Anonymous Referee #1

Review of ACPD manuscript entitled “Detection of dimming/brightening in Italy from homogenized all-sky and clear-sky surface solar radiation records and underlying causes (1959-2013)” authored by V. Manara et al.

General remarks: Using surface observations of surface solar radiation in Italy during 1959-2013, long-term trend of surface solar radiation and its potential causes were studied. The current study has scientific solid approaches for providing data quality control, filling time gaps in the time series and homogenization of the data. The time series used cover an adequate time span for such studies and the spatial distribution of the stations is good enough.

We would like to thank the referee for her/his comments and suggestions. The revisions suggested by the referee are addressed below.

I suggest accept it after following issues are addressed.

1. REFEREE: One of most interesting features of this research is that the authors evaluated SSR trend under clear and cloudy skies to discuss aerosol and cloud effect separately. Clear sky is defined using cloud threshold of 1 okta, which is said to allow to select more samples of clear sky condition, however, there is no indication that how many samples each month are selected on average.

   AC: The average of clear-sky days per station and month is 9% for the 0-okta threshold and 18% for the 1-okta threshold. These fractions are however higher in summer when SSR is more important, reaching the maximum value in July with 17% of 0-okta days and 34% of days with less than 1-okta cloudiness.

   We have added this information in Section 2.4 of the revised manuscript as suggested by the referee.

   REFEREE: Additionally, when we use clear sky SSR measurements or departure to study long-term trend of SSR, we should keep it in mind that SSR varies to some extent with solar zenith angle that varies gradually. Suppose an extreme case, there are only two days selected at first two days in one January and last two days in another January, when we compare SSR values directly, variation of solar zenith angle on SSR may exert potential effect on SSR, so I suggest to use the ratio of SSR measurement to SSR at the top of the atmosphere in order to minimize solar zenith angle effect.

   AC: The referee is right: the availability of a small number of clear-sky days could give rise to problems due to the fact that the solar radiation at the top of atmosphere changes within each month. For this reason, we obtained the clear-sky series with two thresholds: 0 okta and 1 okta. As we explained in lines 281-285 (ACPD manuscript), the advantage of the 0-okta threshold is that it allows to select only the real clear-sky conditions but the limitation of this choice is that it allows to select only a low number of days. On the contrary, using the 1-okta threshold allows to obtain a more stable series selecting a higher number of days, which are however not completely clear. The records obtained with these two thresholds show the same decadal variability (Fig. 6 of the ACPD manuscript) with correlation coefficients ranging from 0.86 to 0.97 in the North and from 0.87 to 0.95 in the South (line 269-271 of the ACPD manuscript). Considering these results, we assumed that the problems due to the fact that the clear sky days may not be representative of the average monthly conditions are negligible. However, in order to further investigate this issue, we followed the suggestion of the reviewer and we obtained the regional clear-sky SSR records (0-okta threshold) transforming the daily station SSR data into clearness index data as first step of data analysis. The results give evidence of very similar records than those we obtained starting from the absolute value data. Figure A (reported below) shows the agreement between the records obtained with the two methods for the annual time scale. At seasonal level (not shown), the differences are slightly greater. However, they are comparable to the differences between the 0-okta threshold records and the 1-okta threshold records we show in Fig. 6 (of the ACPD manuscript). Moreover, the use of the records obtained using the clearness index does not give rise to significant differences for any of the values shown in Table 2 (of the ACPD manuscript).

2. REFEREE: Data homogeneity is a big issue for the evaluation of long-term trend, therefore, it is valuable for carefully evaluation of this issue, however, when we detect abrupt jump in the raw time series using some homogeneity analysis methods, it is very important to determine whether the jump is true or not based on metadata, so the authors should say some words on this issue.

   AC: In order to homogenize our dataset we used a relative homogeneity test based on statistical methods supported by metadata information. Specifically, we compared, by means of the Craddock test (Craddock, 1979), each test series against 10 other reference series. This methodology is suitable to calculate correcting factors, but the identification of an inhomogeneity is not always easy and unambiguous (Brunetti et al., 2006). For this reason, we homogenize a period only when more reference series give coherent adjustment estimates.

In this way, we can be more confident that the inhomogeneity is "real" and ascribable to the test series and not to the reference series. The reference series that result homogeneous in a sufficiently long sub-period centered on the break year, are then selected to estimate the adjustments. We use several series to estimate the adjustments to increase their stability and to avoid unidentified outliers in the reference series from producing wrong corrections.
By comparing the obtained breaks of each series with the corresponding metadata we found in most of the cases a reasonable agreement between the breaks indentified by the statistical method with the information reported by the metadata.

We have clarified this point in Section 2.2 of the revised manuscript.

3. REFEREE: The corresponding author published results on sunshine duration in JGR, I'd wonder whether sunshine duration and SSR are consistency in interannual and decadal variations.

   AC: There is another paper in preparation focused on the comparison between sunshine duration (SD) and SSR where the agreement/disagreement in interannual and decadal variability will be discussed and related to changes in other meteorological variables. Actually the issue is rather complex because it requires the analysis of additional variables besides SD and SSR (e.g. relative humidity) and we think it should be addressed in a specific paper (as we are doing) which aims to investigate the reasons which cause the two records to show specific patters in some periods and in some seasons. Nevertheless, it is worth noting that in this paper we refer to SD (Manara et al., 2015) in the Section 4 (lines 458-474 of the ACPD manuscript) in order to discuss our results with SSR as compared to SD trends in Italy.

4. REFEREE: It was suggested that mineral dust variations on SSR variability may be used to support that the dimming shown regional dependence, however, there is no indication whether long-term trend in the long-range transport of mineral dust from outside agrees with the observed dimming.

   AC: Unfortunately, we have not found studies with this kind of information because the most part of studies on the long-range transport of mineral dust from outside report analyses for particular events and never for periods longer than few years (e.g., De Angelis and Gaudichet, 1991; Bonasoni et al., 2004; Gkikas et al., 2013; Pey et al., 2013).
   We compared the SSR records for Northern and Southern Italy with the Sahel Precipitation Index finding a good agreement with a high correlation coefficient for Southern Italy (lines 424-430 of the ACPD manuscript). But this was not enough to establish a relationship between the SSR variability in Italy and the variability of mineral dust observed in the same area (caused by a variation in the concentration at the source but also by a variability in the long-range transport). However, we know from Maggi et al., (2006) that measurements of dust accumulation in Alpine snow (Colle del Lys, Italian Alps) give evidence of a clear increase of mineral dust since the early 1970s with high values after the 1980s. This suggested that the variation in the dust concentration observed at the source caused also a variation in the concentration of the dust transported in the Alpine region and, as a consequence, a variation of aerosol load over the Mediterranean area. Moreover, African dust is emerged as the largest PM_{10} source in regional background of the Mediterranean area (Pey et al., 2013) with a latitudinal variability both in intensity and frequency, with decreasing values from south to north (Gkikas et al., 2013). Combining all this information, we have hypothesized a higher contribution of mineral dust in the South than in the North and during spring, summer and autumn respect to that observed in winter (Pey et al., 2013) and we have hypothesized that this could be the reason of a stronger dimming in spring, summer and autumn in the Southern region than in the Northern region despite lower pollution. In any case, this point should be investigated in more detail in the future also using other variables, as for example visibility records.

Minor comments:

1. REFEREE: L66-76, there are a few other publications showing significant contribution of cloud to the interannual variation of SSR, for example, in China (Xia X., Spatiotemporal changes in sunshine duration and cloud amount as well as their relationship in China during 1954-2005, JGR, 2010, 115, DOOK06, doi:10/1029/2009JD012879; Xia X., A closer looking at dimming and brightening in China during 1961-2005, Ann. Geophys., 201, 28, 1121-1132). Furthermore, in polluted region such as in Beijing metropolitan area, interannual variation of SSR may be also related to that of air pollution, which was supported by the fact that the correlation coefficient between interannual variation of SSR and AOD may range from -0.44 to -0.81 (Zhang et al., On the drivers of variability and trend of surface solar radiation in Beijing metropolitan area, International J. Climatol., 2015, 35, 452-461). This is not surprising since annual mean aerosol direct effect on SSR (24 Wm-2) is comparable to that of cloud effect (-42 Wm-2) in this polluted region (Li et al., Aerosol

optical properties and their radiative effects in northern China, JGR, 2007, 112, D22S01, doi:10.1029/2006JD007382). Therefore, aerosol and cloud effects on interannual and decadal variation of SSR may depend on aerosol loading level that should be noticed.

AC: The referee is right.

We have added these references in Section 1 of the revised manuscript in order to complete our description.

2. REFEREE: L89-90, Since aerosol loading is highly variable from year to year, interannual variation of clear sky SSR may be related to aerosol direct effect.

   AC: The referee is right. The point that we would like to underline is that African dust is the largest PM_{10} source in regional background of the Mediterranean and as a consequence it should be considered.

   We have clarified this point in Section 1 of the revised manuscript.

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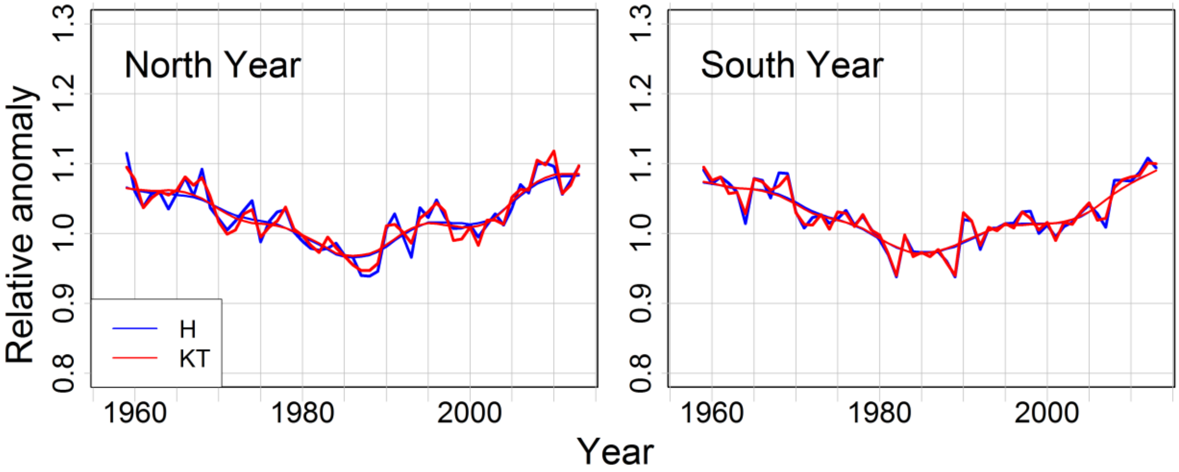
***Fig. A**: Average annual Northern (left) and Southern (right) Italian SSR records obtained under clear-sky conditions (0-okta threshold) plotted together with an 11-year window – 3-year standard deviation Gaussian low pass filter. The series are expressed as relative deviations from the 1976-2005 period. The blue line represents the records obtained starting from the absolute daily station SSR data as already shown in Fig. 6 of the ACPD manuscript. The red line represents the records obtained transforming the daily station SSR data into clearness index data as first step of data analysis.*



Anonymous Referee #2

The authors presented a thorough analysis of daily solar radiation records based on ground-based data measured at 54 stations in Italy. The records cover a time period of 55 years while the data sets were homogenized and spatially gridded in order to obtain valuable scientific results. The techniques used in this research were well documented and justified.

We would like to thank the referee for his/her comments and suggestions. The minor revisions suggested by the referee are addressed below.

I would like to point out some aspects that the authors should include into their revised manuscript:

1. REFEREE: The authors should include the necessary information about the instrumentation they used for their research and provide adequate description of the measurements themselves. Although they have the instrument type in table 1, no information is provided about the characteristics of the two types of solar radiation measuring instruments (Fuess-Robitzsch and CM11Kipp & Zonen). So I expect this information to be provided in section 2 and not only mentioned in table 1 and line 131.

   AC: The data that come from the Italian Air Force (Areonautica Militare Italiana - AM) stations and from the meteorological observatory of Trieste were recorded with the Robitzsch bimetallic actinograph until the 1980s. This instrument was then replaced with the CM11 Kipp & Zonen pyranometer in the first case and with different types of CM Kipp and Zonen pyranometers in the second one; e.g. for more details about AM instruments and instrument changes see: http://wrdc.mgo.rssi.ru/ while for more details about Trieste instruments see Stravisi (2004). The CM11 Kipp & Zonen pyranometer was also used in the stations included in the National Agro-meteorological Database (Banca Dati Agrometeorologica Italiana - BDAN) with the only exception of two stations that use the EP07 Middleton Instruments pyranometer. Finally, the data that come from MeteoSwiss were measured with a CM21 Kipp & Zonen pyranometer.

   The main difference between the Robitzsch bimetallic actinograph and the Keep & Zonen pyranometer is that in the first case the measure is mechanic while in the second one it is thermoelectric. Specifically, the Robitzsch pyranometer consists of a black metallic strip located between two white metallic strips. Due to differential absorption, a temperature difference is created between these strips which serves as a measure of radiation intensity. This temperature difference drives the position of a pen which allows recording radiation intensity on a strip chart. The sensitivity range covers the entire spectrum of solar radiation; only radiation above 2μm is not included, this, however, contributes only very little to the solar irradiance.

   The Kipp & Zonen and Middleton Instruments pyranometers are based on a black-coated surface which is warmed up by solar radiation. The thermal energy is converted into measurable voltage which is used to measure the solar irradiance. These pyranometers are provided with an automatic acquisition system which allows recording solar irradiance on a digital support. The spectral range covers the interval 0.3-2.8 μm.

