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Can Freedom Help to Tackle Global Climate Warming?

A View from Biogeochemical Research

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The climate we live in

Evidence of global climate warming based on the results of a growing number of scientific studies was declared by the latest Assessment Report of the International Panel on Climate Change¹ as unequivocal. Climate change is primarily manifested through a widespread increase in ocean and air temperature at a global level. Air temperature increased on average by 0.6°C during the last century (1901 to 2000), at a growing rate. The warming trend in the fifty-year period between 1956 and 2005 (0.13°C per decade) is almost double that for the 100 year time window between 1906 and 2005 (0.074°C per decade). More recently the World Meteorological Organization² pointed out that the ten warmest years since the beginning of global temperature records in 1850 all occurred after 1997 (Figure 1), confirming the Earth's significant long term warming trend particularly at higher northern latitudes.

Oceans have become warmer up to the depth of 3,000 metres by taking up over 80 per cent of the heat added to the climate system and consistently the sea level showed an increasing trend assessed in 31 millimetres per year for the 1993 to 2003 decade, which threatens the populations of coastal areas and islands. It is estimated that the thermal expansion of marine water contributed to just less than 40 per cent of observed sea level rise with the remaining part being caused by the melting of glaciers and ice caps and reduction of the polar ice sheets.

Remarkably, the Arctic sea-ice cover in September 2010 was the lowest of three consecutive recorded minima since 2007 when the ice retreat opened the Northwest passage,³ the most direct shipping route between the Atlantic and Pacific Oceans, from Russia along the north coast of Canada to Europe, for the first time since satellite records began in 1978.

Figure 1 Global average temperature anomaly, compared with the 1961 to 1990 average result from three Global datasets: NOAA (NCDC Dataset), NASA (GISS dataset) and combined Hadley Center and Climate Research Unit of the University of East Anglia (UK) (HadCRUT3 dataset).

Source: World Meteorological Organization.

Climate changes include also long term variations of the precipitation regimes at different geographical scales (from continental to regional) and in the occurrence of extreme events. Over the 1900 to 2005 period, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia while it decreased all over the Mediterranean basin, in the Sahel and in southern parts of Africa and Asia leading to a likely enlargement of the areas affected by drought.

Heatwaves have become more frequent over most areas in the world, with the result of exacerbating the aridity of typically dry lands and generally enhancing the risk of fire. In this respect it is easy to recollect the catastrophic fires in Russia during July-August 2010, when temperatures exceeded 30°C during thirty consecutive days.⁴ In other cases heatwaves are *per se* a threat to human health, as in the case of an estimated 52,000 deaths in central-southern Europe in August 2003 during two weeks of continuous extremely hot temperatures.⁵ Extremes in the form of heavy precipitation events have also become more frequent over most areas in the world often causing destructive floods.

Drivers of climate warming

The climate system is driven by its energy balance, namely the absorption, scattering and emission of radiation within the atmosphere and at the Earth's surface. When these terms of the balance change, they produce a radiative forcing on the climate with either a cooling or warming effect on the climate system. Changes in atmospheric concentrations of greenhouse gases (GHGs) and aerosols, land cover and solar radiation are all factors which determine a modification of the energy balance.

Concentrations of GHGs such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased due to human activities since 1750 at unprecedented rates. Global increases in CO_2 , monitored with high accuracy measurements started in 1958 at the Mauna Loa observatory in Hawaii by Charles David Keeling, are caused primarily by emissions in the atmosphere produced by the burning of fossil fuels and secondarily associated to land use changes, mainly tropical deforestation. Data from the analysis of composition of the air trapped in bubbles in the Greenland and Antarctica ice cores showed that the range of variation of CO_2 in the last 650 thousand years has been by far lower than present concentration values.⁶ In particular from ten thousand years ago to 1750, CO_2 abundances stayed at about 280 parts per million (ppm)⁷, while as a result of human activities atmospheric CO_2 concentration rose exponentially up to 390 ppm in 2010.

