

On the Saturation & Thermalization of Carbon Dioxide III

by

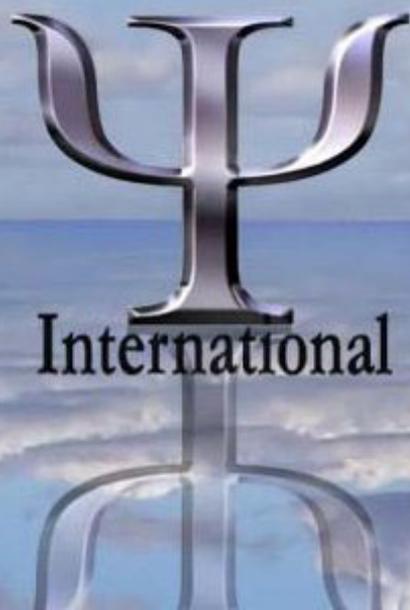
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Introduction

This paper is an update of earlier papers [5]

Infra-red-active gases in the atmosphere are: water-vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), ozone (O₃), laughing gas (N₂O)...

They hinder long-wave (LW) radiation to outer space from the surface of the planet to evacuate the heat which the sun is sending to the planet as short-wave (SW) radiation.

The most important infra-red-active gases are H₂O vapor and CO₂ gas.

In earlier papers the author has studied the hindering of the LW evacuation of heat from the terrestrial surface to outer-space by a mechanism of a stack of fine gauze, simulating the infra-red-active gases. The paper mentions the International Panel on Climate Change (IPCC), which gives alarming messages to the general public by ignoring the physical phenomena thermalization and saturation of CO₂.

Stack model to study the evacuation of heat from the planet.

A finite element method (FEM) has been used.

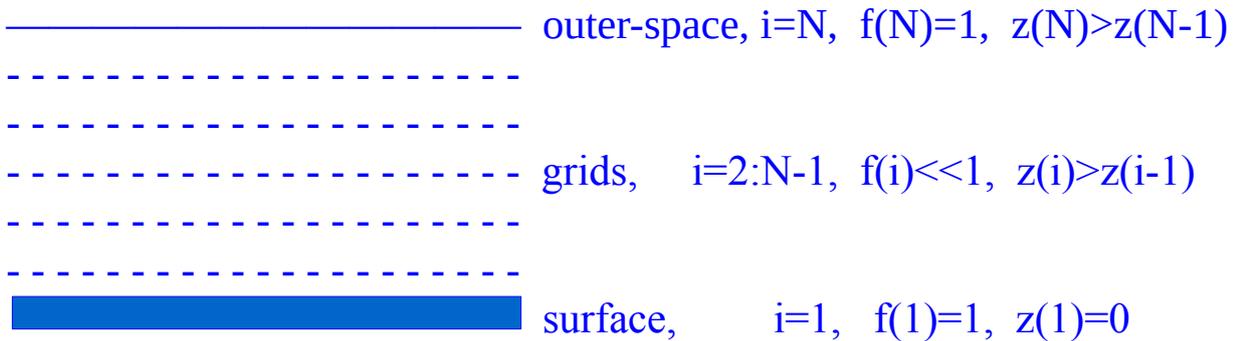
Not in the classical way of solving differential equations, but rather using FEM strategies to model the phenomenon and to deal with a great number of simultaneous algebraic relations using matrix notations [1].

We give a short description of the FEM approach.

We consider in **figure 1** a stack of $N-2$ grids, with dimensionless very small absorption coefficients $f(i) \ll 1$, being the ratio of the cross-section of the wires divided by the total surface. The absorption coefficients are assembled in a vector denoted by a bold character \mathbf{f} of order N , including $f(1)=1$ for the surface and $f(N)=1$ for outer-space.

We define $f_{tot} = \text{sum}(\mathbf{f}) - 2$, being the sum for the atmospheric grids.

Figure 1 Stack of fine gauze



Consider two layers of black grids with coefficients $f(i)$ and $f(j)$, and absolute temperatures (Kelvin) $T(i)$ and $T(j)$, respectively. According to the classical Stefan-Boltzmann relation with $\sigma = 5.67e-8$, the heat flux ϕ by LW radiation between the two grids can be written as :

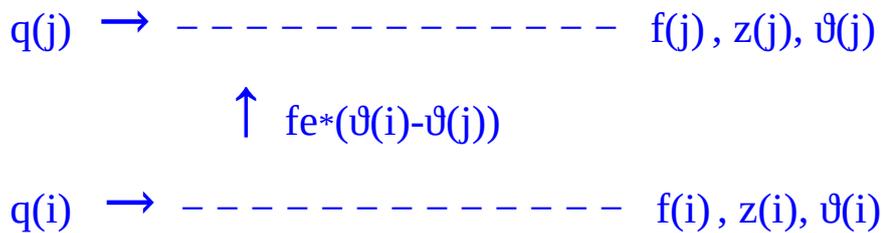
$$\phi (i \rightarrow j) = f(i)*f(j)*\sigma*(T(i)^4 - T(j)^4) \text{ and } \phi(j \rightarrow i) = 0 \text{ for } T(i)>T(j) \quad (1)$$

With $\vartheta = \sigma *T^4$ and $fe = f(i)*f(j)$ relation (1) can be written as:

$$\phi(i \rightarrow j) = fe*(\vartheta(i)-\vartheta(j)) \quad \text{and} \quad \phi(j \rightarrow i) = 0 \quad \text{for } \vartheta(i)>\vartheta(j) \quad (1a)$$

This is the one-stream energy formulation without the nonphysical back-radiation of the two-stream Schwarzschild formulation of 1906. A radiation finite element with nodal parameters is depicted in **figure 2**.

Figure 2 Radiation finite element



- Nodal parameters:
- f absorption coefficient
 - z coordinate [m]
 - ϑ variable representing $\sigma*T^4$ [W/m²]
 - q external heat load into the grids [W/m²]

Constitutive relation : fe element radiation coefficient

By means of a Galerkin-type of variation process, the element heat balance can be written as:

$$\begin{vmatrix} q(i) \\ q(j) \end{vmatrix} = \begin{vmatrix} fe & -fe \\ -fe & fe \end{vmatrix} \begin{vmatrix} \vartheta(i) \\ \vartheta(j) \end{vmatrix} \quad (2)$$

Equations (2) describe, for given $\vartheta(i)$, $\vartheta(j)$ and fe , the flow of heat by LW radiation between grids i and j and the necessary external heat sources $q(i)$ and $q(j)$, for a balance.

For an element with grids in **adjacent** levels i and $j = i+1$, the element transfer coefficient is indeed $fe = f(i)*f(j)$.