We have added all this information in Section 2.1 of the revised manuscript as suggested by the referee.

2. REFEREE: The authors provide the SSR daily values in W/m2. The CM11 instrument can provide measurements at high time frequency, therefor I expect a description of the original data time frequency and the steps towards obtaining the daily values (are they daily mean values?).

   AC: Unfortunately, we have access only to daily values. However, we know that a daily value is determined only in case the data for all hourly intervals of the daytime period are available. If at least one hourly value is missing, the daily value is not calculated (Petrarca et al., 2000; http://wrdc.mgo.rssi.ru/).

3. REFEREE: For the stations were Fuess-Robitzsch were replaced by CM11 pyranometers, are there any intercomparisons for any available common period of deployment?
   Having all this information into section 2 will set the need for homogenization into a more solid basis.

   AC: Unfortunately, we do not have records measured with the two instruments over a common period, which would have allowed us to use a direct homogenization method. Therefore, we homogenized the records only by means of statistic techniques (indirect homogenization methods) and metadata (i.e. information on station relocations, recalibrations and instrument changes) were used only to support this procedure. The method we adopted for homogenization, resulted as one of the best performing within a study performed to compare different homogenization techniques in the framework of a European Union COST action program (Venema et al., 2012).

4. REFEREE: Please check for consistency the comment in lines 258-259. In line 257 you firstly provide a positive trend and then a negative, so it should be brightening for the first trend and dimming for the second.

   AC: The comment concerns the following sentence: “As previously shown, the trend over the whole period under analysis (1959-2013) is significant only in summer in the North (+3.1 Wm^{-2} per decade) and in autumn for both regions (-1.5 Wm^{-2} and -2.2 Wm^{-2} for the North and the South respectively), as a consequence of a weak dimming period in the first case and a weak brightening period in the second one.”

   We consider that the sentence is right. In summer in the North, until the mid of 1980s, the record shows a weak (and not significant) dimming while in the following period the record shows a significant brightening. As a consequence, the trend over the whole period under analysis (1959-2013) is mostly driven by the increasing tendency of the second period resulting positive and significant.
   In autumn for both the regions, the behavior is opposite. The record shows a significant dimming until the end of the 1990s and a not significant brightening in the following period. As a consequence, the trend over the whole period under analysis is mostly driven by the decreasing tendency of the first period resulting negative and significant.

   We have revised this sentence in Section 3.1 of the revised manuscript in order to make it clearer.

5. REFEREE: Line 149: "at least six monthly...", do you mean daily? please revise.

   AC: The comment concerns the following sentence: “We filled the gaps in each monthly record using a procedure similar to that described in Manara et al., (2015). In particular, the median of a set of five estimated values, corresponding to the five highest correlated reference records, was selected in order to avoid outliers resulting from peculiar climatic conditions of the reference station. When less than five reference records fulfilling the requested conditions (distance within 500 km from the record under analysis and at least six monthly values in common with it in the month of the gap) were available, the median was calculated with the available reference series.”

   It is worth mentioning that the gap-filling procedure is performed on a monthly time scale.

6. REFEREE: Line 219: "As a consequence the series shows only some windows of less than 30 years and starting in the 1960s ...". please revise because the flow of the sentence is not coherent. I guess that you only detected time windows of less than 30 years with statistical significant trends ...

   AC: The reviewer is right. Thus, the windows that show a significant trend are less than 30 years long. Those that start in the 1960s have negative sign while those that start in 1980s have positive sign.

   We have revised this sentence in Section 3.1 of the revised manuscript in order to make it clearer.

7. REFEREE: Line 222: "The spring season has a pattern similar to the year with..." I suggest to change year to annual although you use year into the figures.

   AC: Yes, the reviewer is right as “annual” is better than “year”. We have changed it in the revised manuscript.

8. REFEREE: General comment: please have your manuscript revised by a native English speaker.
   Small errors were found (e.g. line 126 "...at (in a) monthly time scale’, line 173 "...for 82% of (the) original...", line 251 "...were calculated (by) averaging...", line 352 " At this purpose..." is not a common expression, ...)

   AC: We have revised the manuscript with a native English speaker in order to improve it.

9. REFEREE: References: please provide some references for the examples used in lines 32-33 and for the digital elevation model referred in line 254, if any.

   AC: The references for the examples used in lines 32-33 are: Hartmann et al. (1986) and Wild (2009, 2012)
   The reference for the Digital Elevation Model is USGS (1996).

   We have added these references in Section 1 and 3.1 of the revised manuscript.

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Detection of dimming/brightening in Italy from homogenized all-sky and clear-sky surface solar radiation records and underlying causes (1959-2013)

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Abstract. A dataset of 54 daily Italian downward surface solar radiation (SSR) records has been set up collecting data for the 1959-2013 period. ~~Particular~~ Special emphasis is ~~placed upon~~given to the quality control and the homogenization of the records in order to ensure the reliability of the resulting trends. This step has been shown as necessary due to the large differences obtained between the raw and homogenized dataset, especially during the first decades of the study period. In addition, SSR series under clear-sky conditions were obtained considering only the cloudless days from corresponding ground-based cloudiness observations. Subsequently,~~ the~~ records were interpolated onto a regular grid and clustered in two regions, Northern and Southern Italy, which were averaged in order to get all-sky and clear-sky regional SSR records. Their temporal evolution is presented, and possible reasons for differences between all-sky and clear-sky conditions and between the two regions are discussed in order to determine to which extent ~~understand which part of the~~ SSR variability depends on aerosols or clouds. Specifically, the all-sky SSR records show a decrease until the mid-1980s (dimming period), and a following increase until the end of the series (brightening period) even though~~if the~~ strength and ~~the~~ persistence of ~~the~~ tendencies are not the same in all seasons. ~~The c~~Clear-sky records present stronger tendencies than ~~the~~ all-sky records during the dimming period in all seasons and during the brightening period in winter and autumn. This suggests that under all-sky conditions the variations caused by the increase/decrease of the aerosol content have been partially masked by cloud cover variations, especially during the dimming period. Under clear-sky the observed dimming is stronger in the South than in the North. This peculiarity could be a consequence of a significant contribution of mineral dust variations to the SSR variability.

1 Introduction

The fraction of solar radiation that reaches the Earth's surface is the source of energy which drives the majority of the processes in the atmosphere and in the oceans and plays a crucial role in a large number of sectors (e.g. agriculture, tourism, solar energy production) (Hartmann et al., 1986; Wild, 2009, 2012). For these reasons, it is very important to study the spatial distribution and the temporal behavior of surface solar radiation (SSR). Continuous observations by~~ a~~ thermoelectric pyranometers at the Earth's surface date back to 1920s, as for example at the Stockholm site since 1923 (Stanhill, 1983; Wild et al., 2009).~~,~~ ~~but s~~Surface radiation measurements started to become available on a widespread basis only in the late 1950s, with the establishment of numerous radiation sites during the International Geophysical Year (IGY) 1957-1958~~ (Stanhill, 1983; Wild et al., 2009)~~.

Studies of the last decades demonstrated that SSR has not been constant over time (Dutton et al., 1991; Liepert et al., 1994; Ohmura and Lang, 1989; Russak, 1990; Stanhill and Moreshet, 1992), as shown by ~~showing~~ decadal fluctuations which exceed~~ing~~ the accuracy limit ~~of the accuracy~~ of observational irradiance measurements (2% on an annual basis) (Gilgen et al., 1998). They report a decrease in SSR, ~~called~~ "global dimming", of about 3-9Wm^{-2} from the 1950s to the 1980s and a subsequent~~following~~ increase, ~~called~~ "brightening", of about 1-4Wm^{-2} from~~since~~ the beginning of 1980s (Wild, 2012). These two periods are highlighted not only by studies focusing on specific regions (Liang and Xia, 2005; Long et al., 2009; Sanchez-Lorenzo and Wild, 2012; Sanchez-Lorenzo et al., 2013, 2015; Wang and Yang, 2014) but also by studies focusing on worldwide data sets (Alpert et al., 2005; Gilgen et al., 1998; Liepert, 2002; Stanhill and Cohen, 2001; Wang et al., 2012; Wild et al., 2005, 2009).

The causes of these decadal variations are not completely clear: it has been suggested~~proposed~~ that changes in the anthropogenic aerosols and cloud cover ~~are the~~can be major causes (e.g., Liepert et al., 1994; Stanhill and Cohen, 2001; Wild, 2009, 2015), while changes in radiatively active gases concentrations have, at least, globally a minor effect (Kvalevåg and Myhre, 2007; Romanou et al., 2007). ~~It is important to underline that a~~Aerosols and clouds can interact in various ways and are therefore not ~~may not be~~ completely independent~~, as they can interact in various ways~~ (Ramanathan et al., 2001). Aerosols act as a modulator of SSR by ~~scattering or~~ absorption or scattering of solar radiation (direct effect) (Radke et al., 1989; Twomey et al., 1984) and by changing the number of cloud condensation nuclei particles (indirect aerosol effect) that also change~~ the~~ albedo and ~~the lifetime of~~ cloud~~s~~ lifetime (Albrecht, 1989; Lohmann and Feichter, 2005). ~~In particular,~~ The increase~~ing~~ of anthropogenic aerosol emissions in the 20th century ~~are~~is thought to be the major cause of the observed decadal SSR reduction until the 1980s (e.g., Liepert and Tegen, 2002; Norris and Wild, 2007; Stanhill and Cohen, 2001), while~~ the~~ measures to reduce air pollution in the late 20th century are possibly ~~have been suggested to be~~ responsible for the renewed increase of SSR (Chiacchio and Wild, 2010; Dutton et al., 2004, 2006; Hansen et al., 1997; Nabat et al., 2014). Nevertheless, the relative contribution of clouds and aerosols is not clear yet, especially after comparing ~~if~~ studies regarding different areas~~ are compared~~.

For these reasons, it is interesting to understand to which extent ~~which part of~~ the SSR variability depends on aerosol variations ~~and~~ or ~~which part depends~~ on changes in cloud characteristics. Different studies tried to estimate this distinction by using global climate models, satellite-derived products and~~/or~~ ground-based observations, finding a good agreement between clear-sky SSR variations and changes in aerosol emissions and concentrations, indicating aerosols as major contributor to SSR variability at decadal scale (Wild, 2015). In addition, ~~analyzing all-sky SSR,~~ some studies analyzing all-sky SSR ~~of them~~ highlighted the important contribution of clouds especially at interannual scale (Folini and Wild, 2011; Mateos et al., 2014; Norris and Wild, 2007; Parding et al., 2014; Xia, 2010a, 2010b). ~~Some o~~Other studies confirmed that changes in aerosols play a major role in the decadal variations of SSR (Li et al., 2007; Zhang et al., 2015), although there is a tendency to underestimate the dimming and~~/or~~ brightening obtained with models with respect to trends ~~that~~ obtained with ground-based observations. This has been attributed to possible deficiencies in aerosol emission inventories or an underestimation of aerosol direct radiative forcing (Allen et al., 2013; Cherian et al., 2014; Folini and Wild, 2011; Ruckstuhl and Norris, 2009). As far as the aerosol radiative forcing is concerned, some studies tried to analyze the problem combining SSR series with optical depth and aerosol concentration observations finding a comparable or higher contribution of the direct aerosol effect with respect to the indirect aerosol effect (Nabat et al., 2014, 2015; Ohmura, 2009; Ruckstuhl et al., 2008; Turnock et al., 2015). ~~It is worth mentioning that~~ However,~~only~~ few studies used only ground-based observations to obtain clear-sky and all-sky SSR series in order to investigate the aerosol-cloud effect (Liang and Xia, 2005; Liepert, 2002; Long et al., 2009; Ruckstuhl et al., 2008; Wild et al., 2005); this is ~~particularly~~ due to the difficulty in~~to~~ recovering high temporal resolution SSR series together with additional information on cloudiness or direct/diffuse radiation to discriminate clear-sky conditions (Long and Ackerman, 2000; Wild, 2009).

~~As far as~~ In Italy~~ is concerned~~, studies on the temporal evolution of SSR and on its relation to aerosol concentrations and cloud cover variability are not available. The best available information concerns sunshine duration (SD) for the 1936-2013 period (Manara et al., 2015).~~ They found~~ It shows an increasing tendency starting in the 1980s preceded by a less evident decreasing tendency. Comparing these trends with corresponding cloud amount series, Manara et al., (2015) ~~they~~ found that the expected negative correlation of these two variables is often not evident. This suggested that during the global dimming/brightening periods there is an important fraction of SD evolution that cannot be explained by cloud cover changes which~~but~~ must therefore depend on other factors such as, for example, changes in aerosol optical thickness. The temporal variations of aerosol optical thickness of the last decades seem to be mainly driven by anthropogenic emissions (Streets et al., 2006, 2009), even though, especially for Southern Italy, also mineral particles originating~~ deflated~~ from Sahara and Sahel areas may have a significant role, as recently suggested for Spain by Sanchez-Romero et al. (2016). This natural atmospheric aerosol, with emissions that are highly variable from year to year, is a significant component of the Mediterranean area ~~-~~(Pey et al., 2013; Varga et al., 2014) causing reflection and absorption of the incoming solar radiation and therefore affecting the energy balance together with anthropogenic aerosols ~~by cutting down the incoming solar radiation via reflection and absorption~~ (Zhu et al., 2007).

