1. Niño 3.4 index

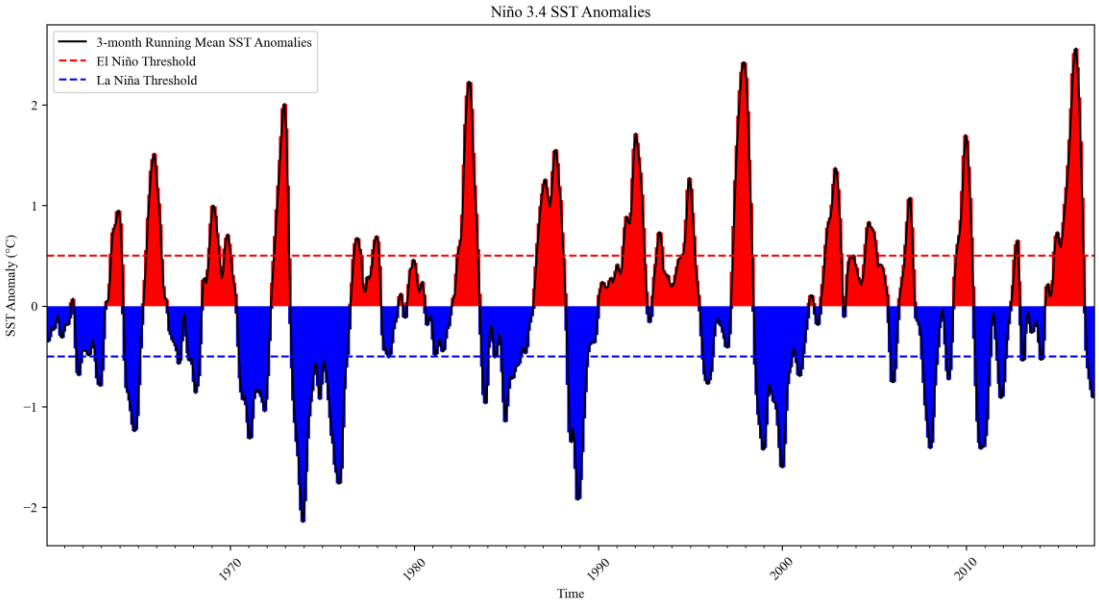
The *Niño 3.4 anomalies* may be thought of as representing the average equatorial sea surface temperatures (SSTs) across the Pacific from about the dateline to the South American coast (`5N-5S`, `170W-120W`). The Niño 3.4 index typically uses a 3-month running mean, and El Niño or La Niña events are 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.

In this problem set, you will use the sea surface temperature (SST) data from NOAA. Download the `netCDF4` file (`NOAA_NCDC_ERSST_v3b_SST.nc`) here.

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

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

使用 plt.axhline 画虚线
使用.bar 画柱状图，然后根据数据是否大于 0 判断颜色。



2. Earth's energy budget

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.

