Sensitivity of the solar resource in solar tower plants to aerosols and water vapor

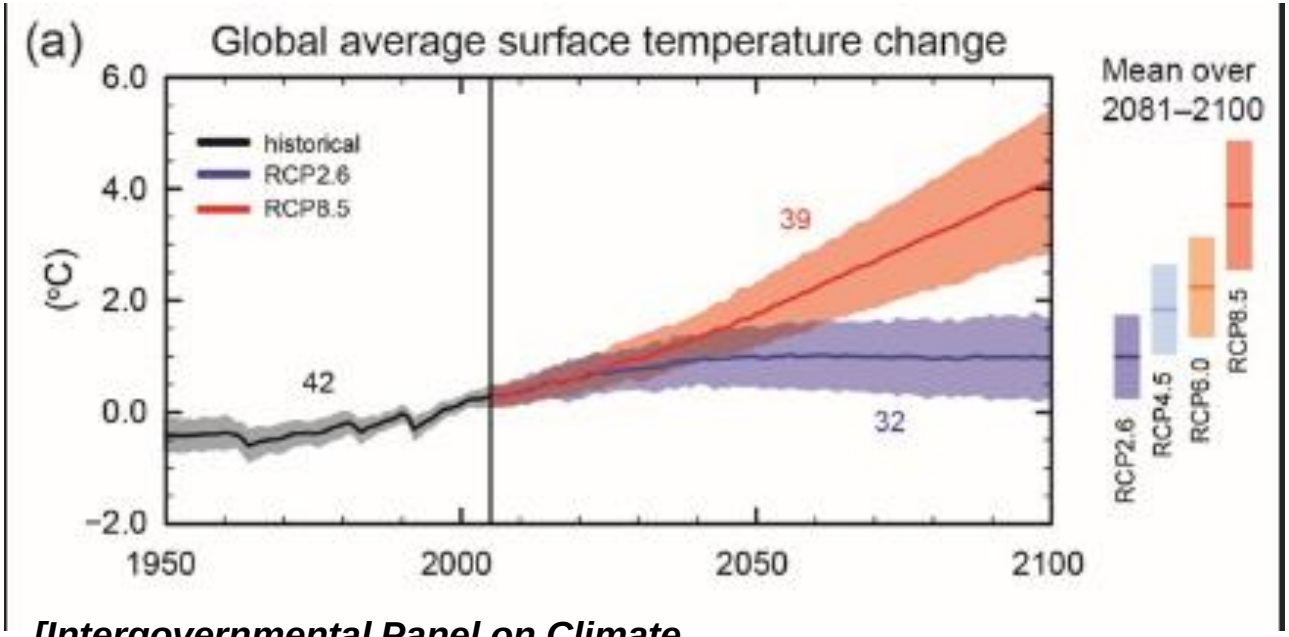
Thierry Elias, Didier Ramon, Mustapha Moulana, HYGEOS, Lille, France
Jean-Florian Brau, EDF R&D, Chatou, France

te@hygeos.com

Aerosols: e.g. desert dust

1. Introduction

Climate change scenarii



[Intergovernmental Panel on Climate Change (IPCC), AR5, 2013]

Several scenarii of global CO_2 emissions

Renewable energy to restrain CO_2 emissions, and the climate change, …

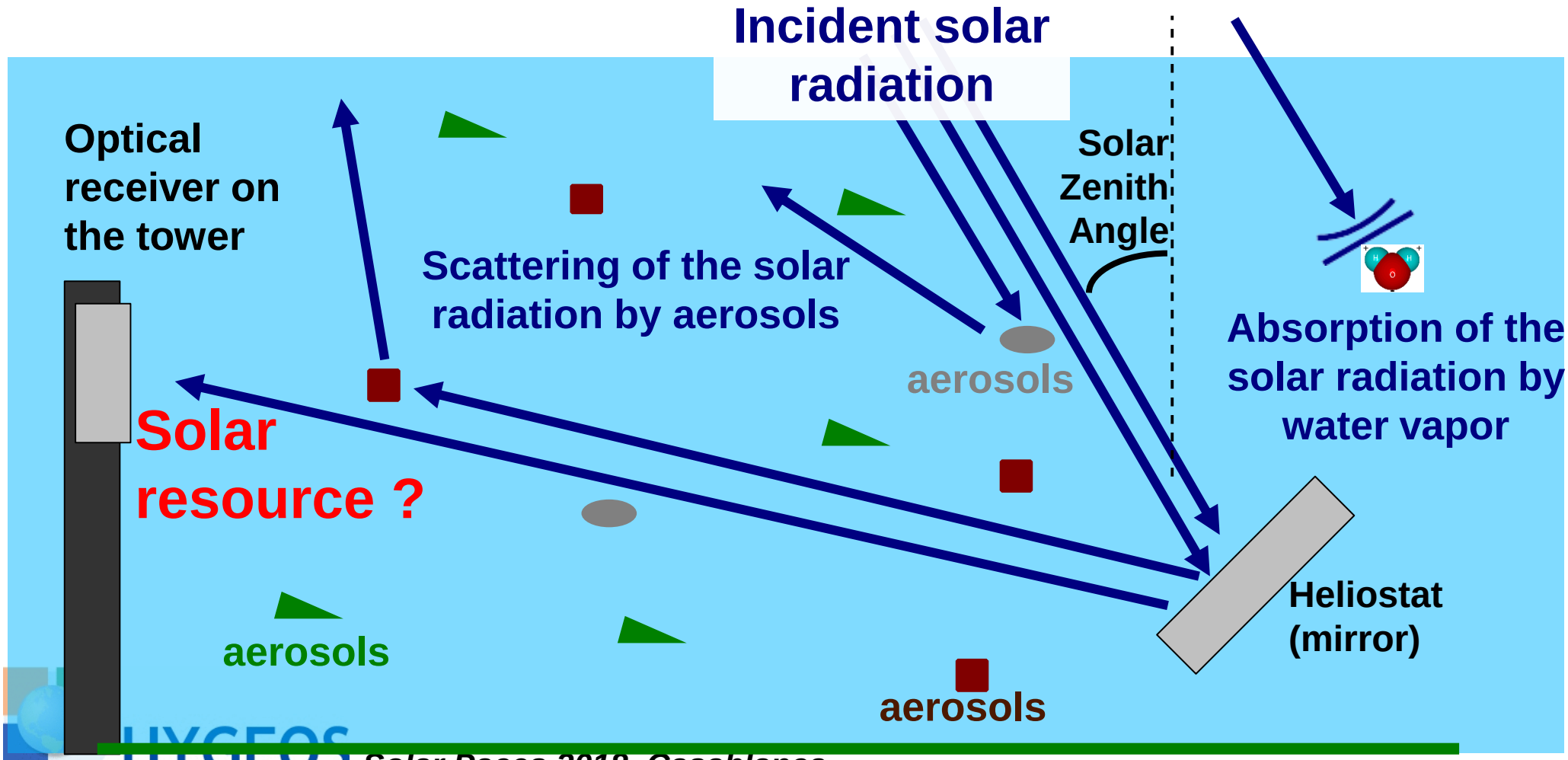
1. Introduction

Variability of the solar resource

Solar plant bankability ? ← **Solar resource estimate**

↑

Atmospheric properties ← **Highly variable and hardly predictable**



1. Introduction

Scattering of solar radiation by the atmosphere

”By afloresm - SOLUCAR PS10 (2), CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=2821738”

Scattering of the solar radiation by the atmosphere

Outline

1. Introduction

2. Variability of the atmospheric optical properties

sensitivity studies:

