THE CONTRIBUTION OF GREENHOUSE GASES FROM AGRICULTURAL ORIGINS

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SUMMARY

Very low concentration greenhouse gases from agricultural sources are shown to make only a minute contribution to the absorption of solar radiant energy and longwave re-radiation back from earth. Water vapour is more than 6,000 times higher in concentration than methane, and greater than 30,000 times that of nitrous oxide. Water vapour is able to absorb radiation well over 80% of the entire energy spectrum at high levels compared to the very small active range of these other greenhouse gases.

It is also shown that water vapour dominates over all the greenhouse gases including carbon dioxide both in atmospheric concentration and total radiation absorption (solar and reradiation from earth). Water also can phase-change (evaporate-condense-precipitate) and as clouds, provide thermal radiation shielding in daylight hours. It is shown that there are other major factors in weather change apart from radiation-alone.

INTRODUCTION

Atmospheric greenhouse gases GHG are those that can absorb and emit solar electromagnetic energy as well as energy re-radiated back from planet earth. Five of these are well known: water vapour, carbon dioxide, methane, nitrous oxide, and ozone (1). The first four can all be 'connected' to agricultural operations in some way (1). Their effectiveness in influencing weather variations depends essentially on three factors;

1. Relative concentration in the atmosphere,
2. The fraction of the total radiant energy-band over which they are most strongly active, and,
3. The ability to be involved in weather in some additional way other than just simply radiation.

Of course, the discussion about greenhouse gases is with reference to weather change and the resulting climate patterns developed long-term as an average of weather. Several other mechanisms apart from radiation must be considered simultaneously, namely, winds, clouds, precipitation, storms, ocean currents etc, to name a few (2).

1. RELATIVE ATMOSPHERIC CONCENTRATION

The main atmospheric gases and their relevant concentrations are presented in Table 1. Water vapour is included because the real atmosphere always contains water and water vapour. Trace pollutants such man-made volatile chemicals, and chemicals such as fluro-hydrocarbons, and dust, are excluded here. The greenhouse gases are denoted by an asterisk* in Table 1.

Table 1 Composition of the actual moist atmosphere (2) including water vapour taken at about 1% (Basis:1% at 20^{0}C; 75% Relative Humidity). Volumetric concentration in parts per million by volume ppm$_v$.

GAS		Volume ppm$_v$	Volume %		Comment
Nitrogen	N_2	780,840	77.17%		
Oxygen	O_2	209,460	20.70%		
Water Vapour *	H_2O	10,000	0.99%*		Basis: 1% at 20^{0}C 75% Relative Humidity. Varies from about 0.01% to 4.5% (tropics) *10 - 45,000ppm*
Argon	Ar	9,340	0.923%		Largest INERT gas: 23 times greater than CO_2
Carbon Dioxide *	CO_2	410	0.0399%		Far less than 5% is man-made (<22ppm). Plankton and photosynthesis moderate the CO_2 level all the time
Neon	Ne	1,828	0.0018%		Inert gas
Helium	He	5.24	0.00052%		Inert gas
Methane *	CH_4	1.79	0.00018%		About 40% natural: <60% man-made.
Hydrogen	H_2	0.5	0.000049%		Trace reactive gas
Nitrous Oxide *	N_2O	0.3	0.00003%		About 60% natural: <40% man-made
Ozone	O_3	0.04	0.000004%		Very reactive gas

Nitrogen, oxygen, water vapour*, and argon are the top four gases making up 99.8% of the atmosphere on a moist-air basis, with the only GHG water vapour in that top group. The remaining gases of the entire moist atmosphere are at ‘trace level’, totalling just over 0.2%. The literature mostly presents the atmospheric data on a dry-air basis, but this is never the case in real life. Even at -60^{0}C water vapour is about 100ppm (3).

The five GHG denoted * in Table 1 can be examined separately, and their relative amounts are presented in Table 2.

