HYGEOS

Simulation of the direct and diffuse components of the solar radiation, to improve the precision in the solar resource estimates

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1. HYGEOS

The company

- 'Cooperative' ('SCOP') created in 2001: daily democratic running

- 11 collaborators
  - 6 Ph. D. scientists, project leaders
  - 3 engineers
  - 1 Ph.D. student ('CIFRE' funding)
  - 1 administrative responsible
  - + few-month internships

- Few departures among the employed staff:
  - ☺ Important stability with benefits for research
  - ☺ Solidarity
  - ☹ Ageing ...

Hosting building, Euratechnologies, Lille

1. HYGEOS

The customers

Spatial agencies

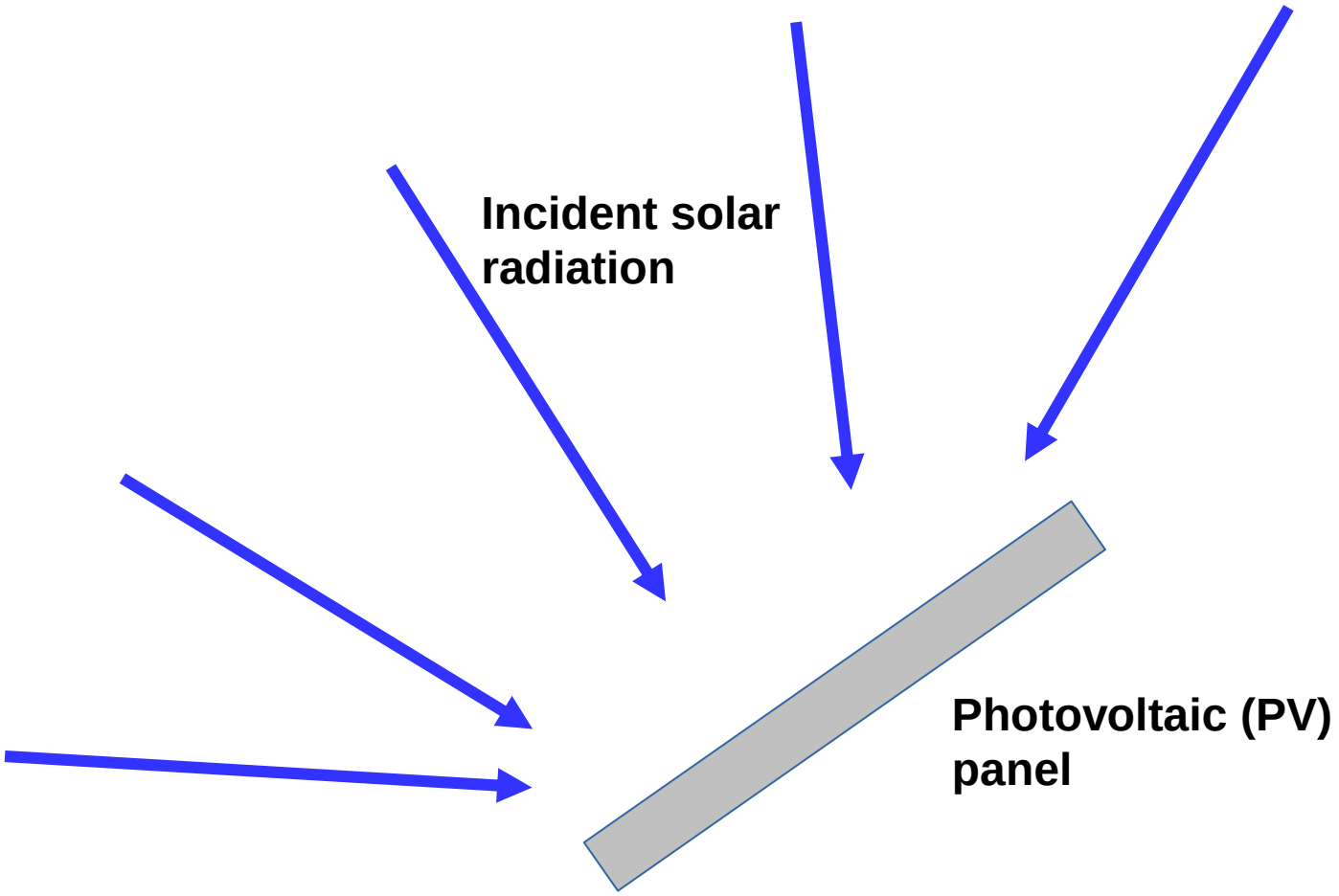
- EUMETSAT
- ESA (European Space Agency)
- CNES (Centre National d'études Spatiales)
- NASA, KORDI, ...

- The European Commission
  - The Copernicus services
  - Research projects (H2020, InterReg, …)

- Industries as
  - EDF: renewable energy
  - CLS: operational oceanography

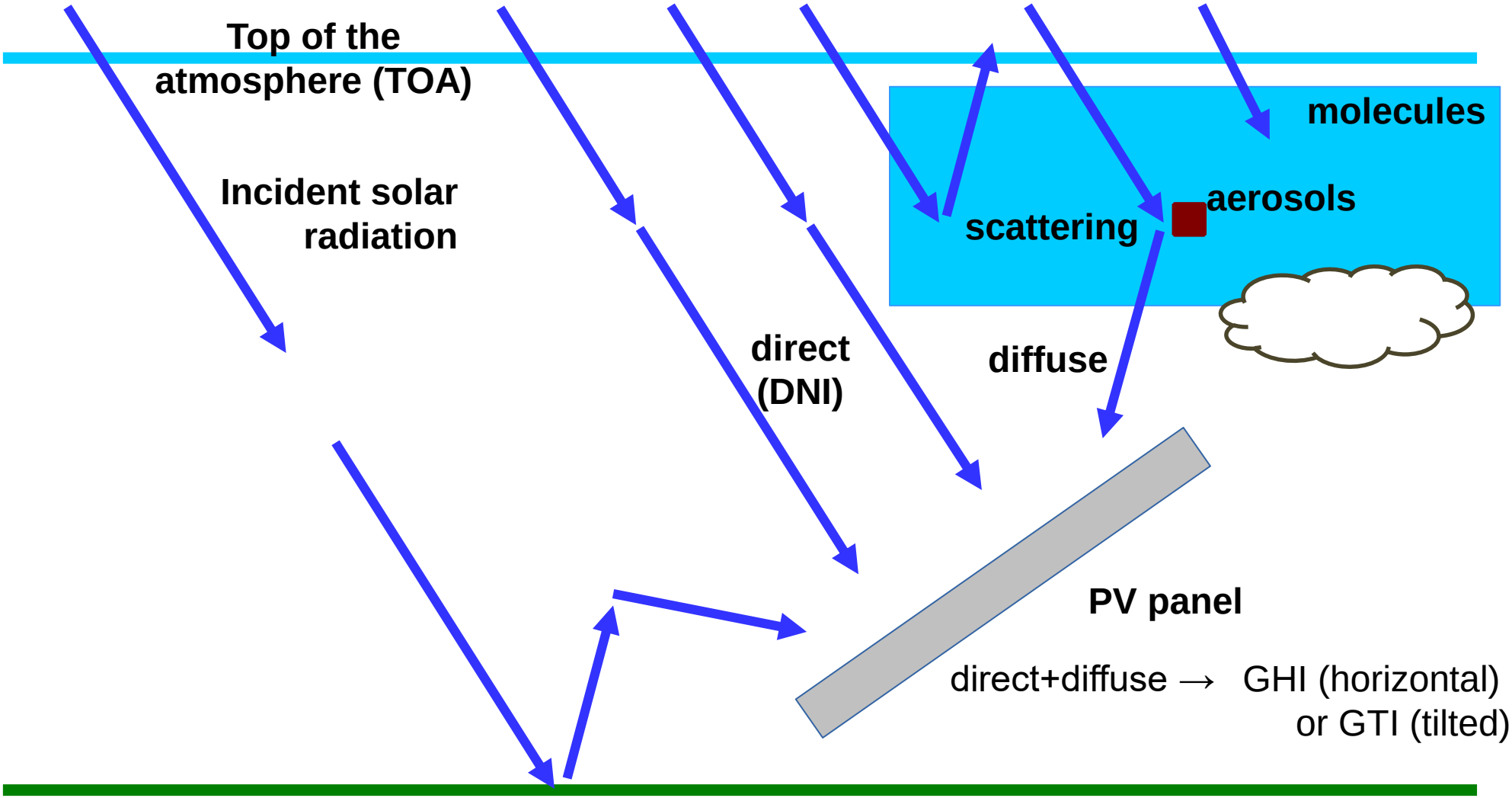
1. HYGEOS

Photovoltaic solar resource



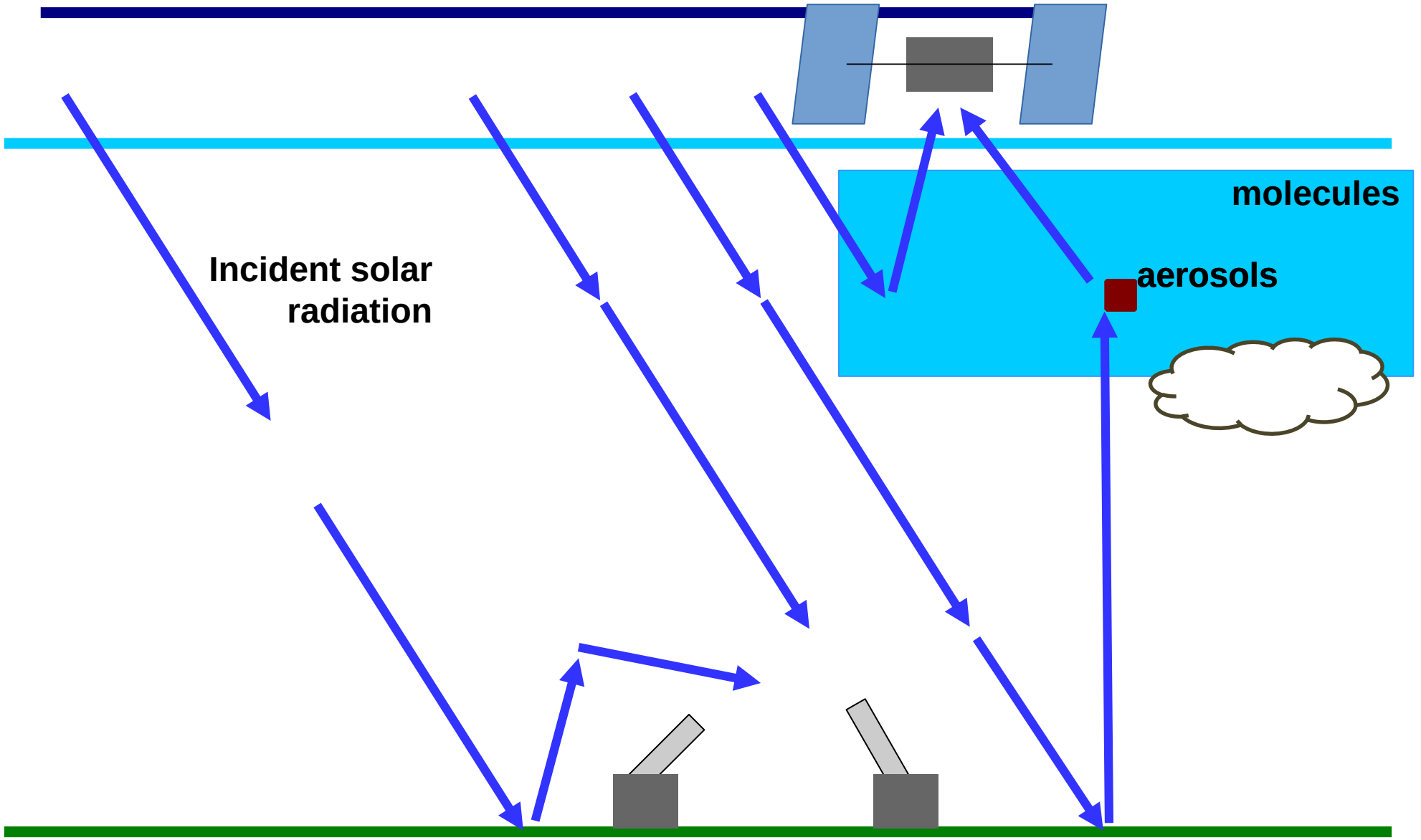
1. HYGEOS

Expert in radiative transfer in the atmosphere.



