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Dynamics between Clear, Cloudy and All-Sky Conditions: Cloud Forcing Effects

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Abstract: The author has analyzed the dynamics of atmospheric changes between all-sky, clear and cloudy sky conditions. The basis of analyses is the calculation of flux values at the balance states. The analyses depend essentially on the time constants of basic processes, which can be analyzed separately. Two time constants are based on the former research results, and three time constants have been developed and estimated in this study. The basic processes in dynamic analyses have been the very rapid changes in cloudiness and cloud temperatures, the rapid change in upward atmospheric long wave radiation caused by solar insolation change, the slow change in temperature of the land and sea, and the transient change in the atmosphere temperature. This transient atmospheric process has an essential role in explaining why the surface temperature increases when at the same time the cloud forcing decreases. The dynamic simulations reveal that in all cases, two rapid changes in the atmosphere can bring the outgoing long wave radiation at the top of the atmosphere almost exactly (a difference of 0% to 0.3%) to the observed pseudo-balance values of clear and cloudy skies. Pseudo-balance values for clear and cloudy skies are not very time-sensitive because the values stay within ±1 W/m^2 from one day to 13 days. According to the true energy balance values, the slightly nonlinear cloud forcing would be -0.56 Wm^{-2} per 1% increase in cloudiness and -0.1 °C per 1% increase in cloudiness over the normal cloudiness range variation from 60% to 70%. According to this study, the commonly used cloud forcing in the units of W/m^2 yields effects that are about 40% too low for the long-term cloudiness changes. Cloudiness changes could alone explain the global warming.

Keywords: Dynamics of atmosphere, energy balance of atmosphere, time constants of climate, cloud forcing

INTRODUCTION AND OBJECTIVES

The objectives of this paper are to find the time dependent behaviors of outgoing long wave radiation (OLR) flux changes caused by the incoming shortwave radiation flux changes due to the cloudiness and albedo changes between all-sky, cloudy and clear sky conditions, and to analyze the time-dependent behavior of the pseudo-balance radiation fluxes of cloudy and clear skies for identifying the dominant time delays. One objective is also to show that the cloud forcing values for the long-term cloudiness changes are bigger than the forcing values based on the values of pseudo-balance skies.

The response times of the Earth's climate system have been studied from various perspectives, and therefore the values vary on a broad scale. The shortest value is from Douglass *et al.*[1], which is a 3-month response time for solar irradiation.

Time constants based on the solar cycle analyses are in the range of 0.4 to 12 years (Scafetta[2]) and 5 ± 1 year (Schwartz[3]). The longest estimates are from Hansen *et al.*[4], which are from 10 to 100 years, and the perspective has been from the long-time changes due to the forcing factors of the climate. Stine *et al.*[5] have analyzed the annual cycles of the surface temperature, and the result is a mean time lag of 56 ± 11 days for oceans and 29 ± 6 days for land.

Besides the relatively long time constants, there are also short time diurnal changes in surface temperatures and in outgoing long wave radiation fluxes. One study of surface temperature changes in the solar irradiation diurnal changes show time constants that are only 5 to 10 minutes (Esala[6]).

There are some factors that may explain this large variation. One factor is a question of the feedback mechanisms of the climate system elements. It seems that when including these mechanisms in the calculation models, the time constants become longer.

Another factor is the mixing of ocean layers and how deep this mixing actually happens. The time domain perspective in this study is relatively quick changes from one sky condition to another – a matter of days. Also the true balance changes have been analyzed and then the time perspective has been in years.

Finally cloud forcing values have been calculated on two theoretical basis and the impacts of the forcing values of long-term cloudiness changes have been compared based on the values of pseudo-balance skies and the true balance skies.

ENERGY BALANCES FOR CLEAR, CLOUDY AND ALL-SKIES

In this text clear sky is indicated by the subscript$_b$, cloudy atmosphere by the subscript$_o$, and all-sky atmosphere by the subscript$_a$. The energy balance values of different skies in pseudo-balance and true balance conditions are presented in **Table 2**.

The values of **Table 2** are based on the research paper of Ollila[7] but the all-sky OLR flux value is updated to be 237.8 W/m^2 (the original value was 236.5 W/m^2). The value 237.8 W/m^2 is closer the most recent research papers and it satisfies the equation used by Ollila[7] in combining the flux values between different skies.

The new OLR_a value changes slightly some other flux values, which have been calculated using the same methods as described by Ollila[7]. The budget calculations are based mainly on the published SW and LW flux data of Zhang *et al.*[8], Bodas-Salcedo *et al.*[9], Raschke *et al.*[10], and Loeb *et al.*[11] but other methods have also been applied in quantifying non-measurable fluxes.

The fluxes in **Table 1** and **Table 2** are in W/m^2, and the fluxes are always stated as such in this paper. The true balance calculations[7] show that the clear sky surface temperature is 24.5 °C, and the cloud sky surface temperature is 13.2 °C.

Table- 1: Shortwave radiation flux values[7] in W/m^2.

Shortwave radiation budget	Abbr.	Clear	Cloudy	All-sky	Uncertainty
Incident solar radiation flux at TOA	SWin	342.0	342.0	342.0	4 – 6[3]
Total reflected SW radiat. flux into space	Rt	53.0	120.0	104.2	5 -10[1]
SW flux reflected by clouds	Rc	0.0	85.40	64.1	7 - 15[3]
SW flux reflected by air	Rp	23.2	14.4	17.4	7 - 15[3]
Incoming SW flux (Sx = SWin-Rc-Rp)	Sx	318.8	242.4	260.5	5 - 10[1]
Incoming SW flux absorbed by clear air	Sb	69.0	52.4	56.1	5 – 10[3]
Incoming SW flux absorbed by clouds	Sc	0.0	18.0	13.6	5 - 10[3]
Total incoming SW absorp. flux by the atm.	Si	69.0	70.4	69.7	5 - 10[3]
SW flux of Rs flux absorbed by cloudy sky	Sr	0.0	1.6	1.3	0.3 – 0.9[3]
Total SW flux absorbed in the atmosphere	Sa	69.0	72.0	71.0	5 - 10[3]
Incoming SW flux reaching the surface	Sd	248.9	171.8	190.8	10 - 15[1]
SW flux reflected by the surface	Rs	29.8	21.8	24.0	5 -10[2]
Reflected Rs flux into space. Ra = Rs-Sr	Ra	29.8	20.2	22.7	5 -10[2]
SW flux absorbed by the surface	Ss	220.0	150.0	166.8	10 - 15[1]
Net incoming SW flux (NSR = SWin – Rt)	NSR	289.0	222.0	237.8	5 - 10[1]
SW flux absorbed by the atm. and surface	ASR	289.0	222.0	237.8	5 - 10[1]

Table- 2: The summary of Earth's energy budgets for clears, cloudy and all-skies (Ollila[7, 12]). The values are in W/m^2.

