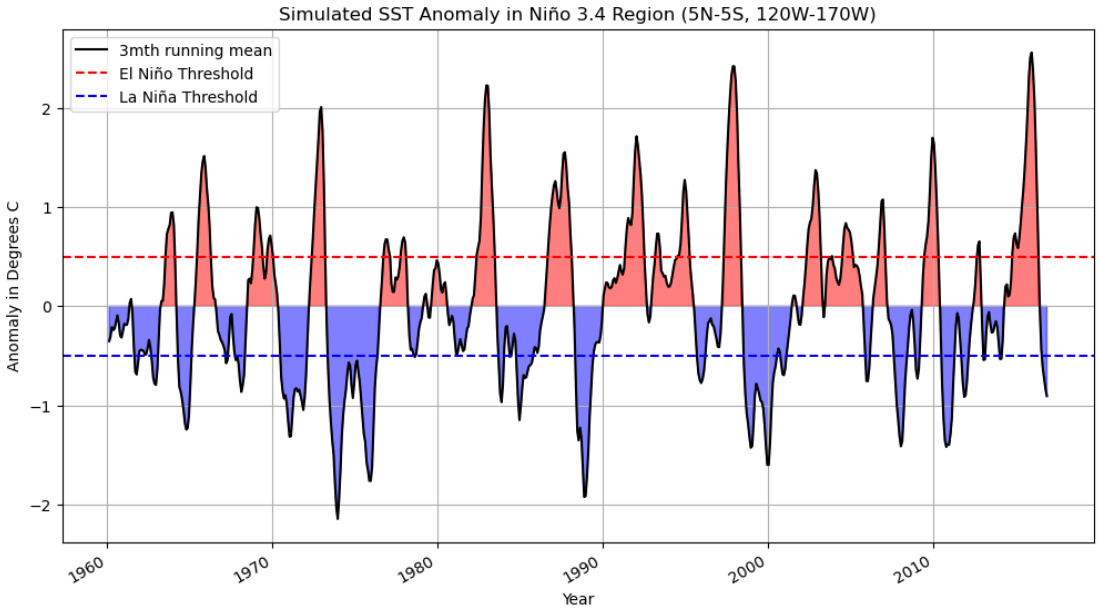
Problem 1

1.1 为了得到 SST 的月数据，通过代码：

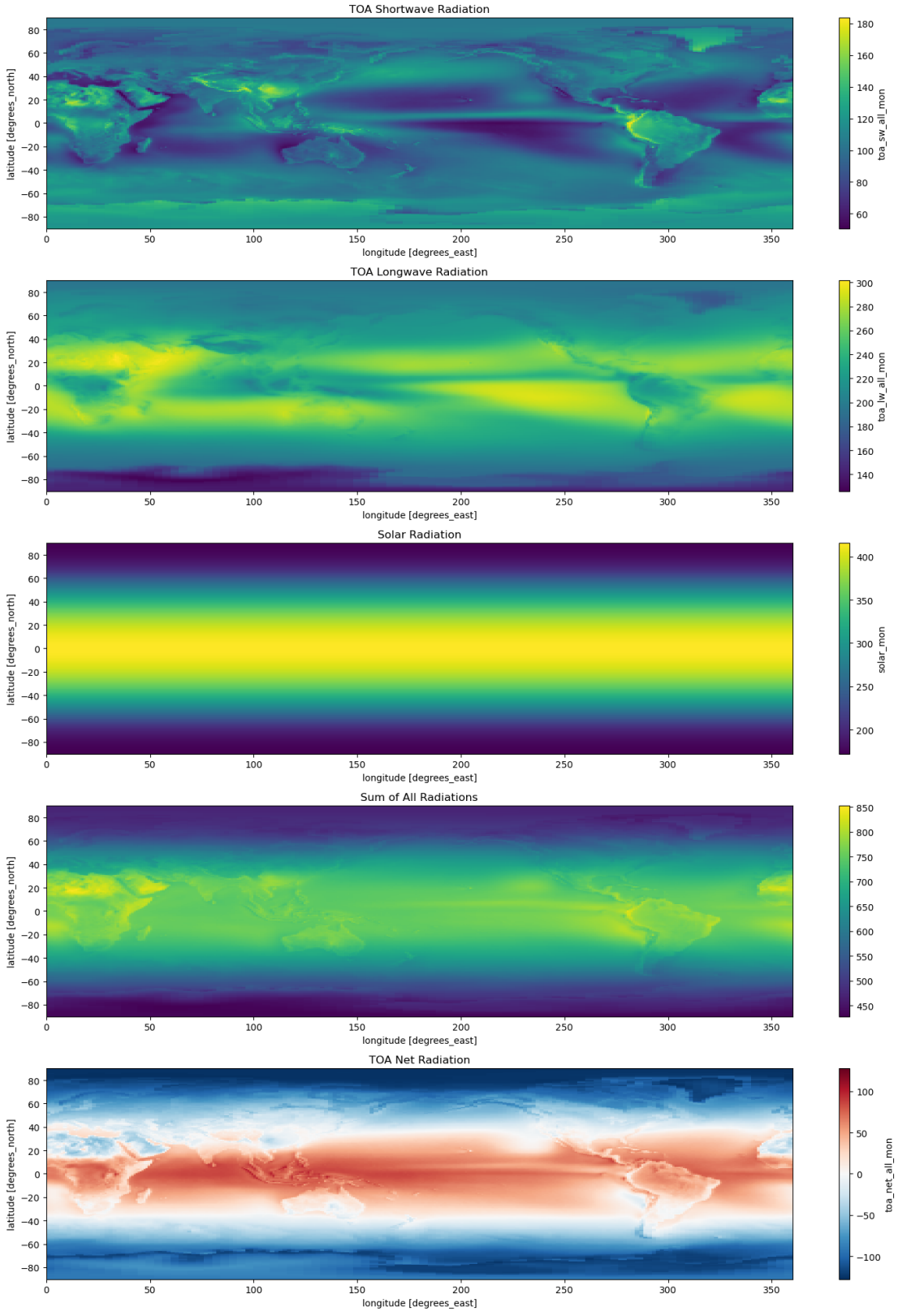
monthly_climatology = nino34_sst.groupby('time.month').mean('time')实现，再用各月份的 SST 减掉平均值，即可得到异常的数据。