1. HYGEOS

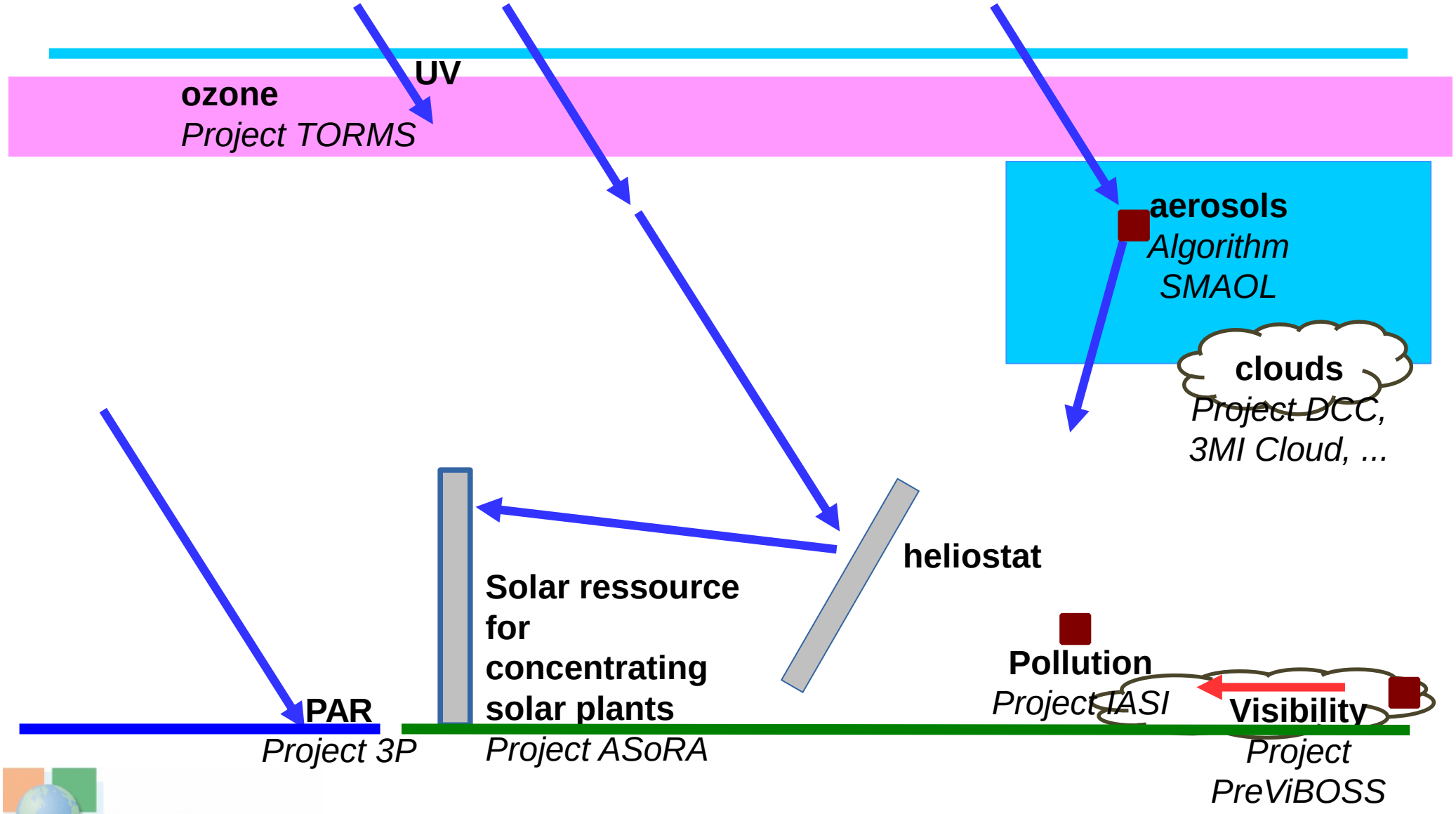
Analysis of the optical signal: satellite data and ground-based measurements



1. HYGEOS

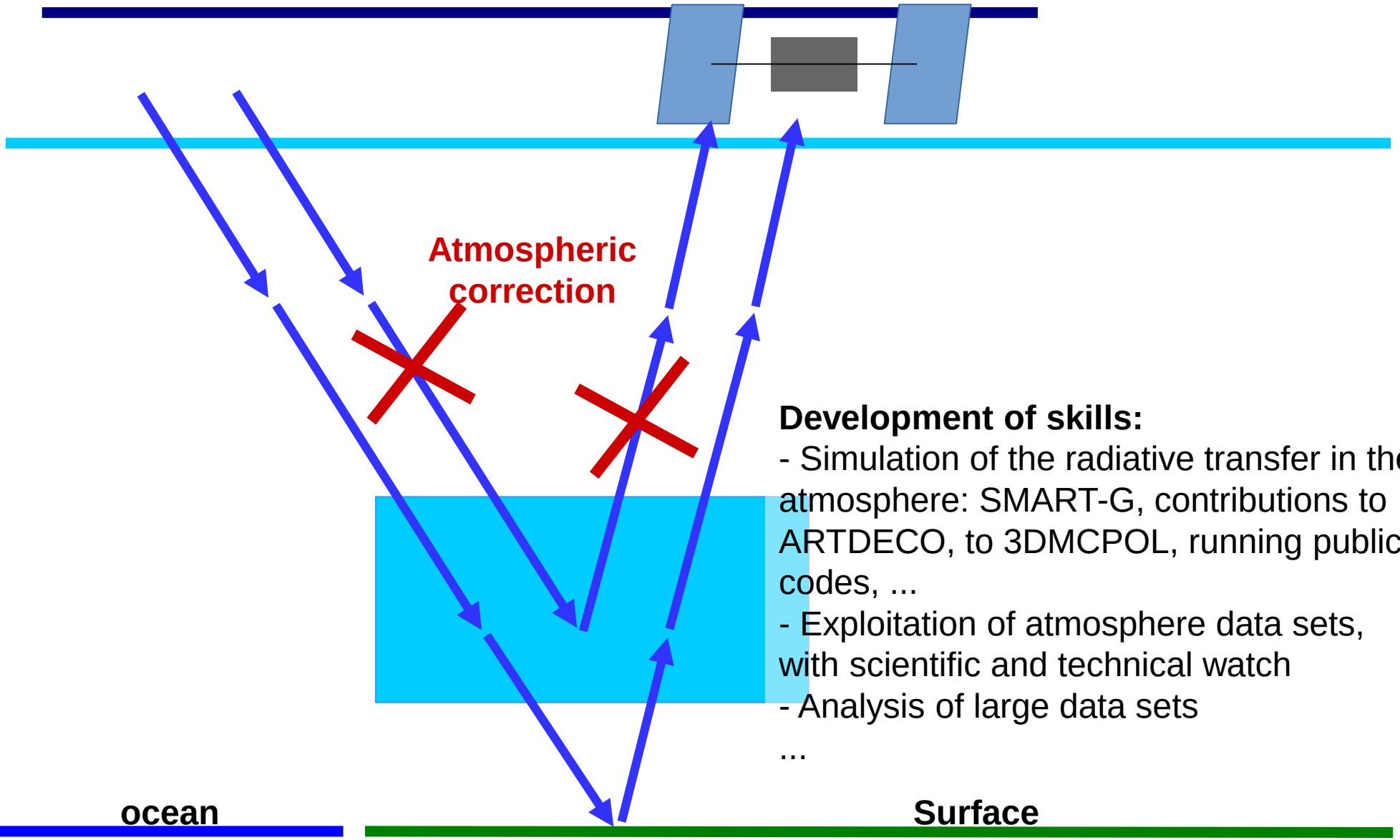
Application fields and parameters

https://www.hygeos.com/projects



1. HYGEOS

Application fields and parameters



Development of skills:

- Simulation of the radiative transfer in the atmosphere: SMART-G, contributions to ARTDECO, to 3DMCPOL, running public codes, ...
- Exploitation of atmosphere data sets, with scientific and technical watch
- Analysis of large data sets

...

ocean

Projects C2X, Globcoast, ...

Surface

Projects ImagineS, Copernicus Global Land Service, Copernicus C3S...

Outline

1. HYGEOS
2. The ASoRA project
3. Solar resource in cities
4. The SMART-G code
5. Atmospheric variability
6. Validation
7. Conclusion

2. The ASoRA project

Solar plant bankability

Solar resource in the largest tower concentration solar plants (CSPs) ?

Strong constraints of precision:
100 MW electricity, loss by only 1% = 1 MW lost !
~1 000 000 000 euros, loss by 1% = large financial cost !

La centrale Gemasolar
en Andalousie : 20 MW
2650 miroirs = 318 000 m2
Tour de 140 m
195 ha

2. The ASoRA project

Impact of the atmospheric scattering in the slant path

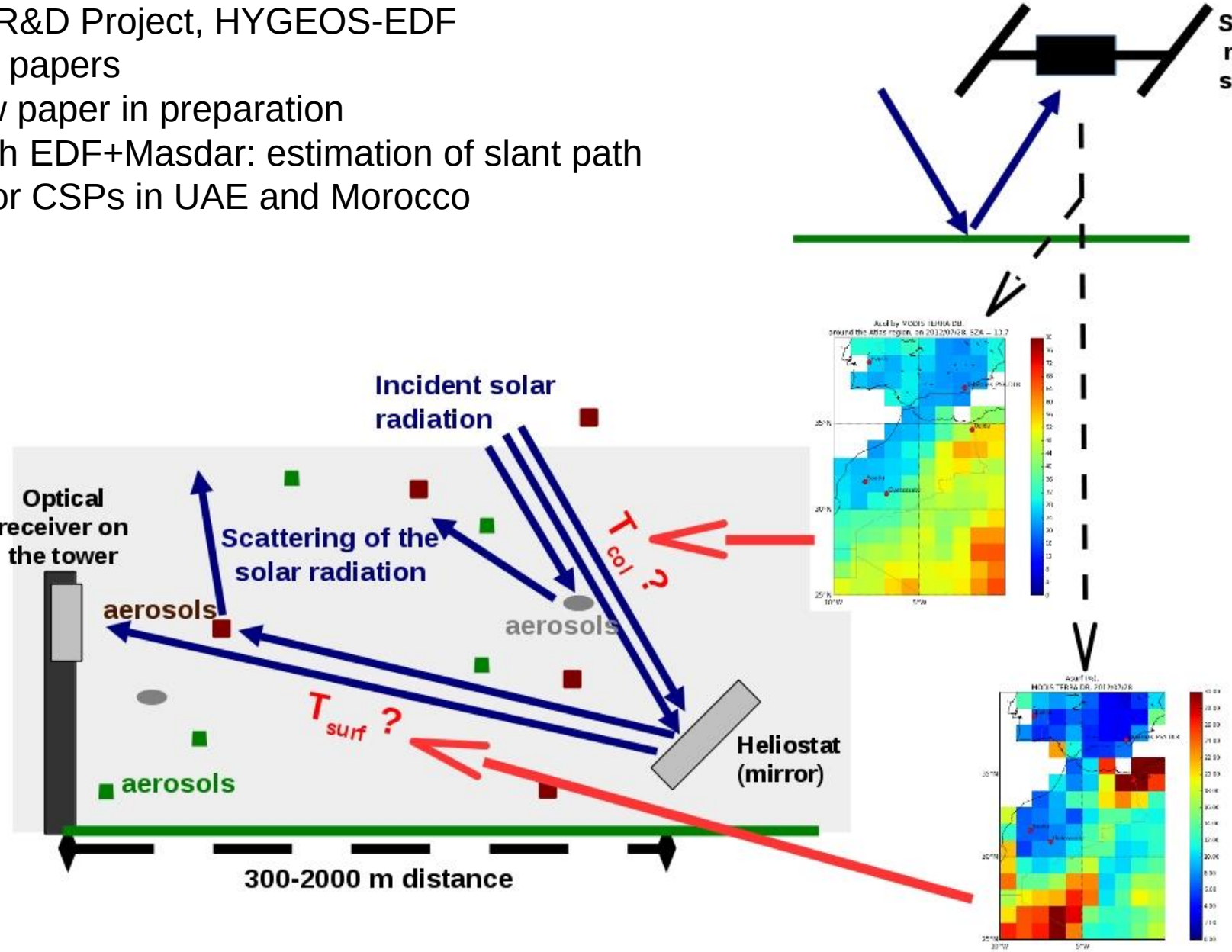
”By afloresm - SOLUCAR PS10 (2), CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=2821738”

