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ENERGY BUDGET TRENDS OVER THE KOREAN PENINSULA IN THE PAST 20 YEARS

Soo-Min Lee*, Yeonwoo Park*, Jun Ahn Choi*

St. Johnsbury Academy Jeju, Seogwipo, South Korea
United World College of South East Asia (East Campus), Singapore, Singapore
Heritage Innovation School (HIS), Toronto, Canada

soomin.lee.2006.0724@gmail.com
park128353@gapps.uwcsea.edu.sg
choijunahn@gmail.com

*Co-first Authors

Abstract. The term “Energy Budget” represents the incoming solar energy, outgoing amounts of energy, and the energy retained in the Earth’s atmosphere. This article aims to analyze the energy budget trend in the Korean Peninsula over the period from 2001 to 2022, focusing on the Earth’s Energy Imbalance (EEI) and the role of cloud cover and how it influences shortwave (SW) and longwave (LW) radiation. Using the dataset obtained from NASA’s CERES satellite, the article investigates the amount of reflected and emitted energy globally and compares it with the Korean peninsula. The findings indicate that globally, the total wave which is the sum of all longwave, shortwave, and cloud shortwave radiation has increased in trend. The plot also displays a decrease in Cloud fraction (CL fraction) or cloud coverage. Contrary to this, the Korean peninsula displayed a relatively stable level of total radiation and an increase in CL fraction. However, further analysis is needed to understand the factors behind these regional differences, including the potential influence of monsoon circulation patterns.

Keywords: Global Warming, Energy Budget, Earth Energy Imbalance, Climate Change, South Korea

1. Introduction

Global warming is a significant threat to the Earth's Energy Imbalance (EEI)–the rate that represents the balance between the amount of solar energy absorbed by the Earth and the amount of energy emitted back into space.[1] The recent 10 years have been the warmest years on record.[2] Since greenhouse gasses trap the heat inside Earth's atmosphere, its increase has led to a significant reduction in the amount of energy sent back into space, consequently inflating the EEI and Earth's temperature by 1.36°C.[3] The warming causes a cyclic effect on the earth's temperature by melting essential agents on the surface for the reflection of energy sent into space, such as snow and ice.

Clouds are one of the key factors in energy imbalance, as they either reflect or trap the sunlight. For instance, cumulonimbus clouds have a cooling effect on Earth's temperature by reflecting shortwaves from the sun. On the other hand, cirrus clouds[4] have a warming effect, as they let light through the heat is trapped in the atmosphere.[5] Past studies have found that clouds have a mean impact of cooling the planet at the top of the atmosphere by about $20Wm^2$. However, this value differs from region to region, as there are regional variations in terms of the shape of the clouds and their consequent impact.

The research specifically aims to examine the Korean Peninsula's energy imbalance over the period from 2001 to 2022 by comparing it with the global trend of EEI and clouds from the Clouds and the Earth's Radiant Energy System (CERES). The comparison indicates the differences between the gradients of the annual mean in various types of waves. Additionally, this study observes the shortwave radiation and area fraction of the clouds to further explore the impact of clouds on climate change. Throughout this analysis, the study aims to underscore the limit of the energy budget over the years in the South Korean peninsula.

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[1] Loeb, Norman G., et al. "Satellite and Ocean Data Reveal Marked Increase in Earth's Heating Rate." Geophysical Research Letters, vol. 48, no. 13, July 2021, https://doi.org/10.1029/2021gl093047.
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2. Data set and methods

2.1 Satellite Data

The dataset used in this study is obtained from the Clouds and the Earth's Radiant Energy System (CERES) polar orbiter satellite provided by NASA. The ENERGY BALANCED AND FILLED (EBAF) edition of CERES specifically provides a global data set on several pieces of information regarding the energy changes on the Earth. In this research, the monthly mean of top-of-atmosphere (TOA), which refers to reflected radiation measured from a space-based sensor flying object higher than that of earth's atmosphere, shortwave (SW), longwave (LW), and the net energy–total–over time are observed to examine the trend of energy change. Moreover, the cloud's impact on climate change is examined by gathering the SW radiation of the clouds by subtracting the SW of the clear sky from the total amount of shortwave. Moreover, the cloud area fraction over time is studied to see the regional impact of clouds in South Korea. The datasets in this study will be between 01/01/2001 to 01/01/2022.