		Pseudo-balance			True balance		Uncertainty
Surface in	Abbr.	Clear	Cloudy	All-Sky	Clear	Cloudy	
SW flux absorbed by surface	Ss	190.0	154.8	166.8	220	150	5 – 101
Downward LW flux emitted by the atm.	Ed	318.0	359.0	344.7	378	302	10 – 153
SFC-balance	Bs	508.0	513.8	511.5	598	452	11 – 223
Surface out							
Thermals	T	26.4	27.3	24.9	33	15	5 – 102
Latent heat flux	L	87.5	90.3	91.0	120	56	5 – 152
LW surface flux transmitted to space	Eu	83.2	0.0	28.3	67	0	3 – 73
LW surface flux absorbed by clouds	Ac	0.0	84.0	55.4	0	79	3 – 73
LW surface flux absorbed by GH gases	Ag	310.9	312.2	311.9	378	302	3 – 73
SFC-balance	Bs	508.0	513.8	511.5	598	452	11 – 223
Atmosphere in							
Incoming SW flux absorbed by clear air	Sb	69.0	52.4	56.1	69	53	5 – 103
Total SW flux absorbed by clouds	Sc+Sr	0.0	19.6	14.9	0	19	5 – 103
Thermals	T	26.4	27.3	24.9	33	15	5 – 102
Latent heat flux	L	87.5	90.3	91.0	120	56	5 – 152
LW surface flux absorbed by clouds	Ac	0.0	84.0	55.4	0	79	3 – 73
LW surface flux absorbed by GH gases	Ag	310.9	312.2	311.9	378	302	3 – 73
ATM-balance	Ba	493.8	585.8	554.2	600	524	11 – 233
Atmosphere out							
Upward LW flux emitted by the atm.	Eg	175.8	166.7	169.8	222	163	7 – 153
Upward LW flux emitted by clouds	Ec	0.0	60.1	39.7	0	59	5 – 103
Downward LW flux emitted by the atm.	Ed	318.0	359.0	344.7	378	302	10 – 153
ATM-balance	Ba	493.8	585.8	554.2	600	524	11 – 233
TOA							
Upward LW flux emitted by the atm.	Eg	175.8	166.7	169.8	222	163	7 – 153
LW surface flux transmitted to space	Eu	83.2	0.0	28.3	67	0	3 – 73
Upward LW flux emitted by clouds	Ec	0.0	60.1	39.7	0	59	5 – 103
OLR	OLR	259.0	226.8	237.8	289	222	5 – 101

DYNAMICS OF ATMOSPHERIC CHANGES

Dynamic Model of the Atmosphere: The term "pseudo-balance" is needed for the clear and cloudy sky conditions. Theoretically the outgoing longwave flux (OLR) at the top of atmosphere (TOA) should be the same as the net incoming SW flux (NSR=ASR), if the Earth is thermodynamically in balance. Only in all-sky conditions this is true but the balance value for OLR cannot be reached in clear and cloudy sky climate conditions. The actual measured values show that for clear and cloudy sky conditions: $NSR_b = ASR_b = 289\ W/m^2$ versus $OLR_b = 259\ W/m^2$ and $NSR_o = ASR_o = 222\ W/m^2$ versus $OLR_b = 226.8\ W/m^2$. The basic reason is in the dynamics of the atmosphere, because the clear and cloudy sky conditions cannot prevail on the global scale for periods of adequate length. In pseudo-balance energy balance calculations Ollila[7] has used an Ss_b value of 190 W/m^2, because it produces the correct balance value at TOA: $Ss_b + Sb_b = 190 + 69 = 259 = OLR_b$. The value of Ss_o can be calculated in the same way: $Ss_o = 226.8 – 72.0 = 154.8$.

In many research papers the clear and cloudy sky OLR values (259 W/m^2 and 226.8 W/m^2 in this study) have been applied as if they were true balance values and therefore applicable for short-term and long-term climate changes. One of the objectives of this study is to show that the pseudo-balance values are applicable for short term climate changes only and the true balance values should be applied for long-term (longer than one year) climate change calculations. The schematic process diagram of the energy fluxes are depicted in Figure 1.

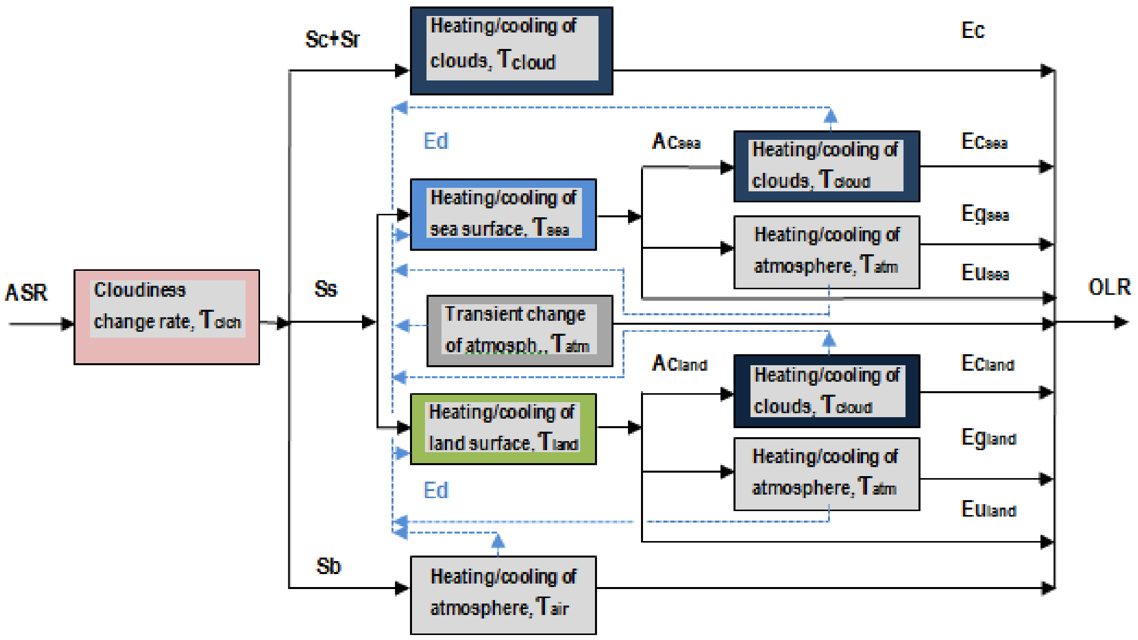

Figure 1: Schematic flow diagram of Earth's energy flux processes in dynamical analysis.

There are three process steps that dominate the atmospheric changes; these are the warming or cooling of the land and sea and the warming or cooling of the atmosphere. The seas cover 71% of the globe, and therefore the global surface temperature is mainly depending on the sea surface temperature. The floating ice decreases slightly the sea cover to 70%. This means that the percentage shares of the surface's radioactive emissions are: sea 70% and land 30%.The first-order dynamic model can be used to estimate the time-domain behavior of even very complex processes, as shown by Ollila[13]. The step change for the first-order process without amplification applied to this process is

$$F_{out}(t) = (1- e^{-t/T}) * F_{in}(t), \qquad 1$$

Where $F_{out}(t)$ is the outgoing LW radiation flux (=process output), $F_{in}(t)$ is the incoming radiation flux (= process input, which can be SW or LW radiation flux), t is time, and T is the time constant of the process. As shown in **Figure 1,**OLR(t) is the sum of the three LW radiation fluxes Eg, Eu and Ec originating from different sources. The time domain behavior of each of these fluxes can be approximated by Equation (1) if there is a stepwise change from one sky condition to another. The typical feature of the first order process is that the output value is 63% from the step input change at the point of the time constant T, and at the point of 4*T, the output is about 98 % of the input value.

Time constants of the main processes: The dynamic analysis of this study means the calculation of the outgoing LW flux (OLR) as a function of time in respect to the step SW insolation change from one sky condition to another. The dynamic processes that dominate the change from one sky condition to another are the very rapid change of cloudiness, the rapid rate of the temperature change of clouds, the rapid change of atmosphere temperature caused by SW insolation flux change, the slow temperature change of the land and sea, and the transient change of the atmosphere temperature. As shown in **Figure 2**, the warming/cooling processes of land and sea must proceed through the atmosphere before they have impact on the outgoing LW flux Eg. Therefore, in dynamic analyses, the change of Eg travels through two sequential dynamic processes with different time constants and all changes start with the cloudiness change process.

