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Inter Annual Variability of Surface Solar Radiation over Iberian Peninsula

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Abstract — In this study, the variability and trends of surface radiation over the Iberian Peninsula using ERA40 reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) are examined. Monthly means of surface incident and net shortwave radiation for 40 years are computed and analyzed. Deviations from the temporal mean for each month and for each year are computed and variations discussed. The relation between the interannual variability of solar radiation over Iberian Peninsula and the cloud cover is analyzed. The trends of surface radiation for each month during the past decades are computed and discussed.

Keywords: Era40; Solar Radiation; Cloud Cover; Iberian Peninsula; Mann-Kendall test;

1 INTRODUCTION

The Climate changes are a top issue all over the world, since it represents a concern related to the socio-economic results that may possibly outcome.

Meanwhile, renewable energy sources are part of the solution for the near future. In particular the solar energy is increasingly becoming a reliable and competitive source of energy.

In recent decades, the scientific community has dedicated some attention to solar radiation and to its variation all over the globe. Examples of the studies carried out may be found in Silva et al (2010) [14], for the Brazilian Northeast, Stjern et al (2009) [17], in Europe, Europez-Lorenzo et al (2009) [13] in the Iberian Peninsula, or Liepert (2002) [5], in United States of America.

It is well known that the most determining factor that shapes the climate of our planet is the solar radiation that reaches the Earth, so any changes will induce modifications on temperature, humidity, rainfall, etc.

According to published studies, between 1950 and mid 80's, there was a decrease of total radiation that reaches the Earth surface, a phenomenon known as "global dimming" (Ohmura and Lang, 1989 [11]; Stanhill and Moreshet, 1992 [16] among others). Later on it was observed the opposite effect - "global brightening" (Wild et al, 2005 [21]). For example, Stjern et al (2009) [17], found, over northern Europe, a considerable decrease in solar radiation at the surface between 1950 and 1980, followed by a slight increase in the subsequent years.

Several attempts have been made in order to explain this observed feature. Changes in the atmospheric aerosol concentrations have been indicated as major agents (eg, Liang et al, 2005 [4] among others), as well as changes in the amount of clouds in the atmosphere (Mace et al, 2006) [7].

Stanhil and Cohen (2001) [19] reported that the aerosols and other air pollutants are a decisive factor. According to Liepert and Tegen (2002) [6] and Norris and Wild (2007) [9], the effect of "Global Brightening" is the result of the effect of aerosols in the atmosphere. Aerosols have the ability to affect directly the solar radiation that reaches the surface of the earth, through the phenomenon of scattering and absorption, or indirectly by modifying the properties and lifetime of the clouds.

Kruger et al (2002) [3] evaluated that about 2% of the planetary albedo was reduced by clouds in Europe, in the late eighties, due to the reduction of aerosols.

Qian et al (2007) [12] suggested that in China, the increase of aerosols in the period 1960 to 1980 was the main factor that led to a decrease in solar radiation in clear sky conditions.

Yang et al (2009) [22] has mentioned that in the period (1965-1999) over the north of China a decrease in sunshine hours was detected and a direct relation between wind speed and aerosols as the dampening effect hour of the "sunshine hour" was proposed.

The study of variations and trends in climatic series (temperature, radiation, clouds, etc.) allows us to check the tendencies over the past and predict possibilities of scenarios for the near future. In this way, the main objective of this work is to study the changes and trends of solar radiation in the Iberian Peninsula and explore its relationship with the clouds using data from the ERA40 re-analysis.

According to Uppala et al. (2005) [18], "the ERA40 reanalysis did not include any aerosol trend or

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temporal variations, due to volcanic eruptions for example, and there was no interaction between its radiation scheme and variable ozone fields. Instead, a fixed geographical distribution of aerosol and a climatological ozone distribution were used for the radiation calculation. Therefore the ERA-40 dataset can not be used in order to investigate the relationship between aerosol and radiation trends".

The work is structured in three parts: section 2 describes the methods, the data and the study area; section 3 presents some results over Europe and Iberia and section 4 summarizes the conclusions.

2 DATA SETS AND METHODS

2.1 Data

The data of radiation and clouds used in this study are the ERA40 reanalysis provided by the European Centre for Medium-Range Weather Forecast (ECMWF), and covers the period from 1957 to 2002 (Uppala et al, 2005) [18]. The ERA40, data can be divided into three periods according to how the data has been acquired:

(1) 1957-1972: Without the presence of satellites;
(2) 1973-1988: Transition period (satellite data have been added);
(3) 1989-2002: Period of satellites.

The radiation data used and their definitions given by the ECMWF are as follows:

a) Surface solar radiation downward (ssrd) corresponds to the incident solar radiation (shortwave);
b) Surface solar radiation (ssr) is the balance of the total radiation;
c) Surface net solar radiation clear sky (ssrc) corresponds to a theoretical parameter which assumed the absence of clouds in the sky;
d) Top solar radiation (tsr) is the total radiation in the upper layerof the atmosphere (shortwave);
e) Top net solar radiation clear sky (tsrc) is a hypothetical field in the absence of clouds in the sky.

The total cloud cover (tcc) data were also obtained from ECMWF for the same period.

In this work we decided to use full years corresponding to a series of 44 years (1958-2001). Monthly means of daily means on a 2.5° × 2.5° resolution grid were used in this work.

2.2 Study Areas

Two domains are considered in this study: Europe and Iberian Peninsula (IP, 35°N-45°N and 10°W-2°E) shown in figure 1.

Trend analysis would focus mainly on IP.

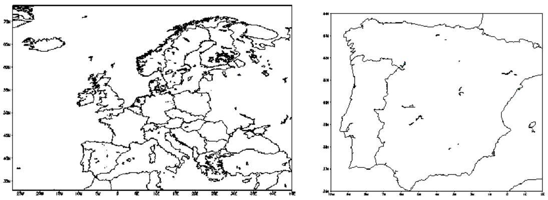


Fig.1: Maps showing the study areas.