1.2 将得到的 SST 异常数据，按照经纬度进行平均，再将大于 0 的部分填充为红色，将小于 0 的部分填充为蓝色，通过 plt.fill_between()实现，得到图像如下：



Problem 2

2.1 将三个量、三个量之和以及 TOA 净通量的图像画出，目测并不相等。



2.2 计算得到 TOA 入射太阳波、出射长波和出射短波如下:

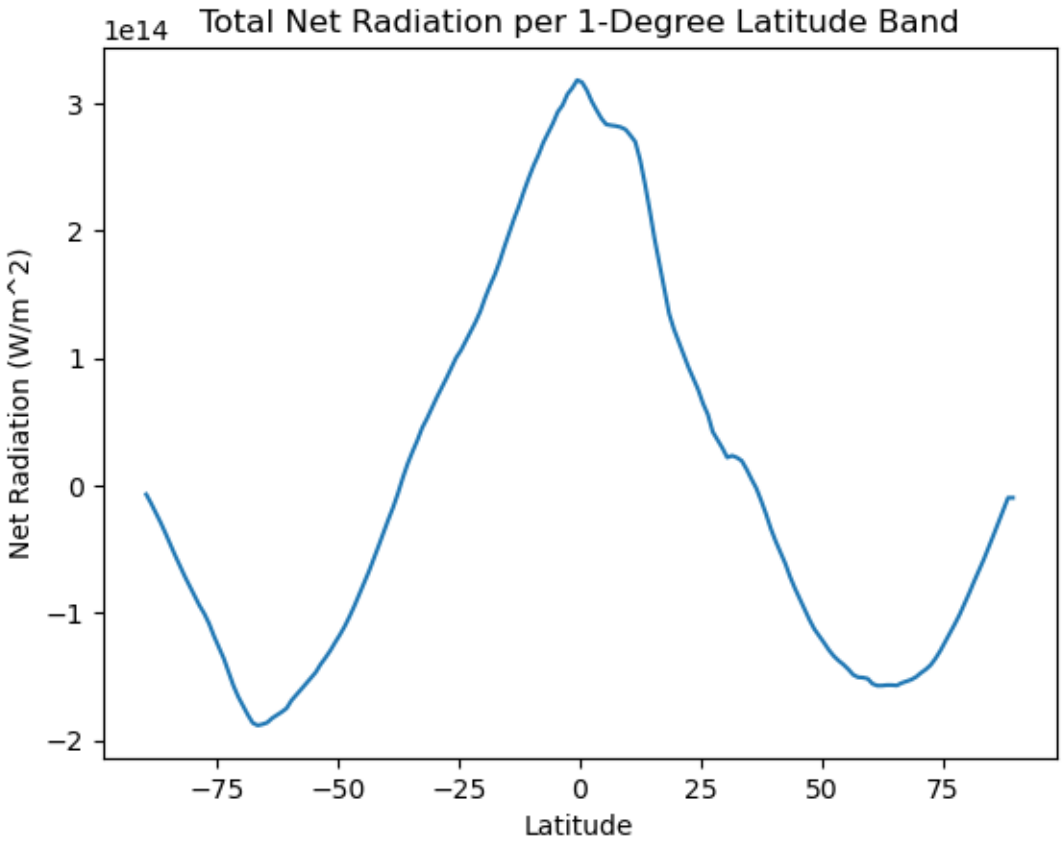
Average TOA Incoming Solar: [2.7065875e+12 2.6541312e+12 2.6088880e+12 2.5831169e+12 2.5819291e+12
2.6067211e+12 2.6491987e+12 2.7035582e+12 2.7515727e+12 2.7810773e+12
2.7813869e+12 2.7544610e+12 2.7072817e+12 2.6540109e+12 2.6095958e+12
2.5831426e+12 2.5823087e+12 2.6055415e+12 2.6483402e+12 2.7024262e+12
2.7504846e+12 2.7805659e+12 2.7821269e+12 2.7551843e+12 2.7089442e+12
2.6548634e+12 2.6100152e+12 2.5839259e+12 2.5811388e+12 2.6048631e+12
2.6484007e+12 2.7012529e+12 2.7497453e+12 2.7802602e+12 2.7810933e+12
2.7544757e+12 2.7075787e+12 2.6545034e+12 2.6094697e+12 2.5827329e+12
2.5810038e+12 2.6046193e+12 2.6477695e+12 2.6986010e+12 2.7487922e+12
2.7790205e+12 2.7798539e+12 2.7528415e+12 2.7060952e+12 2.6531736e+12
2.6081543e+12 2.5821016e+12 2.5803251e+12 2.6046025e+12 2.6484985e+12
2.7014741e+12 2.7496759e+12 2.7791888e+12 2.7787495e+12 2.7521235e+12
2.7060624e+12 2.6529998e+12 2.6080240e+12 2.5819483e+12 2.5805862e+12
2.6045676e+12 2.6474992e+12 2.7007294e+12 2.7488168e+12 2.7782535e+12
2.7790895e+12 2.7522947e+12 2.7063238e+12 2.6533070e+12 2.6087323e+12
2.5822406e+12 2.5803453e+12 2.6036383e+12 2.6469170e+12 2.6998053e+12
2.7480076e+12 2.7777318e+12 2.7788625e+12 2.7523301e+12 2.7067230e+12
2.6535760e+12 2.6085420e+12 2.5820830e+12 2.5800039e+12 2.6033311e+12
2.6461780e+12 2.6991209e+12 2.7478600e+12 2.7777869e+12 2.7792051e+12
2.7519867e+12 2.7051282e+12 2.6522063e+12 2.6074158e+12 2.5814630e+12
2.5801303e+12 2.6040703e+12 2.6473684e+12 2.7003773e+12 2.7487977e+12
2.7780902e+12 2.7786761e+12 2.7516650e+12 2.7056236e+12 2.6525397e+12
2.6078819e+12 2.5817886e+12 2.5802936e+12 2.6040030e+12 2.6471264e+12
2.6999618e+12 2.7484655e+12 2.7778574e+12 2.7788839e+12 2.7524666e+12
2.7066200e+12 2.6537298e+12 2.6087202e+12 2.5823533e+12 2.5807558e+12
2.6042174e+12 2.6472625e+12 2.6999094e+12 2.7485971e+12 2.7781979e+12
2.7793212e+12 2.7529296e+12 2.7072662e+12 2.6548686e+12 2.6097777e+12
2.5831460e+12 2.5808504e+12 2.6040452e+12 2.6469343e+12 2.7001797e+12
2.7493112e+12 2.7793904e+12 2.7804657e+12 2.7534594e+12 2.7064882e+12
2.6536177e+12 2.6086437e+12 2.5828199e+12 2.5810336e+12 2.6057829e+12
2.6492784e+12 2.7019292e+12 2.7502576e+12 2.7797228e+12 2.7797393e+12
2.7529802e+12 2.7070853e+12 2.6538371e+12 2.6094598e+12 2.5834847e+12
2.5817718e+12 2.6055053e+12 2.6485855e+12 2.7008193e+12 2.7492494e+12
2.7789639e+12 2.7793595e+12 2.7520137e+12 2.7078170e+12 2.6545286e+12
2.6095051e+12 2.5830752e+12 2.5813042e+12 2.6051386e+12 2.6480762e+12
2.6997775e+12 2.7497951e+12 2.7794030e+12 2.7808209e+12 2.7550556e+12
2.7089214e+12 2.6558089e+12 2.6103185e+12 2.5834949e+12 2.5817876e+12
2.6045401e+12 2.6473131e+12 2.7005899e+12 2.7493859e+12 2.7790384e+12
2.7804516e+12 2.7534701e+12 2.7065650e+12 2.6528653e+12 2.6082809e+12
2.5824652e+12 2.5810051e+12 2.6049842e+12 2.6483053e+12 2.7011685e+12
2.7495275e+12 2.7785526e+12 2.7780467e+12]
Average TOA Outgoing Longwave: [1.8749819e+12 1.8731676e+12 1.8951976e+12 1.9140556e+12 1.9192191e+12