Table 2 Radiation-absorbing/emitting Greenhouse Gases: only 1.028% of the total atmosphere of which water vapour is 1% at 20^{0}C and 75% Relative Humidity

GAS		Volume ppm$_v$	GHG Volume %		Comment
1.Water Vapour	H_2O	10,000	**96.1%**		Over 24 times greater than CO_2 at 20 ^{0}C (more than 450 times greater than MAN-MADE CO_2). In the tropics: Can be over 100 times greater than CO_2 (>2,000 x man-made CO_2)
2.Carbon Dioxide	CO_2	410	3.88%		About 225 times greater than methane. Total CO_2 is 410ppm; naturally produced CO_2 is about 20 times more than man-made CO_2 (man-made CO_2 is less than 22ppm)
3.Methane	CH_4	1.79	0.017%		About 40% naturally produced: wetlands, soil, ground natural gas, sediments wildfires, ocean floor, volcanoes. Less than 60% man-made: Industry, agriculture, waste processing, landfills
4.Nitrous Oxide	N_2O	0.3	0.0029%		60% naturally occurring: from Nitrogen cycle, fossil fuels, industry. Less than 40% from human activities: agriculture, wastewater treatment, combustion
5.Ozone	O_3	0.04	0.00038%		Vital in protecting UV-B from reaching the earth

We see in Table 2 that water vapour is 96.1% of ALL the GHG's. In the tropics it would be almost 99% of the GHG's.

1. Water Vapour (1,000 to 40,000ppm): Table 2 shows the TOTAL GHG concentration including water vapour is only 1.028% of the atmosphere. Water vapour is 96.1% of that total GHG concentration. Because the oceans cover 70.9% of the earth's surface it is expected that the atmospheric water vapour concentration would be high. The humidity (water vapour in air) varies widely with location and elevation (3) due to the Thermal Lapse Rate being sizeable (lowering of 6.5^0C per kilometre rise in elevation (4)). At the tropics, the atmospheric water vapour can reach well over 40,000 ppm (over 4% of the atmosphere), which is over 100 times greater in concentration than carbon dioxide (3). Water vapour in colder climates (or high elevations) can still be higher than carbon dioxide; over 1,000ppm at -20 ^{0}C and 100% relative humidity. Unlike all other atmospheric gases, clouds form from condensing water which in turn can precipitate and cool the atmosphere (rain, snow, or hail). This additional significant change-of-phase contribution will be discussed further (see Point 3). Water vapour concentration is 2 to over 100 times greater in concentration than carbon dioxide, more than 6,000 times higher in concentration than methane, and greater than 30,000 times that of nitrous oxide.

2. Carbon dioxide (410ppm): At just over 410 ppm (0.041%), carbon dioxide is the second most abundant GHG. Man-made CO_2 is less than 0.002%. However, over 95% (390ppm) of it is derived from natural causes: organic plant decomposition, vegetation, from the ocean (CO_2 less soluble in warm water), from the land, and from volcanoes (80% of all active volcanoes/fissures are below the sea). The remaining CO_2 (<5%) is man-made mainly from industrial processes, power generation, and motor vehicles using fossil fuels. The growth rate of total CO_2 is small at just over 1ppm/year. The growth rate for man-made CO_2 is even smaller, about 0.05 ppm/year. Probably the reasons why CO_2 has received so much attention is the misplaced emphasis on 'the radiation-only mechanism' as the cause of weather changes, as well as the pressure to blame fossil fuels rather than other natural causes. Other energy transfer mechanisms worldwide indeed play a big part in weather change and must also be considered simultaneously eg jet streams, storms, winds, hurricanes, atmospheric precipitation of rain and snow etc..

3. Methane (1.79ppm): The third largest GHG methane is at a very, very low concentration of less than only 0.018% total (CO_2 is 225 time higher in concentration, and water vapour about 6,000 higher). Of course, on spray-irrigated farms or at higher atmospheric temperatures, the water vapour concentration is even higher again. Natural production of methane is estimated to be about 40% of the total methane, and is from marshes and wetlands, forests and natural leakage from the ground. The man-made proportion is less than 60% (1.07 ppm), and comes mainly from livestock, manure, landfill, industrial processes, in particular, natural gas processing (1).

