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Global cooling updates: Reflective roofs and pavements

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ABSTRACT

With increasing the solar reflectance of urban surfaces, the outflow of short-wave solar radiation increases, less solar heat energy is absorbed leading to lower surface temperatures and reduced outflow of thermal radiation into the atmosphere. This process of "negative radiative forcing" effectively counters global warming. Cool roofs also reduce cooling-energy use in air conditioned buildings and increase comfort in unconditioned buildings; and cool roofs and cool pavements mitigate summer urban heat islands, improving outdoor air quality and comfort. Installing cool roofs and cool pavements in cities worldwide is a compelling win–win–win activity that can be undertaken immediately, outside of international negotiations to cap CO_2 emissions. We review the status of cool roof and cool pavements technologies, policies, and programs in the U.S., Europe, and Asia. We propose an international campaign to use solar reflective materials when roofs and pavements are built or resurfaced in temperate and tropical regions.

1. Introduction

A number of scientists have proposed supplementing the full range of mitigation efforts with geo-engineering (manipulation of the Earth's environment) to quickly respond to the threat of climate change [1]. Many proposed geo-engineering techniques are novel and unproven. One simple technology has been in practice for thousands of years: use of materials with high solar reflectance (albedo) of urban built surfaces. "Cool roofs" and "cool pavements" should be among the first geo-engineering techniques used to combat global warming.

Increasing the solar reflectance of the urban surface reduces its solar heat gain, lowers its temperatures, and decreases its outflow of thermal infrared radiation into the atmosphere. This process of "negative radiative forcing" can help counter the effects of global warming. In addition, cool roofs reduce cooling-energy use in air conditioned buildings and increase comfort in unconditioned buildings; and cool roofs and cool pavements mitigate summer urban heat islands, improving outdoor air quality and comfort.

As a result of the low costs premium, substantial energy saving, and the lack of esthetic conflict, it is fairly easy to persuade or require the owners of buildings to select white materials for flat roofs, and in California this has been required for non-residential buildings since 2005 [2]. However, the demand for white sloped roofs is limited in North America for esthetic reasons. California has compromised by requiring only "cool colored" surfaces for sloped roofs, starting in January 2010 [2].

Over 50% of the world population now lives in urban areas, and by 2040 that fraction is expected to reach 70% [3]. Using fine-resolution orthophotos, Akbari and Rose [4] have estimated roof and pavement surface area fractions in four U.S. cities. Roof area fractions varied from 20% for less dense cities to 25% for more dense cities; pavement area fractions varied from 29% to 44% [4]. Akbari et al. [5] estimate that permanently retrofitting urban roofs and pavements in the tropical and temperate regions of the world with solar-reflective materials would have an effect on global radiative forcing equivalent to a one-time offset (hereafter referred as CO_2 offset) of 44 Gt (giga tonne) of emitted CO_2 [5]. They estimate that the use of white roofs increases solar reflectance by about 0.40, yielding to a reduced atmospheric temperature equivalent to reducing CO_2 emissions by 10 t/100 m^2. Cool-colored roofs that increase solar reflectance by about 0.20, yield a one-time CO_2 offset of 5 t/100 m^2. The solar reflectance of pavements can be raised on average by about 0.15 resulting in an equivalent offset of 4 t CO_2/100 m^2.

A more recent study by Menon et al. through detailed simulations has obtained similar results [6]. They performed several sets of simulations with the land component (CLSM) of the NASA GEOS-5 climate model and quantified the effects of changes to radiative forcing and temperature when the albedos of roofs and pavements in urban areas were increased. The simulations were designed to understand the effect of a 0.1 increase in surface albedo over urban areas on radiative forcing and temperature over all global land areas. They found that the land surface temperature decreased by ~0.008 K for an average increase of 0.0003 in surface albedo. Other

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climate variables such as surface energy fluxes (latent and sensible heat) and evaporation. indicated smaller changes that were not as significant. Only changes to the radiation budget were significant, and an average increase in total outgoing radiation of $\sim$0.5 W m^{-2} was obtained for all global land areas. Based on the radiative forcing obtained in their study, the potential emitted CO_2 offset for similar changes proposed by Akbari et al. (a 0.25 and 0.15 increase in albedos of roofs and pavements in urban areas) were calculated to be about 57 Gt of CO_2 [5].

Another recent study has quantified the effects of white roofs on urban temperature, using a global climate model coupled with an urban canyon model [7]. They estimate, averaged over all urban areas, a decrease in urban daily maximum temperature by 0.6 K and daily minimum temperature by 0.3 K. This study has not carried out calculations to estimate the CO_2 offset resulting from the temperature reduction in urban areas.

The current estimates of CO_2 offset are based on a constant (short-term: 50–100 years) radiative forcing of about 0.91 kW/t of atmospheric CO_2. However, the radiative forcing due to a given CO_2 emission will decrease with time owing to the gradual removal of CO_2 by natural carbon sinks and raising global temperature. For example, Matthews and Caldeira showed that only about half of the original radiative forcing from a pulse CO_2 emission remains in the atmosphere after 200 years [8]. Assuming that surface albedo perturbations could be maintained permanently, the relative effectiveness of albedo increases as a CO_2 emission offset would increase over time.

