Next, the mean function is applied to longitude, latitude, and time to obtain the global average shortwave radiation and average longwave radiation. Then, in the low-cloud area, the shortwave and longwave radiations for the low-cloud area are synthesized based on the mask. The where function is used to set areas that do not satisfy the low-cloud area mask to NaN. Afterward, the mean is calculated for longitude, latitude, and time to obtain the average shortwave and longwave radiations for the low-cloud area. Similarly, in the high-cloud area, the shortwave and longwave radiations for the high-cloud area are synthesized based on the mask. Finally, the following results are printed:

toa_sw_all_global: 102.30436

toa_lw_all_global: 224.7552

toa_sw_low_cloud: 97.11116

toa_lw_low_cloud: 247.33109

toa_sw_high_cloud: 111.76594

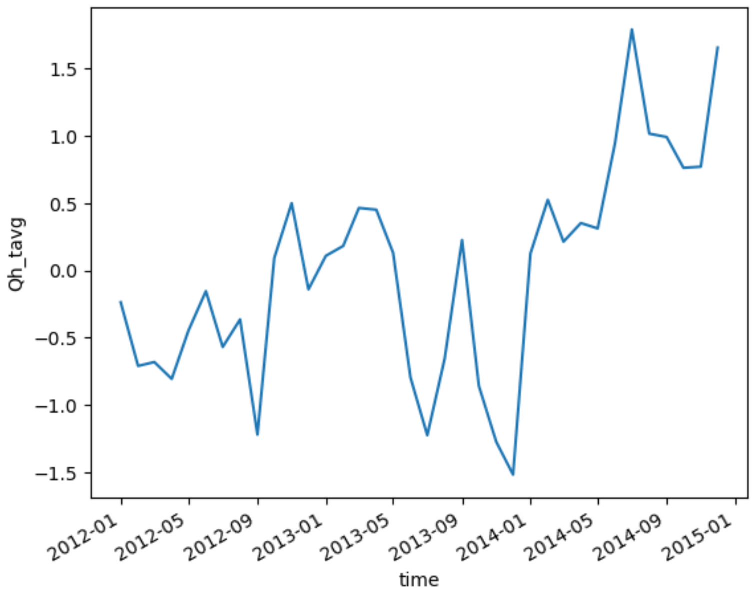
toa_lw_high_cloud: 215.39049

Through calculation, it can be observed that low cloud areas weaken shortwave radiation and enhance longwave radiation, while in high cloud areas, the opposite occurs—high cloud areas strengthen shortwave radiation and weaken longwave radiation.

Problem 3: Browse the NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC) website. Search and download a dataset you are interested in. You are also welcome to use data from your group in this problem set. But the dataset should be in netCDF format, and have temporal information.

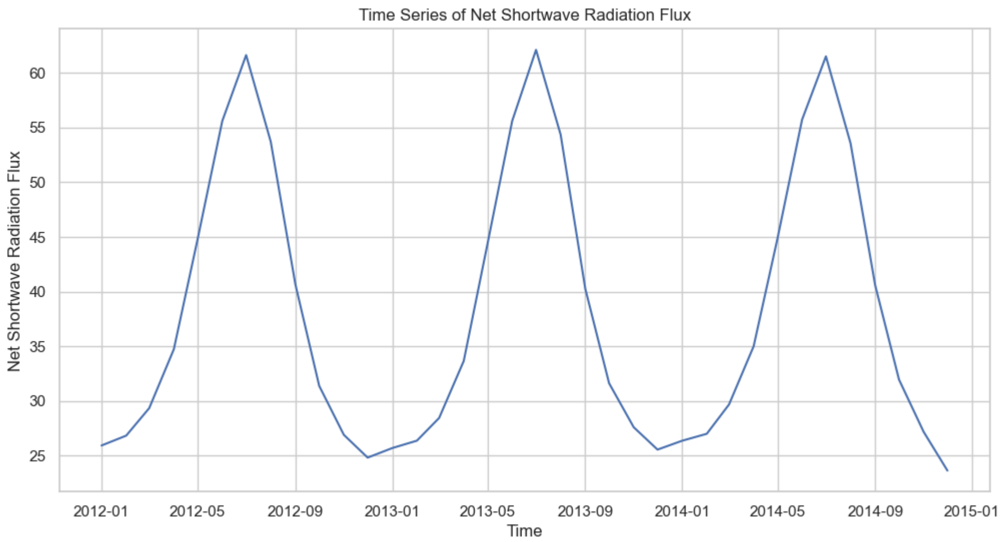
3.1 [5 points] Plot a time series of a certain variable with monthly seasonal cycle removed.

