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Past and future solar radiation variability and change over Sicily

Manara V.*[1], Brunetti M.[2], Maugeri M.[1,2], Pasotti L.[3], Simolo C.[2]

[1]Università degli Studi di Milano Dip. di Fisica, Milano, [2]CNR ISAC, Bologna
[3]SIAS- Regione Sicilia, Catania

*Corresponding Author: veronica.manara@unimi.it

Abstract

We estimate Sicily global radiation 1961-2000 monthly climatologies from already available climatologies (2002-2011) and from a regional sunshine duration anomaly record (1936-2013). We compare these climatologies with corresponding climatologies from 4 RCM-GCM combinations and present correcting factors introduced in order to make the model outputs representative of the observational data. Then, we apply the same correcting factors to future model simulations in order to produce monthly climatologies for the 2001-2050 and 2051-2100 period.

Keywords: global radiation, sunshine duration, past and future climatologies, Sicily

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 [1], [2]. One of the most important variables for many possible applications (e.g. energy production and agriculture) is solar radiation.

In this context, we set up a methodology for estimating high-resolution solar radiation climatologies from these records. This methodology has been presented in SISC 2013 [3] and it has been applied to a network of 41 Sicily stations of the SIAS network [3]. It consists of the following steps that have to be run on a monthly basis:

- calculating global radiation normals for all station sites;
- 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.

In this paper we present a methodology which allows to estimate from the 2002-2011 results, climatologies for any other period of the 1936-2013 interval and which allows to estimate future scenario climatologies too.

2. TEMPORAL EVOLUTION OF SOLAR RADIATION OVER SICILY IN THE 1936-2013 PERIOD

2.1 Introduction

Temporal variability of solar radiation in the last decades is discussed in a number of recent papers [4]. 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” [4], [5].

In this context we studied 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}. Sunshine duration, which is usually measured with an uncertainty of ±0.1h and a resolution of 0.1h, is directly correlated with solar radiation through Angström’s law [6]. A very important advantage of sunshine duration records is that they cover usually a much longer period than global radiation records.

2.2 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), the database of Italian Air Force synoptic stations (47 records) and the Italian National agrometeorological 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. 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).

2.3 Data pre-processing

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

2.3.1 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%.

2.3.2 Data homogenization

We subjected all our monthly records to the relative homogeneity Craddock test [7]. 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.

2.3.3 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.

2.3.4 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 [8]: 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.

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. [Fig. 1] shows these grid-points, together with the stations that we used to calculate the Sicily grid-point records.

2.4 The Sicily sunshine duration record

The average Sicily seasonal and annual sunshine duration regional records are shown in [Fig. 2], 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.

3. ESTIMATION OF GLOBAL RADIATION CLIMATOLOGIES FOR ANY PERIOD OF THE 1936-2013 INTERVAL

3.1 Angström’s law

The dataset used to obtain the results presented in [3] and in section 2 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:

$$K_T = a\frac{S}{S_0} + b \qquad (1)$$

with coefficients *a* and *b* depending on the considered month. A detailed discussion on this relation is reported in [9] and [10], which report also *a* and *b* coefficients obtained by means of about 30 Italian station with both global radiation and sunshine long-term records.

3.2 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 (1):

$$\overline{K_{T_{A-B}}} - b = a\frac{\overline{S_{A-B}}}{S_0} \qquad (2)$$

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 (2) for the corresponding 2002-2011 equation and rearranging the terms, we get:

$$\overline{K_{T_{A-B}}} = \overline{K_{T_{2002-2011}}}\,\frac{\overline{S_{A-B}}}{\overline{S_{2002-2011}}} + b\left(1 - \frac{\overline{S_{A-B}}}{\overline{S_{2002-2011}}}\right) \qquad (3)$$

If we now divide the sunshine duration averages in equation (3) 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 2) 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 2.3.4).

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 [3].

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 [3]. Actually, we used a slightly different approach projecting the station clearness index normals onto the grid-points of 4

RCM combinations before applying the procedure presented in [3]. 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.

4. GLOBAL RADIATION SCENARIOS FOR THE XXIth CENTURY

4.1 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 outputs resulted in agreement with the observational data.

Four RCM-GCM combinations 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.

[Fig. 3] 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.

4.2 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 monthly 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 [Fig. 4a-e] that shows the ratios between the model and the observational normals for March, June, September and December. These comparisons shows that the model outputs have to been adjusted in order to be representative of the real data.

4.3 Adjustment 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 monthly 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 adjusted clearness index normals were available for each model grid-point, the global radiation climatologies were estimated applying the procedure outlined in [3].

In order to better give evidence of the time evolution of global radiation for the model projections, we show maps [Fig. 5a-e] with the ratios between the 2001-2050 and the 1961-2000 climatologies and the ratios between the 2051-2100 and the 1961-2000 climatologies for March, June, September and December. 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 period) derived from the observed data.

