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


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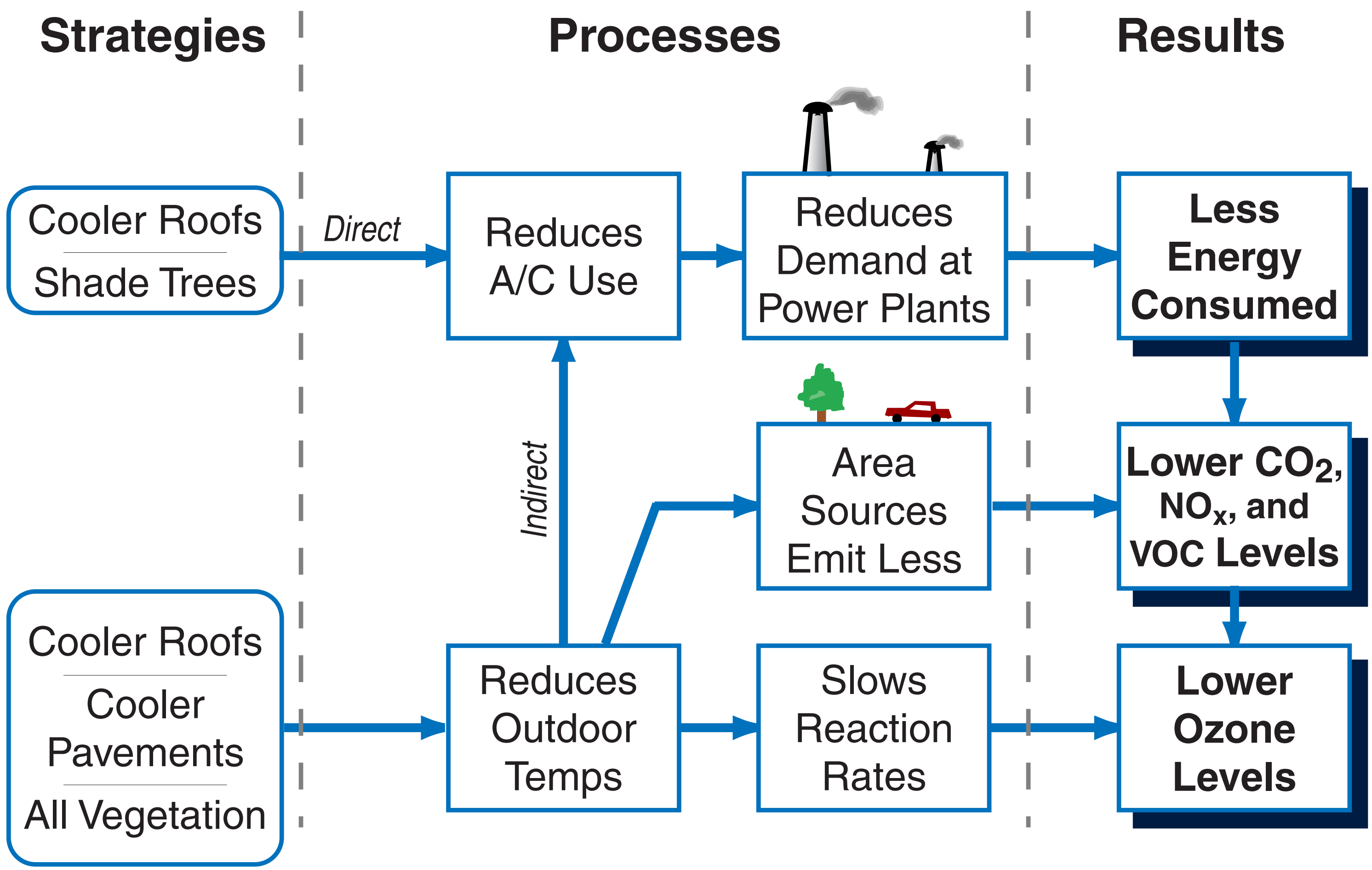
# Cool Roofs, Cool Pavements, and Shade Trees Save Energy and Improve Air Quality