2.3 Statistical methods

In order to analyse the annual and monthly trends in the various radiative parameters, the parametric method of least squares and the nonparametric statistical method of Mann-Kendall (Mann, 1945 [8]) were applied.

The method of Mann-Kendall (MK from this point) has been widely used by several authors in meteorological studies. (Silva et al, 2010 [14], N. Obot et al, 2010 [10]; Cislaghi et al, 2005 [1] among others) and is advised by the World Meteorological Organization (WMO).For a series containing a set of observations, the MK test is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_i - x_j) \qquad (1)$$

where:

$$\begin{aligned} sign(x_i - x_j) &= 1 \text{ if } (x_i - x_j) > 0 \\ sign(x_i - x_j) &= -1 \text{ if } (x_i - x_j) < 0 \\ sign(x_i - x_j) &= 0 \text{ if } (x_i - x_j) = 0 \end{aligned} \qquad (2)$$

The statistical value of the test is given by

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sigma} & \text{if S>0} \\ 0 & \text{if S=0} \\ \dfrac{S+1}{\sigma} & \text{if S<0} \end{cases} \qquad (3)$$

A positive value in equation 1 indicates that there is a positive trend in the observations, a very large value of S reveals that the latest observations correspond to higher values than the first, for the same series; on the other hand, if the result of equation 1 gives a negative value, it can be assumed that there is a negative trend.

$$\sigma = \sqrt{\frac{1}{18}\left(n(n-1)(2n+5)\right) - \sum_{p=1}^{q} t_p \left(t_p - 1\right)\left(2t_p + 5\right)} \qquad (4)$$

To test the null hypothesis (H_0), that there are no trends in the series against the alternative hypothesis (H_A), we used the significance level of 5%, being the null hypothesis rejected when $1.96 < Z_{MK} < -1.96$.

The sequential version of MK (with the acquisition of two series - one regressive and other progressive), slightly modified by Sneyers (1975) [15], allow us to determine the point in time when the trend starts and when it becomes meaningful.

The test consists of the sum of a temporal series whose values for the previous terms $(j < i)$ are lower than that $(x_j < x_i)$ and in accordance with:

$$t_n = \sum_{i=1}^{n} m_i \qquad (5)$$

Assuming that there is a trend (null hypothesis is rejected), the series presents a normal distribution and variance given by:

$$E(t_n) = \frac{n(n-1)}{4} \qquad (6)$$

$$VAR(t_n) = \frac{n(n-1)(2n+5)}{72} \qquad (7)$$

The statistical value of series is given by:

$$u(t_n) = \frac{(t_n - E(t_n))}{\sqrt{VAR(t_n)}} \qquad (8)$$

The progressive series is determined from the begin of the series to the end. The regressive series are determined in a similar way from the last term of the series. The series are significant when the values of statistical data exceed the confidence intervals of 5% and the change occurs by the intersection of the progressive/forward line and regressive/backward within the range of 5%. If both series (progressive and regressive) intersect often implies that there are no trends.

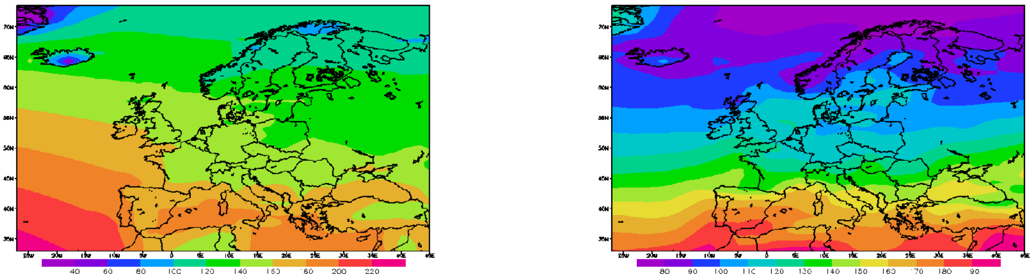
3 RESULTS

3.1 ERA40 radiation and cloud climatology

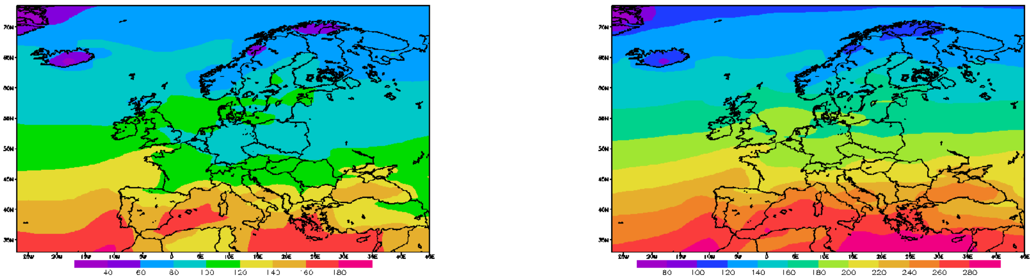
The temporal mean fields over Europe are shown in Figure 2.

The average values of ERA40 radiation fluxes, show higher values at lower latitudes and lower values at higher latitudes, as expected. On the other hand, the mean cloud cover is greater in higher latitudes. In addition to the latitudinal gradients, the figures also show longitudinal variations, namely over the Mediterranean region, where it is possible to see a decrease in cloudiness in contrast to the increase in top solar radiation (tsr), solar surface radiation (ssr) and solar surface radiation downwards (ssrd).

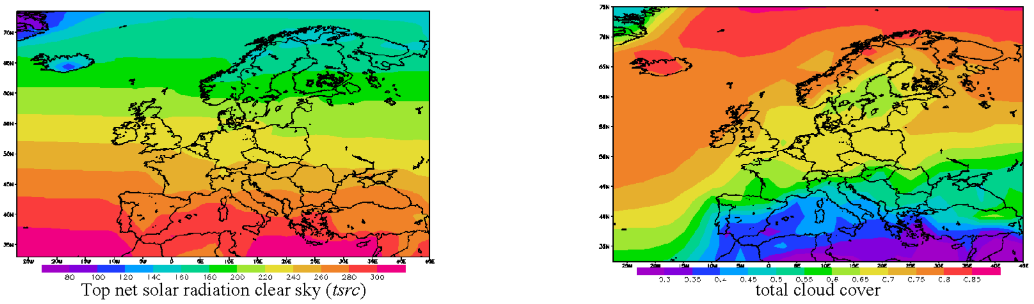
In particular, for solar surface radiation downward (ssrd) it is possible to observe a relative maximum in the southern Iberian Peninsula, particularly in the Algarve (Portugal) and Andalucia (Spain).



