

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/314468477>

Carbon Dioxide: The Good News

Article in SSRN Electronic Journal · January 2015

DOI: 10.2139/ssrn.2674685

CITATIONS

2

READS

826

1 author:



[Indur Goklany](#)

Independent Researcher

98 PUBLICATIONS 1,190 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Empirical trends in the impacts of climate/weather [View project](#)



CARBON DIOXIDE The good news

Indur M. Goklany

With a foreword by Freeman Dyson

The Global Warming Policy Foundation

GWPF Report 18

GWPF REPORTS

Views expressed in the publications of the Global Warming Policy Foundation are those of the authors, not those of the GWPF, its Academic Advisory Council members or its directors

THE GLOBAL WARMING POLICY FOUNDATION

Director

Benny Peiser

BOARD OF TRUSTEES

Lord Lawson (Chairman)	Charles Moore
Lord Donoughue	Baroness Nicholson
Lord Fellowes	Sir James Spooner
Rt Revd Dr Peter Forster, Bishop of Chester	Graham Stringer MP
Sir Martin Jacomb	Lord Turnbull
Peter Lilley MP	

ACADEMIC ADVISORY COUNCIL

Professor Ross McKittrick(Chairman)	Professor Deepak Lal
Adrian Berry	Professor Richard Lindzen
Sir Samuel Brittan	Professor Robert Mendelsohn
Sir Ian Byatt	Professor Ian Plimer
Professor Robert Carter	Professor Paul Reiter
Professor Vincent Courtillot	Dr Matt Ridley
Professor Freeman Dyson	Sir Alan Rudge
Professor Christopher Essex	Professor Nir Shaviv
Christian Gerondeau	Professor Philip Stott
Dr Indur Goklany	Professor Henrik Svensmark
Professor William Happer	Professor Richard Tol
Professor David Henderson	Professor Fritz Vahrenholt
Professor Terence Kealey	Dr David Whitehouse

CREDITS

Cover image CSIRO under CC licence
<http://www.scienceimage.csiro.au/image/3731>

CARBON DIOXIDE **The good news**

Indur M. Goklany

Contents

Foreword	vii
About the author	x
Summary	xi
I The benefits of carbon dioxide	1
1 Introduction	3
2 Impacts of carbon dioxide on biological productivity	4
Evidence for enhanced plant growth	4
Present-day contribution of carbon dioxide to increases in crop yields	6
Impact of carbon dioxide enrichment on pests and weeds	8
Contribution of carbon dioxide to increases in biological productivity in unmanaged ecosystems	8
3 Ancillary benefits of increased biospheric productivity	11
Improved human wellbeing	11
Reduced habitat loss and pressure on biodiversity	11
4 Impacts of higher carbon dioxide on water availability and irrigation requirements	12
5 Impacts of higher carbon dioxide levels on marine life	15
6 Conclusion to Part I	18
II Human and environmental wellbeing	19
7 Empirical trends in climate-sensitive indicators of human wellbeing	21
Crop yields	21
Sea levels	21
Precipitation	22

	Extreme weather	22
	Disease	22
	Access to clean water and sanitation	23
	Living standards	23
8	Why are claims of damage failing to materialise?	23
	Reliance on chains of unvalidated models	23
	Climate models overstate global warming	24
	Climate models don't do local well	26
	Climate models don't do precipitation well	27
	Adaptation methodology is flawed	28
	In summary	31
9	Conclusions to Part II	33
10	Acknowledgements	33
	Notes	35

Foreword

By Freeman Dyson

Indur Goklany has done a careful job, collecting and documenting the evidence that carbon dioxide in the atmosphere does far more good than harm. To any unprejudiced person reading this account, the facts should be obvious: that the non-climatic effects of carbon dioxide as a sustainer of wildlife and crop plants are enormously beneficial, that the possibly harmful climatic effects of carbon dioxide have been greatly exaggerated, and that the benefits clearly outweigh the possible damage.

I consider myself an unprejudiced person and to me these facts are obvious. But the same facts are not obvious to the majority of scientists and politicians who consider carbon dioxide to be evil and dangerous. The people who are supposed to be experts and who claim to understand the science are precisely the people who are blind to the evidence. Those of my scientific colleagues who believe the prevailing dogma about carbon dioxide will not find Goklany's evidence convincing. I hope that a few of them will make the effort to examine the evidence in detail and see how it contradicts the prevailing dogma, but I know that the majority will remain blind. That is to me the central mystery of climate science. It is not a scientific mystery but a human mystery. How does it happen that a whole generation of scientific experts is blind to obvious facts? In this foreword I offer a tentative solution of the mystery.

There are many examples in the history of science of irrational beliefs promoted by famous thinkers and adopted by loyal disciples. Sometimes, as in the use of bleeding as a treatment for various diseases, irrational belief did harm to a large number of human victims. George Washington was one of the victims. Other irrational beliefs, such as the phlogiston theory of burning or the Aristotelian cosmology of circular celestial motions, only did harm by delaying the careful examination of nature. In all these cases, we see a community of people happily united in a false belief that brought leaders and followers together. Anyone who questioned the prevailing belief would upset the peace of the community.

Real advances in science require a different cultural tradition, with individuals who invent new tools to explore nature and are not afraid to question authority. Science driven by rebels and heretics searching for truth has made great progress in the last three centuries. But the new culture of scientific scepticism is a recent growth and has not yet penetrated deeply into our thinking. The old culture of group loyalty and dogmatic belief is still alive under the surface, guiding the thoughts of scientists as well as the opinions of ordinary citizens.

To understand human behavior, I look at human evolution. About a hundred thousand years ago, our species invented a new kind of evolution. In addition to biological evolution based on genetic changes, we began a cultural evolution based on social and intellectual changes. Biological evolution did not stop, but cultural evo-

lution was much faster and quickly became dominant. Social customs and beliefs change and spread much more rapidly than genes.

Cultural evolution was enabled by spoken languages and tribal loyalties. Tribe competed with tribe and culture with culture. The cultures that prevailed were those that promoted tribal cohesion. Humans were always social animals, and culture made us even more social. We evolved to feel at home in a group that thinks alike. It was more important for a group of humans to be united than to be right. It was always dangerous and usually undesirable to question authority. When authority was seriously threatened, heretics were burned at the stake.

I am suggesting that the thinking of politicians and scientists about controversial issues today is still tribal. Science and politics are not essentially different from other aspects of human culture. Science and politics are products of cultural evolution. Thinking about scientific questions is still presented to the public as a competitive sport with winners and losers. For players of the sport with public reputations to defend, it is more important to belong to a winning team than to examine the evidence. Cultural evolution was centered for a hundred thousand years on tales told by elders to children sitting around the cave fire. That cave-fire evolution gave us brains that are wonderfully sensitive to fable and fantasy, but insensitive to facts and figures. To enable a tribe to prevail in the harsh world of predators and prey, it was helpful to have brains with strong emotional bonding to shared songs and stories. It was not helpful to have brains questioning whether the stories were true. Our scientists and politicians of the modern age evolved recently from the cave-children. They still, as Charles Darwin remarked about human beings in general, bear the indelible stamp of their lowly origin.

In the year 1978, the United States Department of Energy drew up a 'Comprehensive Plan for Carbon Dioxide Effects Research and Assessment', which fixed the agenda of official discussions of carbon dioxide for the next 37 years. I wrote in a memorandum protesting against the plan:

The direct effects of carbon dioxide increase on plant growth and interspecific competition receive little attention. The plan is drawn up as if climatic change were the only serious effect of carbon dioxide on human activities...In a comparison of the non-climatic with the climatic effects of carbon dioxide, the non-climatic effects may be:

1. more certain,
2. more immediate,
3. easier to observe,
4. potentially at least as serious.

...Our research plan should address these issues directly, not as a mere side-line to climatic studies.

My protest received no attention and the Comprehensive Plan prevailed. As a result, the public perception of carbon dioxide has been dominated by the computer climate-model experts who designed the plan. The tribal group-thinking of that group of experts was amplified and reinforced by a supportive political bureaucracy.

Indur Goklany has assembled a massive collection of evidence to demonstrate two facts. First, the non-climatic effects of carbon dioxide are dominant over the climatic effects and are overwhelmingly beneficial. Second, the climatic effects observed in the real world are much less damaging than the effects predicted by the climate models, and have also been frequently beneficial. I am hoping that the scientists and politicians who have been blindly demonizing carbon dioxide for 37 years will one day open their eyes and look at the evidence. Goklany and I do not claim to be infallible. Like the climate-model experts, we have also evolved recently from the culture of the cave-children. Like them, we have inherited our own set of prejudices and blindnesses. Truth emerges when different groups of explorers listen to each other's stories and correct each other's mistakes.

Princeton
September 2015

Freeman Dyson FRS, a world-renowned theoretical physicist, is Professor Emeritus of Mathematical Physics and Astrophysics at the Institute of Advanced Study in Princeton where he held a chair for many years. Dyson is the author of numerous widely read science books. He is a member of the GWPF's Academic Advisory Council.

