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Carbon Dioxide Concentration and Emissions in Atmosphere: Trends and Recurrence Plots

Amelia Carolina Sparavigna[1]

[1]Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy

Abstract: The increase of carbon dioxide concentration in atmosphere, due to anthropogenic emissions, is almost generally considered as responsible of global climate changes. Here we show some data of CO_2 concentration and its emission in atmosphere, using the recurrence plots to enhance the visualization of their trends.

Keywords: Carbon dioxide, Environment, Climate, Time series, Recurrence plots, World Bank data

1. Introduction

Carbon dioxide, CO_2, is a gas which is present today in the Earth's atmosphere at a concentration of 0.04 per cent, as given by the monthly average data of the Hawaiian Mauna Loa Observatory [1]. Although a certain amount of this gas occurs naturally, several human activities contribute to its emission in atmosphere. Even breathing and digesting food are producing CO_2, because it is a gas involved in Earth's life cycles, but humans are responsible for high carbon dioxide producing activities, in particular those that include burning fossil fuels. In addition, the use of electricity is producing CO_2 too, because fossil fuels are largely employed in generating it.

Reducing emission of CO_2 can be achieved by a decreasing usage of fossil fuels and by saving electric energy by means of a more efficient use of it. In fact, about one fourth of world electricity is produced for lighting purposes, and therefore the development of new lamps with lower power requirements can help reducing emissions from fossil fuels [2]. Even the Royal Swedish Academy of Sciences has considered this challenge: Nobel Laureates of this year have been awarded because they had invented a new energy-efficient and environment-friendly light source.

Transportation and industrial manufacturing are producing carbon dioxide too; however, in industry, it is the steel and cement production for constructions having the largest impact, because it consumes huge quantities of heat energy to convert raw materials into final products. This is the main reason to have, in the evaluation of carbon dioxide emission of each country [3], the data considering emissions only from the burning of fossil fuels and cement manufacture, but not from deforestation, for instance, or from international shipping and combustion of bunker fuels. These emissions could radically change the ranking of small countries with important ports [3].

Here we show and discuss the trends of CO_2 concentration in atmosphere and of its emissions from some countries. We will use for them the recurrence plots. These plots can represent time series, that is, sequences of data measured at uniform time intervals, with the aim of displaying their recurrences. For instance, if we consider a specific value, we can see when the series under analysis is showing a value arbitrarily close to it again, after some time of divergence. The use of recurrence plots in investigating natural and financial phenomena has been discussed in previous papers (for more details and references, see [4-6]): here we will see how these plots are able to improve the visualization of the trends of some factors involved in the global climate changes.

2. Available data

Carbon dioxide has a relatively small concentration in atmosphere but it is a potent greenhouse gas playing a vital role in the regulation of Earth's surface temperature. In the atmosphere, before the industrial revolution, the photosynthetic organisms, besides other natural phenomena, governed the concentration of this gas. The study of the Antarctic ice cores shows that CO_2 concentration was stable over the past millennium until the early 19th century [7].

Some data about CO_2 are shown in the Figure 1 [1]. In the upper part of the image, the graph is giving the concentration as a function of time, whereas in the lower part we see the corresponding recurrence plot. This plot enhances the growing trend of the curve. The global annual mean CO_2 concentration in atmosphere has increased markedly and it is currently rising at a rate of approximately 2 ppm/year and accelerating [1]. This is clearly shown by the recurrence plot, where colours are narrowing towards the diagonal line. The plot, such as the others shown in this paper, has been obtained with the Visual Recurrence Analysis (VRA), a

✉ d002040@polito.it, amelia.sparavigna@polito.it

software package mainly used for the analysis of nonlinear and chaotic time series [8,9].

