A model component for simulating CO2 emissions growth

Gleb Alexandrov
Russian Academy of Sciences, gleb@ifaran.ru

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Gleb Alexandrov
Russian Academy of Sciences
A.M. Obukhov Institute of Atmospheric Physics
gleb@ifaran.ru

Abstract: Development of comprehensive Earth System models requires a variety of model components related to human feedbacks. Among them are the model components relating energy use to climate change and resource availability. Simulations of the changes in usage of various fuels over the next 25 years are essential for predicting the pathways of CO2 emission reduction needed for climate change mitigation, and considered as a challenging aspect of Earth system modelling (Erickson et al, 2009). Here I present a model component for simulating CO2 emission growth that takes into account the effect of non-renewable resource availability on the rate of consumption and the fact that estimates of available stocks of oil, gas, and coal are changing due to progress in extraction technologies. This model component and numerical tools for fitting model coefficients and model validation were developed using programming language R, an open-source language which is supported by some cloud computing services.

Keywords: limits to growth, logistic growth, carbon dioxide emissions.

1 INTRODUCTION

A number of global environmental problems of societal concern are addressed by Earth system modeling. The creation of an Earth system model traditionally includes development of model components for simulating interconnected physical, chemical processes. The challenge of incorporating human feedbacks has been recognized recently. Discussing the challenges in Earth system modeling, Erickson et al. (2009) said, "Prediction of energy usage and demand as a function of future climate change is a new and evolving aspect of global climate modeling and has a series of complicated and sensitive feedbacks embedded in the science".

According to Allen et al. (2009) if humankind is to limit climate change, then the total cumulative CO2 emission since the start of the Industrial Revolution should be capped. If the total cumulative CO2 emission would be kept at 1000GtC, then peak warming would be limited to 2oC with a 50 percent probability. The total amount of conventional fossil fuel resources is estimated at 1627 GtC, including 323 GtC that has been used, and the reserves of unconventional resources may contain over 1000 GtC (Raupach, 2009). Which part of the total fossil-fuel reserve of more than 2500 GtC would be consumed?

Here I present a model component and software tools for simulating CO2 emission growth which is based on the assumption that cumulative CO2 emission associated with a given type of fossil fuel can be simulated with the model of logistic growth.

2 METHODS

Since fossil fuels are a finite resource, CO2 emissions associated with fossil fuel burning will eventually decline. However, the timing of the peak in the global CO2 emissions is the subject of debate. Here I use the method which is similar to the Hubbert"s method for forecasting oil supply.

Although the methods of this sort are sometimes criticized for neglecting important economic and political variables (Sorrell and Speirs, 2010), it should be taken into account that given "the potential for political, economic, or technological disruptions, no model can provide estimates of great precision" (Miller et al 2014).
To simulate the growth of cumulative CO2 emission resulted from burning fossil fuel of a given type, I use the equation proposed by Meyer (1994):

$$Q(t) = \frac{K}{1 + e^{-\frac{\ln(81)}{\Delta t}(t - t_m)}} \quad (1)$$

where K is the total reserve of this type of fossil fuel, where Δt is the length of the time interval required for $Q(t)$ to grow from 10 to 90% of K, and t_m is the time of achieving the peak in the annual rate of CO_2 emission.

The historical data on CO_2 emissions (Marland et al, 2010) from gas, liquid and solid fossil fuels are used to identify Δt and t_m for given estimate of K. The Gauss-Newton method is used to find the values of Δt and t_m that minimize the root-mean-square deviation of simulated values of cumulative emissions from those reported by Marland et al. (2010). In the case of total CO_2 emissions from all fossil fuels, all coefficients including K are identified from the historical data.

Thus identified values of coefficients depend on the period selected for identification of the model coefficients. For example, coefficients calculated for the period ended in 2000 suggest much higher peak value of total annual emissions than the coefficients calculated for the period ended in 2010 (Figure 4). This fact can be interpreted as an indication of political, economic or technological changes that manifest itself in the curve of emission growth.

3 RESULTS

The software tool for simulating CO_2 emission growth needs the type of fossil fuel, the estimate of the fossil fuel reserve, and the final year of the period selected for identification of the model coefficients to simulate annual CO_2 emissions. The followings types of the fossil fuel could be used as the valid values for this input variable: 'gas', 'liquid', 'solid', and 'total'. If the estimate of the fossil fuel reserve is set at negative number by mistake, the value of K is identified from the historical data. The negative number can be also set at negative number intentionally, if the user would like to identify K from the historical data.

The output of the software tool is illustrated with Figures 1-4.

