# How the Urban Heat Island Effect Influences the $CO_2$ Doubling Temperature and its Implications

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***Abstract***

*Global warming has both root causes and amplification feedback effects. The main root cause, believed to be $CO_2$ greenhouse gas, then creates many feedback amplification mechanisms such as loss of ice and snow albedo decrease, increase in atmospheric water vapor and so forth. The strength of the $CO_2$ mechanism is often assessed by its doubling theory. However, such estimates rely on the fact that $CO_2$ is the primary root cause. Numerous authors including this one have found the Urban Heat Island effect to be significant and should for many reasons be part of our effort to combat global warming problems. Therefore, if one quantifies the UHI effect, it must affect the $CO_2$ doubling theory. In this paper we provide a short overview to illustrate how the $CO_2$ doubling temperature is influenced by the UHI effect. We also discuss its implications related to a lack of IPCC UHI albedo goals.*

## 1. Introduction

The subject of UHI effects having significant contributions to global warming is important. The contention that global warming is only due to $CO_2$ is very risky as it encourages one to neglect the UHI issue. In actuality, this has been stated mathematically in the literature (see Table 2) using doubling theory giving one the false sense that the doubling temperature should be estimated without any influence from the UHI effect. Ignoring the UHI effect is unrealistic where many authors have now shown significance. One well known paper, McKitrick and Michaels (2007), found that the net warming bias at the global level indicated that the UHI effect may explain as much as half the observed land-based warming. This study was criticized (Schmidt 2009) and defended for a period of about 10 years by Mckitrick (see McKitrick Website). Other authors have also found significance (Feddema et al. 2005, Ren et al. 2007, Stone 2009, Yang et al. 2011, and Haung et al. 2015). These studies used land based temperature station data to make estimates. In a recent study by the author (Feinberg 2020), this contention was supported using a totally different approach with a weighted amplified albedo solar urbanization model supplemented with footprint studies for UHI amplification factors and global feedback mechanisms. Significance was observed when UHI amplification effects (see Table 1) increased the footprint so that the effective urbanized solar area was much larger than its own urbanized area.

**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 Amplification Effects →** | UHI Solar Heating Area (Building Areas), UHI Building Heat Capacities, Humidity Effects and Hydro-Hotspots, Reduced Wind Cooling, Solar Canyons, Loss of Wetlands, Increase in Impermeable Surface, Loss of Evapotranspiration. |

Table 1 lists the global warming causes and amplification effects (Feinberg 2020). As one can see from the table, UHI effect is a global warming root cause with its own set of amplification effects. Just as the global climate system has its own sensitive amplification effects, the UHI amplification effects can be significant on its solar footprint as described in Feinberg 2020. One would expect that the stronger the influence that the UHI effect plays, the more it should decrease the $CO_2$ doubling temperature. Therefore, in this paper, we focus on how $CO_2$ doubling theory is influenced by the UHI effect with a brief overview. UHI amplification effects have been measured, and its root cause is a direct heating source compared to CO2, both are population driven since 1950 and can be correlated to warming anomalies (Feinberg 2020). Since numerous authors have found that UHIs are likely a significant contributor to global warming, it is important to include it in $CO_2$ doubling theory and assess its important implications.

**2. Review of the Timeline of $CO_2$ Doubling Theory**

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 estimates based on theory and linked to environmental trends, have decrease as shown in Table 2. The doubling temperature, originally 5-6°C estimated by Arrhenius, shows a range with the last estimates now between 1.5 to 4.5°C per the IPCC. Doubling temperature is logarithmic with PPM of $CO_2$ as shown in Equation 1.

$$13.9^{\circ}C\ (57.02^{\circ}F)+2.36^{\circ}C\ \mathrm{Ln}(412/311.8)/\mathrm{Ln}2=14.85^{\circ}C\ (58.73^{\circ}F),\ 0.95C\ (1.71^{\circ}F)\ \text{Rise} \tag{1}$$

We see that this equation's (discussed more in Sec. 3) doubling temperature of 2.36°C is very close to the Manabe and Wetherald (1975) estimate in the Table. In this equation we are using CO2 2019 estimates versus the reference year 1951. In general, the doubling temperature value of 2.36°C is the temperature increase that one would expect if we doubled $CO_2$ from 312 to 624ppm. Then we would get another 2.36°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.

**Table 2** Key *$CO_2$* doubling theory history and conflicts

| Reference | $CO_2$ Doubling Temperature |
|---|---|
| Arrhenius,1896 | 5-6°C |
| Gillbert Plass,1950's | 3.6°C |
| Manabe and Wetherald,1975 | 2.3°C |
| IPCC (1$^{tst}$-5$^{th}$ Assessment 1990-2014, (ECS) equilibrium change | 1.5 - 4.5°C |
| 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 * |

*Ignoring other GHG

**3. CO2 Doubling Theory Estimates with UHI Influence**

Equation 1 can be solved for the doubling temperature $DT_{CO2}$ as

$$DT_{CO_2}=\frac{\Delta T_{CO_2+\text{Effects}}}{\mathrm{Ln}(CO_{2(2019)}/CO_{2(1950)})/\mathrm{Ln}2} \tag{2}$$

In this case $\Delta T_{CO2+Effect}$=0.95°C, $CO_{2(2019)}$=412ppm, and $CO_{2(1950)}$=311.8ppm (1951 and 2019 ppm and ΔT estimates from NASA databases), giving

$$DT_{CO_2}=\frac{0.95^{\circ}C}{\mathrm{Ln}(412/311.8)/\mathrm{Ln}2}=2.37^{\circ}C \tag{3}$$

as expected form Equation 1. Here $CO_2$ is treated as the main cause of warming and this include all amplification effects such as increase in water vapor greenhouse gas (due to the fact that warm air holds more moisture), snow and ice melting etc.