Burning of carbon-based fuels since the industrial revolution has rapidly increased carbon dioxide concentration in the atmosphere. At the same time, we have experienced the phenomenon of global warming, which is attributed primarily to this increasing CO_2 concentration. In the Figure 2, upper image, we can see the trend of the global temperature obtained with a traditional analysis using only meteorological station data. The Figure 2 is also showing in the lower image the global mean land-ocean temperature index, from 1880 to present. In both cases, the base period is 1951-1980. The data are given in [10,11]. In the Figure 3, we see the corresponding recurrence plots. We have an increasing trend between 1970 and 2000. Again, in this period, the colours of the recurrence plot are narrowing towards the diagonal line.

To see the link of CO_2 concentration and global warming to the use of fossil fuels, we can also display graphs and plots with oil production and import for some industrialized countries. One example is given in the Figure 4, where we see them for the United States (data are coming from Ref.12). Note how the recurrence plot is enhancing the trend: it seems that, today, this system is becoming oscillating about a stationary level. For what concerns the CO_2 emissions in metric tons per capita of industrialized countries, we can use the data available from the World Bank, a component of the World Bank Group and a member of the United Nations Development Group [13]. This Bank collects and processes large amounts of data, which are gradually been made available to the public [14].

Figure 5 shows the carbon dioxide emissions, produced by burning fossil fuels and manufacturing cement, in metric tons per capita of US, Canada, Italy, Japan, UK and China, from 1960 to 2010. Italy and Japan have a similar behaviour. China has a marked increasing trend in the last years. UK shows a quite interesting behaviour with a decreasing trend on fifty years. In the Figure 6, we have the recurrence plots corresponding to the data shown in Figure 5. Note the plot of China: we have the colours that are narrowing towards the diagonal line, meaning that the trend is increasing and that accelerated in the last years. In the UK recurrence plot we see also a texture transition, about 1980. Texture transitions in recurrence plots have been discussed in Ref.6.

From Figure 5, we see that in 2009, with exception of China, CO_2 emissions from fossil fuels declined. However, with exception of Canada, in 2010 the emissions increased again, and therefore we can argue that the decrease of 2009 was likely caused by the global financial crisis.

3. Discussion

In the Figures 5 and 6, we have per capita emissions. Countries with large populations or with strong economies, or both, are the largest emitting countries of CO_2. However, if we use the data concerning absolute emission levels, we have only a partial understanding of the actual situation. The use of "per capita" emission trends serves to nullify the effect of population growth, because, as the population grows, so does the demand for energy. In this manner, these per capita data are representing the income per capita too, since a wealthier country has higher emissions, linked to a more energy-intensive lifestyle of its people. The best should be the decoupling of progress in lifestyle from the use of fossil fuels.

Today, various technological solutions can be considered suitable for a global market penetration, to have a generation of renewable energy with low CO_2 emissions. Without the use of such energy sources, the annual global CO_2 emission level, potentially, could become about 5% higher than it is today [15], with a consequent catastrophic effect on the global temperature.

