Global Warming Due to Highly Evaporating Surfaces and Rain Water Management

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Abstract

In this article we will discuss the possible contributions from Highly Evaporating Surfaces (HES) and Rain Water Management (RWM) to global warming. We describe high evaporation surface rates during precipitation periods from areas like asphalt type roads and cities surfaces. We show in this article that such surfaces without proper irrigation drainage to soil areas have a very high evaporation rates. Reducing wet lands with an effective area many times the size of the HES area itself compared with higher albedo absorbing vegetative areas that also include transpiration. This is significant since water vapor is the most potent greenhouse gas and data on specific humidity shows it is increasing yearly while relative humidity is not following this trend. City surfaces can prove to be enormous when tall buildings are considered. Such high evaporation rates higher entropy into the atmosphere often with high kinetic energy molecules in the troposphere which can decrease relative humidity while increasing specific humidity. It is thought that global warming ocean evaporation-CO_2 feedback is the key contributor. However, here we look at other issues.

Also alarming is rain water management. New York City for example dumps an estimated 27 billion gallons of waste water into the ocean each year. This pattern is followed by cities all over the world. One might ask, what percentage of this water before the industrial revolution made its way to our oceans. The percentage change is lost land water storage as urban impermeable surfaces increase. Numerous concerns are pointed out: 1) warmer runoff to ocean water, 2) followed by loss of wet land storage in vegetative areas, 3) loss of land evaporation and precipitation, 4) increase in ocean precipitation creating higher land temperatures, and 5) dryer regions with draught prone areas. This is key to global warming as rain cools off land, without precipitation over land, global warming will run havoc.

Understanding root causes is always needed to find proper solutions. In climate change, we must ask, what has historically changed? Besides CO_2, we have slight decrease in land albedo, change in the specific and relative humidity, changes in the ocean rising levels with city ocean drainage not helping, followed by changes in lost land water storage and natural evaporation rates,. We all tend to think that solving the CO_2 problem will cure climate change problems. However, we see that other major issues need to be studied and addressed.

1. Introduction - Highly Evaporation Surface and Rain Water Management Feedback

In this paper we look at an effect of Highly Evaporating Surfaces (HES) feedback (Figure 1) and Rain Water Management feedback (Figure 2) contributions to global warming.

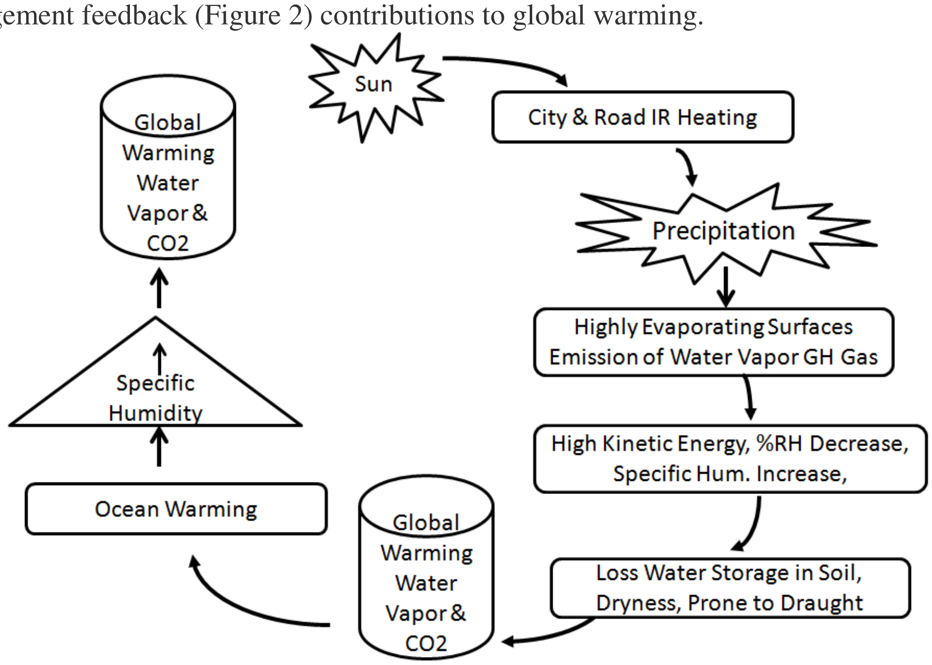


Figure 1A Highly Evaporating Surfaces (HES) feedback view of contribution to global warming

Figure 1A HES feedback may be summarized as follows:

- Low albedo cities and roads absorbing sun light and emitting IR
- Precipitation occurs, followed by evaporation of HES moisture often with high Kinetic Energy water molecules from hydro-hotspots (wet hot surfaces)
- High KE water molecules decrease %RH and a higher increase in the specific humidity
- Loss of water storage due to replacement of vegetative areas with cities and roads
- Increase in local dryness and some correlation to the potential for draught
- Global warming increase due to higher specific humidity GH gas and the known CO_2 increase including ocean temperature rise creating more evaporation and higher specific humidity
- More greenhouse gas in the form of moisture and eventual further warming.

