Urban Heat Island High Local Water-Vapor Feedback Estimates

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Abstract

In this paper, we analyze warming data on Urban Heat Islands in dry versus humid environments to estimate their feedback. We find UHI local warming second difference estimate of about 3 $W/m^2/K$ and an estimate maximum related difference feedback of 4 $W/m^2/K$ for UHI in humid versus dry environments. Relative to global warming water-vapor climate feedback estimates of about 2 $W/m^2/K$, this is a factor of 1.5 to 2 times more feedback for UHIs in humid environments likely due to lapse rate effects. This result is for daytime hours. Water-vapor feedback is known to be one of the most important in our climate system. It is thought that it can double the direct known forcing. In this case we find a much higher UHI water-vapor feedback effect. We suspect that dome heat from urban heat islands and loss of latent heat cooling are key contributor, as warm air holds more water vapor amplifying urban heat especially in humid atmospheres. The only way to mitigate such surfaces is by increasing their reflectivity at least equal to and optimally higher than the average reflectivity of the Earth (≈0.25).

Key Words: *Water-vapor feedback, lapse rate, urban heat islands, humid climates, dry climates, WAVHIS, MODIS*

Introduction:

Observation of excess water vapor steaming off of hot city roads and surfaces during precipitation (black roofs, black roads, black cars etc.) is common place. This is a gross observation that is easy to observe during precipitation periods in UHIs. Even more subtle is the fact that warm air created from such surfaces can increase atmospheric water vapor in the UHI dome [] at higher altitudes compared to rural areas in the same regions since warm air holds more water vapor. The effect likely intensifies during periods of rapid evaporation from atmospheric WAter-Vapor due to Hot Impermeable Surfaces (WAVHIS) during precipitation periods. Water-vapor is the most important greenhouse gas in the atmosphere. It traps heat being radiated from the Earth. In effect, water vapor envelops the Earth in a thick, steamy blanket.

In this paper we present two different analyses based on data taken from a Zhao et al. [1] study to illustrate UHI water vapor feedback. Although not well studied as a local feedback effect we can point several known humidity effects that are likely related to atmospheric WAVHIS:

1. Zhao et al. [1] observed that UHI temperatures increase in daytime ΔT by 3.3°C in humid climates compared to dry climates. They found a strong correlation between ΔT increase and daytime precipitation stating, "the daytime ΔT has a discernible spatial pattern that follows precipitation gradients across the continent. Twenty-four of the cities are located in the humid southeast United States, which coincides roughly with the Koppen–Geiger temperate climate zone. Their daytime annual-mean ΔT is on average 3.9 K and is 3.3 K higher than that of the 15 cities in the dry region. By comparison, the night-time ΔT differs by 0.1 K between the two groups." Their results concluded that albedo management would be a viable means of reducing ΔT on large scales.

   This effect is often attributed to greenspace decrease of surface roughness due to UHI impermeable smooth surfaces which reduces convection cooling efficiency (Zhao et al. [1], Gunawardenaa et al [2]). However, while this is one plausible explanation, an added issue is that UHIs create high evaporation rates and certainly this provides rapid convection cooling as well. Therefore WAVHIS GHG must also have a reasonably strong effect on warming since dome air over cities is warmer (Fan et al. [3]) compared to neighboring rural atmosphere. Since warm air holds more water vapor, this could promote a local GHG effect and also create feedback warming. These effects may to a lesser extend occur on all smooth hot evaporating surfaces (during precipitation periods) including roads and highways. No matter the actual mechanism, the observed data is key and creates a certain amount of additional forcing in humid compared to dry environments.

2. In a study of wetland reduction in China and its correlation to drought, Cao et. al. [4] looked at the wetland distributions and areas for five provinces due to urbanization. These areas showed a total reduction in southwestern China from 1970 to 2008 of 17% ground area, with the highest reduction rate occurring from

2000 to 2008. They found these changes to the wetland area showed a negative correlation with temperature (i.e. wetland decrease, increase in temperature), and a positive correlation with precipitation (i.e. wetland decrease, precipitation decrease).

We suggest that loss of wet land and increases in urbanization drove warmer temperature over the land through a combined situation of atmospheric humidity increase and loss of condensing moisture along with decrease in wetland evaporation contributions having a compounding dryness effect impacting the normal rain budget.