Surface net solar radiation clear sky (*ssrc*) Surface solar radiation downward (*ssrd*)



Surface solar radiation (*ssr*) Top solar radiation (*tsr*)



Top net solar radiation clear sky (*tsrc*) total cloud cover

Fig.2: Annual mean values for all radiation and cloud cover parameters in ERA40. All radiation parameters are expressed in W/m^2.

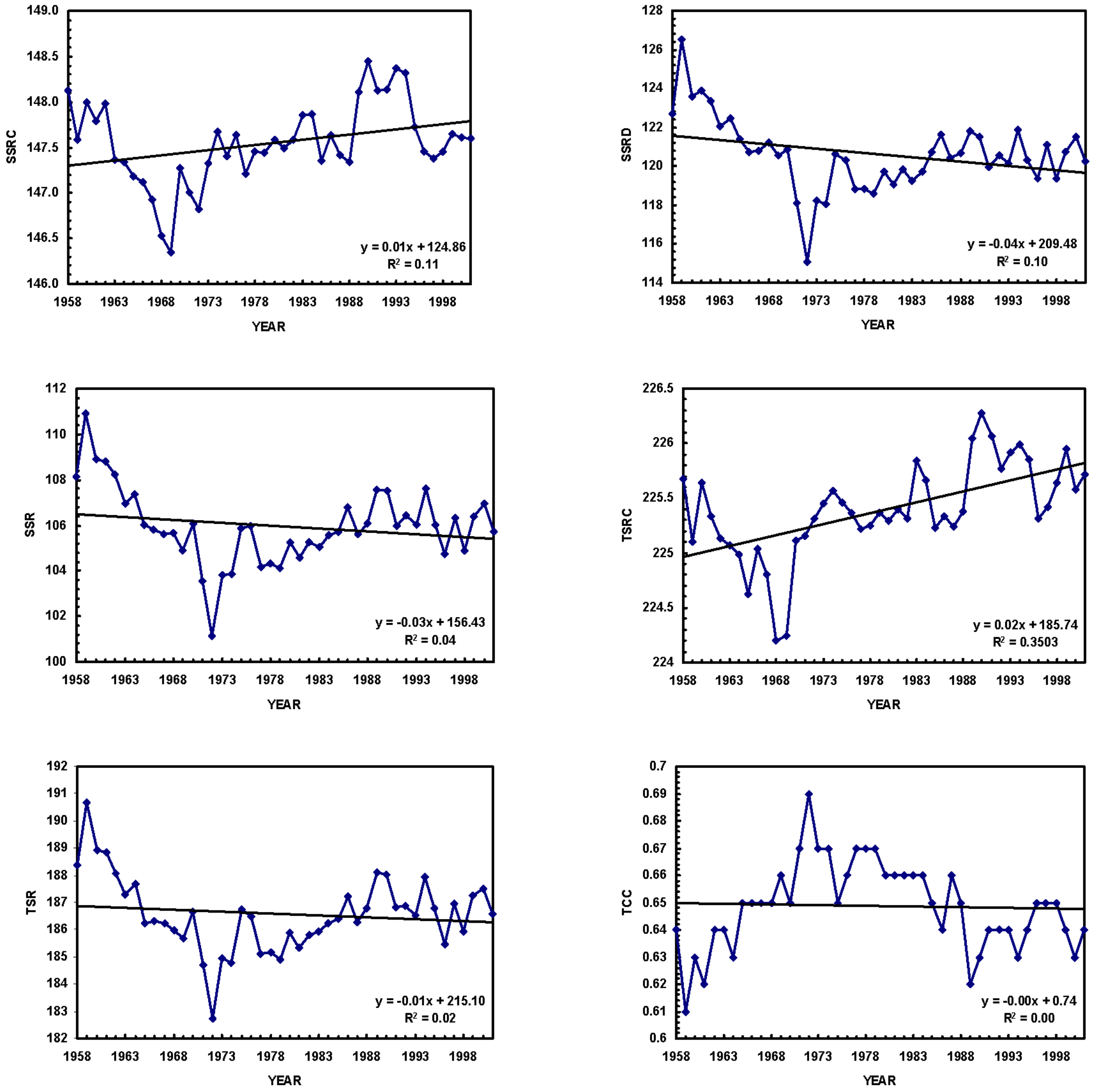


Fig.3: Temporal evolution of Annual mean values of radiation and cloud cover parameters computed in ERA40 (Europe). Radiation parameters are in W/m^2. The line shown is the linear regression fit.

An analysis of the graphs in Fig.3 shows that for the radiative variables there is a decrease by mid-seventies. This is valid for the incident radiation at the surface, as well for the net radiation at the surface and at the top. In contrast, the cloud cover shows an opposite behaviour. The variations in ERA40 are in accordance with those described, for example, in the review paper of Wild (2009) [20].

A statistical analysis using the least squares method, for the entire period of Era40 shows (Fig.3) that there is no tendency in any of the parameters (low values of R^2).

Therefore we applied the statistical MK test to investigate possible trends in ERA40 data. Statistical results are summarized in Table 1.

The graphical version of the MK test has also been applied to the annual mean time series and the results are shown in Figure 4.

The results for the sequential version of MK trend (Figure 4) are statistically significant only for ssrc and tsrc radiation parameters. For the other parameters we don’t find a statistically significant trend since forward and backward lines stay between confidence interval.

Figure 4 shows that there is a decrease of radiation from 1960 and an increase of cloud cover.