1.9168534e+12 1.9062712e+12 1.8798429e+12 1.8665362e+12 1.8654292e+12
1.8657249e+12 1.8642318e+12 1.8657039e+12 1.8759141e+12 1.8976640e+12
1.9078531e+12 1.9216572e+12 1.9249872e+12 1.9041802e+12 1.8856386e+12
1.8753851e+12 1.8669522e+12 1.8669746e+12 1.8734422e+12 1.8724959e+12
1.8840747e+12 1.9032223e+12 1.9141055e+12 1.9261618e+12 1.9237584e+12
1.9131862e+12 1.8892722e+12 1.8729703e+12 1.8657378e+12 1.8741277e+12
1.8750109e+12 1.8809797e+12 1.8813400e+12 1.8959041e+12 1.9132235e+12
1.9241662e+12 1.9211998e+12 1.9104115e+12 1.8948341e+12 1.8753575e+12
1.8717567e+12 1.8662866e+12 1.8749269e+12 1.8738361e+12 1.8801932e+12
1.8933424e+12 1.9137820e+12 1.9172791e+12 1.9220415e+12 1.9079376e+12
1.8932525e+12 1.8727540e+12 1.8639604e+12 1.8710476e+12 1.8763334e+12
1.8745515e+12 1.8827712e+12 1.8882095e+12 1.9121481e+12 1.9252429e+12
1.9232361e+12 1.9102363e+12 1.8937538e+12 1.8766241e+12 1.8690720e+12
1.8614291e+12 1.8676473e+12 1.8737986e+12 1.8738003e+12 1.8896707e+12
1.9152756e+12 1.9260102e+12 1.9245757e+12 1.9111663e+12 1.8898981e+12
1.8749033e+12 1.8671484e+12 1.8774183e+12 1.8774409e+12 1.8804027e+12
1.8830675e+12 1.8966769e+12 1.9062625e+12 1.9224169e+12 1.9220829e+12
1.9140869e+12 1.8948535e+12 1.8764708e+12 1.8667428e+12 1.8603281e+12
1.8717477e+12 1.8741825e+12 1.8782047e+12 1.8911992e+12 1.9077203e+12
1.9212978e+12 1.9155485e+12 1.9038209e+12 1.8879177e+12 1.8729463e+12
1.8634424e+12 1.8653571e+12 1.8691980e+12 1.8674175e+12 1.8808607e+12
1.8931667e+12 1.9033921e+12 1.9211029e+12 1.9238755e+12 1.9097350e+12
1.8930067e+12 1.8758850e+12 1.8649492e+12 1.8764983e+12 1.8737938e+12
1.8816167e+12 1.8781770e+12 1.8974288e+12 1.9108768e+12 1.9195097e+12
1.9240118e+12 1.9095806e+12 1.8906187e+12 1.8792993e+12 1.8680906e+12
1.8637733e+12 1.8737838e+12 1.8777013e+12 1.8764274e+12 1.8851091e+12
1.9065147e+12 1.9236544e+12 1.9258716e+12 1.9179785e+12 1.8877402e+12
1.8711135e+12 1.8668593e+12 1.8677137e+12 1.8638660e+12 1.8708756e+12
1.8737044e+12 1.8931211e+12 1.9139894e+12 1.9164145e+12 1.9188472e+12
1.9115670e+12 1.8949256e+12 1.8707102e+12 1.8622724e+12 1.8748201e+12
1.8742439e+12 1.8712480e+12 1.8807774e+12 1.8915032e+12 1.9099369e+12
1.9154964e+12 1.9236714e+12 1.9098214e+12 1.8956483e+12 1.8722752e+12
1.8690907e+12 1.8712835e+12 1.8741647e+12 1.8773896e+12 1.8786293e+12
1.8902756e+12 1.9121107e+12 1.9237743e+12 1.9223039e+12 1.9097875e+12
1.8947371e+12 1.8740367e+12 1.8665853e+12 1.8765861e+12 1.8758762e+12
1.8747334e+12 1.8820619e+12 1.8944087e+12 1.9108992e+12 1.9227923e+12
1.9230869e+12 1.9125173e+12 1.8979633e+12 1.8767369e+12 1.8714697e+12
1.8752305e+12 1.8874136e+12 1.8802776e+12 1.8907524e+12 1.8965082e+12
1.9079785e+12 1.9229198e+12 1.9226271e+12 1.9125991e+12 1.8962725e+12
1.8764962e+12 1.8682058e+12 1.8766635e+12]
Average TOA Outgoing Shortwave: [7.8164073e+11 7.6557301e+11 7.6469640e+11
7.5486213e+11 7.3535049e+11
7.3196942e+11 7.4909332e+11 8.0517693e+11 8.4372226e+11 8.5842054e+11
8.3023987e+11 8.1367296e+11 7.8009021e+11 7.7142576e+11 7.6460995e+11

