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THE °CLIMATE GROUP

This is part of THE CLEAN REVOLUTION

CLIMATE SCIENCE

PART I: THE FUNDAMENTALS

Insight Briefing | Analyzing the issues that matter to the Clean Revolution

ABOUT

This briefing is the first in a series of non-technical papers on key climate science issues. Along with its companion briefings, it aims to increase awareness of climate science in advance of the publication of the Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC), from September 2013. This first briefing explores the 'fundamentals' behind climate science research. Other briefings in the series cover observed and future climatic impacts, short-lived climate pollutants and the IPCC report production process.

KEY POINTS

- Climate science is grounded in the empiricism of the Scientific Method, which in turn provides the basis for effective, evidence-based decision making
- The basic physical processes behind global warming and climate change (such as the greenhouse effect) are well understood and supported by empirical evidence
- 97% of peer reviewed climate science papers conclude that global warming is occurring and is driven by human activities
- Climate science has a long history dating back over 150 years, with huge advances in understanding made in the last 30 years
- The rise in atmospheric carbon dioxide (CO_2) levels is unprecedented in at least the last 400,000 years

INTRODUCTION

There are few areas of scientific research today as important to society's future as the broad field of climate science. For business and political leaders in particular, an informed understanding of this area of research, especially its predictions of future climatic change, should be a priority.

Within the scientific community the consensus is overwhelming: 97% of all peer-reviewed climate science papers conclude that global warming is real and that human activities are the cause.[1] Failure of today's decision-makers to grasp this reality, risks the future prosperity, health and sustainability of companies and communities around the world.

This briefing looks at the fundamental drivers and processes behind climate change, but begins with an overview of the importance of, and some of the key debates surrounding climate science today. For simplicity, the briefing focuses mainly on the central role and impact of CO_2 on global warming and climate change, rather than the full suite of greenhouse gases (GHGs).

[1] The Consenus Project. http://theconsensusproject.com/. Accessed 12 July 2013.

CLIMATE SCIENCE TODAY: ITS IMPORTANCE AND KEY DEBATES

Any discussion on climate science would be incomplete without an appreciation of the wider context in which climate research takes place. This section provides a brief introduction to the relevance of climate science to decision makers and some of the key debates and issues that shape the subject.

THE BASIS FOR INFORMED DECISION MAKING

Why should climate science matter so much to decision makers? The simple answer is because it provides the evidence for the causes, impacts and necessary mitigation of, and adaptation to climate change. In plain terms, climate research establishes the empirical basis for effective, evidence-based decision-making. It underpins the many good economic, social and political reasons for accelerating the decarbonization of the world economy. And in an imperfect world, it provides the most transparent and independent reference point for debate and action that we have.

THE CONSEQUENCES OF INCONVENIENT TRUTHS

This important field of science has not been without controversy, however. Few other areas of research have attracted as much attention as climate science in recent years; not least because of the difficult questions it raises for today's fossil-fuel based economies. However, arguments have often been more about the proposed policies that follow from the scientific evidence rather than the underlying science itself. But the intensity of the debate between mainstream climate scientists and the (increasingly) small minority of critics has created misunderstanding about climate science in the media and among the general public. This confusion has played into the hands of vested interests and those opposed to ambitious climate action, muddying the waters of what ought to be a clear and rational debate about the evidence and implications raised by scientific research.

THE SCIENTIFIC METHOD: PROVIDING ROBUST, EMPIRICAL EVIDENCE

Despite all this, the systematic observation, measurement, experimentation, formulation, testing and modification of hypotheses, which define the Scientific Method and that underpins all climate research, have never been in question (at least not within the scientific or mainstream policy communities). Away from politics and media, robust scientific debate has continued on the interpretation and analysis of the evidence produced through research programs. This is as it should be, since without continual questioning and natural scientific scepticism, our understanding of the climate system would never have advanced.

