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The long-term effect of increasing the albedo of urban areas

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Abstract
Solar reflective urban surfaces (white rooftops and light-colored pavements) can increase the albedo of an urban area by about 0.1. Increasing the albedo of urban and human settlement areas can in turn decrease atmospheric temperature and could potentially offset some of the anticipated temperature increase caused by global warming. We have simulated the long-term (decadal to centennial) effect of increasing urban surface albedos using a spatially explicit global climate model of intermediate complexity. We first carried out two sets of simulations in which we increased the albedo of all land areas between ±20° and ±45° latitude respectively. The results of these simulations indicate a long-term global cooling effect of 3×10^{-15} K for each 1 m^2 of a surface with an albedo increase of 0.01. This temperature reduction corresponds to an equivalent CO_2 emission reduction of about 7 kg, based on recent estimates of the amount of global warming per unit CO_2 emission. In a series of additional simulations, we increased the albedo of urban locations only, on the basis of two independent estimates of the spatial extent of urban areas. In these simulations, global cooling ranged from 0.01 to 0.07 K, which corresponds to a CO_2 equivalent emission reduction of 25–150 billion tonnes of CO_2.

Keywords: global cooling, CO_2-equivalent offset, urban albedo, cool roofs, cool pavement

1. Introduction

Many technological strategies have been proposed to manipulate Earth's environment as a way of rapidly responding to and potentially offsetting some of the warming resulting from anthropogenic climate change (AMS 2009). This portfolio of geoengineering ideas includes a wide range of approaches and technologies, ranging from sequestration of atmospheric CO_2 to solar radiation management via increasing planetary albedo. For each technology, often novel and unproven, there are almost equal numbers of studies discussing positive and potential negative effects (including cost) of technologies. However, among the proposed approaches, increasing the albedo of the urban areas and human settlements (hence increasing the albedo of Earth as a whole) by increasing the reflectivity of artificial urban surfaces (rooftops, pavements), is based on proven technologies that have been used for centuries with no known negative effect.

Human-made high-albedo surfaces absorb less incoming solar radiation, and all else being equal, will have a lower temperature than surfaces with low solar reflectance. If used in the context of houses and buildings in warm climates, a roof with high solar reflectance can also decrease cooling energy use in air conditioned buildings and increase comfort in unconditioned buildings (Akbari *et al* 2001). Roofs and pavements with high solar reflectance can also mitigate summer urban heat islands, improving outdoor air quality and comfort (Akbari *et al* 2001).

In the urban areas of the United States, it is estimated that roof area fractions vary from 20% for less dense cities to 25% for more dense cities and pavement area fractions vary from 29% to 44% (Akbari and Rose 2008). In other countries with high population densities, the fraction of anthropogenic surfaces may be much higher than those of the United States. One of the main characteristics of these human-made surfaces is that they have to be changed and maintained regularly (e.g,. paved surfaces are typically resurfaced once in a decade and new roofs are installed or resurfaced every 2–3 decades). A coordinated plan to install roofs and pavements with high solar reflectance when they are being maintained can potentially increase the reflectivity of anthropogenic surfaces in 2–3 decades. The promising low costs premium, substantial energy savings, and the lack of aesthetic conflict, has led many countries, states and municipalities to adopt codes and standards for installing roofs with high solar reflectance (Akbari and Levinson 2008). The adoption of pavements with high solar reflectance (aged solar reflectance of about 0.25–0.30 versus existing dark asphalts with solar reflectance of about 0.10) has not been that widespread, mostly because of limited availability of marketable cool pavements. However, anecdotal studies have suggested that cool pavements can have a longer life and hence a lower life cycle cost, which could potentially also decrease GHG emissions because of lower energy requirements for pavement manufacture and installation (Pomerantz and Akbari 1998).

Akbari *et al* (2009b) estimated that permanently retrofitting roofs and pavements in the tropical and temperate regions of the world with solar reflective materials would have an effect on global radiative forcing (RF) equivalent to a one-time offset of 44 Gt of emitted CO_2. The authors estimated that the use of white roofs increased the long-term solar reflectance by about 0.40, yielding reduced atmospheric temperature equivalent to decreased CO_2 emissions (hereafter referred as CO_2 offset) of 0.1 tonnes m^{-2} of modified surface. Cool-colored roofs that increased solar reflectance by about 0.20, yielded a one-time CO_2 offset of 0.05 tonnes m^{-2}, or about half that achieved with white surfaces. The solar reflectance of pavements can be raised on average by about 0.15, with an equivalent CO_2 offset of 0.04 tonnes m^{-2}.

A follow up study obtained similar results through detailed simulations using the land component (CLSM) of the NASA GEOS-5 climate model to quantify the effects of changes to RF and temperature when the albedos of roofs and pavements in urban areas were increased (Menon *et al* 2010). Other climate variables such as surface energy fluxes (latent and sensible heat) and evaporation showed 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 RF obtained in that study, the global potential emitted CO_2 offset for a 0.25 and 0.15 increase in albedos of roofs and pavements respectively was calculated to be about 57 Gt of CO_2.

Oleson *et al* (2010) quantified the effects of white roofs on urban temperature, using a global climate model coupled with an urban canyon model. They estimated, averaged over all urban areas, a 0.6 K decrease in urban daily maximum temperature, and a decrease of 0.3 K in daily minimum temperature. They did not estimate the CO_2 offset associated with this temperature decrease in urban areas.