Table 1. Statistical analysis parameters of radiation and cloud cover in Europe.

parameter	mean	σ	R^2	Z_{MK}
ssrc	148	0.448	0.107	2.24
ssrd	121	1.861	0.096	-1.69
ssr	106	1.670	0.039	-0.33
tsrc	225	0.434	0.351	4.23
tsr	187	1.371	0.018	0.10
tcc	0.649	0.016	0.000	-0.40

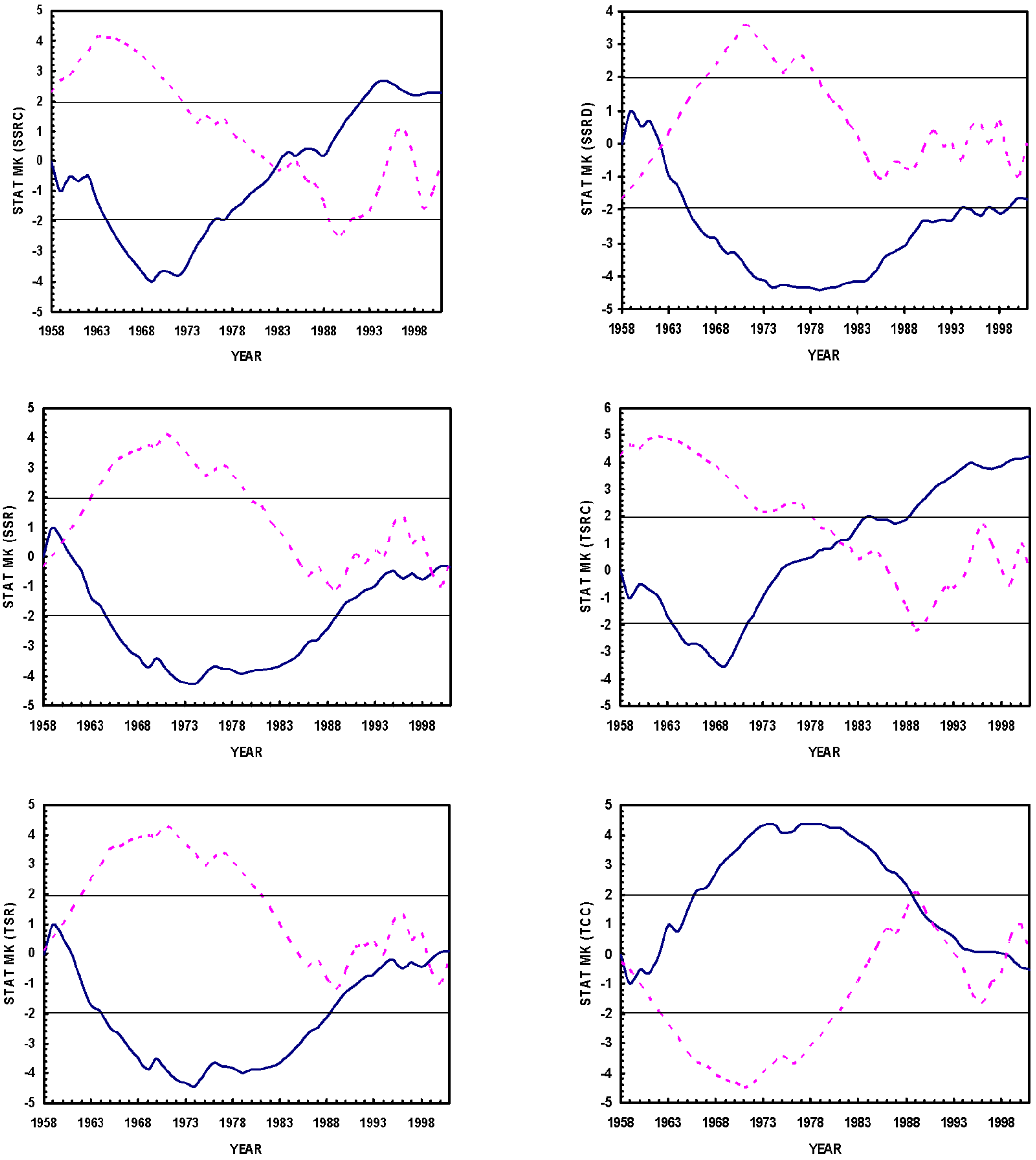


Fig.4 Annual variability and trends for radiation and cloud cover parameters in ERA40 (Europe). The horizontal lines indicate the confidence intervals at 95%. Progressive series is the solid line and backward (regressive) is the dotted line.

3.2 Trends in IP

For IP, as well as for Europe, the least squares method indicates that there are no statistically significant trends for the whole period.

An analysis of figure 5 shows, for all radiative parameters, a decrease until the end of the 80's. Later, it shows an increase of the radiative fluxes. Regarding the cloud cover, the opposite is observed, for IP and Europe. This phenomenon has been identified and it is known as the dimming period (until about 1990) – decreasing of the solar radiation that reaches the surface and the brightening period (after 1990) – increasing of the radiation that reaches the surface. Liepert et al (2002) [6] shows a decrease of the radiation in the United States of America of about 10% between 1960 and 1980.

Table 2 synthesises the statistics for all the parameters (radiation and cloud cover).

Table 2. Results of the analysis by the least square method for the IP annual series.

parameter	mean	σ	R^2	Z_{MK}
ssrc	178	0.288	0.010	0.61
ssrd	165	4.319	0.031	1.39
ssr	145	3.753	0.030	1.26
tsrc	278	0.159	0.168	-1.30
tsr	248	3.025	0.044	-1.55
tcc	0.446	0.034	0.029	-1.31

