Journal of Physics Special Topics

P3_ 7 Meltdown!

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November 12, 2014

Abstract

This paper investigates the change in the albedo of the Earth due to the presence of sea ice and its impact on Earth's surface temperature. If all the sea ice melted, the albedo of the earth would decrease by approximately 7.4%. This would result in an increase of surface temperature by approximately 6˚C.

Introduction

The albedo of the Earth determines the fraction of incident solar radiation which is absorbed by the Earth; hence it would play a significant role in changing the Earth's temperature. Earth's climate is complex and there is variety of factors that would change the albedo of the Earth. In this paper we have investigated the variation of the albedo due to the effect of sea ice only.

Theory

Earth has a very diverse surface with areas of high reflectivity such as ice, snow and sand all of which radiate in the short wave band between 0.1µm- 4µm. On the other hand areas of low reflectivity include ocean, vegetation and soil. Ice has the highest reflectivity of 85% [1]; therefore the melting of sea ice will have a significant effect on the overall reflectivity of the planet. For simplicity in our calculations we consider that the Earth's surface comprises of 60% ocean, 10% sea ice and 30% land covered by vegetation. The reflectivities of these surfaces are shown in Table 1.

Surface type	Vegetation	Ocean	Sea ice
% of surface occupied	**30**	**60**	**10**
Average Reflectivity[%]	**16.5**	**8.5**	**85**

Table 1: Shows different surface types and their fractional areas of Earth used for our calculation below. It also shows the average reflectivity of each surface type [1]

The overall reflectivity of the Earth is estimated using equations 1 and 2 below,

$$A_{total} = A_{ocean} + A_{forest} + A_{ice} + A_{clouds} \qquad (1)$$

$$A_{surface\ type} = \%surface\ area * \%reflectivity\ of\ surface \qquad (2)$$

Single layer gas model

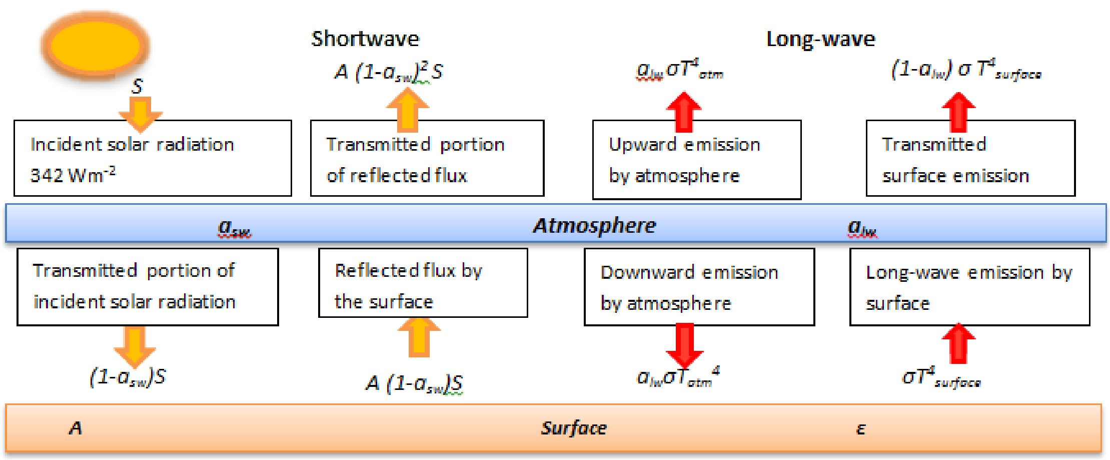

Figure 1: Shows the single layer non-reflecting atmosphere model (adapted from [2]). In this model a_{sw} and a_{lw} are the average absorption coefficients of the atmosphere; *A* is the shortwave albedo, *S* is solar radiation flux. Yellow arrows indicate short-wave radiation (UV/Visible) and red arrows indicate long-wave (thermal radiation).

In the presence of the atmosphere, the temperature of Earth's surface can be approximated using the simple single layer non-reflecting atmosphere radiative model, shown in Figure 1. In Figure 1, a_{sw} and a_{lw} denote the average absorption coefficients of the atmosphere for the short and long wavelengths respectively, ε is the average emissivity of the surface, A is the short-wave albedo of the Earth, S is the incident solar radiation and σ is the Stephan-Boltzmann constant. The total radiation flux at the top of the atmosphere and at the surface of the Earth are given by equations 3 and 4 below [2],

$$Net\ flux\ at\ the\ TOA = (1-a_{sw})^2 S + a_{lw}\sigma T_{atmosphere}^4 + (1-a_{lw})\sigma T_{surface}^4 - S = 0 \qquad (3)$$

$$Net\ flux\ at\ the\ surface = A(1-a_{lw})S + \sigma T_{surface}^4 - (1-a_{sw})S - a_{lw}\sigma T_{atmosphere}^4 = 0 \qquad (4)$$

