The Heliosat-V versatile method for estimating downwelling surface solar irradiance from satellite imagery

Centre O.I.E.

Observation, Impacts, Energy
(Sophia Antipolis, France)

AUTHORS

Benoît Tournadre (O.I.E)
Benoît Gschwind (O.I.E)
Yves-Marie Saint Drenan (O.I.E)
Philippe Blanc (O.I.E)

PARTNERS

Région Provence-Alpes-Côte d'Azur

CONTACT

benoit.tournadre@mines-paristech.fr
www.oie.mines-paristech.fr

Introduction

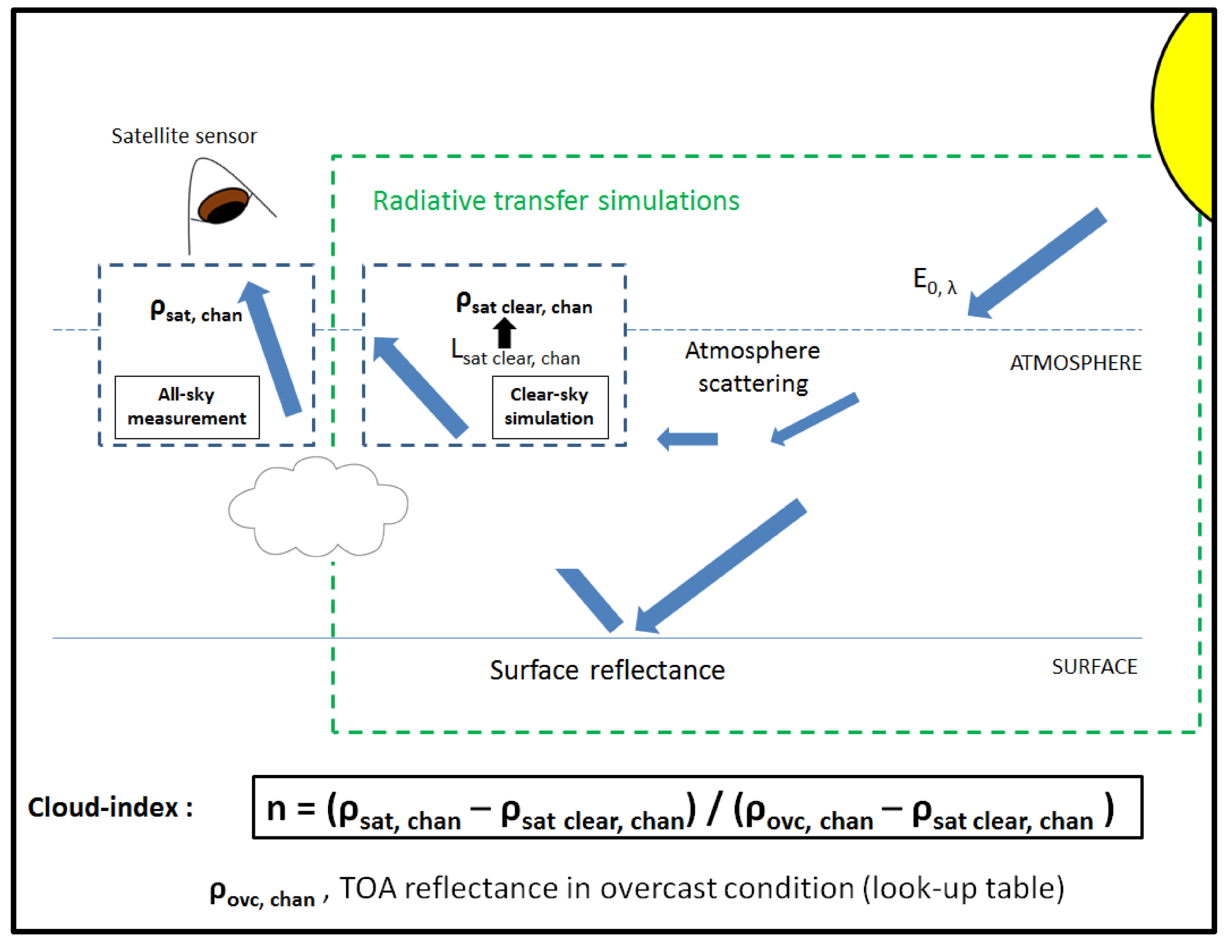
Downwelling surface solar irradiance (DSSI) is considered an Essential Climate Variable by the World Meteorological Organization. Spaceborne instruments have potential to produce estimates of DSSI with a global spatial coverage and hourly+kilometer resolutions.

Heliosat-V (HS-V) is a new method developed to retrieve DSSI from satellite imagery. Its novelty focuses on versatility: HS-V aims at being applied for satellite radiometers on various types of orbits and various spectral sensitivities in the shortwave domain ~[400 nm - 1000 nm].

Methods

HS-V is a cloud-index method relying on a radiative transfer model to simulate clear-sky and overcast reflectances at the top of atmosphere (TOA), as seen by radiometric sensors (resp. noted $\rho_{sat\ clear,\ chan}$ and $\rho_{ovc,\ chan}$). Its general scheme is shown in Fig. 1.

Computations of TOA reflectances (Fig. 3 and 4) are adapted to spectral sensitivities of satellite channels and to solar and viewing geometries.



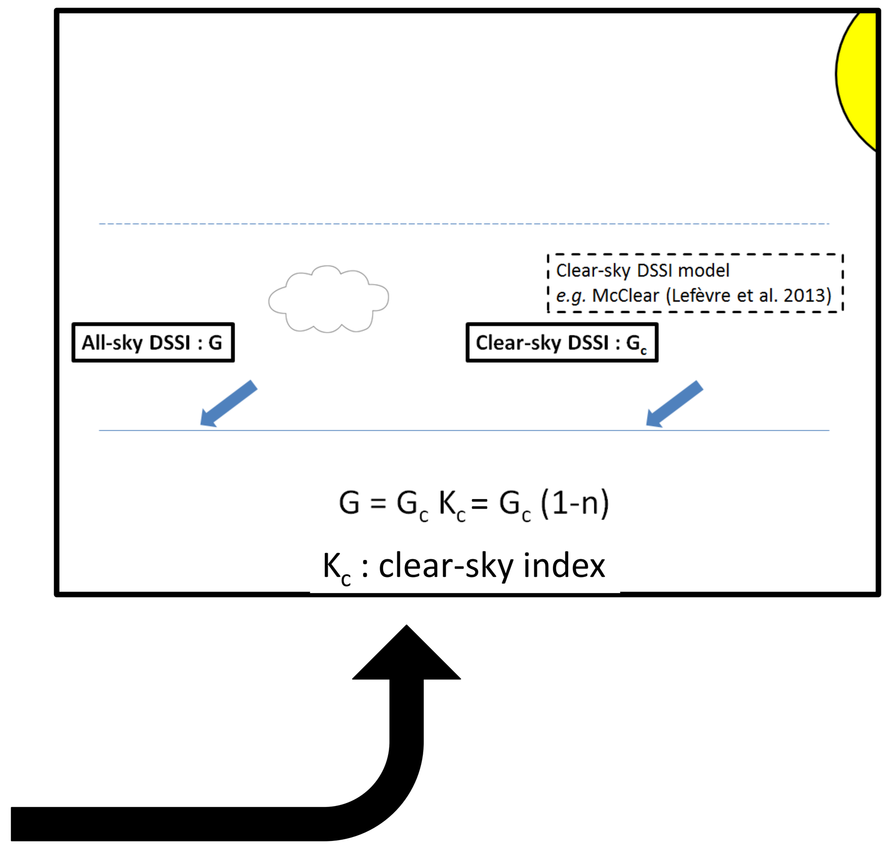


Fig. 1: Description of the method. $L_{sat\ clear,\ chan}$ are simulated clear-sky TOA upwelling radiances. Reflectances ρ_{clear} are derived from $L_{sat\ clear,\ chan}$, considering spectral response functions of the radiometric channel.

The implementation of HS-V is made with libRadtran's *uvspec* model and DISORT solver.

HS-V needs inputs of :

- surface bidirectional reflectance distribution function (BRDF) parameters, here derived from the imagery of the Moderate Resolution Spectroradiometer (MODIS) aboard Terra and Aqua satellites (product MCD43C1 v6) ; the anisotropy of ground reflectance is estimated by the Ross-Li BRDF model.
- Aerosol optical depth (AOD), water vapour and O_3 atmospheric total columns, here provided by CAMS and ECMWF ;
- Clear-sky surface irradiance, here from McClear model (Lefevre et al., 2013)

Results

We apply HS-V on Meteosat Second Generation (Meteosat-9) visible imagery for the year 2011 and its results are compared with operational DSSI products HelioClim3 (HC3) and CAMS-Radiation Service (CAMS-RAD) (Table 1). Reference DSSI data come from 11 ground stations of the Baseline Surface Radiation Network (BSRN, Fig. 2 and Table 1).

→ Quality similar to operational products can be reached without the need for satellite archive.

→ Better results with 0.6 µm channel than 0.8 µm as expected: less reflective clear-sky scenes (better contrast with overcast scenes), less atmospheric absorption (H_2O band in 0.8µm channel, Fig. 4)

→ Next objectives:

- ➢ Improve the LUT for overcast reflectances
- ➢ apply the method to the imagery of other sensors (different channels and time-dependent viewing geometries)
- ➢ Explore the potential for long time series with BRDF and atmosphere climatologies or reanalyses.

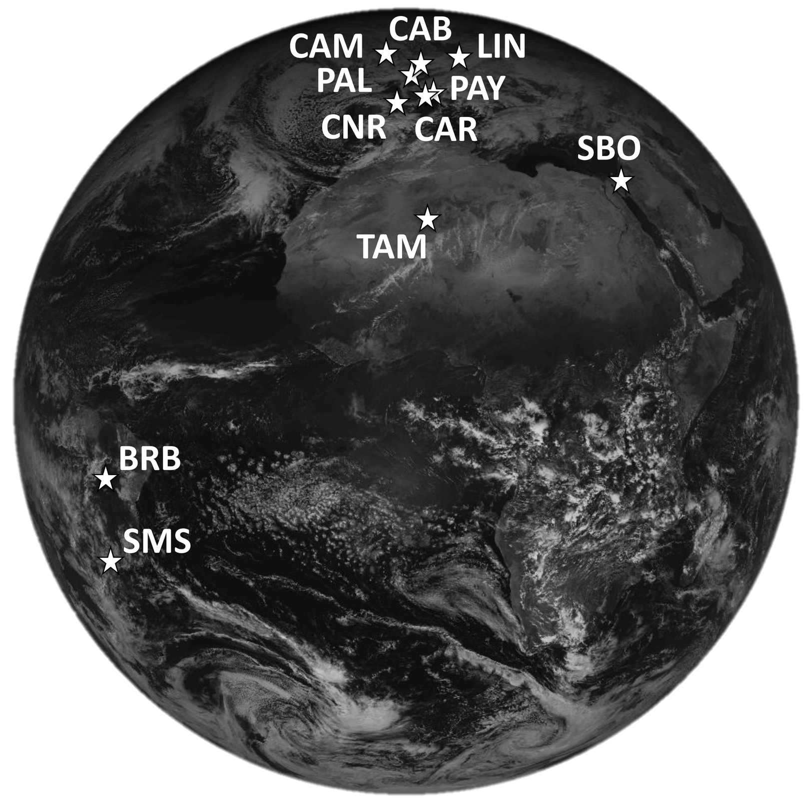


Fig. 2: Locations considered for comparisons between measurements and simulations, here shown with a Meteosat/SEVIRI/0.6 µm picture as a background

