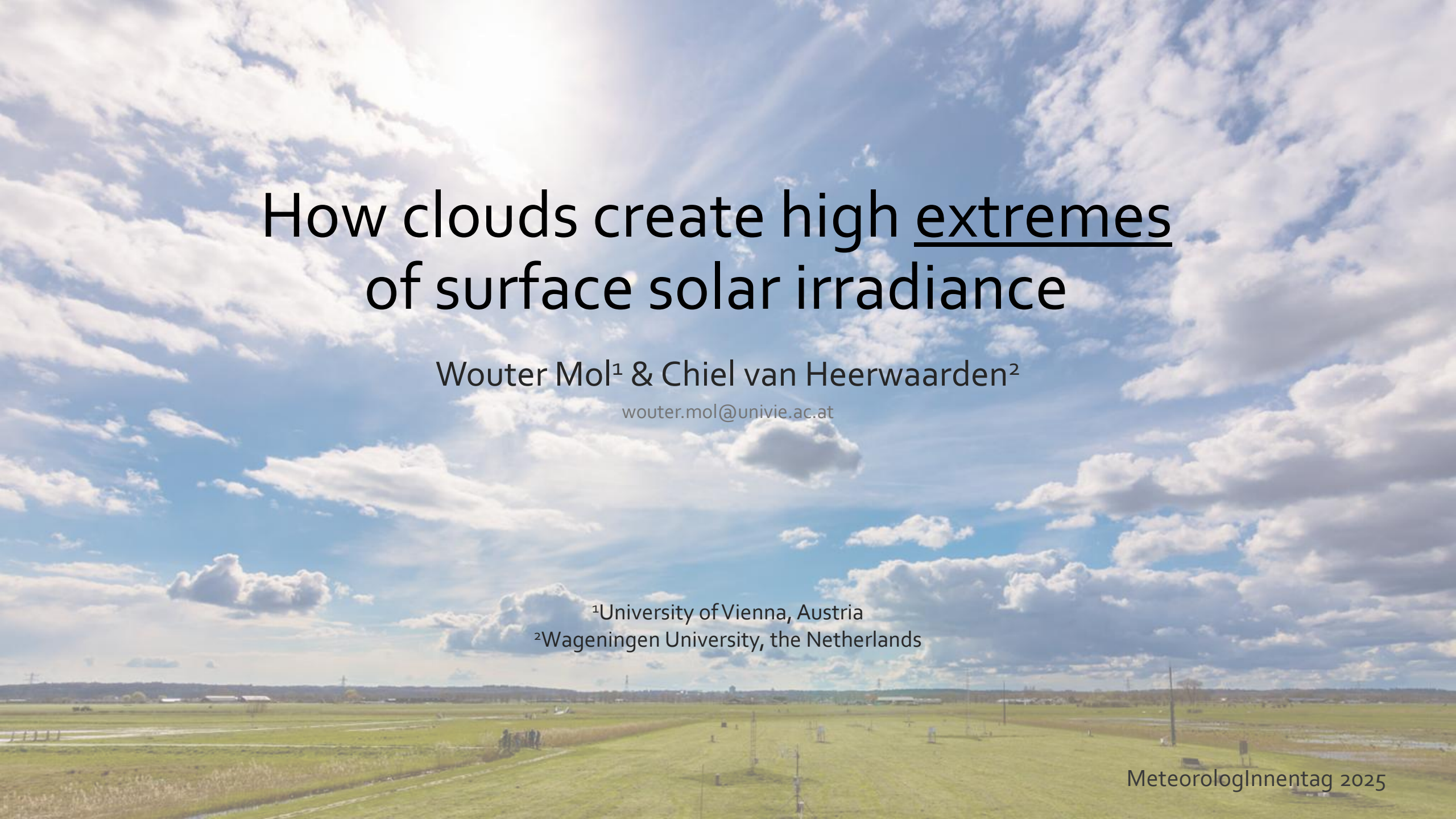

How clouds create high extremes of surface solar irradiance

Wouter Mol[1] & Chiel van Heerwaarden[2]

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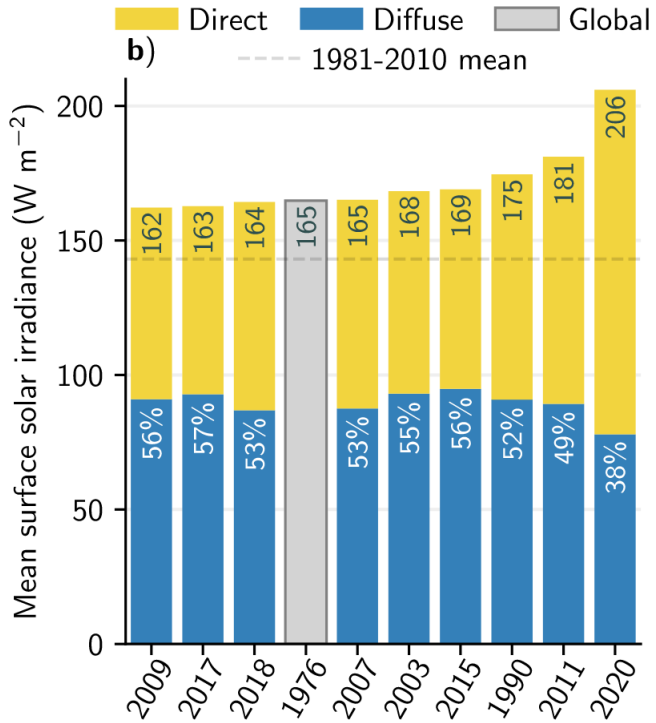
[1]University of Vienna, Austria
[2]Wageningen University, the Netherlands