2.2 Variables

The variables used in this study are gained from CERES. Shortwave (SW), longwave (LW), and total represents data from TOA FLUXES. SW clear and SW cloud are the components inside SW. Cloud parameter of Cloud Fraction in percentage is also used in the study. Through the Jupyter notebook, python was used to plot several graphs.

2.3 Locating South Korea

Based on the geographic location of South Korea, the minimum and maximum latitude and longitude determined by drawing a rectangle that covers the region centering around South Korea. We specifically chose a 30 by 25 resolution, since it enables us to represent the whole region while still capturing the essential details. Hence, the longitude and latitude minimums and maximums used in this study are: 115°, 145°, 25°, and 50°.

2.4 Weighting data

Weighting data is essential to make the data set real-world applicable. Based on the geographic position, some parts of the Earth closer to the equator get much more sunlight compared to regions next to the north pole. In order to represent the distribution of sunlight encergy, cosine is used to add data on the initial data points gathered from CERES. Latitude is used to determine the cosine weight for each data point, as an increase in latitude reflects increase in the area. After multiplying the calculated weights, all the monthly data is added and divided by the time interval.

2.5 Averaging Annual Mean

In order to get the annual mean value, the SW, LW, and total data for each year is gathered by adding up the monthly data and dividing them by 12. Such data is plotted on an earth map to represent the trend of the waves in response to geographic regions. In this research, the most recent data from 2022 and the most recent data from 2001 is used to investigate the changes in the climate over the years.

2.6 Shortwave Cloud Calculation

$$SW_{cloud} = SW_{total} - SW_{clear}$$

To get the estimate for the total shortwave radiation from clouds, SW total was subtracted from the SW clear sky.