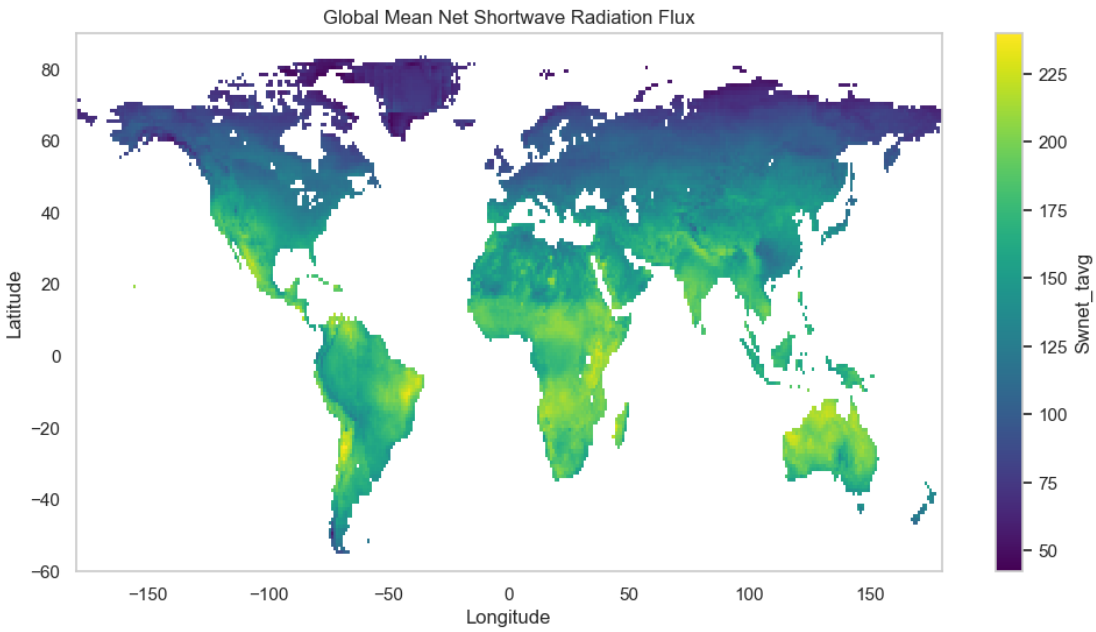
Answer: The result graph is as follows:

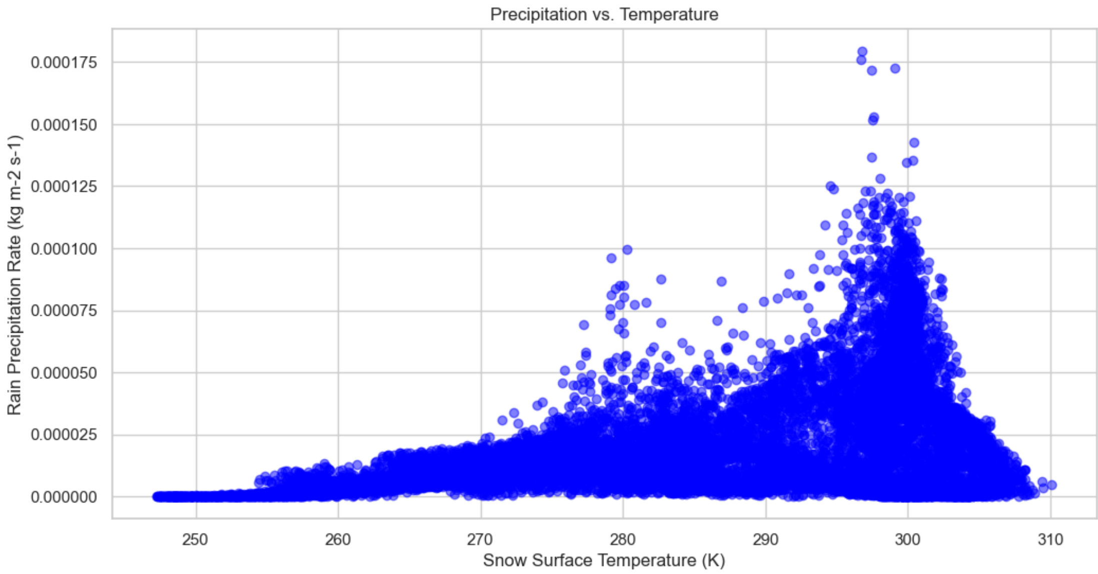


3.2 [5 points] Make at least 5 different plots using the dataset.