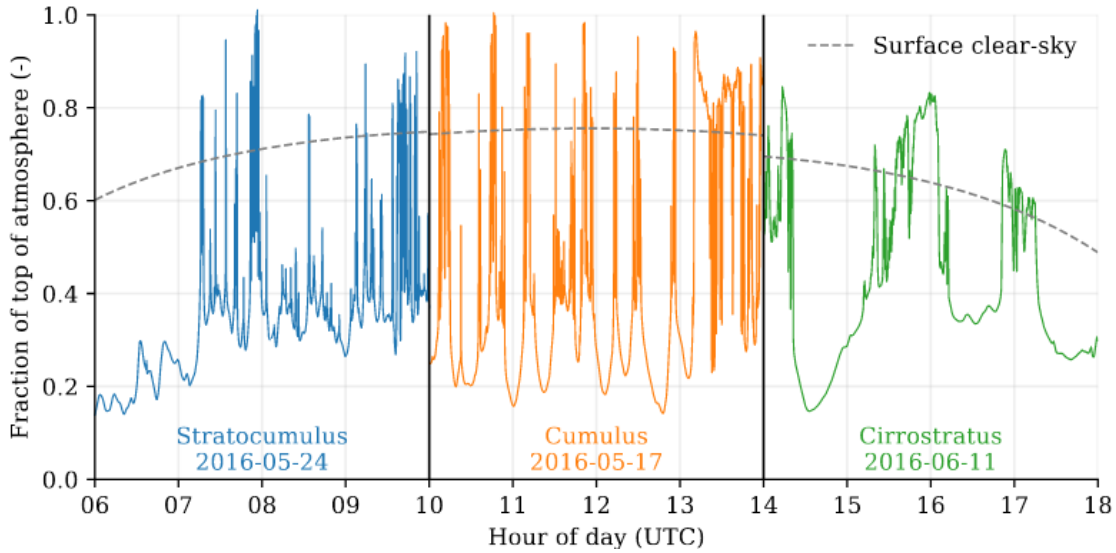
MeteorologInnentag 2025

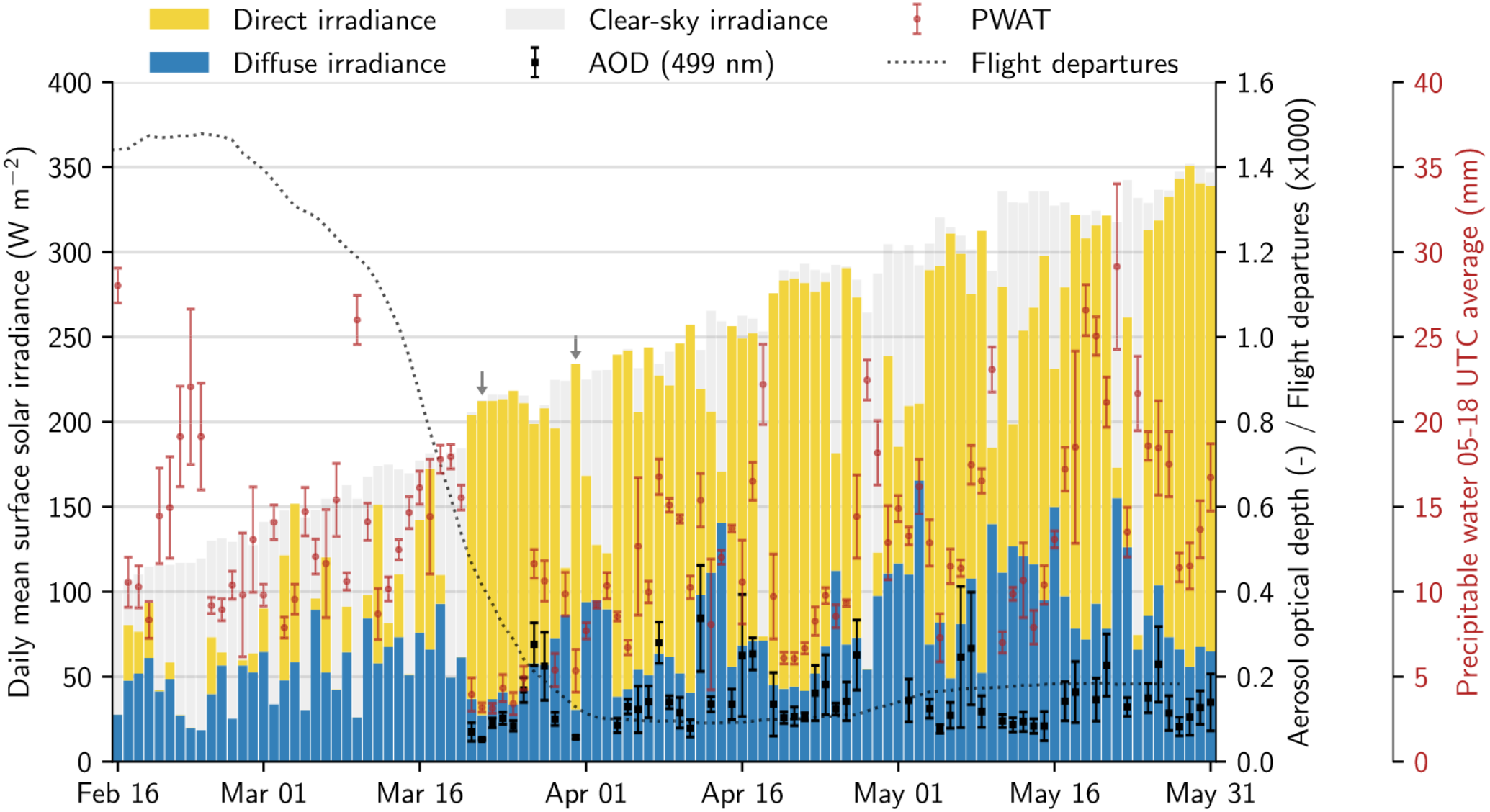
Two types of extremes in this presentation

Seasonal records and long-term trends



Local "cloud-scale" peaks

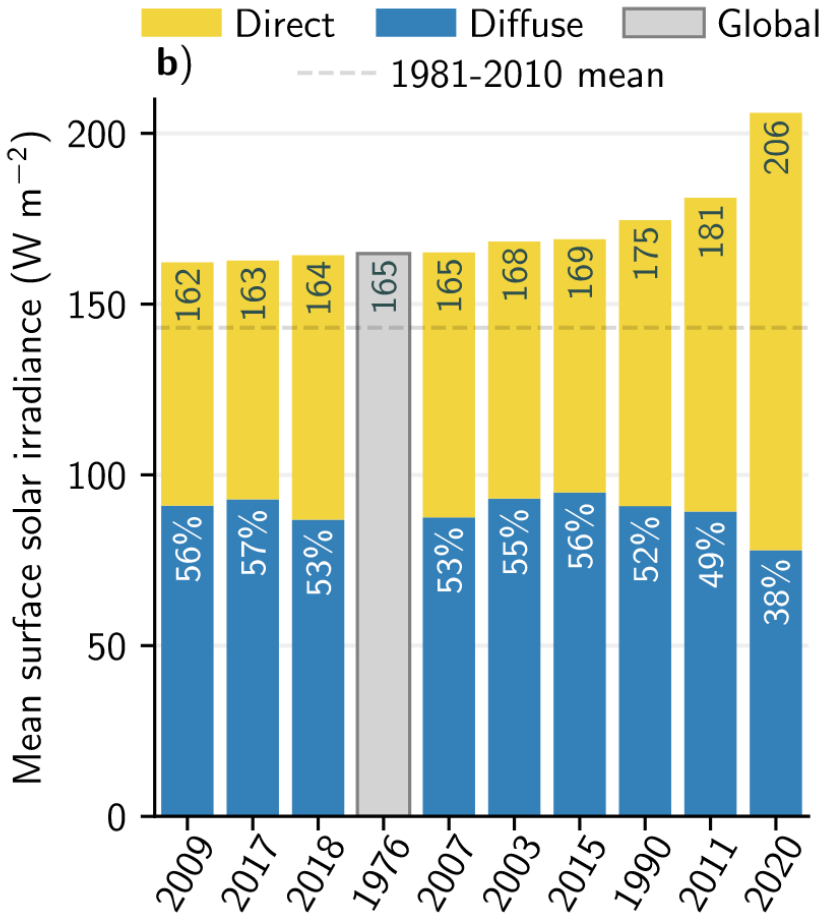




Record 'blue skies' after COVID-19 lockdown

(van Heerwaarden, Mol, and Veerman et al., 2021, https://www.nature.com/articles/s43247-021-00110-0)

Driven by anomalous weather (blocking pattern)



Increased sunshine part of a multi-year trend

Weergegevens vanaf 1901

Vanaf 1 Januari

t/m 1 Juni

aantal jaren 10

Kies een vanaf-datum na de einddatum om de gegevens over 2 opeenvolgende jaren te zien.

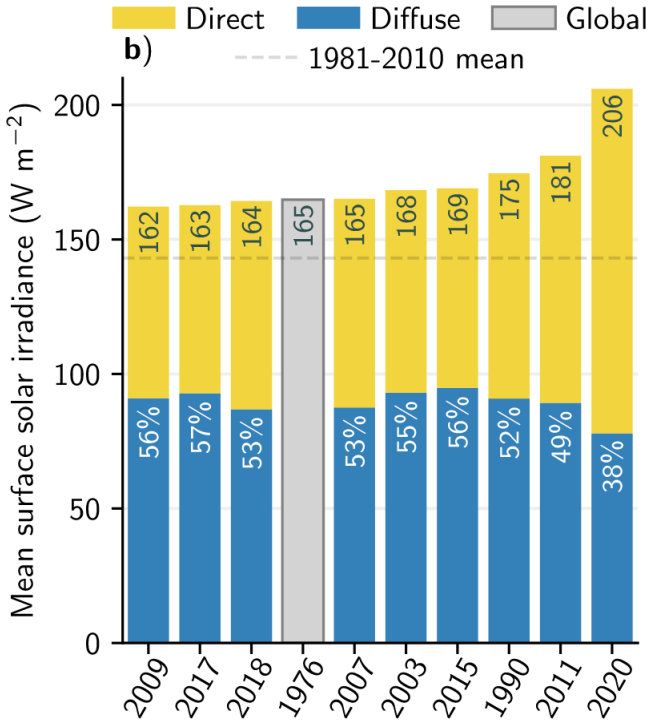
Data t/m 1 juni

	Jaar	Temp. (gem)	Zonuren (som) ▼	Neerslag (som)	Hellmann
1	2025	**8,13**	**976,1**	**189,3**	**6,7**
2	2020	8,96	911,6	299,8	0,0
3	2022	8,60	891,0	338,1	0,0
4	2003	7,12	854,5	267,6	54,4
5	2011	8,32	836,4	212,7	13,0
6	2018	8,10	797,9	286,3	33,6
7	2019	8,15	793,4	312,4	12,1
8	2015	7,10	791,6	303,3	5,4
9	1909	4,99	780,0	252,1	64,7
10	2002	8,34	774,5	335,5	12,0