However, elements of the type of **figure 2** can be overlapped with each other. When between grid i and grid j of one element other grids of other elements are present, the transfer of heat by radiation between grid i and grid j will be hindered and fe of element (i, j) with $j > i+1$ becomes :

$$fe = f(i)*viewfactor(i, j)*f(j) \quad (2a)$$

In (2a) the viewfactor(i, j) takes into account the fact that other grids k are present between grid i and grid j of an element (i, j) .

The viewfactor(i, j) of the element (i, j) can be written as:

$$viewfactor(i, j) = 1 - \sum f(k) \quad \text{for} \quad z(i) < z(k) < z(j) \quad (2b)$$

The element matrices for the different pairs of grids are assembled in a symmetric system matrix, denominated by a bold character **K**.

For a stack with N levels there are $N(N-1)/2$ pairs with a balance like (2) and the system matrix **K** is of order $N \times N$. We use N up to 90 nodes.

Nodal parameters $\vartheta(i)$ and nodal heat loads $q(i)$ are assembled in vectors of order N , denominated with bold characters **ϑ** and **q** , respectively.

The characteristic equations of the atmospheric LW radiation become :

$$q = K*\vartheta \quad (3)$$

The vector relation (3) represents N algebraic relations: for given values of the components of the vector **ϑ** and of the matrix **K** one obtains the vector **q** of external thermal loads into the stack with $\text{sum}(q) = 0$, for a balance.

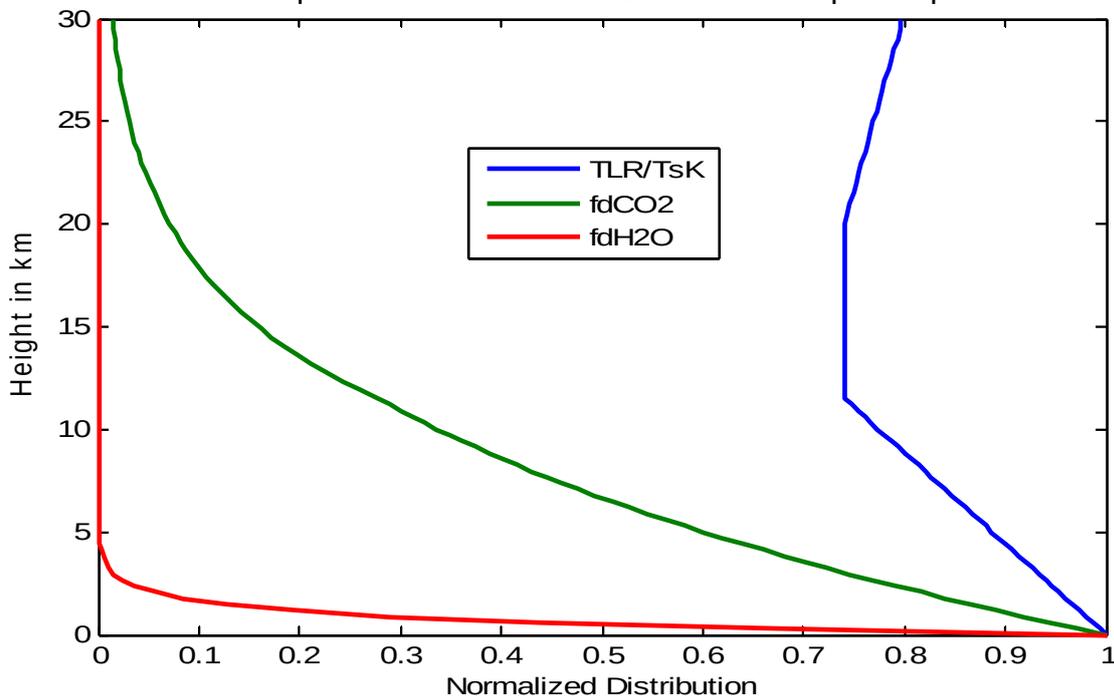
Data for the components of the vector ϑ and the matrix K

The data for these components are shown in **figure 3**: temperature distribution and concentration of water vapor H₂O and of carbon dioxide gas CO₂ over a height of 30 km.

NB *In computer language subscripts are not used. From now on, in this paper, we do not write anymore H₂O, CO₂ but H2O, CO2.*

Figure 3

fig 4.3 Normalized Temperature for TsK=288, water vapor for m = 7 and CO₂ distribution Lower atmosphere ELR= -6.5 K/km. Standard atmosphere up to 30 km



For a height up to 11.5 km the temperature is defined by the surface temperature and the environmental lapse rate, ELR = -6.5 K/km.

It is the basis of the analysis of the heat evacuation through an atmosphere with only water-vapor.

The temperature distribution is converted to the variables $\vartheta(i)$ assembled in the vector ϑ . With the surface temperature TsK we get TLR(i) and $\vartheta(i)$:

$$\text{TLR}(i) = \text{TsK} + \text{ELR} * z(i) \quad \text{and} \quad \vartheta(i) = \sigma * (\text{TsK} + \text{ELR} * z(i))^4 \quad (4)$$

Where $z(i) < 11.5$ is the vertical coordinate of the grid in km.

For $z(i) > 11.5$ km – for the CO₂ analyses – the temperature distribution follows from **figure 3**, which corresponds to the standard atmosphere.

Outer-space temperature is zeroK = 0 or $\vartheta(N) = 0$.

In **figure 3** are also depicted the normalized distribution of H2O vapor and of CO2 gas: fd_{H2O} and fd_{CO2} , respectively.

The normalized H2O distribution is defined heuristically by an exponential drop :

$$fd_{H2O}(z) = \exp(-m \cdot z / \text{height5})$$

The coefficient $m = 7$, for a reference height5 of 5 km, is obtained by comparing the results with the mainstream papers on the subject.

