Energy Flow Budget and Greenhouse Effect for the Earth's Climate:

EBM Usage for the Global Average Surface Temperature of the Earth: A Zero-Dimensional Climate Model

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Abstract

The purpose of this paper is to prove the indication of albedo levels of the earth's surface are linked to the earth warming up. Doing some research from credible source as well as completing calculations will both support these claims. IT isn't so hard to imagine how the idea of white surfaces, what we call albedo of the earth's surface, reflecting portions of sun light and don't absorb as much as say compared to a non-white (darker) surface. Using an EBM model we can do some calculations based on different values of the earth as whole an enter in predicted albedo levels based on our research that hotter temperatures are produced at lower levels of albedo. Based from these calculations we look to our dataset that produces an accurate map of heat levels that match to albedo maps in showing the heating of our earth as the albedo levels decrease on the earth's general surface. We hope to see findings like these are just another form of proof of the heating of the planet that is caused from the destruction of our albedo levels (through the melting of ice and snow effected by greenhouse gases) and find solutions to reverse these effects and aid the planet in recovering it albedo layer to be more present than what it currently is.

Introduction

When looking at the current issues we face with climate change on Earth, there are plenty of actions that have caused the temperature to change. If we were to step back from the man made causes that have led to the increase of the surface temperature we can all come to note of the basic fact that professionals have found which is dependent on the Earth's Albedo levels. To simply describe the concept of Earth's albedo would simply state that it is the reflectivity level of the Earth's surface from the Sun's solar rays. We look at this level in relation to a numerical value from an equation that calculates the earth's climate conditions (Albedo). An albedo value of 1.0 would represent a very cold earth, or “snowball Earth”, that is able to reflect a substantial portion of the sun’s solar rays when hitting the Earth. While on the other hand an albedo value of 0.1 or lower would represent of very hot and scorched Earth. Now to explain what the actual object that represents the albedo of our earth would be the areas of frozen tundra, our polar continents, our ice caps. Simply put that due to different actions currently done today that harms the state of these frozen areas and warm them up will lower the earth’s albedo values and lead to a much hotter earth. For a reference there are calculations made from NASA professionals who have made predictions of the Earth’s surface temperature before the 1950’s (Albedo 1 Month). In the example I bring up there is a measure surface temperature from the year 1750 that measured at about 13.72 C. This in turn has, based on our own calculations of EBM equation, that shows that the albedo value for a temperature like that would be 0.625 which is a value much closer to 1.0 the “snowball Earth” we discussed previously.

The focus of our group’s topic will focus on a certain subject discussed about in our textbook “*Climate Mathematics: Theory and Applications*” by Samuel S.P. Shen on the global average surface temperature of Earth through the usage of energy balance models or EBMs. This topic still holds relevance in our current time as we have been seeing increased temperatures of Earth’s surface due to the effects of global warming caused by greenhouse gases. As mentioned in our textbook (pg. 116) the radiation produced from the sun transmits an energy imbalance of the Earth’s own climate. This essentially creates the drastic climate change issues we see today that we haven’t witnessed in previous climate records decades ago. Our general goal with this topic will be to map out the temperature changes from the past decade 4-5 years to present day temperature and then use the proper formula to model and predict future temperature changes. The formula will be thoroughly explained of how it is able to properly predict temperatures of the Earth's surface and provide proof through our data sets. From the results we produce and the research we conduct, we will be able to make a proper prediction of Earth's surface temperature. We can then explain how the Earth's future climate will shape to be through these predictions and our research of temperature patterns of the Earth's surface. We will make sure to use a proper data set provided from NASA's online database to base our findings. From these findings we will present through readable data visualization as well as show our code of the calculated formula we used to predict accurate temperatures of the Earth's surface.

Data and Methods

When regarding to the data of our topic, it is different from the typical data sets used to solve one's inquiry. In our case its mostly our methods that we make most of our focus on and use data sets as a form of proof to support what our equations produce. To be more specific our EBM tuned equations produce a solution of a temperature measurement and we can call this function a multitude of times with different epsilon values, epsilon being used to represent the variable for albedo levels in the equation. This way we show how the calculation of lower average earth surface temperatures correlate to lower albedo levels that represent larger white surface areas (large areas of land covered in snow and ice) that the earth is made up of that reflects the sun's solar rays. To get a better understanding of the epsilon albedo values correlating with earth's surface temperatures we create a graph of the Nonlinear Albedo Feedback. As explained (Shen, pg. 121) of what this graph shows, is that it is dependent on the albedo of earth's surface temperature. The variable of albedo effect is a positive feedback on temperature, meaning that pattern like transition of albedo changes will in turn amplify the temperature changes of earth. This is because the warming of the earth makes it darker in the sense of a lack of white surface area upon the earth that reflects less solar energy and makes the earth much warmer; and vise versa of a cooling (colder surface temperatures) earth becomes brighter due to reflecting more solar energy (NCEP/NCAR Reanalysis 1: Surface).