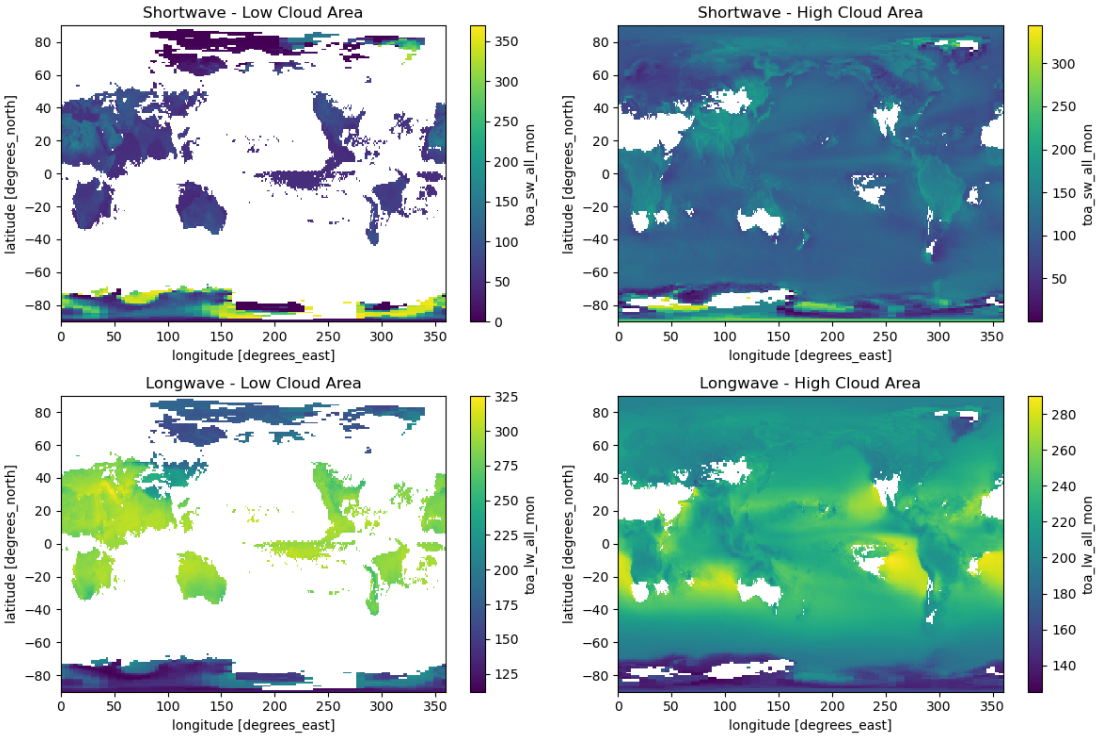
7.5281367e+11 7.3267171e+11 7.3083309e+11 7.4341050e+11 8.0307015e+11
8.3882194e+11 8.6379797e+11 8.4632797e+11 8.1379328e+11 7.8053658e+11
7.6695994e+11 7.5535529e+11 7.5508187e+11 7.3945219e+11 7.3520985e+11
7.4264550e+11 7.8651110e+11 8.4177886e+11 8.5741083e+11 8.3945967e+11
8.0439234e+11 7.7368833e+11 7.6385124e+11 7.6448163e+11 7.4895865e+11
7.3164010e+11 7.2244711e+11 7.4021267e+11 7.8638186e+11 8.3688928e+11
8.5070892e+11 8.3801925e+11 8.0092581e+11 7.8599986e+11 7.5533668e+11
7.6929335e+11 7.5616485e+11 7.2948915e+11 7.2528357e+11 7.3901185e+11
7.8865144e+11 8.3675310e+11 8.4934171e+11 8.3691792e+11 8.0873062e+11
7.7704095e+11 7.6234804e+11 7.5746004e+11 7.5312352e+11 7.3752111e+11
7.2988800e+11 7.4081999e+11 7.9034030e+11 8.3682604e+11 8.4470307e+11
8.3942729e+11 8.0675996e+11 7.7800702e+11 7.6159314e+11 7.5610076e+11
7.4484672e+11 7.3244095e+11 7.2670813e+11 7.3802324e+11 7.9542931e+11
8.3190225e+11 8.5326673e+11 8.3963255e+11 8.0204582e+11 7.7757127e+11
7.5639954e+11 7.5969462e+11 7.4979384e+11 7.3217101e+11 7.2822810e+11
7.4433043e+11 7.8643515e+11 8.4034322e+11 8.6201434e+11 8.4406030e+11
8.0860230e+11 7.6898127e+11 7.6093168e+11 7.5278772e+11 7.4698136e+11
7.2735562e+11 7.2080405e+11 7.4726369e+11 7.8656930e+11 8.4105750e+11
8.4747603e+11 8.3746397e+11 8.0371751e+11 7.7730690e+11 7.5786171e+11
7.5311618e+11 7.4302666e+11 7.3354648e+11 7.2172103e+11 7.4662393e+11
7.8979747e+11 8.4240210e+11 8.5423777e+11 8.4252564e+11 8.0958679e+11
7.7822217e+11 7.6011110e+11 7.6169708e+11 7.5336162e+11 7.3959453e+11
7.2965148e+11 7.4327412e+11 7.9228587e+11 8.4112225e+11 8.5604631e+11
8.4043353e+11 8.0667358e+11 7.7290727e+11 7.6025030e+11 7.6174492e+11
7.5662223e+11 7.3271181e+11 7.2244586e+11 7.3779734e+11 7.8287208e+11
8.3955981e+11 8.6530169e+11 8.3616124e+11 7.9990148e+11 7.8019979e+11
7.6033642e+11 7.5207541e+11 7.4289054e+11 7.3364393e+11 7.2422064e+11
7.4087340e+11 7.8102639e+11 8.3639062e+11 8.5204966e+11 8.4385255e+11
8.0618186e+11 7.7523943e+11 7.6332053e+11 7.5898329e+11 7.5403231e+11
7.3676594e+11 7.2257149e+11 7.4337511e+11 7.8806784e+11 8.3956898e+11
8.5208623e+11 8.3915008e+11 8.0632283e+11 7.7274605e+11 7.5829268e+11
7.5705116e+11 7.5189538e+11 7.3624774e+11 7.1814290e+11 7.3816434e+11
7.8305794e+11 8.3630103e+11 8.5733822e+11 8.3834536e+11 8.0106239e+11
7.7570323e+11 7.5625241e+11 7.5340055e+11 7.4803649e+11 7.2714859e+11
7.1657901e+11 7.3133883e+11 7.7947372e+11 8.3475517e+11 8.5012650e+11
8.3472109e+11 8.0283101e+11 7.7381134e+11 7.5131257e+11 7.5388754e+11
7.3895123e+11 7.2712061e+11 7.2070346e+11 7.3566624e+11 7.8351716e+11
8.2778122e+11 8.4692684e+11 8.2202080e+11]

