Review of Global Warming Urban Heat Island Forcing Issues Unaddressed by IPCC Suggestions Including CO2 Doubling Estimates

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Abstract

In this paper we provide a review Urban Heat Island (UHI) important forcing effects related to albedo, humidity and rain water management issues unaddressed by IPCC suggestions. We first review historical global warming forcing trends by comparing CO2 prediction to Urban Heat Islands (UHIs) complex forcing influences. We review both CO2 and UHI forcing influence indicating that both can predict similar warming trends. In order to provide a more up to date investigate we present alternate results of recent studies. We then reviewed many other complex issues of UHIs pointing out additional related solar heating problems including humidity forcing and warm rain-water management from highly evaporating hot surfaces. Our review concludes that IPCC CO2 suggestions are not adequate to address the urgent need to reduce the rapid global warming trend. More drastic measures are needed, specifically a concerted worldwide geoengineering solar solution, including cool roofs, better UHI design, and reductions of known hotspots to reverse trends and prevent a tipping point.

1. Goal of this Paper

In this paper we review Urban Heat Island (UHI) important forcing effects that are unaccounted for in IPCC suggestions, It is apparent that the IPCC suggestions focus mainly on CO_2 reduction as the key global warming solution. While UHIs have been studied for years [1-4], and the IPCC certainly recognizes many UHI issues, they have yet to address albedo reduction of cities and roads as part of their international goals in terms of global warming reduction efforts [5]. Possibly some studies have been short-sighted. These studies likely did not take into account the complex warming issues related solar surface area increases, Hydro-HotSpot (HHS) activity and have assumed that CO_2 is the dominant issue in global warming. Here we term HHS as water evaporation from Highly Evaporating Hot Surfaces (HEHS). The IPCC suggestions likely are not be adequate as discussed in this review article since UHI pose a number of these complex issues that need serious attention especially in the area of albedo forcing. Some studies conservatively recognize that without adaptive urban design such as cool roofs [10], for example, that by 2100 cities could cause global temperatures rises of 1 to 2°C [11]. Specifically a study in California calculated an offset of 1.31-1.47 °C with 100% deployment of "cool roofs" [11]. While such studies are helpful, we feel they may be far off in timing, as UHIs, as will be reviewed here, are already likely significantly contributing to current global warming trends. The reduction of CO2 is clearly important, but it is simply not practical in terms of reverse global warming in a timely manner. It is logical that only geoengineering a solar solution can reverse global warming and prevent a tipping point. We present data that a tipping point likely has not occurred.

To investigate the urgency for the need of UHI albedo corrective actions suggestions by the IPCC, the goal of this paper is to review the following UHI global warming issues:

- The magnitude of the temperature forcing created by UHI decreases to the global albedo trend with increases of tall building and large solar heating areas since 1950
- The UHI area and radiative forcing quoted by the IPCC in its latest release
- The possible sources of changes to observed humidity
- Humidity forcing issues from HHS
- Yearly storm water cycling of higher temperature water to local streams, lakes and ocean raising local water surface temperatures
- RainWater Management (RWM) issues that can lead to increases in dry days and possibly drought
- Loss of natural vegetation evapotranspiration and associated dryness

1.1 Timeline of CO2 Doubling Theory and UHI Estimates

Greenhouse theory and early predictions started as far back as 1856 with CO_2 experiments by Foote, Tyndall in 1859, and what has become very popular, doubling theory by Arrhenius in 1896. Since Arrhenius, doubling temperature estimations based on theory and linked to environmental trends, have shown a decreasing effect and historically unaccounted UHI effects in CO2 doubling theory. This is illustrated in Table 1 that summarizes some of the key CO_2 history and predictions with the next to last row calculated based on current data in the Reference column and Equation 1.

$$\Delta DT_{CO_2} \ \mathrm{Ln}(412/311.8)/\mathrm{Ln}2=\mathrm{A}\mathrm{x}(14.85^{\circ}\mathrm{C}-13.9^{\circ}\mathrm{C}) \qquad (1)$$