About the author

Indur Goklany is an independent scholar and author. He was a member of the US delegation that established the IPCC and helped develop its First Assessment Report. He subsequently served as a US delegate to the IPCC, and an IPCC reviewer. He is a member of the GWPF's Academic Advisory Council.

Summary

1. This paper addresses the question of whether, and how much, increased carbon dioxide concentrations have benefited the biosphere and humanity by stimulating plant growth, warming the planet and increasing rainfall.
2. Empirical data confirms that the biosphere's productivity has increased by about 14% since 1982, in large part as a result of rising carbon dioxide levels.
3. Thousands of scientific experiments indicate that increasing carbon dioxide concentrations in the air have contributed to increases in crop yields.
4. These increases in yield are very likely to have reduced the appropriation of land for farming by 11–17% compared with what it would otherwise be, resulting in more land being left wild.
5. Satellite evidence confirms that increasing carbon dioxide concentrations have also resulted in greater productivity of wild terrestrial ecosystems in all vegetation types.
6. Increasing carbon dioxide concentrations have also increased the productivity of many marine ecosystems.
7. In recent decades, trends in climate-sensitive indicators of human and environmental wellbeing have improved and continue to do so despite claims that they would deteriorate because of global warming.
8. Compared with the benefits from carbon dioxide on crop and biosphere productivity, the adverse impacts of carbon dioxide – on the frequency and intensity of extreme weather, on sea level, vector-borne disease prevalence and human health – have been too small to measure or have been swamped by other factors.
9. Models used to influence policy on climate change have overestimated the rate of warming, underestimated direct benefits of carbon dioxide, overestimated the harms from climate change and underestimated human capacity to adapt so as to capture the benefits while reducing the harms.
10. It is very likely that the impact of rising carbon dioxide concentrations is currently net beneficial for both humanity and the biosphere generally. These benefits are real, whereas the costs of warming are uncertain. Halting the increase in carbon dioxide concentrations abruptly would deprive people and the planet of the benefits of carbon dioxide much sooner than they would reduce any costs of warming.

Part I

The benefits of carbon dioxide

1 Introduction

Another process which withdraws carbonic acid [carbon dioxide] from the air is the assimilation of plants. ...[If] the percentage of carbon dioxide be doubled, the absorption by the plants would also be doubled. If, at the same time, the temperature rises by 4° , the vitality will increase in the ratio of 1:1.5, so that the doubling of the carbon dioxide percentage will lead to an increase in the absorption of carbonic acid by the plant approximately in the ratio of 1:3. An increase of the carbon dioxide percentage to double its amount may hence be able to raise the intensity of vegetable life...threefold.

Svante Arrhenius, *Worlds in the Making*

By the influence of the increasing percentage of carbonic acid in the atmosphere, we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind.

Svante Arrhenius, *Worlds in the Making*¹

The Swedish chemist Svante Arrhenius, winner of the 1905 Nobel Prize for Chemistry, was the first scientist to develop a quantitative relationship between the increase in atmospheric carbon dioxide and global surface temperature. In 1895 he gave a paper to the Stockholm Physical Society on 'The influence of carbonic acid in the air upon the temperature of the ground'. But this father of anthropogenic global warming theory (AGW) also understood, as should anybody who has ever taken high school biology, that carbon dioxide is plant food and essential to life on earth. From this insight, he deduced that an increase in atmospheric carbon dioxide concentration would benefit mankind by enhancing the growth of plants.

Anyone repeating Arrhenius's conclusion today risks being branded as a 'science denier' by some of the more committed proponents of the dangers of AGW. This group, which tends to see the spectre of global warming in almost every adverse weather event, has arguably had a disproportionate influence on the climate debate because influential elements of the media often conflate, or otherwise fail to sufficiently emphasize the distinction between, their views on global warming and the more nuanced opinions of careful scientists.^{2,3,4,5}

This paper will further explore Arrhenius's notion that, apart from its effects on climate, the direct effects of higher carbon dioxide levels may benefit mankind and the natural world. This is a departure from the vast majority of papers on global warming impacts, which focus instead on the potential damage from higher carbon dioxide levels. Based on the sheer volume of such papers, many believe that anthropogenic

greenhouse gas (GHG) emissions will result in rapid warming, that we are already witnessing its impacts, that these impacts are overwhelmingly negative, and that they will only worsen over time.^{6,7,8,9,10,11} The alleged impacts include escalating hunger, increases in malaria and other vector-borne diseases, accelerating sea level rise, more frequent and intense heat waves, storms, droughts, floods and other extreme events, diminished access to water, and species extinctions. These impacts will, it is claimed, reinforce each other, impoverishing populations and leading to a downward spiral in human and environmental wellbeing, which would be further exacerbated as people try to escape their fate through migration or by resorting to force to obtain food and water, the basic necessities of life.

But, as will be shown in Part II of this study, there is little or no empirical evidence that the warming that has occurred – or any changes it may have caused – since the end of the last ice age or since the putative start of manmade warming around 1950 is actually causing net harm or diminishing human or environmental wellbeing. Yes, there have been changes, but a change is not necessarily detrimental. In fact, the changes have frequently been beneficial, as will be discussed in Section 7, which deals with trends in various climate-sensitive indicators of human and environmental wellbeing. Yet these are routinely ignored in discussions of manmade global warming.

This paper argues that the benefits of increasing carbon dioxide have been underestimated, that the risks from increasing carbon dioxide have been overestimated, and that carbon dioxide emission reduction policies will start to reduce the benefits of higher carbon dioxide concentrations immediately, without reducing climate change and its associated costs until much later, if at all.

2 Impacts of carbon dioxide on biological productivity

Evidence for enhanced plant growth

That carbon dioxide is plant food has been known since the publication in 1804 of Nicolas-Théodore de Saussure's *Recherches Chimiques sur la Végétation*.¹² Thousands of experiments since then have shown that the majority of plants grow faster and larger, both above and below ground, if they are exposed to higher carbon dioxide concentrations. The owners of commercial greenhouses routinely pump in carbon dioxide so as to enhance the growth rates of plants, and the optimal level for plant growth is considered to be between 700 and 900 ppm,¹³ roughly twice today's ambient concentration of 400 ppm. However, plants may continue to respond positively at even higher carbon dioxide levels. For some species such as loblolly pine¹⁴ and cuphea,¹⁵ growth tops out at around 20,000 ppm or more. Indeed, it has been shown that the addition of supplemental carbon dioxide to a greenhouse enhances

the growth of lettuces even if the temperature of the greenhouse is lowered, thus causing a net decrease in the carbon footprint of the operation.¹⁶

A database of peer-reviewed papers assembled from studies of the effect of carbon dioxide on plant growth by the Center for the Study of Carbon Dioxide and Global Change (CSCDGC) shows that for the 45 crops that account for 95% of global crop production, an increase of 300 ppm of carbon dioxide would increase yields by between 5% and 78%.¹⁷ The median increase for these crops was 41% and the production-weighted yield increase was 34.6%.

Experiments also show that the benefits of carbon dioxide for plants are not restricted to faster and greater growth; the efficiency with which they consume water is also increased. Consequently, all else being equal, under higher carbon dioxide conditions, less water is needed to increase a plant's biomass by any given amount. In other words, higher carbon dioxide levels increase plants' ability to adapt to water-limited (or drought) conditions, precisely the conditions that are some environmentalists claim are already occurring – notwithstanding IPCC's findings to the contrary – or will occur in the future.

A recent experimental study on grasslands found that elevated levels of carbon dioxide further lengthened the growing season under warming conditions.¹⁸ The reason for the increased adaptability is that the size and density of stomata – tiny pores on the underside of leaves, which allow air, water vapour, and other gases to enter and leave the plant – are typically reduced as carbon dioxide levels increase. Thus higher carbon dioxide levels reduce water loss from the leaves. For the same reason, higher carbon dioxide levels reduce the rate at which ozone and other gases toxic to plants enter the plant, reducing the damage they inflict. In fact, Taub, in a summary article notes, 'Across experiments with all plant species, the enhancement of growth by elevated carbon dioxide is much greater under conditions of ozone stress than otherwise'.¹⁹

The IPCC AR5 WGI report acknowledges that '[f]ield experiments provide a [sic] direct evidence of increased photosynthesis rates and water use efficiency...in plants growing under elevated carbon dioxide'.²⁰ It also notes that this effect occurs in more than two thirds of the experiments and that net primary productivity (NPP) increases by about 20–25% if carbon dioxide is doubled relative to the pre-industrial level.²¹ Previously it had been argued that these increases might not be sustainable over the long term, but AR5 reports that new experimental evidence from long-term free-air carbon dioxide enrichment (FACE) experiments in temperate ecosystems show that these higher rates of carbon accumulation can be sustained for 'multiple years'.²²

In AR5, the IPCC says that the reduced carbon dioxide fertilisation effect seen in some experiments and the complete absence in others is 'very likely' due to nitrogen limitation in temperate and boreal ecosystems, and phosphorus limitation in the tropics, with a possible effect due to interaction with deficiencies of other micronu-

trients such as molybdenum.²³ The report concludes, '...with high confidence, the carbon dioxide fertilisation effect will lead to enhanced NPP, but significant uncertainties remain on the magnitude of this effect, given the lack of experiments outside of temperate climates'.