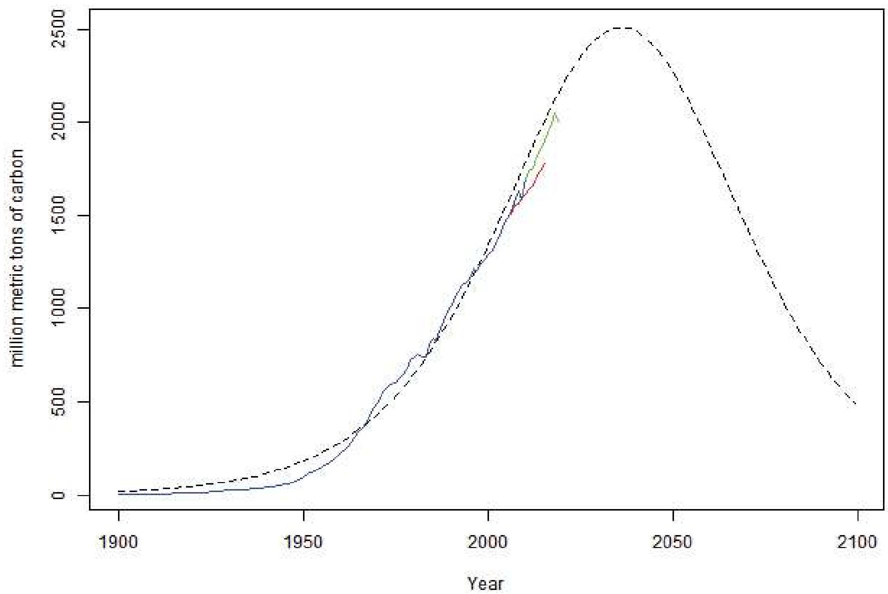

Figure 1. Annual CO_2 emissions from burning gas fossil-fuels: blue line – historical data; black dashed line – simulated by the software tool based on historical data for the period until 2010 (i.e., using the data reported for the period ended 2010 for identifying the model coefficients), red line- ARIMA prediction based on historical data for the period until 2005, green line is ARIMA prediction based on historical data for the period until 2010. Units: MtC/y

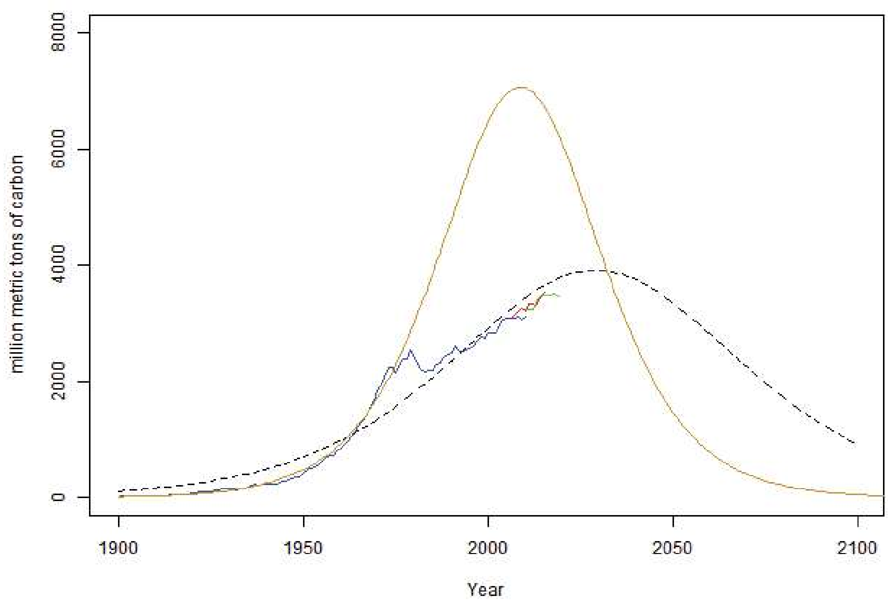

Figure 2. Annual CO_2 emissions from burning liquids fossil-fuels: blue line – historical data; black dashed line – simulated by the software tool based on historical data for the period until 2010 (i.e., using the data reported for the period ended 2010 for identifying the model coefficients), yellow line – simulated by the software tool based on historical data for the period until 1980, red line- ARIMA prediction based on historical data for the period until 2005, green line is ARIMA prediction based on historical data for the period until 2010. Units: MtC/y