For example we might estimate that $CO_2$ is responsible for 1/3 of global warming and the amplification feedback effects are causing ~2/3. There is a wide range of estimates of climate feedback sensitivity driven by uncertainties in how water vapor, clouds, and other factors change as the Earth warms. Climate feedbacks are mixed and some will amplify (positive feedback) or diminish the effect of warming from the root cause effects (see for example Hausfather 2018). The actual feedback is known to be positive (van Nes, 2015). For example, water-vapor feedback alone, which is one of the most important in our climate system, is thought to have the capacity to about double the direct warming (Manabe and Wetherald, 1967; Randall et al., 2007, Dessler et. al, 2008). Then incorporating the feedback, we can write this as

$$DT_{CO_2} = \frac{0.95°C\ \{X_{CO_2} + X_{Feedback}(1\text{-}X_{Other\_GHG})\text{-}X_{Other\_GHG}\}}{Ln(412/311.8)/Ln2} \tag{4}$$

In this section we will assume as an example that $X_{CO2}$=1/3, $X_{Feedback}$=2/3, and let $X_{Other\_GHG}\approx 0$. The $X_{Other\_GHG}$ is for other GreenHouse Gas (GHG) which are a small root cause source (so their temperature influence would need to be subtracted out from the $DT_{CO2}$), as well it would reduce the $CO_2$ feedback portion proportionally if it were to be considered. However, we will treat it as negligible ($X_{Other\_GHG}$=0) in our estimates.

If we have another main root cause, the UHI effect, then the doubling temperature is diminished similarly to the way we had written it for $X_{Other\_GHG}$. Let's say for example that UHI causes $f_{UHI}$ fraction of global warming. For example, if UHI caused 20%, then $f_{UHI}$ =0.2, Incorporating this fractional effect, then the doubling equation becomes

$$DT_{CO_2} = \frac{\Delta T_{CO_2+Effects}\ \{(X_{CO_2} + X_{Feedback}(1\text{-}f_{UHI})\text{-}f_{UHI}\}}{Ln(CO_{2(2019)}/CO_{2(1950)})/Ln2} \tag{5}$$

Here we assume that it shares the amplification feedback effect of $X_{Feedback}$ proportionally, so the $CO_2$ feedback is then diminished by $X_{Feedback}$(1-f). For Example if UHI effect causes 20% of global warming; now $X_{Feedback}$ is reduced to 0.8 $X_{Feedback}$.

Furthermore, the temperature change 0.95°C due to global warming of $CO_2$ is reduced since a fraction is due to UHI effect. For example if UHI causes 20% of global warming (i.e. 0.95°C), then we must subtract of 20% of 0.95°C=0.19°C. In this example where $X_{CO2}$=1/3 and $X_{Feedback}$ =2/3, f=0.2 we have

$$DT_{CO_2} = \frac{0.95°C\ \{1/3+2/3(0.8)\text{-}0.2\}}{Ln(412/311.8)/Ln2} = \frac{0.633°C}{Ln(412/311.8)/Ln2} = 1.57°C \tag{6}$$

Here the global warming $CO_2$ doubling temperature is diminished form 2.36°C to 1.57°C due to the fact that UHI effect is responsible for 20% of global warming.

To check our results, we solve Eq. 2 for $\Delta T_{CO2+effectz}$, and using $DT_{CO2}$=1.57°C, we have

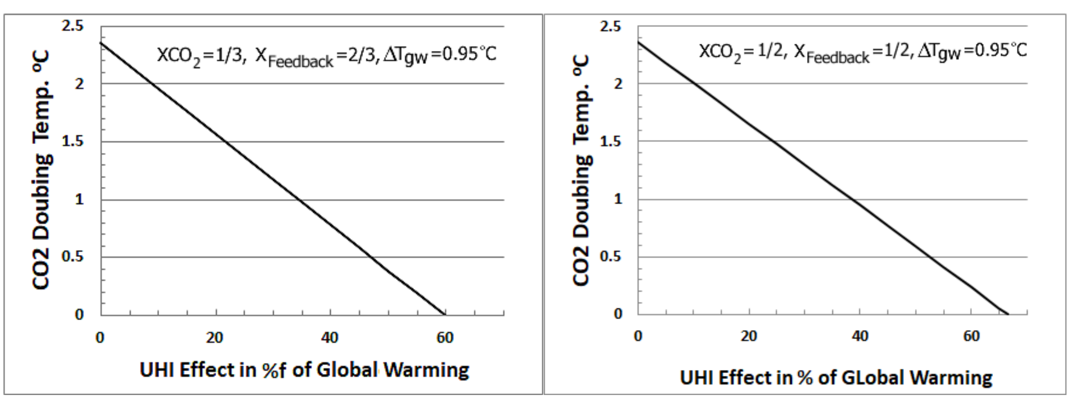
$$\Delta T_{CO_2+effects} = DT_{CO2} Ln(CO_{2(2019)}/CO_{2(1950)})/Ln2 = 1.57°C\ Ln(412/311.8)/Ln2 = 0.633°C \tag{7}$$