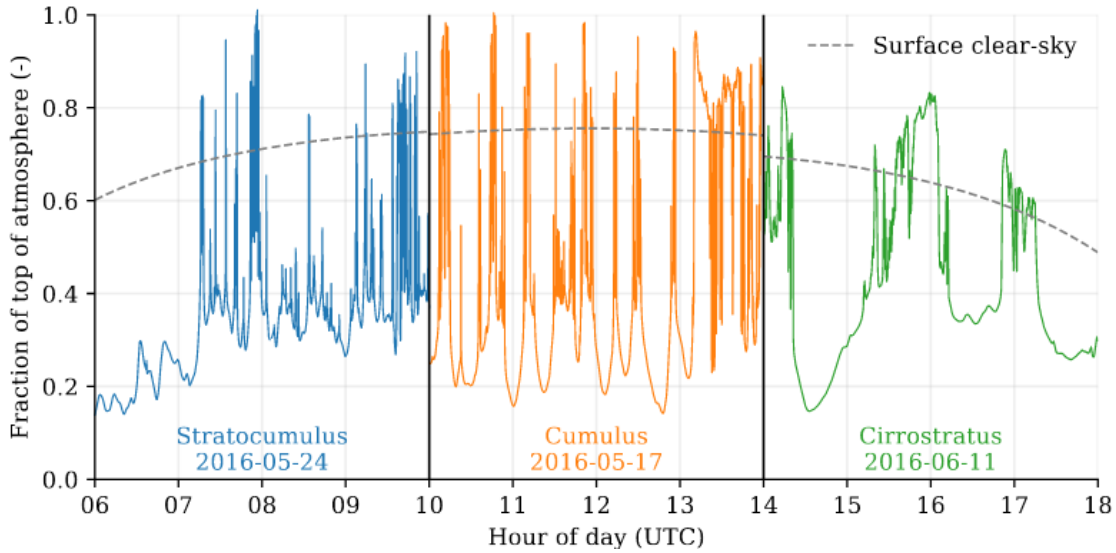
De Bilt (main KNMI / NL station)
https://weerstatistieken.nl

