inDust
Training School on
Dust Products

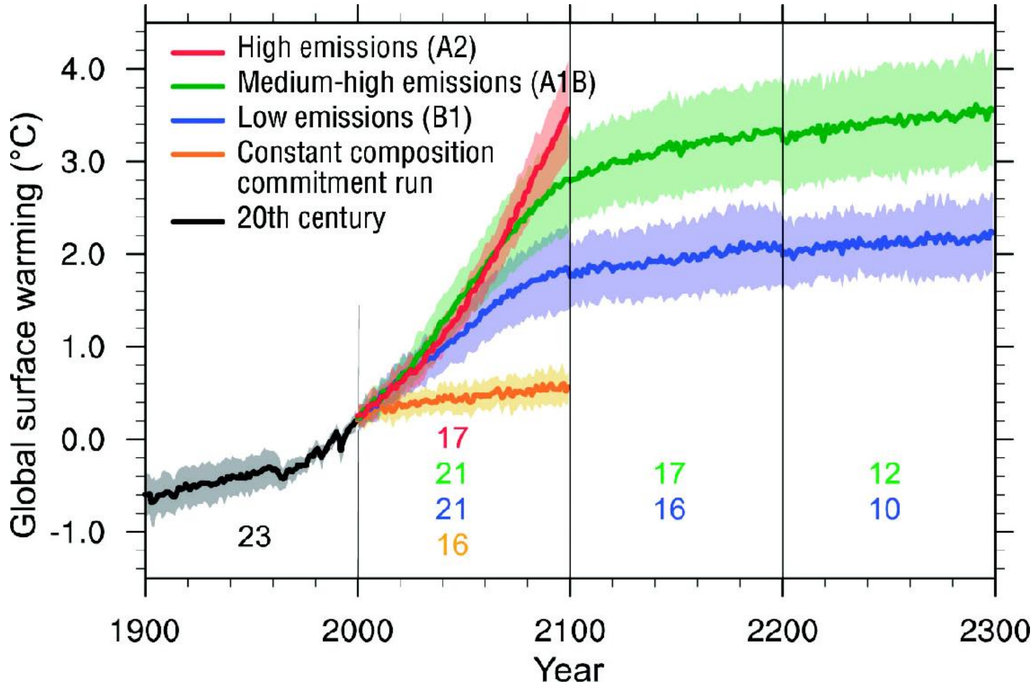
Dust Impacts on Solar Energy

Panagiotis Kosmopoulos, Stelios Kazadzis, Hesham El-Askary

Introduction

- The consequences of rapidly rising global temperatures will be far-reaching and devastating for humans and the environment unless urgent action is taken globally to curb emissions. If left unchallenged, runaway climate change across sub-Saharan Africa would have both a disastrous impact on North Africa and dramatic spill-over effects on all of Southern Europe (e.g. population movements).

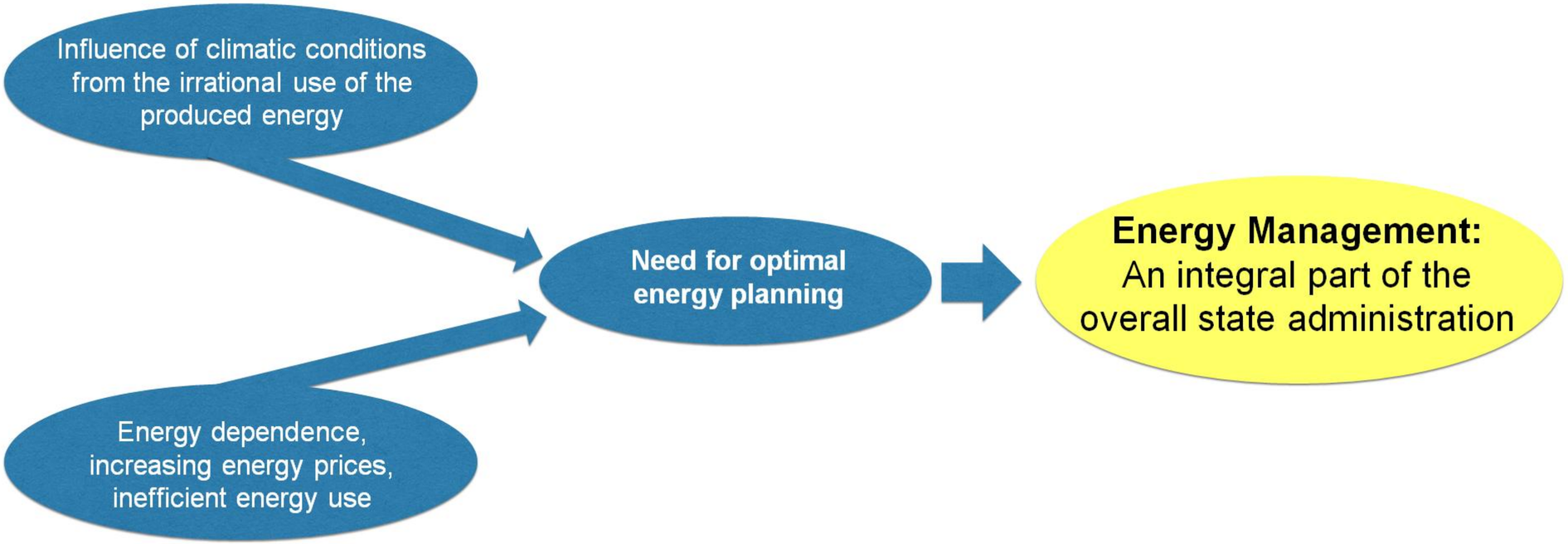
- Southern Europe and North Africa present unique solar energy potential and its exploitation is critical for the regional sustainable development, through an effective energy planning, power transmission and distribution.

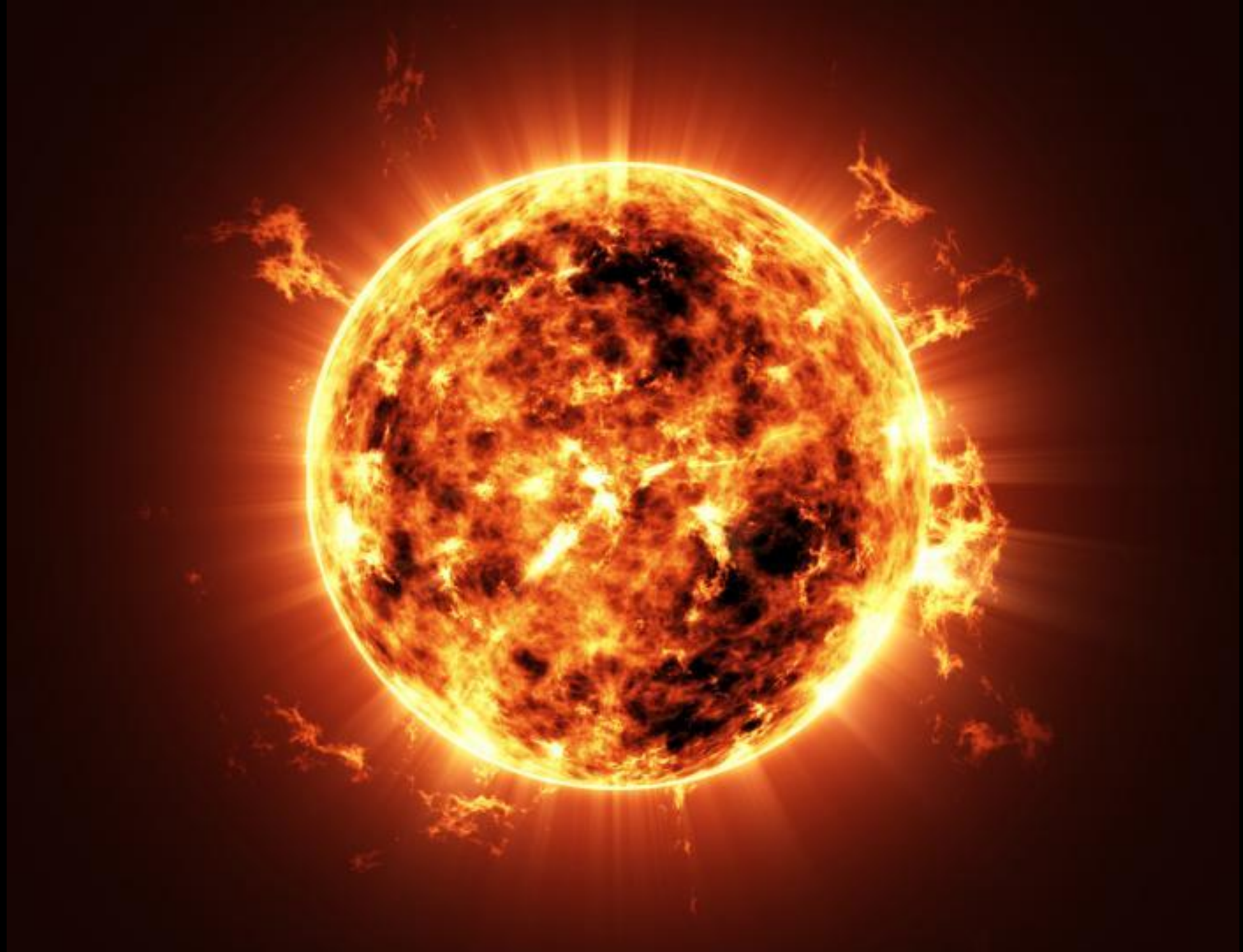


Introduction

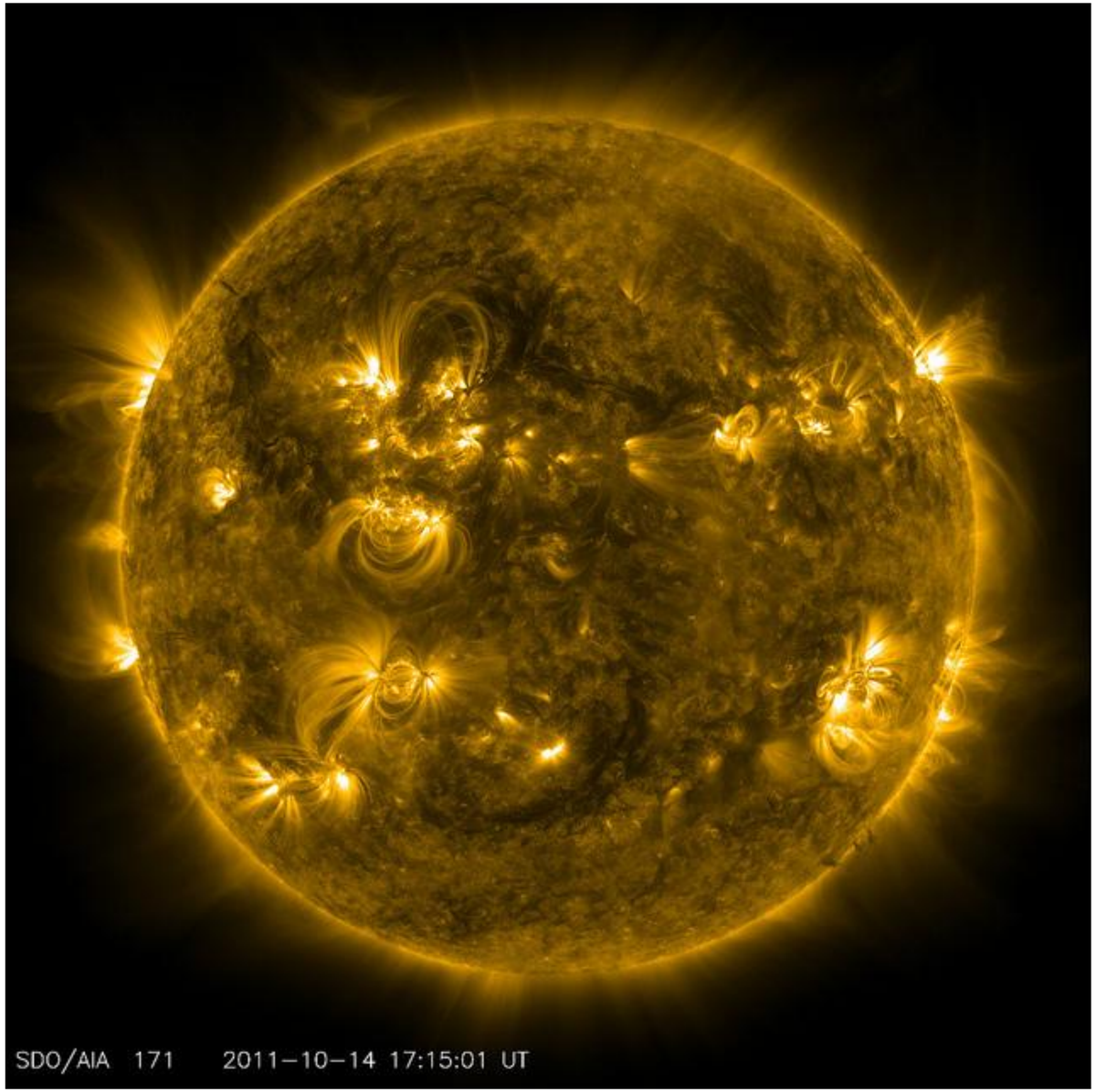
❑ To this direction, on November 2016, the EC published a revised Renewable Energy Directive in order to ensure that the target of at least 27% renewables in the final energy consumption in the EU by 2030 is met. Today, renewables account for more than 22% of the total global electricity generation, of which more than 400 GW produced from solar systems last year (2017). Over the last 5 years (2013-2017), an estimated 15 Gt CO_2eq of emissions was avoided through renewables, compared to the emissions that would otherwise have occurred from fossil fuel-based power.

❑ As a result, the exploitation of renewables is a cornerstone for sustainable development, through efficient energy planning, towards the goal of gradual independence from fossil fuels, while ramping up renewables is essential to meet climate goals (**Sustainable Development Goals**, UN) without decelerating economic growth and reducing welfare.

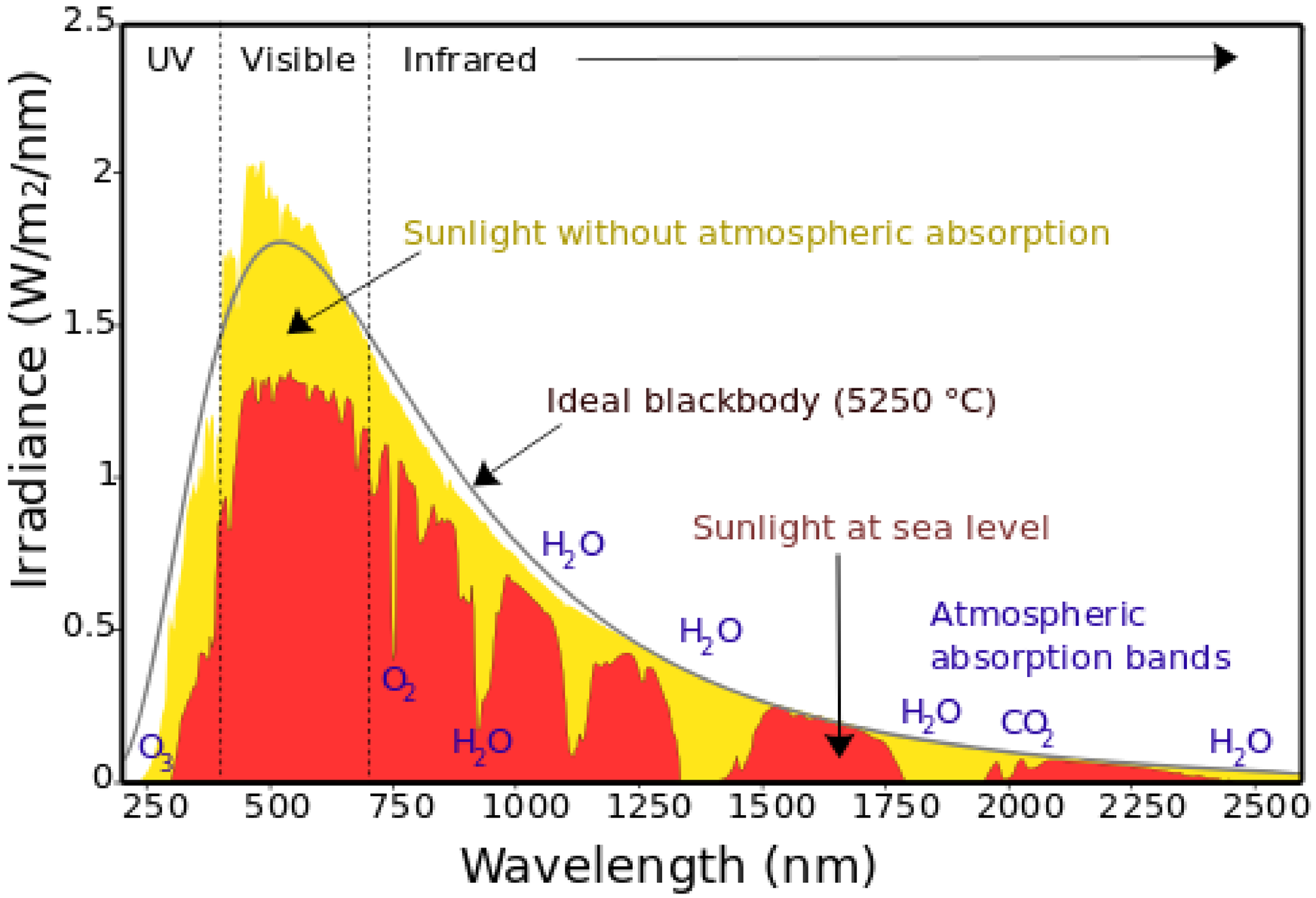




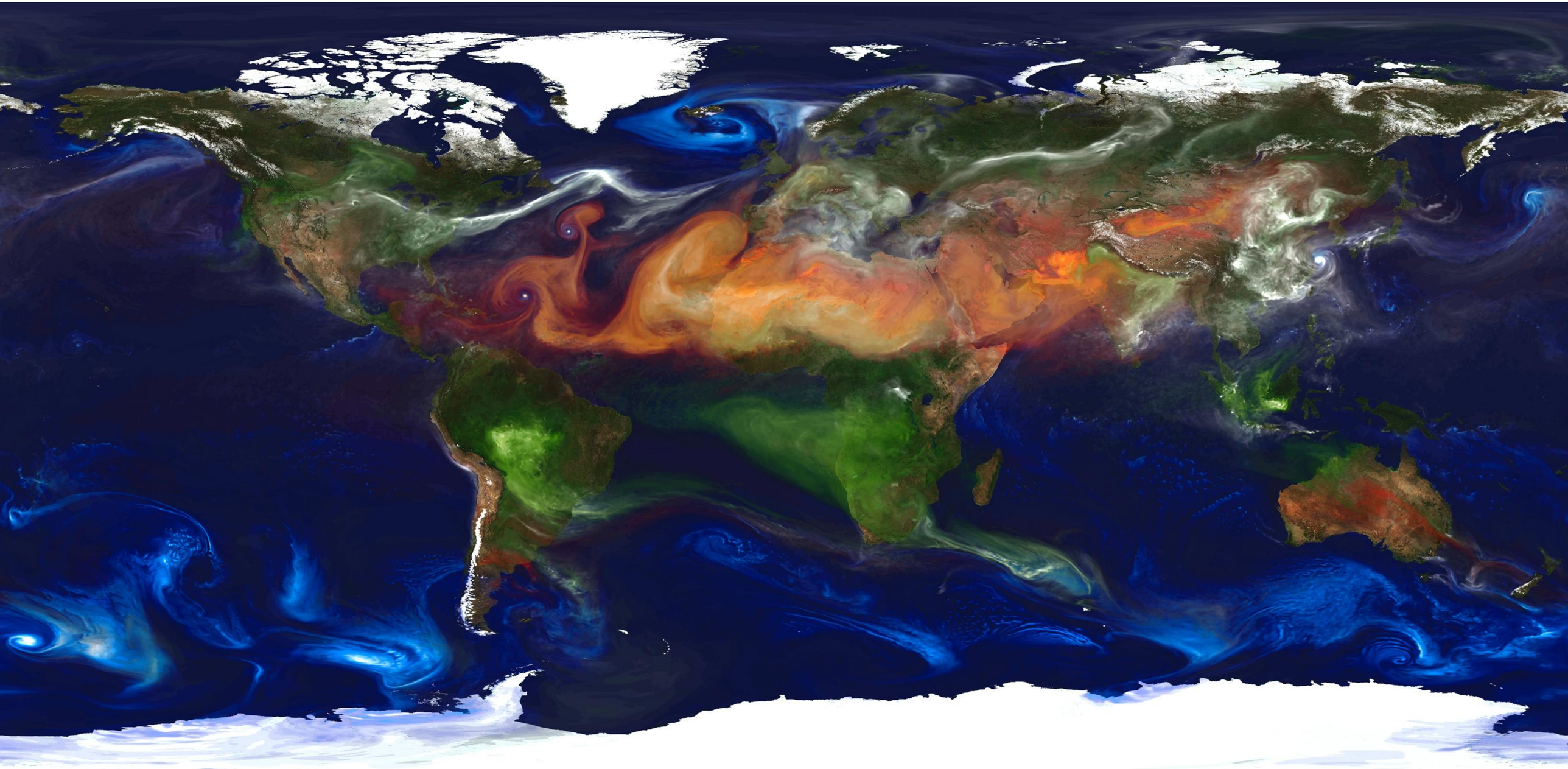
The solar spectrum



Spectrum of solar radiation (Earth)

