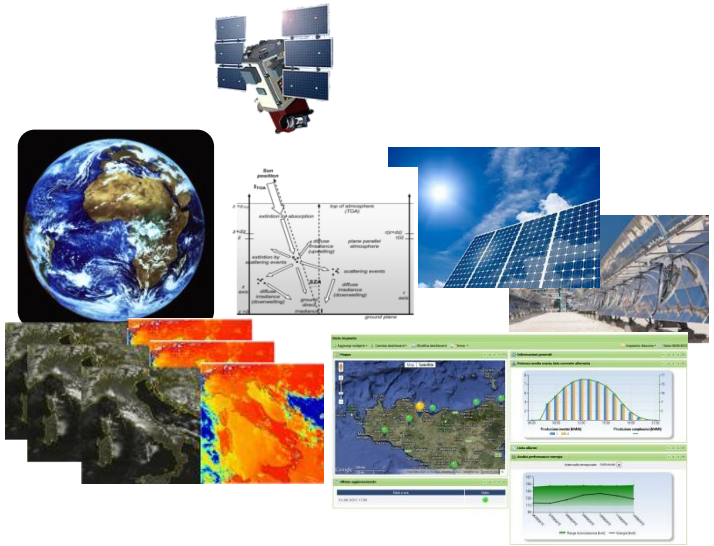
Monitoring the performance of solar energy plants from satellite remote sensing of air temperature and ground solar irradiance through an accurate modelling of the effects of aerosol optical properties



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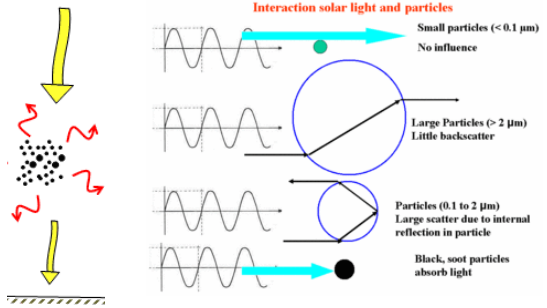
Outline

1. Introduction
2. Method
3. Results
4. Ground based validation
5. Conclusions
6. Outlooks
7. References

Introduction

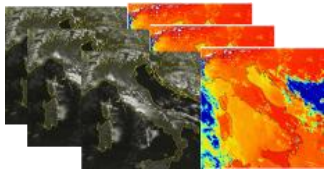
- A satellite-based downstream **service dedicated to solar energy plants near real-time monitoring** has been further developed thanks to the **partnership among Flyby S.r.l., the University of Milano and the University of Genova**

- The methodology, **originally developed in the frame of the FP7 "ENDORSE" project** (Wald, 2011) by Flyby and the University of Genoa (Morelli, 2013), has been improved by the addition of a **novel part dedicated to aerosols optical properties modelling in clear-sky conditions**

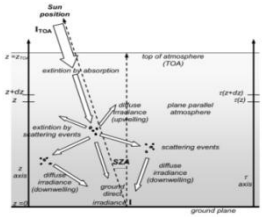


Method: overall scheme

Clouds impact modelling starting from MSG imagery (15min resolution) exploiting an Heliosat2-based (Rigollier, 2004) method

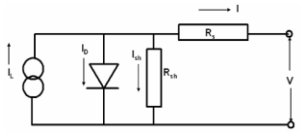


Aerosols impact modelling in clear-sky conditions



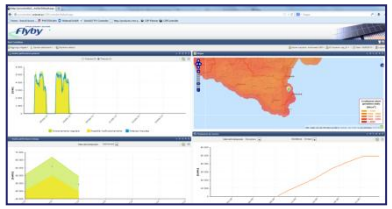
Satellite-based Global/Beam Tilted Irradiance

Satellite-based air temperature modelling



Solar energy plant production modelling

Near real-time expected energy produced by the solar plant



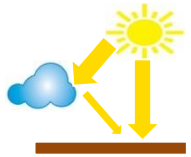
Legenda:

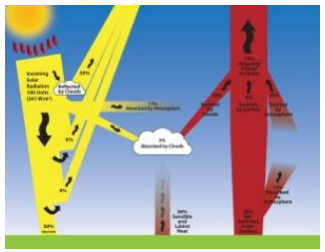
- *Flyby contribution*
- *Univ. Milano contribution*
- *Univ. Genova contribution*

Method: tilted irradiance modelling

Satellite-based GHI calculation

Global Horizontal Irradiance (GHI)





Atmosphere modeling (clear-sky conditions)

Direct-diffuse irradiance decomposition model

Clear-sky GHI

Radiative Transfer Model

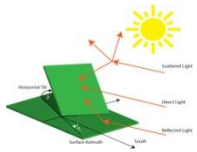
Atmosphere complete profile (ozone, aerosols, etc..)