The rise in CH_4 atmospheric concentration is attributed to fossil fuel use but also to agricultural activities, the latter being predominantly responsible for the increase in N_2O concentration as well. CH_4 concentration in the atmosphere was relatively constant at 700 parts per billion (ppb) from 1,000 years ago until the beginning of the industrial era in the nineteenth century, after which it started building up in the atmosphere up to 1774 ppb in 2005. Such a level was never experienced on Earth during the glacial-interglacial cycles in the last half million years when CH_4 concentration was within the range of 400 to 700 ppb.

It is a property of greenhouse gases that they absorb part of the outgoing thermal (infrared) radiation which the Earth's surface emits to space and re-emit it in all directions including back towards the planet's surface. The consequence of this natural process, well known as 'greenhouse effect', is to warm the Earth's surface and its lower atmosphere. The combined increase in GHG concentration in the atmosphere since the industrial era thus represents an additional energy load (positive radiative forcing) able to warm up the climate system with an estimated power of $+2.3 \text{ W/m}^2$. CO_2 alone is responsible for 80 per cent of the growth in climate forcing. CH_4 and N_2O , despite their much lower abundance, have a warming potential 25 and 320 times higher than that of CO_2 . Aerosols are small particles with very widely varying size and chemical compounds which can be of natural origin (mineral dust, sea salts, volcanic eruptions, biogenic emissions) or the result of fossil fuel and biomass burning

or dust released by surface mining and industrial processes. Aerosols produce an overall cooling effect of the atmosphere by reflecting and absorbing solar and infrared radiation. Changes in the land surface mostly operated through changes in forests, pastures and croplands can exert a forcing on regional climate by changing the ratio of reflected to incoming solar radiation (defined albedo) as well as altering the water and energy balances. Overall, these changes resulted in a negative forcing with more solar radiation reflected by the surface of the Earth. Solar irradiance, on top of its cyclic changes following an eleven-year period, is estimated to have gradually increased since 1750, generating a small positive radiative forcing of $+0.12 \text{ W/m}^2$.

However, considering all the forcing components acting on the climate system since 1750, human activities translated into a warming effect with a radiative forcing of $+1.6 \text{ W/m}^2$ which is by far greater than the forcing arising from natural processes.⁸ Both the magnitude and the rate of change are so great that the epoch since the start of the industrial revolution is often called the 'Anthropocene', according to the definition given by Nobel prize winner Paul Crutzen⁹ at the beginning of present century, and considered as a new geological era distinguished from the preceding Holocene starting about 12,000 years ago. In the Anthropocene human activities are significantly modifying the great natural cycles of carbon, water and nutrients, together with climate biodiversity and other properties of the state and function of the earth system.

A recent survey concluded that biodiversity loss, disturbance of nutrient cycles (nitrogen and phosphorous) and climate change in that order are the three leading planetary systems which have already crossed boundaries for defining 'a safe operating space for humanity'.¹⁰ Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the twenty-first century that would very likely be larger than those observed during the twentieth century.

Future climatic scenarios

Future climatic warming depends on GHG emission scenarios which have been developed by IPCC and issued in a dedicated report,¹¹ on the basis of different projections of demographic, technological and economic development at global level. Nevertheless, these scenarios do not take into account climate policies above those already adopted at the moment of the report's finalization. Future greenhouse gas concentration retrieved from SRES scenarios are used as inputs in climatic models of varying complexity which yield simulations of future changes in climate. The IPCC prediction from a range of emission scenarios is a warming of about 0.2°C during the next two decades. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.

Afterwards, temperature trends increasingly depend on specific emissions scenarios spanning 1.8–4.0°C. The range becomes even larger (1.1–6.4°C) if we consider the divergence in the results within each emission scenario given by the application of different models.

The European Commission, in recognition of the risk associated with the irrevocable consequences of climate warming, has tailored its environmental and energy policy on scientific grounds to limit global warming to a threshold of 2°C above pre-industrial levels, recognized as a safeguard point for the climate system. The acceptable warming level is thus 1.2°C above today's global temperature.

