RACM-2023

An elaborate and realistic Model
of the
average Climate

Version 3

14pt-PRELIMINARY

and not peered

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by

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Some general and applicable Sentences

Ultra posse nemo obligatur

Truth is daughter of time

Nothing is settled before all is settled

Science is never settled (or Science can never be settled, or If Science is settled it is no longer Science, it is Religion)

Knowledge, even when seeming verified by experiments, is commonly constituted by long chains of faiths. When attempting to achieve deeper knowledge, all chains should be identified and rechecked to get closer to the 'true reality'.

Vocabulary / Acronyms

IPCC   The Intergovernmental Panel on Climate Change

AR5   IPCC's Assessment Report No 5

TOA   Top of the Atmosphere

CC   Cloud cover

WV   Water Vapor

LH   Latent Heat (evaporation heat needed to release WV)

SH   Sensible Heat ('wind driven' energy removal from Earth's surface to the air)

SW IR   Short Wave Infrared Radiation

LW IR   Long Wave Infrared Radiation

Contents

Appendices

1. Introduction and Survey

1.1 General Introduction

The reader will find this essay about a model of the average climate system – rightfully – both amateurish and emanating from an engineer's brain, but, nevertheless, the model to be presented is based on both scientific and realistic ideas of energy processes considered to be the most important for the average climate.

The model, called RACM-2023 (for 'Refined Average Climate Model') is coarsely simplified (as all average models have to be) and operating like a physical and dynamic heating system with a structure as a control system and producing time series of the defined state variables, starting from a thought equilibrium state about 150 years ago.

The value of an average climate model is restricted by the facts that a) the variations in both time and space of states are many times bigger than the changes of their averaged values (over e g 10 years) and b) not all essential processes are known well enough to make any model become 'complete' in the sense that it can provide a user with reliable predictions, which is to say that the usefulness (always) will depend on how well the made presumptions correspond to reality.

The RACM-2023-model cannot be claimed to contain 'all essential' climate processes (e g the process that creates the cloud cover is omitted due to missing knowledge) but, the implemented processes are believed to represent well-known physical mechanisms, whose impacts can be studied with certain security (e g changes of atmospheric CO_2 concentration). Therefore, there is no intension to adjust the model's time series of states (e g surface temperature) to coincide with measured data; for the model studies it is sufficient that the states are 'correct' at one time point.

Fig. 1-A Earth's Power Budget according to IPCC / AR5, p 181. energy-budget, The Distribution of Latent Heat and 'solar absorbed atmosphere' upwards and downwards with arrows has been added by the author

Especially and in important contrast to established (and accepted) average climate models, this model operates with the process of evaporation and condensation of water vapour. At the condensation (with creation of clouds) the evaporation energy (moved from Earth's surface, normally called Latent Heat, LH) is released as (molecular) kinetic energy, i e as heated water drops, that will radiate heat (LW IR emission) in all directions.

This is very clearly indicated in the 'established' power budgets of Earth's climate related heat flows, an example in Fig. 1-A. This is a fact that seems to be accepted by all scientists and therefore it is a mystery why the LH appears to not be taken correctly into account in the established average models. A realistic quantification of the impact of LH, as shown in the model results, shows that the LH exerts a very strong cooling of Earth's surface and turns the CO_2 sensitivity down to a harmless level.

The structure of the model, defining how the heat flows interact together, is special by being described as a 'feedbacked control system', which actually is the way that the real climate system operates, see Chapter 2. The chaos-like behaviour of the real climate system cannot be ascribed to this basic heating system itself, but is rather caused by (mostly random) changes of inputs that either relate to the power balance or to parameter changes of the processes (e g absorption and reflection).

A basic prerequisite for the model is that the LH presented in the power budgets represents the <u>net</u> radiative part of the evaporation power, meaning that it is compensated for the part of the released energy that is directly returned back to the surface. This is the accepted apprehension and therefore there are no reasons for omitting the LH. Still, when the impact by released LH is omitted, as it seems to be in most of the 'established' (and commonly accepted) average climate models, then such models will - as it turns out – strongly support IPCCs idea of a very high CO_2 sensitivity.

<u>Simplifications.</u> As is typical for all average climate models, the utmost great complexity of the real climate system has been reduced by selecting overarching and simplified descriptions of the relationships between (what the author considers to be) the most essential state variable processes, based on annual averages, and omitting others, specifically:

a) those operating in the system without contribution to any heating or cooling, but only to even out temperature differences,

b) all time delays of energy transports,

c) temporary power 'injections' from sea currents, jet winds high up in the atmosphere and particles from volcanos e t c,

d) All impacts by cloud cover change on processes; changes are normally 'nulled' due to the uncertainty about its general temperature dependence.

e) The upwelling heat flow from Earth's interior part (in average about 0.08 W/m^2) is disregarded.

Also, in contrast to most similarly simplified average climate models the model here considers the impact by the SW absorption and reflection of insolation.

1.2 A summarized Survey of the modelled physical Processes

a) The considered Heat Flows of the RACM-2023 Model are shown in Fig. 1-B. All radiative heat emission/absorption (without transport of a material, also from/to solid/liquid material) are treated similarly to mechanical heat flows with integrated total power, without spectral considerations, (except, of course, for Green House Gases, GHGs). Heat flows can also be a mix of radiative and mechanical.

Heat flows (LW)

Total Out = P3(LW)+ P3(SW) = 340,00

So = **340,0**

P3(SW) = **101,30**

P3(LW) = **238,70**

SW Abs.
a3(sw) = 0,03000
S2

LW Abs. a3 = 0,5474
IN = UT = W3a = 179,91
W3a = V3 + a3*P2
V3 = 0

P2(SW) 100,00

Xo3 = 89,95

P2(LW) = 328,66

ϑ = 0,00

a2(SW,NO-CL) = 0,06000
a2(SW,CL) = 0,21400
S1

Z2 **80,66**

a2 = 0,8017
IN = UT = W2a = 519,53
W2a = V2 + a2*P1 + a2*Xo3
V2 = Z2 + YLH2 + YSH2

YLH2 = (1-ϑ)*YLH 80,00

YSH2 10,00

P1(SW) 75,77

Xo2 = 277,61

P1 = 347,36

a1(SW) = 0,03000

a1 = 0,7905
IN = UT = W1a = 533,55
W1a = V1 + a1*Ps + a1*Xo2
V1 = YSH1

YSH1 10,00

Yr = ϑ*YLHo 0,00

Se   r1*Se

Si = **155,74**

Pr = Xo1 = **324,93**

Ps = **384,69**

Ts = 287,00 'Thermal Down Surface' = 324,93

Fig. 1-B Heat flows considered in the RACM-2023 Model, Yr is zero but drawn as if a part of LH would return directly to the surface (ϑ = 0.25). Power flows as (W/m^2). Note: given values of some heat flows are not typical.

The model has three atmospheric layers with interacting LW IR flows, where one flow, Z2, comes from the insolation via an absorption process by the clouds, which is more realistic than the transmissions shown in the 'established' power budgets, e g in Fig. 1-A.

A 'near' mass balance between precipitation and Earth's WV production must exist, because WV or water cannot in the long run go on accumulating in the atmosphere. But this 'mass-balance condition' cannot support the idea that all released evaporation energy also returns back to Earth's surface.

b) The general mechanism to establish the surface temperature is the automatic balancing of energy flows, as described in Chapter 2. Our real climate system

today is exposed to several changes of both its inputs and parameters and is far from an equilibrium situation. But nevertheless, here the system will be considered to move from one equilibrium state to another in small time steps (one year).

c) <u>As a general mechanism,</u> a change of a LW IR flow that is hindered by an absorption process can be expected to consume/dispose energy and create further warming/cooling by changes in its process to generate LW IR to a point where there is a balance and no net energy consumption/disposal occurs. The atmospheric temperatures are thus assumed to be results and not causes to the situation with a certain equilibrium state.

The impact by the socalled Laps Rate mechanism of the atmosphere is neglected in the model, based on the general idea explained above that the adjustments of atmospheric temperatures are automatically made by the physical system to suit the need of power transmission (away from the Earth and the atmosphere itself).

d) <u>Average Columns.</u> The coarse simplifications and annual averages of heat flows (per m^2) are the base for the 'engineering-like basic average climate model', RACM-2023, which then physically can be seen as a very high vertical column with 1 m^2 base standing on the surface, surrounded by equal columns that cover Earth's total surface and without any interaction between themselves (since the walls work as perfect reflectors).

e) <u>A simplified Carbon Cycle</u> as a 1st order differential equation (see [1]) is used and gives the accumulating CO2 concentration in the atmosphere with parameters for residence time and for the release of 1) CO2 from the seas and 2) inputs from annual releases of anthropogenic CO2. The annual human emissions can (normally) be defined by a second order polynomial or by tabled values. <u>The rate of release of CO2 from seas</u> at increasing surface temperature, ΔTs, can be adjusted by a manual setting ('Cut and try') of a temperature coefficient (βe1). Its setting has to make the whole system to fulfil an 'one point matching condition' on the atmospheric CO2-concentration (in the case with annually, realistic human CO2 emission with 'ramp-like' temperature response). In that case the time course of the atmospheric CO2-concentration has to reach the single value 410 ± 0.5 ppm at t = 150 (near today). The model can create the annual CO2 emission as a 2nd order time function with two parameters: the slope and an 'acceleration' term. It can fairly easily be adapted to represent the real 'human CO2-emission history'.

The choice of the residence time (for CO2 in the Carbon Cycle) has a great impact on the accumulation of CO2 in the atmosphere and especially how fast it will decay after a stop of the human CO2 emission. See Chapter 3.
<u>A 'Methane Cycle'</u> operates in the same way as CO2 with settable residence time and annual 'human plus temperature defined CH4-emissions'.

f) <u>Three atmospheric layers</u>. The lowest layer lies between Earth's surface and a level where clouds start to be normally existing, the middle is defined as the 'normal altitude range' for clouds and the third layer is the upper rest of the atmosphere ending with (including) the stratosphere, Top of Atmosphere, TOA.

g) LW Absorption is considered as a pure scattering process, i e no energy is assumed to be consumed as heating power (to warm the greenhouse gases, GHGs, and the atmosphere, this heat is taken as the absorbed heat at the surface). The scattering process creates both an upgoing heat flow and a down going. There will be nine heat flows with nine equations to solve to get the heat distribution (similar to those that are used to derive 'Schwarzschild's equation'). The absorption value of each layer (middle Layer 2 has two absorptions: with and without clouds present) is calculated from an exponential function (Van Beer's law) with (average) relative layer concentrations of the GHGs (WV, CO2, CH4 and O3) as inputs. Each GHG (i) has one or more um-range in the power spectrum (of Earth's LW radiation at about 287 K, range 4 – 200 um) where each such range (j) has a defined max value of power content, B_{ij}, available for the absorption. Only two of these um-ranges have components with overlapping absorption. The propagation length in each atmospheric layer is an adjustable parameter, n_i.

The overlapping absorption spectrum for CO2 and WW is taken into account (still using Van Beer's law) which reduces their impact compared to a 'non-competitive' situation.

The 'Line Broadening' property of the CO2 absorption (only in layers 1 and 2) is achieved by a small correction factor that increases the absorption ranges (B_{ij}-values) with increasing CO2-concentration. This correction is here called the 'LB-process' and allows the absorption value to increase (at increasing CO2-concentration) more than the (small) increases that the exponential function would give at high concentrations.

The RL mechanism: When the atmospheric CO2-concentration increases all of it expands into somewhat higher and colder levels of the atmosphere, which means that the heat emission from the atmosphere's higher levels is somewhat lower until temperature is (automatically) restored. In the model an 'engineering-like' way to represent this process is made by adding a special contribution term, a3RL2(n), to the CO2-absorption value in Layer 3, which depends on the rate of change of the (relative) CO2 concentration u3:

$$a3RL2(n) = g1*a3RL2(n-1) + G3*δu3(n)$$
$$δu3(n) = [u3(n) - u3(n-1)]$$

The two cases 'with clouds' and 'without clouds' give different LW absorption values in Layer 2 and are calculated separately. A common absorption value is calculated as the weighted value with respect to the cloud cover value, c.

h) SW Insolation from space and absorption. The same layer definitions are used for the insolation processes. Both reflections and heat dissipation (with LW IR) are taken into account in the absorptions. The variation in space and time of the insolation is smoothed to one and the same constant value, So, coming from space and hitting Earth equally from all directions.

SW absorption by H2O (WV) and CO2 (while O3 omitted) and reflections is coarsely simplified by assuming scattering to occur in all (three) atmospheric layers plus reflection (of incoming SW IR at the entrance to Layer 2 when meeting clouds) and at Earth's surface. Absorption with heat converted to LW IR emission, heat flow Z2, is assumed to occur in the clouds in Layer 2. The Z2

heat flow is an output from the SW absorption system that acts as an input to the LW absorption system, which means that the two systems together keep the equilibrium properties with respect to input-output heat flows, e g, at TOA the sum of outgoing LW IR and SW IR will always be equal to the insolation So.

Upgoing and a down going SW IR power flows are created by the scattering processes with interaction between the layers. There will be nine variables and nine equilibrium equations to solve to get the total heat flow distribution (similar to the LW absorption). The absorption changes of this process can be deactivated (nulled) by the zero setting of a parameter. The reflection coefficients r_1, r_2 and r_{2d} are settable parameters (for each time step).

i) Cloud Cover, CC, state variable c. The starting value of c (called C_o) is assumed to be 0.65. Change of c can be expected to depend partly on the (changes of) atmospheric WV concentration, which would give this part a temperature dependence (and constitute an essential feedback loop), partly on quite unknown processes (not dependent on temperature or CO_2). But the issue about these unknown processes is a matter of debate and means that any model study with a temperature changing CC would be utmost uncertain.

The fact that introduction of a number of cloud properties would make the model utmost complex together with the uncertainty of how cloud cover depends on e g the surface temperature, leads to the idea that CC should only be studied as a possible impact on the other state variables, but without a feedback to CC, thus only as an attempt to reveal its 'strength'. Therefore the 'possible' temperature dependence (by the parameter/coefficient f_3) of CC normally is set to zero, which is a feature that many articles claim to be what measurements show (and most probably is the result of many different impacts).