Two types of extremes in this presentation

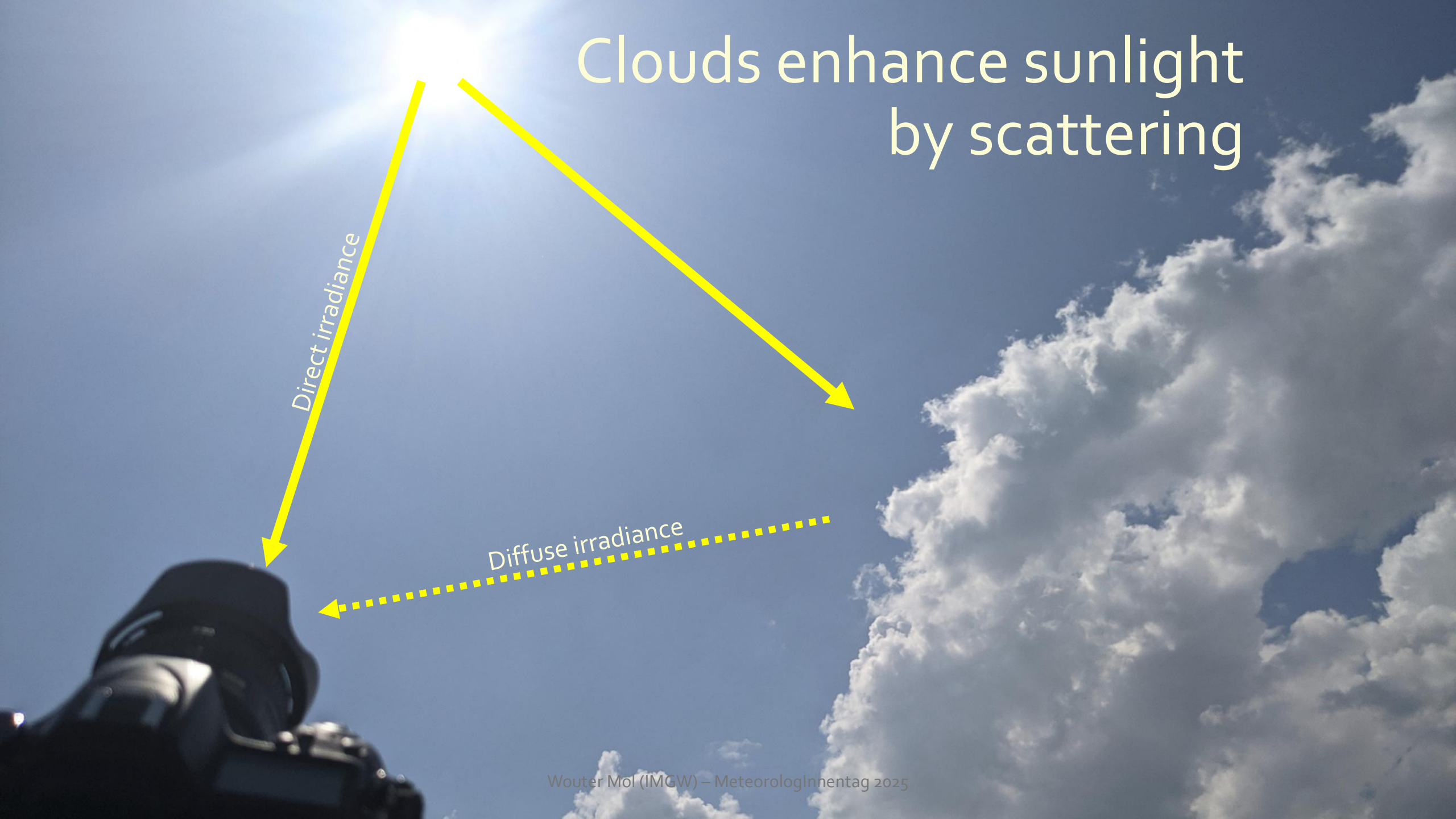
Seasonal records and long-term trends



Local "cloud-scale" peaks

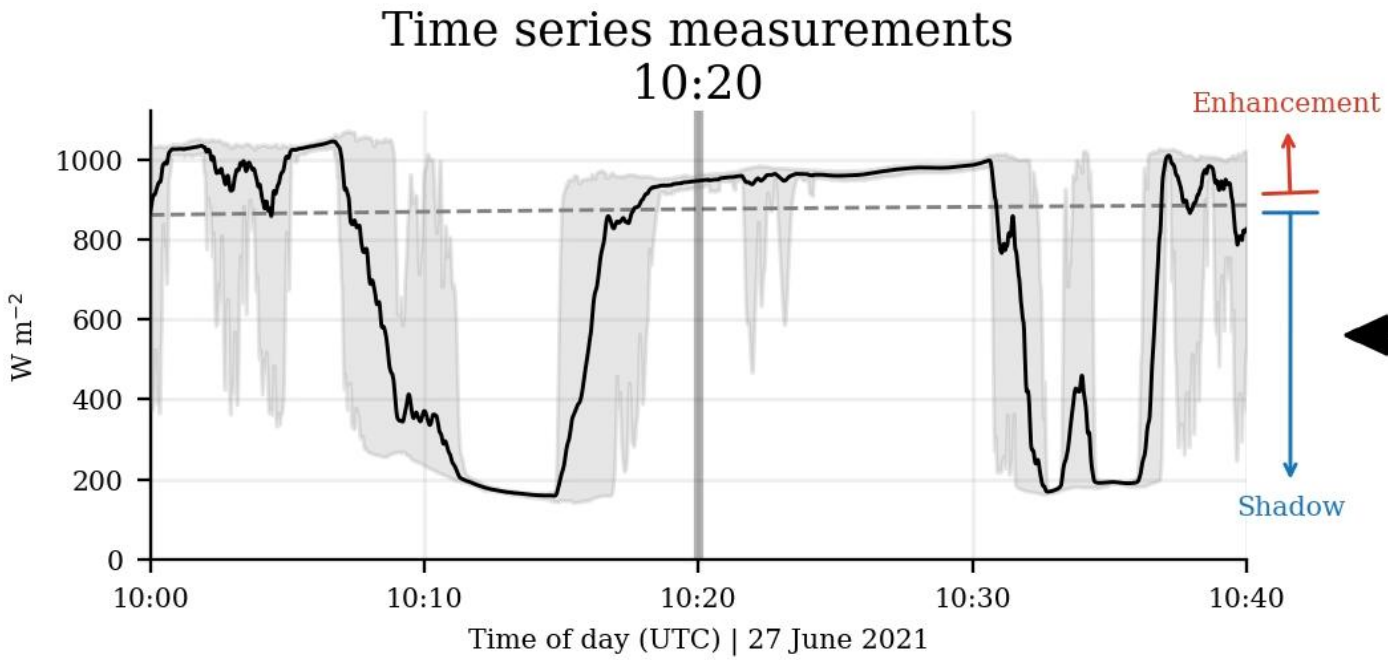


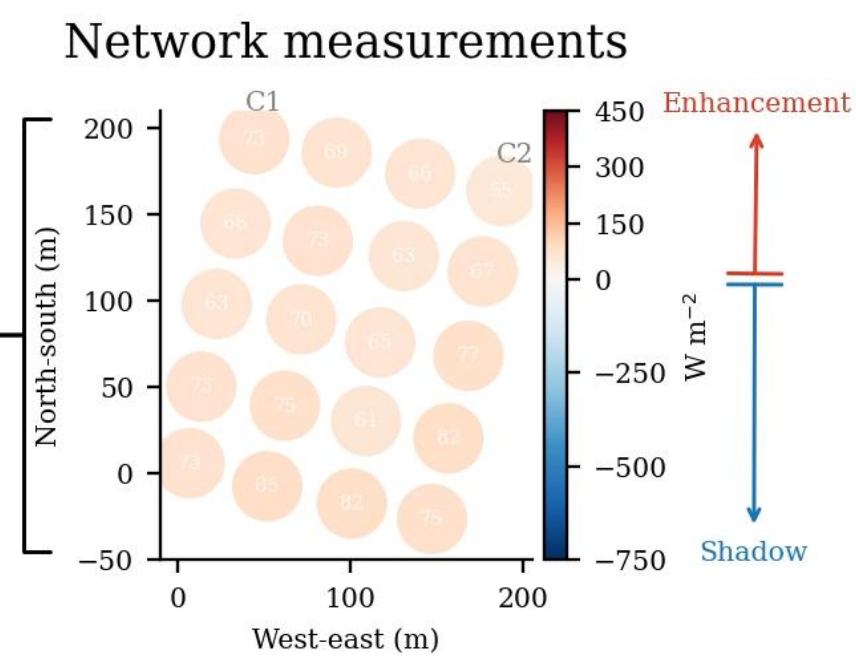
Clouds enhance sunlight by scattering



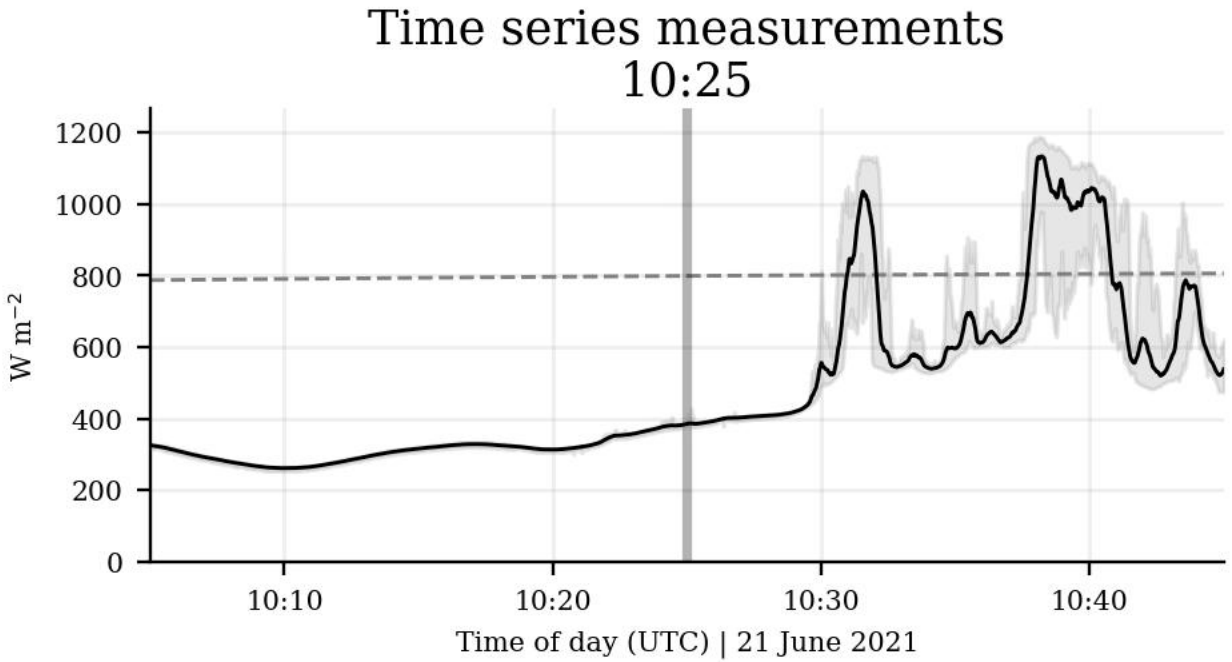

2021-06-27 10:00:26 UTC

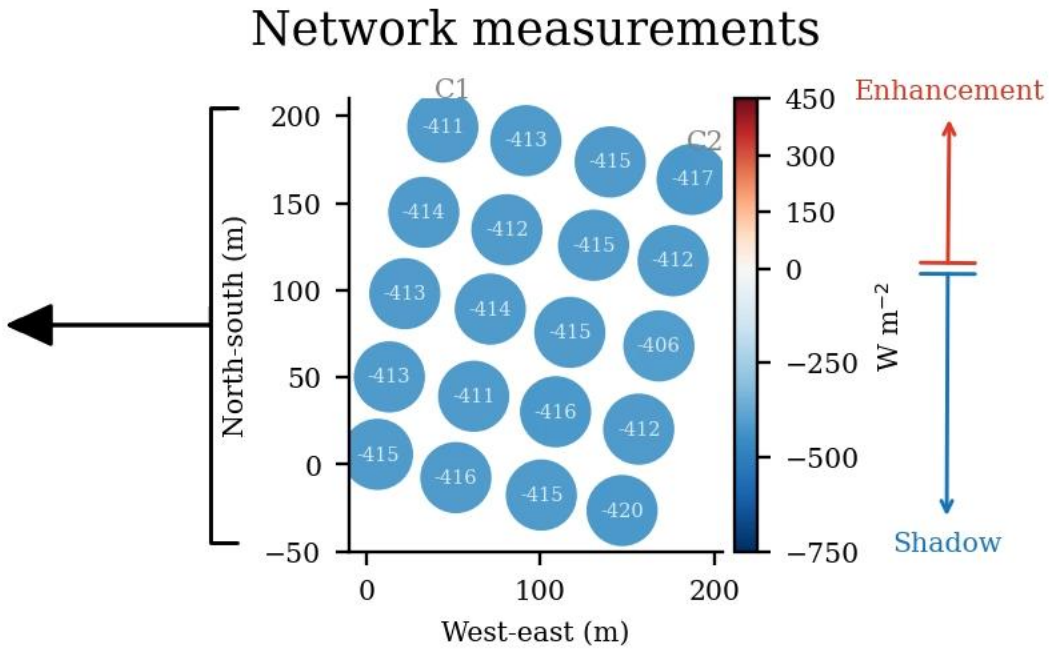

2021-06-27 10:20:02 UTC


Time series measurements
10:20
Enhancement
Shadow
W m^{-2}
1000
800
600
400
200
0
10:00
10:10
10:20
10:30
10:40
Time of day (UTC) | 27 June 2021