5. CONCLUSION

A methodology which allows obtaining Sicily solar radiation climatologies for any period of the 1936-2013 interval has been set up. The clearness index normal values of the 1961-2000 period have been used to validate and adjust the outputs of 4 RCM-GCM combinations. The adjusted scenario clearness index normals have been used to produce 2001-2050 and 2051-2100 climatologies. These climatologies do not give evidence of well defined global radiation trends. In the future we plan to extend these studies to a wide range of RCMs-GCM models and a paper on global radiation scenario will be prepared.

6. ACKNOWLEDGMENTS

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8. IMAGES AND TABLES

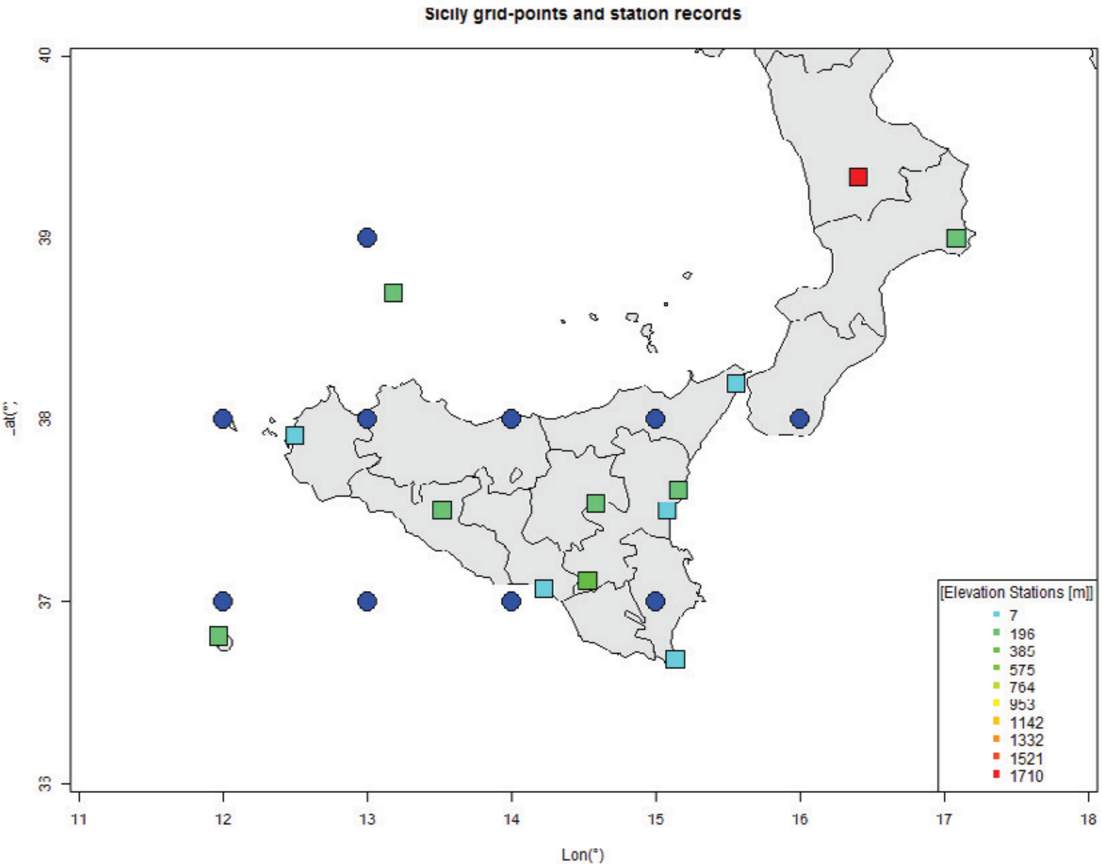

Fig. 1 Sicily grid-points (blue points) and station records (other color squares) we used to calculate the grid-point series.