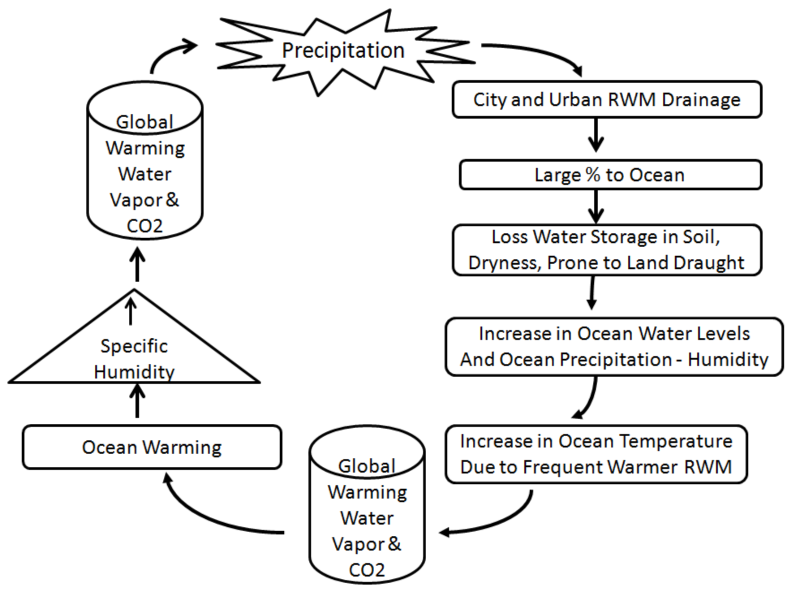


Figure 1B Rain Water Management (RWM) feedback in Climate Change

Figure 1B RWM feedback may be summarized as follows:

- Precipitation is collected off of buildings and streets
- Large percentage is drained to ocean or nearby rivers that may end up in the ocean
- The impermeable city building and roads have replaced vegetative land creating lost area that would have stored the water in soil keeping the land moist.
- This increase land dryness means less land evaporation and less land rain and more ocean rain.
- The RWM is sometimes warmer than ocean water and may contribute somewhat to ocean temperature increase depending on location. Usually warmer environment may runoff more water to the ocean as colder environments have less rain more snow
- This would contribute to a global warming feedback cycle and rising specific humidity

In Section 2 we discuss the different theories on CO_2 feedback mechanism creating a rise in specific humidity compared to how HES and RWM may be a significant contributor as well. Furthermore, in Section 6 we argue why CO_2 feedback mechanism is likely not fully be responsible for specific humidity rise. This leads to the conclusion that HES and RWM are likely major contributors to global warming. In Section 3 we overview relevant data. In Section 4 we describe a simplified expression for the HES evaporation rates and its effective area. In Section 5 we discuss details of RWM and how lost land water storage is correlated to dryness, heat, and draught, and in Section 6 we provide a brief summary, conclusion and suggestions.

2. Specific Humidity Sources – HES & RWM

The key issue on specific humidity is where has the increase humidity come from and how do we account for the global warming trends. This is important as water vapor is a greenhouse gas. It is thought that CO_2 initially increases the temperature including ocean temperature which increase ocean evaporation and thus specific humidity followed by higher temperature rise from the new greenhouse ocean moisture entering the atmosphere observed via the increase in atmospheric specific humidity. It is this feedback mechanism that climatologist claim is entirely responsible for the increase in specific humidity and subsequent justified full temperature increase. Yet we know two things, part of the CO_2 must emit away from the earth, furthermore, there is a high probability that any CO_2 emission gets re-absorbed by other CO_2 molecules since there is a narrow absorption wavelength (about 15um), then re-admits 50% towards Earth.

One could certainly argue that this feedback mechanism increases global warming. Such a correlation has been described [1,2,3]. However, such assessments view the correlation with CO_2 creating warming to the ocean as the cause rather than looking at other sources to specific humidity that have increased with time. They look at yearly trends in CO_2 which has a similar trend to global warming yearly increase. As well they look at complex data sets and have not reviewed observed effective loss of land related to soil moisture, land albedo decrease, and increase in highways and city area HES effects, city and urban RWM water drainage increase away from land. All these play a role in specific humidity, relative humidity and precipitation effects.

- In fact, one could similarly show a correlation chart of global warming and increase to Asphalt and building material usage!

What is hidden is the effective area. Since the area of roads and cities is small (<2% of the Earth Surface), possibly, some may have thought that these do not impact climate change. This may be an incorrect assumption. We show that HES have a very high effective evaporation area. Many times the size of the area itself as it is related to the evaporation rate differences between adjacent soil and say asphalt. We show that RWM can markedly effect land precipitation.

With this understanding, we consider the possibility that loss of soil moisture storage and high evaporation rates in cities, streets and highways, and RWM can contribute significantly to greenhouse water vapor gasses and global warming. Water vapor is known to dominate greenhouse temperatures effects [3, 4]. Such an inference would then create a strong feedback mechanism as illustrated in Figures 1 above.

3. HES Supporting Related Data Trends

The following data and analysis is summarized that supports HES feedback:

- **HES Areas on Average are Hotter:** When evaporation occurs from cities and roads, the albedo is on average lower by comparison to vegetative areas that are replaced. Often evaporation is then from hotter surfaces, molecules then have higher kinetic energy, this expands air and increase relative humidity. Even when surfaces are not hotter, the evaporation rate increase is associated with higher entropy, higher specific humidity and lower relative humidity. This is discussed in Section 4.