- Beam Horizontal Irradiance
- Diffuse Horizontal Irradiance
- Ground-Reflected Horizontal Irradiance

Modeling of the irradiance on sloped surfaces (for each solar receiver of the plant)

Components of the Global Tilted Irradiance (GTI):

- Beam (Direct)
- Isotropic Diffuse from Sky
- Diffuse from Horizon
- Circumsolar Diffuse
- Ground-Reflected

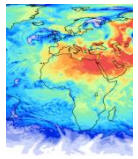


Global/Beam Tilted Irradiance

Method: PV production modelling

Global Tilted Irradiance (GTI)

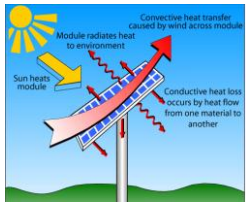
Air temperature



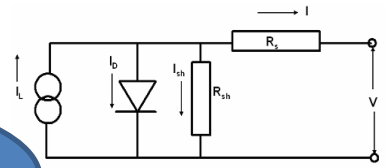
Modeling of PV cell absorption

Modeling of PV modules temperature

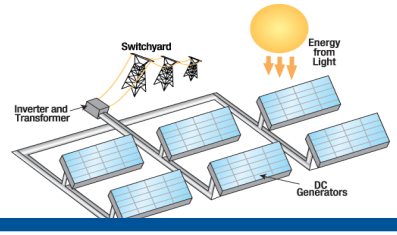
Module temperature of each PV cell

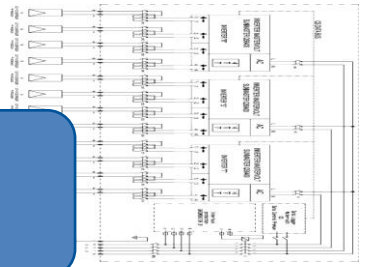


Irradiance absorbed by each PV array of the plant



Modeling of each PV cell in the plant





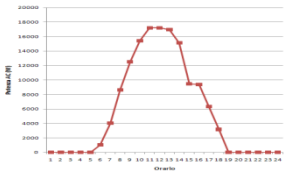
DC power input to each inverter

Operating DC current and voltage of each PV array

Modeling of each inverter

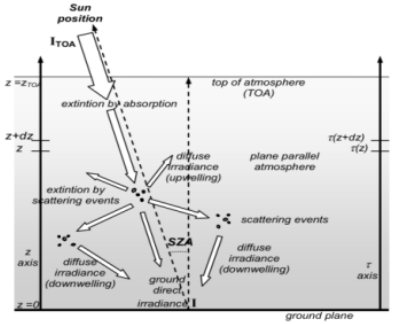
AC power output from each inverter

AC power yield



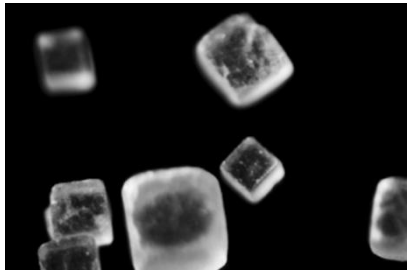
Method: aerosols modelling (clear-sky case)

- The aerosols impact on solar radiative transfer in clear-sky conditions have been modelled by coupling an **accurate modelling of aerosols optical properties** and a **radiative transfer model** (based on libRadtran)



- In particular the **extinction coefficient, the single-scattering albedo and the shape function** of **sea salt aerosols** (coastal environment conditions) have been calculated by using the typical physical properties reported in literature (Chamaillard, 2006)