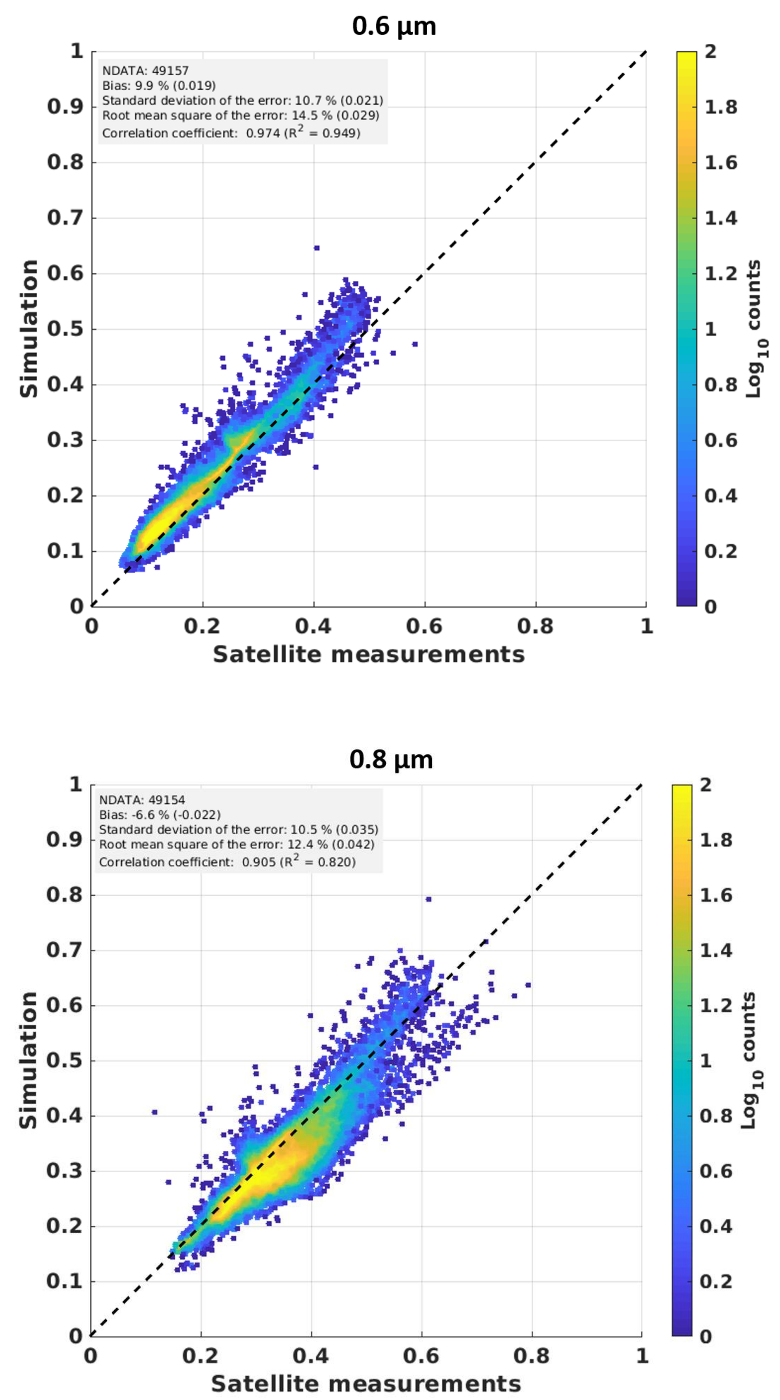


Fig. 3: 2D-histograms of satellite clear-sky reflectances at the top of the atmosphere $\rho_{sat\ clear,\ chan}$ for Meteosat-9 VIS1 and VIS2 channels (all 11 BSRN-station locations)

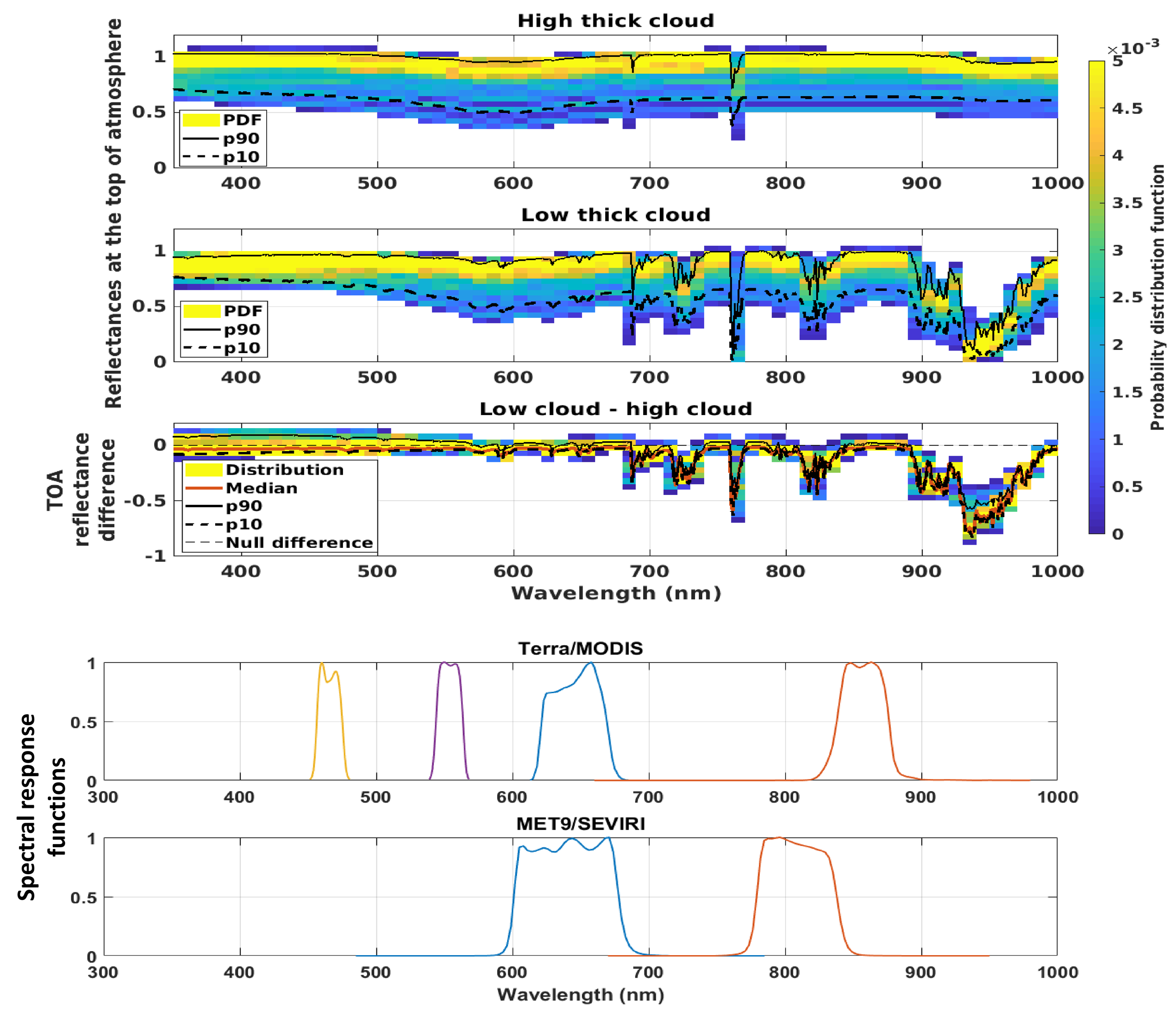


Fig. 4: First two rows : 2D-histograms showing distribution of ρ_{ovc} look-up tables (LUT) for different viewing geometries (solar zenith angle fixed at 30°). Third row: differences of ρ_{ovc} for low and high thick liquid clouds. Last two rows: spectral response functions for channels of satellite data used in this study. (PDF : probability density function)

Fig. 5: 2D-histograms of Heliosat-V DSSI estimates vs. 15-min averaged BSRN measurements (2011). All 11 stations merged.

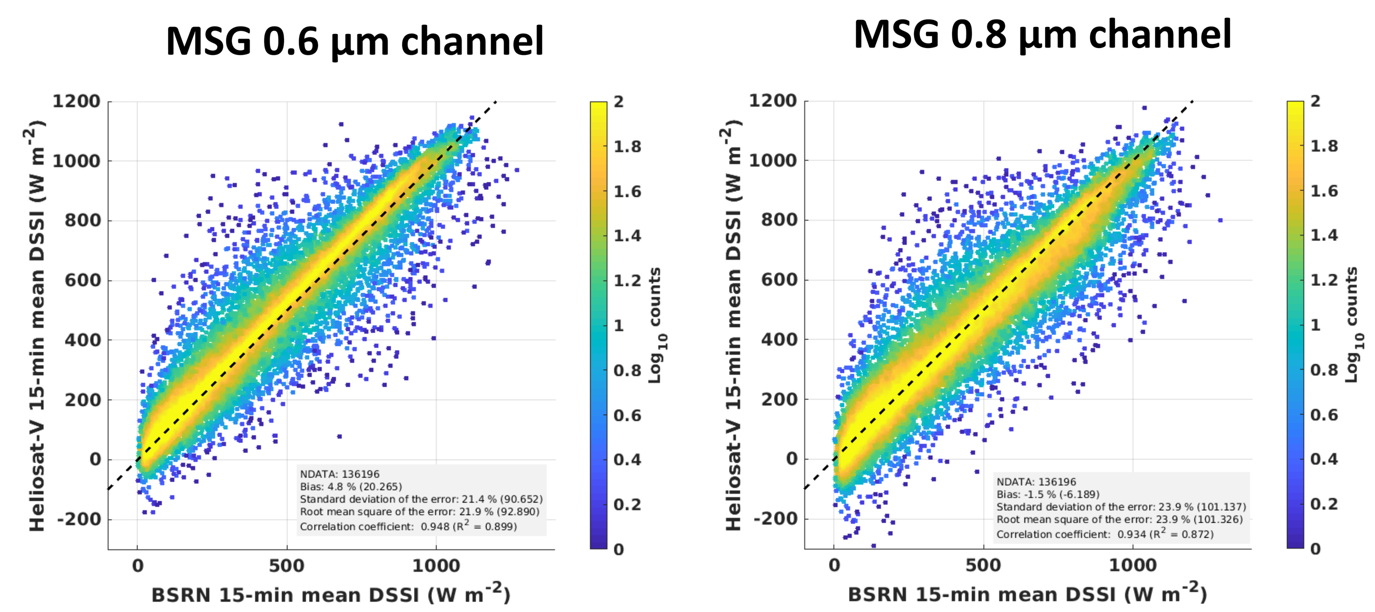


Table 1: Statistics for satellite-based GHI estimates vs. BSRN measurements (15-min averages, year: 2011)

Satellite-based DSSI product		Mean bias error (W m⁻² (%))	Standard deviation of the error (W m⁻² (%))	Root mean square of the error (W m⁻² (%))	Correlation coefficient R
Heliosat-V (this study)	MSG 0.6 µm	20.27 (4.8 %)	90.65 (21.4 %)	92.89 (21.9 %)	0.948
	MSG 0.8 µm	-6.19 (-1.5 %)	101.14 (23.9 %)	101.33 (23.9 %)	0.934
CAMS-RAD		0.10 (0.0 %)	98.14 (23.1 %)	98.14 (23.1 %)	0.937
HelioClim3 v5		1.55 (0.4 %)	87.95 (20.7 %)	87.96 (20.7 %)	0.950

References

Emde et al.: The libRadtran software package for radiative transfer calculations (version 2.0.1), *Geosci. Model Dev.*, 2016

Hess et al.: Optical Properties of Aerosols and Clouds: The Software Package OPAC, *Bull. Am. Meteorol. Soc.*, 1998

Lefevre et al.: McClear: a new model estimating downwelling solar radiation at ground level in clear-sky conditions, *Atmospheric Meas. Tech.*, 2013

Schaaf, C., Wang, Z., 2015, MCD43A1 MODIS/Terra+Aqua BRDF/Albedo Model Parameters Daily L3 Global - 500m. V006. NASA EOSDIS Land Processes DAAC, USGS Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov), last accessed March 18, 2019, at http://dx.doi.org/10.5067/MODIS/MCD43A1.006

Stamnes et al.: DISORT, a General-Purpose Fortran Program for Discrete-Ordinate-Method Radiative Transfer in Scattering and Emitting Layered Media: Documentation of Methodology, Tech. rep., Dept. of Physics and Engineering Physics, Stevens Institute of Technology, Hoboken, NJ 07030, 2000

Tournadre, Gschwind, Saint-Drenan, Wald & Blanc: Heliosat-V: a versatile method for estimating downwelling surface solar irradiance from satellite imagery. Part 1: methodology and preliminary validation, *Atmos. Chem. Phys., in preparation*, 2020.

Baseline Surface Radiation Network (BSRN) data: https://bsrn.awi.de/

Copernicus Atmosphere Monitoring Service (CAMS) data: https://atmosphere.copernicus.eu/

European Centre for Medium-range Weather Forecasts (ECMWF) data: https://www.ecmwf.int/

Meteosat-9 data are provided by EUMETSAT, https://www.eumetsat.int

EGU 2020: Sharing Geoscience Online
2020/05/06

The versatile Heliosat-V method for estimating downwelling surface solar irradiance with satellite imagery

PhD supervised by Philippe Blanc and co-advised by Benoît Gschwind
Observation, Impacts, Energy center (O.I.E.)