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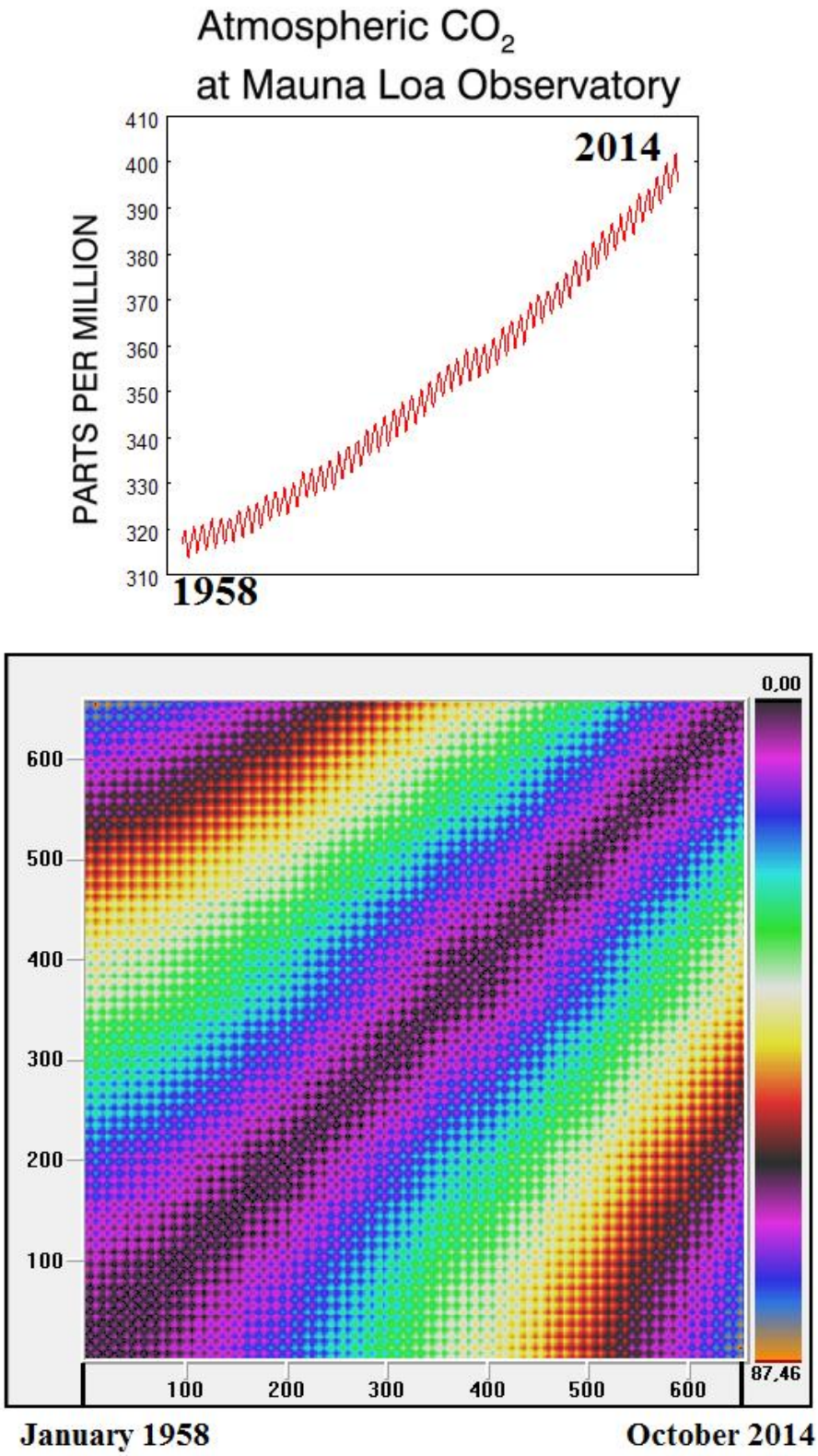

Figure 1 - Data of CO_2 concentration in atmosphere, from [1]. In the upper part of the image, the graph is giving the concentration as a function of time, from January 1958 to October 2014. In the lower part, we see the corresponding recurrence plot. The global annual mean concentration of CO_2 in the atmosphere is currently rising at a rate of approximately 2 ppm/year and accelerating [1]. This acceleration is shown by the recurrence plot, where colours are narrowing towards the diagonal line.

