Solar Surface Radiation and Temperature Trends

over 2001-2020 in De Bilt, Netherlands

EMS 2025-657

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Objectives

Does the increase in solar surface radiation over 2001-2020 explains the raise in near surface temperature in De Bilt?

- Radiation and energy budgets reveal crucial insights to attribution

- Evaluation of
  - Cloud cover dependent emissivity
  - Long Wave-downward radiation
  - Greenhouse effect and CO2 forcing

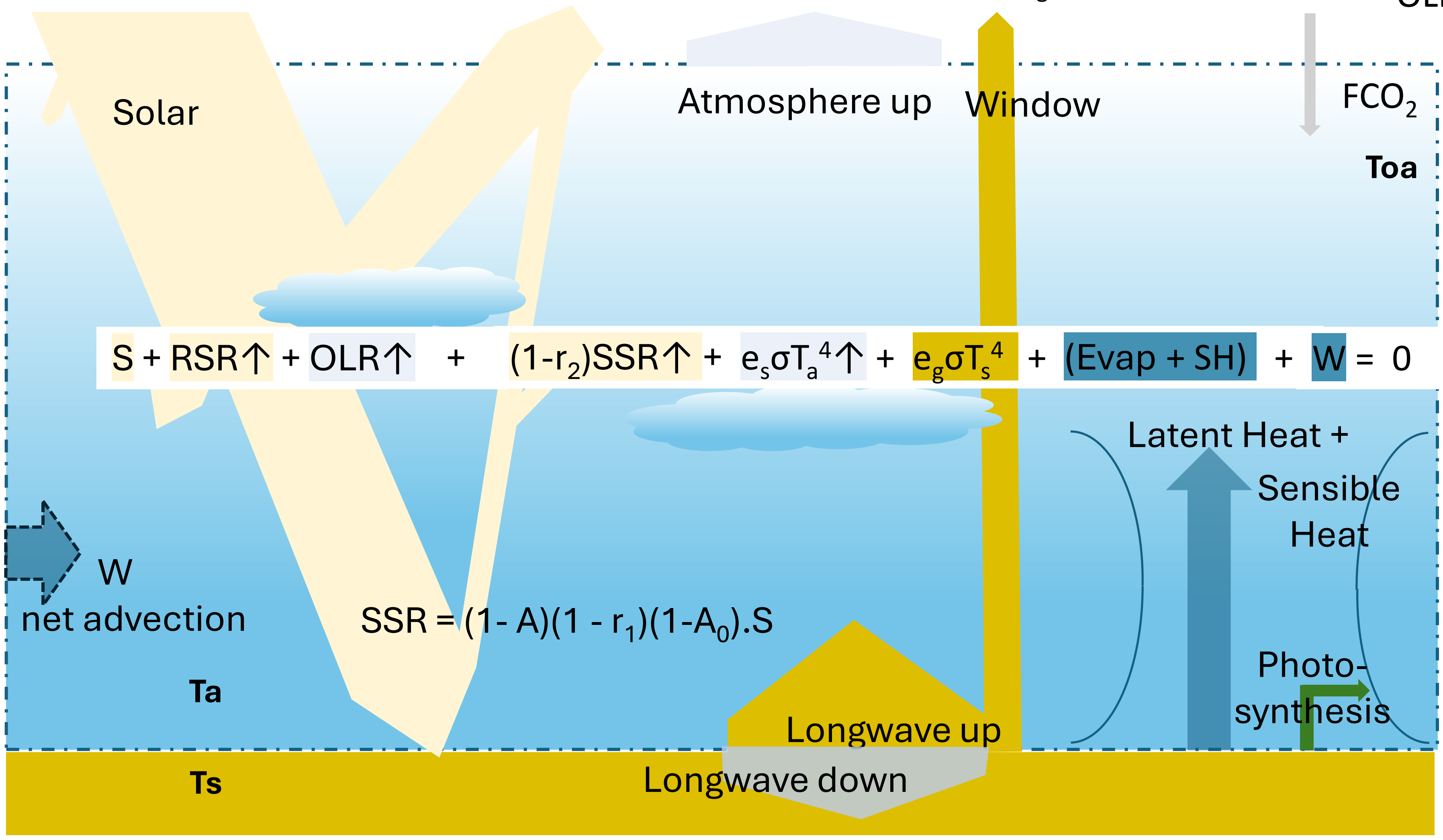
Radiation and energy flux equations of a column above De Bilt

