

Cloud Radiative Effect over 2001-2020

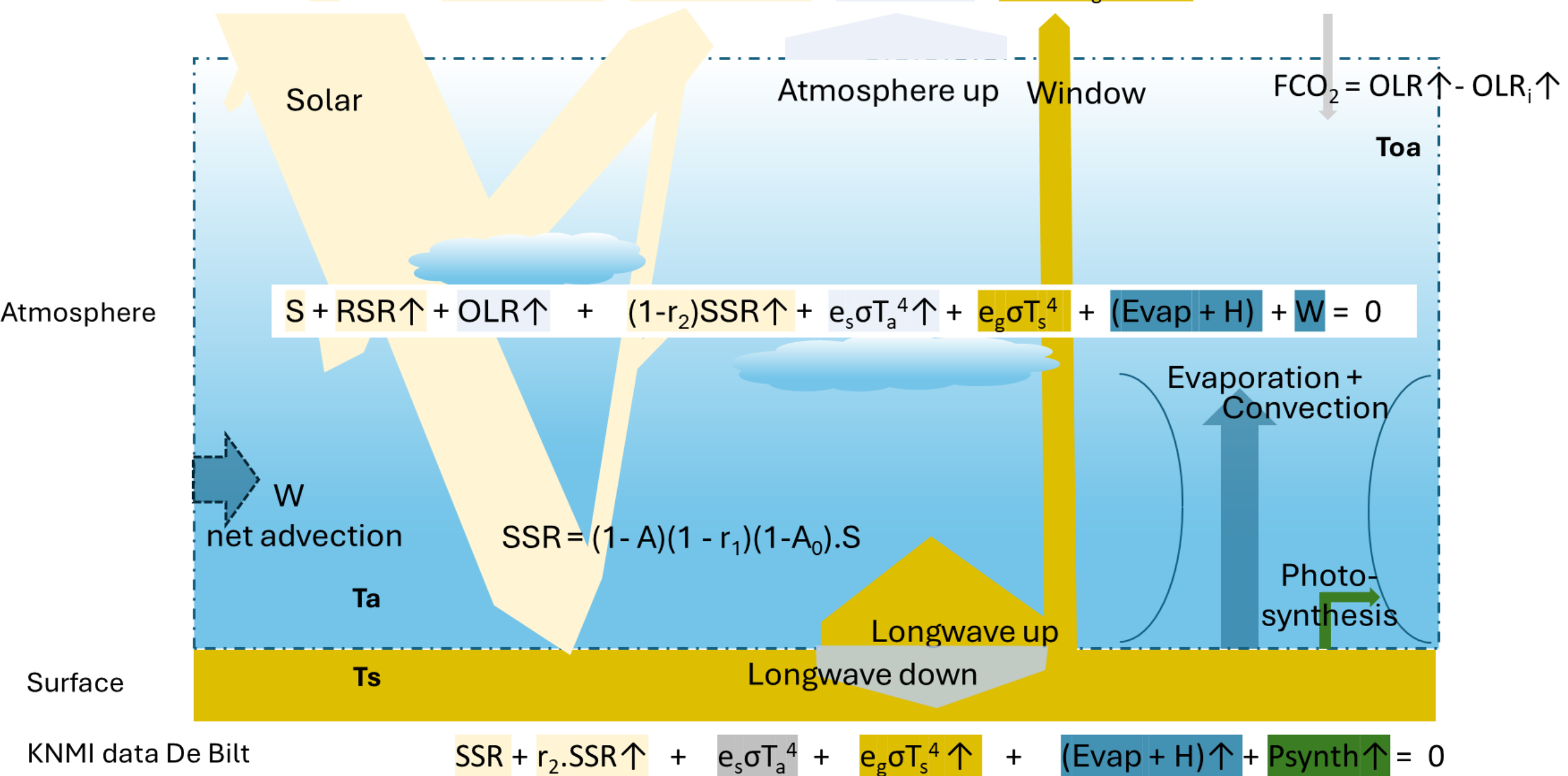
Cloud cover change explains 63%

changes in aerosols and water vapor 37%
of the 1.8 W/m² surface warming (0.35 °C)

