Ateliers expérimentaux Climat et Environnement CLE 2017

Du rayonnement à la production photovoltaïque

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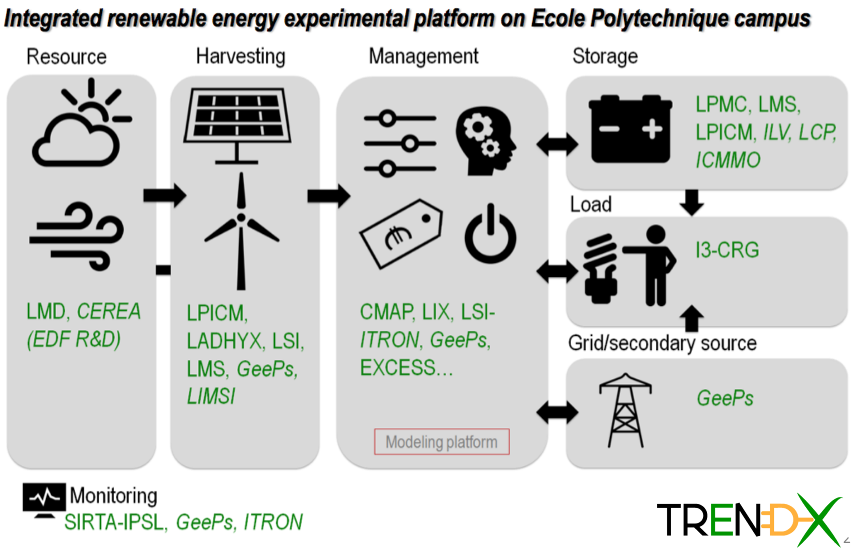
13 avril2017

What do I do ?

TREND-X project:



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Les questions CLEs:

Est-ce que les nuages chauffent ou refroidissent ?

A quel point l'énergie photovoltaïque est une solution fiable ?

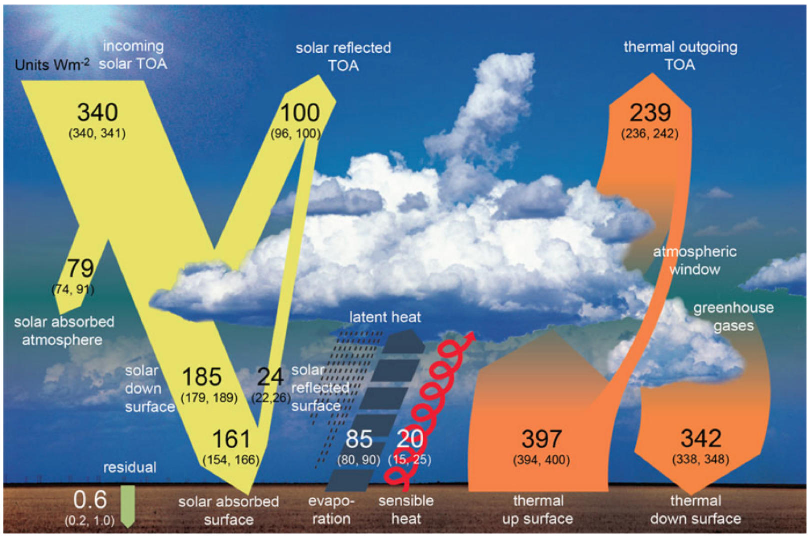
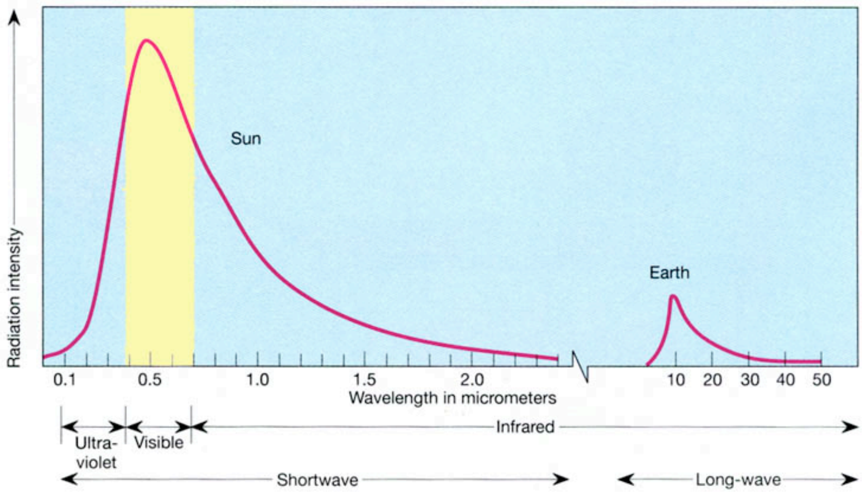


Fig. 1 Schematic diagram of the global mean energy balance of the Earth. *Numbers* indicate best estimates for the magnitudes of the globally averaged energy balance components together with their uncertainty ranges, representing present day climate conditions at the beginning of the twenty first century. Estimates and uncertainty ranges based on discussion in Sect. 5. Units Wm^{-2}

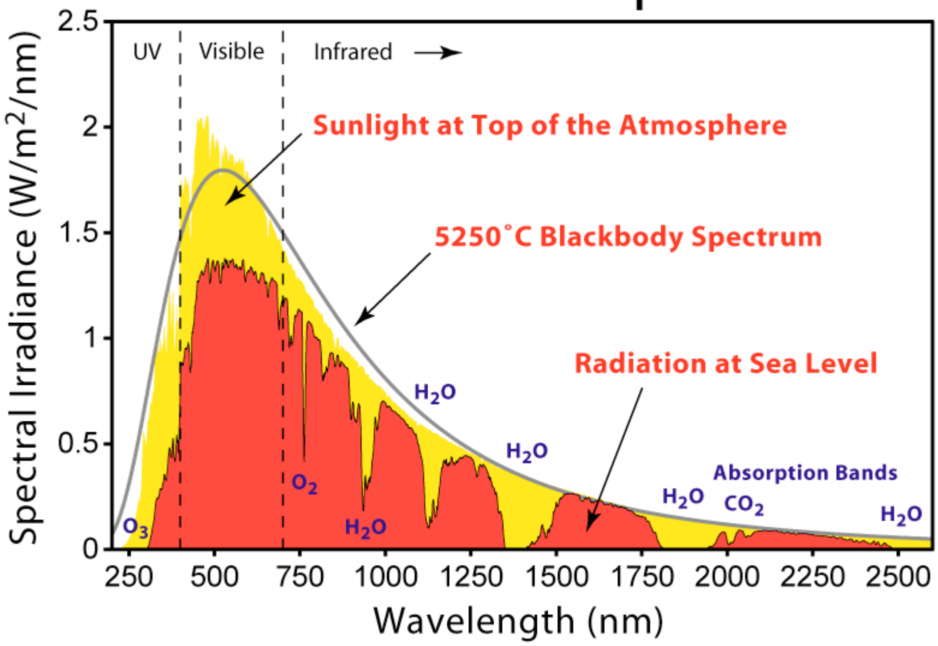
Wild, M., Folini, D., Schär, C., Loeb, N., Dutton, E. G., & König-Langlo, G. (2013). The global energy balance from a surface perspective. Climate dynamics, 40(11-12), 3107-3134.
https://www1.ethz.ch/iac/people/wild/Wild_et_al_ClimDyn_2013.pdf

Figure 2•9 Illustration comparing the intensity of solar and terrestrial radiation. Because of the sun's high surface temperature, most of its energy is radiated at wavelengths shorter than 4 micrometers, with the greatest concentration in the visible range of the electromagnetic spectrum. The earth, on the other hand, radiates most of its energy in wavelengths longer than 4 micrometers, primarily in the infrared band. Thus, we call the sun's radiation *shortwave* and the earth's radiation *long-wave*. *(From Tom L. McKnight, Physical Geography, © 1990, Prentice-Hall, Inc.)*



http://www.ees.rochester.edu/fehnlab/ees215/lect21.html

Solar Radiation Spectrum



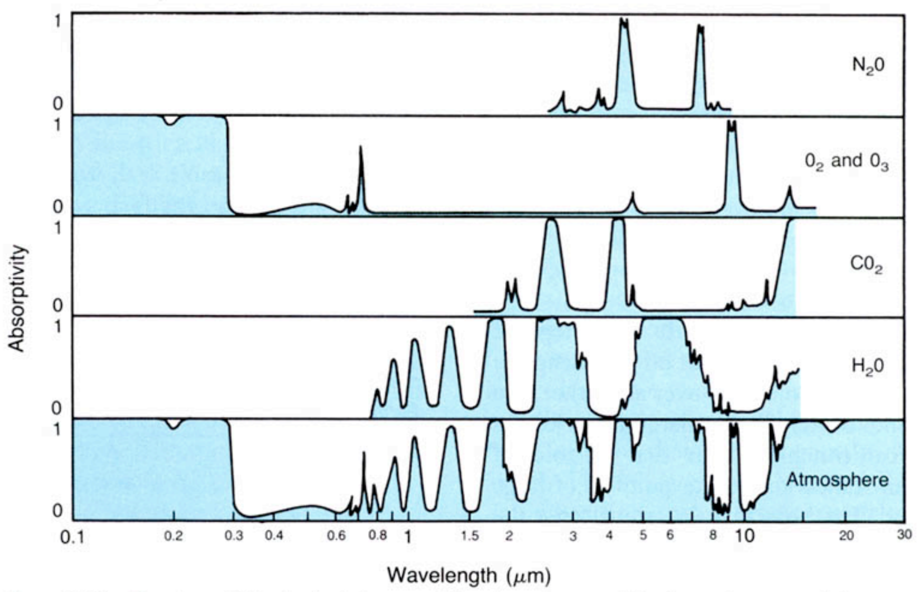
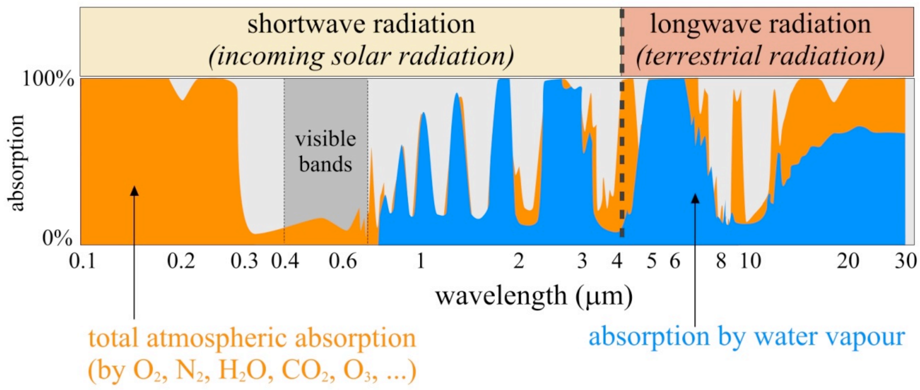


Figure 2•13 The absorptivity of selected gases of the atmosphere and the atmosphere as a whole.

