Enabling Climate Information Services for Europe

DELIVERABLE 6.13

Report on future evolution of sunshine duration and solar radiation over Sicily

Activity:	*WP6 – Energy*
Activity number:	*Task 6.6 - Past and future solar radiation estimation for Sicily*
Deliverable:	*Future evolution of sunshine duration and solar radiation over Sicily*
Deliverable number:	*6.13*
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Summary

This report describes the activities performed by ISAC-CNR to produce Deliverable 6.13 of the ECLISE Project - Future evolution of sunshine duration and solar radiation over Sicily. These activities were performed within *task 6.6 - Past and future solar radiation estimation for Sicily* that also allowed producing *Deliverable 6.12 - Climatology of sunshine duration and solar radiation for Sicily*. Both deliverables were produced on the basis of SIAS (Servizio Informativo Agrometeorologico Siciliano, one of the users of the ECLISE Project) needing. The deliverable mainly consists of maps reporting monthly solar radiation climatologies for a number of time periods of 1961-2100 interval.

1. Introduction

High-resolution datasets of monthly climatological normals (i.e. high-resolution climatologies) have proved to be increasingly important in the recent past, and they are likely to become even more important in the future. They are used in a variety of models and decision support tools in a wide spectrum of fields such as, just to cite a few, energy, agriculture, engineering, hydrology, ecology and natural resource conservation (Daly et al., 2002; Daly et al., 2006). One of the most important variables for many possible applications (e.g. energy production and agriculture) is solar radiation.

It is therefore very important to develop and to apply methodologies that exploit as much as possible the information contained in solar radiation observational records: they consist of both global radiation and sunshine duration records. The latter have the advantage of a much larger data availability, especially when long-term records are considered, the former are more frequently available from present-time station networks.

In this context, we set up a methodology for estimating high-resolution solar radiation climatologies from these records. This methodology is an improved version of that presented in Spinoni (2010) and Spinoni et al. (2012). It consists of the following steps that have to be run on a monthly basis:

- calculating global radiation normals for all station sites or estimating them from sunshine duration normals, when global radiation data are not available;
- estimating, for all station sites, the bias due to shading and adjusting the normal values in order to make them representative of un-shaded sites;
- calculating clearness index normals from these shading-bias-adjusted global radiation normals and decomposing global radiation normals into the direct and diffuse components;
- projecting global radiation normals and the direct and diffuse components onto a high-resolution regular grid, considering flat ground;
- evaluating atmospheric turbidity over the same grid by means of the direct component of global radiation normals;
- calculating normal values for the direct, diffuse and reflected components of global radiation for any grid-cell, taking into account its slope and aspect (i.e. slope orientation) and considering shading from the cell itself and from the neighbouring cells.

A preliminary version of the methodology was already available before the beginning of the ECLISE Project (Spinoni, 2010). The methodology has then been significantly improved within the first part of the ECLISE Project (Spinoni et al., 2012) and it has been used to produce the Sicily monthly global radiation high resolution (30 arc-second) climatologies (1961-1990) that were produced as deliverable 6.12 of this project. In deliverable 6.12 they were mainly based on data from the Italian Air Force meteorological network and the reference period was the 1961-1990. Then, the methodology has been further improved, producing the Sicily monthly global radiation climatologies for the 2002-2011 period (already presented at the second ECLISE annual meeting and general assembly (Chania, 23-26 april 2013)) mainly based on data from the SIAS meteorological network (with a significantly higher spatial density than the Air Force one).

In the last year of the ECLISE Project, we focused our activities mainly on the temporal component of solar radiation over Sicily, considering both observational records (1936-2013) and the simulations of 4 RCM-GCM combinations (1961-2100). These activities allowed obtaining, besides the climatologies for the period with best data availability (2002-2011), also estimated climatologies for any other period of the 1936-2100 interval.

Because of the significant improvements performed to the methodology, the construction of the climatologies is also presented in this report.

2. Solar radiation climatologies for the 2002-2011 period

2.1 Station data, quality checks, clearness index monthly records, homogeneity tests and gap filling

The 2002-2011 solar radiation climatologies we presented at the second ECLISE annual meeting and general assembly (Chania, 23-26 april 2013) are based on a network of 41 global radiation records covering the entire Sicilian territory (Fig. 1). The network is managed by SIAS, an agrometeorological Service of Sicily regional administration (see www.sias.regione.sicilia.it/). SIAS cooperated to the activities of task 6.6 both as data provider and as user of the considered case study. Global solar radiation is measured by means of thermopile pyranometers. The data have hourly resolution.

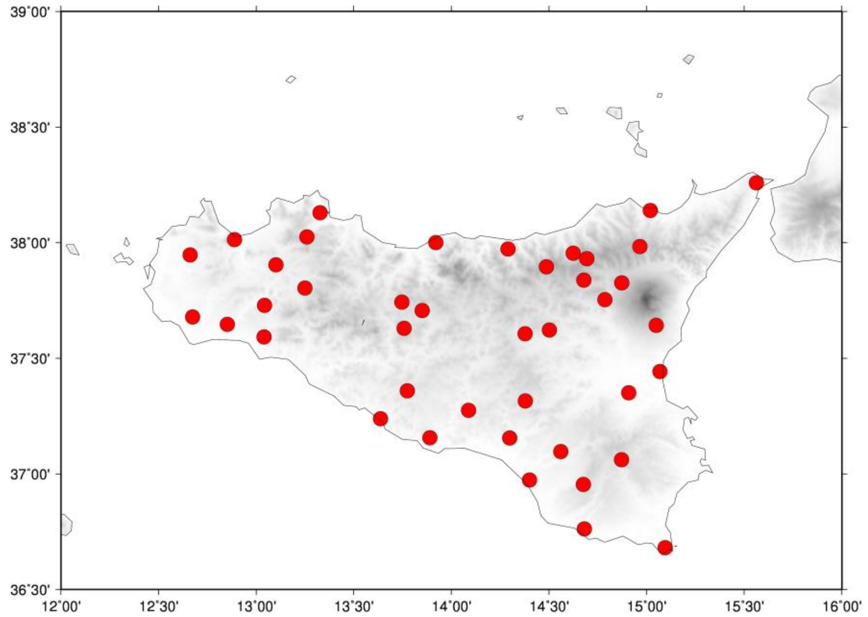

Fig. 1 – network of the 41 meteorological stations considered to produce the 2002-2011 solar radiation climatologies.

Before the analyses the hourly data were subjected to a quality check procedure in order to identify and correct gross errors such as negative values; then daily cumulated values were calculated (Mj/m^{2}day) and they were used to obtain daily clearness index (i.e. the ratio between measured and eso-atmospheric radiation) records. These records were then averaged for all months in order to obtain monthly records.