Scattering of the solar radiation by the atmosphere

2. The ASoRA project

Slant path attenuation by satellite remote sensing

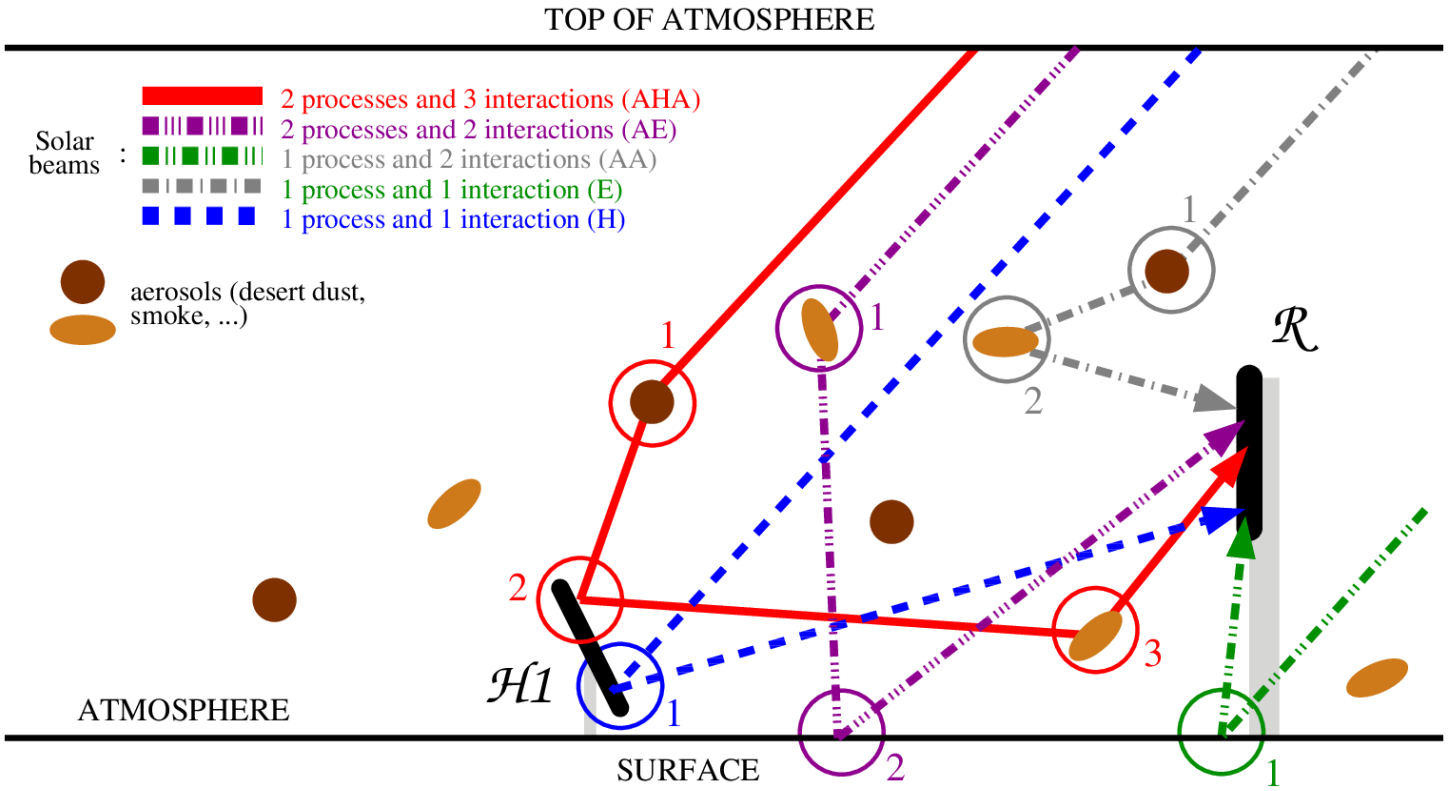
2015-2018 : R&D Project, HYGEOS-EDF
4 proceeding papers
1 peer review paper in preparation
Contracts with EDF+Masdar: estimation of slant path attenuation for CSPs in UAE and Morocco



2. The ASoRA project

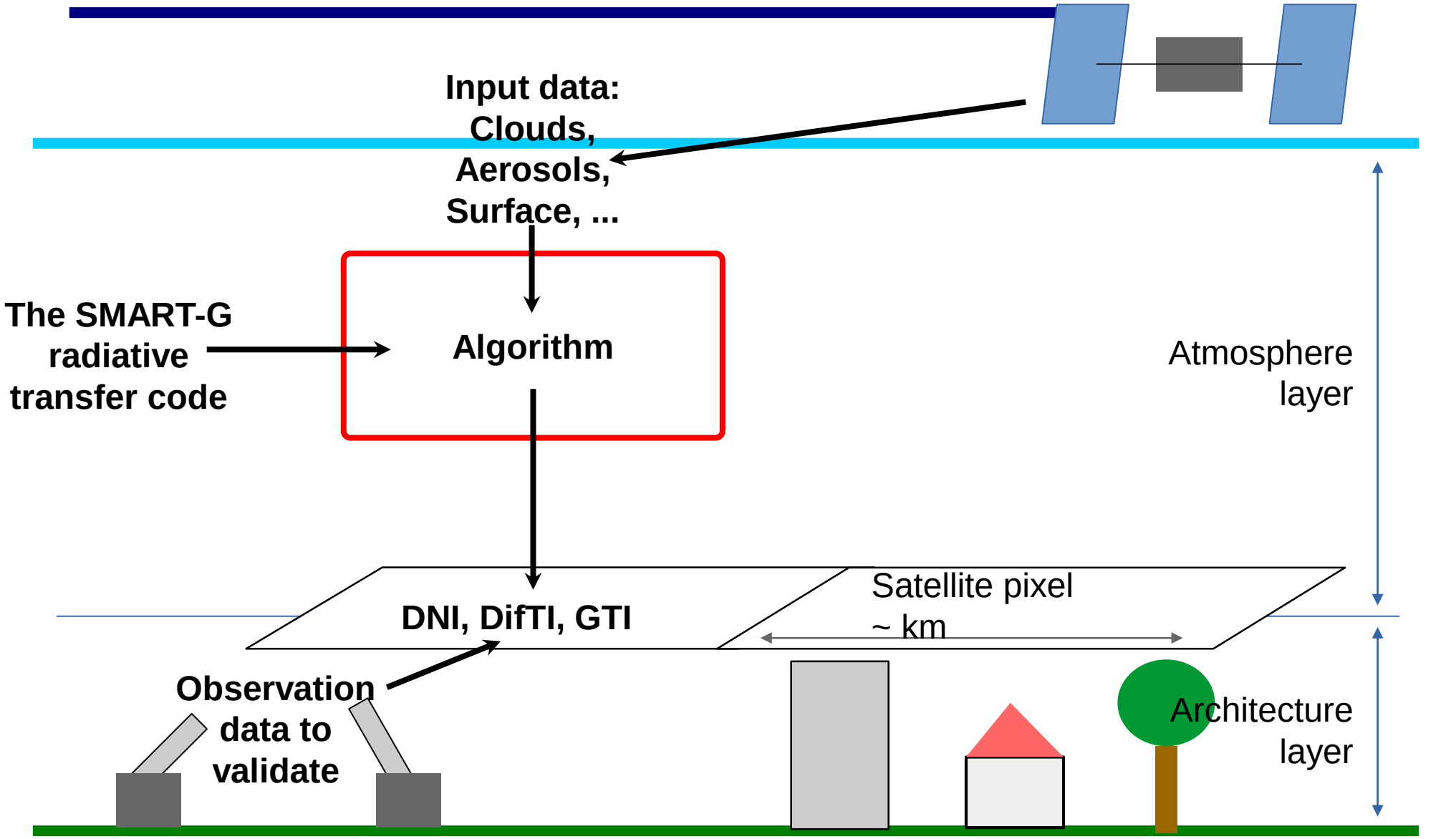
Research in collaboration with the LOA

2017- :
1 Ph.D. thesis supervised in collaboration with the Laboratoire d'Optique Atmosphérique (LOA, Lille, France)
Influences 3D
on DNI
on collected solar resource



3. Solar resource in cities (solar cadastre)

The protocol



4. The SMART-G code

Fast and physical: precise and detailed

Physical: scattering, absorption, reflection
→ **precise and detailed computations**

+ fast

→ Generation of solar resource data sets:
Dedicated (e.g. Lille over 10 years, PV, ...)
Detailed: direct, diffuse inclined, spectral, ...
Resolved: 1 hour, ~1 km²

[Ramon et al., 2018]