- **HES area effect**: A simplified analysis is presented in Section 4 illustrating when all things are equal, the area lost from soil water storage due to roads and cities, for example is given primarily by the differences in evaporation times between the would be vegetative area and the city or road replacement area. For example if it takes a road 2 hours to evaporate a volume of water from a road, while it take soil 48 hours to evaporate the same amount of water in soil, then the effective soil land lost is a factor of 24 times, contributing to the evaporation rate, specific humidity and global warming emitted moisture greenhouse gas. Although we have not formulated for transpiration, the rate should still apply.

- **HES city area effects**: These are hard to estimate. As a rough estimate let's assume each building sides equate to 10x bottom surface area due to having 4 sides and its height. Assume now that buildings take up 50% of a cities area. Now it is estimated that 1.2% of the Earth surface is cities. Then we have 1.2%x50%x10=6% of the earth surface area increase having HES area from buildings worldwide.

- **Specific Humidity Rising:** Figure 2A shows the increase in specific humidity not just to warming oceans but also over land mass. Overall, water vapor in the surface atmosphere has increased over land and ocean since 1970s (specific humidity is rising) [5], while the atmosphere over land is becoming less saturated (relative humidity is dropping) [5].

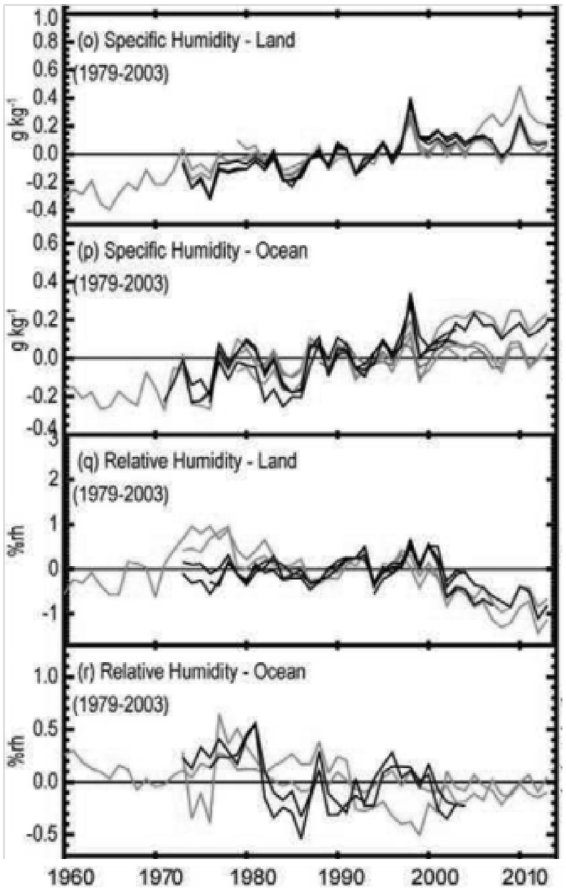
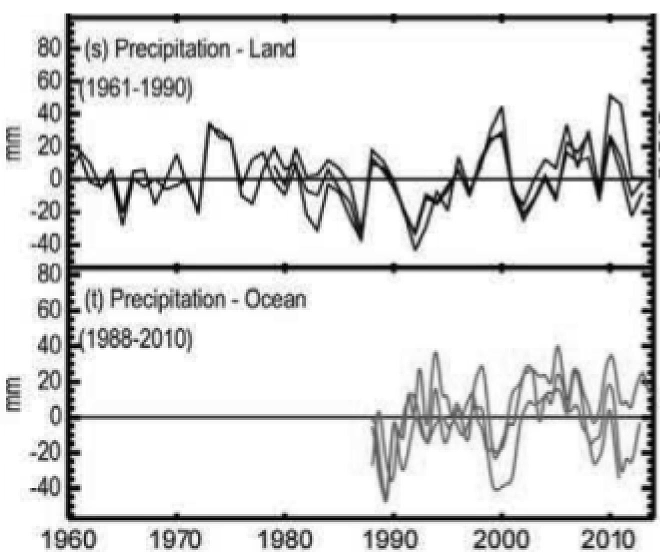


Figure 2A Top two figures show the specific humidity over land and water both increase while the third figure showing the relative humidity decreasing trend primarily over land while the ocean is more stable but likely harder to measure [5].

- **Precipitation:** Figure 2B illustrates that precipitation has remained constant [5] even though the specific humidity has increased. This seems to indicate that the evaporated water vapor in the air is not contributing to precipitation. However in Fig. 7 and 8 we see that in later years it is actually increasing.



- **Figure 2B** A fairly constant precipitation rate in view of the fact that the specific humidity is increasing [5]. In later years Fig. 7, shows precipitation eventually increasing.

- **Soil Moisture:** Figure 3 shows a decrease in soil moisture [5] likely suggesting a correlation to global warming. This increase in dryness is made worse from HES areas in cities and roads increasing over time.

