Complexity in action: the Anthropocene

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Abstract

The framework of complexity is a most appropriate one to understand the Anthropocene concept. After some general considerations on the role of man as a vector for landscape and climate changes, the main features of complex systems are identified in the relationship between man and nature, yielding a thorough justification via complexity theory for the introduction of an Anthropocene baseline in the geological registers. [2]

Key Words: Anthropocene, Climate, Complexity, Landscape.

1. Introduction

Triggered by the well know program started by the Nobel prize winner for Chemistry Paul Crutzen, the current debate on the Anthopocene is a crossroad of disciplines, scientific or not, viewpoints and experiences (Crutzen 2002, Zalasiewicz *et al.* 2008, Schwägerl 2010).

Due to centrifugal forces towards academic and scientific areas pretending to master the most adequate intellectual tools for that purpose, no clear-cut definition of the Anthropocene has as yet been obtained, though integrative attempts are under way stressing the importance and interest of this initially scientific question: so many standpoints and working habits are indeed a mark of complexity. To the naïve observer, Nature is an extremely complex system, and science has historically split it study into a few more or less conventionally chosen subsystems in order to obtain families of manageable models, with the aim of describing, classifying, and predicting in their corresponding areas. Hopefully, a certain number of such models may be assembled together, in order to mimic ever growing parts of actual global natural processes. The Gaia hypothesis formulated by Lovelock and Margulis is one of them (Lovelock 1990). Here emphasis will be concentrated only on the Earth climate, encompassing both physical and chemical energy budget considerations, and accounts of the not always peaceful relationship between man and nature, where social, political, and cultural matters play prominent roles (Oreskes 2004; Gramelsberger and Feichtel 2011).

Climate is one of those Nature subsystems, a very complex one extending over a continuum of temporal and spatial scales, driven by feedback loops connecting its various components, *i.e.* the atmosphere, the oceans, the polar icecaps, and others (Edwards 2010). For Mankind, abrupt or critical episodes showing that natural energy forms cannot be harnessed at man's will are of foremost interest, and they should foster the emergence of joint efforts to obtain a better understanding between Nature and man (Terceiro 2007, Sinn 2008).

Climate natural variation time scales are defined by astronomical cycles acting as long wave carriers for shorter waves of physical interest as well as other near random evolutionary patterns due to biogeochemical outbursts, mainly from volcanoes and earthquakes

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dramatically affecting a number of physical and chemical equilibria on which the overall energy budget depend. The role of the ocean is a key one: first, as buffer for greenhouse gases; second, as record-keeper of past atmospheric surface events stored in the thermocline; third, as temperature stabiliser through the larger thermal inertia of sea water as compared with air. From an extreme point of view, there are even scientists who actually believe that the atmosphere is just a slave system of the world ocean (Feistel and Ebeling 2013).

The concept of a complex system itself is an old one and may be tracked back to the pioneering efforts of Quételet and Comte in the social sciences, where an emergent feature, *l'homme moyen*, marked the starting point for many future developments (Comte 1830, Quételet 1835, Pacheco 2008). In the mathematical sciences, complexity appeared for the first time in classical problems of celestial mechanics addressed in the work of Poincaré and others, although without any particular name. No universally accepted definition is at hand, but the word "complexity" became commonplace in Computer Science in the study of program lengths and computation times, with such popular acceptance that it evolved into an omnibus used by scientists and scholars in many branches with various meanings and interpretations. A comprehensive reference for the ideas expounded in this paragraph is Mainzer 2007.

In any case, the following features are always identified in complex systems and provide a useful framework for further reflection and study:

- *Highly nonlinear* behaviour, representing of *feedbacks* of many different types.
- Activity extending over *a broad range of scales*.
- *Criticality*, or *non-smoothness* in the dependence of some variables on key parameters.
- *Emergence* obtained through *integrative* processes.

The rest of the paper will emphasise on several points of interest showing how the complexity framework is an adequate one to shape the Athropocene concept.

2. Assessing complexity in the relationships between man, landscape, and climate

Although it is doubtful whether he would have written these words in our days, the Portuguese Nobel prize winner for literature José Saramago once wrote that "*O que mais há na terra é paisagem*", the most abundant thing on Earth is landscape. These are the very first words of his novel *Risen from the ground* (Saramago, 1980). Closely related to climate, landscapes may be roughly and locally defined as the sensible result of climate action on the superficial layers of the Earth surface, so they change according to various time and space scales: atmospheric and water composition, glaciers, biota, evolve in a natural way entrained by weather and climate waves. Nevertheless, man also plays a distinctive role in shaping landscapes, and at human scales (decennia, a few kilometres) variations may be observed not only in biotic features, but also in geological ones, such as avalanches, and sedimentation in rivers and lakes, and many others (Schama 1995).