4. Nitrous Oxide (0.3ppm): A small amount of nitrous oxide is naturally present as part of the nitrogen cycle (plants, animals and microorganism reactions). It increases during farming activity, industrial processing, wastewater treatment, and is also a product of fossil fuel combustion. Worldwide less than 40% comes from man-made operations (0.12 ppm total) which include emissions from fertilisers, livestock excrement and urine. Nitrous oxide is generated in the manufacturer of commercial fertilizers, nitric acid, some synthetic plastic products, some combustion processes, and from certain fossil fuels.

5. Ozone (0.04 ppm) (0.00038%): is rare in the atmosphere (1 molecule per ten-million air molecules). Most exists in the stratosphere (~10 km elevation upwards) and UV radiation is required to produce it from oxygen. It is a strong oxidising agent and reacts and breaks down biologically-damaging UV-B to minimise that reaching earth. In the lower troposphere it can initiate photochemical smog and can also be harmful to crops, forests and human health. Certain choro-flurocarbons reduce its formation markedly, although there is a natural lowering of ozone for the winter periods when the poles are dark and the radiant energy production virtually zero for half the year.

The relative concentrations of GHG is just one part of the overall picture as each gas is only potentially active over a small part of the entire electromagnetic spectrum.

2. ACTIVE RANGE OF GHG OVER THE TOTAL ELECTROMAGNETIC SPECTRUM

The second and most important factor is; 'How much radiant energy does each greenhouse gas actually absorb and emit and over what range?'.

The ability of a greenhouse gases to absorb and emit radiation has been investigated extensively. Figure 1 shows the radiation transmitted by the atmosphere as UV, Visible light and infrared radiation (see the *yellow band* in the Figure). The left-hand side of the figure shows the region of incoming solar radiation (0.2 to 3 micrometres wavelength span). The right-hand side denotes the re-radiation from earth as long-wavelength infrared energy covering the 3 to 70 micrometre span.

Each greenhouse gas is labelled in the lower part of the graph. The width and height of each absorption peak for each gas is also clearly shown. The height of the peak denotes the amount of radiant energy that each gas can possibly absorb over that specific wavelength range. The width of each graphical peak clearly shows the wavelength band over which that the particular greenhouse gas is sensitive, and active to that band of radiant energy.

An initial assessment indicates that methane, nitrous oxide, and ozone, only have a few narrow absorption bands with none absorbing 100% at their active wavelength location within the spectrum. Even carbon dioxide only has 4 peaks over 50% absorption level, and these are at relatively narrow and at specific wavelengths. Water vapour in stark contrast operates over a far wider wavelength range with many more peaks, several even absorbing up to 100% radiant energy at their location. Above 20 micrometres wavelength, the energy absorption is all at 100% for water vapour.

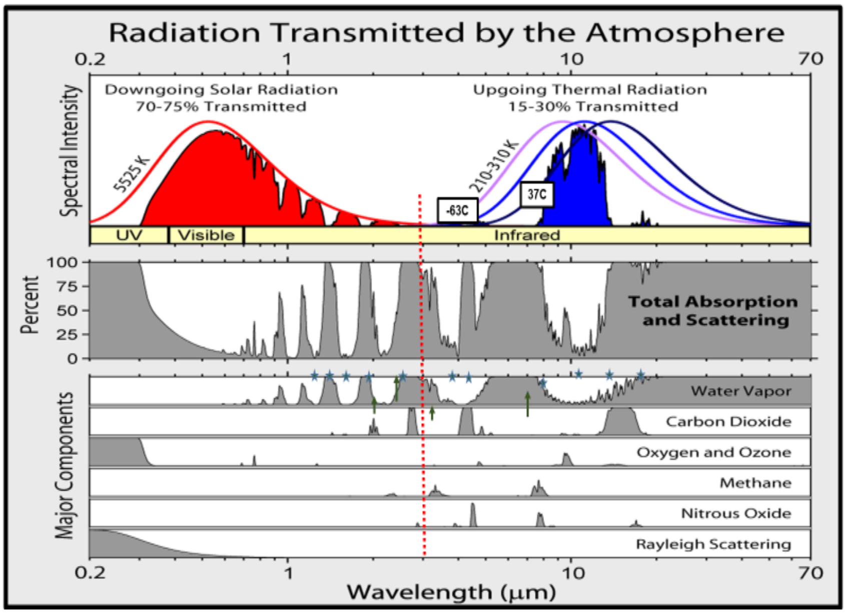


Figure 1 Total radiation transmitted by the Atmosphere (5)