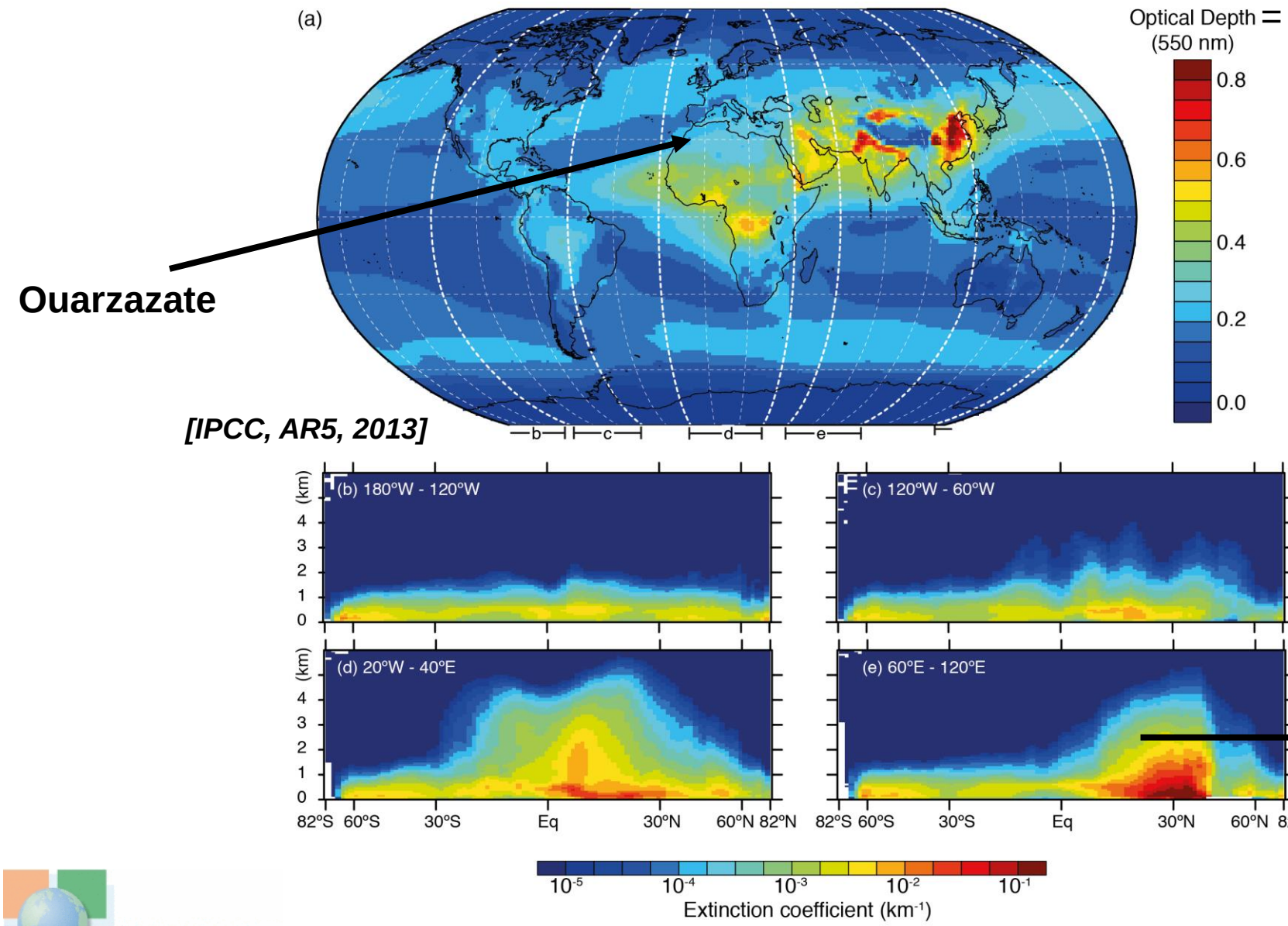
3. Influence of the input parameters: averages

4. Influence of the input parameters: variability

5. Conclusion and perspectives

2. Variability of the atmospheric composition

3D variability of the aerosol scattering



= aerosol optical thickness (AOT) ~ scattering efficiency

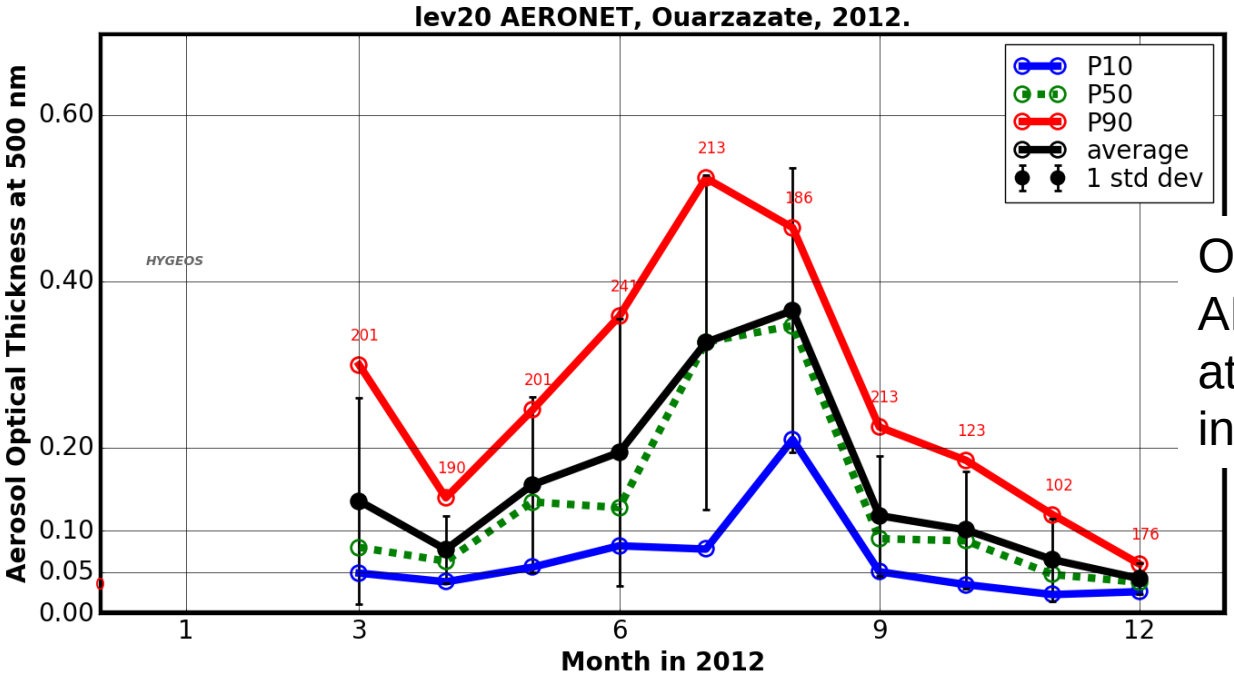
Ouarzazate

[IPCC, AR5, 2013]

aerosol layer height (ALH)

2. Variability of the atmospheric composition

Summer and winter at Ouarzazate, Morocco: Correlated changes of atmospheric properties



Observed by the AErosol RObotic NETwork (AERONET) at Ouarzazate, in 2012.

		background conditions in winter		desert dust in summer
Aerosols	AOT	0.04	x 10	0.40
	Angstrom exponent (~size)	1.0	/ 3	0.3
	Aerosol layer height (ALH, km)	1.3	x 3	4.0

		winter noon		summer noon
	Solar zenith angle (SZA,°)	54.4		14.7
	Water vapor content (WVC, g/cm^2)	0.6	x 2	1.2
	F_{ESD}	1.03		0.97

3. Influence of the input parameters: averages

Simulation of the solar resource

DNI = Direct Normal Irradiance (W/m^2)

$$DNI = \int_{250\,nm}^{4000\,nm} F_{ESD} E_{sun}(\lambda) T_{col}(\lambda) d\lambda$$

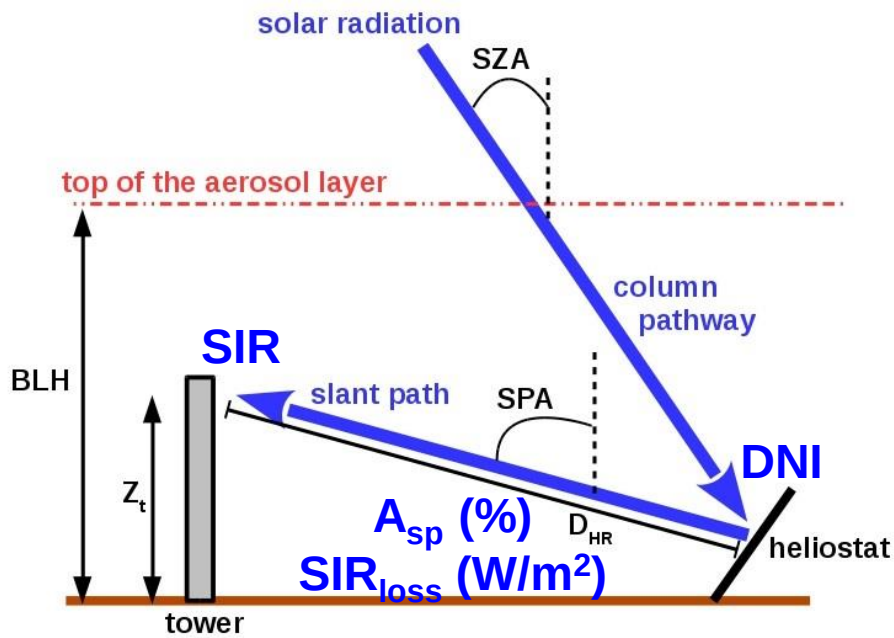
SIR = solar irradiance incident at the receiver (W/m^2)
(= reflected DNI)

$$SIR = \int_{250\,nm}^{4000\,nm} F_{ESD} E_{sun}(\lambda) T_{col}(\lambda) T_{sp}(\lambda) d\lambda$$