A SCIENTIFIC PROCESS STILL SUBJECT TO POLITICAL AND HUMAN INFLUENCES

It would be wrong, however, to characterize climate science research as a faultless, perfect process. Improvements are always possible. One criticism of the climate science community is that it has been too conservative – a consequence perhaps of the human tendency to discount risk. In the area of mitigation, for example, some scientists have expressed concern that emission reduction pathways are being chosen to fit current political and economic models rather than the physical evidence.[2] Charges of conservatism have also been levelled at the IPCC, whose key findings have been shown to understate the rate and intensity of climate change.[3] For governments and businesses alike, this conservatism and the implications it has for underestimating future climate change, need to be factored into decision making.

THE KEY FACTS, CAUSAL LINKS AND RELATIONSHIPS

Climate research in the last three to four decades has established a robust set of empirical facts, explanations and tested models that demonstrate a clear, causal link between GHG emissions, global temperature increases and a changing climate. Table 1 on the following page is a simple illustration of these key facts, causal links and relationships.

[2]Anderson K., Bows, A. 'Beyond dangerous climate change: emission scenarios for a new world'. http://rsta.royalsocietypublishing.org/content/369/1934/20.full.pdf+html . Accessed 16 July 2013.

[3]Scientific America. 'Climate science predictions prove too conservative.' http://www.scientificamerican.com/article.cfm?id=climate-science-predictions-prove-too-conservative. Accessed 16 July 2013.

TABLE 1 Climate science fundamentals

THE 'FUNDAMENTALS'	DEGREE OF SCIENTIFIC CONFIDENCE
1. The molecular structure of CO_2 and other naturally occurring atmospheric gases including methane (CH_4) and nitrous oxide (N_2O) allows these gases to absorb infra-red radiation re-emitted from the earth's surface, thus trapping heat in the atmosphere. This is known as the greenhouse effect (see Figure 1 below).	Empirical fact[4]
2. Levels of CO_2 and other GHGs have been increasing in the atmosphere over at least the last 150 years, but with over half of the increase occurring in the last 30 years.	Empirical fact[5]
3. Human activities, such as the burning of fossil fuels, deforestation and agricultural practices, have been the main source of this increase in GHG concentrations.	Empirical fact[6]
4. There has been a statistically significant increase of about 0.8°C in global atmospheric temperature over the last 100 years.	Empirical fact[7]
5. This increase can only be explained through the increase in GHGs; other explanations, such as changes in the sun's radiation, are insufficient to explain the degree of change.	Very likely[8] (i.e >90% probability)[9]
6. Levels of GHGs are continuing to rise at record rates with concentrations of CO_2 hitting a record 400 parts per million (ppm) in May 2013 – up from a pre-industrial level of 280 ppm (see 'Modern CO_2 measurement' section below).	Empirical fact[10]
7. At current emission rates, scientists' best estimate prediction is global warming of between 2.3-4.5°C by 2100, although higher temperatures cannot be ruled out depending upon the impact of so-called feedback mechanisms in the climate system and the ambition of mitigation efforts.	Likely (i.e. >66% probability)[11]
8. A temperature change of this magnitude has not been seen since the end of the last ice age. The rate of change is also extremely unusual – 20 times faster than anything experienced in the last 2 million years. The predicted temperature increase is therefore outside the bounds of modern human experience.	Empirical evidence from proxy data[12 13]
9. In order to avoid the worst and least manageable impacts of climate change we need to contain the global surface temperature rise (from the pre-industrial average) to 2°C or less.	Concern increasing that important thresholds may be crossed below 2°C[14]
10. For a 50:50 chance of keeping below 2°C, atmospheric CO_2 concentration needs to be restricted to 450 ppm or less. This in turn requires an 80% or more reduction in global emissions by 2050, relative to 1990 levels. NB: The later emissions peak the greater the reduction required (See Part III of briefing series).	Based on assessment of a range of climate models[15]

[4] UCMP. Berkeley University. http://www.ucmp.berkeley.edu/education/dynamic/session5/ sess5_greenhouse.htm. Accessed 10 July 2013

[5] NOAA Earth Systems Laboratory. FAQs. http://www.esrl.noaa.gov/gmd/outreach/faq_cat-3.html#45 Accessed 11 July 2013

[6] IPCC. Fourth Assessment Report, Working Group I SPM. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-human-and.html Accessed 10 July 2013

[7] NASA, Earth Observatory. http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php Accessed 11 July 2013

[8] The IPCC uses a set of defined terms for a range of probabilities. For example, 'Very Likely' describes probabilities greater than 90%; 'Likely' describes probabilities between 66-100% and 'About as likely as not' refers to a probability range of 33% to 66%.