Incoming Solar Energy

Figure 2 shows that the absorption peaks for methane, nitrous oxide, and ozone for incoming solar energy. All are extremely small (far less than 50% absorption) and all very narrow, and thus unreactive to almost all incoming solar radiation. Carbon dioxide only has 2 absorption peaks and only one potentially can absorb 100% across a narrow wavelength band which happens to coincide with the wide water vapour peak anyway (would compete with water vapour gas). In contrast, water vapour has 7 absorption peaks, 3 operating at 100% level and wider than all others, as well as 2 above 50% level.

It can be concluded from the published evidence, that the dominant GHG absorbing solar radiation is water vapour. The absorption potential of solar radiation by the other GHG is miniscule or virtually non-existent. From an agricultural emissions point of view, the ‘culprits’ like methane and nitrous oxide can clearly be discounted as having any appreciable effect on *incoming* solar radiation.

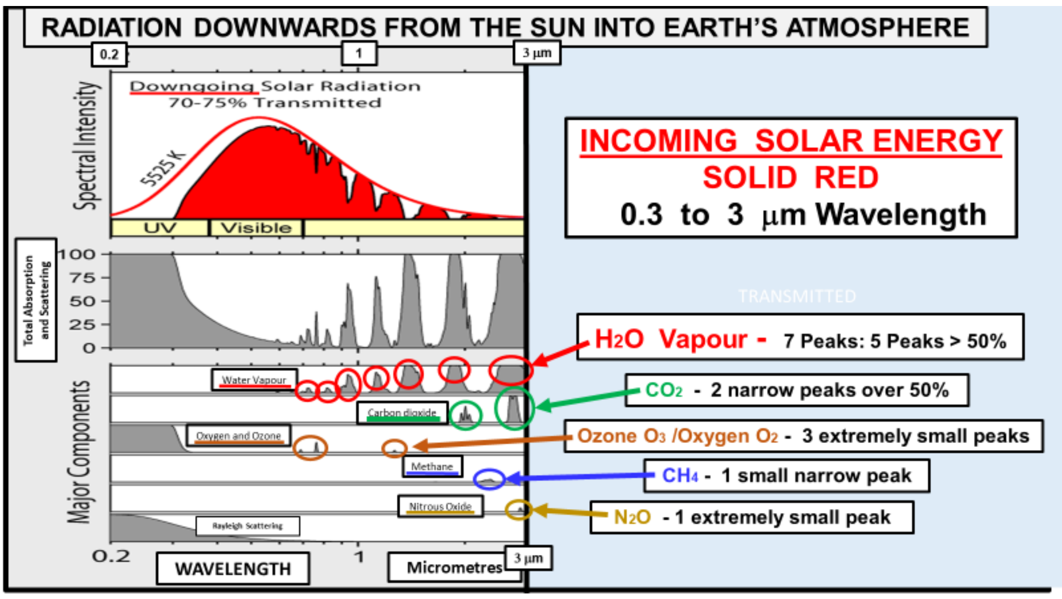


Figure 2 Incoming solar Radiation in the 0.3 to 3 micrometre wavelength range (5)

Outgoing radiation back from earth

Less than 60% of all solar radiation actually ever reaches the planet's surface. When it does, the Solar radiation 'impacts' the earth's surface by 'exciting' all surface molecules (land and sea) to various extents. These molecules vibrate, rotate, twist, or oscillate more and emit longer-wavelength radiation. The energised molecules themselves can now also move faster and collide more with all other molecules, even the non-GHG molecules.

Atmospheric greenhouse gases within the first few hundred metres elevation absorb some of this radiant energy in various ways depending on the structure of the molecule. None absorb over the total span of wavelengths (3 to 70 micrometres). Each gas is sensitive to a specific band of energy as shown in Figure 3. The height of each peak indicates the amount of energy absorbed at each band of wavelengths. The peak width indicates the sensitivity of that greenhouse gas and thus the potential proportion of all the emitted long-wave re-radiation from the planet's surface.