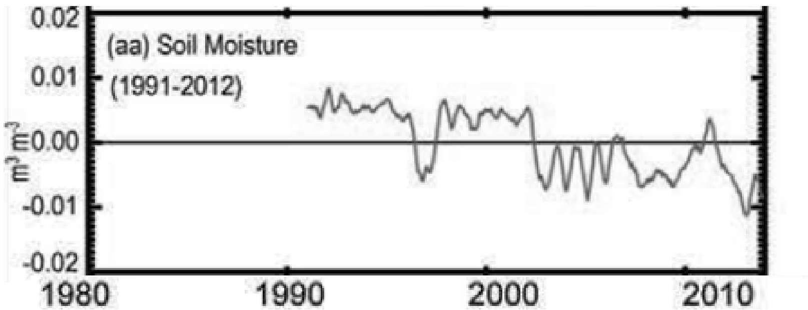


Figure 3 Loss of soil moisture likely due to global warming over land [5]

- **Albedo decline:** In Figure 4, a decline in land albedo [5] is found. One would expect this decrease over land due to the increase in roads and city areas having a much lower albedo value than natural vegetative areas. Global albeto loss has been blamed on glacier loss but here it is illustrated just for land.

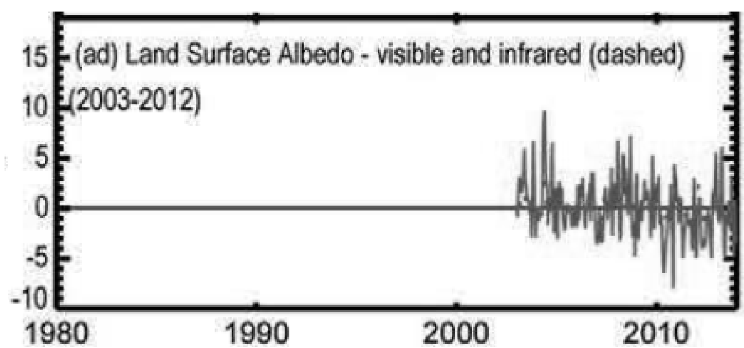


Figure 4 Loss of albedo over land likely due to increase in cities and highways [5]

- **Increase in Asphalt use:** Figure 5 and 6 show an increase in asphalt use (2009-2012) and increase in highway miles (1923-2009), respectively [6,7]. Although the data is limited on asphalt and highway growth, the trend is clear. Climatologist correlate the rising CO_2 greenhouse gas to global warming. Here one could just as well correlate the rising use of asphalt to global warming via contributions from the HES effect and emission of greenhouse water vapor gas**.**

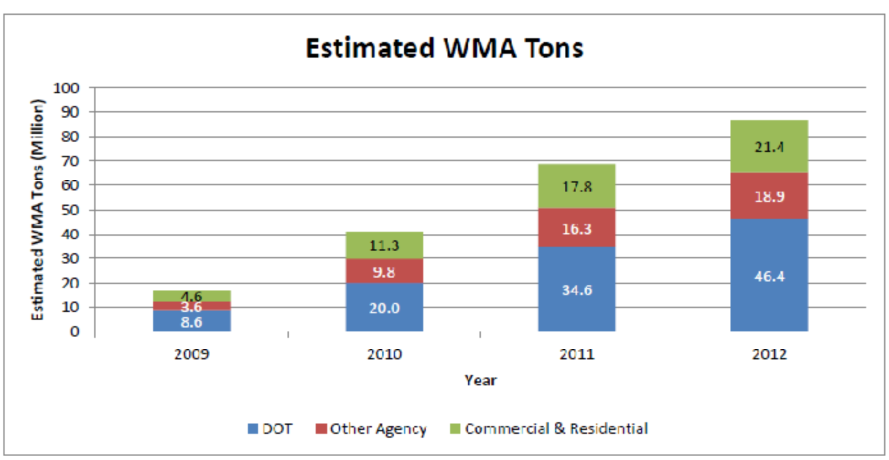
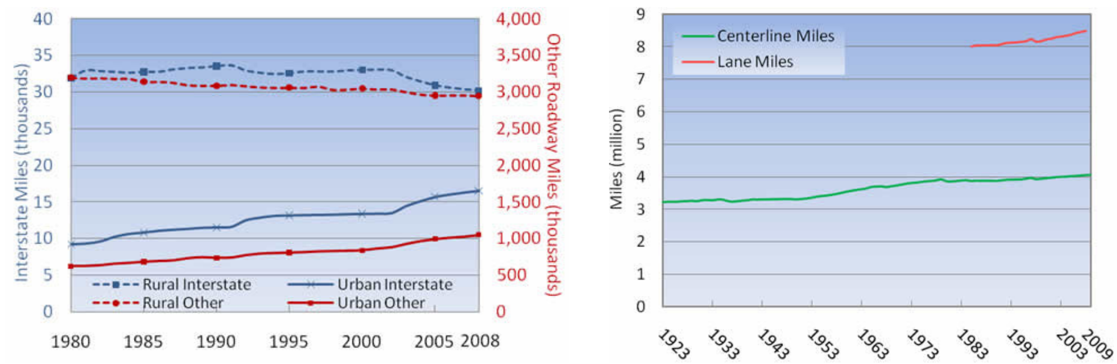


Figure 5 Growth of Warm Mixed Asphalt Usage per year (2009-2012) in USA [6]



(a) (b)

Figure 6 Interstate Miles versus yearly increase in US [7]

- **Specific Humidity Trends and Correlation to Global Warming:** Figure 7 shows specific humidity trends and Figure 8 correlation out to 2017 from various sources [8]. Here the author does not differentiate between specific humidity and precipitation.