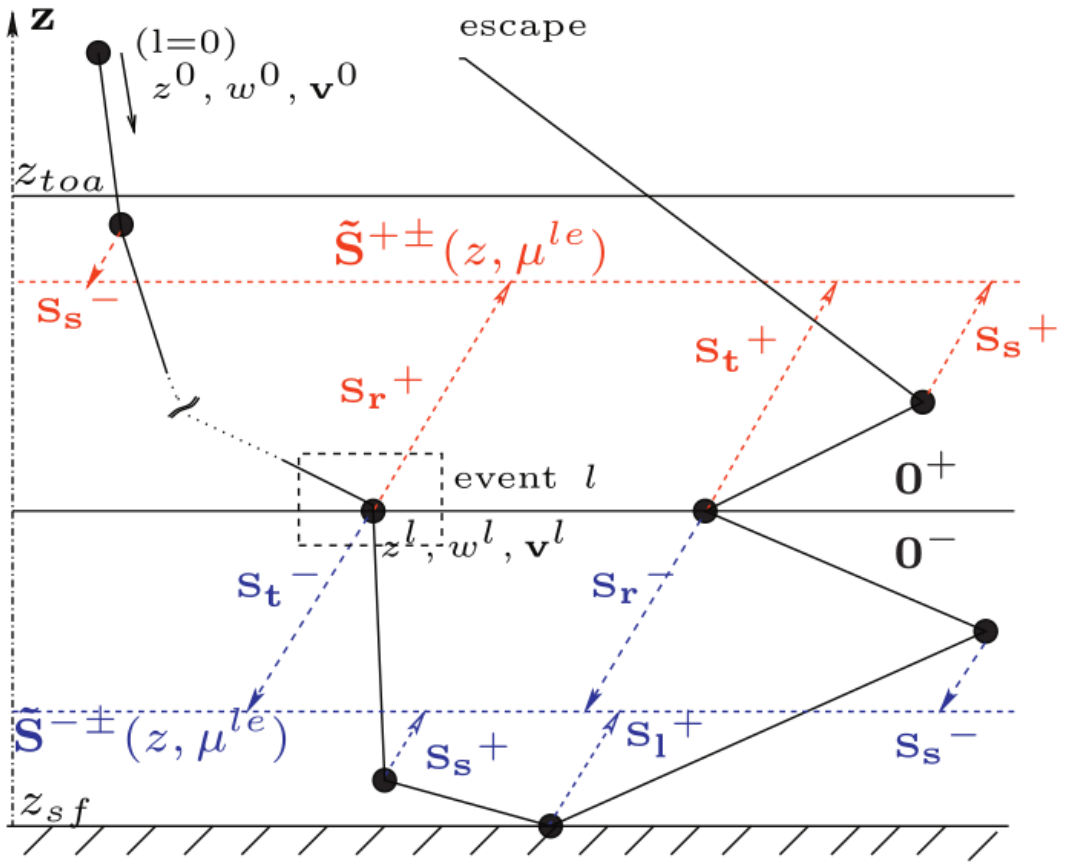
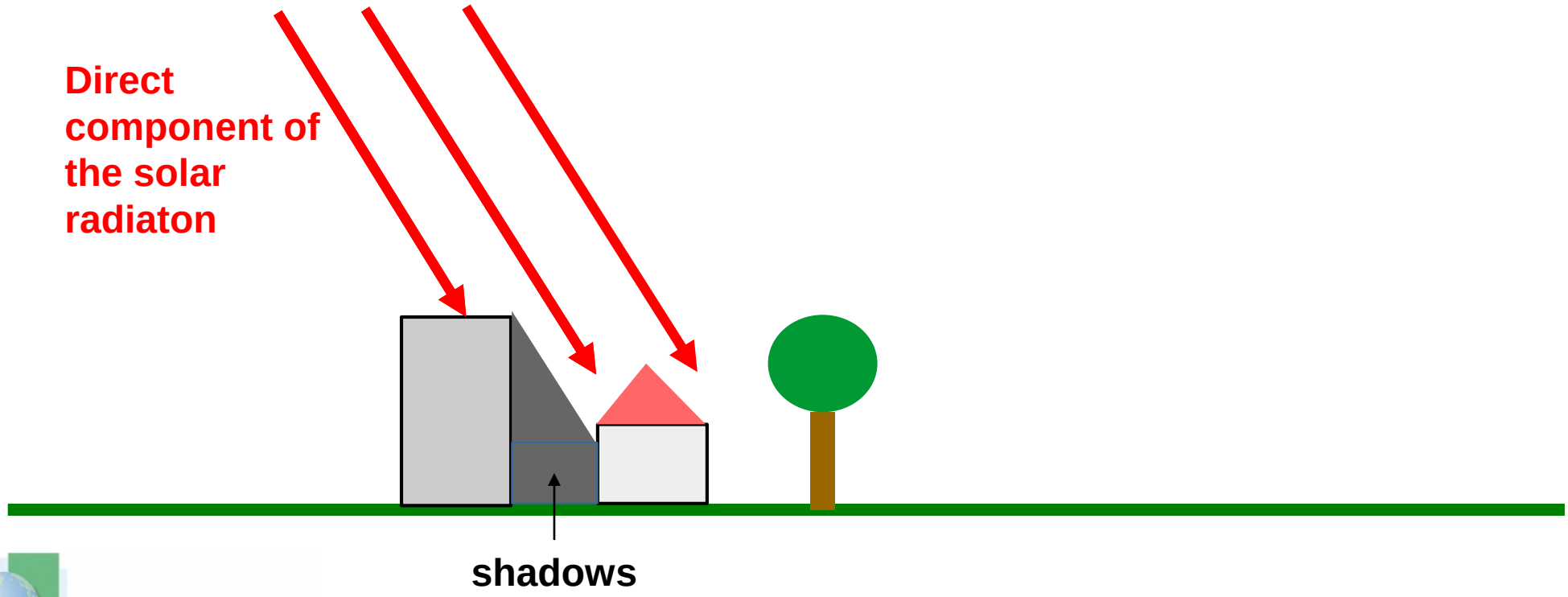


Fig. 3. Various Stokes estimates at different levels for one particular photon. The photon path is in black, with black dots symbolizing random events l starting from $l = 0$ and ending with the escape of the photon. We show here one single direction for local estimate. The red symbols correspond to local estimate of radiance at an altitude z in the atmosphere while the blue symbols correspond to a local estimate of radiance at an altitude z in the ocean (see text).