The monthly clearness index records were then analyzed by means of the Craddock homogeneity test (Craddock, 1979). More precisely, homogeneity testing was performed in sub-groups of 10 series using a revisited version of the HOCLIS procedure (Auer et al., 1999). HOCLIS rejects the a priori existence of homogeneous reference series. It consists of testing each series against other series, by means of a multiple application of the Craddock test, in sub-groups of 10 series. The test is based on the hypothesis of the constancy of clearness index ratios among nearby sites. The break signals of one series against all others are then collected in a decision matrix and the breaks are assigned to the single series according to probability. This procedure allowed identifying some records with inhomogeneous sub-periods with respect to the remaining part of the record: these sub-periods were deleted from the data.

After the inhomogeneous periods were eliminated, the monthly clearness index records were completed over the 2002-2011 period. Missing data estimation was performed for each month and each station by i) selecting all the records which have at least the same data of the station to be completed; ii) transforming the data of all the stations into anomalies with respect to their averages over the years for which the station to be completed has no missing data; iii) filling the gaps of the station to be completed by a weighted average of the anomalies of the other stations, with weights depending on distance and elevation difference and on an additional angular weighting factor introduced in order to take into account the anisotropy in stations' spatial distribution (Sanchez-Lorenzo et al., 2007); iv) converting the estimated anomalies into absolute values.

The completed records were then used to calculate monthly clearness index normals referred to the period 2002-2011 for all stations.

2.2 Adjustment of the station normals to un-shaded station normals

Most of the stations of the SIAS network are located in areas with very limited shading and they are representative of un-shaded sites; there are however also some stations which are located in areas with significant shading, especially in winter. In order to make all stations representative of un-shaded sites we evaluated, by means of the 30 arc-second resolution GTOPO 30 Digital Elevation Model (USGS, 1996) and considering literature values for atmospheric turbidity, the fraction of direct radiation which is lost by each station due to shading, where shading can be caused both by the neighbouring cells and by the cell in which the station is located. Then we performed the same evaluation for diffuse radiation. When at least one of the lost fractions resulted greater than 0.5%, we corrected the station clearness index normals in order to make them representative of un-shaded measurements.

For this purpose we first estimated the station clearness index by means of the (un-shaded) neighbouring stations and used it to split global radiation into the direct and diffuse components in order to get the global radiation deficit from both fractions. Then we estimated the contribution of the reflected radiation and finally we estimated the total effect of the slope and orientation of the stations' cell and of the orography of the neighbouring areas on the global radiation measured at the site. This estimation was used to correct the station clearness index normal and to make it representative of an un-shaded situation. Only 13 out of 41 stations required this kind of correction. Moreover, corrections were generally rather small as only 4 stations have a maximum monthly correction which exceeds 5%. The station with the largest correction is indeed Castellamare del Golfo with values ranging from 4.4% (June) to 10.1% (December): it is shaded in the afternoon by rather steep mountains surrounding the bay in which the station is located.

These results highlight the great care taken by SIAS in selecting the stations' sites.

2.3 Gridding of the un-shaded station normals

Once all station clearness index normals were representative of un-shaded sites, we used a decomposition model (Iqbal, 1983), to estimate the direct and the diffuse fractions corresponding to the station shading-bias-adjusted global radiation normals. Then we interpolated them onto the GTOPO 30 grid. We tested different methods to perform this interpolation, including Inverse Distance Weighting (IDW) and Multi Linear Regression versus latitude and elevation, followed by an Inverse Distance Weighting of the residuals (Manara et al., 2013), with weights depending on distance. The results presented in this report are based on IDW, with weights depending on distance and elevation difference and with an additional angular weight introduced in order to take into account the anisotropy in stations' spatial distribution (Sanchez-Lorenzo et al., 2007). Here, the direct and diffuse components, as well as global radiation normals, are gridded under the hypothesis that the cell is horizontal and that there is no shading from the neighbouring cells. Therefore, these normals are independent from the orography: they only depend on the position of the station, the day of the year and the atmospheric turbidity of the site.

The direct component of solar radiation was then used to estimate the turbidity of the cell, according to the method described in (Spinoni et al., 2012). This is based on the following relation (Iqbal, 1983):

$$H_{dir-flat} = E_0 I_0 \left(\int_{sunrise}^{sunset} \cos(\theta_{inc}) e^{-T_F m_A \delta_R (m_A)} dh \right) \qquad (1)$$

where $H_{dir\text{-}flat}$ is the direct component of global radiation, E_0 is the eccentricity factor (i.e. the correction due to the elliptical orbit of the Earth), I_0 is the solar constant, ϑ_{inc} is the solar angle of incidence and the exponential part explains the attenuation due to the atmosphere: T_F is the turbidity factor, m_A is the optical air mass, δ_R is the Rayleigh's depth of the atmosphere. T_F represents the turbidity of the vertical column of the atmosphere over the grid cell: clouds, water vapour, pollution, fog, ozone, and many other factors are included in T_F.

For each point and each month we searched for the T_F best matching $H_{dir\text{-}flat}$. Details on the calculations can be found in (Spinoni, 2010).

2.4 From the gridded normal to the actual climatologies

Once atmospheric turbidity and the direct and diffuse components on an horizontal un-shaded surface were estimated for each cell of the GTOPO30 DEM, we calculated the normal value of global radiation received by the soil taking into account slope steepness and orientation of the surface and shading. More precisely, direct radiation for inclined surfaces ($H_{dir\text{-}incl}$) was calculated by means of the following relation:

$$H_{dir-incl} = E_0 I_0 \left(\int_{sunrise}^{sunset} J\cos(\theta_{inc}) e^{-T_F m_A \delta_R (m_A)} dh \right) \qquad (2)$$

J is a binary factor representing shading: it was obtained by exploring the grid-cells surrounding each node of the GTOPO30 DEM and checking, with a 5-minute temporal resolution, if the path from the node to the sun does or does not intercept the DEM surface. If the grid cell is shadowed in the 5-minute interval that we used in the integration, J was set to 0, otherwise it was set to 1. In this case ϑ_{inc} is naturally calculated taking into account the slope and the aspect of the surface. Actually, in spite of the analogies of eqs. (1) and (2), they are used in a completely different way: in fact in eq. (1) we know the direct radiation on an idealized surface (flat and un-shaded) and use it to get T_F; on the contrary, in eq. (2) we know T_F and use it to get the solar radiation on a real surface.

Diffuse radiation for inclined surfaces ($H_{dif\text{-}incl}$) was calculated considering diffuse radiation as isotropic and estimating the fraction of energy lost because the inclination of the cell and the orography of the surrounding areas reduce the sky view factor (V_F), i.e. the visible fraction of the sky from the grid-cell.

