

# Radiative closure studies applied to Sentinel-2 data at the Lampedusa Climate Observatory



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Radiative closure studies as complementary methods for calibration and validation of the satellite observations, especially those referred to ecosystem studies. This study proposes the ENEA Climate Observatory of Lampedusa island, in the central Mediterranean Sea, as a marine/terrestrial site where radiative closure studies and independent measurements of geophysical parameters for the validation of the Sentinel-2 products are carried out. The Sentinel-2 observations of the Lampedusa region will be used to study the influence of anthropic pressure on ecosystems in the framework of SMart Urban Solution (SMURBS) project (<http://www.era-planet.eu/index.php/calls/smurbsstrand1/>). The analysis focuses on the Sentinel-2 atmospherically corrected data. Closure studies on ground-based diffuse, and direct solar irradiances are carried out by using the Second Simulation of a Satellite Signal in the Solar Spectrum, Vector (6SV) atmospheric radiative transfer model [2, 3]. The target and the environmental reflectance required by 6SV run for radiative simulation, are selected from the atmospherically corrected Sentinel-2 images with spatial resolution of 60m. In order to perform the solar irradiance simulation by 6SV runs, the atmospheric input are the water vapor ( $wv$ ), the ozone ( $O_3$ ) columnar contents and the aerosol properties (i.e., the  $AOD$  and the aerosol model). The aerosol model is defined by the microphysical properties, size distribution and refractive index, or by predefined model, such as the rural one. Consequently, to evaluate the direct and diffuse components of the downward solar irradiance at a specific MSI/S2 acquisition time, 6SV model runs two times considering two different aerosol conditions, the AERONET products and those used in the iCOR software.

## 1. Study area & Data

Lampedusa is a small island in the central Mediterranean sea, with a surface area of about  $20km^2$ , sparse vegetation, limited pollution sources. The highest elevation of the island is 123m.



**Figure 1:** (left) Central Mediterranean Sea by World Map of SNAP software. (right) Satellite image of Lampedusa island acquired by Sentinel-2A.

### Ground measurements by Lampedusa Climate Observatory

The Station for Climate Observations on the island of Lampedusa (<http://www.lampedusa.enea.it>) has been operational since 1997 and dedicated to longterm measurements of atmospheric parameters related to climate. The experimental site includes an Atmospheric Observatory ( $35.52^\circ N$ ,  $12.63^\circ E$ ), where all essential climate variables (ECVs) are routinely measured, and an Oceanographic Observatory ( $35.49^\circ N$ ,  $12.47^\circ E$ ) dedicated to the investigation of air-sea exchange. The wide set of data measured at Lampedusa include: meteorological parameters, aerosol optical properties, vertical distribution, and chemical composition, downwelling and upwelling broadband solar radiation, downwelling and upwelling spectral irradiance, cloud properties, water vapour, ozone, surface albedo. These parameters can be used for direct retrieval of surface reflectance ([1]), as well as for radiative closure studies with respect to the retrieved reflectance as well as for the validation of satellite products by ground-based radiance and irradiance observations. Once water-leaving reflectance measurements from the Oceanographic Observatory are available, the Lampedusa site may provide valuable data for the validation of surface reflectance from atmospheric correction of Sentinel-2 data. The coexistence of observatories on both land and open sea, in Lampedusa, will allow retrieval of data for land and coastal environment studies from space.



**Figure 2:** (left) Lampedusa Climate Observatory. (center) AERONET station, with direct and inverse product (right) Pyranometer and pyrhelimeter for diffuse and direct components of the downward solar irradiance.

## 2. Methods

### 2.1 MSI/S2A surface reflectance for radiative simulation

THE surface reflectance was provided by applying the iCOR atmospheric correction algorithm, available through the ESA Sentinel Application Platform (SNAP), to the Sentinel-2 image. The processing parameters depend on the surface to be corrected. Over land, the iCOR is able to retrieve the the aerosol optical thickness at  $550nm$  ( $AOD$ ) while over water the  $AOD$  is fixed to 0.1. Furthermore, the rural aerosol model is fixed when iCOR is applied to MSI/S2 image. Finally, iCOR is able to apply the adjacency correction to the image.