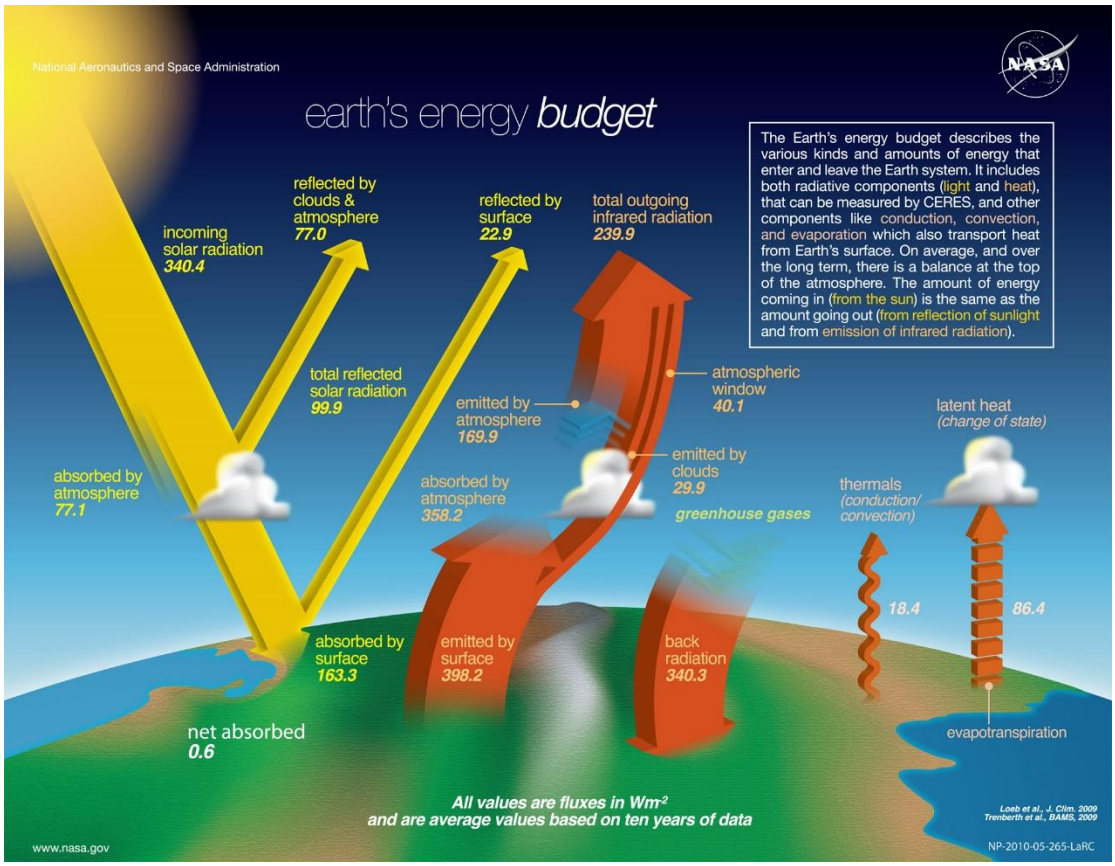


Figure source

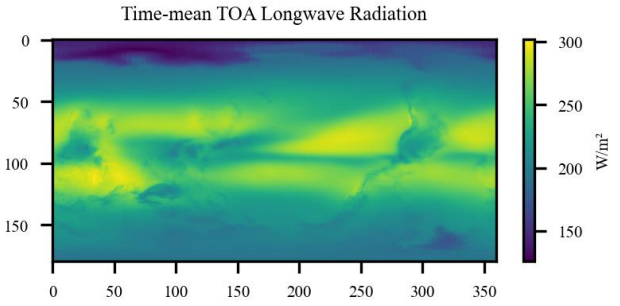
Download the data (`CERES_EBAF-TOA_200003-201701.nc`) here. The size of the data file is `702.5 MB`. It will take a minute or two to download. Start by importing `xarray`, `numpy`, and `matplotlib`.

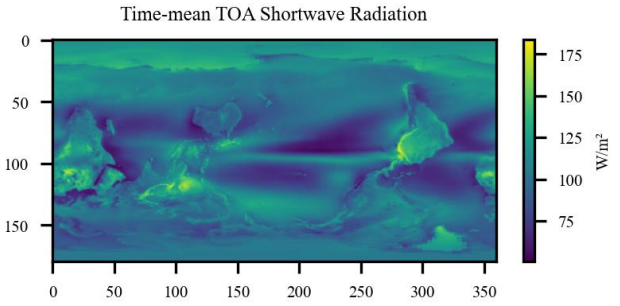
2.1 [5 points] Make a 2D plot of the time-mean TOA longwave, shortwave, and solar radiation for all-sky conditions. Add up the three variables above and verify (visually) that they are equivalent to the TOA net flux.

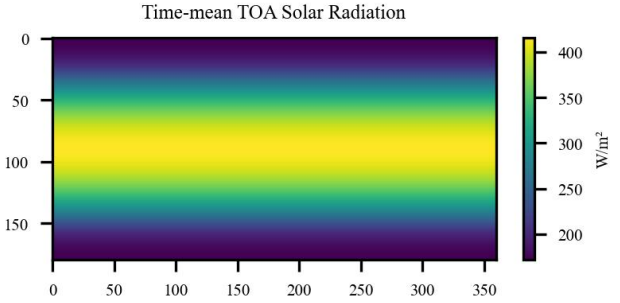
计算辐射的时间平均值：对数据集中的 'toa_lw_all_mon'（全天顶长波辐射）、'toa_sw_all_mon'（全天顶短波辐射）和 'solar_mon'（太阳辐射）进行时间平均。

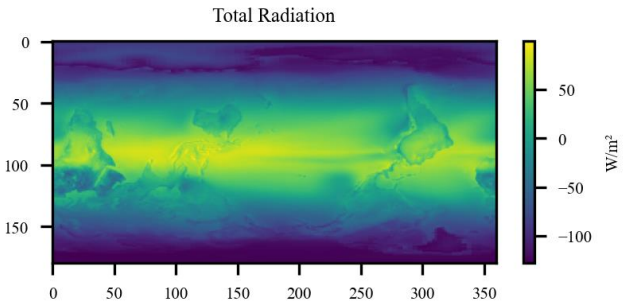
计算总辐射：将太阳辐射减去长波辐射和短波辐射，得到总辐射。

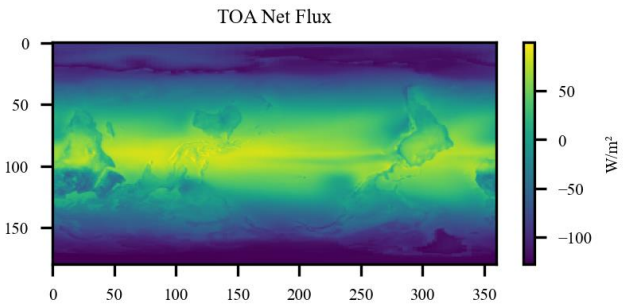
绘制 TOA（顶层大气）净辐射：计算 'toa_net_all_mon'（全天顶净辐射）的时间平均值，并绘制。


