# Does the $CO_2$ float above the other atmospheric gases? If not, can it still be considered a viable greenhouse gas?


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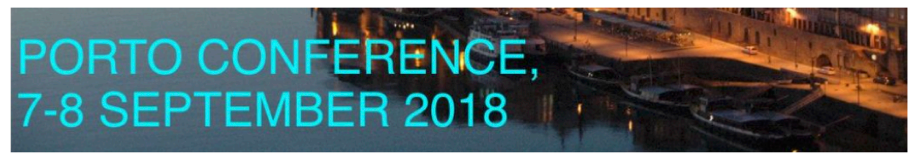
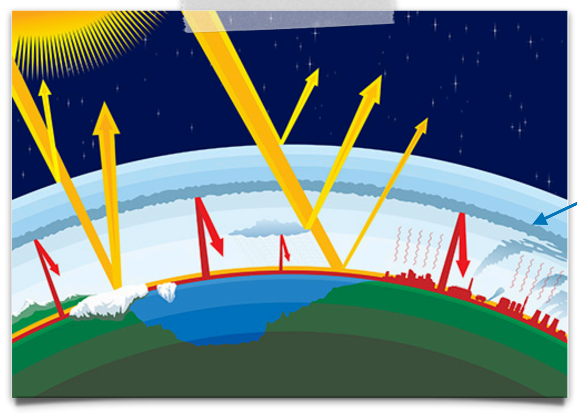
At a recent symposium, held in Lisbon on the headquarters of the Portuguese Engineering Society, I asked a simple question to one of the IPCC members, a Portuguese academic: "Does the $CO_2$ float above the other atmospheric gases?". The response was heartbreaking "Yes, because we measure it!!! And we believe in Science, you know …"



EPA/US suggestion for the Kids about the place of CO2 in the atmosphere!


## Abstract

In the scientific process, measuring is always part of a sequence of events, commonly known as methodology, that are performed in order to help the understanding of a specific phenomena under a known set of constraints. If we measure $CO_2$ concentration in the atmosphere, we need to know how this particular molecule behaves and how is constrained by the natural world.

First, we need to know the proprieties of the $CO_2$ molecule and how these properties relate with those from other molecules present in the atmosphere ($O_2$, $N_2$, $H_2O$, Ar); secondly, we need to know what are the constraints that bound the natural behaviour of these molecules in the atmosphere, we analise the measurements and discuss its quality and significance as a greenhouse gas.

What is sure, is that its measured density at average earth temperature and sea level pressure, is higher than those from the remaining elements at the same conditions which implies its inability to float above them.


## Introduction

- $CO_2$ is a molecule that at the range of pressures and temperatures present on the Earth atmosphere is in its gas phase. So it should be regarded as a normal fluid that interacts with the others according to the normal behaviour of fluid mixtures.
- This said, its important to note that fluids have two very distinct behaviours at the normal pressure and temperatures: laminar and turbulent flows.

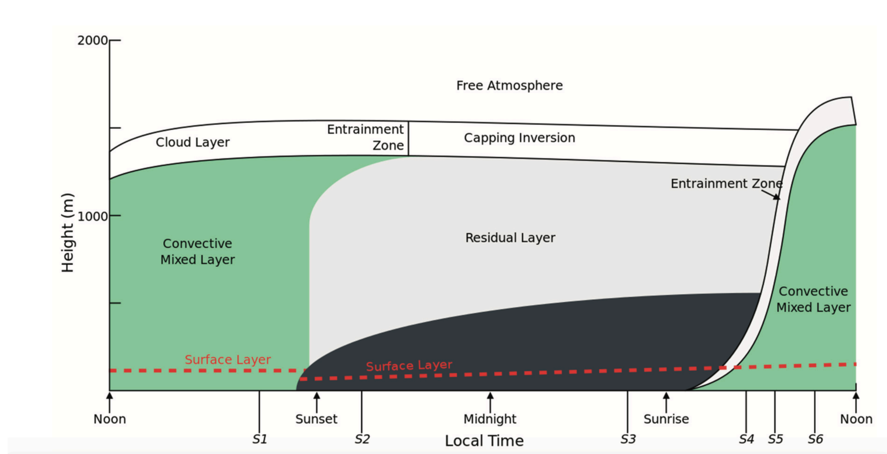



Figure 1. Schematic of the structure of the atmospheric boundary layer in high pressure regions over land, showing daily variations. Source: SHERRI HUNT, U.S. Environmental Protection Agency (NASEM, 2018)