Reflected radiation for inclined surfaces ($H_{ref\text{-}incl}$) was calculated considering the radiation from the obstructed sky (OS_F), expressed by $OS_F = 1\text{-}V_F$ and considering the albedo of the ground (α). In our procedure we assumed for the albedo the value which we attributed to the grid-cell itself, even though the reflection is due to the surrounding cells. This approach is reasonable since the very small contribution of reflected radiation that we have with a DEM resolution of 30 arc-seconds does not justify the much greater complexity which would be necessary in order to take into account the slope, aspect and albedo of the surrounding grid-cells. Albedo was estimated by means of the GLC2000 land cover grid provided by Joint Research Center (http://bioval.jrc.ec.europa.eu/ products/glc2000/glc2000.php).

Once direct, diffuse and reflected radiation normals were available, we simply calculated global radiation normals by their sum. The entire procedure was performed for all the grid-cells of Sicily.

The final results are 2002-2011 monthly global radiation climatologies. The climatologies of March, June, September and December are shown in Fig. 2-5. They show a rather strong North-South gradient in winter, with the lowest values in the Messina area and the highest ones in the Ragusa area. Also in the other seasons the Messina area shows lower radiation than the other parts of Sicily, even though the spatial gradients are lower than in winter.

It is worth noticing that the same procedure we applied to obtain global radiation on a surface inclined as the soil can be applied selecting any combination of slope and aspect. This may be useful for energy applications as solar panels are usually not installed parallel to the ground but in order to collect as much solar radiation as possible.

It is also worth noticing that the global radiation climatologies obtained within the ECLISE Project give much more spatial details than the ones which were available for Sicily before the Project: they were produced interpolating with rather simple methods only a few Air Force stations or using satellite measures (Italian Air Force (Aeronautica Militare),1989; Petrarca et al., 2000).

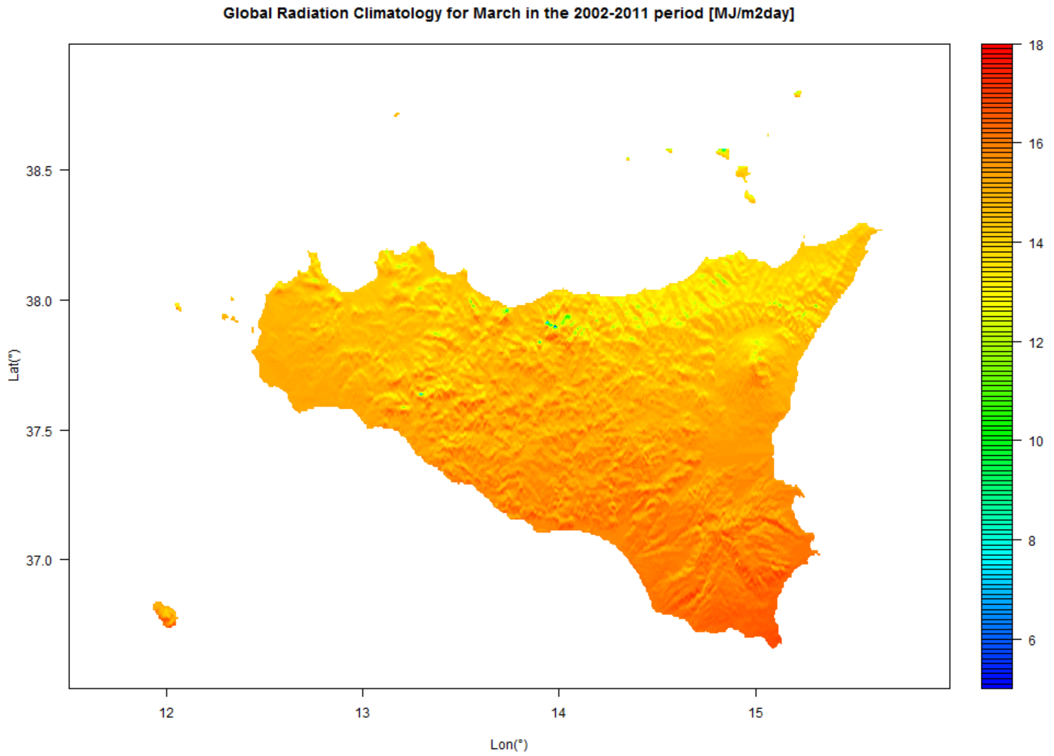

Fig. 2 – Global Radiation Climatology for March in the 2002-2011 period for a surface with the same slope and orientation of the soil.

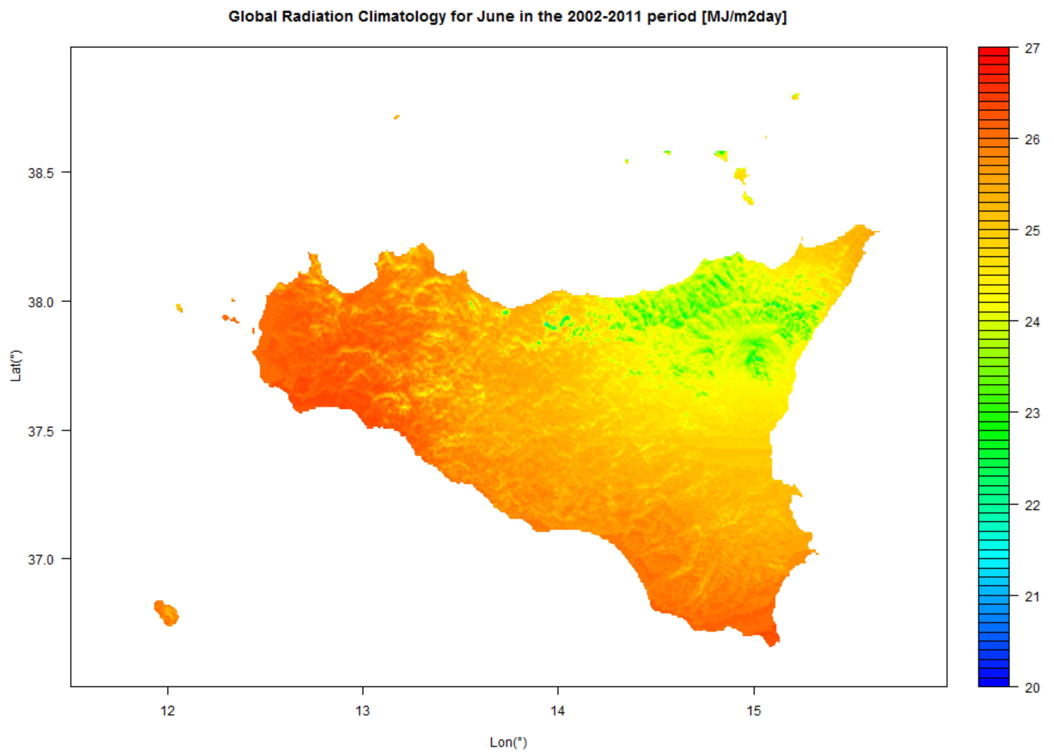

Fig. 3 – Global Radiation Climatology for June in the 2002-2011 period for a surface with the same slope and orientation of the soil.