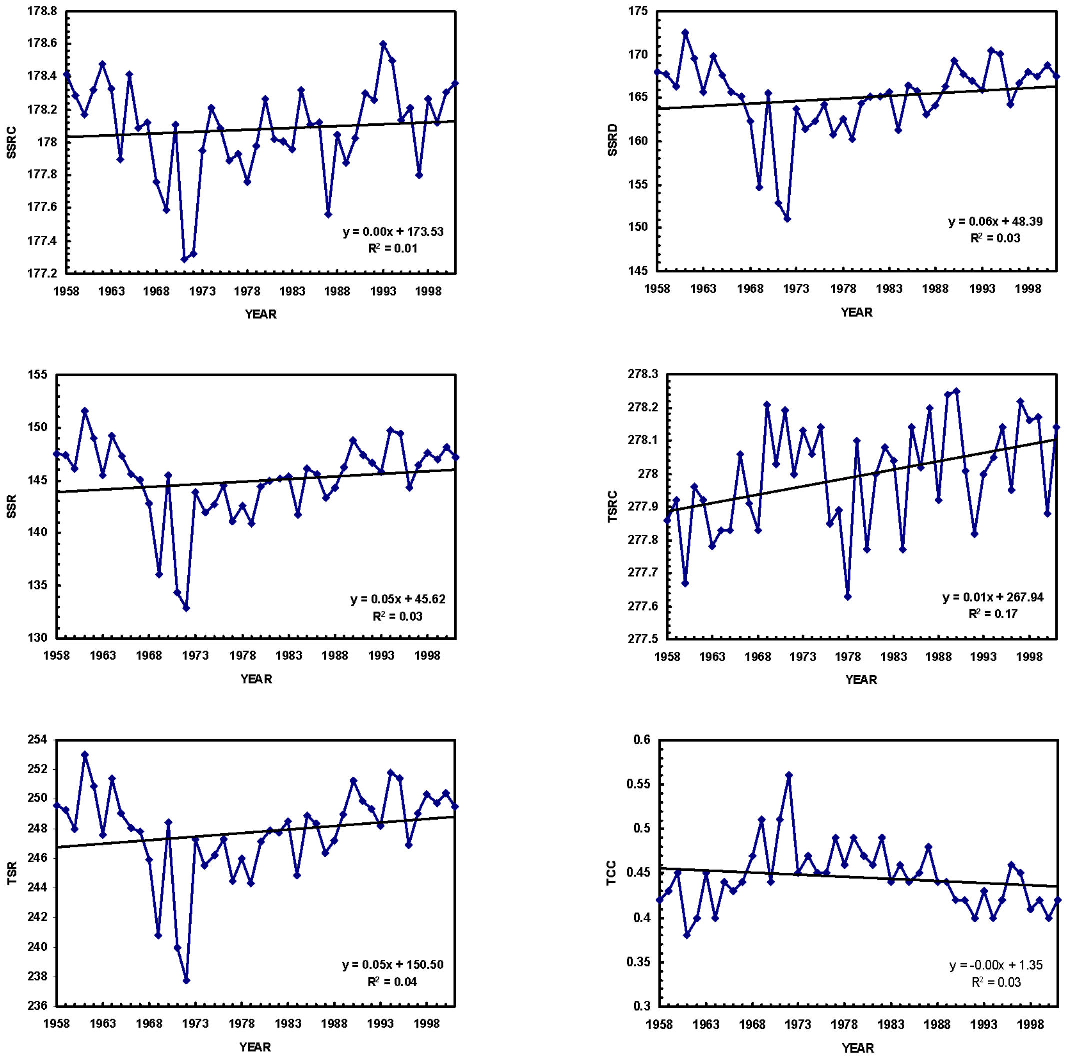


Fig. 5. Trends obtained (linear fit) for the IP's annual series (the radiation's parameters are in W/m^2).

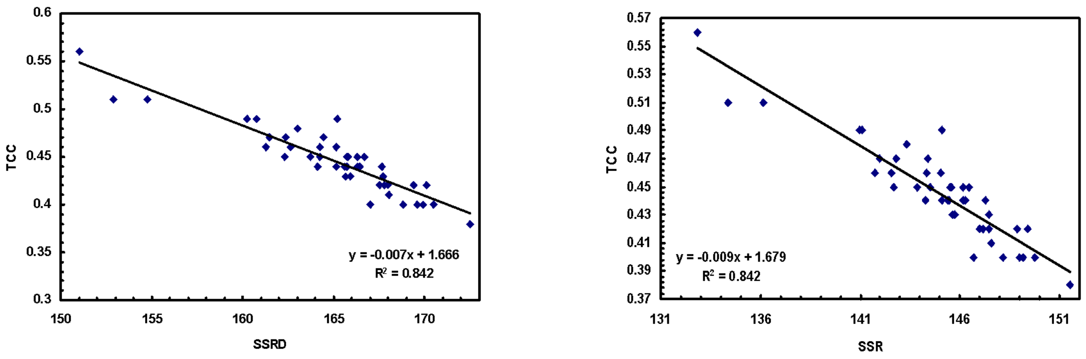


Fig. 6: Annual trends between downward radiation (ssrd), net radiation (ssr) and clouds (tcc) for IP.

When studying the existing relation between the net and the downward radiation at the surface with the clouds, for the research period (1958-2001), the results plotted in the graphs of figure 6 are obtained.

The analysis of fig. 6 clearly shows that the clouds – as we can see in the graphics with a strong tendency – affect the radiation that reaches the surface for all data of ERA40 reanalysis.

Since the analysis of figure 5 with the least squares method don't show significant trends (radiation and clouds), we apply the MK to test the existence of tendencies on IP and, in case they occur, if they are significant and show the same behaviour as for Europe (figure 7).