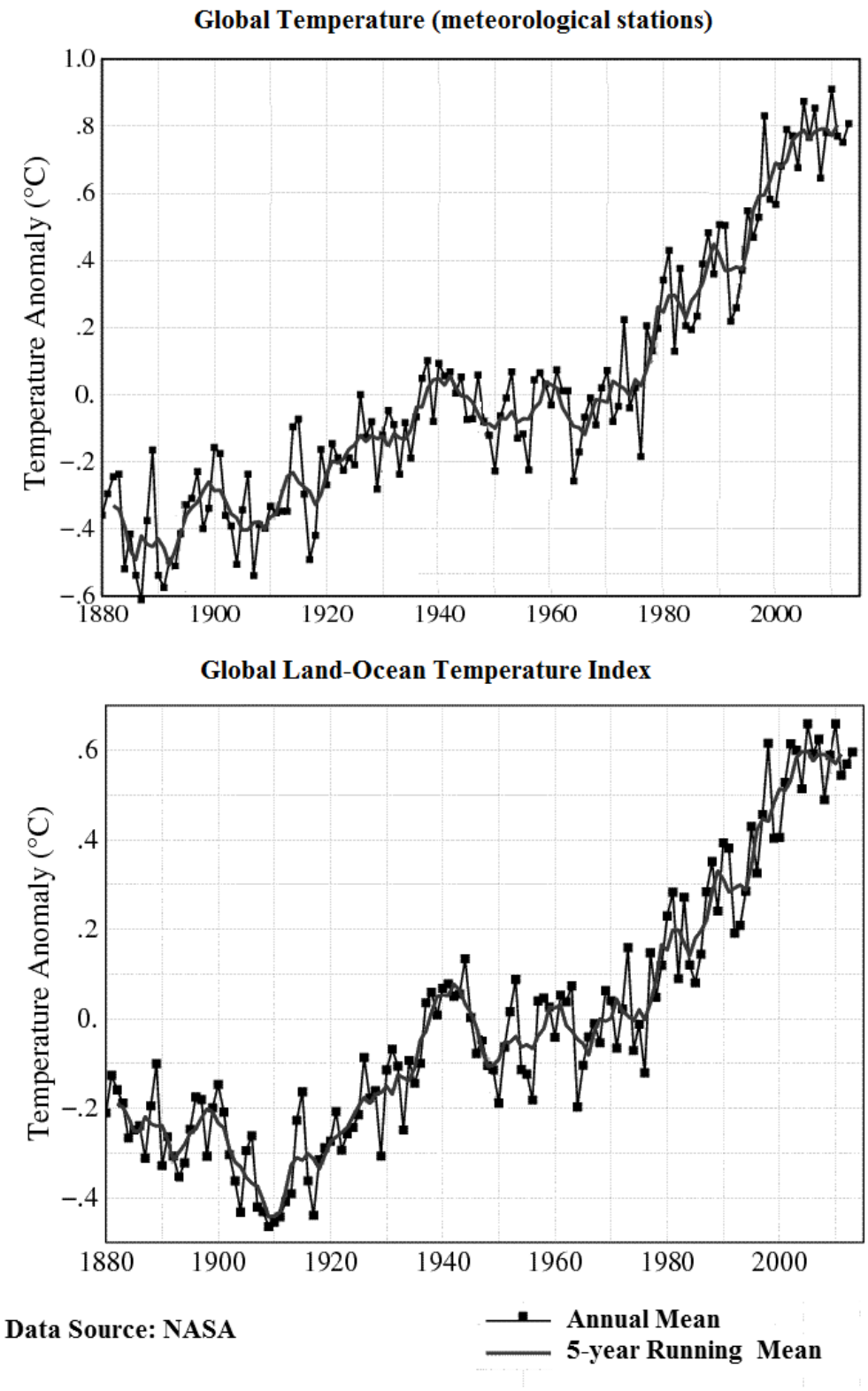

Figure 2 – Here we can see the trend of global temperature, obtained with traditional analysis of meteorological station data, shown in the upper panel. In the lower panel, we see the global mean land-ocean temperature index, from 1880 to present. In both cases, the base period is 1951-1980. The data are coming from [10,11].