### 2.2 Radiative Closure

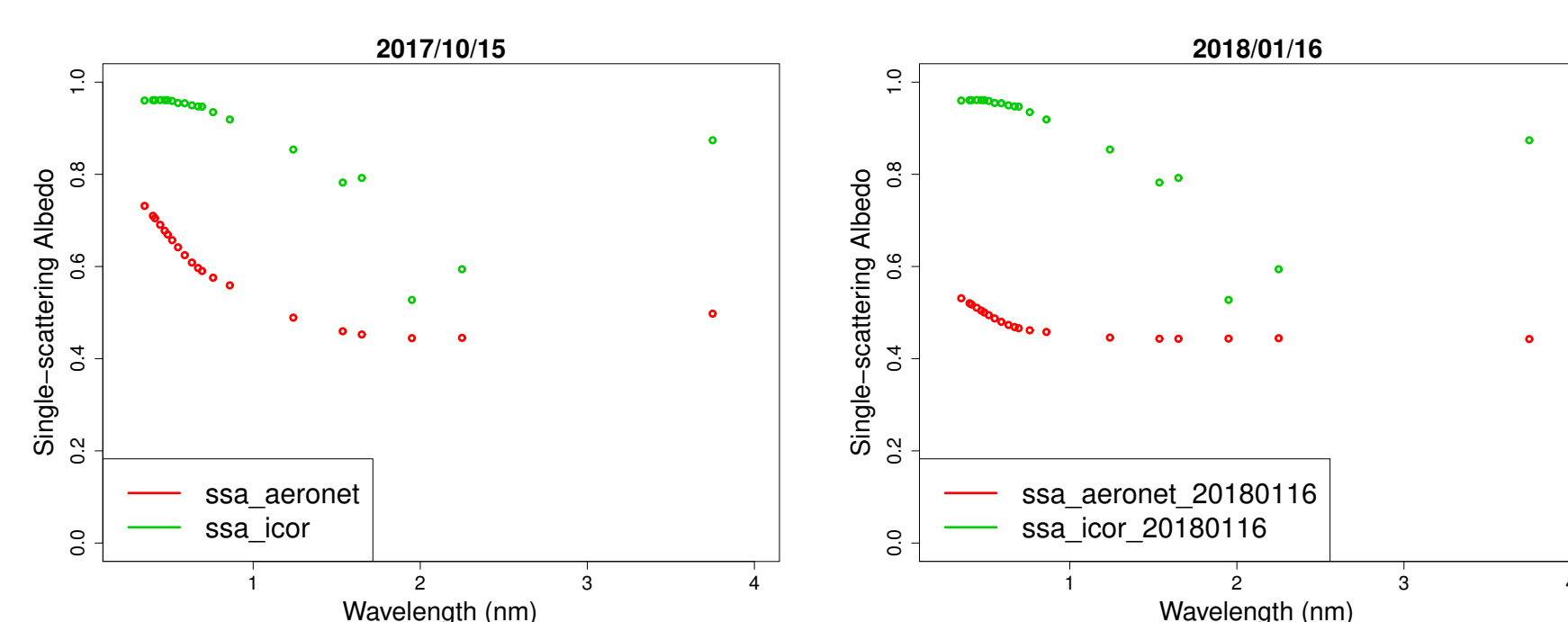
THE closure studies on ground-based diffuse and direct solar irradiances were simulated by using the Second Simulation of a Satellite Signal in the Solar Spectrum, Vector (6SV) atmospheric radiative transfer model [2, 3]. The target and the environmental reflectance required by 6SV run for radiative simulation, are selected from the atmospherically corrected Sentinel-2 images with spatial resolution of 60m. In order to perform the solar irradiance simulation by 6SV runs, the atmospheric input are the water vapor ( $wv$ ), the ozone ( $O_3$ ) columnar contents and the aerosol properties (i.e., the  $AOD$  and the aerosol model). The aerosol model is defined by the microphysical properties, size distribution and refractive index, or by predefined model, such as the rural one. Consequently, to evaluate the direct and diffuse components of the downward solar irradiance at a specific MSI/S2 acquisition time, 6SV model runs two times considering two different aerosol conditions, the AERONET products and those used in the iCOR software.