Funded by

Benoît Tournadre

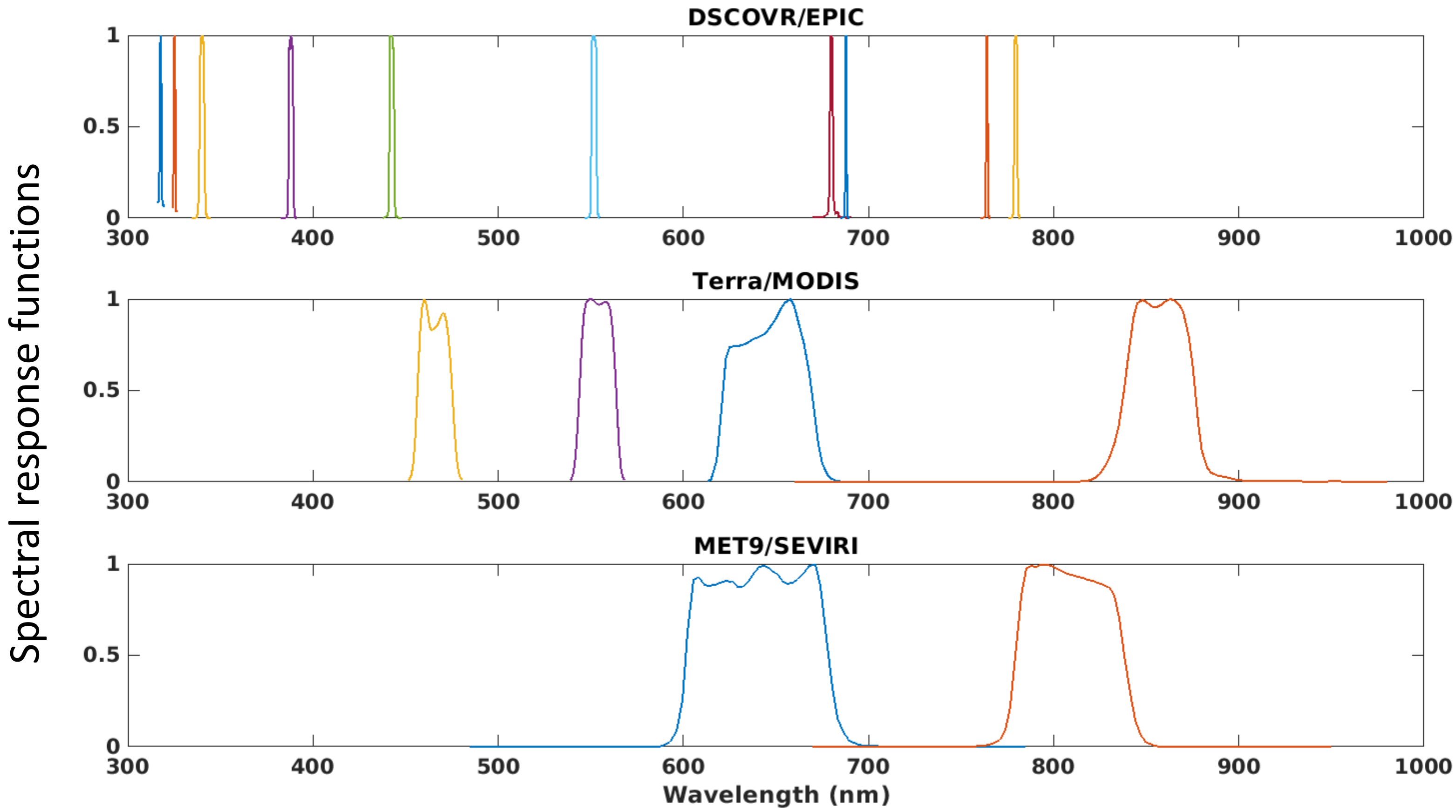
EGU 2020

2020/05/06

We need several satellites to estimate downwelling surface solar irradiance (or global horizontal irradiance, GHI) with ~kilometric and ~hourly resolutions + global coverage on long historic periods.

What are constraints that avoid homogeneous information?

- Differents sensors ➔ different spectral sensitivities

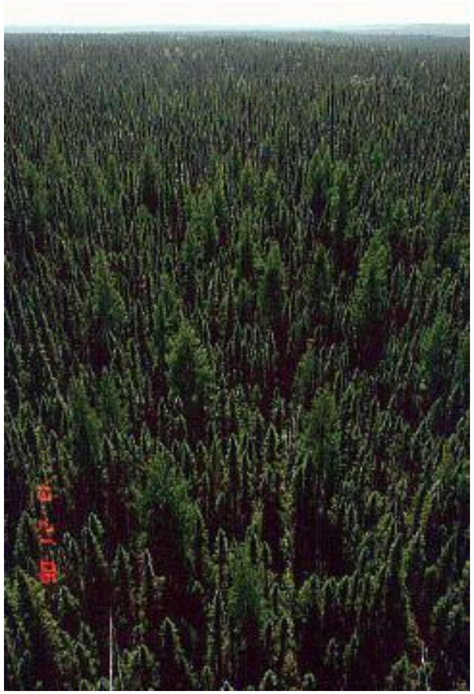


What are constraints that avoid homogeneous information?

- Different viewing geometries : anisotropy of the Earth's reflectance has to be taken into account.

What are constraints that avoid homogeneous information?

- Different viewing geometries : anisotropy of the Earth’s reflectance has to be taken into account.



Credit: Don Deering

GOES-East (0.6 um)
00:00 UTC (around 4 pm in mean solar time, 2020/02/25)

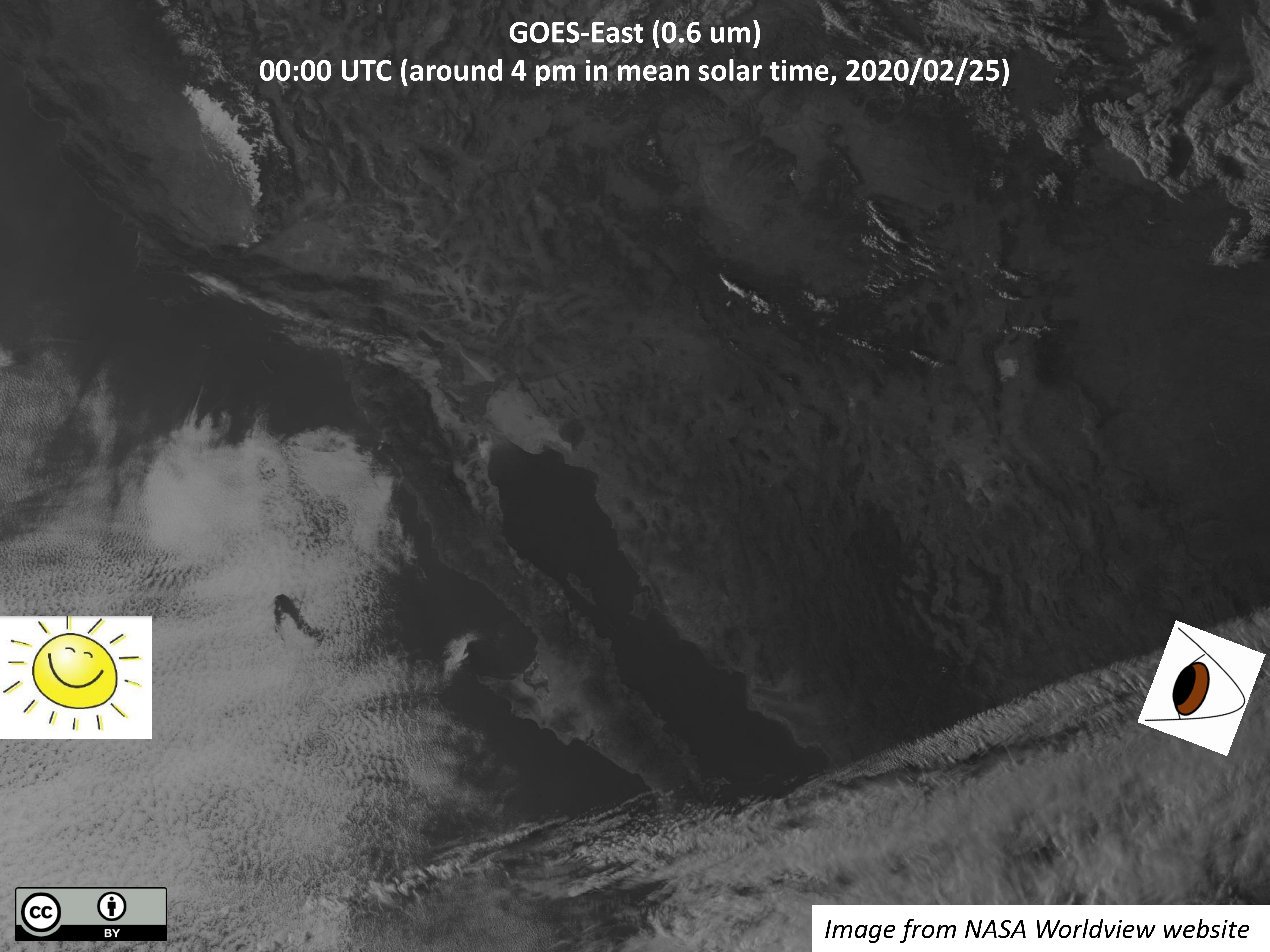


Image from NASA Worldview website

GOES-West (0.6 um)
00:00 UTC (around 4 pm in mean solar time, 2020/02/25)