Slant path attenuation:
A_{sp} = (1 - SIR / DNI) * 100 (in %)

T_{col}: transmittance in the atmospheric column
T_{sp}: transmittance in the slant path, between heliostat and reciever

SIR_{loss} = DNI – SIR = A_{sp} x DNI (W/m^2)



D_{HR} = 1 km
z_T = 200 m

3. Influence of the input parameters: averages

Observed unique aerosol layer at Ouarzazate

Hypothesis 1: single layer
Uniform or exponential decay

[Elias et al., 2016, 2017]

Vertical profile 1 :
AEC(z) = AEC(0) if z < ALH
AEC(z) = 0 if z > ALH

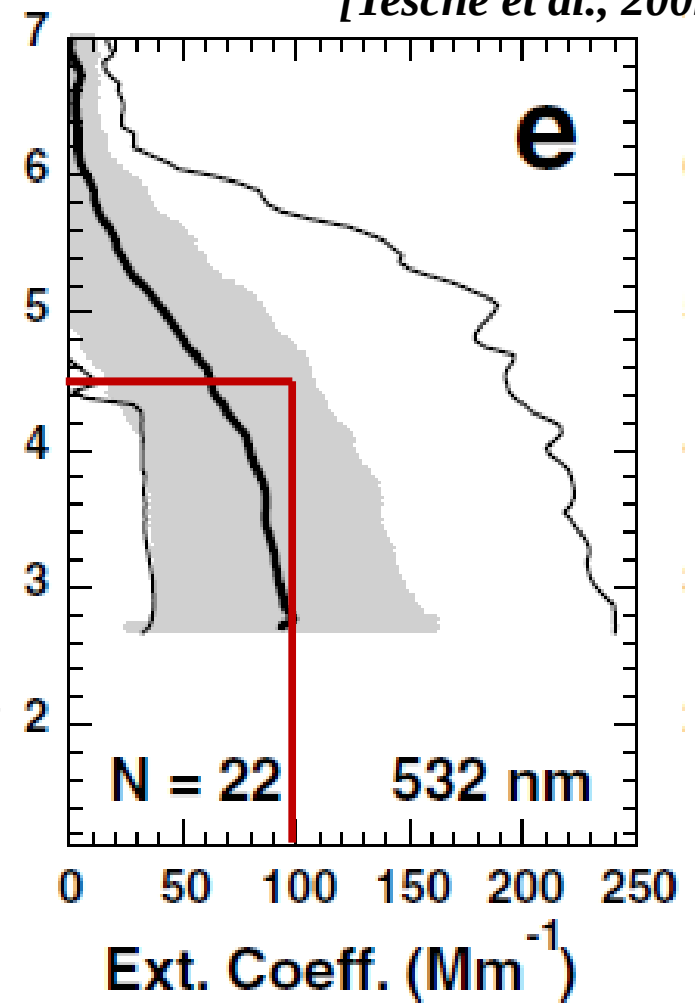
Vertical profile 2 :
AEC(z) = AEC(0) . exp(-z / ALH)

Hypothesis 2: ALH = constant during the day

Hypothesis 3: ALH = boundary layer height (BLH) from ECMWF

→ **AOT = AEC . BLH(15:00)**

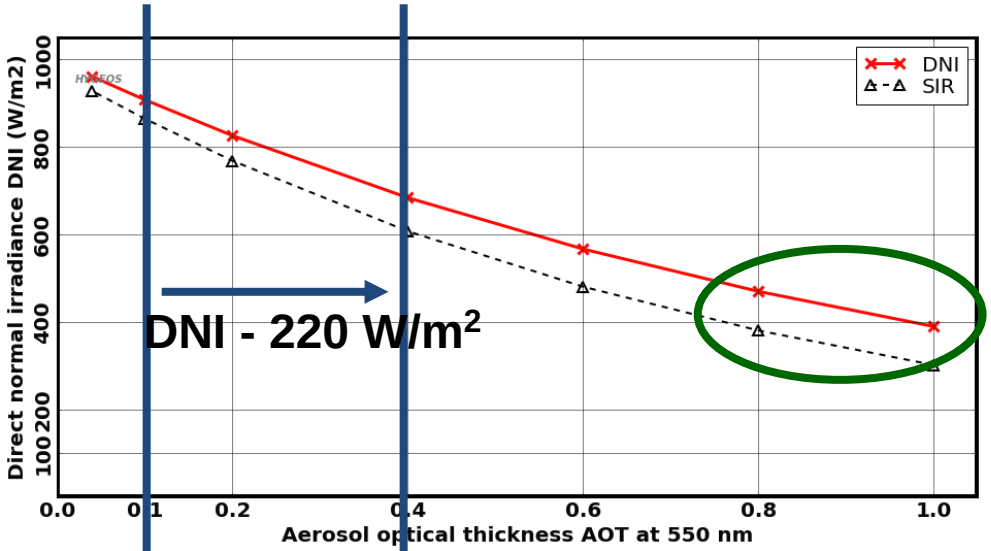
[Tesche et al., 2009]

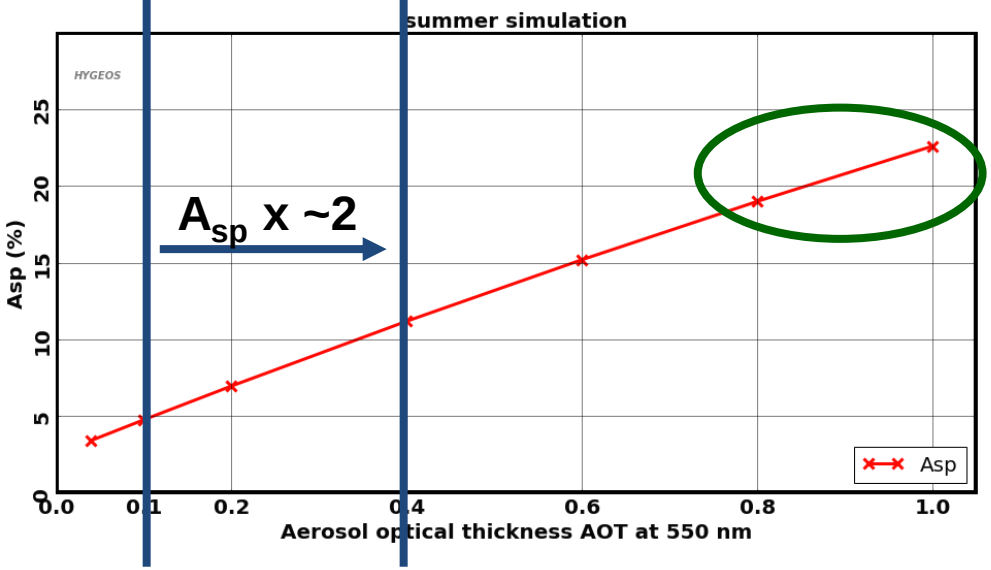


= aerosol extinction coefficient (AEC)

3. Influence of the input parameters: averages

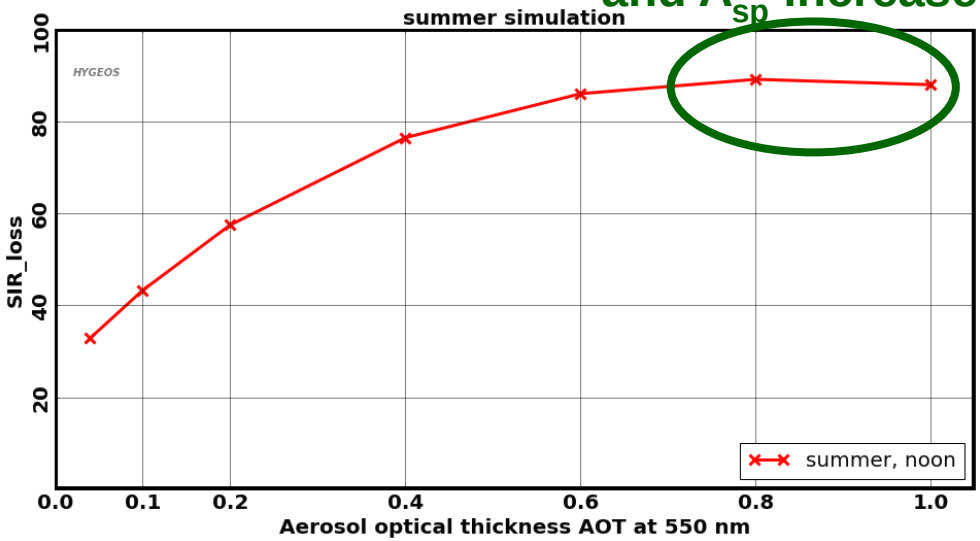
Strong influence of AOT, but compensation on SIR_{loss}