Time-mean TOA Longwave Radiation
0
50
100
150
0
50
100
150
200
250
300
350
300
250
200
150
W/m²


Time-mean TOA Shortwave Radiation
0
50
100
150
0
50
100
150
200
250
300
350
175
150
125
100
75
W/m²


Time-mean TOA Solar Radiation
0
50
100
150
0
50
100
150
200
250
300
350
400
350
300
250
200
W/m²


Total Radiation
0
50
100
150
0
50
100
150
200
250
300
350
50
0
−50
−100
W/m²


TOA Net Flux
0
50
100
150
0
50
100
150
200
250
300
350
50
0
−50
−100
W/m²

longwave, and outgoing shortwave approximately match up with the cartoon above.

[Hint: Consider calculating the area of each grid]

先算出网格的面积，然后最后除以地球表面积

Earth area: 5.2458865e+18 m^2

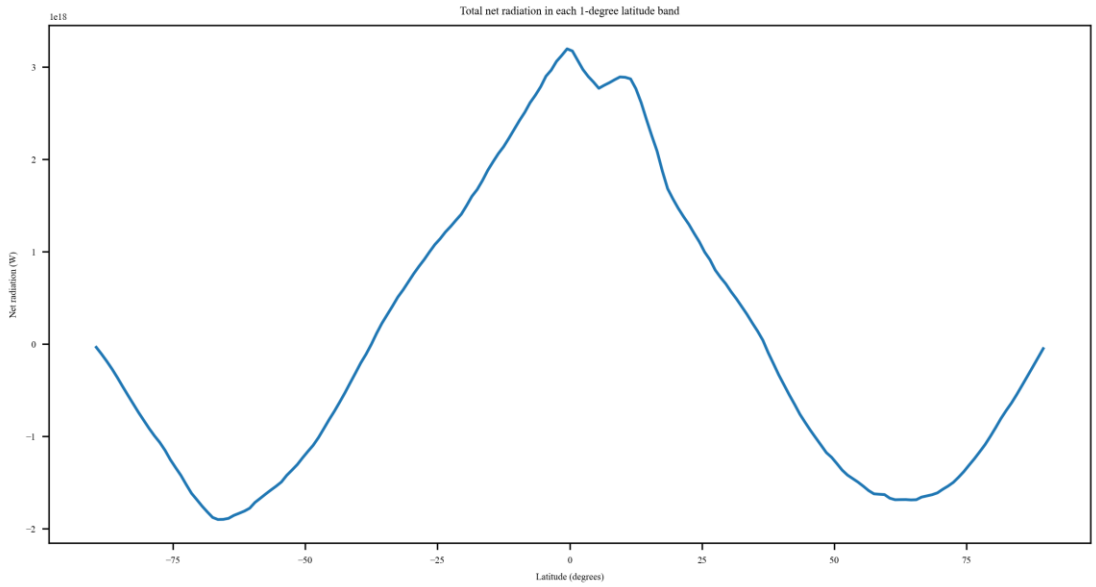
Total incoming solar radiation: 340.2850341796875 W/m^2