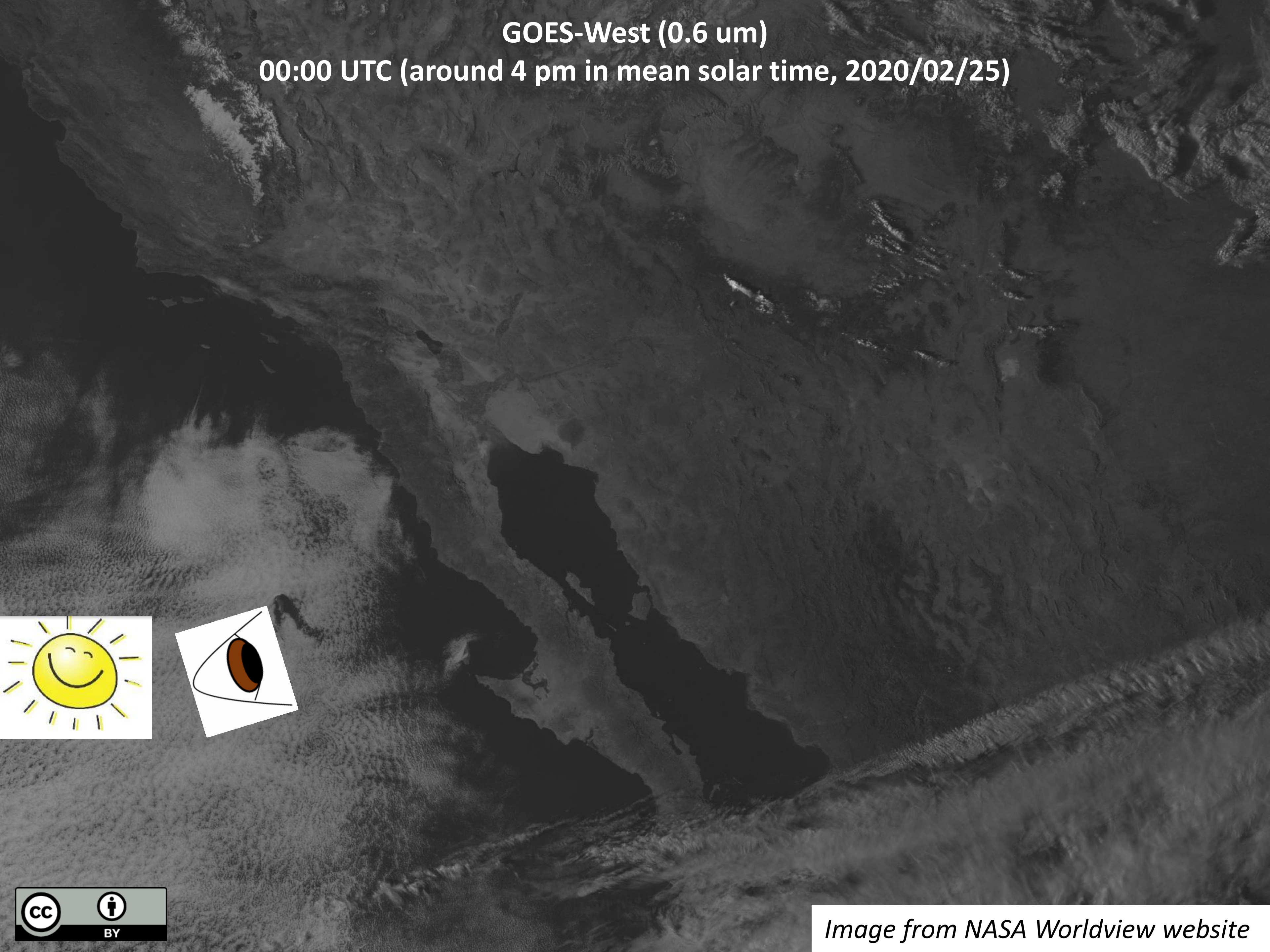
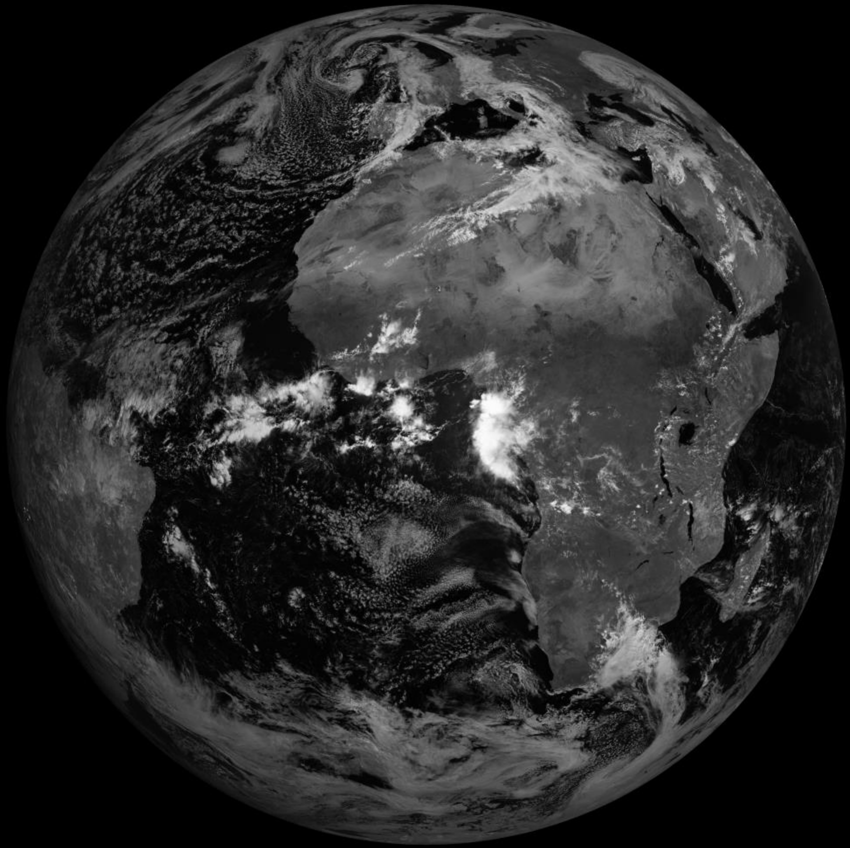
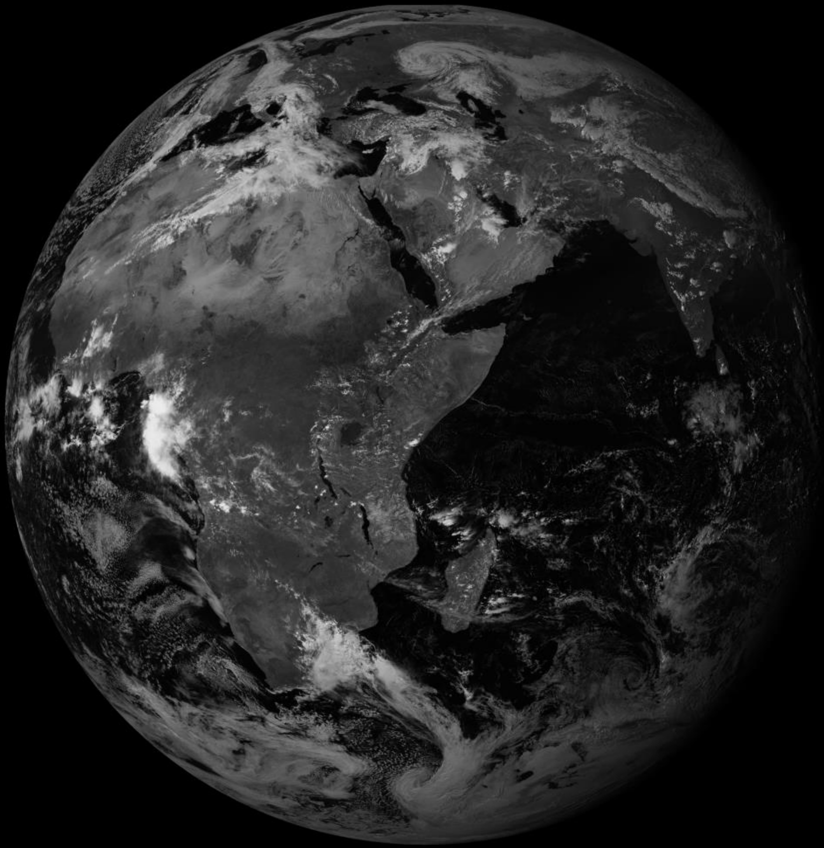


Image from NASA Worldview website

Meteosat
Prime

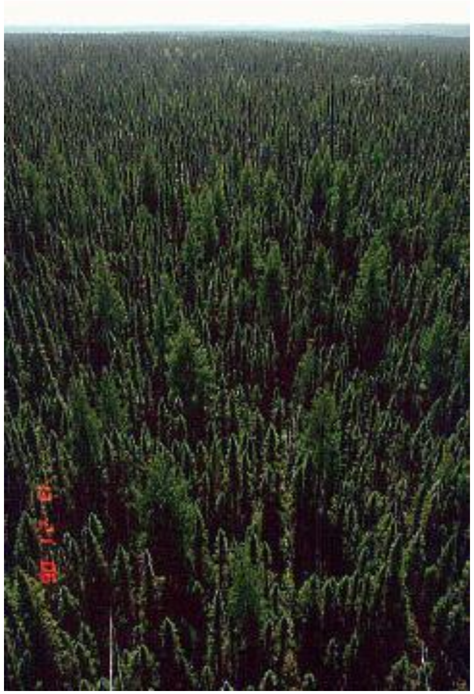


Meteosat
IODC



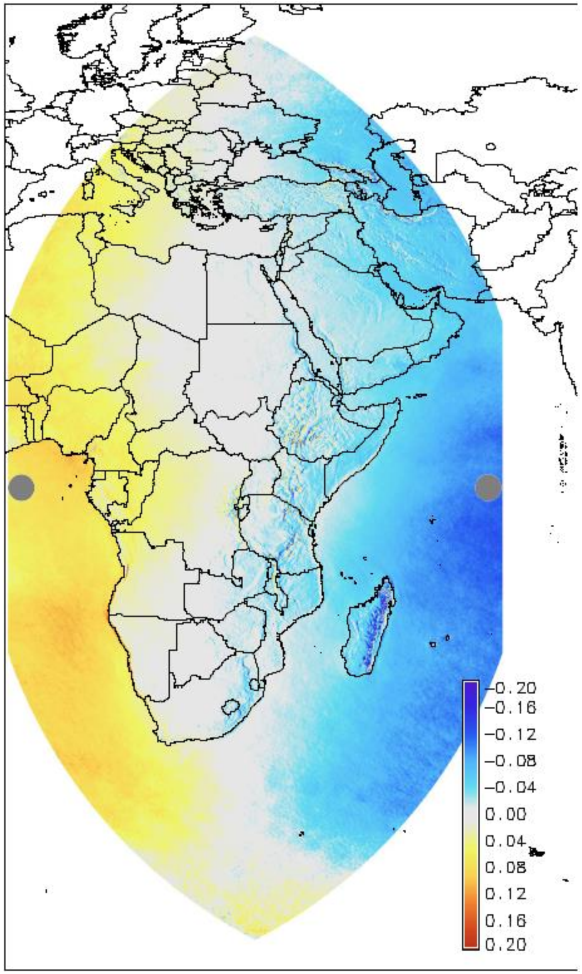
What are constraints that avoid homogeneous information?

- Different viewing geometries : anisotropy of the Earth's reflectance has to be taken into account.



Credit: Don Deering

$$\frac{G_0 - G_{63E}}{G_0} \longrightarrow$$



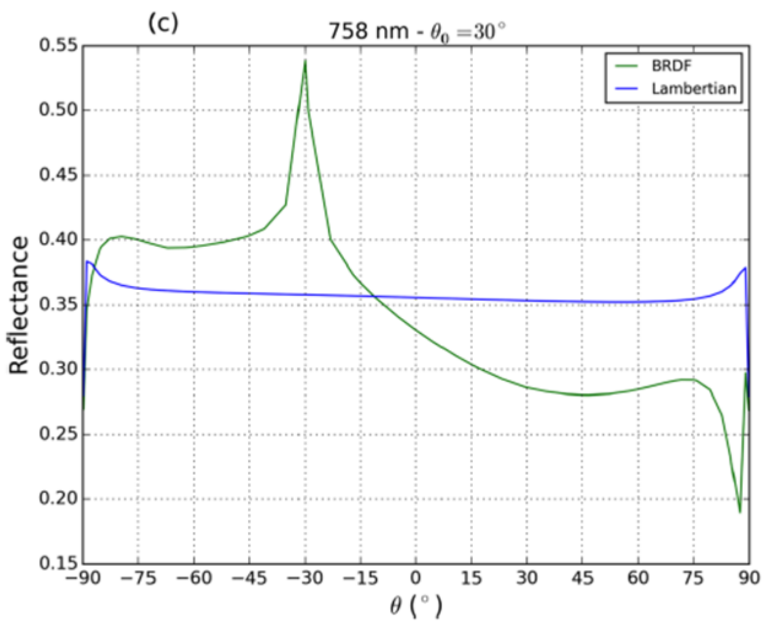
Disrepancies between annual mean surface irradiance from SARAH (Meteosat Prime, G_0) and SARAH-East (Meteosat IODC, G_{63E})

in [Amillo *et al.*, 2014]

What are constraints that avoid homogeneous information?

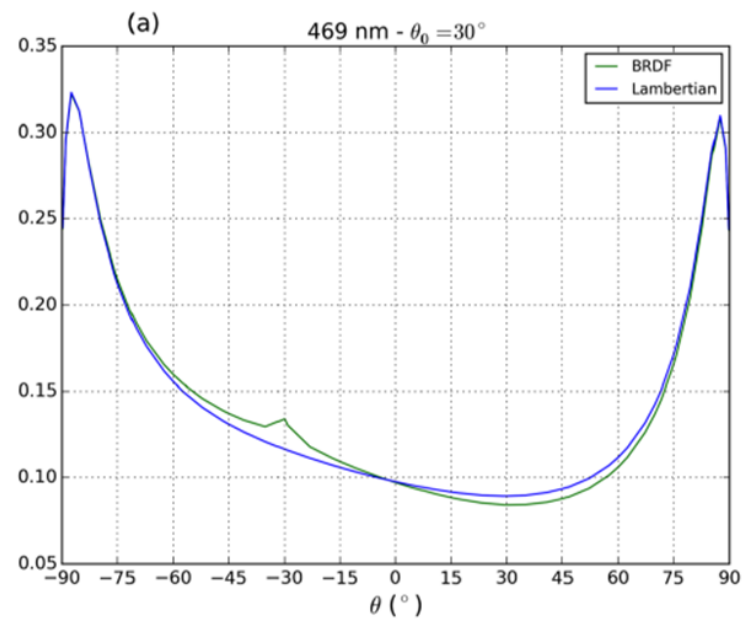
- Different viewing geometries : anisotropy of the Earth's reflectance has to be taken into account.