The transient change of the atmosphere temperature can be realized from the surface temperatures and from the downward LW fluxes (Ed) of the different skies in a pseudo-balance situation. For example, as the sky turns from all-sky to cloudy, the Ed_a flux of 344.7 grows to Ed_o flux 359 and the surface temperature increases from 15.9 °C to 16.0 °C, even though the step input change of the driving force SW insolation has decreased from 237.8 to 222. Finally, the Ed_a would decrease to 302 W/m^2 if the cloudy conditions could prevail long enough. When there is a step change like this, the temperature of the atmosphere moves in the opposite direction (higher temperature) before the very slow change of land and sea temperatures finally decrease the upward LW radiation flux Es_o and thus also decrease the temperature of the atmosphere. The author calls this phenomenon the transient change of atmosphere because it can be analyzed as a separate dynamic process. The dynamics of this process is governed by the time constant of the atmosphere, which has been marked by the acronym T_{atm}.

The transient change in the atmosphere has a small effect on the OLR flux. The magnitude of this change is very small and it is difficult to calculate. Therefore in this study the transient change has been utilized only in the surface temperature change calculations, where it is directly measureable and can be quantified.

Stine et al.[5] have found that the mean time lags between the annual irradiation and temperature cycles are 29±6 days over the land and 56±11 days over the ocean. Kauppinen *et al.*[14] have analyzed different studies of time delays, and they have used these values as a basis for calculating the time constants of the land and the ocean. Their final results were T_{land} = 1.04 months and T_{sea} = 2.74 months, utilizing the dynamic analysis of the sinusoidal input. The author has also used these time constants in this study. The time constant of the atmosphere is not available, and therefore the author has used the heat capacity difference of the ocean, which is 30 times the heat capacity of the atmosphere (Kauppinen *et al.*[14]), resulting in the time constant T_{atm} = 0.091 months = 2.74 days. There are three processes that have very short time constants: the temperature change of clouds, the absorption of SW radiation in the atmosphere and the change in cloudiness, which causes a rapid change of the upward LW flux Eu transmitting into space as well as the rapid change of the upward flux Ec emitted by clouds. Long[15] has estimated the clear sky upwelling fluxes and he has utilized the Atmospheric Radiation Measurement (ARM) Program data of diurnal variations. The author has utilized the same data (ARM[16]) and prepared **Figure 2**, naming the fluxes according to the acronyms used in this paper.

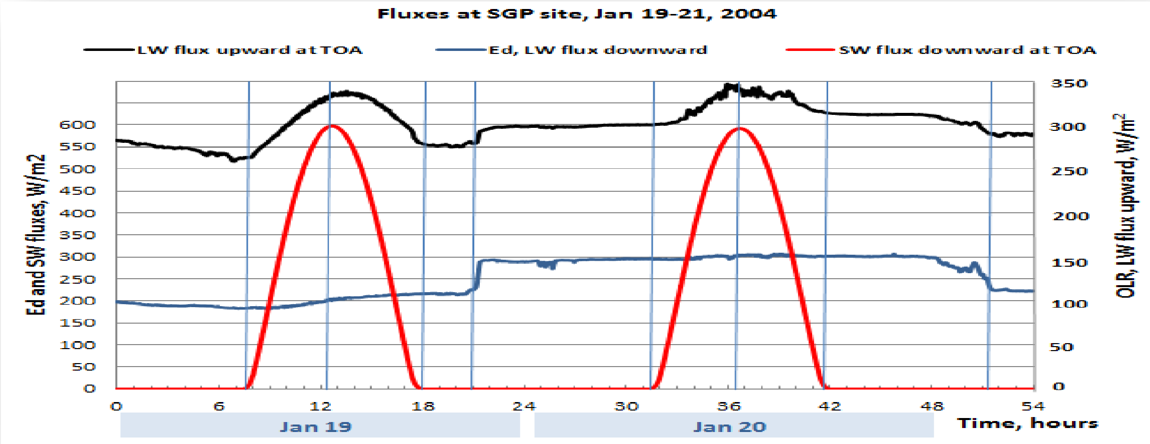

Figure 2: Fluxes at the Atmospheric Radiation Measurement (ARM) SGP site in January 2004 (ARM[16]). The thin vertical blue lines indicate the times of the SW flux changes.

This graphical presentation shows that the cloudiness change (starting at 21:00 on January 19 and ending at about 3:00 on January 20) produces the Ec increase almost instantaneously. The digital data analysis reveals that the time delay is about 15 minutes, corresponding to the time constant T_{clch} = 4 minutes. Theoretically also the temperature of clouds changes, when the cloudy sky stays a long period over the same place. This change can be estimated to be so small that it has no practical effect in dynamic analysis. The top layer of clouds absorbs the same amount of solar insolation in all climate conditions all the time and therefore the temperature is almost constant and therefore emitted radiation upwards remains almost constant. The total amount of water in the atmosphere is $13.2*10^{12}$ tons and only 0.01 % is in liquid form (clouds). The total mass of the atmosphere is $5.3*10^{15}$ tons. The time constant of the clouds (T_{cloud}) can be estimated to be only 0.1 minutes calculated from the atmosphere's time constant. In the clear day, the LW flux at TOA reacts rapidly to the increasing SW insolation. In this situation, OLR flux is the sum of the transmitted flux Eu caused by the warming of land and warming of the atmosphere caused by SW absorption of the clear air. It is impossible to separate these two radiation fluxes from each other during the clear atmosphere. The peak of OLR during daytime on January 20 is caused mainly by the absorption of SW in the atmosphere, because the LW flux Eu is totally absorbed by clouds. The SW absorption process time lag can be estimated with reasonable accuracy. The digital data analysis shows that the time delay is about 30 minutes, giving the time constant T_{air} = 8 minutes. It should be noticed that T_{air} and T_{atm} are different because they are the results of different absorption processes. SW insolation absorption by the atmosphere starts from the upper layers of the atmosphere and it proceeds downwards. The heat capacity of the upper parts of the atmosphere is much smaller than the lower part. The upward LW radiation is slowed down by the heat capacity of the atmosphere before any changes occur in the outgoing LW flux Eg at TOA. The analysis of downward LW flux Ed as shown in **Figure 1** reveals that it reacts slowly with the increasing surface temperature. Ohmura[17] has analyzed the behavior of Ed; the main results are that 67-73% originates from the first 10 m, 89% from the first 1 km, and 95% from the first 2 km. This is perfectly in line with the results of Ollila[12] that LW absorption caused by greenhouse gases takes place 95% during the first 2 km. Because the warming of almost the whole atmospheric mass is needed before the outgoing Eg radiation reaches the equilibrium value, the time constant of 2.74 days is reasonable. Locally, the winds can change this ideal situation very quickly.

DYNAMIC ANALYSES

Change from all-sky to clear sky conditions: Using the information of the division between sea and land processes, the step input change 51.2 W/m^2 from 237.8 W/m^2 to 289 W/m^2 can be divided into three parts. Ec_a disappears very quickly (T_{clch}4 min.), which means that Eu_b is the same as the Eu_a+Ac_a in the beginning of the change. The magnitude of this change is Ac_a - Ec_a = +15.7 W/m^2. The rapid change of Eg flux (T_{air} 8 min.) caused by clear air absorption is Eg_{air} = Eg_b – Eg_a = 175.8 – 169.8 = 6.0 W/m^2. The rest of the change happens through the warming processes of sea and land. The total size of this change is 289 – 237.8 – 15.7 – 6.0 = 29.5 W/m^2. This change happens through the changes of Eu_b and Eg_b. The true balance value of Eu_b is 67, and therefore this change (dynamic delay T_{land}) is 67 – (55.4 + 28.3) = -16.7 W/m^2. The Eg_b changes from the pseudo-balance value of 175.8 to the true balance value of 222 through two processes (T_{land} and T_{atm}), and the size is +46.2 W/m^2. Both changes must be divided between land and sea. These changes have been depicted in **Figure 3**, where the time scale is a combination of two scales. The first part is linear from 0 to 0.1 day and the end part of the scale is logarithmic from 0.1 to 600 days. This arrangement illustrates more accurately the changes around the pseudo-balance states. This time scale presentation has been applied also in other figures.