according to the energy and radiation budget for De Bilt, Netherlands

Radiation and energy flux equations of a column of air

CERES data S + RSR↑ + OLR↑ = imbalance

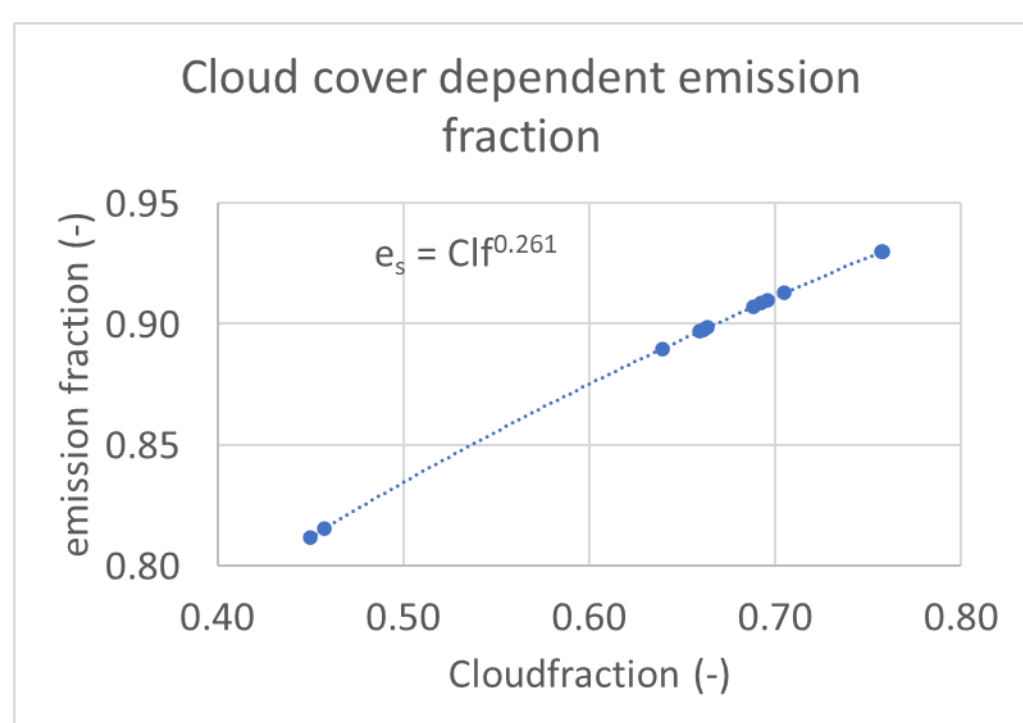
$$\text{Top } S + r_1 \cdot (1-A_0)S \uparrow + r_2 \cdot (1-a)SSR \uparrow + e_a \cdot \sigma T_{\text{pa}}^4 \uparrow + (1-e_s) e_g \cdot \sigma T_s^4 \uparrow = N$$


Assumed constants:

α_0 = stratospheric absorption fraction (0,0395)
 α_a = top atmosphere emission fraction (0,895)
 α_g = surface emission fraction (0,994)
 α_2 = surface reflection fraction (0,23)
 α = reflected SSR absorption fraction (0,203)

Solved variables:

$A = 1 - SSR / ((1 - r_1)(1 - A_0) \cdot S)$
 $r_1 = (RSR - (1 - a)r_2 \cdot SSR) / ((1 - A_0) \cdot S)$
 T_{oa} and T_s : temperature
top and surface



Top Atmosphere	S	-r1.(1-A)S	-(1-a)r2.SSR	-ea0Toa4	-(1-es).eg.oTs4	FCO2	-N	sum
2001-2010	276.3	-88.31	-17.76	-217.12	-10.08	1.79	55.18	0.000
2011-2020	276.3	-85.42	-18.23	-218.20	-10.69	1.97	54.27	0.000

Energy and radiation balance Atmosphere (W/m2)										
Atmosphere	S	-RSR	-OLRi	FCO2	-(1-r2)SSR	-esoTa4	eg.oTs4	Evap+H	W	sum
initial 2001-2010	276.3	-106.07	-227.20	1.79	-94.99	-334.06	366.82	57.63	59.78	0.00
actual 2001-2020	276.3	-103.65	-228.89	1.97	-97.49	-335.16	368.61	59.37	58.94	0.000