可以看出与上图大致匹配。

2.3 计算并绘制每个 1 度纬度带的净辐射总量如下所示:



2.4 绘制低云区和高云区的时间平均输出短波和长波辐射的合成图如下



2.5 计算短波和长波辐射的全球平均值，在高云区和低云区合成:

Global Mean Shortwave Radiation - Low Cloud Area: 97.11116

Global Mean Shortwave Radiation - High Cloud Area: 111.76594
Global Mean Longwave Radiation - Low Cloud Area: 247.33109
Global Mean Longwave Radiation - High Cloud Area: 215.39049

对短波辐射的影响：

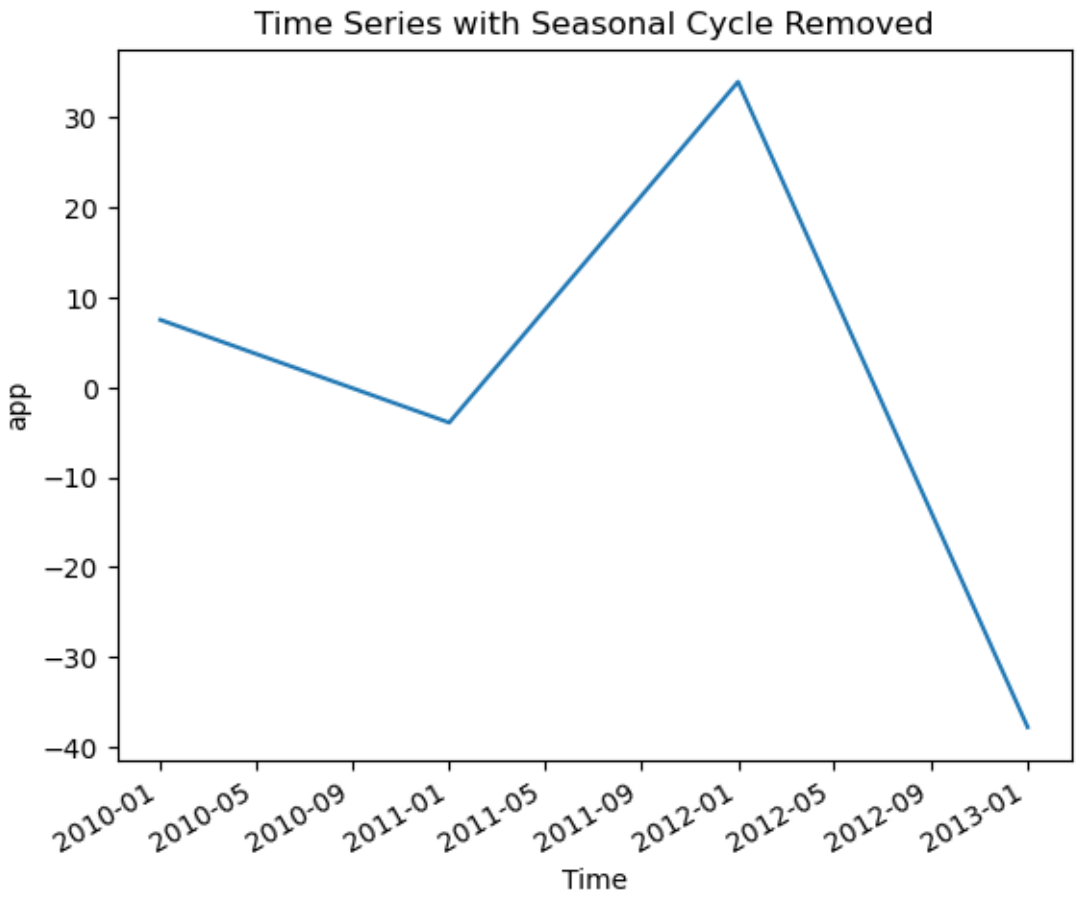
云层能显著反射太阳的短波辐射。高云层（如卷云）通常更薄透明，对短波辐射的反射能力较低，但因为它们高度较高，也能反射一部分太阳辐射。低云层（如层云）则更厚密，能更有效地反射短波辐射，减少到达地面的太阳辐射量。总的来说，云层增加了地球大气层顶的反照率（Albedo），减少了到达地面的太阳能量。