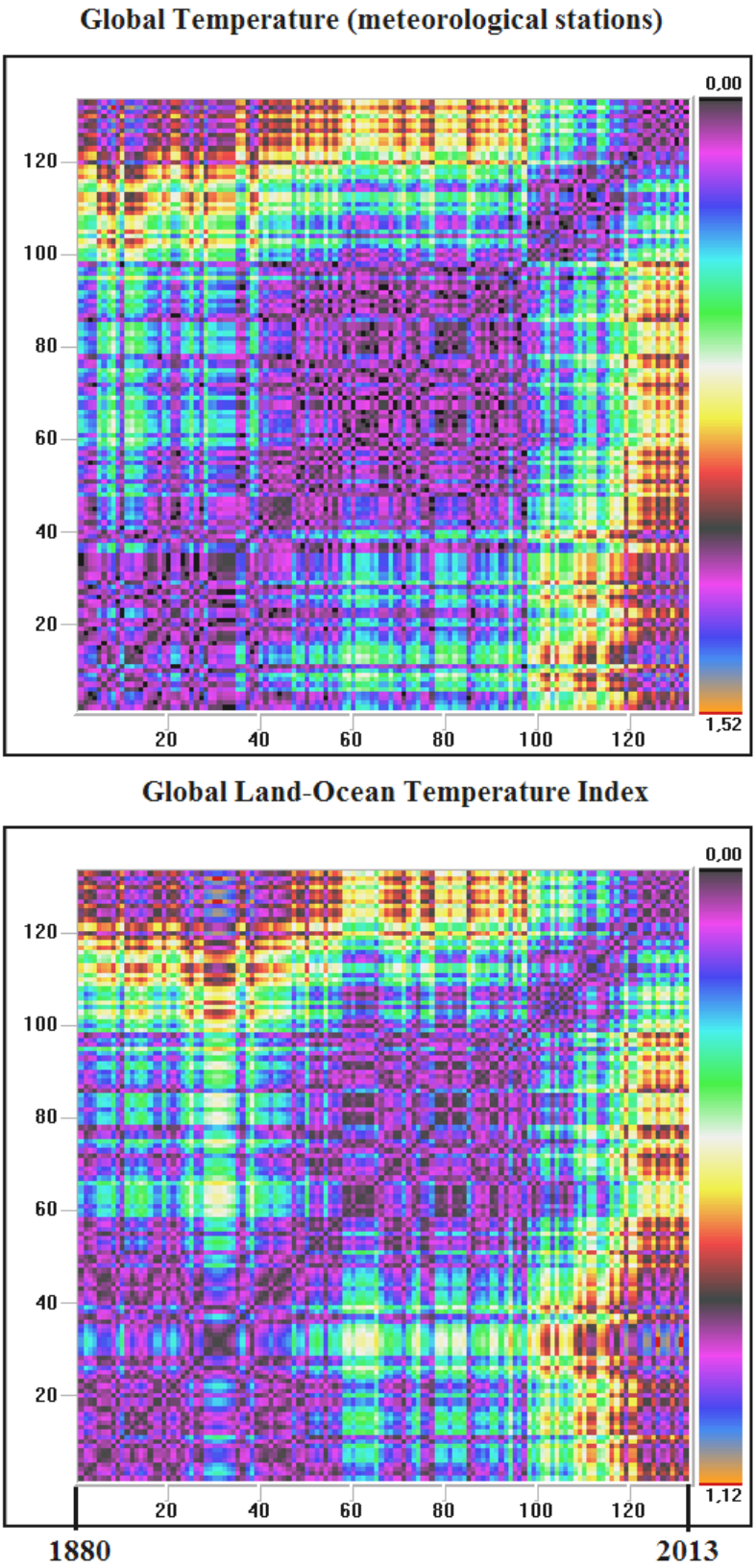

Figure 3 – Here we can see the recurrence plots of data shown in Figure 2. The upper panel corresponds to the meteorological station data, the lower panel to global mean land-ocean temperature index, from 1880 to present [10,11]. The trend is increasing between 1970 and 2000. In this period, the colours are narrowing towards the diagonal line.