Akbari *et al* (2009b) identified four sources of uncertainties in their calculations of the potential CO_2 emission offset associated with urban albedo increases:

(1) estimates of the change in CO_2 concentration (and associated radiative forcing) associated with a given CO_2 emission;
(2) the short-term versus long-term effects of atmospheric CO_2 on global temperatures;
(3) the effect of cloud cover and other climate feedbacks on the regional temperature change associated with increased albedo of land surfaces; and
(4) estimate of available urban areas.

Notably, Akbari *et al*'s (2009b) estimates of CO_2 offsets were based on a constant (over 50–100 yr) RF of about 0.91 kW/tonne of atmospheric CO_2 increase. However, the RF resulting from a given CO_2 emission will decrease with time owing to the gradual removal of CO_2 by natural carbon sinks. For example, Matthews and Caldeira (2008) showed that only about half of the original RF from a pulse CO_2 emission remained in the atmosphere after 200 yr. Assuming that surface albedo perturbations could be maintained indefinitely, this would have a similar climate effect as an immediate CO_2 removal from the atmosphere, followed by additional small reductions over time required to maintain a step decrease in RF. As such, the emissions offset associated with such a step change in radiative forcing would increase slowly with time.

Campra (2008) has performed an analysis of the effect of the uncertainties in assumptions made in Akbari *et al* (2009b). They have also documented the regional cooling resulting from the whitewashing of greenhouses in southern Spain. In a companion study, Campra *et al* (2008) estimated a net top of the atmosphere regional reflected radiation of 2.2 W m^{-2} per 0.01 increase in surface albedo (versus 1.27 W m^{-2} global average estimated by Akbari *et al* (2009b)). Hence, they concluded that the CO_2offsets estimated by Akbari *et al* (2009b) (2.5 kg m^{-2} per 0.01 change in surface albedo) could be as much as 4.3 kg m^{-2}. Muñoz *et al* (2010) extend the analysis of Campra (2008) and Campra *et al* (2008) and develop a methodology to assess the equivalent CO_2 emissions associated with these changes in surface albedo. They used the Bern carbon cycle model (Joos *et al* 2001) to estimate the fraction of emitted CO_2 remaining in the atmosphere over time. Applying their methodology to a greenhouse for farming tomatoes, they estimated that the whitewashing of the greenhouse can offset at much at 90% of the overall CO_2 emissions for farming of tomato.

Lenton and Vaughan (2009) performed a similar analysis for several climate geoengineering options, including increasing the albedo of urban areas. Assuming the same urban surface area (1.5×10^{12} m^2) as Akbari *et al* (2009b), they estimated a similar RF of -0.047 W m^{-2}. In addition, they provided an estimate in which they separated overall urban areas into categories of 'urban' (with area of 2.6×10^{11} m^2) and 'human settlement' (3.3×10^{13} m^2); as a result of decreased estimate of urban areas, they estimated a reduced RF of -0.0081 W m^{-2} (for the case where the albedo of human settlement is increased, they found a reduced RF of -0.16 W m^{-2}). Their estimate of urban and human settlement was obtained from Loveland *et al* (2000), who developed a global land cover characteristics database using 1 km resolution AVHRR data. While the distinction between urban and other human settlement areas is not clearly defined, Lenton and Vaughan's analysis does emphasize the importance of uncertainty associated with estimates of available urban areas as a determinant of the potential effects of albedo modification.

Hamwey (2007) also performed an analysis of the effect of increasing human settlement albedo on climate, including the feedback effects of atmospheric water vapor and cloud cover. They concluded that cloud cover tended to decrease in response to increased surface albedo, but that the overall feedback effect of clouds on the temperature response to urban albedo modifications was small. By contrast, Jacobson and Ten Hoeve (2012), using their own model, found that regional cloud feedbacks in response to urban albedo increases were large enough to offset the local cooling caused by surface albedo increases. While it is clear that cloud responses to changing surface albedo could be an important determinant of temperature responses, the high uncertainty associated with cloud processes and feedbacks precludes any robust assessment of their likely effect.

There is evidence from other studies of surface albedo changes, however, that the expectation of regional cooling from surface albedo increases is robust across a variety of different mechanisms of surface albedo change. For example, Myhre and Myhre (2003) developed a model to estimate the RF associated with surface albedo increases as a result of anthropogenic land cover change. They estimated a negative RF reduction of 0.52–1.2 W m^{-2} for a 0.01 increase in surface albedo, which is similar to that reported by a wide range of studies of the effect of land cover change on climate (e.g., Forster *et al* 2007, Pongratz *et al* 2010). Similarly, Winton (2006) estimated the effect of surface albedo feedbacks on global temperature, and found a consistent decrease in temperature with increasing surface albedo.

In this paper, we present a series of transient model simulations in which we have estimated the short- and long-term effects of urban surface albedo modification on global temperature in the context of two scenarios of future CO_2 emissions. We have used a spatially explicit global climate model with an interactive carbon cycle and realistic representation of ocean carbon and heat uptake. In addition to idealized surface albedo increase experiments, we have made use of two recent datasets of the spatial extent of urban areas to estimate the maximum potential for global temperature modification via the modification of the albedo of urban areas. In addition, we have calculated the equivalent CO_2 emissions offset corresponding to the simulated temperature change from albedo modification, using recent estimates of the anticipated temperature change per unit CO_2 emitted.

