Global Warming Urban Heat Island Forcing Issues Unaddressed by IPCC Goals with Weighted Albedo Amplification Solar Urbanization Model

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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 goals. We first review historical global warming forcing trends by comparing CO_2 prediction to Urban Heat Islands (UHIs) complex forcing influences. We provide a timeline of CO_2 doubling theory and UHI global warming estimates which show that UHI warming effects should be more accurately accounted for by the IPCC. We review both CO_2 and UHI forcing influence by a number of authors indicating the difficulty of estimating UHI influences on global trends. This appears primarily due to making local ground temperature measurements and comparing them to more rural trends. However, many authors are in agreement that there are strong UHI influences. In order to investigate this independently, we take a different approach and present a simplified global weighted albedo amplification solar model. We find with a nominal and worst case analysis, that between 5.7-26.7% of global warming may be due to urbanization and the UHI effect. Much of the variance is related to the discrepancies between urbanization global area estimates from many different studies. We also 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 city surfaces. Our review concludes that IPCC, which is the responsible world's climate agency, should also include UHI albedo goals for numerous reasons.

1. Goal of this Paper

In this paper we provide a nominal and worst case climate analysis using a Weighted Albedo Amplification Solar Urbanization Amplification (WAASU) Model that finds between 5.6 and 25% of global warming may be due to urbanization. To this end, we also review Urban Heat Island (UHI) important forcing amplification effects and the need for improved UHI IPCC albedo goals, It is apparent that the IPCC is focusing mainly on CO_2 reduction as the key global warming solution [1]. While UHIs have been studied for years [2-5], 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 [1] or even to help for the known health reasons! We note that over 50% of the global population now live in cities so albedo goals are very important for health reasons.

- ***Unfortunately, the IPCC is really the only group capable of making such recommendations that would help on a global scale with the UHI albedo climate problems because they are the global climate leaders tasked with this responsibility.***

Possibly some of their reluctance on a global studies have been short-sighted with push-back concerns of albedo changes to cities [6-9] which might create a need for more fossil fuel use in winter time periods. These studies likely did not take into account the complex UHI warming amplification issues related to albedo forcing effect that include, heat capacity, humidity and Hydro-HotSpot (HHS) activity, that contribute to local and likely global climate change. Here we term HHS as water evaporation from Highly Evaporating Hot Surfaces (HEHS). The IPCC may have assumed that CO_2 is so dominant in global warming, that such goals are unnecessary. The IPCC goals are not adequate in this regard as discussed in this article since UHI pose so many complex issues, most of them are albedo forcing related. Therefore, this issue demands immediate serious attention. 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^{o}C [11,12]. Specifically a study in California calculated an offset of 1.31-1.47 °C with 100% deployment of "cool roofs" [11,12]. While such studies are helpful, we feel they may be far off in timing, as UHIs, likely already significantly contributing to current global warming issues.

To assess the need of UHI albedo corrective actions by the IPCC, the goal of this paper is to demonstrate with a WAASU model the possible global effect on climate change that UHI create and to review the many complex UHI issues (also see Table 1 Cause and Effects Reviewed):

- Review IPCC CO_2 goals and their recognition of UHI forcing issues
- Review the UHI area and radiative forcing quoted by the IPCC in its latest release
- Provide an independent assessment of UHI albedo warming trends using the WAASU model in order to demonstrate requirements, and investigate claims by other authors of UHI warming trends

- Review current knowledge base of atmospheric humidity and propose possible UHI sources that could be contributing to global humidity changes
- Review yearly storm water cycling of higher temperature water from UHI to local streams, lakes and ocean raising local water surface temperatures and evaporation rates
- Review issues with UHI Rain Water Management (RWM) issues that can lead to increases in dry days and possibly drought
- Review loss of natural vegetation evapotranspiration and associated dryness

2. UHI Additional Amplification Effects

The table below summarizes global warming cause and amplification effects. In this section we will quickly review the additional amplification effects listed since the root causes and primary amplification effects are fairly well understood.

Table 1 Global Warming Cause and Effects

Global Warming Causes →	Population → Expanding Urban Heat Islands (UHI), Roads & Increases in Greenhouse gas
Global Warming Amplification Effects →	Increase in Specific Humidity, Decrease in Relative Humidity, Decrease in land albedo due to cities & roads, Decrease in water type areas from loss of albedo (reflectivity) due to Ice and snow melting
Urban Heat Island Additional Amplification Effects →	UHI building heat capacities, humidity effects and hydro-hotspots

There are three main additional amplification effects due to heat capacity, humidity and hydro-hotspots effects can be summarized

- ***The humidity amplification effect*** was observed in a study by Zhao et al [42] that UHI temperature increases in daytime ΔT by 3.0^{o}C in humid climates but decreasing ΔT by 1.5^{o}C in dry climates. These relationships imply that UHIs will exacerbate heatwave stress on human health in wet UHI climates. One explanation for this is how heat dissipates through convection which is more difficult in humid climates. Another explanation is that warmer air holds more water vapor. This can increase local moisture so that there is a local greenhouse effect.