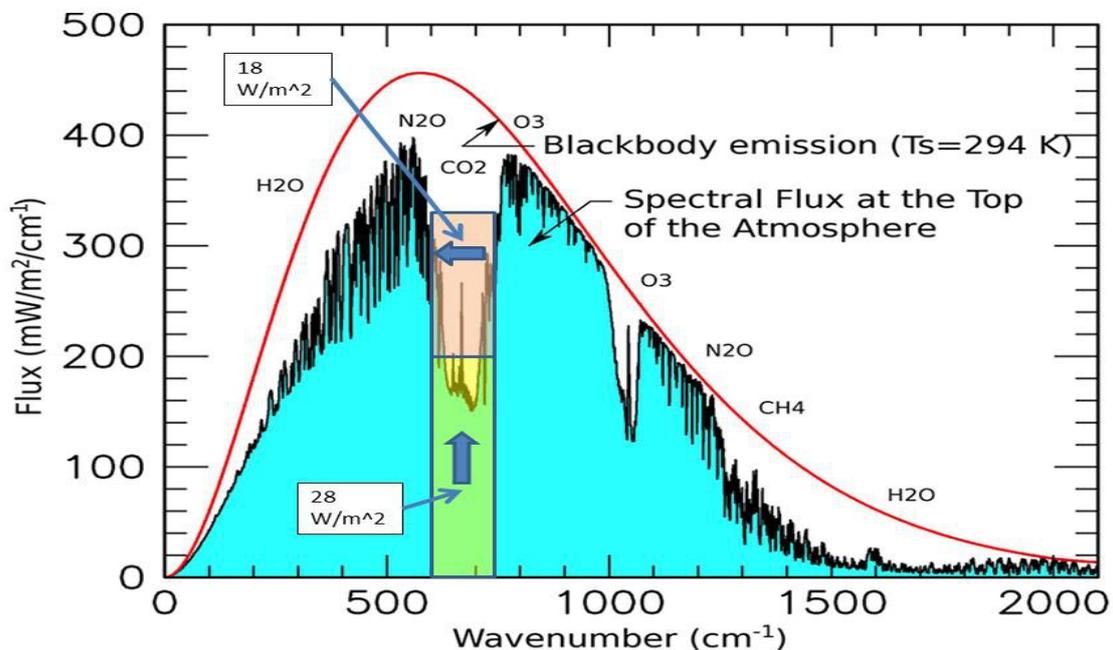
The CO2 distribution is taken proportional to the height dependent density in the atmosphere, assuming the volumetric concentration of CO2 is constant over the height. More details are given in [1].

Fractions of H2O and CO2 in the LW terrestrial spectrum

From **figure 4** we can conclude that the fraction of CO2 in the spectrum is $28 + 18 = 46 \text{ W/m}^2$ of the total Prevost flux $= \sigma \cdot T_s K^4 = 394 \text{ W/m}^2$ for a surface temperature of $T_s K = 288.72$:

$$\text{fractionCO2} = 0.1168 \quad \text{and} \quad \text{fraction H2O} = 1 - \text{fractionCO2} = 0.8832$$

Figure 4 from Pangburn blog [2]



Thermal radiation from below assessed from top-of-atmosphere.

Original graph from NASA

NB $T_s = 294 \text{ K}$ in **figure 4** is a reference value for the red Planck curve.

Other data are for a temperature of $T_s K = 288.72$.

Results of stack model for water-vapor.

From **figure 3** we see, for the evacuation of heat through an atmosphere with only water-vapor, a model with a height of 11.5 km is sufficient. The computer program includes a mesh generator with element sizes based on geometric series: for N=40 nodes of order of 2 meter at the surface and of 2 km at 11.5 km height.

Figure 5 gives a graphical display of the vector relation (3): $\mathbf{q} = \mathbf{K} * \mathbf{\theta}$.

It might be useful to repeat in words what the vector relation means: for a measured temperature distribution given in 40 nodes by a vector of parameters $\mathbf{\theta}$ of order 40 and by multiplication by a radiation matrix \mathbf{K} for water-vapor of order 40x40, one obtains a vector \mathbf{q} of order 40.

What is the physical interpretation of the components of the vector \mathbf{q} ?

They represent: $q(1) = q_{surf} =$ LW surface flux of water-vapor

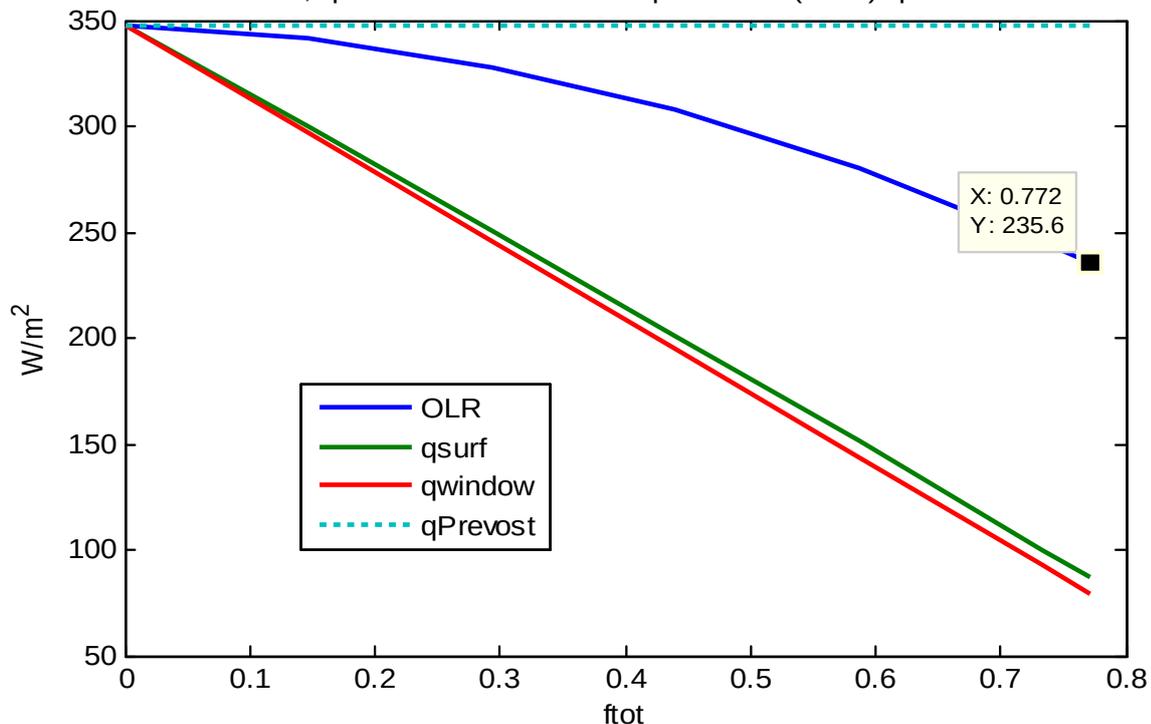
$-q(N) =$ OLR = outgoing LW radiation of water-vapor

We see in **figure 5** these two components of the vector \mathbf{q} , as well as

$$q_{Prevost} = \text{fractionH2O} * \sigma * T_s K^4 = \text{fractionH2O} * \theta(1).$$