758 nm : weak atmospheric scattering



Viewing zenithal angle

469 nm : strong atmospheric scattering



Viewing zenithal angle

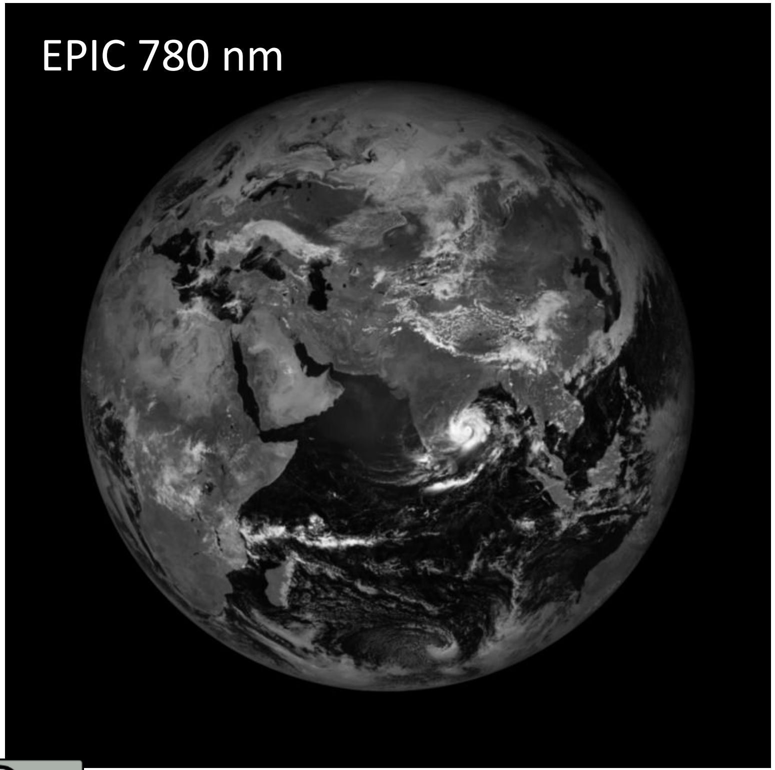
(principal plane)

in [Lorente *et al.*, 2018]

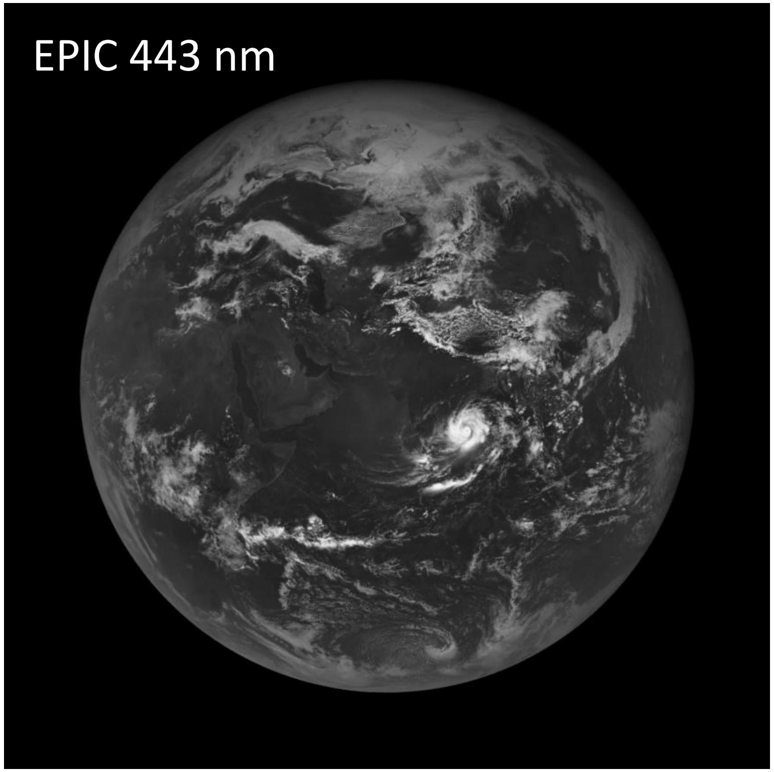
What are constraints that avoid homogeneous information?

- Different viewing geometries : anisotropy of the Earth's reflectance has to be taken into account.

758 nm : weak atmospheric scattering



469 nm : strong atmospheric scattering



Heliosat-V objective :

Deal with those different satellites

+ 1 instant
+ 1 location (1 pixel)
+ 1 spectral channel
+ 1 satellite viewing geometry