The CC issue is further discussed in Chapter 6, where an interesting graph showing the time course of satellite measured CC is shown in Fig. 6-A.

j) The increase of LH due to temperature increase is assumed to follow a linear relationship with the coefficient f_4, which is allowed to be different from the increase of the WV content in the atmosphere. It is a matter of discussion how the LH and WV levels follow the surface temperature and therefore both f_1 and f_4 are settable parameters with their normal values considered to be 6.0 % per 1 °C (corresponding to the change of max. RH per 1 °C according to the Clausius-Clapeyron equation)

k) The increase of SH (being heated air, kinetic energy) follows the increase of the surface temperature, but only a small part of the increase that is assumed to be converted to LWIR and take part in the absorption process (and partly be disposed to space, giving a cooling effect). The separate parameter f_2 for the temperature coefficient only represents this part of SH that is converted to LW IR and normally the (conservative) value 0.01 1/°C is used.

l) Earth's radiative surface temperature is used to represent the temperature above its ground, where the 'official' temperature measurements are made and for the sea surface it is assumed to be the surface water temperature. It is assumed that changes of the model's temperature well represent those of the real climate system.

m) <u>Albedo</u> in the RACM-2023 model is defined as the percent part of the SW IR incoming to Earth, So, that is 'rejected' (appears to be reflected) back to space, P3(SW). The sources for the rejection (of SW IR) are modelled as (two) reflections: 1) at top of the clouds (r2) and 2) reflection at Earth's surface (r1) and 3) the absorbed/scattered SW IR from the three atmospheric layers, which interacts with the reflected heat flows (that have to pass through atmospheric layers with SW absorptions as modelled in the SW absorption process, Chapter 5), and results in the 'totally rejected' part P3(SW).

The reflection r2 can reasonably be assumed to be proportional to the cloud cover, (c).

The absorption (of SW IR) by the solid or liquid water of the clouds is assumed to be converted to LW IR and giving the heat emission Z2, 79 W/m^2, which (after interaction with the LW absorption/scattering process) is partly lost to space.

The albedo η is thus defined as: η = P3(SW)/So and the change
$\Delta\eta$ = ΔP3(SW)/So

Albedo cannot be seen (or modelled) as a single physical variable that can be directly impacted, but rather as a complex result of several physical variables. As an indicator of the efficiency of the insolation the quotient Si/So (where Si is the (average) absorbed/warming heat flow at the surface) is a better indicator.

1.3 Some further general Features of the Model

a) <u>Calculation of the time series for all state variables</u> has no principal problems, since only annual and numerical values of the state variables are considered and an approximative solution is accepted, the principle described in Chapter 2.

b) <u>Auto-tuning</u>. Even small changes of parameter values mean displacements of some state variables that normally also displace the equilibrium, Esurf(0), which can lead to totally false results. Therefore, the calculation program has a special procedure during 10 time steps before the 'real start'. The procedure is an auto-tuning process that operates as a control system with its own main feedbacks that <u>impacts the LW-absorption process</u>, further details about the autotuning is given in Chapter 7.

c) <u>Impact by the emissions of CH4</u> The GHG CH4 represents an input via its impact on the LW absorption process. Parameters are available for setting the levels of both natural (temperature driven from the surface) and human annual emission (beside these there are absorption related parameters available). As for CO2, the annual human emission can be chosen to be taken from a table with manually defined values.

When studying CO2-sensitivity, ΔTss, the state variable U1 is forced to the chosen value of the new CO2-level, and the human and natural emission of CO2 do mot interact with the calculations, although CH4 operates 'as usual'.

The contribution of the 'CH4 Cycle-process' is normally a part of the resulting ΔTss-value, but the impact by changing CH4 concentration can easily be nulled.

2. Model Structure and Heating of Earth's Surface

The average climate model is constituted by a few physical energy transports (with some conversions, see Fig. 1-C) from surface to space and vice versa and thereby becomes a fairly surveyable heating system, which is deterministic and does not exhibit any chaotic features by itself. The modelled (as well as the real) heating and cooling processes make the climate system by laws of nature to strive to a self-adjusting power equilibrium and can perfectly well be modelled, as here, as a control system with the 'set value' being zero for the controlled state, namely the power imbalance between incoming and outgoing power to the surface (and at TOA). The model has the true structure of a fairly simple control system, where the involved processes directly or indirectly depend on the surface temperature and have impacts on the power imbalance at the surface, called positive feedback when increasing the imbalance value, negative feedback when decreasing it.

Fig. 2-A The Control System Structure of the RACM-2023 Model
Red arrows: LW radiated heat flow, Black Arrows: 'mechanical' heat flows

Fig. 2-A shows the climate as a control system with a conventional block diagram of the heating processes, where the surface (more precise: the uppermost layer of the 'averaged surface' with its averaged properties, the green box in Fig. 2-A) has a dual function by automatically a) performing the 'comparison' of the net heating power to a natural zero-reference, i e 'calculation' of the power imbalance Esurf, and b) also performing the time integration (of Esurf) to a temperature. The imbalance Esurf controls the whole system, which (automatically) strives to make Esurf zero (representing an equilibrium state) after an input change or a change of any of the system parameters. It should be noted that the striving to zero cannot be fulfilled by reaching exactly zero Esurf in the case

with ramp-like increase of the input (the atmospheric CO_2 concentration); there has to exist a certain Esurf-value to make the system follow the state increases that the ramp-like input causes.

An essential model property is that, as response to absorption changes by GHGs, changes of the power imbalance Esurf are induced by changes of feedback loop gains. Comparison of impacts (by e g GHG changes) can therefore be deceptive. Neither of the conventional (but mainly confusing) concepts of drives, amplification factor, rapid adjustments etc, are necessary to use; the calculated time courses of the physical states directly show the effects of any manipulation of input or system parameters. This is, of course, very practical at the simulations of today's prevailing situation with ramp like increase of the CO_2-concentration in the atmosphere.

The parameter ϑ is defined as the fraction of YLH (Evaporation Heat) that is directly returned to Earth's surface and thereby only the fraction $(1-\vartheta)$, actually only a part of it, will exert a negative feedback (cooling of the surface) by making a certain fraction of YLH escape to space. However, in this essay the given value of YLH (about 80 W/m^2) is considered as the net the evaporation power (already compensated for losses that has been returned back to the surface), thus $\vartheta = 0$ and no changes of the parameter is studied.

The signal YSH (for the heat power flow Sensible Heat, taken away from the surface and converted to LW IR) is treated similarly to YLH but with a distribution to the two lower of the three layers (not shown in the diagram) and with interaction with the absorption process.

The function boxes normally describe states with static input/output relationships (recalculated after each time step).

Despite the unusual 'time step' method to calculate the surface temperature increase, there is still a fairly good logarithmic relationship between CO_2 concentration and the ΔTs response (at a step wise CO_2-change, see 8.2).

All state variables in this model have calculated numerical values and some are assumed to have linear changes with temperature changes. Their time argument is an integer (starting with zero). The model states do not assume any values between two consecutive time arguments and the model does not directly represent a 'sampled system'.

The state values and its changes are fairly easy to calculate and can, when necessary, easily be numerically integrated to give good approximations of discrete time courses of any of the introduced state variables. The realization of the program is made as an EXCEL-book, with convenient managing of variable relationships and time courses.

The basic equations of the heating are (time step n and n+1):

$$Esurf = e = Si - Pe - (YLH + YSH)$$
$$\delta\Delta Ts(n+1) = D*e(n)$$
$$\Delta Ts(n+1) = \Delta Ts(n) + \delta\Delta Ts(n+1)$$

A 'CO2-step-response with some process details: (Only a theoretical event!)

First there is an instant increase of the absorption with an instant increase of backscattered LW IR, or Back Radiation, which prevails during the first time step, during which the surface starts to warm up, since it now receives more power than it emits (positive power imbalance, $E_{surf}(0)$) = e(0); the surface assumed to have unchanged power insolation. At the end of the time step there has been an increase of the surface temperature, $\delta\Delta T_s(1) = D*e(0)$, and an increase of the LW IR emission (the atmosphere is warmed up at the same time). The new temperature and its emission give a new state (assumed to be in an equilibrium despite the 'driving' power imbalance at the surface), where there is a new 'Back Radiation' value and new values on all the heat flows that determines a new value of the power imbalance of the surface, e(1). This imbalance value is (normally) smaller than e(0) and this in turn means that the temperature increase during the next time step, $\delta\Delta T_s(2)$, will become smaller than the previous $\delta\Delta T_s(1)$, which in turn leads to a sequence of $\delta\Delta T_s(n)$ and e(n) that converges to zero and a total temperature increase $\Delta T_s = \delta\Delta T_s(n1) + \delta\Delta T_s(2) + \ldots + \delta\Delta T_s(n)$.

The speed of heating is defined by a fundamental constant, here called D [$°C/(W/m^2, Year)$]. That the uppermost surface layer becomes heated as a pure integration of the net power it is receiving, is a natural property and also a physical fact that can be shown by application of the general heating equation.

The D-value can be estimated from the properties of the fairly steady increase of Earth's surface temperature during a certain (long) time when a fairly constant power imbalance, E_{surf}, should have prevailed. (A somewhat accelerating temperature would indicate that the 'driving' E_{surf} is also somewhat increasing). The problem is to find the 'true' (average) value of this 'drive'. In the energy budget this value ranges from 0.2 to 1 W/m^2 giving a wide range of reasonable D-values (with the average 0.6 W/m^2). By assuming a steady linear temperature increase ΔT (over N years) due to a constant E_{surf}-value, E, the D-value can be calculated as $D = E/(\Delta T_s*N)$. Reading an increase $\Delta T_s = 0.7 °C$ during 1960-2010, N = 50 years, the average D-value becomes 0.6/(50*0.7) = 0.017. This value for D will be used as the 'normal' value in the model studies, but with checks with using the values 0.14 and 0.20 as well.

Part of the absorbed/scattered power (in the atmosphere) can be assumed to be consumed to warm up the air (by collisions between excited molecules, incl. the GHGs). This warming would mean a less 'Back Radiation' and a less surface heating and emission. But, on the other hand, the increased surface temperature would anyhow mean a certain warming of the atmosphere (i e a small cooling of the surface by convection). When considering only a fairly short time step, the neglection of the (small) warming of the atmosphere can be assumed to well compensate for the neglected 'convected' cooling of the surface. This is further motivated by the uncertainty of the heating coefficient. For the CO2 sensitivity studies the D-value is of no importance, since the time stepping procedure only means an iterative calculation to find the new equilibrium state.

3. Input Generation

3.1 Carbon Cycle for CO2

According to [1] the accumulation of CO2 in the atmosphere, C, can be described by a first order differential equation with separated CO2 inputs: $e_N(t)$ for natural release (emission) of CO2 from seas and $e_A(t)$ for the anthropogenic emission:

$$\frac{dC(t)}{dt} = e_N(T(t)) + e_A(t) - \frac{C(t)}{\tau_R(T(t))}. \qquad (23)$$

with temperature dependence for e_N and residence time τ_R

$$e_N(T(t)) = e_{N0} + \beta_e \cdot \Delta T(t)$$
$$\tau_R(T(t)) = \tau_{R0} + \beta_\tau \cdot \Delta T(t)$$

This description of the accumulation process (as presented in [1]) is general enough to perfectly well adapt C to correspond to the real time sequence of the atmospheric CO2 concentration when fed with the real sequence of human emissions. The model is much more simplified compared to the established so called 'Bern Model' and further, [1] claims that the residence time $\tau_R(T(t))$ in reality is considerably lower than suggested and used in the 'Bern Model'.

In the RACM-2023 model discrete functions and time argument always are used and the equation above is rewritten with U1 for the (total) atmospheric CO2 concentration (ppm) with an integer time argument, t, and new variable names for the emissions:

$$[U1(t+1) - U1(t)]/1 = z(t) - U1(t)/\tau_R(T(t))$$
$$U1(t) = z(t-1) + [1 - (1/\tau_R)]*U1(t-1)$$

where $\quad z(t) = e_N(t) + e_A(t)$

with temperature dependence for e_N and τ_R as above.

Further, it is possible and very practical to consider the accumulation process for U1 to consist of two parallel processes, since U1 consists of the two sources U1ext (originating from the human emission) and U1fb (which originates from the release of CO2 from seas, temperature dependent). With renamed emissions

$$e_A(t) = s1ext(t)$$
$$e_N(t) = s1fb(t) = s1fb(0) + \beta_e*\Delta Ts(t)$$
$$U1(t) = U1ext(t) + U1fb(t)$$
$$U1ext(t+1) = s1ext(t) + m1*U1ext(t)$$
$$U1fb(t+1) = s1fb(t) + m1*U1fb(t)]$$

where $\quad m1 = [1 - (1/\tau_{R1})]$

is a common factor for the CO2 accumulation process (the Carbon Cycle) and

$$\tau_{R1}(T(t)) = \tau_{R1o} + \beta\tau1*\Delta Ts(t)$$

The starting conditions for the model calculations concerning the U1-process are:

s1ext(0) = 0 (meaning that U1ext(0) = 0) and that U1 is constant = Uo. Considering the process that proceeds the starting, when the U1-process only consists of U1fb and for big values of t'.

Then   U1fb(t'+1) = U1fb(t') = Uo   which gives

U1fb(t'+1) = s1fb(t') + m1*U1fb(t') or (for t = 0):

Uo = s1fb(0) + m1(0)*Uo

and so $s1fb(0) = (1 - m1)*Uo = Uo/\tau_{R1o}$

Thus, at the start of a model run there is a natural annual emission s1fb(0) which maintains the constant atmospheric CO_2-concentration Uo

The two parts U1ext and U1fb of U1 can be kept apart at the calculation and facilitate a comparison of their relative sizes.

Obviously, a short residence time τ_{R1} demands a high annual natural emission, s1fb(t), of CO_2, e g for Uo = 280 ppm and τ_{R1o} = 10 years the start value of the annualy emission s1fb(t) becomes 28 ppm/year, which is more than10 times higher than the human yearly CO_2 emission of today. At model runs two different values of τ_{R1} will be used, 10 and 100 years.

The temperature dependence of the residence time τ_{R1}, i e the parameter $\beta\tau1$, is very uncertain and not intended to be studied in the model runs. A fairly low, positive value will be used.
The temperature dependence of the annual natural emission s1fb(t) is simplified to the linear function

$$s1fb(t) = s1fb(0) + \beta e1*\Delta Ts(t)$$

The coefficient $\beta e1$ can be used as an operative parameter for the (manual) adjustment of the total atmospheric CO_2 content at t = 150, i e U1(150) (which should correspond to today's value, about 410 ppm). It should be noted that the natural emission s1fb(t) represents a positive feedback in the climate system, since it will cause an increase of the atmospheric absorption at increasing surface temperature.
Description of the human emission of CO_2, s1ext(t) [ppm/year]. There are two options in the RACM-2023 Model: 1) a 2nd order polynomial defined as:

$$s1ext(t) = d1*t + d2*t^2$$

where d1 is the linear part and can be specified directly in the model program. The second needed parameter, called S1H, is specified as the value that s1ext must assume at t = 150 years (corresponding to today's emission). The two parameters can be manually adjusted to make the s1ext to fit a set of measured values.

2) Table of measured/estimated values (converted from Gigaton/year to ppm/year). Values have to be entered by the user.