The EU members¹² are already on track to reduce their collective emissions in the 2008 to 2012 period to 8 per cent below 1990 levels under the framework of the Kyoto Protocol. Additionally the target to transform Europe into a highly energy-efficient, low carbon economy, is being pursued by the EU governments through a new unilateral commitment to cut emissions by at least 20 per cent of 1990 levels by 2020. This commitment is being implemented by binding legislation and is also meant to foster a new post-Kyoto global agreement, to become effective in 2013, targeted on a more ambitious reduction of GHG emissions by 30 per cent by major emitting countries.

In order to evaluate the potential efficacy of the political measures to tackle climate change, we can take advantage of the knowledge of the relation between the peak warming above pre-industrial temperatures, in other words critical temperature thresholds not to be overcome, and cumulative GHG emissions from human activities. This relation is at present considered statistically robust within quantifiable uncertainty bands.^{13,14,15} To keep climate warming below the 2°C threshold, cumulative emissions should be maintained below 1,000 PgC (billion tonnes of carbon). Considering that cumulative emissions at the end of 2008 were about 530 PgC, it is evident how more than half of the 1,000 PgC quota has been used already. This means that assuming a realistic gradual decrease of future emissions forced by the application of global climate policies, we have already overcome the maximum allowable CO₂ concentration in the atmosphere.

However, emissions continue to rise and constitute an annual input of nearly 10 PgC every year into the atmosphere. The largest increase in fossil fuel emissions in recent years took place in developing countries, counting for almost six billion people driven by emerging economies of China, India and South Korea. Even if in 2009 as a consequence of the world economic crisis fossil fuel emissions decreased by 1.3 per cent, these emissions were the second highest in human history just below 2008 emissions while preliminary data for 2010 indicate a return to an increase of +3 per cent.¹⁶

On the positive side, changes in land use leading to net GHG emissions are in progressive reduction since the 1990s although they are still responsible for net emissions of 1.1 PgC in the last decade. The observed reduction trend is largely the result of the implementation of new land policies, control of illegal deforestation and regrowth of forest on previously deforested areas.

A helping hand from planet earth

Not all the CO₂ emitted by human activities remains in the atmosphere but only a fraction of 47 per cent, if considering the average of the last decade.¹⁷ Atmospheric carbon is indeed part of a global biogeochemical cycle which involves also the oceans and the terrestrial ecosystems as other pools among which the carbon is exchanged through biological, geological and chemical processes. The actual global carbon cycle is not in equilibrium meaning that the increase of CO₂ in the atmospheric pool is partly offset by an uptake in the oceans and in the lands which act as carbon *sinks*. The oceanic sink of CO₂ is a physico-chemical response of the ocean to rising atmospheric CO₂, where the gas dissolves in surface water and is transported to the ocean depths by currents. The sink located over terrestrial ecosystems is determined by the net carbon uptake by forests and grasslands where additional carbon is stored in plants, biomass and soils. The average size of the ocean and land sinks during the last decade (2000 to 2009) was roughly equal and as large as 2.3 and 2.4 PgC yr⁻¹ respectively, thus removing more than half of the anthropogenic CO₂ emissions.

The response of terrestrial and oceanic ecosystems to the increased atmospheric CO₂ has attracted major attention from the scientific biogeochemical community in the last twenty years. A fascinating hypothesis behind the observed sinks is the capacity of living organisms to regulate the Earth's environment maintaining the suitable conditions for life. This hypothesis, formulated in 1965 by J.E. Lovelock as the 'Gaia hypothesis' after the word used in Greek mythology for Mother Earth, compares our planet to a living being with a capacity of auto-regulation.¹⁸

The maintenance of physico-chemical properties at the Earth surface is generally performed through reactions (*feedbacks*) which contrast the changes in the initial conditions. A crucial issue in this respect is improving the understanding of CO₂-climate feedbacks. If Gaia is giving a hand in reducing the rising CO₂ concentration in the atmosphere and in mitigating climate changes through the uptake of carbon in the lands and in the oceans, we should understand for how long this process can be sustained in the future and what are the limiting conditions for its functioning.