- ***The heat capacity amplification effect*** is likely even observable on the daily UHI cycle. Here in most Cities it is observed that while they UHI are hotter during the day right near the surface, they are actually hotter at night in the above atmosphere. For example, in a study by Basara et al. [43] in Oklahoma city UHI it was found that at just 9-m height, the UHI was consistently 0.5–1.75°C greater in the urban core than the surrounding rural locations at night. Further, in general UHI impact was strongest during the overnight hours and weakest during the day. This inversion effect can be the results of the massive heat capacities of building that take in heat by convection in the day, actually cooling the area, but at night as buildings cools down, its convection heating increases atmospheric temperatures.

- ***The Hydro-hotspot amplification effect:*** This effect is not well known and is suggested by the author. Here Atmospheric moisture source is a complex issue due to Hydro HotSpots (HHS). Hydro hotspots occur when buildings are hot due to sun exposure then during precipitation periods, the hot highly evaporation surfaces increase localized excess water vapor in the air. It is well known that warm air holds more moisture since air expands. Since moisture is a greenhouse gas, one might expect this to trap city heat and increase infrared radiation during these periods. For example, (using a thermodynamic Clausius-Clapeyron relation) if the ambient condition when it rains is 25^{o}C/98%RH and the HHS surface temperature is 60^{o}C (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 can increases temporarily locally specific humidity atmospheric concentration building up and could trap UHI heat effectively amplifying IR radiation that can contribute to warming anomalies due to city surface albedo problems. This conceptual type of assessment helps to understand how UHI have complex albedo forcing issues related to humidity.

2.1 Surface Area & Volume Amplification Factors

In order to estimate the UHI amplification effect such as solar surface area, heat capacities and their effect on the climate, which must include average building sizes, mass and side areas (and the fact that buildings have gotten taller [58] since 1950), as well the humidity effects, we use a study by Zhou et al. [27] (2015). In this study [27] they found UHI effect decayed exponentially toward rural areas for majority of the 32 Chinese cities. They found that the "footprint" of UHI effect, including urban areas, was 2.3 and 3.9 times of urban size for the day and night, respectively.

If we assume a circular area of urban radius, then goes the footprint radius is 1.41-2 larger that its own radius. Using this radius, the volume amplification factor goes as the radius of a sphere (r^3) so the spherical volume amplification effect would range from 2.8-8 times its own urbanized volume. These amplification factors are summarized in the table below.

Table A1 Urban Climate Amplification Factors

Urban Climate Amplification	Amplification Factor	Day-Night Average Factor
Area Amplification	2.3-3.9	3.1
Volume Amplification	2.8-8	5.4

In this study, we conservatively used a maximum volume factor of 4. One could take this either as a maximum urbanized area amplification factor or as a low average day-night urbanized volume amplification factor. This is the only study we found of its kind. Therefore, we will be using this as the amplification area factor in the WAASU model.

1.1 Review of the Timeline of CO_2 Doubling Theory and UHI Estimates

It can be helpful to review key CO_2 doubling theory and UHI history as both are climate warming sources (see Table 1). 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 [13,14]. Since Arrhenius, doubling temperature estimations based on theory and linked to environmental trends, have shown some decreasing effect and historically unaccounted UHI effects in CO_2 doubling theory. This is illustrated in Table 2 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 1 and Equation 1 is in agreement with Manabe and Wetherald [16],

$$13.9C\ (57.02F)+\mathbf{2.36^oC}\ Ln\{412/311.8)/Ln2=14.85C\ (58.73F),\ 0.95C\ (1.71^oF)\ Rise \qquad (1)$$

Table 2 Key CO_2 doubling theory history and conflicts

Reference	**CO_2 Doubling Temperature**	**CO_2 Temperature Effect Estimates**	**Moisture Percent Effect***	**UHI Albedo % Forcing Estimates**
Arrhenius (1896) [13, 14]	5-6°C	5-6°C	-	-
Gillbert Plass (1950's) [15]	3.6°C	3.6°C	-	-
Manabe and Wetherald (1975) [16]	2.3°C	2.3°C	-	-
Feddema et al., 2005 [17]	UHI Variance	-	-	Significant
McKitrick and Michaels (2007) [18]	UHI Variance	-	-	50%
Ren et. al. (2007) [19]	UHI Variance	-	-	Significant
Stone, 2009 [20]	UHI Variance	-	-	Significant
Z.C. Zhao (2011) [21]	UHI Variance	-	-	Significant
Yang et. Al. 2011 [22]	UHI Variance	-	-	Significant
IPCC (1^{tst}-5^{th} Assessment 1990-2014,[1] (ECS) equilibrium change	1.5 - 4.5 °C	1/3	2/3	-
Q. Huang, Y.Lu (2015) [23]	UHI Variance	-	-	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 (0.3°C)	2/3 (0.63°C)	0
WAASU Model (this study)	UHI Variance	-	-	5.6-26.7%