AOT=0.10 AOT=0.40

~cst SIR_{loss}
= exact compensation between DNI decease and A_{sp} increase

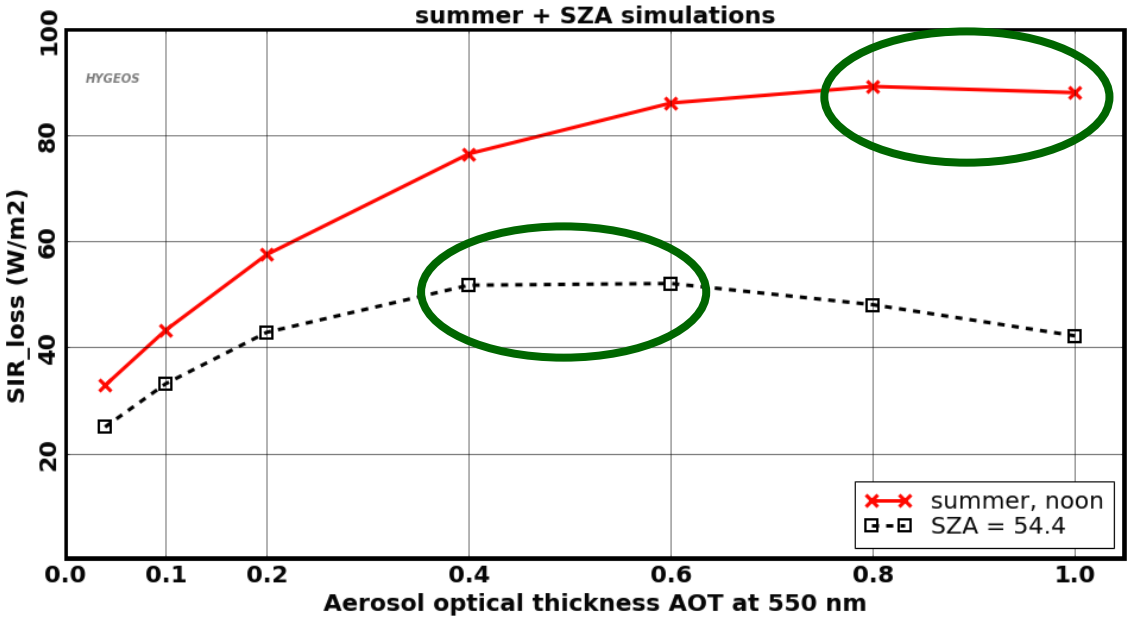


$SIR_{loss} = A_{sp} \times DNI \quad (W/m^2)$

→ reduced variability of SIR_{loss}

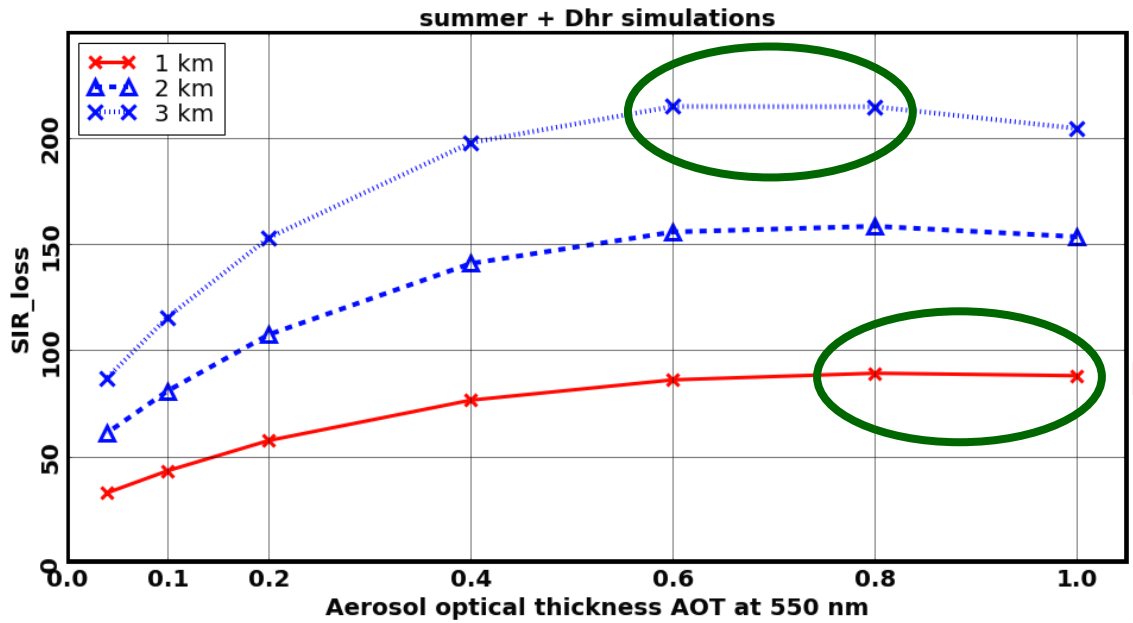
3. Influence of the input parameters: averages

The AOT of SIR_{loss} maximum depends on the optical path



SZA = 14.7°

SZA = 54.4°

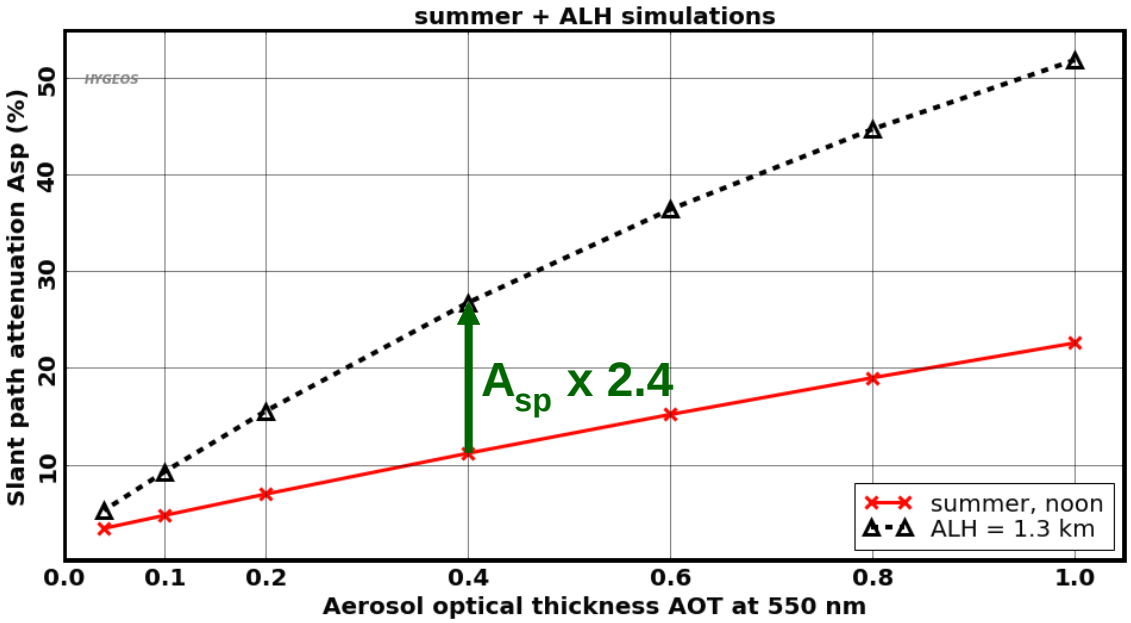


D_{HR} = 3 km

D_{HR} = 1 km

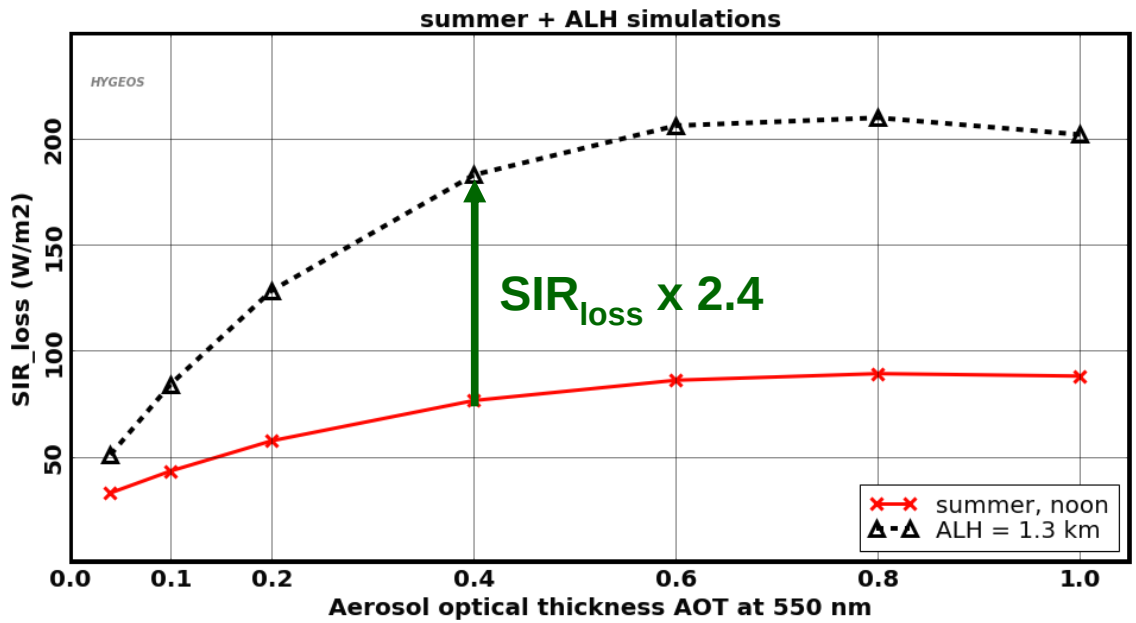
3. Influence of the input parameters: averages