Computation of both direct and diffuse components, and not only GHI

Because shadows on the direct solar radiation

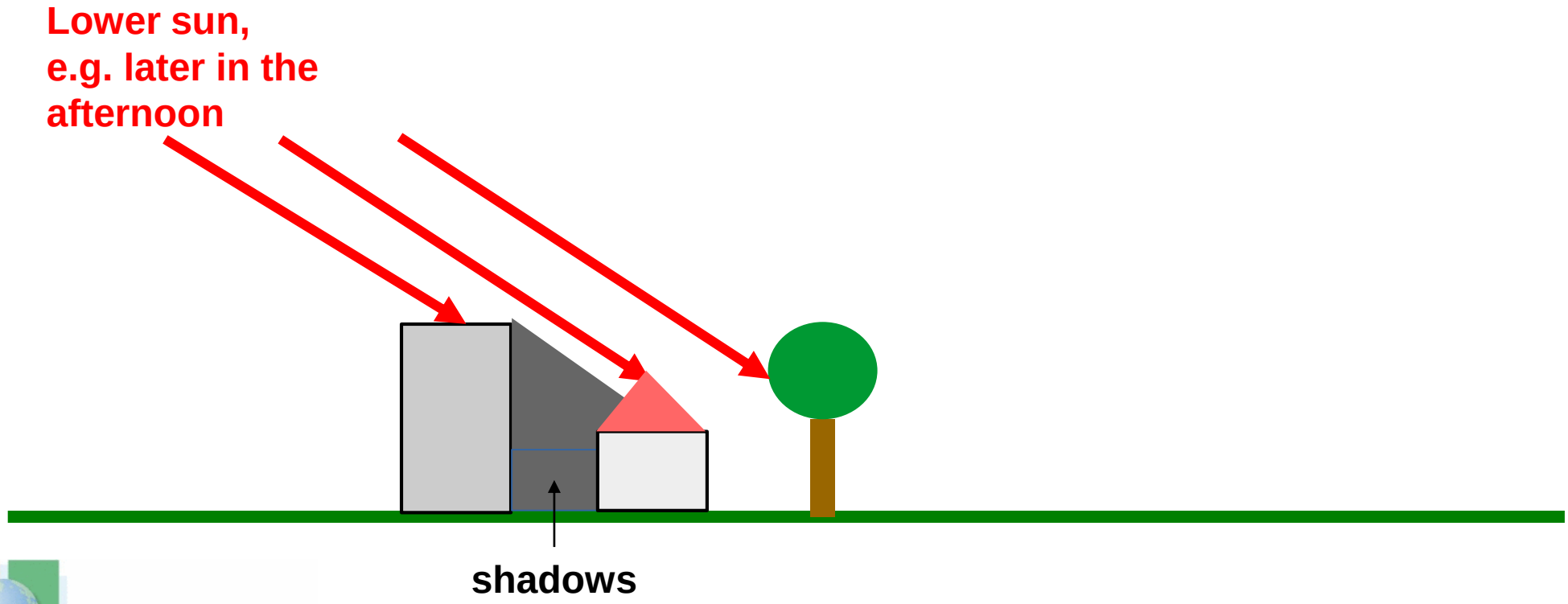


4. The SMART-G code

Direct and diffuse

Computation of both direct and diffuse components, and not only GHI

Because shadows on the direct solar radiation

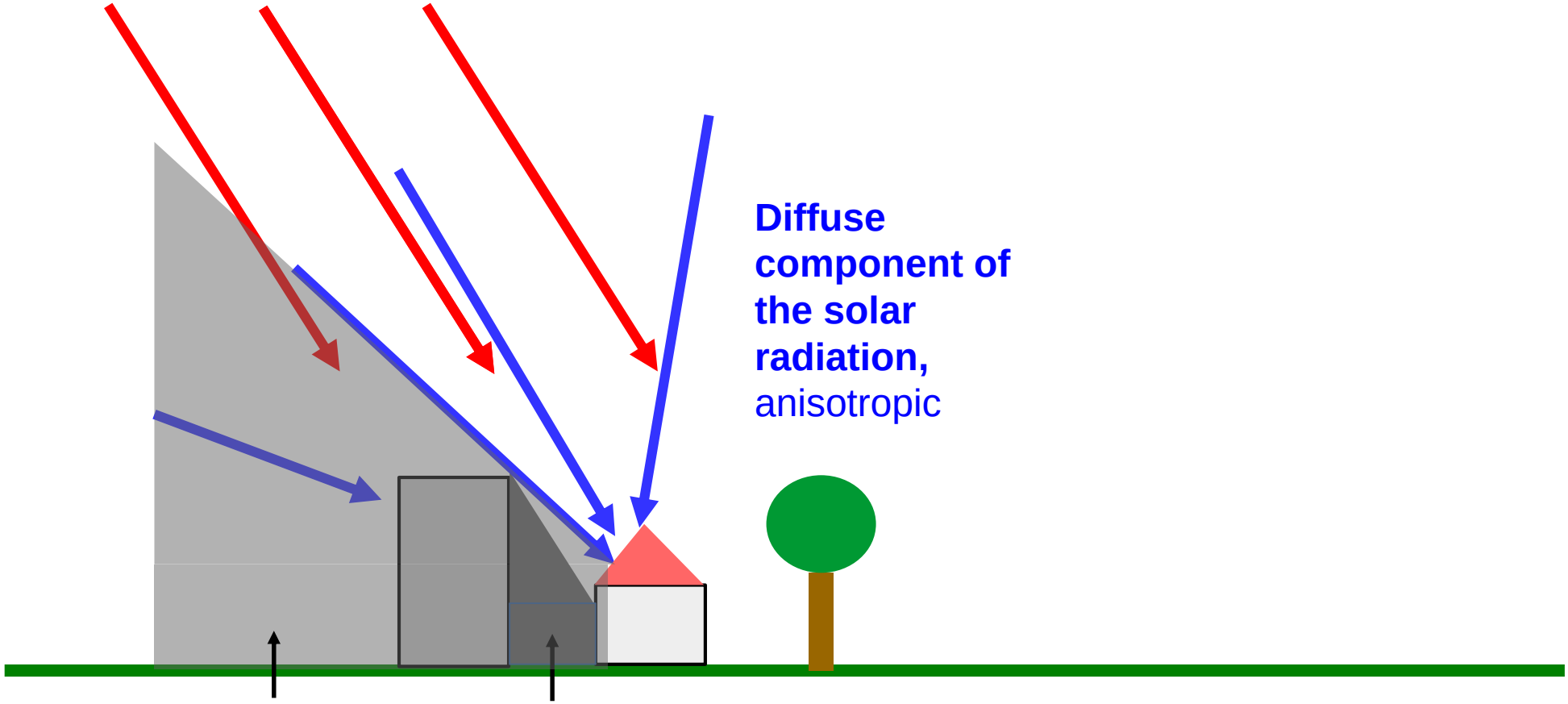


4. The SMART-G code

Direct and diffuse

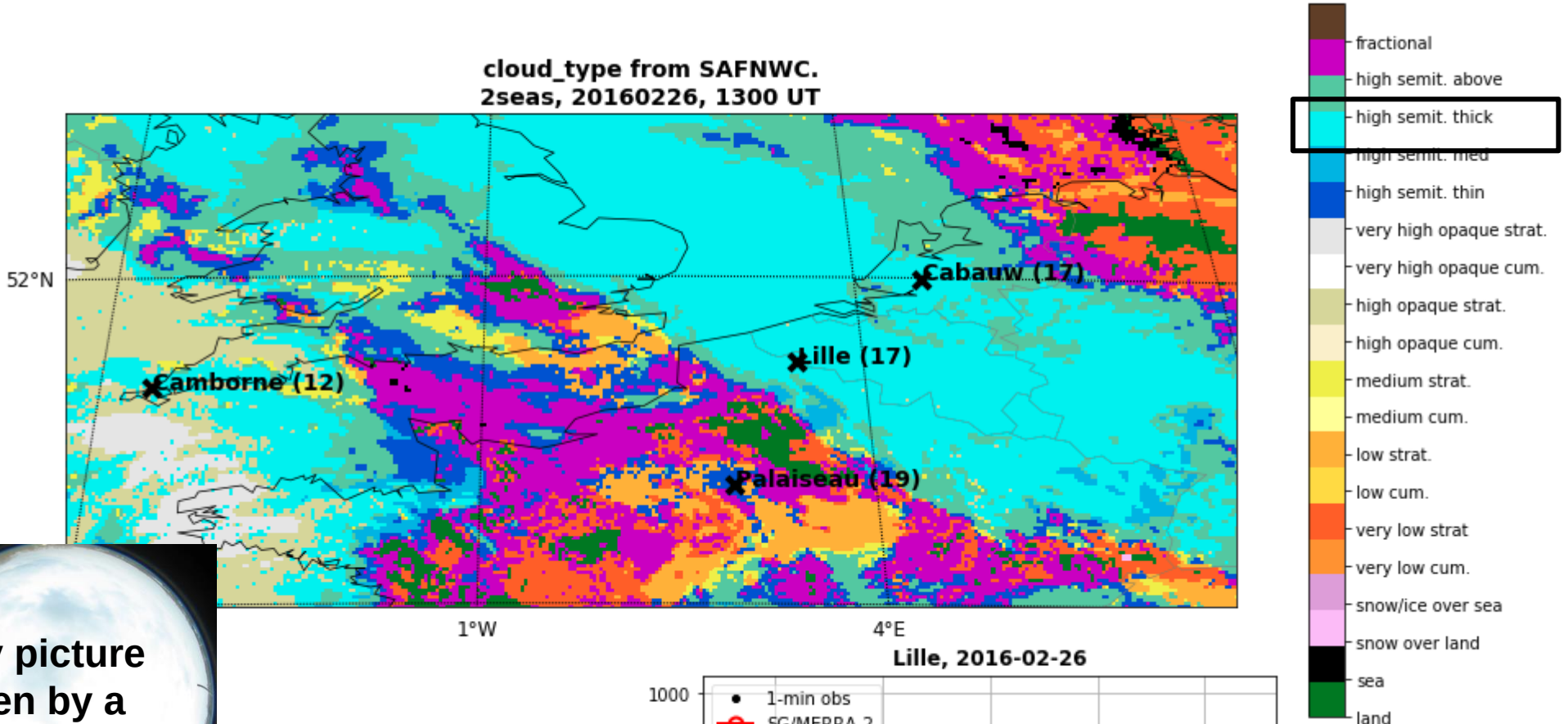
Computation of both direct and diffuse components, and not only GHI

Because mask on the diffuse solar radiation



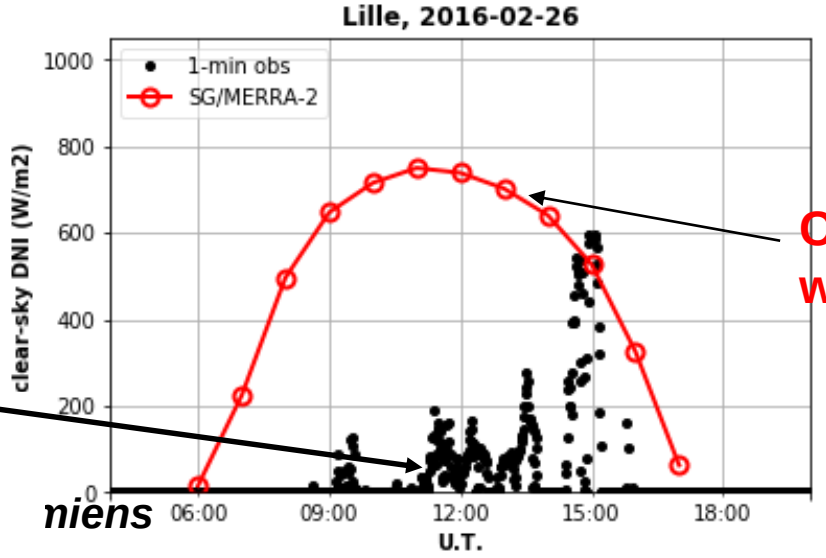
5. Atmospheric variability

1st contributor: clouds



Sky picture taken by a camera

1-minute ground-based observations at Lille



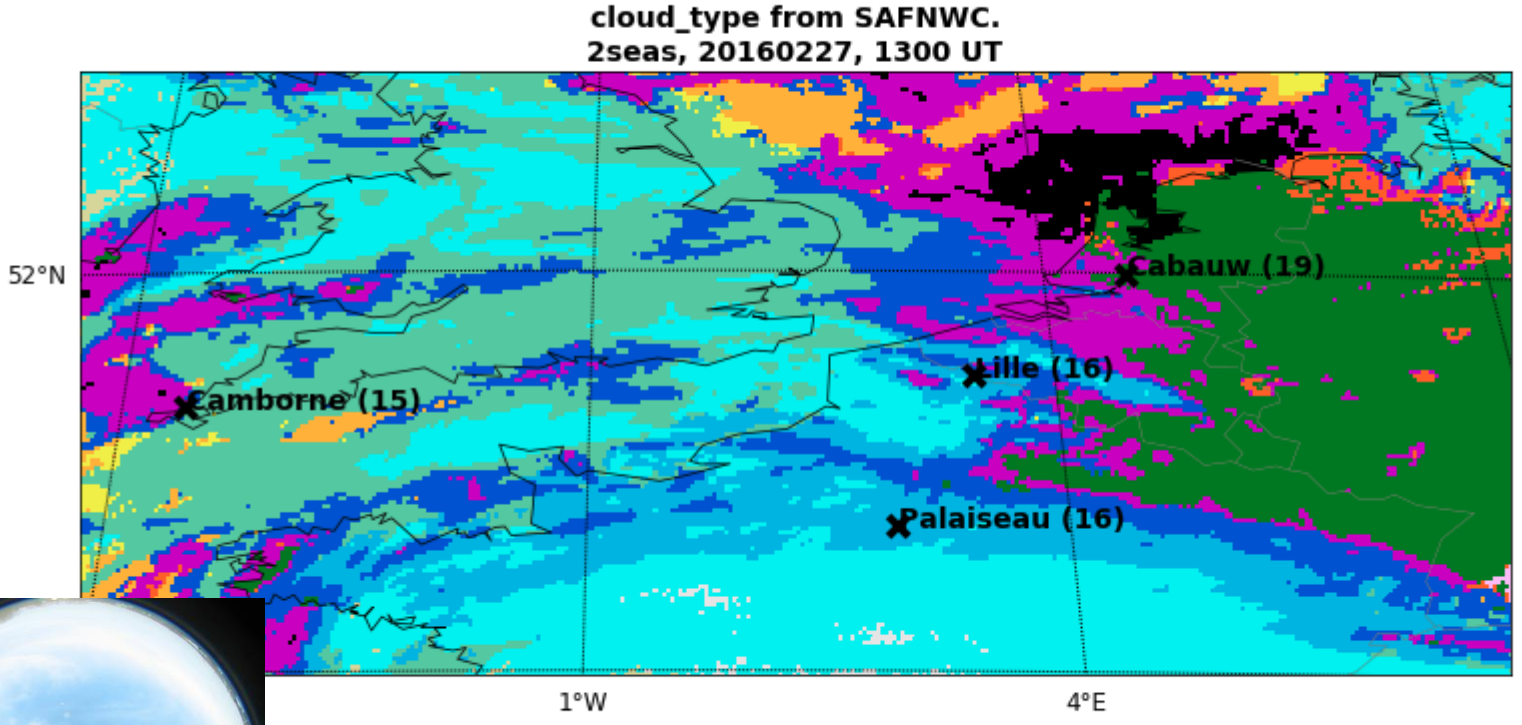
Computation without clouds

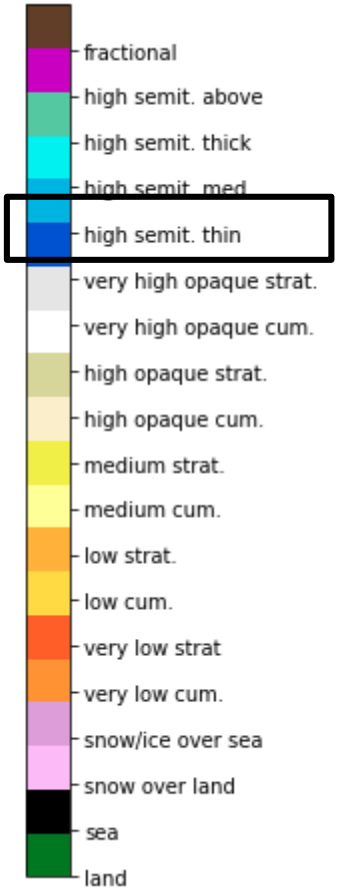
Acknowledgements:
LOA for observation data,
contact: nicolas.ferlay@univ-lille.fr