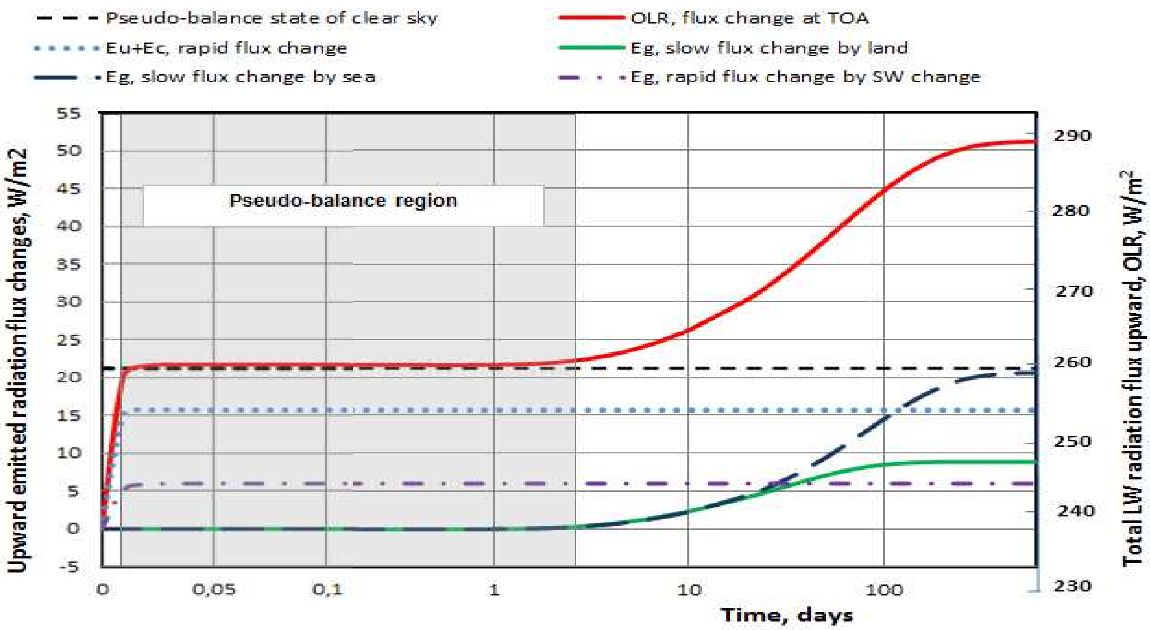

Figure 3: Dynamic response of the OLR_b to the stepwise change from all-sky ASR 237.8 W/m^2 to clear sky ASR_b 289 W/m^2. The pseudo-balance of clear sky is the observed OLR_b 259 W/m^2.

The stepwise change of the solar radiation from all-sky 237.8 W/m^2 to clear sky 289 W/m^2 first causes OLR_b = 259 W/m^2 as observed by Zhang et al.[8] at TOA, which can be called a pseudo-balance value. This value corresponds to a 41.4 % change from 237.8 W/m^2 and on the time scale it happens at the point of 0.02 days. The OLR values between 258 and 260 could be measured during the time span of

0.01 to 3.0 days. The pseudo-balance value is not sensitive for the measurement moment, because it has been caused by two rapid process changes, which shoot Eg_b 0.2 % over the pseudo-balance value.

Change from all-sky to cloudy sky conditions: Also the stepwise change from all-sky conditions to totally cloudy conditions cannot reach the final steady-state value, which would be the SW input ASR_o = 222 W/m^2. The measured (Zhang *et al.*[8]) OLR_o is 226.8 W/m^2, which means that the change (226.8 – 237.8 = -11.0 W/m^2) has reached 69.6% of the total input step (222 – 237.8 = -15.8 W/m^2).

In the change from all-sky to cloudy sky, the three radiation fluxes Eg, Eu and Ec forming the OLR_o behave in different ways. Transmitted radiation into space Eu_a 28.3 W/m^2 disappears totally as soon as the sky turns cloudy. The Ec_o value is 60.1 W/m^2 and the change 60.1 - (28.3+39.7) = -7.9 W/m^2 follows the increase rate of the amount of clouds (time delay T_{clch}4 min. and T_{cloud} 0.1 min). The rapid change of Eg flux caused by clear air absorption (time delay T_{air}8 min.) is Eg_o - Eg_a = 166.7 -169.8 = -3.1 W/m^2.

The rest of the change happens through the cooling processes of sea and land. The total size of this change is 222 – 237.8 + 7.9 + 3.1 = -4.8 W/m^2. This change happens through the changes of Ec_o and Eg_o. The true balance value of Ec_o is 59, and therefore this change is 59.0 - 60.1 = -1.1 W/m^2. Eg_o changes from the value of 166.7 to the true balance value of 163, and the size is -3.7 W/m^2. Both changes must be divided between land and sea. The results are depicted in **Figure 4**.

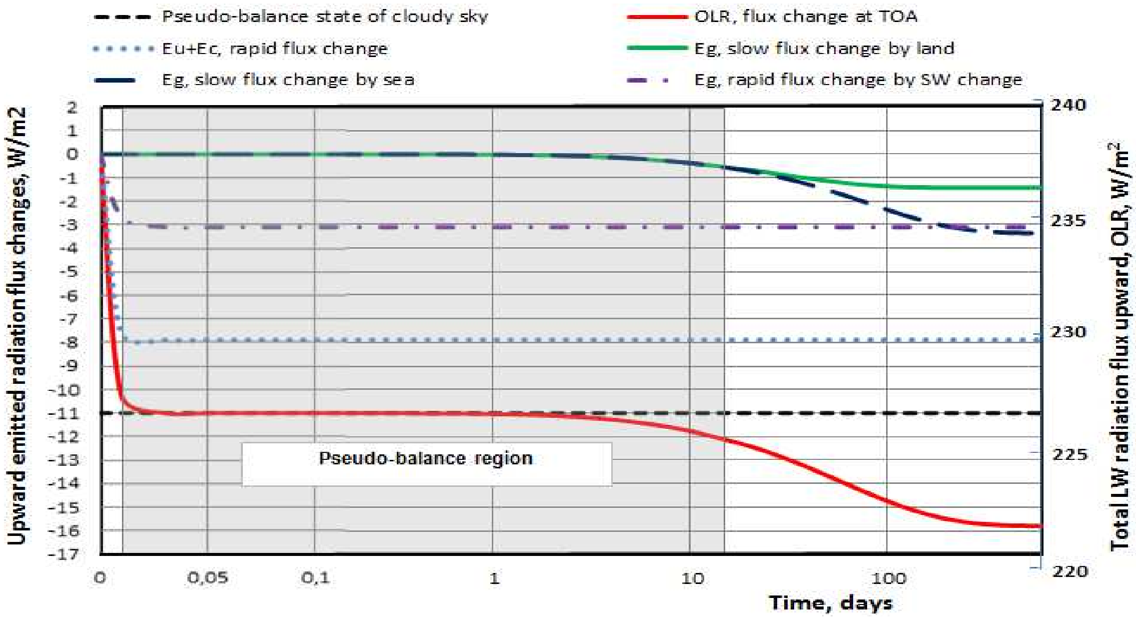

Figure 4: Dynamic response of the OLR_o to the stepwise change from all-sky ASR 237.8 W/m^2 to the cloudy sky ASR_o 222 W/m^2. The pseudo-balance of the cloudy sky OLR_o is the observed 226.8 W/m^2.