In this context, this work aims at collecting, quality checking, homogenizing (Sect. 2) and analyzing an extensive database of Italian SSR records in order to obtain average regional series both under all-sky (Sect. 3.1) and clear-sky conditions (Sect. 3.2). By doing this, we want to describe~~understand~~ how SSR has changed in Italy during about the last sixty years and to explain how these variations depend on aerosols or cloud variability (Sect. 3.3, Sect. 4).

2 Data and data-preprocessing

2.1 Data

The Italian SSR ~~daily~~ series used in this work were obtained at daily scale from the Italian Air Force stations (AM – Areonautica Militare, 29 series – 1959-2013 period) and from the National Agro-meteorological Database (BDAN – Banca Dati Agrometeorologica Nazionale, 19 series – 1994-2013 period). Some information about the history of the AM observations are available in a report of the Italian Air Force (2012) and the data for the 1964-2013 period are also available in the World Radiation Data Centre (WRDC) of the Main Geophysical Observatory in St. Petersburg. In order to increase data availability, especially for the alpine region, we considered also the series from the meteorological observatory of Trieste (1971-2013 period) (Stravisi and Cirilli, 2014) and five series from Switzerland, close to the Italian border, from the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss – 1981-2013 period).

The data that come from the AM stations and from the meteorological observatory of Trieste were recorded with the Robitzsch bimetallic actinography until the 1980s. This instrument was then replaced with the CM11 Kipp & Zonen pyranometer in the first case and with different types of CM Kipp & Zonen pyranometer in the second one (for more details about AM instruments and instrument changes see: http://wrdc.mgo.rssi.ru/, while for more details about Trieste instruments see Stravisi, (2004)). The CM11 Kipp & Zonen pyranometer was also used in the stations included in the BDAN database with the only exception of two stations that used the EP07 Middleton Instruments pyranometer. Finally, the data that come from MeteoSwiss were measured with a CM21 Kipp & Zonen pyranometer.

The main difference between the Robitzsch bimetallic actinography and the Keep & Zonen pyranometer is that in the first case the measure is mechanic while in the second one it is thermoelectric. Specifically, the Robitzsch pyranometer consists of a black metallic strip located between two white metallic strips. Due to differential absorption, a temperature difference is created between the strips which serves as a measure of radiation intensity. This temperature difference drives the position of a pen which allows recording radiation intensity on a paper strip chart. The sensitivity range covers the entire spectrum of solar radiation; only radiation above 2µm in not included, this, however, contributes only very little to the solar irradiance.

The Kipp & Zonen and Middleton Instruments pyranometers are based on a black-coated surface which is warmed up by solar radiation. The thermal energy is converted into measurable voltage which is used to measure the solar irradiance. These pyranometers are provided with an automatic acquisition system which allows recording solar irradiance on a digital support. The spectral range covers the interval 0.3-2.8µm.

The final data set is composed of 54 daily series with data for the 1959-2013 period. All series have at least 15 years of data (Fig. 1 and Table 1).

The spatial distribution of the stations and the length of the series in relation to their location is uniform,~~ with~~ the only exception ~~of~~ are the series in the Alps and Apennines. All series are located in the plains and coastal areas with elevation lower than 600m. Data availability versus time is rather inhomogeneous with a minimum before the beginning of the period covered by the BDAN series (Fig. 2).

2.2 Data homogenization, gap-filling and anomaly records

Before analyzing the time evolution of SSR, we subjected the records to a quality check and to a homogenization procedure. Quality check was performed at a daily time-scale in order to find out and correct gross ~~-~~errors (Aguilar et al., 2003). Specifically, we searched for negative values and values exceeding the radiation at the top of the atmosphere. In addition, the reliability of station coordinates was checked by means of the comparison with station metadata and checking the elevation in relation to position. After quality check, monthly series were calculated when the proportion ~~the fraction~~ of missing data did not exceed 20%.

All monthly records were subjected to homogenization in order to identify and eliminate non climatic signals (Aguilar et al., 2003; Brunetti et al., 2006b). Our aim was ~~The goal was the~~to identif~~ication of~~y time-dependent adjusting factors in order to~~that allow~~ transform~~ing~~ the original records into homogeneous ones. ~~In particular, t~~The homogenization of the series was performed using a procedure based on a relative homogeneity test (Brunetti et al., 2006b) based on statistical methods supported by metadata information.~~,~~ Specifically, each test series is compar~~ing~~ed against 10 other reference series that well correlate with the test one by means of the Craddock test (Craddock, 1979). ~~each test series against 10 other reference series, that well correlate with the test one.~~ This methodology is suitable to calculate correcting factors, but the identification of an inhomogeneity is not always easy and unambiguous (Brunetti et al., 2006b). For this reason, we homogenize a period only when more reference series give coherent adjustment estimates. In this way, we can be more confident that the inhomogeneity is “real” and ascribable to the test series and not to the reference series. The reference series that result homogeneous in a sufficiently long-sub-period centered on the break year are then selected to estimate the adjustments. We use several series to estimate the adjustments to increase their stability and to avoid unidentified outliers in the reference series from producing wrong corrections. By comparing the obtained breaks of each series with the corresponding metadata, we found in most of the cases a reasonable agreement between the breaks identified by the statistical method with information reported by metadata.

The common variance between two stations depends on their distance and for the Italian territory, as previously found for SD (Manara et al., 2015), it falls to 50% at a distance of about 150 km. Homogenization was performed in a~~at~~ monthly time scale. However, a daily version of the adjustments was also generated in order to homogenize the daily series.

All analyzed series showed at least one inhomogeneous period highlighting the importance of homogenization, especially before 1980. The most relevant inhomogeneities fall in the first 20 years of the investigated period where many instrument changes and recalibrations occurred, whereas the inhomogeneities are less relevant from the 1980s when the ~~Fuess~~ Robitzsch pyranograph was replaced in all AM stations by the CM11 Kipp & Zonen pyranometer (Table 1), an instrument with higher quality, as recommended by WMO (Italian Air Force, 2012).

Figure 3a shows the Italian average annual SSR anomaly series (relative anomalies with respect to the period 1976-2005) before and after homogenization with corresponding Gaussian low-pass filters (11-year window; 3-year standard deviation) that allow a better visualization of the decadal variability and long-term trend, while Fig. 3b shows the curve obtained by averaging the mean annual adjustments over all single records, together with their absolute range. The details on how we obtained regional SSR anomaly series will be explained in the following sections.

The average annual records before and after the homogenization show a different decadal variability during the 1959-1970 and 1971-1980 periods where increasing (average adjustment: 1.098) and decreasing (average adjustment: 0.964) correcting factors, respectively, have been applied to the original series. On the contrary, during the 1981-2013 period the two series show a similar behavior, where in fact only small correcting factors have been applied to the original series (average adjustment: 1.008). Overall, the use of the raw series ~~jeopardizes~~ hides the trends obtained during the study period, especially before the 1980s when the dimming period observed in the homogenized series is not evident during the 1960s and early 1970s.

We filled the gaps in each monthly record using a procedure similar to that described in Manara et al. (2015). In particular, the median of a set of five estimated values, corresponding to the five highest correlated reference records, was selected in order to avoid outliers resulting from peculiar climatic conditions of the reference station. When less than five reference records fulfilling the requested conditions (distance within 500 km from the record under analysis and at least six monthly values in common with it in the month of the gap) were available, the median was calculated with the available reference series. After the gap filling procedure, all series had at least 90% of available data during the 1959-2013 period and 99% during the 1976-2005 period (Fig. 2), used as reference period to calculate the anomaly series. So, all the series were transformed into monthly/seasonal/annual relative anomaly series with respect to the monthly/seasonal/annual 1976-2005 normals. Seasons are calculated according to the following scheme: December-January-February (winter), March-April-May (spring), June-July-August (summer), September-October-November (autumn) and the year is calculated for the December-November period. The winter season is dated to the year in which January and February fall and, for the first year, the winter and the annual means are calculated using also the monthly mean of December 1958.

2.3 Gridding and regional average record

Starting from the monthly/seasonal/annual anomaly series, we generated a gridded version of the anomaly series with a resolution of 1° x 1° in order to balance the contribution of areas with a higher number of stations with the contribution of areas with a lower number of stations. This technique, explained in more detail by Brunetti et al. (2006b) and Manara et al. (2015), is based on an Inverse Distance Weighting approach with the addition of an angular term to take into account the anisotropy in the spatial distribution of stations. The resulted grid spans from 7° to 18° E and from 37° to 47° N, with 58 grid points over the Italian territory (Fig. 1).

Then, the monthly gridded anomaly records were subjected to a Principal Component Analysis (PCA) in order to identify areas with similar SSR temporal variability. With this technique, it is possible to identify a small number of variables, which are linear functions of the original data and which maximize their explained variance (Preisendorfer, 1988; Wilks, 1995). The analysis focused on the 1976-2005 period, the same reference period used to calculate the anomaly series. The analysis shows that the first five eigenvectors have an eigenvalue greater than 1 and they explain more than 91% of the total variance of the data set. Then, we selected to rotate the first two empirical orthogonal functions (EOFs), which are those that account for 59% and 23% respectively of the original variance of the data set, in order to obtain a more physically meaningful pattern (Von Storch, 1995). We decided to select these two EOFs because they account for 82% of the original variance while the other three account only for 9%. This procedure allowed to divide the Italian territory in two regions: Northern Italy (29 grid points) and Southern Italy (29 grid points) (Fig. 1). Finally, we calculated the monthly, seasonal and annual mean anomaly series for the two regions by averaging all corresponding grid point anomaly records. From here, we refer to these series as the SSR anomaly series obtained under all-sky conditions to distinguish them from the series presented in the next section (Sect. 2.4) obtained selecting only the clear-sky days.

2.4 Clear sky series

Starting from the 54 homogenized daily SSR series presented in Sect. 2.1 and in Sect. 2.2, we aimed at determining clear SSR days for the 1959-2013 period. For this purpose, we used an updated version (both for number of series and series length) of the total cloud cover (TCC) database presented by Maugeri et al. (2001) as reference to extract the clear-sky days. In particular, we considered only the days with a daily TCC mean of 0 okta. For the SSR series without a corresponding TCC series, we considered the data from nearby stations. The main limitation of the previous procedure is that the condition adopted to select clear-sky days (0 okta of TCC) allows often to select a very low number of days. We tried therefore to apply a less restrictive condition and we extracted also the clear-sky days using as threshold 1 okta. The average of clear-sky days per station and month is 9% for the 0-okta threshold and 18% for the 1-okta threshold. These fractions are however higher in summer when SSR is more important, reaching the maximum value in July with 17% of 0-okta days and 34% of days with less than 1-okta of TCC.

Then, the monthly mean was calculated when at least two clear-sky daily values were available in the considered month. After~~ the~~ gap-filling, the monthly/seasonal/annual relative anomaly series were obtained with respect to the 1976-2005 period using the same technique explained in Sect. 2.2. To calculate the anomaly series we considered only the series with at least 50% (for 0 okta) and 80% (for 1 okta) of available data in the 1976-2005 period after the gap-filling. This reduced the series to 44 in the first case (Table 1). As final step, we interpolated the anomaly series as described in Sect. 2.3 and we obtained the regional anomaly series, for the two regions and the two thresholds, by averaging all corresponding grid point anomaly series.

3 Results

3.1 Trend analysis of the all-sky SSR records

The average Northern and Southern Italy annual and seasonal SSR records obtained under all-sky conditions are shown in Fig. 4, together with the same low-pass filter used in Fig. 3. In order to better understand the depth and the length of the tendencies showed in Fig. 4, we subjected the records to a running trend analysis (Brunetti et al., 2006a) estimating the trend slope of each sub-interval of at least 21 years by applying a linear regression. The results are shown in Fig. 5. Specifically, we represent the length of the period considered for the analysis (y axes) in relation to ~~and ~~the starting year of the window that the trend refers to (x axes)~~., are represented on y and x axes, respectively.~~ Slopes are shown~~ed~~ by means of the colors of the corresponding pixels with large squares for trends with a significance level p<=0.1 and with small squares for trends with a significance level p>0.1 considered here non statistically significant, with significance levels estimated by means of ~~(from here, we refer to these trends as non statistically significant) evaluated by ~~the Mann-Kendall non parametric test (Sneyers, 1992).

At annual scale both regions show a decreasing tendency until the mid-1980s and a following increase until the end of the series, with a period of stabilization in the late~~during the second half of the~~ 1990s. The trends of the two periods are ~~quite~~ comparable, especially in the Southern region. In fact, the trend for the whole period under analysis (e.g., 1959-2013 period) is not statistically significant, as highlighted by the running trend analysis (Fig. 5). However, the intensity of the dimming is slightly higher for the South than the North, especially for some windows starting in the mid-1960s (e.g., about -3% per decade for the North and about -4% per decade for the South for the 1965-1985 period), while the brightening is more intense in the North especially for the windows starting in the mid-1980s (e.g., about +4% per decade for the North and about +2% per decade for the South for the 1980-2010 period).

For the winter season, the records show a well-defined behavior with a dimming and a following brightening only in the Northern region where the record shows statistically significant negative and positive tendencies for some periods starting in the 1960s and 1980s, respectively. On the contrary, the behavior is not well defined in the Southern region, with a minimum in the mid-1980s and two secondary maxima during the 1970s and 1990s (Fig. 4). As a consequence, the series shows only some sub-periods with a statistically significant trend. They are~~windows of~~ less than 35~~0~~ years long and they start~~ing~~ in the 1960s with negative sign~~trends~~ and in late 1970s/early 1980s with positive sign. There is also a ~~as well as one~~ window extending 21 years ~~long sub-period~~ starting in 1990 with a significant decreasing tendency (-4% per decade)~~ and very few positive trend windows starting in late 1970s/early 1980s~~ (Fig. 5).

