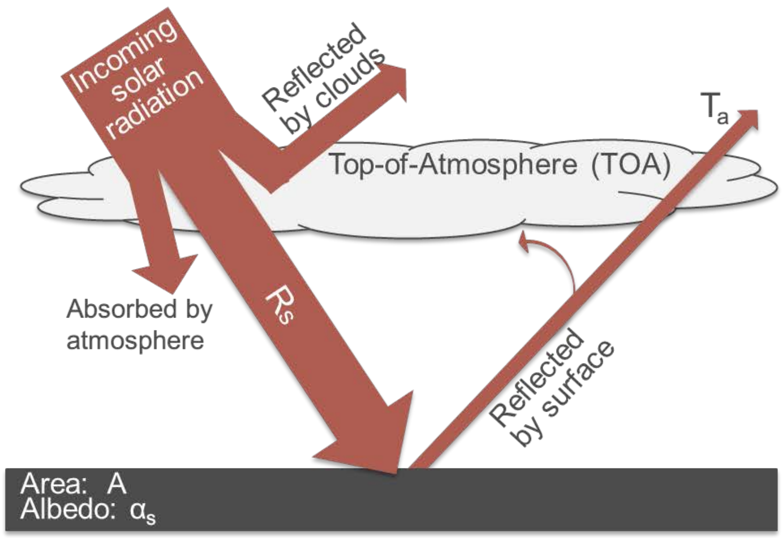
A High-Level Analysis of Context-Dependent Albedo Effects

PROBLEM

Albedo is a measure of surface reflectivity, defined as the fraction of incident radiation reflected by a surface. High-albedo or reflective materials are able to reflect more solar radiation and lower the earth surface temperature. Thus, increasing surface albedo has the potential to alter the earth's energy balance and offset some climate change affects. The effect of changing surface albedo on the earth's energy balance can be estimated using radiative forcing (RF), which is the change in the difference between incoming and outgoing radiation at the top-of-atmosphere (TOA), as shown in Figure 1. Though the factors used to translate albedo to RF are often reported as a single, global average, they are in fact, highly context-dependent, varying by time, location, and surface characteristics.



- Earth has a radiative equilibrium
- Anything that impacts the equilibrium is a "*forcing*", including man-made surfaces
- The radiative forcing of a surface can be quantified using changes in surface albedo that impact reflectivity, and vice versa
  - RF = Δ (incoming solar radiation – outgoing solar radiation)
  - outgoing solar radiation = sum of all radiations reflected back into space

Figure 1. Shortwave solar radiation flows through the atmosphere and the surface. R_s: downward solar radiation at the surface; T_a: atmospheric transmittance factor

APPROACH

This analysis aims to demonstrate the time and location variations of albedo effects based on a model that analyzes land-use changes in agricultural contexts[1]. Global warming potential (GWP) in the unit of carbon dioxide equivalent (CO_2-eq) is used as a measure of the strength of the radiative forcing. The expression for calculating the GWP from changes in surface albedo is given in Eq.1.

$$\Delta m_{CO_2-eq.} = A \times \frac{R_s T_a \Delta\alpha_s}{RF_{CO_2} AF} \qquad Eq.1$$

As shown in Figure 1, *A* is the surface area that is affected by the change in albedo (assume a 1-mile section of four-lane road in this analysis). R_s is downward solar radiation at the Earth's surface (in watts per square meter). T_a is an atmospheric transmittance factor expressing the fraction of the radiation reflected from the surface that reaches the TOA and goes back to space (a global value 0.854 is used). RF_{CO_2} is a constant representing the marginal RF of CO_2 emissions at the current atmospheric concentration (0.908 W/kg CO_2). *AF* is the average CO_2 airborne fraction (0.48 for a 100-year time horizon). Note that RF_{CO_2} and *AF* cannot be shown in the figure. $\Delta\alpha_s$ is the change in surface albedo.

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Consider the example of using a lighter colored pavement, which can improve the albedo by 0.15-0.20 in a newly constructed pavement. We then obtained context-specific data for R_s from a NASA online database of satellite measurements for four locations (Los Angeles, Houston, Chicago and Boston) and calculated the CO_2-eq offset due to a 0.15 increase in surface albedo ($\Delta\alpha_s$=0.15) over an analysis period of 50 years.

FINDINGS

Figure 2 is a plot of monthly CO_2-eq savings from increasing the surface albedo by 0.15 for a 1-mile pavement section at each of the four selected cities. The cumulative GWP savings for 50 years are also listed for each city in the legend. It is obvious that the GWP impact of changing surface albedo varies by time and location. In general, this effect is more pronounced in the summer than in the winter. While all 4 locations benefit due to a change in albedo, Los Angeles presents a greater opportunity for global warming mitigation through mechanisms such as the use of reflective surface materials.

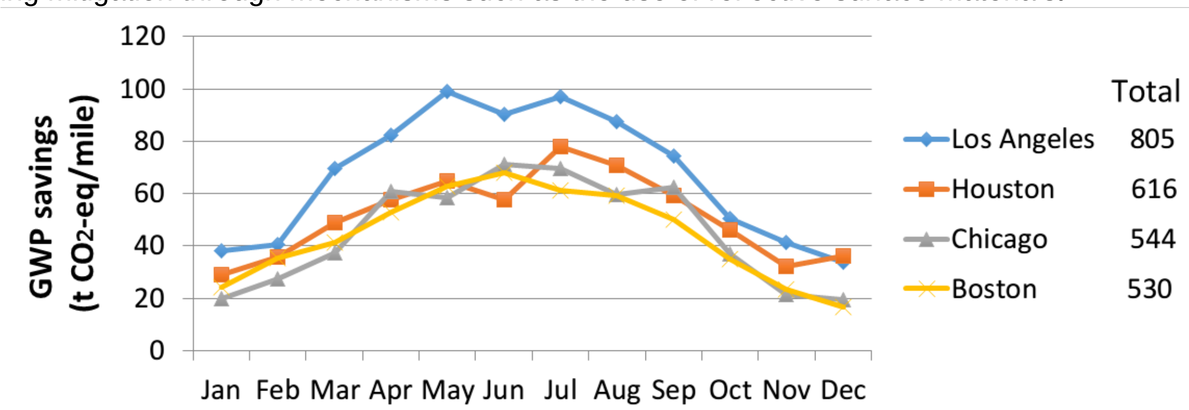

Figure 2. Monthly and cumulative GWP savings from 0.15 increase in albedo at four locations over 50 years

IMPACT

While the exact magnitude of albedo effects depends on contextual factors like geographical or climate conditions, and needs additional studies, it can be seen that increasing the albedo of an area does have positive impact GWP. More comprehensive climate modeling is needed to populate context-specific data for the quantification of albedo effects.

1. Muñoz, I., Campra, P., & Fernández-Alba, A. R. (2010). Including CO_2-emission equivalence of changes in land surface albedo in life cycle assessment. Methodology and case study on greenhouse agriculture. *The International Journal Of Life Cycle Assessment*, 15(7), 672-681

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