In our days we are so used to the availability of all sorts of data that it is easy to forget that in some fields their reliability is restricted, in the best case, to a few decades backwards in time, and that unskilled manipulation of the data can easily yield erroneous conclusions (Foster and Rahmstorf 2011, Roper 2006). In the fields of Meteorology and Climatology reconstruction techniques provide information whose quality is continuously checked and improved, but taking into account proxies not directly translatable into numerical measures is still a need in scientific progress. Lord Kelvin is credited for having stated that only quantitative science is real science: "*I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it*", in *Popular Lectures and Addresses* (1889), Vol. 1, 80-81; nevertheless his estimation of the Earth age was wrong by two orders of magnitude. Therefore, in climate affairs a study of landscape, a classical topic for artists of all sorts, provides an excellent proxy candidate for obtaining some interesting guidelines in reconstructions of climate prior to the instrumental age: depleted woods along rail- and waterways during the prime of steam engines are well known examples. Now we are aware that most of that wood went into the atmosphere as carbon dioxide, but before the discovery of greenhouse gases at the end of the 19th Century, sensible signals of some ongoing change were not provided by chemical measurements, rather they could be read in the disrupted landscape (Arrhenius 1896, Arrow *et al.* 2004, Archer and Pierrehumbert 2011). Gabriel García Márquez in his 1985 novel *Love in the time of Cholera* (García Márquez 1985) provides vivid descriptions of the banks of the Magdalena river in Colombia. See also large parts of the recent book by Von Storch and Krauß 2013.

At medium-range scales, mountains and valleys seem to be stable features, offering a reference frame for geographers, historians and other scholars. However, things are not so easy: the majority of riverine and coastal areas, affected by man for millennia, present fragile and non-resilient enough landscapes, even if human actions took place for very short periods, especially when supported by technological knowledge of various classes. Therefore, although man is a rather recent creature on Earth, it is a most conspicuous element in landscape shaping. Supposedly natural landscapes, *e.g.* the African savannah, actually are the result of human actions: even though the number of people involved in the process could not be too large, the use of some technologies, as well as preserving, transmitting, and improving them, maybe in the sense of Dawkins' *memes* are responsible of the final result (Dawkins 1976). The ability to control fires and to breed livestock are at the origin of the savannah, and modern landscapes shaped by extensive agricultural practices share with it the common status of being deliberate interventions in the cycle of natural succession.

Larger, organised human groups are much more effective in leaving imprints extending over the years. These groups we know as societies: they are complex systems driven by many ***feedback loops*** ruling their internal organisation, or relating them with the environment and other societies. They are ***emergent*** structures that can survive and evolve for periods much longer than the average human generation span -of only some 30 years, the usual climate time unit as well. Their spatial scale range is also a broad one: Hundreds to thousands of kilometres were already common well before the advent of fast and reliable transport techniques, as the history of past empires shows. Mastering the available technologies and controlling their evolution are the clues to the human ability to persist, to survive, and to bloom across ***many scales***, or in today's jargon, man is highly resilient, and presents an inkling for networking and globalisation (Adger *et al.* 2005). This last phenomenon should not be considered a recent one: since the very first human societies, it has been always there as a more or less explicit goal of their existence, embodied in cultures and religions. Table 1 below contains a summary comparison of the joint evolution of human population with a schematic history of science and technology, and climate, during the last three millennia, showing how humans generate their own cycles according to the available technologies and energy sources. In any case, an ever growing number of feedback loops with not well understood mechanisms, has eventually lead anthropic activities to such a degree of interference with natural periods that they appear to be distinctly perturbed, and changing landscapes were a most conspicuous expression of this intercourse. Later on, with reliable instrumental observation, other features at the molecular scale were discovered, showing that impact of mankind on nature is much deeper than thought.

A most apparent consequence of this impact is that human population appears to have been historically divided into a rather small number of large social and economic structures which –at least qualitatively– convey the classical difference between industrialised and developing countries, according to a sort of evolutionary morphogenetic process, see Figure 1.

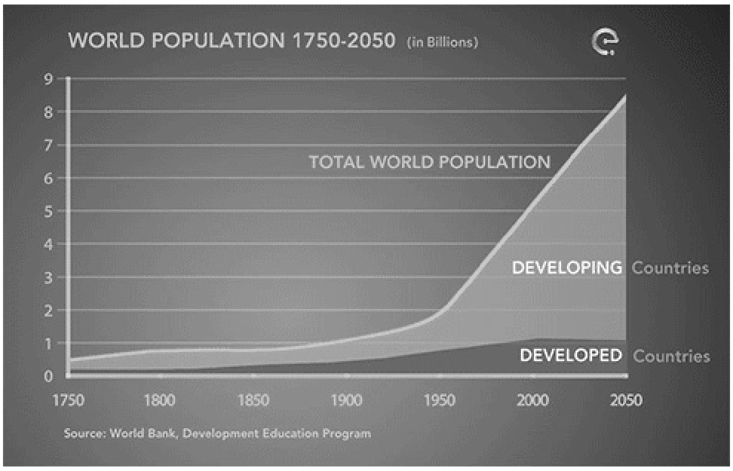

Figure 1. Graph showing the Earth population from the Enlightenment onwards, and a projection until 2050. World Bank at www.ecology.com. Last accessed, December 26th 2013.