Results

3.1 Global Annual Averages

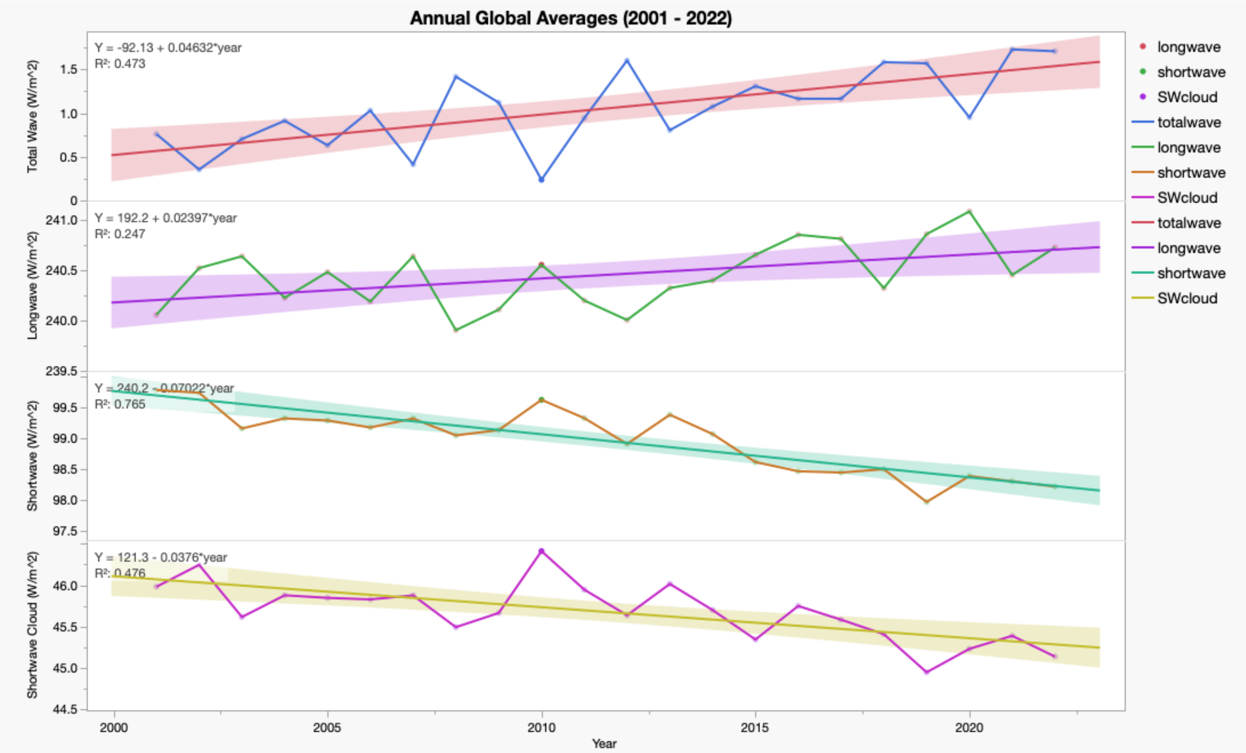
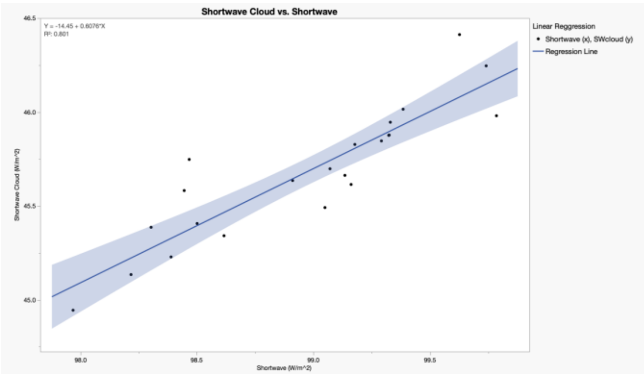


Figure 1. Global Annual Averages of total, longwave (LW), shortwave (SW), and shortwave cloud in W/m^2. Total wave is the net radiation of all types of waves. While LW radiation accounts for the LW emitted from Earth to space, the SW value is the amount that is reflected from the Earth's atmosphere, not including the SW absorbed by Earth. SW cloud is measured by subtracting SW cloud from SW total.

The Global Annual Averages indicates that EEI has been increasing over the last 20 years. The total showed a significant increase in recent two years with gradient of $0.04632\ W/m^2$. Since total is the net value of all the radiation on Earth, its increase indicates that more energy has been released over the last 20 years, supporting the global phenomenon of rise in temperature. However, its components have shown varying patterns over the last 20 years. In case of LW, there has been slight increase of $0.02397\ W/m^2$ per year compared to total, as its gradient is 0.517 times lower than total. This may be due to the fact that Earth is gaining energy, consequently increasing the amount that is sent back to space. Although solely observing at LW seems to communicate that Earth is maintaining its energy balance, as Earth is naturally emitting back more energy as it gains, SW proves the opposite. SW radiation has been significantly decreasing over the years with gradient of $0.07022\ W/m^2$, which is 1.52 times larger than that of total. Its significant decrease indicates that less solar radiation has been reflected over the years, meaning that energies have been filling up over the years. Hence, despite the fact that LW has been increasing, the total kept increasing due to SW reflection. Moreover, SW showed the highest gradient as well. Overall, Figure 1 supports that SW is the most crucial aspect in Earth's temperature rise.



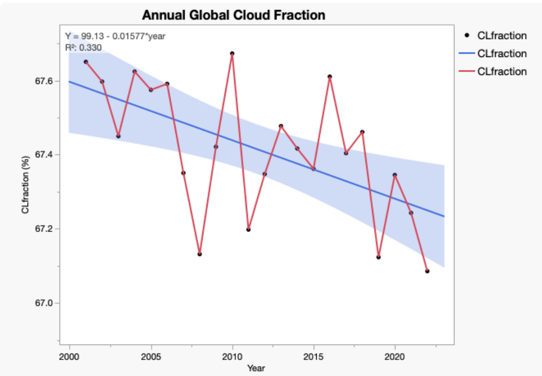


Figure 2. Correlation coefficient graph between SW cloud and SW total. Through linear regression the model plotted their relationship.