2. Methodology and simulation model

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 (Weaver *et al* 2001, Eby *et al* 2009). The atmospheric component of UVic ESCM is a vertically integrated (two-dimensional) atmospheric energy and moisture balance model, with specified wind fields that enable horizontal advection of heat and water. The ocean is a three-dimensional general circulation model, coupled to a dynamic/thermodynamic sea-ice model (Weaver *et al* 2001). The carbon cycle component includes dynamic vegetation on land, land carbon exchange via photosynthesis and decomposition, inorganic ocean carbon cycling in the ocean, and ocean biological carbon uptake (Meissner *et al* 2003, Schmittner *et al* 2008). As a computationally efficient global climate model, UVic ESCM is well suited to simulate the decadal- to centennial-scale climate response to greenhouse gas emissions, and has also been used as an effective tool to assess the climate response to solar radiation management (Matthews and Caldeira 2007, Matthews *et al* 2009a). Owing to the reduced complexity of the atmospheric component of the UVic ESCM, cloud feedbacks are not included, and the albedo of the atmosphere remains constant over time. On the other hand, as a spatially explicit model with reduced atmospheric variability, this model is well suited to assess the climate response the small and spatially variable forcing associated with urban surface albedo modification.

3. Simulation scenarios

All simulations began from a multi-thousand year spin up of the model under preindustrial conditions (zero anthropogenic forcing; CO_2 concentrations set to 280 ppm). We then integrated the model forward to present day, driven by observed increases in atmospheric CO_2 concentrations. After the year 2010, we prescribed CO_2 emissions, allowing atmospheric CO_2 concentrations in the model to vary interactively as a function of prescribed anthropogenic emissions, and simulated land and ocean carbon sinks. For the period from 2010 to 2300, we used two CO_2 emission scenarios: (1) a 'business-as-usual' (BAU) emission scenario, where CO_2 emissions increased dramatically to the year 2100 (following the SRES A2 scenario (Nakicenovic *et al* 2000)), and then decreased linearly to zero at the year 2300 (resulting in total cumulative emissions of close to 5000 GtC or 18 500 Gt CO_2); and (2) an 'aggressive mitigation' (AgMit) scenario, in which CO_2 emissions peaked around the year 2025 and decreased to zero at the year 2100 (resulting in total cumulative emission of 1000 GtC or 3700 Gt CO_2) (see figure 1).

The 'Basecase' simulations therefore represent the climate response to these two CO_2 simulations in the absence of any land surface albedo modification. In addition, we performed additional sets of simulations, which included albedo modification in addition to the above two CO_2 emission scenarios. First, we increased the surface albedo by 0.1 over all land areas between ±20 latitude (Case20), beginning at the year 2010. Second, we applied the same 0.1 albedo increase, but over all land areas between ±45 latitude (Case45). The total land areas between ±20 latitude and ±45 latitude constitute 26.5% and 61.9% of total global land area, respectively.

In addition to these idealized albedo increases, we made use of two global datasets of urban areas to generate a more realistic estimate of the effect of urban surface albedo

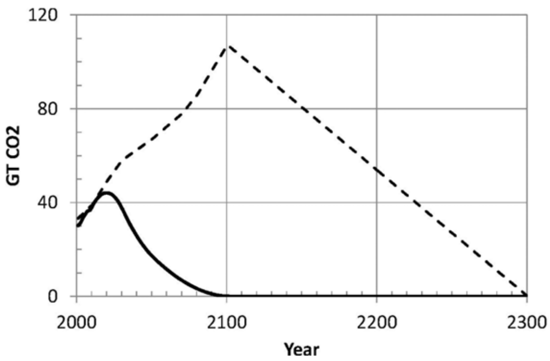

Figure 1. Emission scenarios. Business-as-usual (A2): dashed line. Aggressive mitigation (AgMit): solid line.

modification. The first is the GRUMP (Global Rural and Urban Mapping Project) dataset (CIESIN 2007); the second is that of Schneider *et al* (2009), which is based on analysis of 500 m MODIS satellite data. Importantly, the estimated global urban areas in GRUMP are more than five times larger than in the MODIS data (Schneider *et al* 2009); this represents an important area of uncertainty pertinent to our estimate of global CO_2 offset. We incorporated both datasets of urban areas into UVic ESCM, and increased surface albedo by 0.1 within the fraction of each model grid cell occupied by urban areas.

4. Results

The simulations show that, to first order, the effect of albedo change does not depend significantly on the scenario of CO_2 emission. As can be seen in figure 2, there is a generally similar pattern of atmospheric surface temperature decrease resulting from increased surface albedo (Basecase minus Case45) for both the BAU and AgMit scenarios. The small differences between the two scenarios (a slightly larger temperature decrease in the AgMit) reflects the different magnitude of climate feedbacks at different global temperatures. In particular, the snow-albedo feedback—which contributes to a local amplification at high latitudes of the climate response to any imposed forcing—decreases in magnitude with higher amounts of global warming as a result of decreased snow and sea-ice extent. This results in a slightly larger climate response to surface albedo modification in the