Reduction ('quick stop') of human CO_2-emissions is facilitated in a convenient way by a special function in the s1ext-function. For t > tdo

$$s1ext(t) = s1ext(tdo) - [s1ext(tdo)-Md1]*Gd$$

where $Gd=[1-exp((tdo-t)/Td1]^4$

Fig. 3A -B gives an example of the resulting time series both with and without a 'quick-stop' for the following (typical) parameters: τ_{R01} = 100, $\beta_{\tau 1}$ = 0.2, $\beta e1$ = 1, d1 = 0.01, S1H = 2.85

Definiton of the settable parameters:
- tdo: Time set at which the reduction starts
- td1: A speed factor (inversed!) to reach the set final value for yearly human emissions
- MD1: The final value for annual human CO2 emissions

Fig. 3-A Normal CO2-related variables

Fig. 3-B A 'quick-stop' of human CO2-emission (with tdo = 150, td1 = 2, Md1 = 0)

The concept relative concentration is used in the calculations of atmospheric absorption with the variable u1 = U1/Uo (for CO2 in atmospheric Layer 1, nearest the surface) and with u2 and u3 for Layer 2 and 3 (and both normally = u1).

3.2 CH4 with Emissions similar to the Carbon Cycle

The emissions of CH4 (simultaneously including N2O) are for simplicity considered to have the same nature of accumulation in the atmosphere (with a natural emission and a human related emission) as CO2 and therefore the same equations as for CO2 are used (with quite other parameter values). The variable name for CH4 (including N2O) is V1 and the following relationships (equal to those of CO2) are directly stated without further comments than that there is no 'quick-stop function available.

$$V1(t) = V1ext(t) + V1fb(t) = [s2ext(t) + m2*V1ext(t-1)] + [s2fb(t) + m2* V1fb(t-1)]$$

with $\quad$ m2 = $[1 - (1/\tau_{R2})]$

$\quad\quad\quad$ V1ext(t) = [s2ext(t) + m2*V1ext(t-1)]

$\quad\quad\quad$ V1fb(t) = [s2fb(t) + m2* V1fb(t-1)]

$\quad\quad\quad \tau_{R2}(T(t)) = \tau_{R2o} + \beta\tau2*\Delta Ts(t)$

Further, $\quad$ s2ext(0) = 0

$\quad\quad\quad$ s2ext(t) = d3*t + d4*t^2 with s2ext(150) = s2H

$\quad\quad\quad$ s2fb(t) = s2fb(0) + $\beta e2*\Delta Ts(t)$

$\quad\quad\quad$ s2fb(0) = (m2-1)*Vo = Vo/τ_{R2o}

(The relative concentration v1 = V1/Vo is used for the atmospheric CH4 concdentration and is treated in the same way as u1)

4. LW Absorption

4.1 LW Heat Flows in the Atmosphere

For the representation of the absorption process that the emitted LW IR from Earth's surface is exposed to when passing through the atmosphere, the RACM-2023 model uses three atmospheric layers: The 1st, between Earth's surface and the level above which clouds are assumed to exist (in average) and where the 2nd layer begins. The 3rd layer lies directly above the 2nd and contains no clouds (roughly corresponding to the stratosphere).

Fig. 4-A. Heat flows to/from the three atmospheric layers

The concept of absorption (by gas component X) is here to be understood as 'the fraction of (all) X-molecules that are activated and taking part in an excitation/deexcitation process'. Further, as stated earlier, this process is assumed to be considered as pure scattering, i e the 'activated' molecules do not accumulate energy, but they merely redirect all 'hitting IR-photons' in all directions.

The GHGs considered are WV, CO_2, CH_4 and O_3, where WV is not an 'input GHG' but rather a state variable (with absorption properties) that is involved in the control mechanism. N_2O is a GHG that can be incorporated with CH_4 since their absorption ranges coincide to a great part.

The absorption by each layer is assumed to be homogeneous and their dependence of the GHG concentrations is the core task in this chapter

> [The absorption process with currently ongoing excitation and deexcitation of the GHG-molecules may initially generate heat dissipation (meaning creation of molecules with kinetic energy, i e an energy consumption), but these 'heated' GHG-molecules will interact with other molecules and create IR-photons (i e LW emission) and this will go on until there is an equilibrium temperature where this emission is equal to the absorbed part that creates the heat dissipation (absorption with kinetic energy). Only a certain distortion of the re-emitted/absorbed IR spectrum has occurred and can be overlooked].

The scattering at the absorption creates both up- and downwards heat transports with heat flows in each layer according to Fig. 4-A and, based on the 'energy conservation principle' and the assumption that no heat energy is consumed, the distribution of the heat flows between the three atmospheric layers is possible to calculate, giving a down-going part being reradiated back to the surface (Pr) and the rest being transmitted to space, P3, (and 'lost', giving a cooling power)

Latent Heat Heat, LH, is a LW IR heat flow injected into the middle layer and is quite simply the heat radiation from (the condensed) water drops with a variety of um-spectra determined by the temperature of the different water drops. The radiation is scattered in all directions as if it was the deexcited result of absorption, and – despite the undefined spectrum – its power can be added to the already ongoing radiative situation in the middle atmospheric layer. LH's increase with surface temperature gives the cooling feedback in the system.

Sensible Heat, SH, is also to be considered as the net radiative heat flow caused by winds that carry kinetic energy from the surface upwards into the troposphere where the net part with (most likely) collision processes is emitted as LW IR. The increase of SH with surface temperature also gives a cooling effect, harder to estimate since the emission process is hard to find descriptions of.

4.2 Equations for the Distribution of LW Heat flows

Of fundamental interest is the equations that rules the sizes of the two heat flows 'Outgoing LW' (P3) and 'Back radiation' (Pr) as a function of the heat radiation from Earth's surface, Ps, and the absorptions in each layer. Assuming a prevailing steady state situation in heat transfers and conservation of energy, nine equations (with nine unknown state variables, including P3 and Ps) can be set and solved for. Input states to the absorption processes are:

Ps, a1, a2, a3, V1, V2 and V3,

(a2 is called a2c when dependent on cloud cover c) where Vi represents the 'by input generated' heat power' in layer i (i e the sum Z of SW absorption (converted to LW emission=, released LH and SH). All of the absorption power in each

layer has to be disposed from the layer (sin no energy is assumed to accumulate) and the fraction βi (normally set to 0.5) is assumed to go downwards and the rest, (1 − βi), upwards. Wia represents the total flow of heat into layer i.

The basic energy equations (energy conservation) are:

Layer 1: W1a = V1 + a1*Ps + a1*Xo2   (1)

V1 = Z1 + T1   (2)

P1 = (1-a1)*Ps + (1-β1)*W1a   (3)

Xo1 = (1-a1)*Xo2 + β1*W1a = Pr   (4)

Layer 2: W2a = V2 + a2*P1 + a2*Xo3   (5)

V2 = Z2 + T2   (6)

P2 = (1-a2)*P1 + (1-β2)*W2a   (7)

Xo2 = (1-a2)*Xo3 + β2*W2a   (8)

Layer 3: W3a = V3 + a3*P2   (9)

V3 = Z3 + T3   (10)

P3 = (1-a3)*P2 + (1-β3)*W3a   (11)

Xo3 = β3*W3a   (12)

The output states Pr and P3 cannot directly be calculated by matrix technique (with EXCEL) as functions of the inputs: Ps, Vi, (where Vi = Ti + Zi), and a1, a2 and a3. The calculations for solving the 'unknown' state variable are as well made via intermediate variables as shown in Appendix APP-A.

4.3 Absorption Functions

Each atmospheric layer 'i' is assumed to have a total absorption that consists of a number of individual absorption 'components', aij, which exert absorption independent of each other due to the separated um-ranges (of the emission power spectrum) for each component. With 5 absorption ranges the total absorptions (for each layer) a1, a2 and a3 can be written as

a1 = a11 + a12 + a13 + a14

a2 = a21 + a22 + a23 + a24 +a25   (a25 represents absorption by clouds)

a3 = a31 + a32 + a33 + a34

Five um-ranges 'j' with the following absorption are defined, Fig. 4-B.

j = 1 for 13.5-16.2 um, where WV and CO2 have <u>overlapping</u> absorption

j = 2 for only WV absorption in the following subranges (and only in Layer 1 and 2):
4 – 7.3 um; 8 – 9.4 um; 9.9 – 13.5 um and 16.2 – 200 um

j = 3 for 7.3 – 8 um, where both CH4 and N2O have overlapping absorption with WV.

j = 4 for 9.4 – 9.9 um, where O3 has absorption in Layer 3 and WV in Layers 1 and 2   (without any assumed overlapping with O3).

[**j = 5** for the part of 8 – 13 um where absorption only occurs for clouds]

In Layer 3 particles are assumed to have LW absorption with the constant C3 added in the exponent.

Fig. 4-B

All absorption components follow the structure given below (when CO2 and WV are overlapping and in the case with clouds in Layer 2, see separate descriptions below)

$$a_{ij} = B_{ij} * b_{ij}$$

B_{ij} represents the power available for absorption (Layer i, range j) expressed as % of total power emission (estimated roughly as the um-range's surface of the 'total surface' in the 'power vs um spectrum), and

$$b_{ij} = [1 - EXP(-n_i * K_{ij} * x)]$$ is the relative absorption for the GHG component x:

x_i : WV relative concentration in Layer i (only Layer 1 and 2, $x_3 = 0$)

u_i : CO2 relative concentration (all three layers)

v_i : CH4 (incl. N2O)

w_3: O3 (Layer 3 only)

n_i is 'propagation length' for Layer i

K_{ij} is an absorption coefficient

<u>Relative absorption</u> is here to be interpreted as the percent of the maximal possible absorption (in the actual um-range), i e a number between 0 and 1. The maximal value that e g a11 can assume is per definition B11, which thus represents the 'the maximal available power (that can be absorbed/scattered) in the specified um-range. E g, for the emission Ps the scattered part by CO_2 + H_2O in layer 1 becomes a11*Ps.

By definition all relative concentrations have the value 1 at start equilibrium (for each layer).

A summary of the complete ensemble of absorption parameters (with values) is given in Appendix B, Tables B1, B2 and B3

It should be noted that the absorption by CO_2 in the small range 4 – 4.5 um has not been given an own um-range (the absorption by CO_2 there is account-ed for in the 'j1-range', but assumed to be quite small since Earth's emission is small in that um-range).

<u>Overlapping absorption</u>

<u>in the 'j1-range'</u>, 13.5 – 16.2 um WV and CO_2 have overlapping absorption and the b11-function then becomes:

b11(x1,u1) = 1 – EXP[-n1*(K11e*x1+K11d*u1)]

The K-parameters have been tuned to make the common absorption coin-cide well with laboratory data, [x]. For layer 2 the b21-function has the same parameter values K21e and K21d. This weighted sum of their respective co-efficients means that both components share the available power in the um-range.

<u>in the 'j3-range'</u> 7.3 – 8 um, where both CH_4 and N_2O have overlapping ab-sorption with WV, the relative absorption in Layer 1 becomes

b13(x1,v1) = 1 – EXP[-n1*(K13a*x1+K13b*v1)]

The choices of K13a and K13b (and K23a and K23b as well) have to be based on 'realistic assumptions' due to lack of relevant data.

<u>in the 'j4-range'</u>, 9.4 – 9.9 um, O_3 has absorption in Layer 3 and WV in Lay-ers 1 and 2

b14(x1) = 1 – EXP[-n1*(K14a*x1)]

b24(x2) = 1 - EXP[-n2*(K24a*x2)]

b34(w3) = 1 - EXP[-n3*(K34*w3 + C3)]

The constant/parameter C3 represents absorption by particles (in Layer 3).

<u>Line Broadening of CO2s absorption lines in the 'j1-range' (Layer 1 and 2)</u>

It is a well-known fact that the absorption lines of CO_2 are influenced by the molecular situation (e g molecular density (pressure) and temperature) making the spike-like lines (in the um-spectrum) broader and thereby increase the ab-sorption somewhat compared to the pure exponential function (Van Beer's law). The contribution to the absorption is fairly small, and not explored in liter-ature in a way that it easily could be implemented in the CO_2 absorption in Layer 1 and 2. In the RACM-2023 model the Line Broadening mechanism, LB, is realized in a totally artificial manner by quite simply let the B11 and B21 val-

ues be multiplied by a special factor $[1 + f11(u1)]$ that entirely depends on u1 and u2 (normally u2 = u1) in the following way:

$B11 \rightarrow B11*[1 + f11(u1)]$ where

For $(u1 < u1o)$: $f11 = 0$

for $u1 > u11o$: $f11(u1) = h11o*\{(u1-u1o)^n/[(u1-u1o)^n + a1oo]\}$

and B11o is the (original) start value.

Like-wise for B21: $B21 \rightarrow B21*[1 + f21(u2)]$

For $(u2 < u2o)$: $f21 = 0$

for $u2 > u21o$: $f21(u2) = h21o*\{(u2-u2o)^n/[(u2-u2o)^n + a2oo]\}$

Normally used parameter values:

$u1o = u2o = 1.05$ $h11o = h21o = 0.07$ $a1oo = a2oo = 2.0$

<u>Absorption In Layer 2 with a cloud cover c</u> is called a2(c) and is calculated as the weighted average of the two cases with 'no clouds' and 'only clouds'

$$a2(c) = (1-c)*a2_{NO-CLOUD} + c*a2_{CLOUD}$$

Here a2NO-CLOUD is calculated as described above but a2CLOUD is modified to get extra contributions by a constant C2 and also with absorption a25 = B25*b25cl in the 'j-range'.

$a2_{CLOUD}(x2,u2,v2) =$ B21*b21cl + B22*b22cl + B23*b23cl + B24*b24cl + B25*b25cl

or

$a2_{CLOUD}(x2,u2,v2)$	$= B21*\{1-EXP[-n2*(K21e*x2+K21d*u2 + C2)]\} +$	
	$+ B22*\{1-EXP[-n2*(K22*x2+C2)]\} +$	
	$+ B23*\{1-EXP[-n2*(K23a*x2+K23b*v2+C2)]\} +$	
	$+ B24*\{1-EXP[-n2*(K24*x2+C2)]\}$	
	$+ B25*\{1-EXP[-n2*C2]\}$	

<u>Impact by the cooling of the atmosphere at increasing CO2 concentration</u> is a dynamic property of the climate system, which is motivated by the fact that when CO2 expands in the atmosphere all its 'shells' are cooled off a bit and (before warmed up) and this will make the IR-emission (also out to space) reduced a bit. A fairly simple way to realize this mechanism, here called RL, is to let the reduction of emission from Layer 3 be equivalent with an increase of its absorption by the contribution a3RL. The fact that all layers (or shells) considered in Layer 3 successively warm up (and reaches its original temperature state) can be described by the discrete 'diffusion function' for the 'hindering' a3RL-contribution)

$a3RL(n+1) = z(n) + g1*a3RL(n)$

$z(n) = \delta u3(n)*G3 = [u3(n) - u3(n-1)]*G3$

When $u3(n+1) \rightarrow u3(n)$ i e when $z(n) \rightarrow 0$, then also $a3RL(n) \rightarrow 0$ (the impact disappear), which, e g, is the situation at simulations with a doubling of the CO2 concentration.