Figure 3. Annual Global Average of Cloud Fraction (cloud coverage) measured in percentage.

SW clouds seem to be one of the essential factors influencing SW radiation. The SW cloud showed a decreasing trend with the gradient of $0.0376\ W/m^2$. Although it's not increasing significantly compared to SW, as shown in Figure 2, there seems to be positive correlation between the two. With the R^2 value of 0.801, the graph also supports that there is close relation between two variables as well. Although there is directional ambiguity in their relation, the data indicates that SW clouds are among the factors that influence Earth's temperature rise. Figure 3 further supports these findings, as the annual global cloud fraction tends to decrease over the years. With a gradient of -0.01577% per year, less areas are being covered with clouds, consequently leading to decrease in reflection of solar radiation. Hence, the result supports that cloud plays a significant factor in SW, which also aligns with previous studies[6] as well.

3.2 Global Data for Clouds

[6] Loeb, Norman G., et al. "Satellite and Ocean Data Reveal Marked Increase in Earth's Heating Rate." Geophysical Research Letters, vol. 48, no. 13, July 2021, https://doi.org/10.1029/2021gl093047.

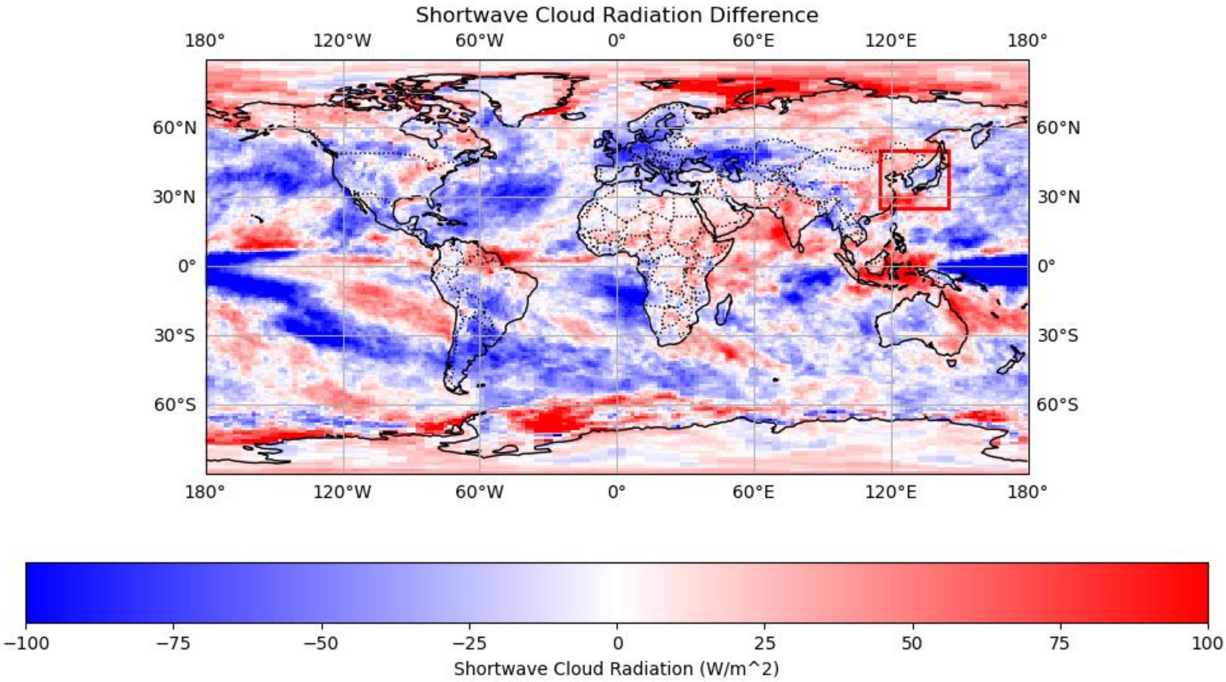


Figure 4. a. Difference in the amount of Shortwave cloud radiation during the years 2018-2022 compared to the years 2001-2005