Figure 5

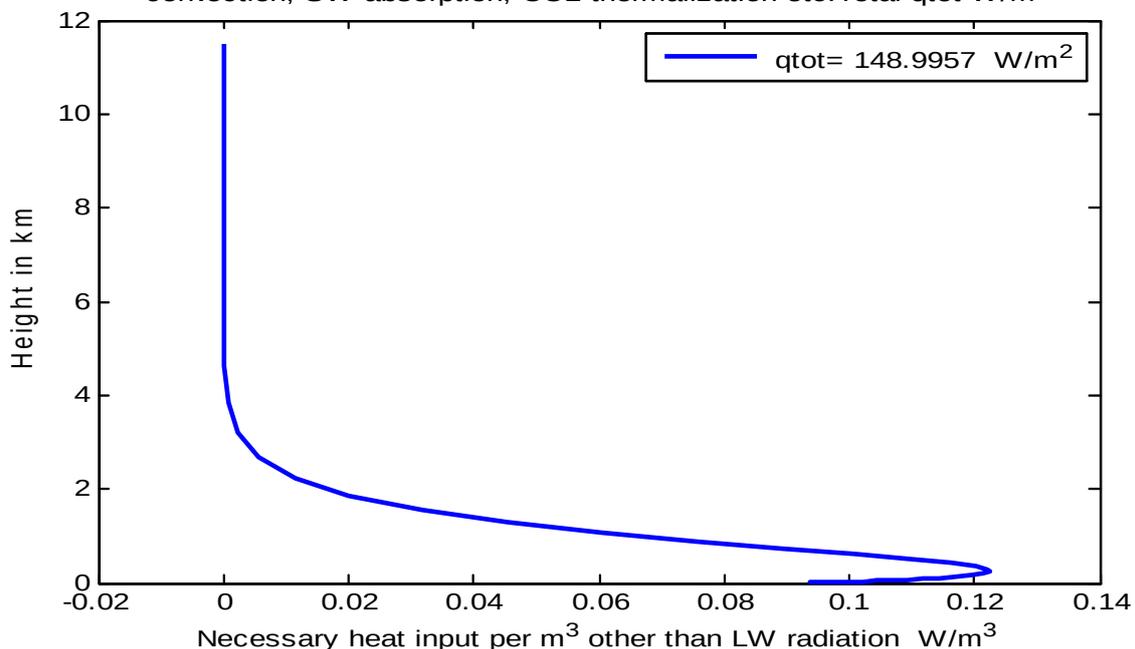
fig 2.1 Result of water vapor analysis
 nods = 40 m = 7 height = 11.5 km ELR = -6.5 K/km
 ftot = 0.772 TsK = 288.7209 fractionH2O = 0.88325 qtoa = 235.65 qPrevost = 347.9998
 OLR, qsurf as function of ftot. qwindow = (1-ftot)*qPrevost



OLR_{H2O} of 235.65 W/m² is the average of the global outgoing LW radiation at H2O frequencies, for which the stack model gives ftot= 0.772 and a window of (1-ftot) = 0.228. With OLR_{CO2} = 4.35 from **figure 9**, the classical total outgoing flux at top of atmosphere is: qtoa = 240 W/m². The calculated values of the other components of **q** are given in **figure 6**, not as nodal values with dimension W/m² but as distribution in W/m³.

Figure 6

fig 2.2 Result of water vapor analysis
 nods = 40 m = 7 height = 11.5 km ELR = -6.5 K/km
 ftot = 0.772 TsK = 288.7209 fractionH2O = 0.88325 qtoa = 235.65 qPrevost = 347.9998
 Distribution of necessary heat deposit by other than LW radiation, such as;
 convection, SW absorption, CO2 thermalization etc. Total qtot W/m²



These additional sources of heat are needed, in order that the temperature distribution indeed corresponds to the measured one, shown in **figure 3**. The stack model calculates, apart from LW radiation, the necessary additional heat input distribution with a total value of: 149 W/m².

Possible other heat inputs are from:

- *absorption of incoming SW radiation by aerosols*
- *convection from the surface of sensible and latent heat, and*
- *thermalization of CO2 i.e. absorbance in the atmosphere of a part of the infra-red-active gas by LW radiation from the surface but not re-emitted. The heat is given by collisions to the bulk of the atmospheric molecules: 80% N2 , 19% O2 and the trace gas water-vapor H2O.*

The first two contributions are also mentioned by mainstream authors on the subject, the third possible contribution, the thermalization of CO₂ introduced by Pangburn [2], seems to be ignored by IPCC. We come back on the phenomenon further on.

Dependence of OLR on surface temperature

For studies related to the dependence on the ambient temperature of the evacuation of heat from the planet by LW radiation, we need the variation of OLR with the surface temperature TsK.

We use a Taylor expansion of OLR around TsK.

For that purpose we differentiate relation (4) with respect to TsK:

$$TLR(i) = TsK + ELR * z(i) \quad \text{and} \quad \vartheta(i) = \sigma * TLR(i)^4 \quad (4)$$

$$dTLR(i) / dTsK = 1 \quad \text{and} \quad d\vartheta(i) / dTsK = 4 * \vartheta(i) / TLR(i) \quad (4a)$$

The derivatives of the components $\vartheta(i)$ of the vector $\boldsymbol{\vartheta}$ (or **theta**) with respect to TsK are assembled in a vector: **dtheta/dTsK**.

By differentiating the stack equation $\mathbf{q} = \mathbf{K} * \boldsymbol{\theta}$ we find, for constant **K**:

$$\mathbf{dq} / dTsK = \mathbf{K} * \mathbf{dtheta} / dTsK \rightarrow \text{component N: } dOLR / dTsK = - dq / dTsK(N)$$

The result is: $dOLR / dTsK = 3.3089 \text{ [W/m}^2\text{/K]}$

We find a relation for the increase of OLR due to the surface temperature increase. We use the IPCC name for it, forcingOLR:

$$\text{forcingOLR} = (dOLR / dTsK) * \Delta TsK \quad (5)$$

Saturation of dense infra-red-active gases

In **figure 7** are given the results of analyses for water-vapor concentrations with $f_{tot} > 1$.

We see that the OLR is not decreasing any more for $f_{tot} > 1$.