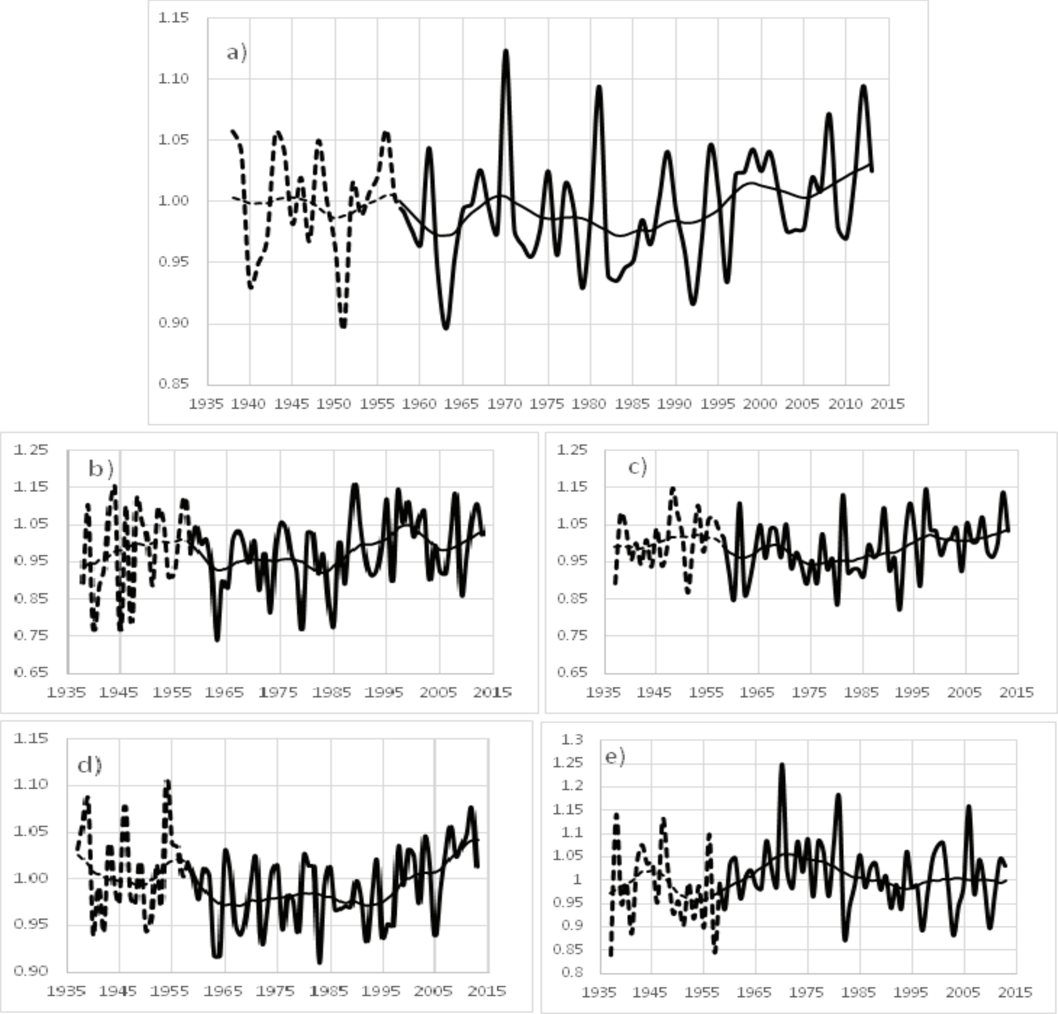

Fig. 2 Average Sicily sunshine duration (thin line), plotted together with an 11-y window - 3-y standard deviation Gaussian low-pass filter (thick line) for (a) year; (b) winter; (c) spring; (d) summer; (e) autumn. The series are expressed as relative deviations from the 1984-2013 means. Dashed lines are used prior to 1958 owing to the lower number of records for this initial period.

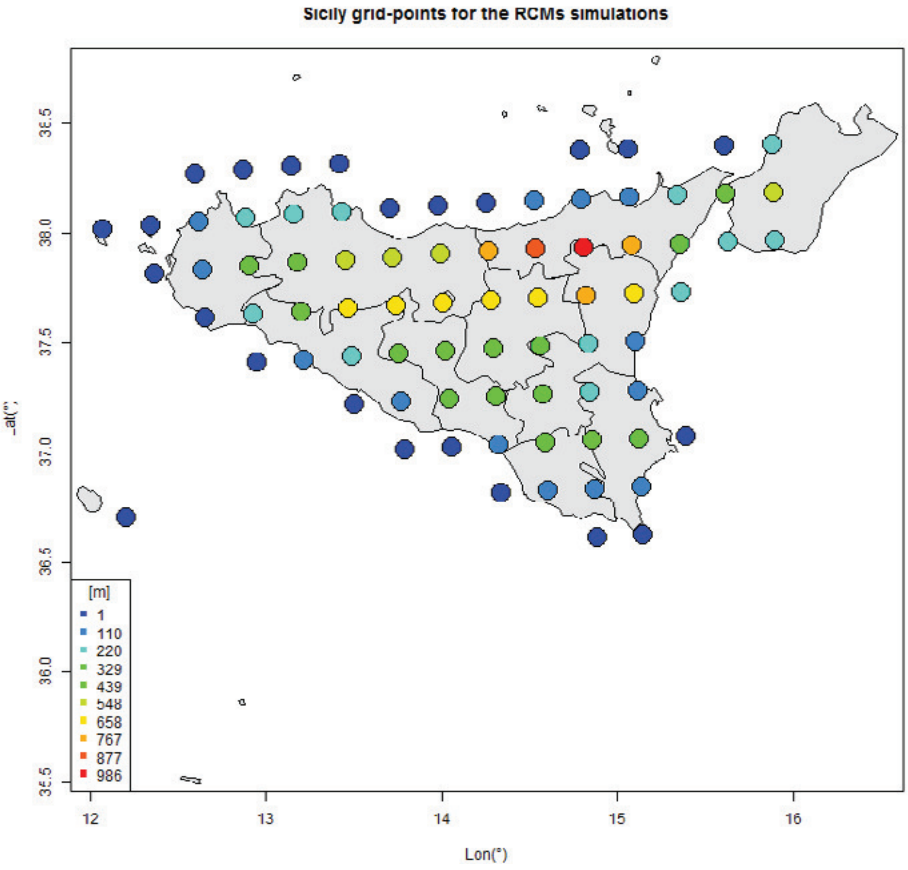

Fig. 3 Sicily grid-points for the RCMs simulations. The colors indicate the elevation of the model grid-points.