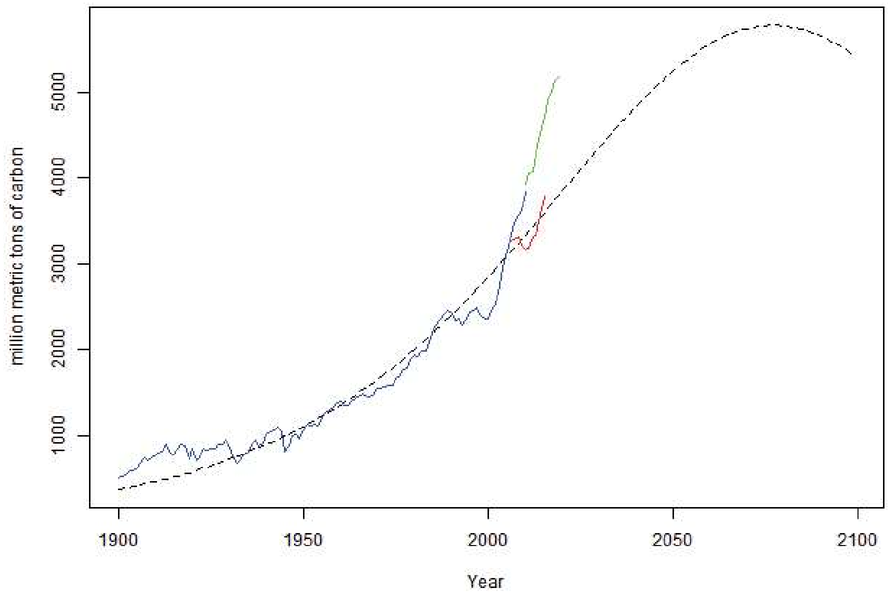

Figure 3. Annual CO_2 emissions from burning solids fossil-fuels: blue line – historical data; black dashed line – simulated by the software tool based on historical data for the period until 2010 (i.e., using the data reported for the period ended 2010 for identifying the model coefficients), red line- ARIMA prediction based on historical data for the period until 2005, green line is ARIMA prediction based on historical data for the period until 2010. Units: MtC/y

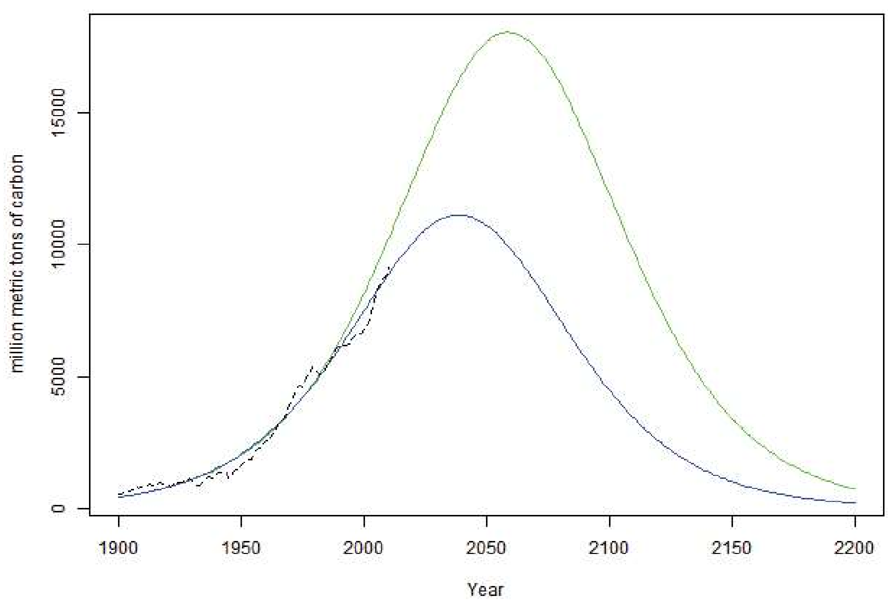

Figure 4. Annual CO_2 emissions from burning all fossil-fuels: black dashed line – historical data; green line – simulated by the software tool based on historical data for the period until 2000, blue line – simulated by the software tool based on historical data for the period until 2010 Units: MtC/y

4 CONCLUSIONS

The R language is an open–source functional programming language offered by cloud computing services (e.g., by Amazon Web Services), which is being increasingly used for data analysis. The software tool presented in this paper is designed for analyzing the historical data on CO_2 emissions and coming to conclusions about the timing of the peak in the global CO_2 emissions and the amount of CO_2 that will be totally emitted due to fossil fuel burning. The conclusions could be updated every year reflecting the changes in the tendencies of world development. For example, the historical data prior to 2000 imply that the amount of CO_2 that will be totally emitted due to fossil fuel burning will be as high as 2300 GtC, whereas the historical data prior to 2010 imply that this amount will not exceed 1400 GtC. The results of such analysis should be supported by a detailed analysis of economic and political trends, but nevertheless, discovering the tendencies from the data is essential for detecting possible changes in the trends.

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