Then the temperature rise due to the UHI+amplification feedback effect is

$$\Delta T_{UHI+Effects} = \Delta T_{gw}(f + X_{Feedback} f) = 0.95°C(0.2+0.666(.2)) = 0.3165°C \tag{8}$$

Therefore, the global warming increase is as required

$$\Delta T_{gw} = \Delta T_{CO_2+Effects} + \Delta T_{UHI+Effects} = 0.633°C + 0.3165°C = 0.95°C \tag{9}$$




(a) (b)

**Figure 1** $CO_2$ doubling temperature with UHI effect (%f) increasing influence with a) $X_{Feedback}$=2/3, b) $X_{Feedback}$=1/2

Figure 1 provides an overview of the Equation 5 doubling temperature versus f when $\Delta T_{gw}$=0.95°C, $X_{CO2}$=1/3, $X_{Feedback}$ =2/3 or $X_{CO2}$=1/2, $X_{Feedback}$ =1/2.

We note the author feels from his work (Feinberg 2020) that a 10-20% range is a likely estimate for the UHI effect on global warming.

**4. Model Findings and Implications**

Using the model we can assess the McKitrick and Michaels 2007 contention that the net warming bias at the global level may explain as much as half the observed land-based warming. This would indicate in our model that the $CO_2$ doubling temperature would diminish between 0.39°C to 0.59 °C according to Equation 5 depending on the feedback proportion estimated of $X_{Feedback}$=2/3 or $X_{Feedback}$=1/2 respectively (see Figure 1). If that were the case, we see that the $CO_2$ effect would essentially breakdown. Such a contention would promote pushback as it has (see McKitrick Website). Although it is less likely to be that high in magnitude, it does suggest that there is a reasonable probability we should not restrict our efforts to going down one path in only focusing on $CO_2$. This current path is likely putting our planet at risk if it turns out the McKitrick and Michaels work is reasonably accurate along with the many other authors cited in the introduction including this author. We see that one cannot guarantee with 100% probability that our current $CO_2$ path is correct, as a lack of UHI albedo goals by the IPCC suggests. There are currently no goals for UHI warming rectification while this concern by many authors now goes back about 15 years.

It is unclear why the many authors' findings have not been influential enough to encourage UHI IPCC goals. There is really no real reason for the IPCC and its authors not to address this issue through setting albedo goals as they have for $CO_2$ especially given the uncertainty in $CO_2$ doubling theory. Each day we take almost no action to try and cool off our cities is valuable wasted time in our fight against global warming while we lose more and more ice and snow that partially could be due to the UHI global effect. We have of course minimal suggestions of cool roofs, yet there is very little on-going coordinated global effort to make such changes. We continue to use the worst case colors for our roads and roofs, and allow unreflective architecture into our cities and ignore many other mitigating urban choices. There is absolutely no reason why we could not after all this time be using a better safe than sorry policy and have goals for both $CO_2$ and the UHI effect. Given the uncertainty in all our models, it seems that a continual lack of IPCC albedo goals is a highly risky global policy.

**5. Summary**

We have provided a short review of $CO_2$ doubling theory and how its doubling temperature changes due to the UHI effect on global warming. Both the magnitude of $CO_2$ and the UHI effect are obviously hard to estimate on how much influence each has on global warming anomalies. A reasonable assessment is even difficult at this time. Therefore, we should accept that we most likely have two main root causes of global warming. In our paper (Feinberg 2020) we provided suggestions related to the Urban Heat Island effect which we would like to include here. As of the time of this paper, the IPCC authors are still (approximately 15 years) treating the UHI as only a local effect.

- *We feel this is a serious error on a global scale. We stress that the IPCC is the main governing force and the only agency capable of promoting such albedo goals for cities and roads. Therefore, whether it is just for UHI known health reasons or due to studies that have found significance, we strongly urge the IPCC to set albedo goals and include such goals in their global meetings.*

Therefore our suggestions remain (Feinberg 2020):

- Creating IPCC goals to include the need for albedo enhancements in existing UHIs and roads
- A directive for future albedo design requirements of city and roads
- Recommend an agency like NASA be tasked with finding applicable solutions to cool down UHIs.
- Recommendation for cars to be more reflective. Here although world-wide cars likely do not embody much of the Earth's area, recommending that all new manufactured cars be higher in reflectivity (e.g., silver or white) would help raise awareness of this issue similar to electric cars that help improve CO2 emissions

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