But the IPCC protests too much. It overstates the uncertainty regarding the magnitude of the effect under *real world* conditions. Consider managed ecosystems, particularly agriculture and forestry. Nutrient and micronutrient deficiencies are among the many routine challenges faced by farmers and foresters. Managing them is not *terra incognita*. Moreover, adaptations to cope with such deficiencies become more likely as technology inexorably advances and societies become wealthier, as indeed they are projected to become under all IPCC emission scenarios.^{24,25} Therefore, farmers and foresters should be able to adapt successfully, unless some technologies are foreclosed under a perverse application of the precautionary principle.²⁶ Such perversity, however, cannot be ruled out given the antipathy of many environmentalists towards biotechnology. Foreclosing options such as GM crops that would be more resistant to drought, water logging, or other adverse conditions will increase the likelihood that environmentalists' warnings – that AGW will lower food production and increase hunger – become self-fulfilling prophecies.

It has also been suggested that carbon dioxide enrichment inhibits the assimilation of nitrate into organic nitrogen compounds, which then may be largely responsible for carbon dioxide acclimation, and a decline in photosynthesis and growth of C3 plants, as well as a reduction in protein content because of the resulting increase in the C/N ratio.^{27,28,29} While the precise cause(s) and biochemical pathway(s) responsible for such acclimation are still being investigated, several approaches have been proposed to limit, if not overcome, such acclimation. These include making more nitrogen available to the plant to match the increase in carbon, for example through increased nitrogen fertilisation, greater reliance on ammonium rather than nitrate fertilizers, or improving nitrogen uptake and nitrogen-use efficiency through the development of new crop varieties via conventional breeding or bioengineering.^{30,31}

Present-day contribution of carbon dioxide to increases in crop yields

If more carbon dioxide increases the productivity of plants, how much have crop yields increased so far because of carbon dioxide increases since pre-industrial times?

Currently, the carbon dioxide level is at 400 ppm (0.04%). By comparison, the pre-industrial level is estimated to have been 277 ppm (0.028%).³² If one assumes that the carbon dioxide fertilisation effect on productivity increases linearly, then the AR5 estimate of a 20–25% yield increase for a doubling of carbon dioxide levels since pre-industrial times translates into a 9–11% yield increase so far. Alternatively, a 34.6% increase in yield from a 300-ppm increase in carbon dioxide concentration, as cal-

culated by the CSCDGC,* translates into a 15% yield increase due to anthropogenic emissions to date. These are underestimates if the growth response to increasing carbon dioxide levels bends downwards at higher concentrations.

These estimates suggest that a portion of the crop yield increases seen in recent decades, which most observers credit to technological change, should actually be credited to carbon dioxide fertilisation. A recent econometric analysis, which pooled sixty years of historical data on US crop yields with output from FACE trials and records of temperature, precipitation, and carbon dioxide levels, estimated that significant proportions of observed yield increases could be attributed to carbon dioxide rather than technological change (see Table 1).³³ These estimates suggest that the beneficial effect of carbon dioxide could be even greater than the 9–15% yield increase estimated by CSCDGC.

Table 1: Proportion of yield increases attributable to carbon dioxide

Crop	Proportion %
Cotton	51
Soybeans	15
Wheat	17
Corn	9
Sorghum	1

The same study also found that higher carbon dioxide levels are associated with lower variation in yields for each crop. This is consistent with the notion that increased carbon dioxide levels reduce the sensitivity of yield to other factors (e.g. water shortages and air pollution). All else being equal, lower variation translates into a more stable supply of food, as well as more stable food prices, which benefits all consumers everywhere.

Idso (2013) has attempted to translate these yield increases into a monetary value. He finds that over 50 years the extra produce grown by farmers has been \$274 billion for wheat, \$182 billion for maize and \$579 billion for rice, and that the current value of the carbon dioxide fertilisation effect on all crops is currently about \$140 billion a year. Of course, these numbers cannot be precise, but note that they are based on actual experimental data and existing yields, so they are far less speculative than monetary measures of the harm due to future climate change and its impacts on food security using models that have not been externally validated (see Section 8).³⁴

* See p. 5

Impact of carbon dioxide enrichment on pests and weeds

All crops are engaged in a battle of attrition with fungal parasites, insect predators and plant competitors, among other pests. Human intervention to help the crops prevail, using pesticides, genetic modification or by changing agronomic practices, is the main determinant of how much of the crop is lost. However, it is possible that carbon dioxide enrichment can improve the capacity of plants to resist pests.³⁵ Insects do not grow faster in higher concentrations of carbon dioxide, and while some experiments show that carbon dioxide enrichment reduces crop resistance to pathogens,³⁶ others show that it can help crops resist such enemies. For example, in one experiment doubling carbon dioxide levels in the air fully compensated for any growth reduction caused by a fungal pathogen in tomatoes.³⁷ In another study, the parasitic weed *Striga hermonthica*, which devastates many crops in sub-Saharan Africa, was shown to do only half as much damage to rice yields when carbon dioxide concentrations are doubled.³⁸

In another study, higher carbon dioxide levels were found to enhance the production of phenolic compounds in rice and, since these are known to inhibit the growth of the most noxious weeds in rice fields, the authors conclude that the rise in the air's carbon dioxide concentration may well 'increase plant resistance to specific weeds, pests and pathogens'.³⁹

Moreover, many crops are C3 plants and many weeds are C4 plants, which respond less to carbon dioxide enrichment. Thus as carbon dioxide levels rise, C3 crops may enhance their growth rates more than C4 weeds do. A Chinese experiment tested this idea by enriching carbon dioxide levels over plots of rice to almost twice the ambient level. This enhanced the ear weight of the rice by 37.6% while reducing the growth of a common weed, barnyard grass, by 47.9%, because the faster-growing rice shaded the weeds.⁴⁰ Figure 1 illustrates the differing responses to elevated carbon dioxide concentrations of rice, a C3 plant, and the green foxtail *Setaria viridis*, a grass sometimes proposed as a genetic model system to study C4 photosynthesis.^{41,42} It is worth noting that the vast majority of plants are C3, perhaps because higher carbon dioxide levels are more the norm in Earth's history.

Contribution of carbon dioxide to increases in biological productivity in unmanaged ecosystems

As early as 1985, Bacastow and colleagues detected a steady increase in the amplitude of seasonal variation in the carbon dioxide levels in the northern hemisphere,⁴³ and deduced that it implied an increase in summer vegetation. This was the first hint of global greening, a phenomenon now established by satellite observations. More recent aircraft-based observations of carbon dioxide above the north Pacific and the Arctic Ocean indicate that between 1958–61 and 2009–11 the seasonal amplitude at altitudes of 3–6 km increased by 25% for the northern hemisphere from 10°N to

Carbon dioxide: the benefits

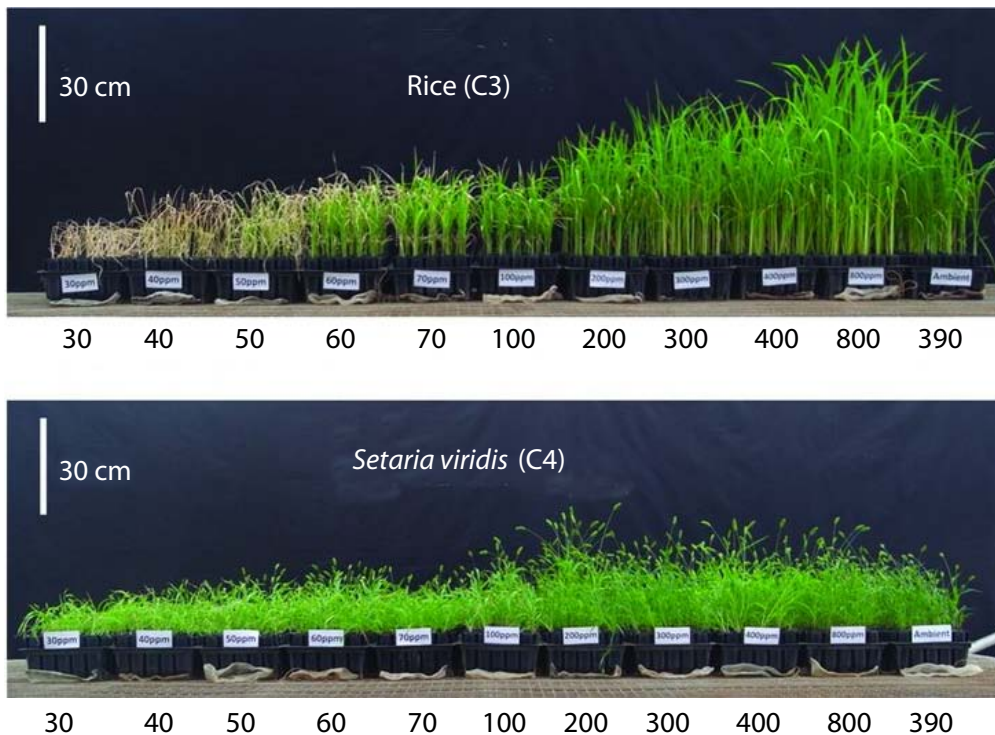


Figure 1: Carbon dioxide fertilisation of C3 crop and C4 weed

Source: von Caemmerer et al. (2012).