The colours in this map shows the difference in the amount of shortwave cloud radiation, which is the amount of solar energy reflected by clouds, between the years 2001-2005 and 2018-2022. The redder an area is, the higher the increase in shortwave cloud radiation, and the bluer an area is, the higher the decrease in shortwave cloud radiation. The X and Y axis represent the longitude and latitude. When we observe this map, we notice that the shortwave cloud radiation changes are vastly different depending on which region we observe. All the trends that we can see are regional and there is no clear global trend. When we look at the region of South Korea, its temperature is relatively neutral.

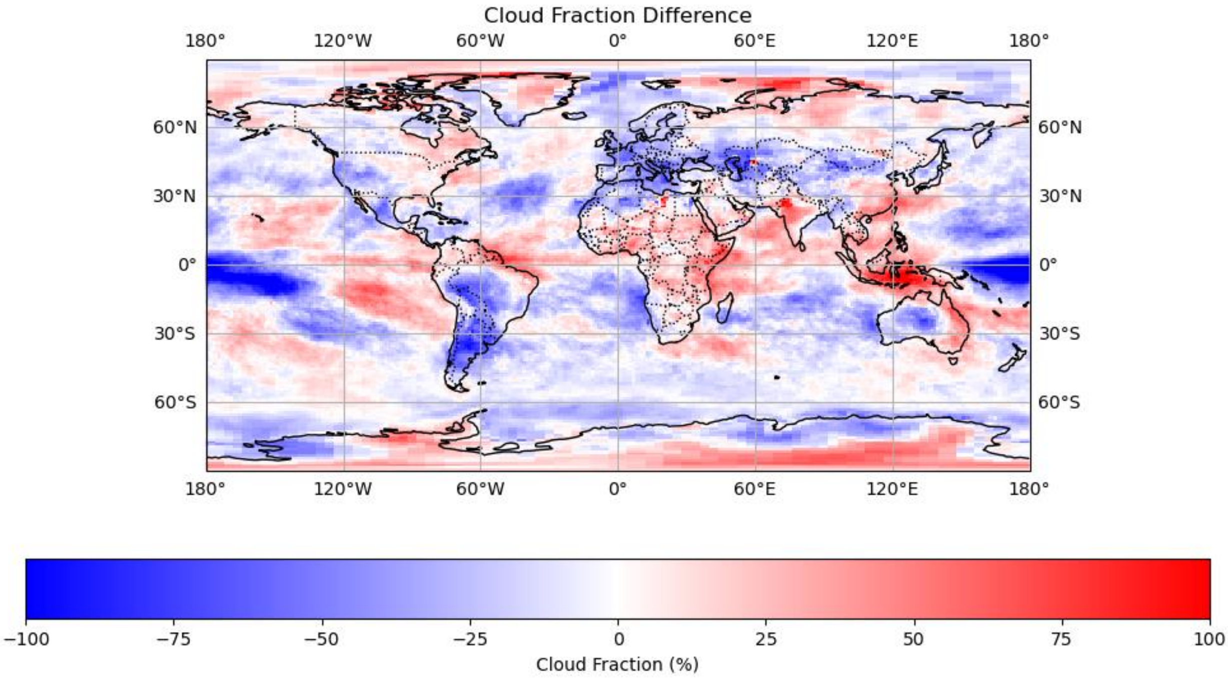


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Figure 4. b. The difference with of CLfraction (Cloud Coverage) during the years 2018-2022 compared to the years 2001-2005 indicated by colors.