Total outgoing longwave radiation: 240.4961395263672 W/m^2

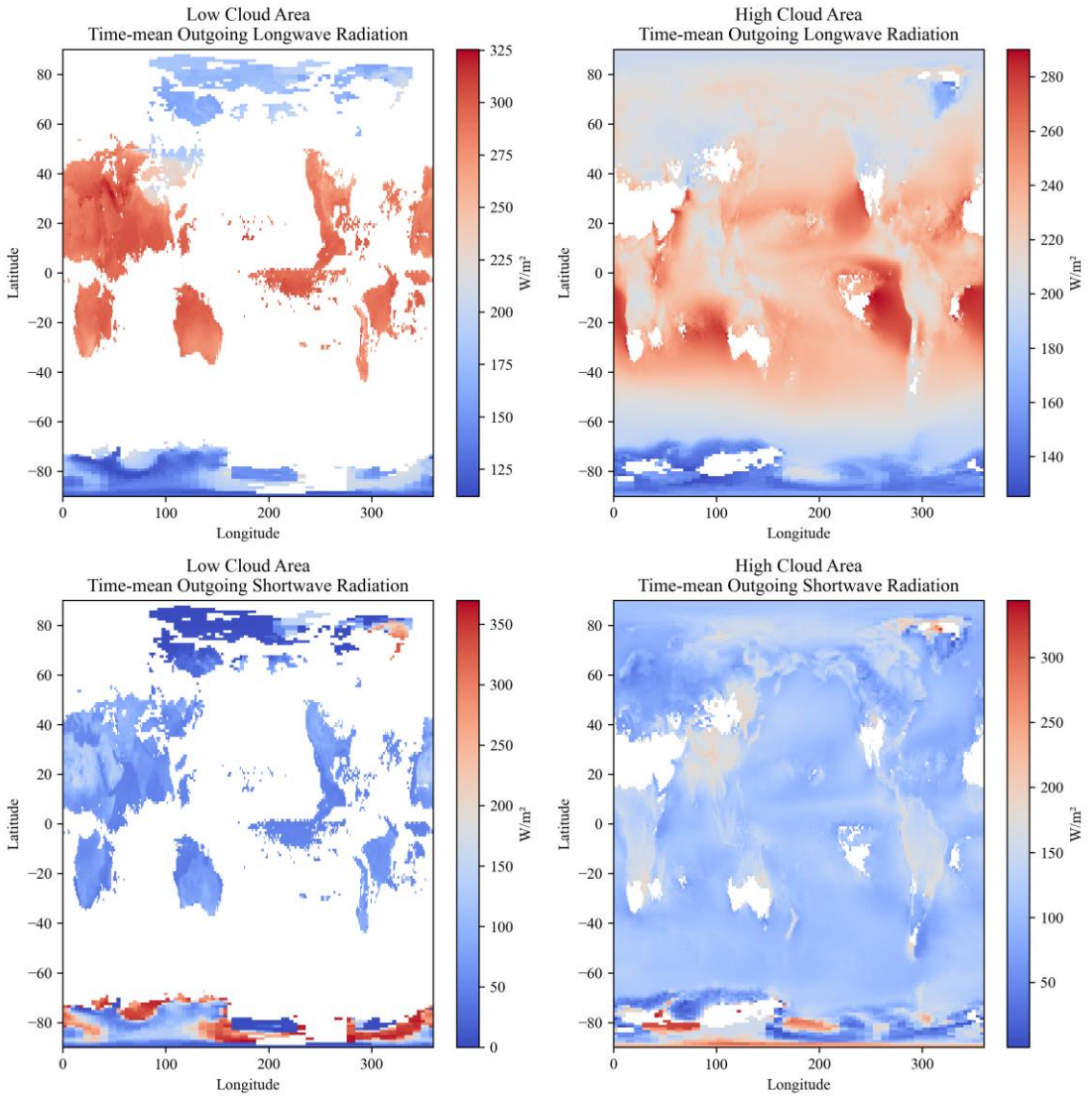
Total outgoing shortwave radiation: 98.21063232421875 W/m^2

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

要乘网格面积



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 $\leq 25\%$ and high cloud area as $\geq 75\%$. Your results should be 2D maps.



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?

Global mean outgoing longwave radiation in low cloud area: 247.33109 W/m^2

Global mean outgoing longwave radiation in high cloud area: 215.39049 W/m^2

Global mean outgoing shortwave radiation in low cloud area: 97.11116 W/m^2

Global mean outgoing shortwave radiation in high cloud area: 111.76594 W/m^2

云层对短波和长波辐射的影响可以通过比较低云区和高云区的辐射值来分析。对于长波辐射（通常指地球表面向大气散发的热辐射），低云区的全球平均出射长波辐射为 247.33109 W/m^2，高云区的为 215.39049 W/m^2。这表明低云区的出射长波辐射比高云区的要高，云层越低，长波辐射的损失越小。这是因为低云区比高云区更暖和，因此它们会向外辐射更

多的热能。对于短波辐射（通常指太阳辐射），低云区的全球平均出射短波辐射为 97.11116 W/m^2，高云区的为 111.76594 W/m^2。这表明高云区的出射短波辐射比低云区的要高，云层越高，反射回太空的短波辐射越多。这是因为高云层位于大气较高的位置，更能有效地反射阳光。
综上所述，云层对短波辐射有着显著的反射作用，特别是高云区对短波辐射的反射作用更为强烈。而对于长波辐射，低云区比高云区有更低的辐射损失。因此，总体来看，云层会增加地球系统的反射短波辐射，并减少逸出到太空的长波辐射，这对地球的辐射平衡和气候系统有着重要影响。