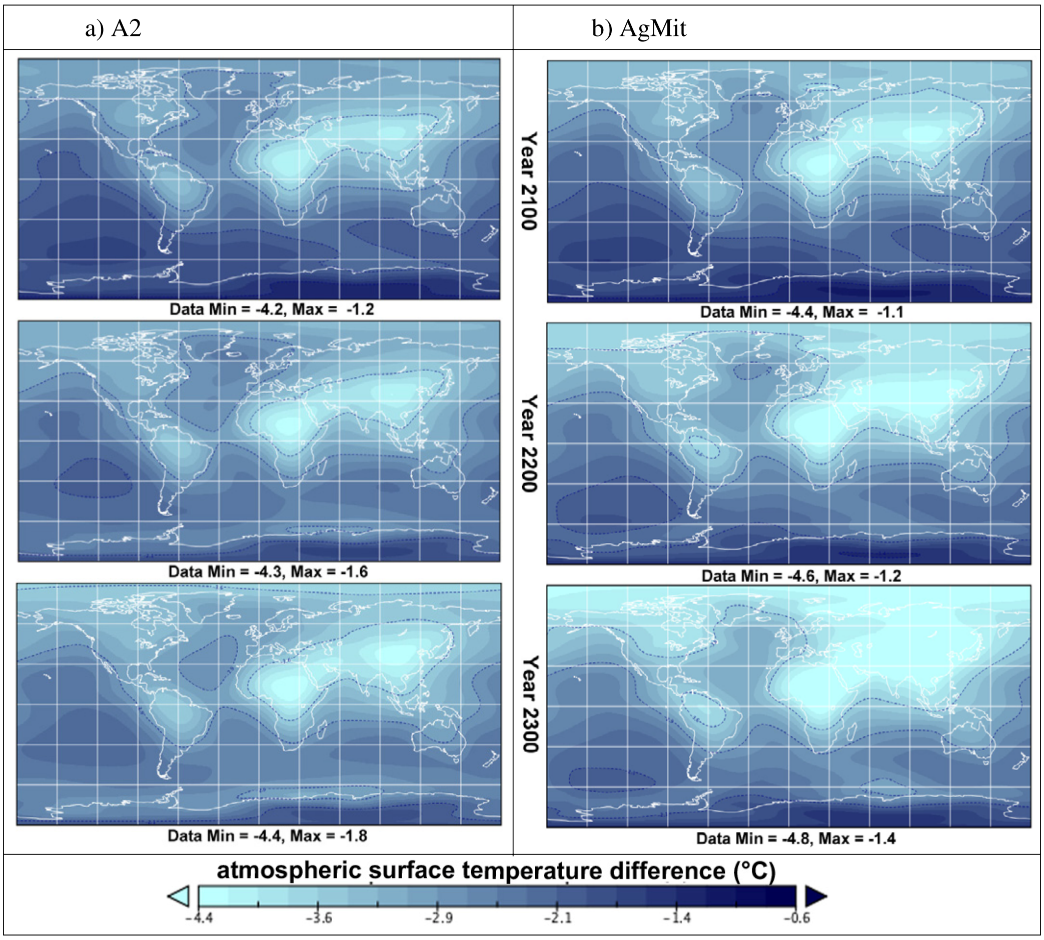

Figure 2. Atmospheric surface temperature difference at years 2100 (top), 2200 (middle) and 2300 (bottom) as a result of increasing the surface albedo of land areas by 0.1 between ±45° latitude: (a) business-as-usual (A2) scenario, (b) aggressive mitigation (AgMit) scenario.