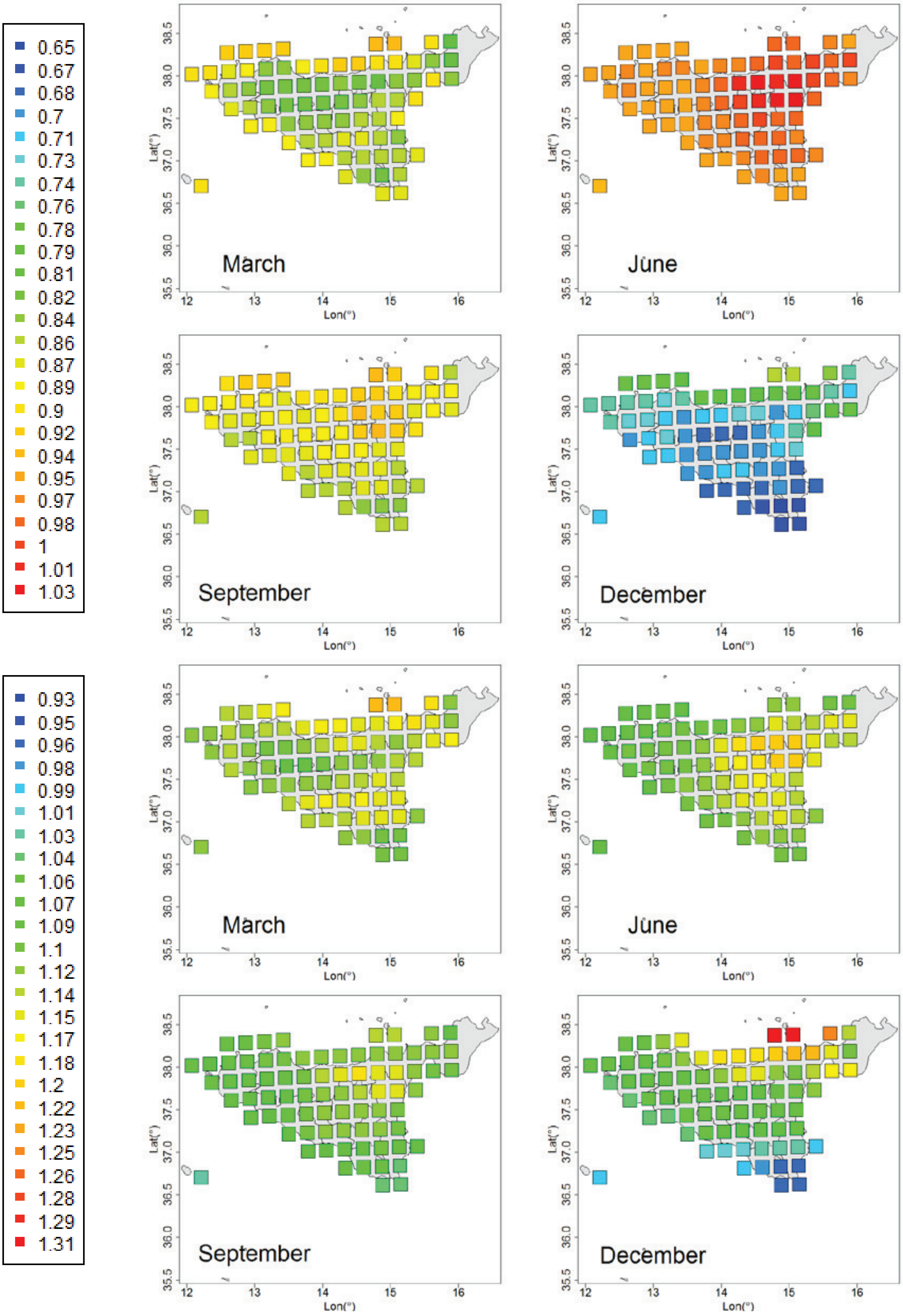

Fig. 4a-b Ratios between model and observational normals for the 1961-2000 period: March, June, September and December. Upper graphs KNMI-ECHAM5; lower graphs SMHI-ECHAM5 model.

