Energy Flow Budget and Greenhouse Effect for the Earth Climate

Bhagyashri Patil

San Diego State University

Address: 5485 55th St, San Diego, CA 92115

Contact: bpatil0085@sdsu.edu

Cell: (619) 844-3051

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Introduction

When we consider the present challenges of climate change on Earth, we can see that a variety of factors have contributed to the shift in temperature. If we take a step back from the man-made factors that we have contributed to the rise in global surface temperatures, we can all see the underlying truth that scientists have discovered which is unrelated to the Earth's Albedo levels. To put it simply, Earth's albedo is the amount of reflectance of the Earth's surface from the Sun's solar radiation. This level is compared to a numerical number calculated from an equation that determines the Earth's climatic conditions. An extremely cold Earth, or snowball Earth, with an albedo value of 1.0 can reflect a significant amount of the sun's solar rays when they contact the Earth. On the other side, an albedo value of 0.1 or below would indicate a burned or heated Earth. To clarify, the areas of frozen tundra, our polar continents, and our ice caps are the real objects that represent the albedo of our planet. Simply said, various present behaviors that degrade the status of these frozen places and warm them up would reduce the planet's albedo values, resulting in a significantly hotter world. There are estimations by NASA specialists who predicted the Earth's surface temperature was recorded at around 13.72 degrees Celsius in the year 1750. This, in turn, reveals that the albedo value for a temperature like that would be 0.625, which is far closer to 1.0 the 'snowball earth' we mentioned earlier, based on our own calculations of the EBM equation.

The focus of our group's work will be on a topic mentioned in our textbook, 'Climate Mathematics: Theory and Applications' by Samuel S.P. Shen, which is the global average surface temperature of Earth using energy balance models or EBMs. This subject is still relevant in our day since we are observing rising temperatures on the Earth's surface because of global warming produced by greenhouse gases. As stated in our textbook (Page no. 116) the sun's radiation causes an energy imbalance in the Earth’s climate. This effectively causes the severe climate change difficulties we’re seeing now, which haven’t been seen in earlier climate data dating back decades. Our overall objective with this topic will be to map out temperature changes from the previous decade to the present, and then utilize the appropriate formula to forecast and anticipate future temperature changes. The algorithm will be clearly discussed along with verification from our data sets, of how it is able to accurately estimate temperatures on the Earth’s surface. We will be able to make a proper projection of Earth’s surface temperature based on the data we create and the study we do. We may then use these projections and our temperature prediction studies to describe how the Earth’s future climate will shape up.

Data and Methods

We gathered data from a variety of sources for this research. Initially, we utilized a function with a variety of epsilon values, with epsilon representing the variable for albedo levels in the equation. We can see how the computation of lower average earth surface temperatures correlates to lower albedo levels, which signify bigger white surface regions (vast expanses of land covered in snow and ice) that reflect the sun’s solar rays that the planet is made up of. We make a graph of the nonlinear Albedo Feedback to better understand how epsilon albedo levels correlate with earth’s surface temperatures. What this graph demonstrates, as described (Shen, page no. 121), is that it is reliant on the albedo of the earth’s surface temperature. The albedo effect is positive feedback on temperature, which means that patterns like albedo transitions will exacerbate the earth’s temperature variations. This is because the earth’s warming makes it darker in the sense that there is less white surface area on the planet, which reflects less solar energy and makes the earth considerably warmer; and vice versa, the world appears brighter owing to reflection as it cools (colder surface temperatures).

```
def ab (T, a1 = 0.7, T1 = 250, T2 = 280):
    #'a2' is a variable based on the a1 parameter, it is supposed to be the opposite end of the perceived snowball earth albedo value
a2 = 1 - a1
    # a list called 'a' is created to hold all the surface temperature values to be plotted on the graph.
a = []
    try
        for i in T:
            if i < T1:
                a.append(a1)
            else:
                if i < T2:
                    # The line below is where we add values into our list, these values being calculated through smooth function that shows a transitional behaviour of the albedo
                    a.append(((a1-a2) / (T1-T2) ) * (i-T2) + a2)
                else:
                    a.append(a2)
        return a
# This except call is just for any issues that occur from certain values inputted if one where to use values different from the set parameters.
```

```
except TypeError:
    if T < T1:
        a.append(a1)
    else:
        a.append(a2)
    return a
```