对长波辐射的影响：

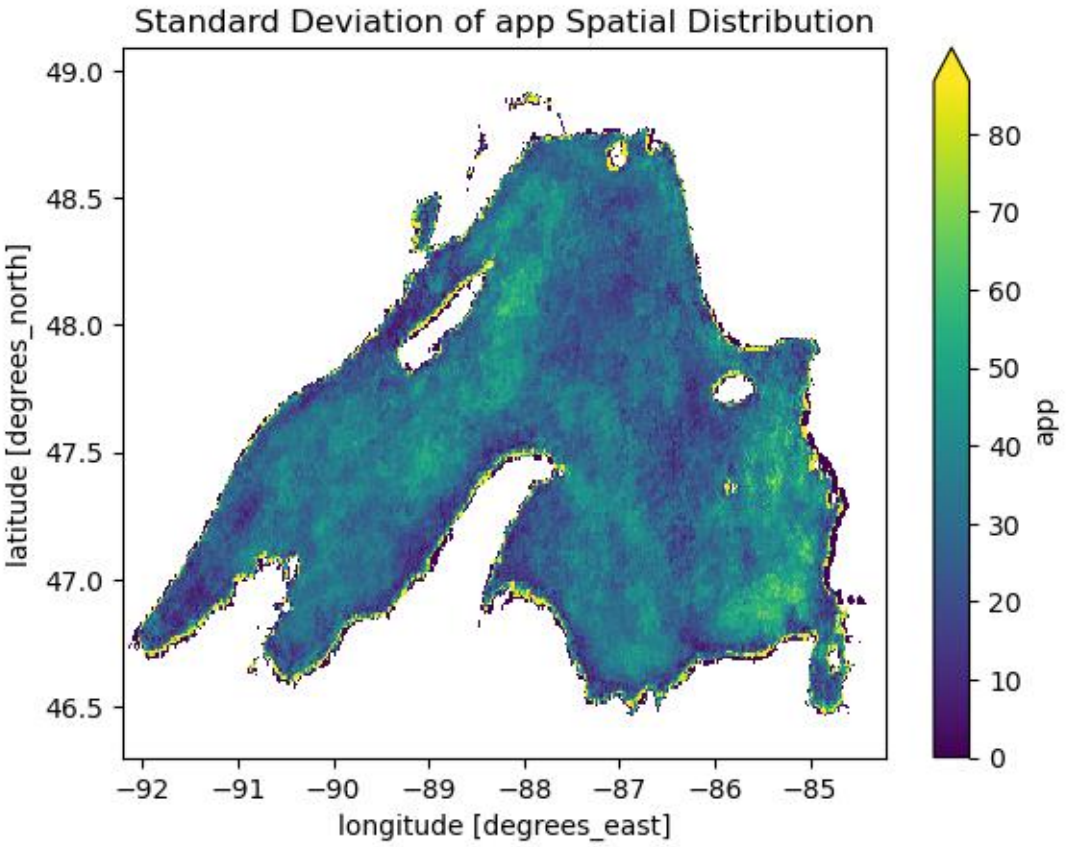
云层能吸收地球表面及大气层的长波辐射（即地球自身的热辐射）。云层吸收这些长波辐射后，会重新向所有方向辐射能量，包括向地球表面的辐射。这种向下的长波辐射有助于保持地表温暖，被称为“温室效应”。云层的这种特性特别在夜间显著，因为此时没有太阳短波辐射，长波辐射成为主要的能量交换方式。