3. Drought feedback leads to forest fire feedbacks that not only damage forests that would otherwise remove CO_2 from the air, but that also releases CO_2 and other GHGs into the atmosphere. Therefore, this is a major offset in CO_2 worldwide reduction efforts. This suggests the urgent need for supplementary albedo reverse forcing efforts.

4. Novel data from the Atmospheric Infrred Sounder (AIRS) on NASA's Aqua satellite measures precisely the humidity throughout the lowest 10 miles of the atmosphere. The imagery is capture somewhat in a video [5] illustrating that even in October the hot areas over the Earth have concentrated amounts of water-vapor over land and certainly over numerous city areas include for example LA, south America, Africa, India and so forth. Courtiers and cities in warm areas are experiencing a lot of atmospheric humidity in all altitudes in the troposphere. This is increasing overtime according to Dessler et al. [6] research and could also be partly due to atmospheric WAVHIS issues. Although Dessler attributes it mainly to ocean evaporation due to warming. His results were for an average *feedback for various altitudes finding* 2.04 $W/m^2/K$. We note his study was global and he did discern any contributions from UHIs and the role it might play from atmospheric WAVHIS issues.

Method and Data

From the Stefan–Boltzmann Equation the dry climate difference estimate can be written as

$$\left(\frac{P_U}{\varepsilon\sigma}\right)^{1/4}_{Dry} - \left(\frac{P_R}{\varepsilon\sigma}\right)^{1/4}_{Dry} = \left(T_U - T_R\right)_{Dry} = \Delta T_{Dry}$$

Denoting

$$\Delta P = \left(P_U^{1/4} - P_R^{1/4}\right)^4$$

Using this substitution

$$\Delta P_{Dry} = \sigma\,\varepsilon\,\Delta T^4_{Dry}$$

Similarly in wet climates

$$\Delta P_{Wet} = \sigma\varepsilon\,\left(T_U - T_R\right)^4_{Wet} = \sigma\varepsilon\,\Delta T^4_{Wet}$$

We then denote the second difference forcing estimate $\Delta P_{\Delta W-\Delta D}$ as

$$\Delta P_{\Delta W-\Delta D} = \Delta P_{Wet} - \Delta P_{Dry} = \sigma\varepsilon(\Delta T^4_{Wet} - \beta\Delta T^4_{Wet})$$

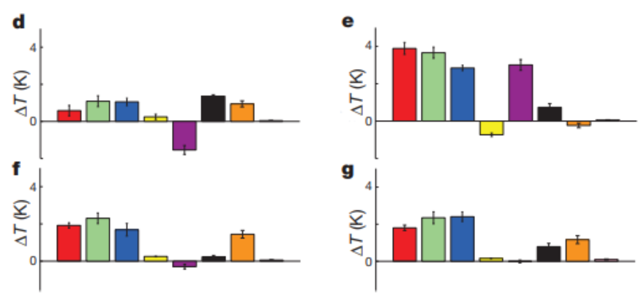

Figure 1 From Zhao et al. [1] where d) Daytime value of dry cities vs. e) wet cities with red bar MODIS ΔT, f and g are night time dry and wet cities respectively

An estimate from Zhao et al. data indicates on average they found $\Delta T_{Wet} \approx 3.9^oK$ and $\Delta T_{Wet} \approx 0.6^oK$ (represented by NASA MODIS DT red bar data in Figure 2d,e so that

$$\Delta P_{\Delta W-\Delta D} = \sigma\varepsilon(\Delta T^4_{Wet} - \beta\Delta T^4_{Dry}) = \sigma 0.62(3.9^4 - 0.6^4) = 9.98\,W/m^2$$

Where we use ε=0.62 (see Feinberg [10]). Then the second difference feedback is

$$\overline{\lambda}_{\Delta W-\Delta D} = \frac{\Delta P_{\Delta W-\Delta D}}{\Delta T_{U-R}} = \frac{9.98 W/m^2}{3.3K} = 3.03\ W/m^2/K$$