*Ignoring other GHG

We would expect the doubling temperature to drop off if one takes into account that UHI contribute significantly to global warming. The phrase "UHI Variance" (Column 2) indicates that that the authors conclude that UHI warming trends are more "Significant" (Column 5) than currently taken into account in CO_2 doubling theory by IPCC estimates and goals; this is part of our review. The word "Significant" or later we use "UHI Significant" is used to indicate that the authors have demonstrated aspects of UHI global trends but are not well quantified to provide a percentage value.

One issue well known and in IPCC reports (discussed in more detail in Section 2.1) is the fact that land surface air temperatures are in fact increasing at a higher rate than sea surface temperatures. The IPCC attributes this to (see Sec 2.1) the differences in evaporation, land–climate feedbacks and changes in the aerosol forcing over land with a warming ratio of about 1.6. It is also reported with high confidence that the difference in land and ocean heat capacity is not the primary reason for faster land than ocean warming. Given such observations, in an alternate view, it seems to strengthen views of the lower troposphere warming origin as described in the referenced "conflicting" studies in Table 2. As well, we could not find significant acknowledgement of these studies in IPCC reports or suggestions that UHI are significantly influential cause and effect (Table 1) to global warming large scale trends.

2. Review of Key IPCC 2020 Goals and Risks

The IPCC report SYR_AR5 [1] 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 CO_2 emissions from all anthropogenic sources since 1870 to be limited to about 2900 Gt CO_2 when accounting for non-CO_2 forcing as in the RCP2.6 scenario, with a range of 2550 to 3150 GtCO_2 arising from variations in non-CO_2 climate drivers across the scenarios considered by WGIII. About 1900 [1650 to 2150] GtCO_2 were emitted by 2011, leaving about 1000 GtCO_2 to be consistent with this temperature goal"

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

A review of the IPCC report AR4 [1] indicates that UHI concerns occupy a very small portion of that report which does not recognize UHI concerns on global warming. One paragraph discusses it

- In WG1-AR4 (2007) (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-m^2 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 to disagree with a 2005 GRUMP [24-26] study by a factor of about 10-20 (see Appendix A) and needs to be updated. 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.

In AR5 (2014) there are no relevant updates related to Table 2, one statement indicates that there is a high confidence that: "UHI effect makes heat waves more intense in cities by 1.22–4°C, particularly at night".

In an updated Chapter 2 (2018-2019) on Land-Climate interactions [1] regarding to land vs. sea warming trends we find.

- "Analyses of paleo records, historical observations, model simulations and underlying physical principles are all in agreement that land surface air temperatures are increasing at a higher rate than sea surface temperature as a result of differences in evaporation, land–climate feedbacks and changes in the aerosol forcing over land (*very high con dence*). For the 2000–2016 period, the land-to-ocean warming ratio (about 1.6) is in close agreement between different observational records and the CMIP5 climate model simulations (the *likely* range of 1.54–1.81)." Also see (Lickley and Soloman 2008)… There is also *high confidence* that difference in land and ocean heat capacity is not the primary reason for faster land than ocean warming."

Chapter 8 (2014) AR5 Urban Areas, Aromar Revi et. Al [1], does provide a reference to UHI influence related to cool roofs or white reflective roofs … "which lowers the surface temperature of buildings compared to conventional (black) roofs…There is also some work on roads and pavements with increased reflectivity". However there was no recommendations/goals for UHI changes on a large scale and no significant acknowledgement of the references in Table 2 or similar discussion found.

The main recognition for UHI influences are for local climates in Chapter 8 (2013):

- "Urbanization alters local environments via a series of physical phenomena that can result in local environmental stresses. These include urban heat islands (higher temperatures, particularly at night, in comparison to outlying rural locations) and local flooding that can be exacerbated by climate change. It is critical to understand the interplay among the urbanization process, current local environmental change, and accelerating climate change. For example, in the past, long-term trends in surface air temperature in urban centers have been found to be associated with the intensity of urbanization (numerous cited references not included)."

We conclude that there has been no significant acknowledgement of UHI influence on global warming similar to the ones in Table 2 [17-23] in the many IPCC reports.