Top: CERES data $S + RSR\uparrow + OLR\uparrow = \text{imbalance}$

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

$$OLR\uparrow = FCO_2 + OLR_i\uparrow$$

Atmosphere



$$S + RSR\uparrow + OLR\uparrow + (1-r_2)SSR\uparrow + e_s\sigma T_a^4\uparrow + e_g\sigma T_s^4 + (Evap + SH) + W = 0$$

$$SSR = (1- A)(1 - r_1)(1-A_0).S$$

Surface
KNMI data

$$SSR + r_2.SSR\uparrow + e_s\sigma T_a^4 + e_g\sigma T_s^4\uparrow + (Evap + SH)\uparrow + Psynth\uparrow = 0$$

Calculated fluxes

Top
in - out = Imbalance

$$S - r_1.(1-A_0)S - r_2.(1-a)SSR - (1-e_s)e_g.\sigma T_s^4 - N = \mathbf{e_a.\sigma T_{oa}^4}$$ Flux top atm

Atmosphere
in - out = 0

$$S - RSR - OLR - (1-r_2)SSR - (e_s\sigma T_a^4) + e_g\sigma T_s^4 + Evap + SH = -\mathbf{W}$$ Net advection

Surface
in - out = 0

$$SSR - r_2.SSR + e_s\sigma T_a^4 - (Evap + SH) - Psynth = \mathbf{e_g\sigma T_s^4}$$ Longwave up surface

Assumed constants:
A_0 = stratospheric absorption fraction (0.0395)
e_a = top atmosphere emission fraction (0.895)
e_g = surface emission fraction (0.994)
r_2 = surface reflection fraction (0.23)
a = reflected SSR absorption fraction (0.203)

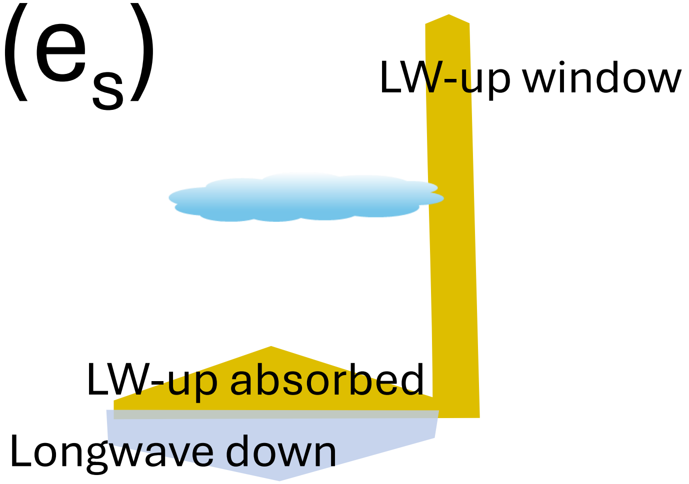
Solved variables:
$A = 1 - SSR/((1-r_1)(1-A_0).S)$

$r_1 =(RSR-(1-a)*r_2*SSR)/((1-A_0).S)$

T_{oa} and T_s : temperature top and surface

How to solve the near surface emission fraction e_s

Near surface Emission fraction (e_s)