Now that the purpose of this function has been defined, we can proceed to using it to get data values for our nonlinear albedo feedback graph. Here's the code we'll use to make the graph. We establish a variable 't' that stores a temperature range of roughly 1001 data points between the lower and upper bounds.

```
t = np.linspace (200, 350, 1001)
plt.figure(figsize = (12, 9))
plt.plot(t, ab(t), 'b')
plt.ylim(0, 1)
plt.xlabel("Surface temperature [K]")
plt.ylabel("Albedo");
plt.title("Nonlinear Albedo Feedback")
plt.show()
```

The code above simply runs the ab() function that we previously explained about and will then plot the graph using the plot() function from above and will also have some labeling to make it more readable. Here is the resulting graph:

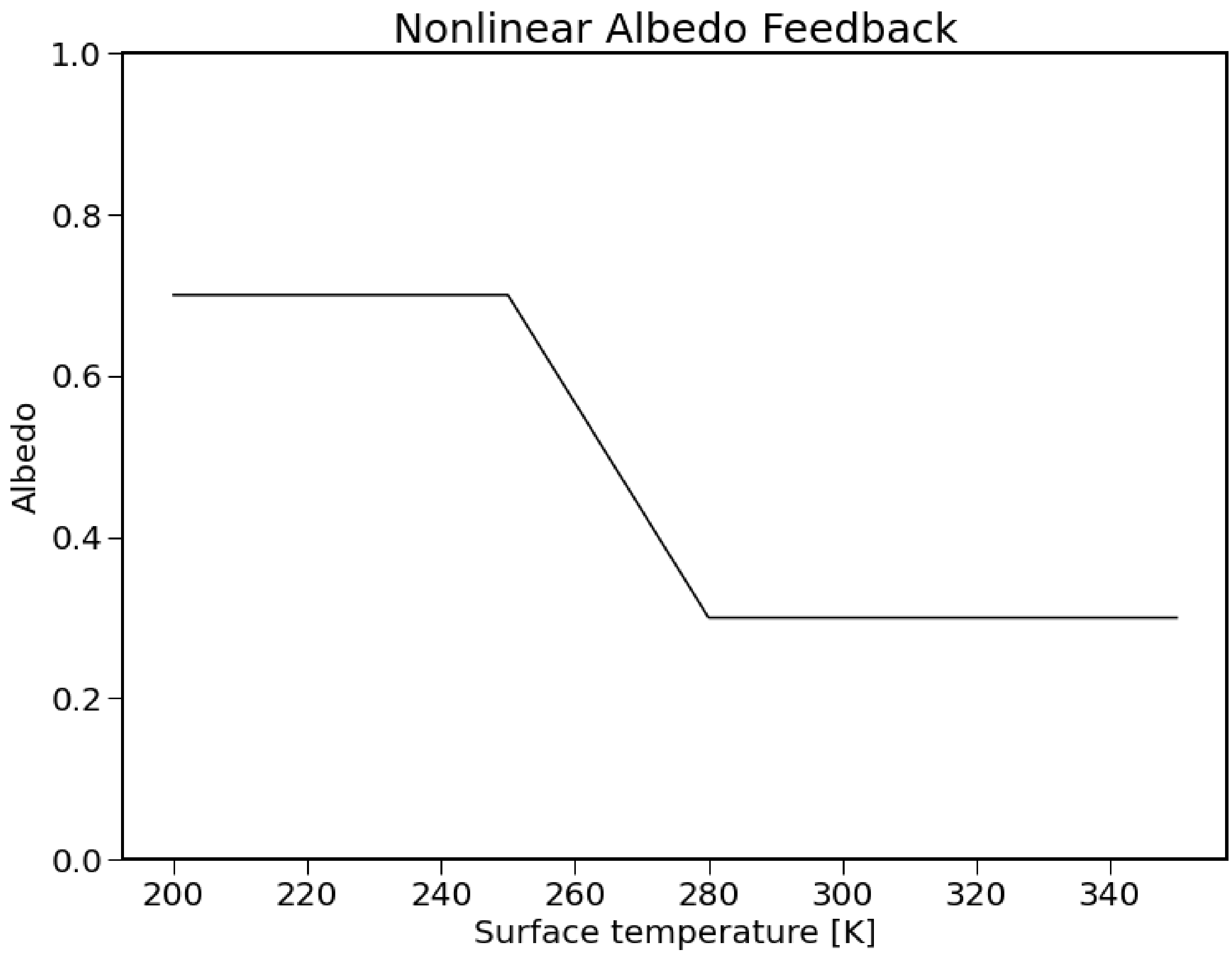

Figure (1): Albedo Effect as a Nonlinear function of T

The nonlinear relationship between albedo and surface temperature can be observed in the graph above.

Finally, we may use EBM models to investigate our calculations. The degradation of the Earth's albedo levels (its white surface that is equal to snow and ice existing on the earth's surface that reflects solar rays) may be used to substantiate our assertion that greenhouse gases are warming the planet. So, using a handful of questions from our textbook, we can compute our claims (Shen, page no. 136). We choose these two questions since they have the same goal and are calculated in the same way. These questions respectively are 5.5 ("Tune the "snowball" uniform

Earth EBM parameters to find three types of climate conditions for the Earth. Discuss the numerical results generated by Python.") and also, 5.6 ("Repeat the above problem for a given emissivity epsilon and for the case of the nonlinear albedo-feedback EBM with the albedo modeled by a tanh() function of temperature α = α1 - α2 * tanh((T-Tc)/Ts); where α1, α2, and Tc are constants, and the temperature unit is K. Choose your own values for epsilon, α1, α2, Tc, and Ts; so that the EBM has three solutions, one of which is close to the global average temperature of the present Earth, i.e., around 15°C.").