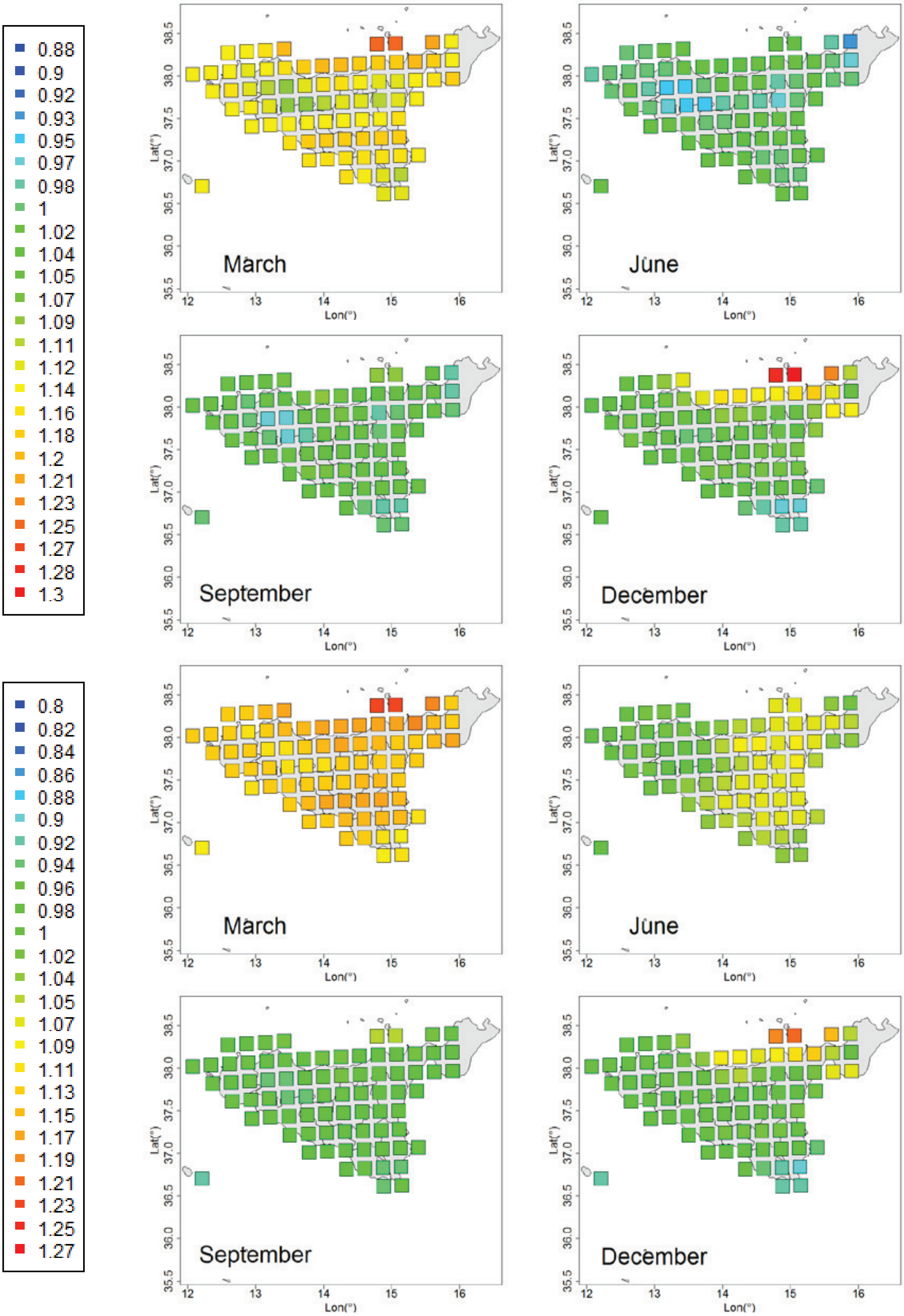

Fig. 4c-d Ratios between model and observational normals for the 1961-2000 period: March, June, September and December. Upper graphs SMHI-BCM; lower graphs SMHI-Had model