3. Explore a `netCDF` dataset

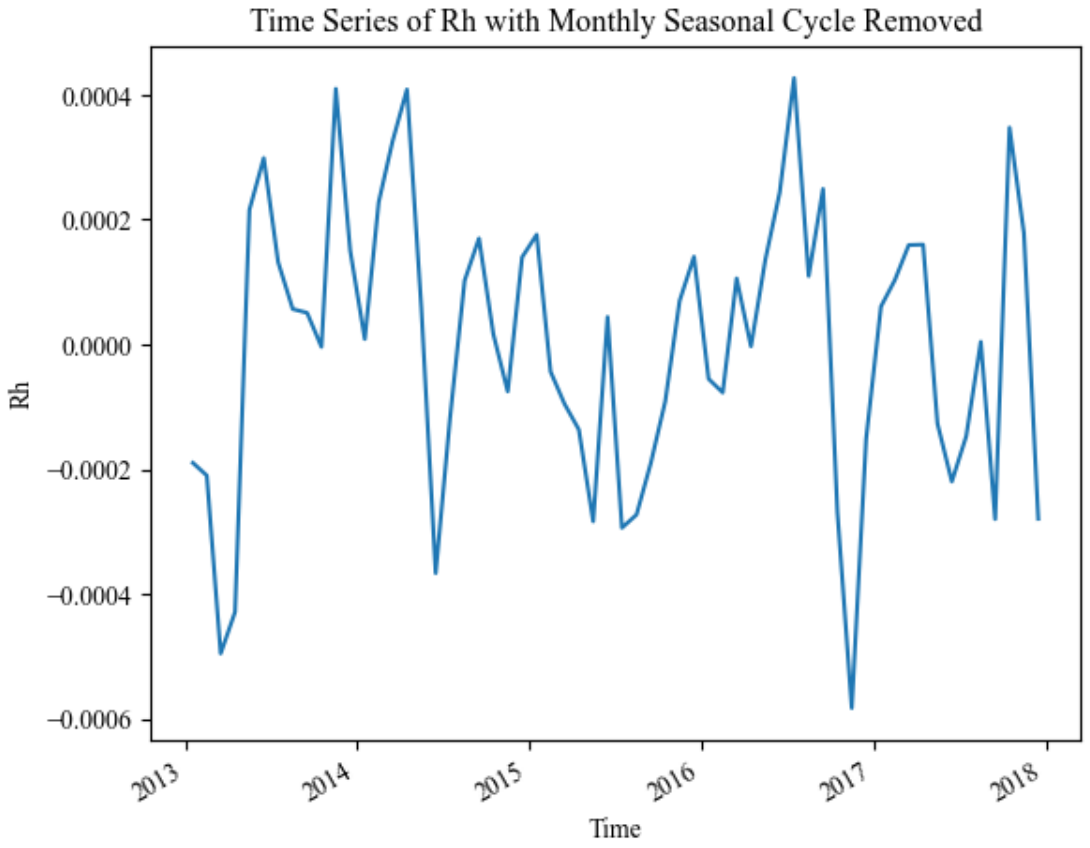
Browse the NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC) website. Search and download a dataset you are interested in. You are also welcome to use data from your group in this problem set. But the dataset should be in `netCDF` format, and have temporal information.