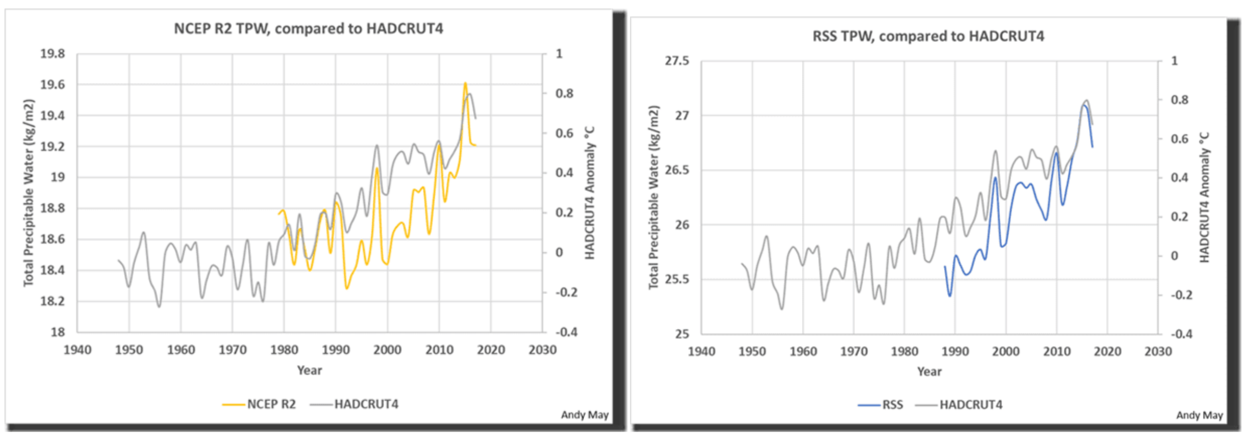


Figure 7 Specific humidity and global warming trends from two different agencies [8]. Here the author does not differentiate between specific humidity and precipitation.

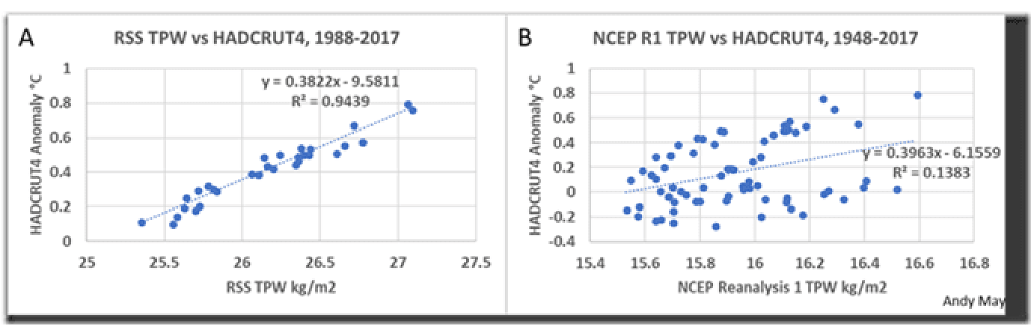


Figure 8 Correlation of specific humidity - Total Precipitation Water (TPW) for different data sets with global warming [8]. Here the author does not differentiate between specific humidity and precipitation.

The primary effect that we are looking at with respect to data is possible contribution to the evaporation rate and its effect to the rising specific humidity in the troposphere (lower 10 miles of atmosphere). Other related effects are likely dry conditions that are a necessary but not sufficient condition for draught. Hot roads and city walls also expand air and not only drive up specific humidity during precipitation but lower %RH. One other critical effect that is hard to calculate is loss of plant water storage and transpiration. When impermeable surfaces replace vegetation, the rate of evaporation is exceedingly high compared to transpiration which is said to account for 10% of all evaporation [9]. Climate change is then hard to predict. Lost wet lands can lead to dry condition with less increase in specific humidity.

4. HES Effective Area of Evaporation and Temperatures

HES areas are likely hotter. We term this hydro-hotspots. Meaning evaporation from hot surfaces as shown in Figure 1A. Below is a list of Albedos average values and associated temperatures in strong sunlight.