After comparing the two maps, we see that the areas with a large amount of cloud coverage also have a large amount of reflected shortwave and areas with low amounts of cloud coverage have smaller amounts of reflected shortwave. This shows that clouds cause a significant decrease in reflected shortwave.

3.3 Korea Annual Average

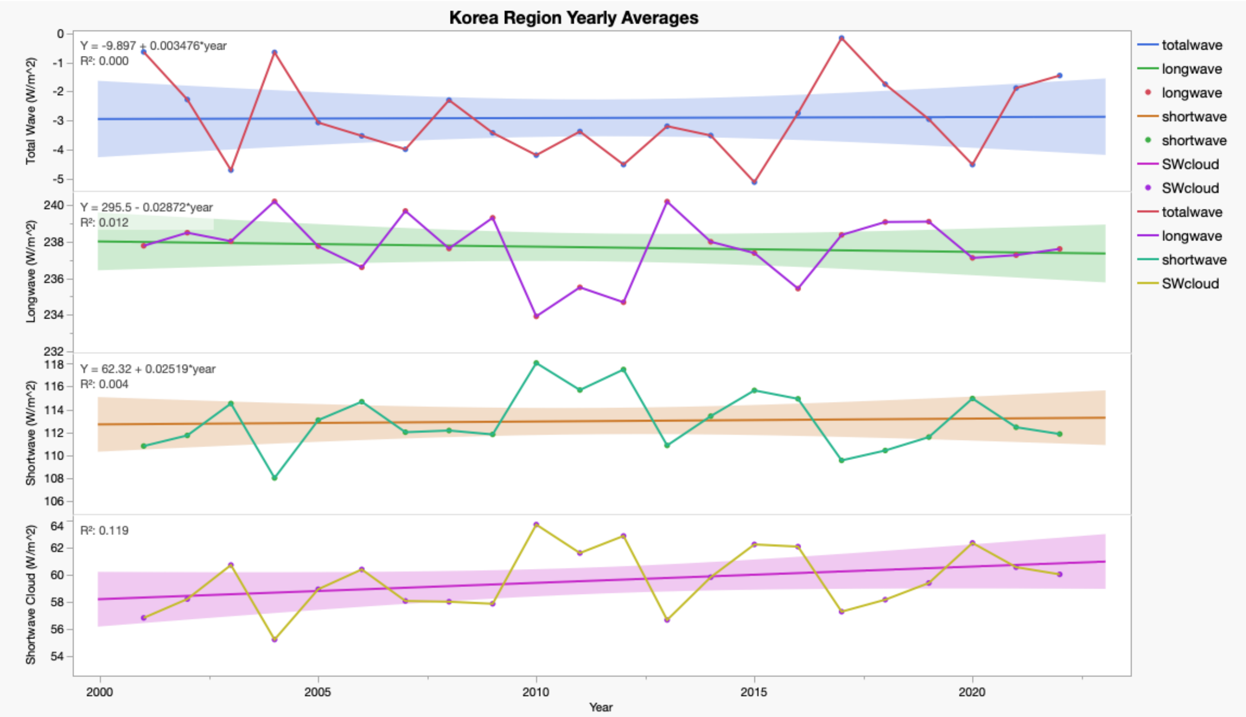

Figure 5. Annual trend of Total Wave, Longwave, Shortwave and Shortwave Cloud over the Korean region.