The values of the parameters G3 and g1 are troublesome to determine by physical calculations and therefore a 'cut and try' procedure has been used in order to get reasonable behaviour and impact.

Used as 'normal' are G3 = 0.40 and g1 = 0.25

Path length impact on the absorption is introduced by the parameters n1, n2 and n3 for each layer (in each relative absorption expression, as shown above)

The walls of the 'standard' 1 m^2 column acts as reflectors but a certain reflected path can be seen as a straight line. Geometrical analyse of the average path length of all possible directions that the evenly distributed directions of the upwelling IR-photons have, shows that the average length is a multiple of the altitude h of the layer in the range about 1,5 to about 3 (depending on h). Geometrical variables are shown I Fig. 4-D.

Fig. 4-C Three 1 m2 columns   Fig. 4-D Geometrical views
          beside each other

The normal used values are n1 = n2 = 1.5 and n3 = 2, which makes the absorption situation in RACM-2023 (considerably) less saturated than what is expected to be the 'real' case. This means that the model's absorption changes are overestimated (making the ΔTs-responses overestimated).

5. SW Insolation and Absorption

In a similar way as the LW-absorption, the down-going SW insolation heat flow creates upgoing flows when the SW IR photons become scattered by the absorption (excitation and deexcitation) process. Together with the reflected insolation there is a considerable 'Back Radiation', P3(SW), to space, as also indicated in the power budget diagram (totally about 100 W/m^2), see Fig. 1-A, where the reflections from ground and clouds can get through the atmosphere without any interaction, which is quite unrealistic and makes any estimation of the size of changes very uncertain. This bad situation is avoided in the heat flow diagram for the simplified case with only three atmospheric layers, as used in the RACM-2023 model, as shown in Fig. 5-A. The input So (also called S3) gives the 'resulting' output Si, which is the absorbed part that heats up Earth's surface, and the output Z2, being the sum of the two parts Z2a and Z2b created by 'absorption by solid materia' (i e clouds with water drops), meaning a conversion of SW IR photons to LW IR photons (i e heat radiation). The LW IR emission Z2 leaves the 'SW absorption system' and adds to the emission that is created by the heated water drops created at the condensation. The way this is done cannot be modelled physically correct without detailed data from the two 'heating' processes; it seems fair to accept that there are two known 'sources' for LW IR (heat) emission in Layer 2 beside the part that is scattered from Earth's LW IR emission (by atmospheric absorption).

The unknown heat flows S1, S2, Si, P1, P2, P3, X1, X2 and X3 can be solved for the given SW absorption values a1, a2, a2c and a3, and reflections values r1, r2 and r2d. The equations needed can be directly derived from the definitions of the heat flows given in the diagram of Fig. 5-A. The absorption by the clouds is considered to occur stepwise: first the parts Z2a respectively Z2b are 'removed' by the factor t2c = 1-a2c (and then the remaining heat flow is transmitted 'normally' by the factor t2 = 1-a2.

Fig. 5-A

Details about the solving of the equation system is given in Appendix APP-B.

Temperature dependence of the SW absorption by clouds. The total heat created at the SW heat absorption in the 'cloud drops' could be expected to be

(roughly) proportional to the 'amount' of clouds and thereby also to the cloud cover c. Since c shows no clear temperature dependence it is kept constant in the RACM-2023 model, but a possible temperature dependence for Z2 is still introduced by the 'coefficient parameter' f5 for an increase of a2c(sw,cl) at increasing WV content due to increasing surface temperature:

$$a2c(sw,cl) = a2co*(1+\Delta Ts*f5)$$

where $\quad$ Z2a = a2c*(1-r2)*S2 and Z2b = a2c*P1

The f5-value 0.02 is normally used. The 'starting value' Z2o about 79 W/m^2, has to be manually trimmed (changing a2co) to make the whole starting situation to match the 'budget power', Fig. 1-A (with somewhat lower Si, Z2 and P3 values). Reflection parameters r1, r2 and r2d are normally kept constant.

Atmospheric absorption.

Fig. 5-B (= **Figure 6.4** in Solar spectral irradiance (flux) at the top of the atmosphere and at the surface).
From http://irina.eas.gatech.edu/EAS8803_Fall2009/Lec6.pdf

In Fig. 5-B there is a considerable unexplained difference between 'Solar Irradiance Curve Outside Atmosphere' and 'Solar Irradiance Curve at Sea Level', which most likely is the result of a mix of a 'Reflection Process' and 'Absorption by Particles', despite that the curves could be assumed to have no such impacts or any impacts from the presence of clouds. Whichever cause this 'loss of power' has, the changes of the transmitted power can be assumed to depend dominantly of the changes in absorptions in the three atmospheric layers used also for the SW-absorption.

As can be seen in Fig. 5-B, WV has some (about 8) small absorption ranges for the transmission through the atmosphere, while there seems to be only one small range for CO2. Each Layer's total starting value for the absorption by H2O and CO2 used in the RACM-2023 model are the parameters a1o(SW), a2o(SW), a2co and a3o(SW), see Table 5-A, which are chosen quite low (to prevent an exaggeration of cooling). The parameters A11 etc are calculated from the more convenient parameters p and q, see Table 5-B.

Table 5-A Absorption Start Values and Functions

a1o(sw)	Fraction of SW abs./scattered in L1 (H2O & CO2)	**0,0600**
a2o(sw,no-cl)	Fraction of SW abs./scattered in L2 (H2O & CO2)	**0,0600**
a2co [a2co(sw,cl)]	Fraction of SW absorbed as heat by clouds (L2)	**0,2140**
a3o(sw)	Fraction of SW abs./scattered in L3 (O3 & CO2)	**0,0300**
r1o	Reflection coff. Surface	**0,3130**
r2o	Reflection coeff. from Space to clouds	**0,1110**
r2do	Reflection coeff. from Earth's surface to clouds	**0,1010**

Calc. starting (main) heating SW-flows: **SW-OUT(P3) =**   101,298

Z2 = 78,946

Si = 159,757

Sum: 340,000

Absorption functions							

a1(sw) = A11*[1- EXP(-G11*x1)]/[1- EXP(-G11)] + A12*[1-EXP(G12*u1)]/[1- EXP(-G12)]

a2(sw,no-cl) = A21*[1- EXP(-G21*x2)]/[1- EXP(-G21)] + A22*[1-EXP(G22*u2)]/[1- EXP(-G22)]

a2c(sw,cl) = a2co*(1+ΔTs*f5)

a3(sw) = A31*[1- EXP(-G31*u3)]/[1- EXP(-G31)] + A32*[1-EXP(-G32*w3)]/[1- EXP(-G32)] + A3P

Note: x1 (Layer 1) and x2 (Layer 2) are the relative WV-conc., u1, u2 and u3 are the same for CO2. w3 is the rel. conc. of O3 in Layer 3.

Table 5-B SW-Absorption Parameters

SW-Absorption Parameters ('User adapted')		
p11	Fraction of a1o(sw), H2O-abs. in L1	0,84
p21	Fract. of a2o(sw,no-cl), H2O-abs. in L2	0,84
p31	Fract. of a3o related to CO2-abs. in L3	0,10
p32	Fract. of a3o related to O3-abs. in L3	0,20
q11	Absorpt.level at start, H2O in L1	0,84
q12	Absorpt.level at start, CO2 in L1	0,90
q21	Absorpt.level at start. H2O in L2	0,84
q22	Absorpt.level at start. CO2 in L2	0,95
q31	Absorpt.level at start CO2 in L3	0,50
q32	Absorpt.level at start, O3 in L3	0,50

Calculated SW-Absorption parameters (by the program)		
A11	L1: A11 = p11*a1o(sw)	0,05040
A12	L1: A12 = (1-p11)*a1o(sw)	0,00960
G11	L1: G11 = - LN(1-q11)	1,83258
G12	L1: G12 = - LN(1-q12)	2,30259
A21	L2: A21 = p21*a2o(sw,no.cl) H2O	0,03360
A22	L2: A22 = (1-p21)*a2o(sw,no-cl) CO2	0,00640
G21	L2: G21 = -LN(1-q21) H2O	1,83258
G22	L2: G22 = -LN(1-q22) CO2	2,90042
A31	L3: A31 = p31*a3o(sw) CO2	0,00285
A32	L3: A32 = p32*a3o(sw) O3	0,00600
A3P	L3: A3P = (1-p31-p32)*a3o(sw) Particles	0,02115
G31	L3: G31 = - LN(1-q31) CO2	0,69816
G32	L3: G32 = - LN(1-q32) O3	0,69315

Note that the parameter A3P (as calculated from the a3o-value) gives a constant contribution to absorption in L3 and can be used for adaption purpose (e g for the 'loss of Power' mentioned above, which has not been made here).

The p-parameters are easy to use: e g p11 = 0.84 gives automatically the fraction of CO2 in L1 to become 16 % (of the total absorption a1(SW))

The q-parameters are also practical to use, since they define the 'starting point on the exponential absorption curve' without changing the absorption fraction at start. The higher value that is given (but below 1), the closer to saturation will the starting level of the absorption be.

It should be noted that the combination of the parameters r1o, r2o, all pij and qij is not unique for a desired set of Si-, P3(SW)- and Z2-values that would match the power budget values of these heat flows (considered as start values), especially when they should be allowed to have a tolerance range, e g ±0.5 W/m2.

When choosing a considerably higher value of a3o, e g 0.15, (as an attempt to match the 'unknown loss of power'), the initial power state of the SW-insolation becomes strongly displaced from the values of Si, P3(SW) and Z2 (that should match the given power budget). By (a manual) adaption of e g a2co, r1o, r2o and r2do it is possible to retrieve the 'budget state' (within ±0.5 W/m2) and the CO2-sensitivity values given by the model (for the different activations of functions) will remain the same as in the original case (with a3o); the changes will typically be less than ±0.05 °C.

6. WV Production, Clouds and Cloud Cover

<u>The estimation of YLH</u> To get a coarse estimation of how the evaporation heat LH changes with temperature it is reasonable to assume that it directly follows the change of the amount of WV in the atmosphere. One way for the estimation (suggested in [2c]) is to consider the fact that the starting level 80 W/m^2 has been developed along with a temperature raise of about 15 °C (with the reasonable assumption that it would be close to zero at 0 °C). A time linear rise would indicate (the coefficient) 5.3 W/m^2 per 1 °C (or 6.7 %/°C). Alternatively, assuming that the dependence would follow a fairly 'weak exponential' curve, similar to the Clausius-Clapeyron equation for the saturated concentration (and assuming a constant RH), would indicate a coefficient of about 6.3 % per 1 °C or 5.0 $W/(m^2,°C)$. In the RACM-2023 model there are two separate parameters related to the change of WV concentration with temperature: a) f1 setting the atmospheric concentration (mass/°C), relevant for defining a common relative WV concentration x1 used for the absorption functions, x1 = 1 + f1*ΔTs, b) f4 used for the change of LH with temperature: $Y_{LH} = Y_{LHO}*(1 + f4*ΔTs)$ where Y_{LHO} is the starting value, about 80 W/m^2 in). As normal values f1 = f4 = 0.06/°C is used. Both parameters, f1 and f4, have a fundamental impact on the model's properties, especially f4 since it represents a powerful negative feedback.

<u>Some aspects on the CC variable c.</u> The impact by clouds on the climate is – as also acknowledged by IPCC – a challenge, when regarding the large number of different types of clouds at different altitudes and their different features and impacts on the heat transfer situation. Not only the features of clouds are of importance, their creation (condensation) and 'termination' (precipitation) are also of fundamental importance for the dwelling/residence time of the clouds, which has to be directly associated with the CC. In an average climate model, as this RACM-type, only one variable is used to represent the CC created by all types of clouds (in order to keep the complexity on a practical level). IPCC admits that the uncertain description of the clouds' impact is the number one cause of the varying features (like CO2 sensitivity) of 'accepted' models.

In the RACM-2023 model the 'single cloud' impacts are represented by the variable c, which has impacts on absorptions, both SW and LW, and SW reflection (coefficients r2 and r2d), where the latter – as a good approximation – could be assumed to be proportional to c (and the impacts do not depend on how the c-value is created). Absorption is considered to be the weighted sum of the two cases 'with clouds' and 'without clouds'. The modelled impacts by c turns out to give a cooling at increasing c. As seen in the model responses to assumed reasonable changes of the variable c, the impact is fairly strong (and much stronger when the induced change of c is impacted by the induced change of temperature).

The basic problem with CC is to define its inputs and how the c-function is generated. Partly it may contain dependence on the amount of accessible WV (and this part would then be dependent on the surface temperature), partly other unknown impacts by physical circumstances, (as e g access to condensation nuclei, 'cosmic rays' and Earth's magnetic field). This uncertainty means

that a possible or reasonable feedback (to change c) should not be built-in into the model, especially as no clear temperature dependence for c seems to prevail (as commonly claimed e g by IPCC).

When no realistic 'cloud impact' can be modelled with any high degree of certainty, the accuracy of models with parameter adaption for fitting to measured time series, is undermined and models should not be used for prediction purpose. Unknown processes are built in and may change considerably over 10 to 20 years ahead. [Without 'curve fitting' the impacts by the modelled processes can still be estimated and compared to available measured data].

Still, in the RACM-2023 model the simple, but speculative, assumption can be realized, that a deterministic change of c is proportional to the change of LH, i e the parameter f3. This feedback gives a strong negative (cooling) feedback by the variable c, but such results must be considered as pure speculations. In the model studies (Chapter 8) c is kept constant by setting f3 = 0 and the constant c-value 0.65 is used.

An important premise for any 'speculated' external impact on c (to explain 'external' impacts on the climate) is that it has to have a slowly operating component with time scales of 100 years (as exemplified in Fig. 6-B and 6-C), but also be allowed to have short term variations, which could be one possible cause for the seemingly chaotic behaviour of the climate system.

A perhaps somewhat unusual picture of the real situation is given in Fig. 6-A for surface temperature change ΔTs (as anomalies) and the satellite measured CC, c, plotted (separately) versus the same time scale for the years 1980 to about 2016. Spontaneously, no pronounced coupling seems apparent, and no support for the idea that some external process has a major impact on CC.

It is worth noticing that before 2000 the c-level was significantly higher than it was some years after, and with some uncertainty it seems as if the rate of increase of the average ΔTs was smaller during that time period than it was after, which is what is expected when c decreases.