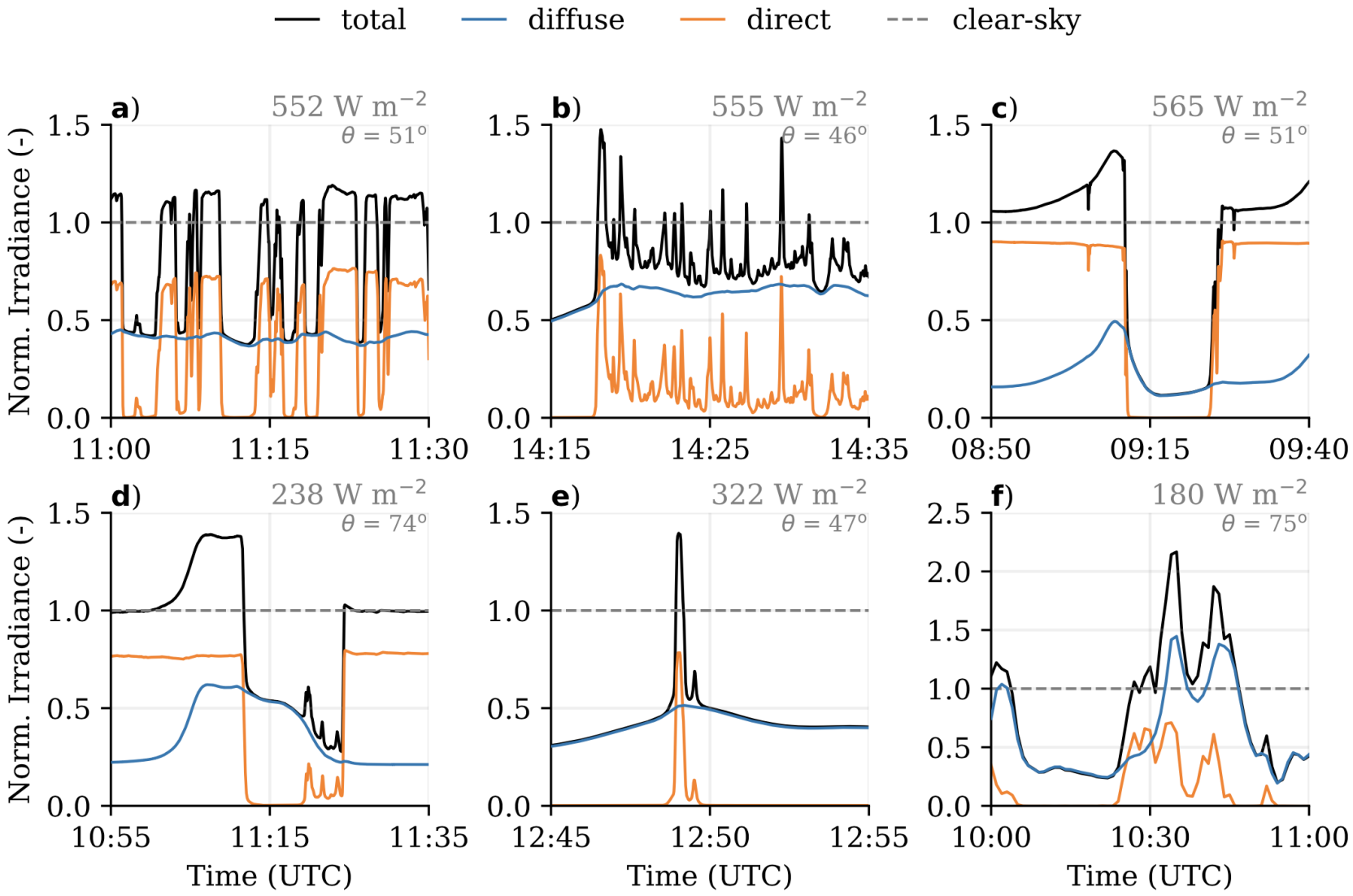

Network measurements
C1
C2
North-south (m)
West-east (m)
200
150
100
50
0
−50
0
100
200
450
300
150
0
−250
−500
−750
W m^{-2}
Enhancement
Shadow


2021-06-21 10:25:01 UTC


Time series measurements
10:25
W m^{-2}
1200
1000
800
600
400
200
0
10:10
10:20
10:30
10:40
Time of day (UTC) | 21 June 2021

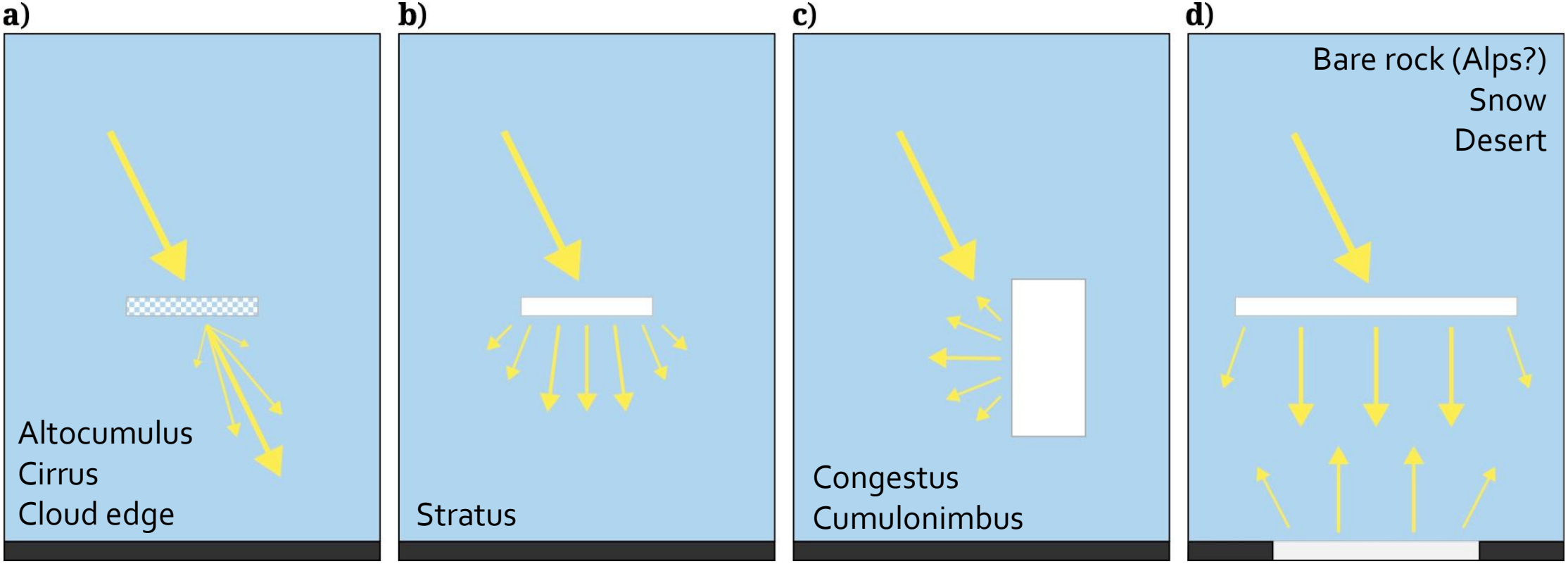

Network measurements
C1
C2
-411
-413
-415
-417
-414
-412
-415
-412
-413
-414
-415
-406
-413
-411
-416
-412
-415
-416
-415
-420
North-south (m)
200
150
100
50
0
−50
0
100
200
West-east (m)
450
300
150
0
−250
−500
−750
W m^{-2}
Enhancement
Shadow

Surface solar irradiance under different cloud types



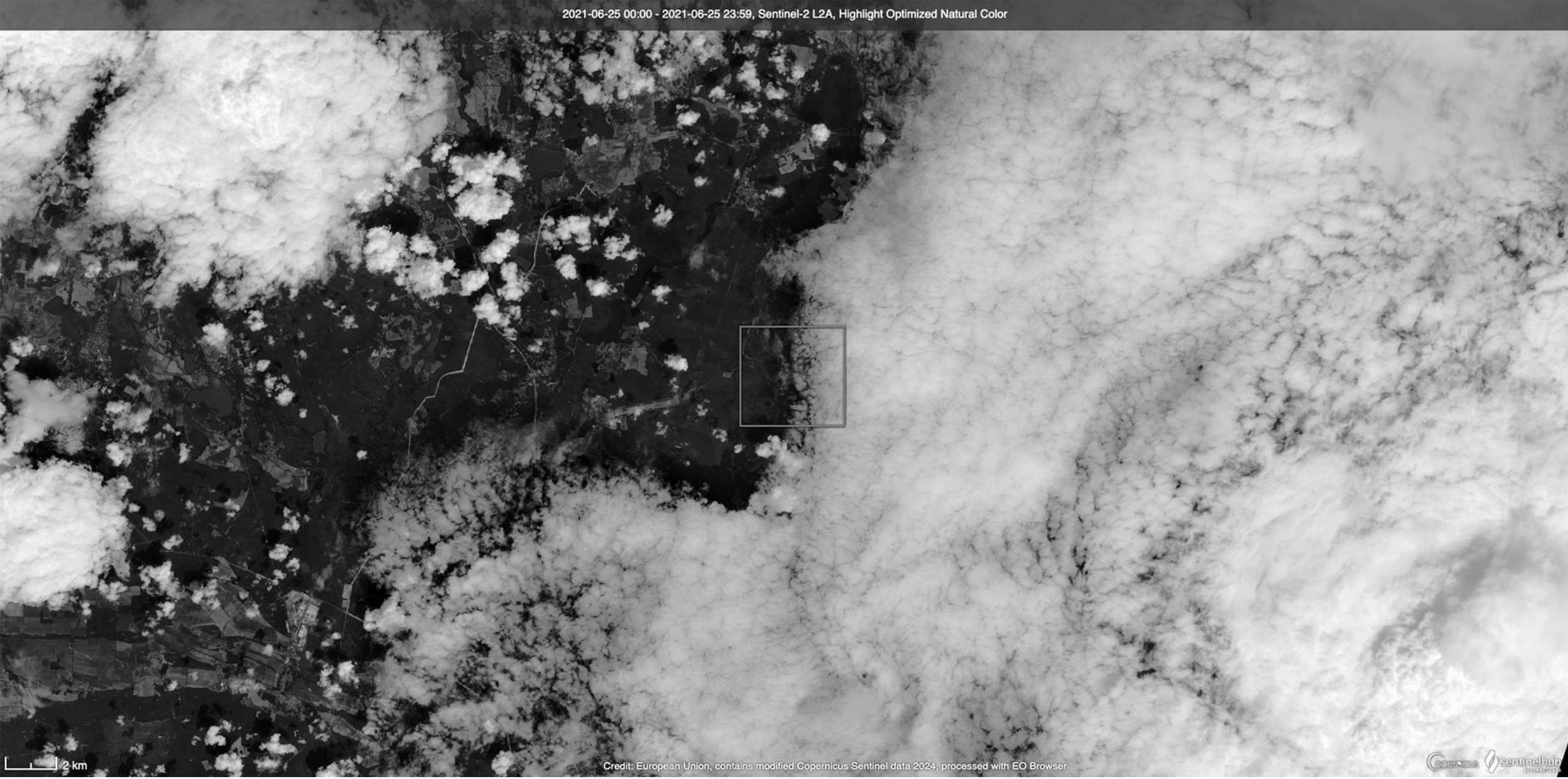
How to generate irradiance peaks?