- Laminar flow facilitate the fluid separation, notably in the atmosphere by effect of the gravity, by contrast turbulent flow enhances the mixture and counter acts the gravity.
- In the atmosphere, near the surface, we mainly have turbulent flows and at altitude we encounter persistent laminar behaviours. From Fig. 1 (NASEM, 2018) it is clear that the height of the Atmospheric Boundary Layer (ABL) that separates both regimes oscillates from 1500 m during the day to around 500 m at night.

## Data Collection

- The average composition of the dry atmosphere is commonly assume to be 78% $N_2$, 21% $O_2$, 1%Ar and the remaining 0,..% distributed between $CO_2$ and other gases.
- However in the presence of water vapour this scenario changes and for an average 3% $H_2O$ we have values of around 75,7% $N_2$, 20,3% $O_2$, 0,9% Ar and the same residual 0,…% for $CO_2$ and others. Table I presents the data collected by NOAA in 2002 in the Mauna Loa Observatory in Hawaii.

| | | dry air | 3% wet air |
|---|---|---|---|
| Nitrogen | | 780,900 | 757,473 ppm |
| Oxygen | | 209,400 | 203,118 |
| Water vapor | | 0 | 30,000 |
| Argon | | 9,300 | 9,021 |
| Carbon Dioxide | | 372 | 360.8 |
| Neon | | 18 | 17.5 |
| Helium | | 5 | 4.9 |
| Methane | | 2 | 2 |
| Krypton | | 1 | 1 |
| trace species (each less than 1) | | 1 | 1 |
| | Total | 1,000,000 | 1,000,000 ppm |

Table 1.The table above gives an example for 372 ppm CO2 in dry air (this is roughly the average amount of CO2 in the atmosphere in the beginning of the year 2002). All species have been expressed as ppm, turning 78.09% nitrogen into 780,900 ppm. The rightmost column shows the composition of the same air after 3% water vapor has been added. Source: Pieter Tans and Kirk Thoning, NOAA Earth System Research Laboratory, Boulder, Colorado

- The densities of the different gases can be obtained easily from any textbook of general chemistry and for the purpose of this reflection are expressed in Table 2. where is visible the diference between the $H_2O$ and $CO_2$.

| Gas | Chemical formula | Molar Mass | Density | Density Variation with Air |
|---|---|---|---|---|
| | | g/mol | kg/m**3 | % |
| Air | - | 28,96 | 1,274 | 100.0 |
| Water Vapour | **H2O** | 18,05 | 0,597 | **46,86** |
| Nitrogen | N2 | 28,1 | 1,2323 | 96,73 |
| Oxygen | O2 | 32,0 | 1,4076 | 110,49 |
| Argon | Ar | 39,5 | 1,7572 | 137,93 |
| Carbon Dioxide | **CO2** | 44,01 | 1,9359 | **151,95** |

Table 2. Atmospheric gases properties for normal average pressure and temperature. Its important to note that CO2 is almost 4 times more dense than water vapor. This implies a very high probability of encountering the CO2 underneath the H2O in Natural Environment.

## Discussion

- Buoyancy is a well known property of the fluids, its formulation dates back to Archimedes of Syracuse (c. 287 – c. 212 BC).
- Diferences in gas densities promotes buoyancy as we well know from balloons (party and meteorological) or from the new and modern airship or dirigible balloon like the new 2010 Zeppelin NT D-LZZF (Figure 2).