But the rapid drop of c from 1995 to 2003 seems to be associated with a pronounced stop of the increase of ΔTs, which is not to be expected at all. Rather, a slow (and somewhat delayed and somewhat accelerating) temperature increase could be expected. This supports the idea that there are also other 'unknown' processes (than CC related) that may have – seemingly fast – impact on the surface power imbalance and thereby its temperature.

Fig. 6-A Cloud Cover, CC, % as satellite measured and ΔTs

Fig. 6-B and 6-C show the slow changes of Earth's magnetic field strength and North Pole position, being (speculative) candidates for impact on the climate.

Fig. 6-B

Fig. 6-C

From: https://en.wikipedia.org/wiki/Earth%27s_magnetic_field

7. Soft-ware Realization and some Help-Functions

Some general features: The EXCEL-file 'RACM-2023-GEN3-RAMP-1000.xlsx' realizes the whole model (also 'step-response', by parameter setting). Almost all of its parameters are available on the sheet 'Main+Op.Param.' for survey and to change by typing changed values into their cells (with the absolute condition that only blue-coloured numbers are parameters that are allowed to be changed. All parameters can be typed in at any time and an automatic recalculation is immediately done.

Some parameters can be programmed to be changed during a run and then the parameter changes are of a totally different nature compared to the normal case with a run with new (constant but changed) parameter values from start. E g, starting with the normal So-value gives one result, starting with a somewhat changed value gives another, only little changed result, but introducing the same change of So after the start (always including the autotuning function) gives a quite different result even with relatively small changes.

All starting state parameters are settable and preset to values somewhat lower than those of the 'established' power budget in Fig. 1-A. E g start temperature To (about 150 years ago), is preset to 287 K, near 14 °C, and starting CO_2 concentration Uo = 280 ppm. The same adjustments of the starting values of Ps(0), Pr(0) and YLH(0) have been made without any elaborate calculations since the starting values (within say ±3 %) do not have any significant impact on the results.

The autotuning of the starting power imbalance to zero. Since any change of a parameter value causes a displacement of the starting equilibrium an automatic sequence of 10 time steps proceeds the ordinary model calculations with a special feedback mechanism that makes the surface power imbalance, Esurf, to rapidly converge to zero. This feedback mechanism adjusts some of the model's LW absorption parameters: n1, n2, n3, (path-lengths) and B11, B12, B21, B22 and B31 ('range power' parameters). The absorption changes make the Pr-value to change and thereby also the Esurf-value to strive to zero, while the Ts and Ps-values are kept constant.

The two parallel feedback loops (of the autotuning) are operating with parameters (settable in 'Mains+Op.Param.'-sheet): Loop-amplifications ANo for the ni-parameters and ABo for the Bij-parameters. Also, a common reduction factor F(n) = A/(A+n) (where n is the step number starting with 0 at the first step (where t = - 10) and A, like Abo and ANo, are easily trimmed, but already preset to good performance (and normally need no improvements).

A common algorithm is used according to the following pattern:

Auto-tuning & feedback parameters	
n1o = 1,50	n1(1) = n1o - Esurf(0)*ANo*F(1)
n2o = 1,50	n1(2) = n1(1) - Esurf(1)*ANo*F(1)
n3o = 2,00	B11(1) = B11o - Esurf(0)*ABo
ANo = 0,0200	B11(2) = B11(1) - Esurf(1)*ABo
ABo = 0,0013	
A = 13,700	
For n = 1 and 2: F(n) = 1, for n > 2: F(n) = A/(A+n)	

The preset values of the parameters ABo, ANo and A are:

$$ABo = 0.0013, \quad ANo = 0.020, \quad A = 13.7$$

Esurf(-5) is normally less than 0.005 W/m^2. The quotient ABo/ANo sets a sort of weighting factor.

The changing of the n_i-values should be interpreted as a changing of all K_{ij}-values (with an unchanged propagation length), since in the functions describing the absorption parts (a11, a12 etc) it is the product $K_{ij}*n_i$ that determines the absorption, e g: the contribution (to a1) a11 =

$$B11*\{1 - EXP[-n1*(K11e*x1+K11d*u1)]\}$$

The convergence towards zero for Esurf is shown in Fig. 7-A

Fig. 7-A

<u>A help-routine to find the βe1-value that gives makes the value U1(150) correct.</u>

U1(150) is the CO2 conc. at t = 150, also called U1*, and should normally be 410 ppm. (A similar routine is available for CH4's V1* = V1(150), with small differences compared to CO2's, see sheet 'CH4-Cycle')

A 'desired' value of U1(150) has to be typed in first (default value is 410). In a table it is possible to save/store two pairs of model results X1/Y1 corresponding to a run with βe1 and the result U1 (ppm) and another run with another βe1-value and another U1-value. Several runs can be tried before saving/storing is made and thus get one run with U1 just under U1* and the other just above. A straight linear interpolation is made and the βe1*-value giving U1* is presented in a cell that is meant to be copied and saved/stored in the cell for the 'current used' βe1-value. The result is normally a U1*-value within 0.1 ppm.

Manual Tuning of βe1 to fulfil condition U1(150) = U1*			
Try/type in desired value of U1* = U1(150) ppm :		410,0	
Type in Chosen βe1 →	5,7730		
Result/Current U1(150):	560,00		
SAVE Chosen βe1 & U1 in the following		5,5000	←(=X1)	NOTE: SAVE =
two cells (1st pair X1/Y1):		406,46	←(=Y1)	Copy & Paste'
Try/type a new βe1-value into 'Chosen βe1'			
Again, SAVE Chosen βe1 & U1 in the		6,0000	←(=X2)	
following two cells (2nd pair X2/Y2)		413,31	←(=Y2)	
Calculation of the 'desired' βe1*			
k = (X2-X1)/(Y2-Y1) =		0,0730	
x = βe1* = X1+k*(U1*-Y1)		5,7582	
Apply and check the resulting βe1* (x) by Saving it into Cell F19 ('Current βe1')			

Help-routines to simulate Time dependent Changes of:

      5.1 Cloud Cover, c

      5.2 TSI, solar insolation So

      5.1 Reflection Factor r1 (of incident SW to Earth's Surface

The following menu on sheet 'Main+Op.param' explains the options:

5. Time dependent bias for enhancing model ΔTs output for t =1 to t = tA		
tA	For time t > tA: δSoA, δSoB & δSoC are set to 0; α1 & r1 set to orig. values	**200**
5.1 Cloud Cover: c = [1 + f3*(Ts – To)]*Co*(1 + α1*t/10000)		
α1	Coeff for time chng of cloud cover c, %/(100yr)	**0,000**
5.2 So Changes	So → Soo+δSoA+δSoB+δSoC	
ON-So-Time-Dep		**1**
δSoA [W/m2]	**Step δSoA**	**0,000**
α5 [W/m2 per 100 yr]	Ramp coeff.: δSoB(100) = α5 [W/m2]	**1,710**
α6 [W/m2 per 100 yr]	Accel. coeff: δSoC(100) = α6 [W/m2]	**1,747**
5.3 Ramp-change Albedo: r1 → r1o*(1 + α2*t/10000)		
α2 [%-units]	**for t =100: r1 = (1+α2) % of r1o**	**0,000**

The calculations are performed on sheet 'Si-ai(SW)' for So- andr1-changes and on sheet '(c, x1,u1..9' for c-changes.

The chosen So-change has to be activated by choosing 'ON-So-Time-Dep' to 1 (deactivation of all parts by choosing zero) from time step 1 (first step after auto-tuning) until the chosen time step tA. The three available time functions are shown in the following diagram with values according to the table above (the diagram is shown on both the sheets 'Main+Op.param' and 'Si-ai(SW)'.

Time dependence of So, δSoA, δSoB & δSoC

8. Results of Model Studies

Note that somewhat lower values of Ps(0), Pr(0) and LH(0) than in the established power budget, Fig. 1-A, have been used.

8.1 CO2-sensitivity (ECS, CO2-change from 280 to 560 ppm), ΔTss.

At these runs the CO2-level is directly forced to 560 ppm regardless of the emission from seas (and therefore the residence time for CO2, τ_{R1}, being 100 years, has no impact). Changes of CC are not allowed, c is kept zero by f3 = 0. The RL-function is deactivated, because it has no impact on the final ΔTs-value, i e on ΔTss.

When 'Line Broad' is activated the CO2 absorption is amplified by a factor 1.022. The case with CH4-emission (Run 4 and 5) need some explanation: CH4's temperature coeff, β_{e2} is adjusted so that the resulting ΔTss-value creates an increase (by emission from seas/land) of the CH4 concentration from 2.0 ppb to 3.5 ppb

Five different function set ups and their resulting ΔTss-values are studied:

Table 8.1A

Run No	LH & SH temp depend	Line Broad	SW-absorpt.	CH4 emiss. temp depend	ΔTss (°C)	Change ΔTss (°C)
1	ON	OFF	OFF	OFF	0.445	
2	ON	ON	OFF	OFF	0.563	+ 0.118
3	ON	ON	ON	OFF	0.513	- 0.051
4	ON	ON	ON	ON	0.630	+ 0.117
5	OFF	ON	ON	ON	1.394	+ 0.764

Run 3 represents the common situation for an 'conventional' (and 'established') average climate model, where the impact by CH4 is excluded, with a ΔTss-value of 0.51 °C for the RACM-2023 Model. With a realistic impact by CH4, as shown in Run 4, the ΔTss-value becomes 0.63 °C, which reveals a fairly small climate impact (about 0.12 °C) by CH4, and makes the ΔTss-value to be only about 25 % of the 2.5 °C claimed to be the average of IPCC's studied models.

The strong impact by the released 'Latent Heat' (together with the much smaller impact by the 'Sensible Heat') is demonstrated by the removal of its impact in Run 5: the ΔTss-value is more than doubled compared to the model's value at Run 3. At Run 4 ΔTss was enhanced 0.12 °C by the CH4-emission.

All 5 runs with parameters and selected data are stored/saved in the file: RACM-2023-GEN-2-STEP-run1-5.xlsx.

There are other ways that CO2 sensitivity can be estimated with an equilibrium state, see Fig. 8-B. By using the stop-function available in the ramp-like input (of the 'CO2-cycle'), it is possible to make the total U1-value converge to a constant level just about 560 ppm, as demonstrated later in Run 11. In the latter case the ΔTss value became 0.65 °C, which is quite near the 0.63 °C at the step-response method.

8.2 Verification of the relationship ΔTsa = k·LN(U1a/Uo)

The stepwise changes of U1 from Uo = 280 ppm to U1a gives responses with final ΔTsa-values for the temperature change according to Table 8.1B

The functional set up here has τ_{R1o} = 100 years and is:

> (LH+SH)=ON, Line Broad=ON, SW-ABS=ON & CH4-EMISS=ON
> Parameters as for previous Run 4

The CH4-Emission has a constant temp. coefficient ($\beta e2$ = 1.112) for all tried U1a-values that gives an increase of the CH4 concentration from 2.0 to 3.5 ppb for the U1 step from 280 to 560 ppm.

Table 8.1B

Ua	Ua/Uo	LN(Ua/Uo)	ΔTsa
140,0	0,500	-0,6931	-0,623
280,0	1,000	0,0000	0,000
420,0	1,500	0,4055	0,328
560,0	2,000	0,6931	0,606
700,0	2,500	0,9163	0,802
840,0	3,000	1,0986	0,925
980,0	3,500	1,2528	1,001
1120,0	4,000	1,3863	1,048

Fig. 8-A

The RACM-2023 model shows a fairly good linear relationship for ΔTsa between – 0.7 to 1.0 °C. Above 1.0 °C there seems to be a saturation effect for ΔTsa. The logarithmic relationship depends on the fact that absorption changes increases exponentially when the atmospheric concentration decreases. An interesting finding was that at the 'course' towards the low Ua = 70 ppm, the system became unstable. This issue will not be further investigated here.

Time courses, i e the convergence for Esurf and ΔTs (to its new equilibrium) are shown in Fig. 8-B and -C. Note that the time courses only are approximatively correct, due to the discrete calculation method.

Fig. 8-B

Fig. 8-C

8.3 ΔTs-responses at ramp-like inputs with CO2 emissions.

The model's response to a growing concentration of atmospheric CO2 is studied for some different stopping situations of the human CO2 and CH4 emission.

Input generation. The input is generated by the two cycles for CO2 and CH4. The ramp-like (slowly accelerating) human CO2 emission (s1ext) has the value SH1 = 1.8 ppm per year at t = 150 year (corresponding to today) and the starting residence time, τ_{R1o}, has either the value 100 years or 10 years for comparison. A low value as 10 years means that the natural emission will dominate over the human. The temperature coefficient βe1 of the natural CO2 emission has to be manually adjusted in order to fit one point on the time course of a ΔTs-response to a certain value at t=150, se 'normalization' below.

The CH4-cycle also has a human and a natural emission, whose starting residence time parameter τ_{R2o}, always has the value 2 years (the same as in the previous Run 1 - Run 11). Example of time courses of CO2 and CH4 related concentrations from Run 12 are shown in Fig. 8-D and 8-E with the used stopping function of s1ext.

Fig. 8-D

Fig. 8-E

Normalization of runs. Manual adjustments are needed to achieve the 'normal' (measured) situation at t =150: the total atmospheric CO2 concentration, U1(150), has to assume the value 410 ppm (when starting with 280 ppm) and for CH4 a value about 2.9 ppb (when starting with 2 ppb) and, at the same time, the total temperature increase ΔTs(150) has to assume the value 1.0 °C.

When using only βe1 and βe2 (and no 'external 'bias') it turned out that the values of βe1 and βe2 that gave fulfilment of U1(150) = 410 only gave ΔTs(150) about 0.30 °C (with τ_{R1o} = 10; almost the same result for τ_{R1o} = 100, but with different βe1- and βe2-values). To fulfil also the temperature condition ΔTs(150) = 1.0 °C an 'external' bias has to be introduced (The alternative with positive feedback by states – e g SW-reflection at the surface – that could possibly depend indirectly on temperature should be analyzed, but not here).

Manual 'cut & try' showed that there existed a unique triplet of values of the used 'impact by bias parameters' and βe1- and βe2-values that made the 'normalization conditions fulfilled. For simplicity a slowly, only time dependent, accelerating increase of the insolation So, called the 'So-bias', has been used, see Fig. 8-F. The 'bias' is normally zero set after t=200, since the model's 'biased' behaviour for t > 150 is of minor interest.

The ramp like 'So-bias' enhances the ΔTs-response and thereby the natural release/emission of CO2 increases and facilitates a situation with 'correct' ΔTs(150) and U1(150).

Fig. 8-F

Function settings and runs. The 'normal' processes of the model are all activated (parameters as in the previous runs 1-11). The 'stopping-function' of the human CO2 emission is activated (to zero) at either t=150 (thus showing its impact for the coming 50 years) or at t>300 (in the case with saturation of the 'unbiased' climate model). Stopping the human CH4-emission is done at t=250 to reveal its impact.