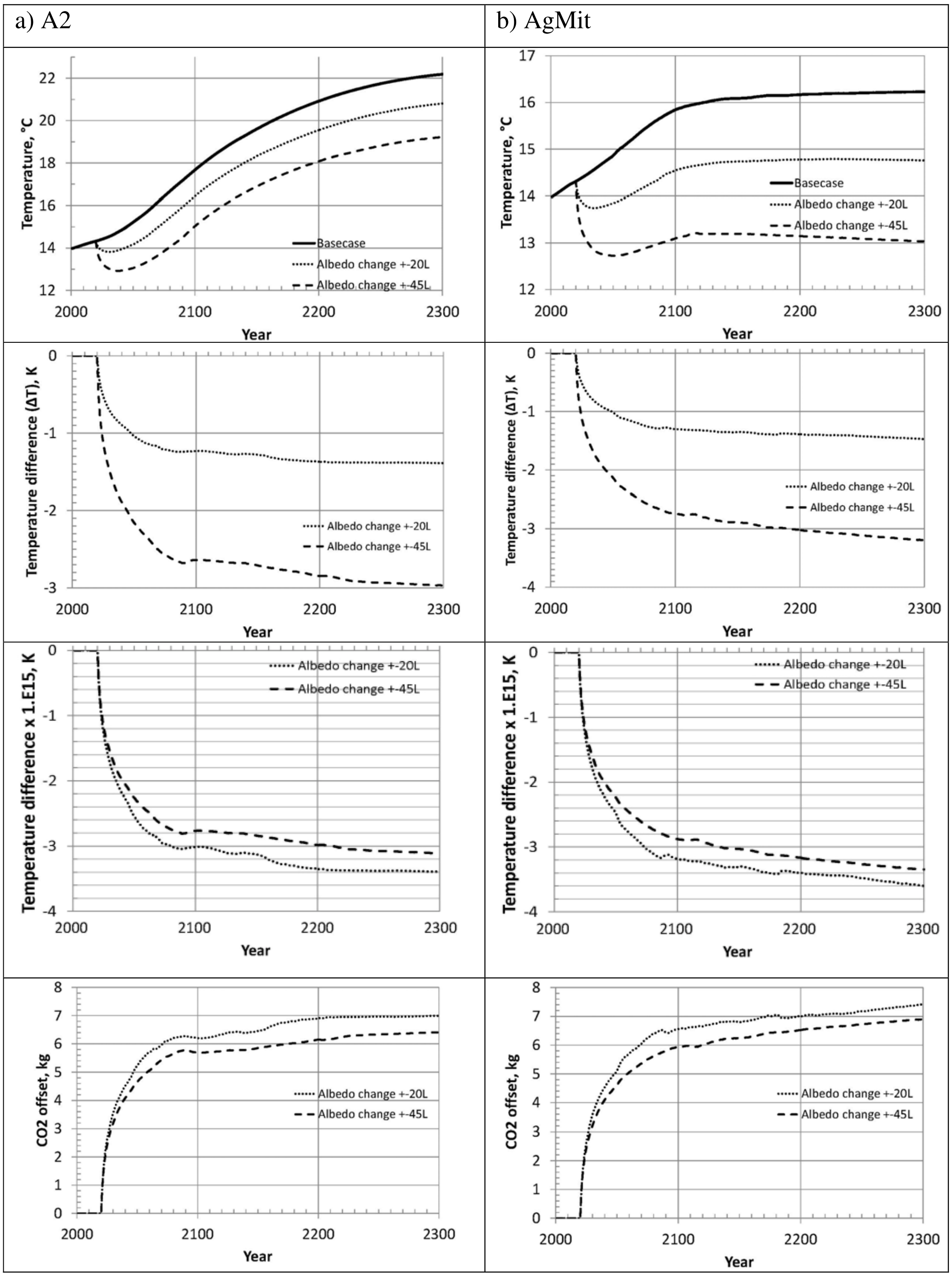

Figure 3. Global temperature change in the basecase simulation (solid line), and in the simulations with increased surface albedo over land areas by 0.1 between ±20° (dotted line) and ±45°(dashed line) latitude, for business-as-usual (a) and aggressive mitigation (b) CO_2 emissions. Differences from the Basecase simulation are shown in the second row. The third row shows the temperature change per unit area per albedo increase of 0.01. Equivalent CO_2 emissions are shown in the bottom row: increasing the albedo of 1 m^2 of a surface by 0.01 decreases the long-term global temperature by about 3×10^{-15} K, offsetting 6.5–7.5 kg of CO_2 emissions.

AgMit case (with more snow and ice and hence a stronger ice-albedo feedback) as compared to the BAU case.

The simulated time series of the global temperature is shown in figure 3. Changing the albedo has significant effect on global temperature, which increases with time in line with the climate system's response time to an abrupt change in forcing. Figure 3 also shows the temperature difference between the albedo modified cases and the Basecase. Increasing the albedo by 0.1 for Case45 (Case20) resulted in a temperature decrease of about 2 K (1 K) in about 20 yr, increasing to about 3 K (1.3 K) after 200 yr. Again, we can see here that the temperature response is very similar