(From R. G. Fleagle and J. A. Businger, An introduction to Atmospheric Physics. © 1963 by Academic Press; reprinted by permission of the publisher)

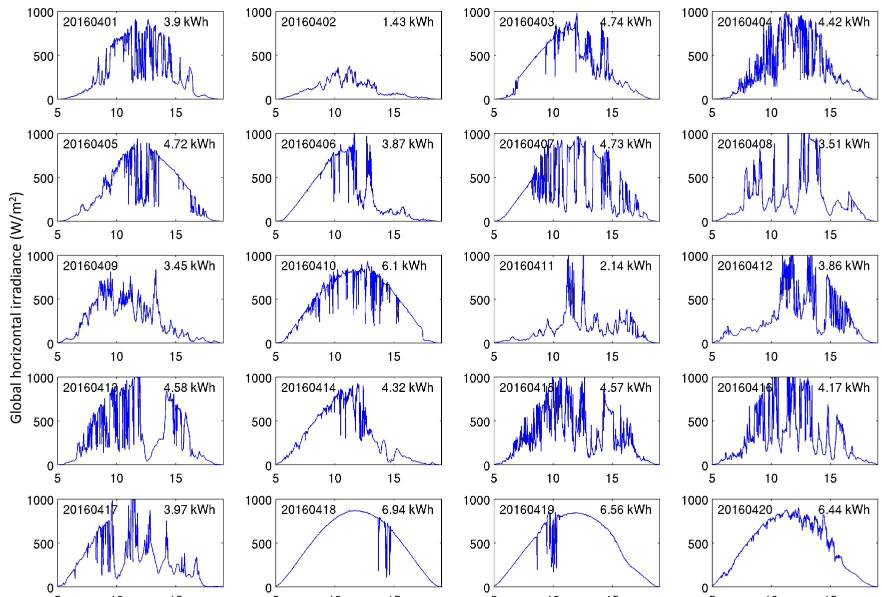


http://elte.prompt.hu/sites/default/files/tananyagok/atmospheric/
ch01s03.html

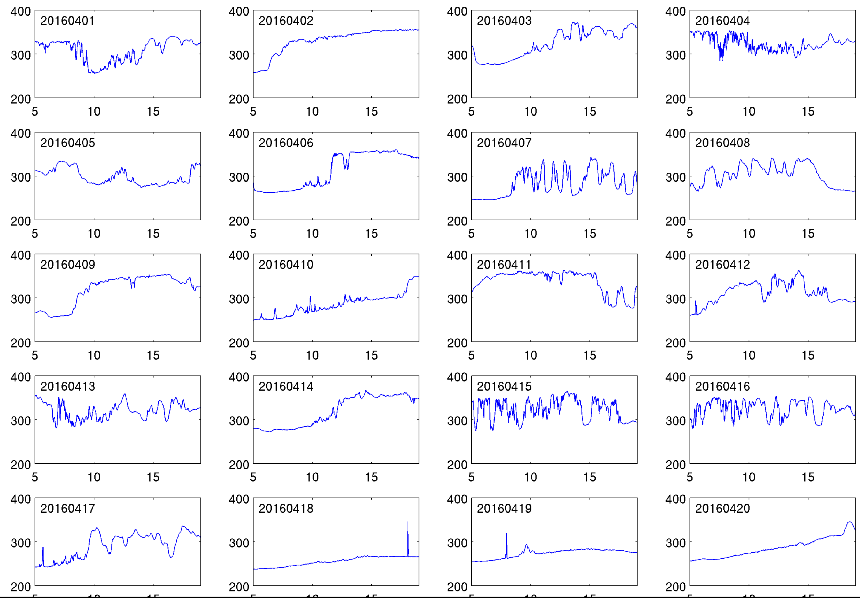
TABLE 2-3 Albedo (reflectivity) of various surfaces

Surface	Percent Reflected
Fresh snow	80–90
Old snow	50–60
Sand (beach, desert)	20–40
Grass	5–25
Dry soil (plowed field)	15–25
Wet earth (plowed field)	10
Forest	5–10
Water (Sun near horizon)	50–80
Water (Sun near zenith)	5–10
Thick cloud	70–85
Thin cloud	25–30
Earth and atmosphere (overall total)	30

Irradiance solaire mesuré des derniers 20 jours



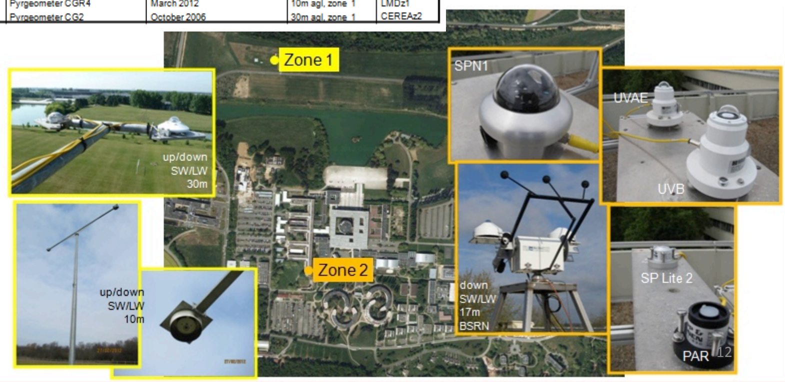
Irradiance tellurique (infrarouge) mesuré des derniers 20 jours



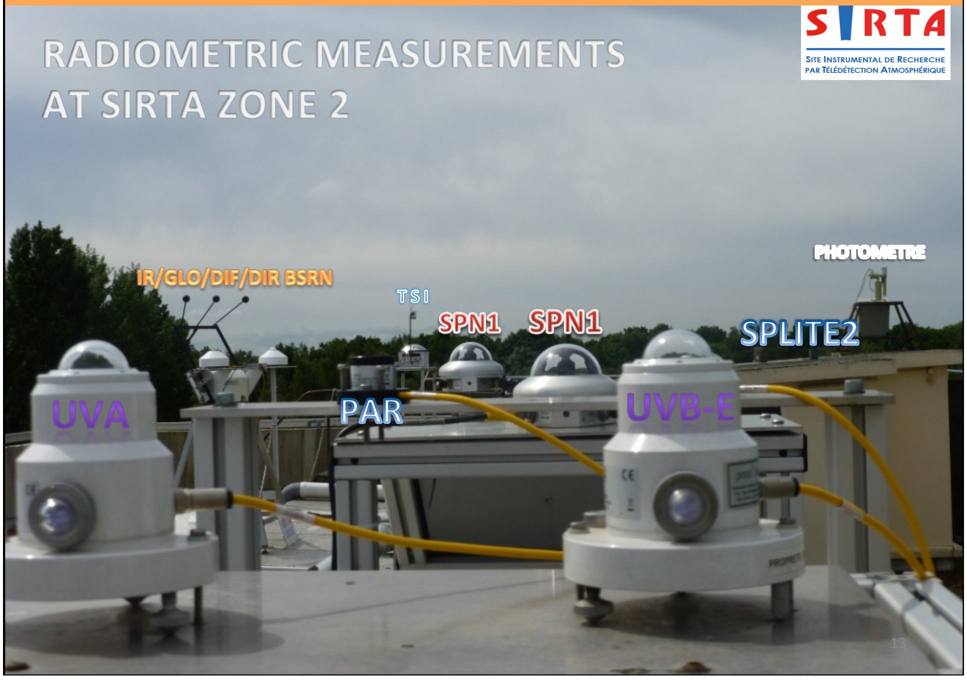
Radiative measurements at SIRTA

Measurement	Sensors	Start date	Location	Ref
Ultraviolet irradiance				
Downwelling UVAE	UVS-AE-T K&Z	April 2010	17m agl, zone 2	LMDz2
Downwelling UVB	UVS-B-T K&Z	May 2012	17m agl, zone 2	LMDz2
Shortwave irradiance				
Downwelling direct	Pyrheliometer CH1 K&Z	April 2003	17m agl, zone 2	BSRN
Downwelling diffuse	Pyranometer CMP22 K&Z SPN1	April 2003 June 2011		BSRN CEREAz2
Downwelling global	Pyranometer CMP22(1) K&Z Pyranometer CMP22(1) K&Z Pyranometer CM21 K&Z SPN1 Delat T SP Lite 2 K&Z	April 2003 March 2012 October 2006 December 2010 May 2012	17m agl, zone 2 10m agl, zone 1 30m agl, zone1 17m agl, zone2 17m agl, zone 2	BSRN LMDz1 CEREAz1 CEREAz2 LMDz2
Upwelling	Pyranometer CMP22 Pyranometer CM21	March 2012 October 2006	10m agl, zone 1 30m agl, zone1	LMDz1 CEREAz1
Longwave irradiance				
Downwelling	Pyrgeometer(1) CGR4 Pyrgeometer(1) CGR4 Pyrgeometer CG2	April 2003 March 2012 October 2006	17m agl, zone 2 10m agl, zone 1 30m agl, zone 1	BSRN LMDz1 CEREAz1
Upwelling	Pyrgeometer CGR4 Pyrgeometer CG2	March 2012 October 2006	10m agl, zone 1 30m agl, zone 1	LMDz1 CEREAz2

SITE INSTRUMENTAL DE RECHERCHE PAR TÉLÉDÉTECTION ATMOSPHÉRIQUE



Radiative measurements at SIRTA



Radiative measurements at SIRTA

PV platforms on the Campus

Key points

Solar energy
- Is the largest energy source on the Earth
- Is growing as energy source for electricity
- Not constant (0 at night, max at noon for cloudless conditions)
  Highly modulated by clouds (big changes in few seconds)
- Not concentrated in one point (plants of different sizes and spatial distribution).
- Generally not correlated with consumption peaks.

Challenges:
- Balancing
- Smart grids
- **Forecasting**
- Storing

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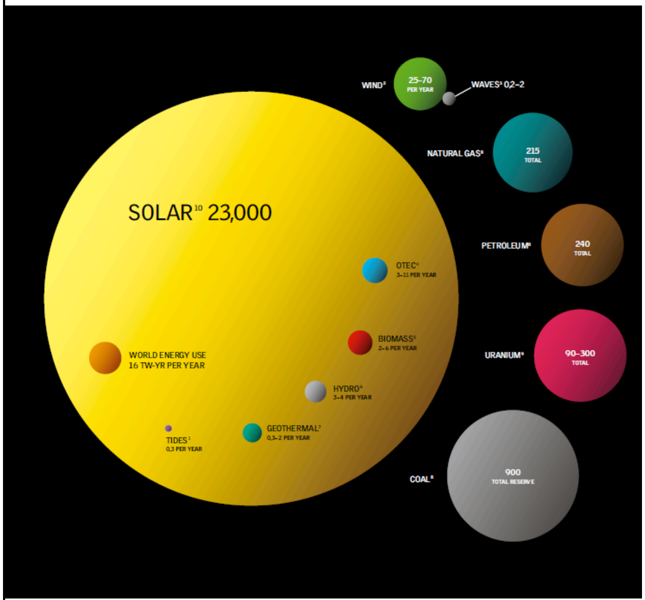
THE GREAT SOLAR RESOURCE



The available solar energy exceeds the world's energy comsumption by a factor of 1.500. Fossil fuels like oil and coal alone could fulfil our energy needs for another three or four generations, but would do so at a considerable environmental cost.

http://www.asrc.cestm.albany.edu/perez/Kit/pdf/Making%20the%20case%20for%20solar%20energy.pdf

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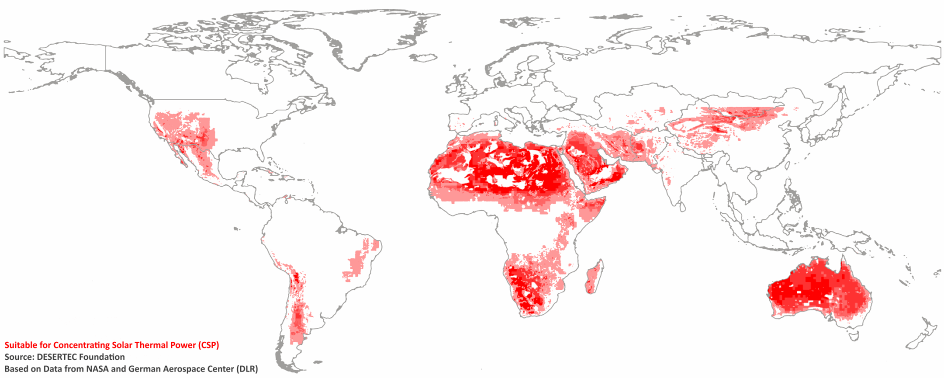
THE GREAT SOLAR RESOURCE



"Within 6 hours deserts receive more energy from the sun than humankind consumes within a year", calculated Dr. Gerhard Knies, German Physicist and member of the Supervisory Board of the DESERTEC Foundation.