3. Short Review of UHI Assessments Showing Significance

Of the numerous studies on Urban Heat Island (UHI) effects, only a handful has tried to show "significance" for global warming. Most of the studies are related to local effects. We try to capture some of the ones in Table 2 that are in some way "conflicting" with the IPCC views on such "significance"

McKitrick and Michaels [18] used data grids doing specific hypotheses testing regarding the independence of observed temperature trends from surface processes and determinants of inhomogeneities and determined from 1979 to 2002:

- "our analysis does suggest that nonclimatic effects are present in the gridded temperature data used by the IPCC and that they likely add up to a net warming bias at the global level that may ***explain as much as half the observed land-based warming trend."***

Huang et. Al. [23] estimate are from surface stations and locally oriented, using regression t-test and p-test assessments to make conclusions that influence a very large area mass in China:

"Our results on the relative contribution of the UHI to climate warming are consistent with previous studies. Ren et al. [19] found that urbanization-induced warming for Beijing (Wuhan) was significant and accounted for 80.4% (64.5%) of the warming over 1961−2000 and 61.3% (39.5%) of the warming over 1981−2000… The warming rate due to the UHI and its contributions to the climate warming in the ***fifth report of the IPCC can still be regarded as conservative in the urban agglomeration region.*** Some studies (Yang et. Al [22]) have ***suggested that "significant" contribution of urbanization to temperature changes might be comparable to that of GHG emission for metropolises and large cities.***

"Our analysis of daily average, minimal and maximal air temperature observations at 41 stations in the YRDUA over 1957−2010 has revealed significant long-term warming due to the background warming and the UHI. The warming rate ranging from 0.108 to 0.483 °C/decade for average air temperature is generally consistent with the warming trend of other urban regions ***in China and in other urban agglomerations worldwide***. Significant positive correlations were found between three urbanization factors (urbanization rate, population, and built-up area) and the warming rates. All three factors could explain more than 80% of the variability in the warming rate. Our attempt to estimate the contribution of the UHI to the observed warming based on multiple linear regression and warming rates suggests that 37.1%–78.3% of the warming in the last few decades could be explained by local urbanization at various urban sizes. The results of this study showed that urbanization significantly enhanced local climate warming."

Ren et. Al.(2007) [19]noted:

"In summary, temporal trends of annual and seasonal mean SAT for time periods of 1961-2000 and 1981-2000 at Beijing and Wuhan stations and their ***nearby rural stations are all significantly positive***, and the annual and seasonal urban warming for the two periods for Beijing and Wuhan stations ***is also positive and significant***. The annual urban warming at the city stations can account for about 65-80% of the overall warming in 1961-2000, and about 40-61% of the overall warming in 1981-2000."

Yang et. Al. 2011 noted:

"Therefore, for metropolises and large cities in east China, the significant contribution of urbanization to temperature change may be comparable to that of GHG concentration, suggesting that land-surface processes can play a vital role in shaping future climate change Feddema et al., 2005 [17]… The increasing divergence between urban and rural surface temperature trends highlights the limitations of the response policy to climate change; these policies focus only on GHG reduction Stone, 2009 [20]. ***Policymakers need to address the impact of land use such as urbanization*** and deforestation on climate change in addition to that of GHG emissions. ***Serious measures for broadening the range of management strategies beyond GHG reductions and a land-based mitigation framework should be included in the scheme for mitigating climate change***.

These references cited here reported issues as early as 2005, but so far most do not appear in the updated IPCC report or are reflected in any of their goals. No considerations in goals for UHI influences on global warming trends despite numerous findings of "significance" in global warming trends by UHIs.

4. Global Warming Estimates Using the Weighted Amplification Albedo Solar Urbanization Model

In order to investigate independently, we took a different approach to ground station assessment with actual radiative forcing values using a straight forward method that can more easily be refined with better data. We developed a simplified global Weighted Amplification Albedo Solar Urbanization (WAASU) model with solar surface area assessed in Appendix A and a formulated albedo model in Appendix B. Our model uses a direct approach that is independent of surface temperature data and only based on solar surface areas and estimated albedo city values. The WAASU model in review has some advantages, it is non probabilistic and in line with the way typical energy budgets are calculated, it uses only two key parameters (area, and surface albedo). This provides some simplistic transparency. Absolute numbers are obtainable, although the actual numbers are not as important as the conceptual approach and trends to help verify UHI "significance". In review, the role of UHI area forces issues which need to be formulated:

- What is the area of cities (24-26)?
- What is the UHI Solar Heating Area (Appendix A, [27])?
- How much do UHI changes the surface area of the Earth requiring renomalization (Appendix B)?
- What is the average albedo of cities (Appendix B)?

Appendix A describes our estimates for the effective solar area that includes UHI and urbanization extents from a worst case GRUMP area study [24-26,45, 54] and a nominal study of Schneider et. al. [54] projected to 1950 and 2019.