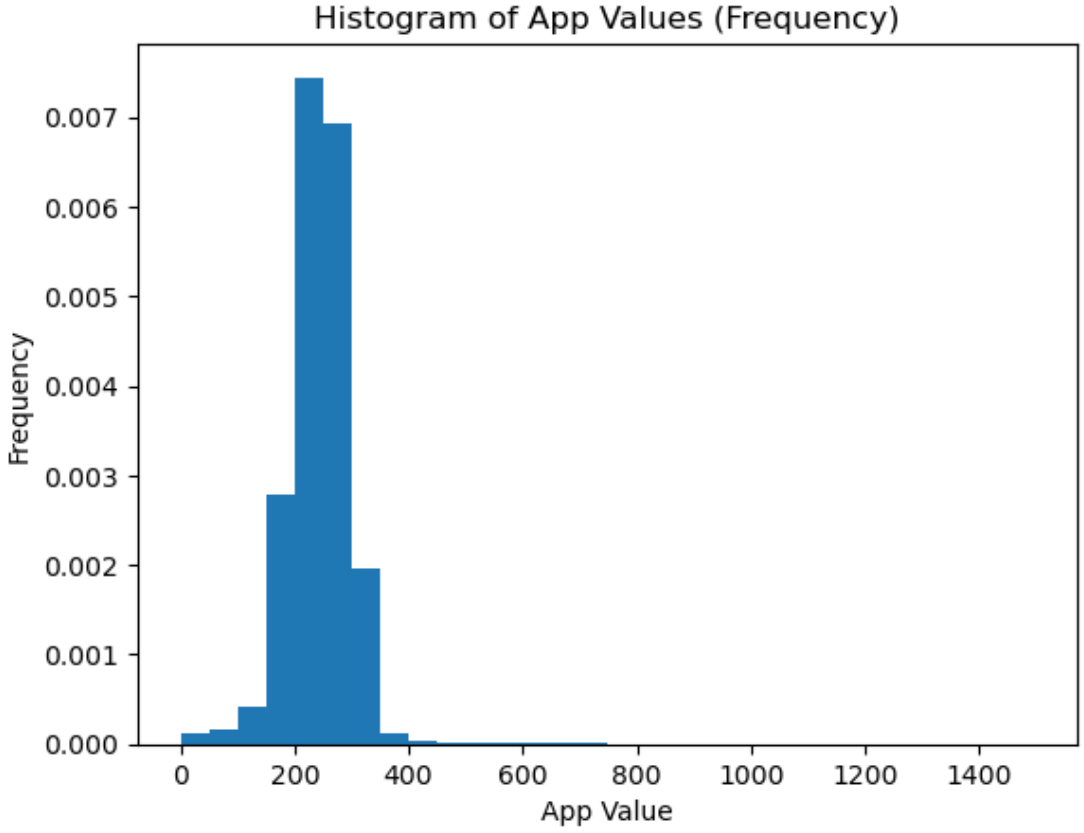
Problem 3

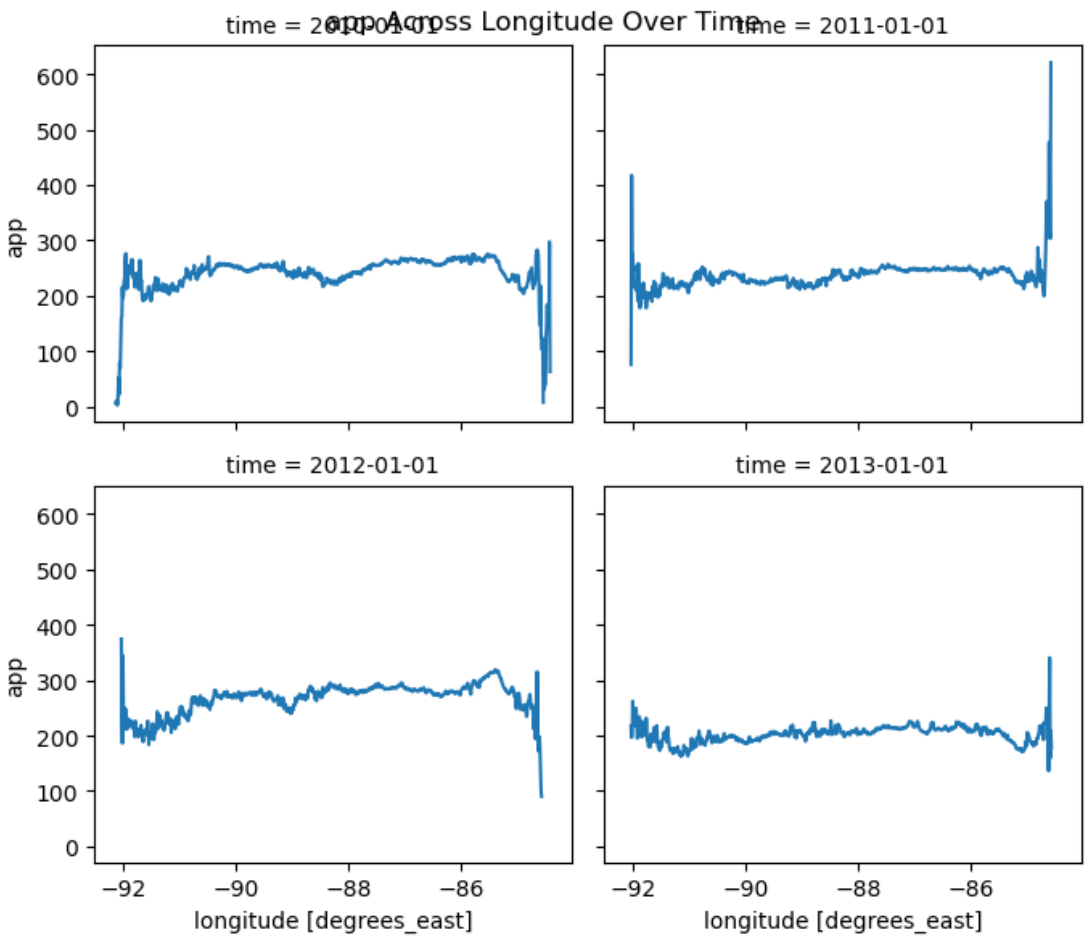
3.1 绘制 app 的时间序列，去掉月季节周期，得到：

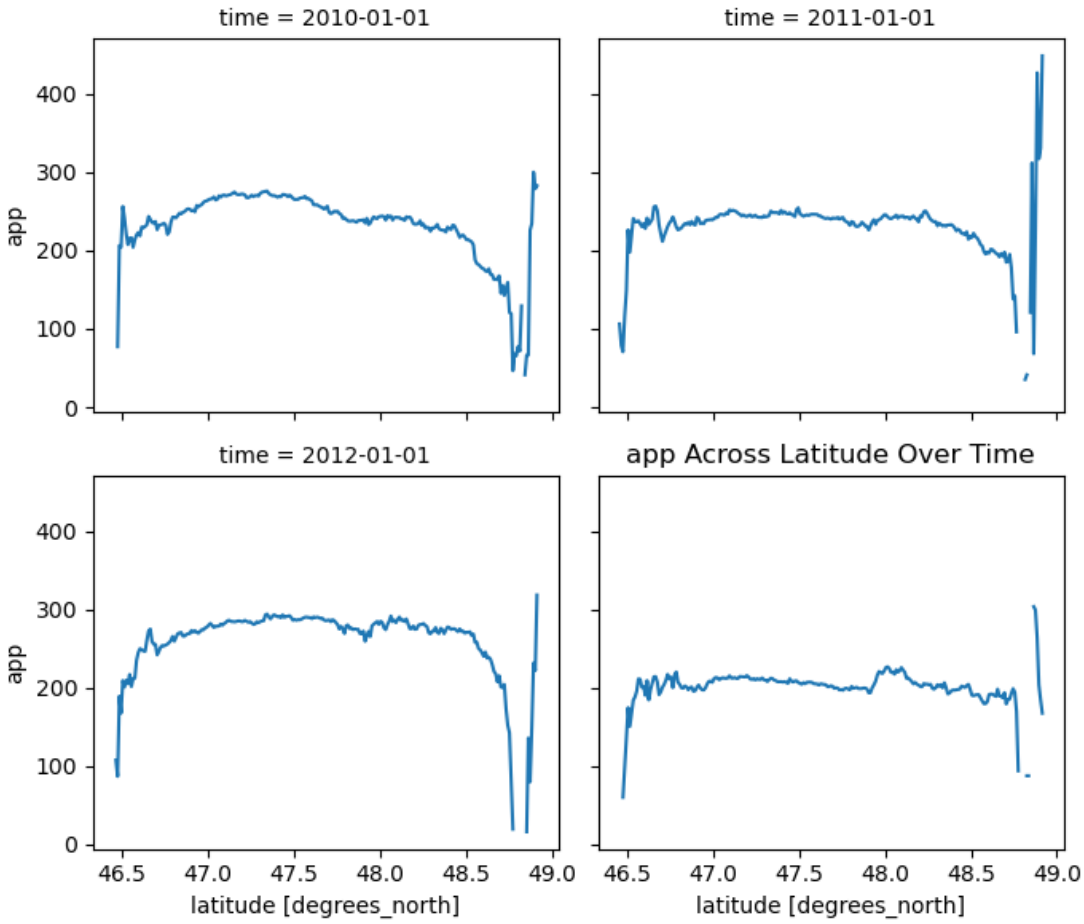


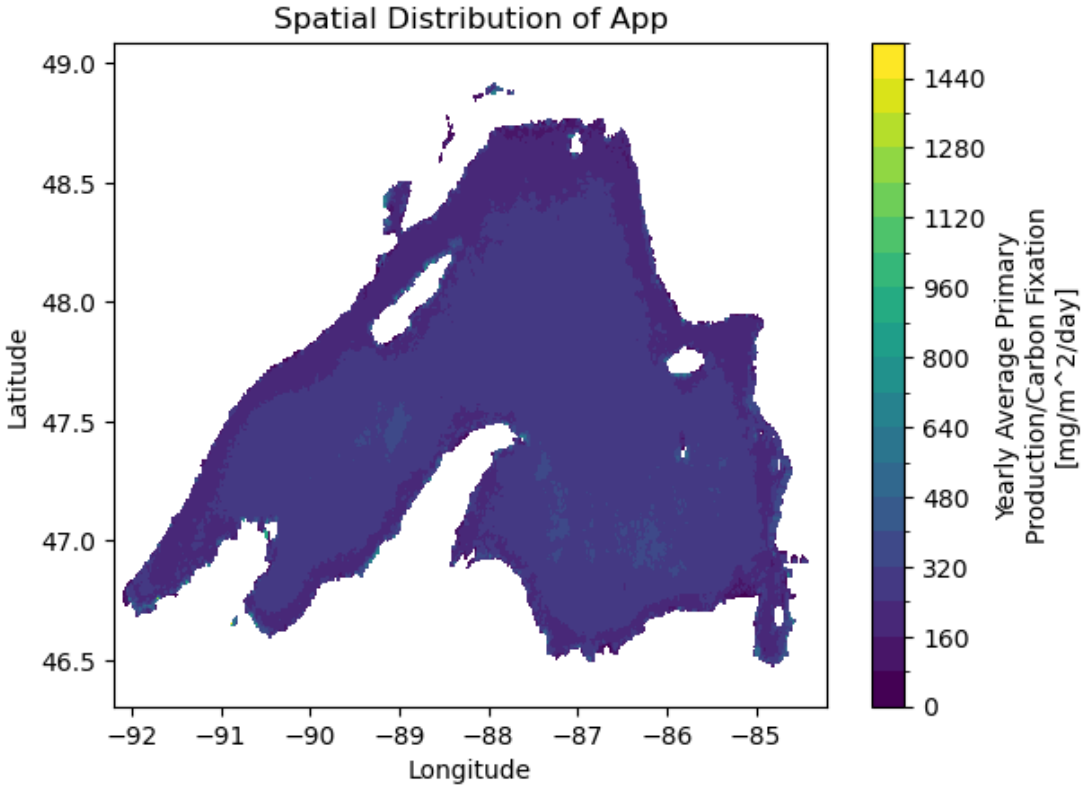
3.2 绘制 app 的经纬度标准差热图、直方图、经度-时间图、纬度-时间图、经纬度热图分别如下：


Standard Deviation of app Spatial Distribution
49.0
48.5
48.0
47.5
47.0
46.5
latitude [degrees_north]
−92
−91
−90
−89
−88
−87
−86
−85
longitude [degrees_east]
80
70
60
50
40
30
20
10
0
app


Histogram of App Values (Frequency)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Frequency
0
200
400
600
800
1000
1200
1400
App Value


app Across Longitude Over Time
time = 2010-01-01
time = 2011-01-01
time = 2012-01-01
time = 2013-01-01
app
0
100
200
300
400
500
600
−92
−90
−88
−86
longitude [degrees_east]


time = 2010-01-01
time = 2011-01-01
time = 2012-01-01
app Across Latitude Over Time
app
400
300
200
100
0
46.5
47.0
47.5
48.0
48.5
49.0
latitude [degrees_north]


Spatial Distribution of App
Latitude
Longitude
49.0
48.5
48.0
47.5
47.0
46.5
−92
−91
−90
−89
−88
−87
−86
−85
Yearly Average Primary Production/Carbon Fixation [mg/m^2/day]
1440
1280
1120
960
800
640
480
320
160
0