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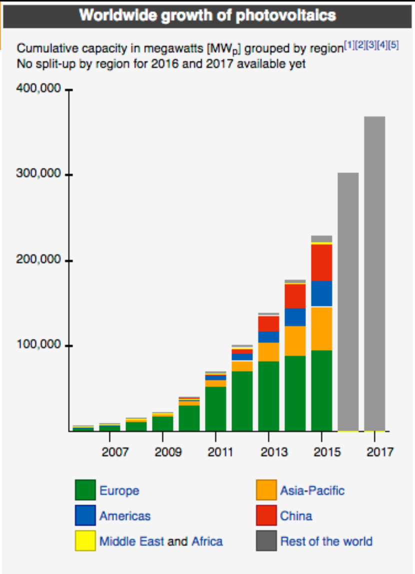
Worldwide growth of photovoltaics



Recent and projected capacity (MWp)

Year-end	2012	2013	2014	2015	2016	2017
Cumulative	100,504	138,856	178,391	229,300	*302,300*	*368,000*
Annual new	30,011	38,352	40,134	50,909	*73,000*	*65,700*
Cume growth	43%	38%	28%	29%	*32%*	*22%*

http://en.wikipedia.org/wiki/Growth_of_photovoltaics

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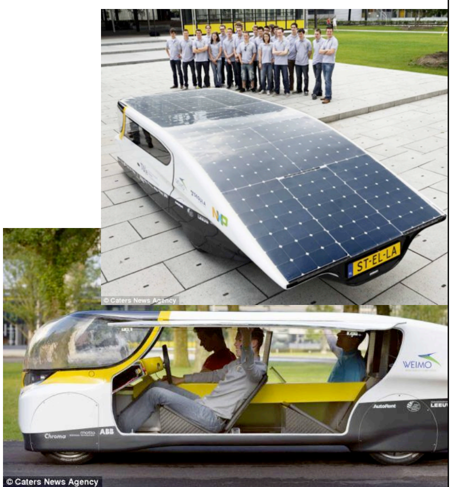
PV applications growth

http://www.designboom.com/technology/sol-solar-powered-laptop-runs-on-ubuntu/

The world's first solar-powered family car that can travel 420 miles on a sunny day and creates TWICE as much energy as it uses

Read more: http://www.dailymail.co.uk/sciencetech/article-2385976/Stella-solar-powered-family-car-travels-420-miles-sunny-energy-positive.html#ixzz2blO5GJn7
Follow us: @MailOnline on Twitter | DailyMail on Facebook

Solar powered window socket
@inventions



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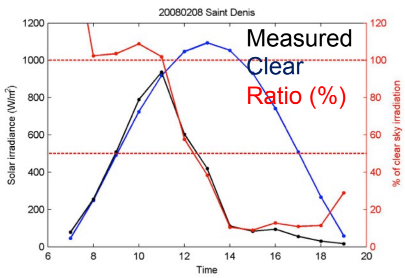
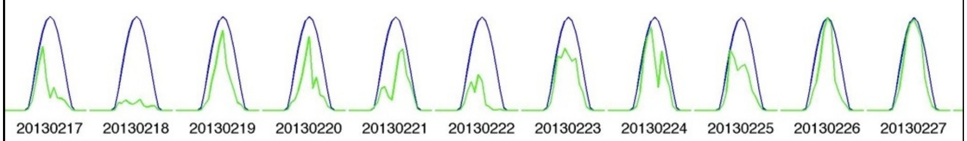
PV applications growth

http://www.planetsolar.org/fr/le-bateau

Solar radiation is not constant

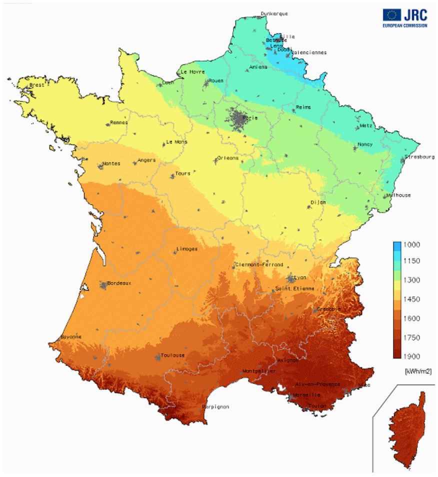
Solar global irradiance brutal ramp



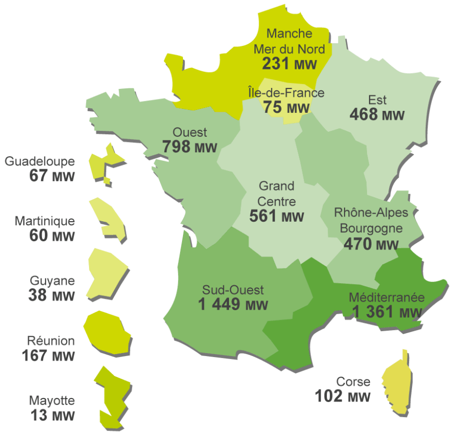


Spatial distribution of PV systems

Solar resource



Installed capacity distribution



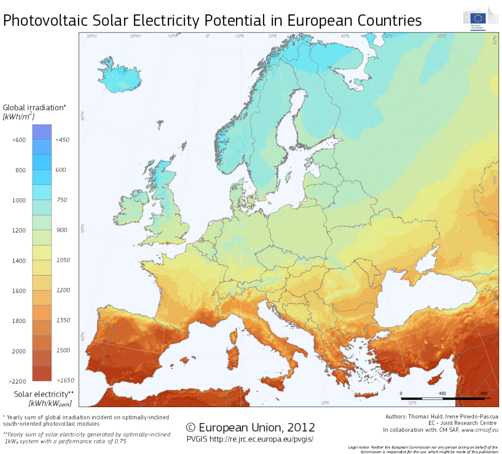
Parc photovoltaïque raccordé au réseau au 31 mars 2015
(Tableau de bord éolien-photovoltaïque, juin 2015 - SOeS d'après ERDF, RTE, EDF-SEI et les principales ELD)

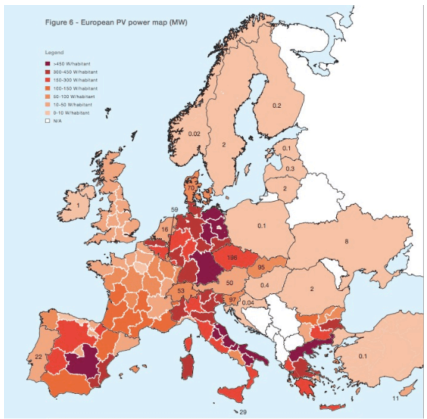
http://blog.solorea.com/energie-solaire-france

Spatial distribution of PV systems

Solar resource

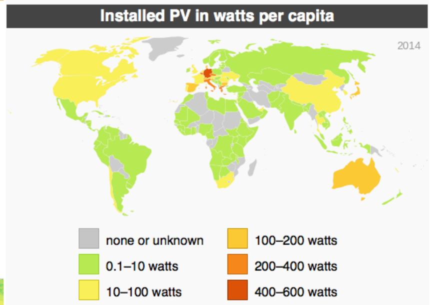
Installed capacity distribution





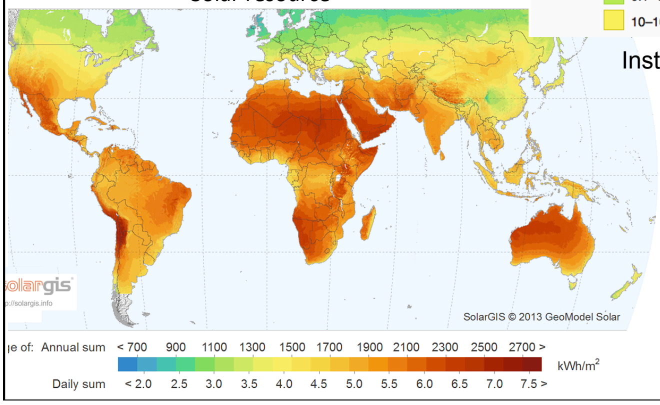
http://re.jrc.ec.europa.eu/pvgis/cmaps/eu_cmsaf_opt/PVGIS_EU_201204_presentation.png

Spatial distribution of PV systems



Installed capacity distribution

Solar resource



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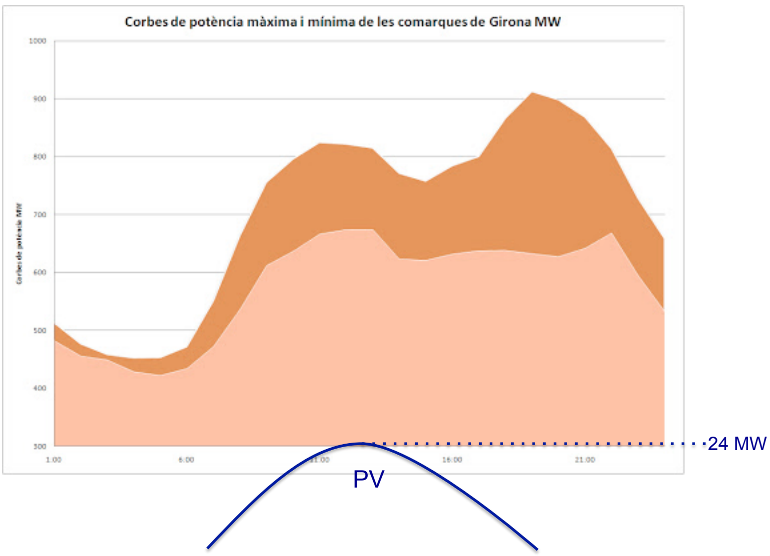
Electricity consumption during the day

Energy demand in Girona region



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http://emprenem.ara.cat/enersociety/2010/12/25/la-corba-de-demanda-electrica/

UNITS

Time:
UT: Universal time, used as reference in meteorology (in particular in weather forecasting) and for meteorologycal measurements. The official time (clock time) in most of Europe is UT+1 in winter and UT +2 in summer.

Solar radiation:
Irradiance (W/m^2): Power (energy per second) on a 1 m^2 surface.
Irradiation (J/m^2 ou Wh/m^2): Integrated power over time. Energy
(1 Wh/m2 is the energy of a constant power of 1W during 1h = 3600 J/m2)

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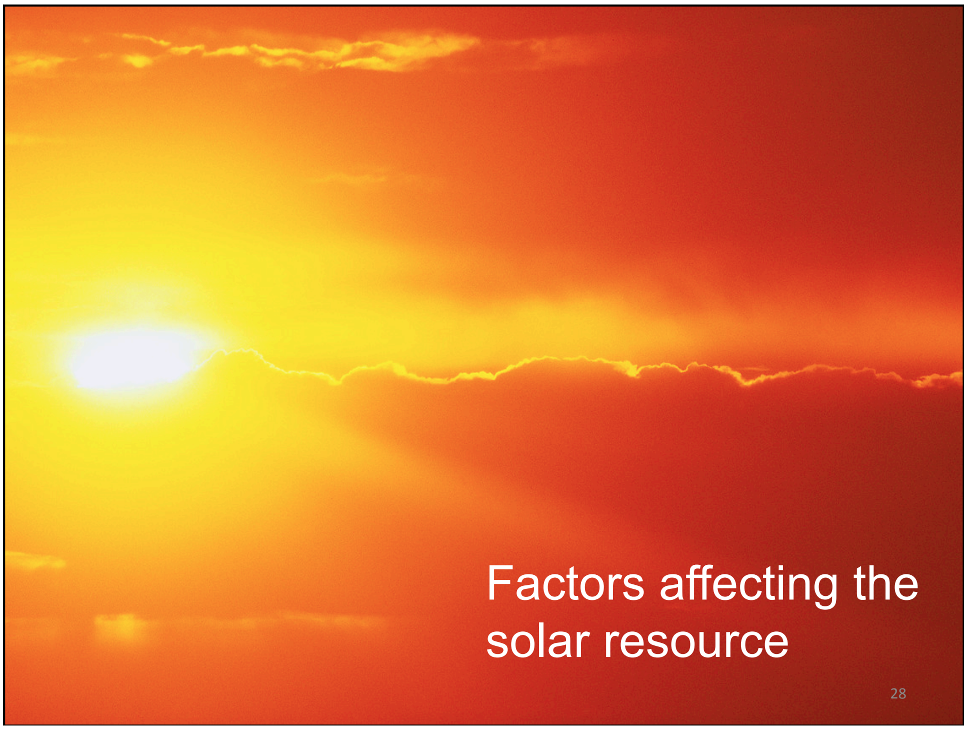

Factors affecting the energy reaching a solar panel

- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- Shading effects
- Inclination and orientation of the solar collector
- Panel type and conditions

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Factors affecting the energy reaching a solar panel

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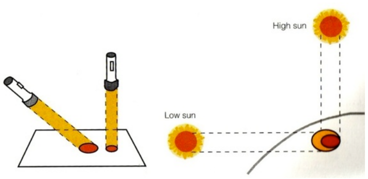
Since the Earth is a round surface, the incident angle of solar flux is lower near the poles and this reduces the energy per m2 over there. At the same time, the low incident flux goes through a thicker atmosphere layer meaning more radiation extinction, so reducing even more the solar flux reaching the ground.