Energy and radiation balance Surface (W/m2)								
Surface	SSR	-r2.SSR	es0Ta4	-eg.σT4	-Evap	-H	-PSynth	sum
initial 2001-2010	117.3	-22.28	334.06	-366.82	-45.71	-11.92	-4.60	0.000
clear sky	184.3	-35.01	303.99	-355.61	-73.21	-19.10	-5.34	0.000
actual 2011-2020	120.4	-22.87	335.16	-368.61	-47.08	-12.28	-4.67	0.000
clear sky	192.7	-36.61	304.45	-359.65	-75.71	-19.75	-5.43	0.000

Composition All sky downward radiation to the surface 2001-2020 and Total Cloud Effect					
Flux W.m-2	type	All sky	Clear sky	Cloudy sky	TCE(W/m2)
initial 2001-2010	Short Wave (SSR)	117.3	187.0	-69.7	-25.6
	Long Wave down	334.3	290.2	44.1	

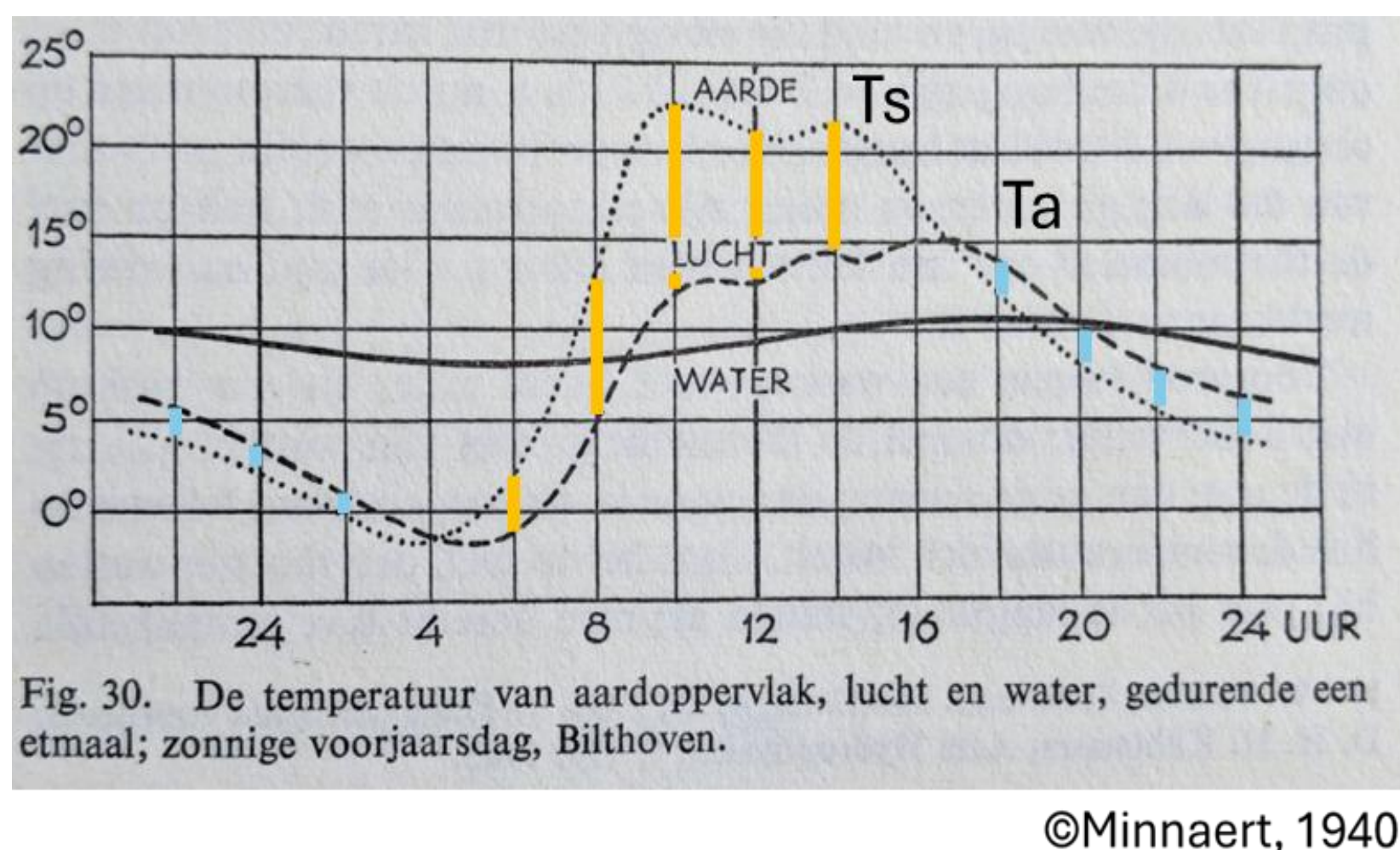
actual 2011-2020	Short Wave (SSR)	120.4	189.2	-68.9	-23.2
	Long Wave down	335.2	289.4	45.7	