Figure 2. A modern airship, Zeppelin NT D-LZZF. Picture taken by *AngMoKio* in 2010 over the Lake Constanza in the German- Suisse border. Source: Wikimedia.

- We know from the literature that buoyant fluid parcels, having a characteristic displacement scale, after being advected by turbulent flows when entering a calm laminar flow will drift to their equilibrium density levels under its own buoyancy forces (which is also known as the restratification) (Fernando, 2002).
- We also know that for average weather conditions the pressure variation from 0 to 1500 m height is almost linear and just varies 16%, which means that the same amount of particles occupies more 16% of volume 1500 m above sea level.
- If we consider by hypothesis that suddenly all the the turbulent processes in the lower atmosphere stopped to a point of perfect rest, during a time long enough to allow a full restratification process to develop, we would naturally obtain a atmosphere composition shown in figure 3, with only the $CO_2$ accumulated in the first layer of just 56 cm above the ground (dry air) or 54 cm if we consider a normal 3% moisture.
- This question of location of the $CO_2$ is poorly addressed in the literature for the lower atmosphere, namely within the boundary layer, which can have very dramatic changes in locations where the different components are localised from one day to another. A very interesting study (Gadhavi & Jayaraman, 2006) using Lidar technology show very different distributions for aerosols for two consecutive days with important implications on their cooling effect on earth (Fig. 4). The top figure shows the aerosols concentrated near the top limit of the ABL which is consistent with a fully developed turbulent state.