Slant path attenuation strongly dependent on ALH



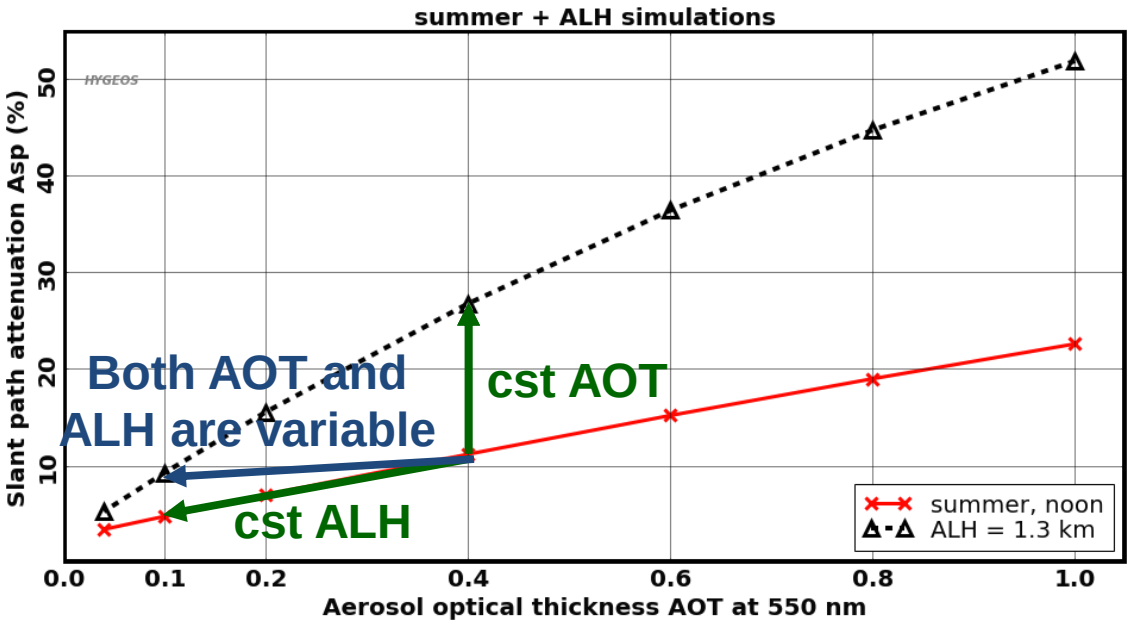
ALH = 1.3 km

ALH = 4.0 km



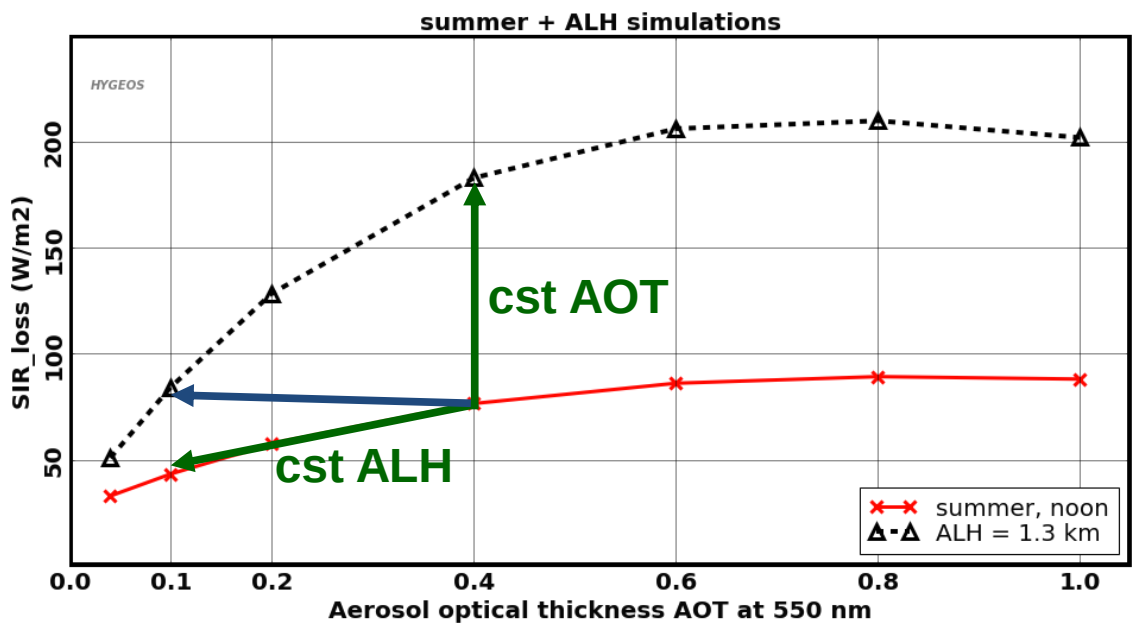
3. Influence of the input parameters: averages