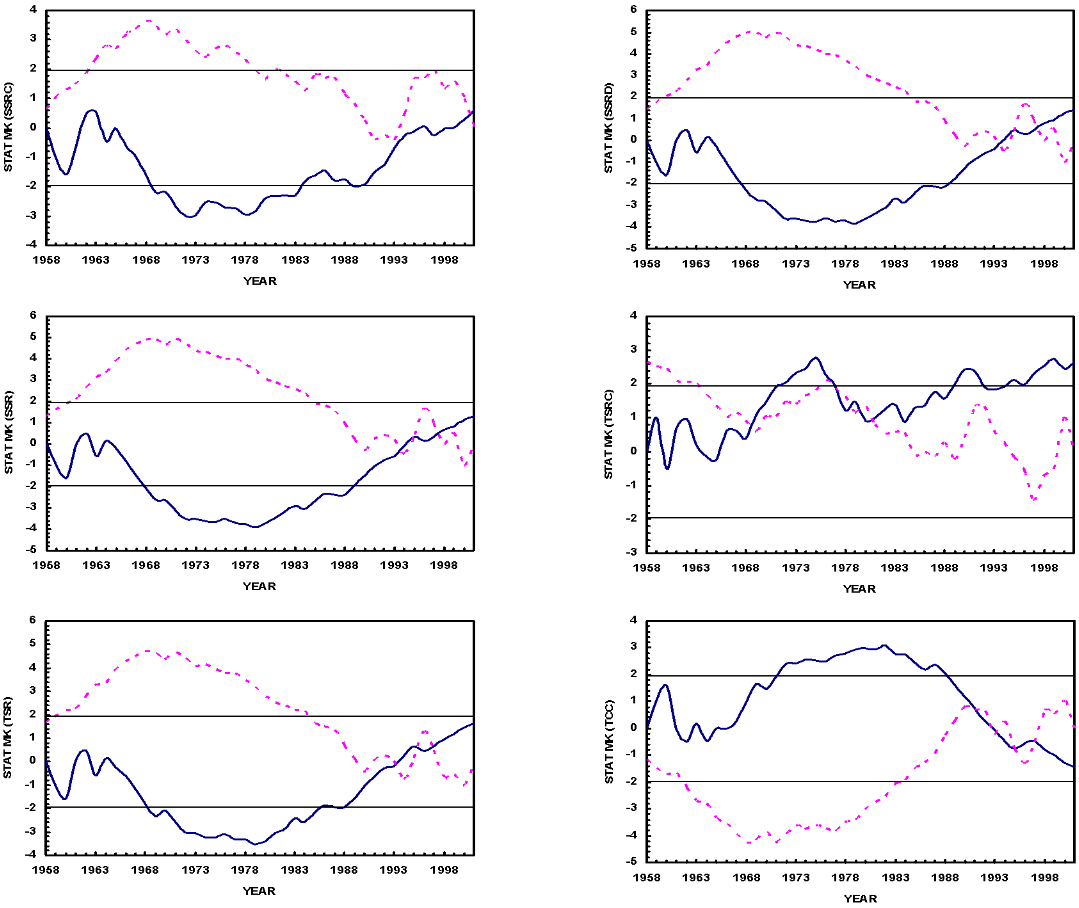


Fig. 7. Obtained trends for the IP annual series. The horizontal lines show the confidence intervals at 95% and the progressive series is the solid line and the backward the dashed line.

This analysis allows us to see that there are no statistically significant tendencies (with the exception of the tsrc parameter). According to the obtained results, the sequential version of the MK method was applied to two separate periods (before and after the 80's). Results are shown in figure 8), 9) and 10).

From the analysis of the graphics it is possible to see that, for the first period (1958-1980), there is a decreasing trend of the downward and net radiation which turns out to be statistically significant from the end of the 60's.

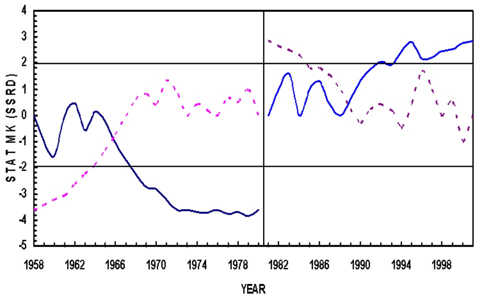


Fig. 8. MK applied on IP for solar surface radiation downward divided in two periods (1958-1980 and 1981-2001). The forward series is the solid line and backward line is the dashed line.

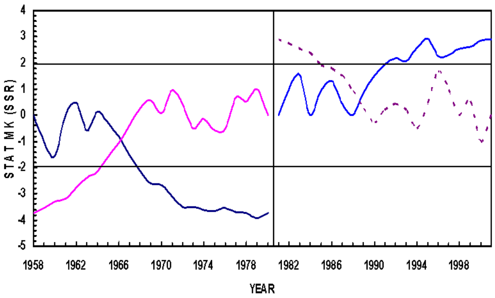


Fig. 9. MK applied on IP for solar surface radiation divided in two periods (1958-1980 and 1981-2001). (Colour lines as in fig.8)

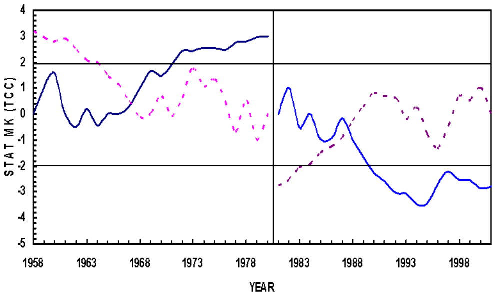


Fig. 10. MK applied on IP for cloud cover divided in two periods. (1958-1980 and 1981-2001). (Colour lines as in fig.8)

On the second period (1981-2002), we see an increase of the radiation from the end of the 80's on, which becomes statistically significant after 1991 for both the radiation parameters. Cloud cover presents an opposite behaviour (fig. 10).

This analysis is consistent with the one made by Stjern et al (2009) [17] for Northern Europe, where the authors observed that, in the majority of the studied seasons, there was a "global dimming" until the end of the 80's.

During the following years, Stjern et al (2009) [17] concluded that the meteorological stations showed an increase of the luminosity.

Silva et al (2010) [14], in a study done for North-eastern Brazil, found that there was a marked reduction on the surface radiation balance, in the period 1948 to 2009, which was explained by the authors as an evidence of the "global dimming" effect.

Changming et al (2010) [2], in China, using the MK method, showed that the direct solar radiation had a significant decrease on the period between 1957 and 2008, while the diffuse radiation increased.

The figures 11), 12) and 13) show the linear fit in the same separate periods. It is possible to observe the trends in radiation (downward and net at surface) and in cloud.