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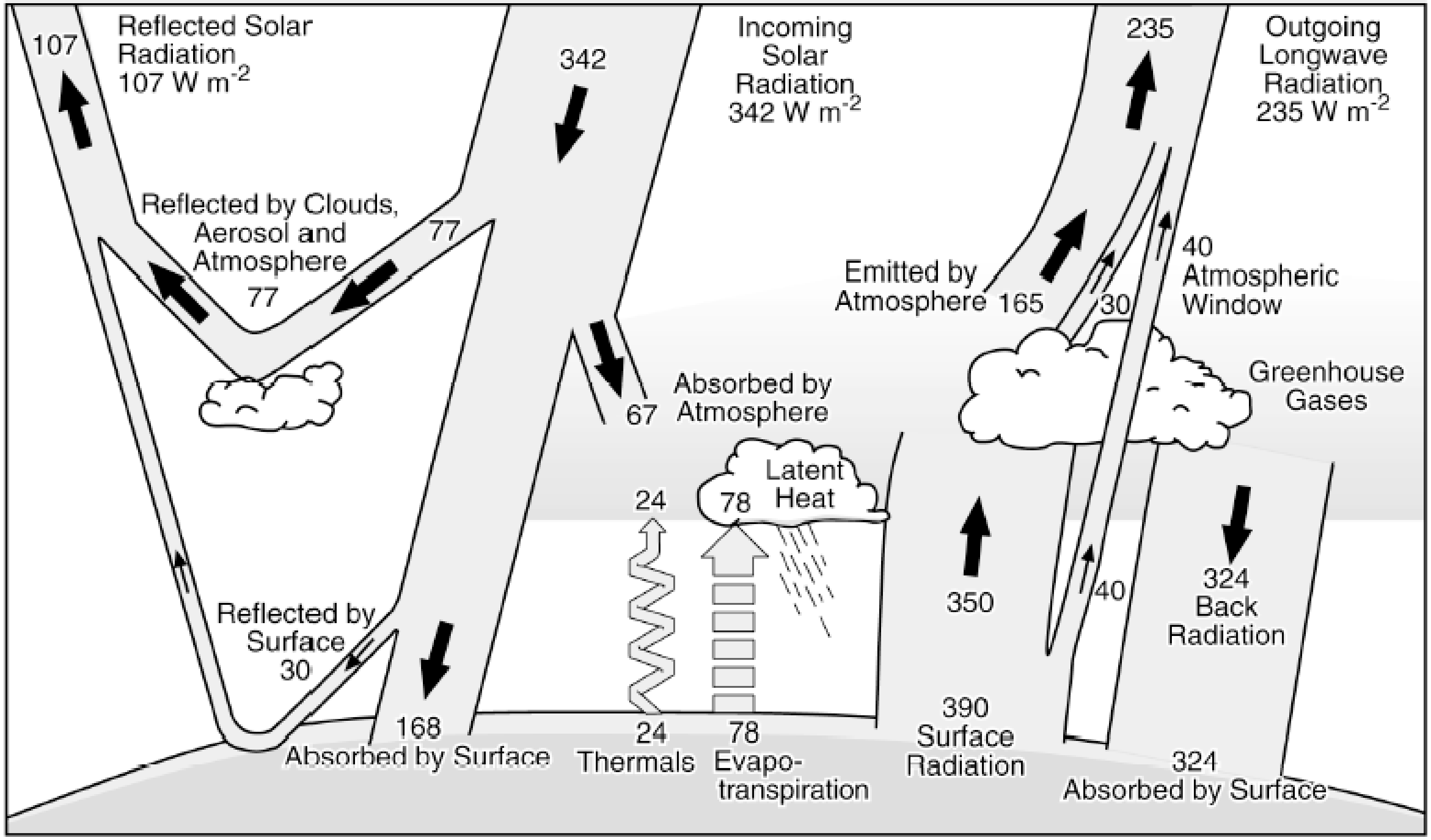
# Cool Surfaces also Cool the Globe

- 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

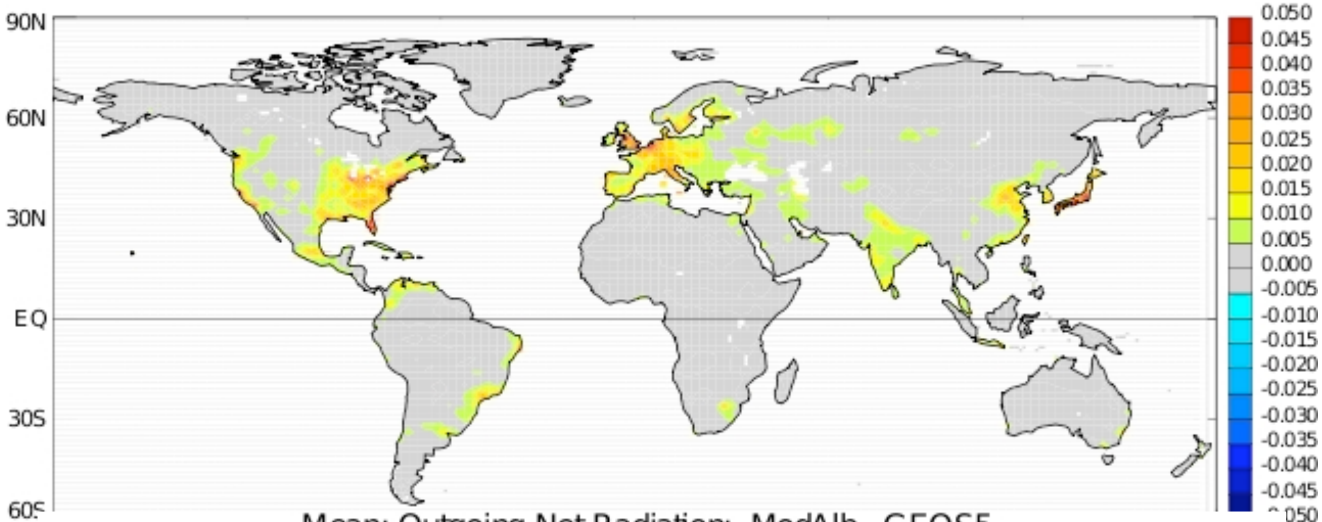
- Hansen et al (1997) estimate a RF of -3.70 $Wm^{-2}$ for increasing the albedo of 'Tropicana' by 0.2. We estimate that Tropicana is 22% of the land area or about 1/16$^{th}$ of the global surface. For reflective surfaces, the RF per 0.01 increase in albedo is -2.92 W/($m^2$ of Tropicana land)
- Using 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