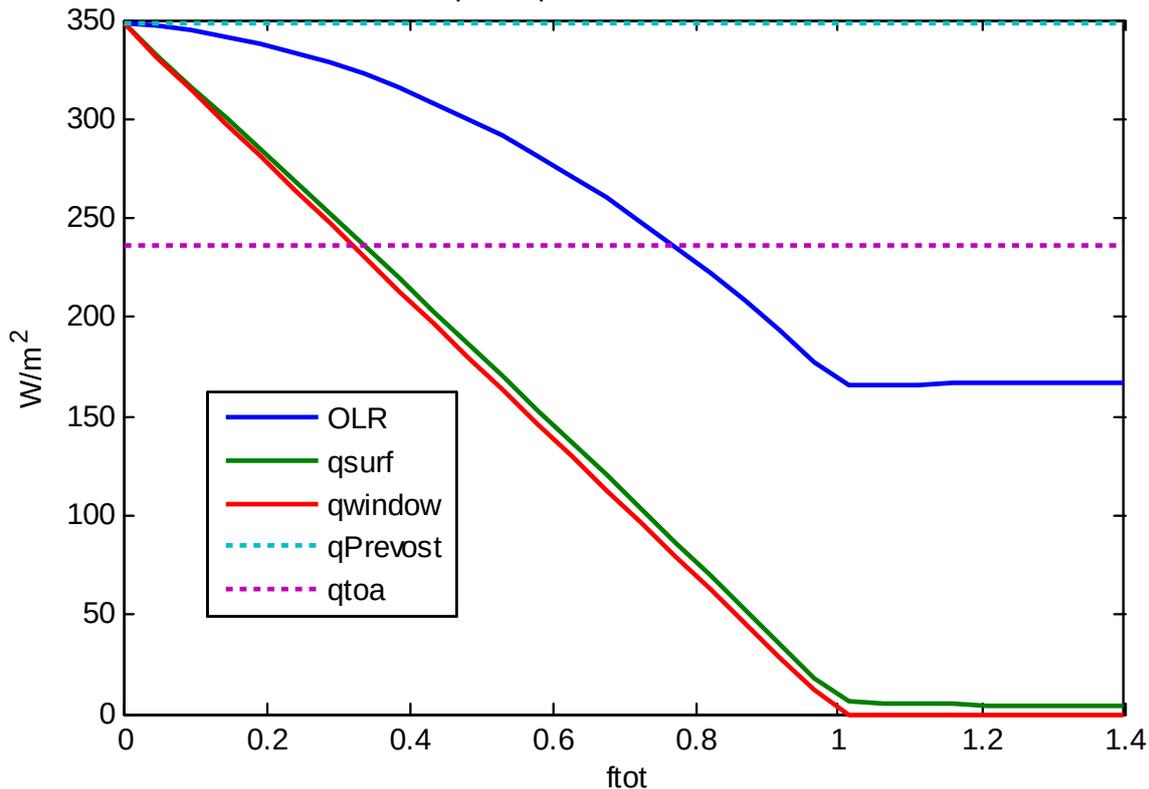
The phenomenon is called saturation and is explained by equation (2b), repeated here:

$$\text{viewfactor}(i,j) = 1 - \sum f(k) \quad \text{for} \quad z(i) < z(k) < z(j) \quad (2b)$$

For $\sum f(k) > 1$ the viewfactor(i , j) becomes negative and it is put to zero.

Figure 7

fig 3.1 The "saturation" phenomenon for water vapor by the stack model
 nods = 40 m = 7 height = 11.5 km ELR = -6.5 K/km
 ftot = 1.4 TsK = 288.7209 fractionH2O = 0.88325 qtoa = 235.65 qPrevost = 347.9998
 OLR, qsurf, qwindow as function of ftot



The saturation phenomenon does not appear for water-vapor with $ftot < 1$. It is shown here for water-vapor, for demonstration purposes only, because it is important for CO2 analyses further on, with $ftotCO2 > 1$. IPCC is hiding the CO2 saturation phenomenon, although it is one of the reasons — *saturation and thermalization of CO2* — for the planet not heating up, as will be shown in the next sections.

Results of the stack model for CO2

The stack model for H2O is a one-stream, mono-chromatic model of the evacuation of heat from a planet with only water-vapor. It turns out to be accurate enough when compared to the results of mainstream authors on

the subject, adjusted for the non-physical back-radiation in the two stream models. It can also be used for the analysis of CO₂ with saturation for values of $ftotCO_2 > 1$.

For the CO₂ analysis we take a model with a height of 30 km with the three 3 temperature zones, according to figure 3.

We use $N = 90$ nodes to model the three zones: 60, 15 and 15.

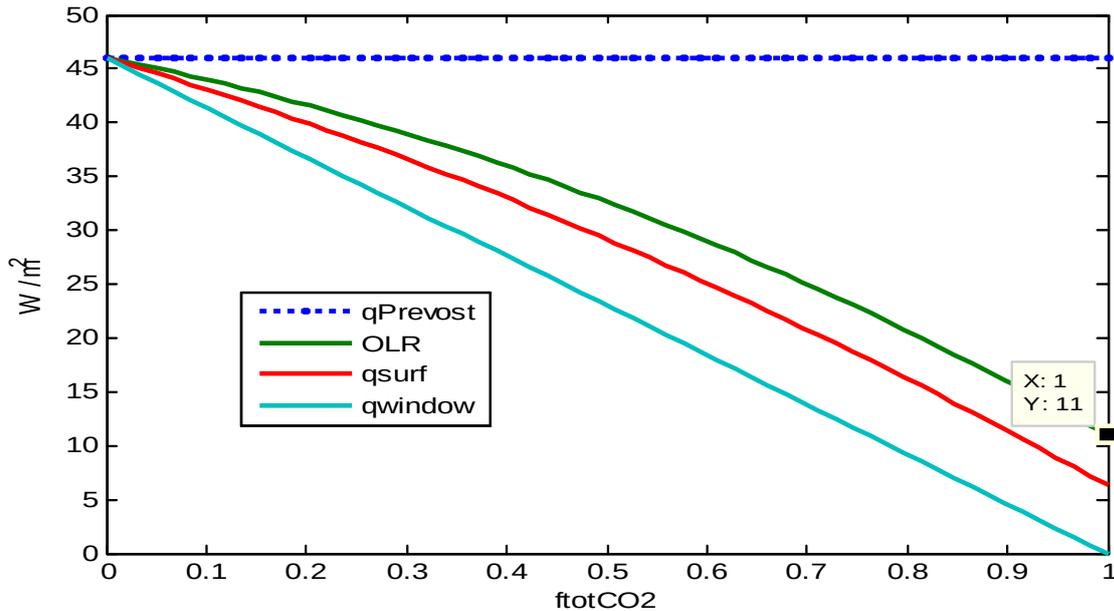
The results of the vector relation (3) for CO₂, $\mathbf{q} = \mathbf{K} * \boldsymbol{\vartheta}$, are given in **figure 8**, which is equivalent to **figure 5** for the water vapor analysis.