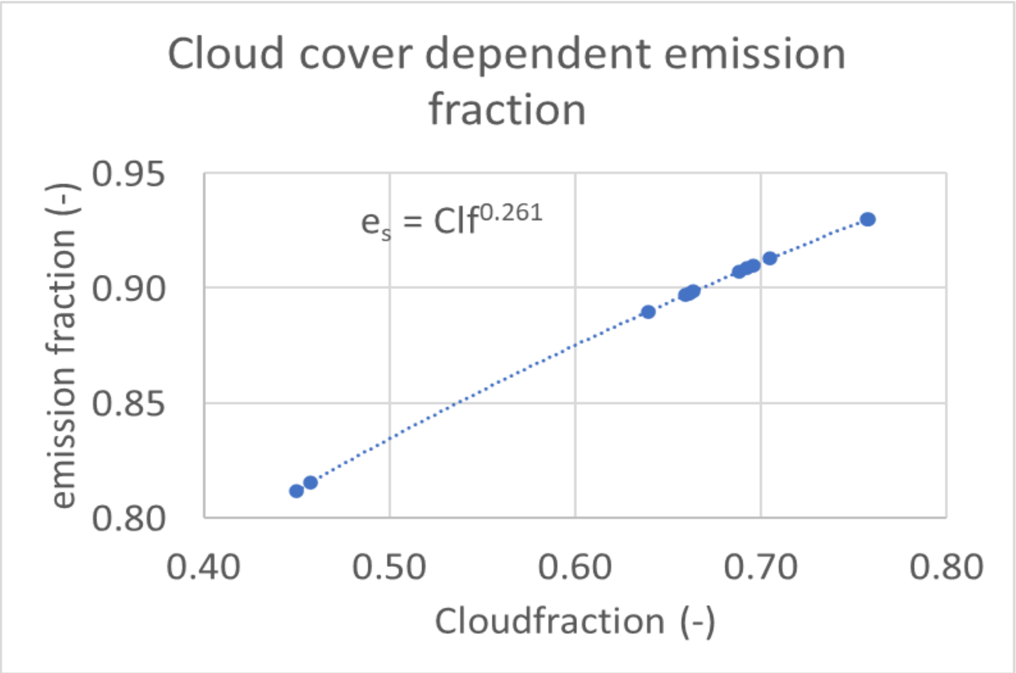


e_s controls

- LW-down = $e_s\ \sigma\ T_a^4$
- LWup-absorbed = $e_s\ .\ e_g \sigma\ T_s^4$
- LWup-window = $(1-e_s)\ e_g \sigma\ T_s^4$

e_s is cloud cover dependent

- Empirical relation: $e_s = (\mathrm{Clf})^Z$
- One parameter $z = 0.261$ fits e_s for Seasons, Clear sky and All sky



Radiation and energy balance Atmosphere 2001-2020 (W/m2)

Atmosphere	S	-RSR	-OLRi	FCO2	$-(1-r_2)SSR$	$-e_s\sigma T_a^4$	$e_g.\sigma T_s^4$	Evap+SH	W	sum
initial 2001-2010	**276.3**	**-106.07**	**-227.20**	**1.79**	**-94.99**	**-334.06**	**366.82**	**57.63**	**59.78**	**0.000**
winter	111.9	-53.83	-212.16	1.82	-26.93	-308.72	321.13	11.99	154.83	**0.000**
spring	353.3	-132.00	-226.13	1.80	-127.20	-326.82	376.26	72.68	8.08	**0.000**
summer	443.3	-158.33	-243.40	1.73	-162.18	-363.33	412.02	108.01	-37.85	**0.000**
fall	196.7	-80.10	-227.12	1.78	-61.95	-337.68	359.00	36.73	112.66	**0.000**
actual 2011-2020	**276.3**	**-103.65**	**-228.89**	**1.97**	**-97.49**	**-335.16**	**368.61**	**59.37**	**58.94**	**0.000**
winter	111.9	-52.57	-211.33	2.00	-27.33	-314.49	326.61	12.64	152.60	**0.000**
spring	353.3	-127.77	-229.31	1.98	-133.33	-324.78	376.67	76.28	6.93	**0.000**
summer	443.3	-156.33	-244.61	1.94	-164.58	-364.39	413.51	109.89	-38.77	**0.000**
fall	196.7	-77.93	-230.30	1.97	-63.06	-337.09	358.63	37.56	113.56	**0.000**