Compensating effects of AOT and ALH



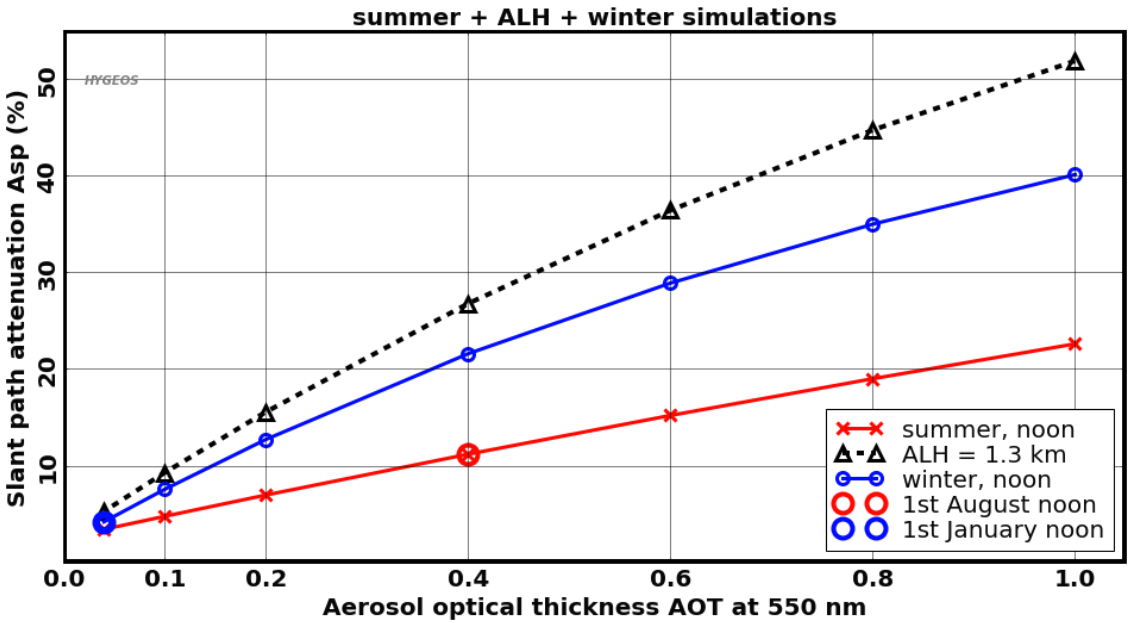
ALH = 1.3 km

ALH = 4.0 km



3. Influence of the input parameters: averages

Compensating effects of several input parameters

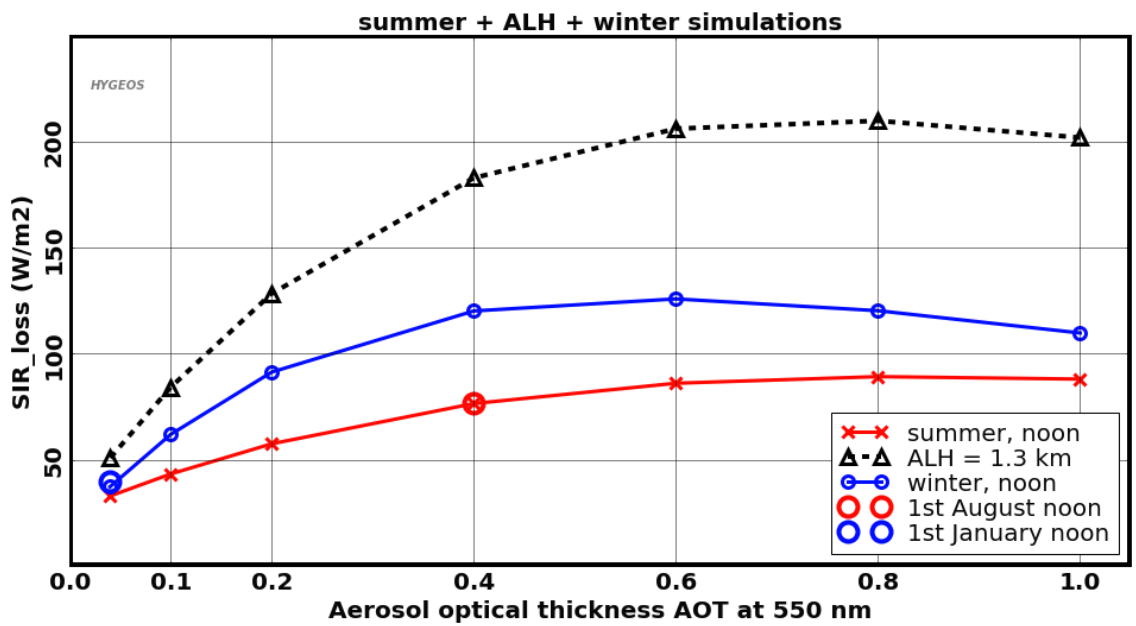


Summer, but change in ALH

Winter: Changes in SZA, ALH, Angstrom, and WVC.

Summer

Correlation between atmospheric parameters
-> Best correlation
at the minute-hour time resolution



4. Influence of the input parameters: variability

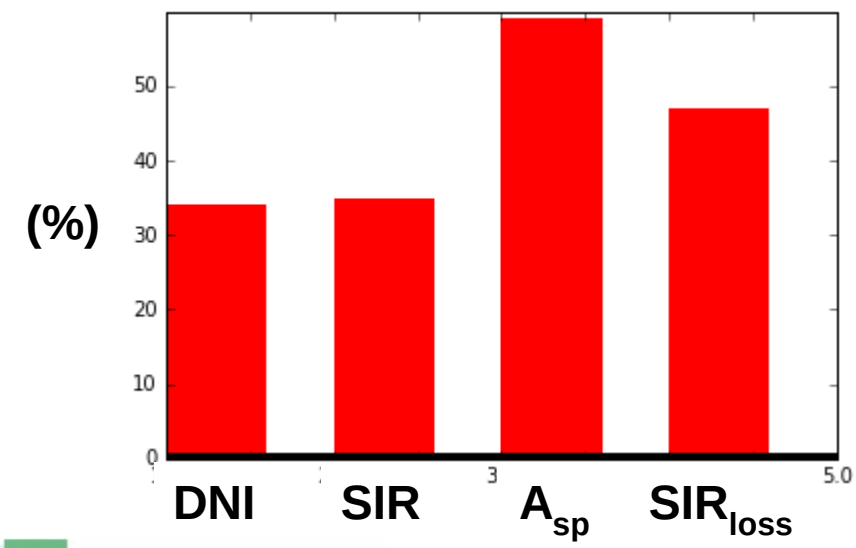
Computation of SIR at the finest time resolution

Correlation between atmospheric parameters

-> Best correlation at the minute-hour time resolution

AERONET: AOT, AE, WVC 1 hour
Computations: SZA 1 hour
ECMWF: BLH 1 month

Relative standard deviation on:



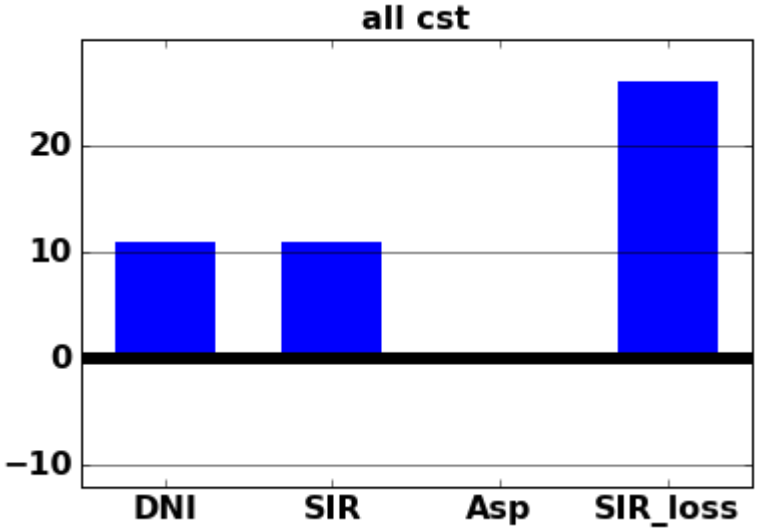
	Hourly variability
SZA (°)	51±20
AOT	0.16±0.16
AE	0.72±0.43
ALH (km)	3.3±1.0
WVC (g/cm^2)	0.95±0.40
DNI (W/m^2)	**717±245**
SIR (W/m^2)	**679±240**
A_{sp} (%)	**5.9±3.5**
SIR_{loss} (W/m^2)	**38±18**

717 x 0.059 = 42 ≠ **38**

4. Influence of the input parameters: variability

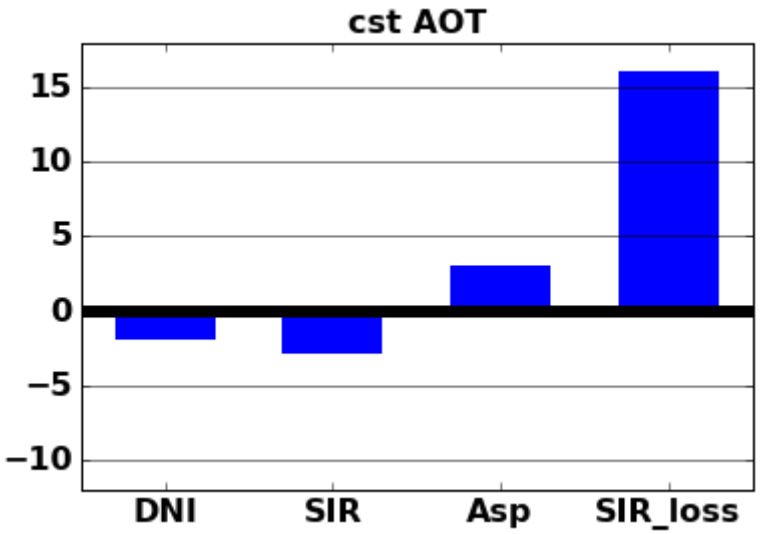
Computation of the solar resource at the finest time resolution

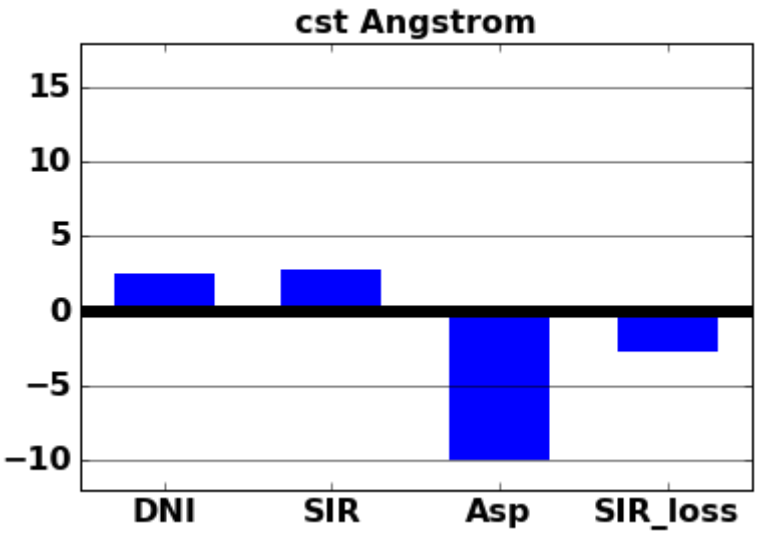
	Hourly variability		all constant
SZA (°)	51±20		51
AOT	0.16±0.16		0.16
AE	0.72±0.43		0.72
ALH (km)	3.3±1.0		3.3
WVC (g/cm^2)	0.95±0.40		0.95
DNI (W/m^2)	717±245	→ +11 %	800
SIR (W/m^2)	679±240	→ +11 %	752
Asp (%)	5.9±3.5		5.9
SIR_{loss} (W/m^2)	38±18	+26 %	48