The spring season has a similar pattern~~ similar~~ to the annual one~~year~~ with a clear negative-positive sequence and a period of stabilization during the second half of 1990s both for Northern and Southern Italy. The records show a comparable dimming for the two regions for periods longer than 30 years with variations of about -3% per decade (e.g. 1962-1992 period), while it is slightly stronger in the North if sub-periods starting in the mid-1960s with less than 30 years are considered in which ~~with~~ variations range~~ing~~ between -7% and -5% per decade. As far as the brightening is concerned, it is stronger in the Northern region, both for long and short sub-periods with values of about +6% per decade for some windows starting in the 1980s.

For the summer season the sequence of the dimming and brightening is evident and very similar to the annual and spring behavior only in the South. In the North, during the dimming period, there are only very few sub-periods with a significant decreasing trend, while in the South the most part of the windows starting in the 1960s have significant trends with variations of about -3% per decade (e.g. 1960-1990 period) indicating~~ the presence of~~ a reduction of SSR. On the contrary, the brightening period is quite comparable for the two regions and reaches values of about +4% per decade (e.g. 1983-2013 period). The trends of the longest ~~sub-~~periods are significant and positive with values of about +1% per decade (e.g. 1959-2013 period) only in the North as a consequence of its weaker dimming in the early period.

The autumn records (Fig. 4) start with a period without any trend for both regions and then they show a decrease between the beginning of 1970s and the beginning of 1990s and a following increase, which is stronger in the Northern than in the Southern region. This picture is evident also in the running trends (Fig. 5), especially for the brightening period where some sub-periods have a positive trend after the beginning of the 1980s in the North and none has a positive trend in the South with the only exception of one 21-year sub-period starting in the 1990s. On the contrary most of the sub-periods starting in the 1960s and 1970s have significant and negative trends with values of about -3% per decade. The trend over the whole period under analysis (~~e.g.~~ 1959-2013 period) is significant and negative for both regions with values of about -2% per decade.

In order to give a more accurate information on the variations highlighted by Fig. 4 and Fig. 5, we estimated the trends in Wm^{-2} per decade for some key periods (Table 2), including 1959-2013 (the entire period covered by the records), 1959-1985~~ and~~, 1986-2013 (the dimming and brightening periods according to the Northern and Southern Italy

~~yearly~~annual records) and other periods to allow a direct comparison with some relevant dimming/brightening papers (Sanchez-Lorenzo et al., 2015; Wild, 2012). Specifically, we calculated the absolute series for each grid-point multiplying each seasonal/annual anomaly series obtained under all-sky conditions by the corresponding seasonal/annual normals and then we calculated the seasonal and annual regional records, by averaging all corresponding grid point absolute series. The seasonal/annual normals were calculated by averaging the corresponding monthly normals obtained using the same data and the procedure explained by Spinoni et al. (2012). In particular, the monthly normals were obtained starting from a database of SD normals for the Italian territory ~~representative~~ referring to ~~of~~ flat and non-shaded sites. These normals were ~~at~~ first transformed into SSR normals by means of the Ångström law and then interpolated onto the USGS GTOPO 30 Digital Elevation Model grid (USGS, 1996) by means of an Inverse Distance Gaussian Weighting spatialization model.

As previously shown, the trend over the whole period under analysis (1959-2013) is significant only in summer in the North (+3.1Wm^{-2} per decade) and in autumn for both regions (-1.5Wm^{-2} and -2.2Wm^{-2} for the North and the South respectively). In the first case, considering the weak (and not significant) dimming, the trend over the whole period is mostly driven by the increasing tendency of the second period while in the second case, considering the weak brightening, the trend over the whole period is mostly driven by the decreasing tendency of the first period.~~, as a consequence of a weak dimming period in the first case and a weak brightening period in the second one.~~ Considering the 1959-1985 period, as reference for the dimming period, the trend is significant in all the seasons both for the North and the South with values ranging between -7.2Wm^{-2} per decade in spring and -3Wm^{-2} per decade in winter for the North and between -8.5Wm^{-2} per decade in spring and -4.2Wm^{-2} per decade in autumn for the South. As far as the brightening period is concerned, considering the 1986-2013 period, the trend is significant in all the seasons in the Northern region with values ranging between +3.2Wm^{-2} per decade in winter and +12.3Wm^{-2} per decade in summer, while in the Southern region it is significant only at annual scale and during spring (+7.6Wm^{-2} per decade) and summer (+13.5Wm^{-2} per decade).

3.2 Trend analysis of the clear-sky SSR records

The average Northern and Southern Italy seasonal and annual SSR records obtained under clear-sky conditions using 0 okta and 1 okta as thresholds to select the clear days are shown in Fig. 6. The correlations between the records obtained with the two thresholds are comprised between 0.86 for the spring season and 0.97 for the winter season in the North and between 0.87 for the winter and autumn season and 0.95 for the summer season in the South. The agreement increases if the correlation between the filters is considered (it is always higher than 0.96). The decadal variability shown by the trends using the two thresholds is very similar with the exception of few periods where one of the two records shows a higher interannual variability causing slight differences in the resulting trends. This is evident for example before the 1980s during the spring season in the North and during the winter season in the South; in both cases the 0 okta series shows higher variability than the 1 okta series. The difference in the resulting variability over the whole period under analysis (1959-2013) is particularly evident in the North where it is always higher in the 0 okta than in the 1 okta series (the standard deviation of the residuals from the low-pass filter is comprised between 0.02 and 0.04 for the 0 okta series and between 0.01 and 0.03 for the 1 okta series), while it is less evident in the South where the two series show the same variability (the standard deviation of the residuals from the low-pass filter is comprised between 0.02 and 0.05 for both the thresholds). The advantage of 0 okta as threshold is that it allows to select only the real clear-sky conditions but the limitation of this choice is that it allows to select only a low number of days (in the North it is particularly due to the higher frequency of cloudy days), thereby increasing the variability of the obtained series. On the contrary using 1 okta as threshold allows to obtain a more stable series selecting a higher number of days, which are however not completely clear.

In order to better understand the magnitude and the length of the tendencies shown in Fig. 6, we subjected the clear-sky records to a running trend analysis (Brunetti et al., 2006a), as previously illustrated for the all-sky series. The running trend obtained for the two different thresholds is very similar, so we show and discuss only the one obtained with 0 okta as threshold (Fig. 7).

At annual scale the clear-sky records show a comparable decreasing and following increasing tendency both for the North and the South as highlighted by the lack of a significant trend for the whole period under analysis (e.g., 1959-2013 period). However, the dimming period is slightly stronger in the Southern region, especially if the sub-periods with less than 30 years and starting before the 1970s are considered (e.g., about -4% per decade for the South and about -3% per decade for the North for the 1961-1991 period), while the brightening period is slightly more intense in the Northern region (e.g., about +4% per decade for the North and about +3% per decade for the South for the 1981-2011 period).

During the winter season~~ the~~ trends show a dimming and a ~~following ~~subsequent brightening for both regions. The dimming is slightly stronger than the brightening and, as a consequence, the trend over almost the whole period under analysis is negative (e.g., -2% per decade during the 1959-2009 for both regions). ~~The r~~Records show a period of stabilization during the mid-1970s and during the 2000s (Fig. 6) and, so~~as a consequence,~~ some sub-periods especially in the South do not show a significant trend after the beginning of 1980s.

The spring season has a ~~pattern ~~similar pattern to the annual one~~year~~ with a clear negative-positive sequence after a starting period without any significant trend and a period of stabilization in the 1990s, both for Northern and Southern Italy. The dimming period is stronger in the South than in the North where all the sub-periods with less than 30 years and starting before 1970 show a significant trend with values comprised between -8% per decade and -3% per decade. On the contrary, the brightening period is slightly stronger in the North especially after the mid-1980s with values reaching +6% per decade.

During the summer season the two regions show a different trend with a stronger dimming period in the South than in the North (e.g., about -3% per decade for the South and about -2% per decade for the North for the 1961-1991 period) and a stronger brightening period in the North, with all the sub-periods with less than 30 years showing a significant trend. Summer in the North is the only season that shows a significant positive trend for the longest window (e.g., +1% per decade for the 1959-2013 period) while the summer season in the South, that shows a very similar behavior to the annual series, shows a negative trend for the windows that cover almost the whole period under analysis (e.g., -2% per decade for the 1959-2009 period).

For the autumn season~~ the~~ trends show a decrease until the mid-1980s followed by an increase until the end of the series in both regions, even if in the North a period of stabilization is observed during 1970s as already highlighted by the winter trend. The dimming period is stronger in the South than in the North (e.g., about -5% per decade for the South and about -4% per decade for the North for the 1961-1991 period), while the brightening is stronger in the North even if a period of stabilization is observed during 1990s as already highlighted by the winter trend (e.g., about +4% per decade for the North and about +3% per decade for the South for the 1981-2011 period). Overall, in the northern region the trends of the two periods are comparable while in the South the trend is stronger in the dimming period than in the brightening period resulting in a significant negative trend over the whole period under analysis (e.g., about -2% per decade for the 1959-2013 period).

3.3 Comparison between all-sky and clear-sky SSR records

In order to better investigate the differences between the trends illustrated in Sect. 3.1 and in Sect. 3.2 and so ~~in order~~ to determine to which extent ~~better understand which part of the~~ SSR variability depends either on cloud~~s variability and which part depends~~ or on aerosol~~s~~ variability, we compared ~~, in Fig. 8 the comparison between~~ the annual and seasonal low-pass filter series for all-sky and clear-sky conditions (considering 0 okta as threshold) as shown in Fig. 8~~is reported~~. For clarity, ~~O~~only filters of the time series are indicated.~~shown for clarity.~~

~~Interestingly, t~~The comparison between the trends obtained under the two different conditions shows that without the contribution of ~~the~~ clouds, ~~the~~ dimming and ~~the~~ brightening become more intense and significant in all seasons both for ~~the~~ North and ~~the~~ South. The differences are particularly evident during ~~the~~ winter and autumn seasons. Specifically, considering the winter season for both regions, the dimming period is more intense under clear-sky conditions than under all-sky conditions with a significant trend for almost all sub-periods starting before the mid-1970s (see Fig. 5 and Fig. 7). As far as the brightening period is concerned, in the Northern region it is comparable under clear and all-sky conditions ~~the two conditions~~ if the trend intensity ~~of the trend~~ is considered while it presents some differences if ~~the shape of the~~ curve~~s~~ shapes are ~~is~~ taken into account. On the contrary, in the Southern region the brightening becomes stronger and significant under clear-sky conditions even if a period of stabilization is evident in the mid-1990s. After removing cloud~~the~~ contribution ~~of the clouds~~, during ~~the~~ autumn season the length and ~~the~~ intensity of ~~the~~ dimming and ~~/~~brightening periods change for both regions. This is due to a shift in the trend inversion from the beginning of 1990s in the North and the end of 1990s in the South to the mid-1980s as already observed for the other seasons both for all-sky and clear-sky conditions. This shift causes a shorter dimming period and a longer and more significant brightening period.

~~The d~~Differences between all-sky and clear-sky trends are less evident in spring and summer. Nevertheless, some differences are relevant~~evident~~ in both ~~periods~~ seasons especially during summer in the North where under all-sky conditions there is only a weak decrease while it becomes more intense and significant under clear-sky conditions.

The differences between the all-sky and clear-sky anomaly records are highlighted also considering the ratios between the latter and the former records. Before 1980~~,~~ ~~the~~ low-pass filters applied to these ratios (figures not shown) show~~give evidence of~~ values higher than one in all seasons with the only exception of autumn. Also at annual ~~a yearly~~ scale ~~the~~ ratios are higher than one before about 1980 with maxima, ~~respectively~~ of 1.025 in the North (1967) and~~-~~ 1.024 in the South (1968) ~~value in the North (1967) and in the South (1968) and~~ with a clear decrease in the 1970s. These results seem to suggest that in Italy ~~the~~ global dimming has been partially hidden by a decreasing tendency of cloudiness and that without these changes in cloudiness the decrease in SSR in the dimming period would have been greater.

The comparison between~~among the~~ clear-sky and ~~the~~ all-sky anomaly records allows also to quantify the effect of cloudiness on the observed SSR trends and so the effect due to other factors. ~~At this purpose~~In this case, we have assumed that if cloudiness did not change, ~~the~~ clear-sky and ~~the~~ all-sky anomaly records would have had the same behaviour. ~~Under~~With this hypothesis virtual constant-cloudiness SSR trends were estimated ~~by simply~~ transforming, by means of the all-sky normals already presented in Sect. 3.1, the trends of the clear-sky anomaly records (obtained with 0 okta as threshold) into constant-cloudiness all-sky absolute trends. ~~The t~~Trends expressed in Wm^{-2} per decade for the same periods considered in Table 2 for the all-sky series~~,~~ were calculated and the results are reported in the same table.

These values confirm what has already been highlighted by Fig. 8. Assuming no changes in cloudiness, at the annual~~yearly~~ scale the trend during the dimming period (1959-1985) decreases to -6.3Wm^{-2} per decade in the North and to -8.4Wm^{-2} per decade in the South (the corresponding all-sky trends are -4.4 and -6.4Wm^{-2} per decade, respectively), confirming that the variations of cloudiness partially masked the all-sky decreasing trends. On the contrary, the influence of the cloudiness variability is not evident during the brightening period (1986-2013) in the North where the all-sky and estimated constant-cloudiness records have almost the same trend, while it is more important in the South where the trend increases from +6.0Wm^{-2} per decade (all-sky) to +7.9Wm^{-2} per decade (estimated constant-cloudiness). This behaviour reflects the variations observed during winter, spring and summer. During autumn the cloudiness variability influenced in a significant way both periods and regions. In particular, during the brightening period the trend changes in the North from +4.8Wm^{-2} per decade (all-sky) to +6.5Wm^{-2} per decade (estimated constant-cloudiness) and in the South from a not significant value (all-sky conditions) to +5.4Wm^{-2} per decade (estimated constant-cloudiness).