In this case, the exact observed OLR_o value of 226.8 can be measured immediately. The OLR values between 227.8 – 225.8 could be measured during the time span of 0 to 13.0 days. The observed value of OLR_o 226.8 W/m^2 can be explained by the fact that the rapid process changes in the atmosphere cause 100% of the change. Because the pseudo-balance value is close to the real balance value, the small errors in measurements and data can easily change the time scale behavior.

Change from cloudy sky to clear sky conditions: The initial state in this analysis is cloudy sky in the pseudo-balance state. In this change Ec_o disappears very quickly (T_{clch}4 min) and it is replaced by Ac_o. The magnitude of this change is $Ac_o – Ec_o$ = 84 – 60.1 = +23.9 W/m^2. The rapid change of Eg flux (T_{air}8 min) caused by clear air absorption is $Eg_b – Eg_o$ = 175.8 – 166.7 = 9.1 W/m^2.

The rest of the change happens through the warming processes of sea and land. The total size of this change is 289 – 226.8 – 23.9 – 9.1 = 29.2 W/m^2. This change happens through the changes of Eu_b and Ac_b. The true balance value of Eu_b is 67, and therefore this change is 67 – 84 = -17.0 W/m^2. Eg_b changes from the pseudo-balance value of 175.8 to the true balance value of 222, and the size is +46.2 W/m^2. Both changes must be divided between land and sea. The results of this change are depicted in **Figure 5**.

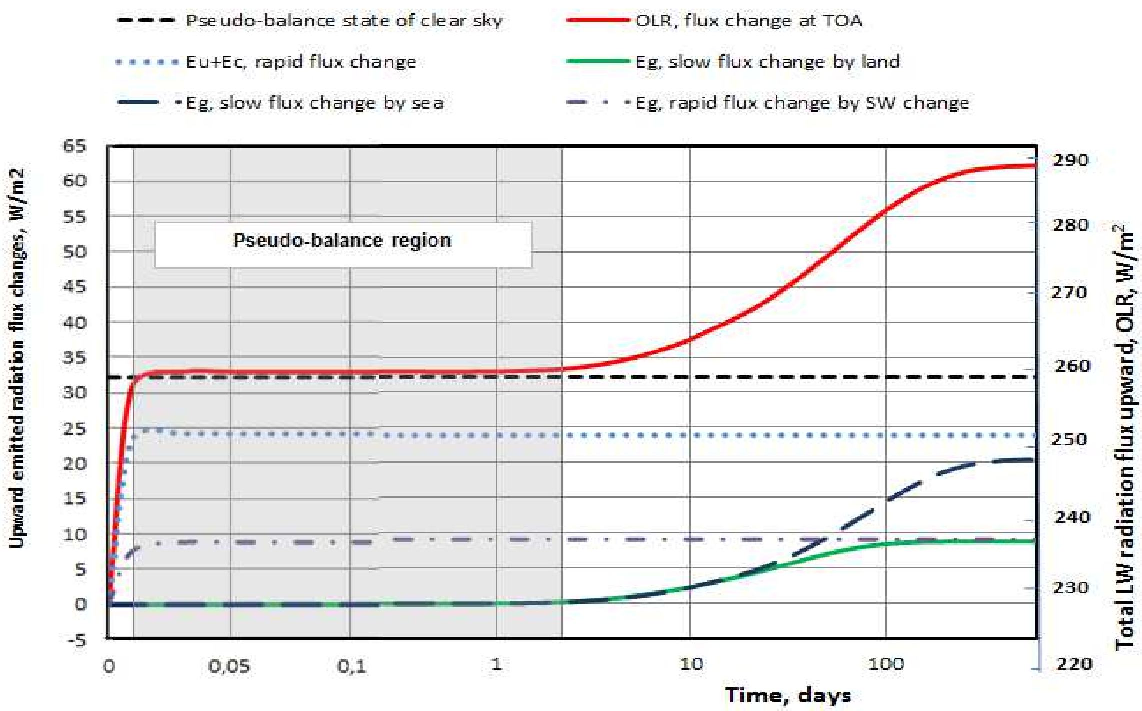

Figure 5: Dynamic response of the OLR_b to the stepwise change from cloudy sky ASR 226.8 W/m^2 to clear sky ASR_b 289 W/m^2. The pseudo-balance of clear sky is the observed OLR_b 259 W/m^2.

The stepwise change of the solar radiation from the cloudy sky 226.8 W/m^2 to clear sky 289 W/m^2 first causes the observed OLR_b 259 W/m^2 at TOA. This value corresponds to a 54% change from 226.8 W/m^2, and on the time scale it happens immediately. The OLR values from 258 to 260 could be measured during the time span of 0 to 2.0 days. Also in this case, the pseudo-balance value is not sensitive for the measurement moment because it has been caused by two rapid process changes, which shoot Eg_b 0.3 % over the pseudo-balance value, and the rest of the change is very slow.

Temperature trends between different skies: In this analysis the transient change impact has been utilized. The step changes to cloudy and clear skies start from the all-sky conditions. As shown in the earlier step changes, the pseudo-balance conditions will be reached very quickly – even in hours. The measured Es fluxes emitted by surface in pseudo-balance reveal that the phenomenon "the transient change" exists. Es values of the different skies reported by Zhang et al.[8] are: Es_b = 394.1, Es_o = 396.3, and Es_a = 395.6. These values correspond to the following black surface temperatures: 15.6°C, 16.0°C, and 15.9°C. The clear sky value of 15.6°C is the lowest values but if the clear sky conditions could prevail long enough – and locally it can happen – the surface temperature would be the highest of all. The reason for this seemingly illogical situation is that clouds prevent cooling of the surface during the night time and this effect exceeds the slow warming of the surface caused by increased SW solar radiation during day time even for several days. The dynamic analysis will reveal, how long time this situation can prevail. The transient time of this phenomenon is the time required that the temperature of the atmosphere corresponds to the new flux emitted by the surface. This time depends on mainly the time constant T_{atm} (2.74 days) of the atmosphere. The size of the transient change is 0.1°C for the cloudy sky change and 0.3°C for the clear sky change.