Long wave and short wave contributions to change in All sky downward radiation					2001-2020
Forcing W.m-2,dec type		Δ All sky	Δ Clear sky	Δ Cloudy sky	Δ TCE
actual - initial	Δ Short Wave (SSR)	3.1	2.2	0.9	2.5
	Δ Long Wave (esoTa4)	0.9	-0.7	1.6	
	Δ total downward	4.0	1.5	2.5	

Error propagation										
Surface	SW All sky	SW Clear sky	2001-2020	LW All sky	LW Clear sky	SW All sky	SW Clear sky	2011-2020	LW All sky	LW Clear sky
Add data				283.7	285.17				284.12	284.82
Component	SSR	SSRclear		Ta	Ta	SSR	SSRclear		Ta	Ta
SE	4.033	21.04		0.6	1.63	5.836	27.227		0.58	1.333
SE	SE(SSR)	SE(SSRclear)		SE(LWdown)	SE(LWclear)	SE(SSR)	SE(SSRclear)		SE(LWdown)	SE(LWclear)
SE	1.275	6.653		0.860	2.141	1.845	8.610		0.861	1.740
SE (CE)	SE(SCE)=	6.774		SE(LCE)=	2.307	SE(SCE)=	8.806		SE(LCE)=	1.941
SE (TCE)			SE(TCEint)=	7.156				SE(TCEint)=	9.017	
SE (ΔTCE)					SE(ΔTCE) W/m2	11.5				

Conditions for adjusting calculated emission fraction
atmosphere e_s (0.85-0.99) and surface e_g (0.88 – 0.98)

- In spring over 24 hours:
 T_s surface minus T_a air = 2.6 degrees C



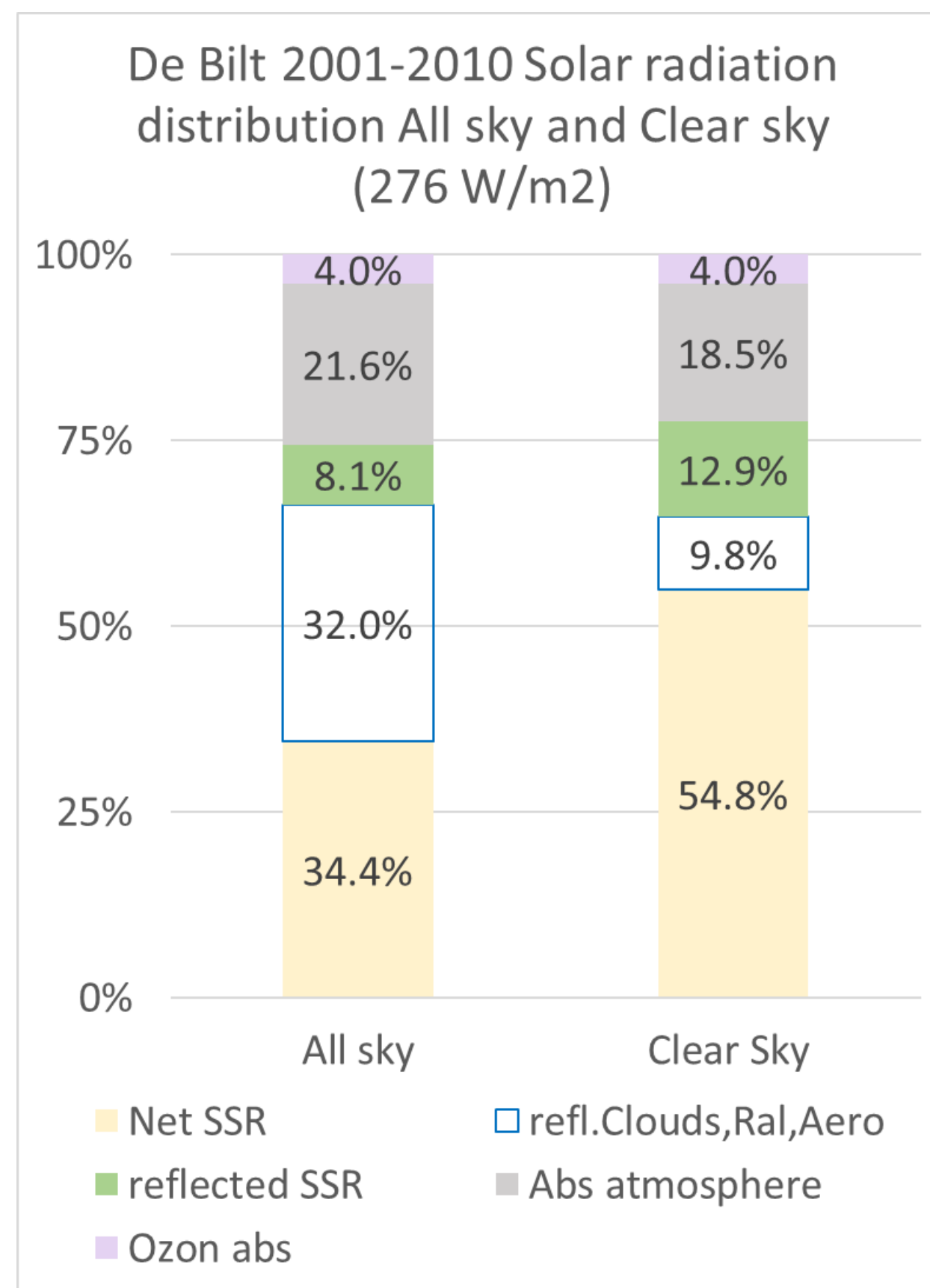
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- Aligning total forcing per temperature change with the Stefan-Boltzmann derivative