Without ~~the~~cloud contribution, ~~of the clouds~~ the correlation between ~~the~~ North and ~~the~~ South becomes higher: the correlation coefficients range ~~between~~from 0.53 (winter) ~~and~~to 0.78 (year) under all-sky conditions and from ~~between~~ 0.67 (autumn) ~~and~~to 0.86 (year) under clear-sky conditions. The largest variation is observed in winter, the season more affected by clouds, where the correlation coefficient increases from 0.53 (all-sky) to 0.84 (clear-sky) while the smallest variation is observed in summer where the correlation coefficient changes from 0.74 (all-sky) to 0.76 (clear-sky). Under all-sky conditions the correlation between the two regions is higher in spring (~~coefficient are~~ 0.64 for anomalies and 0.94 for filters) and summer (~~coefficients are~~ 0.74 for anomalies and 0.89 for filters) while under clear-sky conditions the correlation is higher in winter (~~coefficients are~~ 0.84 for anomalies and 0.96 for filters).

4 Discussion and conclusions

A new dataset of long-term Italian SSR records has been set up collecting data from different sources. Particular emphasis is placed upon the quality control and the homogenization of the records in order to ensure the reliability of the resulting trends, which can be affected by non-climatic signals. The majority~~most part~~ of the inhomogeneities detected in the series happen~~fall~~ before 1980, when many recalibrations, changes in instruments and station relocations occurred, while they become less relevant in the subsequent ~~following~~ period. This is also highlighted by the Italian annual mean series where the dimming observed in the homogenized series is not evident in the raw series during the 1960s and early 1970s, showing how at regional level systematic biases in the original records can hide a significant part of the long-term trend.

Starting from the homogenized daily records, besides SSR series under all-sky conditions, SSR series under clear-sky conditions were also obtained selecting clear days from corresponding ground-based TCC observations. Then, these series were projected onto a regular grid (1° x 1°) covering the entire Italian territory and clustered in two regions (Northern and Southern Italy) by means of a Principal Component Analysis. The records of these areas were averaged in order to get the corresponding regional all-sky and clear-sky SSR records for the 1959-2013 period.

The clearest feature of the Italian all-sky SSR is a significant dimming from the beginning of the series to the mid-1980s and a subsequent~~following~~ brightening until the end of the series for the annual mean, as well as during winter and spring in the Northern region and spring and summer in the Southern region. The trend over the whole period (1959-2013) is significant only during summer (positive) in the North and during autumn (negative) for both regions, as a consequence in the first case of a very weak dimming and in the second one of a very weak brightening.

In ~~Considering~~ the clear-sky SSR records, ~~the~~ dimming and ~~the~~ brightening trends become stronger and they are significant for all seasons and for both regions. The strength of the clear-sky trends is higher than that observed for the all-sky records especially during winter in the South and during summer in the North. The most evident differences between all-sky and clear-sky series are observed in autumn for both regions where not only the variations become more intense and significant but also the change point from dimming to brightening moves from the mid-1990s to the mid-1980s. So, the fact that the change point under all-sky and clear-sky conditions differs by several years in autumn and the intensity of the two periods changes in all seasons supports the hypothesis that clouds contribute in a significant way to the SSR variability under all-sky and confirms the hypothesis formulated by Manara et al. (2015) for SD, suggesting that cloud cover variations have partially masked the dimming caused by the increasing aerosol concentration, especially in the Northern region. This is also confirmed by Maugeri et al. (2001) who found a highly significant negative trend in TCC all over Italy during the period 1951-1996.

The resulting trends without the contribution of the clouds show a more coherent pattern over the Italian territory. The peculiarities of a very weak dimming in summer for the North and a very weak brightening in winter for the South, as well as a strong and long dimming in autumn for both regions and the subsequent absence of brightening, are in fact attenuated under clear-sky conditions. The resulting trends under clear-sky conditions for both regions are in agreement with the changes in aerosol and aerosol precursor emissions that occurred during the period under analysis. More specifically, in Italy sulphur dioxide emissions which can be converted to sulphate aerosols show an increasing tendency until the 1980s due to the combustion of solid and liquid fuels (Mylona, 1996) and a decreasing tendency in the following years (Maggi et al., 2006; Vestreng et al., 2007). In parallel, the trends of black carbon and particulate organic matter show a change of tendency starting~~yet~~ in the mid-1970s, earlier with respect to the sulphate aerosols due to the reduction of the coal use in residential and commercial sectors as well as improved diesel engines (Novakov et al., 2003). So, the combination of these trends could explain to some degree the SSR variability under clear-sky conditions suggesting anthropogenic aerosols as a relevant contributor of SSR variations in Italy under clear-sky conditions.

The dimming in the South ~~The stronger~~ in spring, summer and autumn is stronger~~dimming in the South~~ than in the North under clear-sky and this fact may challenge the above hypothesi~~e~~s as the North is more affected by air pollution due to higher emissions. Nevertheless, ~~it is worth noting that~~ Southern Italy is more affected by coarse aerosols (Bonasoni et al., 2004), causing a significant contribution of natural aerosols to SSR variability as for example mineral dust intrusions from the Sahara and Sahel (Prospero, 1996). In particular, we highlight that a comparison between the Northern and Southern Italian clear-sky SSR variations and the Sahel Precipitation Index ~~gives evidence of~~shows a good agreement, especially in Southern Italy and during the Sahel rainy season (summer and autumn). The correlation coefficients between these two variables over the period 1959-2013 are 0.85 and 0.79 for the South and 0.74 and 0.79 for the North, respectively for the summer and autumn seasons suggesting a possible connection between SSR and Sahel Precipitation Index variability. They show a similar behavior with a decreasing tendency from the beginning of the series until the mid-1980s and an increasing tendency in the following period. The results are also coherent with the fact that mineral dust transportation from North Africa into Europe shows a pronounced seasonal cycle with a maximum in summer and a minimum in winter (Pey et al., 2013; Varga et al., 2014) and a distinct gradient with the highest values near the northern coast of Africa (Gkikas et al., 2013; Prospero, 1996).

Long-term variations of dust transport into Europe are confirmed by measurements of dust accumulation in Alpine snow, which show~~give evidence of~~ a clear increase of mineral dust since the early 1970s with quite high values after the 1980s. This suggests an increase of dust mobilization and transport from North Africa to the north across the Mediterranean and into Europe (De Angelis and Gaudichet, 1991; Maggi et al., 2006) during the first part of the period covered by the SSR series. All this~~ese~~ information supports the hypothesis that mineral dust contributes in a significant way to the SSR variability with a higher contribution in the Southern part of Italy than in the Northern part especially during summer and autumn. This could also explain why the summer correlation between the North and the South remains low even under clear-sky conditions, suggesting that cloud cover is not the cause of this low correlation, thus pointing to a different source, such as dust transport, that affects the two regions in a different way. On the contrary, the stronger dimming observed in the North during winter could be a consequence of higher concentrations of anthropogenic aerosols in that region with respect to the South. However, in order to confirm all these hypotheses on the role of natural and anthropogenic aerosols there is need for a better understanding of the factors influencing dust generation and transport and a better understanding of the spatial distribution and temporal evolution of the different types of aerosols that characterize the atmosphere in Northern and Southern Italy.

It is also worth noticing that the time series, both for all-sky conditions and for clear-sky conditions, show in some seasons relevant minima in the periods 1982-1983 and 1992-1993 possibly as a consequence of the El Chichón (April 1982) and Pinatubo (June 1991) volcanic eruptions, which injected high amounts of sulfur dioxide into the stratosphere causing a worldwide reduction in direct solar radiation (e.g., Robock, 2000; Sanchez-Lorenzo et al., 2009).

The observed trends under all-sky conditions are ~~quite~~ in good agreement with those observed in other worldwide areas and Europe. In particular, we compared the Italian trends with those obtained by Sanchez-Lorenzo et al. (2015), using a new version of the GEBA (Global Energy Balance Archive) dataset updated to 2012, for Southern Europe. This comparison shows similar~~gives evidence of comparable~~ trends in the dimming period while in the brightening period the trends are significantly stronger for Italy than for Southern Europe. This is in agreement with the SD trends reported by Manara et al. (2015) for Italy where the brightening especially in the Northern region appeared to be stronger as compared to Europe.

The all-sky SSR trends presented for the Italian territory show some discrepancies with respect to the trends of SD obtained for the same areas reported by Manara et al. (2015), despite the fact that the correlations between the two variables over the period 1959-2013 are comprised between 0.71 in autumn and 0.88 in spring in the North and between 0.58 in autumn and 0.75 in spring in the South. The deviation of the SSR series with respect to the SD series is a trend reversal shifted from the mid-1980s to the beginning of the 1980s and a dimming period that is more intense and significant. The agreement between the two variables increases if the correlations between the residuals (ratio between the anomaly series and the filter) are considered; they are comprised between 0.72 in summer and 0.91 in winter in the North and 0.62 at annual scale and 0.84 in spring for the South highlighting a good year-to-year correlation between the two variables.

The fact that the dimming in SD is weaker than in SSR could indicate that the long-term increase in aerosols affects the two variables in a different way inducing a more significant reduction in the intensity of SSR than in SD. The discrepancies between SSR and SD trends could also be a consequence of a different sensitivity to changes in the diurnal cycle and decadal variability of cloud cover, temperature and humidity that could modify the measurements of SD differently than SSR, but the reasons for these differences need further research. However, Sanchez-Romero et al. (2014) in a review reported some studies that found similar discrepancies between SD and SSR trends in different areas of the world as for example Germany (Power, 2003), China (Che et al., 2005; Zhang et al., 2004), United States (Stanhill and Cohen, 2005) and Canadian Prairie (Cutforth and Judiesch, 2007).

A more detailed understanding of the mechanisms driving the SSR variability in Italy both under all-sky and clear-sky conditions calls for further research including also the study of other variables as for example temperature, visibility, aerosols and cloudiness.

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Table 1. Details on the network, station location, instruments and length of the records in the SSR data set. The last column shows which ~~if the~~ records haves been considered to calculate the regional mean under clear-sky conditions (see Sect. 2.4).