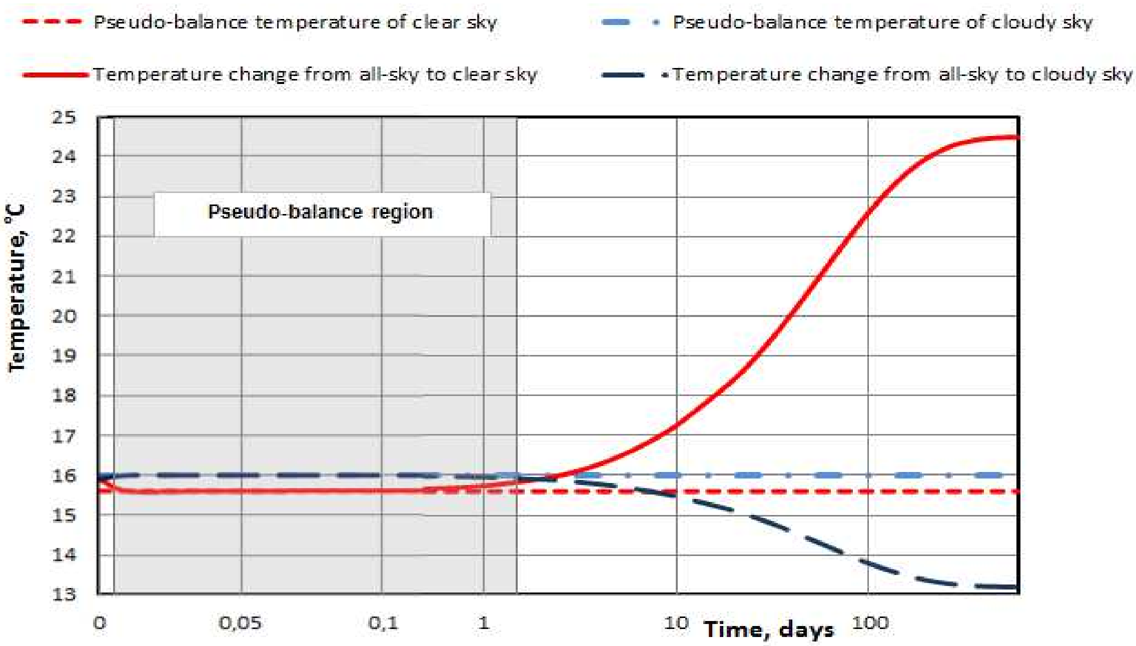

Figure 6. Dynamic responses of the surface temperatures to the stepwise changes from all-sky conditions to the clear and cloudy sky conditions. The pseudo-balance values are the observed values. The temperatures have been calculated from the LW upward fluxes emitted by the surface. The all-sky surface temperature is 15.9 °C. The surface temperature is related to the upward LW flux Es (=Ag+Ac+Eu) emitted by the surface. The total change from Es_a 395.6 to Es_b 445 (= the true balance value) is 49.4 W/m^2 and the change from Es_a 395.6 to Es_o 381.0 (= the true balance value) is -14.6 W/m^2. The temperature change can be calculated as described above dividing the flux changes between land and sea and using the corresponding time constants. Finally the surface temperature can be calculated based on the Es values. This relationship needs radiation emission and absorption calculations applying the average global atmosphere as described by Ollila[7]. The temperature graphs

are depicted in **Figure 6**. The all-sky surface temperature is 15.9 °C, the clear sky true balance value is 24.5° C and the cloudy sky true balance temperature is 13.2° C (Ollila[7]).The pseudo-balance temperatures can be reached and explained only by the fact the atmosphere temperature moves in the beginning to the opposite direction as the final change.

CLOUD FORCING

Traditional Calculation Method: The differences between sky conditions are due to the degrees of cloudiness in different skies. This effect is generally called cloud forcing. Normally the cloud forcing has been calculated at TOA as the difference between clear sky and all-sky in pseudo-balance conditions. The albedo change is the difference between Rt_b and Rt_a, which is -51.2 W/m^2 (using the values of this study). The outgoing LW radiation decrease is the difference between OLR_b and OLR_a, which is 21.2 W/m^2. According to the most common definition, the cloud forcing (CF) is the sum of these two fluxes, which in this case is -30.0 W/m^2, a cooling effect. This value is close to the values used in other studies (Ohring and Clapp[18], Harrison *et al.*[19], Ardany *et al.*[20], Zhang *et al.*[8], Raschke *et al.*[10], Loeb *et al.*[11], Stephens *et al.*[21]), which vary between -17.0 and -28 W/m^2 average being -23.4 W/m^2. Using the CF value of -30 Wm^{-2} and the cloudiness change 66% between clear and all-sky, the CS (Cloudiness Sensitivity) would be -0.46 Wm^{-2}/CL-%. It should be noticed that the calculation of CF with the traditional method is sensitive for small errors in SW and LW flux values. Spencer and Braswell[22] have created a more complicated calculation method for cloud forcing by separating causes and effect of the clouds. Their final conclusion is that clouds have a negative impact on the surface temperature. Dressler[23] has analyzed the TOA radiation budget in response to short-term climate variations from the years 2000 to 2010, and his results showed positive feedback of the clouds. So the issue of cloud forcing still remains unclear without common acceptance and understanding. The author's approach is to use the results of the energy balance calculations and the analyses of the dynamic behavior of the climate system. On the global scale, the climate is in the all-sky condition. Locally the sky can be clear or cloudy for shorter or longer periods. Actually the global values of the clear and cloudy skies have been calculated by combining locally measured flux values because on the global scale the real clear and cloudy skies do not exist.

Cloudiness and albedo effects on the surface temperature: The simplest possible way to analyze the cloudiness and albedo effects on the surface temperature is through the total energy balance of the Earth equalizing the absorbed and emitted radiation fluxes according to the following equation

$$SC * (1-\alpha) * (¶r^2) = sT^4 * (4¶r^2), \qquad 2$$

Where SC is solar constant (1368 W/m^2), α is the total albedo of the Earth, s is Stefan-Bolzmann constant (5.6704*10^{-8}), and T is the temperature (K). The temperature T_a can be calculated from this equation:

$$T_a = (SC * (1 - \alpha) / (4s))^{0.25} \qquad 3$$

Where T_a is the temperature of the atmosphere corresponding the emitted LW flux. The average albedo according to this study values (Ollila[7]) is 104.2/342 = 0.30468. Using this albedo value, the temperature T_a would be -18.7 °C according to equation (3). Using this temperature and the Planck's equation, the emitted LW radiation flux of the Earth would be 237.8 W/m^2, which is the measured value of OLR_a and the same as used in this study. The temperature T_a calculated according to Equation (3) is not the actual surface temperature of the Earth but the temperature at a certain level in the atmosphere corresponding to the LW radiation flux emitted by the Earth's atmosphere into the space. The most common global surface temperature of the Earth calculated as the average value of the surface measurements is 15 °C which means that the greenhouse effect would be 33.7 °C. Because Equation (3) does not include the GH effect, the surface temperature T_s has been taken into account by adding 33.7 K into T_a

$$T_s = T_a + 33.7 \quad (4)$$

The Earth's albedo depends mainly on the cloudiness. Ollila[7] has used the following values of cloudiness and albedos for clear, all-sky and cloudy sky conditions: (0%, 53/342), (66%, 104.2/342), and (100%, 120/342). The second-order polynomial can be fitted through these points and the result is

$$\alpha = 0.15497 + 0.0028623 * CL - 0.000009 * CL^2 \quad (5)$$

Where CL is cloudiness-%.The surface temperatures T_s can be now calculated according to equations (3) and (4) by using the different cloudiness (CL) and the albedo values of equation (5). The minimum and maximum values of the Earth are 10.6 °C and 27.7 °C, which gives the average CS of 0.171 °C/CL-%. The graphical presentation of the surface temperature as the function of cloudiness and albedo is depicted in **Figure 8**.

Cloud forcing according to true balance values: Figure 7presents a graph of the cloudiness trend copied from the website of ISCCP[24] (International Satellite Cloud Climatology Project).In this illustration we can see that the long-term changes in cloudiness level may take years. Utilizing the true balance values of the different skies[7,8] (222 W/m^2, 237.8 W/m^2 and 289 W/m^2), a graph can be prepared where the differences of the net incoming SW flux (NSR) are functions of the cloudiness percentage. The surface temperatures follow the same relationship for the three different skies[7] (13.2 °C, 15.9 °C and 24.5 °C).