The components of \mathbf{q} and $q_{Prevost}$ represent now:

$$\begin{aligned} q(1) &= q_{surf} = LW \text{ CO}_2 \text{ surface flux} \\ -q(N) &= OLR = \text{outgoing LW CO}_2 \text{ radiation} \\ q_{Prevost} &= \text{fractionCO}_2 * \sigma * T_s K^4 = \text{fractionCO}_2 * \vartheta(1). \end{aligned}$$

Figure 8 *no thermalization and no saturation*

fig 4.1a Result of CO₂
 nods =90 height =30 km ftotCO₂ =1 TsK =288.7209 K fractionCO₂ =0.11675 qPrevost =46
 alfatherm= 0



Surface temperature increase due to CO₂

In **figure 8** we see a decreasing OLR_{CO₂} flux, from $q_{Prevost} = 46 \text{ W/m}^2$ for $ftotCO_2 = 0$ towards lower values. The decrease ΔOLR_{CO_2} as function of OLR_{CO₂} — i.e. also a function of $ftotCO_2$ — becomes:

$$\Delta OLR_{CO_2} = - (q_{Prevost} - OLR_{CO_2}) \quad (6)$$

In order to keep the total OLR constant, the necessary increase of OLR_{H_2O} due to the increase of the surface temperature T_sK , called forcingOLR by IPCC, is the opposite:

$$\text{forcingOLR} = - \text{deltaOLR}_{CO_2} = (q_{\text{Prevost}} - OLR_{CO_2})$$

With the corresponding temperature increase from equation (5) repeated here:

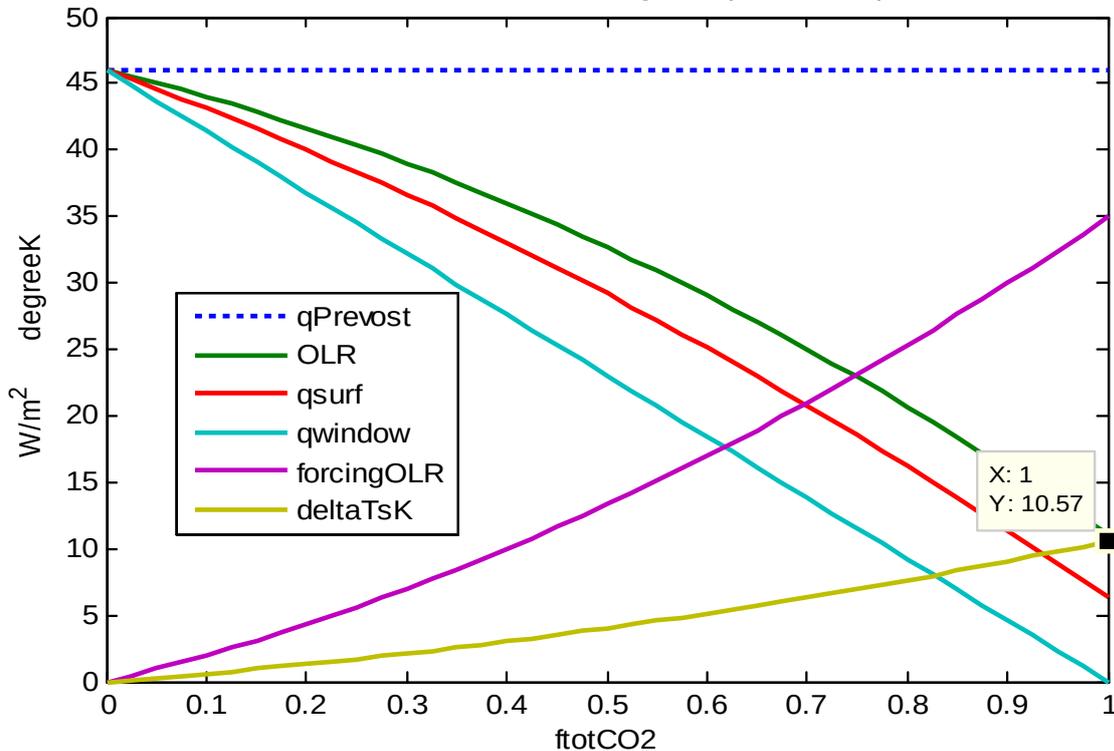
$$\text{deltaTsK} = \text{forcingOLR} / (dOLR/dTsK) \tag{5}$$

In figure 8a are given the results from equations (5) and (6)

Figure 8a *no thermalization and no saturation*

fig 4.1a Result of CO2

nods =90 height =30 km ftotCO2 =1 TsK =288.7209 K fractionCO2 =0.11675 qPrevost =46
dOLRdTsk = 3.3089 deltaTsK = forcingOLR/(dOLRdTsk) alfatherm= 0



Due to CO2 increase from ftotCO2 = 0 to 1 which corresponds from 0 to 400 ppm CO2, we see a temperature increase of 10.57 degree C. This increase of 10.57 is too high.

For ftotCO2 = 0.7 ,corresponding to the pre-industrial 280 ppm, the temperature increase from figure 8a is 6.34.

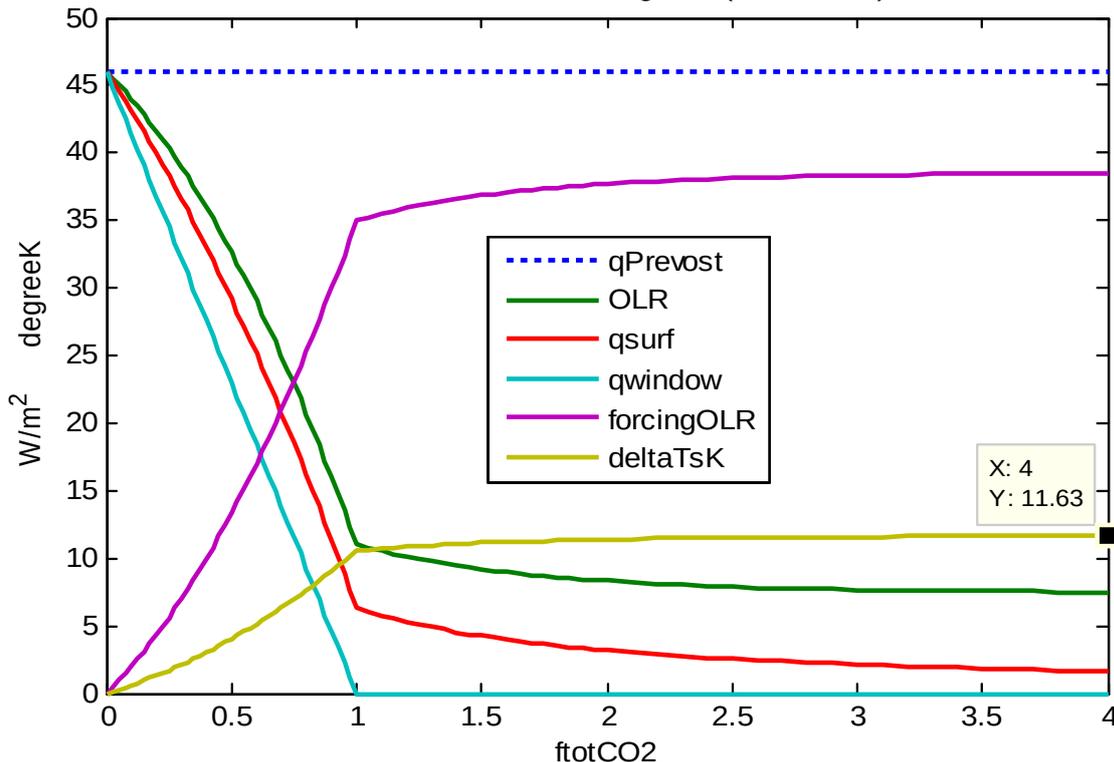
The difference becomes 10.57 - 6.34 = 4.23. This difference has been measured to be much lower, of the order of 1.5 degree C.