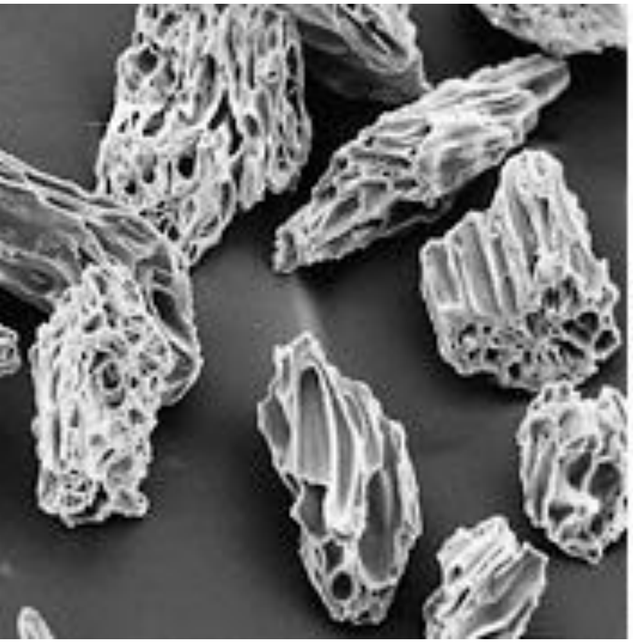
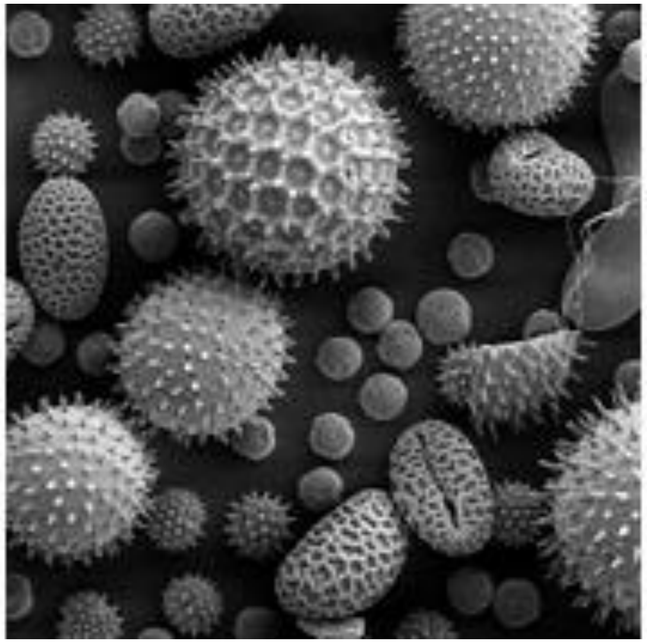
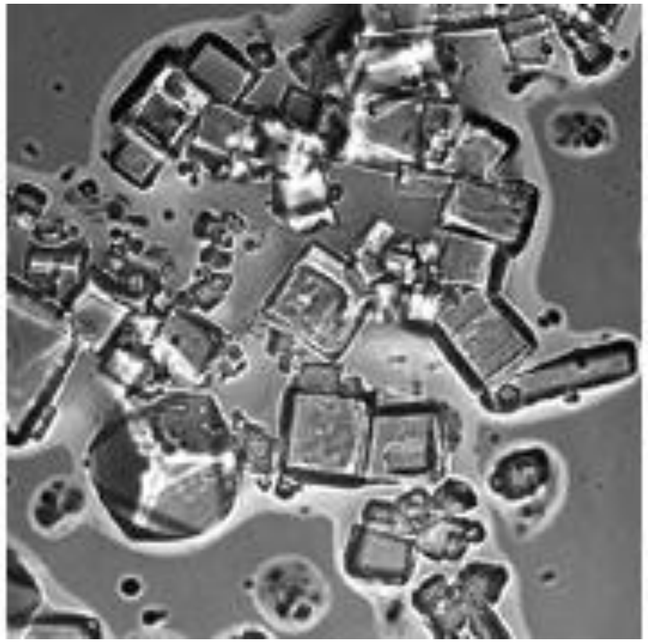
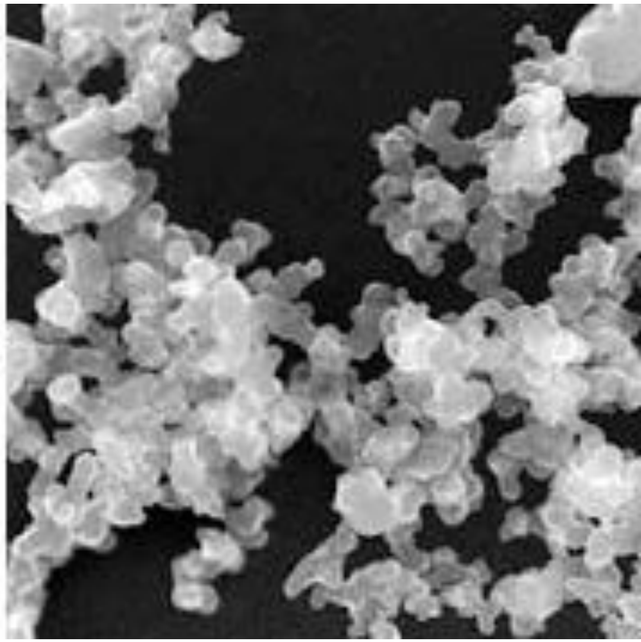


Aerosols



Aerosol types

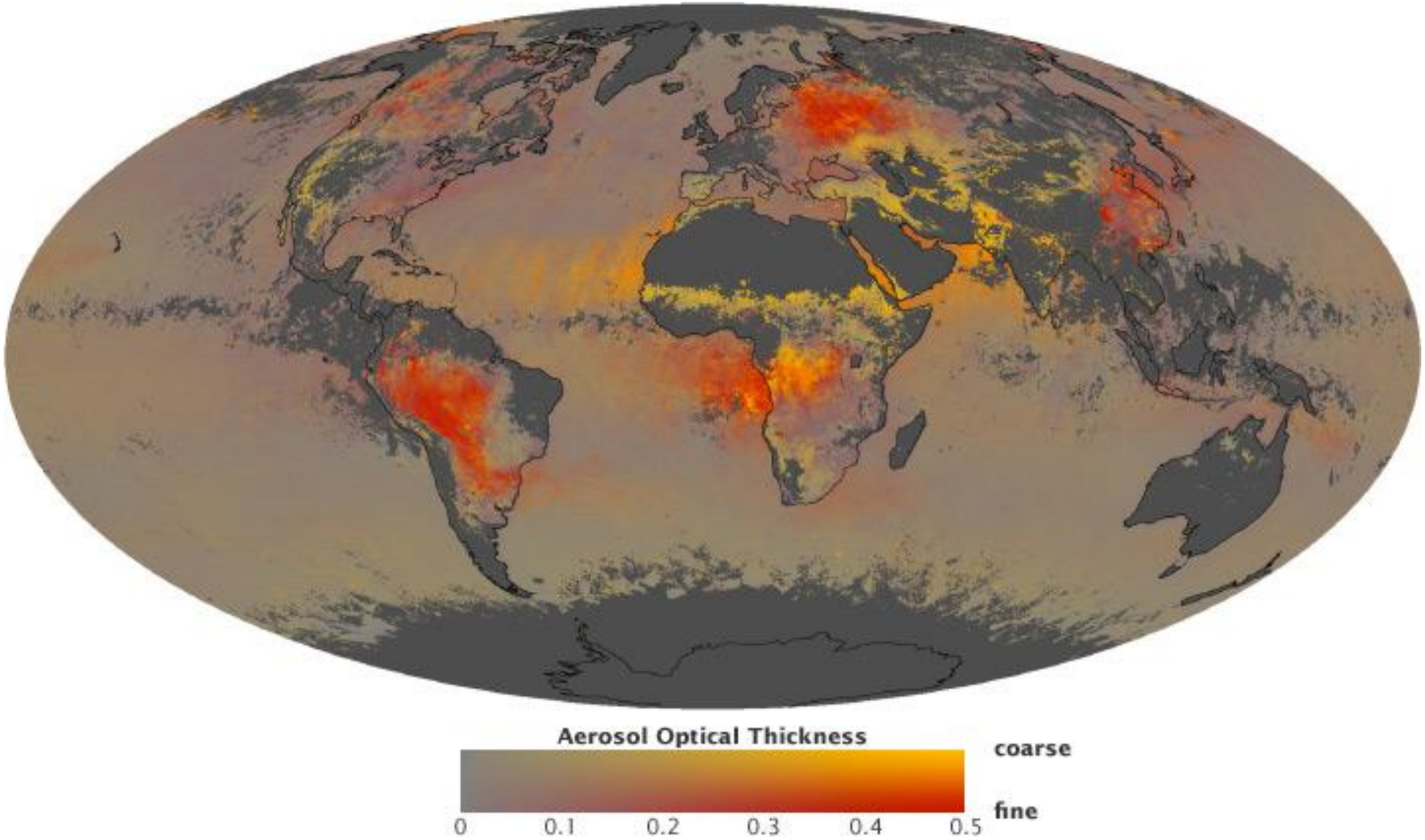
Aerosol shapes

Aerosol sources

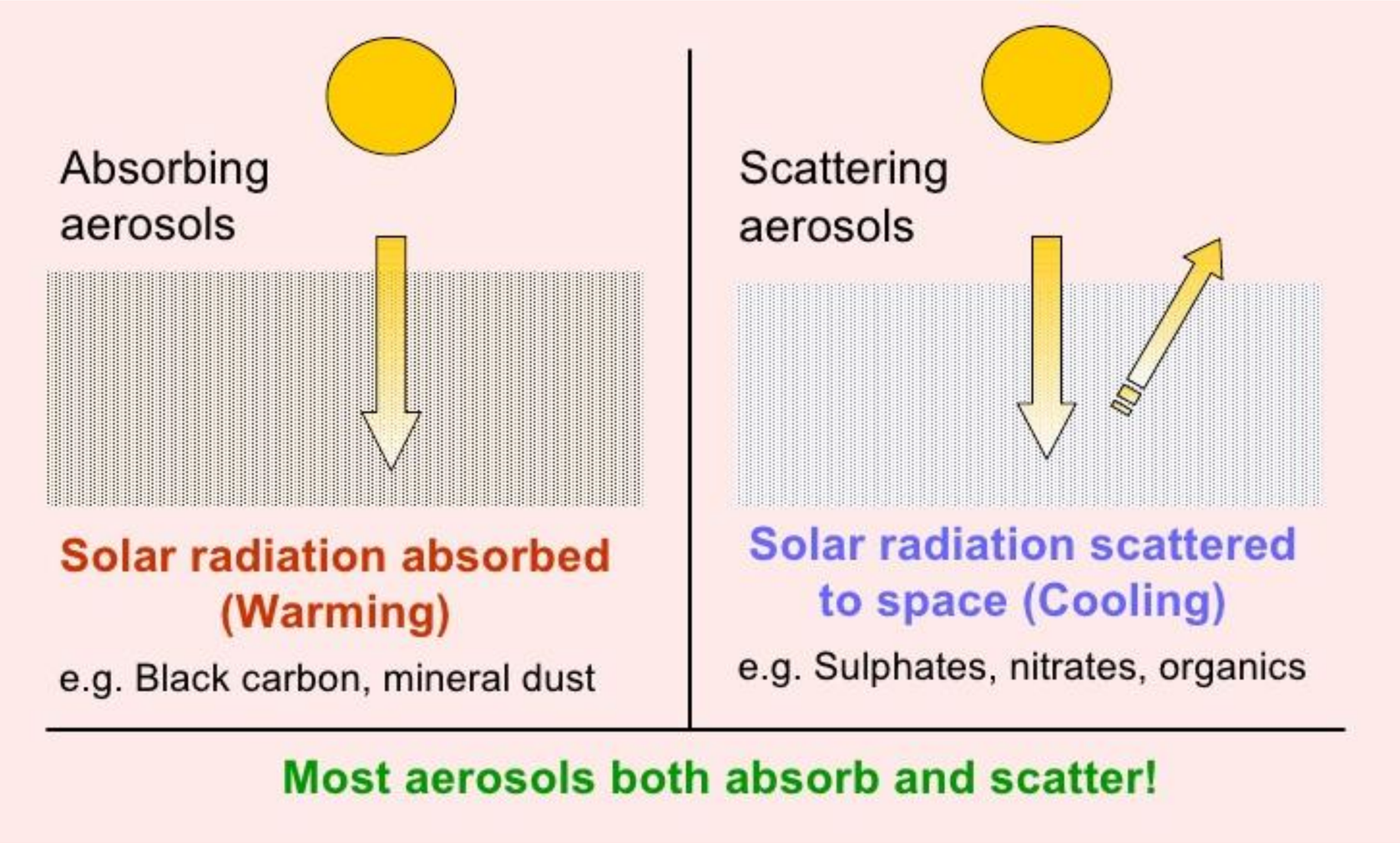



Aerosol global distribution



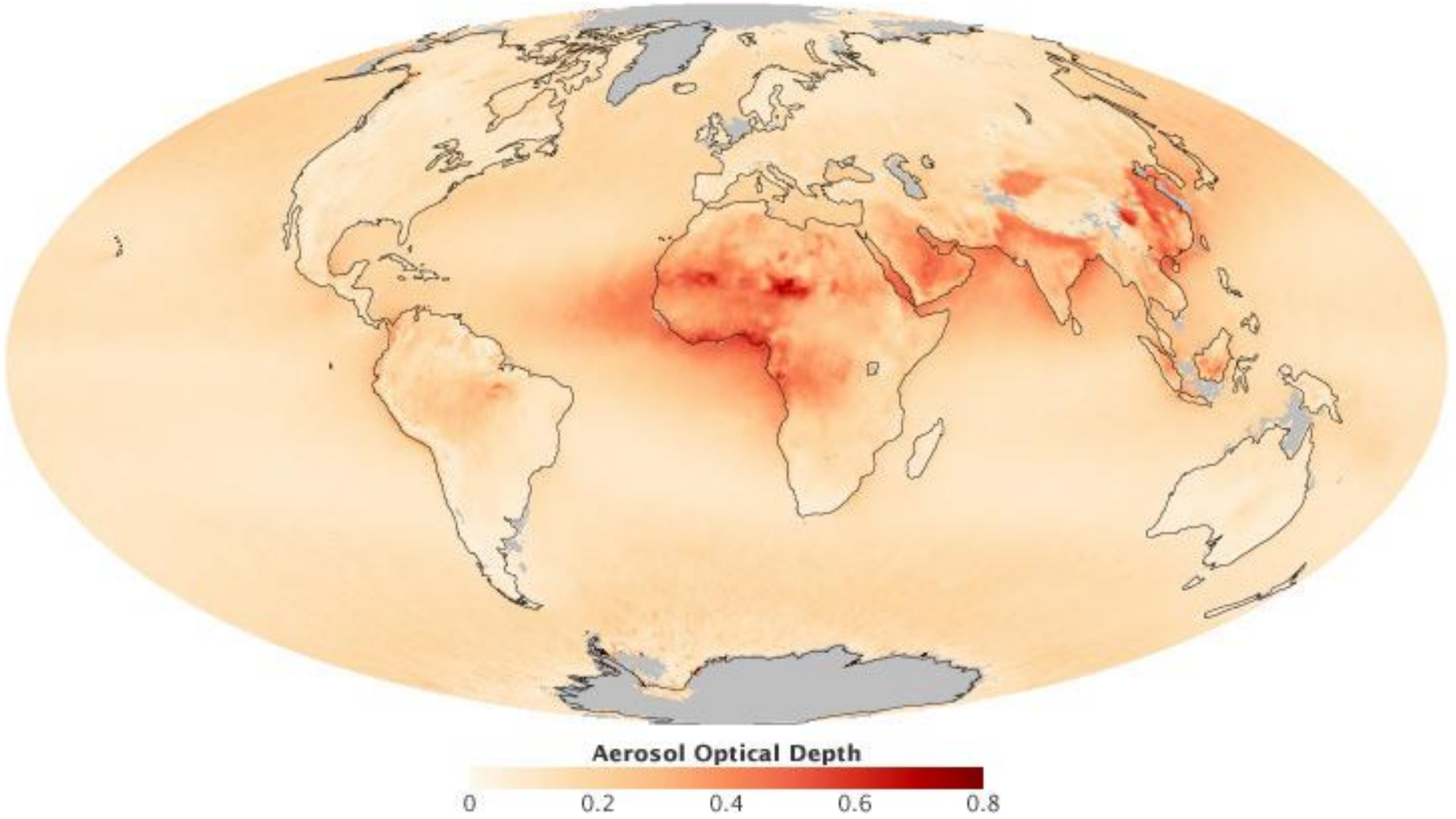
Aerosols and incoming sunlight

Direct effect

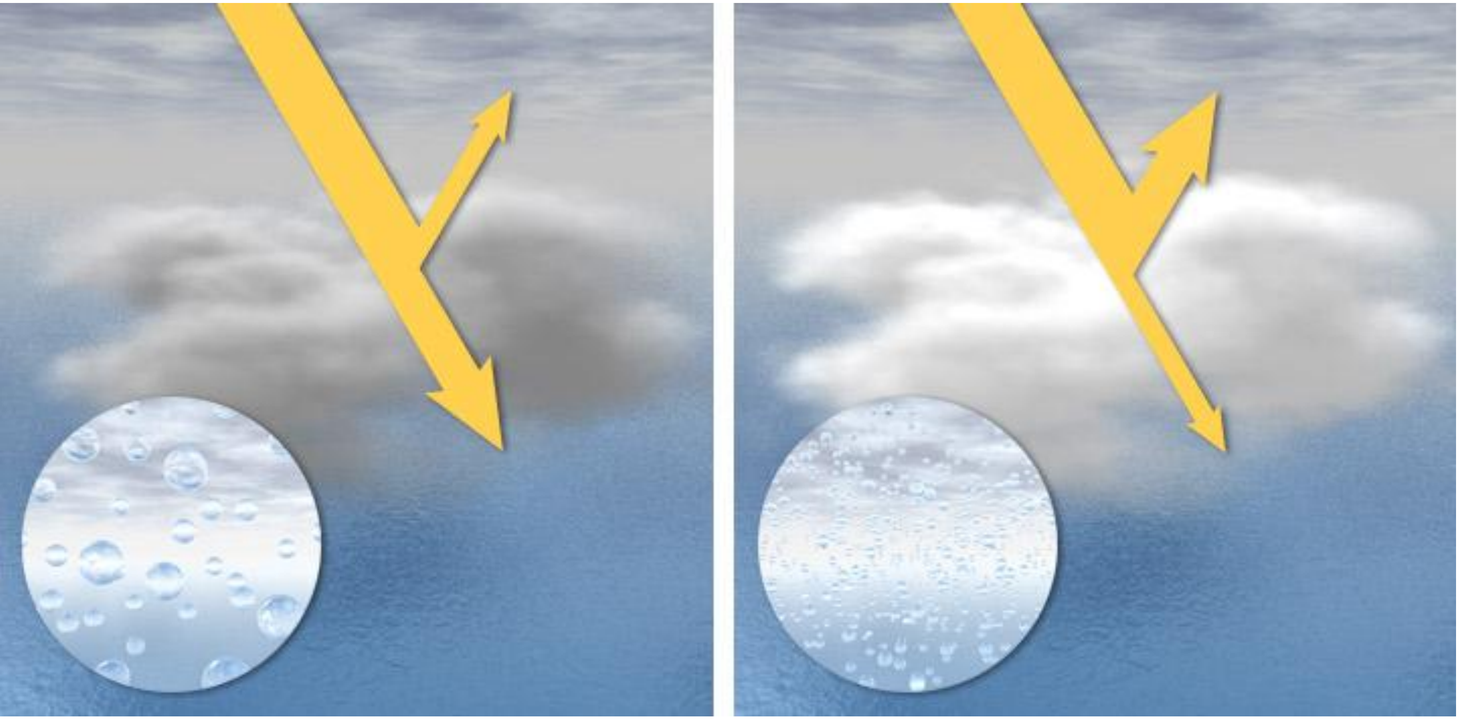


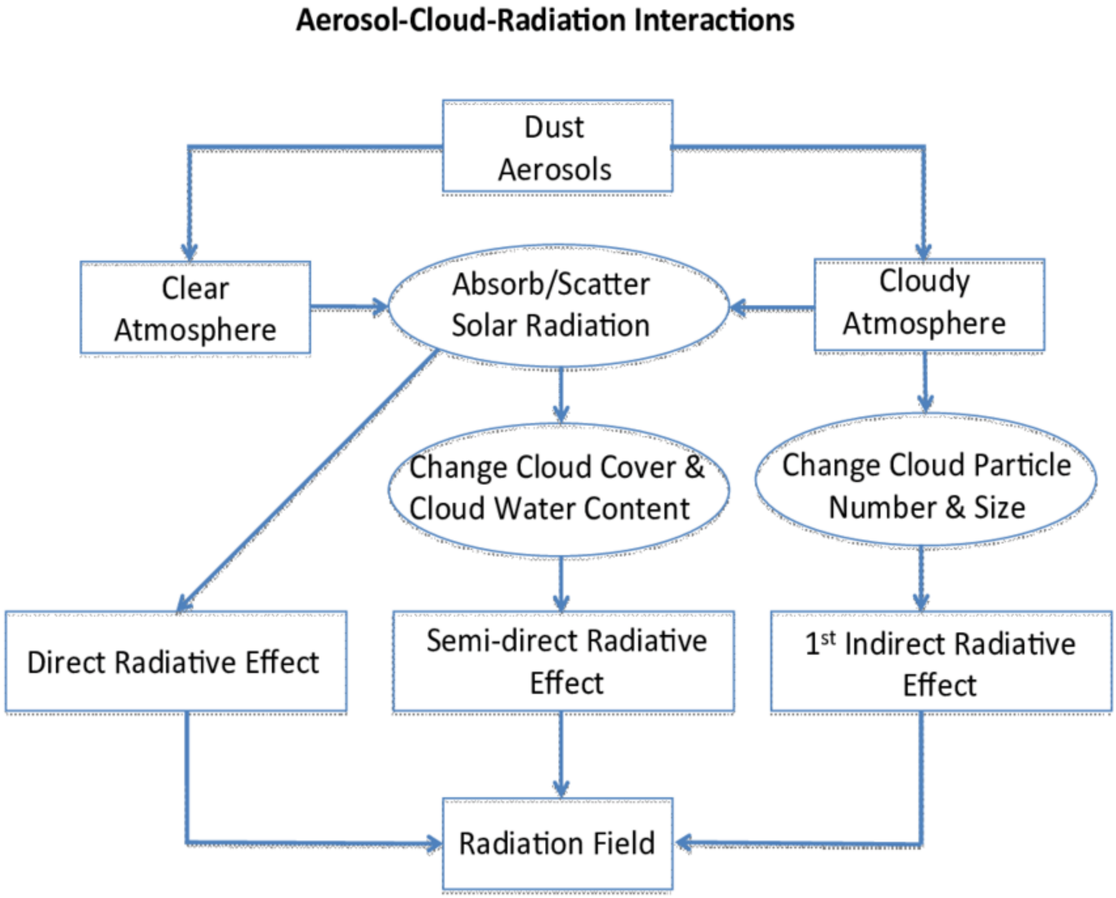
Aerosol impact on climate

Measuring aerosols

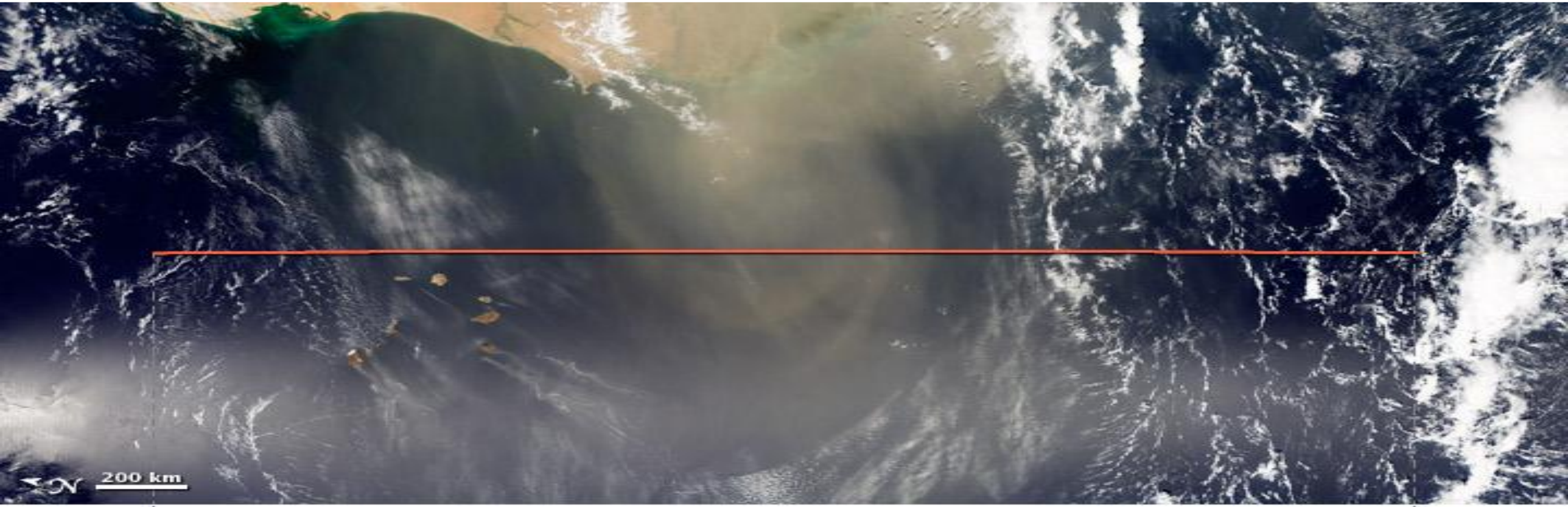


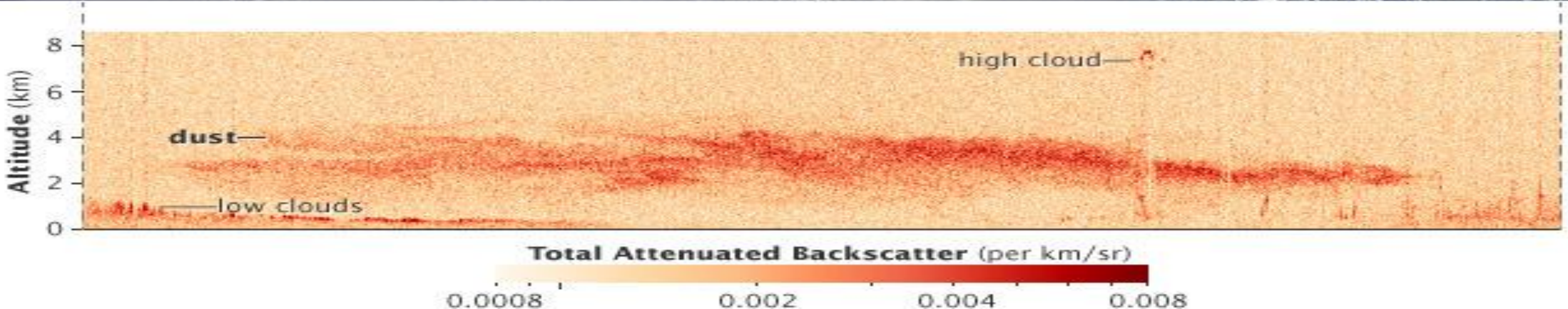
Aerosol and clouds (Indirect effects)