Using these three points of the different skies, a mathematical fitting can be made showing a slight nonlinear dependency. Proper fittings are second-order curves, which are the following polynomials:

$$CF_F = -0.98105 * CL + 0.0031105 * CL^2 \quad (6)$$

$$CF_T = 24.5 - 0.16389 * CL + 0.0005089 * CL^2 \quad (7)$$

Where CF_F is the cloud forcing in W/m^2, CF_T is the cloud forcing in °C, and CL is the cloudiness percentage. The surface temperature according to Equation (7) is also depicted in **Figure 8**. The differences between the surface temperatures of the two curves in **Figure 8** are due to the different calculation bases. In Equation (4) the surface temperature is based on the global temperature measurements. The temperature of Equation (7) is based on the measured LW flux values emitted by the Earth's surface. The difference is 15.9 °C – 15.0 °C = 0.9 °C when the cloudiness is 66%. The explanation for this difference is in the accuracies and methods applied in calculating the average global values.

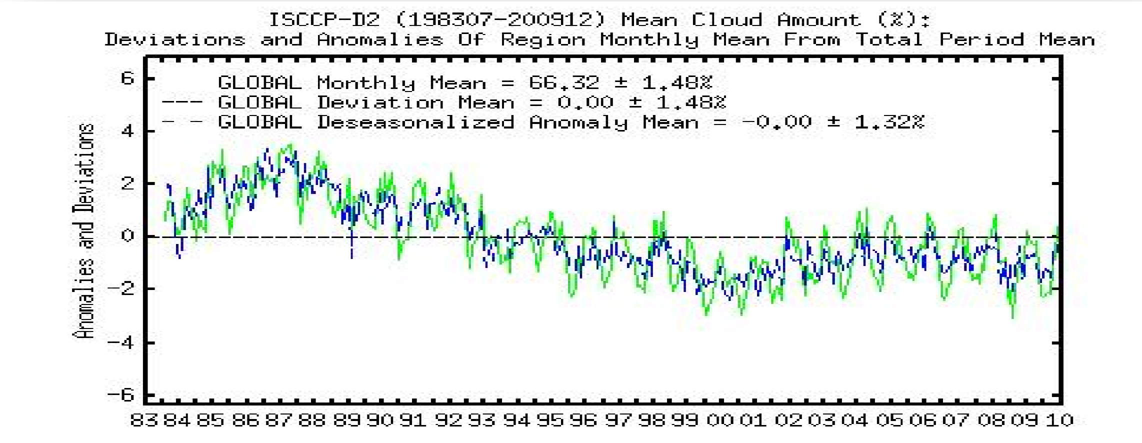

Figure 7. The average global cloudiness (%) graph as monthly means from 1983 to 2010, presented as anomalies of the global monthly mean of 66.32% (ISCCP[24]).

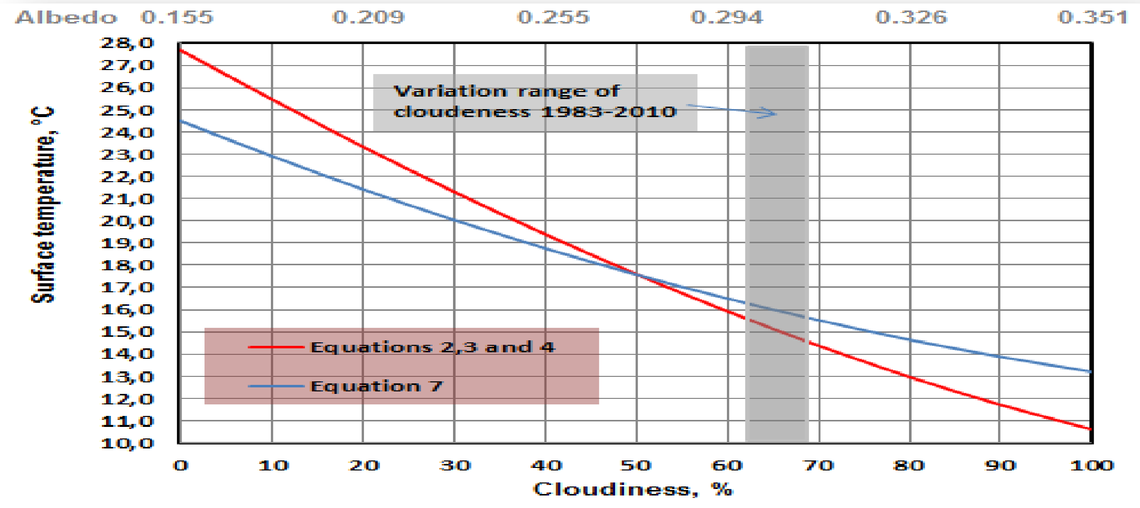

Figure 8: The surface temperatures as the functions of the cloudiness percentage and albedos based on the energy balance calculations and radiation flux analyses.

The cloudiness forcing can be calculated over the whole range from 0% to 100% and the cloud forcing values would be 0.67 Wm^{-2}/CL-% or 0.113 °C/CL-% (24.5 °C – 13.2 °C). In reality the average global cloudiness can be estimated to vary in the range from 60% to 70%, as can be seen from the behavior of the cloudiness during the last 30 years. That is why a linear fitting is a good estimate in this limited range. The angle coefficients of these fittings are -0.564 W/m^2 per CL-% and -0.096 °C/CL-%. These values are the CF values for the cloudiness changes, assuming that the change has settled to another level during the longer time period. This time span is about one year, based on the time constants of land and sea as previously analyzed.

Analysis of different cloud forcing values: In **Table 3** is a summary of different cloud forcing values calculated by different methods.

Table-3: The summary of cloud forcing values. The asterisk (*) values have been calculated by using the climate sensitivity parameterλ. According to IPCC[25] a typical λ value is 0.5* but according to the AR5[26], the value of λ is only 0.85 K / 2.34 Wm^{-2} = 0.363** K/(Wm^{-2}) .

Method	Cloud forcing, Wm-2/CL-%	Cloud forcing, °C/CL-%
Traditional, average value (-23.4 Wm-2)	-0.36	-0.18*, -0.13**
Traditional, this study (-30.0 Wm-2)	-0.46	-0.23*, -0.17**
Radiation balance equations (eq. 2-4)	-0.471**	-0.171
Total energy balance, cloud. range 0-100%	-0.67	-0.11
Total energy balance, linearized 60%-70%	-0.564	-0.096

The difference between 0.363 W/m^2 and 0.46 W/m^2 calculated in the traditional way is due to the different SW and LW flux values measured at TOA. These flux values are measured in clear and all-sky conditions. The final result is that clouds should have a negative impact on the surface temperature. At the same time the measured LW fluxes emitted by the surface show that the all-sky LW flux upward[8] is 395.6 W/m^2 corresponding to a temperature[7] of 15.9 °C and the clear sky values[7,8] are 394.1 W/m^2 and 15.6 °C. If we compare the cloud impacts and the real surface temperatures, there is a most profound contradiction: the cooling effect of CF has caused the increased surface temperature!

The explanation is in the dynamical delays of the climate system. The pseudo-balance values as depicted in **Table 2** show that the real measured values of the upward LW radiation fluxes from the surface (and the surface temperatures) move in the beginning toward the opposite direction when compared to the final change. As previously analyzed, this behavior is due to the warming effects of clouds at night and the heat capacity of the atmosphere. This state is temporary and will vanish in about one week. This dynamic behavior may lead to the wrong conclusion that an increase in cloudiness has a positive impact on the surface temperature, which is not possible in the long run.