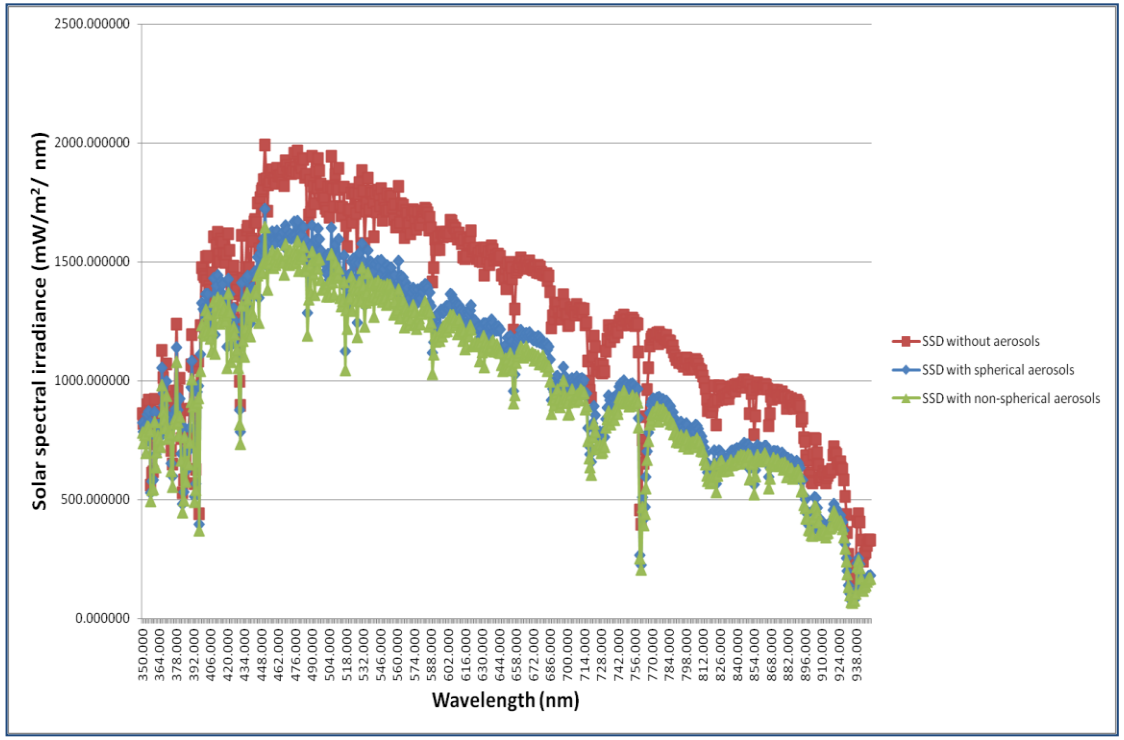
- In particular also the **effects of non-sphericity** of sea-salt aerosols have been investigated



Results: sea-salt aerosols impact

Clear-sky shortwave solar downwelling (SSD) spectral irradiance (W/m^2) has been modelled in three different conditions:

- **without a aerosol layer**
- with a **spherical-shape aerosol** layer (Mie theory)
- with a **non-spherical shape (cubic) aerosols** layer, in order to simulate sea-salt aerosols (coastal environment)