Observation technologies

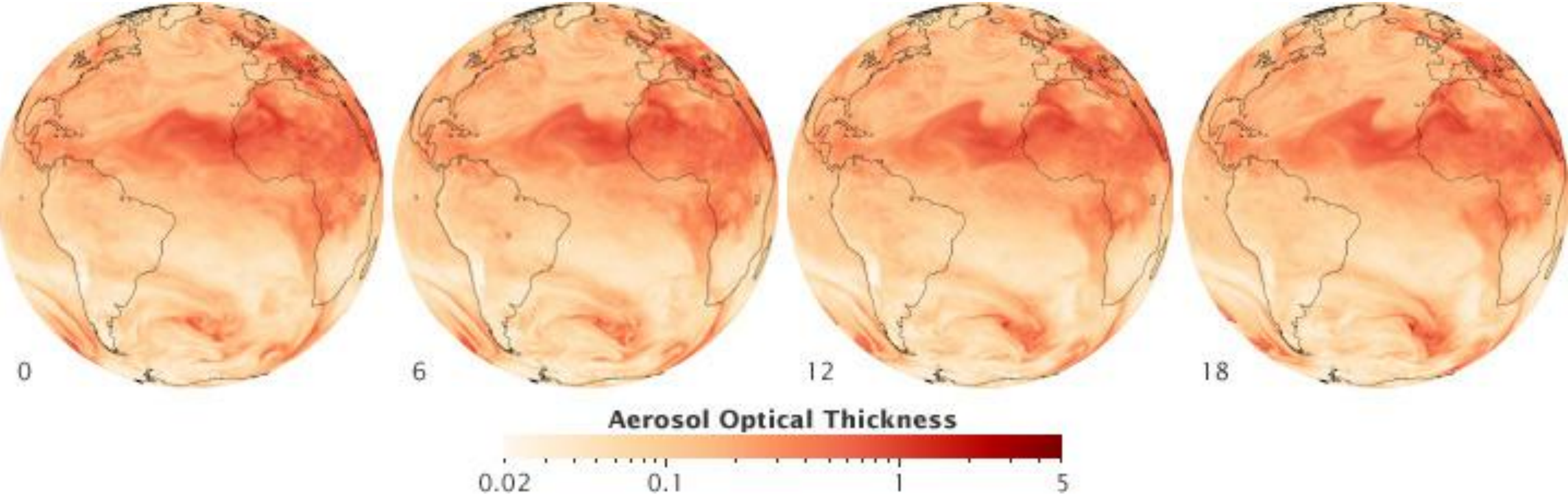




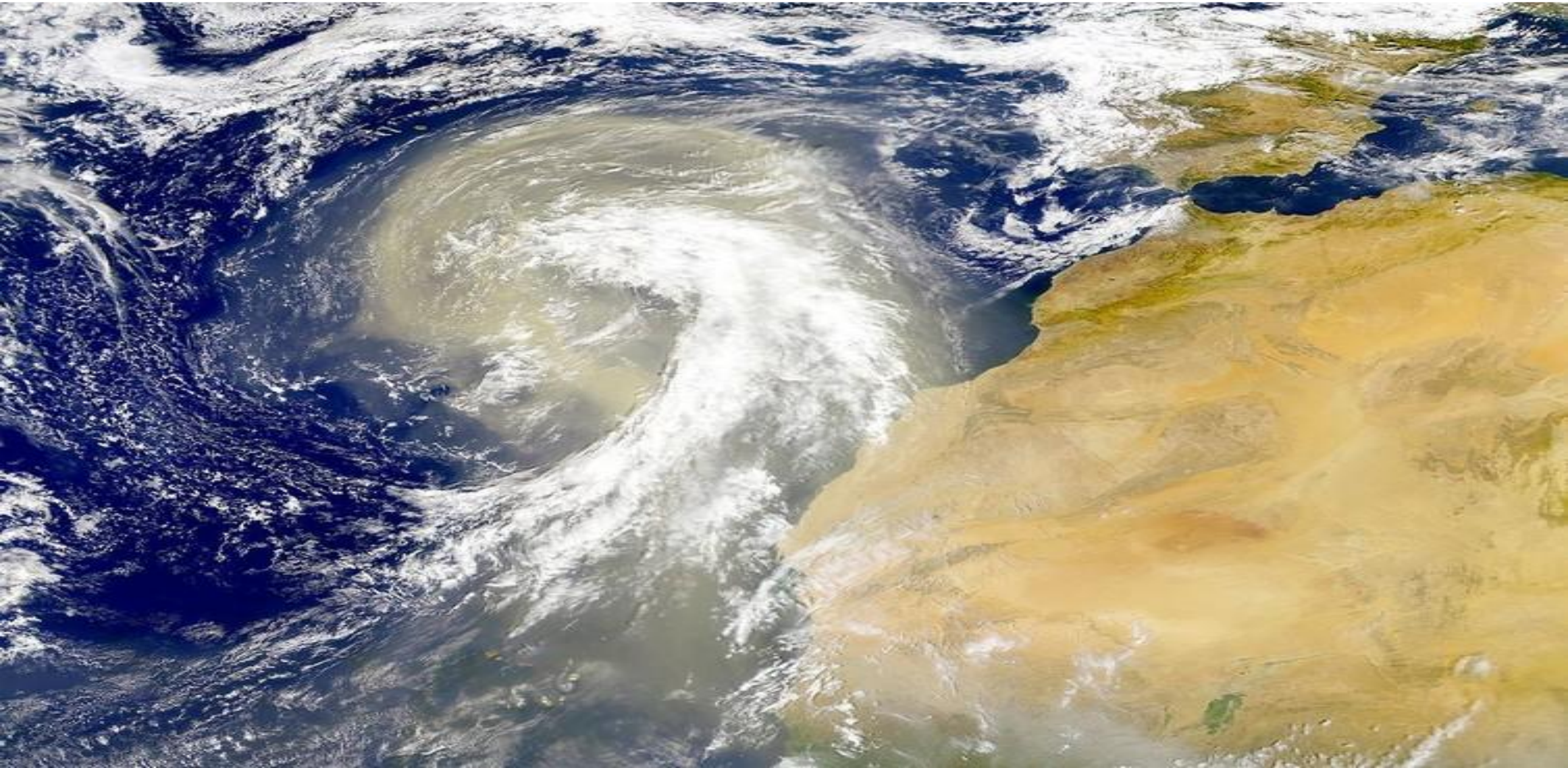
Ground measurements

Dust aerosols

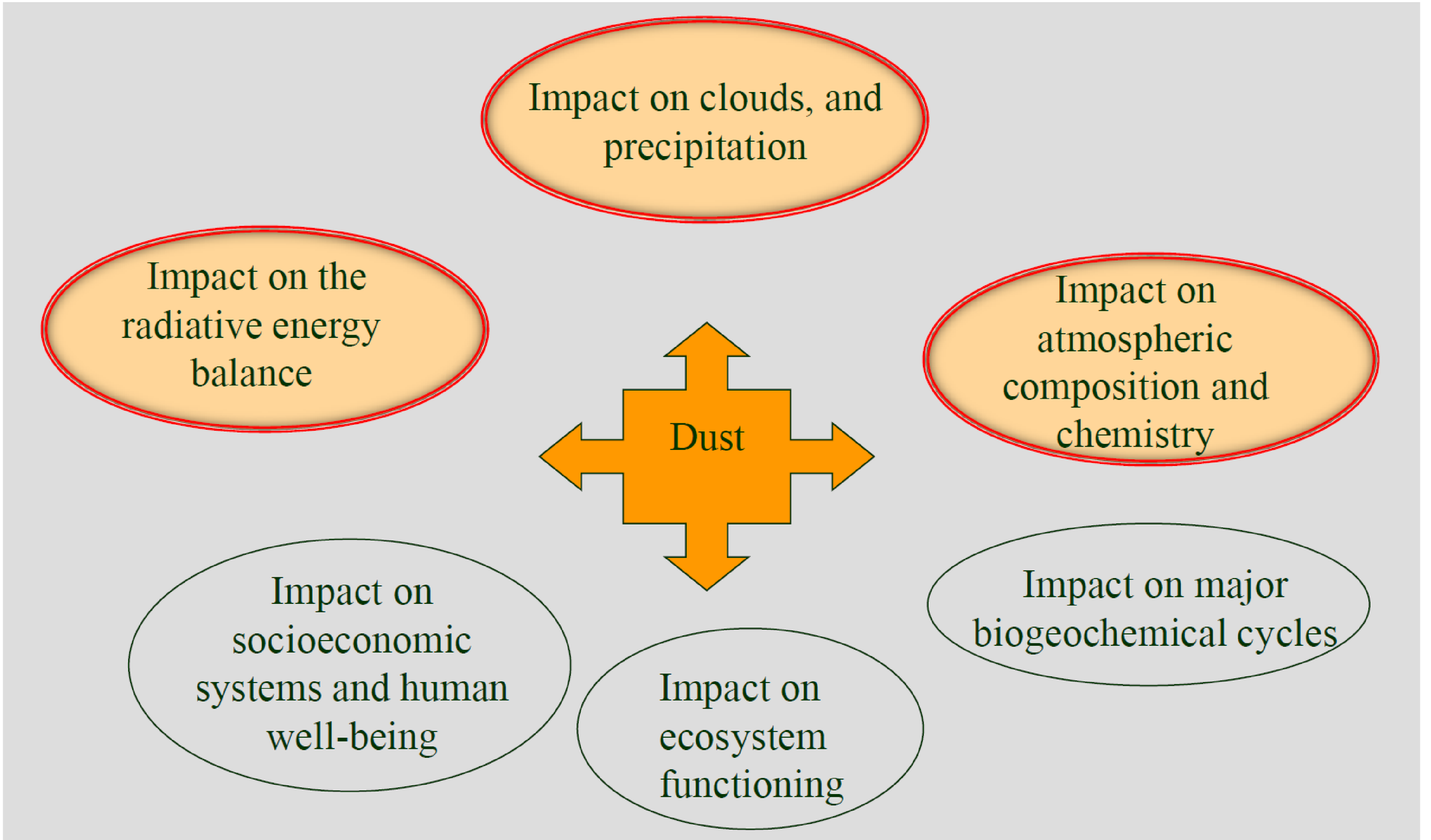
Dust aerosols



Dust likes spring season!



Multiple dust impacts

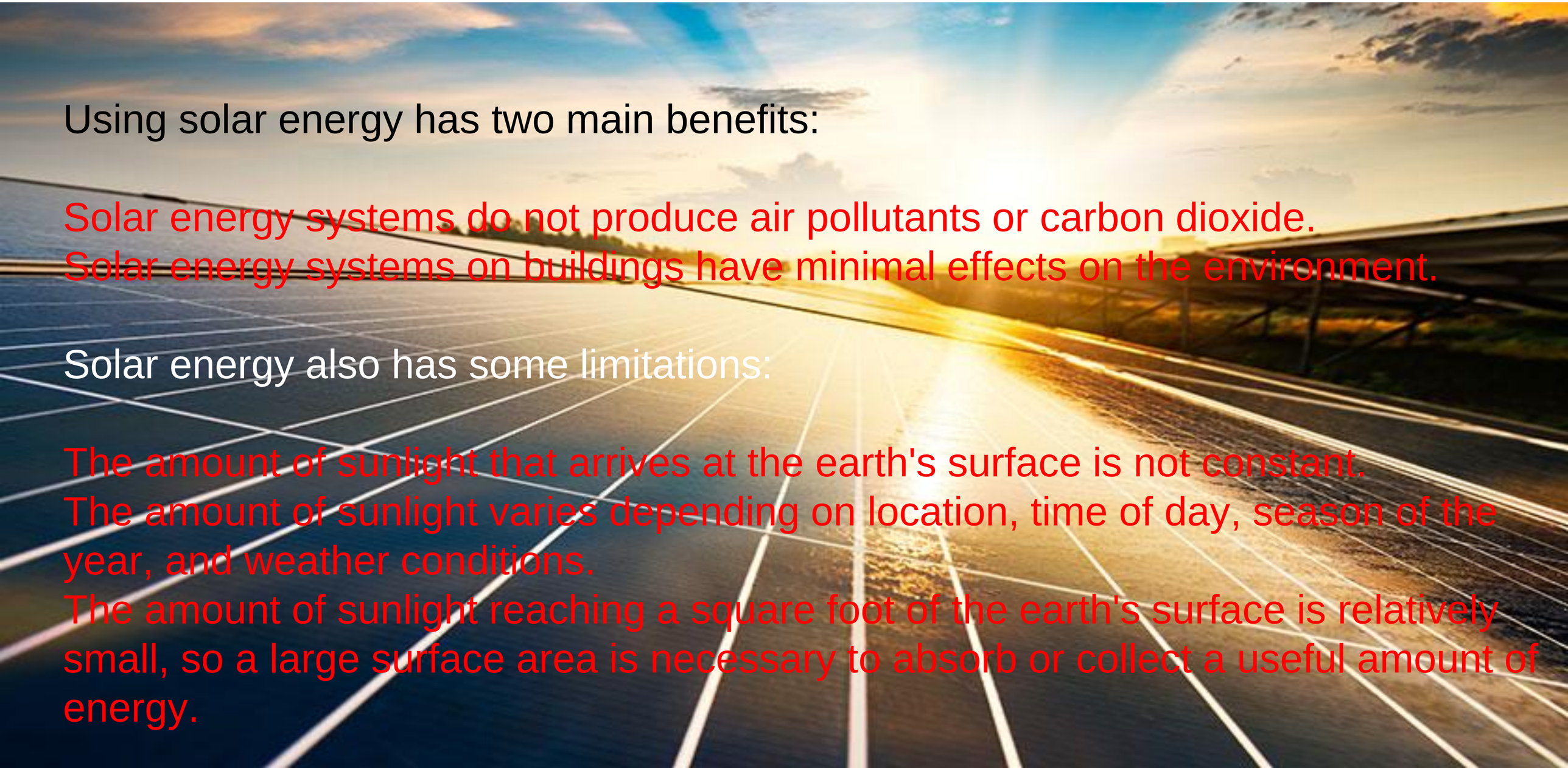


Dust dust dust!

Energy from the sun

What is solar energy?

Solar energy benefits and limitations



Using solar energy has two main benefits:

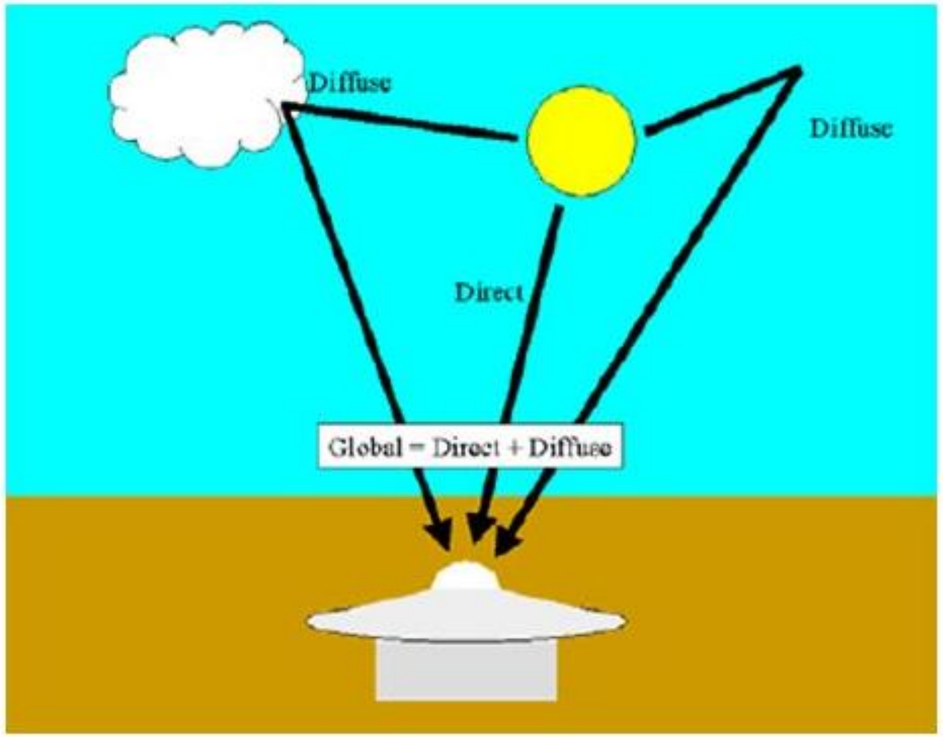
Solar energy systems do not produce air pollutants or carbon dioxide.
Solar energy systems on buildings have minimal effects on the environment.

Solar energy also has some limitations:

The amount of sunlight that arrives at the earth's surface is not constant.
The amount of sunlight varies depending on location, time of day, season of the year, and weather conditions.
The amount of sunlight reaching a square foot of the earth's surface is relatively small, so a large surface area is necessary to absorb or collect a useful amount of energy.

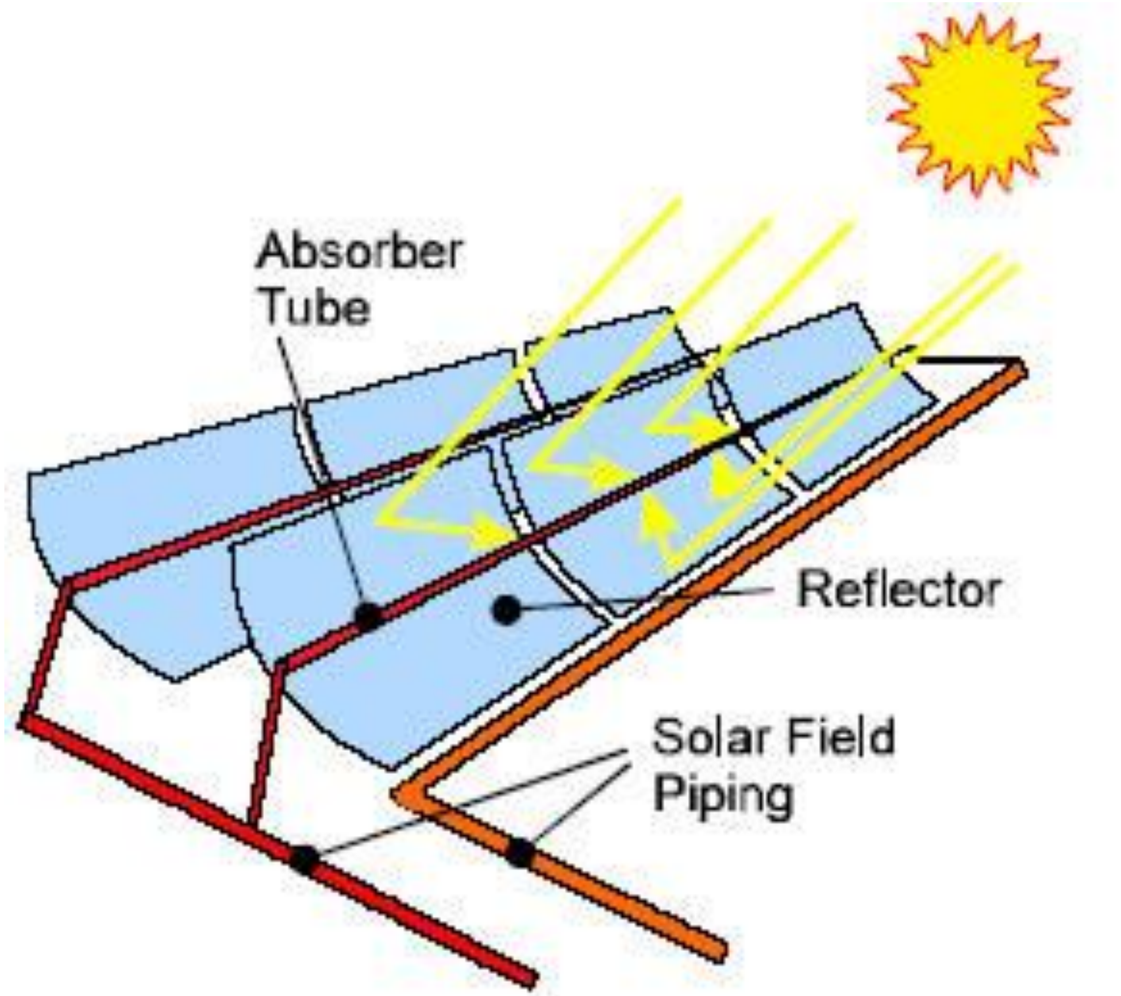
Concentrated solar power (CSP) plants

GHI and DNI

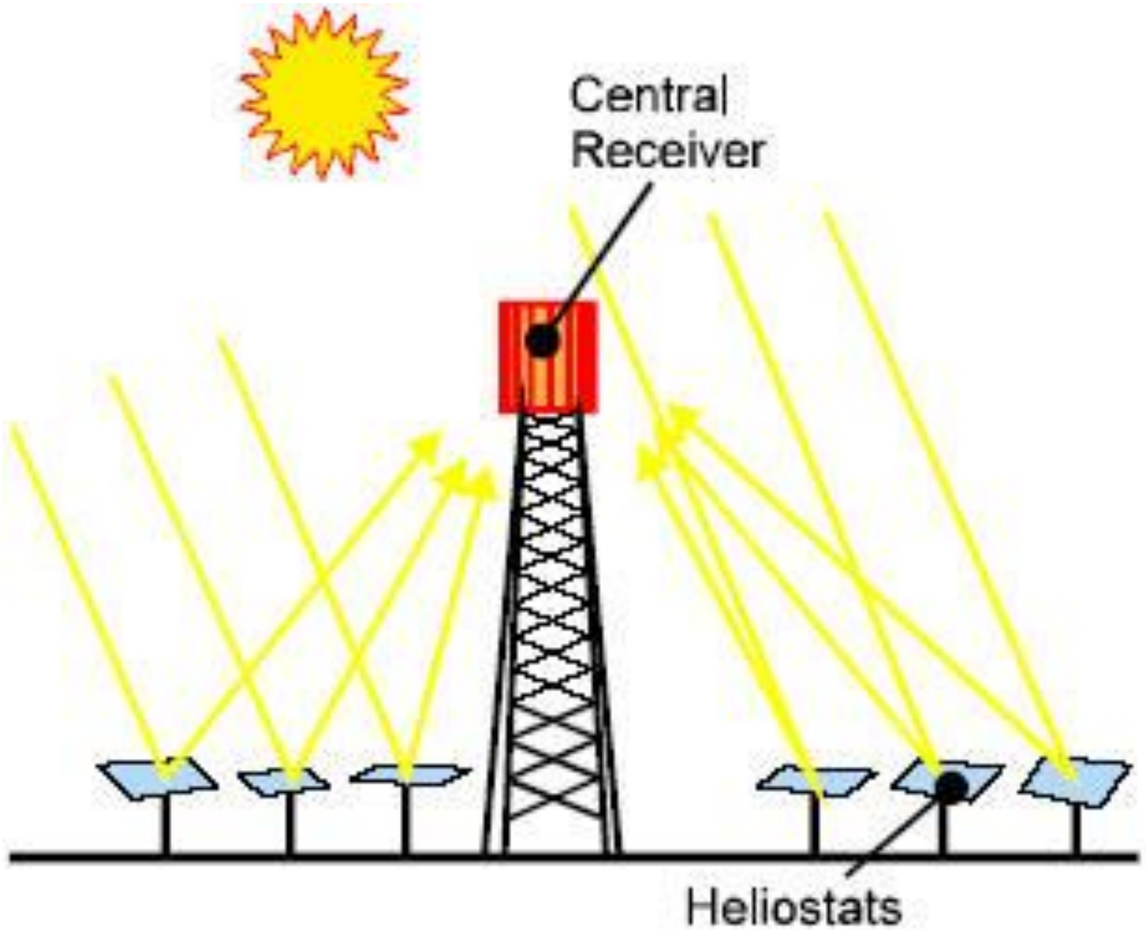


1. Global Horizontal Irradiance (GHI) - [W/m^2]
2. Direct Normal Irradiance (DNI) - [W/m^2]
3. Diffused Horizontal Irradiance (DHI)- [W/m^2]