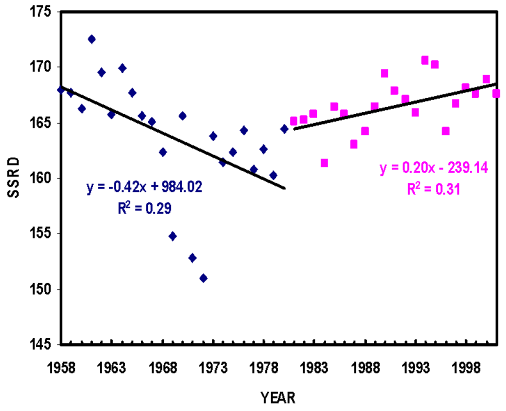


Fig. 11. Linear regression fit for ssrd

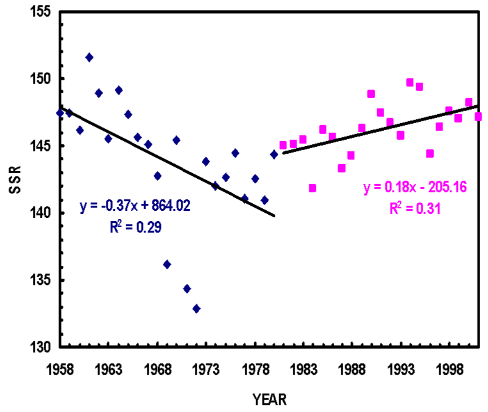


Fig. 12. Linear regression fit for ssr.

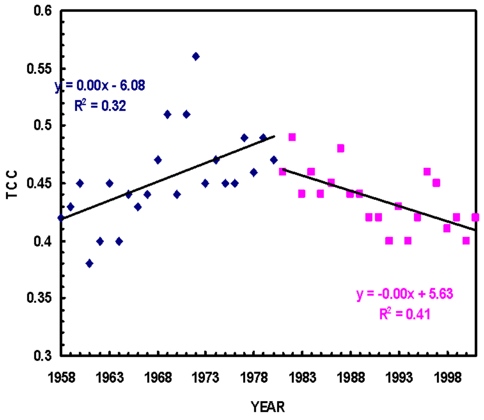


Fig. 13. Linear regression fit for cloud cover (on both periods).

The spatially averaged monthly trends for all parameters were also computed.

Table 3 shows the results of the monthly tendencies, the grey colour indicates the existence of a statistically significant trend and the sign indicates positive (+) or negative (–) trends.

The analysis allows checking that there are common trends in every parameters (radiation and clouds) only in February and March (see figure 14).

Table 3. MK statistical analysis of the monthly averaged variability in the IP. The dark (light) grey indicates the existence of trends with a confidence level of 95% (90%)

	J	F	M	A	M	J	J	A	S	O	N	D
ssrc	+	+	+	+				–		–	–	
ssrd		+	+									
ssr		+	+									
tsrc	+	+	+	+	+			–	–	–		
tsr		+	+									
tcc		–	–		+							

For March, the behaviour is slightly different: the trends became significant from the mid 80's, with ssrd and ssr having a strong increasing tendency from the beginning of the 90's on, tcc presents an opposite behaviour.

The table shows that, for IP, on those two months, there was a significant decrease in the cloud cover and, as a consequence, a significant increase on the shortwave radiation parameters (incoming, surface and top net).

In February, the downward radiation (shortwave) and the net radiation (shortwave) at the surface, shows a decrease in the beginning of the ERA40 period, even though there was a statistically positive trend by the end of the last century

On the other side, the clouds, in the same month, present a reverse tendency (they increased until the end of the last century, becoming significant and with decreasing tendency only after that).