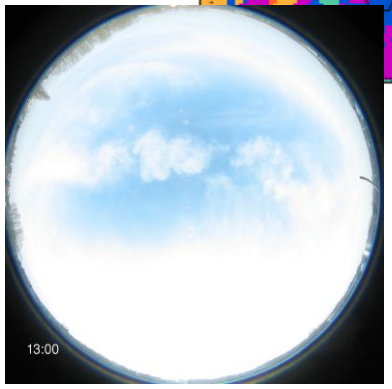
niens

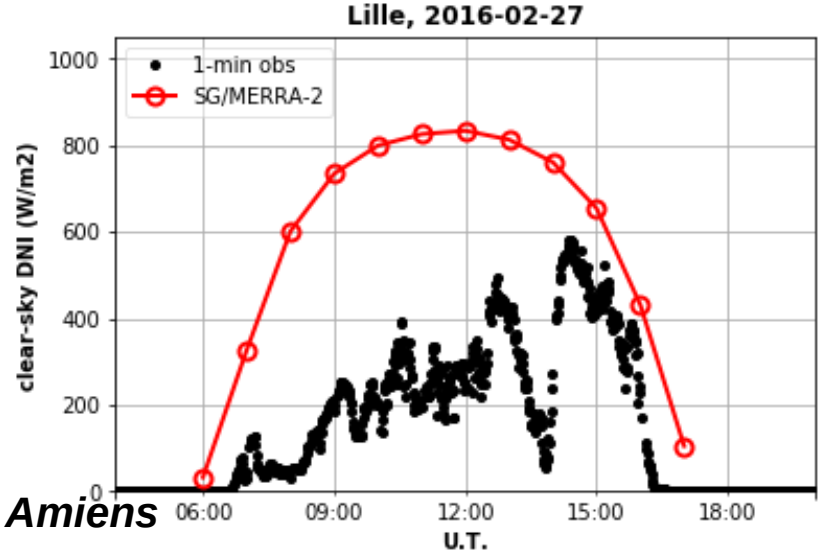
5. Atmospheric variability

1st contributor: clouds



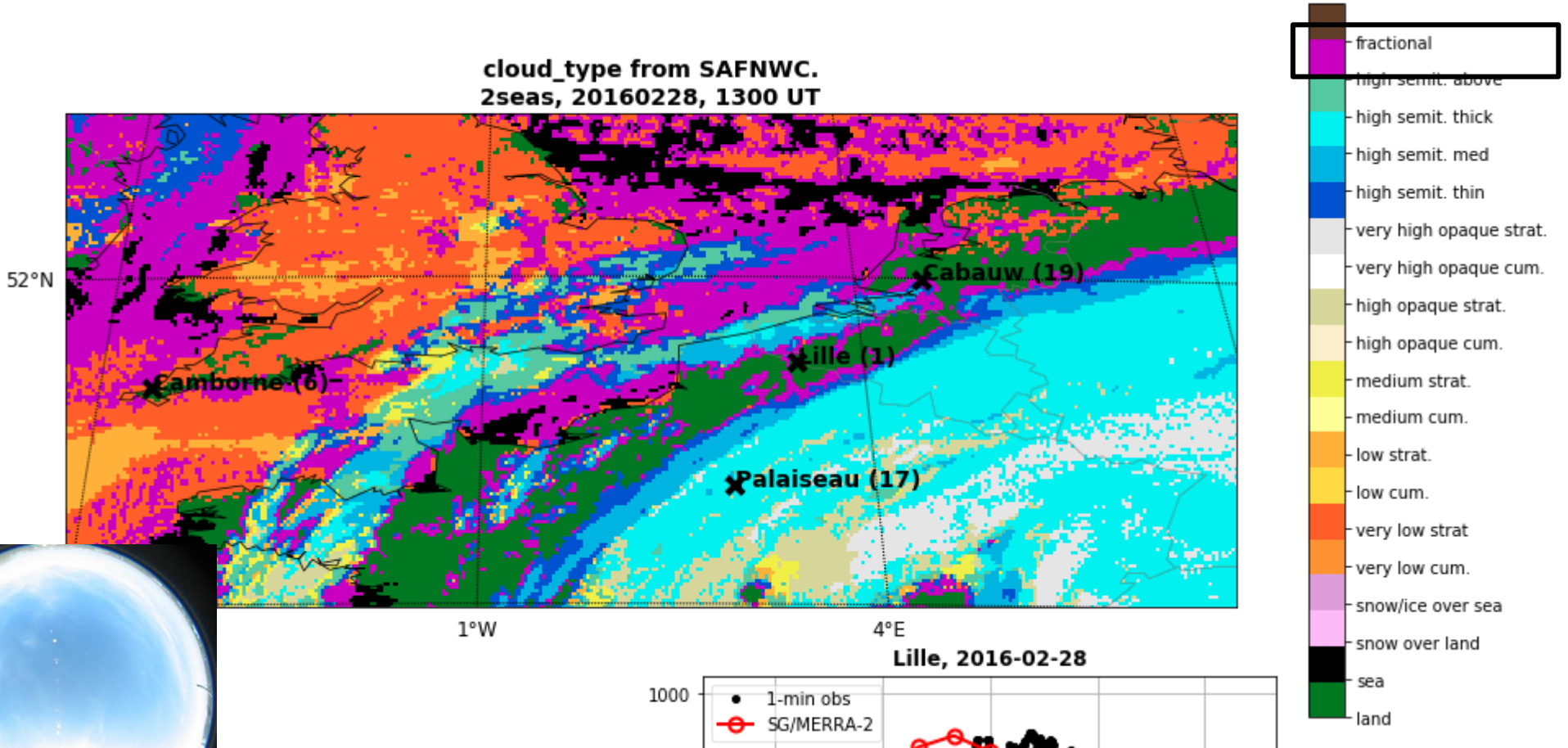


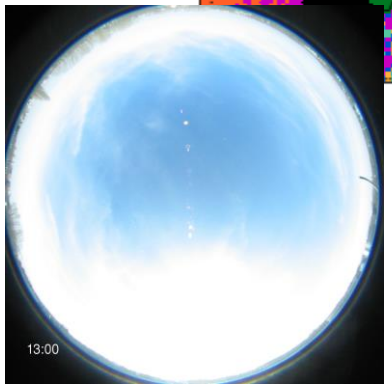


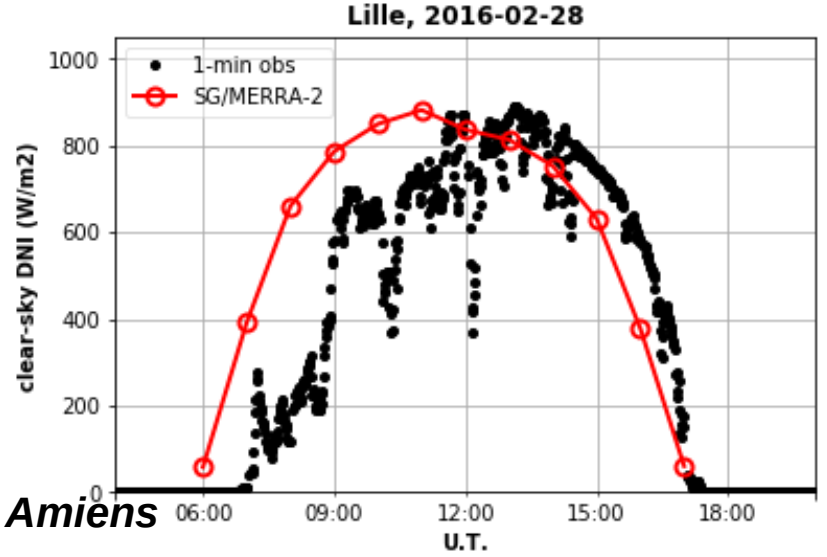


5. Atmospheric variability

1st contributor: clouds

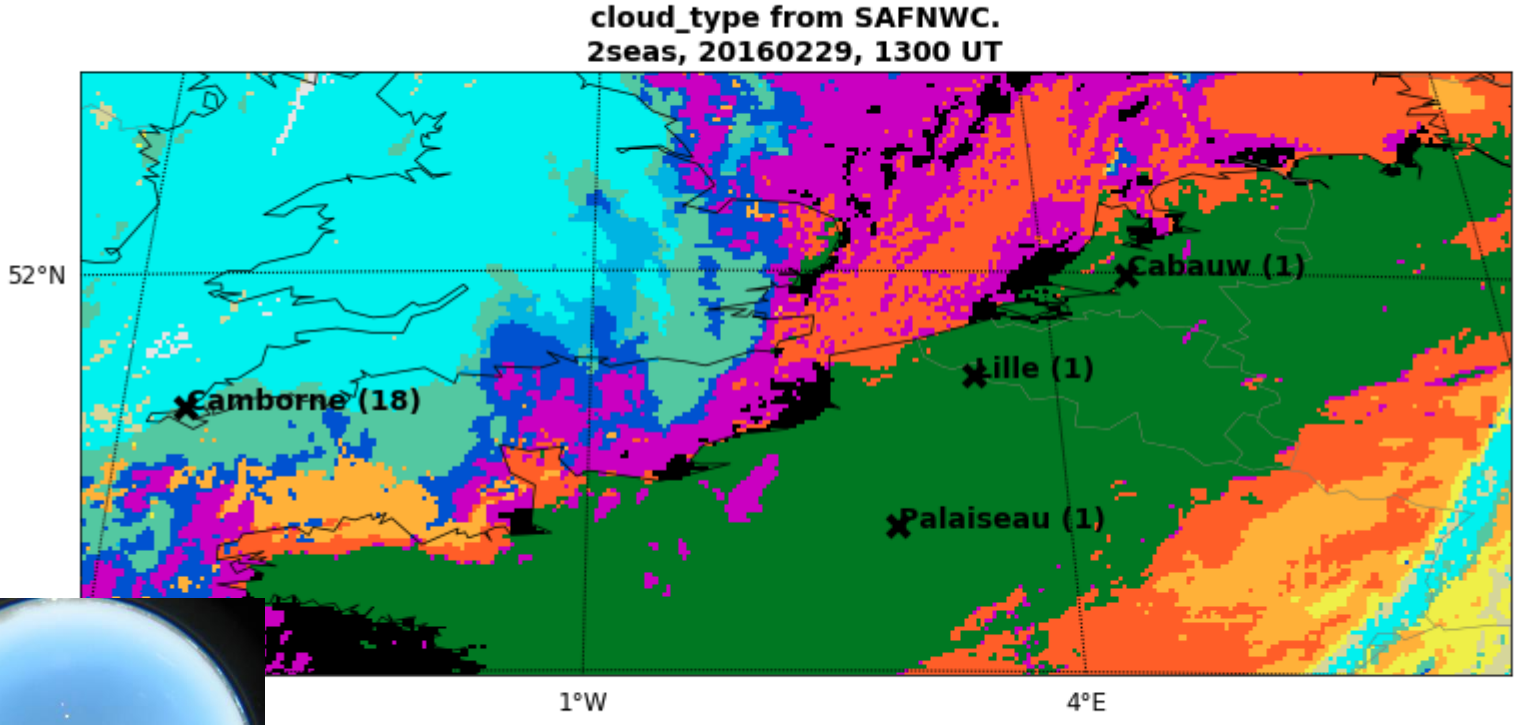


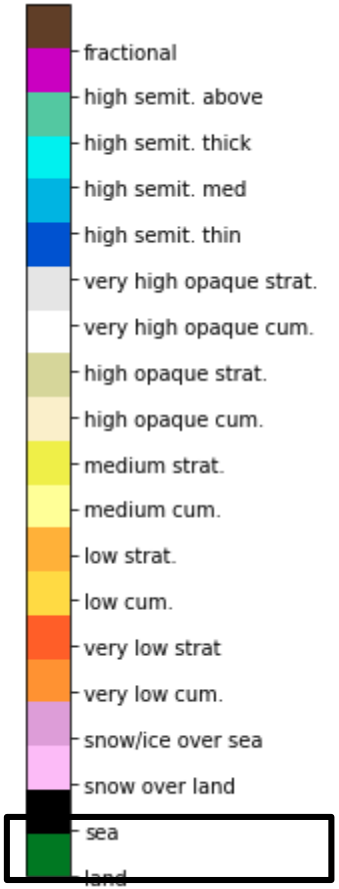


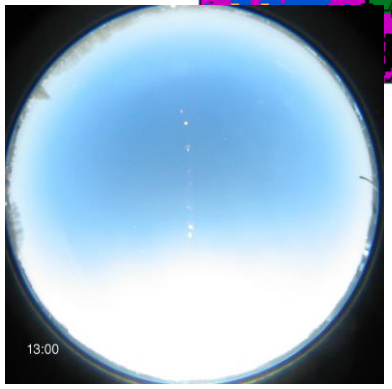


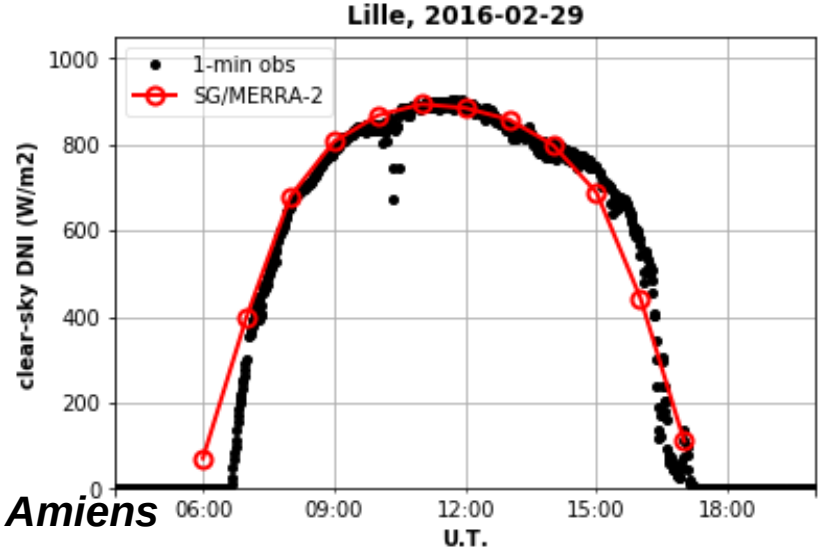
5. Atmospheric variability

1st contributor: clouds



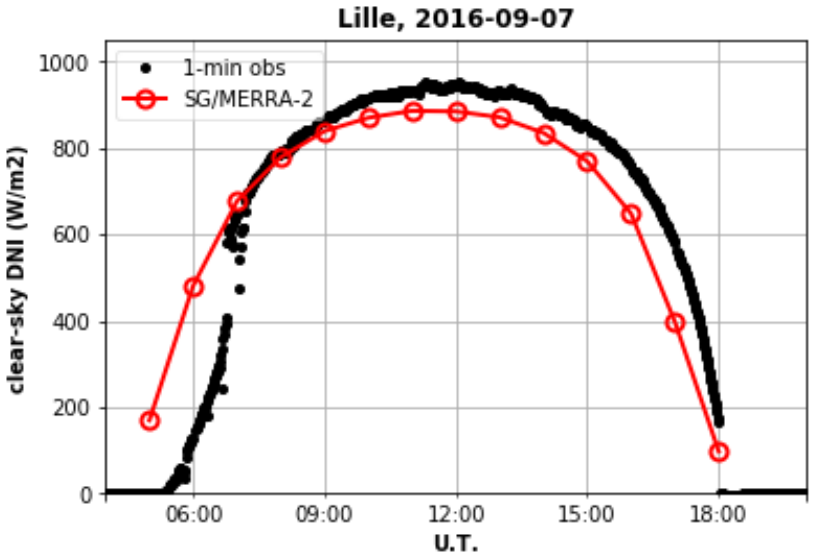


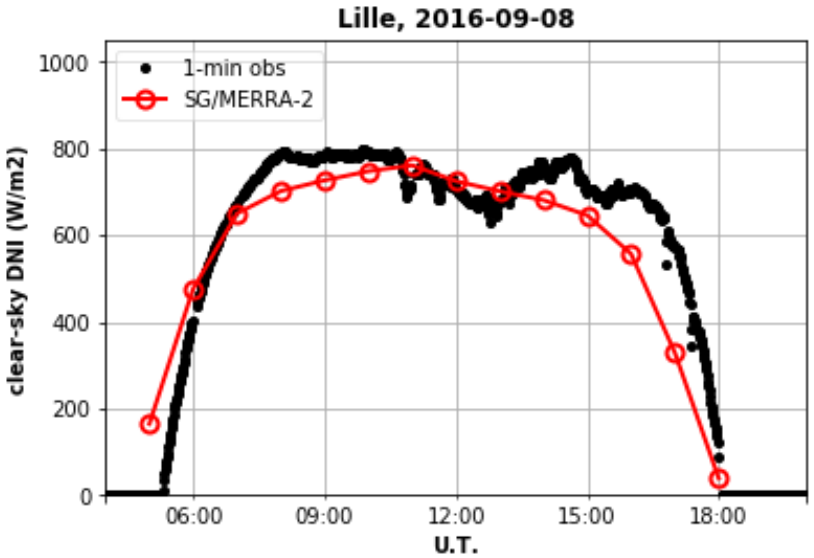




5. Atmospheric variability

2nd contributor: aerosols





6. Validation

The protocol is validated