As a preface for the organization of my paper, I wish to have my code listed down in our writing and have full comments within the lines of code explaining how parts of the code work and function and what they ultimately produce. Here we will show the code of the graph that we have mentioned above and show off the resulting image that occurs. There will be comments written down to explain the logic of the code and what it should be printing out. We can first go ahead with explaining the ab() function as whole before diving into the specifics; that being that the ab() function is based on above-defined piecewise function. It has four parameters that it passes, with three of them having a default set value. ‘T’ is the surface temperature, ‘a1’ is the albedo value that is assumed to be ice and snow earth surface, a default value of 0.7. ‘T1’ is the respective temperature value (in Kelvin) of ‘a1’. Similarly to T1, ‘T2’ is the opposing temperature value (a Kelvin temperature of a much hotter earth) that is reflective of a variable ‘a2’ that will have more explanation to it below. Keep in mind that my code will have comments withs explanations in between lines to explain what most of these functions intend to do and possibly return as well.

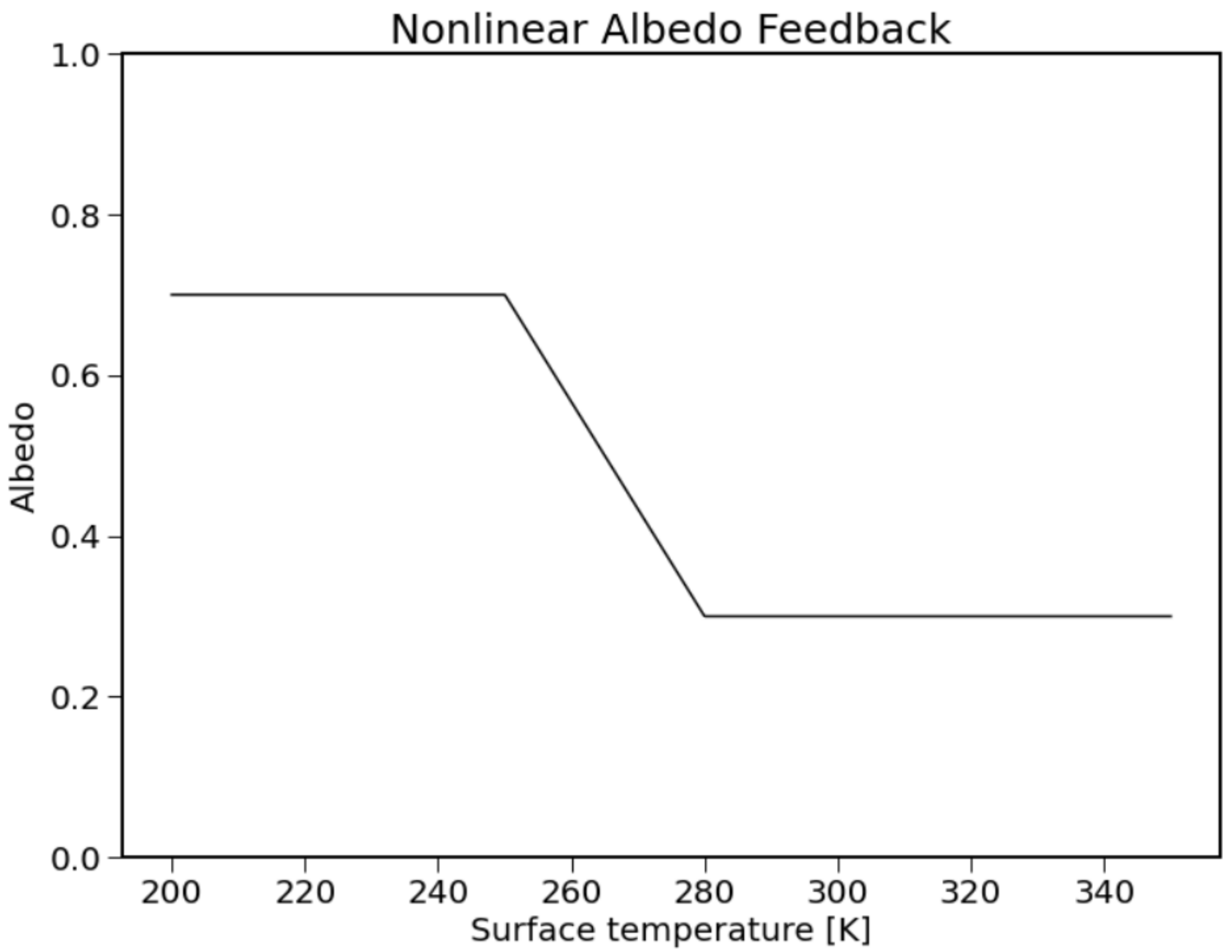
```
def ab(T, a1=0.7, T1=250,T2=280):
    # ‘a2’ is a variable based on the a1 parameter, it is supposed to be the opposite end of the
perceived snowball earth albedo value
    a2 = 1 - a1
# a list called ‘a’ is created to hold all the surface temperature values to be plotted on the graph.
    a = []
    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 behavior 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:
            if T < T2:
                a.append(((a1-a2)/(T1-T2))*(T-T2) + a2)
            else:
                a.append(a2)
        return a
```