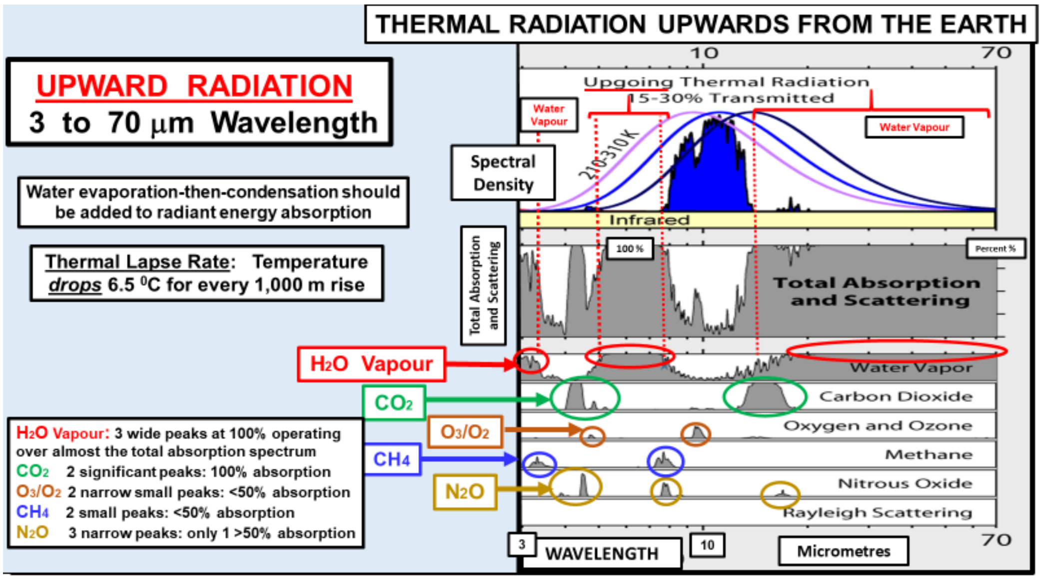


Figure 3 Total Re-radiation from earth in the 3 to 70 micrometre wavelength range (5)

Clearly both methane and ozone are very limited; each with 2 narrow bands and each absorbing less than 50% of radiant energy over their specific and small absorption bandwidths. Nitrous oxide has 3 very narrow bands; only one band reaches almost 100% absorption, and that just at one wavelength point. As all three (methane, ozone, nitrous oxide) are very, very low in concentration and cannot possibly absorb much long-wavelength radiation anyway. Their effective contributions overall are simply extremely small.

Carbon dioxide only has 2 bands. They are slightly wider than methane and nitrous oxide, but operate over a very small proportion of the total re-radiation span from earth (<8% of the total wavelength range). In stark contrast, water vapour which is at a far higher concentration, is fully active over more than 80% of the total span *(note Log Wavelength Scale).*

Clearly from Fig. 3, water vapour is active over more than 80% of the entire re-radiation region. If radiation is the key concern (but noting there is far more happening), then the focus must simply be on water vapour. Carbon dioxide makes a very small contribution, and methane, nitrous oxide and ozone are really inconsequential.

3. OTHER ENERGY TRANSFER MECHANISMS THAT MUST BE EXAMINED SIMULTANEOUSLY

Energy transfer on the planet and atmosphere is simply more than radiation-only (2). Weather changes are complex. Large-scale convective mixing, evaporation-condensation, and conduction are all in-play all the time, in addition to thermal radiation. Massive ocean conveyer systems and ocean up-wellings, El Nino and La Nina changes, storms, sub-surface saline currents, monsoons, tornados, Jet Streams and Trade Winds, are all highly significant, and must be included (2). The magnitude of these effects vary as the earth rotates (overnight or diurnal cycles), as the earth revolves around the sun (seasonal changes), and depends strongly on location (latitude), and position (continent, island, and closeness to the sea etc).

The mechanism that is often discounted or overlooked is phase-change. With 70.9% of the world surface as oceans and lakes, the amount of water evaporation followed by condensation as clouds is enormous (423 trillion tons/year). All other greenhouse gases cannot do that. Clouds can also act as solar umbrellas on hot sunny days. They also can form, amalgamate or dissipate over a very short period, so they adapt to compensate thermal energy transfer in the atmosphere.