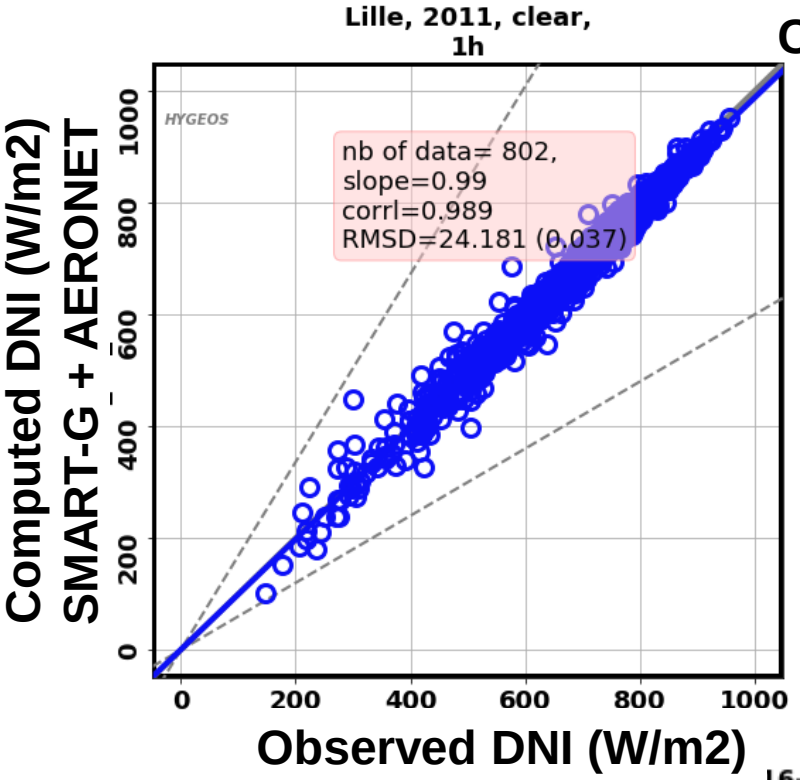
AERONET: global network for aerosol observation

→ **best precision in clear-sky conditions**

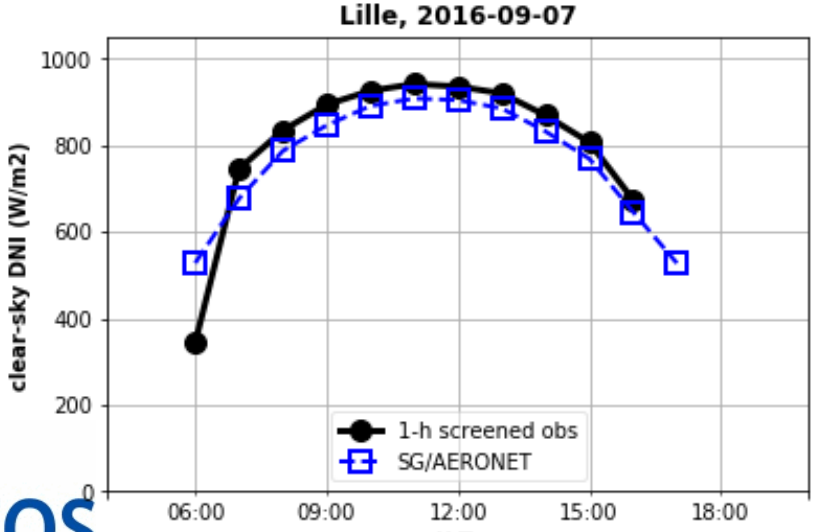
Great agreement in DNI with observation made at Lille in 2011

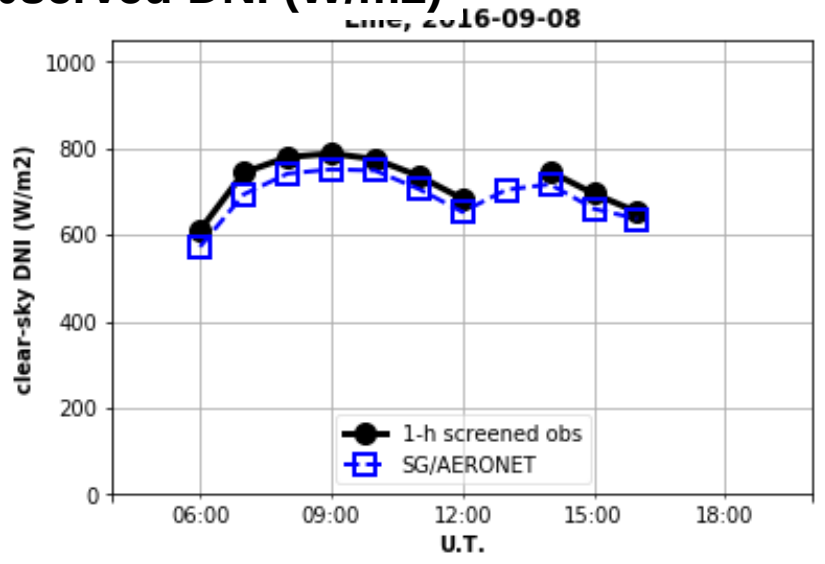
The protocol is validated !

Comparison of DNI for 1 year



Hourly comparison of DNI for 2 days with contrasted aerosol load





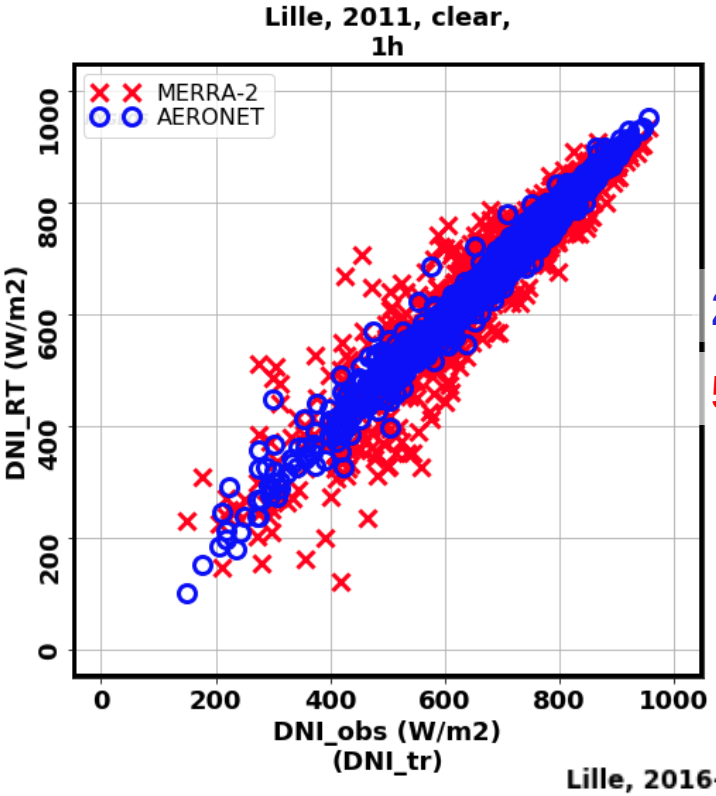
6. Validation

Precision depends on the input data

AERONET: global network for aerosol observation
Not available everywhere

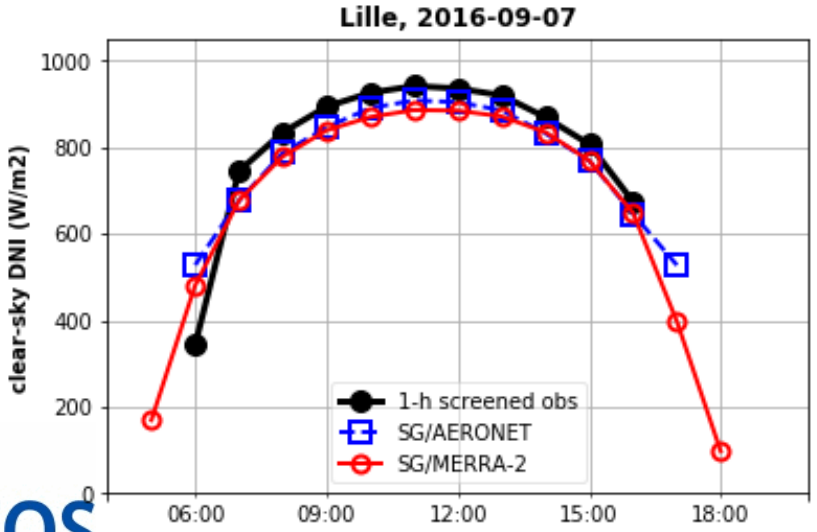
MERRA-2: reanalysis global data set

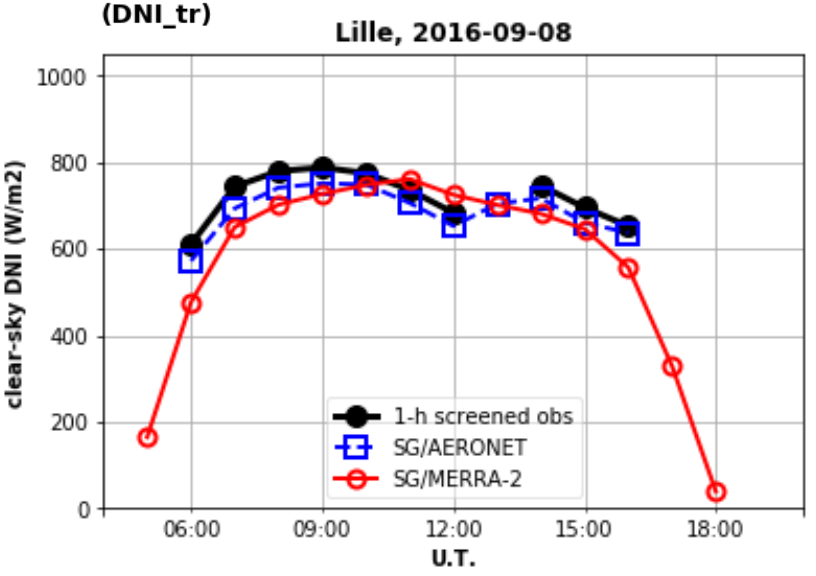
Satisfying agreement with observation made at Lille in 2011