Now that the function of this has been explained we can move forward with running this function to obtain data values that will create our nonlinear albedo feedback graph. Here is the code that we use to basically create the graph. We create a variable ‘t’ that holds a range of different temperatures with about 1001 data points between the lower and upper bound range.

```
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:



As the graph shows above, we can see the nonlinear relationship between albedo and surface temperature.

Finally, we can look into our calculations using EBM models. Through this we can prove our claim of the effect of greenhouse gases warming up the earth through the deterioration of the Earth's albedo levels (its white surface that is equivalent to snow and ice present on the earth's surface that reflects solar rays). So we can calculate our claims through a couple of questions that are asked in our textbook (Shen, pg. 136). We use these two questions because they are similar in their objective and are calculated in similar manners. 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 R (Python in our case not R).”) 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 $\alpha = \alpha1 - \alpha2 \times \tanh((T-Tc)/Ts)$ 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 more 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)

T2 = ebm55(alpha, S, sigma, .625)

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

```
T22 = ebm55(alpha, S, sigma, .50)
print("Epsilon Parameter changed to 0.50 (Celsius): ", T22)
T3 = ebm55(alpha, S, sigma, .20)
print("Epsilon Parameter changed to 0.20 (Celsius): ", T3 )
```

This is my code, and will now explain the logic behind it. First we see that another function is being defined, that is called ebm55() that takes in four parameters. For a preface this function is based off of 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).

$\varepsilon\sigma T^4 = (1-\alpha(T))(S/4)$ 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 vise 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

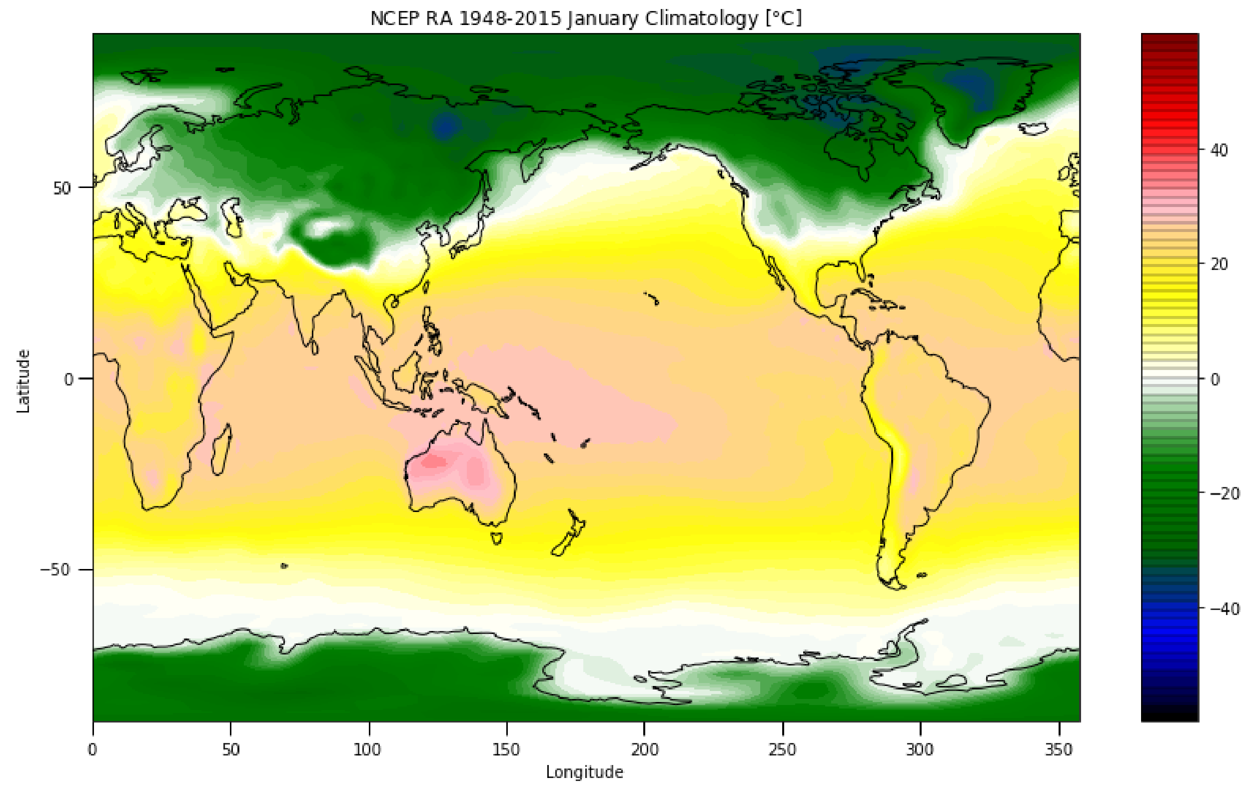
Epsilon Parameter changed to 0.20 (Celsius): 108.0216837986028

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 make up 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.



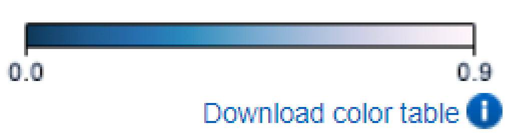
Code for the creation of the map above is as follows below, with comments explaining how the notable lines function.