45°N, and 50% from 45°N to 90°N.⁴⁴ Satellite observations confirm that the increase in greenness of the globe is not confined to managed ecosystems (such as croplands), but is happening in unmanaged and lightly managed ecosystems too. Trend analysis of global greenness using satellite data indicates that from 1982 to 2011 – a period during which atmospheric carbon dioxide concentration increased by 15% – 31% of the global vegetated area became greener while 3% became less green (see Figure 2).⁴⁵

The productivity of global ecosystems has increased by 14% in aggregate. Notably, all vegetation types have greened,⁴⁶ including tropical rain forests, deciduous and evergreen boreal forests, scrubland, semi-deserts, grasslands and all other wild ecosystems, including those that do not even have indirect input of man-made nitrogen fertilizer. Some ecosystems show a relatively poorer response in NPP at higher carbon dioxide levels. The progressive nitrogen limitation (PNL) hypothesis⁴⁷ argues that this is due to nitrogen deficiency. However, the human activities that are major emitters of greenhouse gases – fossil fuel consumption and the use of nitrogen fertilizers for agriculture – also emit so-called ‘reactive’ nitrogen, which can be used directly or indirectly by biological organisms to grow. The concentration of N₂O has

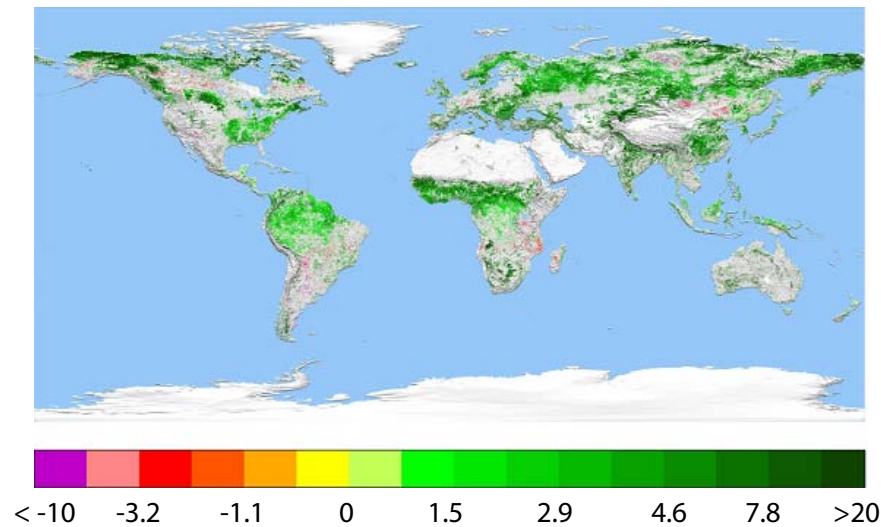


Figure 2: Greening of the Earth, 1982–2011

Trends in gross annual productivity per decade in percentage terms.
Source: Zhu & Myneni 2014

risen by 7% over those 30 years. However, the evidence regarding the PNL hypothesis is mixed.^{48,49,50,51,52,53,54}

The increased greening detected via satellite and aircraft measurements is consistent with the increases in crop yields seen over the past 50 years or more,^{55,56} but also with a bottom-up estimate of changes in the amount of carbon sequestered in forests.⁵⁷ These forest stock-and-flux estimates are derived from on-the-ground forest inventory data and long-term ecosystem carbon studies, and represent 3.9 billion hectares of global forests, or 95% of the total. They indicate that from 1990 to 2007 forests served as a net carbon sink, to the tune of 1.1 Pg C per year.

Other long-term on-the-ground observational records also find increased forest growth. For example, an analysis of data from unmanaged or lightly managed stands in central European forests, going back in some instances to 1870,[†] indicates that the volume of 75-year-old stands of the dominant tree species grew 10–30% faster in 2000 than in 1960.⁵⁸ The standing stock volumes were also greater in 2000 than in 1960, by 6–7%. Similarly, data ranging over 5–18 years indicate that carbon uptake increased in six out of seven forests across the northeast and midwest United States.⁵⁹

However, the 14% increase in global vegetation cannot be attributed entirely to higher carbon dioxide levels and nitrogen deposition: part of it could also be due to a more equable climate for plant growth, possibly because of AGW.

Donohoe et al. analyzed satellite observations after first processing them to re-

[†] Norway spruce and European beech.

move the effect of variations in rainfall.⁶⁰ Their results showed that the vegetation cover across arid environments, where water is the dominant constraint to growth, increased by 11% during the period 1982–2010, largely because of increased water-use efficiency by plants at higher carbon dioxide concentrations. Unfortunately, estimates of productivity increases solely from carbon dioxide increases are not available for other ecosystems or the globe as a whole.

Of course, increases in plant production are likely to result in increases in aggregate animal biomass too.

In summary, higher carbon dioxide levels increase both crop yields and biosphere productivity more generally.

3 Ancillary benefits of increased biospheric productivity

Improved human wellbeing

Higher agricultural yields reduce food prices in general. This provides a double dividend for humanity. Firstly, it reduces chronic hunger, but secondly a reduction in chronic hunger is the first step toward improvements in public health.^{61,62}

Reduced habitat loss and pressure on biodiversity

No less important, higher yields also provide a double dividend for the rest of nature. Firstly, they free up habitat for the rest of nature, which reduces the pressure on ecosystems. Had it not been for the increase in yields of 9–15%, global cropland would have had to be increased by a similar amount to produce the same amount of food, all else being equal. That figure means that an area equivalent to the combined area of Myanmar, Thailand and Malaysia has been saved from the plough. Secondly, land that has not been appropriated by humans also produces more food for other species. Consequently, this increases the aggregate biomass – that is, the product of number of species and representatives of each species – that the planet can sustain.

How much would the food available for other species have decreased in the absence of anthropogenic increases in atmospheric carbon dioxide? To calculate this figure, assume that:

- the productivity of unmanaged ecosystems also increased by 9–15% because of higher carbon dioxide concentrations (as estimated for crops)
- human beings currently ‘appropriate’ 25% of the earth’s NPP.⁶³

Therefore, had there been no anthropogenic increase in carbon dioxide, satisfying current human demand for food, timber, feed for domesticated animals and other plant-derived product would have required the share of NPP available for the

rest of nature to decline by 11–17%. Alternatively, if one assumes that human beings currently use 40% of global NPP⁶⁴ and retain the other assumptions intact then the present share of NPP available for the rest of nature would have had to decline by 14–22%. In either case, in the absence of any carbon dioxide fertilisation there would have been a significant increase in the number of species at risk of extinction.

Notably, one of the factors invoked to explain the latitudinal gradient in biodiversity – the greater abundance of species as one moves from the poles to the tropics – is greater ecological productivity.⁶⁵ It has also been suggested that an even more important factor might be that metabolic and other processes speed up as temperatures increase, consistent with the Arrhenius rate equation.^{66,67} Whatever the explanation, it reminds us that in a world with higher temperatures, at the very least the higher latitudes would support more biomass, other things being equal. The increasing amplitude of the seasonal variation in atmospheric carbon dioxide in these areas is one manifestation of this.⁶⁸

4 Impacts of higher carbon dioxide on water availability and irrigation requirements

It is generally expected that, if the globe warms, evaporation will increase, which should increase the amount of moisture in the atmosphere if relative humidity stays constant, as is generally assumed in climate models. Note, however, that long-term trends in pan evaporation from many areas around the world contradict this assumption.⁶⁹ More moisture in the atmosphere ought to increase total precipitation over the Earth's surface. However, the increased precipitation would be distributed unevenly, so some areas could become wetter, others drier. To exacerbate matters in the latter areas, the increased evaporation should reduce soil moisture, which could reduce the growth of vegetation and crop yields in rain-fed areas, and increase irrigation demand elsewhere. Increased evaporation should also reduce runoff, which would mean a reduction in water available for other human uses. However, each of these negative impacts may be partly, if not wholly, counteracted by the fact that higher carbon dioxide levels, by reducing the size of stomata, generally increase the water-use efficiency of plants. This should enable them to better cope with reduced soil moisture, reduce irrigation demand and, unless increased plant growth compensates for the increased water-use efficiency, increase runoff. Further complicating the overall picture are factors such as the variation of water-use efficiency with nutrient availability, the amount of sunlight exposure, and precipitation, and also the fact that stomatal density usually declines as atmospheric carbon dioxide increases.^{70,71}

Analyses of changes in the ratio of carbon isotopes in woody species over time suggest that intrinsic water-use efficiency has increased in many species in recent

decades but has plateaued in others and even declined in some instances.⁷² A recent study of unmanaged forest sites in the USA and elsewhere around the Northern Hemisphere found that carbon uptake and water-use efficiency had increased at the majority of sites.⁷³ Increases in the water-use efficiency exceeded projections by a range of biosphere models. Other studies have produced similar results for water-use efficiency:

- increases of 34–52% for two tropical forest species in Brazil from 1850–2000;⁷⁴
- an increase of 29% for rainforest trees in Sabah, Malaysia;⁷⁵
- an increase of 5–20% from 1974–2003 in a pine forest in the dry Mediterranean (Israel);⁷⁶
- an increase of 12% from pre-industrial to post-industrial times in a pine species in Finland.