Network / Data Source	Station name	Country	Region	Latitude (deg)	Longitude (deg)	Elevation (m)	Period	Instrument (pyranograph, pyranometer)	Selected clear-sky 0 okta
METEO SWISS	ACQUAROSSA COMPROVASCO	CH	N	46.459	8.936	575	1988-2013	CM21 Kipp & Zonen	N
AM	ALGHERO	I	S	40.630	8.280	23	1959-1989	~~Fuess-~~Robitzsch	N
AM	AMENDOLA	I	S	41.530	15.720	57	1959-2010	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
AM	ANCONA CAPPUCCINI	I	N	43.623	13.516	104	1959-1978	~~Fuess-~~Robitzsch	Y
AM	BOLOGNA	I	N	44.530	11.300	36	1959-1989	~~Fuess-~~Robitzsch	Y
AM	BOLZANO	I	N	46.467	11.333	241	1959-1988	~~Fuess-~~Robitzsch	Y
AM	BRINDISI	I	S	40.650	17.950	15	1959-2013	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
AM	CAGLIARI ELMAS	I	S	39.250	9.050	4	1959-2013	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	N
AM	CAPO MELE	I	N	43.958	8.170	220	1964-2003	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
AM	CAPO PALINURO	I	S	40.025	15.280	184	1959-2013	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
UCEA-BDAN	CARPENETO	I	N	44.681	8.624	230	1994-2013	CM11 Kipp & Zonen	Y
UCEA-BDAN	CHILIVANI	I	S	40.610	8.919	216	1994-2013	CM11 Kipp & Zonen	N
UCEA-BDAN	CIVIDALE	I	N	46.096	13.414	130	1997-2013	CM11 Kipp & Zonen	Y
AM	CROTONE	I	S	38.996	17.080	155	1959-1989	~~Fuess-~~Robitzsch	Y
UCEA-BDAN	FIUME VENETO	I	N	45.920	12.724	19	1996-2013	CM11 Kipp & Zonen	Y
AM	GELA	I	S	37.076	14.225	33	1965-1997	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
AM	GENOVA SESTRI	I	N	44.417	8.850	2	1959-1989	~~Fuess-~~Robitzsch	Y
UCEA-BDAN	LIBERTINIA	I	S	37.541	14.581	188	1994-2013	CM11 Kipp & Zonen	N
METEO SWISS	LOCARNO MONTI	CH	N	46.172	8.787	383	1981-2013	CM21 Kipp & Zonen	N
METEO SWISS	LUGANO	CH	N	46.000	8.967	273	1981-2013	CM21 Kipp & Zonen	Y
METEO SWISS	MAGADINO CADENAZZO	CH	N	46.167	8.883	197	1981-2013	CM21 Kipp & Zonen	Y
AM	MESSINA	I	S	38.201	15.553	59	1959-2006	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
AM	MILANO LINATE	I	N	45.433	9.283	107	1959-2010	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
AM	NAPOLI	I	S	40.850	14.300	88	1959-1989	~~Fuess-~~Robitzsch	Y
AM	OLBIA	I	S	40.900	9.517	13	1959-1988	~~Fuess-~~Robitzsch	Y
UCEA-BDAN	PALO DEL COLLE	I	S	41.055	16.632	191	1994-2013	EP07 Middleton Instrument	Y
AM	PANTELLERIA ISOLA	I	S	36.817	11.967	191	1959-2009	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	N
AM	PESCARA	I	S	42.433	14.189	10	1959-1987	~~Fuess-~~Robitzsch	Y
UCEA-BDAN	PIANO CAPPELLE	I	S	41.113	14.827	152	1994-2013	CM11 Kipp & Zonen	Y
AM	PIANOSA ISOLA	I	N	42.586	10.094	27	1959-1979	~~Fuess-~~Robitzsch	Y
UCEA-BDAN	PIETRANERA	I	S	37.541	13.517	158	1994-2013	CM11 Kipp & Zonen	Y
AM	PISA SAN GIUSTO	I	N	43.683	10.400	2	1959-2013	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
UCEA-BDAN	PIUBEGA	I	N	45.217	10.514	38	1997-2013	CM11 Kipp & Zonen	Y
UCEA-BDAN	PONTECAGNANO	I	S	40.623	14.911	38	1997-2013	CM11 Kipp & Zonen	Y
AM	ROMA CIAMPINO	I	S	41.800	12.583	129	1959-2009	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
UCEA-BDAN	SAN CASCIANO	I	N	43.670	11.151	230	1994-2013	CM11 Kipp & Zonen	Y
UCEA-BDAN	SAN PIERO A GRADO	I	N	43.668	10.346	3	1994-2013	CM11 Kipp & Zonen	Y
UCEA-BDAN	SANTA FISTA	I	N	43.523	12.130	311	1994-2013	CM11 Kipp & Zonen	Y
UCEA-BDAN	SANTA LUCIA	I	S	39.982	8.620	14	1994-2013	CM11 Kipp & Zonen	N
UCEA-BDAN	SANTO PIETRO	I	S	37.120	14.525	313	1994-2013	CM11 Kipp & Zonen	Y
UCEA-BDAN	SIBARI	I	S	39.738	16.449	10	1994-2013	CM11 Kipp & Zonen	Y
METEO SWISS	STABIO	CH	N	45.843	8.932	353	1981-2013	CM21 Kipp & Zonen	Y
UCEA-BDAN	SUSEGANA	I	N	45.853	12.258	67	1994-2013	EP07 Middleton Instrument	Y
AM	TORINO CASELLE	I	N	45.217	7.650	301	1959-1985	~~Fuess-~~Robitzsch	Y
AM	TRAPANI BIRGI	I	S	37.917	12.483	7	1959-1996	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	N
AM	TRIESTE	I	N	45.683	13.750	4	1959-2001	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
Observatory of Trieste	TRIESTE HORTIS	I	N	45.648	13.766	35	1971-2013	~~Fuess-~~Robitzsch and CM Kipp & Zonen	Y
UCEA-BDAN	TURI	I	S	40.924	17.005	230	1994-2013	EP07 Middleton Instrument	N
AM	UDINE CAMPOFORMIDO	I	N	46.029	13.196	94	1959-1978	~~Fuess-~~Robitzsch	Y
AM	UDINE RIVOLTO	I	N	45.983	13.050	51	1964-2010	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
AM	USTICA ISOLA	I	S	38.700	13.183	250	1959-1997	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y
AM	VENEZIA TESSERA	I	N	45.500	12.333	2	1959-1989	~~Fuess-~~Robitzsch	Y
UCEA-BDAN	VERZUOLO	I	N	44.603	7.480	420	1995-2013	CM11 Kipp & Zonen	Y
AM	VIGNA DI VALLE	I	N	42.081	12.211	275	1959-2013	~~Fuess-~~Robitzsch and CM11 Kipp & Zonen	Y

Table 2. Absolute SSR trends in Northern and Southern Italy under all-sky conditions and estimated trends assuming no changes in cloudiness (see Sect. 3.3). The results concerning the dimming and brightening periods according to the Northern and Southern Italy annual~~yearly~~ records are highlighted in grey[a].

		Year	Winter	Spring	Summer	Autumn
North All-sky	1959-2013	+	+	+	**3.1±0.8**	**-1.5±0.7**
	1959-1985	**-4.4±0.8**	**-3.0±1.3**	**-7.2±2.2**	-3.9±1.6	-3.5±1.9
	1986-2013	**7.7±1.1**	**3.2±1.3**	**10.4±2.9**	**12.3±1.9**	**4.8±1.9**
	1970-2013	**2.9±0.7**	**1.4±0.7**	**4.8±1.5**	**6.1±1.0**	-
	1970-1985	**-4.0±1.9**	-	-	+	-7.8±4.6
	1981-2000	+	+	+	+	-
	1981-2013	**6.1±0.9**	**2.2±1.0**	**9.4±2.2**	**9.8±1.5**	+
South All-Sky	1959-2013	-	-	+	+	**-2.2±0.5**
	1959-1985	**-6.4±1.1**	**-4.6±1.4**	**-8.5±2.3**	**-8.1±2.0**	**-4.2±1.3**
	1986-2013	**6.0±1.2**	+	**7.6±2.0**	**13.5±2.3**	+
	1970-2013	**2.1±0.7**	+	**3.7±1.2**	**5.2±1.3**	**-1.5±0.8**
	1970-1985	-5.9±2.6	-	-	-	**-7.4±3.0**
	1981-2000	**5.0±1.9**	**6.5±2.6**	+	**9.3±3.5**	-2.4±1.7
	1981-2013	**5.4±0.9**	+	**6.9±1.7**	**11.6±1.8**	+
North Clear-Sky Estimated	1959-2013	+	-	+	+	-
	1959-1985	**-6.3±0.8**	**-3.2±0.8**	**-5.8±2.7**	**-8.2±1.6**	**-6.0±1.3**
	1986-2013	**7.6±0.9**	**3.6±0.7**	**9.7±1.6**	**10.0±1.5**	**6.5±1.3**
	1970-2013	**2.7±0.7**	0.9±0.4	**2.8±1.2**	**5.1±0.9**	**1.8±0.8**
	1970-1985	**-5.7±1.5**	-	-	**-6.9±2.4**	**-7.5±2.7**
	1981-2000	**5.3±1.6**	**3.2±1.4**	+	**7.1±2.1**	5.3±2.3
	1981-2013	**6.4±0.7**	**2.7±0.6**	**8.0±1.2**	**9.3±1.1**	**5.5±1.0**
South Clear-Sky Estimated	1959-2013	-	-	+	+	**-1.9±0.6**
	1959-1985	**-8.4±1.0**	**-4.4±1.2**	**-10.3±2.5**	**-10.7±1.8**	**-9.1±1.1**
	1986-2013	**7.9±1.0**	**3.9±1.3**	**10.2±1.6**	**11.4±1.9**	**5.4±1.1**
	1970-2013	**2.8±0.7**	**1.5±0.7**	**4.2±1.2**	**4.3±1.2**	+
	1970-1985	**-8.1±1.8**	-	**-11.3±5.2**	**-11.8±3.3**	**-10.2±2.1**
	1981-2000	**6.4±1.5**	**7.2±2.3**	**7.7±2.4**	**10.7±2.5**	+
	1981-2013	**7.1±0.8**	**3.7±1.0**	**9.2±1.2**	**10.7±1.5**	**4.5±0.8**

[a] Values are expressed in Wm^{-2} per decade. Values are shown for significance level 0.05< p<=0.1 with a thin character and for significance p<=0.05 with a bold character. For not significant trends, only the sign of the slope is given.

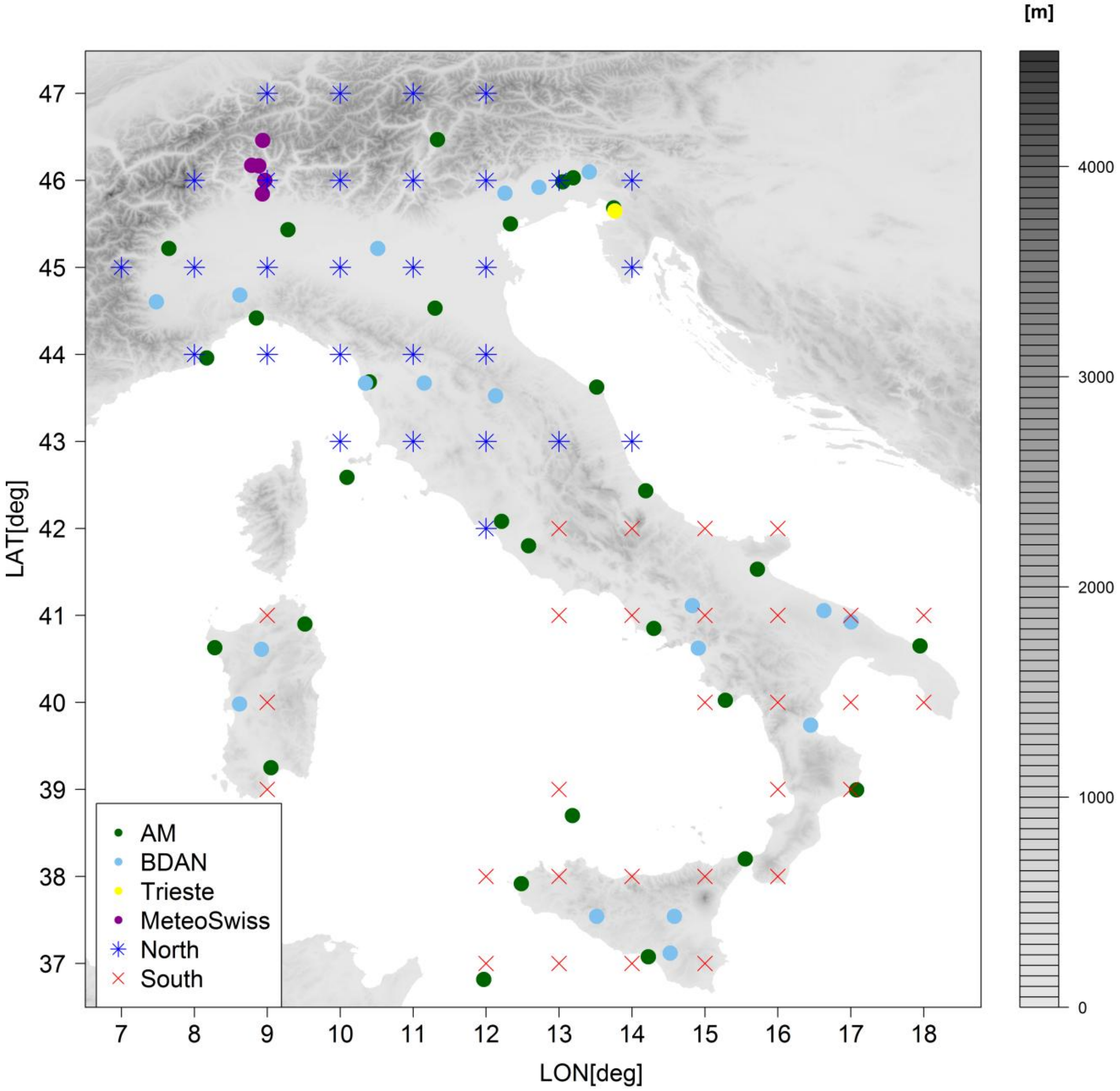

Fig. 1. Spatial distribution of the stations and of the grid-mode version of the data set (see Sect. 2.3): stars and crosses represent, respectively, Northern (29 points) and Southern (29 points) Italy grid points as clustered by a Principal Component Analysis. The figure also shows the orography of the region and gives evidence of the sources of the station records, with green circles for AM series (29 series), blue circles for BDAN series (19 series), yellow circle for the Trieste observatory and violet circles for MeteoSwiss series (5 series).