Take one or more of the following mechanisms:



Important | Important | Not (locally) important | Increases existing peaks

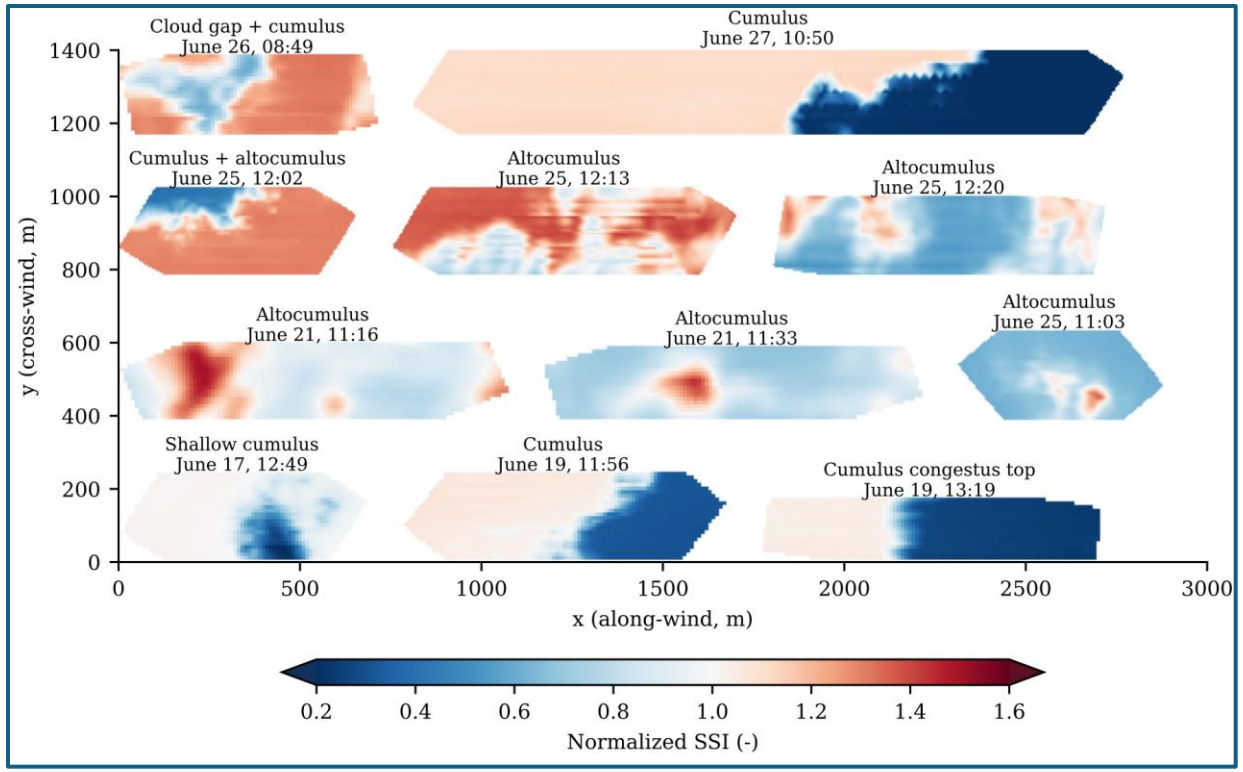
From *Mechanisms of surface solar irradiance variability under broken clouds*
(Mol and van Heerwaarden, 2025, https://acp.copernicus.org/articles/25/4419/2025/)


2021-06-25 00:00 - 2021-06-25 23:59, Sentinel-2 L2A, Highlight Optimized Natural Color
2 km
Credit: European Union, contains modified Copernicus Sentinel data 2024, processed with EO Browser

Methodology

Observations:

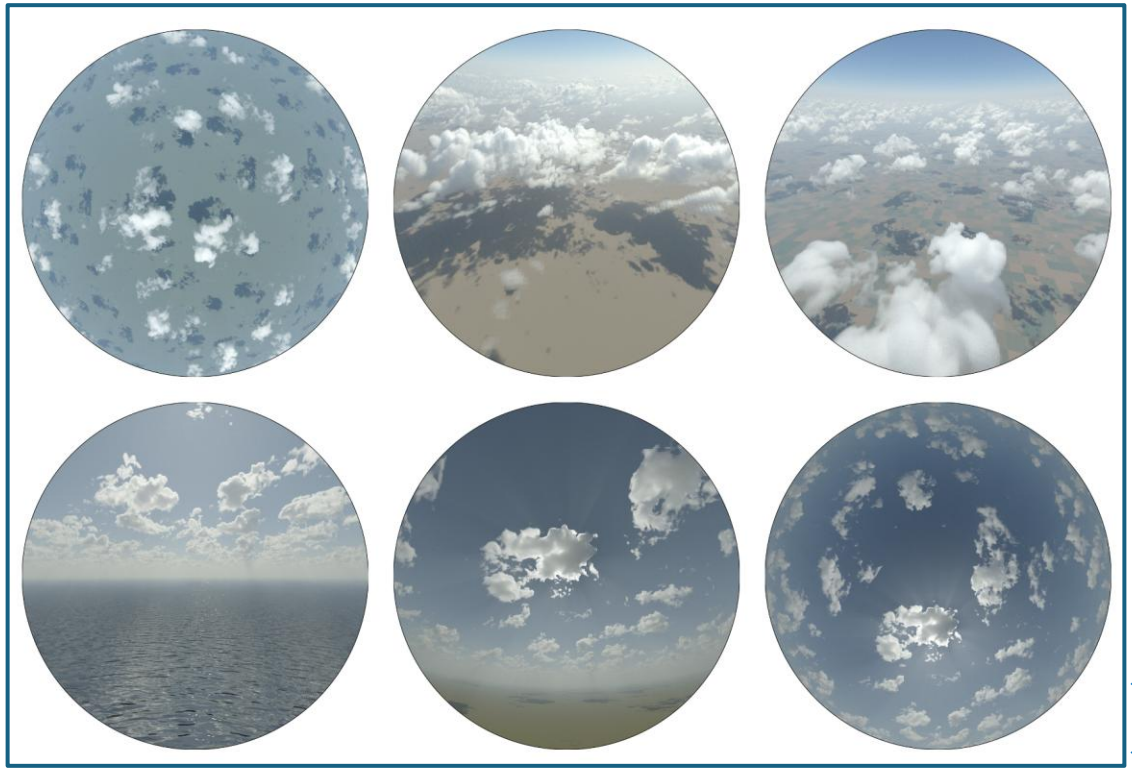
Small-scale spatial sensor network and long-term detailed time series



Mol et al. (2024)

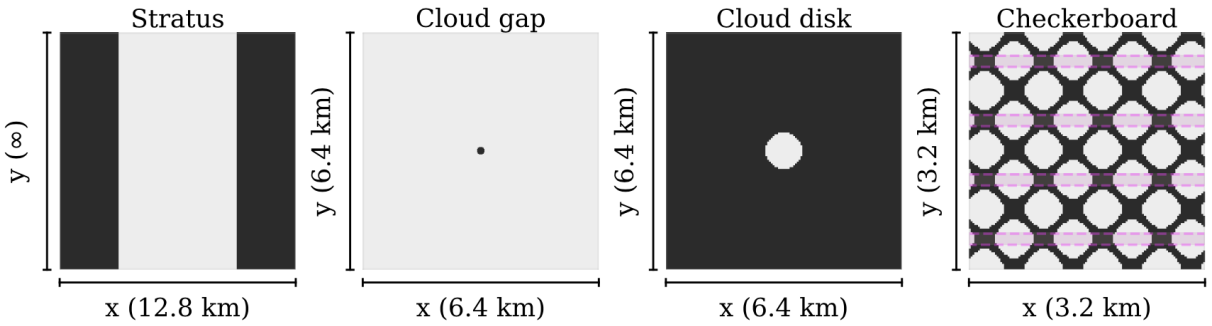
Simulations:

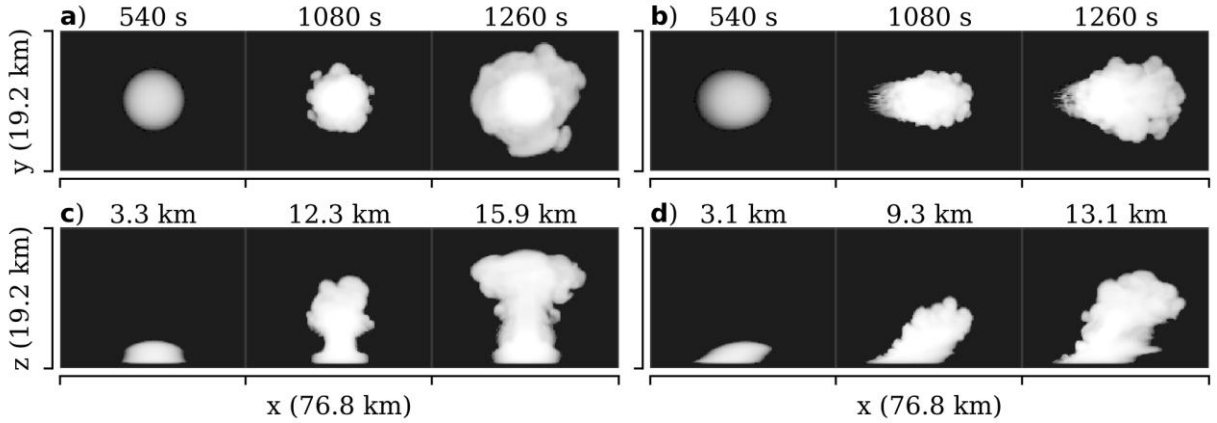
Cloud-resolving large-eddy simulation and 3D Monte Carlo ray tracing

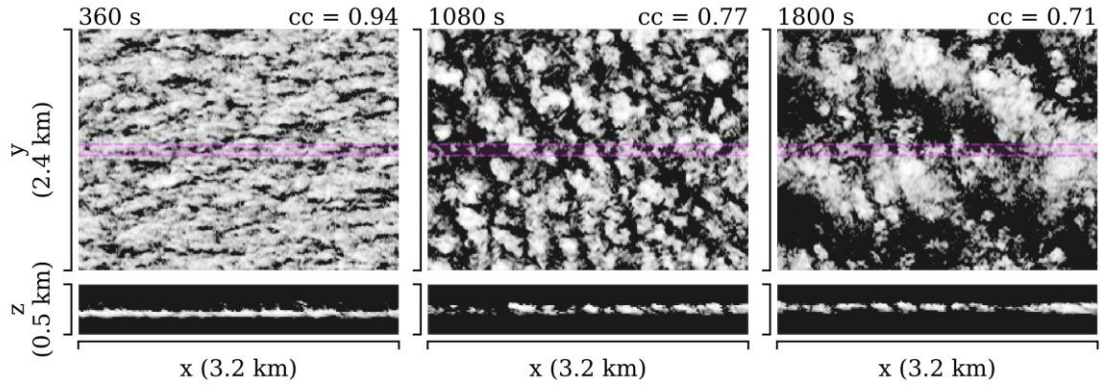


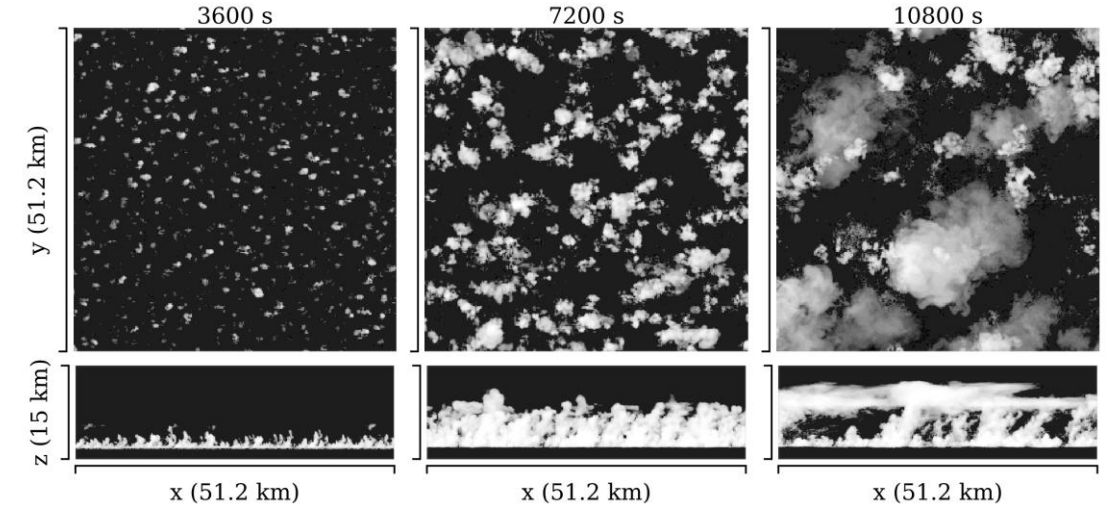
Veerman et al. (2022)