Open questions and priorities in the carbon cycle science

The main need of the carbon cycle research community in facing the climate change challenge is to understand the role of the natural and managed carbon cycle in the dynamics of the climate system. This entails quantifying the effect of human activities, determining the response of natural ecosystems to the disturbed carbon cycle and forecasting future fluxes between the atmosphere, the land and the oceans. Currently a significant part (about 40 per cent) of

the uncertainty on the magnitude and rate of climate change for the twenty-first century depends on the lack of understanding of the feedbacks between anthropogenic emissions, the carbon cycle and the climate system.¹⁹

Only after a breakthrough in the understanding of the processes underlying the carbon cycle will it be possible to explore strategies for the management of the carbon-climate-human system aimed at stabilizing atmospheric concentrations of GHGs. Research priorities are therefore represented by a better depiction of the contemporary global carbon cycle, including the quantification of carbon sources and sinks with a reduced margin of uncertainty, their geographical distribution and future dynamics. In particular the quantitative assessment of the anthropogenic disturbance on the carbon-climate system is needed to adopt efficient mitigation policies for a given target of acceptable temperature level above pre-industrial levels.²⁰

Moreover, climate treaties need continuous improvement if tools based on sound science are to monitor and verify mitigation activities. The same is required by the emerging carbon market for which transparent and scientifically-based monitoring and verification of the results of emission reduction projects are crucial. A key development of biogeochemical research would be also the identification of climatic thresholds beyond which irreversible processes start to take place. For instance the potential thawing of permafrost (frozen soils at high latitudes containing massive amounts of carbon), the increase in fire occurrence and vegetation replacement due to the interactions between reduced rainfall and tropical deforestation, the drying of peatlands and associated fires, are all processes able to accelerate the climate warming by releasing extremely large quantities of carbon into the atmosphere and becoming uncontrollable once temperatures have passed specific thresholds.

The relevance of ethical and intellectual freedom in tackling global climate warming

Climate change is a global problem and ideally it should be tackled through an effort at a global scale. Certainly the search for and application of effective measures to mitigate climate changes requires a very large number of synergies at all levels of society. Synergies are particularly needed also within the research sector for a major advancement in this field of science and for several aspects, finding these synergies requires a certain degree of freedom for scientists. This freedom should be protected and promoted at at least three levels: implementation of a network of observation sites, freedom in data collection and sharing, and effective dissemination.

With regard to the first point, most of the scientific questions outlined before can only be answered through the implementation of an optimal carbon

observation system based on a network of observation sites all over the globe. Regional networks of field sites for the measurements of climate, GHG fluxes and the main ecosystem attributes already exist and have increased in number, reaching more than 500 sites worldwide at present. A growing bulk of sites and relative data poses the problem of the standardization of measurement methodologies and data processing, an issue currently being addressed by projects such as FLUXNET, which coordinates the analysis of fluxes of CO₂ at a global scale. Standardization is a necessary aspect to come up with aggregated figures of the global carbon cycle and to deliver routine updates of carbon budgets: this standardization may appear to limit the ethical freedom of scientists, who can in principle use different methodological approaches when collecting measurements or treating data for their own specific research aims and submitting their results for publication. This, however, does not in reality limit, but enhances freedom of science, in that it allows scientists to operate on a global scale, and, as explained above, in this field of science operating on a global scale is essential.

Networks, however, are only meaningful and effective as long as a large number of scientists can coordinate their research plans. In this respect it should be mentioned that in the last decade many international programs have been initiated to try to develop a globally coordinated research strategy. The mission of research programs such as the GTOS (Global Terrestrial Observation System) or the ESSP (Earth System Science Partnership) has been to compile the essential knowledge on the functioning of the Earth, bringing together researchers from different fields of science all over the world. These programs facilitate communication and cooperation among existing projects and provide valuable information to researchers and policy makers who deal with environmental changes. The ethical choice of individual scientists to share their knowledge is here at the base of the success of such initiatives.