In addition to reflecting light back into the atmosphere, it is well established that cool roofs reduce energy use in air conditioned buildings and increase comfort in unconditioned buildings [9,10]. Similarly, the widespread application of cool roofs and cool pavements helps to mitigate summer urban heat islands, thereby further reducing the overall air conditioning load and improving outdoor air quality and comfort [9].

In this paper, we briefly discuss the long-term effects of surface albedo modification. Then we discuss policy options to encourage installing high-albedo roofs and pavements in urban areas. We then propose an international “100 Cool Cities” campaign to mobilize the 100 largest cities in the world to use solar reflective materials when roofs and pavements are built or resurfaced in temperate and tropical regions.

2. Long-term effects of increasing urban albedo

We used the University of Victoria Earth System Climate Model (UVic ESCM), an intermediate complexity global climate model which includes an interactive global carbon cycle [11]. This model is used to calculate the long-term effect of surface albedo modification, combined with an increase in atmospheric CO_2 on global temperature [11]. Three simulations were performed: Basecase, Albedo + 0.05, and Albedo + 0.10. The Basecase simulation is performed using specified business-as-usual CO_2 emissions (SRES A2; [12]) from 1800 to 2100, followed by constant emissions until the year 2200 as shown in Fig. 1 [12]. The Albedo + 0.05 and Albedo + 0.10 are the same as the Basecase but the albedo of all land area between 45°N and 45°S (about 65.4% of land area) is increased by 0.05 and 0.10 in year 2000, respectively. Fig. 2 shows the time series of the average global albedo for the Basecase and the modified cases.

The simulated time series of global temperature is shown in Fig. 3 Changing the albedo has significant effect on global temperature and the effect is further enhanced as the time proceeds. Fig. 4 shows the temperature difference between the albedo modified cases and the Basecase. Increasing the albedo by 0.05 (0.10) has resulted in a temperature decrease of about 1 K (2 K) in about

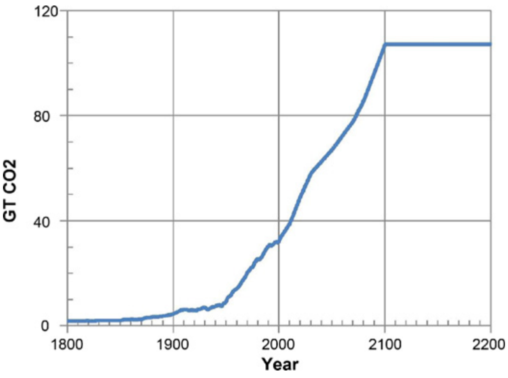

Fig. 1. CO_2 emissions: A2 (Business as usual) emissions, followed by constant emissions after 2100 [12].

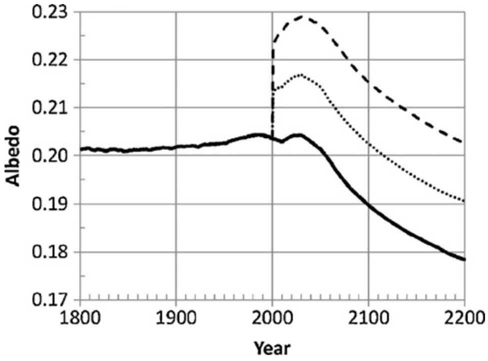

Fig. 2. Global albedo. The lower line is the control. The other two lines have land surfaces between 45°N and 45°S increased in albedo at 2000 by 0.05 and 0.1, respectively.

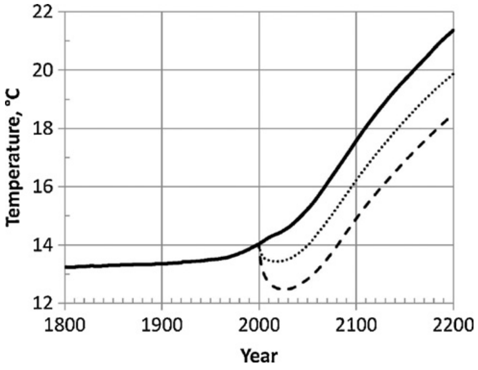

Fig. 3. Temperature change1800–2200: this is the globally averaged time series that corresponds to the above three runs.

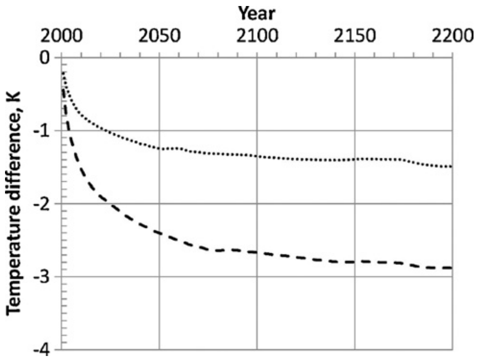

Fig. 4. Temperature difference between the Basecase and Albedo + 0.05 and Albedo + 0.10.