➡

1 GHI estimate

Cloud-index methods

$$G = G_c \, K_c$$

G : all-sky GHI

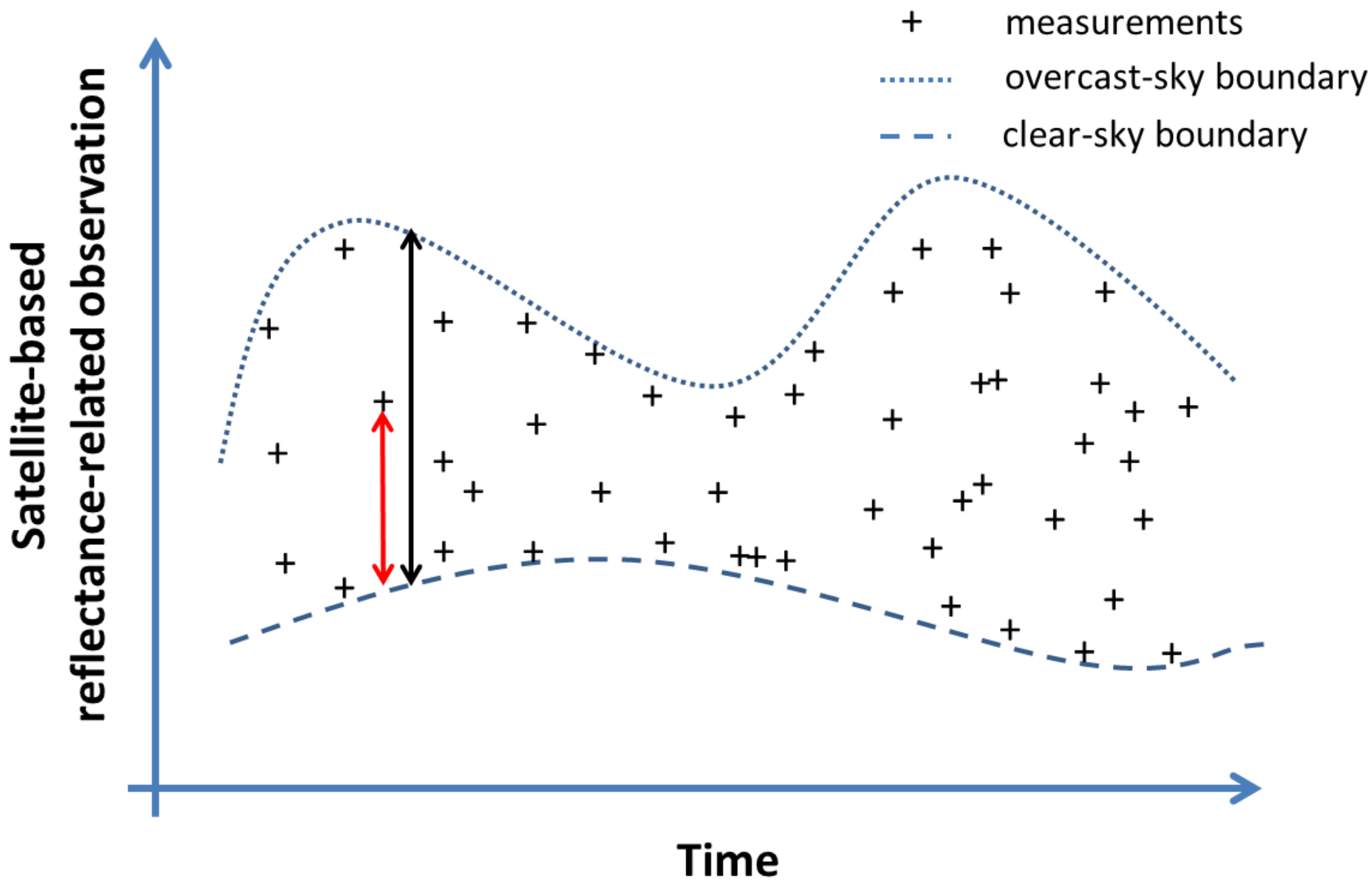
G_c : clear-sky GHI

K_c : clear-sky index

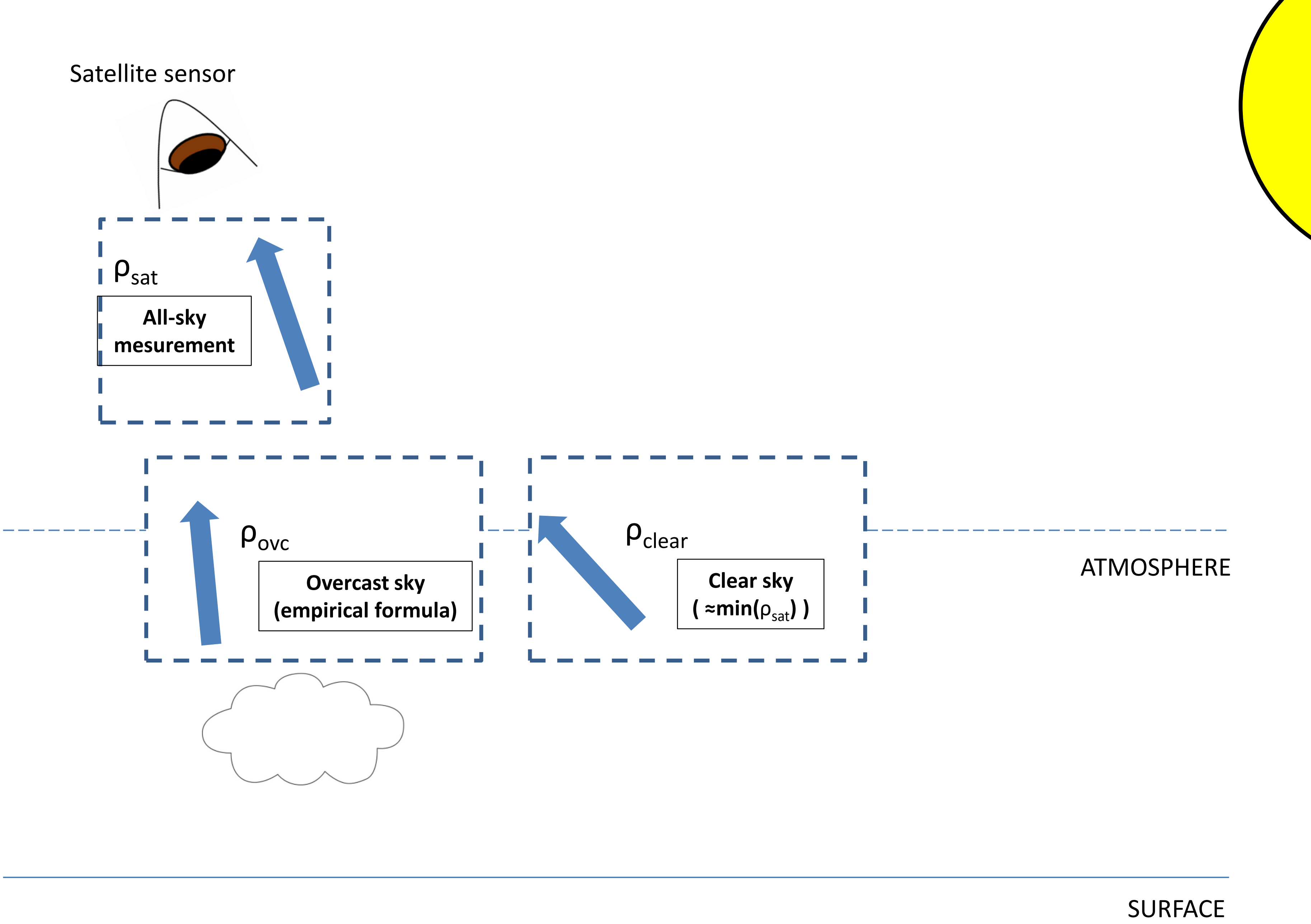
$$K_c = 1\text{-}n$$

n : cloud index

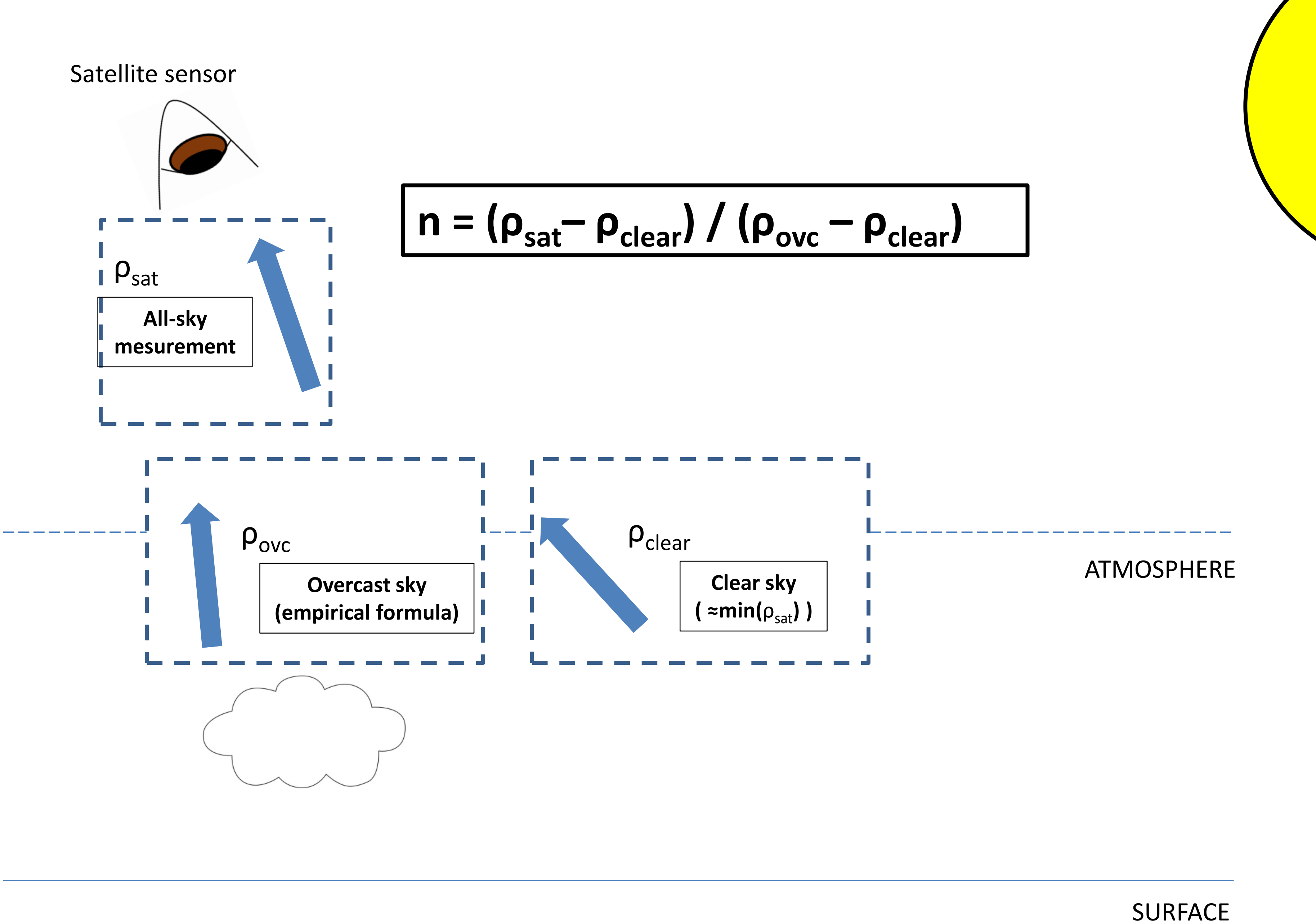
The principle of a cloud-index based method



The cloud index is the ratio between the distances
"measurement to clear-sky“ (red arrow) and "overcast-sky to clear-sky" (black arrow)


Satellite sensor
ρ_{sat}
All-sky mesurement
ρ_{ovc}
Overcast sky (empirical formula)
ρ_{clear}
Clear sky (≈min(ρ_{sat}))
ATMOSPHERE
SURFACE

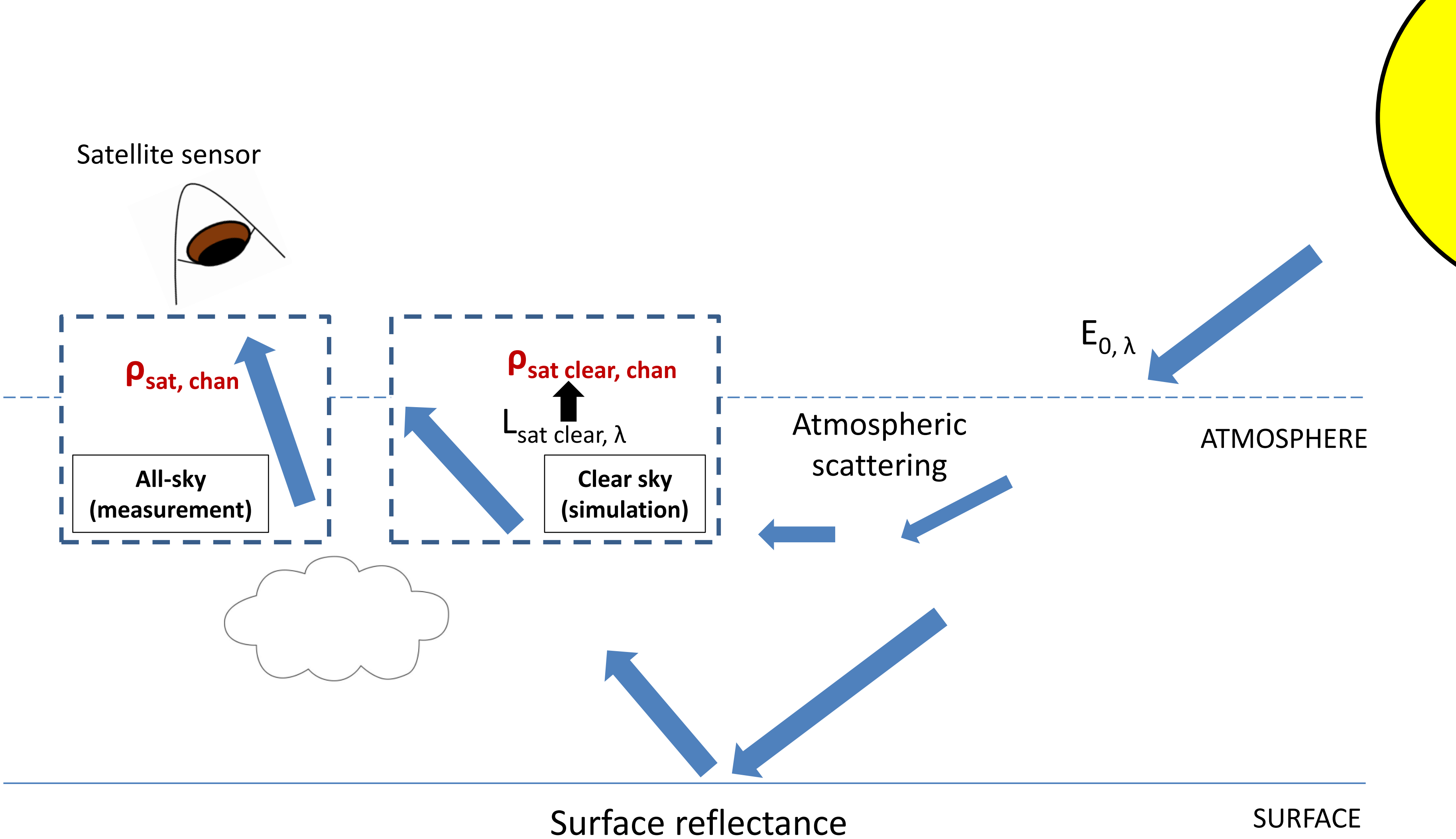
$$n = (\rho_{sat} - \rho_{clear}) / (\rho_{ovc} - \rho_{clear})$$



Questions

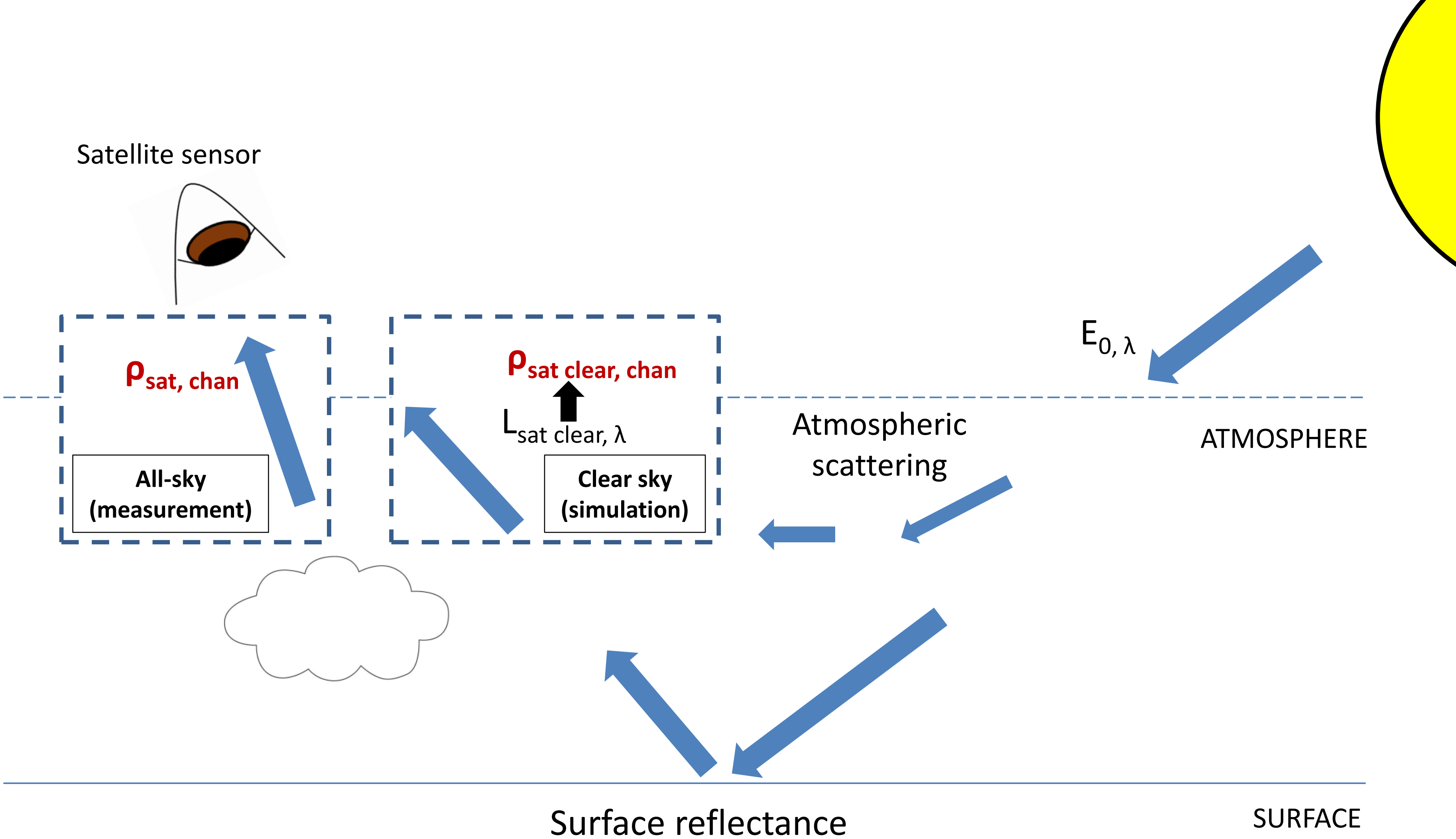
Is it possible to adapt the cloud-index approach to various viewing geometries and different spectral sensitivites?

Can we do that without the need for archives that leads to drift issues in clear-sky reflectances estimates at the top of the atmosphere?