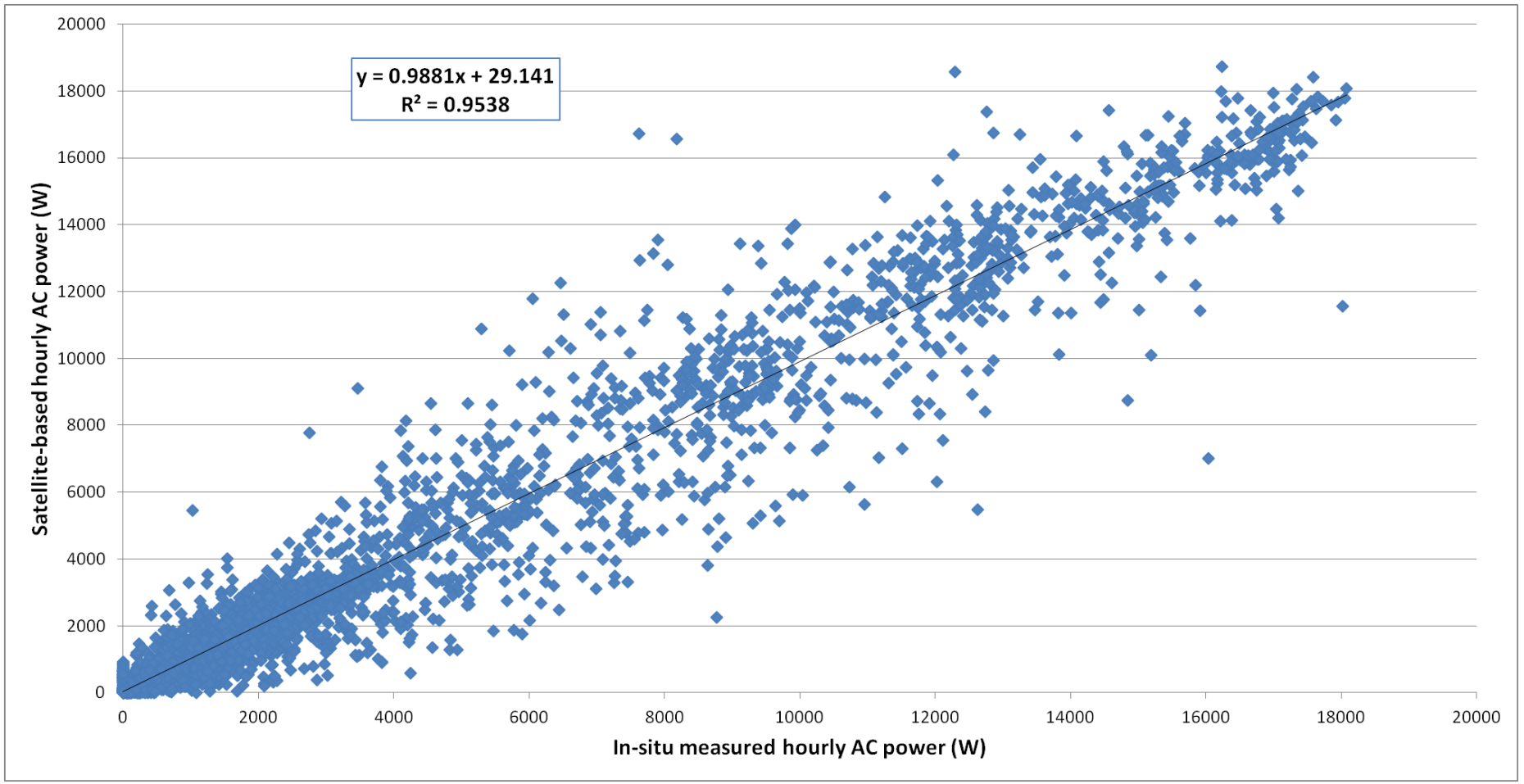


Ground-based validation: meteo station

A solar radiation monitoring station has been installed in Livorno – Italy (near to the sea, i.e. mainly sea salt aerosols expected) on Flyby's headquarters roof in order to compare satellite-based data with ground-based ones through:

- 2 pyranometers (Delta Ohm)
- 1 photovoltaic plant (3 PV panels)

Ground-based validation: comparison plot



Ground-based validation: discussion

- The comparison among low-aerosols and high-aerosols days (as in the case of Sept. 1st and Sept. 6th) shows that **aerosols have a sensible impact on solar energy production** that could be modelled

- The **shape of the aerosols** has an impact that should be taken into account in order to properly model their effect on radiative transfer

- The method developed currently allows to **model the aerosol's impact on solar energy production** in coastal environments with **good performances**

Conclusions

- an innovative methodology has been developed to calculate in near real-time the solar energy plants production taking into account also the role of aerosols
- at the moment this methodology reported **good performances in a coastal site** by modelling only sea-salt aerosols in clear-sky conditions
- this methodology is exploited in **downstream service dedicated to solar energy plant monitoring** that has been originally developed in the frame of the FP7 ENDORSE project
- the **collaboration among Flyby, University of Milano and University of Genoa has been (and is going to be) fundamental** for the development of such methodology

Outlooks

- the **optical properties of other types of aerosols** will be modelled in order to further expand the applicability of the methodology developed
- the method should be further developed in order to automatically take into account the type of aerosol in the solar energy plant's site (e.g. by exploiting AERONET or MACC data)
- **cloudiness nowcasting** based on the elaboration of the last available time-series of satellite imagery could improve the accuracy of the methodology overcoming the limitations related to 15-min resolution
- the solar irradiance calculation in **highly variable meteorological conditions should be improved**

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Many thanks for your attention!

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