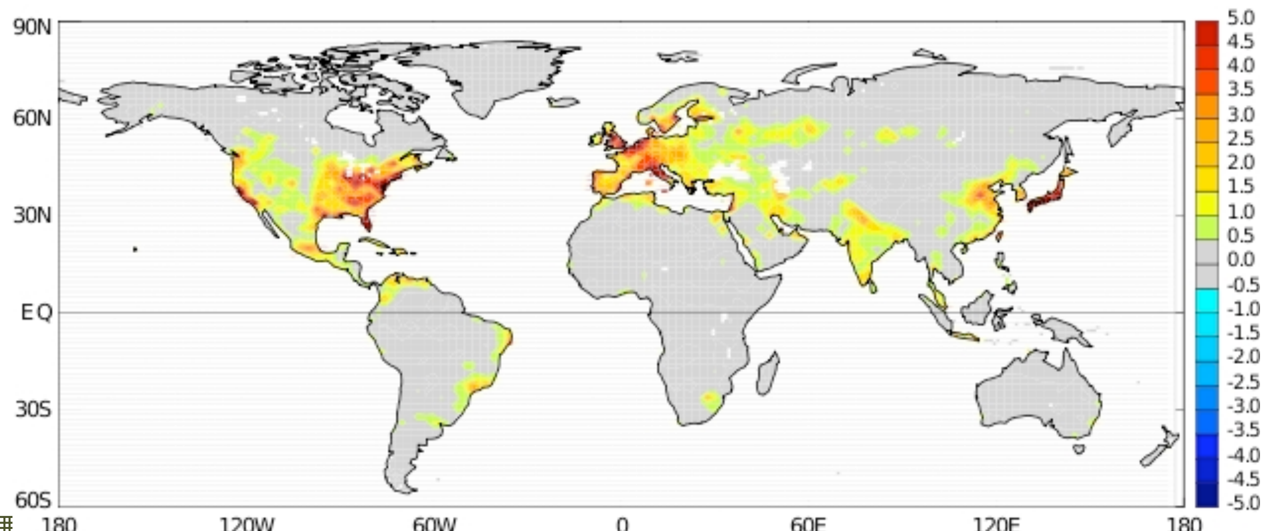
- RF of increasing atmospheric $CO_2$ = 0.91 kW/tonne = 0.91 W/kg
- RF of increasing solar reflectance of a surface by 0.01 = -1.27 $W/m^2$
- Atmospheric $CO_2$-equalence of increasing solar reflectance of a surface by 0.01 = -1.27 [$W/m^2$]/ 0.91 [W/kg] = -1.40 $kg/m^2$
- IPCC (2007) estimates that 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



# $CO_2$ 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 = $508 \times 10^{12}$ m$^2$
- Land Area (29%) = $147 \times 10^{12}$ m$^2$
- Area of the 100 largest cities = $0.38 \times 10^{12}$ 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 = $3 \times 10^{12}$ m$^2$
- Dense, developed urban areas only 1% of land
  = $1.5 \times 10^{12}$ 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 = $0.25*1.5x10^{12}$ $m^2$ = $3.8x10^{11}$ $m^2$ (0.38 M $km^2$)
- Emitted $CO_2$ offset for cool roofs
  = 63 kg $CO_2$ /$m^2$ * $3.8x10^{11}$ $m^2$ = 24 GT $CO_2$
- Paved area = 0.35 *$1.5x10^{12}$ $m^2$ = $5.3x10^{11}$ $m^2$ (0.53 M $km^2$)
- Emitted $CO_2$ offset for cool pavements
  = 38 kg $CO_2$ /$m^2$ *$5.3x10^{11}$ $m^2$ = 20 GT $CO_2$
- Total emitted CO2 offset for cool roofs and cool pavements
  = 44 GT $CO_2$

# $CO_2$ 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 = $1.5 \times 10^{12}$ m$^2$ [5] *(0.1/0.7)[δ albedo of cities/ δ albedo of mirror]
  = $0.2 \times 10^{12}$ m$^2$ = 200,000 km$^2$ {This is equivalent to an square of 460 km on the side}
  = 10% of Greenland = 50% of California