Table 1 Key CO2 doubling theory history and conflicts

Reference	CO_2 Doubling Temperature	CO_2 Temperature Effect Estimates	Moisture Percent Effect*	UHI Albedo % Forcing Estimates
Arrhenius (1896) [1, 2]	5 - 6°C	5 -6°C	-	-
Gillbert Plass (1950's) [3]	3.6 °C	3.6 °C	-	-
Manabe and Wetherald (1975) [4]	2.3 °C	2.3 °C	-	-
McKitrick and Michaels (2007) [5]	Conflicting	-	-	50%
Z.C. Zhao (2011) [6]	Conflicting	-	-	30%
IPCC (1[tst]-5[th] Assessment 1990-2014,[7]	1.5 - 4.5 °C	1/3	2/3	-
Q. Huang, Y.Lu (2015) [8]	Conflicting	-	-	30%
Current Trend, Eq. 1. Based on going from 311.8ppm to 412 PPM from 1951 to Dec 2019, with a *0.95°C (1.71°F)* rise	2.36 °C *	1/3 (0.31°C)	2/3 (0.63 °C)	0
UHI albedo modeling (this paper)	Conflicting (1.15°C*)	See Table 4	See Table 4	33%

*Ignoring other GHG

A is the attribution factor for anthropogenic CO_2. When A is 1, the doubling temperature DT_{CO2} is 2.36°C. This is very close to the Manabe and Wetherald (1975) estimate in the Table. Since other GHGs are partly responsible, then A is <1. In this equation we are using CO_2 2019 estimates versus the reference year 1951. Because 2019 is recent, this equation represents a TCR (transient Climate Response) value. The ECS (Equilibrium Climate Sensitivity) value is say 1.25-1.65 larger.

- ***In general, this equation is based on real data, not theory. It is basically equivalent to experimental global results. So we should not take it lightly.***

In general, the TCR doubling temperature value Ax2.36°C, is the temperature increase that one would expect if we doubled CO_2 from 312 to 624ppm. Then we would get another Ax2.36°C increase if we again doubled it to 1248ppm. The rate and magnitude of global climate change is determined by radiative forcing, climate feedbacks and the storage of energy by the climate system. Because A<1, it is difficult to obtain published ECS estimates shown in Table 2 and if we incorporate the UHI effect, it would make things even more difficult.

We would expect the doubling temperature to drop if one takes into account any UHI contribution to global warming. A full overview of the CO2 doubling temperature taking into account feedback effects and UHI contributions is given in Feinberg [44].

2. IPCC 2020 Goals and Risks

The IPCC report SYR_AR5 [7] recommendations are to meet a goal of less than 2°C rise. This to be achieved by focusing on CO_2 reduction:

> "Multi-model results show that limiting total human-induced warming to less than 2°C relative to the period 1861–1880 with a probability of >66% would require total CO2 emissions from all anthropogenic sources since 1870 to be limited to about 2900 GtCO2 when accounting for non-CO2 forcing as in the RCP2.6 scenario, with a range of 2550 to 3150 GtCO2 arising from variations in non-CO2 climate drivers across the scenarios considered by WGIII. About 1900 [1650 to 2150] GtCO2 were emitted by 2011, leaving about 1000 GtCO2 to be consistent with this temperature goal"

2.1 IPCC Report and the Attention Given to UHI Radiative Albedo Forcing

A review of the IPCC report indicates that UHI concerns occupy a very small portion of the report which does not recognize any UHI concerns. One paragraph discusses it

- In WG1-AR4 (Chapter 2) city areas indicates that UHI occupy only 0.046% of the Earth's surface and uses a reference by Loveland et al. (2000) as verification, and shows only 0.03 W-m2 heat flux (reference to Nakicenovic, 1998).

The actual paragraph and statements made about UHI is narrow in scope. The assessment of the area does not look at the solar city area adjustment for building and appears out of date. Current area estimate range between 0.188% ti 0.95% [45]. Area amplification effects are estimated between 3.1 and 8.4% [45] Their statement on energy per unit area relates to anthropogenic activities of local appliance and building heating flux, possibly pointing to concerns related to CO_2 emissions. Since fossil fuel heating accounts for <0.1 Watt/M^2 then the argument would need to be updated in order to properly address Global Warming concerns. We note that the area referenced of Loveland et. al. study is not meant to take into account cites' solar heating area so it is not the best estimate . This seems to be the only area in the IPCC report providing some consideration to UHI effects, The minor assessment is apparently incomplete and leads one to believe that UHIs do not contribute significantly to global warming.