However, a study of dwarf birch in Sweden and Finland found a plateauing rather than an increase.⁷⁷

In many cases, growth increases along with water-use efficiency, but there are exceptions.⁷⁸ An analysis of data from 47 study sites around the world found that from the 1960s to the 2000s, a period during which carbon dioxide concentrations increased by 50 ppm, intrinsic water-use efficiency in boreal, wet temperate, Mediterranean, semi-arid and tropical biomes increased by 20.5%.⁷⁹ However, for the 35 sites for which growth data were estimated, half showed a positive trend in growth, a third showed negative growth and the remainder showed no growth. According to the authors, this could have been due to drought, nutrient limitation or photosynthetic acclimation to carbon dioxide.

Regardless of whether, how and under what conditions carbon uptake and water-use efficiency are related, global ecosystem productivity increased by 14% from 1982–2011 (Figure 1),⁸⁰ while vegetation cover increased by 11% in *arid* areas from 1982–2010.⁸¹ And with regard to agricultural productivity, global crop yields have increased. For instance, from 1961 to 2013, cereal yields per hectare increased by 85% in the least developed countries and 185% worldwide. These yield increases show no sustained sign of decelerating (Figure 3).

It is unclear whether the increases in water-use efficiency have helped increase runoff and water availability for human uses.⁸² This is because changes in runoff can result from changes in a host of factors in addition to the physiological and morphological responses of stomata due to increased carbon dioxide.^{83,84} These include:

- changes in meteorological and climatic factors, such as precipitation, temperature, humidity, solar radiation and wind speed
- changes in land use and land cover
- other human modifications to adapt to or cope with water related problems, or take advantage of any opportunities.

Thus attributing runoff changes, if any, to carbon dioxide relies on computer modelling,^{85,86,87} but the results are fraught with uncertainty. Nevertheless, some studies indicate that, all else being equal, higher water-use efficiency could in the future reduce global irrigation demand and increase global runoff, which should reduce water stress.^{88,89,90,91} However, none of these studies included any allowance for human adaptation, so they exaggerate the net negative impact (and understate the positive). Konzmann et al. estimate that by the 2080s global irrigation demand will decline by '~17% in the ensemble median, due to a combination of beneficial carbon dioxide effects on plants, shorter growing periods and regional precipitation increases'. With respect to water availability, Wiltshire et al. estimate that the net global population at risk of high water stress will increase from 2.6 billion in 2000 to 4.1 billion in the 2080s because of population growth alone. However, under the IPCC's A1FI scenario (the one with the fastest warming), they expect this number to be reduced to 3.2 billion because of climate change (but ignoring the direct effects of carbon dioxide; see Figure 4).⁹² Direct carbon dioxide effects should further reduce the net population at risk of high water stress, to 2.9 billion. Notably, as indicated by Figure 4, the warmer the scenario, the greater the reduction in the population at risk of water stress from climate change alone. Similarly, the higher the carbon dioxide levels, the greater that reduction.

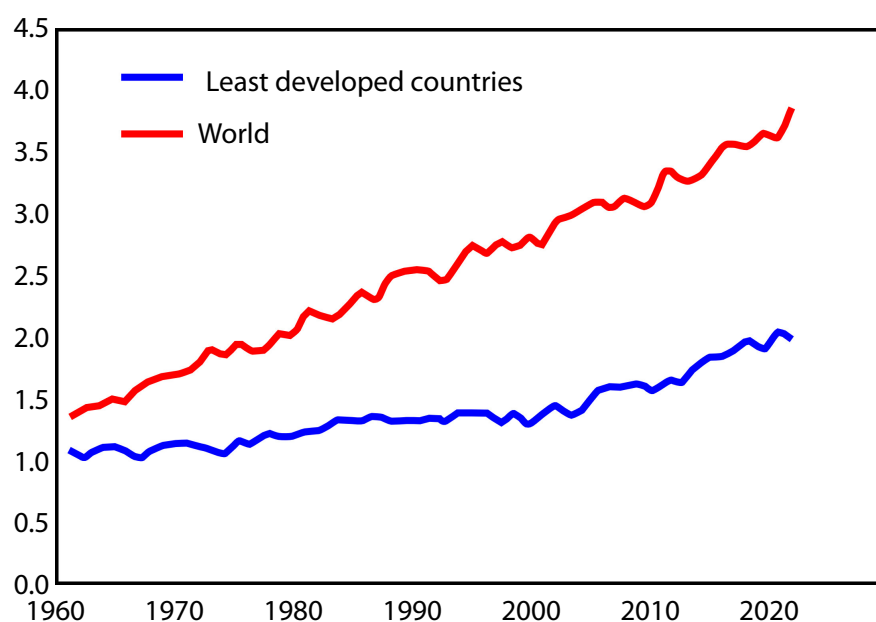


Figure 3: Cereal yields, 1961–2013

Tonnes per hectare. Source: FAOSTAT, October 6, 2014.

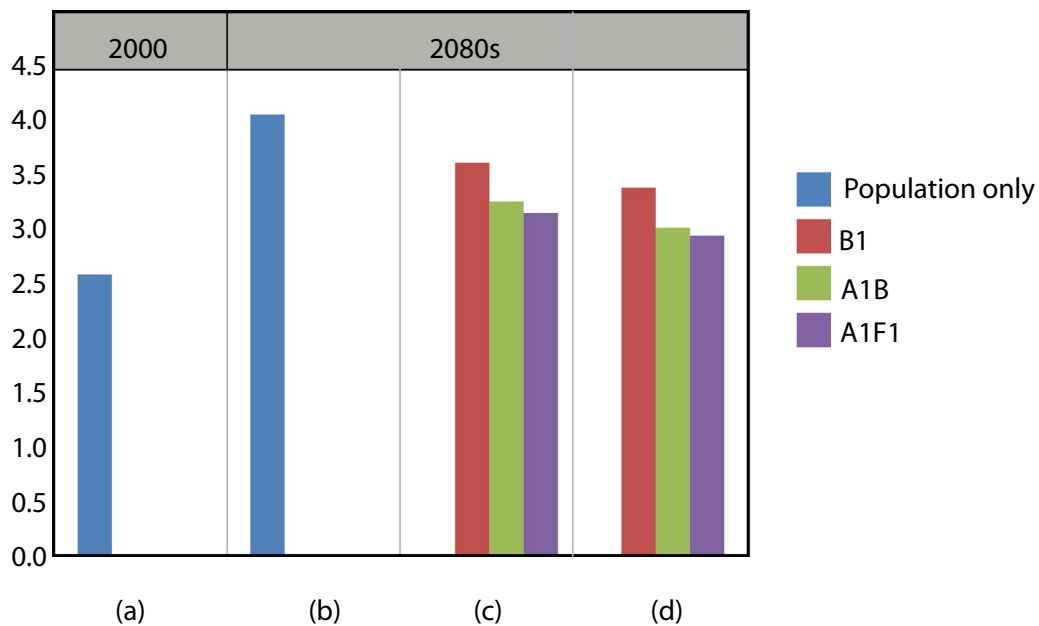


Figure 4: Population at risk of high water stress in the 2080s

Billions at risk. (a) Baseline per 2000, (b) For 2080 – no climate change but with increased population. (c) For 2080 – increased population and increased temperature. (d) Population, climate and carbon dioxide levels are different from 2000 levels. The B1, A1B and A1F1 scenarios correspond to global temperature increases in the 2080s of the order of 1°C, 2°C, and 3°C above the 2000 levels, respectively. Source: Wiltshire et al. (2013).