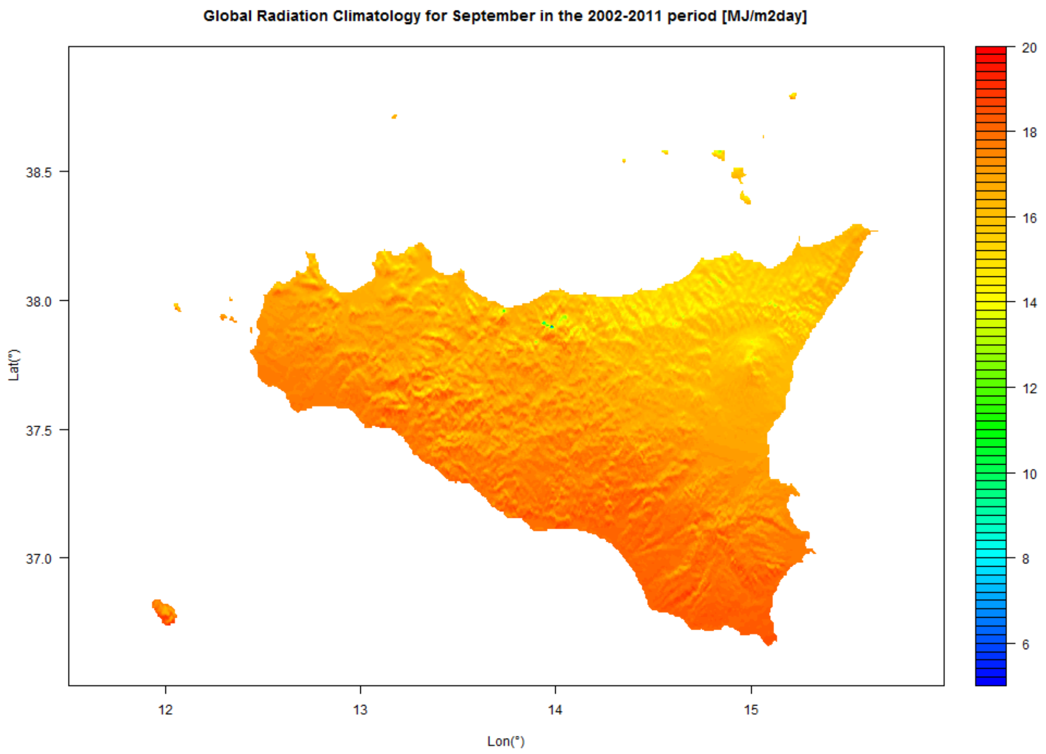

Fig. 4 – Global Radiation Climatology for September in the 2002-2011 period for a surface with the same slope and orientation of the soil.

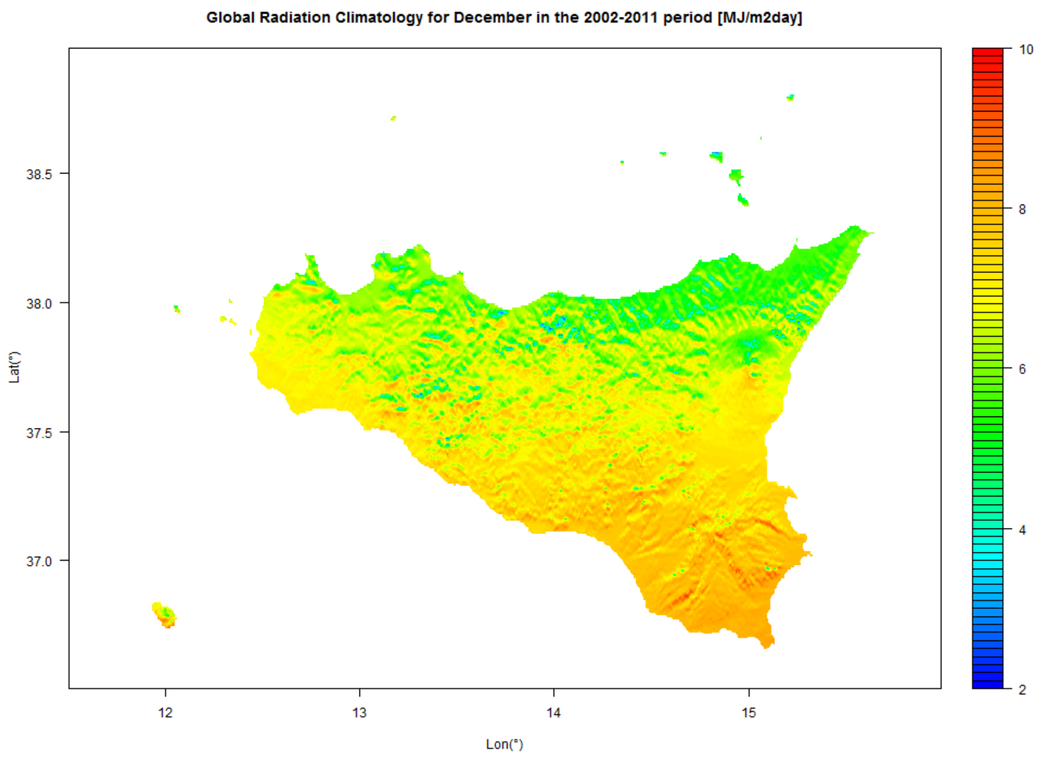

Fig. 5 – Global Radiation Climatology for December in the 2002-2011 period for a surface with the same slope and orientation of the soil.

3. Temporal evolution of solar radiation over Sicily in the 1936- 2013 period

3.1 Introduction

Temporal variability of solar radiation in the last decades is discussed in a number of recent papers (see Wild, 2009 for a review). The results suggest a widespread reduction of solar radiation between the 1960s and the early 1980s and a tendency toward an opposite trend starting from the 1980s. The first phenomenon is known as “global dimming”, the second as “global brightening” (Stanhill and Cohen, 2001; Wild, 2009; Wild, 2012).

In the second part of the ECLISE Project, we focused our Task 6.6 activities mainly on the study of the temporal evolution of solar radiation in the last decades over Italy. Specifically we studied sunshine duration: it is defined as the length of time in which direct solar radiation on a plane normal to it is above a certain threshold, usually taken at 120 Wm^{-2} (Sanchez-Lorenzo et al., 2008). Sunshine duration, which is usually measured with an uncertainty of ±0.1h and a resolution of 0.1h (WMO, 2008), is directly correlated with solar radiation through Angström’s law (Angström, 1924). A very important advantage of sunshine duration records is that they cover usually a much longer period than global radiation records.