```
# 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 set up 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 before hand 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.



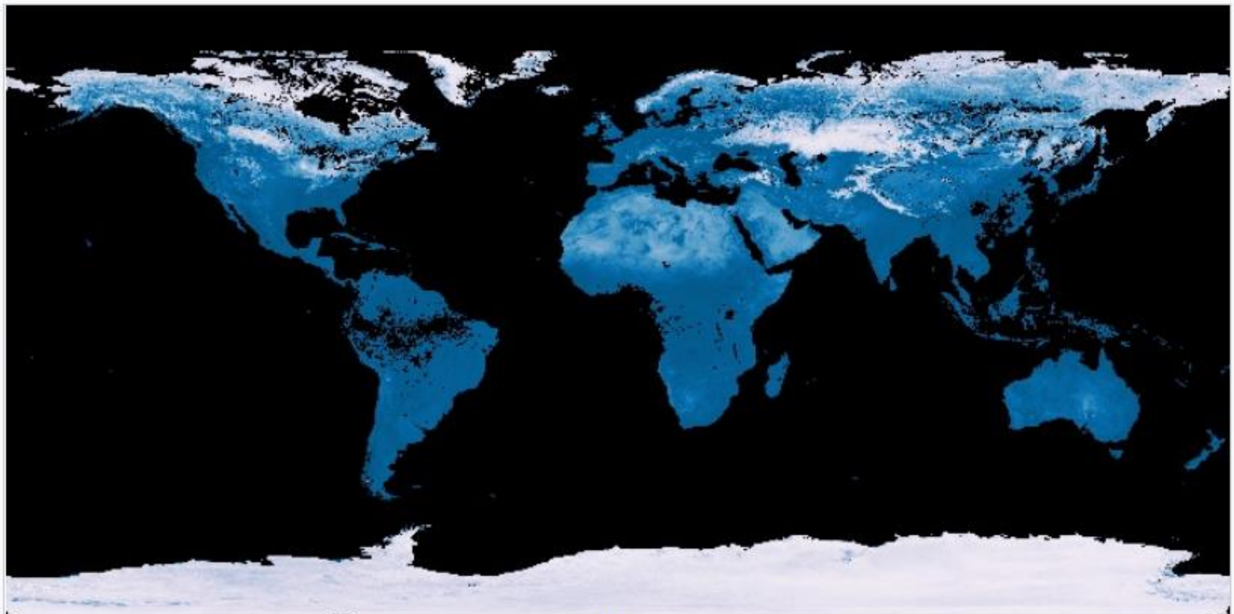


Figure 2. Albedo values for the Earth for February 2015.[4]