Table 1 Albedo different surfaces and temperature at 1000 W/m^2 for 1m^2

Surface **Water**	**Albedo (0-1)**	**Temperature For 1M^2 at 1000 W/M^2**
Snow Ice Open Ocean	0.8 0.6 0.06	-29.5 C 16.7 C 85.7 C
Land		
Roads (0.04) Urban Cov (0.12) Forest (0.17) Grass lands (0.26) Desert (0.4)	0.04 0.12 0.17 0.26 0.4	87.6 C 79.8 C 74.7 C 64.8 C 47.6 C

When precipitation falls on roads after being exposed to sun, the rapid evaporation initially 20^{o}C hotter than grass lands in similar sunlight of 1000W/m2 for 1 m2 area emits energetic water molecules. Often we have more energetic molecules evaporated into the air from such surfaces. This not only increase the specific humidity but decrease the relative humidity. (Air is expanded at higher temperatures, that is warm air can hold more moisture greenhouse gas). Higher evaporation rates even for the same temperature surfaces also increase entropy which not only increase specific humidity but lowers relative humidity.

A simplified expression for the equivalent HES area found in Appendices A, B, and C roughly given by

$$A_{EfHES} = (\frac{t_{Soil}}{t_{HES}})A_{Soil} = (\frac{t_{Soil}}{t_{HES}})(A_{HES} - A_{HES-\%IG})$$

Where

A_{EfHES}=Effective HES area,

A_{Soil}=soil area, this is set equal to an equivalent to A_{HES} area, subtracte from

$A_{HES-\%IG}$ any % run off of irrigated water falling on the roads or city surface areas to vegetation areas

t_{Soil} is the evaporation time of the soil

t_{HES} is the evaporation time of the asphalt or city surface after precipitation occurs.

As we mentioned above, if it takes a road 2 hours to evaporate a volume of water from a road, while it take soil 48 hours to evaporate the same amount of water in soil, than the effective soil land lost is a factor of 24 times contributing to the evaporation rate and specific humidity. This is for roads with zero percent irrigation-equivalent area running off water to adjacent land.

The factor $(\frac{t_{Soil}}{t_{HES}}) = \Delta R$ provides an evaporation rate related to time rate of change. In the above example we see that the rate would be 24 times faster than if roads were not constructed. In the appendix this rate is shown as a function of

- $\Delta R\{(Exp\text{-}(E_a/k_B\ T))$, average soil vs asphalt specific heat Cv, dCv/dt, dm/dt, average Δalbedo, soil diffusion rate, evapotranspiration, windspeed}

5. Data on Rain Water Management (RWM), Draught, Global Warming Trends

Rainwater management may be an important factor. It can impact where it rains! Rain follows local evapotranspiration. Apart from precipitation, evapotranspiration is the major component in the hydrologic budget. Evapotranspiration involves the process of evaporation from open bodies of water, wetlands, snow cover, and bare soil and the process of transpiration from vegetation. If ocean precipitation increases, then land precipitation can decrease.

When it rains in a city, much of the land in urban areas is covered by pavement or asphalt. Because rain can't soak into the soil underneath, these covered areas are impermeable surfaces. As the amount of impermeable surface increases with urbanization, so too does the amount of runoff. As an example, in urban cities 30% is often estimated for evapotranspiration, 10% shallow soil infiltration, 5% deep soil infiltration, and RWM takes 55% into runoff.

- New York Environment Report, in 2014 reported [10], "Every year, old sewers flooded by storm water release more than 27 billion gallons of untreated sewage into the New York Harbor alone."

- Fry et al [8] 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.

As roads and cities have increase, in cities like LA, RWM runoff has increased into the ocean. Thus, land can becomes dryer as there is less water storage in wetlands as shown in Figure 1B. As the water storage is shifted from land to the ocean, local precipitation can be affected. The precipitation could change to more over the ocean and less over the land. This makes the local area prone to draught and higher average temperatures. When it does rain over draught areas, the runoff is warmer possibly warming the ocean increasing evaporation and moisture greenhouse gas. This could create a feedback cycle of higher temperature on land and again warmer runoff see Fig. 1B.

As an example of the importance in losing wet land (water storage), Cao et. al. [12] did a study on wet land reduction in China and correlation to draught 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)." [12]

Hirshi et al. [13] 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."

Below is the graph from their study [13]

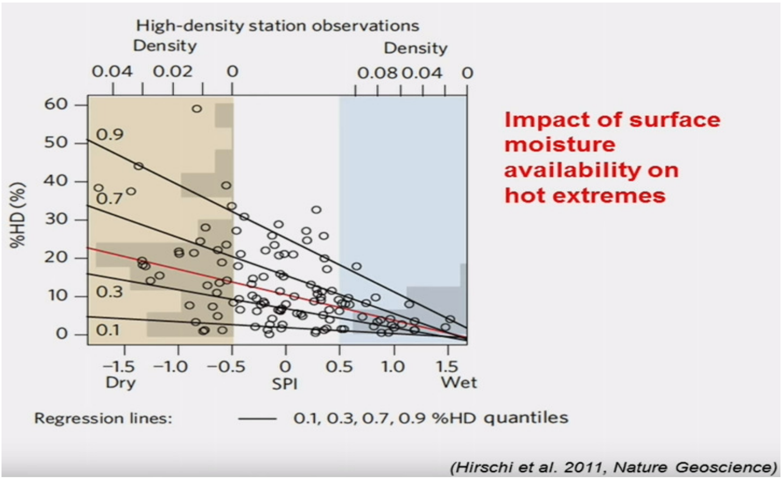


Figure 9 Percent Hot Days (HD) correlated to dry vs wet areas [13]

As another example, it is found that in large areas of the Southwest, evapotranspiration is virtually equal to 100 percent of the precipitation, which is only about 10 inches per year [9].