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	**$\Delta e_g.\sigma T_s^4$**	**1.797**	29.3%
Evap+SH	**$-\Delta(Evap+SH)$**	**1.736**	28.3%
lateral wind	**ΔW**	**-0.844**	
total forcing	**$\Sigma\Delta F_i = \Delta e_s\sigma T_a^4$**	**1.102**	100.0%

Forcings 2001-2020 yearly data (W/m2.dec-1)
Actual – Initial values atmosphere

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

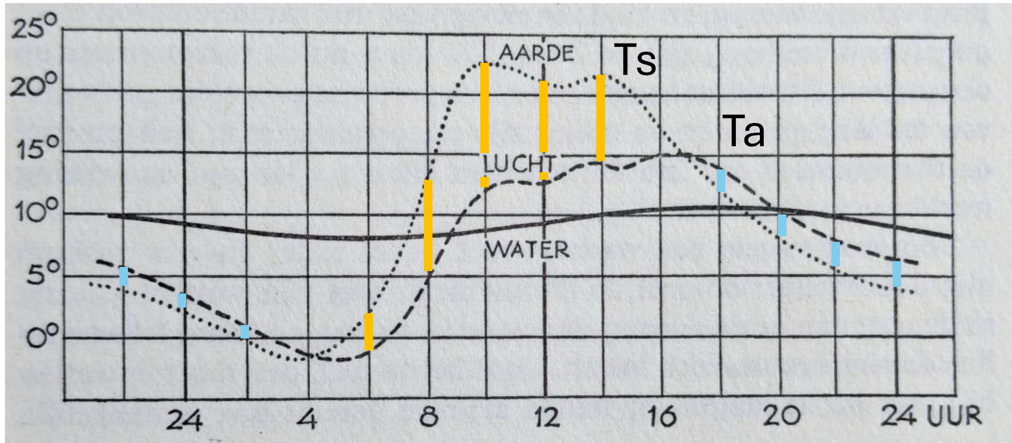


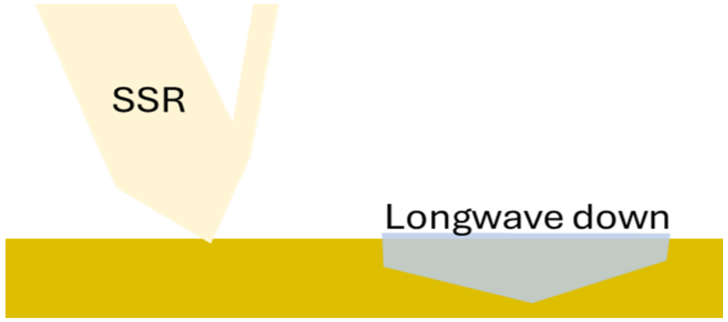
Fig. 30. De temperatuur van aardoppervlak, lucht en water, gedurende een etmaal; zonnige voorjaarsdag, Bilthoven.

Calibrated spring temperature difference			
			z = 0.261
KNMI data	Ts(grC)	Ta(grC)	Ts - Ta (grC)
2001-2010	11.667	10.534	1.134
winter	3.830	3.458	0.373
spring	12.549	9.927	2.623
summer	18.481	17.565	0.916
fall	10.761	11.053	-0.291