In order to provide the answer to the open scientific questions outlined above, and thus to respond effectively to the challenges posed by climate changes, it is also essential that scientists are granted the freedom, and are encouraged, to operate in key regions of the world and at an increasing number of locations, to collect data which can contribute to reducing the uncertainty in the state of the art knowledge of the global carbon budget and its year to year variation. Barriers in this sense are represented by restrictive national legislation of some countries controlling the access and the circulation of people through and within their national boundaries, the permissions to take measurements or biological samples and export them abroad to analyze them in specialized laboratories. Rather frequently barriers are nevertheless represented by severe financial constraints to the activity of researchers, with the exception of those countries where science is most supported by governments (USA, Japan, France, Germany and UK among those with the highest expenditures) and scientists can rely upon larger budgets to deploy their projects.

After that scientists should be in the position to share the data they collect in order to participate in research networks or contribute to databases, each of which is however usually managed applying a certain regulation, not necessarily limiting, in respect to the access and the use of data. Thankfully, data sharing policies are carried out in most of the leading countries in science and have lately been greatly advanced also in important emerging countries such as China where they were poorly developed only few years ago, and where in parallel an increasing share of the gross domestic product (from about 0.9 per cent in 2000 to 1.5 per cent in 2007) has been assigned to the sector of research and development.²¹

Finally, the results of a research project, even if very valuable, risk being under evaluated if they are not disseminated effectively, making the efforts behind them almost vain. Engagement in the climate change debate and alignment of research with policy processes are thus both critical for effective interactions between science, policy and society. Opportunities of disseminating at the international level are represented for instance by the participation of scientists in technical panels of the United Nations Framework Convention on Climate Change (UNFCCC) as well as with regional and national policy institutions. However, there is a growing need for engagement with the broader society, informing public opinion through media releases of new research findings and through an active participation in discussions about climate change. If on the one hand the evidence of a climate change and the responsibility of human activities are nowadays unequivocal for the scientific community, on the other hand the media also give space to arguments which deny the warming trend of the planet, minimize the risks associated to it and in any case clear the human society from being the cause of the observed change. According to research published in November 2007 by Maxwell Boykoff at the University of Oxford, UK,²² the majority of US newspaper articles from 1990 to 2004 balanced the view that humans cause climate change with the opposite viewpoint going along with the media's need to appear unbiased. As a result of this attitude, journalists have been confronting science with scepticism, balancing evidence with emotion even when the very large scientific consensus on the topics could make the arguments conclusive.

The large majority of arguments against climate change are not based on scientific grounds and in many cases hide the interests of industrial lobbies in the exploitation of fossil fuels or their concern about the policy measures associated with a reduction of GHG emissions. For instance, in 2006 the UK scientific academy, the Royal Society, accused one of the world's major oil companies of funding thirty-nine groups that 'misrepresented the science of climate change by outright denial of the evidence' and later in the *Guardian* newspaper reported that the same company offered scientists and economists money for articles that attempted to undermine the scientific consensus on climate change by confuting the findings of the IPCC. For the public, however,

it is very often hard to discern the solidity and credibility of contrasting arguments in the debates on climate change. This is not to deny that alternative opinions have legitimacy in science, or that freedom of expression should be limited. Scientific theories would be hardly accepted as credible if they were simply imposed. However, debates on climate change, as well as on any other area of science, should be informed and based on evidence, rather than on ideology or financial interests. A transparent and well informed debate that involves the public may also put people in the position to adopt virtuous behaviour and take action to reduce their level of emissions. Clearly, if every single person felt responsibility for climate change, and the power to interfere positively with it, the effects of the actions of every single person on a global scale would be significant.

An effective communication of science to the largest possible audience is needed, although it is difficult, given the degree of complexity of science itself. Improving the diffusion of a scientific culture among society should be a task for scientific communicators and journalists, as well as for the education system of a country. Only with such dissemination will all members of society be enabled to understand the facts and consequences of climate change, and called to form their own opinion in the most free but responsible way.