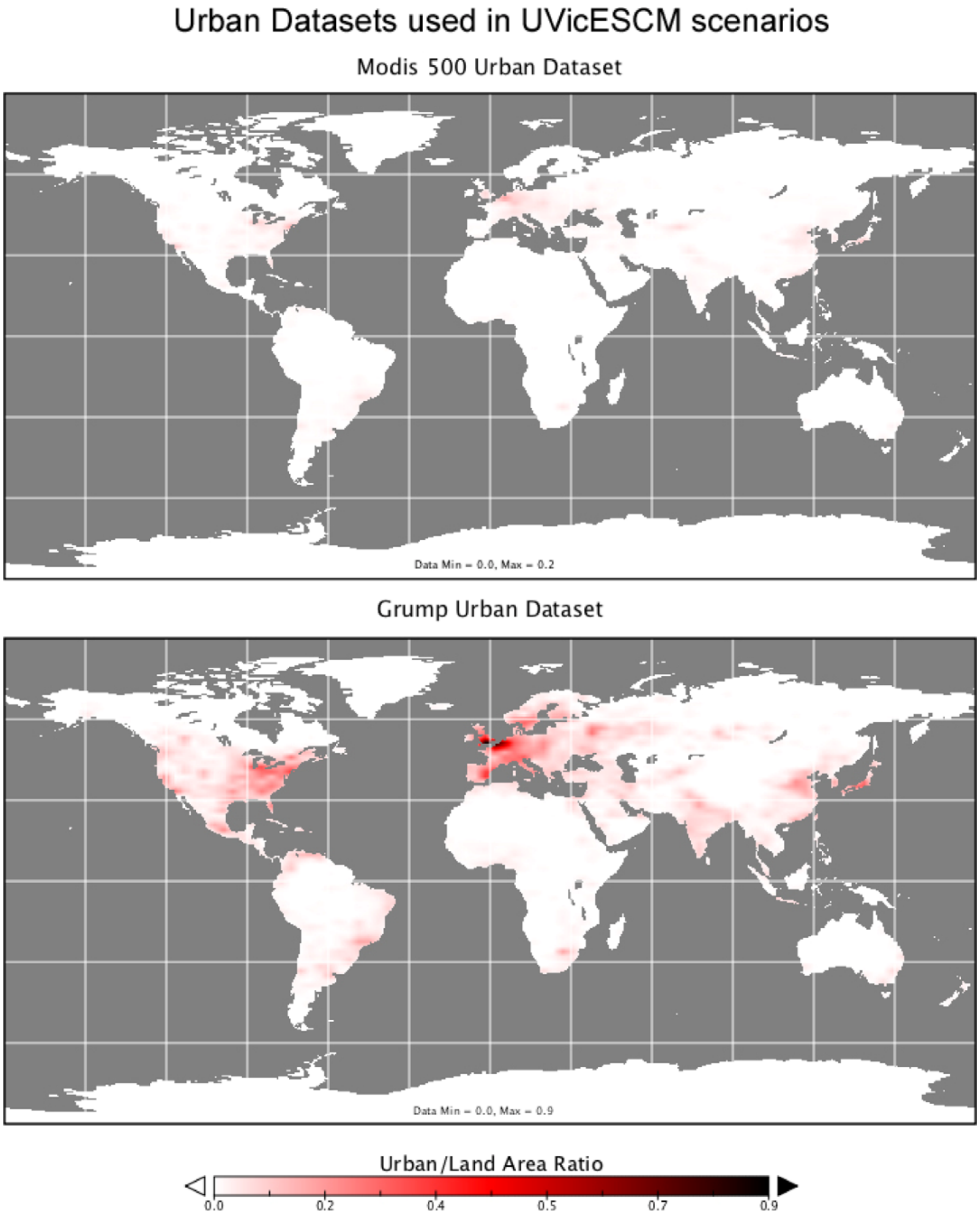

Figure 4. MODIS (top) and GRUMP (bottom) datasets of urban areas.

between the BAU and AgMit cases; as noted above, stronger ice-albedo feedbacks associated with lower temperatures in AgMit led to about a 10% larger temperature change.

In an earlier study, Akbari and Matthews (2012) showed that the change in global temperature is a linear function of albedo change. In figure 3, we show the effect of a 0.01 increase in surface albedo per m^2 of land surface on the global temperature. Increasing the albedo of 1 m^2 of a surface by 0.01 decreases the long-term global temperature by about 3×10^{-15} K (3 femtoKelvin: 3 fK). As can be seen in the lower panels, the temperature change per unit area of albedo modification was about 10% larger in Case20 compared to Case45, indicating that increasing surface albedo at lower latitudes may be slightly more effective in reducing the global temperature, compared to the effect of mid-latitude albedo increases.

To compare these simulated temperature changes to the effect of CO_2 emissions reductions, we have made use of recent estimates of the temperature response to cumulative carbon emissions over time. Matthews *et al* (2009b) showed that global average temperature changes linearly as a function of total CO_2 emissions, and additionally that this temperature change per unit CO_2 emitted is approximately constant in time and independent of atmospheric CO_2 concentration. Based on this finding, Matthews *et al* (2012) estimated that each 1000 GtC emitted (or 3700 Gt CO_2) results in a best guess of 1.75 K of global temperature change, with an uncertainty range of 1–2.5 K owing to uncertainty in the carbon cycle and