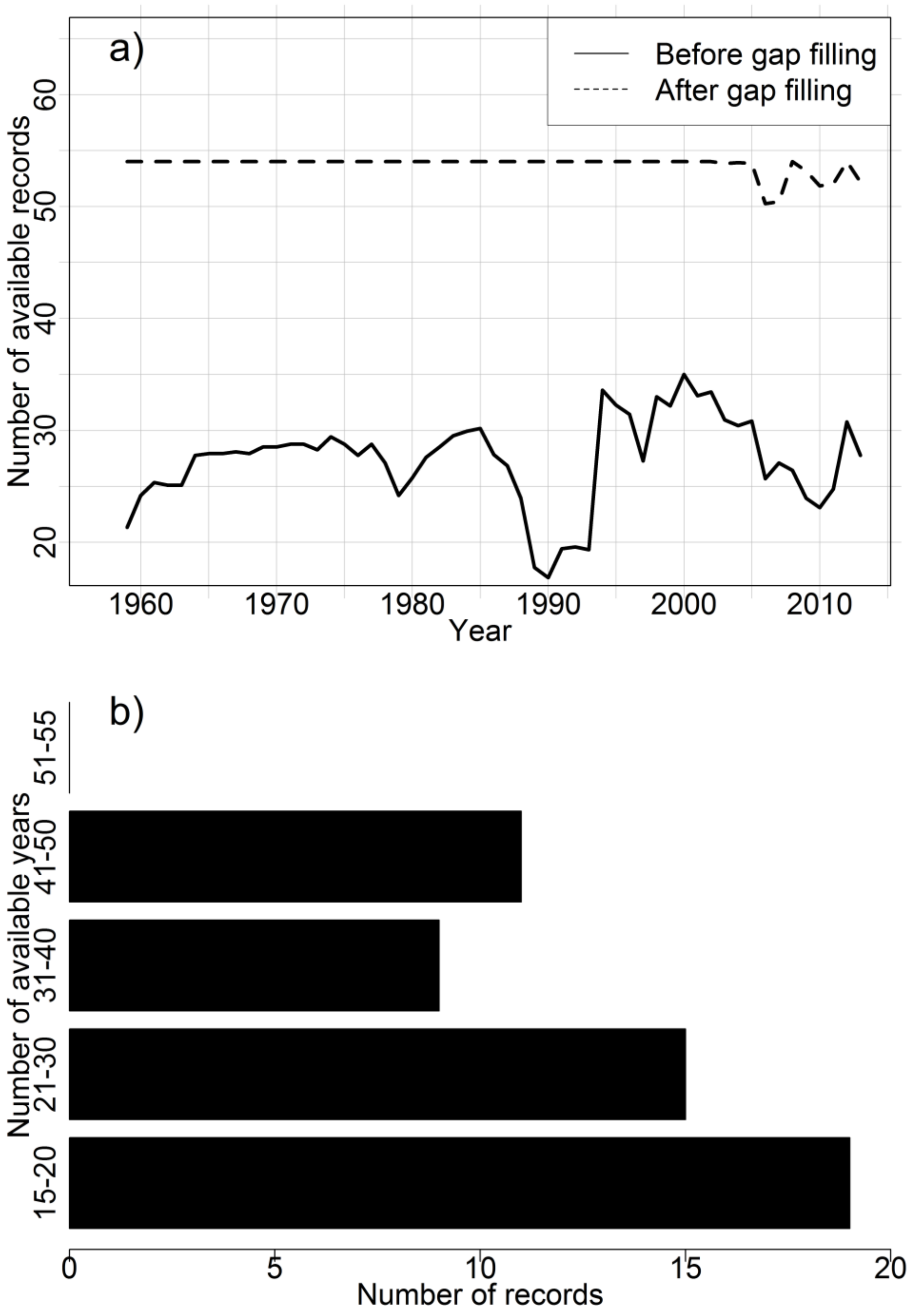

Fig. 2. (a) Temporal evolution of the number of available records per year before (bold line) and after the gap-filling procedure (dashed line) (see Sect. 2.2); (b) The histogram shows the number of records as a function of the number of available years before the gap-filling procedure.

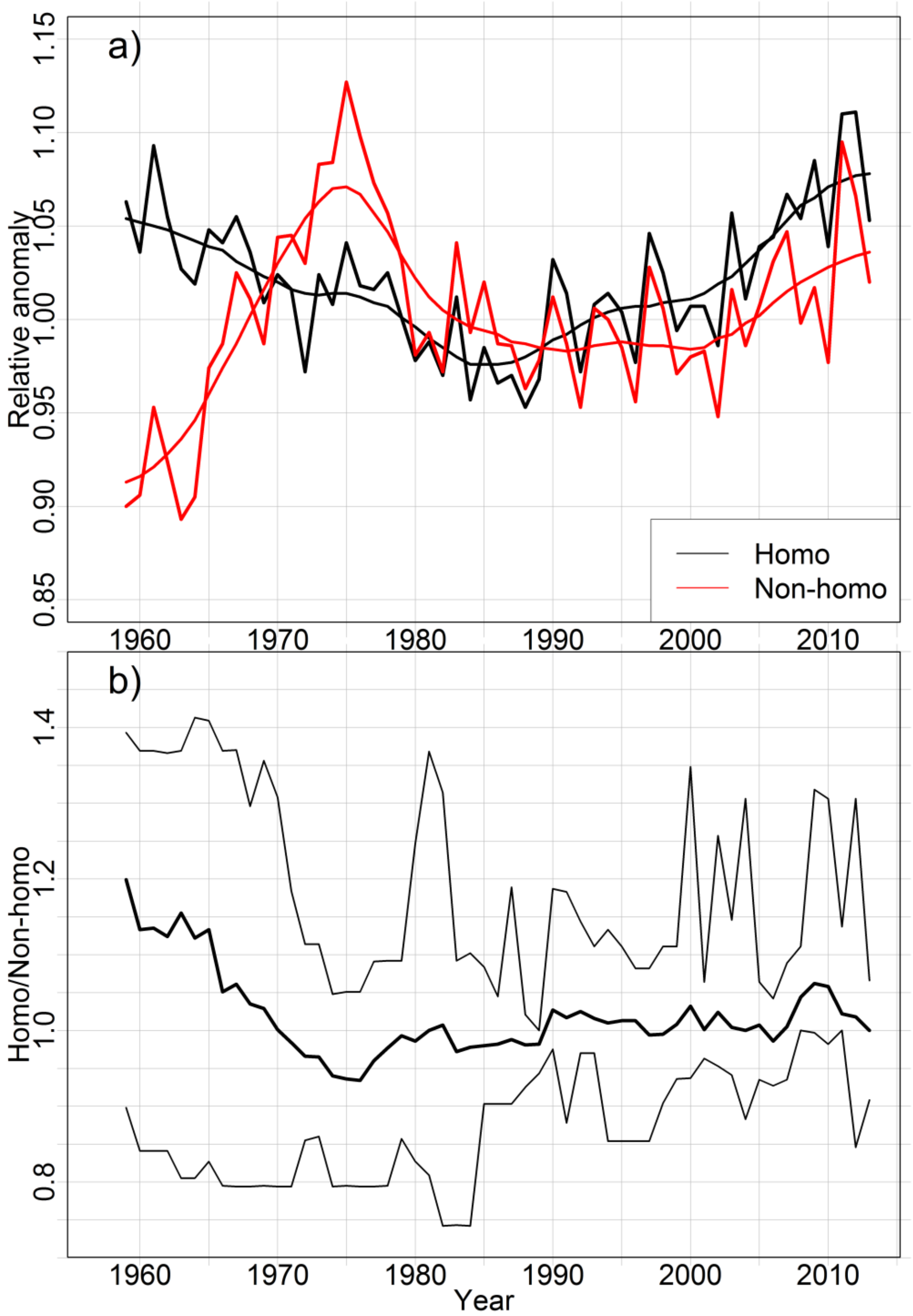

Fig. 3. (a) Average annual Italian SSR series plotted together with an 11 year window – 3-year standard deviation Gaussian low-pass filter before (red line) and after (black line) the homogenization procedure; (b) Mean annual adjustment series obtained calculating the annual average adjustment over all series (bold line). The figure shows the maximum range in the adjustments too.

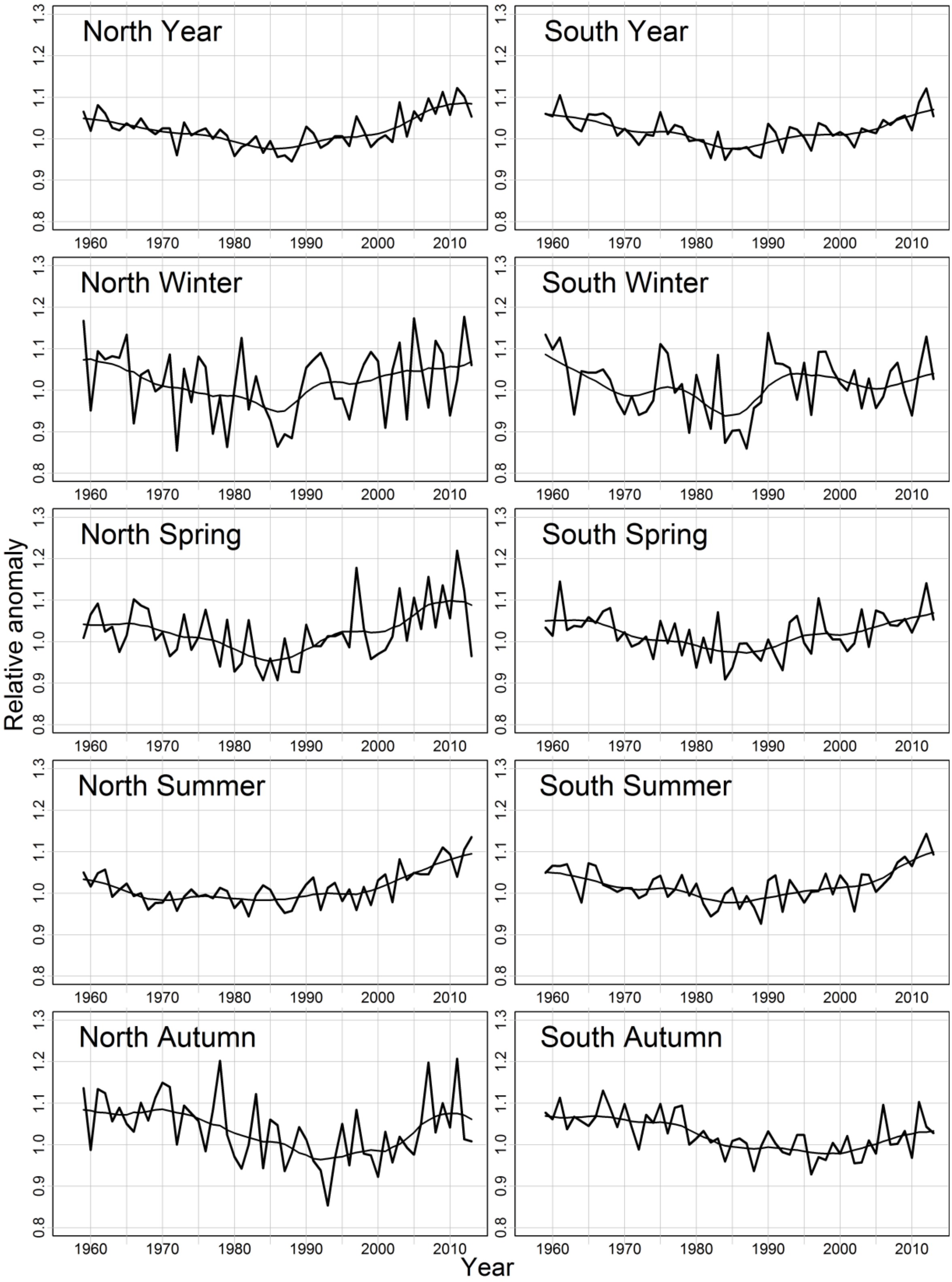

Fig. 4. Average annual and seasonal Northern (left column) and Southern (right column) Italy SSR records obtained under all-sky conditions (bold lines), plotted together with an 11 year window – 3-year standard deviation Gaussian low-pass filter (thin lines). The series are expressed as relative deviations from the 1976-2005 means.

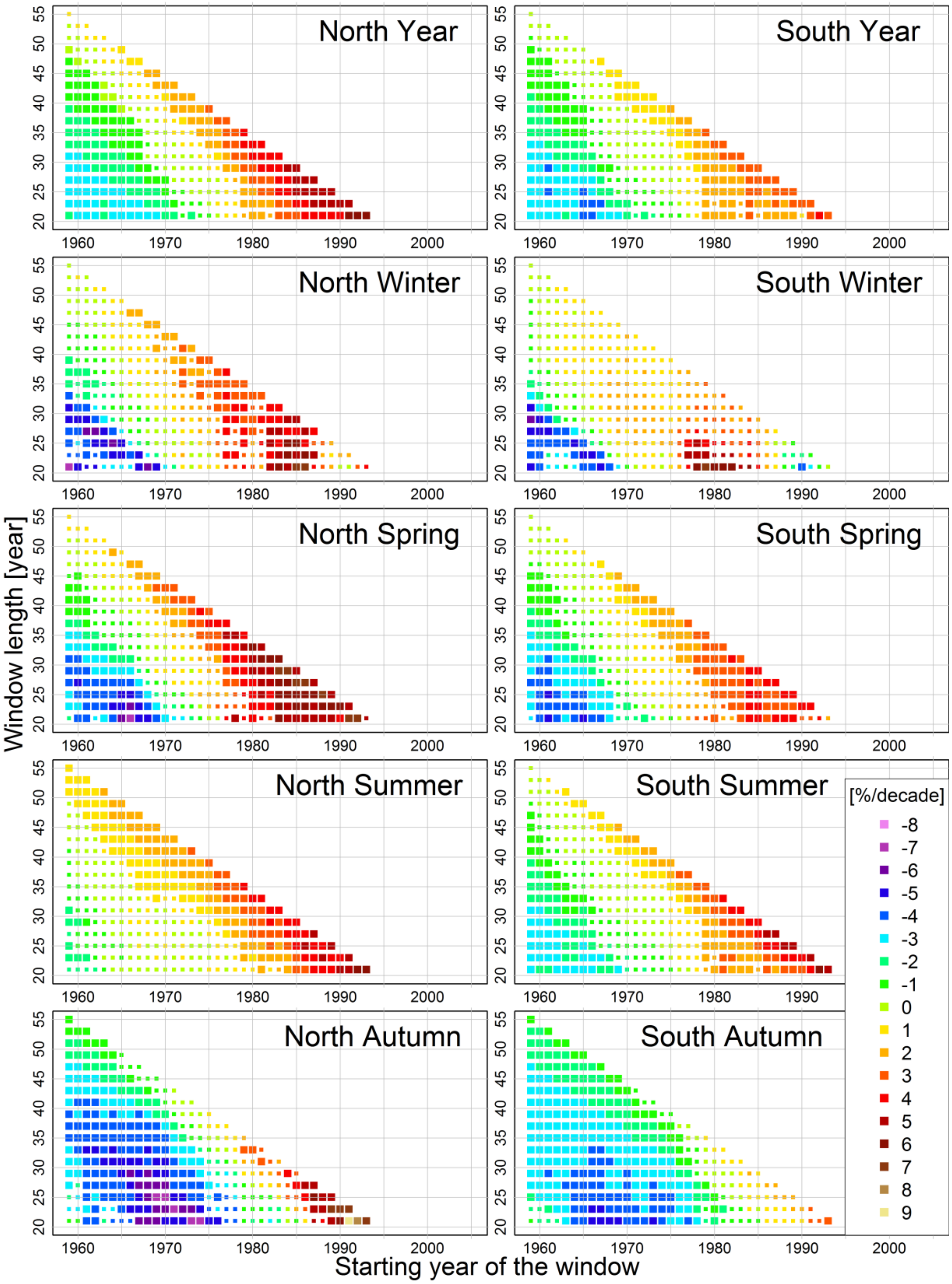

Fig. 5. Running trend analysis for annual and seasonal Northern (left column) and Southern (right column) Italy SSR records obtained under all-sky conditions. The y and x axis represent the length and the first year of the period under analysis, respectively, while the colored pixels show the trend expressed in %/decade with a significance level p<=0.1(large squares) and p>0.1(small squares).