As a consequence, the tropical regions receive much more solar energy than the areas near the poles.

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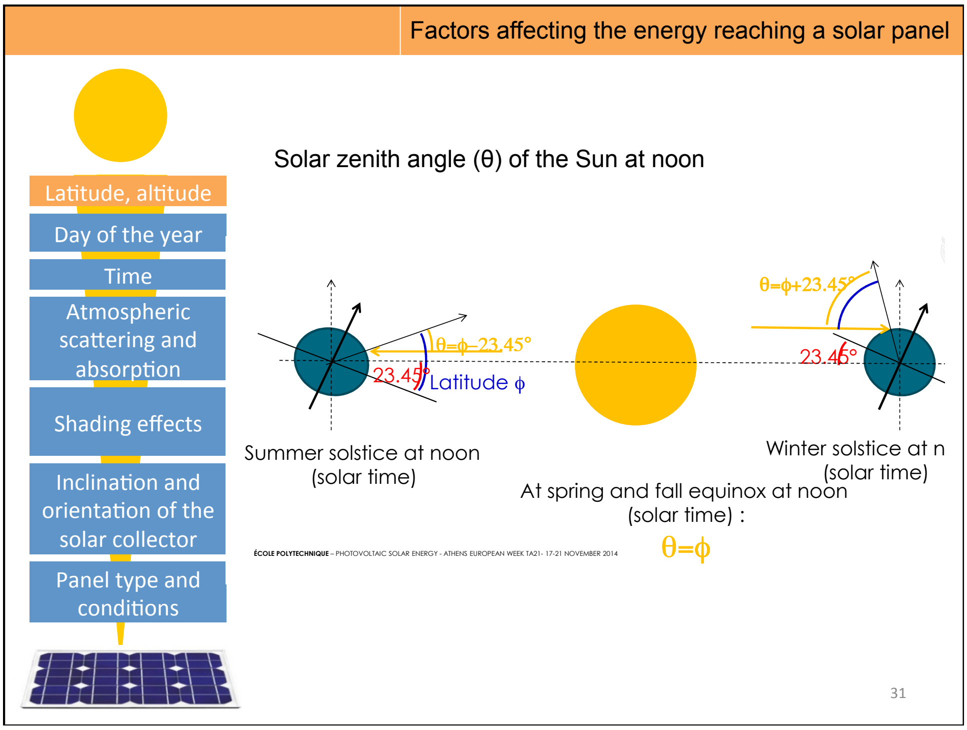

Factors affecting the energy reaching a solar panel
Latitude, altitude
Day of the year
Time
Atmospheric scattering and absorption
Shading effects
Inclination and orientation of the solar collector
Panel type and conditions
Solar zenith angle (θ) of the Sun at noon
θ=φ–23.45°
23.45°
Latitude φ
θ=φ+23.45°
23.45°
Summer solstice at noon (solar time)
Winter solstice at n (solar time)
At spring and fall equinox at noon (solar time) :
θ=φ
ÉCOLE POLYTECHNIQUE – PHOTOVOLTAIC SOLAR ENERGY - ATHENS EUROPEAN WEEK TA21- 17-21 NOVEMBER 2014
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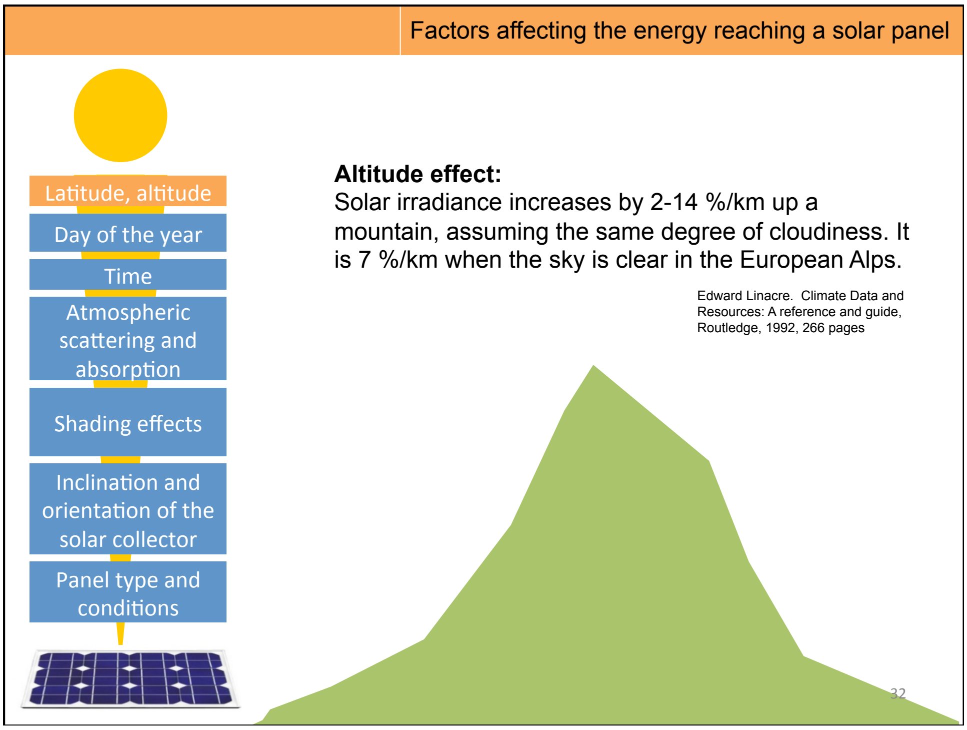

Factors affecting the energy reaching a solar panel
Latitude, altitude
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Panel type and conditions
Altitude effect:
Solar irradiance increases by 2-14 %/km up a mountain, assuming the same degree of cloudiness. It is 7 %/km when the sky is clear in the European Alps.
Edward Linacre. Climate Data and Resources: A reference and guide, Routledge, 1992, 266 pages
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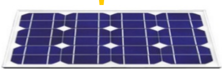
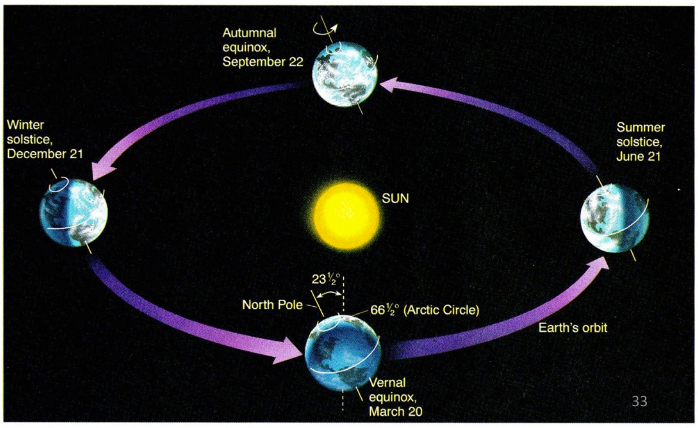


Obliquity: the axial tilt of the Earth

The axial tilt of the Earth is 23.44º . This is the inclination in between the rotational axis of the Earth (day rotation axis) and the orbital axis plane (around the sun). It affects the incidence angle on the surface of the planet along a year, affecting the amount of radiation received by a specific place on the planet. The further from the equator, the bigger the effect.



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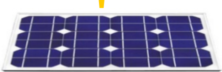
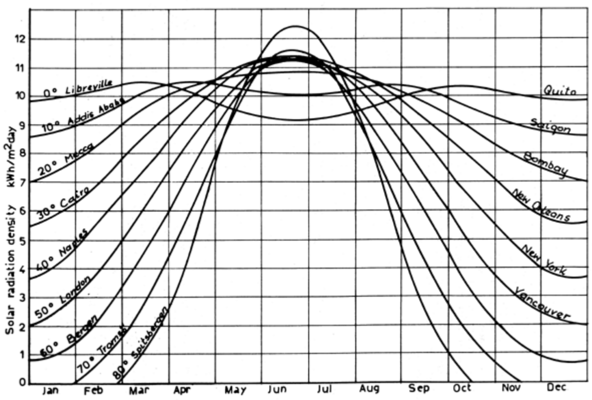


The axial tilt of the Earth

Regions further from the equator are more affected of this ciclic variations: seasonality.



http://jisibhlphysics.wikispaces.com/8.4.13+Outline+reasons+for+seasonal+and+regional+variations+in+the+solar+power+incident+per+unit+area+of+the+Earth%E2%80%99s+surface.

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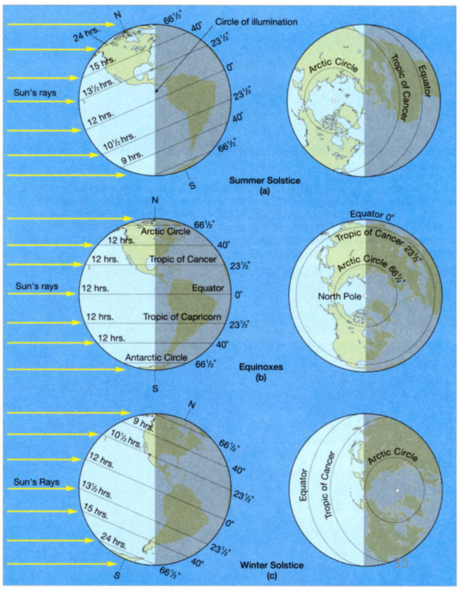
The axial tilt of the Earth

Another effect of the axial tilt of the Earth is the day length. It also present seasonality, specially in middle latitudes.

The more extreme effect is observed at the Poles! Days and nights of 6 months!

For latitudes > 66.5º, we can observe the midnight sun in summer time. Day lasts 24h at least one day a year, determining what we call The polar Circles limits (arctic - Antarctic)

Figure 2•5 Characteristics of the solstices and equinoxes.



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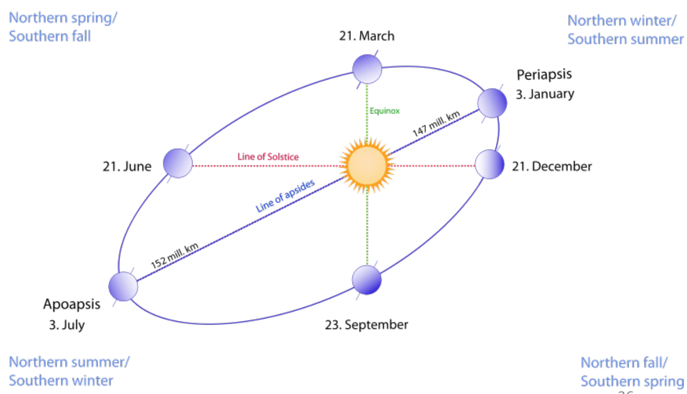
The Earth – Sun distance

The Earth – Sun distance is also variable in a a year cycle. Its mean value is 1 AU (= 149.6 millions de km). The Earth is closer to the Sun on the 3rd of January (minimum distance value = 0.984 AU) , and its maximum distance takes place on the 3rd of July (1.017 AU)
The effect on the radiation is a variability of about +/- 3.5% .