As an example, in 2019 the worst case solar area used in our analysis was 3.81% of the Earth, this is a worst case assessment from a GRUMP study that found 2.7% of land is urbanized in 2the year 2000 (0.027x29%=0.783), this extrapolates to 0.952% in 2019 (see Appendix A). We then estimated the effective climate effect that included city solar heating area increase using an amplification factor of 4 giving 3.81 %. This factor comes from a Zhou et al. [27] (2015) that found UHI changes the climate in area 2–4 times larger than its own area in China. In 1950 the extrapolated area from the GRUMP study was 0.316 using the population growth rate. We chose not to use an amplification effect since 1950 is the baseline reference year that is commonly to estimate global warming change from. The Solar Albedo model for 2019 is shown in Table 3.

The compiled results from the solar albedo model that includes amplification factor of 4, found that

- ***urbanization likely has contributed to global warming between 5.7% and 26.7%.***

The table also includes "what if" estimate we could change urbanization to be more reflective from 0.12 shown in the Table to an albedo of 0.5, we see the results indicates that

- ***global warming can be reduced by 14.4% to 40.3% cooler***

Table 3 Results of GW Temperature Budget Change With City Surface Areas and Albedos

Year	**Urban Extent Global Area (App. A)**	**Effective Global Surface Area of UHI (App. A)**	**Albedo Roads**	**Albedo Cities**	**Global Weighted Albedo**	**Temperature (no GH gases)***	**UHI Radiative Forcing**	**Percent Of Global Warming**
Nominal Case IPCC Schneider Study [33]								
1950	0.059	0.059%	0.04	0.12	30.05%	-18.62°C	0	Par
2019	0.188	0.753	0.04	0.12	29.99	-18.56°C	0.204 W/m^2	**5.7%**
Future Cool Roofs	0.188	0.753	0.04	0.5	30.14	-18.7°C	-0.51 W/m^2	-14.4% (Cooler)
Worst Case GRUMP Study [26-28]								
1950	0.316%	0.316	0.04	0.12	30.03	-18.60°C	0	Par
2019	0.952%	3.81%	0.04	0.12	29.75	-18.34°C	0.96 W/m^2	**26.7%**
Future Cool Roofs	0.952%	3.81%	0.04	0.12	30.45	-18.98°C	-1.43 W/m^2	-67.4% (Cooler)

*where Temperature Budget is given by: P_{Total}= 1361W/m2 {0.25 x (1-Albedo)} =σT^4

To summarize the table these findings:

- Nominal case analysis 1950 to 2019 is 0.06C (-18.56-(-0.18.62) due to Cities & Road increases, 5.7% in global warming
- Worst case analysis 1950 to 2019 is 0.26C (-18.34-(-0.18.60) due to Cities & Road increases, 26.7% in global warming in agreement with other authors [17-23] "UHI significance".
- "what if" corrective action results using cool roofs shows that changing city albedos range from 14.4 to 67.4% cooler for reducing global warming

This UHI albedo radiative forcing model provided above for cities and roads worst case (in support of other authors [17-23]) indicate that IPCC global warming goals may be insufficient at the present time.

5. Review of Some Atmospheric Humidity Data and 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 [28,29], while the relative humidity is dropping [29,29]. Some highlights of this type of data are illustrated in Table 3. 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 the 4 year period identified for low albedo surface area changes. As well in the last row showing, we see a factor of 3.75 growth in road and building materials from 1950 to 2006 to support the high rate of city growth occurring in general.

Table 4 Specific Humidity, Relative Humidity, and Warm Mixed Asphalt changes

Source	Change	Period of Change
Specific Humidity Change [28]	Specific Humidity Change Land & Ocean about the same Increase of 0.45 g kg^{-1}	1960-2013
Total Atmosphere Water [29]	18.4-19.3kg/m2 NECP R2 25.5-26.6 kg/m2 RSS	1980-2017 1990-2017
Relative Humidity Change [28]	Δ%RH (land)~1% decrease Δ%RH (ocean)~0.5% decrease	1960-2013
Albedo Change [28]	ΔAlbedo (land)~4 units Units not defined (possibly reflectivity %)	2003-2012
US Warm Mixed Asphalt [30]	16.8 to 86.7 Million Tons ΔWMA=69.9 Million Tons	2009-2012
USGS, Building Materials Roads & Buildings [31]	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 [1,32-37] 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. That is, 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, some of this might come from impermeable surfaces of cities and roads create HHS with Highly Evaporating Hot Surfaces (HEHS) which also can contribute to increases in specific humidity.

In review of IPCC documentation, there is no reference to UHI and roads contributing to the observed increase in atmospheric greenhouse moisture gas. To investigation atmospheric humidity contribution to global warming, we looked at the evaporation rate as a metric. We investigate the rate of evaporation growth since 1950 from cities' HHS and compared to the ocean evaporation rate increase since 1950 in Appendix D.