2.2 Independent UHI Albedo Forcing Assessment

Of the numerous studies on Urban Heat Island (UHI) effects, a few publications given in Table 1, that found UHIs are significantly contributing to global warming. McKitrick and Michaels [14] found that half of global warming trends from 1979 to 2002 is caused by UHI. Research in China [15, 16] indicates that UHI effects contribute to climate warming by about 30%. Another study found that UHI changes the climate in area 2–4 times larger than its own area [17]. These references reported issues as early as 2007, but do not appear in the IPCC report or reflected in their goals.

Table 2 summarizes an elaborate independent assessment by the author [45]. Results are shown in red that indicate UHIs can contribute between 4.6-43.6% of global warming issues. These findings are based on a weighted albedo model and a review of findings by other authors. Albedo model weighting takes into account the UHI area, irradiance in the Sea Ice and some basic estimates by other authors. In terms of area, one can see that there is a wide variance between a Schneider and a GRUMP UHI area studies. These mainly account for the variance. Additionally, UHIs have amplification effects. Two model were used, one with an area amplification and one with a Dome amplification factor. This accounts for the large variance. We can see from these estimates that it is very difficult to know the contributions from UHIs. However, one can ask, how much do GHGs contribute to global warming. Models are not that accurate. They may appear accurate, but they have some knowledge base as obtaining estimates from first principles on our complex climate is not possible. The IPCC models likely do not account for UHIs as the treat the areas as too small to contribute. This is absolutely incorrect, as area amplification factors are in the neighborhood of 3.1-8.5. Furthermore, from the way the IPCC author define the albedo contribution [46], they simply do not take into account an albedo-GHG re-radiation effect which is another 1.6 factor [47]. Furthermore, it is difficult to measure the global albedo from satellite data. Observing a likely 1-3% change since 1950 for example, would not be likely because of cloud coverage issues.

Table 2 Global warming contributions (2019)

Warming Component	Temperature Contribution (°C)	GW Percent Root-Cause Contribution* (Re-radiation)†	Percent of GW	Temperature Contribution (°C)	GW Percent Root-Cause Contribution* (Re-radiation)†	Percent of GW
Schneider Study	UHI Area Amplification=3.1			UHI Dome Amplification=8.4		
Urbanization ΔT	0.0112	2.87, (4.6)	1.18%	0.03	7.32 **(11.7)**	3.16%
Greenhouse gases (40%) ΔT	0.38	97.13 (95.5)	40.0%	0.38	92.68 (88.3)	40.00%
Sea ice melt feedback ΔT- rise	**0.15**		**15.8%**	**0.15**		**15.8%**
Water-vapor feedback ΔT- rise	0.3944		41.5%	0.41		43.2%
X (Other) ΔT	0.01435		1.51%	-0.02		-2.14%
Total	**∑0.95**			**∑0.95**		
GRUMP Study	UHI Area Amplification=3.1			UHI Dome Amplification=8.4		
Urbanization ΔT	**0.0542**	**12.47** (20)	**5.70%**	**0.1425**	**27.27** (43.6)	**15.00%**
Greenhouse gases (35%) ΔT	0.38	87.53 (80)	40%	0.38	72.73 (56.4)	40.00%
Sea ice melt feedback ΔT- rise	0.15		15.8%	0.15		15.8%
Water-vapor feedback ΔT-rise	0.43		45.3%	0.51		53.2%
X (Other) ΔT	-0.065		-6.82%	-0.2275		-23.95%
Total	**∑0.95**			**∑0.95**		

* $\%\Delta T_{GHG} = \Delta T_{GHG}/(\Delta T_{GHG}+\Delta T_{Urbanization})$ and $\%\Delta T_{Urbanization} = \%\Delta T_{Urbanization}/(\Delta T_{GHG}+\Delta T_{Urbanization})$, † Considering a 1.6 re-radiation factor for the UHI effect from GHGs

2.3 Tipping Point Has Yet to Occur

From Table 2, we note the sea ice melt is contributing about 0.15C rise or about 16% to global warming. This of course does not take into account snow melting effects and other related feedbacks. Yet it is a large portion of concern. Because analysis shows it is less that say even 25% of the issue, it is likely that a tipping point has yet to occur as some have suggested [48]. The primary reason for this is that in the poles, specifically the artic, the irradiance is only about 40% which helps slow the melting. Thus, reverse solar geoengineering is still possible.