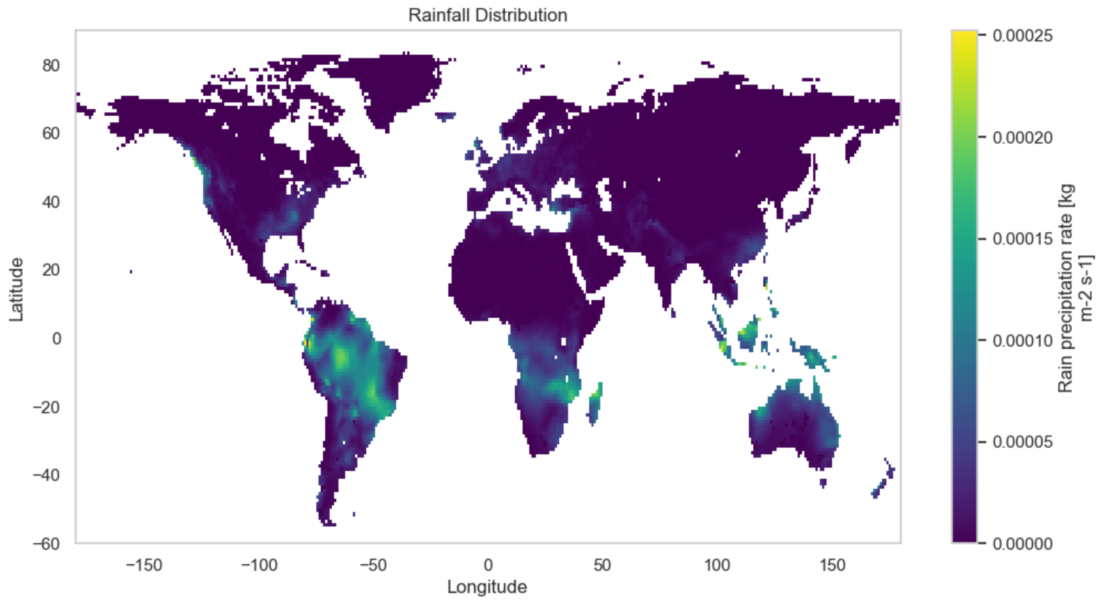
Answer: The result graphs are as follows:



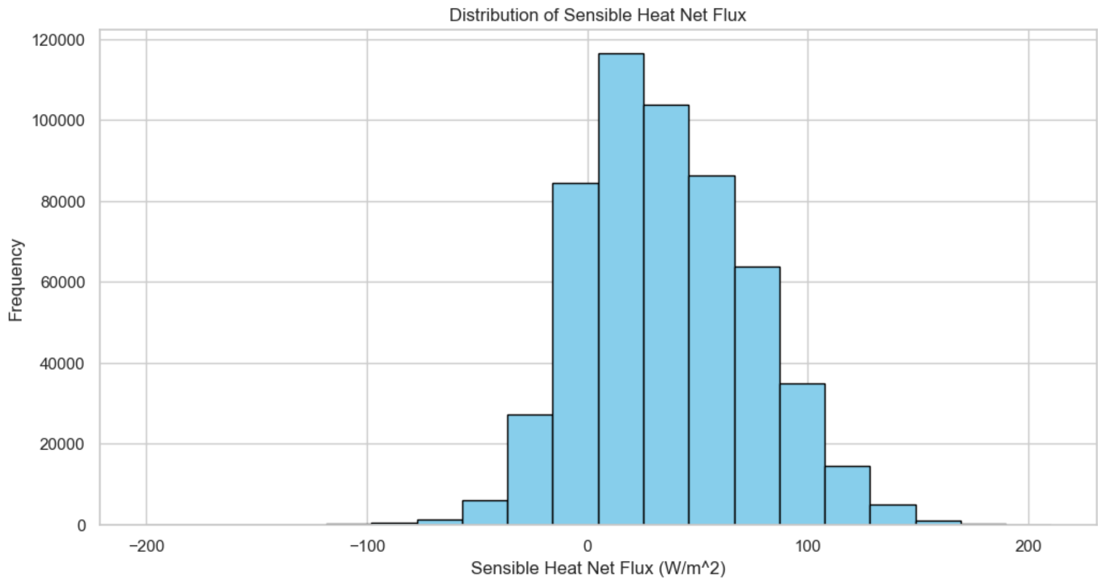




Precipitation vs. Temperature
Rain Precipitation Rate (kg m-2 s-1)
0.000175
0.000150
0.000125
0.000100
0.000075
0.000050
0.000025
0.000000
250
260
270
280
290
300
310
Snow Surface Temperature (K)



Rainfall Distribution
Latitude
80
60
40
20
0
−20
−40
−60
−150
−100
−50
0
50
100
150
Longitude
Rain precipitation rate [kg m-2 s-1]
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000



Distribution of Sensible Heat Net Flux
Frequency
120000
100000
80000
60000
40000
20000
0
−200
−100
0
100
200
Sensible Heat Net Flux (W/m^2)