Summing up, human population has a distinctive characteristic: It is very resilient, in the sense of adaptable to, and recoverable after, changes ***across many scales***. These are not only time and spatial ones, for economic, industrial, cultural, and social scales also play ever increasing roles (Behringer 2011). Abrupt events, developed in a short time interval but out of range in other measurements, seem to unchain non-desirable and dramatic effects, and therefore are generally considered as serious threats to the resilience of human societies. At larger scales, the threat of an abrupt climate change, presumably triggered by anthropogenic-induced causes, is one such issue as suggested by the 2013 IPCC report.

3. Quantitative information

For public information, complexity should be transmitted not only in qualitative and more or less rhetoric forms. Climate history is stored in a sort of –very thick- logbook known as the stratigraphic register, where events affecting all intervening subsystems, *e.g.* volcanic eruptions, massive gas emissions, etc., reach the whole planet via the global wind system and marine currents that spread globally the results of local episodes. After precipitation, traces may be read worldwide in sediments, ice cores, and other structures like atmospheric or marine stratification profiles. This is true as well for human activity outcomes, both on climate and landscape, as historians, geographers, and archaeologists know well. Landscape is the most classical proxy for quantification of a number of features, and its evolution deserves being attentively considered, especially in highly populated areas, usually coastal ones where networks of delicate equilibria depending on sediment transport always play a distinctive role (Cox and Richard 2005).

In that logbook, chapters, sections, subsections and other subdivisions are indeed present, and their separation marks are specific strata, known as bases, where typical materials present peak or at least distinctive concentrations as witnesses of changes in environmental conditions at the global scale. Another perspective, more prone to prediction, is to consider this logbook as a calendar or clock (Rahmstorf 2003). Table 2 contains the most important information.

The Anthropocene should be included as a last entry in the logbook, according to the usual classification scheme:

Eon: Phanerozoic, the time of *visible life*. Base: 542 myr ago.
Era: Cenozoic, when *newer life* was blooming. Base: 65.5 myr ago.
Period: Quaternary: 2.58 myr ago.
Epoch: Holocene, the last of the interglacial periods, with *life everywhere*. Base: 11.7 kyr ago.
Anthropocene: man is the 'new kid on the block'. Is it a new epoch or simply a sub-epoch? Base: Somewhere between 1700 and 1800 AD, to be established. See Table 2 below.

A current and actually hot debate is under way and on a foreseeable future one of the most urgent needs for the world scientific community will be the emergence –through collaboration of a number of actors ranging from purely scientific ones to social forces, educational instances, and decision-makers- of a rule set to reasonably determine the extent and depth of human influence in the environment, and therefore on climate.

If a definition of a new geological division or entry in the index of the geological logbook should be accepted, it would be indeed the result of joint efforts of many instances, in other words, as an ***emergent feature*** from the complex system we live in.

4. Conclusions

The thread of this paper is to draw attention towards the idea of complexity as a tool for considering the Anthropocene as a new scientific reference frame: every characteristic mark of complexity may be observed in the processes from which the Anthropocene idea derives. Here some conclusions and comments are presented.

- Earth and man are connected by ***feedback*** chains, for changing climates have forced human groups to develop survival strategies once and again. As an example, water shortage in Agriculture led to dam building; in turn, a boost in farming occurred, but dams changed sediment transport and deposition and; as a rule, new species were introduced for maximal yield, diversity decreased; then land was depleted and partly abandoned, therefore denudation occurred and the sedimentary budget was modified… (see Hansen 2007*,* Reuveny 2007).
- ***Across many scales***. Societies, cultures and technologies are cornerstones on which living across scales relies. On their own, human individuals have a life span of decennia and a spatial mobility of a few kilometres. The circumstances under which a continuous transmission and storage of knowledge, cultures, and technologies in organised groups or societies are ultimately based on biological facts: people of all ages in a range from 0 to say 80 are present at any time and the period before adulthood is a rather long one. If individuals cannot survive under some circumstances, societies can do and therefore extend themselves beyond the individual scales. This leads to the next mark:
- ***Criticality***. During human development, a number of critical events are detected as inflection points or changes in population growth rates. As a rule, those events depended on a certain mastery of some technical advancements and on the actual population number that could profit from them at the time: History tells "the stone age", "the bronze ages" and so on. Steam technology led to a flexible energy supply for many purposes at the end of the 18th Century, the world population reached a critical value of 1000 million people and the growth rate consequently increased. The next critical point, in the first years of the 20th Century, was the discovery of atmospheric nitrogen fixation through the Haber-Bosch process, which to a

large extent freed agriculture of the dependence on natural fertilisers, thus favouring a population explosion. This inflection point is strongly correlated with the increase of gases of anthropic origin in the atmosphere, most of them greenhouse gases like carbon dioxide and methane, which were detected and measured for the first time in the same time period.