Beside the response without 'So-bias', Run 14 & 18, the response of the 'So-biased' system without human CO2 and CH4 emissions is of interest and performed in Run 15.

Table 8.2A defines the performed runs with τ_{R1o} set to 100 years and the same runs are then repeated with τ_{R1o} = 10 years (with resulting ΔTs(150)-values).

Table 8.2A

Run No	Residence time τ_{R1o} (year)	So-Bias	STOP human CO2-Emiss. For t >	STOP human CH4-Emiss. For t >	ΔTs(150) °C
12	100	ON	150	250	0.998
13	100	ON	250	250	0.998
14	100	OFF	150	250	0.208
15	100	ON	0	0	0.797
16	10	ON	150	250	0.999
17	10	ON	250	250	0.999
18	10	OFF	150	250	0.084
19	10	ON	0	0	0.922

The ΔTs time courses for all Runs 12 – 19 are given in Fig.8-G and -H.

Fig. 8-G

Fig. 8-H

The main result is that an 'external bias', here the 'So-bias, is the dominant source of the heating process. For the case with residence time τ_{R1o} = 100 years, the 1 °C temperature rise without the 'So-bias' after 150 years is only about 0.2 °C, or 20 % when all of the assumed absorption processes of the

model (included also the RL-mechanism) are active. For the lower τ_{R1o}-value 10 years, the impact on ΔTs(150) is still smaller, only 0.084 °C, due to the total domination of the natural emission of CO2 (a smaller amount of CO2 is needed to reach the neccessary concentration 410 ppm CO2).

The low impact by CO2, (small CO2-sensitivity), also means that the impact to reduce the ΔTs(150)-value by stopping human emission of CO2, is quite small. 50 years after the complete stop of human CO2 emission (at t=150, see Run 12 in Fig. 8-G), the reduction is only about 0.17 °C (with the condition that the 'external bias' has the same pattern of increase during these 50 years). For τ_{R1o} =10 years this reduction is only about 0.064 °C !

8.4 Impact on the ΔTs 'ramp-response' for different values of the heating constant D [°C/(yr,W)/m^2]. The ΔTs-response is studied for a function set up of the model according to previous Run 12 (all assumed energy processes active) and for three values of D: 0.014 (Run 20), 0.017 (Run 21) and 0.020 (Run 22).

For these three cases the same normalization (and stopping of So-bias) is used as in the previously (8.3) and the resulting ΔTs-responses are shown in Fig. 8-Ia and -b for the case with τ_{R1o} = 100 and Fig. 8-Ja and -b for τ_{R1o} = 10.

Fig. 8-Ia

Fig. 8-Ja

Fig. 8-Ib

Fig. 8-Jb

Impact by different D-values.	ΔTs(200) °C
(TauR1o=100) Run 20 (D=0.014):	1,534
Run 21(D=0.017):	1,512
Run 22(D=0.020):	1,497

Impact by different D-values.	ΔTs(200) °C
(TauR1o=10) Run 20 (D=0.014):	1,594
Run 21(D=0.017):	1,576
Run 22(D=0.020):	1,564

The differences between the ΔTs(150)-values (with common τ_{R1o}-value) are quite small, less than 0.03 °C. The value of D is thus not crucial for the results.

8.5. 'Biasing' impact by slowly, ramp-like decrease of reflection parameter r1

Instead of using (slowly with time increasing) insolation So for enhancement of the model's ΔTs-response, slowly with time decrease of reflection parameter r1 can be used. Whether it represents a possible impact in the real climate system is uncertain and should be considered as a speculation.

The time dependent change of r1: $r1 = [1+t*\alpha2*/10000]*r1o$

where α2 [%-units] is defined as the increase of r1 in percent units after 100 years after start (i e for t =100: $r1 = (1+\alpha2/100)*r1o$)

The normalization of parameters is performed in the same way as described in 8.3 and means a unique value of α2, βe1 and βe2 that makes U1(150) = 410 ppm and ΔTs(150) = 1.0 °C, which is fulfilled with α2 = - 4.16.

Result from model Run 19-x2 with τ_{R1o} = 10 and r1o = 0.3130 gives:

 Δr1(150) = - 0.0195

The albedo-change after 150 years, Δη:

$$\eta_o = P3(SW) / So = 0,2979$$

 $\Delta\eta(150) = \Delta P3(SW,150)/So = - 0,0103$

The fairly small decrease of about 4 & per 100 years of r1 is sufficient to enhance the ΔTs(150) from about 0.3 to 1.0 °C! The 'shape' of the ΔTs time course is 'ramp-like' as that of r1, which is the dominating 'source' for the ΔTs response, see Fig. 8-K.

Fig. 8-K

8.6 ΔTs-response to extremely high natural CH4 emission. A time dependent enhancement of the annual natural CH4 emission, (s2fb(t)), is introduced to start at t = 150 ('today'), and called CH4-bias', so:

$$s2fb(t) \rightarrow s2fb(t) + \alpha7*[1-EXP(-t'/T7)] \text{ with } t' = t - 150.$$

By choosing α7 high enough, the atmospheric CH4 concentration, V1, will rapidly grow to high enough values to make the absorption due to CH4 become saturated (being the 'worst case').

To further enhance the impact by CH4 the absorption coefficients K13b, K23b and K33 (and the 'cloud' and 'particle coefficients C2 an C3) have been made considerab ly smaller, see Table 8.6A

Table 8.6A	Original value	Used value	Used value/Original
C2 =	0.2000	0.1500	0.750
C3 =	0.2658	0.2000	0.752
K13b =	0.3500	0.1750	0.500
K23b =	0.3500	0.1750	0.500
K33 =	0.7000	0.3500	0.500

This means that the starting point on the absorption curve (for CH4) is more distant from saturation (and the absorption changes will become bigger.

Four runs are made, combining the two cases with and without stopping the So-bias (which gives the 'correct' state condition at t = 150) and with and without 'CH4-bias' (after t = 150) see Table 8.6B. For all four runs τ_{R1o} = 10 and the processes 'LH', 'LB' 'RL' and 'SW-absorption' are activated.

The essential result is two time series from Run 30A and 30B, both with 'So-bias' = ON, see Fig. 8.6-L; when the enhanced 'CH4-bias' is introduced (Run 30B) with the $\alpha 7$-value = 10 (meaning that the CH4-conc. is amplified more than a factor of 20 after 50 years), the extra contribution to ΔTs after 50 years, after today', called $\Delta\Delta Ts$ becomes about 0.22 °C (not very alarmistic!).

In order to confirm the big increase of CH4-absorption related states of the model, Table 8.6C shows how they have changed in the three atmospheric layers have after 150 years (today) and t = 200 years.

Table 8.6B

(Run 30A)	TauR1o=10,So-Bias=ON, CH4-bias=OFF,tdo=tdC=250
(Run 30B)	TauR1o=10,So-Bias=ON, CH4-bias=ON,tdo=tdC=250
(Run 30C)	TauR1o=10,So-Bias=OFF, CH4-bias=ON,tdA=250,tdC=250
(Run 30D)	TauR1o=10,So-Bias=OFF, CH4-bias=OFF,tdA=250,tdC=250
	tA = 200 for all runs

ΔTs °C vs time (year), TauR1o = 10

Fig. 8.6-L

Table 8.6C Changes of CH4-related absorption states

b13, b23 and b33: relative absorption for CH4
a13, a23 and a33: CH4's contribution to total absorption
a1, a2(c) and a3: total layer absorption

RUN 30A	CH4-related variables	Value at t = 0	Value at t = 150	Value at t = 200	Δ(150-0)	Δ(200-150)	
	b13 =	0,83947	0,87508	0,89352	0,03561	0,01844	
Layer 1	a13 =	0,03190	0,03325	0,03395	0,00135	0,00070	
	a1 =	**0,82072**	**0,82745**	**0,83586**	0,00673	0,00841	
	b23 =	0,83947	0,87508	0,89352	0,03561	0,01844	
Layer 2	a23 =	0,03190	0,03325	0,03395	0,00135	0,00070	
	a2(c) =	**0,82608**	**0,82986**	**0,85057**	0,00378	0,02071	
	b33 =	0,72934	0,82042	0,86126	0,09107	0,04084	
Layer 3	a33 =	0,02757	0,03101	0,03256	0,00344	0,00154	
	a3(witha3RL) =	**0,51059**	**0,53007**	**0,53769**	0,01948	0,00762	
Total	ΔTs =	0,000	0,998	1,643	0,998	0,645	
	V1fb =	2,000	2,572	2,979	0,572	0,406	

RUN 30B	CH4-related variables	Value at t = 0	Value at t = 150	Value at t = 200	Δ(150-0)	Δ(200-150)	Δ(30B-30A)
	b13 =	0,83947	0,87508	0,99748	0,03561	0,12240	
Layer 1	a13 =	0,03190	0,03325	0,03790	0,00135	0,00465	
	a1 =	**0,82072**	**0,82745**	**0,84245**	0,00673	0,01500	0,0066
	b23 =	0,83947	0,87508	0,99748	0,03561	0,12240	
Layer 2	a23 =	0,03190	0,03325	0,03790	0,00135	0,00465	
	a2(c) =	**0,82608**	**0,82986**	**0,85057**	0,00378	0,02071	0,0000
	b33 =	0,72934	0,82042	0,99999	0,09107	0,17957	
Layer 3	a33 =	0,02757	0,03101	0,03780	0,00344	0,00679	
	a3(witha3RL) =	**0,51059**	**0,53007**	**0,54445**	0,01948	0,01438	0,0068
Total	ΔTs =	0,000	0,998	1,865	0,998	0,867	
	V1fb =	2,000	2,572	25,699	0,572	23,127	
						ΔΔTs =	**0,2219**

It is worth noticing that the 'extra' contribution $\Delta\Delta Ts$ in the case without 'So-bias' (Run 30C and 30D) also is about 0.22 °C (50 years after the CH4 concentration was extremely enhanced). This value is thus to be understood as the maximal contribution (added to the current CO2 induced ΔTs impact) that absorption changes of CH4 can exert (in the model with its already enhanced sensitivity to CH4 changes)

9. Concluding Remarks and Discussion

The RACM-2023 model is special by its dynamical operation with physical energy processes, of which heat emission (from Earth's surface) and its atmospheric absorption are common with the conventional (and also simplified) average climate models, and, in important contrast, also the evaporation process with condensation (also called the LH process), with a transport of energy from surface to clouds). A few other processes are implemented into the RACM-2023 model, e g 'Line Broadening' (at LW absorption) and 'SW absorption' (of insolation).

The LH process is claimed to be treated in a physically correct way, where, at condensation, liquid (or solid) water drops are created (and also heated by the released evaporation energy) and will, without doubt, radiate heat in all directions with the (total and average) power of about 80 W/m^2. When Earth's surface temperature increases, so will also the amount of released WV and thus there is by law of nature a temperature dependence of the radiated LH from the clouds.

The RACM-2023 model (with three atmospheric layers) gives an answer to the question: Where does the LH go?: About 40 % of it radiates towards space (gives a cooling), the resting 60 % returns to the surface (when assuming that the radiated heat takes part in the LW absorption).

The introduced LH process gives the RACM-2023 model a strong cooling feedback, which seems to be absent in the conventional models. As well-known from control systems theory a strong negative feedback means a good ability to counteract interferences (e g annual human CO2 emissions) and make the deviation response (from power balance) become small.

Consequently, the RACM-2023 model shows a significantly lower CO2 sensitivity (ESC, here called ΔTss), than is typical for conventional models. E g, for the RACM-2023, ΔTss was found to be about 0.63 °C in the realistic case with increased atmospheric CH4 concentration due to the temperature increase (which is normally not considered in the conventional models), while conventional models show ΔTss-values in average about 2.5 °C.

The RACM-2023 model, when disturbed with annual human CO2 emissions (and without any external 'bias'), responds with a time series of increasing ΔTs-values, that after 150 years, i e today, becomes as low as 0.2 – 0.3 °C. Another important result of 'ramp-input' runs is that a total stopping of the human CO2 emission (today) would have a hardly noticeable effect on the surface temperature within 50 years, especially for the case with an assumed residence time for CO2 of only 10 years.

An unfortunate and problematic coincidence prevails here; due to the absence of the cooling by the LH process in the conventional models, their responses to the annual human CO2 emissions are insufficiently reduced, and therefore their ΔTs-value developed for 150 years (i e until today) happens to reach the relatively high level 1 °C, which happens to be what measured data shows and is expected of a (realistic) model. Here is the rub, because (too) many scientists seem to have fully accepted these conventional models because of their

good match with measured temperature data, which was seen as evidence for the 'correctness' of the models, and therefore the model presumptions were not further questioned and became the base for a consensus of CO2s alarming role in the climate situation.

In Ref. [13], p 4, an 'experiment' on a computer model of the average climate is described (1999): with unchanged WV concentration/state the ΔTs response at a doubling of the atmospheric CO2 concentration became slightly more than 1 °C and, when the WV concentration was allowed to increase with temperature (the normal operation of the model) the ΔTs value (the CO2-sensitivity) became quite high, 3.4 °C (higher than near the 'normal' value 2.5 °C). The experiment supported (and still does) IPCC's idea of an 'amplification factor' exerted by WV. Although the model work itself was highly appreciated, the 'experiment' very clearly showed (for those who were well acquainted with the premises of an average climate model) that the model could not have a correctly working 'LH process'. But, the 'experiment' can be seen as a sort of 'litmus' test to detect the absence of a correctly working LH process. How many of today's 'established' computer models (not only of the average climate) do not have the LH process built-in correctly and how many scientific users are aware of how their model takes care of the LH energy? (Perhaps 97 %!). When the same 'experiment' is made on the RACM-2023 model (with the LH process operating), the result is a reduction of the ΔTs-value, i e there is no amplification at all of ΔTs by WV processes.

The fear for alarmistic temperature increase due a strongly enhanced natural emission (natural release) of methane (CH4) is not justified according to a model simulation (see 8.6), which shows that the additional increase of temperature (within 50 years from now, 2023) will certainly not exceed 0.25 °C.

When accepting both the LH process and its model representation in the RACM-2023 model as a process of the real climate, then the logical conclusion is that the real climate system has to be exposed to strong impacts by other processes, here called 'external', meaning other than those 'normally' considered (changes of GreenHouse Gas concentration and temperature driven feedbacks, incl LH as in the RACM-2023). Common for most of the 'external' impacts has to be their slow and persistent nature.

The question about which 'external' processes that would be possible candidates and details about their nature of impacts (and how they combine) is far beyond the scoop of this essay, but a few speculative thoughts will still be presented. One important part of this issue concerns the changes of the cloud cover, CC (variable c), which can be suspected to be exposed to 'external processes that have impact on both the creation of clouds and their 'termination' (with precipitation). In the RACM-2023 model the parameter f3, defining the temperature dependence of c, is zero, meaning no changes of SW reflections at the upper and lower side of the clouds, no changes of LW absorption (due to c). Heat SW absorption of the clouds is, however, assumed to have a temperature dependence by the parameter f5, preset to 0.02 /°C.

