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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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**

**Legend:**
- Blue: Flyby contribution
- Red: Univ. Milano contribution
- Green: Univ. Genova contribution
Method: tilted irradiance modelling

Satellite-based GHI calculation → Global Horizontal Irradiance (GHI) → Direct-diffuse irradiance decomposition model → Clear-sky GHI → Radiative Transfer Model → Modeling of the irradiance on sloped surfaces (for each solar receiver of the plant) → Global/Beam Tilted Irradiance

Atmosphere complete profile (ozone, aerosols, etc..) → Components of the Global Tilted Irradiance (GTI):
- Beam (Direct)
- Isotropic Diffuse from Sky
- Diffuse from Horizon
- Circumsolar Diffuse
- Ground-Reflected

Radiative Transfer Model

Clear-sky GHI

Direct-diffuse irradiance decomposition model:
- Beam Horizontal Irradiance
- Diffuse Horizontal Irradiance
- Ground-Reflected Horizontal Irradiance

Global Horizontal Irradiance (GHI)
Method: PV production modelling

- Global Tilted Irradiance (GTI)
  - Modeling of PV cell absorption
  - Irradiance absorbed by each PV array of the plant
  - DC power input to each inverter
  - Modeling of each inverter

- Air temperature
  - Modeling of PV modules temperature
  - Module temperature of each PV cell
  - Operating DC current and voltage of each PV array

- 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

\[ y = 0.9881x + 29.141 \]

\[ R^2 = 0.9538 \]
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**


• L. Wald et al, *The project ENDORSE: exploiting EO data to develop pre-market services in renewable energy*, Proc. of the 25th EnviroInfo Conference – Ispra, Italy (2011)
Many thanks for your attention!

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