We can start with question 5.5 that asks about obtaining the three types of climate conditions for the earth's surface. That I interpreted as being a frozen, "snowball" earth, are warmer current earth, and finally an earth with a warmer surface than present time as a sort of prediction of the earth's average surface temperature increasing if things stays the same in terms of interaction with our climate. Here is the code used to calculate temperatures using the EBM model.

```
alpha = 0.30

S = 1368

ep = 1.0

sigma = 5.670373e-8

def ebm55(alpha, S, sigma, ep):

    T1 = ((((1-alpha)*(S/4)) / (sigma*ep))**0.25) - 273.15

    return T1

T1 = ebm55(alpha, S, sigma, ep)

print("Parameters for a Snowball Planet (Celsius): ", T1, "\n")

T2 = ebm55(alpha, S, sigma, 0.60)
```

```
print("Epsilon Parameter changed to 0.60 (Celsius): ", T2, "\n")

T22 = ebm55(alpha, S, sigma, 0.50)

print("Epsilon Parameter changed to 0.50 (Celsius): ", T22, "\n")

T3 = ebm55(alpha, S, sigma, 0.20)

print("Epsilon Parameter changed to 0.20 (Celsius): ", T3, "\n")
```

This is my code and will now explain the logic behind it. First, we see that another function is being defined, that is called EBM 55() that in four parameters. For a preface this function is based off the mathematical EBM equation. We take this equation and reshape it to solve for a value of T. Here is the mathematical EBM equation that we based our code off (Shen pg. 121). $\epsilon\sigma T4 = (1-\alpha(T))(S/4)$ which we transform into this for our code: ((((1-α)*(S/4))/(σ * ep))**0.25). Keep in mind that in our code we do have an additional constant of -273.15 to convert the Kelvin measurement to Celsius.

Results

Looking at the graph we created we can see that higher values of epsilon are geared to a colder earth surface temperature and vice versa. We decided to pick a low, high, and in-between epsilon values to calculate. Here are our results for this code.