The absence of any clear temperature dependence of c may very well be due to some 'external processes' that dominates over the access of WV, and it may

be possible that there does not exist any 'natural' temperature dependence at all, and that could (partly) explain the chaotic behaviour of the climate system, since, at the same time, the CC value has a quite strong impact on e g the ΔTs value (even on a relatively short time scale).

An example of a slow parameter change representing a 'geological' impact is a slowly changing (decreasing) of the reflection of the incoming SW insolation at Earth's surface, r1, see 8.5, which, e g, can be assumed to be a consequence of growing population. When introducing a (linear) time dependent change of r1 from start, it is sufficient with a decrease of only 4.2 per cent units per 100 years to make the modelled climate system equal with today's situation with $\Delta Ts = 1$ °C and total atmospheric CO_2 concentration = 410 ppm.

Despite the high level of cooling feedback present in the RACM-2023 model, even small long term external impacts can make today's ΔTs become four times bigger than the impact by only CO_2 (and CH4) increases.

10. Some inspiring Documents

[1]   **Scrutinizing the Carbon Cycle and CO2
Residence Time in the Atmosphere** by **Hermann Harde**

Helmut-Schmidt-University Hamburg, Experimental Physics and Materials Science

http://dx.doi.org/10.1016/j.gloplacha.2017.02.009

[2a] **Radiation Transfer Calculations and Assessment of Global Warming by CO2**
by **Hermann Harde**

https://www.hindawi.com/journals/ijas/2017/9251034/

[2b] **Radiation and Heat Transfer in the Atmosphere: A Comprehensive Approach on a Molecular Basis**, by **Hermann Harde**, *(Laser Engineering and Materials Science, Helmut-Schmidt-University Hamburg,*

https://www.hindawi.com/journals/ijas/2013/503727/

[2c] **Advanced Two-Layer Climate Model for the Assessment of Global Warming by CO**2,
by **Hermann Harde**, *(Experimental Physics, Helmut-Schmidt-University)*

https://www.researchgate.net/publication/268981652_Advanced_Two-Layer_Climate_Model_for_the_Assessment_of_Global_Warming_by_CO2

[3] **Earth's Global Energy Budget,** Kevin E. Trenberth, John T. Fasullo and Jeffrey Kiehl,

National Center for Atmospheric Research.

http://www.cgd.ucar.edu/staff/trenbert/trenberth.papers/BAMSmarTrenberth.pdf

[4]   **REMOTE SENSING APPLICATIONS WITH METEOROLOGICAL SATELLITES**

by W. Paul Menzel, University of Wisconsin, Madison, WI

http://www.wmo.int/pages/prog/sat/documents/SAT-PUB_SAT-28-TD-1078-Applications-with-meteorological-satellites-Menzel-2001.pdf

[5a] **Investigation of the Kinetics of Condensation**, Owe Berg & Douglas George, Journal of Geophysic Research, Vol. 73, No 10, May 15, 1968 (available from P Sundberg)

[5b] **Discussion of Paper by T. G. Owe Berg & Douglas C. George, Investigation of the Kinetics of Condensation' by BURTON G. SCHUSTER,** Journal of Geophysic Research, Vol. 74, No 13, June 20, 1969 (available from P Sundberg)

[6] **Radiation from Earth**, From Owe Bergs **"Tidskrift för Teknisk Fysik, Volym1, Feb. 1994, p 29-32, (**available from P Sundberg)

[7] About Consensus (http://www.klimatupplysningen.se/?s=97+) in swedish

[8] (Jasper Kirkby, kosmisk inverkan) https://www.youtube.com/watch?v=z61tDzOjsWA

and https://www.youtube.com/watch?v=ZPNt30zKA-A

[9] H. Svensmark https://www.nature.com/articles/s41467-017-02082-2

and N. J. Shaviv https://www.thegwpf.com/prof-nir-shaviv-the-cosmic-ray-climate-link/

[10] https://en.wikipedia.org/wiki/Earth%27s_magnetic_field

[11] **Taking Greenhouse warming seriously by Richard Lindzen**, ENERGY & ENVIRONMENT, Vol. 18 No 7+8, 2007

[12] **Greenehouse molecules, their spectra and functions in the atmosphere,** by Jack Barrett from Energy and Environment, Vol. 16, No. 6, 2005

[13] **The global atmospheric water cycle,** by Lennart Bengtsson, IOP Publishing, Environmental Research Letteres, 2010
The global atmospheric water cycle - IOPscience

Appendices
APP-A Calculation of the atmospheric LW Heat flows

W1a is eliminated by setting (1) into (3) and (4)

$$P1 = (1-a1)*Ps + (1-\beta1)*[V1 + a1*Ps + a1*Xo2] =$$
$$= Ps - a1*Ps + V1 + a1*Ps + a1*Xo2 - \beta1*[V1 + a1*Ps + a1*Xo2]$$
$$P1 = (1-\beta1)*V1 + (1- a1-a1*\beta1)*Ps + a1*(1-\beta1)*Xo2$$

$$P1 = c1 + c2*Ps + c3*Xo2 \tag{13}$$
$$c1 = (1-\beta1)*V1 \quad c2 = (1-a1*\beta1) \quad c3 = a1*(1-\beta1) \tag{14}$$

Put (1) into (4):

$$Xo1 = (1-a1)*Xo2 + \beta1*[V1 + a1*Ps + a1*Xo2] =$$
$$Xo1= \beta1*V1 + a1*\beta1*Ps + (1-a1+a1*\beta1)*Xo2$$

$$Xo1 = d1 + d2*Ps + d3*Xo2 \tag{15}$$
$$d1 = \beta1*V1 \quad d2 = a1*\beta1 \quad d3 = (1-a1+a1*\beta1) \tag{16}$$

In the same way eliminate W2a =V2 + a2*P1 + a2*Xo3

$$P2 = (1-a2)*P1 + (1-\beta2)*[V2 + a2*P1 + a2*Xo3]$$
$$= (1-\beta2)*V2 + (1-a2*\beta2)*P1 + a2*(1-\beta2)*Xo3$$

$$P2 = e1 + e2*P1 + e3*Xo3 \tag{17}$$
$$e1 = (1-\beta2)*V2 \quad e2 = (1-a2*\beta2) \quad e3 = a2*(1-\beta2) \tag{18}$$

$$Xo2 = (1-a2)*Xo3 + \beta2*[V2 + a2*P1 + a2*Xo3] =$$
$$Xo2 = \beta2*V2 + a2*\beta2*P1 + (1-a2+a2*\beta2)*Xo3$$

$$Xo2 = f1 + f2*P1 + f3*Xo3 \tag{19}$$
$$f1 = \beta2*V2 \quad f2 = a2*\beta2 \quad f3 = (1-a2+a2*\beta2) \tag{20}$$

Eliminate W3a: W3a = V3 + a3*P2

$$P3 = (1-a3)*P2 + (1-\beta3)*[V3 + a3*P2] =$$
$$P3 = (1-\beta3)*V3 + (1-a3*\beta3)*P2$$

$$P3 = g1 + g2*P2 \tag{21}$$
$$g1 = (1-\beta3)*V3 \quad g2 = (1-a3 + a3*\beta3) \tag{22}$$

$$Xo3 = \beta3*W3a = \beta3*(V3 + a3*P2) =$$
$$Xo3 = \beta3*V3 + a3*\beta3*P2 = h1 + h2*P2 \tag{23}$$
$$h1 = \beta3*V3 \quad h2 = a3*\beta3 \tag{24}$$

Summed:

$$P1 = c1 + c2*Ps + c3*Xo2 \tag{13b}$$
$$Xo1 = d1 + d2*Ps + d3*Xo2 \tag{15b}$$
$$P2 = e1 + e2*P1 + e3*Xo3 \tag{17b}$$
$$Xo2 = f1 + f2*P1 + f3*Xo3 \tag{19b}$$
$$P3 = g1 + g2*P2 \tag{21b}$$
$$Xo3 = h1 + h2*P2 \tag{23b}$$

Now 6 equations with 6 unknown variables remain. Continued solution by elimination shows that two equations (below: (26) and (28)) only contain P1 and P2, which thus can be solved for and used to solv the remaining variables. (23b) is put in into (17b) and (19b):

$$P2 = e1 + e2*P1 + e3*Xo3 = e1 + e2*P1 + e3*[h1 + h2*P2]$$
$$P2 = e1 + e2*P1 + e3*[h1 + h2*P2] = (e1+e3*h1) + e2*P1 + {}+e3*h2*P2$$
$$P2*(1-e3*h2) = (e1+e3*h1) + e2*P1$$

$$P2 = (e1+e3*h1)/(1-e3*h2) +[e2/(1-e3*h2)]*P1$$
$$P2 = j1 + j2*P1 \qquad (25)$$
$$j1 = (e1+e3*h1)/(1-e3*h2) \quad j2 = e2/(1-e3*h2) \qquad (26)$$
$$Xo2 = f1 + f2*P1 + f3*Xo3 = f1 + f2*P1 + f3*[h1 + h2*P2]$$
$$Xo2 = (f1+f3*h1) + f2*P1 + f3*h2*P2 \qquad (27)$$

(27) is put in into (13b):

$$P1 = c1 + c2*Ps + c3*[(f1+f3*h1) + f2*P1 + f3*h2*P2]$$
$$P1 = [c1+c3*(f1+f3*h1)]+c2*Ps + c3*f2*P1 + c3*f3*h2*P2$$

Thus $\quad (1-c3*f2)*P1 = [c1+c3*(f1+f3*h1)]+c2*Ps + c3*f3*h2*P2$

giving $\quad P1 = [c1+c3*(f1+f3*h1)]/(1-c3*f2) + [c2/(1-c3*f2)]*Ps +$
$$+ [c3*f3*h2/(1-c3*f2)]*P2$$

$$P1 = m1 + m2*Ps + m3*P2 \qquad (28)$$
$$m1 = [c1+c3*(f1+f3*h1)]/(1-c3*f2)$$
$$m2 = c2/(1-c3*f2 \quad m3 = [c3*f3*h2/(1-c3*f2)] \qquad (29)$$

With (25) and (28) P1 and P2 can be solved

$$P2 = j1 + j2*P1$$
$$P1 = m1 + m2*Ps + m3*P2$$
$$P2 = j1 + j2*[m1 + m2*Ps + m3*P2] = j1 + j2*m1 + j2*m2*Ps +$$
j2*m3*P2
$$P2*(1-j2*m3) = (j1+j2*m1) + j2*m2*Ps$$
$$\mathbf{P2 = [(j1+j2*m1) + j2*m2*Ps]/(1-j2*m3)} \qquad (30)$$

Now P1 can be calculated from (28):
$$\mathbf{P1 = m1 + m2*Ps + m3*P2} \qquad (28b)$$
And P3 from (21)
$$\mathbf{P3 = g1 + g2*P2}$$

Xo3 is needed for calculation of Xo2, which is needed for the desired Xo1 (= Pr)

$$\mathbf{Pr = Xo3 = h1 + h2*P2} \qquad (23c)$$
$$\mathbf{Xo2 = f1 + f2*P1 + f3*Xo3} \qquad (19b)$$
Finally $\quad \mathbf{Pr = Xo1 = d1 + d2*Ps + d3*Xo2} \qquad (15b)$

For each time step, starting with a new value of ΔTs giving a new surface temperature Ts and emission Ps and with new absorption values a1, a2 and a3 (while all βi are assumed to be constant), all intermediate variables are calculated and facilitating the calculation of P2, P1 and P3 (in that order) and, finally, the Pr-value (which settles the Esurf-value and thereby the next value of ΔTs for the next time step to come)

Table A1 Summary of intermediate variables:

c1 = (1-β1)*V1	c2 = (1-a1*β1)	c3 = a1*(1-β1)	P2 = [(j1+j2*m1) + j2*m2*Ps]/(1-j2*m3)
d1 = β1*V1	d2 = a1*β1	d3 = (1-a1+a1*β1)	P1 = m1 + m2*Ps + m3*P2
e1 = (1-β2)*V2	e2 = (1-a2*β2)	e3 = a2*(1-β2)	P3 = g1 + g2*P2
f 1= β2*V2	f2 = a2*β2	f3 = (1-a2+a2*β2)	
g1 = (1-β3)*V3	g2 = (1-a3 + a3*β3)		Xo3 = h1 + h2*P2
h1 = β3*V3	h2 = a3*β3		Xo2 = f1 + f2*P1 + f3*Xo3
j1 = (e1+e3*h1)/(1-e3*h2)		j2 = e2/(1-e3*h2)	Xo1 = d1 + d2*Ps + d3*Xo2
m1 = [c1+c3*(f1+f3*h1)]/(1-c3*f2)		m2 = c2/(1-c3*f2)	
m3 = [c3*f3*h2/(1-c3*f2)]			

APP-B LW Absorption Parameters

Table B1 Absorption without presence of clouds

L1	$a1(x1,u1,v1) = a11(x1,u1) + a12(x1) + a13(x1,v1) + a14(x1) =$ $= B11*b11(x1,u1) + B12*b12(x1) + B13*b13(x1,v1) + B14*b14(x1)$ $b11(x1,u1) = 1 - EXP[-n1*(K11e*x1+K11d*u1)] = 1 - EXP(-n1*e11)$ $b12(x1) = 1 - EXP[-n1*K12*x1] = 1 - EXP(-n1*e12)$ $b13(x1,v1) = 1 - EXP[-n1*(K13a*x1+K13b*v1)]$ $b14(x1) = 1 - EXP[-n1*K14a*x1]$
L2	$a2(x2,u2,v2) = a21(x1,u1) + a22(x1) + a23(x1,v1) + a24(x1) =$ $= B21*b21(x2,u2) + B22*b22(x2) + B23*b23(x2,v2) + B24*b24(x2)$ $b21(x2,u2) = 1 - EXP[-n2*(K21e*x2+K21d*u2)] = 1 - EXP(-n2*e21)$ $b22(x2) = 1 - EXP[-n2*K22*x2] = 1 - EXP(-n2*e22)$ $b23(x2,v2) = 1 - EXP[-n2*(K23a*x2+K23b*v2)] = 1 - EXP[-n2*e23]$ $b24(x2) = 1 - EXP[-n2*K24a*x2] = 1 - EXP[-n2*e24]$
L3	$a3(u3,v3,w3) = a31(u3) + a33(v3) + a34(w3) + a35$ $= b31*B31 + b33*B33 + b34*B34$ $b31(u3) = 1 - EXP[-n3*(e31+C3))$ $b32 = 1 - EXP[-n3*C3]$ $b33(v3) = 1 - EXP[-n3*(e33+C3)]$ $b34(w3) = 1 - EXP[-n3*(K34*w3 + C3)] = 1 - EXP[-n3(*e34+C3])$ $b35 = 1 - EXP(-n3*C3)$