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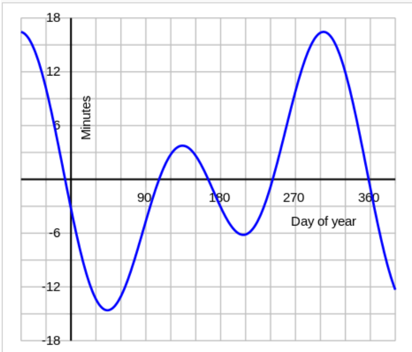
Equation of time

The equation of time describes the discrepancy between two kinds of solar time. These are apparent solar time, which directly tracks the motion of the sun, and mean solar time, which tracks a fictitious "mean" sun with noons 24 hours apart



The equation of time — above the axis a sundial will appear *fast* relative to a clock showing local mean time, and below the axis a sundial will appear *slow*.

https://en.wikipedia.org/wiki/Equation_of_time

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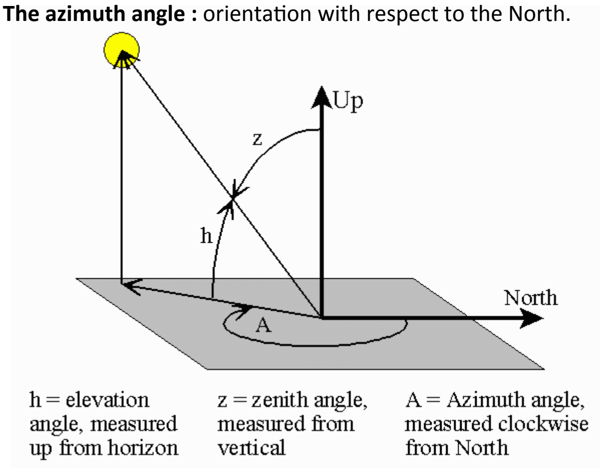
The Sun's position changes through the day

3 angles are needed to refer a place from the sun's position:
- **The elevation angle:** from 0º (horizon) to 90º (vertical)
- **The zenith angle :** the complementary angle of the elevation (90-z).
- **The azimuth angle :** orientation with respect to the North.



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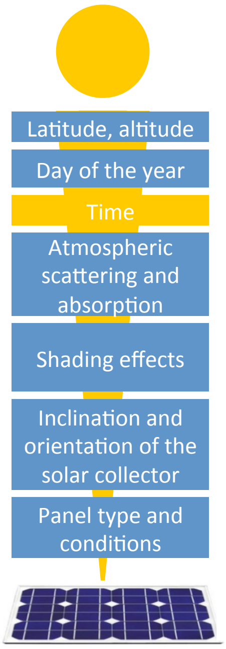
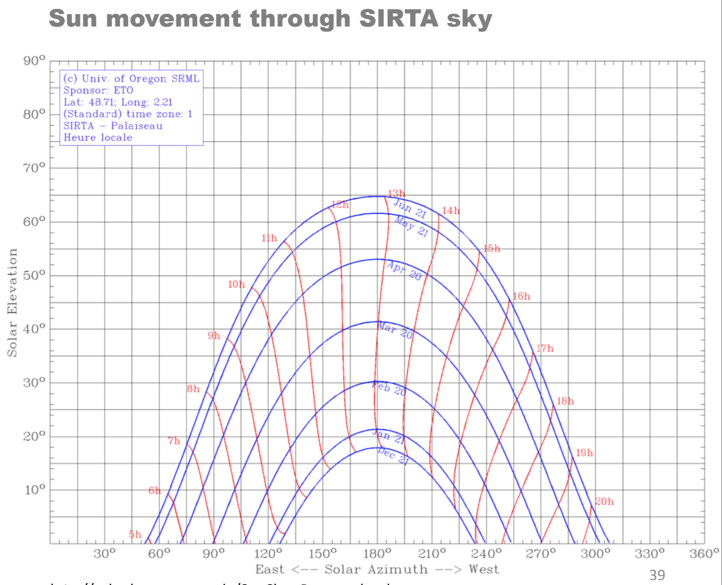
http://www.srrb.noaa.gov/highlights/sunrise/glossary.html

Factors affecting the energy reaching a solar panel





http://solardat.uoregon.edu/SunChartProgram.html

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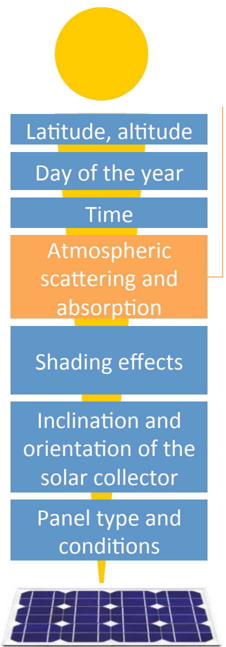
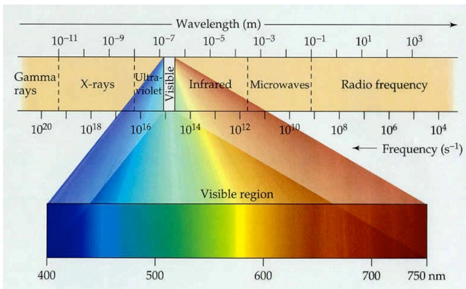
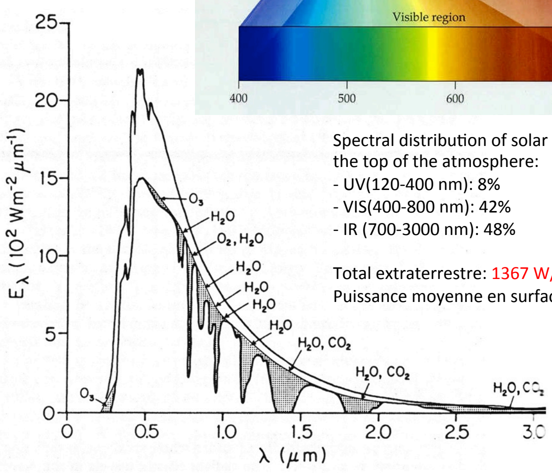
Factors affecting the energy reaching a solar panel



Gas absorption





Spectral distribution of solar irradiance reaching the top of the atmosphere:
- UV(120-400 nm): 8%
- VIS(400-800 nm): 42%
- IR (700-3000 nm): 48%

Total extraterrestre: 1367 W/m^2
Puissance moyenne en surface: 342W/m^2

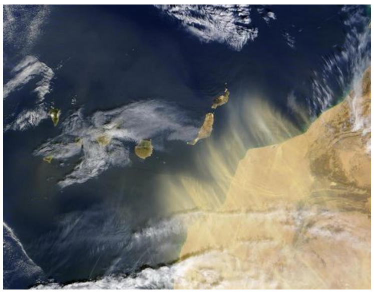
40

Factors affecting the energy reaching a solar panel

- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- Shading effects
- Inclination and orientation of the solar collector
- Panel type and conditions

Aerosols

Aerosols are particles suspended in the air which comes from the ground surface from advection, turbulence, transportation processes or anthropogenic emissions. The effect of aerosols on solar radiation is limited to <10% for rural regions, and can be as high as 15-20% in polluted environments (big cities).



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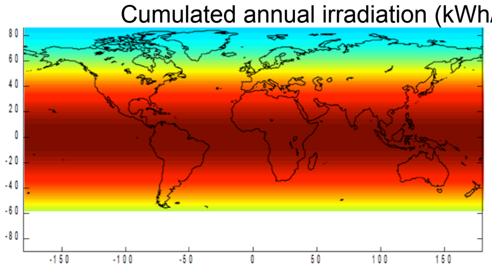
Factors affecting the energy reaching a solar panel

- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- Shading effects
- Inclination and orientation of the solar collector
- Panel type and conditions

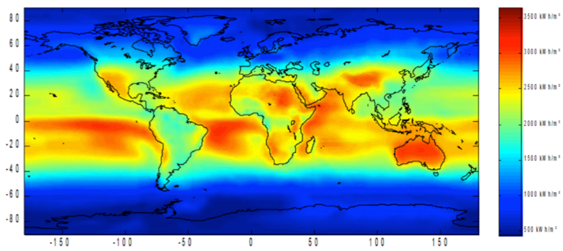
Overall atmospheric effect

Cumulated annual irradiation (kWh/m2)

Incident radiation on the atmosphere upper layers



Observed surface radiation



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ATHENS Programme / IDEA League - MINES ParisTech

Factors affecting the energy reaching a solar panel

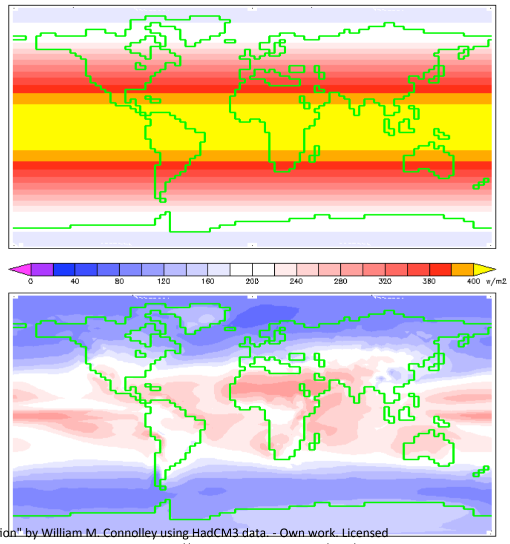
- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- Shading effects
- Inclination and orientation of the solar collector
- Panel type and conditions

Overall atmospheric effect

Average irradiance (W/m2)

Incident radiation on the atmosphere upper layers

Observed surface radiation



"Insolation" by William M. Connolley using HadCM3 data. - Own work. Licensed under CC BY-SA 3.0 via Commons - https://commons.wikimedia.org/wiki/File:Insolation.png#/media/File:Insolation.png

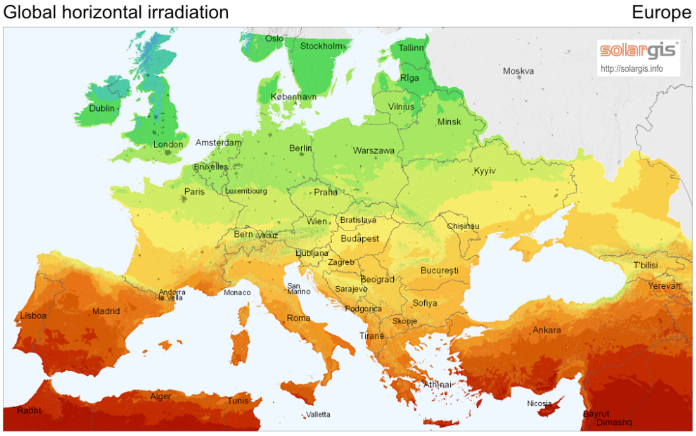
Factors affecting the energy reaching a solar panel

- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- Shading effects
- Inclination and orientation of the solar collector
- Panel type and conditions

Mean solar resource in Europe

Global horizontal irradiation

Europe



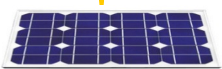
Average annual sum (4/2004 - 3/2010)

< 700 | 900 | 1100 | 1300 | 1500 | 1700 | 1900 > kWh/m²

0 | 250 | 500 km

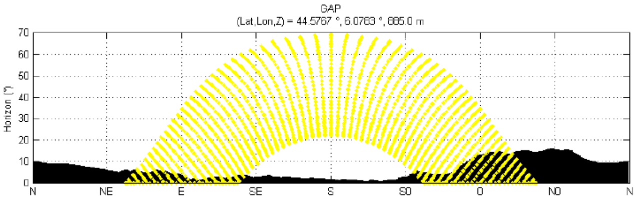
Factors affecting the energy reaching a solar panel