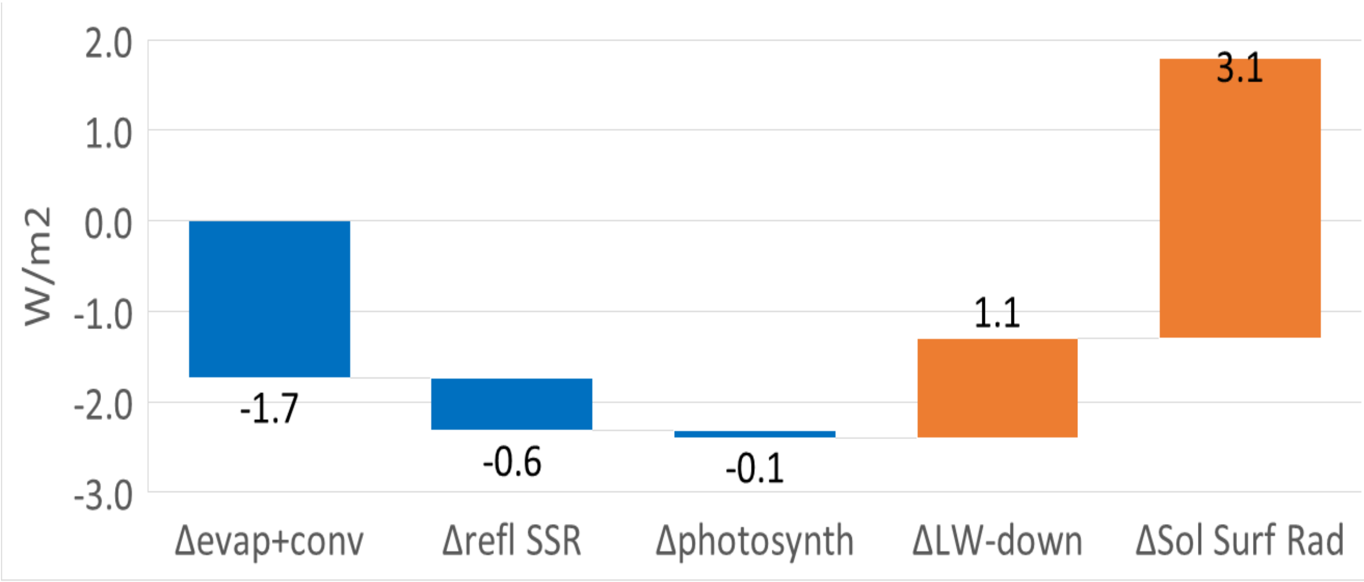
- Aligning total forcing per temperature change with the Stefan-Boltzmann derivative

Surface component		**actual - initial** W/m2	warming %
Solar surface	**ΔSSR**	3.090	73.7%
reflected Sol surf	**-Δr2SSR**	-0.587	
LW-down	$\Delta e_s \sigma T_a^4$	1.102	26.3%
evaporation	**-ΔEvap**	-1.376	
sensible heat	**-ΔSH**	-0.359	
photosynthesis	**-ΔPsynth**	-0.073	
total forcing	$\Sigma \Delta F_i = \Delta e_g \sigma T_s^4$	**1.797**	100.0%
temperature change	ΔT_s (gK)	0.347	
emperical $f_{eedback} = -\Delta F / \Delta T_s$		-5.175	
theoretical $f_{eedback} = -4.e_g.\sigma T_s^3$		-5.166	

Contributions to 1.8 W/m2 Surface Warming 2001-2020 ($\Delta Ts = 0.35\ ^0C$)



- Solar Surface Radiation 74% (43-100%)
- LongWave downward radiation 26% (0-56%)