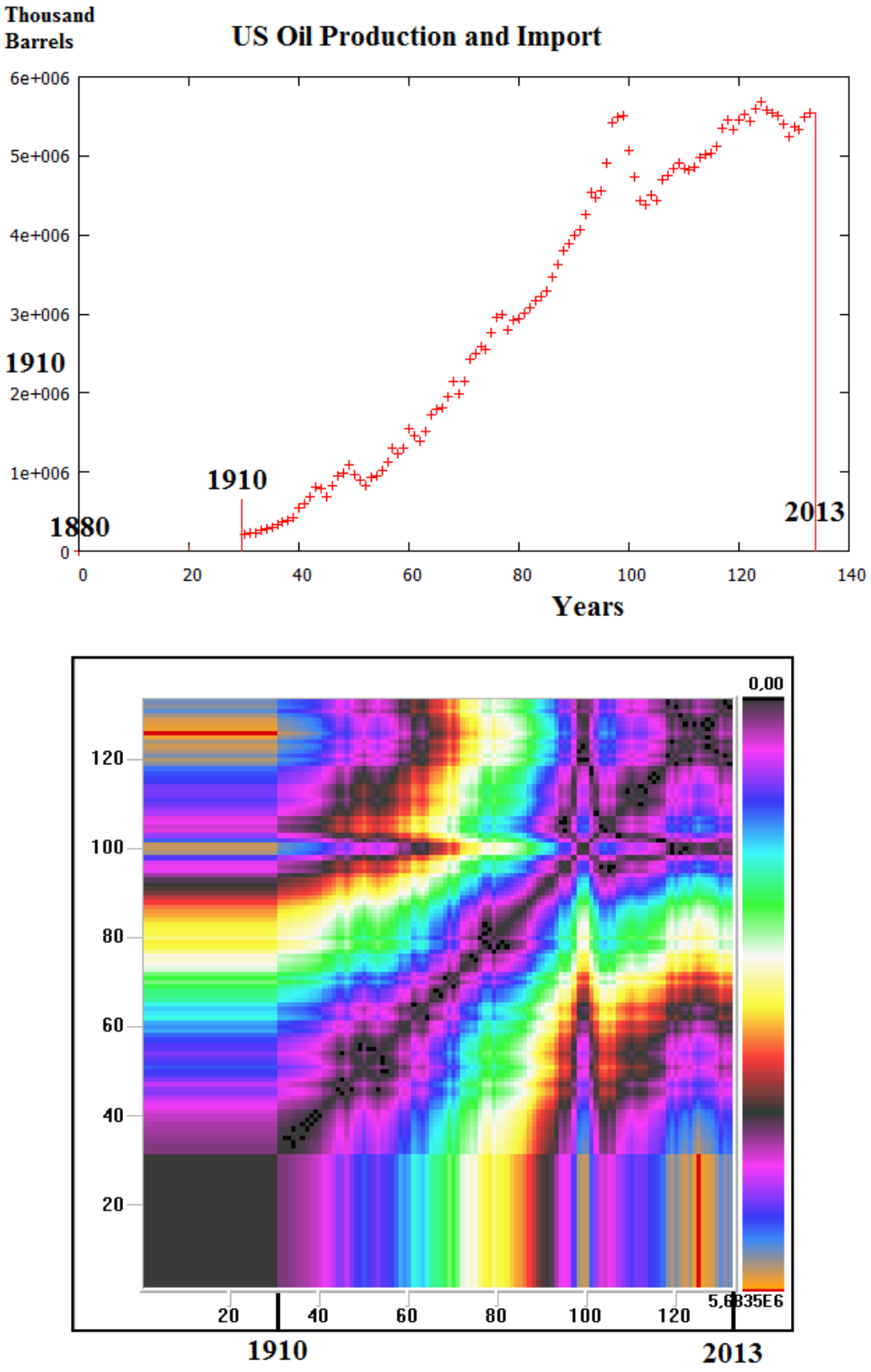

Figure 4 - About 1970, the oil production and import of US had a sharp peak (data from Ref.12). Note how the corresponding recurrence plot evidences this peak.