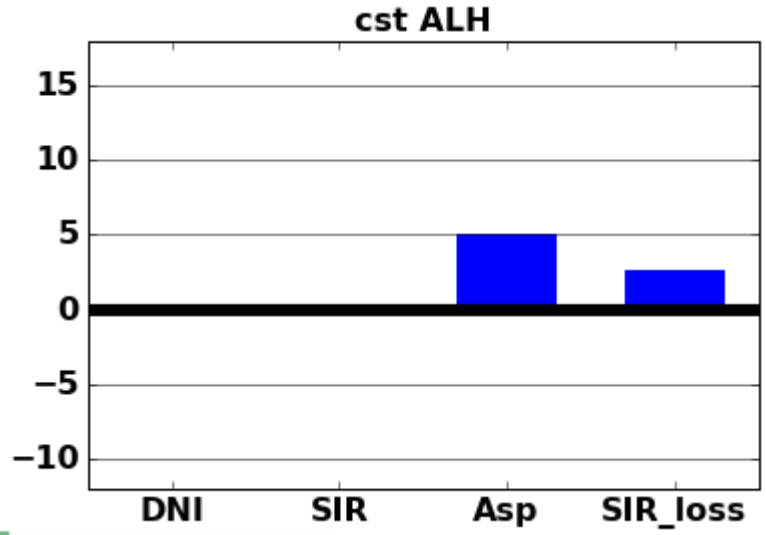


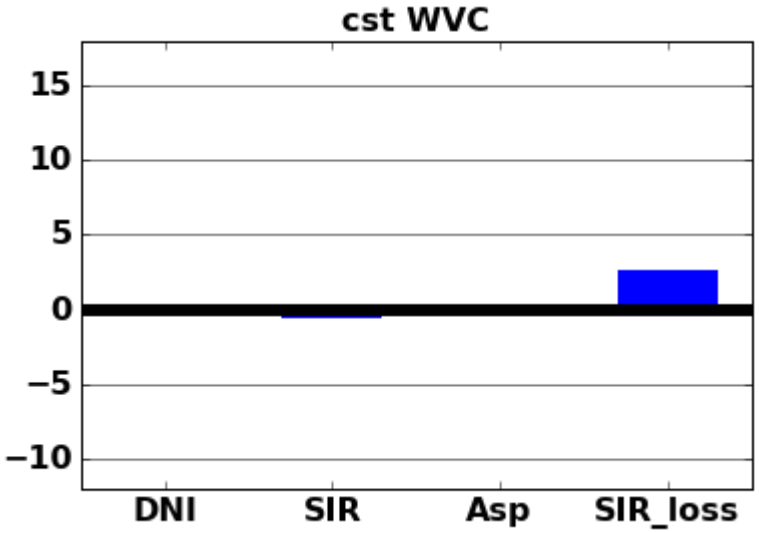
4. Influence of the input parameters: variability

Computation of the solar resource at the finest time resolution









5. Conclusions and perspectives

Aerosol parameters changing at the hourly resolution

Solar radiation incident at the receiver: computation at the hourly resolution
Input data: SZA, AOT, Angstrom at the hourly resolution (correlations)
Column water vapor: annual average ok.

Vertical distribution

Water vapor at surface level ?

Aerosols: AOT-ALH correlation at the monthly resolution. Daily ?
Single and uniform layer. High altitude aerosol layer ?
Needs studies with ground-based lidar.

Ouarzazate 2012 by AERONET+ECMWF

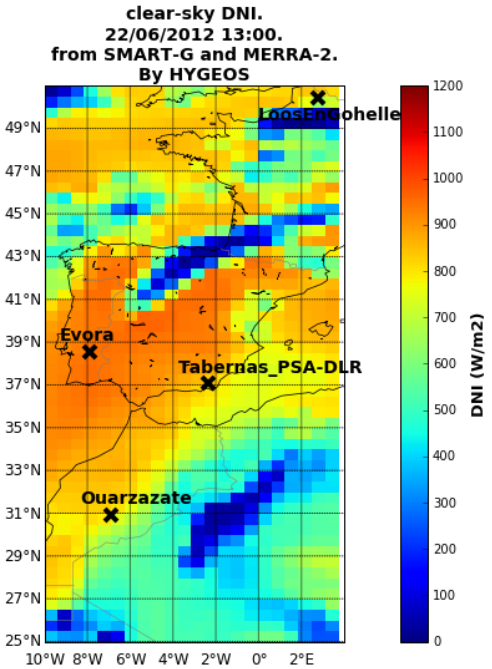
SIR = 679±240 W/m^2, with SIR_{loss} = 38±18 W/m^2

https://www.hygeos.com/pages/solar_Ouarzazate_2012

AERONET: ok.
Other data sets ?