5 Impacts of higher carbon dioxide levels on marine life

Increasing carbon dioxide levels in the atmosphere clearly increase the growth rate of land plants, other things being equal. Is the same true for marine photosynthesisers such as algae, phytoplankton and symbiotic zooxanthellae in corals? Carbon dioxide dissolves in seawater and there is good evidence that this causes enhanced growth rates in many taxa. This is despite the fact that dissolved carbon dioxide forms bicarbonate ions, which slightly decrease the pH of the water, leading to what is often inaccurately called 'ocean acidification'. There is no likelihood of the ocean's average pH getting anywhere near as low as 7 because of elevated carbon dioxide concentrations during the next three centuries. Ocean pH currently averages about 8 and is forecast to fall by 0.2 pH units or so during the present century. This change is considerably smaller than the difference in pH between different parts of the ocean, different days in the same part of the ocean, and even different times of day in coral reef lagoons. An examination of upper-ocean pH for a wide variety of ecosystems ranging from polar

to tropical, open-ocean to coastal, kelp forest to coral reefs, indicates that variations in month-long pH spanned a range of 0.024 –1.430 pH units, and found that many organisms 'are already experiencing pH regimes that are not predicted until 2100.'⁹³ In other words, the projected change in pH is much smaller than the noise in its natural variation. So it is highly speculative that this small long-term trend will bring problems for marine life that are greater than the benefits of extra carbon dioxide for photosynthetic marine organisms and hence the whole marine biosphere.

Here follow some examples of studies finding positive or neutral impacts of lower pH on different groups of marine photosynthesisers:

Coccolithophores Iglesias-Rodriguez et al. found evidence that 'calcification and net primary production in the coccolithophore species *Emiliania huxleyi* are significantly increased by high carbon dioxide partial pressures' in the laboratory while 'field evidence from the deep ocean is consistent with these laboratory conclusions, indicating that over the past 220 years there has been a 40% increase in average coccolith mass.'⁹⁴ Coccolithophores are among the most abundant phytoplankton in the oceans. Notably, Duarte et al. classify the evidence for a decline of calcifiers due to ocean acidification for this century as weak.⁹⁵

Diatoms In diatoms, 'no significant change in the yield was found between the low and high carbon dioxide levels' and 'increased dissolved carbon dioxide concentration did not affect the mean cell size and cell volume of *Phaeodactylum tricornutum*'.⁹⁶

Foraminifera Vogel and Uthicke found that 'the species investigated were still able to build up their calcite skeletons in carbon dioxide conditions predicted for the year 2100 and beyond', and 'contrary to expectations, *M. vertebralis* showed significantly increased growth rates in elevated carbon dioxide'.⁹⁷

Marine algae and other marine plants In marine algae, many studies find that enhanced carbon dioxide results in faster growth. In other marine plants such as eel-grasses, Palacios and Zimmermann concluded that 'ocean acidification will stimulate seagrass biomass and productivity, leading to more favorable habitat and conditions for associated invertebrate and fish species'.⁹⁸ Indeed, according to Hendriks et al, the carbon dioxide fertilisation effect might reverse acidification: 'sea-grass photosynthetic rates may increase by 50% with increased carbon dioxide, which may deplete the carbon dioxide pool, maintaining an elevated pH that may protect associated calcifying organisms from the impacts of ocean acidification',⁹⁹ at least in their vicinity.

Thus for many primary producers in the ocean, increased levels of dissolved carbon dioxide will stimulate ecosystem productivity with positive implications for the food chain. Studies suggest that this effect will probably outweigh any drawbacks from slightly lower pH.

Could the same be true for corals? Corals build reefs by calcification, depositing

calcium carbonate in their skeletons. This process is energetically costly and the energy cost increases at lower pH. However, the energy is supplied by symbiotic zooxanthellae in the corals, which photosynthesise.¹⁰⁰ Thus the limiting factor on coral growth may be biological rather than chemical. Muscatine et al. conclude that 'symbiotic algae may control calcification by... modification of physico-chemical parameters within the coral polyps'.¹⁰¹ This could explain why the growth rate of coral reefs shows no signs of declining as predicted. As Kleypas et al. argue with respect to benthic corals, '[t]he drawdown of total dissolved inorganic carbon due to photosynthesis and calcification of reef communities can exceed the drawdown of total alkalinity due to calcification of corals and calcifying algae, leading to a net increase in aragonite saturation state'.¹⁰²

The general finding that calcifier organisms do not deposit less calcium when carbon dioxide concentrations increase is borne out by an experimental study by Findlay et al. using three molluscs, one barnacle and a brittle star. They write that 'contrary to popular predictions, the deposition of calcium carbonate can be maintained or even increased in acidified seawater'.¹⁰³ Similarly, a 'field growth experiment revealed seven times higher growth and calcification rates of [blue mussel *Mytilus edulis*] at a high carbon dioxide inner fjord field station... in comparison to a low pCO₂ outer fjord station...'.¹⁰⁴

Recent laboratory experiments to investigate the variation in the coral calcification rate of the scleractinian coral *Siderastrea siderea* – an abundant reef-builder in the Caribbean Sea – with warming and changes in pH found that under a more-or-less constant temperature of 28°C, calcification rates increased as atmospheric carbon dioxide was increased from near-pre-industrial levels of 324 ppm to 447 ppm, remained relatively unchanged at the predicted end-of-century value of 604 ppm and then returned to near-pre-industrial rates at 2500 ppm.¹⁰⁵ It also found that while holding the carbon dioxide level at 488 ppm, calcification rates increased as the temperature increased from 25°C to 28°C, but it declined by 80% when temperature was increased to 32°C. These results suggest that rapid ocean warming will pose a threat to *S. siderea* in the longer term but that ocean acidification will be little or no threat for several centuries. Moreover, the experimentally determined calcification rates might have been adversely affected by the disruption to the coral due to the need to cut, transplant and prepare it for analysis. No less important is the fact that the changes in pH and temperature were imposed over a period of just a few months. In the real world such changes would occur over a century or more, which means some adaptation cannot be precluded, for example via symbiont shuffling.¹⁰⁶

By far the largest peer-reviewed meta-analysis of the effect of ocean acidification upon marine life came to a strikingly unfashionable conclusion. Hendriks et al. studied the results of 372 experiments involving raised carbon dioxide levels on 44 species and found 'limited experimental support' for the theoretical predictions of negative

impacts of ocean acidification. Marine organisms, they conclude, are 'more resistant to ocean acidification than suggested by pessimistic predictions...', and thus this phenomenon 'may not be the widespread problem conjured into the 21st century'.¹⁰⁷

Although some corals are growing more rapidly because of increases in calcification rates perhaps due to, rather than despite, higher sea surface temperatures¹⁰⁸ and, possibly, higher carbon dioxide levels, in other areas they are being lost or degraded. The primary causes for the loss, however, are overfishing, pollution, coastal development, and dredging and blasting rather than manmade global warming.^{109,110}

6 Conclusion to Part I

Both satellite and in situ data show that biological productivity has increased globally for a broad range of managed, lightly managed and also unmanaged ecosystems. Although this increase is not universal, in aggregate increased biological productivity has increased food resources per acre over what they would be otherwise for both human beings and the rest of nature. Consequently, the earth is greener, farms are more productive, and the planet can support both a larger biomass and more human beings, precisely as surmised by Arrhenius over a century ago.

Part II

Human and environmental wellbeing

7 Empirical trends in climate-sensitive indicators of human wellbeing

Do the benefits of higher carbon dioxide concentrations identified in Part I translate into net benefits for humanity and the environment, or are they overwhelmed by the harmful effects of carbon dioxide? The benefits for the environment have been discussed in Sections 2 and 5. What follows is a brief discussion that compares some major claims¹¹¹ about the adverse impacts of global warming on human beings with empirical reality.

Crop yields

Crop yields have increased (see Figure 3) and global food production, far from declining, has actually increased in recent decades. Between 1990–92 and 2011–13, although global population increased by 31% to 7.1 billion, available food supplies increased by 44%. Consequently, the population suffering from chronic hunger declined by 173 million despite a population increase of 1.7 billion.¹¹² This occurred despite the diversion of land and crops from production of food to the production of biofuels. According to one estimate, in 2008 such activities helped push 130–155 million people into absolute poverty, exacerbating hunger in this most marginal of populations. This may in turn have led to 190,000 premature deaths worldwide in 2010 alone.¹¹³ Thus, ironically, a policy purporting to reduce AGW in order to reduce future poverty and hunger only magnified these problems in the present day.

Sea levels

Sea level has risen about 400 feet in the past 20,000 years, and continues to rise, albeit much more slowly than in many times past. That it continues to rise today is unremarkable. Its rise indeed signals a global warming, but not necessarily *anthropogenic* global warming. Anthropogenic global warming should cause an acceleration in sea-level rise but several observational studies have failed to detect one.^{114,115,116} IPCC AR5 notes that, 'it is likely that [global mean sea level] rose between 1920 and 1950 at a rate comparable to that observed since 1993'.¹¹⁷ Some studies actually indicate a recent *deceleration*. For example, Chen et al. find that the global sea level rose at a rate of 3.2 ± 0.4 mm/yr during 1993–2003, but that rate has decelerated since 2004. By 2012, the rate of rise had slowed significantly to 1.8 ± 0.9 mm/yr.¹¹⁸ Another study, however, suggests that, correcting for interannual variability, there has been no significant change in the rate of SLR.¹¹⁹ Consonant with this, yet another study indicates that 'it could be several decades before...[there is]...a discernable acceleration in individual tide gauge records'.^{120,121}

Precipitation

According to many climate change activists, wet areas will get wetter while dry areas will get drier.^{122,123} Therefore, both floods and droughts should become longer and more intense globally. The IPCC AR5 report confirms that CMIP5 models indicate that this will occur with *high confidence* although it hastens to add that empirical data are 'discordant' and, moreover, 'the models tend to underestimate observed trends in precipitation (Noake *et al.*, 2012) and its observed sensitivity to temperature (Liu *et al.*, 2012)'.¹²⁴ (Citations in the original.) The 'discordant' study, a recent analysis of monthly precipitation data over the global land surface from 1940 to 2009, indicates that the dry areas get wetter, while wet areas become drier.¹²⁵ Another study, using data from 1940–2005, found that in general there is no relationship one way or another; that is, for the most part dry gets neither drier nor wetter, and vice versa.¹²⁶ Clearly, it is premature to say that 'the science is settled.' Regardless, it is not surprising that globally floods and droughts have not followed the climate change script.