• And ***emergence***: New societal relationships and organisational modes usually emerge as integrative processes after critical episodes, and today's globalisation emerged from a number of social, economical, cultural, and popular conditions, whose most apparent environmental long-term impacts are deep changes in the way energy is used, or rather misused, with an enormous amount of garbage as byproduct, and dramatic diversity losses in biota, functional, managerial, social and cultural aspects.

Emphasis should be made not only on the purely scientific –albeit an interesting and important one- struggle for the recognition of the Anthropocene. Rather, and the sooner the better, more visibility and awareness of the current state of affairs and their prospective, and the construction of a solid and stable multidisciplinary framework for future understanding between the many involved fields would be the desirable result. (Biermann *et al.* 2012, Gramelsberger and Feichtel 2011, Mason 2011).

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Table 1: A synoptic evolution of energy sources, activities, landscapes, climate, and human population.

Timeline	**Energy**	**Efficiency of energy use**	**Activities**	**Anthropic perception and impact of climate**	**Changes detected**	**Population**
I Antiquity to the Middle Ages	Fire (wood), hydraulic, wind, muscle	Extremely low	Farming, livestock, mining, commerce	Exploration, new settlements	Apparent on local landscapes. Negligible at larger scales.	Small, nearly constant or with very slow growth
II Renaissance, the Americas, the Enlightenment	Fire (wood+coal), hydraulic, wind, muscle	Very low	Farming (new species), livestock, mining, commerce, industry	**Climate as a commodity**: First modern colonial empires	Very apparent on local landscapes. Still negligible at large scales.	Very slow growth, linear with small slope
Transition hit: Watt's regulator for steam engines	Fire, steam, hydraulic, wind, muscle	Low	Farming, Industry, commerce, farming, livestock	Systematic exploitation: colonial empires	Remarkable on local landscapes and already visible in climate: **denudation rate increases**	First growth boost, transition to exponential (Malthus). 1000 million people reached in the last third of the 18th Century
III The 19th Century	Steam, electricity, hydraulic, wind, muscle, fossil fuel	Improving	Economy industry, commerce, farming, livestock, **telegraph**	Depletion of high quality agricultural land. lack of fertilisers	Visible at larger scales, distinctive records in sediments	Exponential with small exponent
Transition hits: Haber-Bosch process. Steam engines reach performance limit. **Discovery of greenhouse gases**	Electricity, fossil fuel, hydraulic, wind, muscle,	Improving	Economy industry, commerce, farming, livestock	New synthetic fertilisers	Sensible, **measurable** changes in physico-chemical atmospheric behaviour	Exponential growth: exponent increases
IVa The 20th Century	Fossile fuel, electricity, **nuclear,** hydraulic,	Reaching today's standards	Finance, economy, industry, commerce, farming, livestock, **electronics**, **telecommunica-tions**	**Climate as a commodity**: globalisation, tourism, near-depletion of the world fishery	Coastal landscapes dramatically changed, the ghost of abrupt change	Exponential growth: The exponent **seems** to decrease
IVb beyond our time	Depletion of fossil fuels	?	**Information, modelling**	**Climate as "a product"?**	**Freshwater shortage**	Transition to **logistic growth**?

Table 2. On establishing the Anthropocene base.

Item	During Holocene, up to 1750 AD	Detected / predicted trend
Atmospheric CO2	Constant concentration for more than 11000 yrs: approx. 290 ppm	Increasing (over 400 ppm today)
Average Air Temperature	Fluctuating around the average 15 ºC, variability range around 0.5 ºC	Increasing (according to IPCC 2013) both in average and variability
Sea level	Constant for some 5000 yrs (even to the beginning of the 21^{st} Century)	Increasing (according to IPCC 2013)
Population (see Table 1)	Nearly constant with a few punctual growth episodes (1000 million by 1750)	Modulation from linear to exponential and (possibly) logistic growth
Sediments	Distinctive deposition of agricultural and industrial residues since the beginning of the 18^{th} Century, caused by denudation processes	Increasing deposition. Currently it is around 300 m/myr.