Parameters for a Snowball Planet (Celsius): -18.245131928146066

Epsilon Parameter changed to 0.60 (Celsius): 16.47784771008338

Epsilon Parameter changed to 0.50 (Celsius): 29.984682759878638

Epsilon Parameter changed to 0.20 (Celsius): 108.0216837986028

So, we can go ahead and now check our dataset that lists temperatures of earth's surface temperature over a range of years from 1948 to 2015 (Center for Satellite Applications and Research - NOAA / NESDIS / Star). However, for this case we would like to use the year 2015 to support our claim. When looking at our solutions we see how albedo values closer to the middle, more specifically to albedo level of .60, will have results of around 16 Celsius. If we were to take a look at our dataset, an .nc file called 'air.mon.mean.nc', we created a visualization of the month of January of the focused year and evaluated the makeup of the results. Before evaluating the map there is some lines of code used to read and establish our nc dataset so that we can later use the data to create visualization as well as other functionalities.

```
#Import Data of the nc file from our data folder
datamat = nc.Dataset("./data/air.mon.mean.nc")
#Preparing data for plotting
Lon = datamat.variables['lon'][:]
Lat = datamat.variables['lat'][:]
Time = datamat.variables['time']
precnc = datamat.variables['air']
```

This established variables that hold values derived from the nc dataset that we will use in part of creating our map.