By contrast, in the conterminous United States, the estimated mean annual evapotranspiration is greatest in the Southeast (about 35 inches per year or about 70 percent of the precipitation), which is an area of abundant precipitation, permeable soils, and substantial solar radiation; it is least in the semiarid region of the Southwest where precipitation is limited. The ratio of estimated mean annual evapotranspiration to precipitation is least in the mountains of the Pacific Northwest and New England where evapotranspiration is about 40 percent of the precipitation [9].

Some efforts have been made to improve storm water innovation in RWM. The effort is called LID [11]. "Low Impact Development (LID) is a planning and design approach that aims to mimic naturalized water balances. It combines infiltration, evaporation and transpiration while limiting runoff. The goal of LID is to restore processes that are lost in a built-up urban environment. LID includes several types of low-level new and innovative stormwater technologies that together let water infiltrate the ground and evapotranspire into the air.

5.1 Effect on Ocean

Rising oceans levels are anticipated with global warming due to the fact that the ocean expands as it warms. Its level also will increase due to glacier melting. However, it doesn't help to have RWM also contributing from cities all over the world with water runoffs into the ocean. Prior to the industrial revolution, much of this water went to natural vegetation, streams and lakes. Urban and city changes for RWM may be instrumental. RWM runoff into the ocean biggest impact of course is the reduction of wet lands. Shifting precipitation from land to over oceans is a large concern. Most climate models do not agree on precipitation and draught areas as climate is hard to predict [14].

"The average of the models shows large increases in precipitation near the equator, particularly in the Pacific Ocean[14]"

It would be close to impossible to tall if RWM has a direct bearing on precipitation in certain areas. However, we have illustrated a number of studies that suggest logically that RWM is very important.

6. The Contention Against CO_2 Feedback Being Solely Responsible for Specific Humidity Increase

Here we provide some contention that an increase in specific humidity cannot be solely due to CO_2 feedback. We can do a rough though experiment. The reason it is hard to blame this increase on CO_2 emissions is the following thought process:

1) Ocean area for heating 68.7%
2) Emissions towards Earth 50%
3) The emitted CO_2 radiation is narrow band 15 um with some spectral width. Only a portion of this radiation is likely re-absorbed by other CO_2, say 25%
4) Then a portion is absorbed by water vapor in the atmosphere say 60%
5) A portion of 3 and 4 are re-radiated away from earth 50%

This leaves 0.687 x 0.5 x 0.75 x 0.4 x 0.5 = 5.2% re-radiates back to Earth for global warming. These are numbers pulled out of a hat. But the point is, we see there are likely other contributions from RWM and HES that are likely contributing to global warming trends besides CO_2.

6. Summary - Solutions

From data and analysis, we do not anticipate that solving the CO_2 problem will fully stop global warming form occurring. We find that it is highly likely that HES areas and RWM are contributing to global warming, and that more studies are needed to assess the impact and how much it is contributing compared to the CO_2 feedback mechanism.

HES and RWM Reduction Solutions

- Further studies required in this area to understand the effect and contribution to GW
- Change Albedo of Roads Reducing KE of molecules and allowing for increase in irrigation time
- Reduce driving speeds during rain to reduce evaporation rates
- Improve HES irrigation to soil
- Improve vegetation in run off areas, plant millions of trees in HES areas
- Require negative population growth to reduce increase HES surfaces
- Adopt Low Impact Development (LID) in city planning and improvements for design approach aiming at mimicing naturalized water balances.
- More rain on the Earth means a cooler Earth. RWM is of utmost importance
- Severe RWM changes are required to stop runoff into the ocean world wide.

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Appendix In Development
Appendix A Thought Experiment 1:

We take two identical pieces of asphalt having different albedos and areas. One is measuring 1 meter^2 while the second area is to be determined such that they both have the same evaporation rate when water is on the surface. The first asphalt piece is black and has an albedo of 0.05 while the second is painted white and has an albedo of 0.8. Then looking at the temperature profiles with about 1000 W/M^2 of sunlight falling on them, the temperature is approximated as

$$T_i(albedo) = \left(\frac{(1 - Albedo_i)Eo}{\sigma} \right)^{0.25} \tag{1}$$

Taking E_o=1000W/m^2, then T(0.05)=360°K=87°C, and T(0.8)=340°K=67°C. This shows that we have 20°C difference.