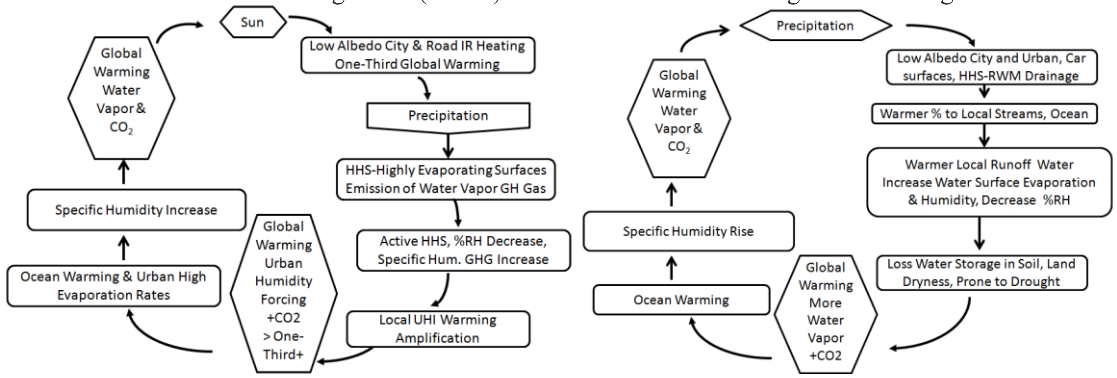
5.1 Concept Assessment of Urban Local Greenhouse Amplification Effect from Hydro-Hotspots

Atmospheric moisture source 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 and increase infrared radiation during these periods. For example, (using the Clausius-Clapeyron relation) if the ambient condition when it rains is 25^{o}C/98%RH and the HHS surface temperature is 60^{o}C (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 can increases temporarily locally specific humidity atmospheric concentration building up and could trap UHI heat effectively amplifying IR radiation that can contribute to warming anomalies due to city surface albedo problems.

This conceptual type of assessment helps to understand how UHI have complex albedo forcing issues related to humidity.

5.2 Review of Highly Evaporation Surfaces 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 Rain Water Management (RWM) feedback contributions to global warming.



(a) (b)

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-HEHS 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 (with the 1/3 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 creating more humidity issues

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 compared to HHS runoff.
- This increases land dryness and can mean less land evaporation and more ocean rain since precipitation often follows evaporation areas as discussed below.
- 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.

6. Review of Some Data Information on Rainwater Management (RWM) Trends

Another important aspect not addressed by the IPCC is high temperature storm water runoff. Rainwater management is an important factor in UHI as it too can influence global warming trends and should be included in its goals. 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 [38], “Every year, old sewers flooded by storm water release more than 27 billion gallons of untreated sewage into New York Harbor.”
- Fry et al. [39] 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 [40]

- Sydney Paper reported [41]: "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 [42]) 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.

6.1 Review of Some Data Information on Rainwater Management (RWM) Causing Dry Day Increases

As an example of the importance in losing wet land (water storage), Cao et. al. [43] 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)." [43]

Hirshi et al. [44] 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 [44] they observed a negative linear relationship between wet land decrease and dry days increase.

Wetland issues are recognized by the IPCC in Chapter 2 (2019), "warming trends over dry lands are twice the global average (Lickley and Solomon 2018) [52]. However, there is little connection to UHI rainwater runoff being dumped into oceans and this in part causing some of the dry lands.

7. Conclusions and Suggestions

From our review of data and its analysis presented, it is our opinion that the IPCC goals focused solely 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. This will also reduce HHS contribution to atmospheric moisture issues. Of course, we also feel more studies are needed to assess these impacts such as better estimates of global UHI solar surface areas. In this review we exemplified CO_2 doubling theory which one would anticipate that the doubling temperature would be reduced given any additional source of UHI global warming. The results indicated a drop from 2.36 to about 1.37^{o}C found in the doubling temperature in our suggested model. Since the doubling temperature significantly drops as one might expect upon recognizes UHI warming influences, one might anticipate concerns in CO_2 doubling theory. Below we provide suggestions and corrective actions related to Albedo and HHS reduction that includes:

- Creating new IPCC goals to include and recognize albedo forcing issue of UHI and roads
- Recommending 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)
- Mandating 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
- Requiring all cars to be silver or white
- Thoroughly assess and making goals for rain water management issues including evapotranspiration and rainwater runoff allowed temperatures released into streams, rivers, lakes and oceans

- Requiring negative population growth to reduce increase HHS-HES surfaces and fossil fuel use
- Improve HHS-HES irrigation to soil
- Improving vegetation in runoff areas
- Adopting Low Impact Development in city planning and improvements for design approach aiming to mimic naturalized water balances with semi-permeable surfaces
- Requiring severe HHS-RWM changes to reduce runoff into the ocean worldwide that can cause loss of wet lands and local increase in dry days and increase in evaporation rates
- Providing new studies on albedo and humidity forcing from UHI to better understand their effects, address conflicts with CO_2 theory. Providing updated UHI radiative forcing contribution to GW. Provide a modern microclimate doubling experiment if possible to verify doubling claims.