A theoretical problem in calculating the CF in the traditional way is the OLR_b value of the clear sky (259 W/m^2), which is actually a pseudo-balance value caused by the cloudiness change from 66% to 0%. The real CF is same as the net SW radiation change, which is 289 - 237.8 = 51.2 W/m^2 in the cloudiness range 0-66% and 289 - 222 = 67 W/m^2 in the cloudiness range 0-100%. As shown above, the change needs time, because the surface temperature has increased at the same time as the CF has caused a cooling effect. Using the pseudo-balance OLR_b value of the clear sky is simply not the right choice in calculating cloud forcing, because this OLR_b flux is not a direct forcing but it is a result of the real forcing caused by SW radiation change.

The author's choice is to calculate the CF value by applying the total SW radiation change caused by cloudiness change, to use true balance values, and to calculate the CF for cloudiness percentage in the cloudiness range from 60% to 70%, which is the normal range of cloudiness variation. The value of the climate sensitivity parameter λ seems to vary in IPCC's reports and which means that the right value of λ is still unclear.

There is a difference, if compared 0.171 °C/CL-% to the value of 0.11 °C/CL-%. The latter value is based on the GH effect calculations in the atmosphere but the radiation balance equations (2-5) does not take GH effect into account and in this respect the CS value of 0.171 °C/CL-% can be assessed to be more theoretical. The CF value of 0.67 Wm^{-2}/CL-% is 45.6% bigger than the 0.46 Wm^{-2}/CL-% calculated on the traditional way. This difference is same as is the difference between pseudo-balance and true balance values of radiation fluxes at TOA.

A short analysis can also be carried out to find out whether a cloudiness change could have a role in global warming. According to IPCC[27], the historical warming till 2005 has been 0.76 °C. Applying the cloud forcing value 0.096°C/CL-% of this study, the 7.9 cloudiness-% decrease is needed for the same increase if no other impacts have been included. This kind of change may be possible if compared to the trend graph of **Figure 7**.

DISCUSSION AND CONCLUSIONS

In this study, dynamic analyses have been carried out for the changes between different sky conditions. The time constant of the land process has been 1.04 months and for sea process 2.74 months. The author has analyzed the real time data (ARM[16]) and found that the time constant for the cloudiness change process is 4 minutes, cloud heating/cooling 0.1 minutes, and for absorption/emission of SW radiation the time constant is 8 minutes. The accuracies of these time constants are not critical. The time constant of the atmosphere warming/cooling as a response to the LW upward radiation has been estimated to be 2.74 days. The accuracy of the time constants of land and sea processes has a dominant effect on the time domain behavior of the true balance value. The true balance values of radiation fluxes are quite theoretical and cannot be achieved on the global scale if applied to the clear and cloudy sky conditions. On the other hand the cloudiness changes having surface temperature effects may reach new true balance states, because the changes can take years.

The simulations of dynamic changes using the achieved time constants reveal that in all changes, two rapid changes in the atmosphere can bring the outgoing LW radiation at TOA almost exactly (difference from 0% to 0.3%) to the observed pseudo-balance values of clear and cloudy skies (259 W/m^2 and 226.8 W/m^2). Actually so small differences mean that the pseudo-balance values have been reached after the atmospheric flux changes. These rapid processes are the cloudiness change process and the SW insolation absorption process in the atmosphere. Because the time constants of these processes are only 4 minutes and 8 minutes, the pseudo-balance values can be measured as quickly as diurnal variations have been included in the data. Because the main change depends on the very slow change of the temperature of land and sea, according to dynamic analyses, the pseudo-balance values stay within ±1 W/m^2 from 1 to 13 days depending on the change type. This means that the measurement time of pseudo-balance values for clear and cloudy skies is not very time-sensitive.

The analysis of pseudo-balance radiation fluxes reveal why the surface temperature moves in the beginning of the change to the opposite direction as the final change. For example, the change from all-sky to cloudy sky increases the LW upward and downward fluxes in the beginning so much that at pseudo-balance, the surface temperature has increased from 15.9 °C to 16.0 °C, but finally the true balance value of the cloudy sky surface temperature would be 13.2 °C. The reason for this phenomenon is the temporary warming of the lower atmosphere because of clouds. In cloudy conditions the night time cooling, according to Sfefan-Bolzmann's law, is so much smaller than the corresponding cooling under a clear sky that the average temperature will increase slightly even though the daytime insolation is higher. There is a good illustration of this phenomenon in **Figure 2** based on the real data. The author has called this process the transient change of atmosphere. The time constant of this process has been assumed to be the same as warming and cooling of the atmosphere due to the LW radiation change, which is estimated to be 2.74 days.

The only explanation for the small changes in opposite directions in the beginning of the change is this transient process of the atmosphere. The measured emitted flux values by surface in the pseudo-balance skies could be a reason that some researchers have concluded that the clouds have a positive impact on the surface temperature. When the climate effects and changes are addressed, the time scale should be at least one year and preferably 10 years.

The calculated results mean that the cloudiness increase from 0% to 66% decreases the balance temperature of the earth from 24.5 °C to 15.9 °C and the further increase to 100% would decrease the surface temperature to 13.2 °C. The cloud effect would be -0.65 W/m^2 per 1 CL-% and -0.113 °C/CL-% over the whole cloudiness range. Kauppinen and his research team (their research paper is in a review process - private communications) have calculated this sensitivity based on a dynamic physical analysis, with the value being -0.11 °C/CL-%, which is the same value as calculated on the basis of the total energy balance.

It should also be noticed that the common used cloud forcing values of 21-28 W/m^2 (cooling) is applicable only for short term impact calculations because this value is based on the pseudo-balance values of the clear sky. The cloudiness change based on the long-term changes originating, for example, from the sun and cosmic radiation changes, happens over a span of years, and it means that a new balance state can be reached. Scientists report different results on the impact of clouds. The majority of researchers have found that clouds have cooling effects on the climate. Some researchers, e.g. Dressler[23] and Lacis *et al.*[28], have reported warming effects of clouds in the GH phenomena. In this sense, the results of this study are very clear: long term cloudiness changes have a negative impact on surface temperatures as well as on the OLR fluxes, which is already a known fact.

According to the IPCC[26], the radiation forcing value of 1.6 W/m^2 of 99 ppm CO_2 increase has caused the temperature increase of 0.76 °C from 1750 to 2005 assuming that the warming effect has totally reached the new balance value. Utilizing the linearized cloud forcing values 0.564 Wm^{-2}/CL-% and 0.096 °C/CL-% calculated according to the true balance method, 3% cloudiness change would cause 1.6 W/m^2 climate forcing corresponding to only 0.29 °C increase and 7.9% cloudiness decrease is needed for 0.76 °C increase. Ollila[12] has calculated the warming value of 0.2 °C for the 99 ppm CO_2 increase utilizing spectral calculation methods.

Two potential reasons could explain the results of IPCC. One explanation is that the water feedback, which doubles the CO_2 impact, has been used in the calculations referred by IPCC and/or the water content of the atmosphere has been smaller than in the real global average atmosphere, which increases the warming effect of CO_2. IPCC has omitted the cloud forcing effects in its warming analyses even though 6% cloudiness change and the conservative climate sensitivity value of 0.3 Wm^2/CL-% would cause 1.8 Wm^{-2} forcing having the same effect as CO_2.

The primary energy comes always from the sun and the LW radiation fluxes depend on this energy source in the long run. The real cloud forcing starts therefore from the SW radiation flux changes, which force the climate finally to another balance state. The forcing process goes through the different atmospheric processes including the changes of LW radiation fluxes caused by clouds. The cloud forcing issue can be also simplified by calculating the long-term (min. 1 year) surface temperature changes caused by the global cloudiness changes. The increased cloudiness always decreases the surface temperature in the long run.

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