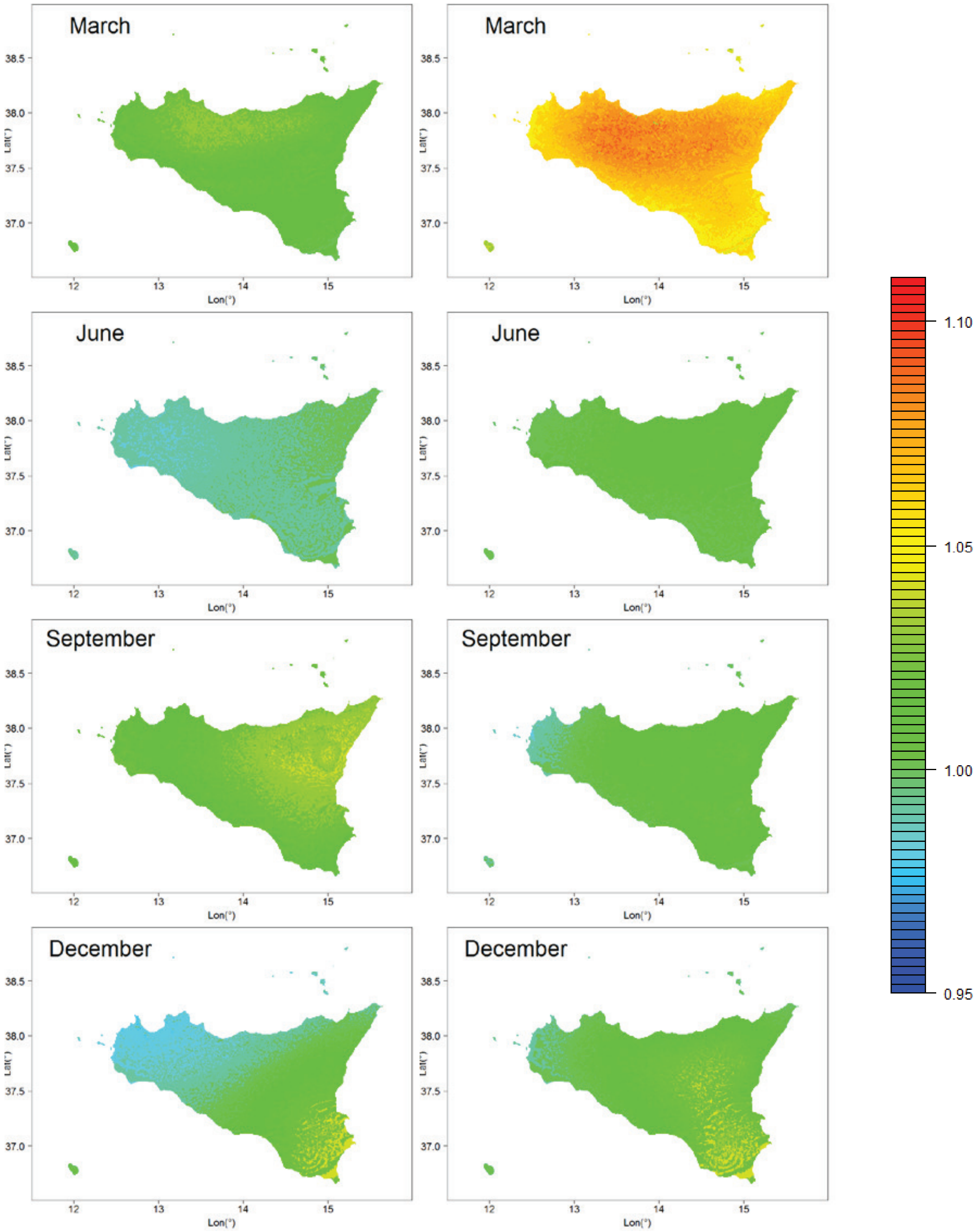

Fig. 5a Ratios between the 2001-2050 and the 1961-2000 climatologies (left column) and ratios between the 2051-2100 and the 1961-2000 climatologies (right column) for March, June, September and December for the KNMI-ECHAM5 model.