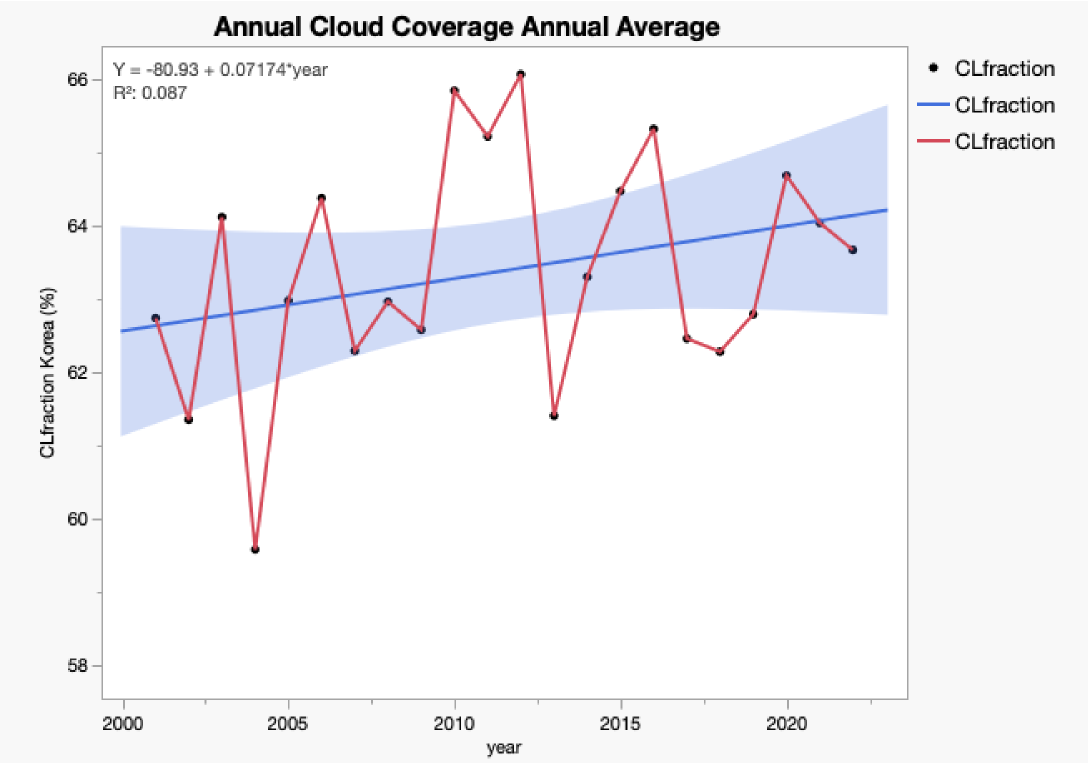

Figure 6. Annual trend of CLfraction (Cloud Coverage) over the Korean Peninsula.

The Korean dataset looks specifically into the Korean peninsula from a latitude of 115 to 135 degrees and a longitude of 25 to 45 degrees. Figure 5. shown above displays the annual average data for the total radiation, longwave radiation, shortwave radiation, and the cloud shortwave radiation (Shortwave radiation reflected by the cloud). The annual average total radiation, shortwave radiation, and longwave radiation all remained nearly constant as they displayed respectively an increase of 0.003476 W/m^2, 0.02519 W/m^2, and 0.02872 W/m^2. Although some peaks could be observed in the total wave in 2018 and 2005, the trend stays constant. However, the shortwave cloud radiation has an upward trend. Analyzing the Annual Cloud Coverage in Korea, it also shows an upward trend at 0.07174% increase every year, possibly being responsible for the rise in Shortwave Cloud radiation. Comparing the plot from the global annual average plot and the Korean annual average plot, while the total radiation, the longwave radiation showed an upwards trend and the shortwave radiation and the cloud shortwave radiation showed a downwards trend, Korea’s plot was consistent other than cloud shortwave radiation, which showed an upward trend. This could indicate that the Korean peninsula has been relatively unaffected regarding energy balances. The reasoning for this would need to be further analyzed using different parameters such as the monsoon cycle and the Northern Hemisphere Jet Stream.

Conclusion

The findings of this research can lead to some further explorations behind this phenomenon. In Figure 4. A, the heat was centered in the East Sea of China. This may be due to the monsoon circulation happening around the South East Asia region. Monsoon circulation refers to the change of temperature and weather due to the significant difference between the temperature on land and sea. Due to the monsoon circulation, the hot wind from that area may be moving upwards toward the Korean peninsula, which is near the East Sea of China. Through examining the wind or heat data, further studies could prove the reason behind the Korean peninsula’s climate change.

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