Simulated cloud fields: from simple to complex



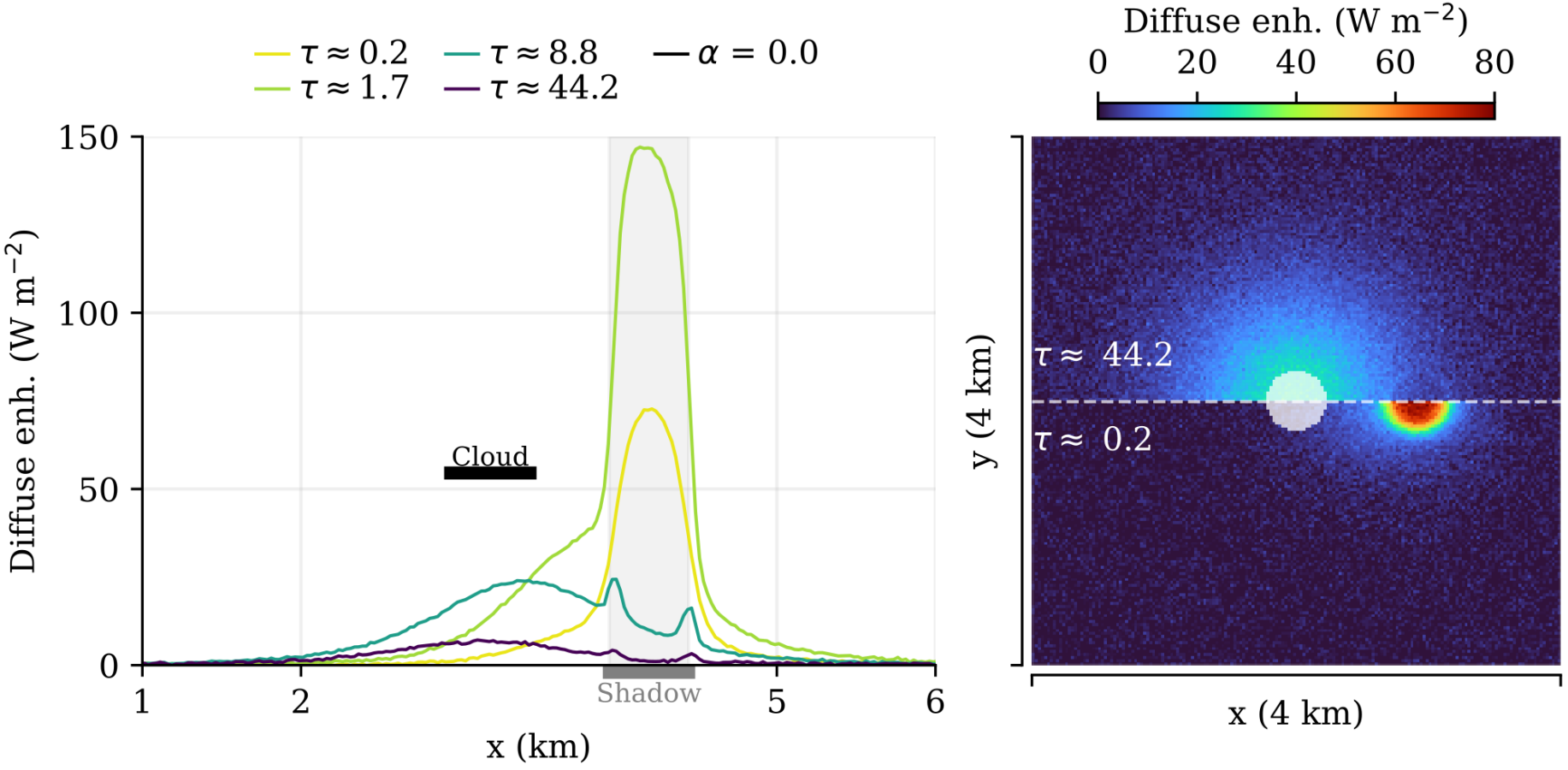




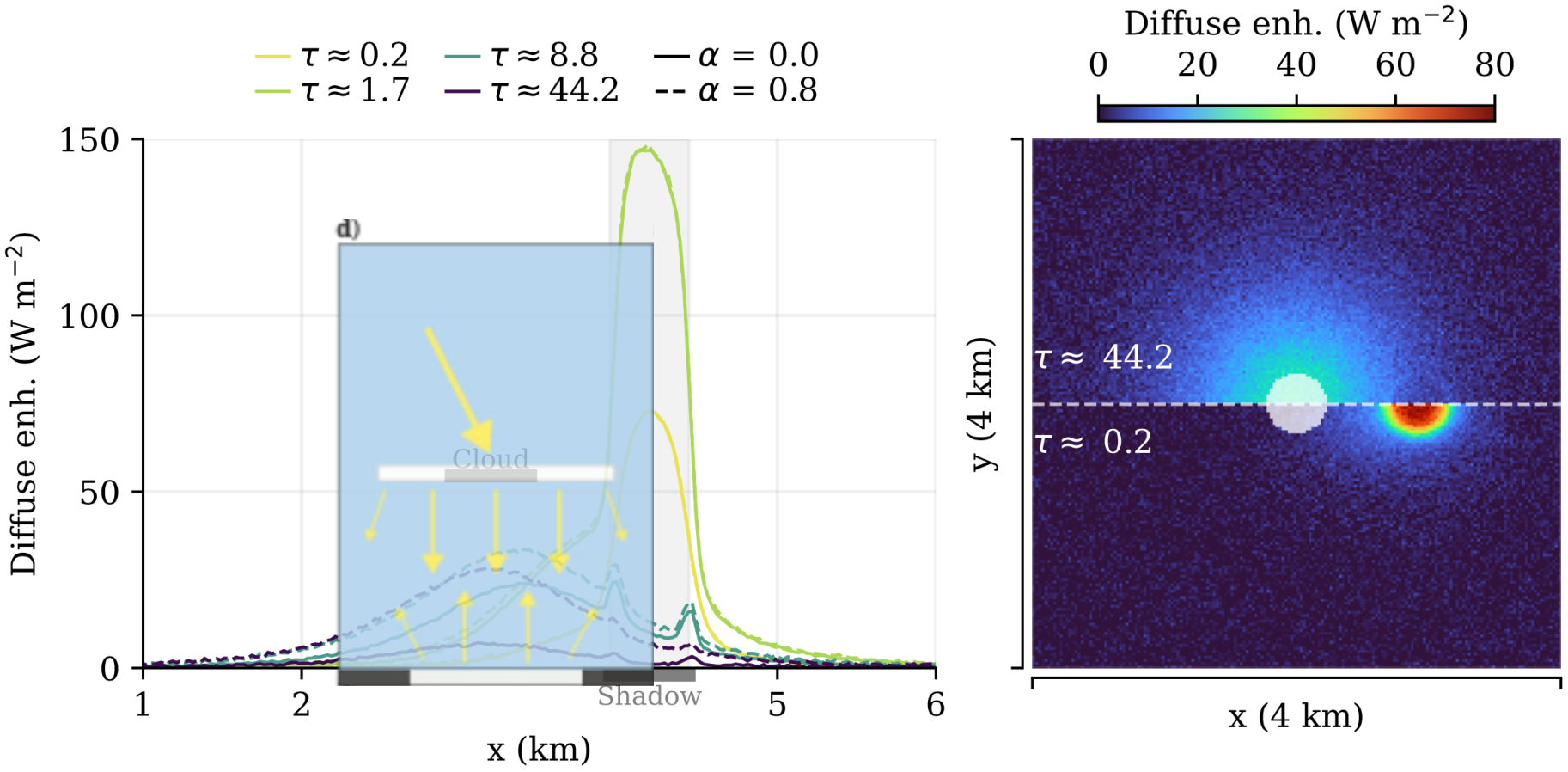


Forward vs *downward escape*

Transition at $\boldsymbol{\tau} \backsimeq 5$ to 6

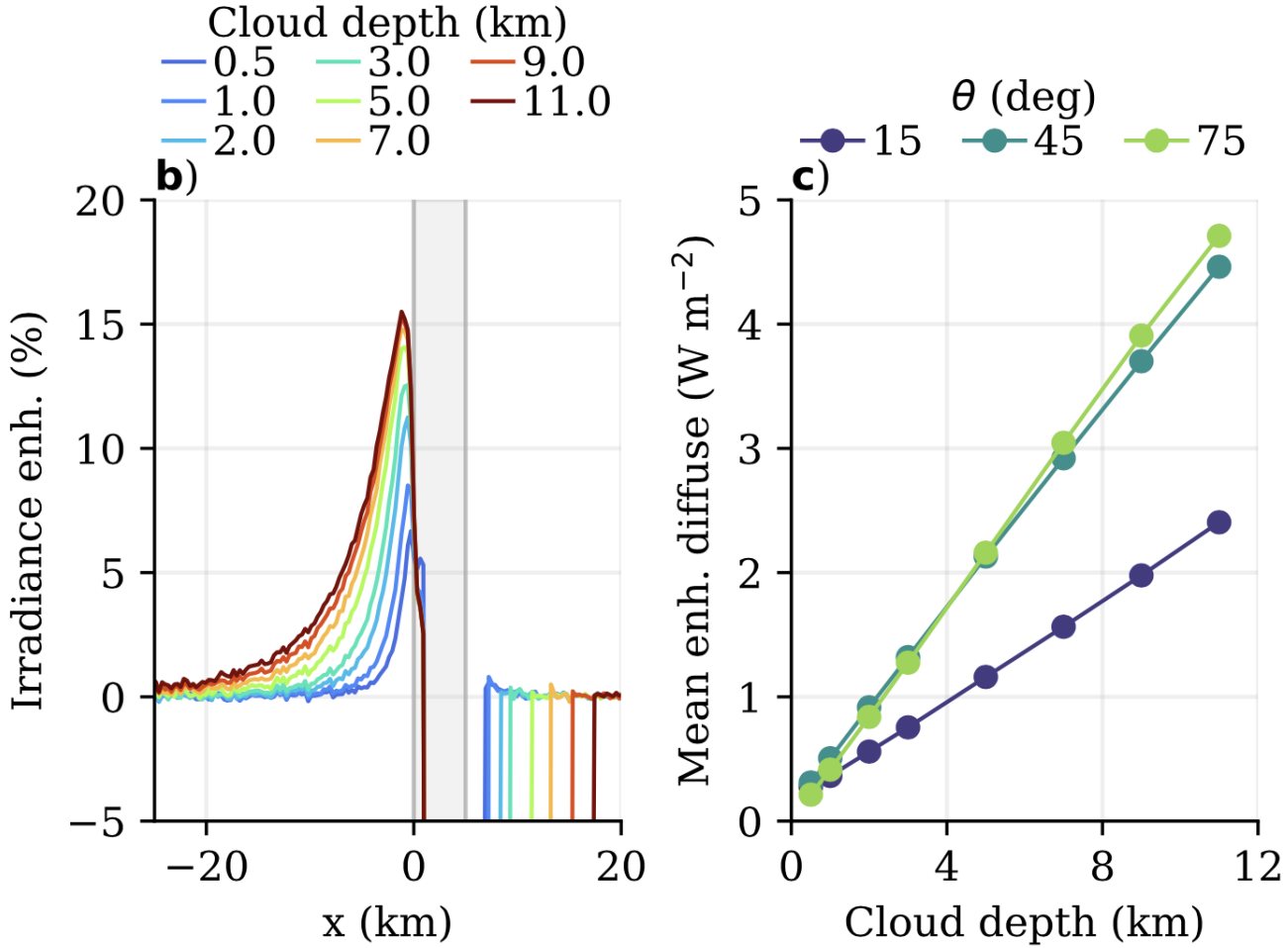


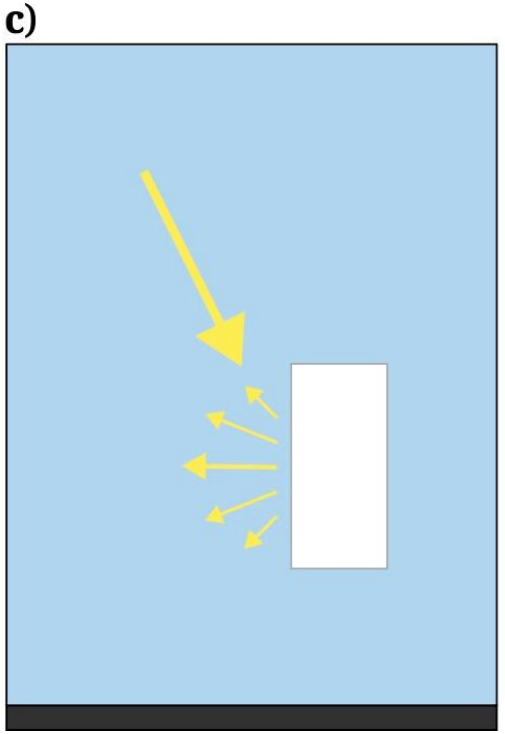
Surface albedo enhances the effect of *downward escape*



Side escape enhances SSI at the sunlit side of clouds

(not a cloud reflection!)





Combination of mechanisms as cloud geometry increases in complexity