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

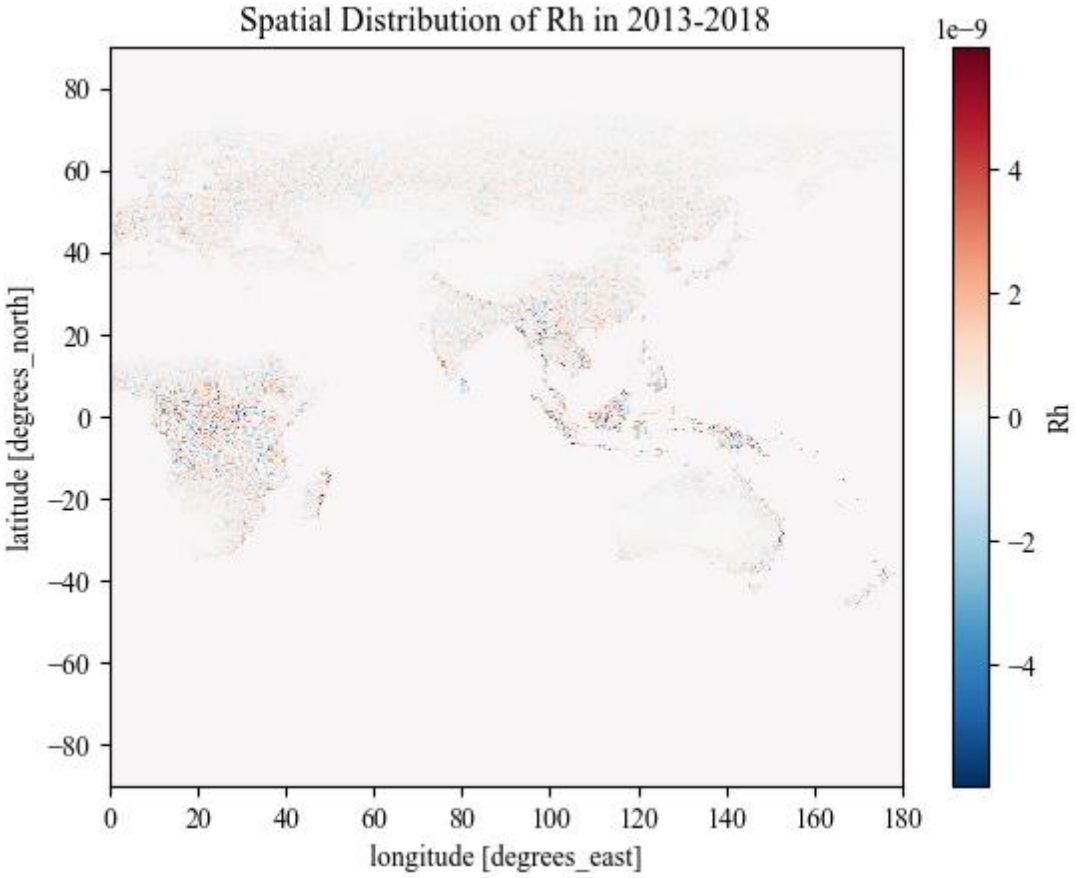
选择数据：从合并的数据集中选择变量 'Rh'，并限制纬度和经度的范围。