The second difference feedback $\Delta P_{\Delta W-\Delta D}$ is not a common metric and it would be good to compared it with a more straight forward difference feedback metric. Therefore, to simplify and provide a comparison, assume $T_{R\text{-}Dry}=T_{R\_Wet}$ for the rural areas. This allows us to write a type of difference forcing given as

$$\Delta P_{W_U-D_U} = \left(P_{Wet\_U} - P_{Wet\_R}\right) - \left(P_{Dry\_U} - P_{Dry\_R}\right) = P_{Wet\_U} - P_{Dry\_U} = \varepsilon\sigma T_{U-Wet}^4 - \varepsilon\sigma T_{U-Dry}^4$$

where $P_{WET\_R}=P_{DRT\_R}$, Consider a maximum average upper estimate assume $T_{U\_Dry}=30^oC$. Then from Zhao et al. we then take T_{U_Wet}=33.3C (since we have assumed $T_{R\_Wet}=T_{R\_Dry}$). Then from this type of difference yields a maximum forcing of

$$\Delta P_{W_U-D_U} = 310.06 W/m^2 - 296.92 W/m^2 = 13.14 W/m^2$$

This yields a maximum difference feedback of

$$\left(\lambda_{W_U-D_U}\right)_{Max} = 13.14 W/m^2/3.3K = 3.98\ W/m^2/K$$

By comparison this maximum difference feedback of 4 $W/m^2/K$ is about 1 $W/m^2/K$ higher than the second difference feedback of 3 $W/m^2/K$ at the local UHI level. The water-vapor feedback is strongly positive, and Dessler et al [6] estimated climate feedback of λ_q = 2.04 $W/m^2/K$. We note Dessler et al. studies were for various altitudes. It is expected due to lapse rate effects that one would find higher feedback values at lower altitudes in humid environment. However, Dessler et al. did not estimate the feedback over UHI humid areas at low portions of the troposphere. Here we note that UHI are a factor of 1.5 to 2 times higher in our analysis than Desslers [6] estimate. If all things we set equal for water-vapor feedback, on would expect higher values at lower altitudes due to the lapse rate temperature in general. However, this is amplified significantly over UHI where surface temperatures are high.

Conclusion

It may be difficult to assess how this may affect global warming. However thermodynamic atmospheric effects are cumulative. Therefore, we consider atmospheric dome type WAVHIS a serious issue that likely impacts UHIs contribution to global warming. Although it is not easy to estimate the humidity portion on UHI contribution to global warming, one should not minimize its importance by stating that it only has a local effect. The Dessler et al. conclusions attribute warming due to water-vapor feedback a consequence of CO2 forcing and other GHGs. Dessler points out that as surface temperature increase so does water-vapor. This is also true of UHIs. However, Dessler et al. made no attempt to quantify atmospheric WAVHIS issues which must also contribute to forcing effects. In a study recently by the author [11] about 11-16% of global warming was attributed to UHIs and land cover/land uses. However, no additional factor was provided to account for the humidity effect over cities in humid environments as noted by Zhao et al. [1]. In general, it is important not to trivialize the potential of global warming contribution form UHIs and land/cover land/use as only of local significance. This type of assumption allows further albedo management of cities, roads, rooftops, vehicle colors unattended promotes undue risks in our attempts to mitigate the global warming crisis. The continual choice of black as the color of choice promotes warming at many levels. The only way to remove water vapor out of the atmosphere and back into the rain budget is through atmospheric cooling. This is a huge undertaking to expect it can fully be accomplished solely by CO_2 reduction, especially in the presence of a high rate of deforestation. Considering the albedo reverse forcing advantage, UHI albedo controls and other reflectivity solutions are urgently needed {10, 11] as a supplement and should be advocated by policymakers. Therefore as we have in all our publications, we continue to suggest the following recommendations:

The following albedo management suggestions and corrective actions are recommended:

- Modification of the Paris Climate Agreement to include albedo controls and solutions
- Albedo guidelines for UHI impermeable surfaces, cool roofs, and roads similar to on-going CO_2 efforts

- UHI albedo goals: we suggest an albedo increase by a factor of 4 (from typical UHI albedo value of 0.12), which could reduce GW by about 30% or more, based a study by the author [6]
- Government funding for geoengineering and implementation of albedo solutions
- Centralize albedo solution efforts in a single government agency (possibly NASA)
- Guidelines for future albedo design considerations of urbanization areas such as requiring all new building to have flat roofs with highly reflective surfaces
- Requires cars to be more reflective. Although world-wide vehicles do not comprise much of the Earth's solar area, recommending the preferential manufacturing of cars that are higher in reflectivity (e.g., silver or white) would raise awareness of this issue similar to electric automobiles that help improve CO_2 emissions.

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