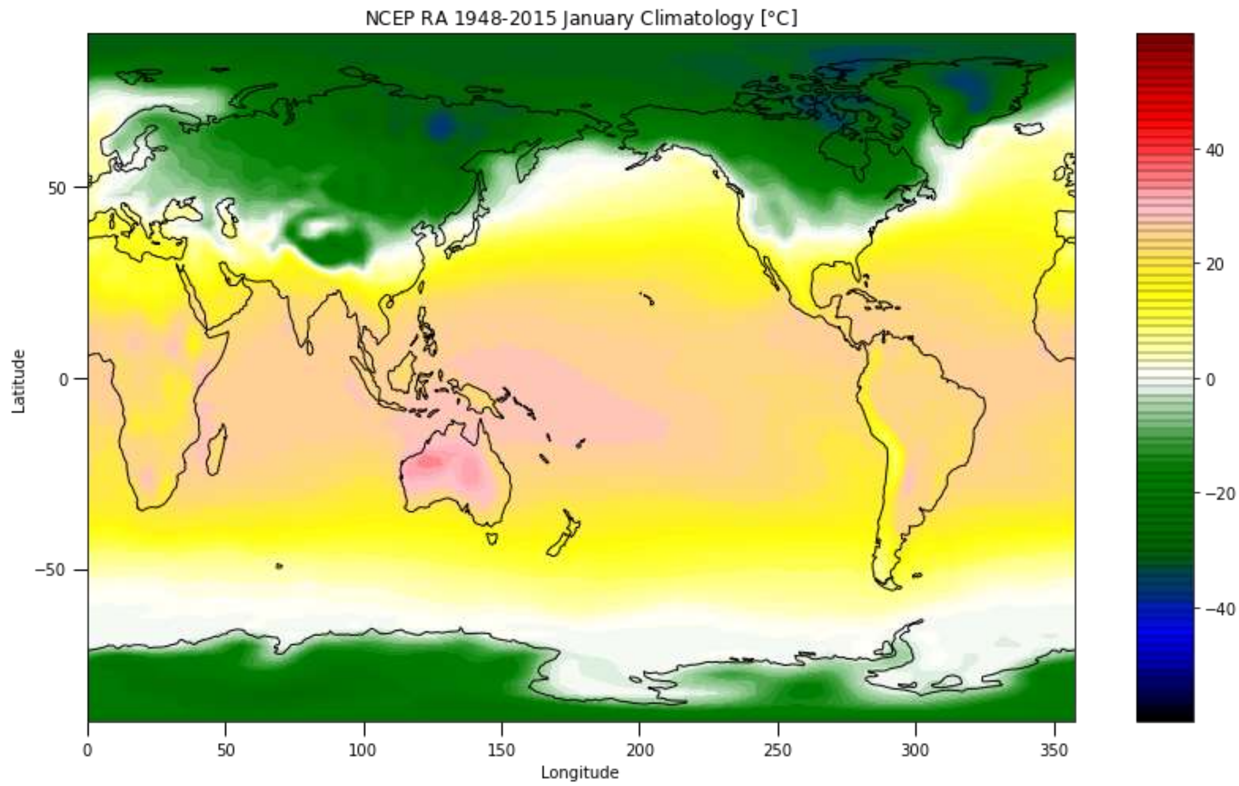

Figure (2): Albedo Effect for the range of Years from 1948 to 2015 January

Code for the creation of the map above is as follows below, with comments explaining how the notable lines function.

```
# set up variables for map as well as number of colors that correspond to data values
contour_levels = np.linspace(-50,50,81)
# create color palette of the map, a section of code called newColMap is created for establishing
a color map
myColMap = LinearSegmentedColormap.from_list(name='my_list',
                        colors=['black','blue','darkgreen','green','white','yellow',
                          'pink','red','maroon'], N=100)
```

#There is a section of code that is created for reading the .nc file of our dataset and reads the mean of it ‘precnc’. We also establish many ranges for the map to use.

```
JMon = precnc[12*np.arange(68)]

sdmat = np.std(precnc, axis=0)

climmat = np.mean(JMon, axis=0)

levels1 = np.linspace(-50, 50, 81)

levels2 = np.linspace(0, 20, 81)


# set up figure using cartopy as well as labeling.

fig, ax = plt.subplots(figsize=(14,8))

ax = plt.subplot(111, projection=cartopy.crs.PlateCarree(central_longitude=180))

ax.coastlines()

ax.set_title("NCEP RA 1948-2015 January Climatology [$\degree$C]")


# plot data from the setup from above.

contf = ax.contourf(Lon-180, Lat, climmat, levels1, cmap=myColMap)


# add colorbar and labels to make the graph much more readable

colbar = plt.colorbar(contf, drawedges=True, aspect=12, ticks=[])

colbar.set_ticks([20*i for i in range(-2, 3)]) #Using a for loop to establish a cleaner range to read,
the color bar

ax.set_aspect('auto')

ax.set_yticks([50*i for i in range(-1, 2)], crs=cartopy.crs.PlateCarree())
```

```
ax.set_ylabel("Latitude")
ax.set_xticks([50*i for i in range(8)], crs=cartopy.crs.PlateCarree())
ax.set_xticklabels([50*i for i in range(8)])
ax.set_xlabel("Longitude")
ax.tick_params(length=9, width=1)

# show plot after all the set up and plotting
fig.show()
```

Now when reading this map, we can see a large portion of the map reads as around the range from 20 to -20 Celsius, though it is proper to mention that more area of the earth are warmer areas than cold which leads to a warmer average. Reports of temperatures of the year 2015 ranging from 14-17 degrees Celsius, match our calculations as well as our map. If we wish to delve in deeper to some more proofing, we can look into some mappings of albedo levels upon a map as provided from NASA. We can evaluate the following maps below; it is mentioned on the site but not physically shown on the map itself that the darkest blue is an albedo value of 0.0 while white is 1.0 and following the hues as such (Albedo 1 Month). We can clearly see that near the winter seasons more whitish hues are present on the map while near the summer season most of the albedo feedback are values of 5.0 and higher as more areas are heating up with few albedo sources. While it is obvious that a value of 0.0 isn’t present on the maps as we have calculated beforehand that a more scorching hot earth would replicate but the earth’s surface is more inclined to be generally blue which indicated values of 6.0 and lower.