Extreme weather

Although there has been an increase in warm days, accompanied by a decline in cold days, there have been no general increases in the intensity or frequency of other weather extremes, such as hurricanes, tornadoes, floods, or droughts.^{127,128,129} Other recent studies confirm this for droughts¹³⁰ and floods.¹³¹ Tropical cyclones, a category that includes hurricanes and typhoons, are neither more frequent nor more powerful. Data from 1970 onward indicate that global and Northern Hemisphere accumulated cyclone energy is currently below average.¹³² There has not been a major hurricane landfall in the US since 2005 (as of this writing). Moreover, the average number of strong-to-violent tornadoes over the past few years is lower today than it was in the 1950s, 1960s or early-to-mid-1970s.¹³³

More importantly, despite a four-fold rise in population and much more complete reporting of such events, since the 1920s deaths from all extreme weather events, including those caused by extreme heat, have declined by 93%, while death rates have declined by 98%.¹³⁴

There has been no increase in economic losses from extreme weather once one accounts for the growth in aggregate wealth, a factor which automatically increases the economic assets at risk.¹³⁵

Disease

Claims that vector-borne diseases such as malaria will increase are also not borne out by the facts. The global mortality rate for malaria has declined: from 194 per 100,000 in 1900 to 9 per 100,000 in 2012, a reduction of 95.4%.^{136,137} Equally important, it is less prevalent and substantially less endemic in its reduced range.¹³⁸

Access to clean water and sanitation

Despite population increases, the numbers of people with access to cleaner water and improved sanitation have actually increased worldwide.¹³⁹ Between 1990 and 2012 an additional 2.3 billion people gained access to safer water, increasing the global population with such access from 75.9% to 89.3%, despite increases in population and any global warming. Over the same period, an additional 2.0 billion people got access to improved sanitation. The benefits of safer water and improved sanitation filter down to improvements in health and life expectancy.

Living standards

Despite claims that human wellbeing will suffer, living standards, measured by GDP per capita, have never been higher globally. Consequently, the absolute poverty rate – the share of population living on less than \$1.25 per day in 2005 dollars – was more than halved between 1981 and 2010. As a result, there were over 723 million fewer people living in absolute poverty in 2010 than in 1981 although the developing world's population increased by 2,174 million.¹⁴⁰ In low income countries, life expectancy, probably the single best indicator of human wellbeing, increased from 25–30 years in 1900 to 42 years in 1960 and 62 years today.¹⁴¹

8 Why are claims of damage failing to materialise?

Why have the imagined damages from global warming failed to materialize, and why do climate-sensitive indicators of human and environmental wellbeing continue to improve?

Reliance on chains of unvalidated models

Chains of models, cascades of uncertainty

The impacts of global warming are generally estimated using chains of linked computer models. Each chain begins with a climate model, which itself is driven by a set of socioeconomic scenarios based on assumptions for population, economic development and technological change over the entire period of the analysis (often 50–100 years or more). The climate model is followed by various biophysical, economic and other downstream models to estimate changes in different aspects of human activity or welfare, for example agriculture, forestry, health or biodiversity. The uncertain outputs of each upstream model serve as the inputs of the subsequent downstream model, with the uncertainties cascading down the chain so that the individual streams of uncertainty combine into a regular torrent.

For example, to estimate the impacts on agriculture and food security, the outputs of the climate model are fed into various crop models to estimate yields, which

then are linked to economic models to estimate supply and demand for the various crops. Supply and demand are then reconciled via national, regional and global scale trade models.¹⁴² Notably, despite the cascade of uncertainties, to date no climate change impact assessment has provided an objective estimate of the cumulative uncertainty, starting with the socioeconomic scenarios through to the impact estimate. The ranges of uncertainty presented in the IPCC impact reports are generally based on the uncertainties only from using different climate scenarios. But these are much narrower than the true uncertainties that would have been estimated had the full cascade of uncertainties been considered.

Models have not been validated

One reason that doom-laden predictions about the human wellbeing have failed is that orthodox climate scientists have neglected to apply the scientific method: specifically they have not checked their hypotheses and biases embodied in their models against empirical reality. As we have seen, simple reality checks show that environmental and human wellbeing is *not* currently deteriorating. Validation of these models using such reality checks would have limited their divergence from reality, and also reduce the uncertainties that are inevitably compounded as one progresses down the chain of models.

Climate models overstate global warming

Firstly, the global climate has not been warming as rapidly as projected in the IPCC assessment reports. Figure 5 compares observed global surface temperature data from 1986 through 2012 versus modelled results. It confirms that models have been running hotter than reality. But *these* are the projections that governments have relied on to justify global warming policies, including subsidies for biofuels and renewable energy while increasing the overall cost of energy to the general consumer – costs that disproportionately burden those that are poorer.

A comparison of performance of 117 simulations using 37 models versus empirical data from the HadCRUT4 surface temperature data set indicates that the vast majority of the simulations/models have overestimated warming.¹⁴³ The models indicated that the average global temperature would increase by $0.30 \pm 0.02^\circ\text{C}$ per decade during the period from 1993 to 2012 but empirical data show an increase of only $0.14 \pm 0.06^\circ\text{C}$ per decade.¹⁴⁴ Model performance was even worse for the more recent 15-year period of 1998–2012. Here the average modelled trend was $0.21 \pm 0.03^\circ\text{C}$ per decade, quadruple the observed trend of $0.05 \pm 0.08^\circ\text{C}$. Considering the confidence interval, the observed trend is indistinguishable from no trend at all; that is, warming has, for practical purposes, halted. Even the IPCC acknowledges the existence of this ‘hiatus’.¹⁴⁵ Moreover, the HadCRUT4 temperature database indicates that the global warming rate declined from 0.11°C per decade from 1951–2012 to 0.04°C per

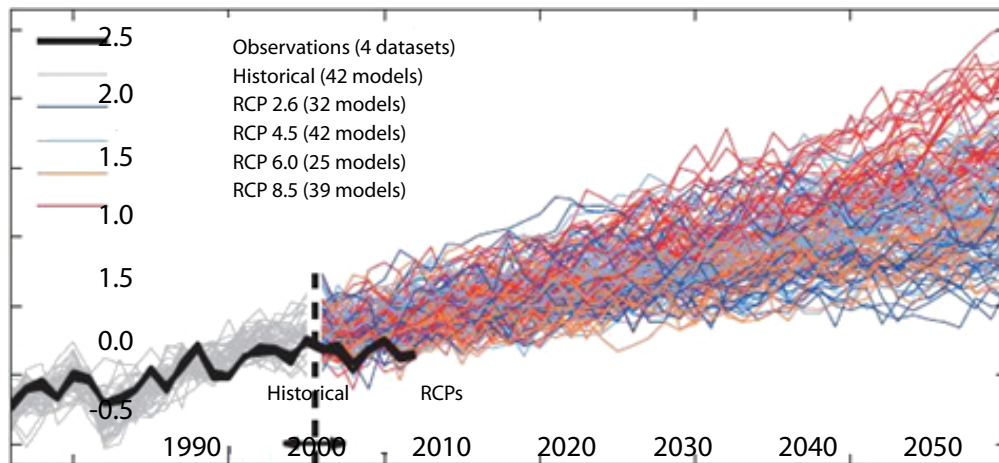


Figure 5: Models versus reality: global surface temperature anomaly

Figures in degrees centigrade. The observations are land-based measurements, 1986–2012. Source: IPCC, AR5 WG1 (2013), p. 1011.

decade from 1998–2012.¹⁴⁶ This is despite the fact that, per the IPCC, the anthropogenic greenhouse gas forcing for 2010 (2.25 W/m^2) exceeded what was used in the models for 2010 ($1.78\text{--}1.84 \text{ W/m}^2$) by around 25%.¹⁴⁷