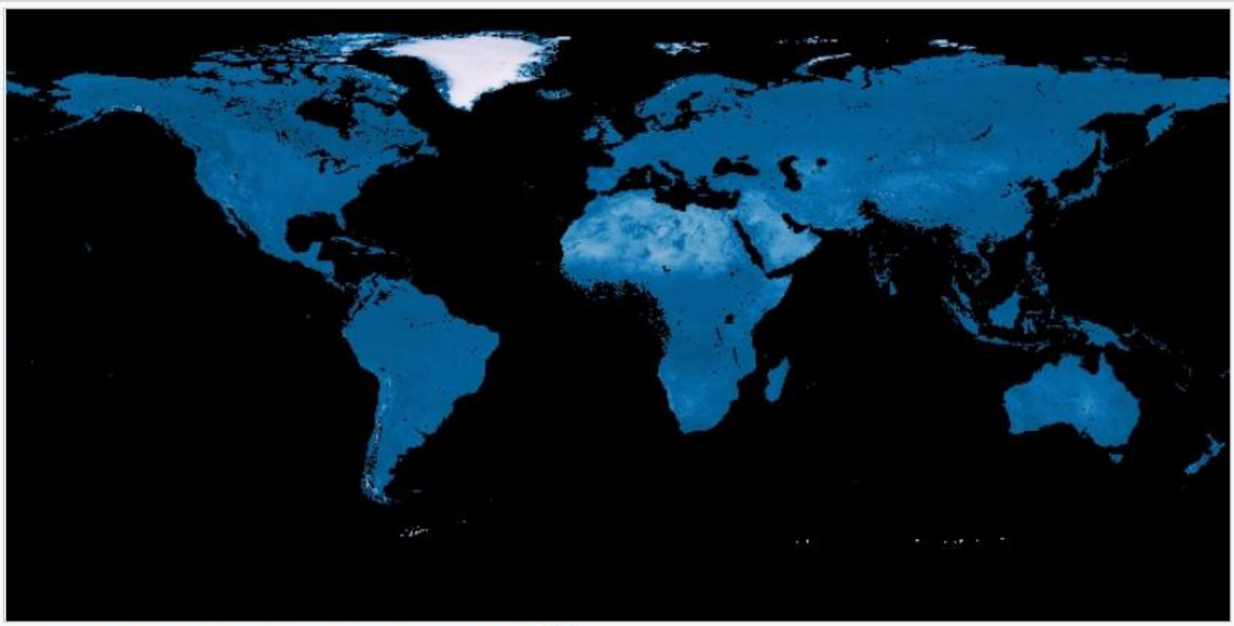


Figure 3. Albedo values for the Earth for July 2015.[4]

As we provided calculations of temperature predictions based on albedo levels, we also see the our many references and data visualizations come to support our findings and claims a great deal. Moving forward some general statements to be made after these findings, is that if we wish to see a prevention of our planet from cooking itself we need to see our albedo levels rise for the earth's surface to help better reflect the sun's solar rays.

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, it's 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

"Albedo (1 Month)." *NASA*, NASA, https://neo.gsfc.nasa.gov/view.php?datasetId=MCD43C3_M_BSA&year=2015.

"Albedo." *Albedo - Energy Education*, https://energyeducation.ca/encyclopedia/Albedo.

"Center for Satellite Applications and Research - NOAA / NESDIS / Star." *NOAA / NESDIS / STAR Website*, https://www.star.nesdis.noaa.gov/jpss/albedo.php.

"Data Overview." *Berkeley Earth*, https://berkeleyearth.org/data/.

"GPCC: Global Precipitation Climatology Centre." *GPCC: Global Precipitation Climatology Centre | NCAR - Climate Data Guide*, https://climatedataguide.ucar.edu/climate-data/gpcc-global-precipitation-climatology-centre.

"NOAAGLOBALTEMP." *National Centers for Environmental Information (NCEI)*, 28 Oct. 2021, https://www.ncei.noaa.gov/products/land-based-station/noaa-global-temp.

Serge, PLANTON. "The Average Temperature of the Earth." *Encyclopedia of the Environment*, 29 July 2020, https://www.encyclopedie-environnement.org/en/climate/average-temperature-earth/.

Shen, Samuel S. P., Richard C. Somerville. Climate Mathematics. Cambridge University Press, 20190919. VitalBook file.

Team, PSL Web. "NCEP/NCAR Reanalysis 1: Surface." *PSL*, https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.surface.html.