Most gases are distributed fairly evenly my diffusion and mixing. Air density drops quickly with increasing altitude with simultaneous temperate lowering (Thermal Lapse Rate of 6.5 C per drop km rise in elevation). Water vapour is different. It is non-uniform in the atmosphere as it cools it can condense to make clouds, mists, or fogs. Certain clouds with the right conditions precipitate liquid water (rain) or snow, and even ice (hail). These cool the lower atmosphere and planet's surface, while scrubbing dust and some carbon dioxide from the atmosphere. Hence, water offers some degree of self-regulation and self-compensation not offered by other greenhouse gases. If the planet heats up for any reason, the large oceans will heat up also. Hence more water will evaporate, the atmosphere will increase in humidity, more clouds will form, thus more cloud umbrella shielding, precipitation, and atmospheric and planet cooling.

CONCLUSION

The GHG concentration of the actual atmosphere is 1.028% of the total atmosphere, based on water vapour being 1% (20^0C, 75% Relative Humidity). The main gases from possible agricultural sources (methane and nitrous oxide) total only 0.02% of all the GHG, or 0.00021% of the total atmosphere. Also, less than half of those two gases are possibly man-made (0.0001% total). Methane and nitrous oxide have been shown to have only have a few narrow radiant energy absorption bands with none absorbing 100% at their active wavelength location within the total spectrum. Hence, it can be concluded from all the available evidence, that their contribution to any potential change in weather is miniscule.

REFERENCES

1. Overview of Greenhouse Gases, USA Environmental Protection Agency EPA; https://www.epa.gov/ghgemissions/overview-greenhouse-gases

2. Weather; https://en.wikipedia.org/wiki/

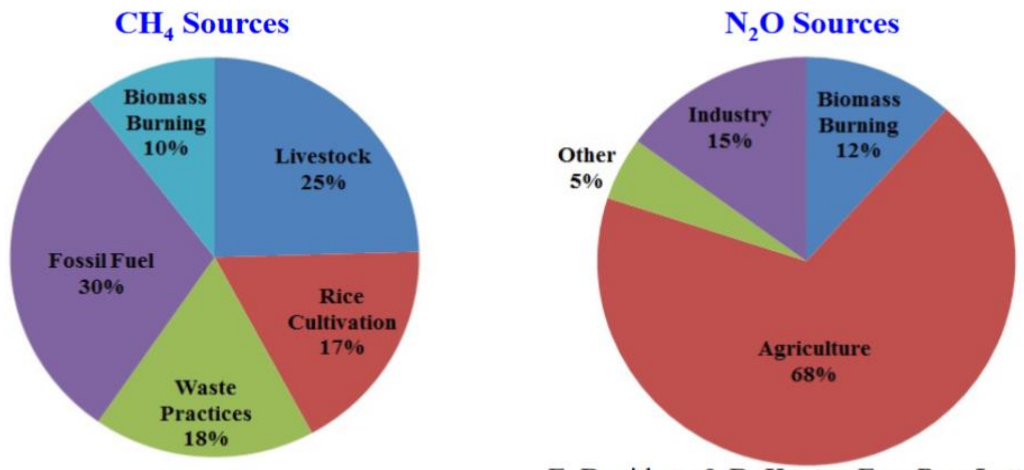
3. Humidity Calculator: http://www.lenntech.com/calculators/humidity/relative-humidity.htm

4. Thermal Lapse Rate: https://en.wikipedia.org/wiki/Lapse_rate

5. Weather Atmospheric Transmissions; https://commons.wikimedia.org/wiki/File:Atmospheric_Transmission.png

Anthropogenic Increase of Greenhouse Gases

Gas	Preindustrial (ppm)	2018 Level (ppm)	Increase Rate (% / yr)	Doubling Time (yr)	Atmospheric Lifetime (yr)
CO_2	280	400	0.5	200	30 – 95
CH_4	0.7	1.8	0.1 - 0.4	250 – 1000	12
N_2O	0.25	0.32	0.25	400	120



P. Bousquet et al, Nature **443**, 439 (2006)

E. Davidson & D. Kanter, Env. Res. Lett. **9**, 10512 (2014)