Global Cooling: Increasing World-wide Urban Albedos to Offset CO_2

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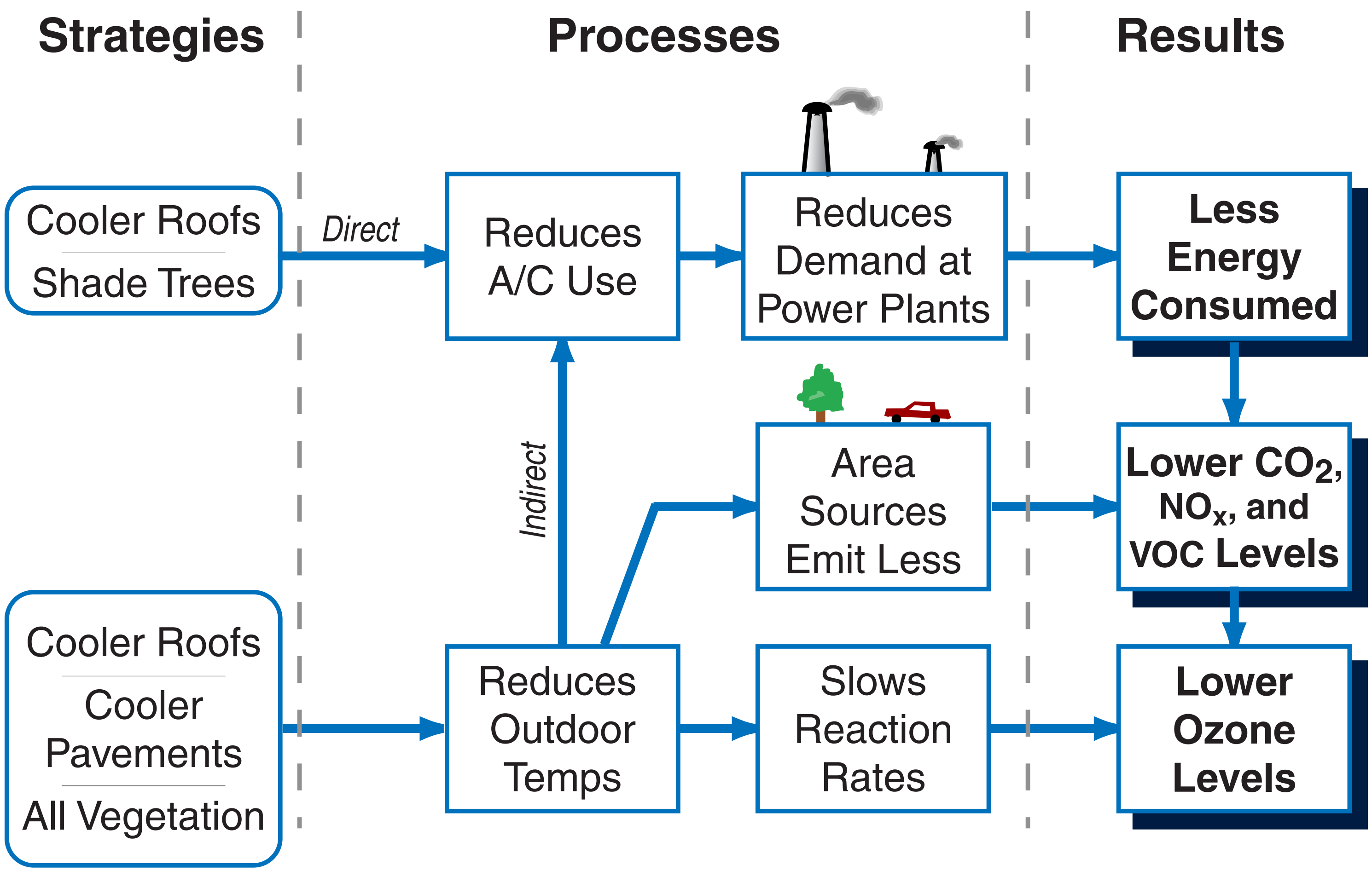
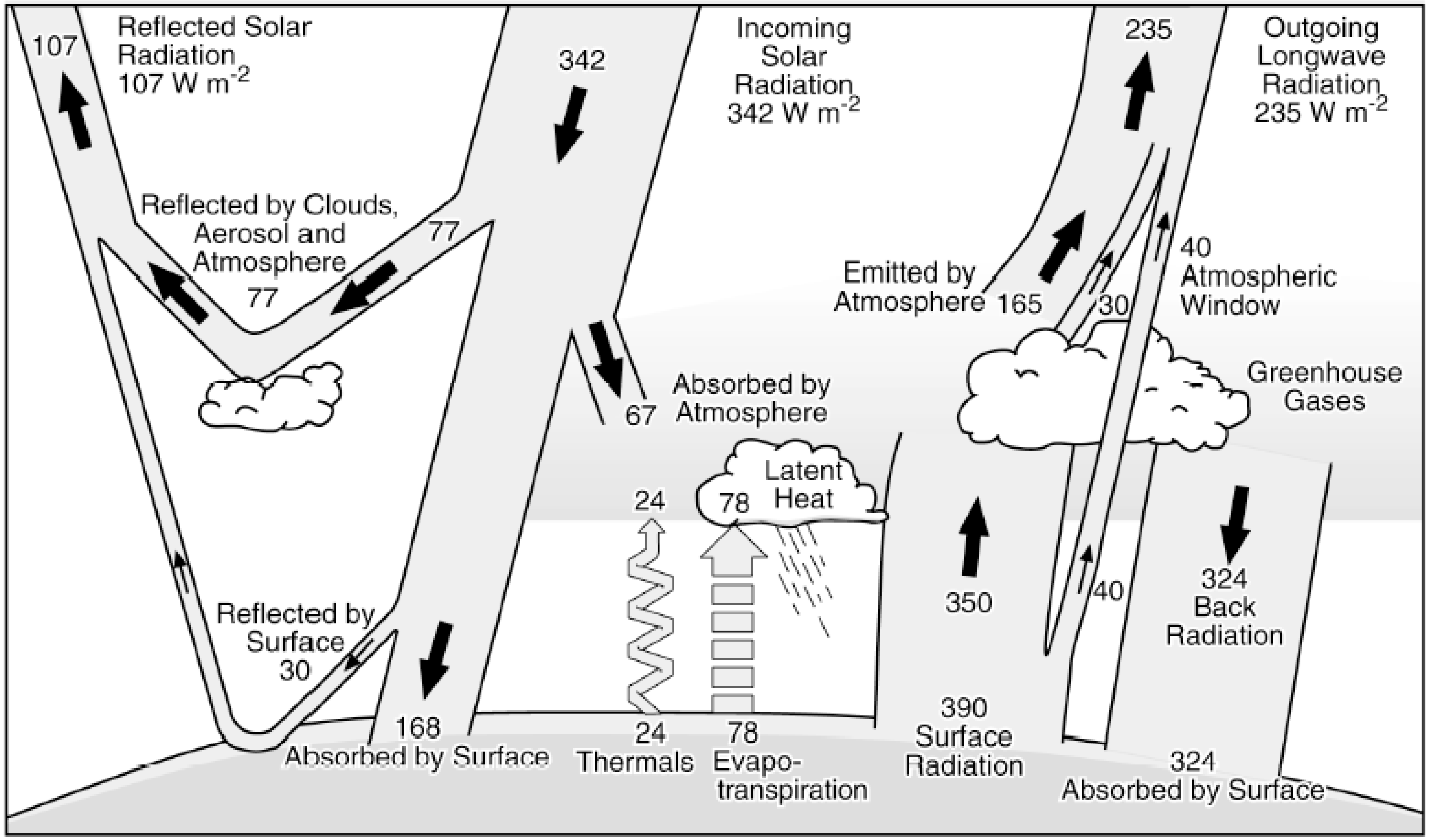
Cool Roofs, Cool Pavements, and Shade Trees Save Energy and Improve Air Quality