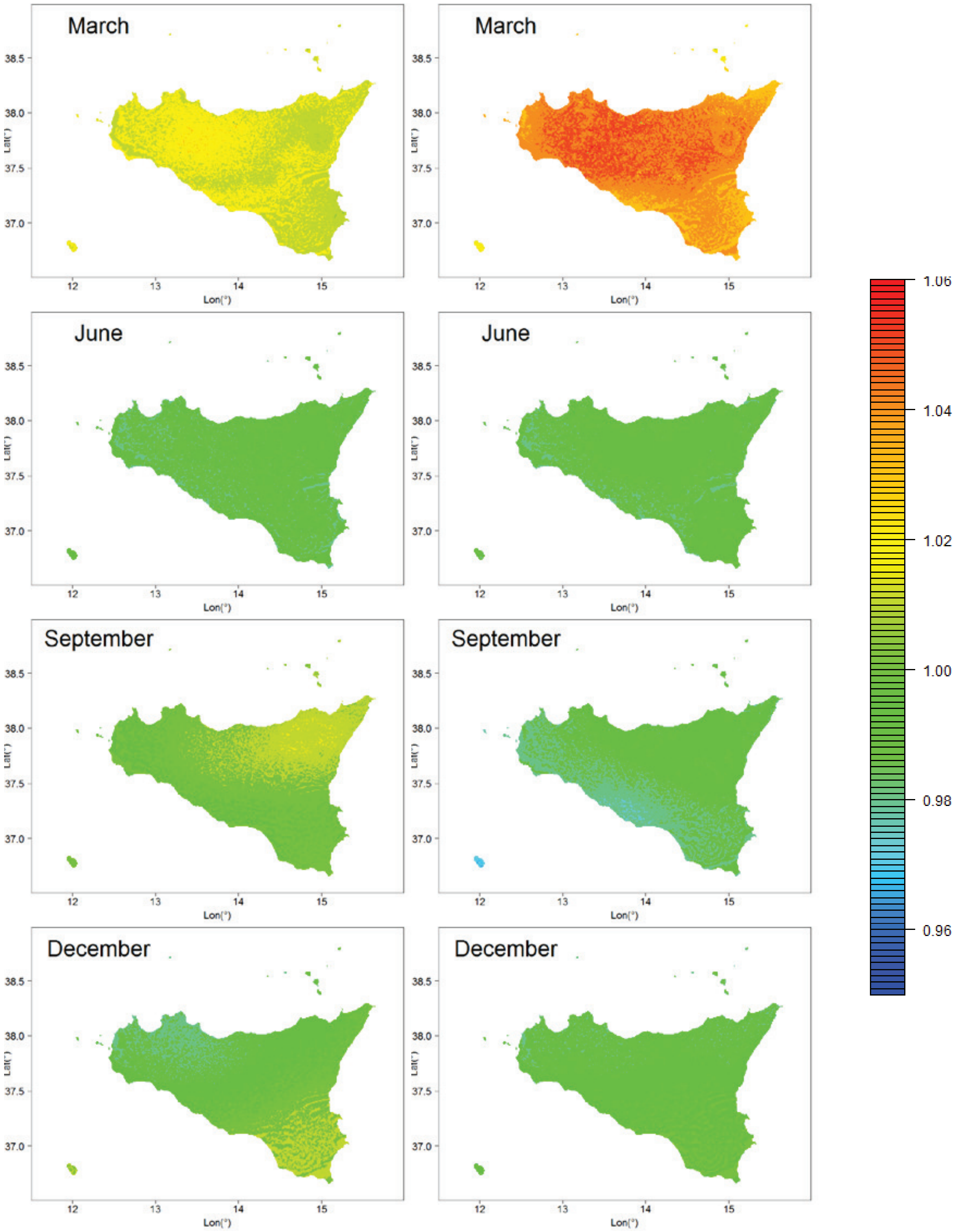

Fig. 5b Ratios between the 2001-2050 and the 1961-2000 climatologies (left column) and ratios between the 2051-2100 and the 1961-2000 climatologies (right column) for March, June, September and December for the SHMI-ECHAM5 model.