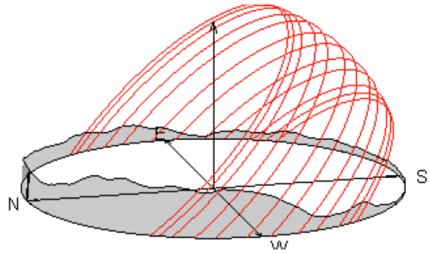
- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- **Shading effects**
- Inclination and orientation of the solar collector
- Panel type and conditions



Mountains shading

Shadow effects from close objects (buildings, trees) as well as orography can affect sensibly the net radiation of an area.
Exemple de Gap (Hautes-Alpes)





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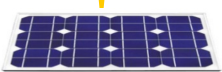
ATHENS Programme / IDEA League - MINES ParisTech

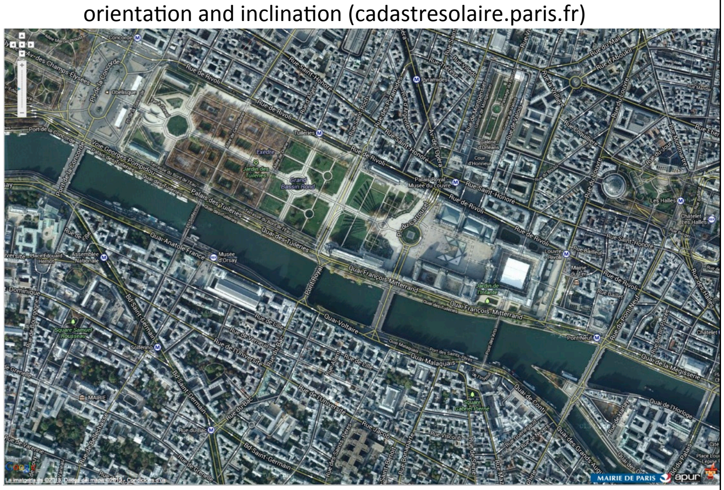
Factors affecting the energy reaching a solar panel

- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- **Shading effects**
- Inclination and orientation of the solar collector
- Panel type and conditions



Surrounding objects shading

Solar resource variability in Paris due to shades and rooftops orientation and inclination (cadastresolaire.paris.fr)



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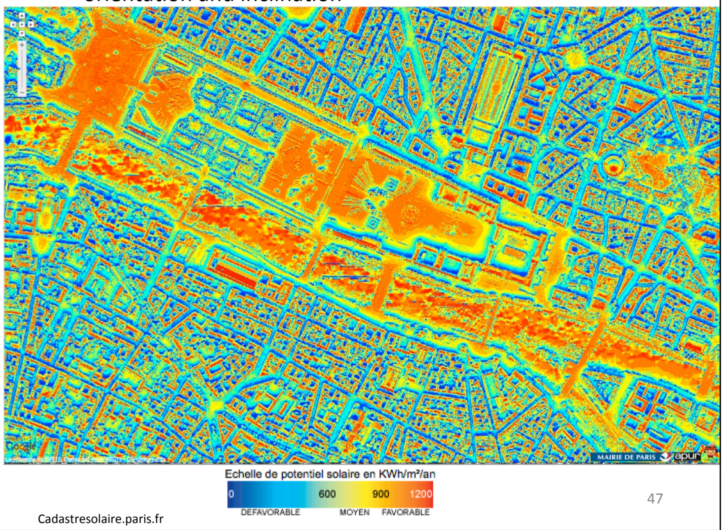
ATHENS Programme / IDEA League - MINES ParisTech

Factors affecting the energy reaching a solar panel

- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- **Shading effects**
- Inclination and orientation of the solar collector
- Panel type and conditions

Surrounding objects shading

Solar resource variability in Paris due to shades and rooftops orientation and inclination



Cadastresolaire.paris.fr

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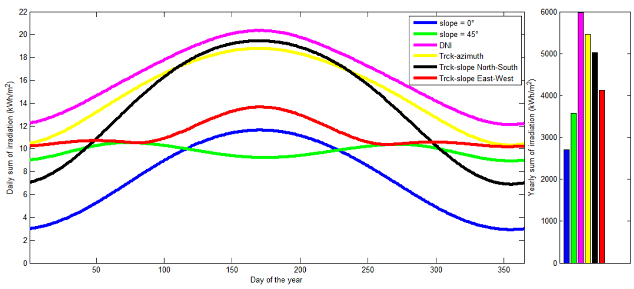
Factors affecting the energy reaching a solar panel

- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- Shading effects
- **Inclination and orientation of the solar collector**
- Panel type and conditions

Surface inclination + orientation effect - Extraterrestrial radiation collected.

Exemple for latitude = 45º



ATHENS Programme / IDEA League - MINES ParisTech

http://pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-tilted-surface

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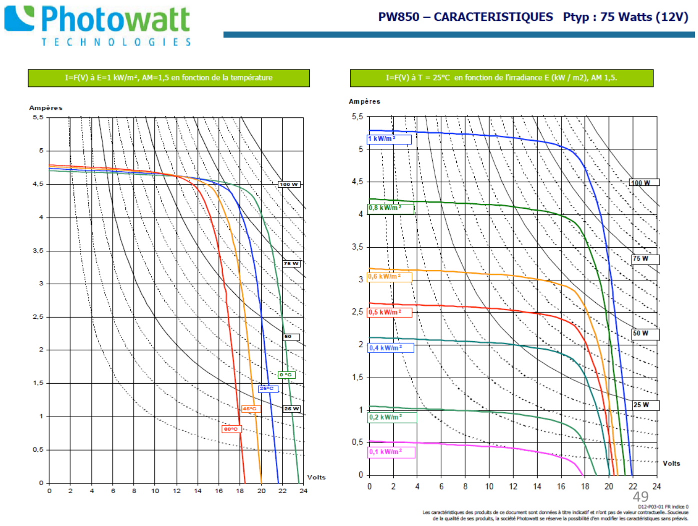
Factors affecting the energy reaching a solar panel

- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- Shading effects
- Inclination and orientation of the solar collector
- Panel type and conditions

Solar panels production highly depend on solar irradiance and panel temperature



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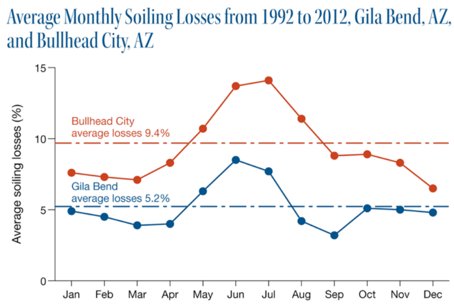
Factors affecting the energy reaching a solar panel

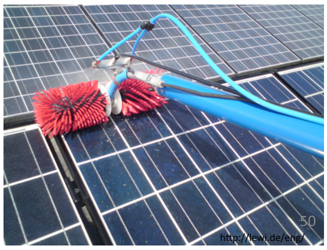
- Latitude, altitude
- Day of the year
- Time
- Atmospheric scattering and absorption
- Shading effects
- Inclination and orientation of the solar collector
- Panel type and conditions

Solar panels production can be remarkably reduced by soiling



Graph 3 Soiling losses in Bullhead City are almost twice those in Gila Bend. Gila Bend gets 1.5 more rain events per year, and rainfall is more evenly distributed throughout the year. The two cities are approximately 250 miles apart.

http://solarprofessional.com/articles/operations-maintenance/impacts-of-soiling-on-utility-scale-pv-system-performance



http://ewi.de/en/

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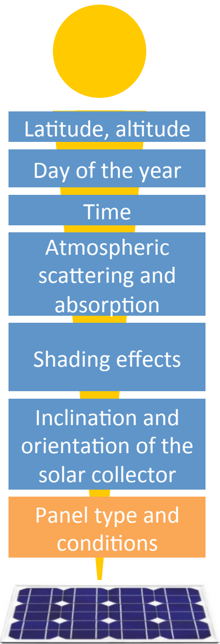
Factors affecting the energy reaching a solar panel



Snow is major factor of PV production reduction and uncertainty, sometimes affecting big regions

http://2greenenergy.com/2011/01/29/winter-wonderland-and-solar-panels/

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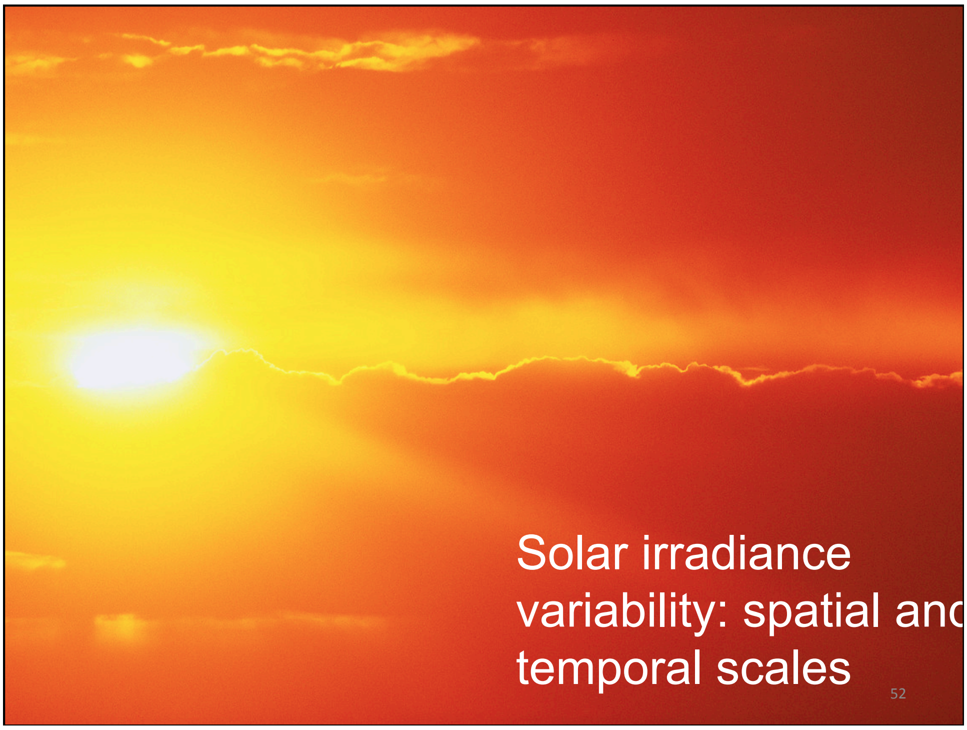


Solar irradiance variability: spatial and temporal scales

52

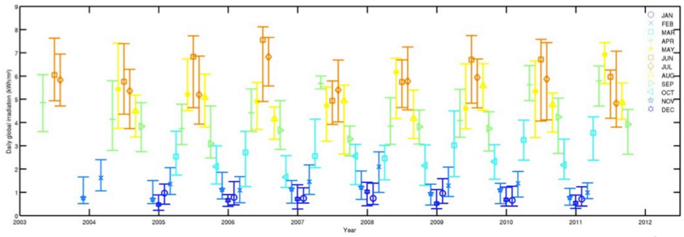
VARIABILITY

- Annual
- Seasonal
- Day to day
- Infra daily
- Spatial

Solar resource is highly variable in both spatial and temporal scales because of heterogeneous and rapidly changing cloudiness.

The characterization of this variability is essential to enhance penetration of solar energy systems such as photovoltaic or thermal farms.

The figure below shows the monthly means (and the bars account for the standard deviation) of the daily solar irradiation at the SIRTA's observatory in Palaiseau.



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VARIABILITY

- Annual
- Seasonal
- Day to day
- Infra daily
- Spatial

30 days of measured solar irradiance

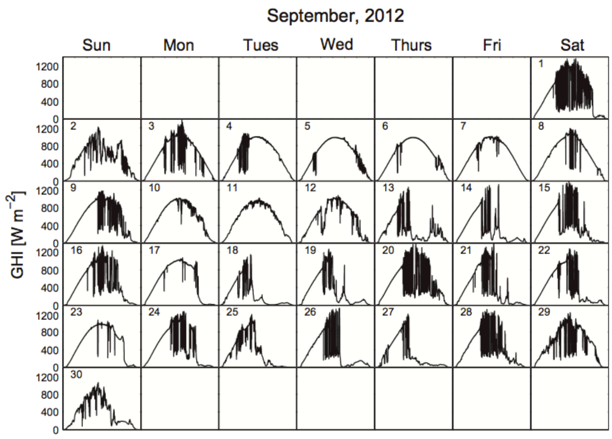

FIGURE 7.9 Calendar showing the daily GHI profiles at Mayaguez, Puerto Rico, in September 2012.