Cool Surfaces also Cool the Globe

- Cool roofs, cool pavements, and shade trees save energy, improve air quality, and improve comfort; we estimate savings of > $50B/year
- But higher albedo surfaces (roofs and pavements) directly cool the globe, quite independent of avoided CO_2

The Earth's Radiation Budget



Source: Kiehl and Trenberth, 1997

Methodology

- Changing albedo of urban surfaces and changing atmospheric CO_2 concentrations both result in a change in radiative forcing (RF)
- Comparing these two radiative forcings relates changes in solar reflectance of urban surfaces to the changes in atmospheric CO_2 content

Caveats

- Time dependence of physical effects (e.g., sequestration in land or ocean) and economics are ignored
- We account for the effect of multiple scattering and absorption of radiation within the atmosphere
- Calculations are performed for the entire globe

Radiation Forcing of $2XCO_2$

- Hansen et al (2005) estimate a $2XCO_2$ radiative forcing (RF) on the top of the atmosphere of 3.95 ± 0.11 W/m^2, yielding a RF of 0.93 ± 0.03 kW/tonne of atmospheric CO_2
- IPPC [based on Myhre (1998) formula] estimate a RF of 3.71 W/m^2, yielding a RF of 0.88-0.91 kW/tonne of atmospheric CO_2
- Matthews and Caldeira (2008) found a 0.175 K temperature increase for every 100 GtC emitted, yielding a 0.47 kW/tonne of atmospheric CO_2
- We use a RF of 0.91 kW/tonne of atmospheric CO_2