Appendix A: ***Solar Urbanization Surface Area & Volume Amplification Estimates***

Estimating urbanization that include UHI areas of cities globally with amplification effects is a non trivial task. We are interested in providing a worst case and a nominal scenario for the albedo modeling to estimate global warming from 1950 to 2019. Estimates of how much of our land has been urbanized vary widely in the literature and this is in part due to the definition of what is urban and the datasets studies use. Despite the growing importance of urban land in regional to global scale environmental studies, it remains extremely difficult to map urban areas at coarse scales due to the heterogeneous mix of land cover types in urban environments, the small area of urban land relative to the total land surface area, and the significant differences in how different groups and disciplines define the term 'urban'.

To be consistent, we use satellite data from two studies. For the worst case estimate, we used a GRUMP v3 [24-26, 45, 54] study released in 2005 (which has its critics [45,54]) indicate the surface area relative to the Earth's land coverage is 2.7% (or 0.027 x 29%=0.783% area of the Earth) in the table below. For the nominal case we looked at the reference used by the IPCC in Urban Area report 2014 [1] quoted a 2009 study by Schneider et al. [54] of 0.5% of land (0.0051x29%=0.15% area of Earth) and 1% in western Europe. The IPCC also said "their physical and ecological footprints are much larger". In general there have been numerous studies and these are summarized in Table A2.

Using the GRUMP, worst-case study in 2005, we project it to 1950 and 2019 by using the world population growth rate [57] which varies by year as shown in Figure A1. We chose the average rate per ½ decade for iterative projection from 1950-2019.

Then for the worst case scenarios, we took this as the GUMP study and use the amplification effect applied to the area of 4 for 2019 as discussed in Section 2.1. Since 1950 is taken as the reference year (for most global warming estimates) we did not use any amplification factor. Next we assumed that the amplification factor was related mainly to the solar surface heating area. Therefore, under this assumption, the urban effective amplification results are shown in the table below. The last column shows the results of the effective area used in the solar albedo model.

Table A1 Values used to estimate the Solar Surface area in cities

Year	Percent of Earth	UHI Amplification Factor effect (Section 2.1)	UHI Surface Amplification Area Effect
Worst Case GRUMP Study [24-26,45]			
1950	0.316%	1	**0.316*** **
2000	0.027**x29%=0.783%		
2019	0.952%*	4	**3.81%**
IPCC Schneider Study [54]			
1950	0.059*	1	0.059
2000-2001	0.0051*29%=0.148		
2019	0.188*	4	**0.753**

*Growth rate of cities using non linear world population growth rate per year Fig A1, ** GRUMP (2005) study,***not increased as this is considered global temp. reference year.

Note that Table A2 summarizes the GRUMP and Schneider study used here. As well, we also list a number of other urbanization studies. A 2010 study indicates it's much lower to 0.3% [46]. OECD Green Growth Studies Indicators 2014 [59] showed about 1.8% of land (0.018x29%=0.52%). A global map from a 2000 NASA data set [55,56] showed people live on 1% of the land [55,56] (0.29 of Earth). A 2015 study based on 2000 data set shows about 0.5% of the total land area but ranges widely [40].

Table A2 Summarizing Literature Urbanization Area Estimates

Percent of Land	Percent of Earth	Reference and Issues
2.7	0.783	(2005) GUMP (NASA Satellite, Light study, blooming issues) [24-26,45]
1.8	0.52	(2014) OECD [59]
1%	0.29	(2000) NASA data set [Satellite, 55, 56].
0.5	0.15	(2009) Schneider et al. based on 2000-2001 data [54] from IPCC 2014 reference [1]
0.5%	0.145	(2015) based on a 2000 data set [60]
0.3	0.09	(2010) only most populated about 50% estimated [46]

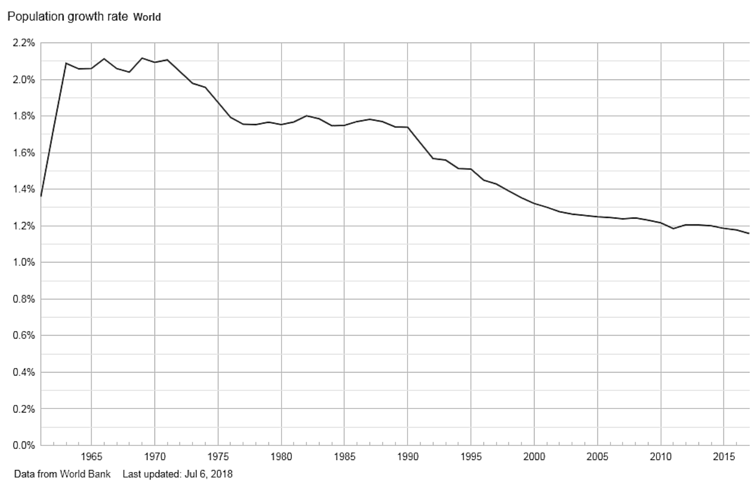


Figure A1 Population growth rate by year from 1960 to 2018 [57]