Parabolic trough systems

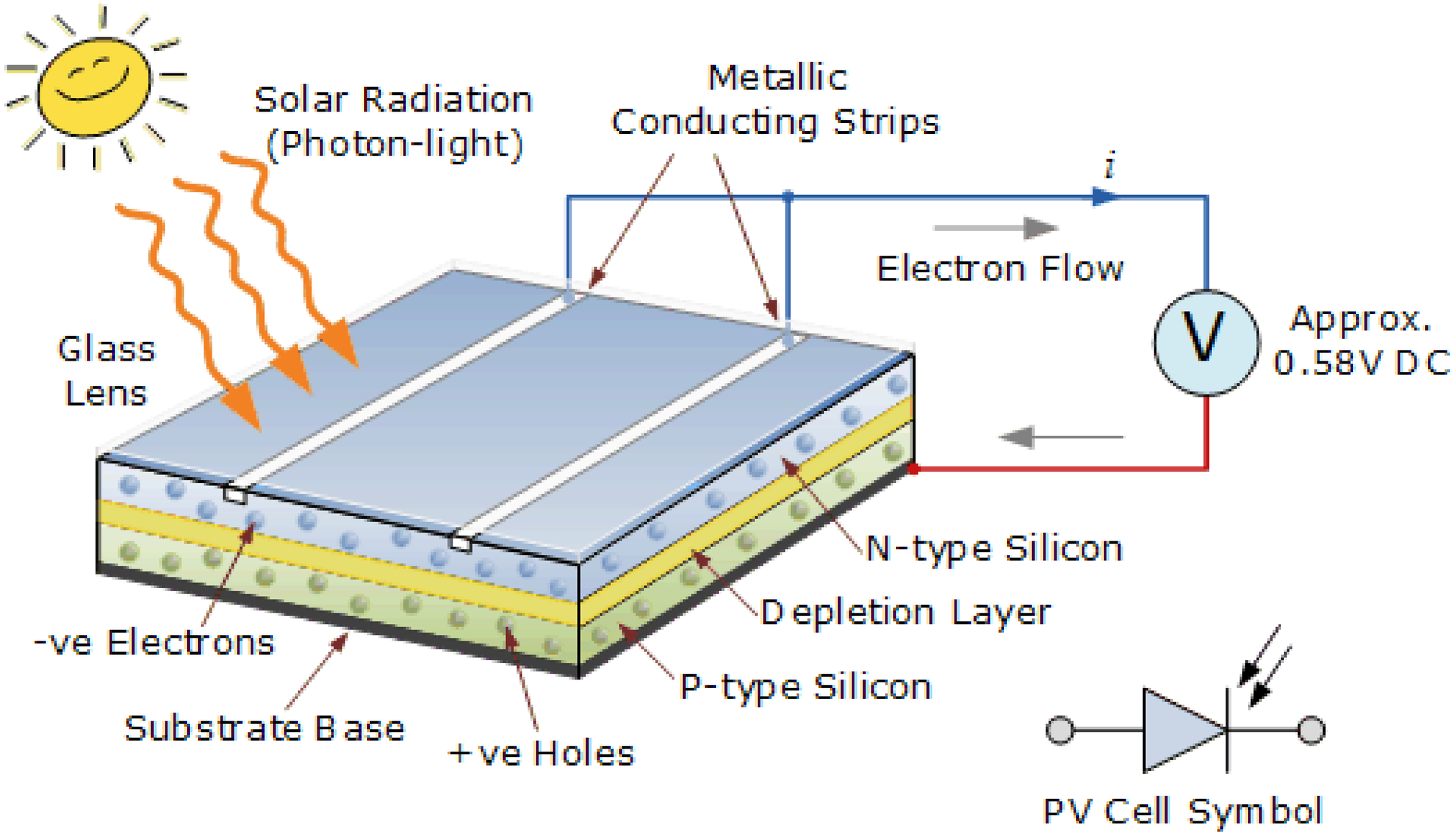


Solar tower

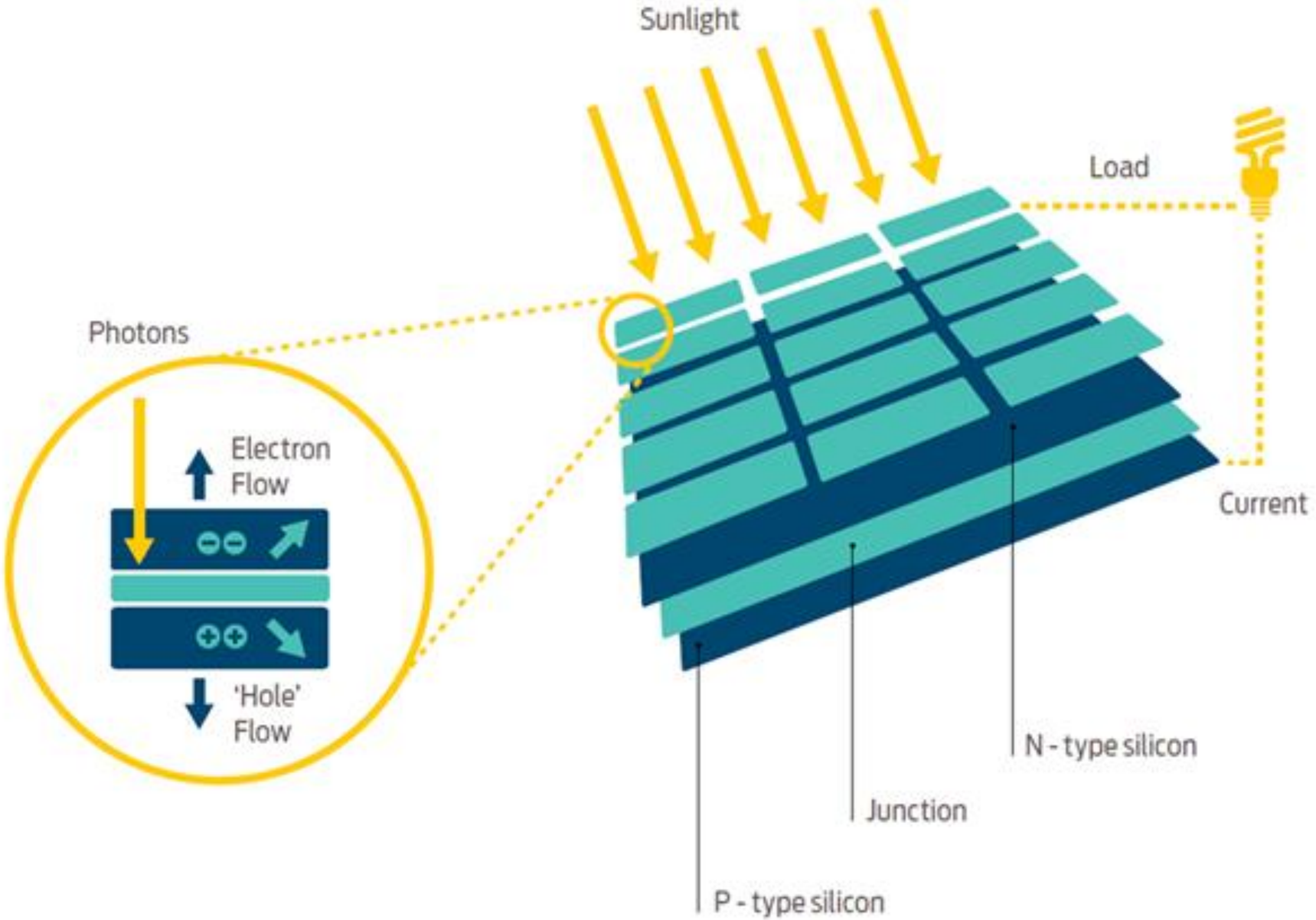


Photovoltaics (PV)

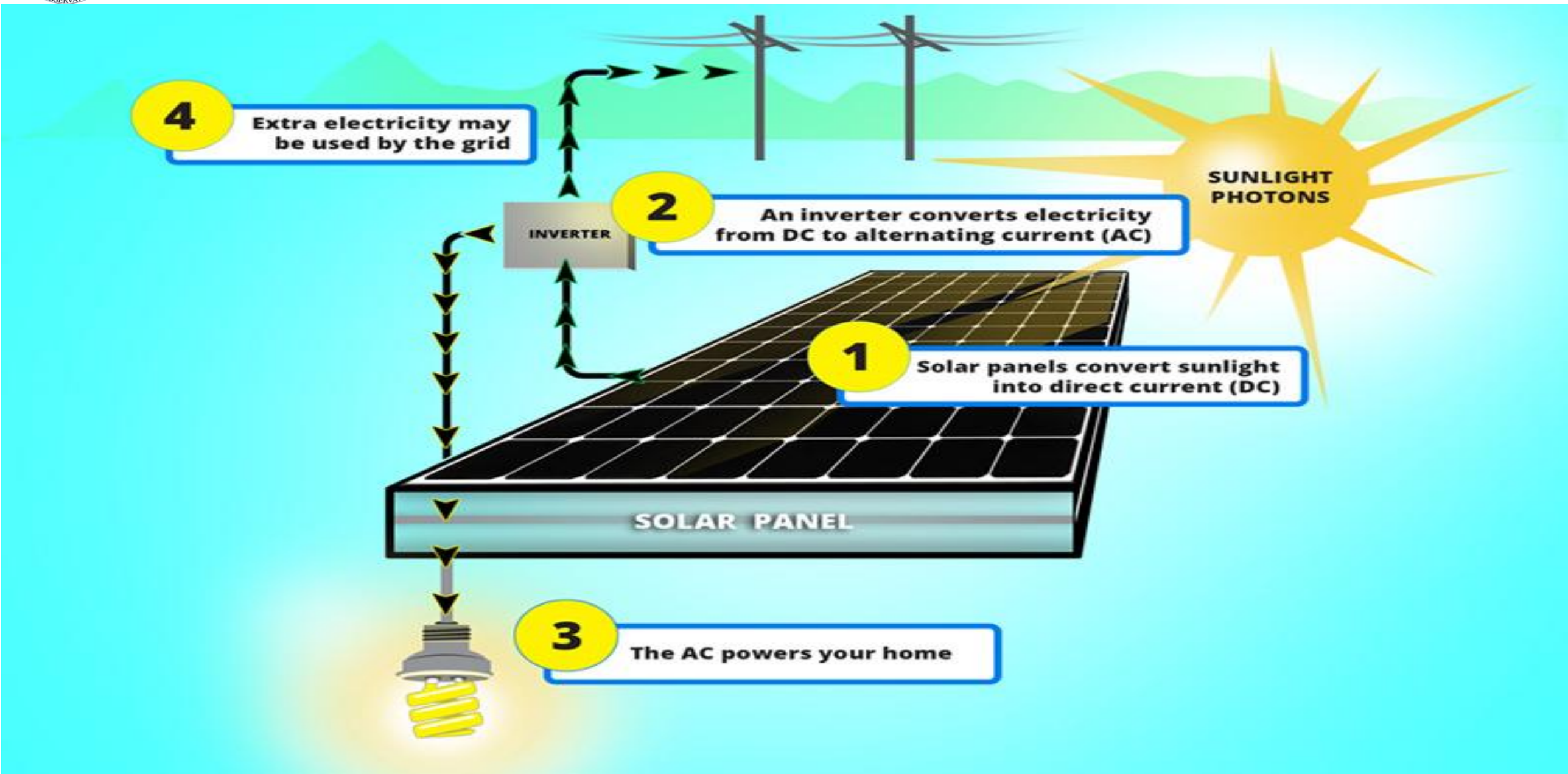
How does the PV process work?



How do solar panels work?



How do panels generate electricity?



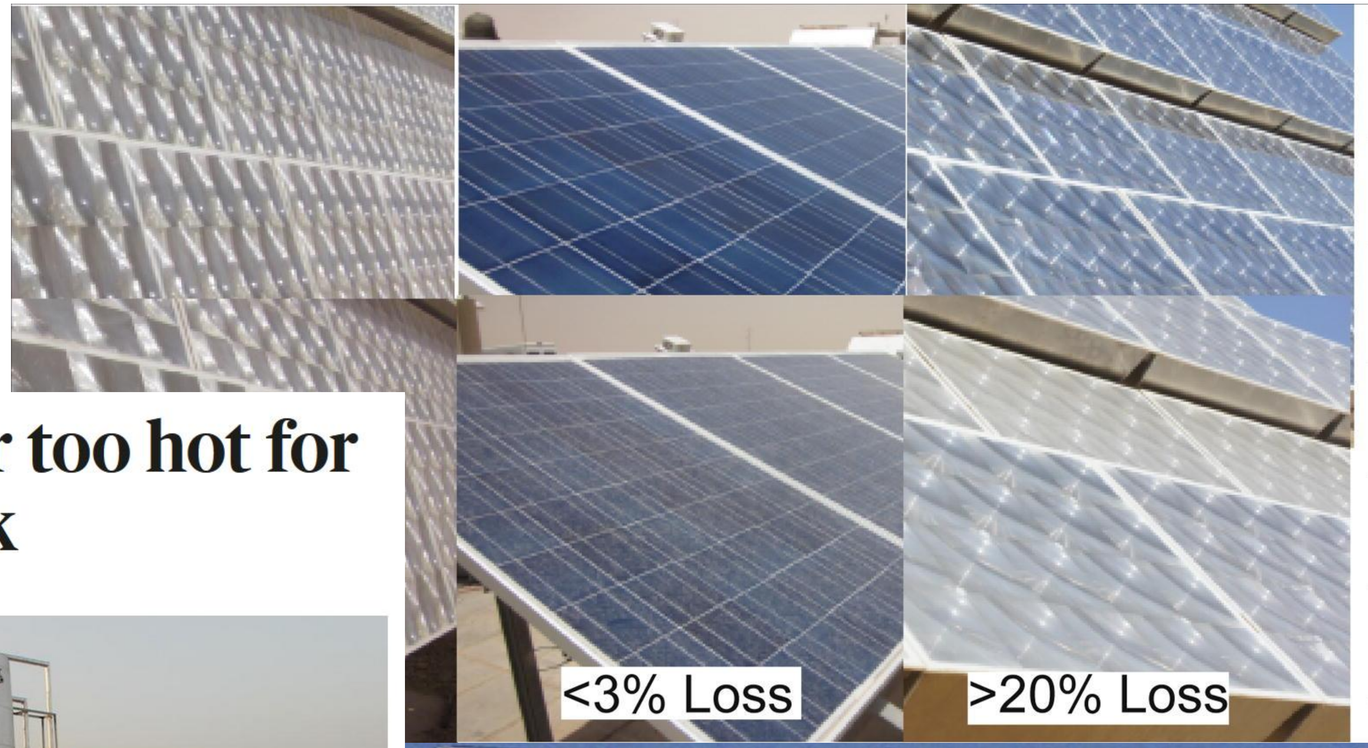
Soiling

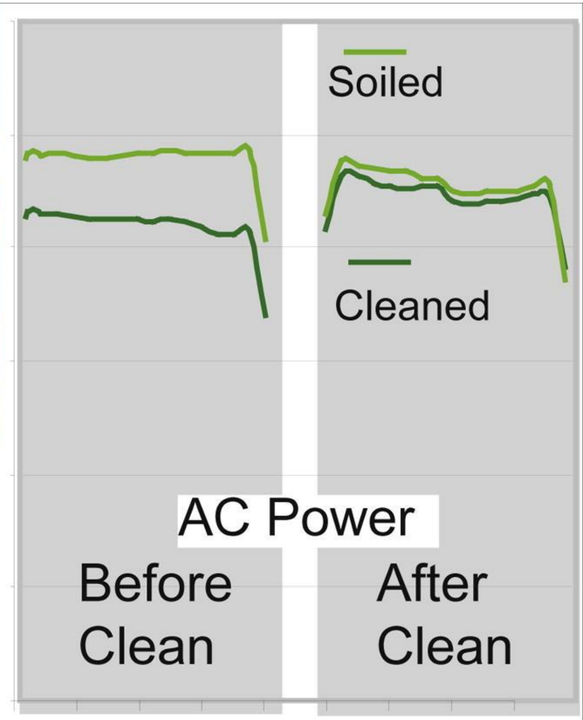
Introduction

Dust impact services

There are two main services related to the solar energy sector:
Seasonal predictions for solar energy
Mineral Dust Short term forecasts for solar energy

Soiling

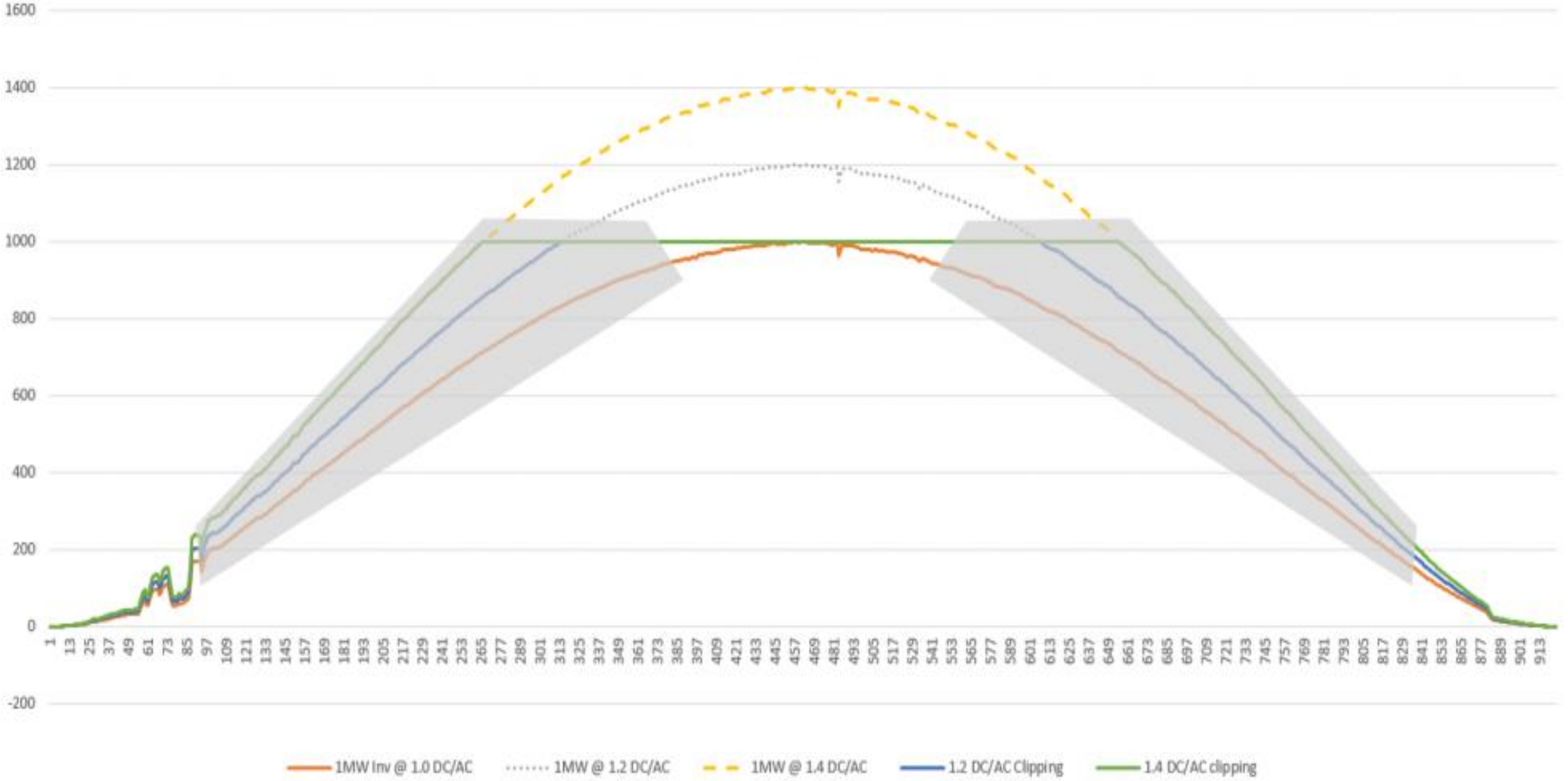




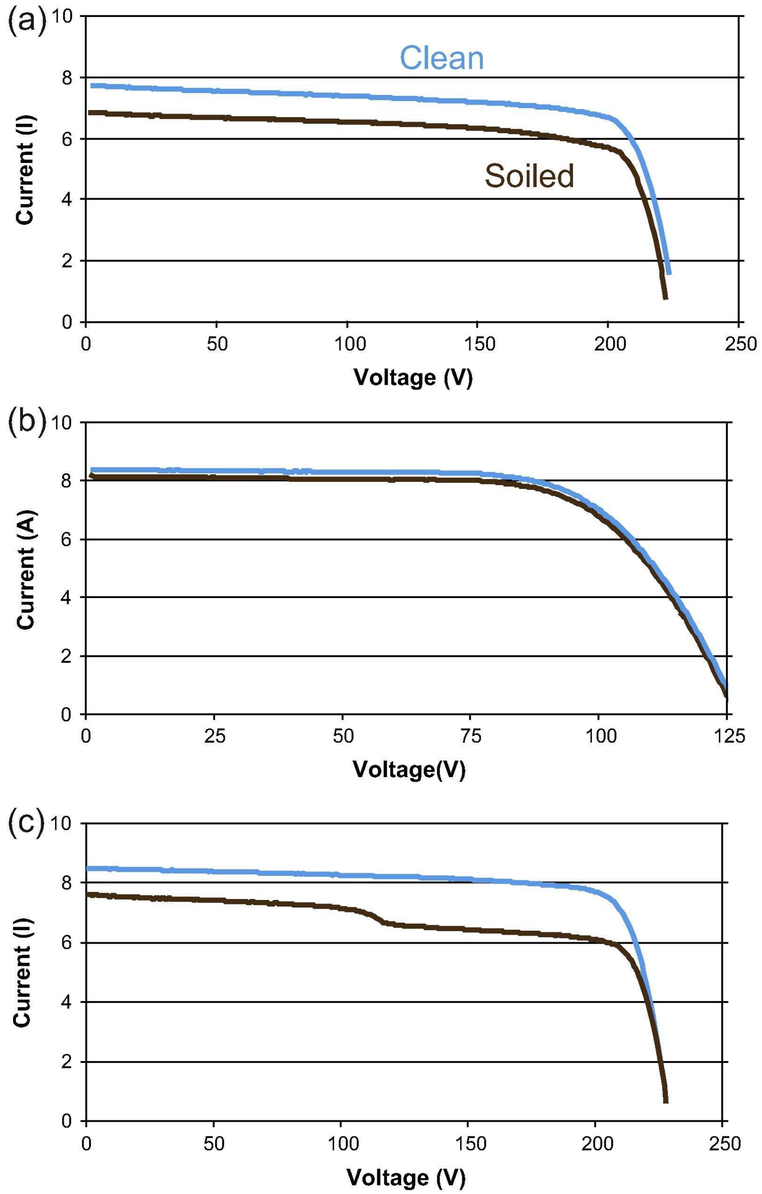
Desert sun in Qatar too hot for solar panels to work