3.2 Data

We collected sunshine duration data not only for Sicily, but for the entire Italian territory. The sunshine duration records were recovered from three main data sources: the paper archive of CRA-CMA (http://cma.entecra.it/homePage.htm) that is the former Italian Central Office for Meteorology (24 records, most of them digitalized within the ECLISE Project), the database of Italian Air Force synoptic stations (47 records) and the Italian National agro-meteorological database (BDAN, 59 records). Beside the records we recovered from these data sources, we considered also two records (Modena and Trieste) from university observatories, one record (Pontremoli) from an observatory managed by a volunteer joining the Italian Society for Meteorology and one record (Varese) from a meteorological observatory managed by a local association.

For some sites we set up composite records, merging data of the same station from different sources. In particular 18 of the BDAN records were used to update the records provided by Italian Air Force. Moreover, for eight records we merged data from different sites. They concern stations at short distances and belonging to areas with homogeneous geographical features.

The final data set encompasses 104 sunshine duration daily records covering the entire Italian territory. It refers to the 1936-2013 period. The spatial distribution of the stations is rather uniform, with the only exception of the Alpine area, which is covered only by 3 stations. The station coverage is rather low also in the Apennine area as only 4 of the 70 stations of peninsular and insular Italy have altitude over 800 meter a.s.l.. So most of the records concern Italian plain or coastal areas. 11 of the stations are in Sicily.

Data availability versus time is rather inhomogeneous. The best data coverage concerns 1958-1964, 1971-1977 and 1982-2013, whereas 1965-1970 and 1978-1981 have lower data availability. The period with the most critical situation in terms of data availability corresponds to the first 14 years (1936-1949).

3.3 Data pre-processing

Before data analysis, the records were pre-processed in order to get quality checked and homogenised gridded records.

3.3.1 Quality check and calculation of monthly records

All daily records were checked in order to identify and correct gross errors. A further check concerned the position of the stations: all coordinates were checked for consistency (i.e. elevation was checked in relation to position) by means of Google Earth mapping tool. Moreover, we verified the consistency of the coordinates with the information from stations metadata.

All records were expressed in hours and tenths of hour, corresponding to a time resolution of six minutes. They were then converted into relative sunshine duration (i.e. the ratio between measured and eso-atmospheric sunshine duration) records and corresponding monthly average records were calculated only when the fraction of missing data did not exceed 10%.

3.3.2 Data homogenization

We subjected all our monthly records to the relative homogeneity Craddock test already described in section 2. When a break was identified, the portion of the series that precedes it was corrected, leaving the most recent portion of the series unchanged in order to allow an easy updating of the record when new data become available.

Applying the homogenization procedure to the database, only 34 out of 104 records resulted homogeneous, whereas the remaining 70 were homogenized. A total number of 116 breaks was found.

3.3.3 Gap filling and calculation of monthly anomaly records

After homogenisation, we filled the gaps in the monthly records. Specifically, each missing datum was estimated by means of the closest record – in terms of distance and elevation difference – among those with available data within the same geographical region. The selection of the record to use for the estimation of the missing datum was performed considering only the records fulfilling two conditions: distance within 500 km from the record under analysis and availability of at least 10 monthly values in commune with it in the month of the break. If no records fulfilled these conditions, the missing datum was not estimated.

After gap filling, only the 95 records for which at least 90% of the data were available in the 1984-2013 period were considered. These records were then transformed into anomaly records, with respect to the monthly normals of this period.

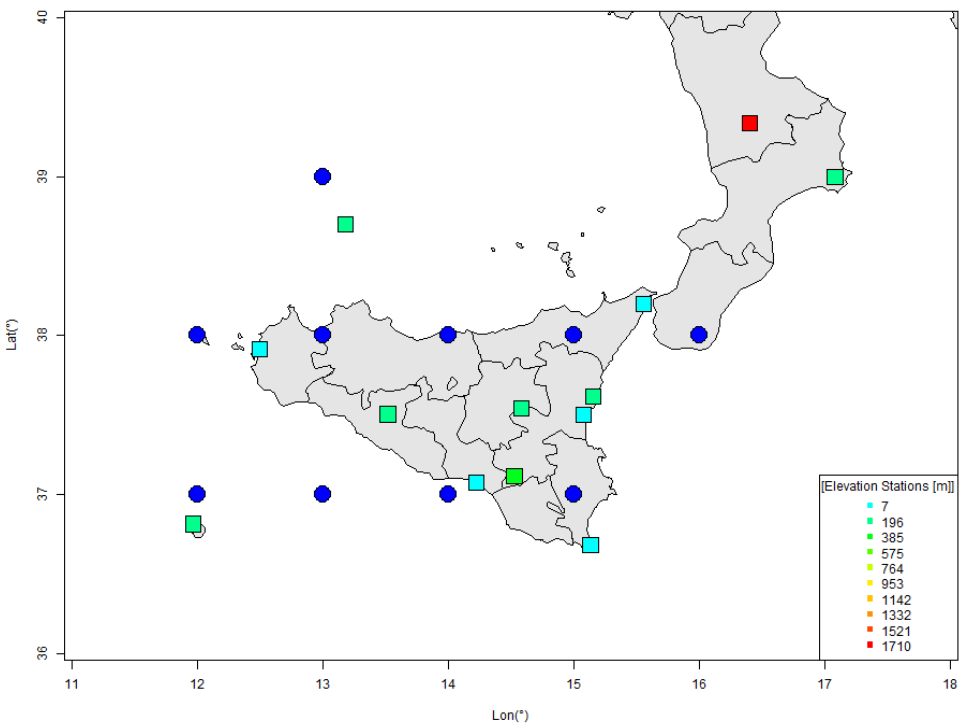

Fig. 6 – Sicily grid-points (blue points) and station records (other color squares) we used to calculate the grid-point series.

3.3.4 *Gridding and calculating Sicily average sunshine duration record*

Starting from the 95 gap-filled anomaly records, we generated a gridded version of monthly sunshine duration anomalies. This gridded version has the advantage of balancing the contribution of areas with a higher number of stations with those that have a lower station coverage. We used a grid with 1 degree resolution both in latitude and longitude, following the technique described by Sanchez-Lorenzo et al. (2007): it is based on Inverse Distance Weighting approach (distance and elation difference), with the addition of angular term weight introduced in order to take into account the anisotropy in stations' spatial distribution.