[9] IPCC. Fourth Assessment Report. Working Group I Summary for Policymakers. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-understanding-and.html. Accessed 11 July 2013.

[10] Scripps Institution of Oceanography. http://keelingcurve.ucsd.edu/. Accessed 11 July 2013.

[11] Potsdam Institute for Climate Impact Research and Climate Analytics. 'Turn down the Heat' http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pdf. Viewed 11 July 2013

[12] NOAA National Climatic Data Center http://www.ncdc.noaa.gov/paleo/globalwarming/paleobefore.html. Accessed 11 July 2013.

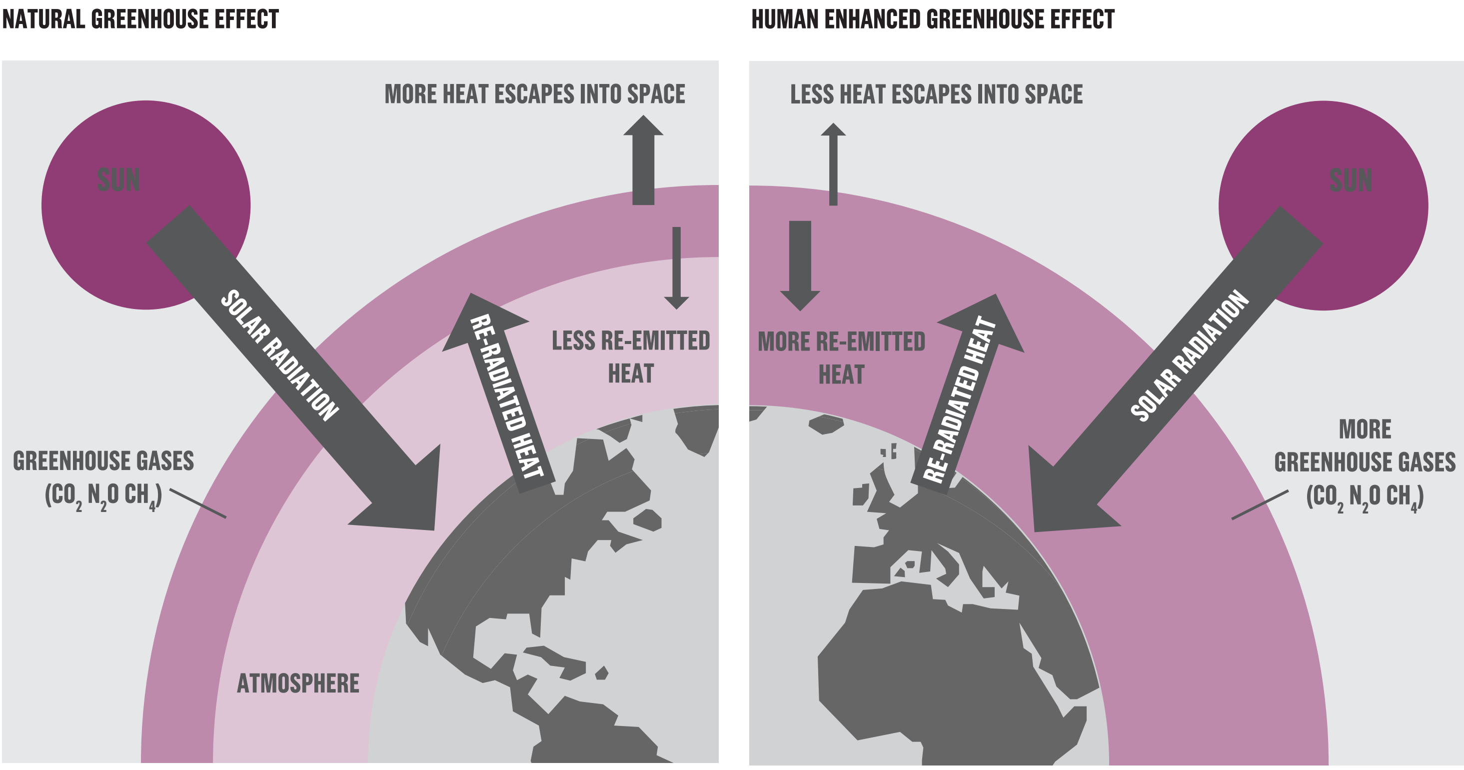
[13] NASA Earth Observatory. http://earthobservatory.nasa.gov/Features/GlobalWarming/page3.php. Accessed 11 July 2013