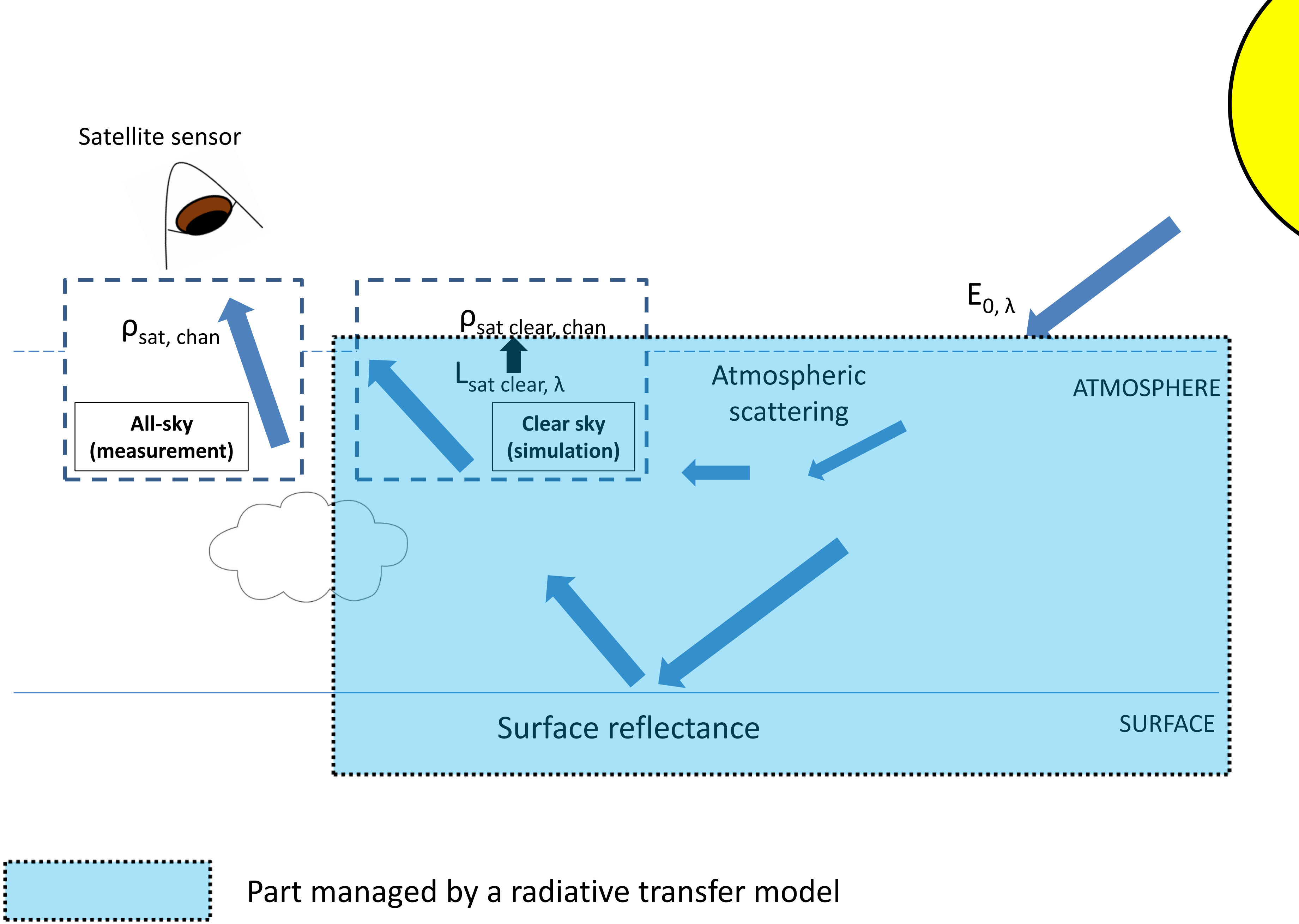
$$n = (\rho_{sat,\ chan} - \rho_{sat\ clear,\ chan}) / (\rho_{ovc,\ chan} - \rho_{sat\ clear,\ chan})$$

$\rho_{ovc,\ chan}$, TOA reflectance in overcast conditions for a given spectral channel

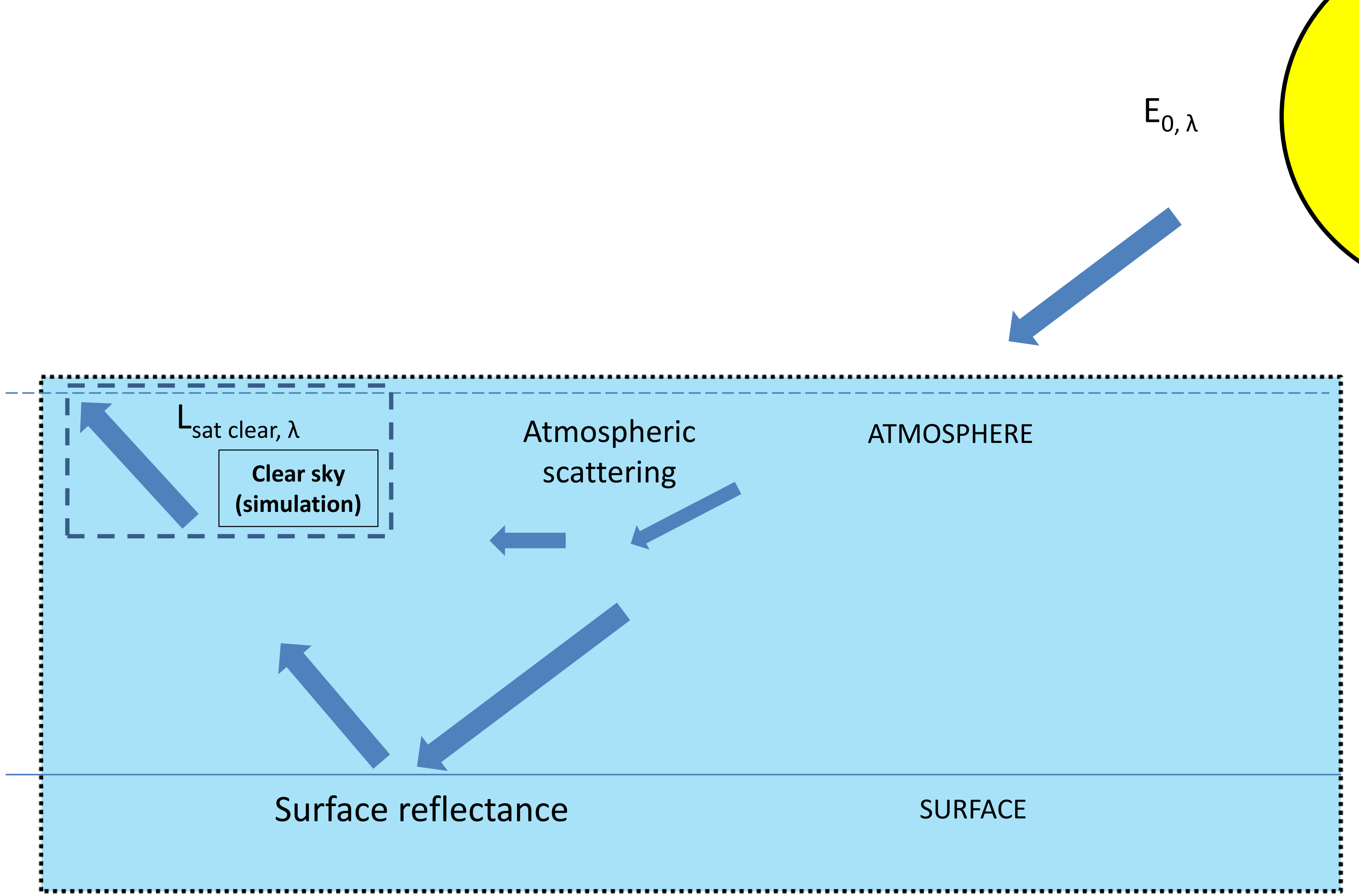


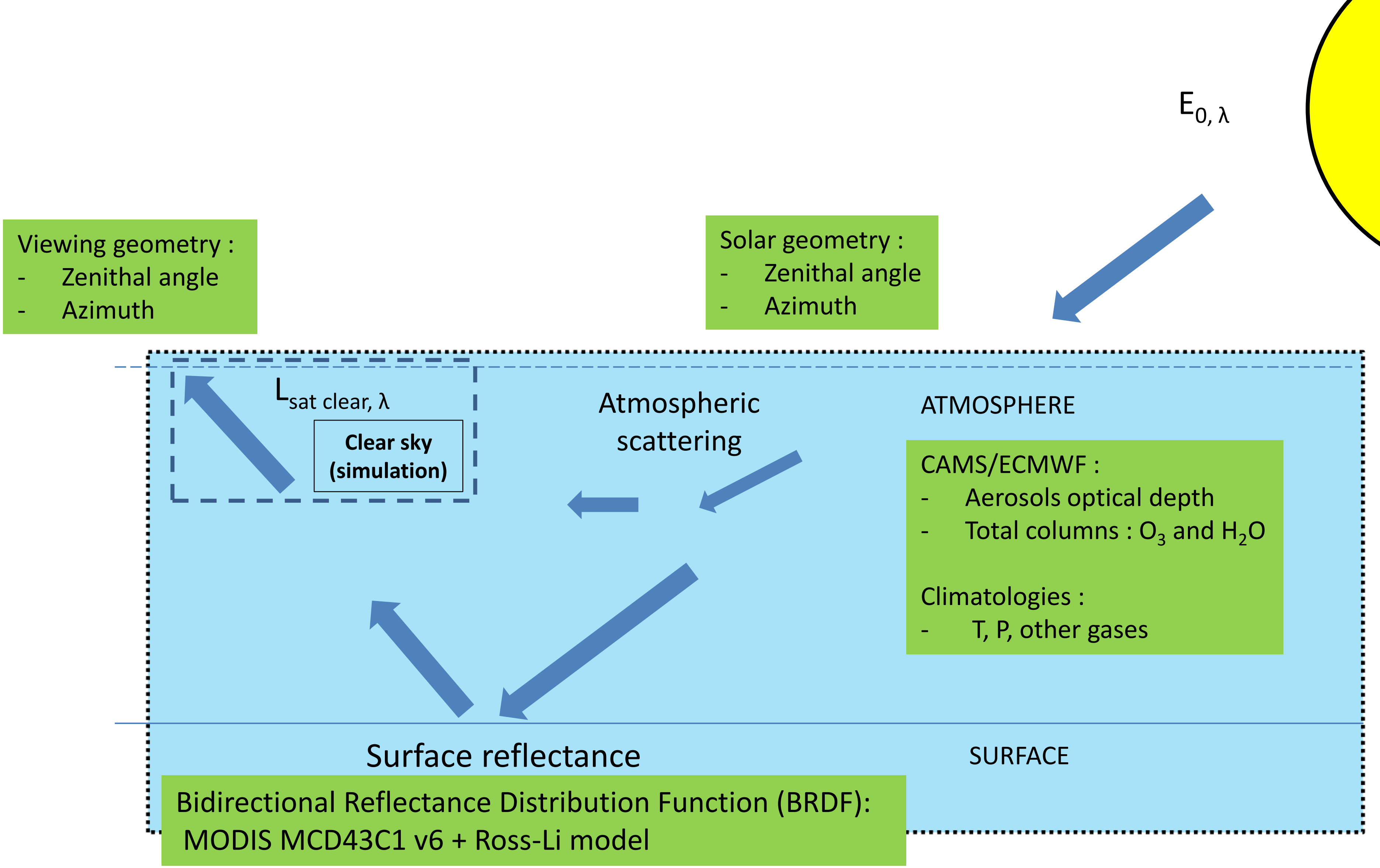
$$n = (\rho_{sat,\ chan} - \rho_{sat\ clear,\ chan}) / (\rho_{ovc,\ chan} - \rho_{sat\ clear,\ chan})$$

$$\longrightarrow \quad K_c = 1 - n$$



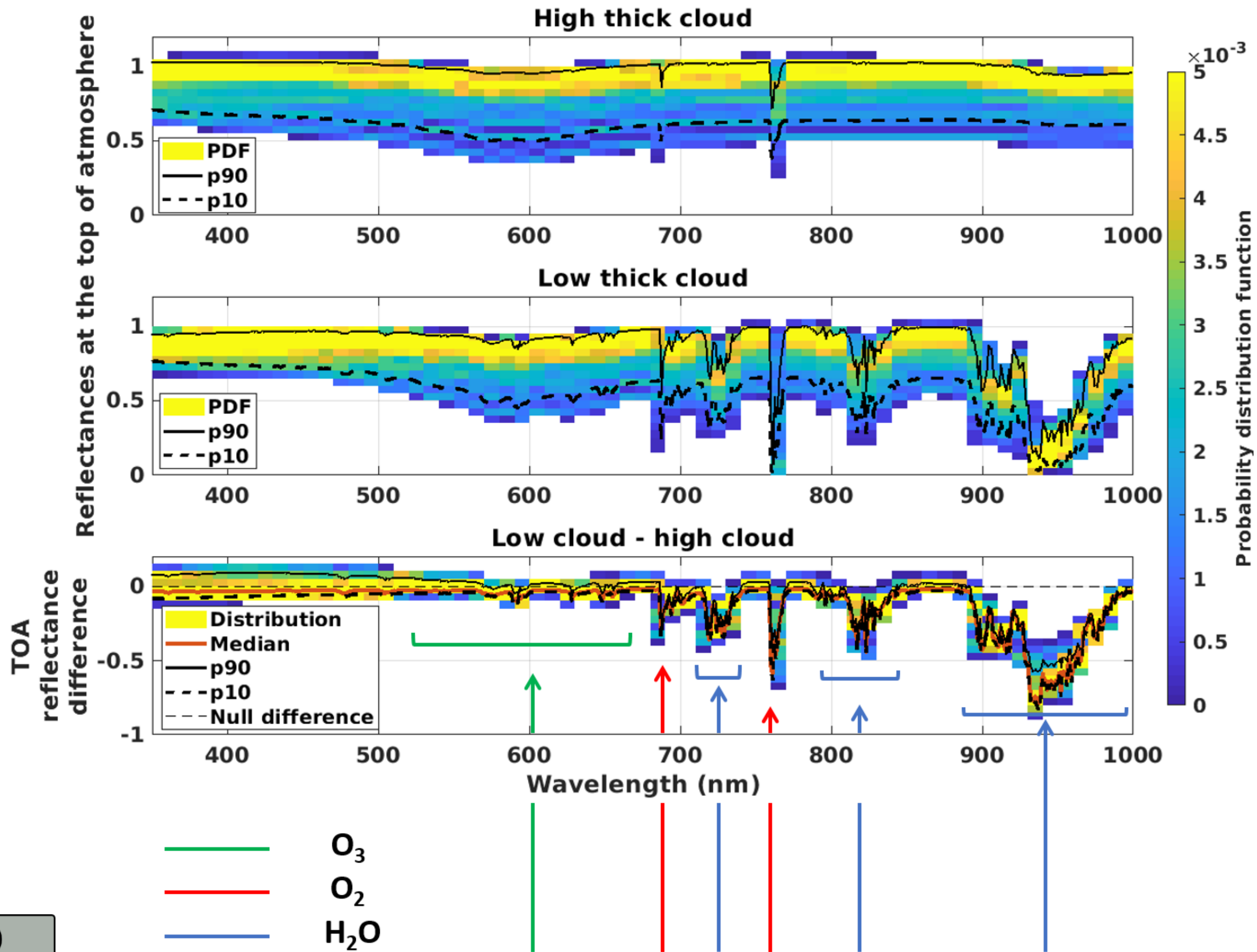
Satellite sensor
ρsat, chan
All-sky
(measurement)
ρsat clear, chan
Lsat clear, λ
Clear sky
(simulation)
E0, λ
Atmospheric
scattering
ATMOSPHERE
Surface reflectance
SURFACE
Part managed by a radiative transfer model