The grid was constructed from 7 to 19 degree E and from 37 to 47 degree N, selecting 68 points covering the Italian territory. The gridded records in most cases cover the entire 1936-2013 period and there are only a few grid points with some missing data, especially in the first ten years. 10 of the grid-points concern Sicily.

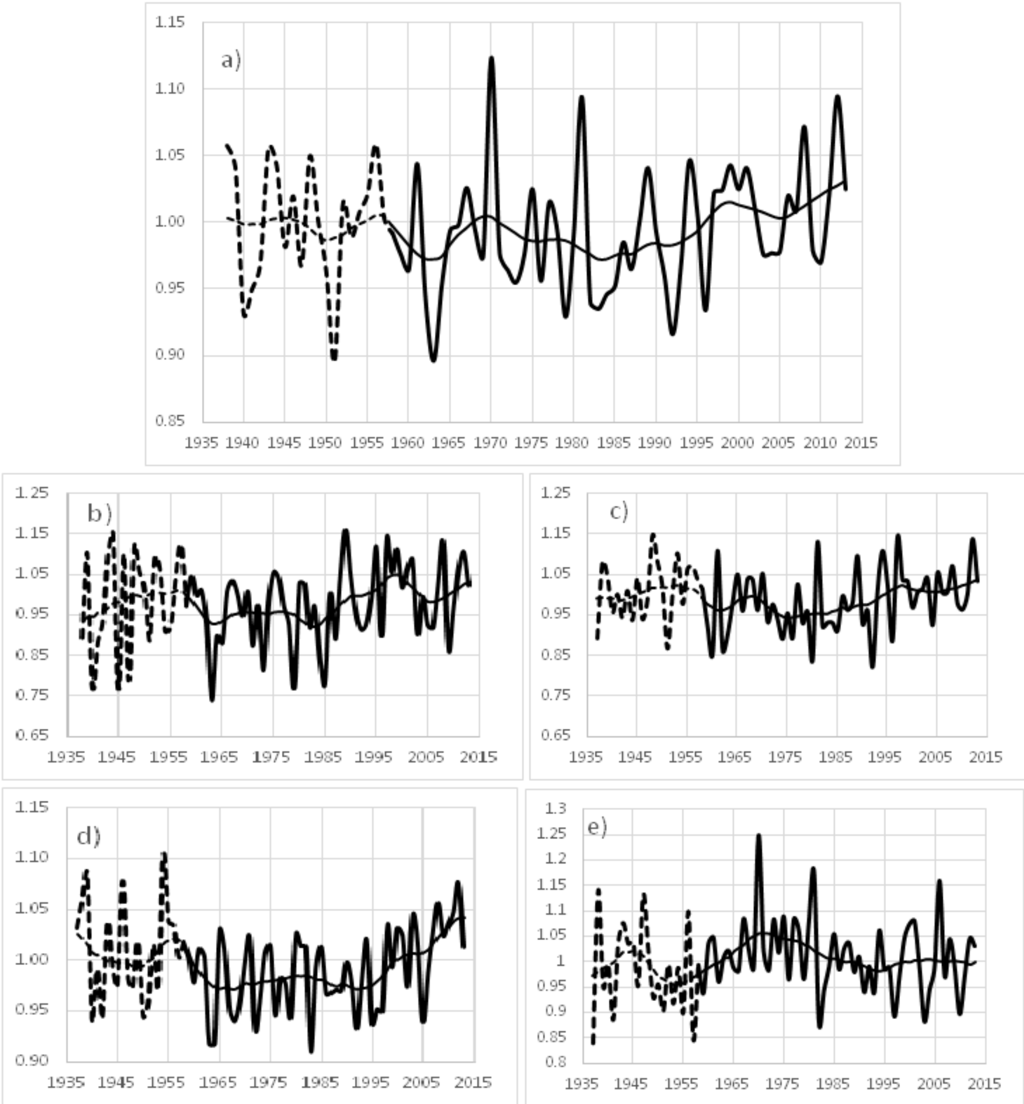

Fig. 7 – Average Sicily sunshine duration (thin line), plotted together with an 11-y window - 3-y standard deviation Gaussian low-pass filter (thick line) for (a) year; (b) winter; (c) spring; (d) summer; (e) autumn. The series are expressed as relative deviations from the 1984-2013 means. Dashed lines are used prior to 1958 owing to the lower number of records for this initial period.

The gridded records can be used to calculate national and regional records simply by averaging all corresponding grid-point anomaly records belonging to the region of interest. Here we present the Sicily record which has been obtained averaging all Sicily grid point records. Figure 6 shows these grid-points, together with the stations that we used to calculate the grid-point records.

3.4 The Sicily sunshine duration record

The average Sicily seasonal and annual sunshine duration regional records are shown in Figure 7, together with a 3-year standard deviation Gaussian low-pass filter working on 11-year windows.

The figure gives evidence of a clear brightening phase starting at about the mid of the 1980s, whereas the dimming phase of the 1960s and 1970s is less evident.

A paper on the temporal evolution of sunshine duration over Italy will be submitted to a scientific journal within short time. In this paper, a more complete analysis of the records will be presented, including the comparison with sunshine duration records of other datasets and other areas and with records of other proxy variables of solar radiation such as cloudiness and daily temperature range.

4. Estimation of global radiation climatologies for any period of the 1936-2013 interval

4.1 Angström's law

The dataset used to obtain the results presented in sections 2 and 3 includes both global radiation and sunshine duration records. In particular, the 2002-2011 spatial patterns are based on global radiation data, whereas the temporal evolution in the 1936-2013 period is based on sunshine duration data.
Sunshine duration and global radiation are linked by Angström's equation. It links the clearness index (K_T i.e. the ratio between the global radiation received by a surface (H_T) and the exo-atmospheric radiation received by the same surface (H_0)) to the relative sunshine duration (i.e. the ratio between the number of sun hours measured by a sunshine recorder (S) and the solar day length from sunrise to sunset (S_0)) by means of the following linear relation:

$$K_T = a\frac{S}{S_0} + b \qquad (3)$$

with coefficients *a* and *b* depending on the considered month. A detailed discussion on this relation is reported in Spinoni (2010) and Spinoni et al. (2012), which report also *a* and *b* coefficients obtained by means of about 30 Italian station with both global radiation and sunshine long-term records.
It is worth noticing that equation (3) allows to obtain sunshine duration climatologies from the corresponding global radiation climatologies. They can be obtained by first calculating the relative sunshine duration from the clearness index under the hypothesis of flat ground and second by taking into account shading, trough the binary factor *J* presented in section 2.4. As SIAS - the user of the case study considered in task 6.6 – was much more interested on global radiation than on sunshine duration, we present in this report only the climatologies for the former variable. We underline, however, that the methodology we set up allows to construct sunshine duration climatologies too.