## 3. Results

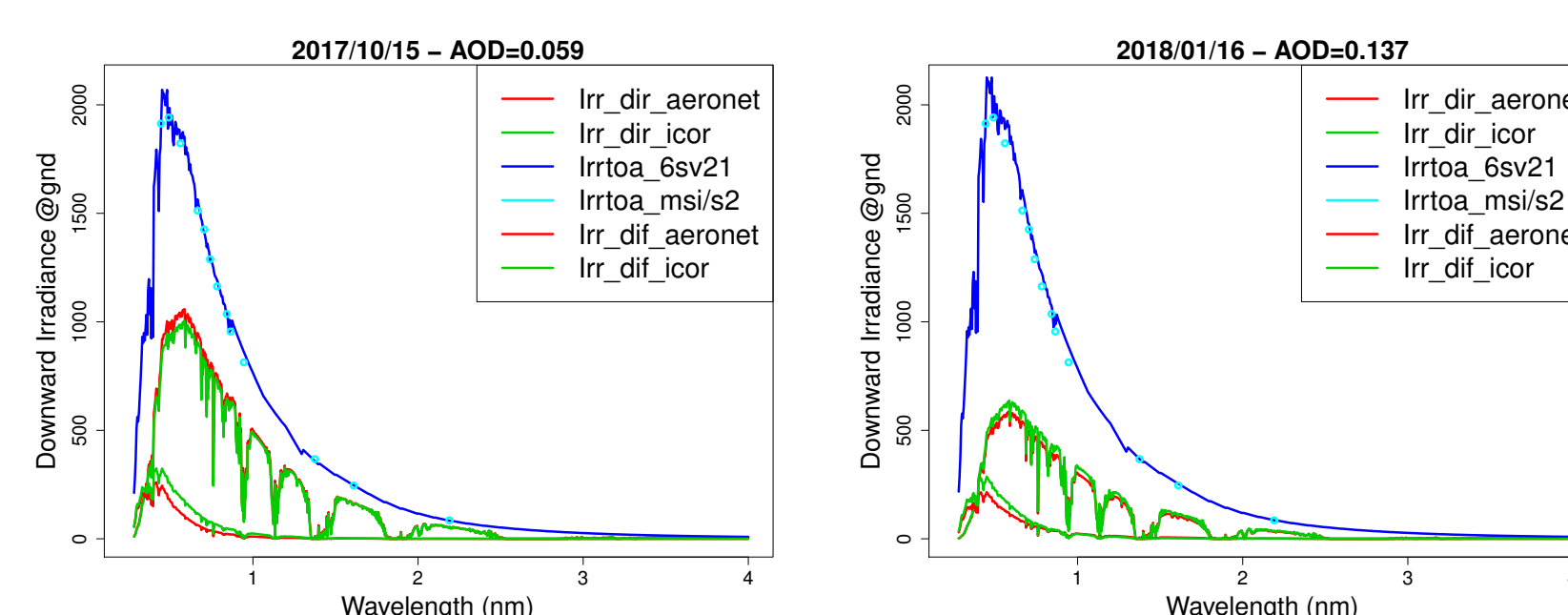
THE two MSI/S2A images were acquired quasi-synchronously with AERONET, pyranometer and pyrhelimeter available data. The iCOR software was applied to the images for surface reflectance retrieval. The target and the environmental reflectance required for irradiance simulation, was selected from the iCOR image output at 60m spatial resolution. For each surface reflectance, two 6SV runs for irradiance simulation were performed considering the  $wv$  and the  $O_3$  fixed at the AERONET values reported in Table 1. The direct and diffuse irradiance components were simulated by 6SV for the two aerosol conditions. The 6SV model was first run with the  $AOD$  (Table 1), the size distribution and the refractive index as provided by AERONET. Later, the 6SV was run with the  $AOD$  fixed to 0.1 and the rural aerosol model, implemented in the iCOR software.