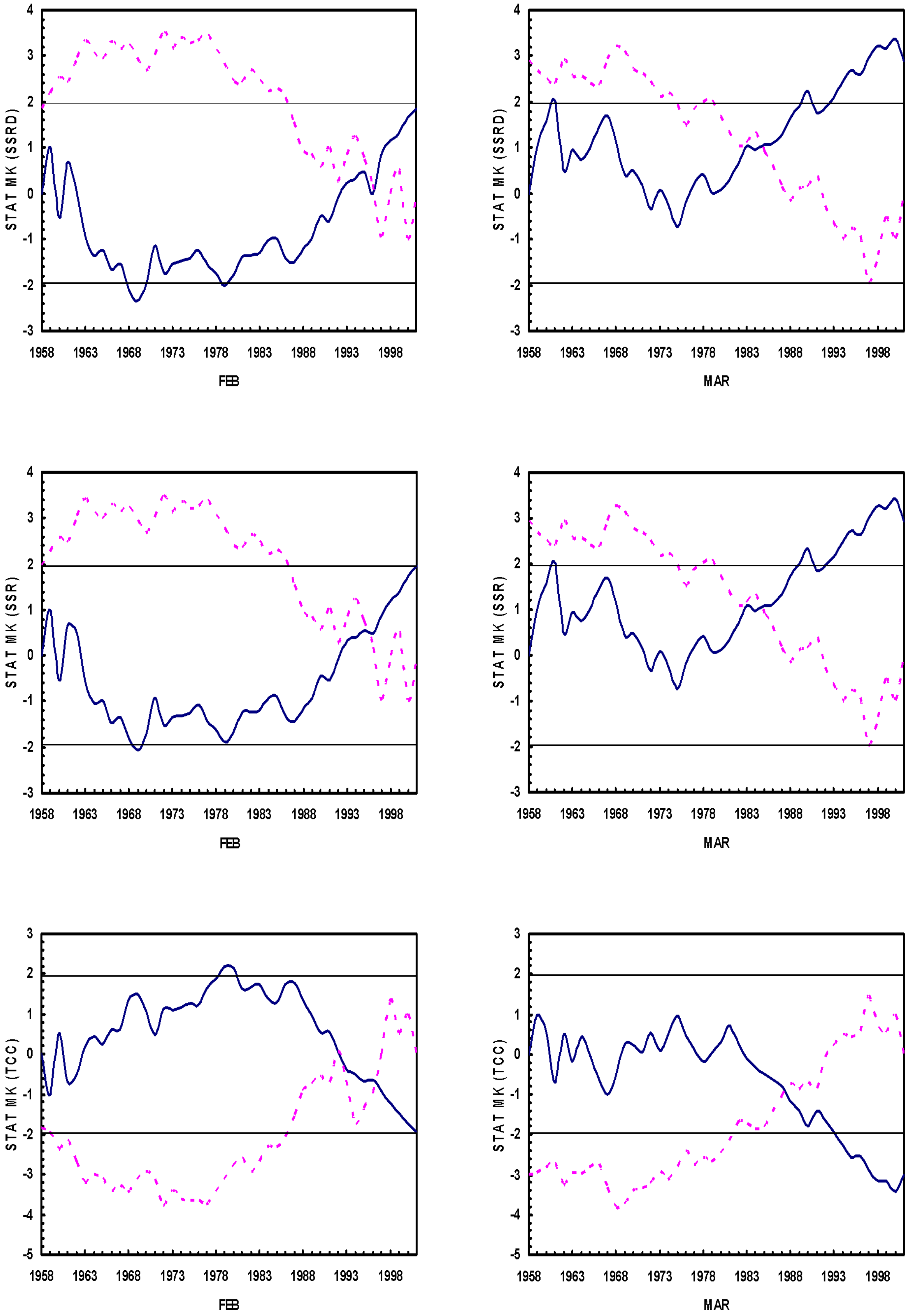


Fig. 14. MK for February and March for IP. Progressive series is the solid line and backward (regressive) is the dotted line.

The standard deviation of the ERA40 monthly means in these two months on IP are plotted in Figures 15 to 17. The analysis will only focus on the three main parameters (downward radiation – ssrd; net radiation at surface – ssr; and the total cloud cover – tcc).

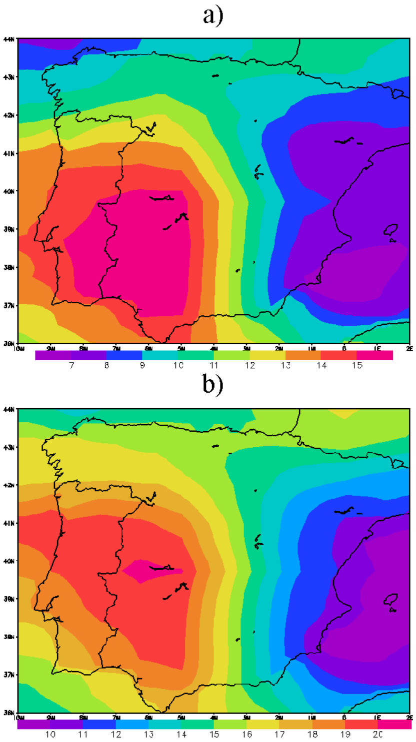


Fig. 15. Standard Deviation for February [a)] and for March [b)] – parameter ssr.

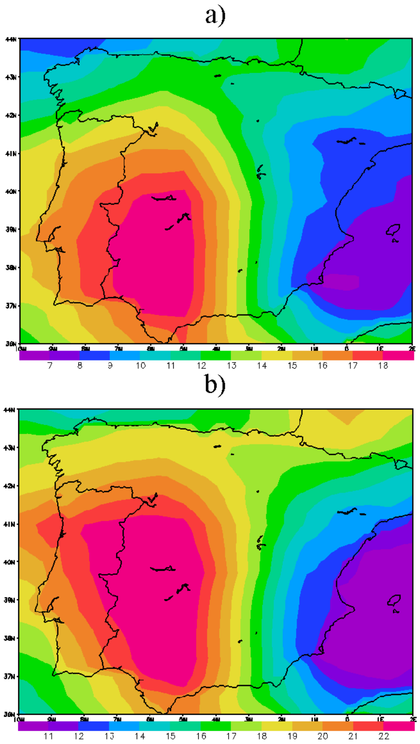


Fig. 16. Standard Deviation for February [a)] and for March [b)] – parameter ssrd.

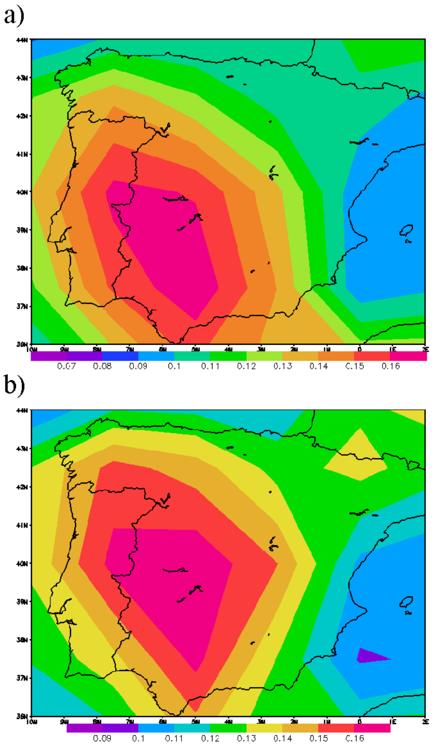


Fig. 17. Standard Deviation for February [a)] and for March [b)] – parameter tcc.

The Figures show that during Era40 period, there is a significant dispersion of about 5% concerning the shortwave radiation parameters (incoming and net) and cloud cover on the months analyzed. Those differences are more evident in Portugal, in the Spanish Extremadura and Andalucia and lack a more careful analysis.

4 CONCLUSIONS

The obtained results are consistent with the studies done by other authors. The main ideas to take out of this work are:

(1) Identification of two different periods in Era40 shortwva radiation dataset;
(2) Decreasing of the shortwave radiation until the middle of the 80's, followed by an increasing;
(3) Increase of the cloud cover during the first period followed by a decrease (around 1990);
(4) Nonexistence of annual linear trends using the least squares method for the radiation and cloud cover parameters in Era40, for Europe and Iberia (Low values of R^2);
(5) Strong statistical linear negative trend between the incident radiation at the surface and the clouds during the considered period of time;
(6) The Mann-Kendal methods revealed that, for IP, there is a statistically strong relation between the radiation and the clouds on the periods (1958-1980) and (1981-2001), especialy on February and March.

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