Pangburn [2] has given the reason: thermalization of CO₂ which will be dealt with in later sections of this paper.

For higher CO₂ concentrations there is saturation as shown in **figure 8b**, up to $ftotCO_2 = 4$, corresponding to 1600 ppm.

Figure 8b *with saturation only, no thermalization*

fig 4.1a Result of CO₂
 nods =90 height =30 km $ftotCO_2 = 4$ $TsK = 288.7209$ K $fractionCO_2 = 0.11675$ $qPrevost = 46$
 $dOLRdTsk = 3.3089$ $deltaTsK = forcingOLR/(dOLRdTsk)$ $alfatherm = 0$



The temperature increase from $ftotCO_2=1$ up to $ftotCO_2 = 4$ is small:
 $11.63 - 10.57 = 1.06$ degree C.

This result of small temperature increase beyond $ftotCO_2 = 1$ due to the saturation, agrees with the Happer numbers as shown in version II of this paper. See [5] and [4] for further examples of saturation only.

Thermalization of CO₂.

The classical Stefan-Boltzmann relation (1) assumes that the information exchange concerning the temperatures between surfaces and thereby exchange of energy is immediate. There are however different time delays in the process, according to Pangburn [2].

Relaxation time:

The time it takes for absorbed energy to be shared with surrounding molecules. It is of the order of a few microseconds.

Decay time:

The time between the absorption process of a molecule CO₂ and the re-emission process, it averages about 1.1 second.

Since the relaxation time is much smaller than the decay time, a CO₂ molecule in the absorption phase collides many times with the surrounding 80% nitrogen N₂ molecules and 19% oxygen O₂ molecules, as well as with infra-red-active water-vapor H₂O molecules.

The CO₂ molecule loses the surplus energy before it has been built up completely for emission.

The CO₂ molecule is said to be thermalized, the surplus energy goes to the bulk of the molecules of the atmosphere. The exchanged energy has lost its CO₂ identity, it uses H₂O frequencies of radiation to outer space according to **figure 6**.

According to Pangburn at lower altitudes all the CO₂ radiation is thermalized but at higher heights some back-thermalization takes place.

See **figure 4** and Pangburn blog [2] for further details.

The phenomenon has been confirmed to the author by le Pair [3].

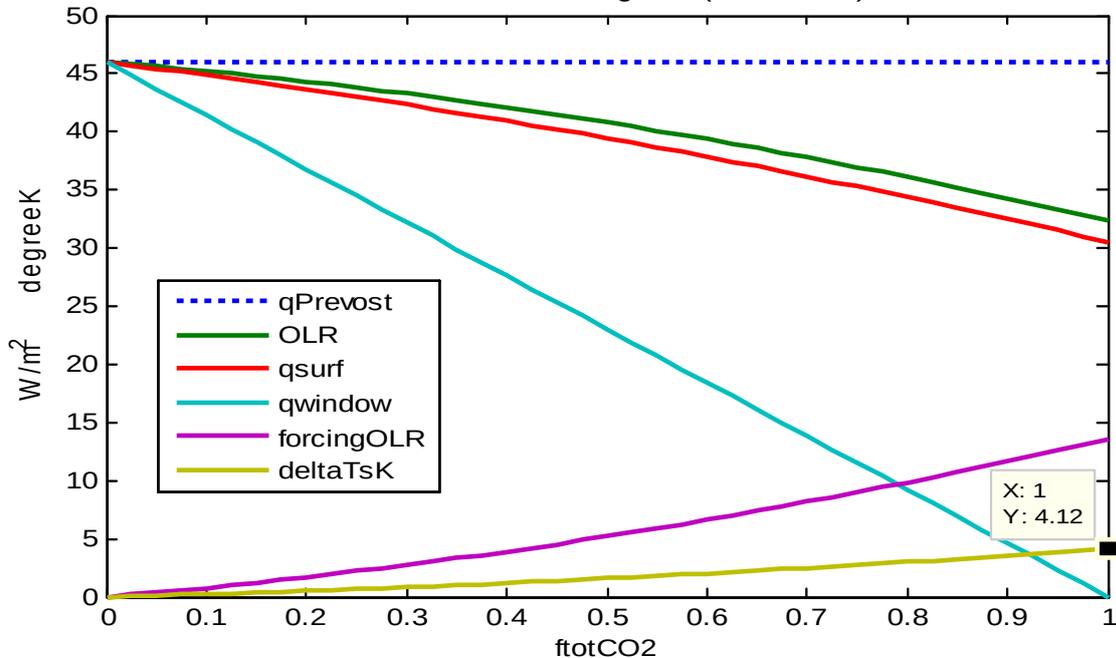
In the stack model we can take into account the results of Pangburn, by claiming that from the Prevost flux in **figure 3** of 46 W/m², a fraction $\alpha_{\text{fatherm}} = 28/46 = 0.61$ is thermalized and radiated to outer space by the water vapor molecules according to **figure 6**.

Figure 9 with $\alpha_{\text{fatherm}} = 0.61$ give the results between $f_{\text{totCO}_2} = 0$ up to $f_{\text{totCO}_2} = 1$ with thermalization.

It has to be compared with **figure 8a**, which is without thermalization.

Figure 9 with thermalization, saturation not applicable for $ftotCO_2 < 1$

fig 4.1a Result of CO2
 nods =90 height =30 km $ftotCO_2 = 1$ $TsK = 288.7209$ K $fractionCO_2 = 0.11675$ $qPrevost = 46$
 $dOLRdTsk = 3.3089$ $deltaTsK = forcingOLR/(dOLRdTsk)$ $alfatherm = 0.61$



For $ftotCO_2 = 1$:

$q(1) = qsurf =$ surface flux LW CO2 radiation

$-q(N) = OLR =$ outgoing LW 4.37 CO2 path + 28 H2O path, total 32.37 W/m² as compared to 11W/m² in **figure 8**

Pangburn results [2] were given for $ftotCO_2 = 1$ or 400 ppm.