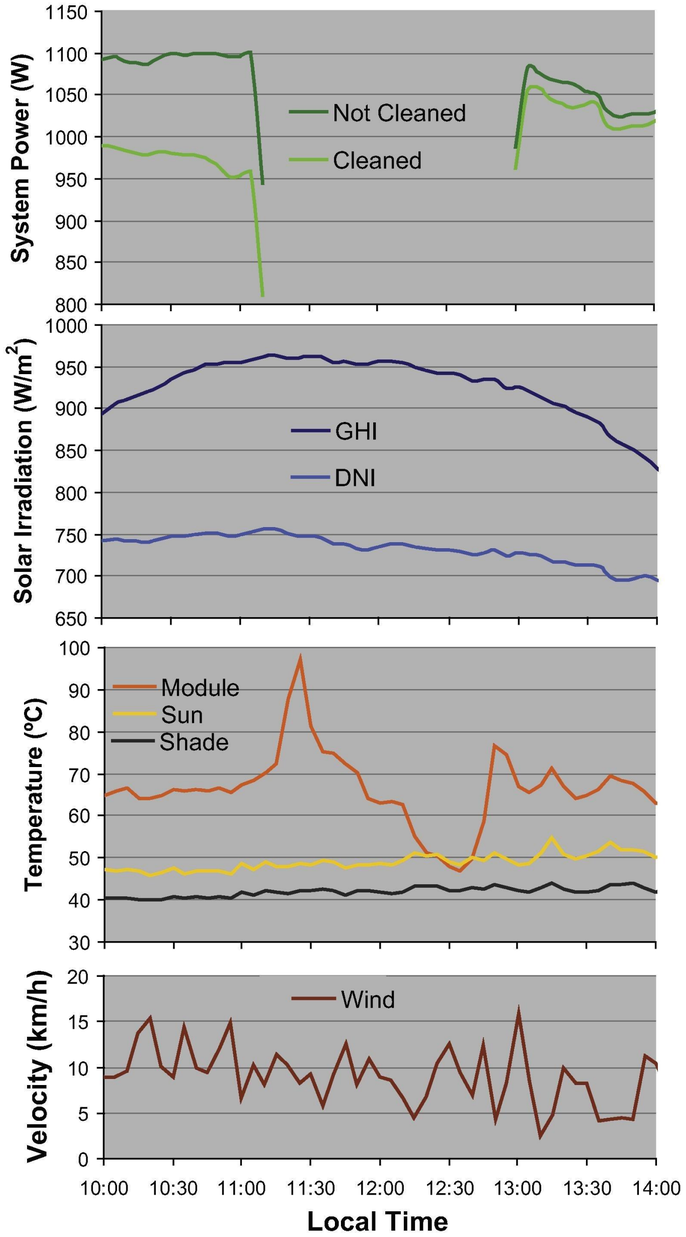
The efficiency of some panels could decline by 30 per cent as temperatures in the panels reached 75C
FADI AL-ASSAAD/REUTERS

Dust impact on solar energy production



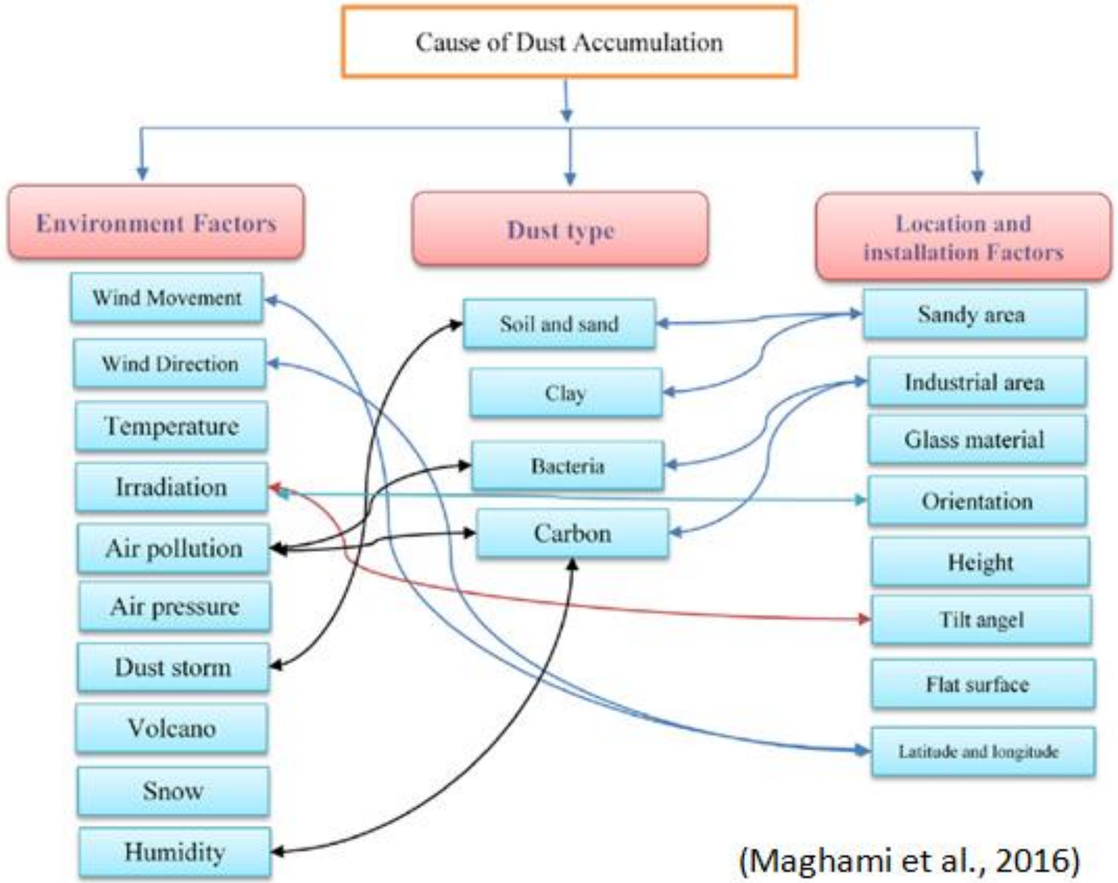
Soiling


(a)
Clean
Soiled
Current (I)
Voltage (V)
(b)
Current (A)
Voltage(V)
(c)
Current (I)
Voltage (V)


System Power (W)
Not Cleaned
Cleaned
Solar Irradiation (W/m2)
GHI
DNI
Temperature (ºC)
Module
Sun
Shade
Velocity (km/h)
Wind
Local Time

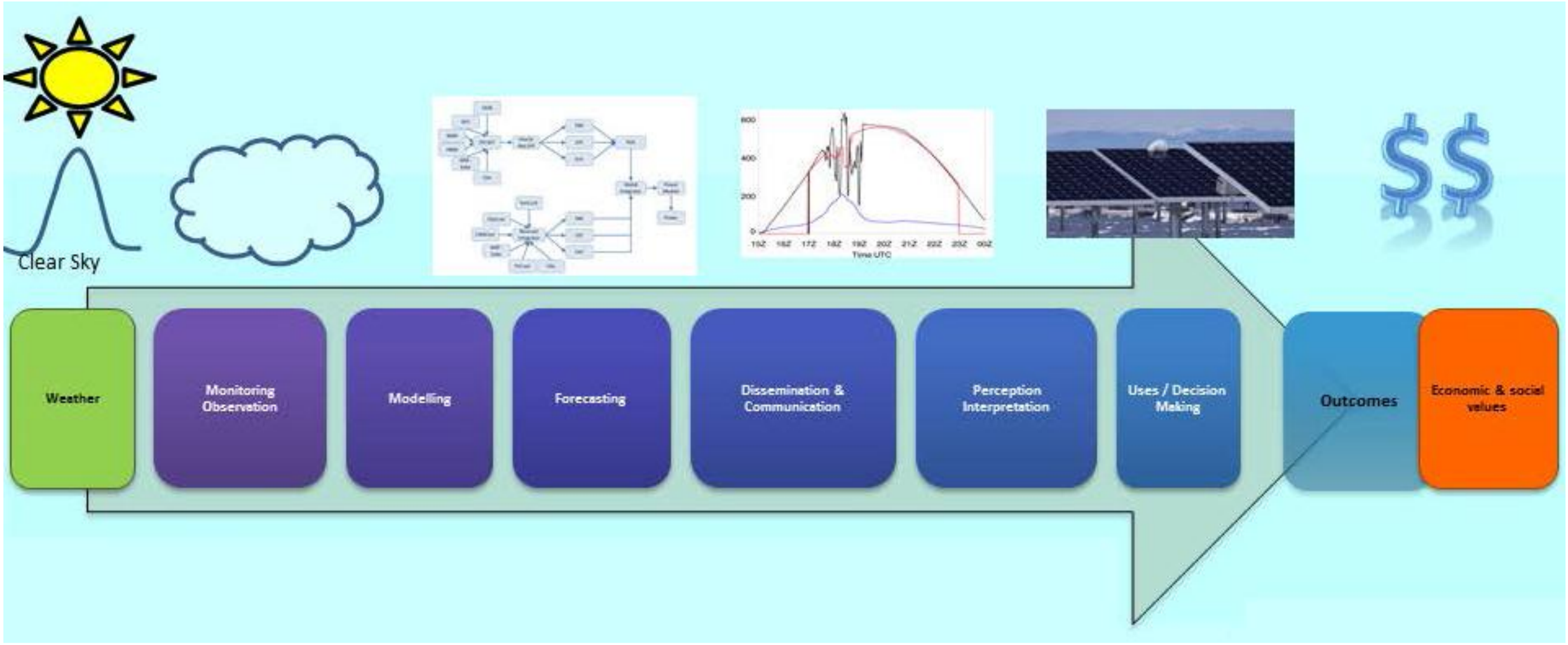
Dust accumulation and impacts

The amount of accumulated dust on the surface of the PV module affects the overall energy delivered from the PV module on a daily, monthly, seasonal and annual basis. The figure in the right presents the causes of dust accumulation. There are two inter dependent parameters that effect on characterization of soiling accumulation on solar panels, the property of dust and the local environment. Sometimes soil patches such as leaves, bird dropping sand dirt patches that block some cells of a PV module but not the whole, have a severe effect on PV modules. There are two types of soil shading on PV modules, namely, hard shading and softshading, while many ways recommended to cleaning PV from dust accumulation. As a result, dust products can be used for efficient solar energy exploitation by energy managing authorities, transmission and distribution system operators, solar farm investors and maintaners.



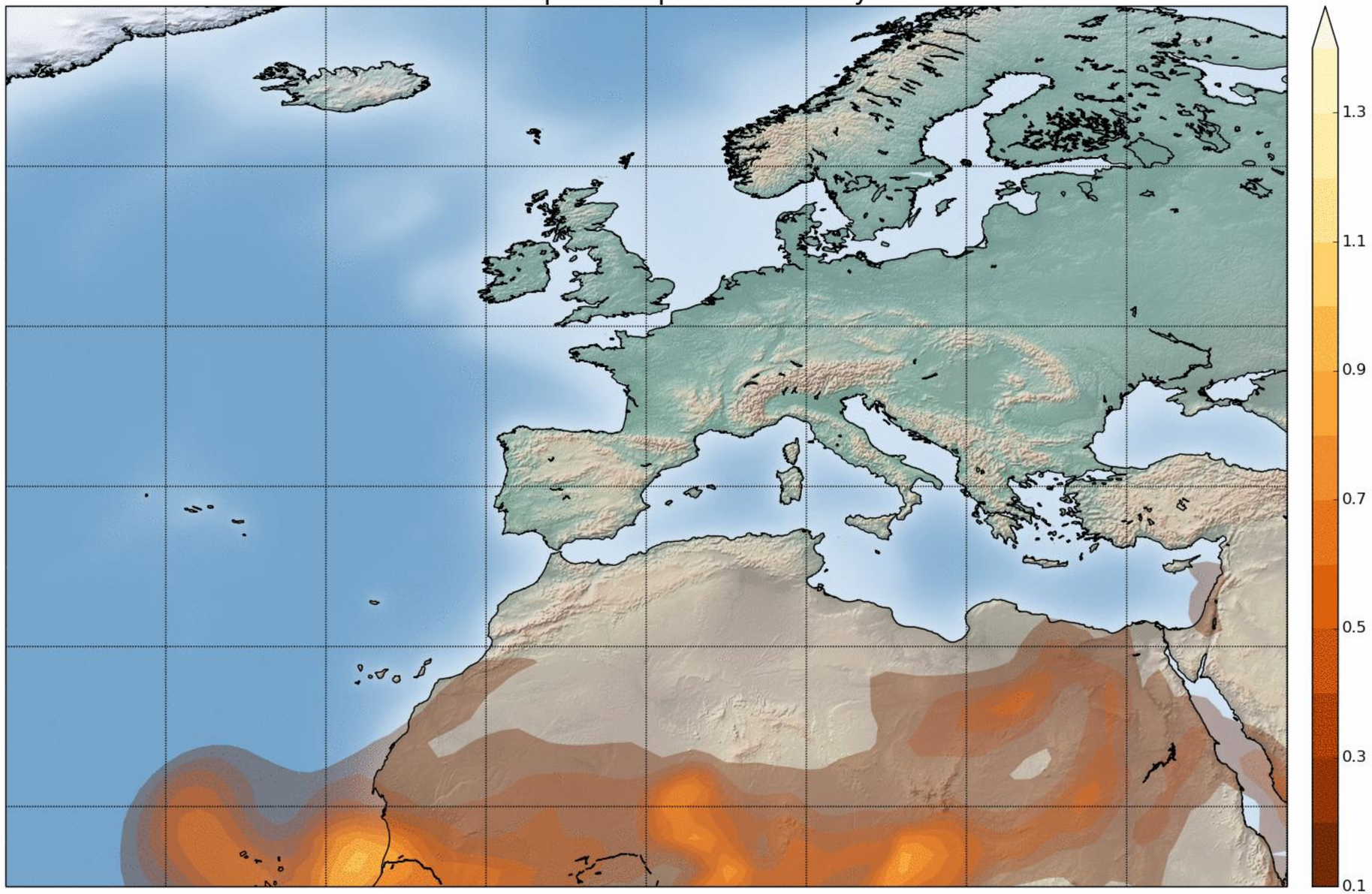
(Maghami et al., 2016)

Solar energy support applications



Accurate solar energy forecasts are crucial in the **energy market**, where on-the-spot energy prices are defined by supply and demand equilibriums. If the energy suppliers can have an accurate estimation for the solar energy production from the solar systems (e.g. 3 hours ahead), this provides them with a comprehensive advantage with clear economic benefits for their day-to-day market operations.

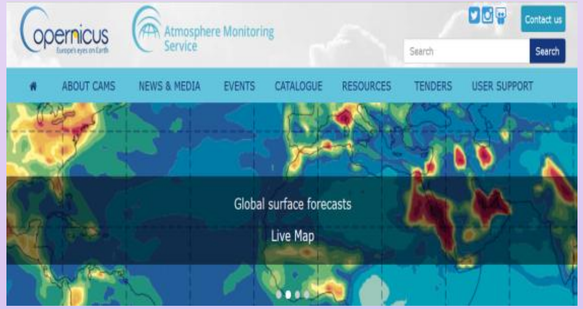
Dust modelling and forecasting



Energy management system

Inputs

Sentinel/EUMETSAT Satellite data



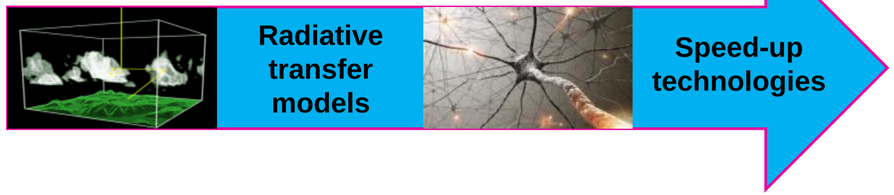
Copernicus atmosphere monitoring services

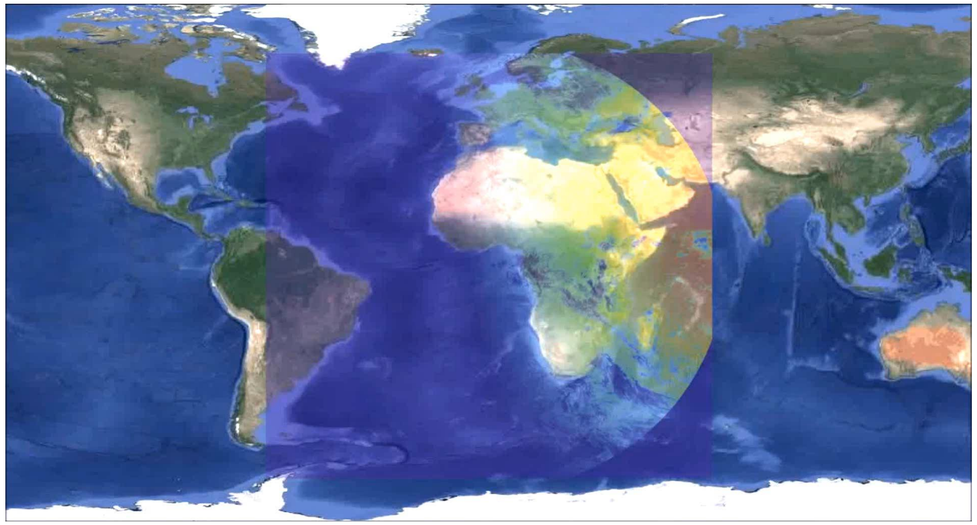
Actinometric platform

Initiatives

GEO GROUP ON EARTH OBSERVATIONS · GEOSS Global Earth Observation System of Systems · Atmosphere Monitoring Service · GEO CRADLE · Geo Vision for Energy (GEO-VENER) · Euro GEOSS

SENSE basics





System outputs

Realistic assessment of solar energy potential

Provision of real-time solar energy (GHI, DNI, PV) applications

Solar potential forecasts for energy production and planning

Applicability anywhere

Potential end-users

Public and private energy managing authorities

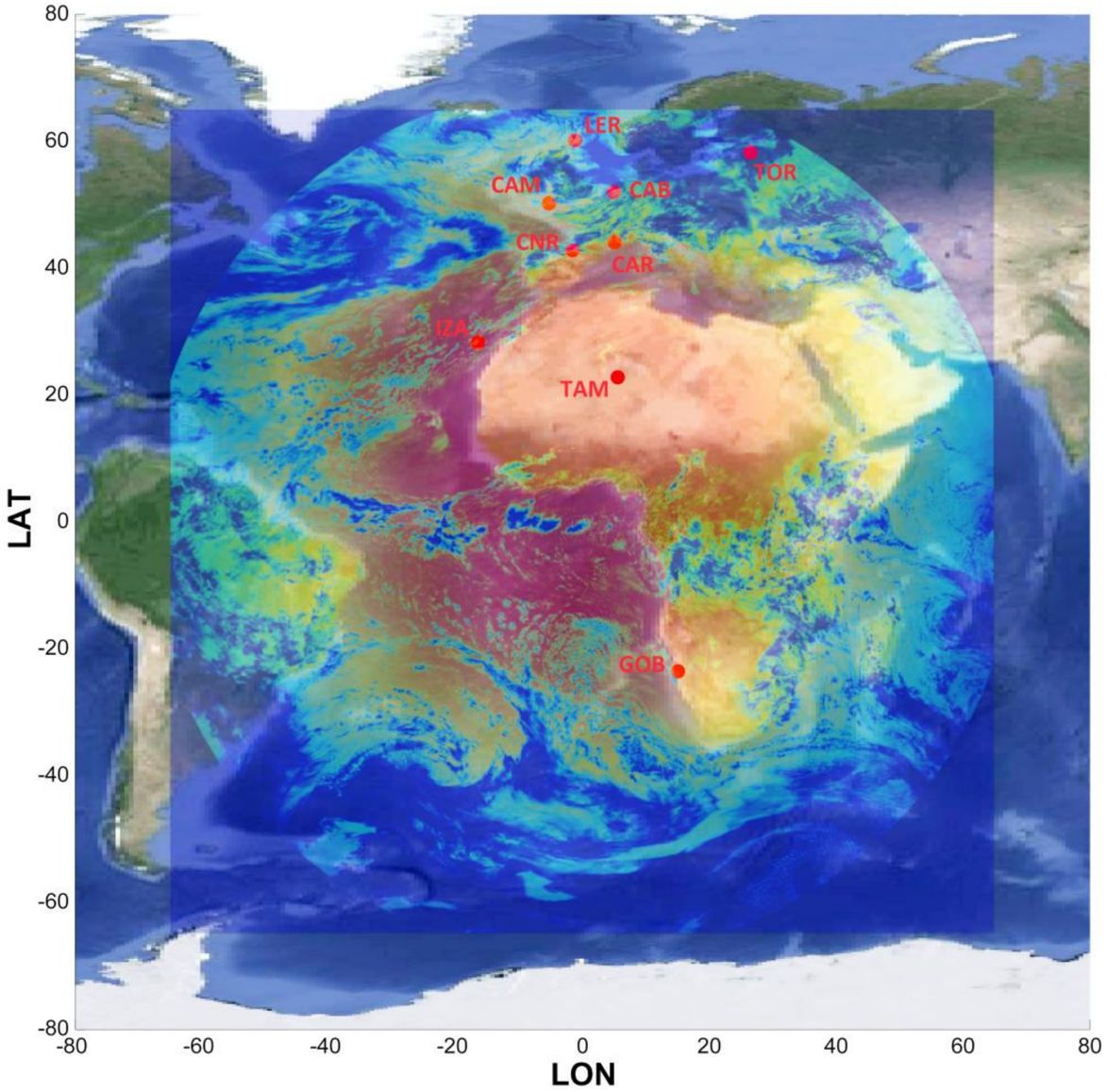
Energy and environmental political leadership