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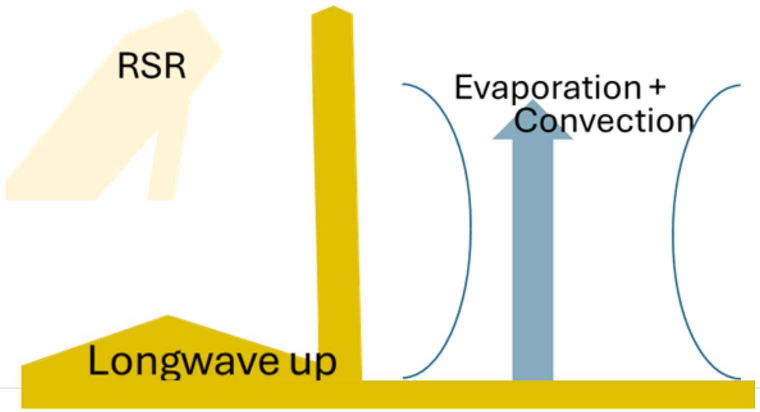
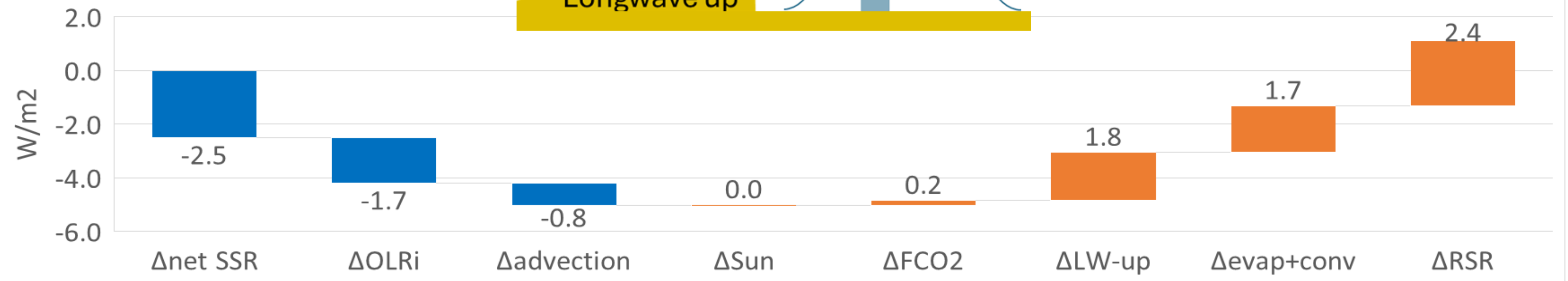
Contributions to 1.1 W/m2 Atmospheric Warming 2001-2020 (ΔT_a =0.44 ^{0}C) at 2 Meters

Reflected Solar Radiation 39% (-2-80%).
Longwave up radiation 29% (6-52%).
Evaporation and Convection 28% (-6-63%)

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	$\Delta e_g.\sigma T_s^4$	**1.797**	29.3%
Evap+SH	$-\Delta(Evap+SH)$	**1.736**	28.3%
lateral wind	ΔW	**-0.844**	
total forcing	$\Sigma\Delta F_i = \Delta e_s \sigma T_a^4$	**1.102**	100.0%
	ΔT_a (grK)	**0.438**	
	$f_{eedback} = -\Delta F/\Delta T_a$	**-2.517**	W/m2.K-1
	$f = -(de_s/dT_a.\sigma T_a^4 + 4e_s\sigma T_a^3)$	**-2.519**	W/m2.K-1





Impact Greenhouse effect (including CO2 forcing)

on 2001-2020 warming at 2 M height : 7% (0.297 W/m2)

Raval and Ramanathan, 1989:

> **Determination of the greenhouse effect**
>
> If E is the longwave flux emitted by the surface at a certain location, and F is the flux leaving the top of the atmosphere (TOA) directly above that location, then the greenhouse effect G for that location can be defined as $G = E - F$.

Atmosphere component		**actual - initial** W/m2	GHE W/m2	warming %
irradiance sun	**ΔS**	**0.000**	**0.000**	
reflected solar	**$-\Delta RSR$**	**2.417**	**2.417**	54.3%
net Solar Surf	**$-\Delta(1-r_2)SSR$**	**-2.503**	**-2.503**	
out longwave i	**$-\Delta OLRi$**	**-1.688**		
forcing CO2	**$\Delta FCO2$**	**0.188**	**0.297**	6.7%
LW-up surface	**$\Delta e_g.\sigma T_s^4$**	**1.797**		
evap+conv	**$-\Delta(Evap+H)$**	**1.736**	**1.736**	39.0%
lateral wind	**ΔW**	**-0.844**	**-0.844**	
total forcing	**$\Sigma\Delta F_i = \Delta e_s\sigma T_a^4$**	**1.102**	**1.102**	100.0%