Equations 3 and 4 can be re-arranged to calculate the temperature of the surface;

$$\mathrm{T_s} = \{\frac{S}{\sigma}.[1-(1-a_{sw})A].\left(\frac{2-a_{sw}}{2-a_{lw}}\right)\}^{\frac{1}{4}} \qquad (5)$$

Results

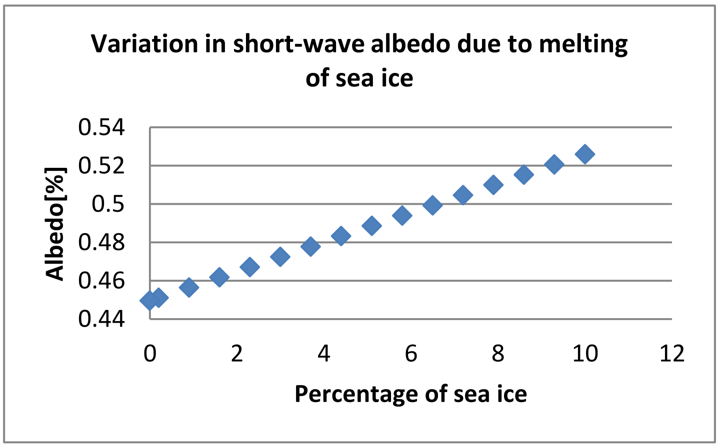

Figure 2: Shows that the total albedo decreases as the sea ice shrinks

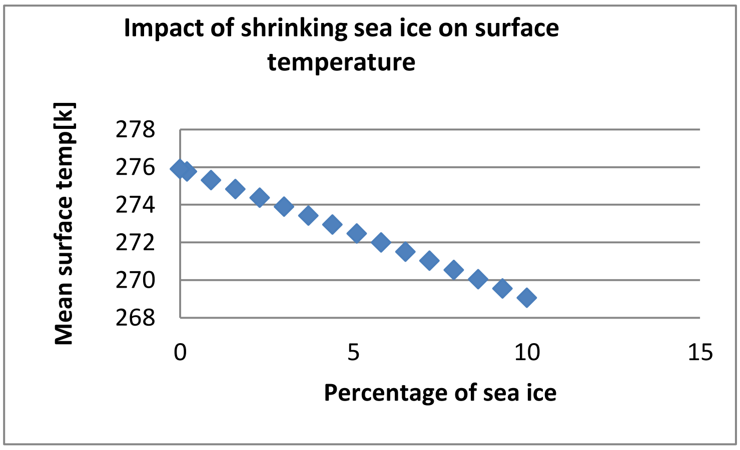

Figure 3: Shows that the mean surface temperature increases as the sea ice shrinks.

As the sea ice shrinks, the percentage of ocean covered by ice would decrease. This factor is taken into account while calculating individual surface albedos using equation 1. Using the figures obtained from equation 1, we calculate the total albedo values using equation 2, where A_{clouds} was assumed to be 22.2 % [2]. These albedo values are displayed in Figure 2.

Figure 2 shows the variation of the total albedo of the Earth as the sea ice decreases, and shows that the melting of the ice will decrease the albedo value by approximately 7.6% (using the difference in initial and final albedos). Here the atmospheric properties remain constant and we only consider the effect of the surface reflectivity. The properties of the atmosphere are approximated as; a_{SW}=0.2, a_{SW}=0.8, S=342 Wm^{-2}[3], ε=1 and σ= $5.67x10^{-8}$ W m^{-2} K^{-4} [2]. The albedo values plotted in Figure 2 are then substituted into equation 5 to generate Figure 3. Results shows that Earth's surface temperature would increase by approximately 6˚C due to melting of all the sea ice.

Conclusion

Using our simplified model of the Earth and the atmosphere, we estimate the effect of the sea ice melting on the overall reflectivity of the Earth and its mean surface temperature. However this is a very simplified approach to problem and a sophisticated model would be required to obtain a better estimate. Our results would be affected by the solar zenith angle, the use of different values for the albedo (which are dependent on the reflectivity of the atmosphere) and the spectral dependence of absorption coefficients for the emissivity and reflectivity; factors which are not considered in this paper.

References

[1] http://www.climatedata.info/Forcing/Forcing/albedo.html accessed on 12/11/2014
[2] Petty, G.W., (2004): A First Course in Atmospheric Radiation. Sundog Publishing, Madison, WI, 444 pp.
[3] http://www.azimuthproject.org/azimuth/show/Solar%20radiation accessed on 21/11/2014