Table B2 Cloud cover c, Layer 2

$a2_{CLOUD}(x2,u2,v2) = B21*\{1-EXP[-n2*(K21e*x2+K21d*u2 + C2)]\}$
 $+ B22*\{1-EXP[-n2*(K22*x2+C2)]\} +$
 $+ B23*\{1-EXP[-n2*(K23a*x2+K23b*v2+C2)]\} +$
 $+ B24*\{1-EXP[-n2*(K24*x2+C2)]\}$
 $+ B25*\{1-EXP[-n2*C2]\}$

$a2(c) = (1-c)*a2_{NO-CLOUD} + c*a2_{CLOUD}$

Table B3 Parameter Values: C2, C3, n1 – n3 and Bij- and Kij-values

C2	Cloud absorption constant, L2	0,2000
C3	Particle absorpt const, L3	0,2658
n1o	Thickness factor L1, Initial value before Autotunimng	1,50
n2o	Thickness factor L2, Initial value before Autotunimng	1,50
n3o	Thickness factor L3, Initial value before Autotunimng	2,00
Absorption parameters		
B11o	L1, Initial value (before autotuning) Max power (CO2+WV)-absorption	0,2000
B12o	L1, Initial value (before autotuning) Max power, WV-absorption	0,5120
B13o	L1, Initial value (before autotuning) Max power, (CH4 + N2O)-absorpt	0,0380
B14o	L1, Initial value (before autotuning) No O3-absorption !	0,0371
B15o	L1, (Calculated, Do not type in) No absorption here!	0,2129
B21o	L2, Initial value (before autotuning) Max power (CO2+WV)-absorption	0,1890
B22o	L2, Initial value (before autotuning) Max part WV-absorption	0,4864
B23o	L2, Initial value (before autotuning) Max part (CH4 + N2O)-absorpt	0,0380
B24o	L2, Initial value (before autotuning) No O3-absorption, only cloud absorb !	0,0390
B25o	L2, (Calculated, Do not type in) Only clouds absorb here !	0,2476
B31o	L2, Initial value (before autotuning) Max power, CO2 and particls absorb	0,1700
B32o	L2, Initial value (before autotuning) Max power, only particls absorb	0,4500
B33o	L2, Initial value (before autotuning) Max part, (CH4+N2O) & particles absorb	0,0378
B34o	L2, Initial value (before autotuning) Max power for O3 ans particls abs.	0,0350
B35o	L3, (Calculated, Do not type in) only particles absorb here	0,3072
K11d	L1 (original value K11d is 2.21)	3,5000
K11e	L1 (original value K11e is 1.34)	1,4000
K12	L1 (original value K12 is 3.6)	2,8000
K13a	L1	0,8000
K13b	L1	0,3500
K14a	L1	0,8000
K14b	L1	0,0000
K21d	L2 (original value K21d is 2.21)	3,5000
K21e	L2 (original value K21e is 1.34)	1,4000
K22	L2 (original value K22 is 3.6)	2,8000
K23a	L2	0,8000
K23b	L2	0,3500
K24a	L2	0,8000
K24b	L2	0,0000
K31	L3 (original value K31 is 0.735)	0,6000
K32	L3	0,7350
K33	L3	0,7000
K34	L3	0,7350

APP-C. Calculation of the atmospheric SW Heat flows

Layer 1:

$$Si = (1-r1)*Se \qquad (i)$$

$$Se = t1*S1 + X1 \qquad (ii)$$

$$X1 = (1/2)*(a1*S1 + a1*r1*Se) \qquad (iii)$$

$$X1 = b1*(S1 + r1*Se) \qquad (iv)$$

$$Po = t1*r1*Se + X1 \qquad (v)$$

IN = OUT $S1 = Po + Si = Po + (1-r1)*Se \qquad$ (vi-a)

$$Po = P1 + X4 \qquad \text{(vi-b)}$$

$$X4 = r2d*Po \qquad \text{(vi-c)}$$

Layer 2 $\quad S1 = S2c + X2 + X4 \qquad$ (vii)

$$S2a = S2 – S21 = S2 – r2*S2 = (1-r2)*S2 \qquad \text{(viii)}$$

$$S2b = S2a – Z2a = (1-r2)*S2 - Z2a \qquad (7)$$

$$S2c = t2*S2b = t2*[(1-r2)*S2 – Z2a] \qquad \text{(ix)}$$

$$S1 = S2c + X2 + X4 =$$

$$S1 = t2*[(1-r2)*S2 – Z2a] + X2 + X4 \qquad (x)$$

$$X2 = (1/2)*(a2*S2b + a2*P1a) \qquad \text{(xi)}$$

$$P1a = P1 – Z2b \qquad \text{(xii)}$$

$$X2 = b2*[S2b + (P1 - Z2b)] =$$

$$X2 = b2* [(1-r2)*S2 - Z2a + (P1 – Z2b)] \qquad \text{(xiii)}$$

$$P2 = t2*P1a + X2 + S21 =$$

$$P2 = t2*(P1 – Z2b) + X2 + r2*S2 \qquad \text{(xiv)}$$

$$P1 = Po – X4 \qquad \textbf{(xiv-a)}$$

$$P2 = t2*(Po – X4 – Z2b) + X2 + r2*S2 \qquad \textbf{(xiv-b)}$$

IN = OUT: $S2 + Po = S1 + P2 + (Z2a + Z2b) \qquad$ (xv)

Layer 3 $\quad (S3 = So)$

$$X3 = (1/2)*(a3*S3 + a3*P2) = b3*(So + P2)$$

$$X3 = b3*(So + P2) \qquad \text{(xvi)}$$

$$P3 = X3 + t3*P2 \qquad \text{(xvii)}$$

$$S2 = t3*So + X3 \qquad \text{(xviii)}$$

IN = OUT $So + P2 = S2 + P3 \qquad$ (xix)

Step 1, L1:   (Input is So) Eliminate X1 and Se

$$Se = t1*S1 + X1 \qquad (1)$$

$$X1 = b1*(S1 + r1*Se) \qquad (2), (iv)$$

$$Po = t1*r1*Se + X1 \qquad (3), (v)$$

$$S1 = Po + (1-r1)*Se \qquad\qquad \textbf{(4), (vi-a)}$$

2 into 1: $Se = t1*S1 + \underline{b1*(S1 + r1*Se)}$

$Se = r1*b1*Se + (t1+b1)*S1 \qquad (t1+b1) = 1-b1/2+b1 = 1-b1/2 = (1-b1)$

$Se - r1*b1*Se = (1-b1)*S1$

$Se = [(1-b1)/(1-r1*b1)]*S1$

$Se = c1*S1 \qquad\qquad \textbf{(5)} \quad c1 = [(1-b1)/(1-r1*b1)]$

5 into 4: $Po = S1 - (1-r1)*c1*S1 = c2*S1$

$Po = c2*S1 \qquad\qquad (6) \quad c2 = [1- (1-r1)*c1]$

Step 2, L3: (S3 = So) Eliminate X3

$X3 = (1/2)*(a3*S3 + a3*P2) = b3*(So + P2)$

$X3 = b3*(So + P2) \qquad\qquad (7)$

$P3 = X3 + t3*P2 \qquad\qquad (8)$

$S2 = t3*So + X3 \qquad\qquad (9)$

IN = OUT $So + P2 = S2 + P3 \qquad\qquad (10)$

7 into 8: $P3 = [b3*(So + P2)] + t3*P2$

$P3 = b3*So + (b3+t3)*P2 = b3*So + (1-b3)*P2$

$P3 = b3*So + (1-b3)*P2 \qquad\qquad \textbf{(11)}$

11 into 10: $S2 = So + P2 - [b3*So + (1-b3)*P2] = (1-b3)*So + b3*P2$

$S2 = (1-b3)*So + b3*P2 \qquad\qquad \textbf{(12)}$

S2 and P3 becomes known when P2 is known

Step 3: Layer 2, elimination of X2

$S1 = t2*[(1-r2)*S2 - Z2a] + X2 + X4 \qquad\qquad (13)$

$P1 = Po - X4 \qquad X4 = Po - P1 \qquad\qquad \textbf{(xiv-a)}$

$P2 = t2*(Po - X4 - Z2b) + X2 + r2*S2 \qquad\qquad \textbf{(xiv-b)}$

$Po = c2*S1 \qquad\qquad \textbf{(6)}$

$X4 = r2d*Po \qquad P1 = (1-r2d)*Po \qquad\qquad \textbf{(vi-c)}$

$Z2a = a2c*S2a = a2c*(1-r2)*S2 \qquad\qquad (14)$

$Z2b = a2c*P1 \qquad\qquad (15)$

$X2 = b2* [(1-r2)*S2 - Z2a + (P1 - Z2b)] \qquad\qquad (16)$

14, 15 & 16 & (vi-c) into 13

$S1 = t2*[(1-r2)*S2 - \{a2c*(1-r2)*S2\}] + b2* [(1-r2)*S2 - \{a2c*(1-r2)*S2\} + (P1 - \{a2c*P1\})] + X4$

$S1 = t2*(1-r2)*S2 - t2*a2c*(1-r2)*S2 + b2* [(1-r2)*S2 - b2*a2c*(1-r2)*S2 + b2*[P1 - a2c*P1] + X4 =$

$= t2*(1-r2)*(1-a2c)*S2 + b2*(1-r2)*[S2 - a2c*S2] + b2*(1-a2c)*P1 + X4 =$

$= t2*(1-r2)*(1-a2c)*S2 + b2*(1-r2)*(1-a2c)*S2 + b2*(1-a2c)*P1 + X4 =$

$= (t2+b2)*(1-r2)*(1-a2c)*S2 + b2*(1-a2c)*P1 + X4$

Inserting (vi-c) and (t2+b2) = 1-b2

$$S1 = (1-b2))*(1-r2)*(1-a2c)*S2 + b2*(1-a2c)*(1-r2d)*Po + r2d*Po$$

$$= (1-b2)*(1-r2)*(1-a2c)*S2 + [r2d + b2*(1-a2c)*(1-r2d)*Po$$

$$\mathbf{S1 = d1*S2 + d2*Po} \qquad (17) \qquad \mathbf{d1 = (1-b2)*(1-r2)*(1-a2c)}$$

$$\mathbf{d2 = r2d+b2*(1-a2c)*(1-r2d)}$$

Step 4 Further reductions: (Po = c2*S1)

6 into 17: $\mathbf{S1 = d1*S2 +d2*c2*S1} \qquad \mathbf{S1*(1-c2*d2) = d1*S2}$

$$\mathbf{S1 = e1*S2} \qquad\qquad\qquad (18) \qquad \mathbf{e1 = d1/(1-c2*d2)}$$

_____

The definition of P2 can be expressed as depending on S2

$$\mathbf{P2 = t2*(P1 - Z2b) + X2 + r2*S2} \qquad (19)$$

$$\mathbf{X2 = b2*[(1-r2)*S2 - Z2a + (P1 - Z2b)]} \qquad (xiii)$$

$$P1 = (1-r2d)*Po \qquad \mathbf{Po = c2*S1}$$

$$Z2a = a2c*S2a = \underline{a2c*(1-r2)*S2}$$

$$Z2b = a2c*P1$$

$$X2 = b2*[(1-r2)*S2 - a2c*(1-r2)*S2 + P1 - a2c*P1] =$$

$$X2 = b2*(1-r2)*[S2 - a2c*S2] + b2*(1-a2c)*P1 =$$

$$X2 = b2*(1-a2c)*(1-r2)*S2 + b2*(1-a2c)*(1-r2d)*Po$$

$$X2 = e2*S2 + e3*Po \qquad\qquad \mathbf{e2 = b2*(1-a2c)*(1-r2)}$$

$$\mathbf{e3 = b2*(1-a2c)*(1-r2d)}$$

$$P2 = t2*(1-a2c)*P1 + \{\underline{b2*(1-a2c)*(1-r2)*S2} + b2*(1-a2c)*(1-r2d)*Po\} + r2*S2 =$$

$$P2 = (t2+b2)*(1-a2c)*(1-r2d)*Po) + \underline{b2*(1-a2c)*[(1-r2)*S2} + r2*S2 =$$

Further: 6 & 18: $\mathbf{[S1 = e1*S2)}$

$$\mathbf{Po} = c2*S1 = \mathbf{c2*e1*S2} \qquad\qquad (20)$$

Thus $P2 = (t2+b2)*(1-a2c)*(1-r2d)*\underline{c2*e1*S2} + b2*(1-a2c)*(1-r2)*S2 + r2*S2 =$

$$\mathbf{P2 = e4*S2} \qquad\qquad\qquad (21)$$

With $\mathbf{e4 = (1-b2)*(1-a2c)*(1-r2d)*\underline{c2*e1} + b2*(1-a2c)*(1-r2) + r2}$

Finally: Using 12:

$$\mathbf{S2 = (1-b3)*So + b3*P2 = (1-b3)*So + b3*e4*S2}$$

$$\mathbf{(1-b3*e4)*S2 = (1-b3)*So}$$

$$\mathbf{S2 = f1*So} \qquad\qquad\qquad (22) \quad \mathbf{f1 = (1-b3)/(1-b3*e4)}$$

Knowing S2 gives the total result:

By 18: $S1 = e1*S2$

By 6: $Po = c2*S1$

$$X4 = r2d*Po$$

$$P1 = (1-r2d)*Po$$

By 21: $P2 = e4*S2$

By 11: $\quad$ P3 = b3*So + (1-b3)*P2

By 5: $\quad$ Se = c1*S1

By (i); $\quad$ Si = (1-r1)*Se

By (14) $\quad$ Z2a = a2c*(1-r2)*S2

By (15): $\quad$ Z2b = a2c*P1

$\quad\quad\quad\quad$ Z2 = Z2a + Z2b

By 2: $\quad$ X1 = b1*(S1 + r1*Se)

By 16: $\quad$ X2 = e2*S2 + e3*Po

By 7: $\quad$ X3 = b3*(So + P2)

$\quad\quad\quad\quad$ P1a = P1 – Z2b

$\quad\quad\quad\quad$ S2c = t2*S2b

c1 = [(1-b1)/(1-r1*b1)]

c2 = [1- (1-r1)*c1]

d1 = (1-b2)*(1-r2)*(1-a2c)

d2 = r2d+b2*(1-a2c)*(1-r2d)

e1 = d1/(1-c2*d2)

e2 = b2*(1-a2c)*(1-r2)

e3 = b2*(1-a2c)*(1-r2d)

e4 = (1-b2)*(1-a2c)*(1-r2d)*c2*e1 + b2*(1-a2c)*(1-r2) + r2

f1 = (1-b3)/(1-b3*e4)