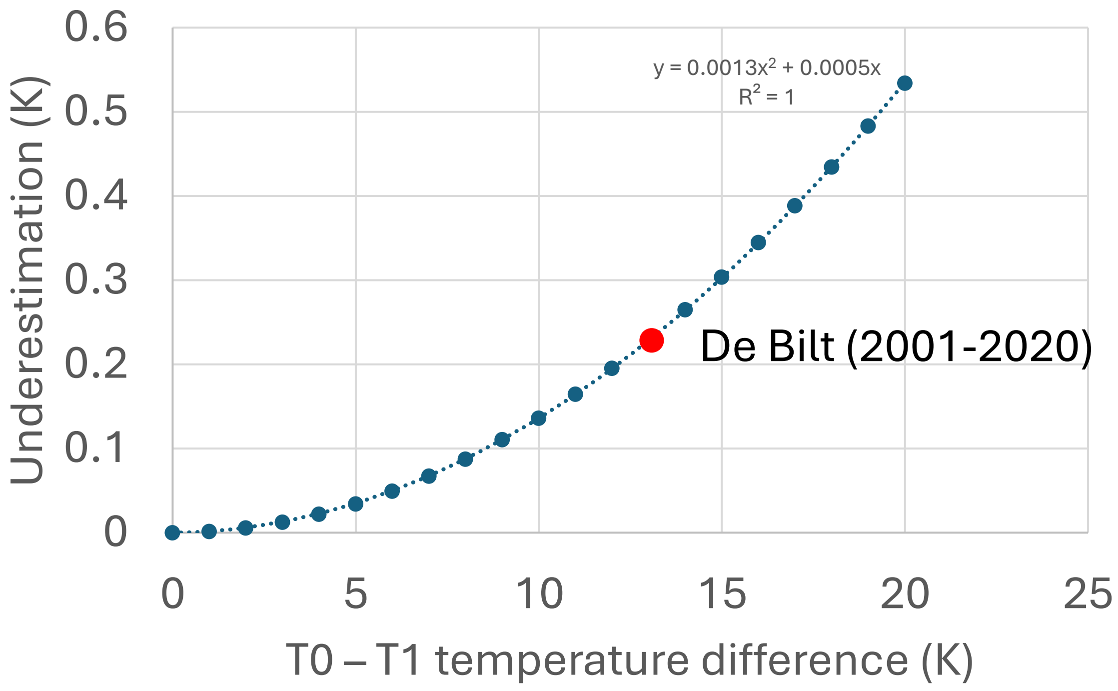
GHE Greenhouse effect 2001-2020

	$e_g.\sigma T_s^4$	**- OLR**	**= GHE**	**ΔGHE**
2001-2010	366.82	-225.42	141.40	**0.297**
2011-2020	368.61	-226.92	141.70	

Latest advancement
better agreement with SB derivative

- Emission fraction top atmosphere (e_a) as a linear function of e_s: $e_a = p.e_s$
- Underestimation of the Radiative mean temperature: $T_m = (\Sigma T_i^4/n)^{0,25}$

Temperature difference and underestimation of radiant mean temperature (270-290K) $(T_0+T_1)/2$ versus $((T_0^4+T_1^4)/2)^{0,25}$



Conclusion

It is possible to explain long term temperature changes in De Bilt in terms of causative fluxes using budget equations

- Surface warming: 74% ΔSSR and 26% ΔLW-down
- Atmospheric warming at 2 meters:
  57% Δ upward surface fluxes
  39% Δ Reflected Solar Radiation
- Huge error margins
- The role of cloud cover is crucial as it links the emissivity at the surface

Thank you for your attention

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 ^{0}C)

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

Temperature dynamics and underestimation of the radiant mean temperature

Daily average temperature from hourly data over 2001-2020 in De Bilt is **0,24 K to low** (1 W/m2)

- $E = \sigma \, . \, T^4$
- $E_{average} = (E1+E0)/2$
- $T_{av}{}^4 = (T_0{}^4 + T_1{}^4)/2$

Radiative mean temperature:
$T_m = (\Sigma T_i{}^4/n)^{0,25}$