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VARIABILITY

Solar irradiance variability depends on the considered time resolution

- Annual
- Seasonal
- Day to day
- Infra daily
- Spatial

R. Perez et al. / Solar Energy 85 (2011) 1343–1353 1351

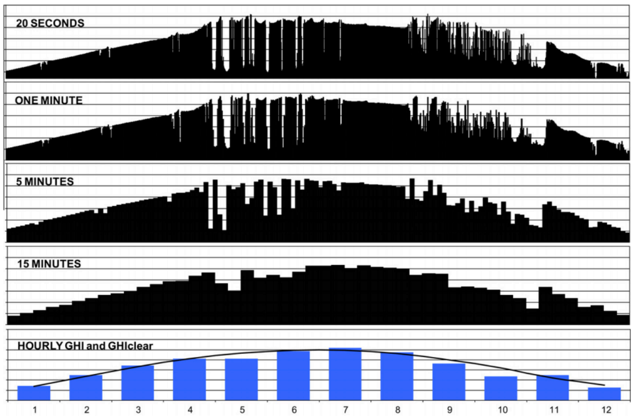

Fig. 11. Comparing GHI for all selected Δt sampling rates for ARM site's central facility on May 25, 2001. The bottom plot reports hourly GHI model input and clear sky background.

Perez et al, 2011 Parameterization of site-specific short-term irradiance variability *Solar Energy, Volume 85, Issue 7, July 2011, Pages 1343-1353*

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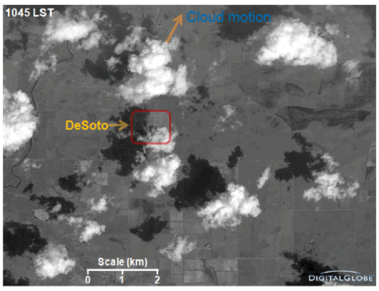
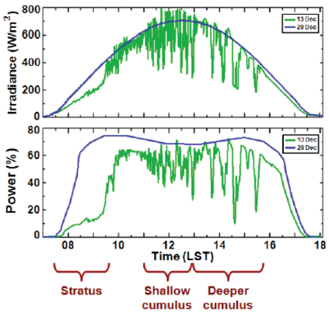
VARIABILITY

Cloud Impact Example

- Annual
- Seasonal
- Day to day
- Infra daily
- Spatial





Example of clouds over the DeSoto PV site

Solar energy ramp events are influenced by cloud type, size and speed

Mark Ahlstrom, CEO, Adam Kankiewicz, Research Scientist
Solar Power: Making High Penetrations Possible October 15, 2010
http://www.nrel.gov/eis/pdfs/solar_power_high_penetration_ahlstrom.pdf

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VARIABILITY

Solar irradiance variability is reduced when aggregating different geographic points

- Annual
- Seasonal
- Day to day
- Infra daily
- Spatial

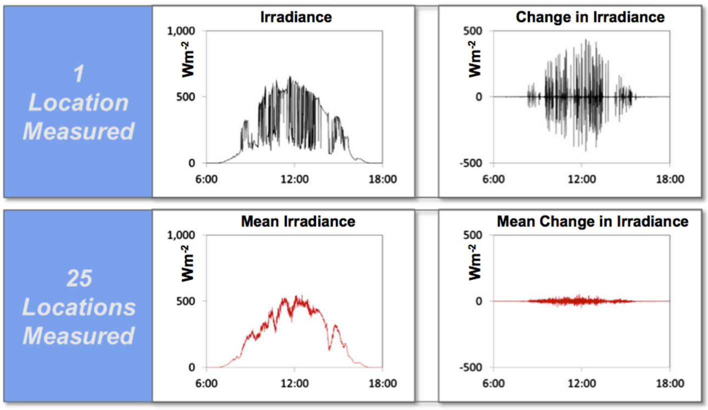

FIGURE 6.2 Dispersion-smoothing effect occurring at 25 locations dispersed over a 4 × 4 km area *(Data from the Cordelia Junction network, San Francisco Bay area, California.) This figure is reproduced in color in the color section.*

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Kleissl, Jan. Solar Energy Forecasting and Resource Assessment. Academic Press, 2013.

VARIABILITY

The bigger are the farms the larger are the compensation cloud effects.

- Annual
- Seasonal
- Day to day
- Infra daily
- Spatial

Cloud shadows on the DeSoto field during construction

Mark Ahlstrom, CEO, Adam Kankiewicz, Research Scientist
Solar Power: Making High Penetrations Possible October 15, 2010
http://www.nrel.gov/eis/pdfs/solar_power_high_penetration_ahlstrom.pdf

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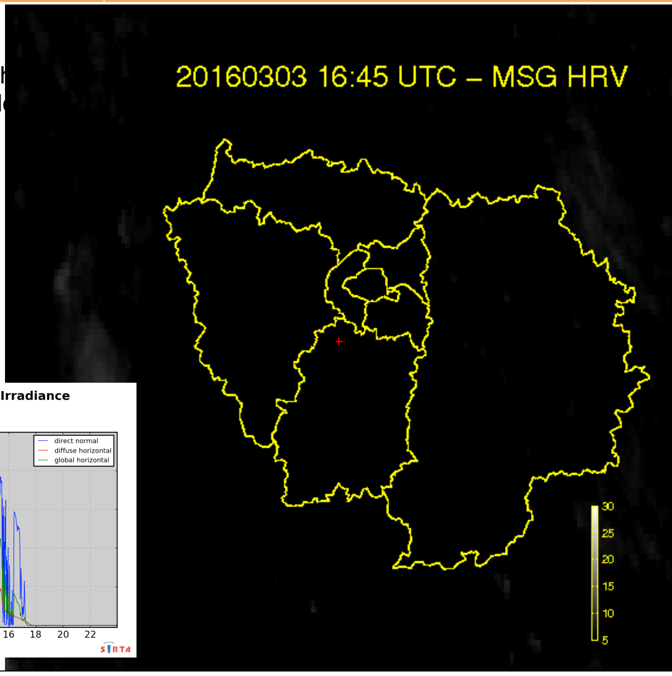
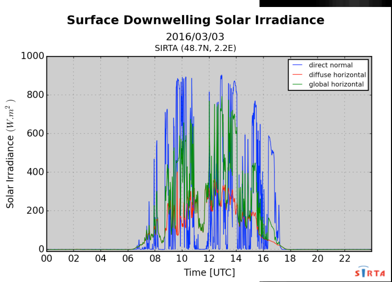
VARIABILITY

Th
cl

- Annual
- Seasonal
- Day to day
- Infra daily

- Spatial



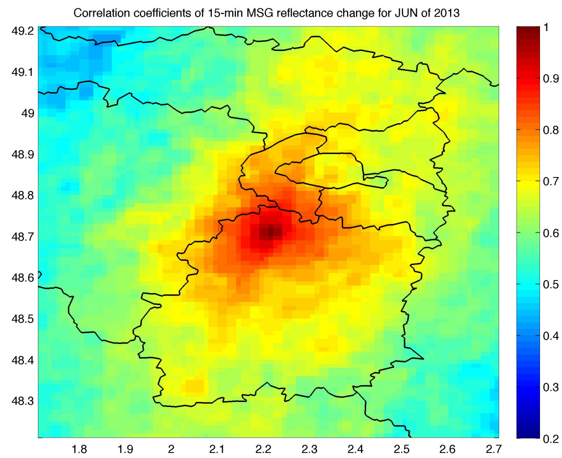


VARIABILITY

- Annual
- Seasonal
- Day to day
- Infra daily

- Spatial

Solar irradiance discorrelation with station-to-station distance



Station-to-station correlation coefficient of MSG 15-min reflectance change (par with respect to SIRTA pixel) for June 2013.

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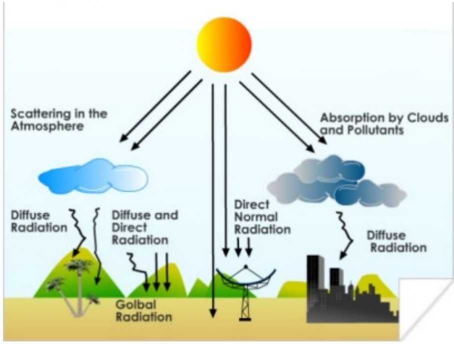
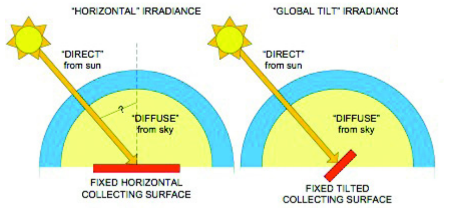
How we characterize solar irradiance?

Global = Direct*cos(Z) + Diffus



http://www.enertglobal.com/technology_e.html



Cloud effect

- Global ↑↓
- Direct =↓
- Diffus ↑ **(except for very thick clouds)**

Aerosol effect

- Global ↑↓
- Direct ↓
- Diffus ↑

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Mesure du rayonnement au SIRTA

Suiveur solaire (de Kipp&Zonen) qui permet la mesure du rayonnement solaire direct, diffuse et global.

Pyrheliometer CH1

Pyranometer CM22

The direct solar flux is measured with a pyrheliometer aiming at the sun. The diffuse flux is measured using a pyranometer and masking the solar disk. The global flux is also measured using a pyranometer.

A pyranometer is an hemispheric radiometer capable of measuring the solar radiative flux incident to the surface from all directions (2π solid angle). The detector is aligned horizontaly and the response of the instrument depends of the incidence angle of the radiation ray.

A pyrheliometer is sensitive to the radiation from 0.4 to 3 or 4 mm depending of the filter used (basic glass or quartz).

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http://sirta.ipsl.fr/

Mesure du rayonnement au SIRTA

A pyrgeometer is an hemispheric radiometer capable of measuring the infrared flux incident to the earth surface from all directions (2π solid angle). The detector is aligned horizontaly and the response of the instrument depends of the incidence angle of the radiation ray. A pyrgeometer is sensitive to the infrared radiation in a domain from 4 to 30 or 40 mm depending of the filter. The roof platform of SIRTA is equipped with an Kipp & Zonen CG4 pyrgeometer.

http://sirta.ipsl.fr/

Mesure du rayonnement au SIRTA

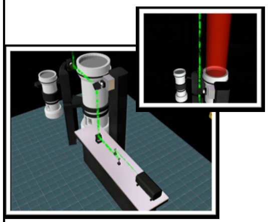
A sun-photometer is an instrument that points towards the Sun and measures radiation at several chosen wavelenghts (340, 380, 440, 500, 670, 870, 940 and 1020 nm in the case of CIMEL Sunphotometer). Among other parameters, it allows the retrieval of the Aerosol Optical Depth (AOD) at each wavelength.

More information: https://aeronet.gsfc.nasa.gov/new_web/system_descriptions_instrument.html

http://sirta.ipsl.fr/

Détection de nuages au SIRTA

The **Total Sky Imager** (TSI) is an automatic, full-color sky imager system that provides real-time display of daytime sky conditions. The system captures images into industry-standard JPEG format data files, which are then analyzed for parameters such as fractional cloud cover.



The **clouds and aerosols Lidar** (LNA) is an active remote sensing instrument using a laser. The instrument is capable of retrieving the optical and microphysical caracteristics of clouds and aerosols particles in the boudary layer and the troposphere (between 0.1 km and 15 km). Two wavelengths are emitted by the laser: 532 nm and 1.064 µm ; the detection system is capable of measuring the signal at 532 nm with the same polarization than the emitted beam, the signal cross polarized (according to the emitted polarization), and 1.064 µm, and 607 nm from the Raman diffusin of the diazote molecule. Another backscattering lidar (at 355 nm) is automatically operated.