3. Review of UHI Atmospheric Humidity Forcing Issues from Cities

It is well known that overall, water vapor in the atmosphere has increased over land and ocean since the 1970s as indicated by a rise in specific humidity [18,19], while the relative humidity is dropping [18,19]. Some highlights of this type of data are illustrated in Table 2. We also include in the next to last row some indication showing road growth from 2009 and 2012, a factor growth of five in just 4 years of low albedo surface area. As well in the last row showing a factor of 3.75 growth in road and building materials from 1950 to 2006.

Table 3 Specific Humidity, Relative Humidity, and Warm Mixed Asphalt changes

Source	Change	Period of Change
Specific Humidity Change [18]	Specific Humidity Change Land & Ocean about the same Increase of 0.45 g kg^{-1}	1960-2013
Total Atmosphere Water [19]	18.4-19.3kg/m2 NECP R2 25.5-26.6 kg/m2 RSS	1980-2017 1990-2017
Relative Humidity Change [18]	Δ%RH (land)~1% decrease Δ%RH (ocean)~0.5% decrease	1960-2013
Albedo Change [18]	ΔAlbedo (land)~4 units Units not defined (possibly reflectivity %)	2003-2012
US Warm Mixed Asphalt [25]	16.8 to 86.7 Million Tons ΔWMA=69.9 Million Tons	2009-2012
USGS, Building Materials Roads & Buildings [xyz] Ref: USGS, Materials in Use in U.S. Interstate Highways, https://pubs.usgs.gov/fs/2006/3127/2006-3127.pdf	Building and roads building materials 800 to 3000 x 10^6 Metric Tons Δ=2200 x 10^6 Metric Tons	1950-2006

The IPCC and it authors have asserted that two-thirds of global warming trends are caused by increase moisture content in the atmosphere [7, 17-20] due to ocean evaporation feedback. Here CO_2 creates initial warming raising ocean temperatures with warmer air that holds more water vapor (i.e. per the Clausius-Clapeyron relation).

In this section we review, the sources to the actual increase in specific humidity. Where does the moisture originate from? Is it all ocean feedback or in part humidity forcing related to UHI?

- Instead of mainly ocean feedback scenario, we should consider that impermeable surfaces of cities and roads create HHS with Highly Evaporating Surfaces (HEHS) which also can contribute to increases in specific humidity.

3.1 Urban Local Greenhouse Amplification Effect from Hydro-Hotspots

Atmospheric moisture sources is a complex issue from warm air effects that increase moisture greenhouse gas. This is also true of active HHS during precipitation periods which one might expect could help to trap city heat, increasing infrared radiation during these periods. For example, (using the Clausius-Clapeyron relation) if the ambient condition when it rains is 25^oC/98%RH and the HHS surface temperature is 60^oC (1000Watt/m^2, albedo=0.3, prior to rain cooling) then the local relative humidity at the hotspot surface is reduced from 98%RH to 15.6%RH. This increases temporarily locally specific humidity atmospheric concentration building up and could trap UHI heat effectively amplifying IR radiation which can contribute to warming anomalies due to city surface albedo problems..

3.2 Highly Evaporation Surface and Rainwater Management HHS Feedback Mechanisms

In this section we briefly review UHI related global warming issues by summarizing issues with the aid of Figures 1a and 1b. Figure 1a which shows Hydro-HotSpots (HHS) from Highly Evaporating Surfaces (HES) feedback and Figure 1b illustrate RainWater Management (RWM) feedback contributions to global warming.