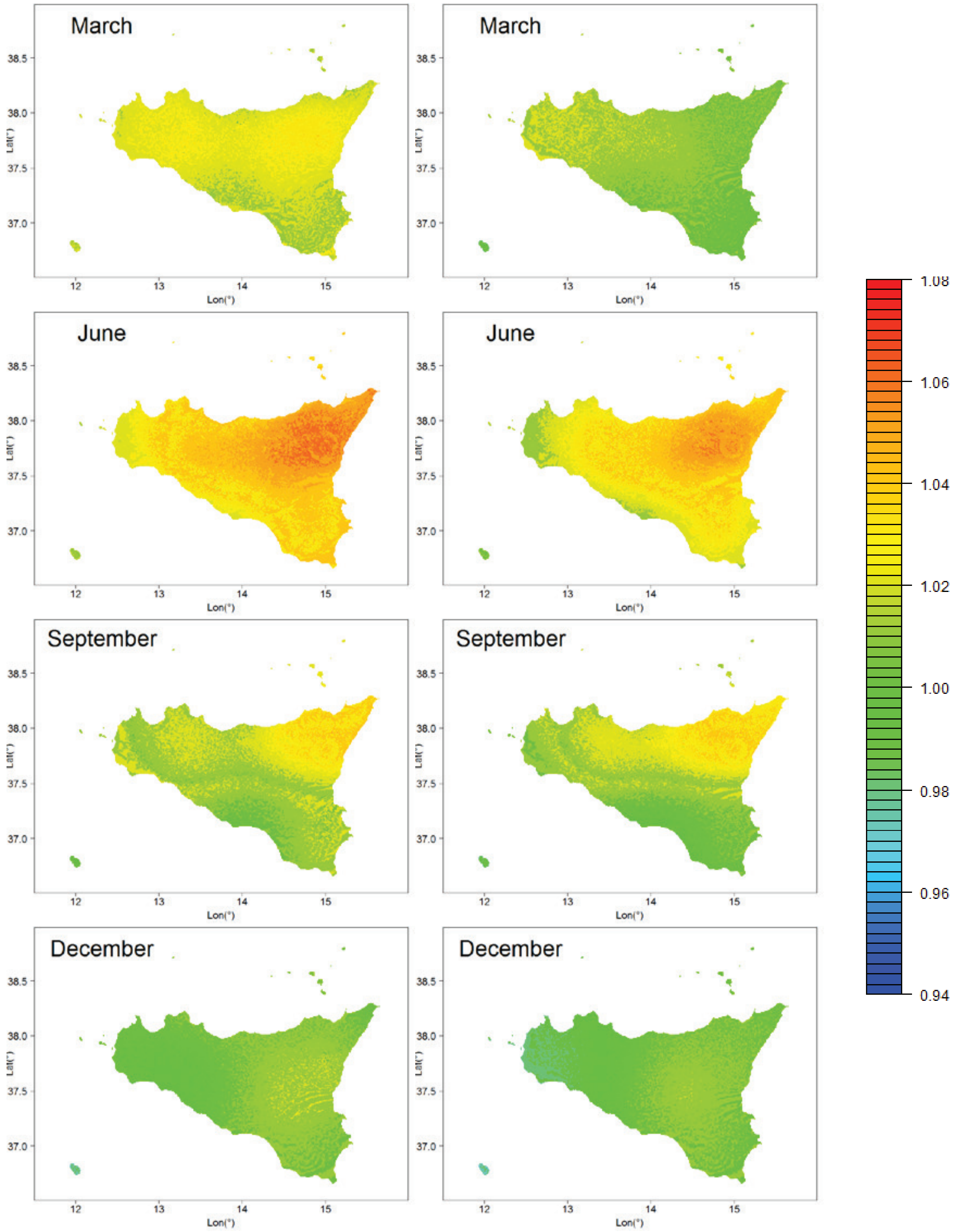

Fig. 5c Ratios between the 2001-2050 and the 1961-2000 climatologies (left column) and ratios between the 2051-2100 and the 1961-2000 climatologies (right column) for March, June, September and December for the SHMI-BCM model.

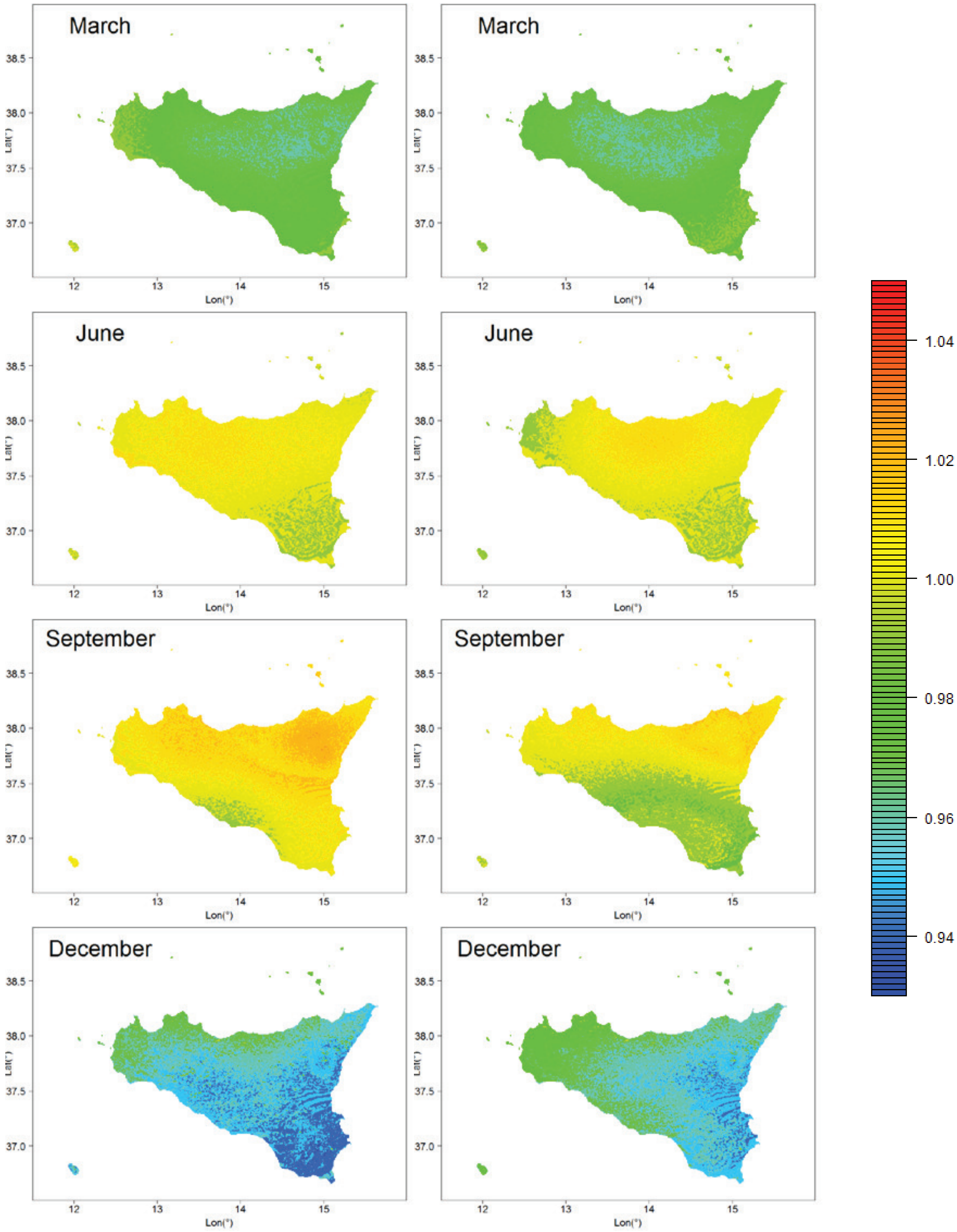

Fig. 5d Ratios between the 2001-2050 and the 1961-2000 climatologies (left column) and ratios between the 2051-2100 and the 1961-2000 climatologies (right column) for March, June, September and December for the SHMI-Had model.