The **Ceilometer CL31** from Vaisala is a compact and lightweight instrument for cloud base height and vertical visibility measurements. It is uses a 910nm laser (InGaAs)

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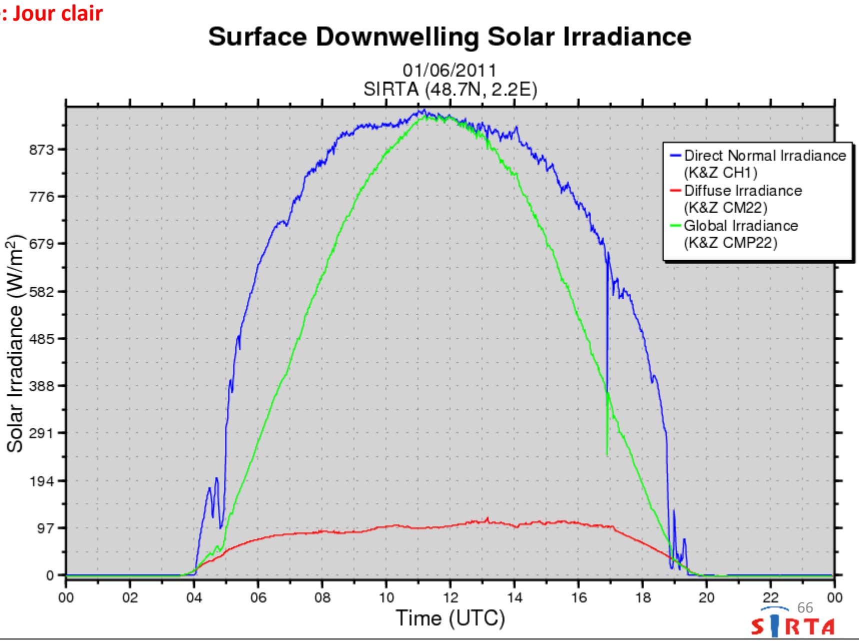
http://sirta.ipsl.fr/

Rayonnement mesuré au SIRTA

Été: Jour clair



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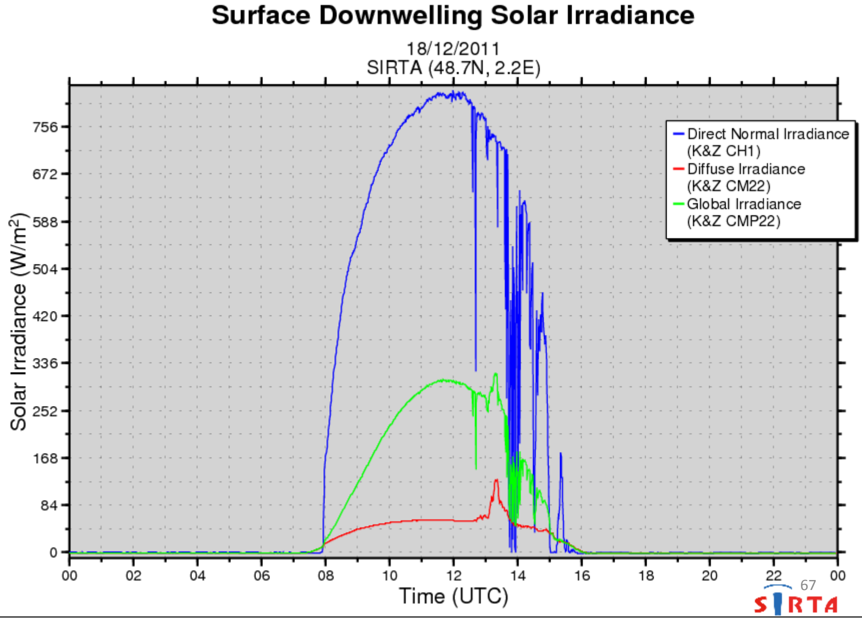
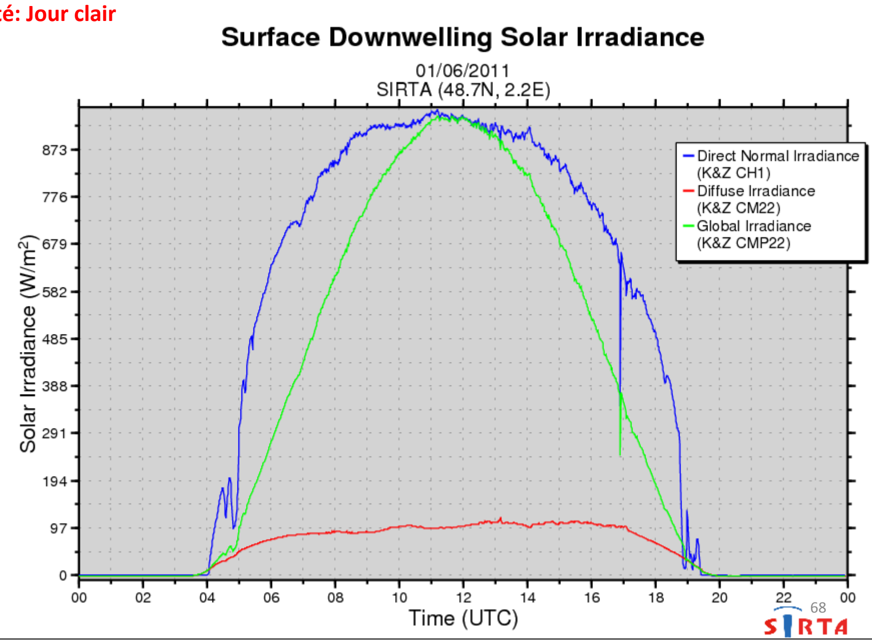
Rayonnement mesuré au SIRTA

Hiver: Jour clair



Rayonnement mesuré au SIRTA

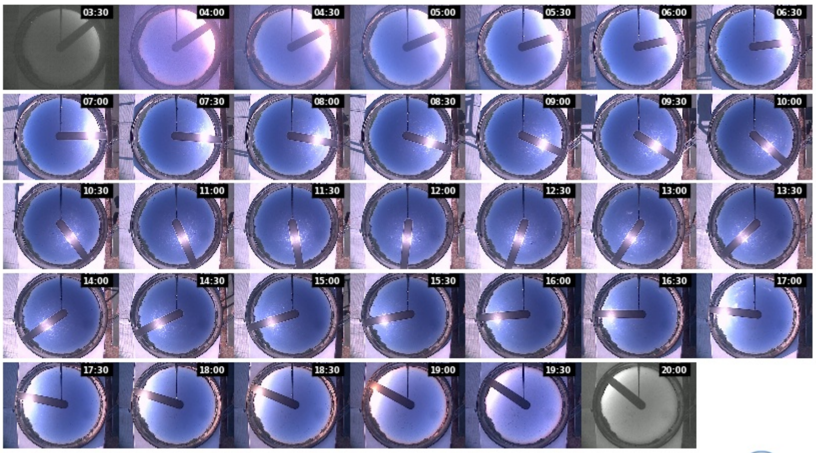
Été: Jour clair



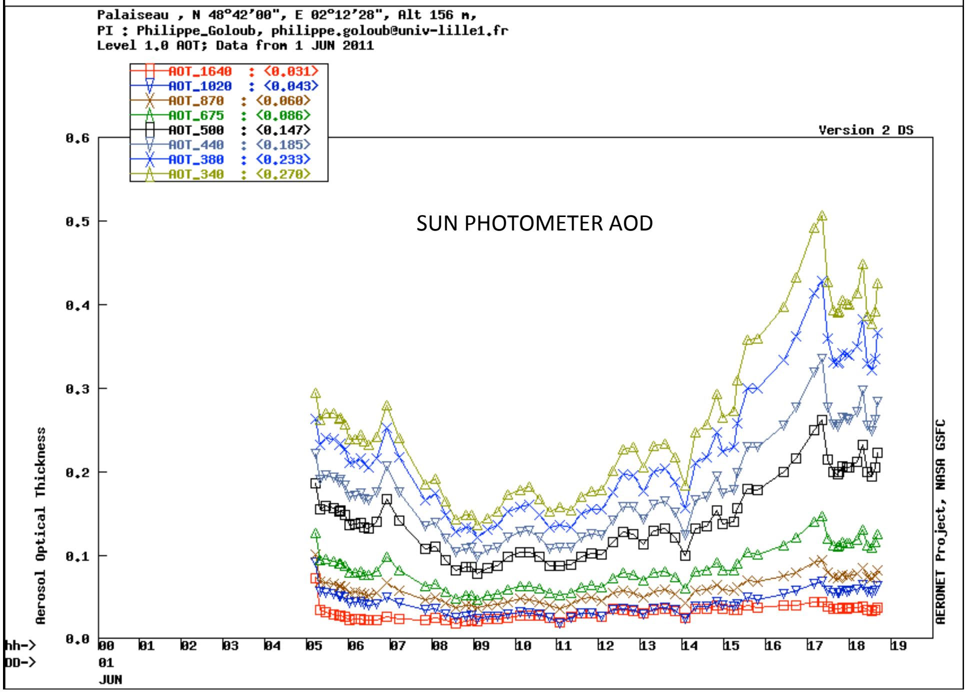
TSI-440 Total Sky Imager

2011/06/01

SIRTA (48.7N, 2.2E)

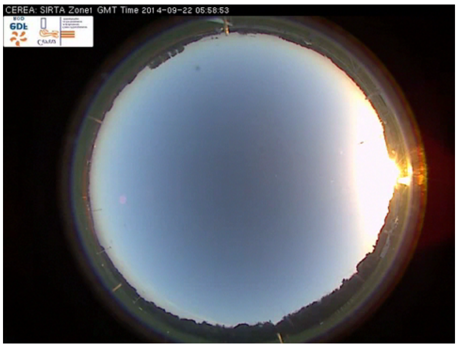


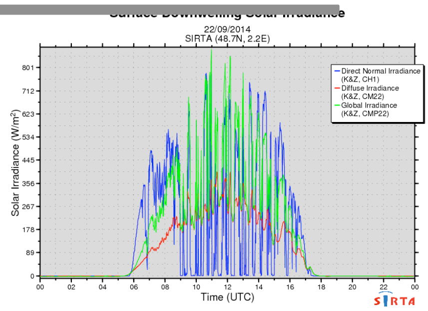
SIRTA 69

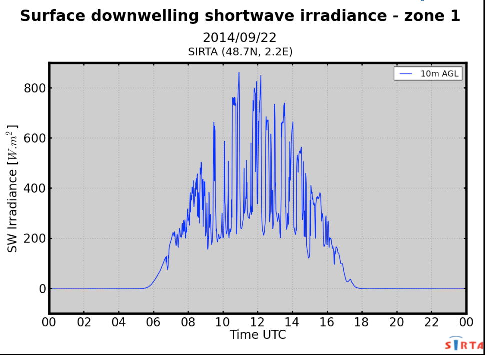


Rayonnement mesuré au SIRTA

Variable day



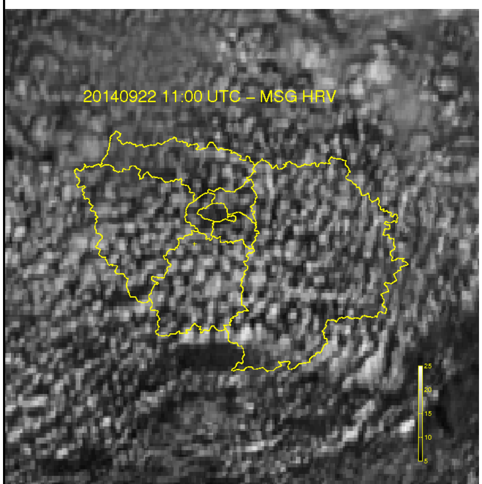




Video from:

Rayonnement mesuré au SIRTA

Variable day



Meteosat satellite reflectance images