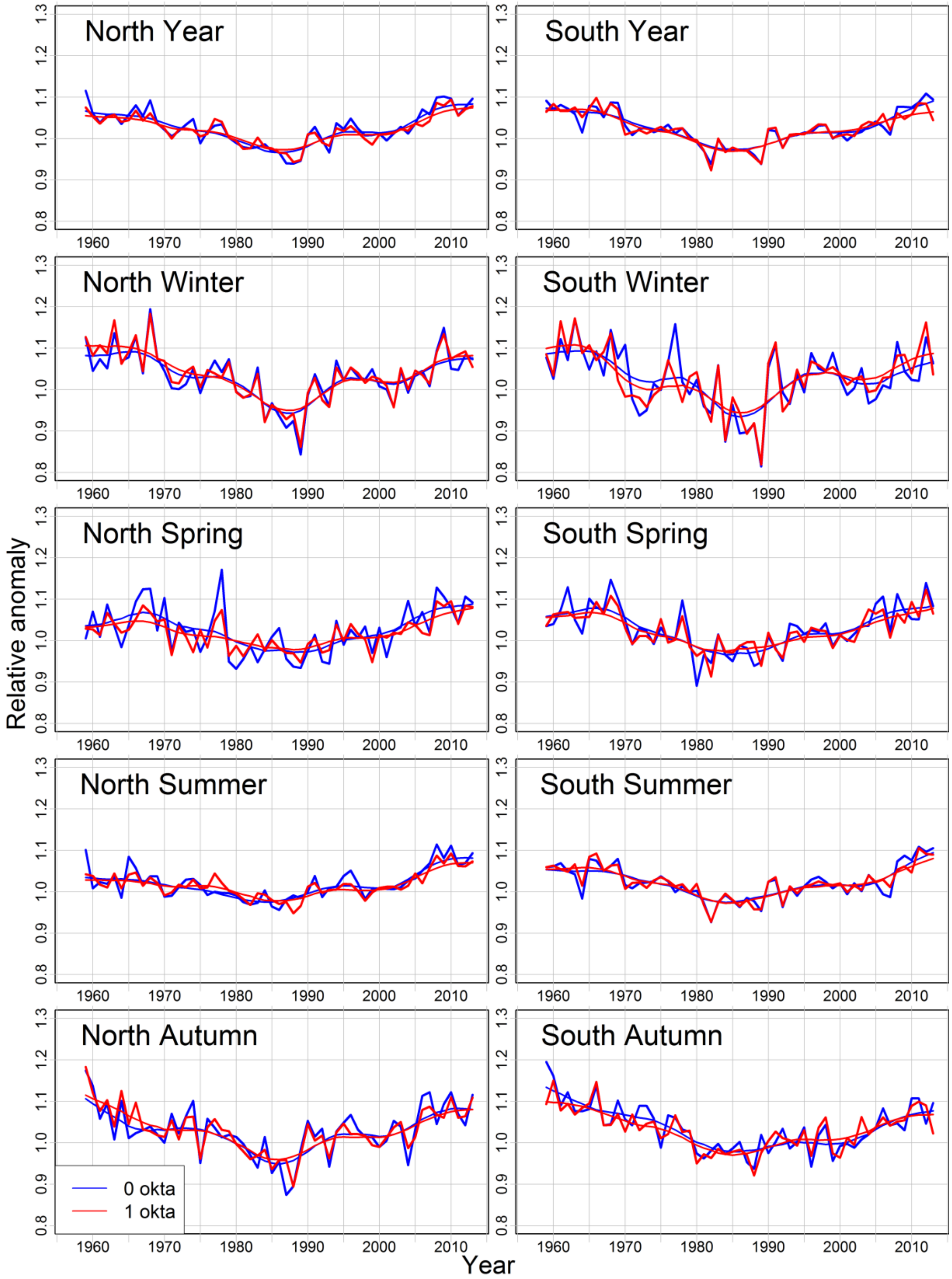

Fig. 6. Average annual and seasonal Northern (left column) and Southern (right column) Italy SSR records obtained under clear-sky conditions (bold lines), plotted together with an 11 year window – 3-year standard deviation Gaussian low-pass filter (thin lines). The series are expressed as relative deviations from the 1976-2005 means. The blue lines represent the records obtained using 0 okta of TCC as threshold to select clear days and the red lines the ones using 1 okta.

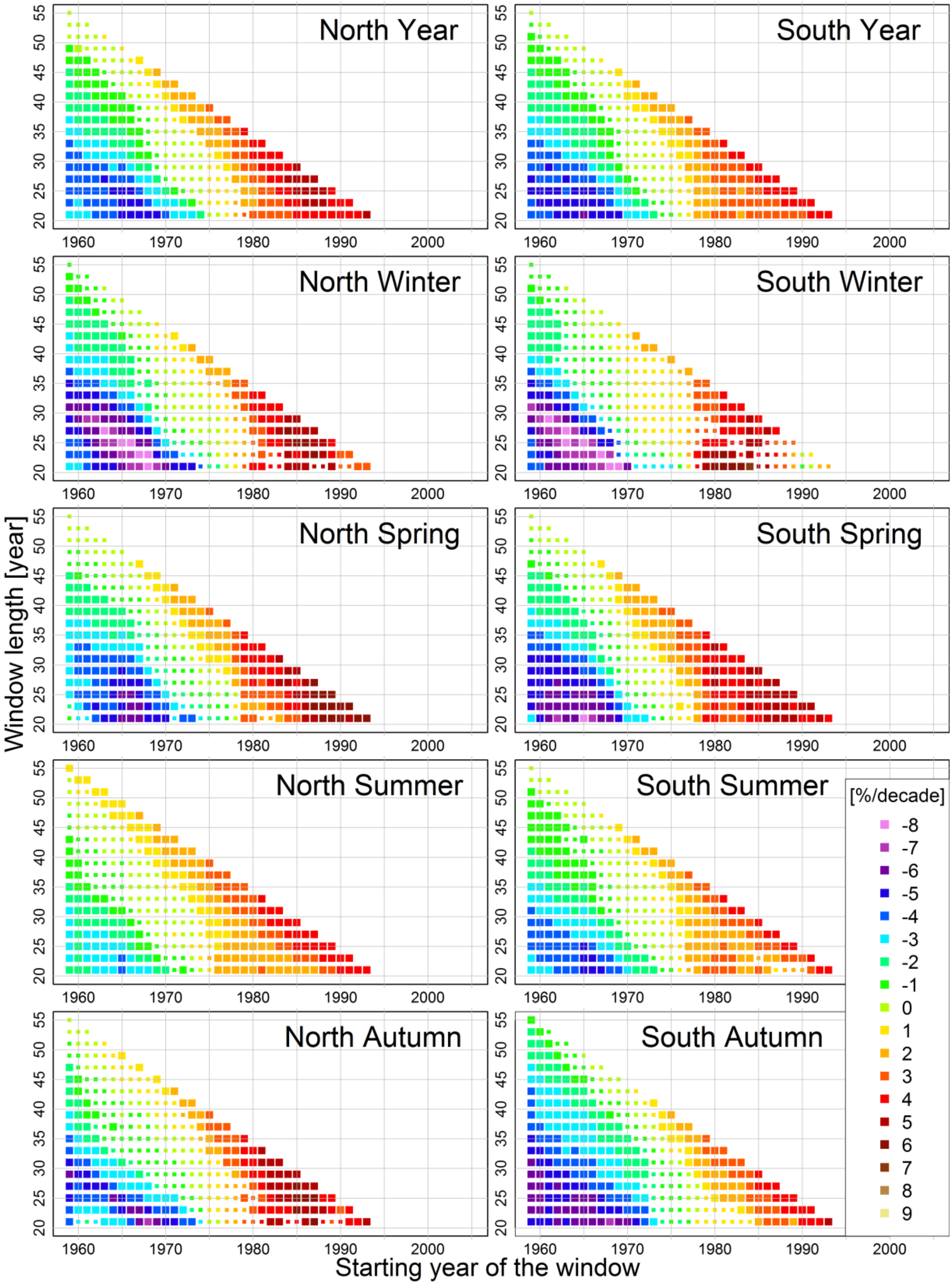

Fig. 7. Running trend analysis for annual and seasonal Northern (left column) and Southern (right column) Italy SSR records obtained under clear-sky conditions (0 okta of TCC as threshold). The y and x axis represent the length and the first year of the period under analysis, respectively, while the colored pixels show the trend expressed in %/decade with a significance level p<=0.1(large squares) and p>0.1(small squares).

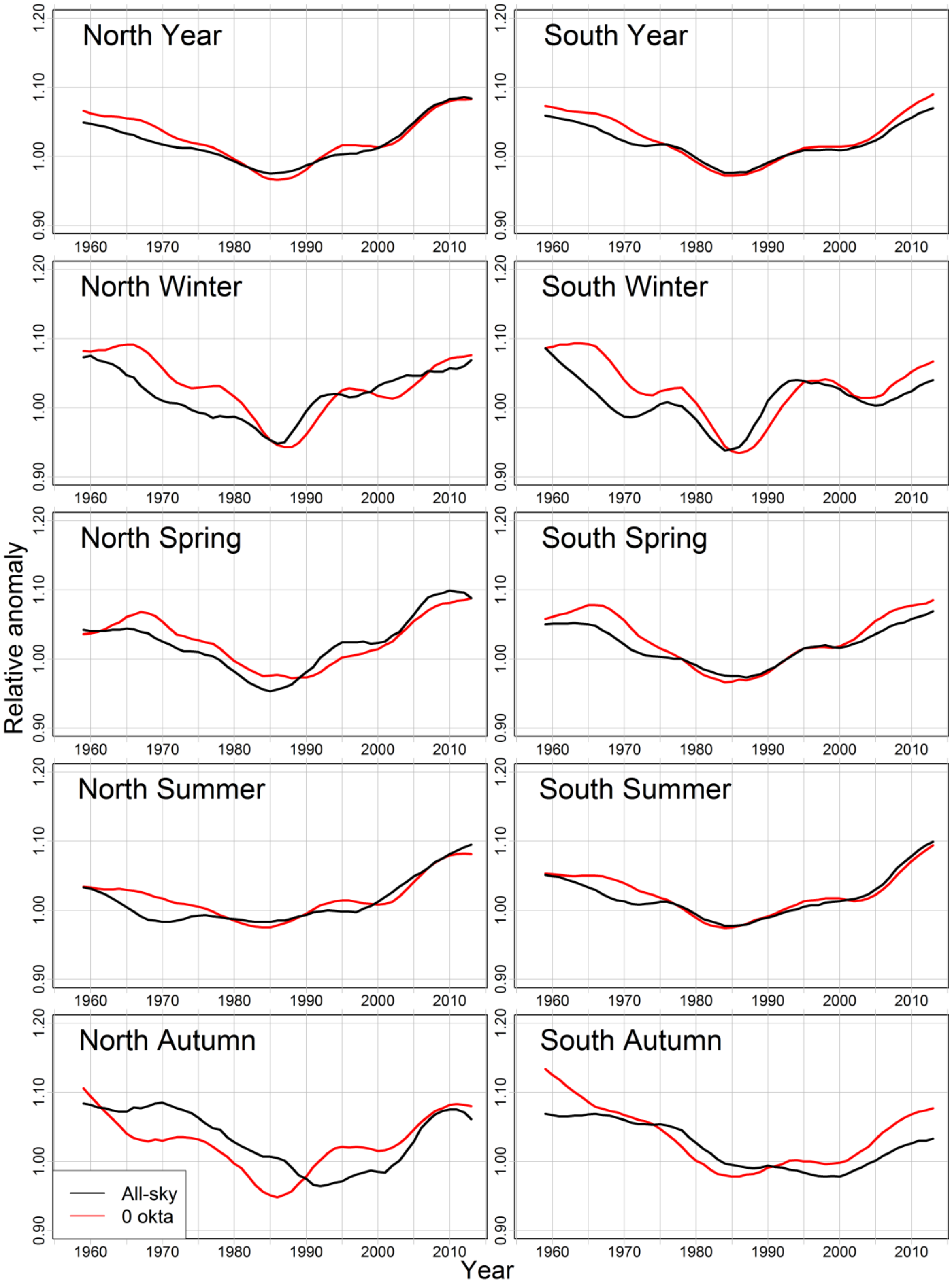

Fig. 8. All-sky (black lines) and clear-sky 0 okta (red lines) SSR annual and seasonal low-pass filter for Northern (left column) and Southern (right column) Italy. The filters are the same as in Fig. 4 and Fig. 6.