A.1 Some information on the GRUMP study vs. the Schneider study

We note the GRUMP study incorporates population estimate from 1990, 1995, and 2000, it combines census data with satellite data. Schneider study uses satellite data, a map the global distribution of urban land use at 500 m spatial resolution using remotely sensed data from the Moderate Resolution Imaging Spectroradiometer (MODIS) from 2000-2001. The Schneider study criticizes the GRUMP noting, “The extreme variability in these estimates calls into question the accuracy of each map’s depiction of urban and built-up land, and yet past efforts to validate the maps have been minimal”. They also note, regionally, our results reveal that previous estimates of urban extent (2–3%, CIESIN 2004, i.e. GRUMP) drawn from global urban maps may over-estimate the true extent of built-up areas. However, the Schneider study does show that the GRUMP study has the highest producer accuracy, which is a measure of omission.

Appendix B: Weighted Albedo Amplification Solar Urbanization Amplification (WAASU) *1950 & 2020*

Below is a simplified author’s WAASU model to estimate the Earth’s total albedo decrease with increase in city and road solar areas as provided in Appendix A. Note in our WAASU modeling all Earth constituents constant except the urban area. The Earth weighted Albedo since 1950 is only a function of changes to cities except for renormalization. This allows us to focus on causes and not effects. Renormalization occurs since as city amplification area grows we need to renormalize all other Earth constituents to obtain 100% area. Note city areas will increase the surface area of the Earth however we also include their amplification effect in the renormalization. The goal of the simplified global WAASU model is to illustrate the sensitivity of global albedo change from 1950 to 2019 in order to show global UHI cause feasibility. The simplistic model allows for later refinement and aids one’s ability to argue the importance of UHI cause issue on a global scale.

Results of the simplified model are exemplified in Table B1-B3 with the full estimates provided in Table 3.

Table B1: Albedo=0.30, 1950

Surface	Enter % of Earth Area	Enter Albedo (0-1)	Weighted Albedo in % Results
Water	71		
Sea Ice	15	0.66	9.90
Open Ocean	56	0.06	3.36
Land	29.006		
Roads (0.04)	0.09	0.04	0.00
Urban Cov (0.12)	0.316	0.12	0.04
Forest (0.17)	3.3	0.17	0.56
Forest (Snow)	5	0.81	4.05
Grass lands (0.26)	3.7	0.26	0.96
Grass Lands Snow	7	0.81	5.67
Desert (0.4)	9.6	0.4	3.84
Sum % of Earth Area	100.006		
Weighted Earth			28.38
Clouds (0.47)	60	0.472	31.68
			Global Weighted Albedo in
Global=Average(Clouds & Weighted Earth) %			30.03
Global=Average(Clouds & Weighted Earth)			0.3003

Table B2: Albedo=0.2975, 2019

Surface	Enter % of Earth Area	Enter Albedo (0-1)	Weighted Albedo in % Results
Water	68.593		
Sea Ice	14.493	0.66	9.57
Open Ocean	54.1	0.06	3.25
Land	31.399		
Roads (0.04)	0.09	0.04	0.00
Urban Cov (0.12)	3.68	0.12	0.44
Forest (0.17)	3.189	0.17	0.54
Forest (Snow)	4.83	0.81	3.91
Grass lands (0.26)	3.575	0.26	0.93
Grass Lands Snow	6.76	0.81	5.48
Desert (0.4)	9.275	0.4	3.71
Sum % of Earth Area	99.992		
Weighted Earth			27.83
Clouds (0.47)	60	0.472	31.68
			Global Weighted Albedo in
Global=Average(Clouds & Weighted Earth) %			29.75
Global=Average(Clouds & Weighted Earth)			0.2975

Equation B1 is the weighted albedo by area,

$$EWA = \sum_i \{\% \, Earth\ Area_i \ x \ Surface\ Item\ Albedo_i\} \tag{B1}$$

Here EWA is the Earth's Weighted Albedo. Equation B2 is the average weighted albedo with clouds.

$$Global\ Weighted\ Albedo = Average\{(Clouds\ Albedo)\, x\,\% \ Coverage) + (Earth\ Weighted\ Albedo)\} \tag{B2}$$

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Biography

Alec Feinberg is the founder of DfRSoft. He has a Ph.D. in Physics and is the principal author of the books, Design for Reliability and Thermodynamic Degradation Science: Physics of Failure, Accelerated Testing, Fatigue, and Reliability Applications. Alec has presented numerous technical papers and won the 2003 RAMS best tutorial award for the topic, "Thermodynamic Reliability Engineering." Alec has studied degradation systems for his entire professional career.

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