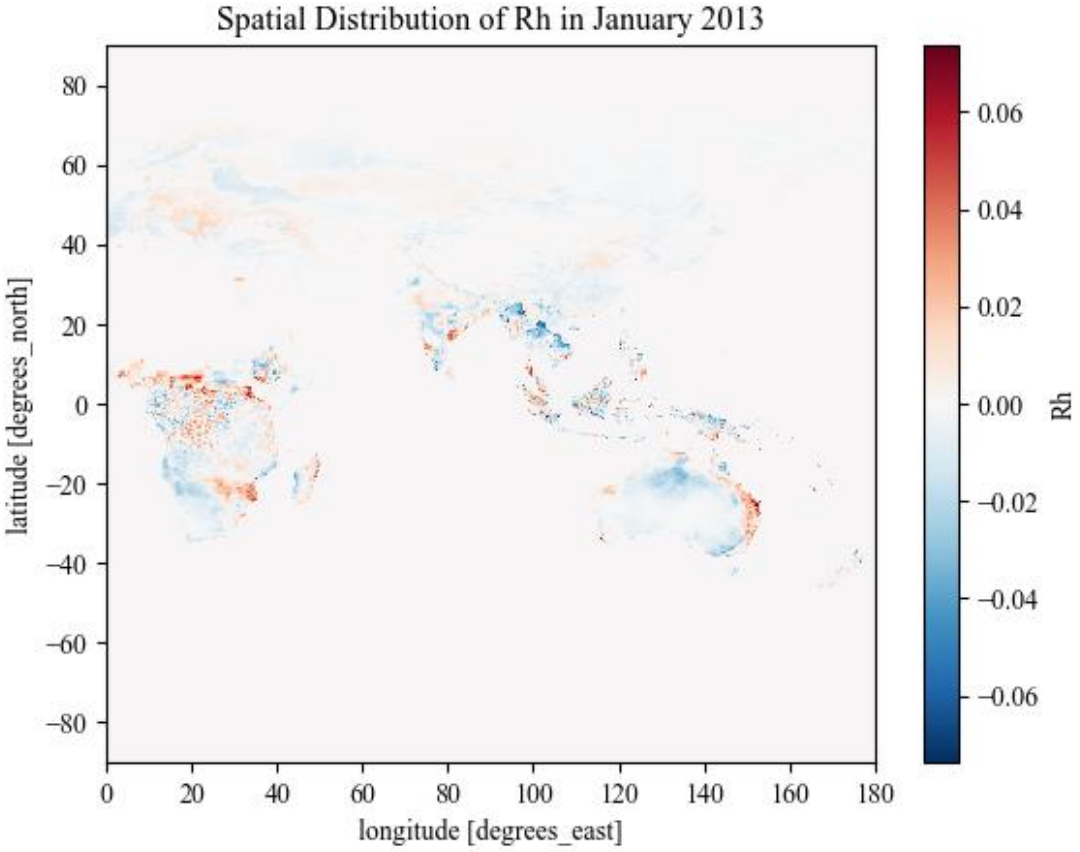
去季节化处理：对 'Rh' 数据进行去季节化处理，即减去每个月的平均值。

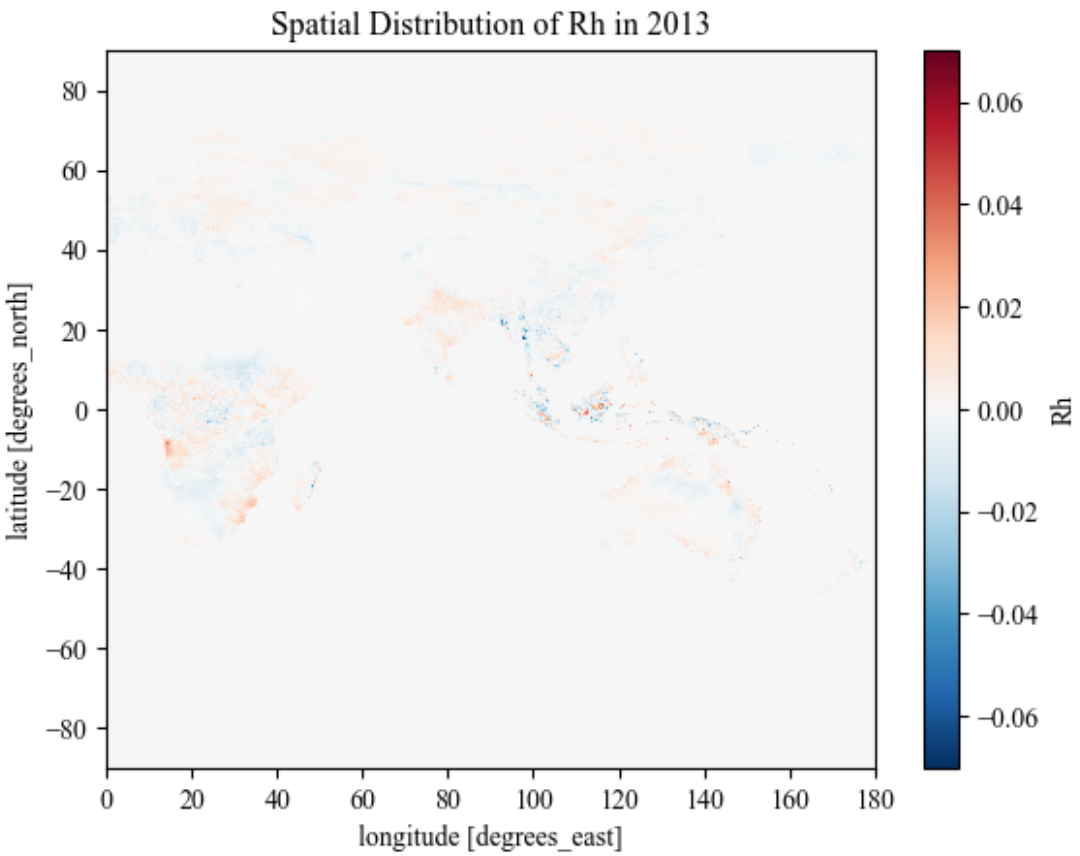
绘制时间序列图：计算去季节化处理后的 'Rh' 数据的平均值，并绘制时间序列图。