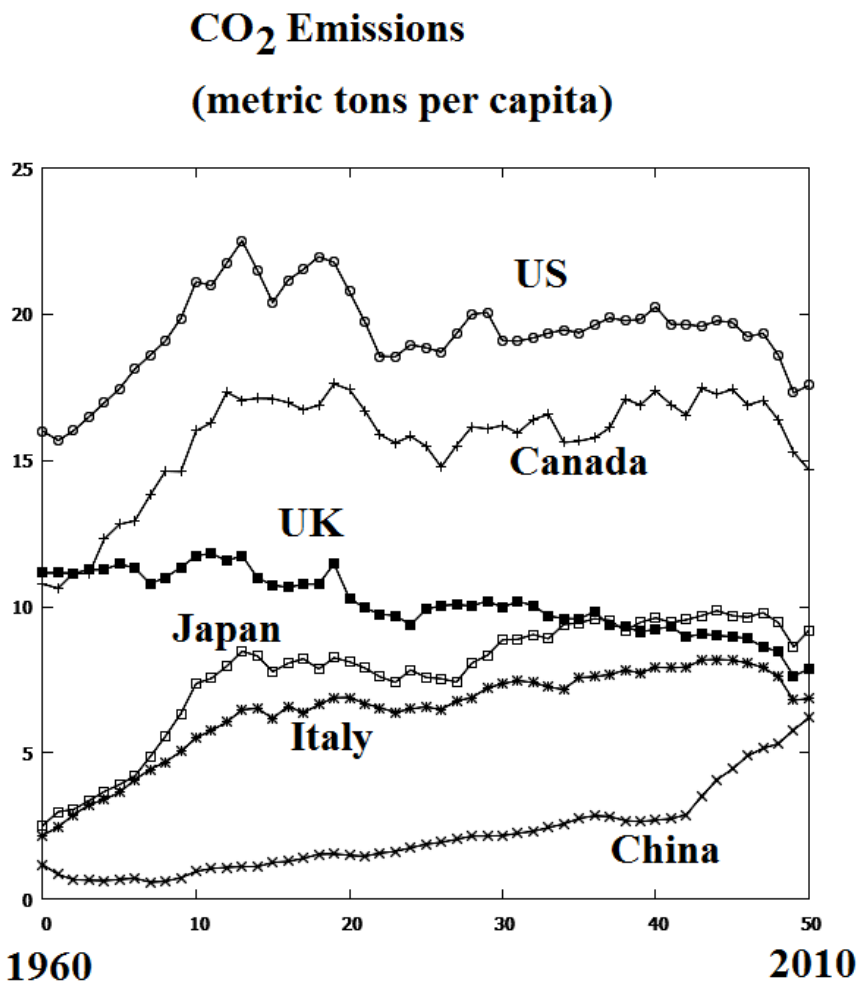

Figure 5 – Here the emissions in metric tons per capita of US, Canada, Italy, Japan, UK and China. The plots are obtained using the data available from the World Bank [13]. This bank is a component of the World Bank Group and a member of the United Nations Development Group. It collects and processes large amounts of data, which are gradually been made available to the public. In the figure, we have data from 1960 to 2010: they are showing the carbon dioxide emissions coming from the burning of fossil fuels and the manufacture of cement, including carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. Note that these are per capita emissions. Italy and Japan have a similar behavior. China has strong increasing trend in the last years. UK shows a quite interesting behavior with a decreasing trend on fifty years.