PV constructors

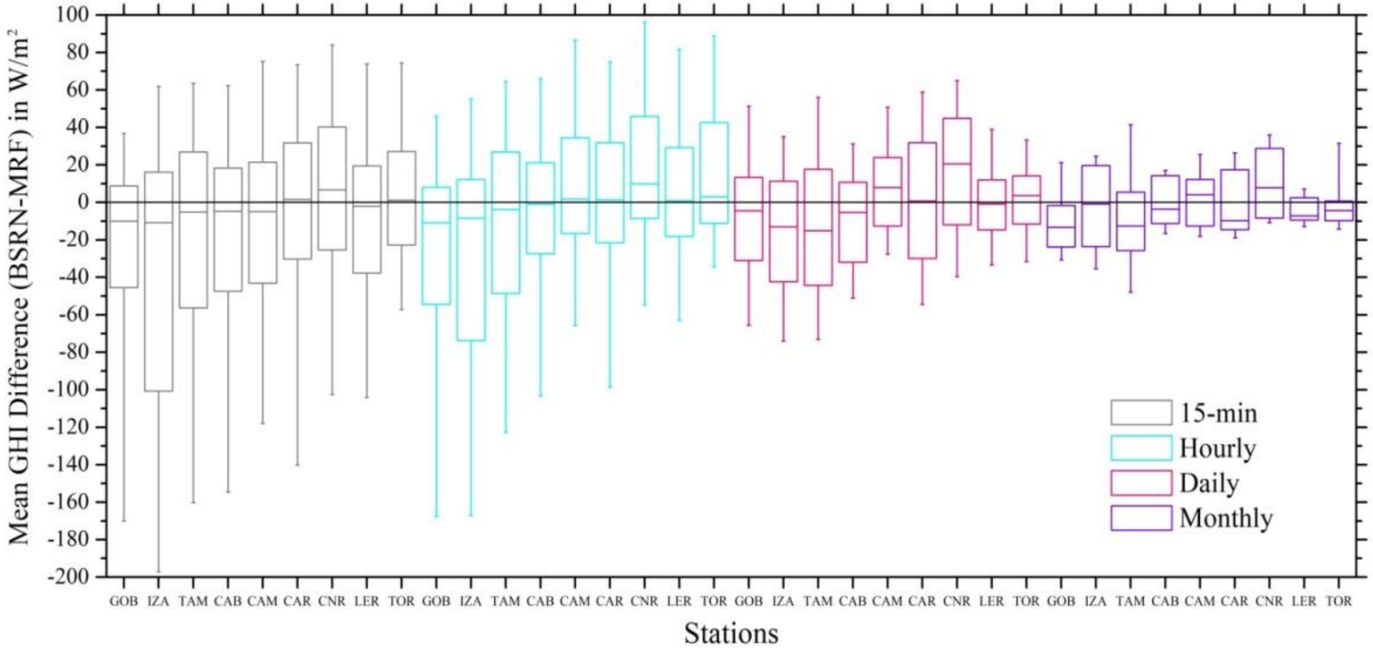
Energy investors, suppliers and users

Scientific community

Reliability of SENSE



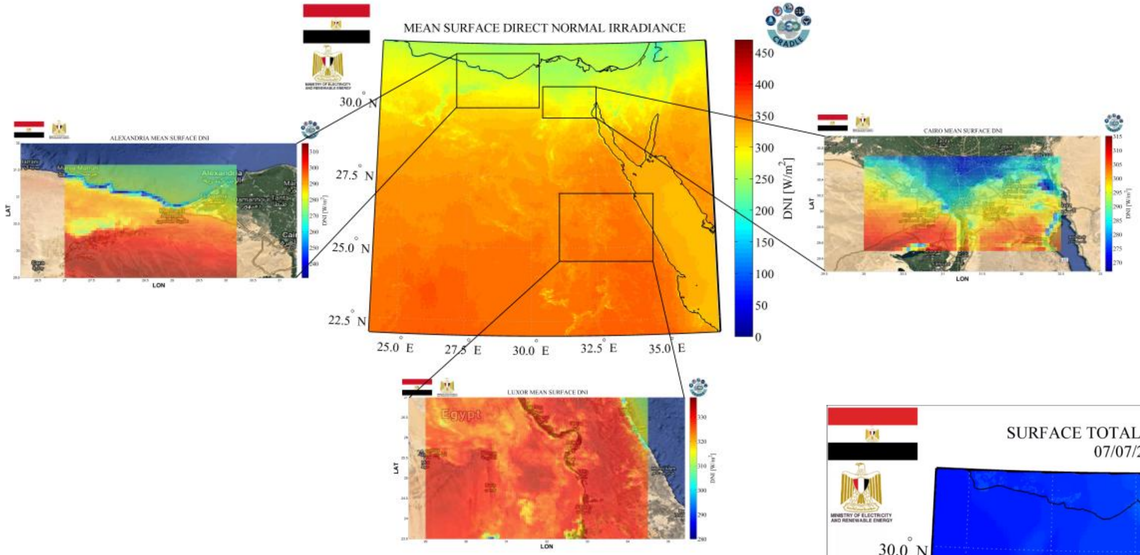
Mean GHI differences in W m^{-2} derived by SENSE as compared to the BSRN stations for various time horizons.



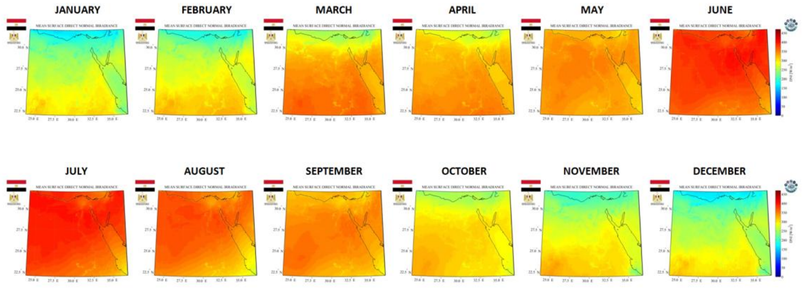
15-min:	-100 to 40 W/m^2
Hourly:	-70 to 40 W/m^2
Daily:	-40 to 30 W/m^2
Monthly:	-20 to 20 W/m^2

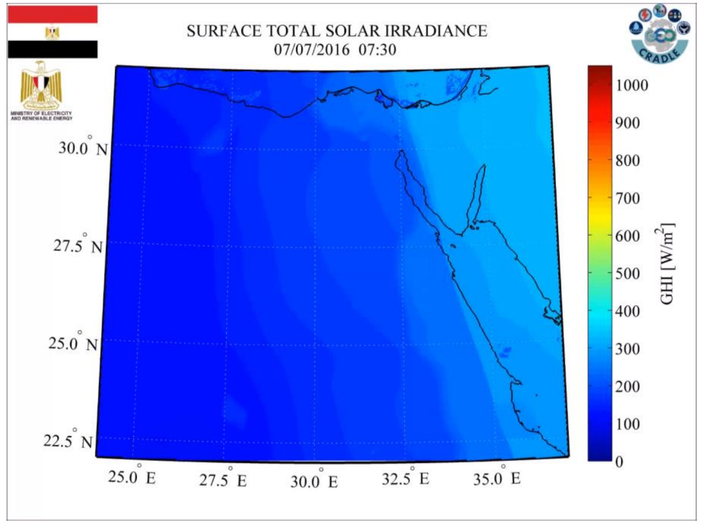
Solar energy applications using SENSE

Operational and solar atlas services

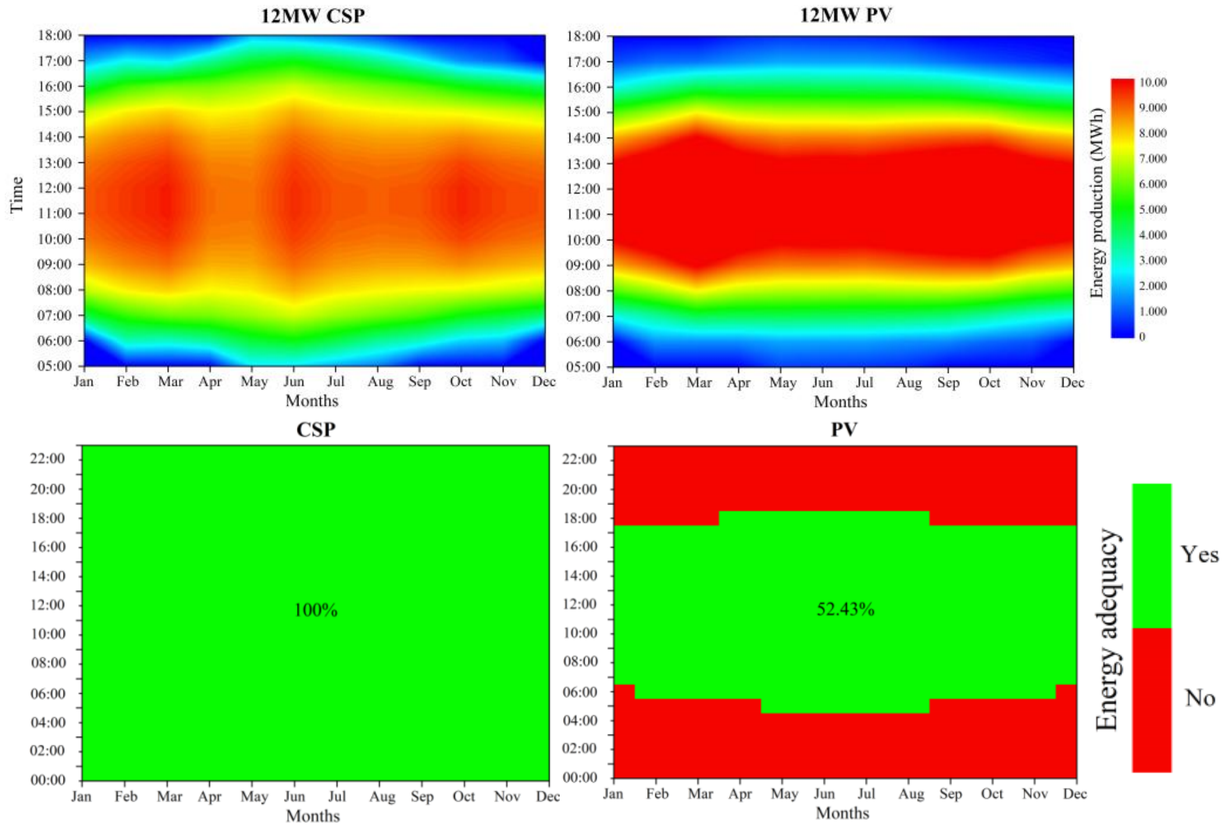


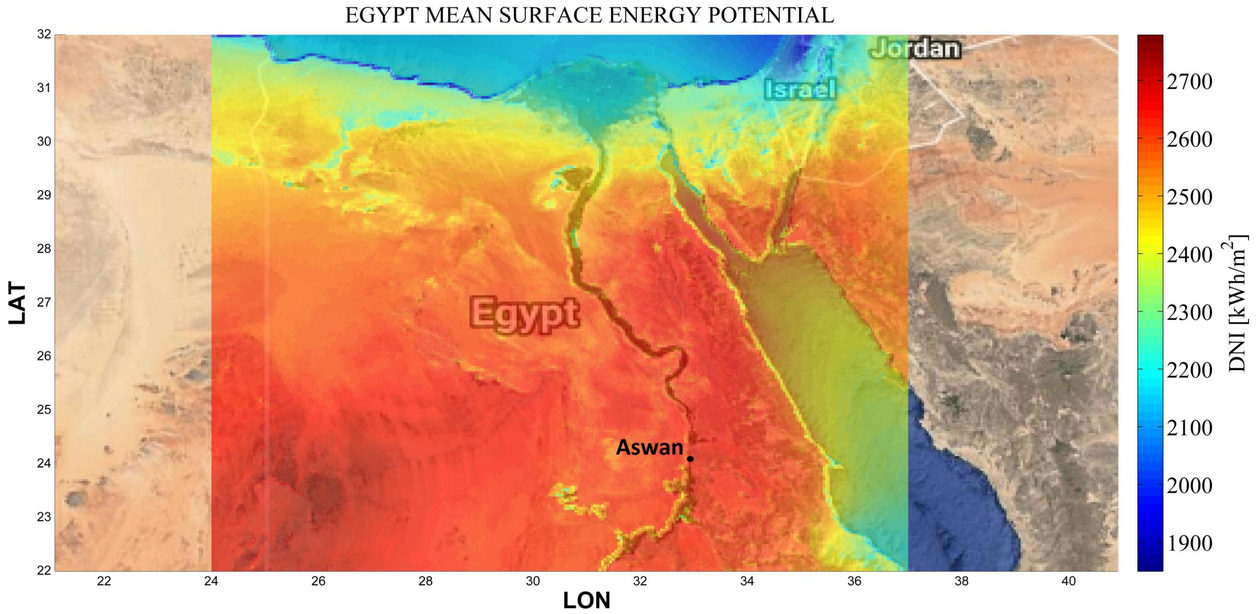
MINISTRY OF ELECTRICITY AND RENEWABLE ENERGY



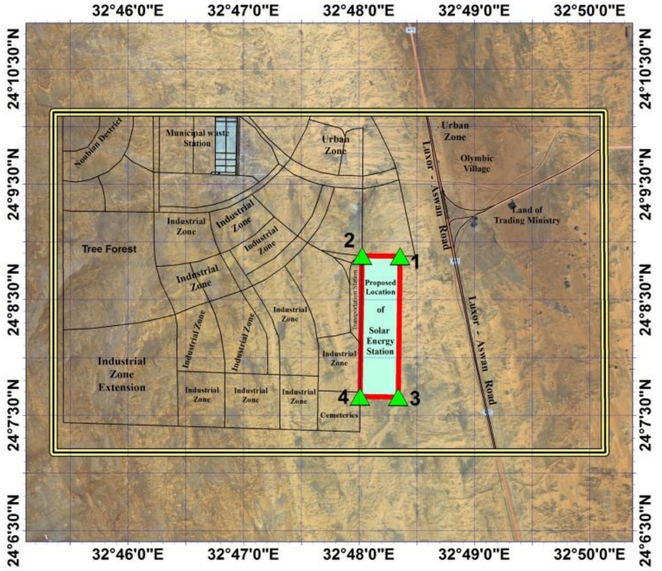


Solar energy applications using SENSE





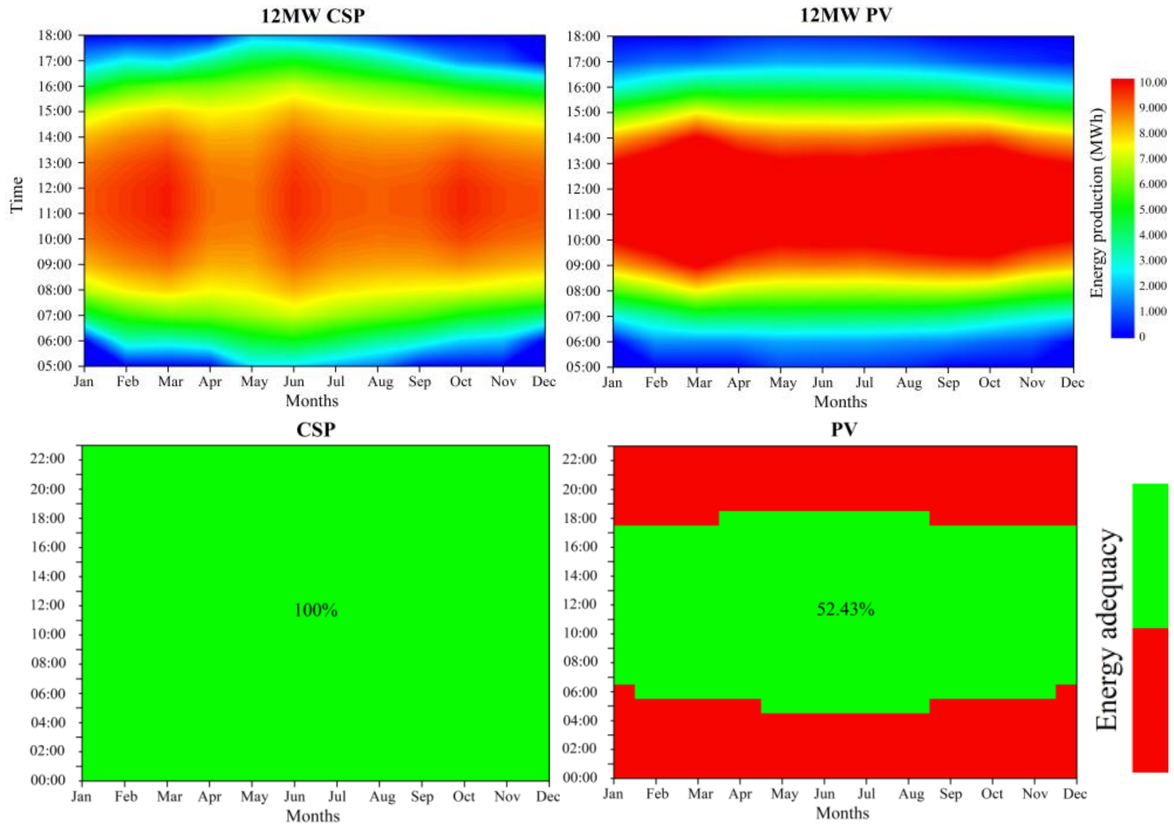
Development of business plan for establishment, operation and exploitation of a solar farm in Aswan (Egypt).



Area = 1260000 m2 (300 Feddan)

CORNERS	NORTH	EAST
1	N 24° 48' 05.54"	E 32° 48' 21.94"
2	N 24° 05' 52.27"	E 32° 48' 01.55"
3	N 24° 07' 59.07"	E 32° 48' 20.70"
4	N 24° 07' 39.18"	E 32° 48' 00.97"

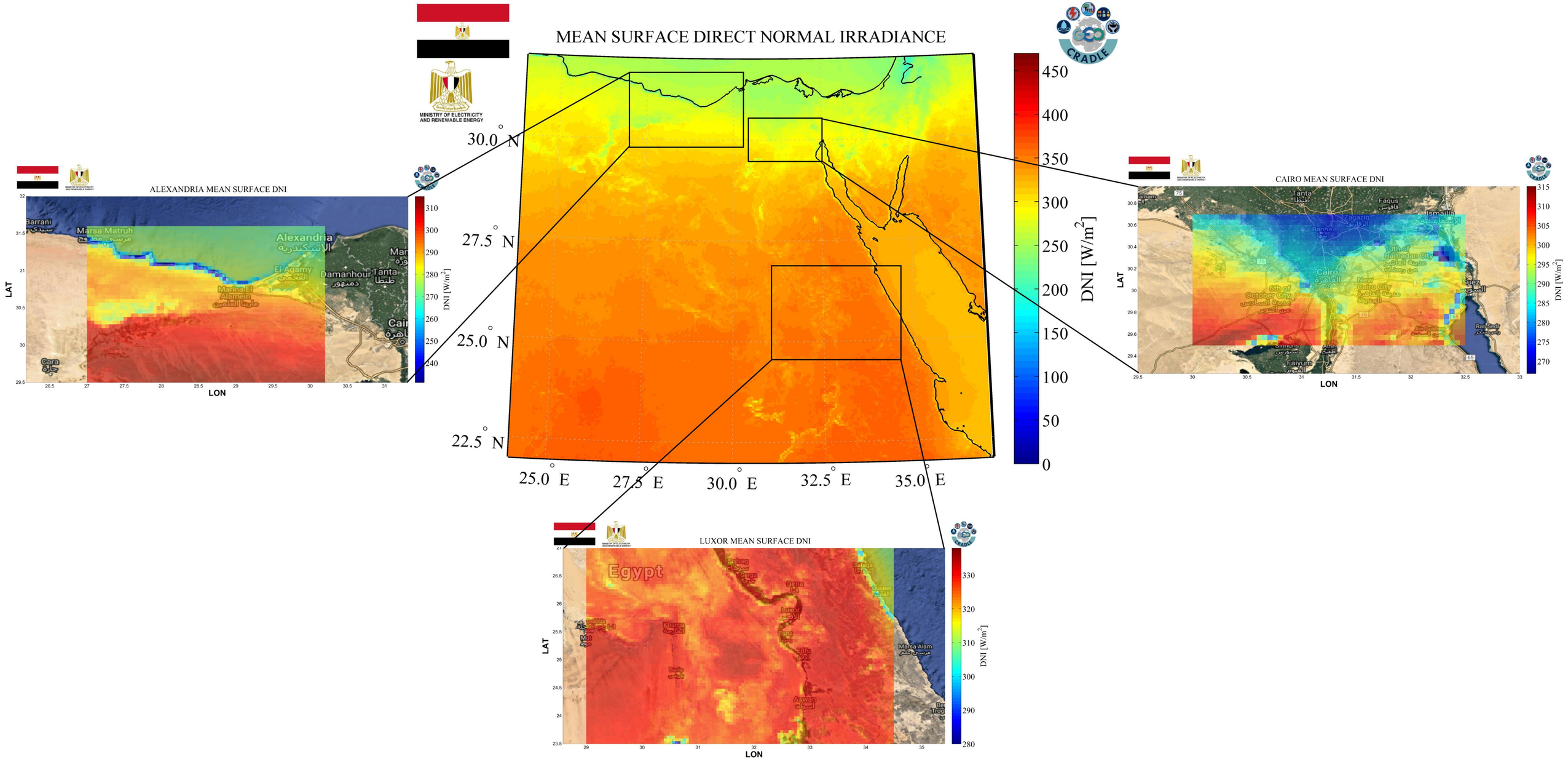
Solar energy applications



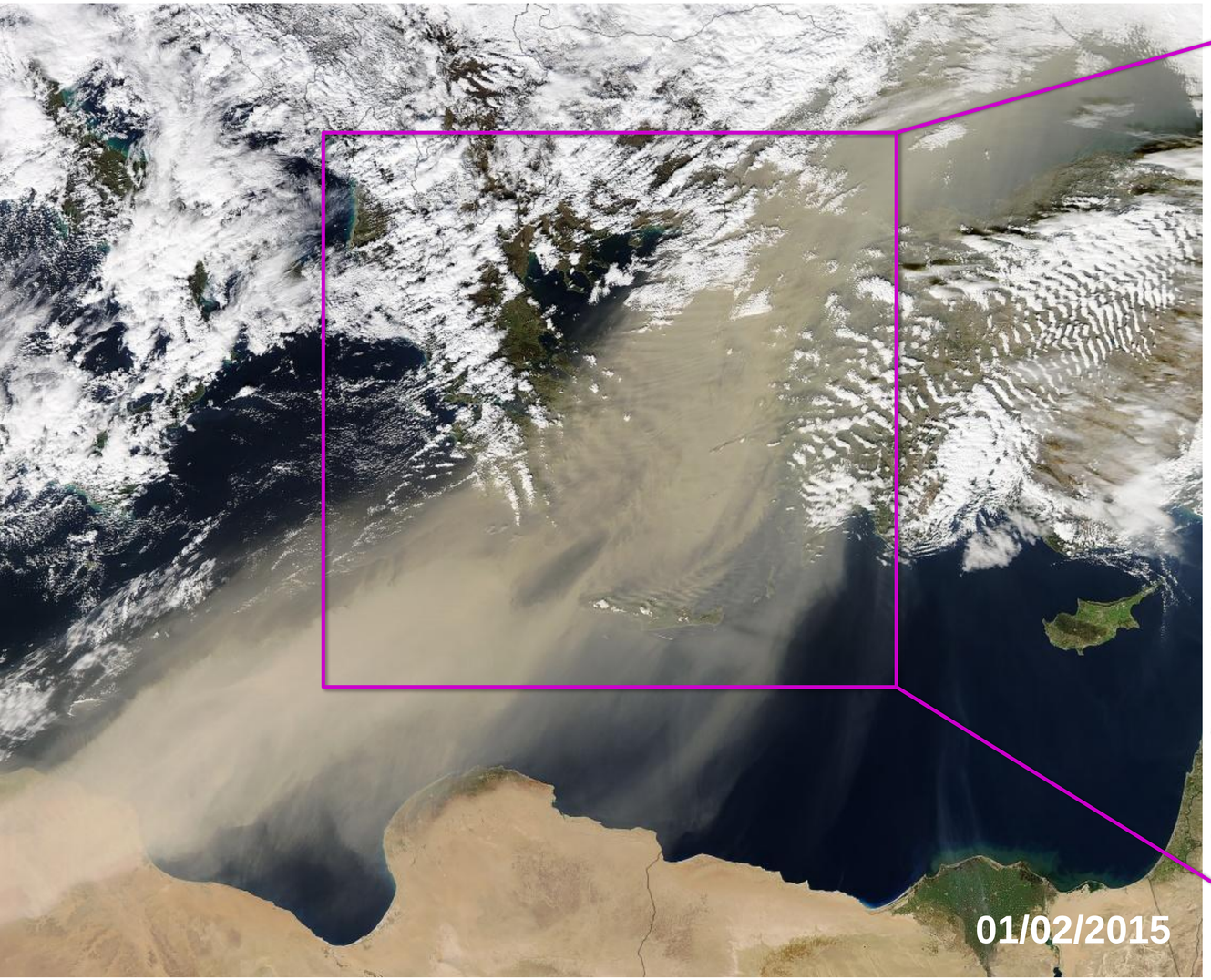
Development of business plan for establishment, operation and exploitation of a solar farm in Aswan (Egypt).