Surface component		actual - initial W/m2 warming %
Solar surface	ΔSSR	3.090 73.7%
reflected Sol surf	$-\Delta\sigma_{2SSR}$	-0.587
LW-down	$\Delta\epsilon_s\sigma_a^4$	1.102 26.3%
evaporation	$-\Delta Evap$	-1.376
convection	$-\Delta H$	-0.359
photosynthesis	$-\Delta Psynth$	-0.073
total forcing	$\Sigma \Delta F_i = \Delta\epsilon_s\sigma_a^4$	1.797 100.0%
temperature change	$\Delta T_s \text{ (gK)}$	0.347
emperical $f_{feedback} = -\Delta F / \Delta T_s$		-5.175
theoretical $f_{feedback} = -4 \cdot \epsilon_g \cdot \sigma T_s^3$		-5.166

Atmosphere component		actual - initial	
		W/m2	warming %
irradiance sun	ΔS	0.000	
reflected solar	$-\Delta RSR$	2.417	39.4%
net Solar Surf	$-\Delta(1-r_2)SSR$	-2.503	
out longwave i	$-\Delta OLRI$	-1.688	
forcing CO2	$\Delta FCO2$	0.188	3.1%
LW-up surface	$\Delta e_g \sigma T_a^4$	1.797	29.3%
evap+conv	$\Delta(Evap+H)$	1.736	28.3%
lateral wind	ΔW	-0.844	
total forcing _i	$= \Delta e_g \sigma T_a^4$	1.102	100.0%
	ΔT_a (grK)	0.438	
	$f_{feedback} = - \Delta F / \Delta T_a$	-2.517	W/m2.K-1
	$f = -(de_g/dT_a \sigma T_a^4 + 4e_g \sigma T_a^3)$	-2.519	W/m2.K-1

Green House Effect over 2001-2020
 $\Delta GHE = 0,297 \text{ W/m}^2$ is 7% of the near surface warming



Surface warming: changes in clear and cloudy skies

Clear-sky change = changes aerosols + water vapor

Cloud change = change cloud cover

Latest advancements

-Emission fraction near surface (e_s) as a function of

-Emission fraction top atmosphere (e_s) as a linear

function of e_s : $e_a = p.e_s$

-Radiative mean temperature: $T_m = (\sum T_i^4/n)^{0.25}$