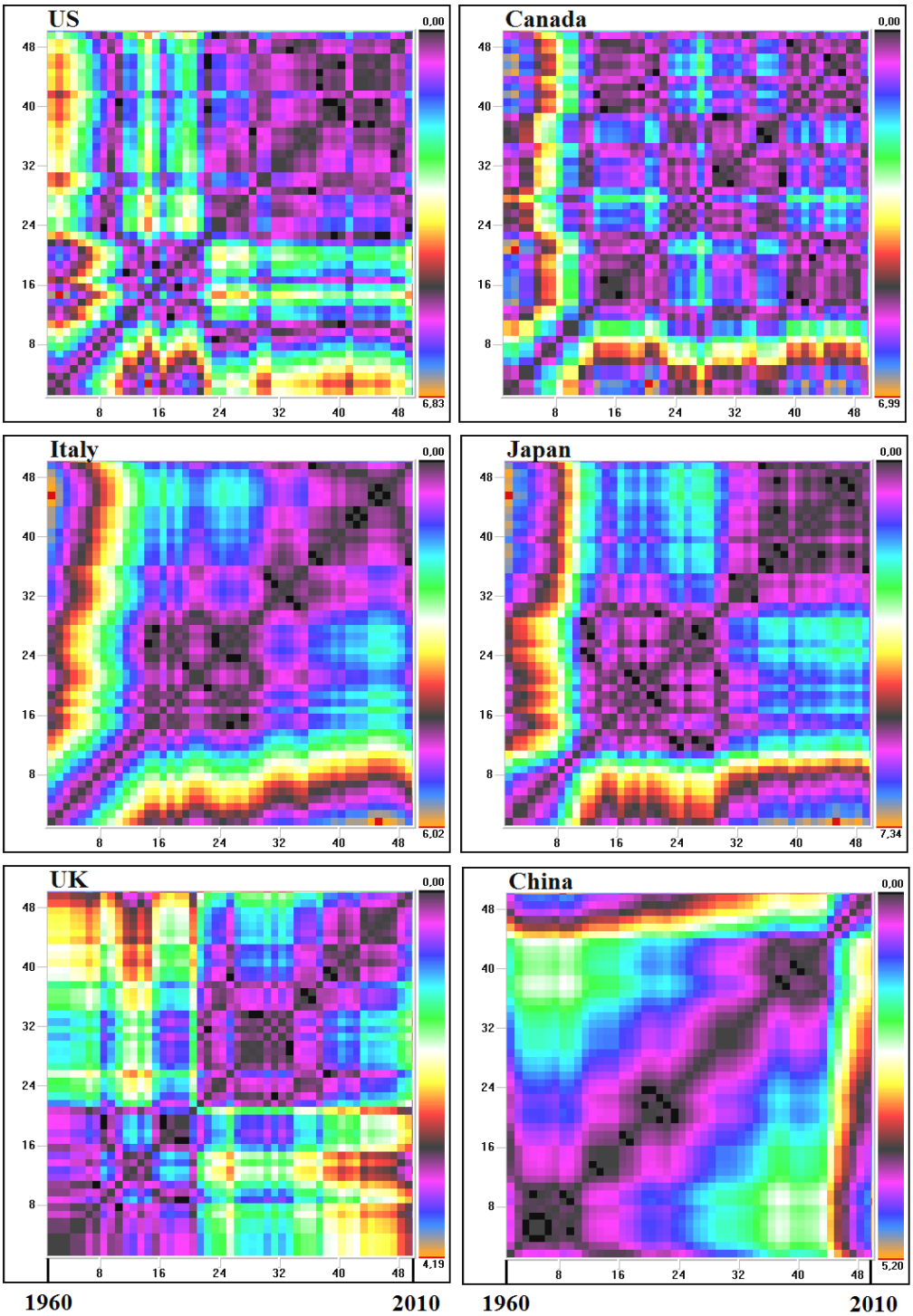

Figure 6 – Here the recurrence plots of data shown in Figure 5. Note the plot of China, which looks like that in Figure 1: we have colours that are narrowing towards the diagonal line, meaning that the increasing trend accelerated. Italy and Japan recurrence plots have a similar behaviour. UK shows a texture transition, about 1980. Texture transitions in recurrence plots have been discussed in Ref.6.