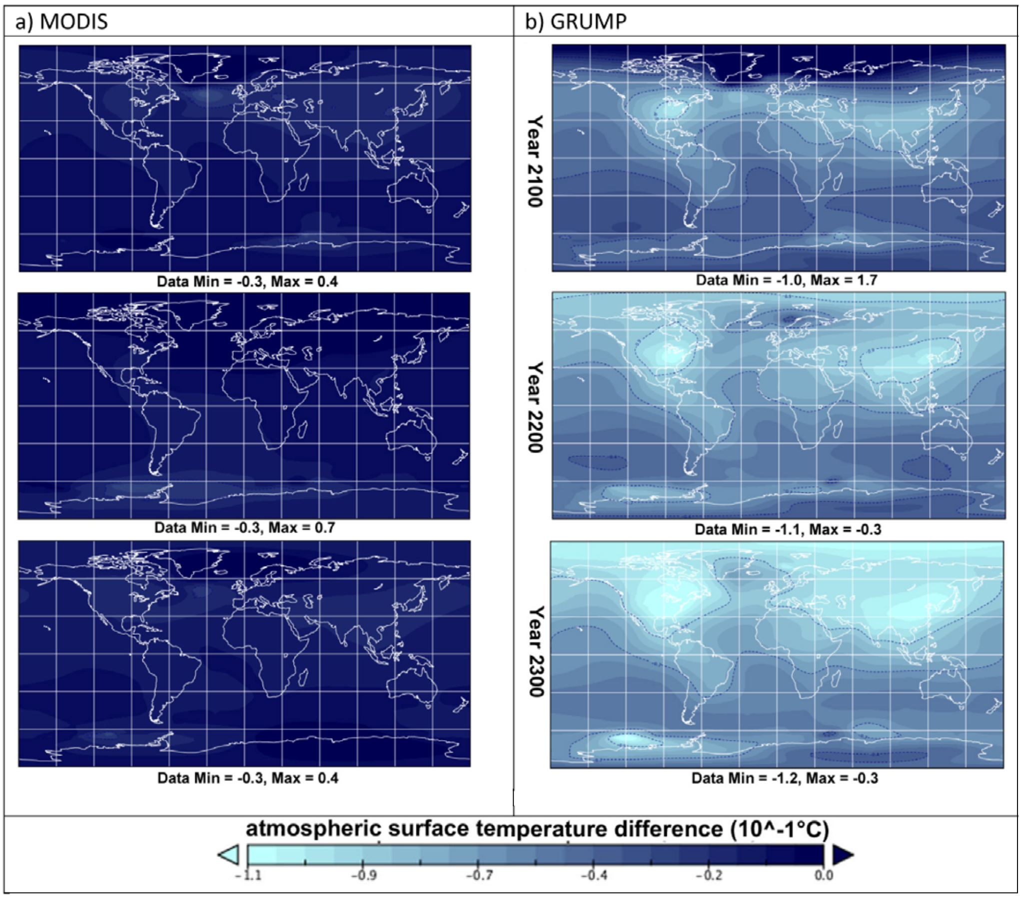

Figure 5. Atmospheric surface temperature difference at year 2100 (top), 2200 (middle) and 2300 (bottom) for an AgMit scenario as a result of increasing the surface albedo of only urban areas by 0.1, based on estimates of urban areas by (a) MODIS and (b) GRUMP.

climate response to CO_2 emissions. Using the central estimate from Matthews *et al* (2012), we can therefore calculate that anthropogenic CO_2 emissions of 21 Gt CO_2 increase global temperature by approximately 0.01 K. Using this constant conversion ratio, in figure 4, we calculated the offset in the CO_2 emissions in terms of the effect of temperature reduction for changing the albedo of 1 m^2 surface area.

The results show that increasing the albedo of 1 m^2 of a surface by 0.01 would have the same effect on global temperature as decreasing emissions by 6.5–7.5 kg of CO_2. Akbari *et al* (2009b) estimated that total urban areas (3×10^{12} m^2) represent about 2% of the global land surface. They estimated further that the urban areas in the hot and temperate regions of the world (1.5×10^{12} m^2) represent approximately 1% of the total land area. We can therefore calculate to first order the potential for realistic urban surface albedo modification to affect global temperatures. Changing the albedo of the target urban areas (1% of land) by 0.10 would represent in a change of global land surface albedo of 0.001. An albedo increase of 0.1 in urban areas corresponds to increasing the albedo to roofs by an average of 0.25 and the albedo of pavements by 0.15. This would lead to a global temperature reduction equivalent to decreasing CO_2 emissions by (6.5–7.5 kg m^{-2}) $\times$ (0.10/0.01) $\times$ (1.5×10^{12} m^2) = 10×10^{13} kg–11×10^{13} kg, or 100–110 Gt CO_2.

To further refine the effect of increasing urban albedo on global cooling, we performed two simulations using the MODIS and GRUMP datasets of global urban areas, in which we increased the surface albedo of urban areas only in the model by 0.1. As shown in figure 4, urban area extent in the GRUMP dataset are much larger (more than five times) than those based on MODIS satellite data (Schneider *et al* 2009). Correspondingly, the global temperature response to albedo modification in our simulations depended strongly on the dataset used. While the spatial pattern of warming is similar in the two datasets (figure 5), the GRUMP urban areas show a much more extensive and widespread pattern of cooling. By contrast, the difference between emissions scenarios was not large. For both the A2 and AgMit scenarios, the long-term cooling effect was about 0.07 K using the GRUMP database and only 0.01 K using the MODIS database (see figure 6). In terms of the CO_2 offset, these temperature changes correspond to equivalent CO_2 emissions of 130–150 Gt CO_2 using the GRUMP estimate of urban areas, and 25–30 Gt CO_2 using the MODIS estimate of urban areas.

The time series of the simulated atmospheric temperature for Case20 and Case45, where the albedo of Earth changed significantly, are fairly smooth (see figure 3). By contrast, the simulation results for the urban albedo cases shown in figure 6 are more variable; this simply reflects the internal variability in the climate model, which is more apparent with