24 W/m2

59 W/m2





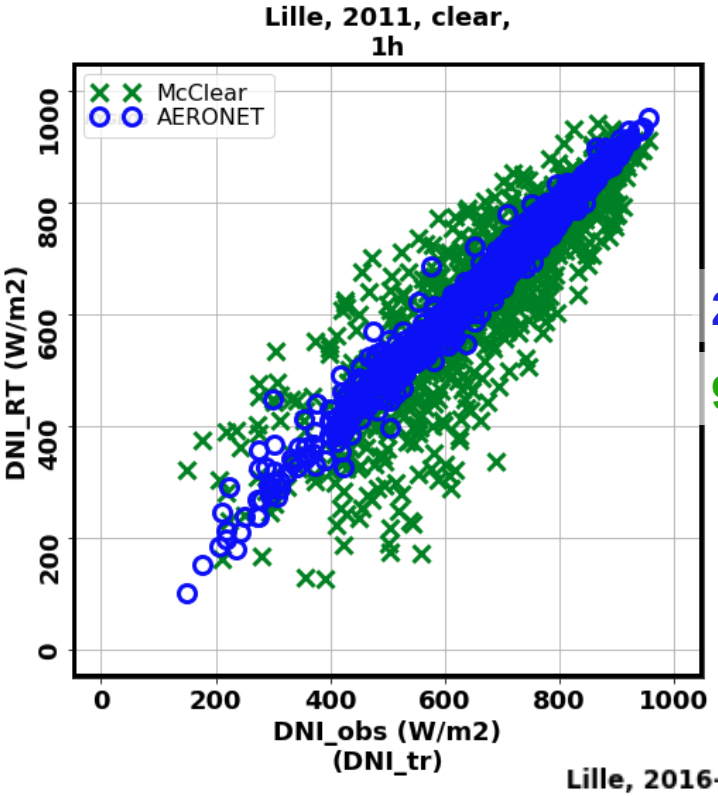
6. Validation

Input data for aerosols: MERRA-2

MERRA-2: global data set

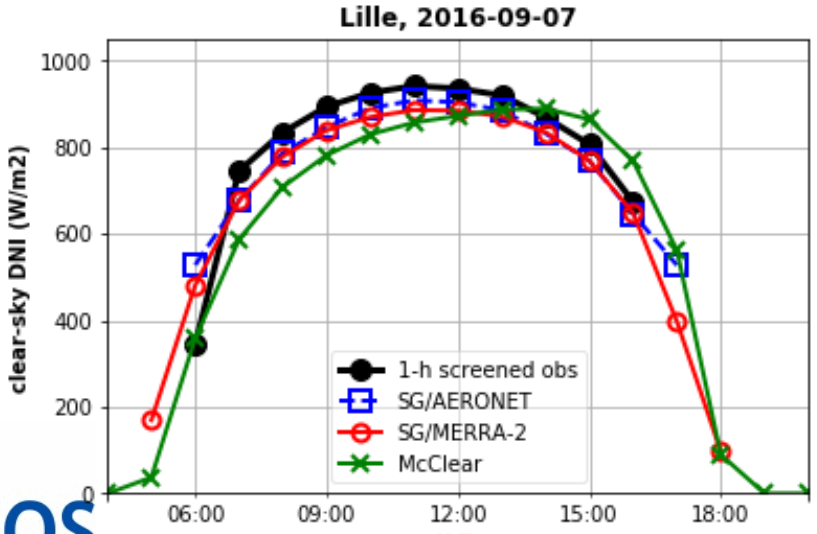
Better agreement by MERRA-2 than by operational products

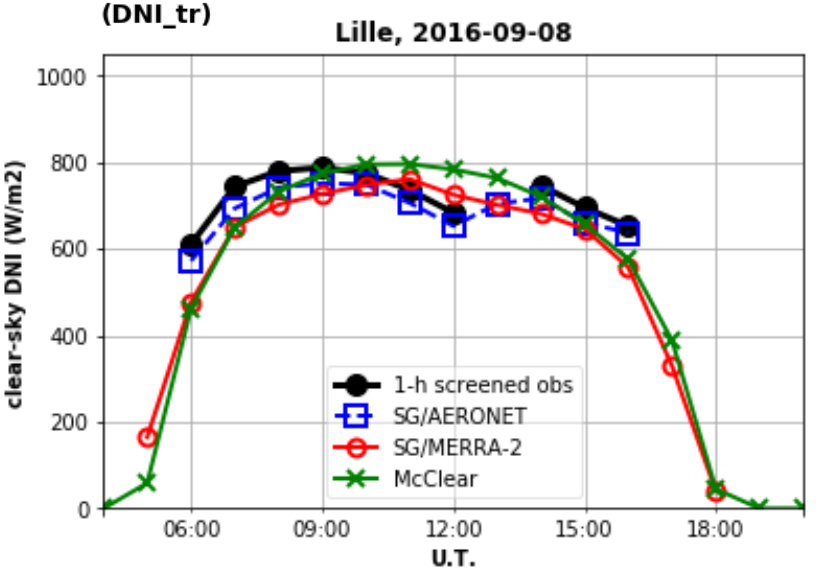
MERRA-2 is validated for aerosols



24 W/m2

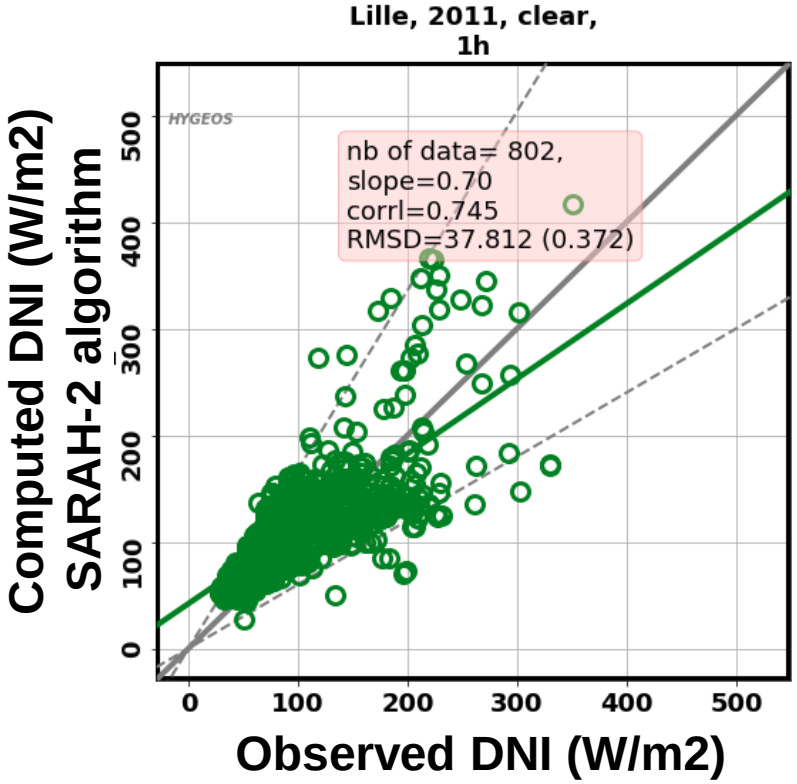
98 W/m2

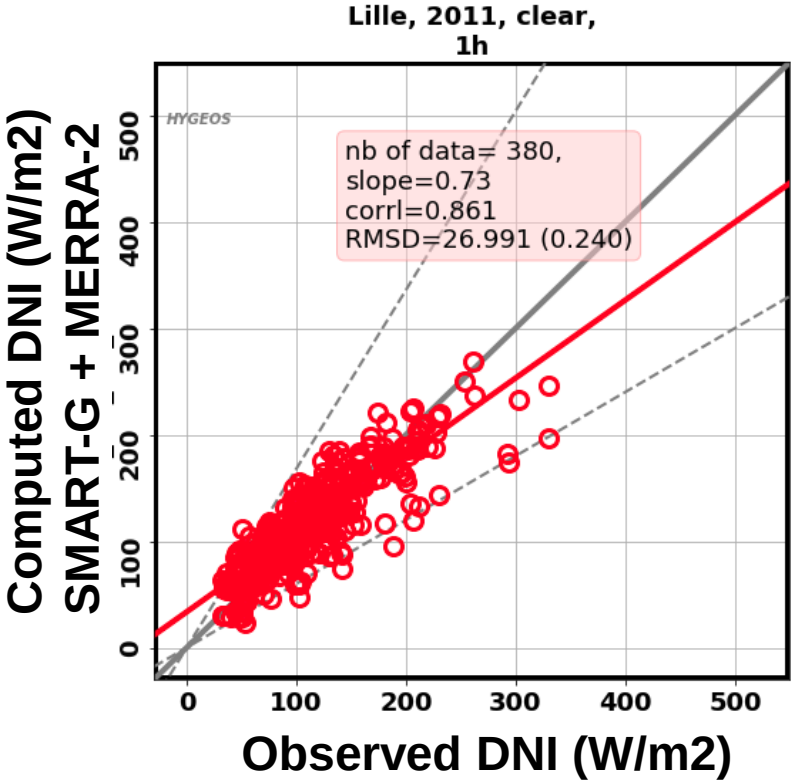




6. Validation

Confirmed in diffuse





GHI → DifHI: 121 (+1) models !

[Abreu et al., 2019]

Best model: Kd = {1+[A(Kt-0.5)2 + B(Kt-0.5) + 1]-n}-1/n

	RMSD (W/m2)	relative (%)
Evora (all-sky):	70	55
Our computations for Lille: (clear-sky in 2011/01-06)	27	24

7. Conclusion and perspectives

Ongoing tests for input data sets for clouds

HYGEOS: radiative transfer in the atmosphere & data sets

For a solar cadastre application:
HYGEOS provides the radiative parameters above the roof layer.
Not only GHI, but also the direct and diffuse components are precisely computed.

Validation of the protocol:
24 W/m2 (4%) difference in DNI between computations and observations in clear-sky conditions at Lille in 2011.

Precision also depends on the input data set:
59 W/m2 in DNI with MERRA-2, 27 W/m2 (24%) in DiffHI,
smaller than with other operational products.

Validation to be done with measurements of GTI

Tests of cloud input data sets