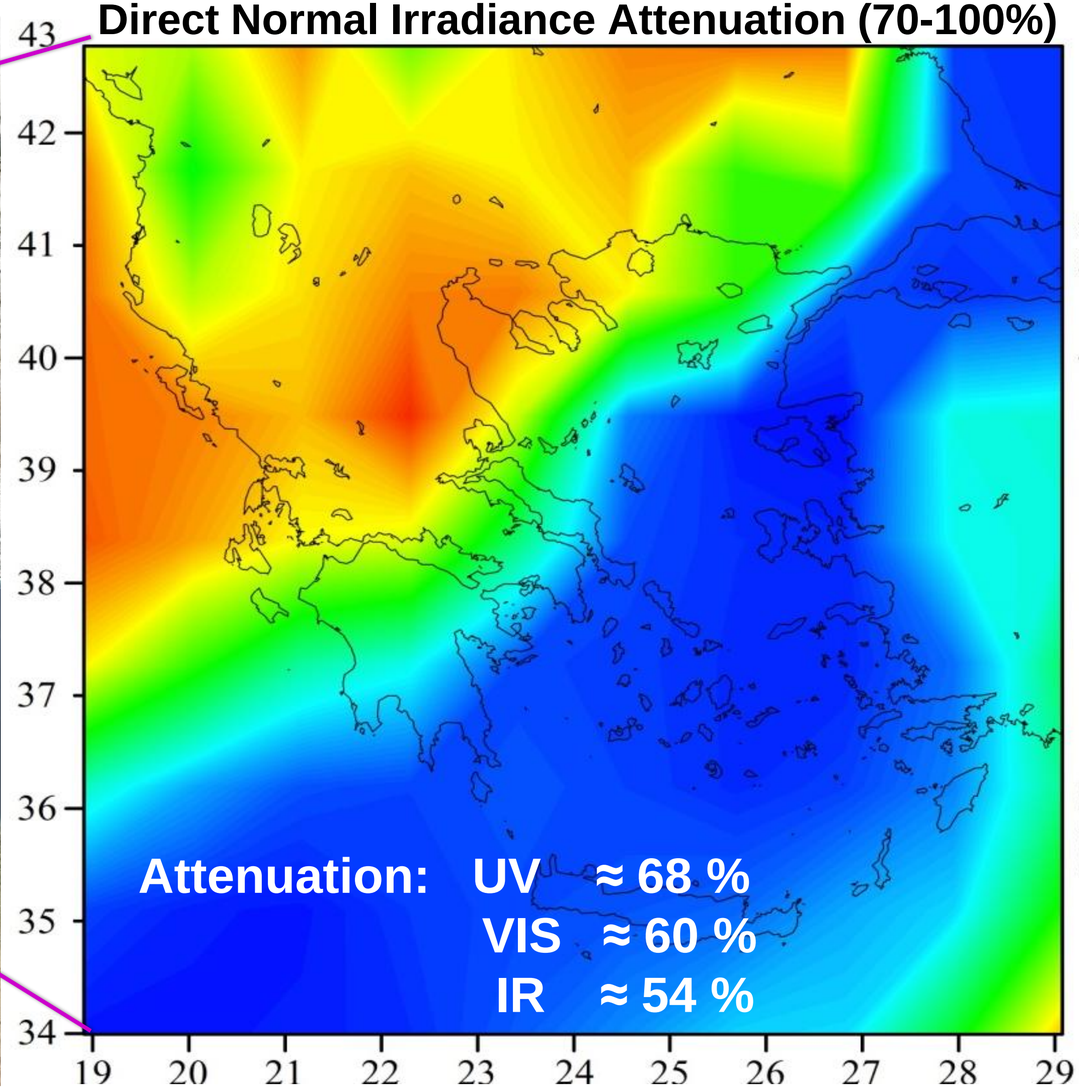
- Night electricity cost
- Actual revenue over the lifetime of solar systems
  - Annual flow of incoming-outgoing funds
  - Break-even of solar energy investments

Solar Atlases using Earth Observation

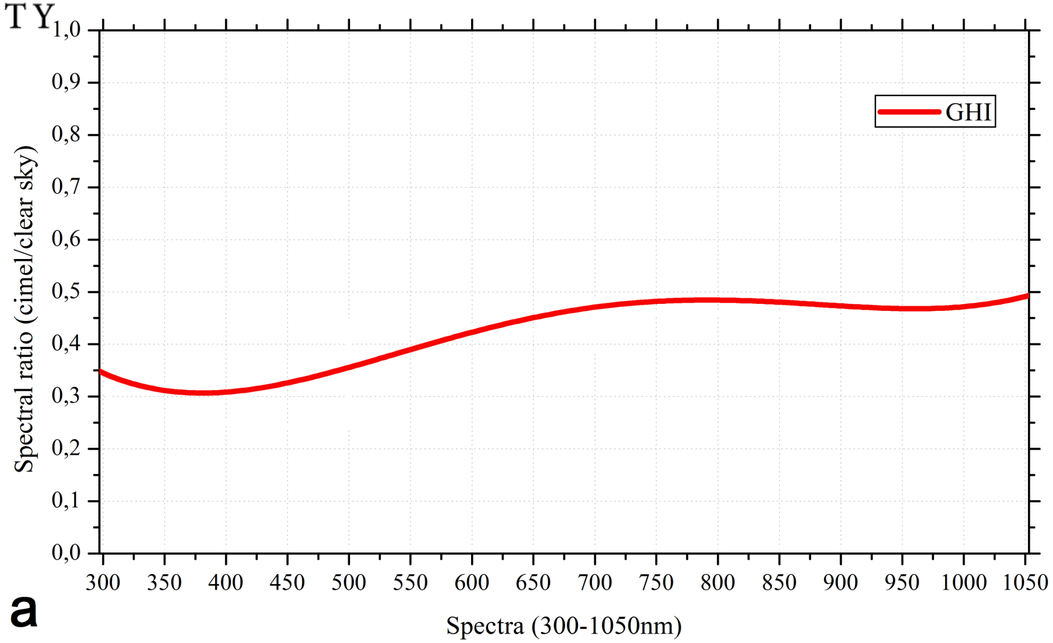


Dust Impact on solar energy

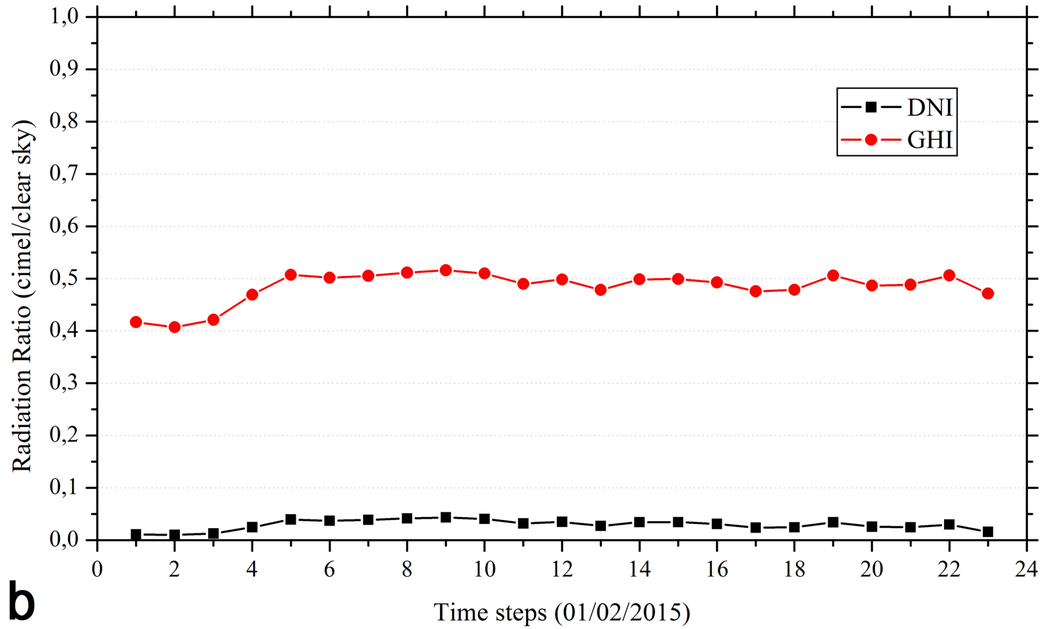




Spectral impact of dust on solar energy



a



b

Study region - Egypt

Relevant action through the inDust project

- European cooperation in science and technology (COST action).

- Establish a network involving research institutions, service providers and potential end users of information on airborne dust that can assist the diverse socio-economic sectors affected by the presence of high concentrations of airborne mineral dust.

Forecasting dust impact on solar energy in Egypt (FINDING)

- Investigation of dust effects on solar energy estimations and forecasting.

- Application for the local energy managing authorities

- Social-economic impacts

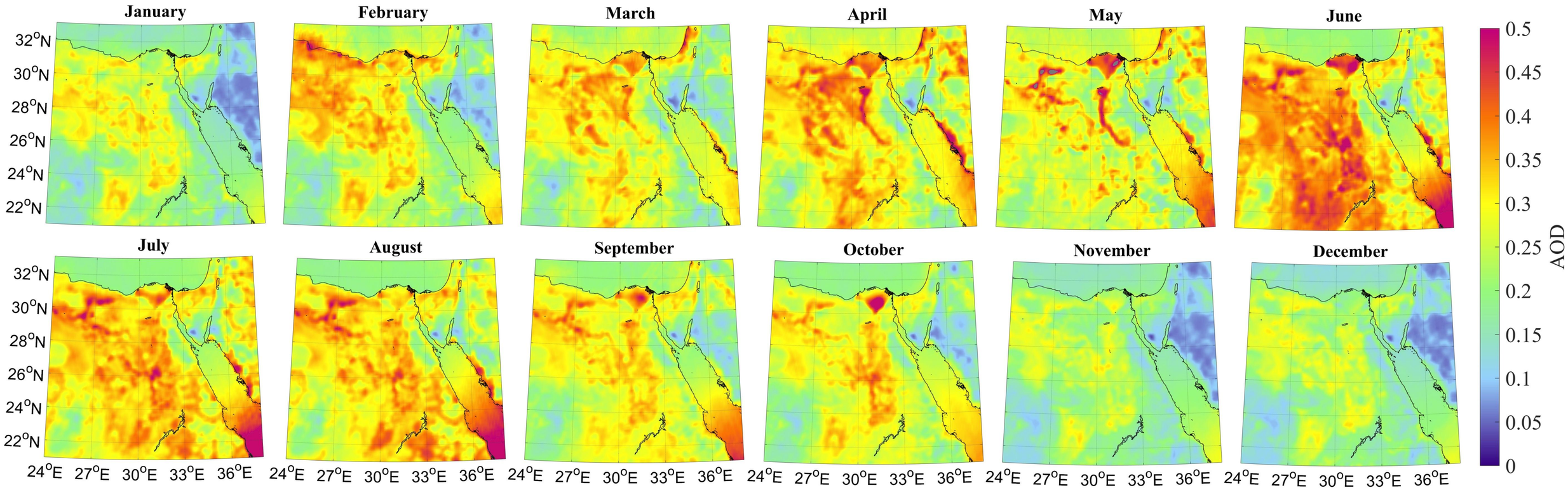
MINISTRY OF ELECTRICITY AND RENEWABLE ENERGY

MAGDI YACOUB HEART FOUNDATION
ASWAN HEART CENTRE

NREA

Climatology of AOD in Egypt

AOD = 0.034 – 0.966

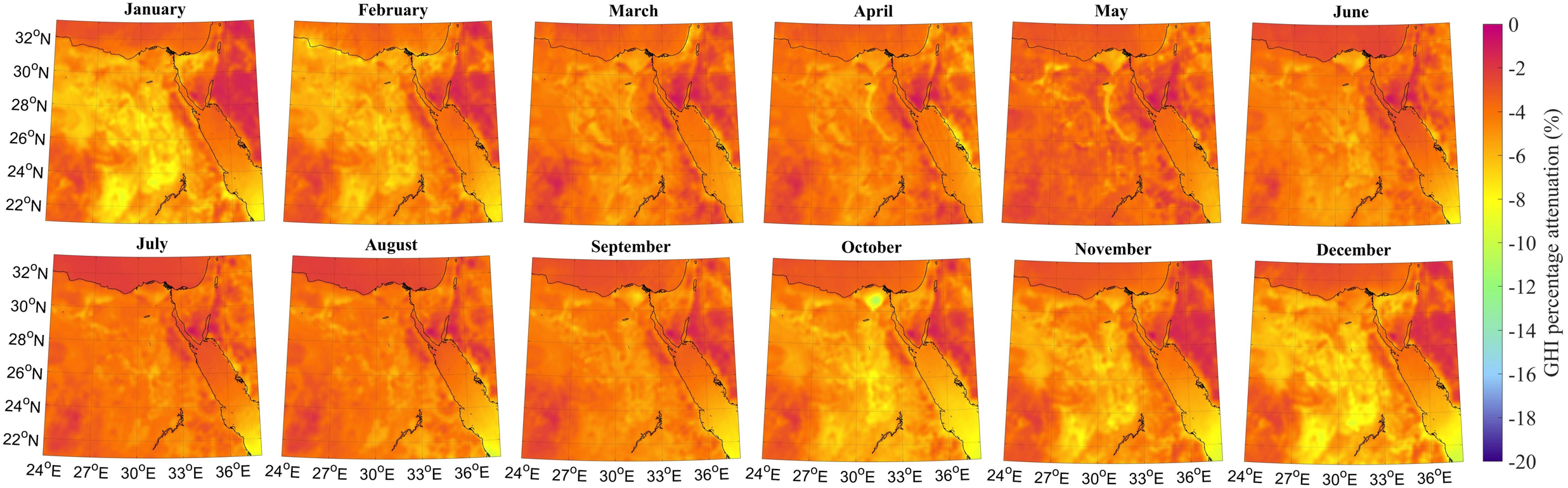


Monthly averages of AOD at 550 nm using the Dark Target and Deep Blue Combined Level 2 product of MODIS for the period 2002 - 2017.

Spatial resolution = 0.1 x 0.1 degrees (≈ 10 km)

Impact on GHI

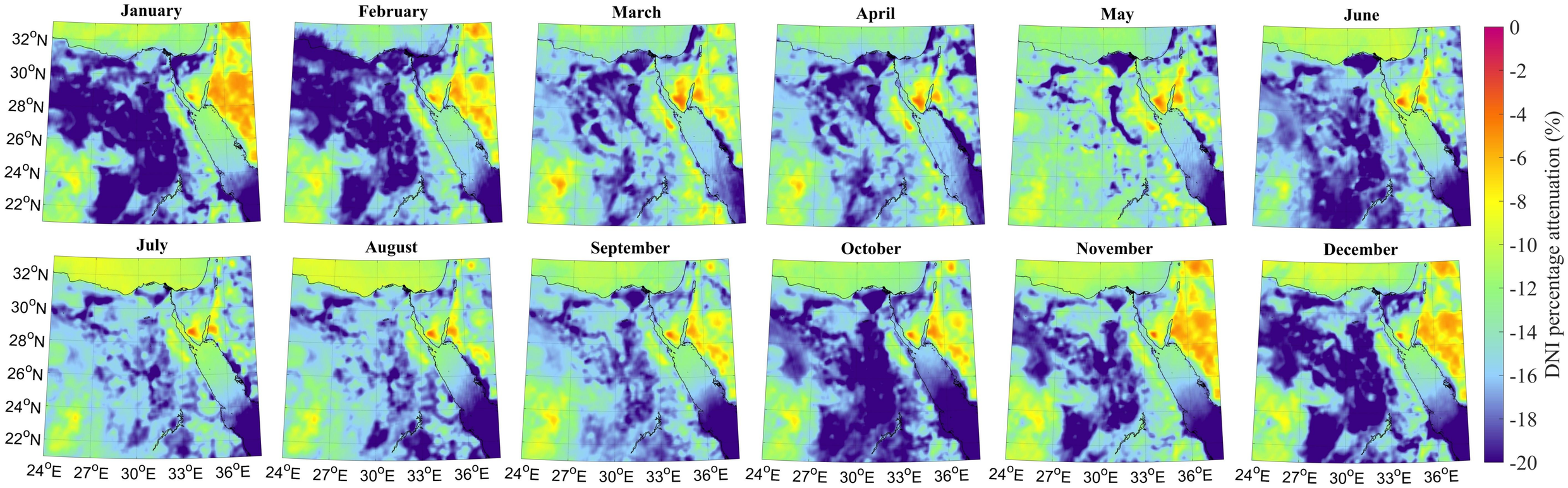
GHI attenuation = -0.7 – -12.9 %



Monthly averages of GHI solar energy percentage attenuation
relative to the aerosol-free simulations under MODIS-based AODs.

Impact on DNI

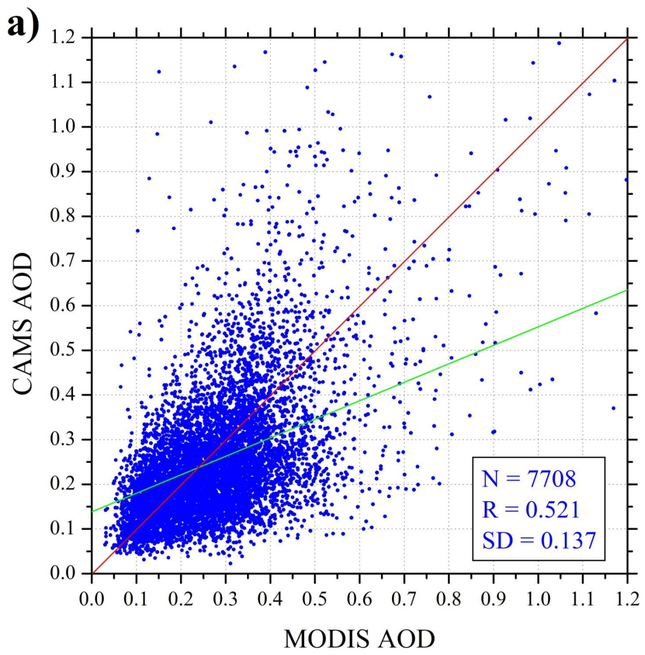
DNI attenuation = -2.9 – -41.0 %



Monthly averages of DNI solar energy percentage attenuation
relative to the aerosol-free simulations under MODIS-based AODs.

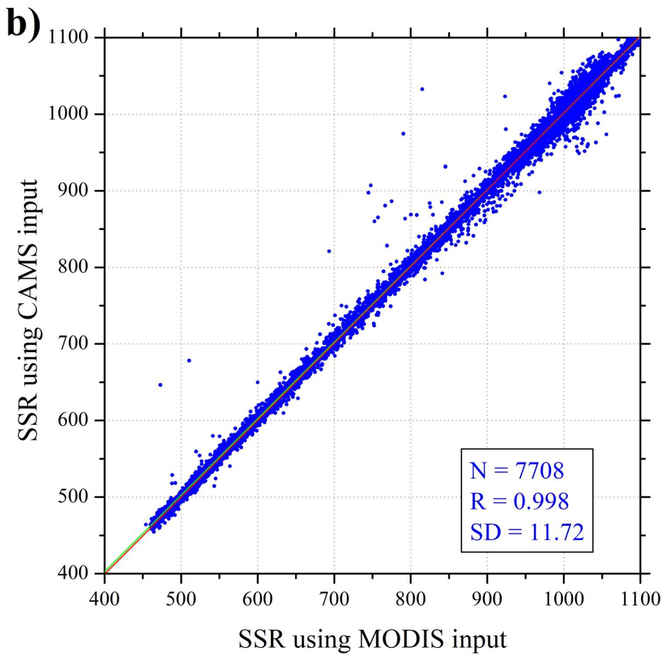
Forecasting reliability

AOD differences



CAMS forecasted AOD
vs
MODIS observations

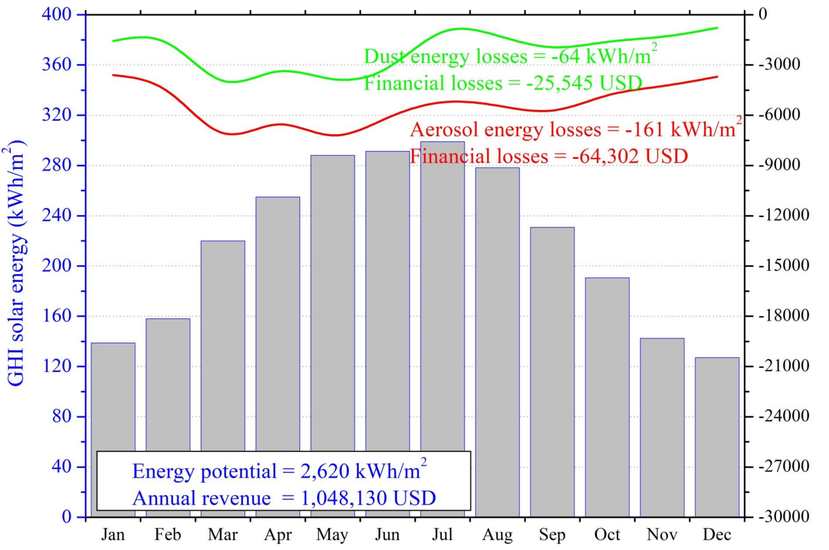
SSR differences



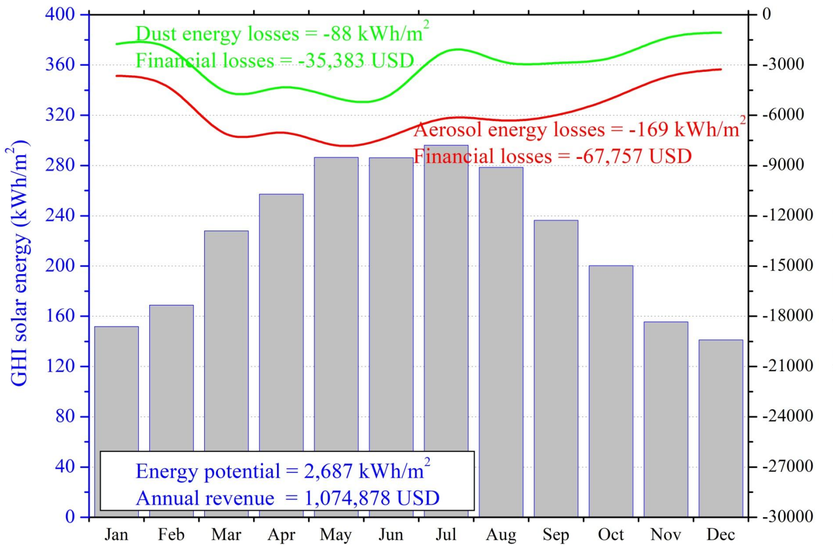
SENSE with CAMS inputs
vs
SENSE with MODIS
observations