**Table 1:** Acquisition time, solar zenith angle (SZA) and atmospheric conditions for the 6SV runs

| Date<br>(YY/MM/DD) | Time<br>(hh:mm) | SZA<br>[°C] | $AOD$<br>AERONET | $AOD$<br>iCOR | $O_3$<br>[DU] | $wv$<br>[gm <sup>-2</sup> ] |
|--------------------|-----------------|-------------|------------------|---------------|---------------|-----------------------------|
| 17/10/15           | 09:59           | 46.2        | 0.059            | 0.100         | 286           | 1.70                        |
| 18/01/16           | 10:04           | 59.3        | 0.137            | 0.100         | 315           | 1.26                        |



**Figure 3:** Single-scattering of the aerosol simulated by 6SV with AERONET products (aeronet) and rural model fixed in iCOR software (icor). The properties are simulated during the acquisition time of the Sentinel2: 2017/10/15 (left) and 2018/01/16 (right).



**Figure 4:** Direct and diffuse solar downward irradiance ( $W/m^2$ ) simulated by 6SV considering the aerosol AERONET products,  $Irr\_dir/dif\_aeronet$ , and the rural aerosol model,  $Irr\_dir/dif\_icor$ . The Irradiance at TOA contained in the MSI/S2A metadata ( $Irrtoa\_msi/s2$ ) and in the 6SV source code ( $Irrtoa\_6sv21$ ) are also reported.

**Table 2:** Comparison of the direct and diffuse components of downward solar irradiance simulated by using 6SV model and measured at the ENEA station by a pyrhelimeter and a pyranometer, respectively. The two 6SV runs were performed with rural aerosol model (fixed in the iCOR software) and with the microphysical properties of the aerosol as provided by the AERONET Lampedusa station. The results were compared with the measured irradiance.

| Direct component of downward solar irradiance, $W/m^2$  |                             |                                       |                                      |  |
|---|-----------------------------|---------------------------------------|--------------------------------------|--|
| Date  | Measurement<br>Pyrhelimeter | Simulation by 6SV<br>AERONET products | simulation by 6SV<br>iCOR conditions |  |
| 2017/10/15  | 652                         | 663 (2%)                              | 634 (3%)                             |  |
| 2018/01/16  | 399                         | 413 (4%)                              | 439 (10%)                            |  |
| Diffuse component of downward solar irradiance, $W/m^2$ |                             |                                       |                                      |  |
| Date  | Measurement<br>Pyranometer  | Simulation by 6SV<br>AERONET products | simulation by 6SV<br>iCOR conditions |  |
| 2017/10/15  | 68                          | 70 (2%)                               | 102 (49%)                            |  |
| 2018/01/16  | 76                          | 75 (1%)                               | 92 (22%)                             |  |

## 4. Conclusion

THE study highlights the role of the aerosol properties used in the atmospheric correction of MSI/S2 images through the analysis of simulated spectral downward solar irradiance (Figure 4) and the studies of radiative closure (Table 2).

In this work, two dataset (2017/10/15 and 2018/01/16) composed each one by MSI/S2 image acquired over Lampedusa island and quasi-synchronous radiative measurements of the ENEA Climate Observatory were considered. Each MSI/S2 image were atmospherically corrected by using the iCOR software to provide the target and environment surface reflectances required for the simulation of the direct and diffuse components of the downward irradiance by the 6SV atmospheric radiative transfer model.

The analysis was performed for each date separately. Firstly, the 6SV run with the atmospheric condition provided by the AERONET station. Later, the 6SV run with the atmospheric condition provided by the iCOR software. Both the conditions are reported in Table 1.

The direct and diffuse components of the downward solar irradiance (Figure 4) have different behaviours if the simulation was performed with local aerosol, AERONET products, or with iCOR atmospheric conditions,  $AOD$  and rural aerosol model. The Figure 3 shows the single-scattering albedo simulated for the two atmospheric conditions in both the dates.

From the Table 2, the direct component of the downward solar irradiance is well-simulated independently on the atmospheric conditions used during the 6SV simulation. However with regard to the diffuse component, the simulation is strongly influenced by the atmospheric conditions. The iCOR aerosol ( $AOD$  and rural aerosol) are not representative of the local aerosol (AERONET products) leading to an accuracy decrease of 49% (2017/10/15) and 22% (2018/01/16).

Therefore, the analysis of simulated spectral downward solar irradiance (Figure 4) and the studies of radiative closure (Table 2) are basic to simulate accurate spectral components useful during atmospheric correction (i.e. adjacency effect) or for additional Sentinel-2 products, such as photo-synthetically active radiation (PAR),

## 5. Acknowledgements

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