Between values 0 and 1 of $ftotCO_2$, it is supposed that the thermalization is linear between 0 and 28 W/m².

For $ftotCO_2 = 0.7$ or 280 ppm the value of ΔTsK becomes 2.437 and for $ftotCO_2 = 1$ the value of $\Delta TsK = 4.12$: a difference of 1.647.

This difference is presented in **Table 1**.

The temperature difference between, the present value of $ftotCO_2 = 1.05$ and the value of $ftotCO_2 = 0.7$, gives a data point: it is said to be 1.5 degree. This discrepancy remains subject of further research.

In **figure 9** for $ftotCO_2 < 1$, only the thermalization is taking into account. For CO2 concentrations beyond the 400 ppm of the year 2015 AD, there is not only thermalization but also saturation, as shown in **figure 10**.

Figure 10

with both thermalization and saturation

fig 4.1a Result of CO2

nods =90 height =30 km ftotCO2 =4 TsK =288.7209 K fractionCO2 =0.11675 qPrevost =46
dOLRdTsk = 3.3089 deltaTsK = forcingOLR/(dOLRdTsk) alfatherm= 0.61

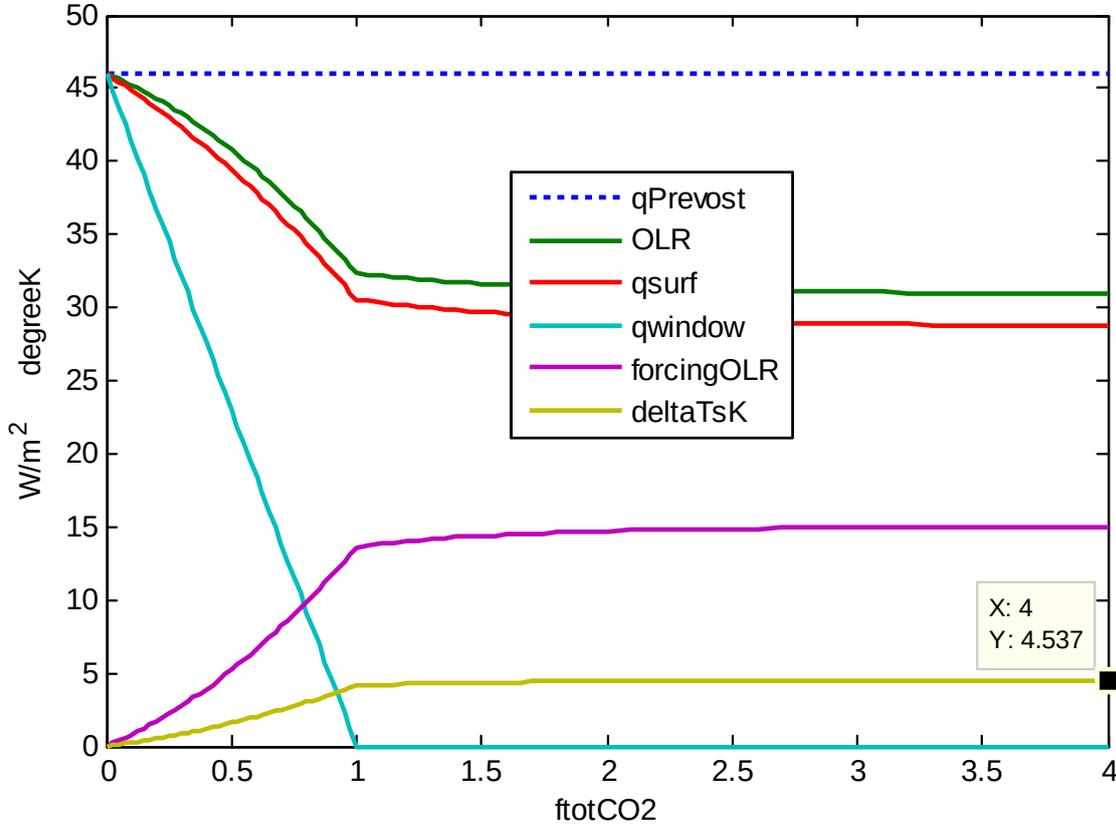


Table 1 summarizes the result of **figure 9** and **figure 10**, giving the temperature increase from ftotCO2 = 0 to ftotCO2 = 4, or 1600 ppm of the year AD 2615, assuming an increase of 2 ppm/yr.

Table 1 Temperature variations in degree C from ftotCO2 = 1. due to thermalization (alfatherm = 0.61) and saturation

ftotCO2	ppm	deltaTsK	deltaTsK -4.12	year AD
0.7	280	2.437	-1.647	
1	400	4.12	0	2015
2	800	4.443	0.323	
4	1600	4.537	0.417	~ 2615

The indicated temperature increases are only due to the increase of CO2 concentrations but for constant sun intensity.

Conclusions

The one-stream, chicken-wire stack model for infra-red-active trace gases, already validated for the analysis of LW radiation through an atmosphere with water-vapor, has now also been applied to the analysis of CO₂ gas. The stack model deals with the issues of thermalization and saturation of CO₂ in a transparent way.

The two phenomena, thermalization and saturation of CO₂, give rise two very small temperature increases, while

- before the year AD 2015 with CO₂ concentration below 400 ppm the thermalization of CO₂ has been ignored by IPCC
- since the year AD 2015, with higher than 400 ppm CO₂, both thermalization **and** saturation of CO₂ are ignored by IPCC.

Stack results with only saturation have also been given in version II of this paper [5] with similar results for temperature increases $\Delta T_{CO_2} = 1$ to 2, as reported by Happer [4].

Thermalization of CO₂ as reported by Pangburn [2], give even lower temperature increases as compared to the saturation only analyses.

The infra-red-active gas CO₂ is harmless and non-polluting.

Until nuclear power has been installed back again, we need fossil fuels to generate electricity and for combustion engines of cars, boats and planes.

Burning fossil fuels — **fortunately** — will increase the concentration of CO₂, also called "greenhouse" gas, which indeed is used in nursery greenhouses to boost the growth of vegetables and flowers.

CO₂ is food for plants

We need more atmospheric CO₂ to feed the growing world population.

Acknowledgment

The author wants to thank Claes Johnson [6] who inspired him to write this paper based on the one-stream LW radiation to outer space, avoiding the nonphysical back-radiation. The author interpreted the one-stream proposals from Johnson by using the Stefan-Boltzmann relation all ways for a pair of surfaces, enabling the concept of standing waves between resonating infra-red-active molecules with the same eigen-frequency.

Thanks to Dan Pangburn [2] for his authorization to include **figure 4** in this paper, and his explanations about thermalization.

Thanks to John O'Sullivan at Principia Scientific International for the publication of this paper.

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