Forecasting dust impact on solar energy

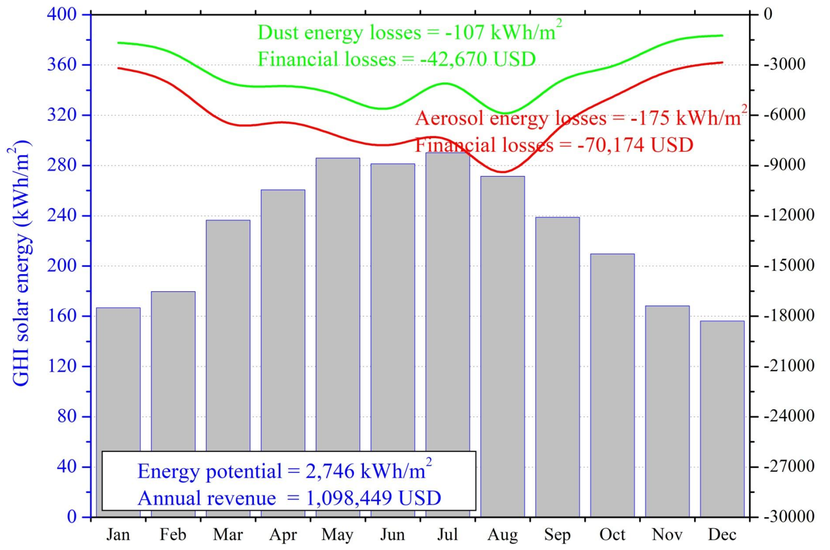
Photovoltaic (PV) installations



Cairo



Asyut

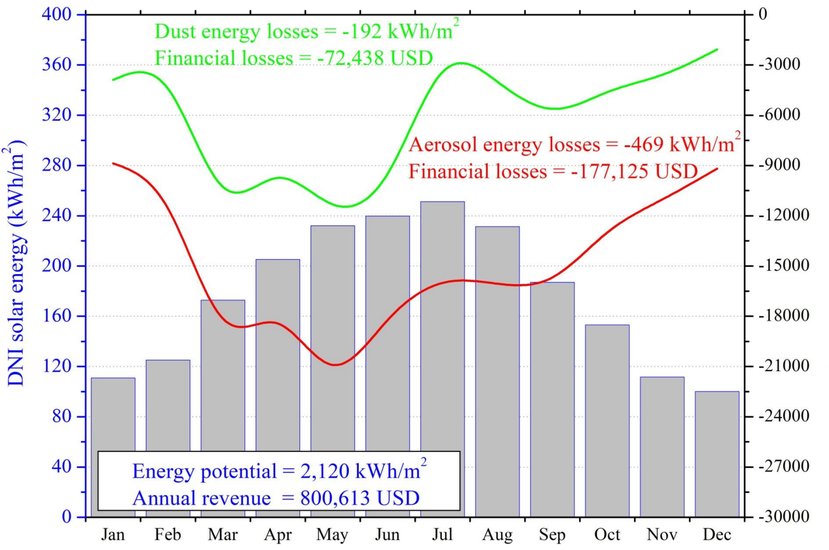


Aswan

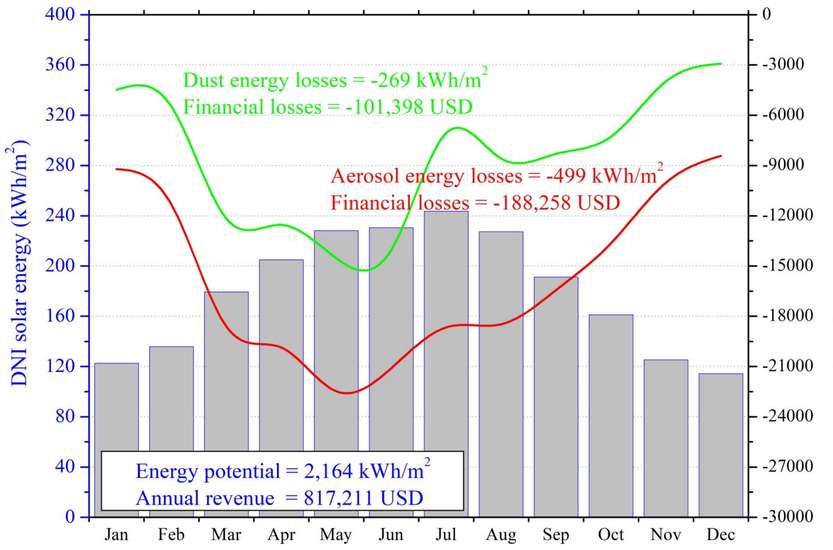
Simulated scenario: 10 MW (produces annually almost 25,687 kWh or 976,000 USD)

Forecasting dust impact on solar energy

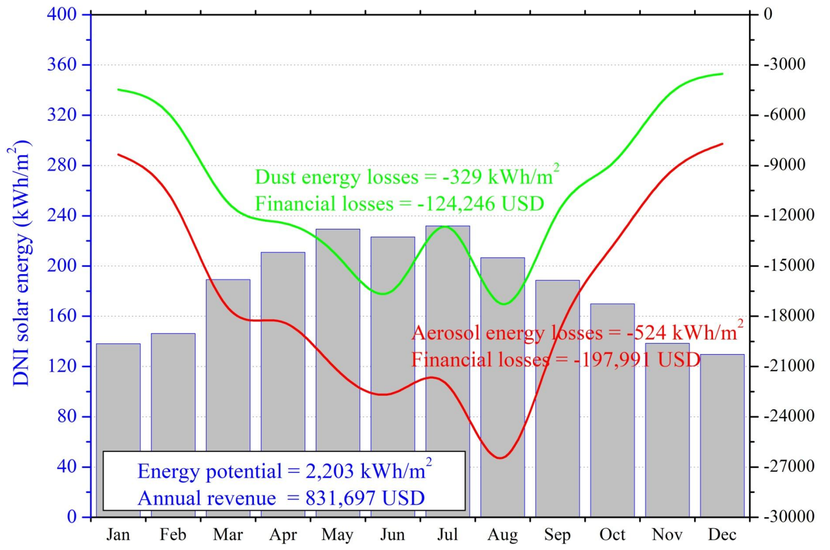
Concentrated Solar Power (CSP) plants



Cairo



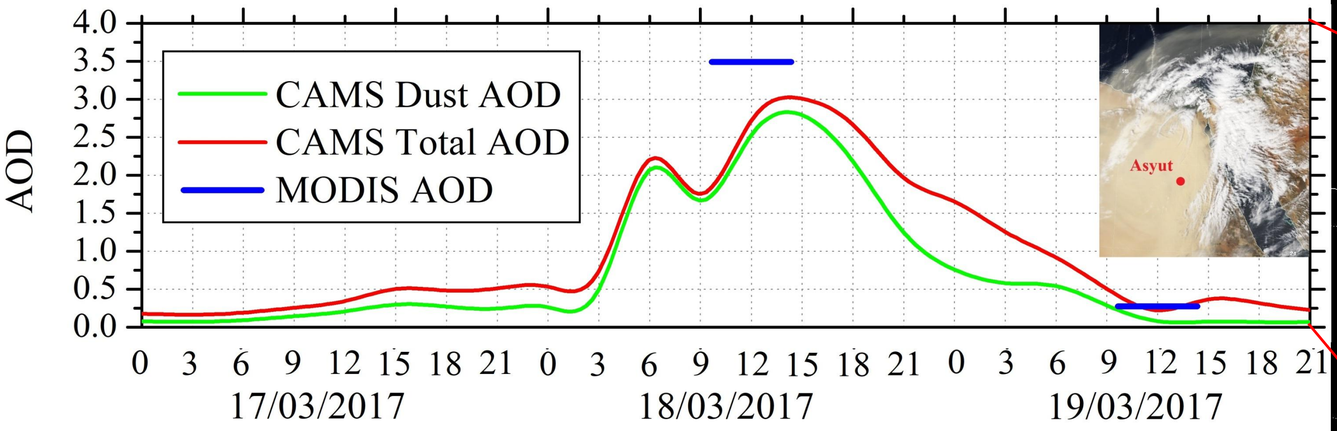
Asyut

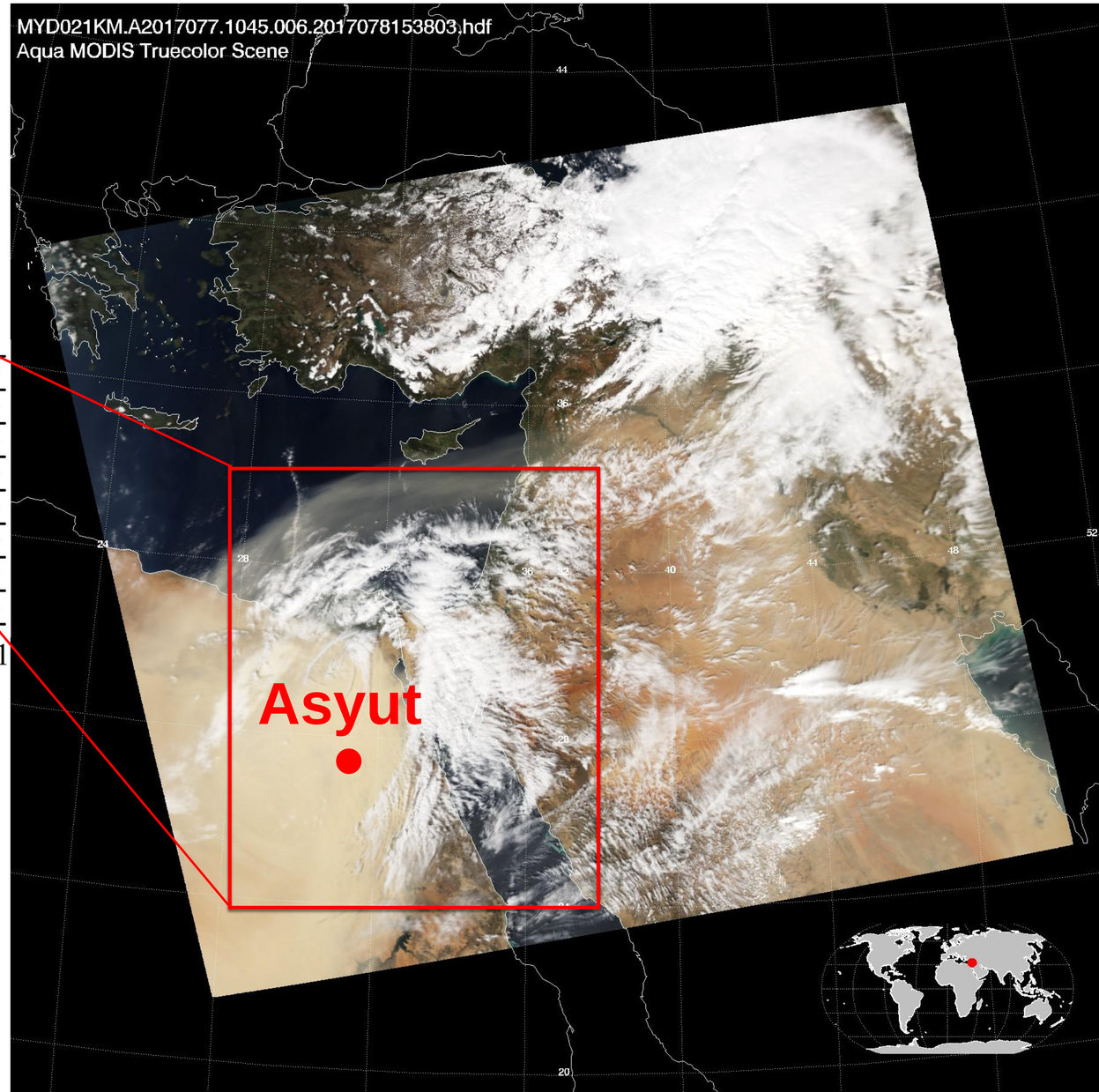


Aswan

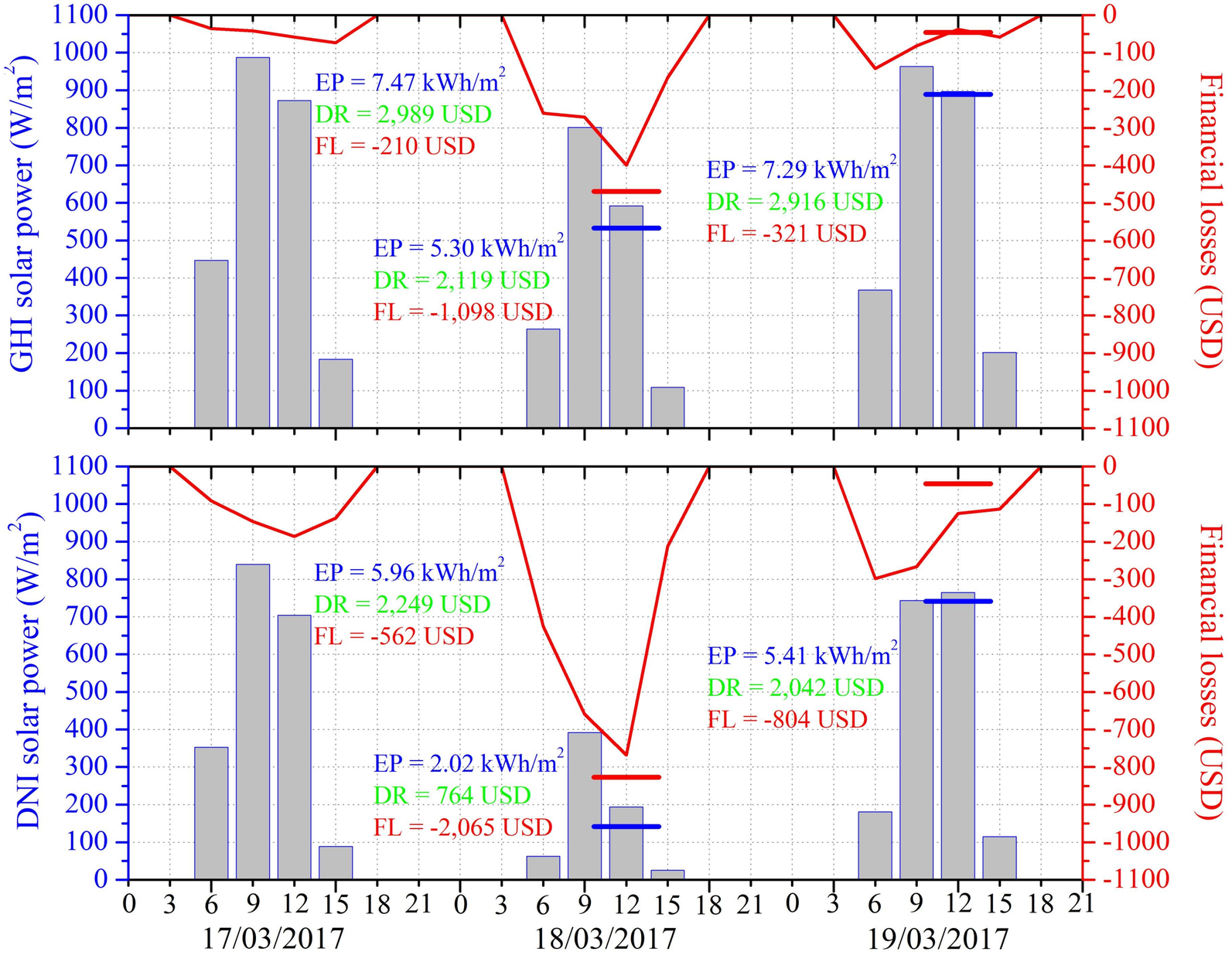
Simulated scenario: 10 MW (required area = 130,000-150,000 km^2 for PV and 280,000-360,000 m^2 for CSP)

Forecasting **extreme** dust impact on solar energy





Forecasting **extreme** dust impact on solar energy

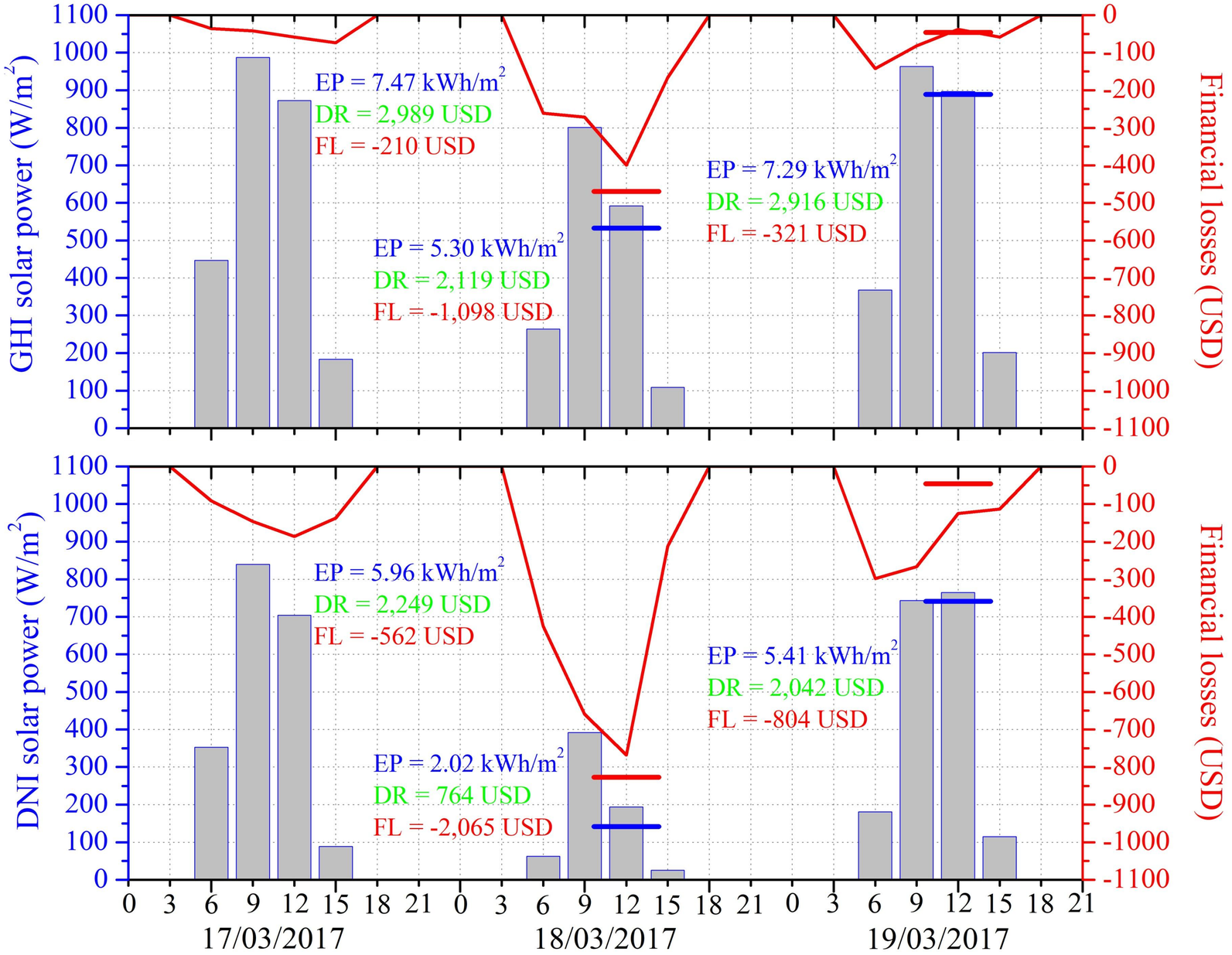


EP = Energy production

Under preparation
DR = Daily revenue
FL = Financial losses

The blue insets show the solar power (and FL in red), using as input the MODIS observations.

Forecasting **extreme** dust impact on solar energy



EP = Energy production

Under preparation
DR = Daily revenue
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The blue insets show the solar power (and FL in red), using as input the MODIS observations.

Conclusions

Solar energy management systems (e.g. SENSE) using EO dust and energy data are able to provide:

- Realistic assessment of solar energy potential.
- Provision of solar energy applications of high precision in real time.
- Solar potential forecasts for efficient energy planning and electrical production control.

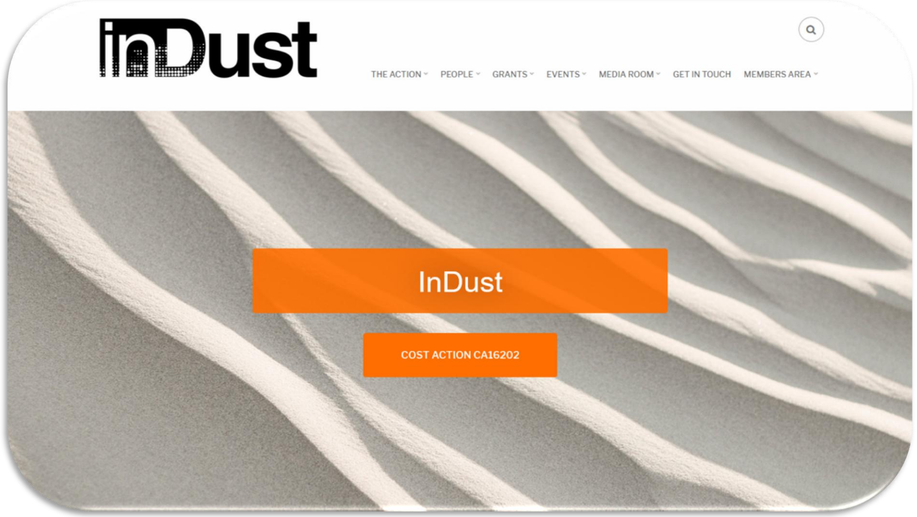
Major applications & contribution to emerging technology

- **Location studies** for the placement of PV and CSP installations.
- **Large scale** and **precise solar energy calculations** to assist public authorities in **energy planning** policy.
- Supporting the work of **various scientific communities**.
- Provision of specialized data of high spectral precision for private and public sectors dealing with **health protection**, **energy consumption** and **solar energy exploitation**.

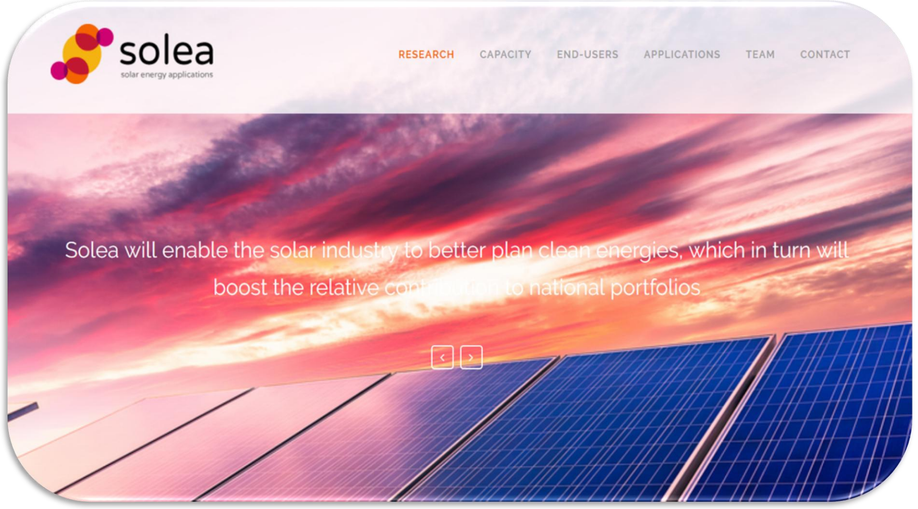
The exploitation of EO data through GEO activities and SENSE will provide access to advanced solar energy related products, in support to large scale solar farm projects, grid operators, national and private electrical transmission and handling entities, so as to guarantee the uninterrupted energy flow and the power grid stability.

Relevant publication and portals

www.cost-indust.eu



http://solea.gr/



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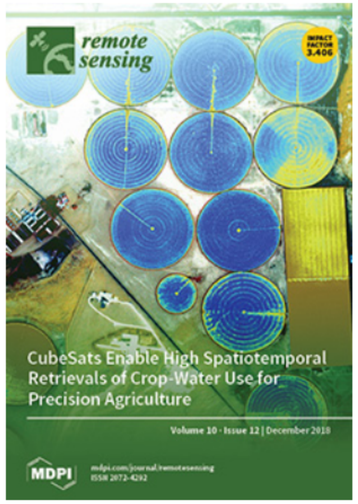
Volume 10, Issue 12



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Earth-Observation-Based Estimation and Forecasting of Particulate Matter Impact on Solar Energy in Egypt

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In 14 and a half seconds, the sun provides as much energy to Earth as humanity uses in a day.