4.2 From the 2002-2011 climatologies to other reference periods

We used Angström's equation to estimate the clearness index normal values corresponding to any period of the 1936-2013 interval from the 2002-2011 ones. This estimation is rather easy. In fact, considering a fixed month and a given station, we get from relation (3):

$$\overline{K_{T_{A-B}}} - b = a\frac{\overline{S_{A-B}}}{S_0} \qquad (4)$$

where the over bar denotes a temporal average and A-B denotes the corresponding time period.
Writing the same equation for period 2002-2011, dividing equation (4) for the corresponding 2002-2011 equation and rearranging the terms, we get:

$$\overline{K_{T_{A-B}}} = \overline{K_{T_{2002-2011}}}\,\frac{\overline{S_{A-B}}}{\overline{S_{2002-2011}}} + b\left(1 - \frac{\overline{S_{A-B}}}{\overline{S_{2002-2011}}}\right) \qquad (5)$$

If we now divide the sunshine duration averages in equation (5) for the corresponding averages in the 1984-2013 period, we have simply to calculate the average of the sunshine duration anomaly record over period A-B. It is therefore simply necessary to project the sunshine duration anomaly records (see section 3) over the SIAS stations. This projection was performed with the same technique we used for the projection of the sunshine duration anomaly records onto a regular grid (see section 3.3.4).

This procedure allowed estimating the clearness index normal values for the 41 SIAS stations over any period of the 1936-2013 interval. Here we obviously used the shading-bias-adjusted value presented in section 2.

Once we estimated the clearness index monthly normals over period A-B for all 41 SIAS stations, the corresponding climatologies could simply be obtained applying to them all the procedure presented in section 2. Actually, we used a slightly different approach, projecting the station clearness index normals onto the grid-points of RCM before applying the procedure presented in section 2. In this way, the climatologies we get from the observational data are easier to compare with the results from the RCMs and they can be better used to adjust model results.

The climatologies produced for the 1961-2000 period for sloped surfaces are available on ISAC-CNR web-site (www.isac.cnr.it/climstor/ECLISE-project.html) and on SIAS web site (http://www.sias.regione.sicilia.it/ECLISE).

4.3 Global radiation climatologies for any 10-year period of the 1961-2010 interval

The monthly global radiation climatologies for any 10-year interval of the 1961-2010 period are available on ISAC-CNR web-site (www.isac.cnr.it/climstor/ECLISE-project.html) and on SIAS web site (http://www.sias.regione.sicilia.it/ECLISE). As task 6.6 is part of an energy WP of the ECLISE Project, these climatologies were calculated for not-sloped surfaces. On the contrary, the climatologies reported in figures 2-5 were calculated for surfaces oriented as the ground: they are particularly interesting for agricultural applications. Actually, solar plants are rarely not-sloped, but, when possible they are oriented southwards in order to maximize the collection of solar radiation. We produced therefore, also monthly global radiation climatologies for southward oriented surfaces, considering a slope of 30 degrees. These climatologies are available on the ISAC-CNR web-site (www.isac.cnr.it/climstor/ECLISE-project.html) and on SIAS web site (http://www.sias.regione.sicilia.it/ECLISE). In this case we present only the average climatologies for the 1961-2000 period and we present, for comparison, the corresponding average climatologies for not sloped surfaces too.

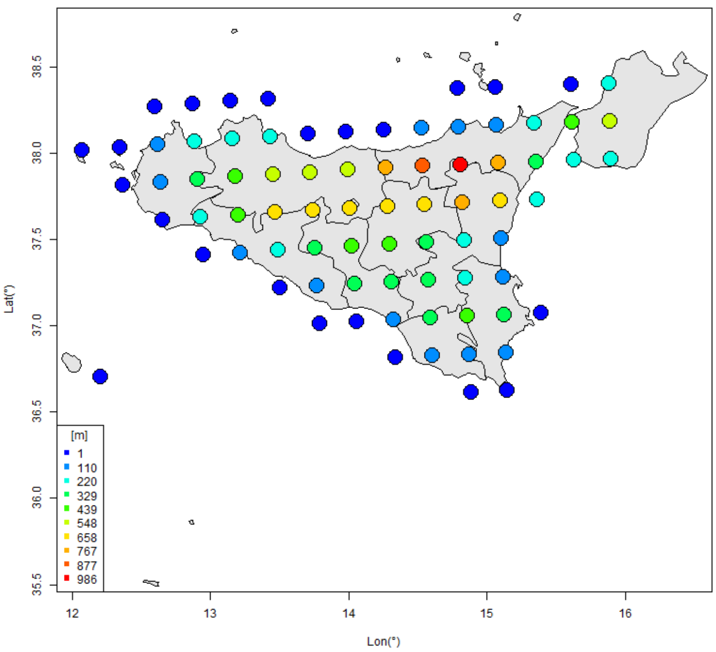

Fig. 8 – Sicily grid-points for the RCMs simulations.

5. Global radiation scenarios for the XXIth century

5.1 Regional Climate Models

Thanks to the robust high-resolution past reconstruction of global radiation for Sicily, it was possible to evaluate the ability of some ENSEMBLES Regional Climate Models (RCMs) in reproducing global radiation in this region. In particular, we evaluated whether the spatial distribution and the range of the model output resulted in agreement with the observational data.
Four RCMs were taken into account: KNMI-ECHAM5, SMHI-ECHAM5, SMHI-BCM and SMHI-Had. We considered the historical run of the models forced by GCM and their future projections under the A1B scenario.
Figure 8 shows the 78 grid-points we considered for RCMs scenarios. We underline that, in order to allow an easier comparison between model and observational data, we projected the SIAS stations' clearness index normals on these grid-points before estimating the climatologies for the 1961-2000 period.