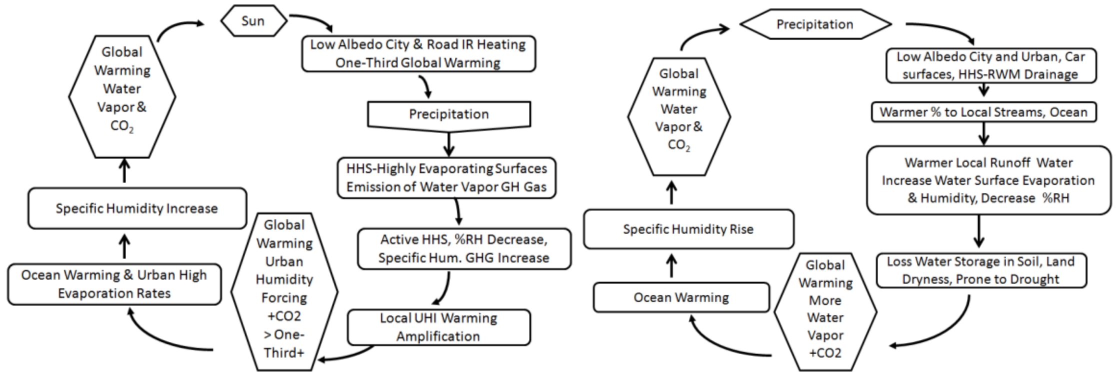

Figure 1 a) HHS- HES feedback view of contribution to global warming, b) HHS Rainwater Management (RWM) high temperature water cycling in Climate Change

Figure 1a shows HHS-HES feedback that may be summarized:

- Low albedo cities and roads emitting infrared radiation (IR), increased warming (approx. 1/3)
- Precipitation occurs, followed by evaporation of HHS-HES moisture, lower %RH increase specific humidity GreenHouse gas in warmed city area
- Local heat amplification, less local cooling with increased specific humidity amplifies heat index
- Local warming radiates heat increasing Global warming more than 1/3 original estimate
- Evaporation increases in cities and ocean primarily from UHI and roads creates lower %RH and higher specific humidity globally along with CO_2 increase more evaporation

Figure 1b Shows HHS-RWM feedback that may be summarized:

- Higher temperature storm water is collected off of HHS buildings, streets and hot cars
- A large percentage is drained to nearby rivers, lakes or ocean
- Warmer air allows for increase in specific humidity
- The impermeable city building and roads have replaced vegetative land creating lost area that would have stored cooler water in soil keeping the land moist with less generated heat.
- This increases land dryness can mean less land evaporation and more ocean rain.
- The RWM is often warmer from HHS activity raising storm water temperatures from hot city buildings and street cycling each year billions of gallons of rainwater to local streams, lakes and ocean contributing to local surface water temperature increases depending on location. These runoffs affect atmospheric warming trends and GH gases (see Sec. 4).

4. Data Information on Rainwater Management (RWM), Drought, Global Warming Trends

Rainwater management is an important factor as it too can influence global warming trends. It can also impact where it rains! Rain sometimes follows local evapotranspiration. Apart from precipitation, evapotranspiration is the major component in the hydrologic budget.

When it rains in a city, much of the land in urban areas is covered by pavement or asphalt. These impermeable surfaces in urban cities commonly estimated around 55% runoff, with 30% for evapotranspiration, 10% shallow soil infiltration, 5% deep soil infiltration. Water temperatures from runoffs are often hotter due to HHS. For example,

- The New York Environment Report, in 2014 reported [28], “Every year, old sewers flooded by storm water release more than 27 billion gallons of untreated sewage into New York Harbor.”
- Fry et al. [29] reported that in February of 2019 California estimated that 18 trillion gallons of rain in February alone had most of the water going to the Pacific Ocean. The article goes on to point out the LA dept. of water captured 22 billion gallons of water during recent storm.
- In August 2001, rains over Cedar Rapids, Iowa, led to a 10.5C rise in the nearby stream within one hour, which led to a fish kill. Similar events have been documented across the American Midwest, as well as Oregon and California [30]
- Sydney Paper reported [31]: “Every year around 132 billion gallons of storm water – enough to fill Sydney Harbor – runs from Sydney to the sea.”