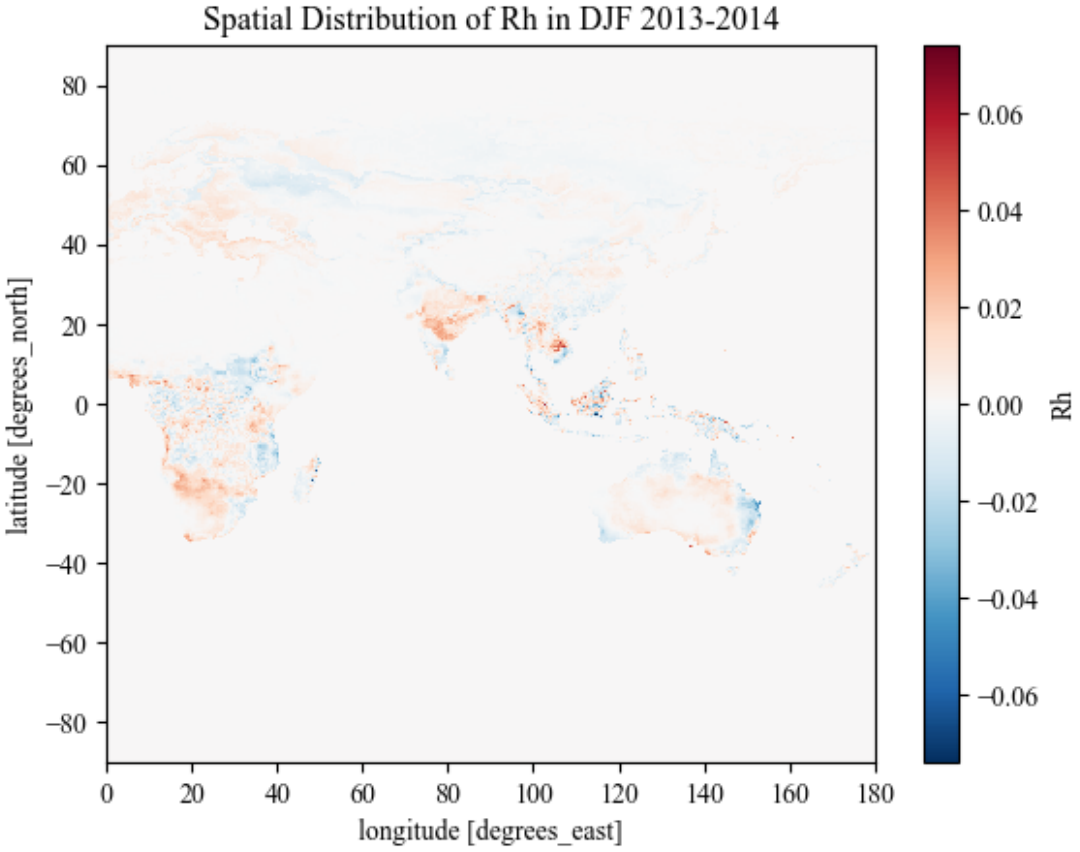


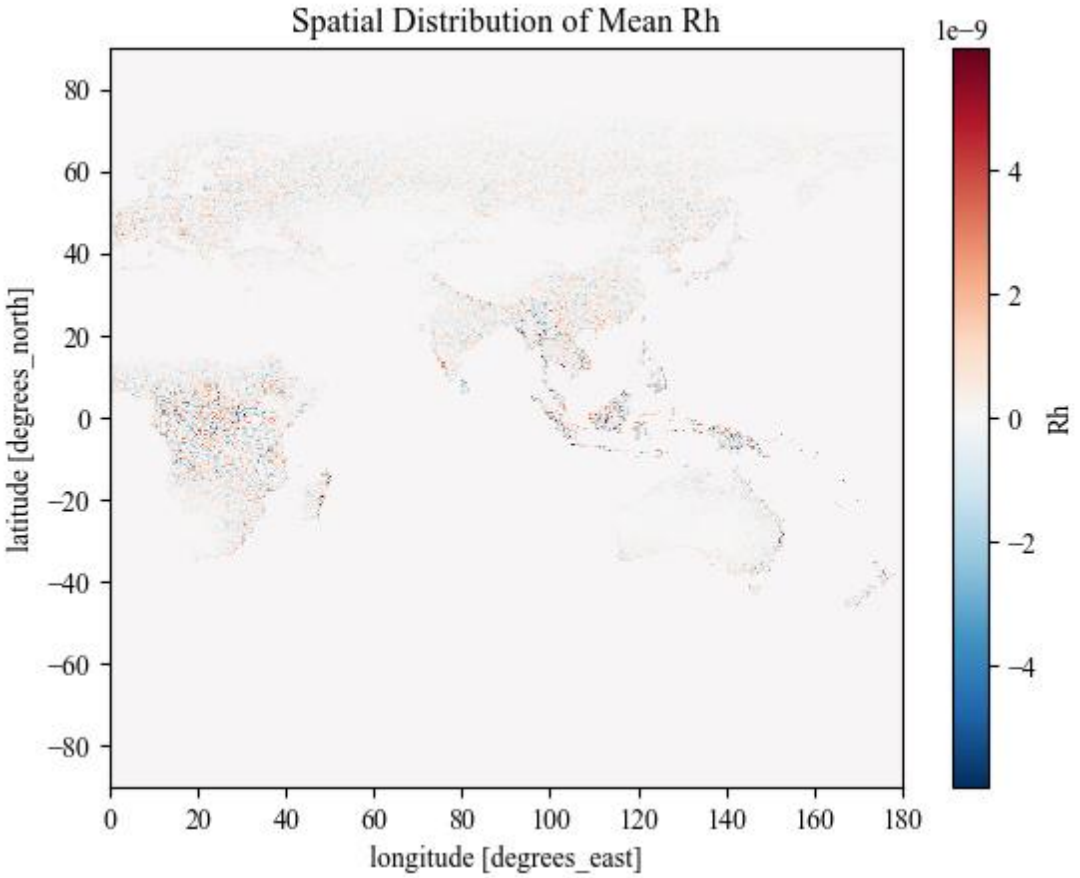
3.2 [5 points] Make at least 5 different plots using the dataset.




Spatial Distribution of Rh in January 2013
latitude [degrees_north]
longitude [degrees_east]
Rh
80
60
40
20
0
−20
−40
−60
−80
0
20
40
60
80
100
120
140
160
180
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06


Spatial Distribution of Rh in 2013
latitude [degrees_north]
longitude [degrees_east]
Rh
80
60
40
20
0
−20
−40
−60
−80
0
20
40
60
80
100
120
140
160
180
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06


Spatial Distribution of Rh in DJF 2013-2014
latitude [degrees_north]
longitude [degrees_east]
Rh
80
60
40
20
0
−20
−40
−60
−80
0
20
40
60
80
100
120
140
160
180
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06


Spatial Distribution of Mean Rh
1e−9
latitude [degrees_north]
longitude [degrees_east]
Rh
80
60
40
20
0
−20
−40
−60
−80
0
20
40
60
80
100
120
140
160
180
4
2
0
−2
−4