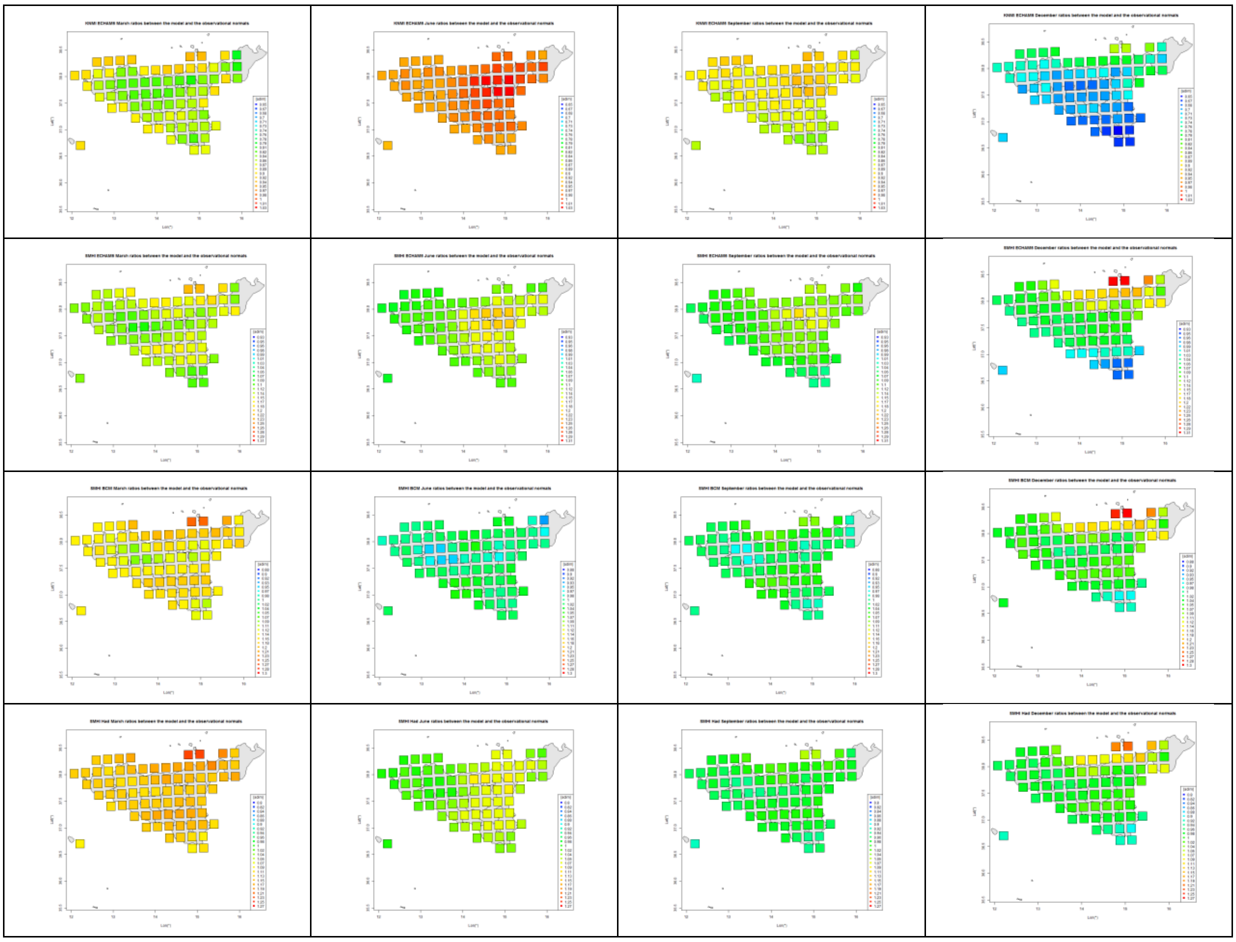

Fig. 9 – Ratios between the model and the observational normals for March, June, September and December for the RCMs simulation: 1°row) KNMI-ECHAM5, 2°row) SMHI-ECHAM5, 3°row) SMHI-BCM and 4°row) SMHI-Had.

5.2 Comparison of observed and modelled global radiation

In order to compare global radiation from the RCMs with observed global radiation, we calculated the clearness index normal values from the model records for the 1961-2000 period and compared them with the corresponding observational normals. The results of this comparison are reported in figure 9 that shows the ratios between the model and the observational normals for March, June, September and December for the four Regional Climate Models.
Then, as the model data highlighted significant bias, we adjusted the model outputs in order to make the model simulation representative of real global radiation over Sicily.

5.3 Adjustement of the RCM clearness index normals and estimated future solar radiation climatologies

The ratios between the modelled and the observed clearness index normals in the 1961-2000 period have been used to adjust the future climate simulations. More precisely, for each model grid-point, the clearness index normals calculated from the model data for the periods 2001-2050 and 2051-2100 have simply been multiplied for the ratio between the clearness index normals of the observed and modelled data in the 1961-2000 period.

Once these downscaled clearness index normals were available for each model grid-point, the global radiation climatologies were estimated applying the procedure outlined in section 2. The resulting climatologies and the ensemble mean climatologies are reported on the ISAC-CNR web-site (www.isac.cnr.it/climstor/ECLISE-project.html) and on SIAS web site (http://www.sias.regione.sicilia.it/ECLISE).

We report on both web sites also monthly maps with the ratios between the 2001-2050 ensemble mean climatologies and the 1961-2000 observational climatologies and the ratios between the 2051-2100 ensemble mean climatologies and the 1961-2000 observational climatologies. These maps highlight that the trend pattern is not well defined, with results depending on the considered month and model. Moreover, the variations from one period to the other are always within the variability of 30-year climatologies (e.g. 1951-1980 and 1984-2013) derived from the observed data.

As far as sunshine duration is concerned, we underline once more that our methodology allows producing the climatologies for this variable in a rather easy way when the corresponding global radiation climatologies are available.

6. Conclusions

A methodology which allows obtaining solar radiation climatologies for any period of the 1936-2100 period has been developed. The results allow both to describe the spatial distribution of global radiation over Sicily and to show the spatio-temporal behaviour of the variability and change for this variable. These high resolution dataset has been used to validate the outputs of ENSEMBLES RCM-GCM over the past and to estimate the bias corrections to by applied to the future runs.

The final result consists of high resolution (1-km^2) monthly global radiation climatologies for different time intervals of the 1961-2100 period. These climatologies were provided to SIAS.

The scenario data highlight a not well-defined trend pattern, with results depending on the considered month and model. Moreover, the variations from one period to the other are always within the variability of 30-year climatologies (e.g. 1951-1980 and 1984-2013) derived from the observed data. In the future we plan to extend these studies to a wide range of RCMs-GCM models.

The results produced in the present deliverable were used by the user (SIAS) as the base for the 2014-2020 PSR (Rural Development Plan) plan for Sicily (see http://www.psrsicilia.it/ for the 2007-2013 PSR).

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Links to concrete results:

ECLISE Project web site http://www.eclise-project.eu/

SIAS web site http://www.sias.regione.sicilia.it/ECLISE

ISAC−CNR web site http://www.isac.cnr.it/climstor/ECLISE-project.html

References to activity meetings:

The objectives of task 6.6 have been presented at the ECLISE Kick-off meeting (De Bilt - 09 March 2011).

The methods and results have been presented at the First and Second ECLISE meetings (Norrkhoping - 6-7 March 2012; Chania – 23-26 April 2013)

The results of the present deliverable were presented at the SISC (Società Italiana per le Scienze del Clima) First Annual Conference (Lecce 23-24 September 2013) and will be presented to the second SISC (Società Italiana per le Scienze del Clima) conference (Venice – 29-30 September 2014).