It is of course very difficult to tell the global thermodynamic influences of higher temperature water cycling. However, Australia might be a good extreme example, on the Sydney-Melbourne South-East side, the Tasman Sea is about 1 to 2 deciles range warmer (NOAA Sea Map [32]) than the South -West coast of Australia and about 5 deciles range warmer that the far south west coast. This might in part be an example of cyclic ocean heating. We tend to think of the ocean as an infinite temperature sink, but over 70 years of cycling, it can take a toll and perhaps this is somewhat of what we are seeing on the Sydney – Melbourne side and costal issues.

4.1 Data Information on Rainwater Management (RWM) Dry Day Increases

As an example of the importance in losing wet land (water storage), Cao et. al. [33] did a study on wet land reduction in China and correlation to drought with the following conclusion

- "The wetland distributions and areas of the five provinces of southwestern China in the 1970s, 1990, 2000 and 2008 show that the total reduction of wetland area was 3553.21 km^2 in the five provinces of southwestern China from 1970 to 2008, accounting for about 17% of the ground area, and thus the average annual reduction area is about 88.83 km^2. The reduction rate was comparatively fast from 2000 to 2008 with an average annual reduction of 329.31 km^2. The changes to the wetland area show a negative correlation with temperature (i.e. wetland decrease, increase in temperature), and a positive correlation with precipitation (i.e. wetland decrease, precipitation decrease)." [33]

Hirshi et al. [34] did the following study

- "We analyzed observational indices based on measurements at 275 meteorological stations in central and southeastern Europe, and on publicly available gridded observations. We find a relationship between soil-moisture deficit, as expressed by the standardized precipitation index, and summer hot extremes in southeastern Europe. This relationship is stronger for the high end of the distribution of temperature extremes. We compare our results with simulations of current climate models and find that the models correctly represent the soil-moisture impacts on temperature extremes in southeastern Europe, but overestimate them in central Europe."

In Hirshi et. al. study [34] they observed a negative linear relationship between wet land decrease and dry days increase.

5. Summary - Solutions

From a review of data and its analysis presented, it is our opinion that the IPCC suggestions focused mainly on CO_2 reduction appears not to be enough to stop global warming trends from occurring. Our conclusion is that albedo reduction of UHI is needed to help stop global warming anomalies and reverse trends. Trends can only be reversed if a concerted effort is made to commence with a full scale geoengineering solar solution. This will also reduce HHS contribution to atmospheric moisture issues. Of course, we also feel more studies are needed to assess these impacts. In this review we exemplified CO2 doubling theory which one would anticipate that the doubling temperature would be reduced given the additional source of UHI global warming. A summary suggestion and corrective actions related to Albedo and HHS Reduction include:

- Create new IPCC suggestions to include and recognize albedo forcing issue of UHI and roads
- Recommend changes for albedo of roads and cities to reducing HHS and the area effect dramatically, i.e. paint roads and building with reflective colors (have minimally albedo requirements, 0.25 – 0.5)
- Mandate future albedo design requirements of city and roads
- Roads to be more HHS eco-friendly
- Reduce driving speeds during rain to reduce evaporation rates can also reduce KE molecules
- Change to electric cars with HHS - cooler hoods
- Require all cars to be silver or white
- Thoroughly assess and make goals for rain water management issues including evapotranspiration and rainwater runoff allowed temperatures released into streams, rivers, lakes and oceans
- Require negative population growth to reduce increase HHS-HES surfaces
- Improve HHS-HES irrigation to soil
- Improve vegetation in run off areas
- Adopt Low Impact Development (LID) in city planning and improvements for design approach aiming to mimic naturalized water balances with semi-permeable surfaces
- Severe HHS-RWM changes are required to stop runoff into the ocean worldwide
- Provide new studies on albedo and humidity forcing from UHI to better understand their effects, address conflicts with CO2 theory. Provide updated UHI radiative forcing contribution to GW. Provide a modern microclimate doubling experiment if possible to verify doubling claims.

- Provide a concerted effort with a full scale geoengineering solution to reverse global warming prior to a tripping point occurring.

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Biography

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