Figure (3): Albedo Effect for the Year February 2015, Source of NASA

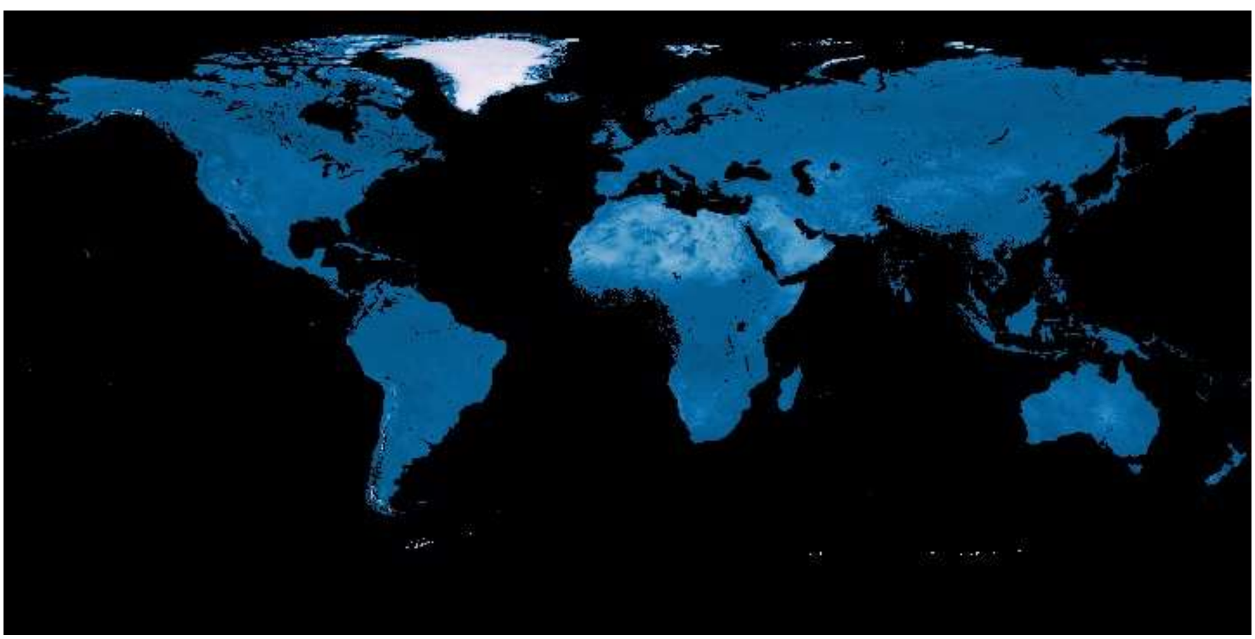

Figure (4): Albedo Effect for the Year July 2015, Source of NASA

Abstract

Our group's project is about a certain topic mentioned in the textbook. That being the energy flow budget and greenhouse effect for the Earth's Climate. We decided that this subject was quite an interesting topic to look into as it is relevant and important to the situation of our current environment and how it can possibly impact us in the future. As mentioned in our textbook, the radiation produced from the sun transmits an energy imbalance of the Earth's own climate and essentially creates the drastic climate change issues we see today. Our general goal with this topic is to map out the temperature changes from the past decade to present day temperature and then use the proper formula to model and predict future temperature changes over the span of the next decade or two (susceptible to change). From the results we produce and the research we look into on the topic, we are able to make a proper prediction and explanation of how the Earth's future climate will shape to be. We have used data sets provided from the textbook as well as from credible source online to base our findings on and do some research on the nature of this topic when we come to present the findings on our paper. We have also made use to create proper data visualization charts and mappings.

Conclusion

To wrap up our work we come to the final mark of our findings. We have provided with credible source that have done studies to look at the general reasoning of why the earth has been heating up in terms of the environment itself. As mentioned we see that the earth's surface does plenty of work in reflecting solar rays with the white surfaces that we label as albedo levels. Through the decline of these levels (as seen through a range of 1.0 meaning mostly white to 0.0

hardly white) the planet heads to a direction of warming up at a steady pace that wasn't seen before. Observing our data set of air temperature from many years ago show a clear sign of comparison of more recent years adopting higher anomaly values which translate to warmer average temperatures.

As a general statement to be made of these reporting's, we can clearly see that this trend will continue for years to come and find average temperatures of the near future rising as our albedo levels of our surface decrease. To prevent things like this to happen we must support actions that prevent to degrading of what makes this planets albedo, as mentioned, its ice bound surfaces as well as the development of larger cloud covered areas, which are degraded from warmer temperatures just like our areas of snow and ice. If the albedo levels weren't a clear enough clue as to the warming up of our earth, we see that this also has effects of other climate conditions that affect the earth such as decline of precipitation (GPCC: Global Precipitation Climatology Centre) that also translate to a lack of wide body of clouds that are as said to be another form of albedo surfacing for the earth's surface. A decline of these levels will cause a more difficult situation for many of this earth as well as its environment, change must be done to counteract it.

References

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