Radiation Forcing of Cool Surfaces

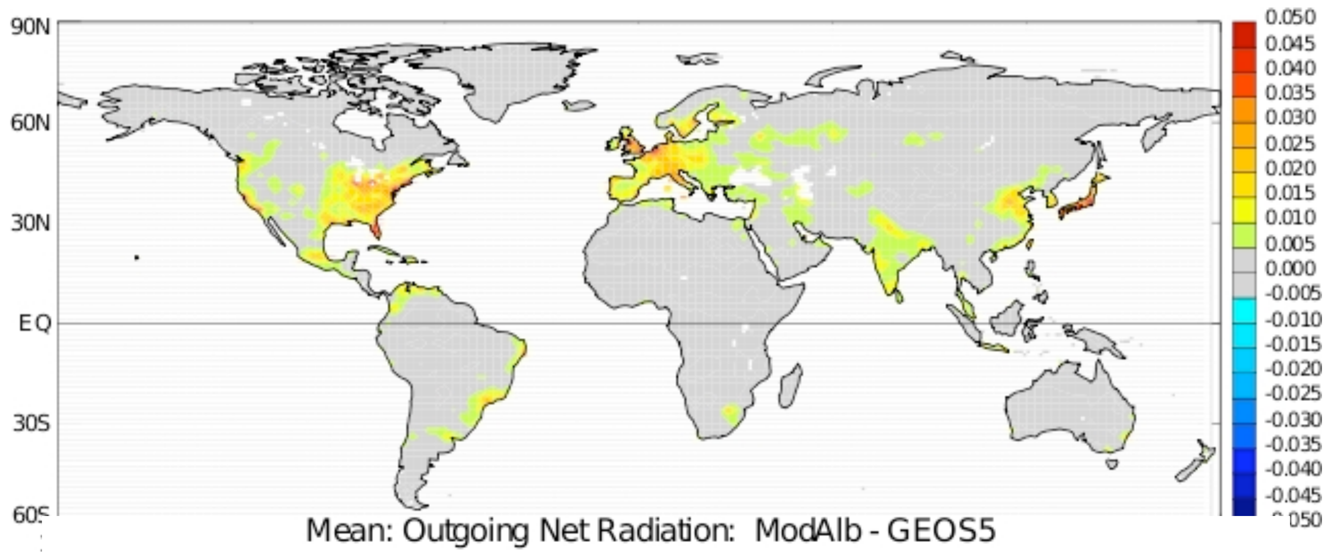
- Hansen et al (1997) estimate a RF of -3.70 Wm^{-2} for increasing the albedo of 'Tropicana' by 0.2. We estimate that Tropicana is 22% of the land area or about $1/16^{th}$ of the global surface. For reflective surfaces, the RF per 0.01 increase in albedo is -2.92 W/(m^2 of Tropicana land)
- Using Kiehl and Trenberth (1997) and Hatzianastassiou et al (2005), we calculate a RF of -1.27 W/m^2 per 0.01 increase in albedo of modified surfaces
- Note that our calculations apply for the average cloud cover over the earth; we estimate higher RF for CA

CO_2-Equalence of Reflective Surfaces

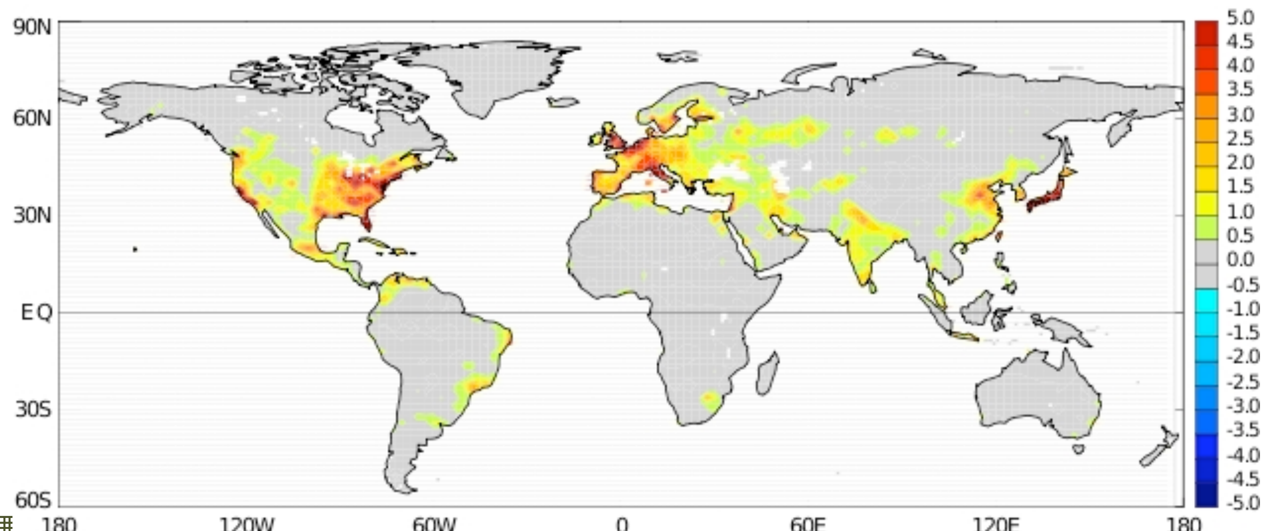
- RF of increasing atmospheric CO_2 = 0.91 kW/tonne = 0.91 W/kg
- RF of increasing solar reflectance of a surface by 0.01 = -1.27 W/m^2
- Atmospheric CO_2-equalence of increasing solar reflectance of a surface by 0.01 = -1.27 [W/m^2]/ 0.91 [W/kg] = -1.40 kg/m^2
- IPCC (2007) estimates that only 55% of the emitted CO_2 stays in the atmosphere
- Emitted CO_2-equalence of increasing solar reflectance of a surface by 0.01 = -1.40 [kg/m^2]/0.55 = -2.5 kg CO_2 per m^2