[14] NIWA Climate Brief http://www.nzclimatechangecentre.org/sites/nzclimatechangecentre.org/files/images/NZCCC_Climate_Brief_1_%28November_2011%29.pdf. Accessed 11 July 2013

[15] IPCC Fourth Assessment Report, WGII. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch19s19-4-2-2.html. Accessed 11 July 2013.

UNDERSTANDING THE GREENHOUSE EFFECT

FIGURE 1 Climate science fundamentals



Source: http://www.nps.gov/goga/naturescience/climate-change-causes.htm

Figure 1 illustrates the natural and enhanced greenhouse effects. In a steady-state world, naturally occurring greenhouse gases, such as CO_2, methane (CH_4) and nitrous oxide (N_2O), keep the planet warmer than it would otherwise be. This makes Earth habitable for life as we know it.

The greenhouse effect occurs because of the way CO_2 and other GHGs respond to radiation of differing wavelengths as a result of their molecular structure. GHGs are effectively transparent to incoming, short-wave, ultra-violet radiation from the sun, which then heats the earth's surface. By contrast, the outgoing, long-wave, infra-red radiation that is re-radiated from the earth is readily absorbed by GHGs.[16]

As GHG concentrations rise – as they have done through the combustion of fossil fuels and deforestation over two centuries – the amount of outgoing radiation emitted to space is increasingly restricted, while the amount of incoming radiation is unaffected. The net result under an enhanced greenhouse effect is that more heat (i.e. energy) is trapped, the temperature increases and other changes in the climate system begin to occur.

[16] Most people will be familiar with UV radiation as the cause of sunburn, while IR radiation is simply the same as the heat produced from any household heater.

BOX 1. A SHORT HISTORY OF CLIMATE RESEARCH

Research into how the atmosphere regulates the earth's climate can be traced back nearly 200 years. French scientist Jean Baptiste Joseph Fourier was the first person to argue that the earth could not be as warm as it was based simply on heat received from the sun. In the 1820s, Fournier suggested that the atmosphere acted as an 'insulating blanket' trapping heat.

It took another 40 years, however, before Irishman John Tyndall was able to show that water vapor and the trace atmospheric gas CO_2 were highly effective in trapping heat. In the 1890s, Swedish scientist Svante Arrhenius built on this work and calculated that a doubling of atmospheric CO_2 would lead to a global temperature rise of 5-6ºC. This was not considered a problem at the time, since it was thought that such doubling would take centuries based on estimated emission rates of the period.

Through the early part of the 20th century, little research was conducted on CO_2's role in the atmosphere. In the 1930s, however, US physicist E.O. Hulburt calculated that a doubling of CO_2 would lead to a 4ºC rise in temperature. And in 1938, Englishman Guy Callendar discovered a warming trend in international temperature records and a 10% increase in CO_2 concentration. According to Callendar's calculations a doubling of CO_2 would lead to a 2ºC rise in temperature.[17]

Driven in part by the military demands of the Cold War, important advances in understanding how CO_2 behaves in the atmosphere were made in the 1950s and 1960s. The creation of radioactive carbon isotopes as a result of nuclear testing, for example, enabled scientists to track the global circulation of CO_2 as well as identify its origin (i.e. from the natural carbon cycle or fossil fuel combustion). Scientists also developed a better understanding of the ocean's role in absorbing and releasing CO_2.

Through the 1960s, 70s and 80s, the scope of climate research continued to expand. The creation of computer models, research into the cooling effect of aerosols, the use of ice-core data, and geological research, helped build a more comprehensive picture of how the climate system works.