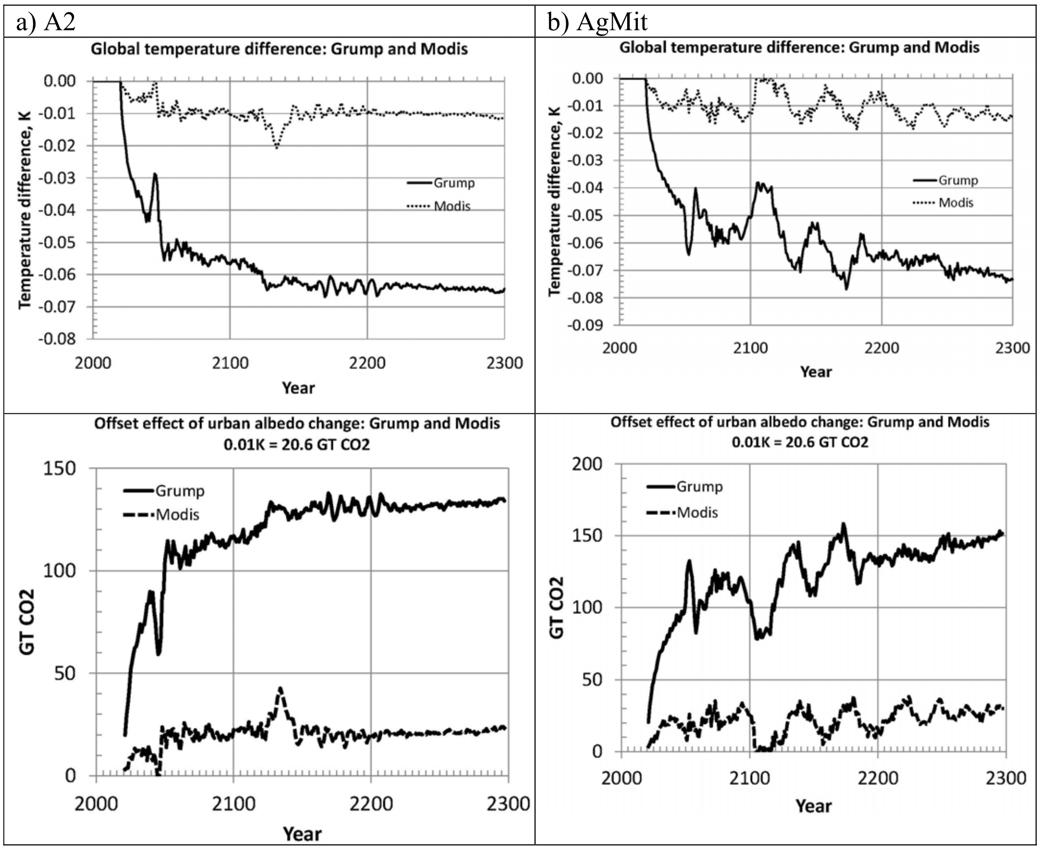

Figure 6. Global temperature change (top) and the equivalent CO_2 emissions offset as a result of changing the albedo of only urban areas by 0.1 based on estimates of urban areas by GRUMP (solid line) and MODIS (dotted line), and for business-as-usual (a) and aggressive mitigation (b) CO_2 emissions scenarios.

smaller perturbations. In the case of the albedo modifications over urban areas only, the overall change in the global albedo less than 3×10^{-4}, which resulted in simulated temperature changes (0.01–0.07 K) which are small relative to the natural variability in the climate model.

5. Discussion and conclusions

Solar reflective urban surfaces (white roof and light-colored pavements) can increase the albedo of an urban area by about 0.1. In turn, increased albedo of urban and human settlement areas can decrease atmospheric temperature and counter some of the anticipated temperature increase from global warming. As such, this may be an effective strategy to complement climate mitigation efforts as a way of further slowing the rate of global temperature increase in response to continued greenhouse gas emissions.

Our analysis has concluded that increasing the albedo of 1 m^2 of a surface (in hot and temperate regions of the world) by 0.01 decreases the long-term global temperature by about 3 fK. The equivalent long-term CO_2-equivalent offset is 6.5–7.5 kg. The modeled temperature change per unit of surface area albedo increase are consistent for all scenarios simulated in this study: surface albedo increase of 0.1 over all land areas between ±20 latitude (Case20), surface albedo increase of 0.1 over all land areas between ±45 latitude (Case45), surface albedo increase of 0.1 over all urban areas as estimated by MODIS database, and surface albedo increase of 0.1 over all urban areas as estimated by GRUMP database.

Akbari *et al* (2009b) discuss the sources of uncertainty in this calculation, identifying the estimate of man-made surfaces as a major source of uncertainty in estimating the global cooling effect. There is a significant difference between estimates of urban (human settlement) land areas in the MODIS and GRUMP, which represents the largest source of uncertainty in our simulations. This uncertainty affects the global CO_2 offset by simply scaling of the available surface area for increased albedo: the equivalent CO_2 emissions offset is 130–150 Gt CO_2 using the GRUMP estimate of urban areas, and only 25–30 Gt CO_2 using the MODIS estimate of urban areas. Per unit of urban area, however, the global cooling effect and CO_2-equivalent offset was the same for both cases: 3 fK and 6.5–7.5 kg CO_2, respectively, per m^2 of a surface that its albedo increased by 0.01.

Another sources of uncertainty is the estimate of long-term global temperature change of 1.75 K (uncertainty range of 1–2.5 K) resulting from emission of 3700 Gt CO_2 (Matthews *et al* 2012). Accounting for this uncertainty, the global cooling effect of CO_2-equivalent offset is estimated to be in the range of 4.9–12 kg CO_2 per m^2 of a surface that its albedo increased by 0.01. The resulting global equivalent CO_2 emissions offset is estimated to be in the range of 91–260 Gt CO_2 using the GRUMP estimate of urban areas, and 18–53 Gt CO_2 using the MODIS estimate of urban areas.

We propose customizing local ordinances, standards, policies and programs to promote the use of white or light color urban surface materials as they are replaced (Levinson *et al* 2005, Akbari and Levinson 2008, Akbari *et al* 2009a). Typically roofs are resurfaced (or changed) about every 20–30 yr; paved surfaces are resurfaced about every 10 yr. When roofs or paved surfaces are installed, they can be changed to materials with high solar reflectance, typically at no incremental cost. A recent study by the Royal Society (RS 2009) performed a cost analysis for 'painting' the roofs of buildings in urban areas white. Painting roofs white just to counter global warming is one of the least attractive methods to increase the urban albedo. In addition, it may cause negative environmental effects (e.g., emitting volatile organic compounds).

Cool roofs save air conditioning energy and reduce CO_2 emissions. Cool roofs and cool pavements (Cool Cities) reduce the urban heat island, improve comfort, and reduce urban smog (Akbari *et al* 2001). As urban surfaces can cool the globe without any or negligible cost, Cool Cities are one of the most lucrative and effective methods to counter global warming.

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