GCM Simulations (GEOS-5)

Mean: Total Albedo: ModAlb - GEOS5



Mean: Outgoing Net Radiation: ModAlb - GEOS5



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CO_2 Offset of Cool Roofs and Cool Pavements

- Δ albedo for aged white roofs = 0.40
- Emitted CO_2 offset for white roofs
  = [0.40/0.01]*[-2.5 kg CO_2 /m^2] = -100 kg CO_2/m^2
- It takes about 10 m^2 of white roof to offset 1 T CO_2 emitted
- Δ albedo for typical residential and non-residential cool roofs = 0.25
- Emitted CO_2 offset for cool roofs
  = [0.25/0.01]*[-2.5 kg CO_2 /m^2] = -63 kg CO_2/m^2
- Δ albedo for cool pavement = 0.15
- Emitted CO_2 offset for cool pavements = -38 kg CO_2/m^2

Dense Urban Areas are 1% of Land

- Area of the Earth = 508×10^{12} m^2
- Land Area (29%) = 147×10^{12} m^2
- Area of the 100 largest cities = 0.38×10^{12} m^2
  = 0.26% of Land Area for 670 M people
- Assuming 3B live in urban area, urban areas
  = [3000/670] x 0.26% = 1.2% of land
- But smaller cities have lower population density,
  hence, urban areas = 2% of land = 3×10^{12} m^2
- Dense, developed urban areas only 1% of land
  = 1.5×10^{12} m^2 (1.5 M km^2)

CO_2 Equivalency of Cool Roofs and Pavements

- Typical urban area is 25% roof and 35% paved surfaces
- Roof area = $0.25 * 1.5 \times 10^{12}$ m^2 = 3.8×10^{11} m^2 (0.38 M km^2)
- Emitted CO_2 offset for cool roofs
  = 63 kg CO_2 /m^2 * 3.8×10^{11} m^2 = 24 GT CO_2
- Paved area = $0.35 * 1.5 \times 10^{12}$ m^2 = 5.3×10^{11} m^2 (0.53 M km^2)
- Emitted CO_2 offset for cool pavements
  = 38 kg CO_2 /m^2 * 5.3×10^{11} m^2 = 20 GT CO_2
- Total emitted CO2 offset for cool roofs and cool pavements
  = 44 GT CO_2

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CO_2 Equivalency of Cool Roofs and Pavements (cntd.)

- 44 GT CO_2 is over one year of the world 2025 emission of 37 GT CO_2
- At a growth rate of 1.5% in the world's CO_2 -equivalent emission rate, 44 GT CO_2 would offset the effect of the growth in CO_2-equivalent emissions for 11 years

Equivalent Value of Avoided CO_2

- CO_2 emissions currently trade at ~$25/tonne
- 44 GT worth $1100, for changing albedo of roofs and paved surface
- Cooler roofs alone worth $600B
- Cooler roofs also save air conditioning (and provide comfort) worth several times $600B

A Global Action Plan: The big picture

- Develop a United Nation program to install cool roof/pavement in 100 largest cities
- This is a simple measure that we hope to organize the world to implement AND
- WE BETTER BE SUCCESSFUL!
- We can gain practical experience in design of global measures to combat climate change

Conclusion

1000 ft^2 of a white roof, replacing a dark roof, offset the emission of 10 tonnes of CO_2

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Cooler Cities as a Mirror

- Mirror Area = 1.5×10^{12} m^2 [5] *(0.1/0.7)[δ albedo of cities/ δ albedo of mirror]
  = 0.2×10^{12} m^2 = 200,000 km^2 {This is equivalent to an square of 460 km on the side}
  = 10% of Greenland = 50% of California