Early computer modeling, for example, predicted 2ºC of warming for a doubling of CO_2, while aerosol research highlighted the cooling effect of small airborne particles (such as sulphur dioxide) in the atmosphere. The latter work was the basis for the media's interest during the 1970s with the threat of a new ice age. This theory was undermined as air quality legislation reduced the level of aerosols, removing the masking effect they had on the underlying CO_2-driven warming trend.

Ice-core and geological research from the 1980s onwards offered a glimpse of climates of the distant past. Trapped ancient air in Antarctic and Greenland ice cores, drilled from a depth of up to 2 kilometers, provided 150,000 years of climate history, for example. The observed changes in CO_2 showed a strong, consistent relationship with re-constructed temperature records.

Meanwhile, geological evidence highlighted CO_2's key role in shaping Earth's climate millions of years ago. Evidence captured in rock strata showed that major changes in carbon sinks and sources had acted as a powerful influence on the climate. Worryingly, when changes in CO_2 had been geologically very rapid (i.e. over a few tens of thousands of years) this had often been accompanied by mass extinctions as environmental change outpaced the ability of species to adapt.

By the mid-1980s, the convergence in understanding about the causes, speed and possible impact of CO_2 driven climate change had reached a critical mass in the scientific and policy communities. In recognition of the need for a consensus view on the state of climate science – and as a means of underpinning collective action at a political level – the IPCC was established in 1988.

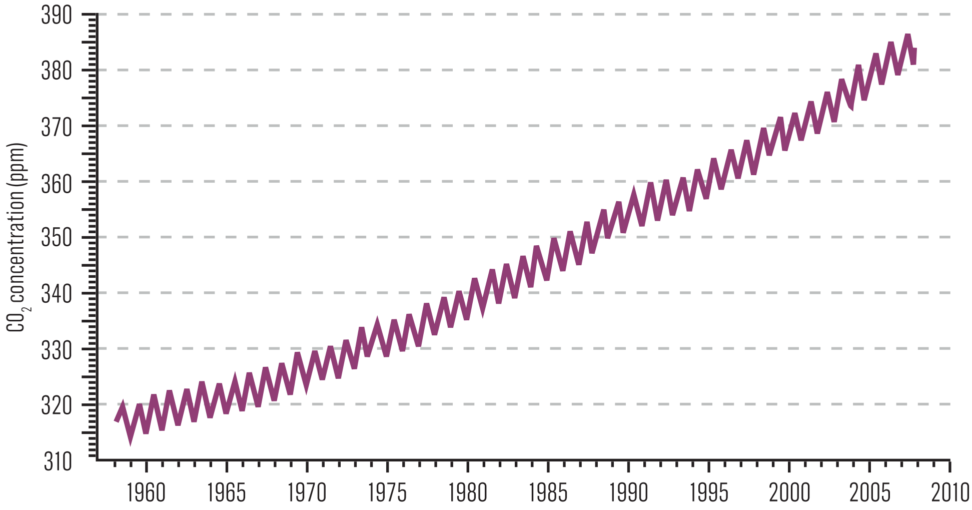
NB: This box is a very short summary of an excellent essay by John Mason on the Skeptical Science website http://www.skepticalscience.com/history-climate-science.html

[17]NB: the variation in calculations of expected temperature increase of the early researchers reflects a combination of factors, including the sophistication of the equipment used and the sources of the air sampled. Interestingly, however, the temperatures predicted by these scientists (from 2ºC up to 5-6ºC) still falls within the IPCC's current range of predictions.

MODERN CO_2 MEASUREMENT

The systematic and regular monitoring of atmospheric CO_2 concentrations began in the late 1950s by US scientist Charles David Keeling. The now famous Keeling Curve, based on measurements taken from the Mauna Loa Observatory in Hawaii, has gone on to record a steady and relentless rise in CO_2 concentration that has continued to the present day (Figure 2).