Consider now the general case with a piece of asphalt at temperature T, area A, material constant R_o in an environment with air pressure P, relative humidity RH, and wind speed is r. Now consider a mass m of water spread uniformly on the surface. We then take the evaporation rate E for the non soluble surface approximated as

$$E = \frac{dm}{dt} = R_o A_i \exp\{-\frac{E_a}{K_b}(\frac{1}{T_i})\} f(P, RH, r) \tag{2}$$

Here *f* is some function of the variables *P, RH,* and *r*. We take a second surface of the same material but at different temperature T and area A and look at the ratio of the evaporation rates yielding

$$E(2,1) = \frac{dm_2 / dt}{dm_1 / dt} = \frac{A_2}{A_1} \exp\{\frac{E_a}{K_b}(\frac{1}{T_{1Lower}} - \frac{1}{T_{2Upper}})\} \tag{3}$$

Here we have held variable *P, RH, r,* and R_o left unchanged so they cancel. We allow T_2>T_1. We then find that for A_1 to have the same evaporation rate as A_2 will occur when E(2,1)=1, so that A_1 is found just from the temperature rate as

$$A_1 = A_2 \exp\{\frac{E_a}{K_b}(\frac{1}{T_{1Lower}} - \frac{1}{T_{2Upper}})\} \tag{4}$$

As an example, for typical water evaporation from a surface at temperature T, a common value for E_a=40.8KJ/Mole=0.423eV. Using the values found above for different albedo temperatures we had T(0.05)=360°K=87°C, T(0.8)=340°K=67°C, and inserting these values into the above equation gives

$$A_1 = 2.3\, A_2 \tag{5}$$

Another way of saying this is that if we paint the asphalt a different color with an albedo of 0.8 compared with the typical value of black asphalt of 0.05, we actually make the area 2.3 times smaller in terms of evaporation rate. This also allows more time for water to run off and be stored in the land.

We can simplify this result and make a generalization from the above equation related to the effective area for evaporation between two surfaces, and this is

$$A_1 = (\tau_2 / \tau_1)\, A_2 \tag{6}$$

Where τ_i is the evaporation time since the rate goes as the Arrhenius function, for the ith surface at different temperatures all other evaporation factors being the same.

This is an important relation for road design, if we can slow down the evaporation rate from a road, we can decrease its effective evaporation area. Besides albedo change, other design factors can be thought of such a water runoff to land, road irrigation, road water storage similar to soil, transpiration, material changes with lower specific heat capacity. Engineering roads to be more eco-friendly is one conclusion in this paper.

Appendix B-Thought Experiment 2:

We take two surfaces, one with heat capacity Cv1 and Area A1, and the second with Cv2 and Area A2. Both surfaces are evaporating water and start at the same temperature, however we let $C_{v2}=2C_{v1}$. What is the equivalent area if they both are required to evaporate at the same time.

Time to change Q is

$$t = \frac{Q}{P} = \frac{C_v m \Delta T}{P} = \frac{C_v m \Delta T}{pA} \tag{7}$$

where Q is the change in heat occurring from ΔT change, m is the mass, P is the power in Watts, p is the sunlight power in W/m2, A=Area. For example for asphalt Cv = 900 J/kg K, if m=1000Kg and ΔT=20K, then ΔQ=900 J/kg K x 1000Kg x 20K=18 E6 Joules. If 1000 W/m2 falls on a 1 m2 surface area then the time for this temperature change is

$$t = \frac{18E6J}{1000J/\sec} = 300\,\text{min}.$$

given that both areas have the same mass and same p, and both change by an amount ΔT we find, in general

$$\frac{t_1}{t_2} = \frac{C_{v1}A_2}{C_{v2}A_1}$$

if Cv2=2Cv1 then for t1=t2 we must have

$$A_1(C_{v1}) = 2A_2(2C_{v1}) \tag{5}$$

Here we see that if Area A2 has a larger Cv, that evaporation times are only equivalent if A1 is larger proportionately. This can again be summarized by their evaporation times such that

$$A_1 = (\frac{t_1 C_{v2}}{t_2 C_{v2}})A_2 = (\frac{t_{1Cv}}{t_{2Cv}})A_2 \tag{8}$$

Thought Experiment 3

Consider now the complex case of a vegetative area being replace by an Asphalt highway. The specific heat of soil and mass can vary as water evaporates. This is untrue of asphalt. The specific heat of water is 4186 J/kg K compared to asphalt *=900 J/kg K. We see that soil hold heat actually 4 times larger than Asphalt. However, soil varies with mass. When it rains, the asphalt cools while it evaporates water. On the other hand, the rain cools the earth at a faster pace since soil has a low Cv and the temperature is cool. In order to evaporate from the soil in sunlight after it rains it takes time to heat the surface area. We see that the change in heat is a complex function of time as the soils mass and Cv changes with time.*

$$\frac{d\Delta Q}{dt} = (dm/dt\, C_v + m\frac{dC_v}{dt})\Delta T \tag{9}$$

To simplify the complex problem we take an average

$$\overline{\Delta Q} = \overline{m}\,\overline{C_v}\Delta T \tag{10}$$

Furthermore as water evaporates at the surface of the soil the stored water below diffuses to the top surface. Therefore the time is further lengthening by the diffusivity of water in the soil. So the equation is modified and simplified again so it is just a function of time to estimate the area ratios

$$A_1 = \left(\frac{t_1 \overline{D m C}_{v2} \overline{\Delta T}_2}{t_2 m C_{v2} \overline{\Delta T}_1}\right) A_2 = \left(\frac{t_{1 \overline{m D C} v \Delta T}}{t_{2 m C v \Delta T}}\right) A_2$$

The results demonstrates that the area effect can be simplified to the evaporation time. For example if water evaporates from a highway in 5 hours and on land the same amount of water evaporation takes 50 hours, then lost area is a factor of 10.

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."