MODIS satellite: no ALH, Angstrom exponent to be checked

MERRA-2 : ok



5. Conclusions and perspectives

The SMART-G Monte Carlo code: all optical losses …

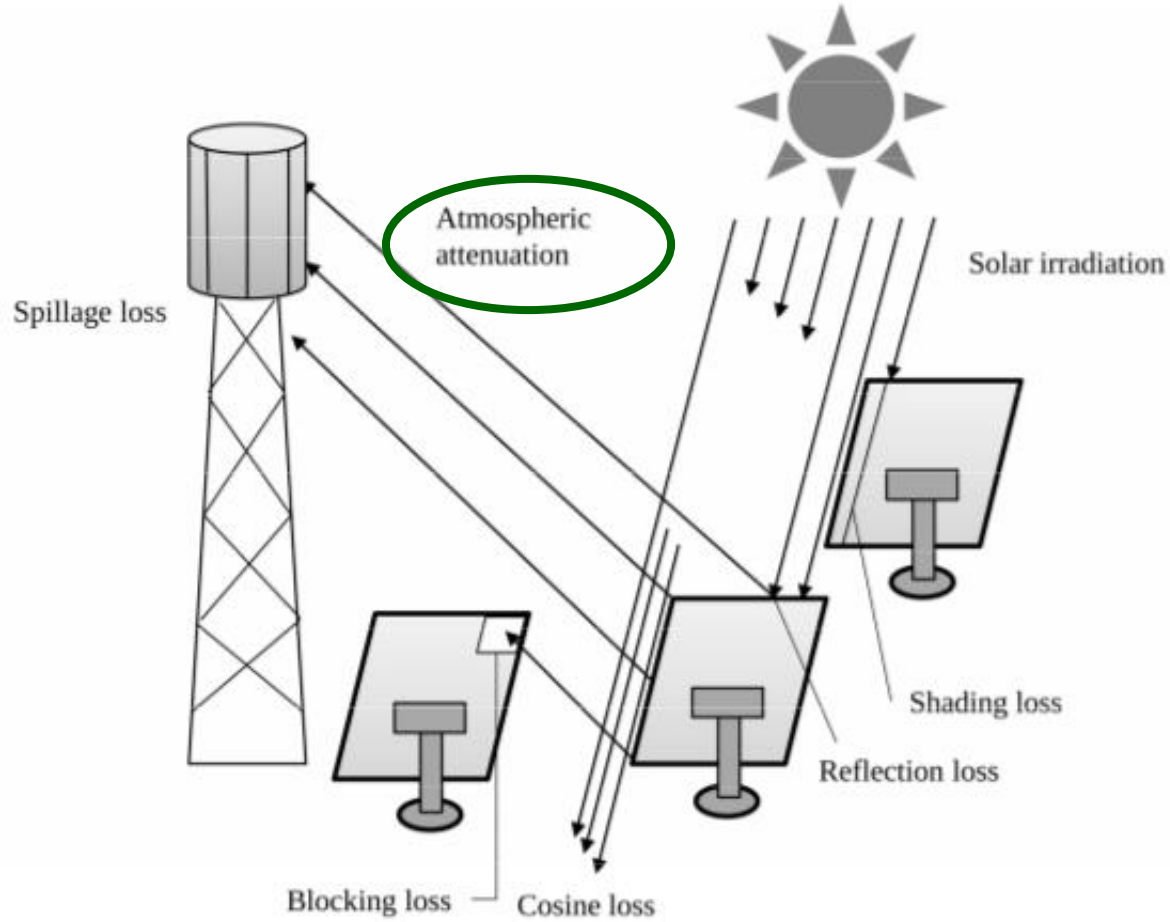


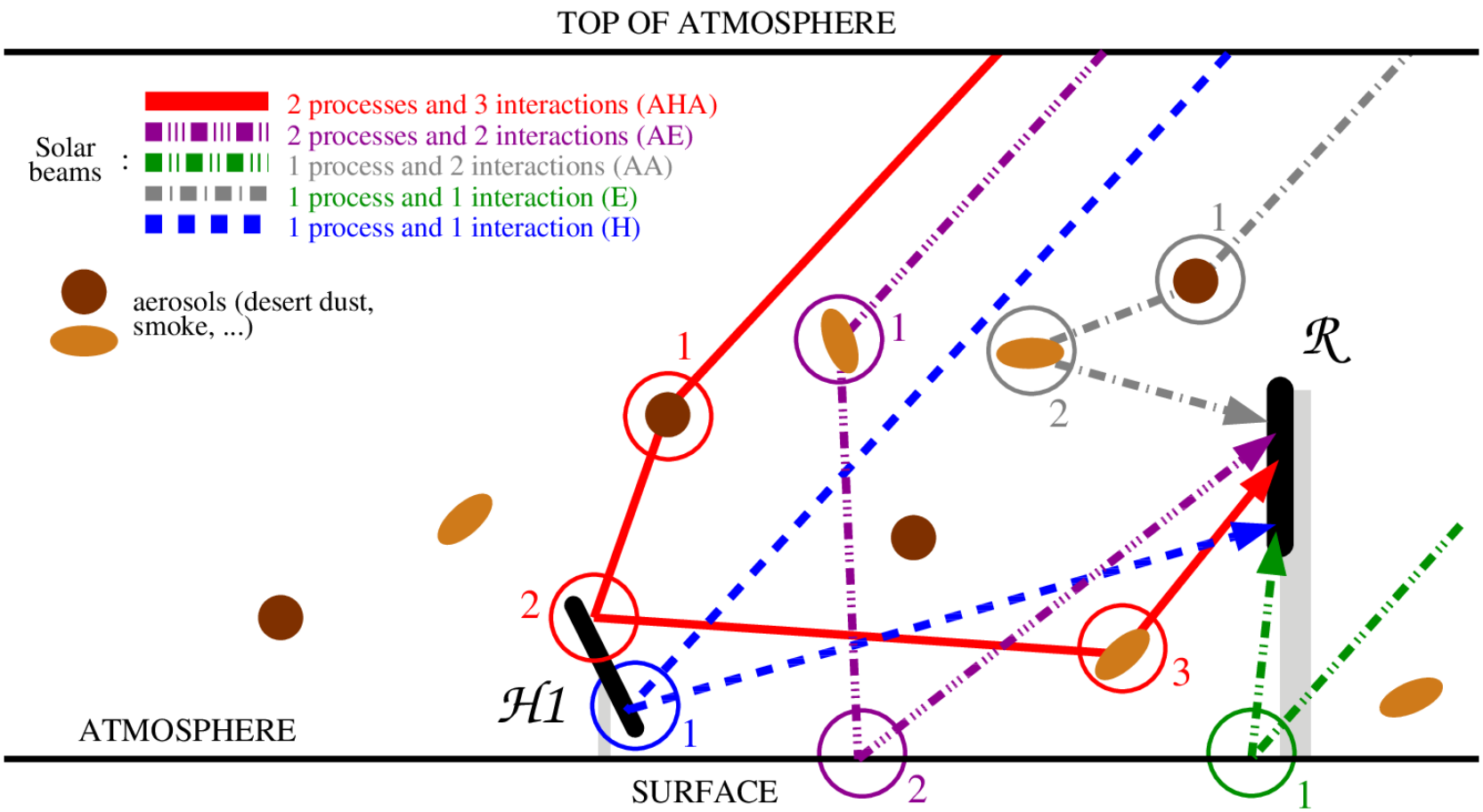
Fig. 3. Optical losses in an SCR system that are pertinent to the definition of the optical efficiency [3].

[Li et al., 2016]

#259119
Received 8 Feb 2016; revised 25 Apr 2016; accepted 25 Apr 2016; published 19 May 2016
© 2016 OSA
11 Jul 2016 | Vol. 24, No. 14 | DOI:10.1364/OE.24.00A985 | OPTICS EXPRESS A993

5. Conclusions and perspectives

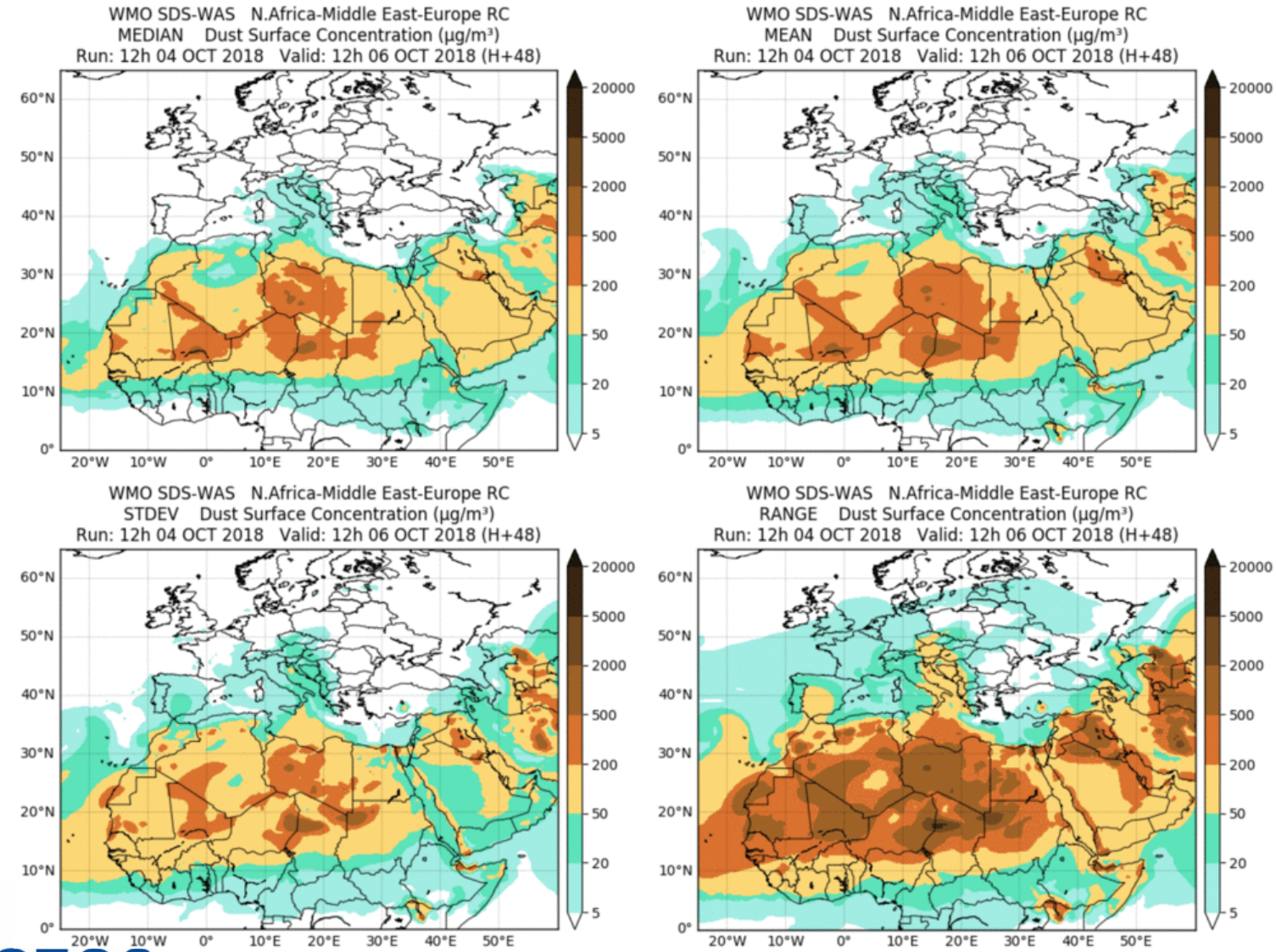
… and gains by atmospheric scattering, surface reflection, …



By Mustapha Moulana: **mm@hygeos.com**
Ph. D. student, LOA/HYGEOS

Solar PACES 2018 poster

5. Conclusions and perspectives

Dust forecasted during the Noor 3 visit ?

https://sds-was.aemet.es/forecast-products/dust-forecasts