FIGURE 2 The Mauna Loa Atmospheric CO_2 record

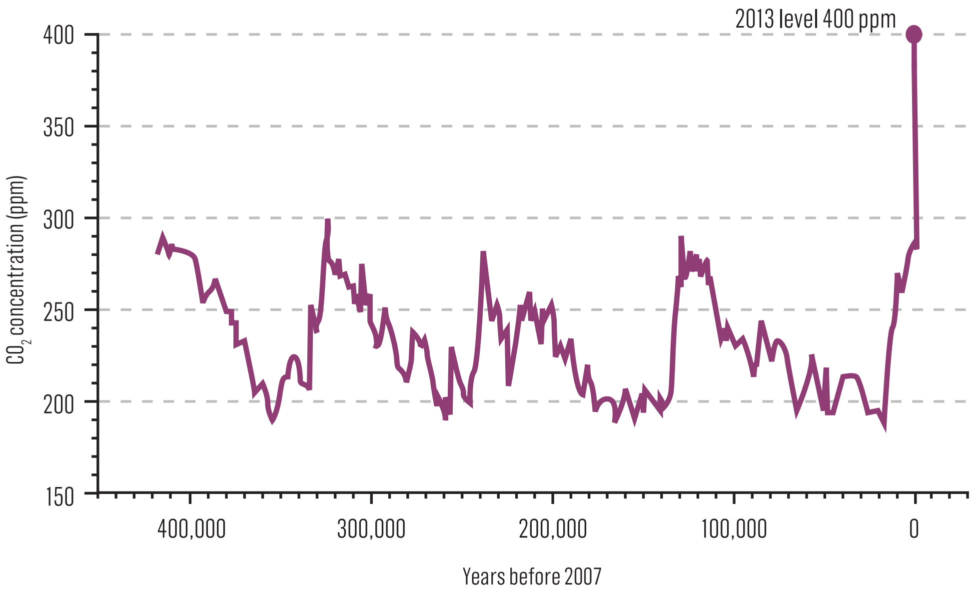


Source: http://scrippsco2.ucsd.edu/program_history/keeling_curve_lessons.html

NB: The saw-tooth pattern reflects seasonal change as the Earth's biosphere absorbs and releases CO_2 through summer and winter respectively.

In May 2013, CO_2 concentration passed the 400 ppm mark for the first time in at least the last 400,000 years (and probably much longer). CO_2 measurements obtained from ice cores and reconstructions from the geological record, show that the modern rate of CO_2 increase is unprecedented. Figure 3 highlights the nature of the rapid rise in CO_2 seen in the Mauna Loa measurements compared to the reconstructed geological record.

FIGURE 3 Atmospheric CO_2 concentrations over the last 400,000 years



Source: http://scrippsco2.ucsd.edu/program_history/keeling_curve_lessons_4.html

CONCLUSION

The accumulation of empirical data through the Scientific Method has provided climate scientists with a clear understanding of the causes and mechanics of global warming and climate change. The insights of early climate scientists have proven to be robust, through a century or more of research and testing.

As the concentration of CO_2 continues to climb in the atmosphere, it is now the responsibility of decision-makers in business and government to act on the empirical evidence in front of them. Without action ground in the physical reality of the earth's climate system, the opportunities and benefits of a prosperous, safe, low carbon future will be lost, replaced instead by the dangers and costs of an increasingly warming world.

FURTHER READING

IN THIS SERIES OF CLIMATE SCIENCE BRIEFINGS:

Part II: Observed climatic impacts

Part III: Future climatic impacts

Part IV: The IPCC and its work

Part V: Short-lived climate pollutants (available from September 2013)

(Freely available to The Climate Group partners and otherwise on request – see contact details below.)

USEFUL AND AUTHORITATIVE SOURCES ON THE WEB INCLUDE:

Skeptical Science http://skepticalscience.com

A very accessible source of information and explanations on climate science issues for non-experts

Real Climate http://www.realclimate.org

In-depth, technical information and discussion on climate science from climate scientists

Met Office (UK) http://www.metoffice.gov.uk/climate-change

The UK's leading public institution engaged in climate change research and communication

NOAA http://www.noaa.gov/climate.html

One of the key US government agencies engaged in climate science research, especially with respect to the ocean

NASA http://climate.nasa.gov

One of the key US government agencies engaged in climate science research, especially with respect to satellite observation

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