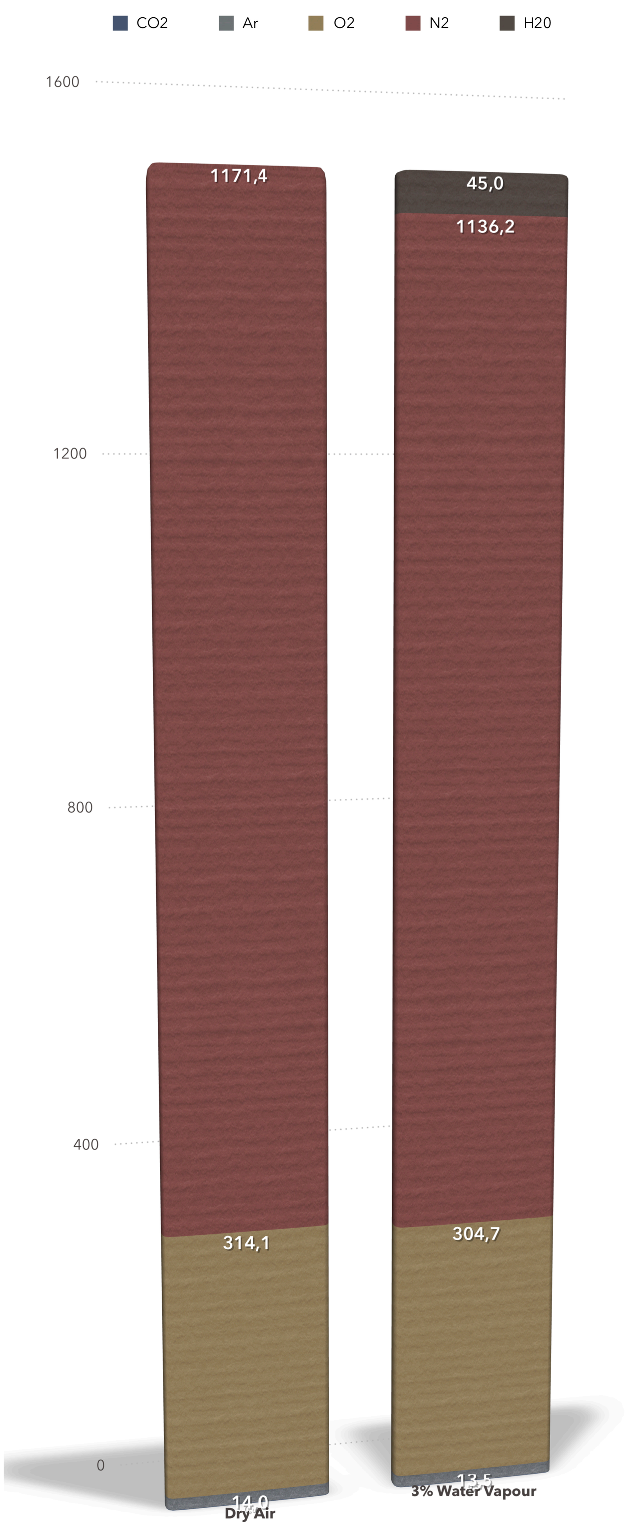



Figure 3. Schematic distribution of the different gases of atmosphere in a fully separated stratification by density. The CO2 layer is totally invisible!!!

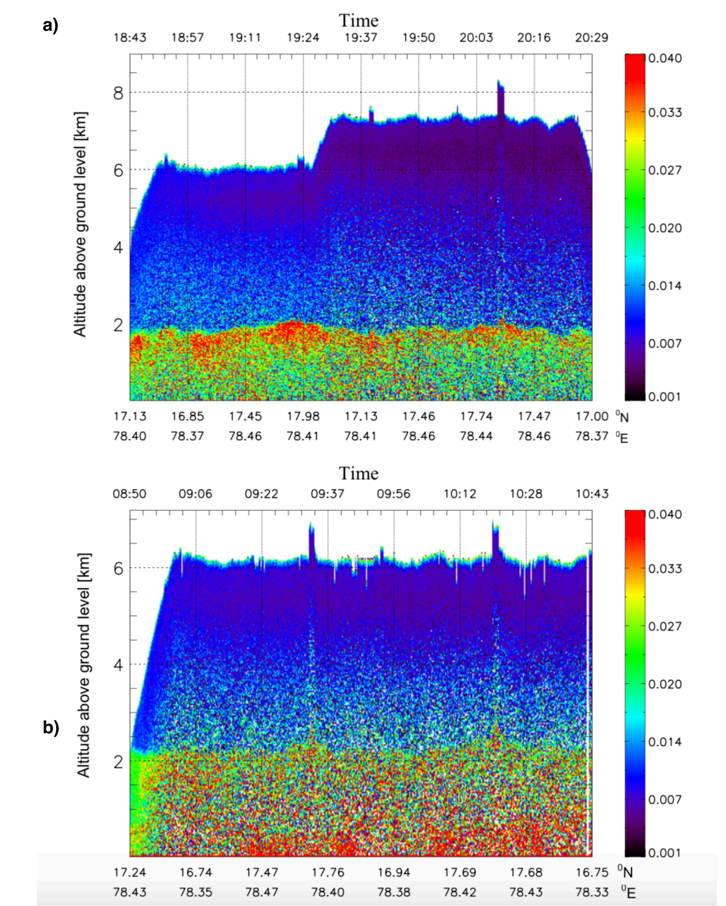



Figure 4. Normalised Relative Backscatter values in arbitrary unit photons obtained from the airborne lidar measurements made on (a) 17 (late afternoon) and (b) 18 February 2004 (early morning) over Hyderabad, India. Latitude and longitude of the ground track are according to measurement sequence. Source: (Gadhavi & Jayaraman, 2006).

## Conclusion

This leads to the final conclusion that, if we are speaking about the radiative effect of the gases and their effect on heating of the atmosphere, we need to know how they behave in the air column. This knowledge is only possible when we gather a better understanding of what happens in the mysterious Atmospheric Boundary Layer and when we fully understand how this complex interactions of positive and negative feedbacks operates in our environment.

### References


Fernando, H.J.S. (2002) Turbulence in stratified fluids. In: Grimshaw R (ed) Environmental stratified flows, vol III. Kluwer Academic Publishers, Norwell, 296 pp

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