$E_{0,\lambda}$
$L_{sat\ clear,\lambda}$
Clear sky
(simulation)
Atmospheric
scattering
ATMOSPHERE
Surface reflectance
SURFACE

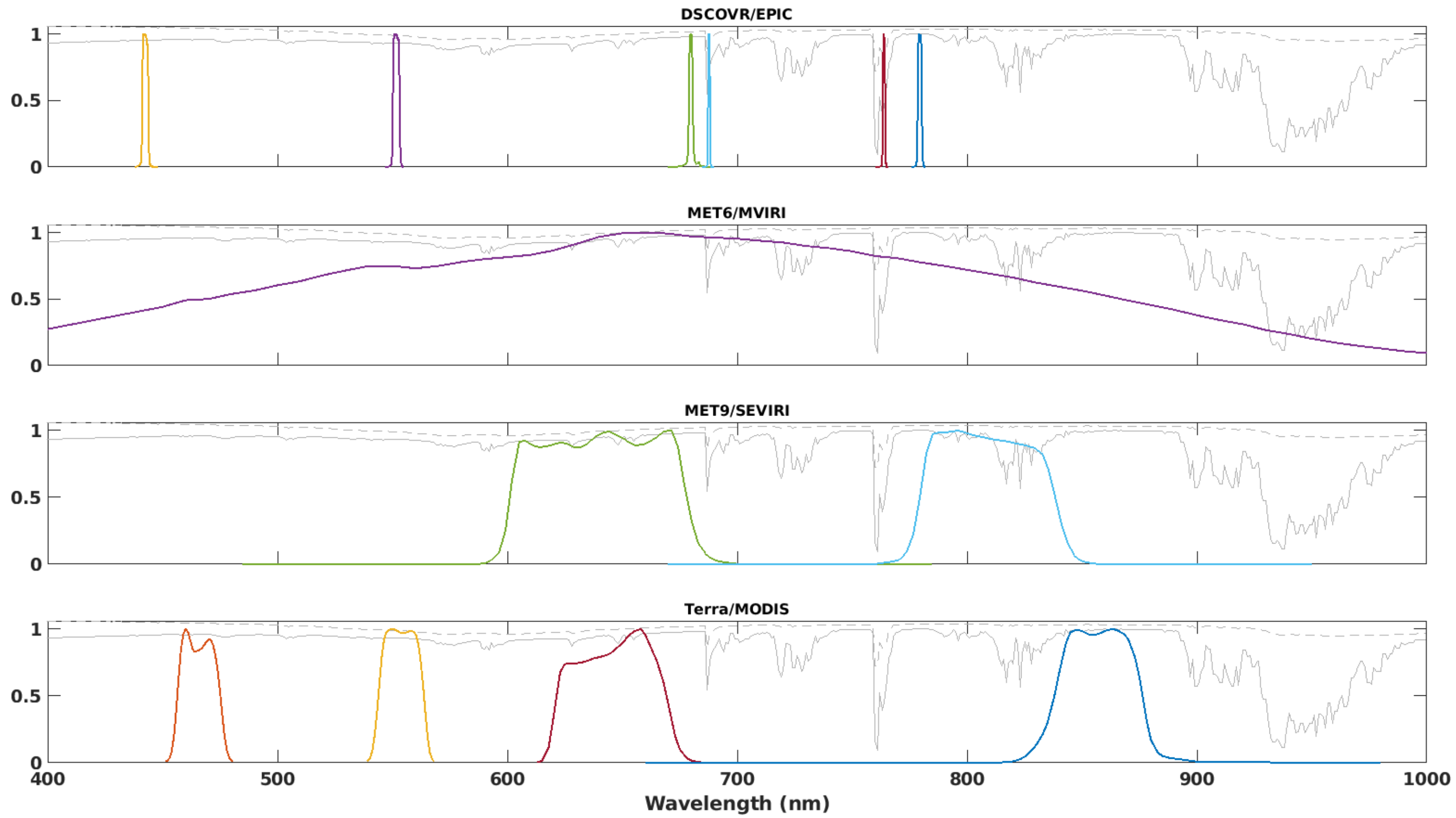


$E_{0, \lambda}$
Viewing geometry :
- Zenithal angle
- Azimuth
Solar geometry :
- Zenithal angle
- Azimuth
$L_{sat\ clear, \lambda}$
Clear sky (simulation)
Atmospheric scattering
ATMOSPHERE
CAMS/ECMWF :
- Aerosols optical depth
- Total columns : O_3 and H_2O
Climatologies :
- T, P, other gases
Surface reflectance
SURFACE
Bidirectional Reflectance Distribution Function (BRDF):
MODIS MCD43C1 v6 + Ross-Li model

Look-up table of overcast-sky spectral reflectances at the top of the atmosphere for different viewing and solar geometries (here, solar zenith angle = 30°). Cloud optical thickness = 150.



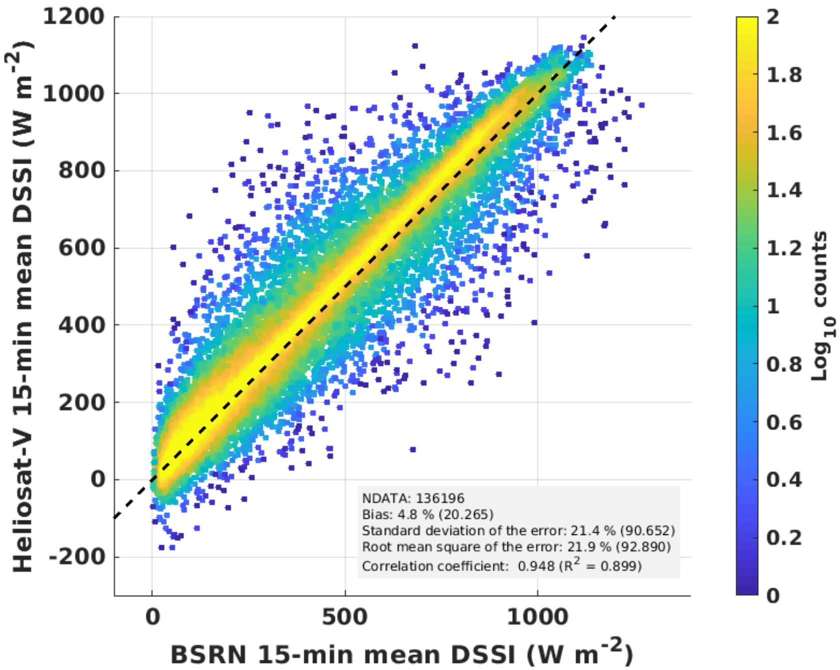
→ Avoid spectral bands with H_2O or O_2 absorption to get rid of cloud top height effects on TOA reflectances.



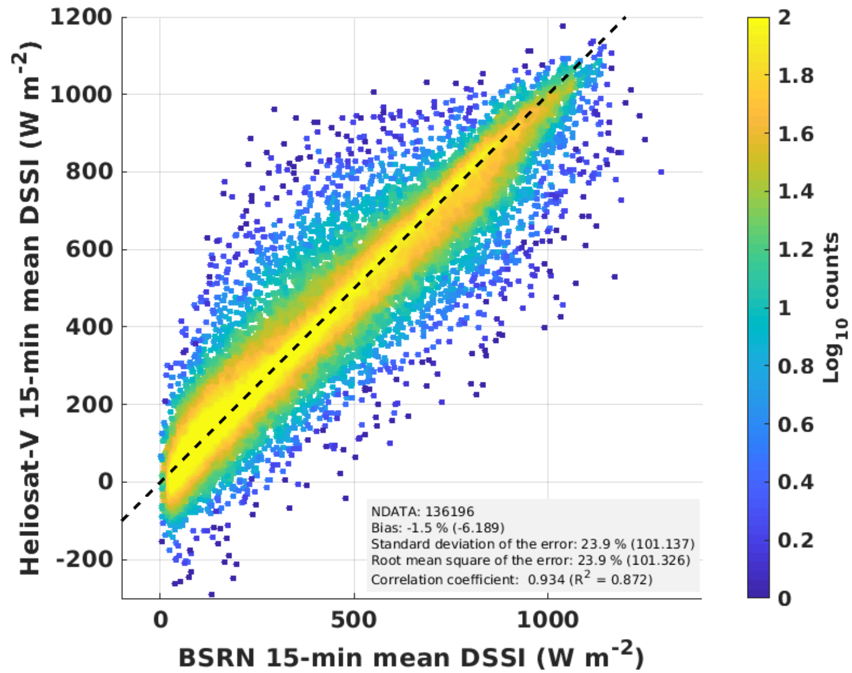
Color lines: spectral response functions of various satellite radiometric channels.
Grey dashed line: reflectance at the TOA for a high thick cloud (15 km)
Grey full line: reflectance at the TOA for a low thick cloud (500 m)

Preliminary validation of the method

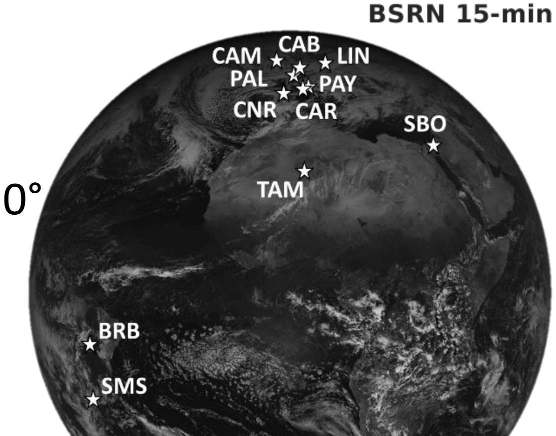
0.6 µm



0.8 µm



- Meteosat Second Generation 0°
- year 2011
- 11 BSRN stations
- channels 0.6 µm et 0.8 µm



Statistics for satellite-based GHI estimates vs. BSRN measurements (15-min averages, year: 2011)

Satellite-based DSSI product		Mean bias error ($W\ m^{-2}$ (%))	Standard deviation of the error ($W\ m^{-2}$ (%))	Root mean square of the error ($W\ m^{-2}$ (%))	Correlation coefficient R
Heliosat-V (this study)	MSG 0.6 µm	20.27 (4.8 %)	90.65 (21.4 %)	92.89 (21.9 %)	0.948
	MSG 0.8 µm	-6.19 (-1.5 %)	101.14 (23.9 %)	101.33 (23.9 %)	0.934
CAMS-RAD		0.10 (0.0 %)	98.14 (23.1 %)	98.14 (23.1 %)	0.937
HelioClim3 v5		1.55 (0.4 %)	87.95 (20.7 %)	87.96 (20.7 %)	0.950

References

- **This study**:
  - Tournadre *et al.*, 2020: Heliosat-V: a versatile method for estimating downwelling surface solar irradiance from satellite imagery. Part 1: methodology and preliminary validation, *Atmos. Chem. Phys., in preparation*.
- **Other references:**

  - Amillo *et al.*, 2014: A New Database of Global and Direct Solar Radiation Using the Eastern Meteosat Satellite, Models and Validation, Remote Sensing 6(9), 8165–8189
  - Lorente *et al.*, 2018: The importance of surface reflectance anisotropy for cloud and NO2 retrievals from GOME-2 and OMI, Atmospheric Measurement Techniques 11(7), 4509–4529.