Some have argued that satellite temperature data should be preferred over surface datasets. In fact, satellite coverage is more comprehensive and more representative of the Earth's surface than is achievable using surface stations, even if the latter were to number in the thousands. A recent review paper notes that satellites can provide 'unparalleled global- and fine-scale spatial coverage' presumably because of 'more frequent and repetitive coverage over a large area than other observation means'.¹⁴⁸ In addition, surface measurements are influenced by the measuring stations' microenvironments, which will vary not only from station to station at any given time, but also over time at the very same station, as vegetation and man-made structures in their vicinity spring up, evolve and change.¹⁴⁹

Satellite temperature data indicates that the globe has been warming at the rate of $0.12\text{--}0.14^\circ\text{C}$ per decade since 1979;¹⁵⁰ by contrast, the IPCC assessments over the last 25 years have been projecting a warming trend of $0.2\text{--}0.4^\circ\text{C}$ per decade.^{151,152} The differences between modelled trends and those from satellites and weather balloons are shown in Figures 6 and 7.¹⁵³

Nevertheless, based on these chains of unvalidated computer models, orthodox thinkers on climate change claim that global warming will, among other things, lower food production, increase hunger, cause more extreme weather, increase disease, and threaten water supplies. The cumulative impact will, they claim, diminish living standards and threaten species, and if carbon dioxide and other greenhouse gases are

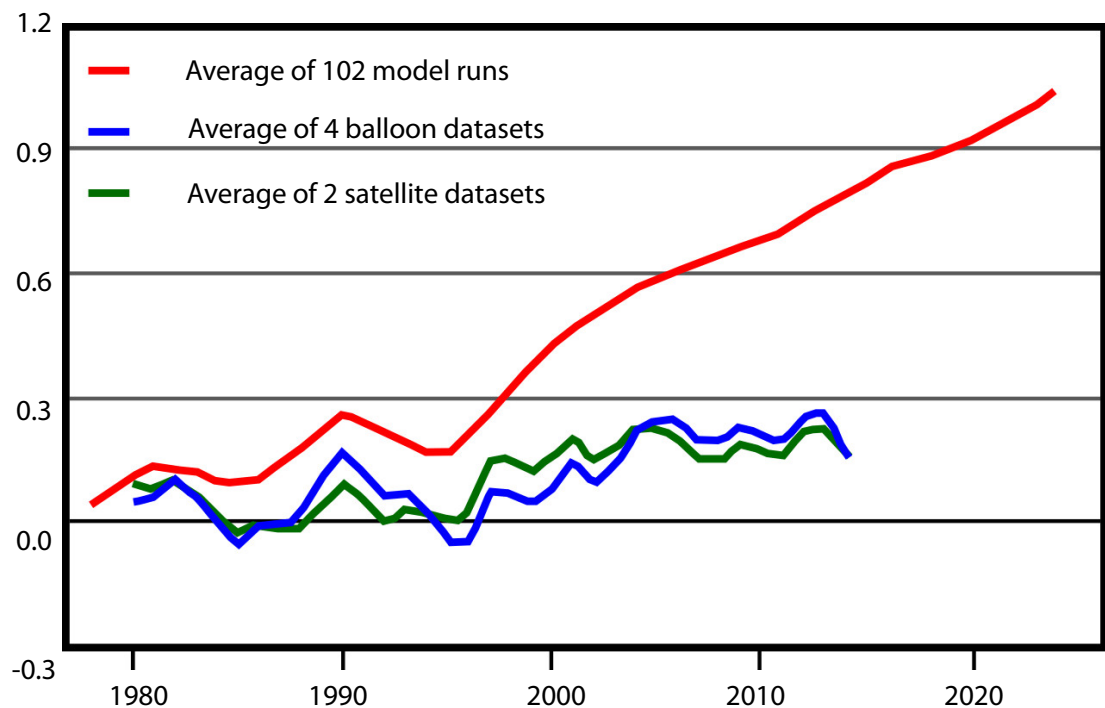


Figure 6: Models versus reality

5-year averages from models versus satellite and balloon data.

Source: Redrawn from McNider, Richard, and Christy, John, 'Why Kerry is flat wrong on climate change', *Wall Street Journal*, February 19, 2014s.

not curbed soon, pose an existential threat to humanity and the rest of nature. Some claim it may already be too late.¹⁵⁴ The group 350.org, for instance, agitates for reducing atmospheric carbon dioxide levels, currently at 400 ppm, to 350 ppm, a level the earth last experienced in 1988.¹⁵⁵ But since then, global GDP per capita has increased 60%, infant mortality has declined 48%, life expectancy has increased by 5.5 years, and the poverty headcount has dropped from 43% to 17% despite a population increase of 40%. Nostalgia for a 350 ppm world seems somewhat misplaced, if not downright perverse.^{156,157}

Climate models don't do local well

It is not clear what logical process was used to arrive at these allegations. It may stem from the fact that orthodox thinkers on climate, in the grip of confirmation bias, are unable or unwilling to acknowledge that, unless a climate or weather event is truly unprecedented then the default assumption – the 'null hypothesis' in scientific parlance – should be that it is part of normal climate variability rather than manmade global warming. Some have used the results of modelling exercises that purport to

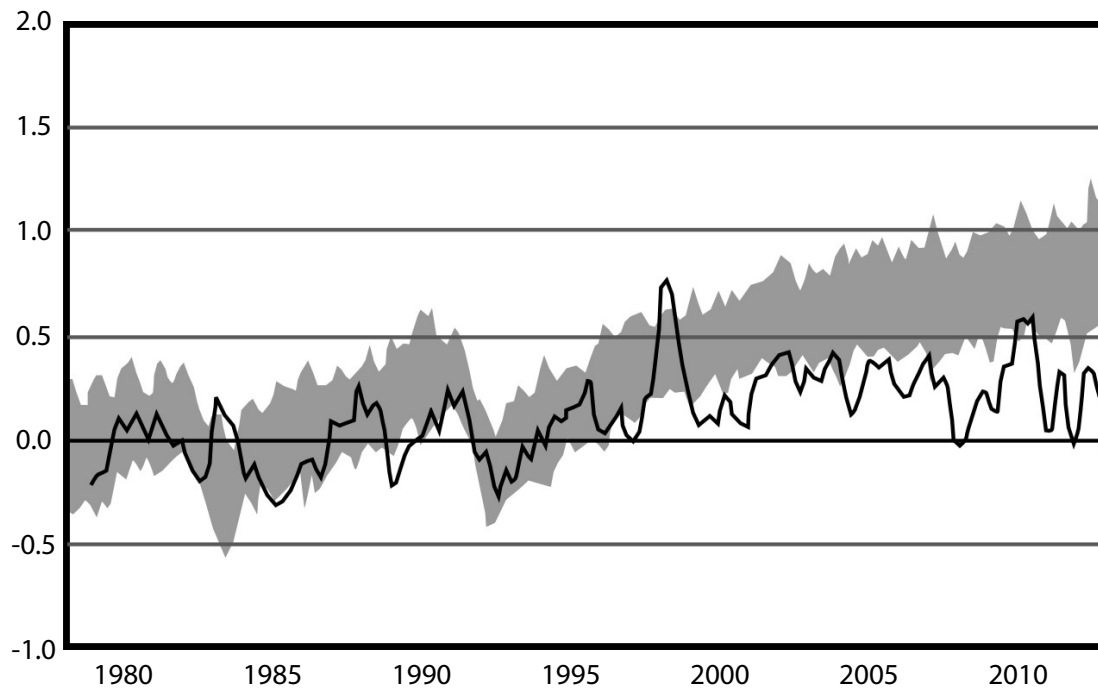


Figure 7: Models versus reality

Global (80S–80N) departure from 1979–84 mean temperature of the lower troposphere. Black line: satellite observations (RSS V3.3 MSU/AMSU); grey band: 5–95% range of output from CMIP5 climate models. Source: RSS.

assess the future impacts, usually in the latter part of this century, and then ‘interpolated’ these results back to the present day.^{158,159,160} The first step in such an exercise relies on climate models to project the future climate. But we have seen that these models have failed the reality test with respect to globally averaged surface temperature over the past two decades or more. To compound matters, the performance of climate models relative to reality worsens as one attempts to project surface temperatures at smaller geographical scales.

Climate models don’t do precipitation well

More importantly, the wellbeing of human beings and the rest of nature is probably more sensitive to changes in precipitation than temperature, and precipitation is highly variable from spot to spot. But climate models perform even worse for precipitation than they do for temperature, regardless of the geographic scale. In fact, for several areas many models are unable to reliably *hindcast* past precipitation, let alone forecast the future.^{161,162} Not surprisingly, precipitation projections using different models often contradict each other. For example, a recent study of annual precipitation changes in California using 25 model projections indicates that ‘12 projections

show drier annual conditions by the 2060s and 13 show wetter.’¹⁶³ Thus impact assessments that use as their starting point the outputs of these climate models cannot and should not be relied upon to develop policies, although they may have scientific diagnostic value for improving our understanding of climate mechanisms and processes.

Adaptation methodology is flawed

Failure to properly account for adaptation Even if climate models represented reality perfectly and were able to foretell the future climate, impact assessments would still be suspect. This is because most global warming impact assessments assume little or no endogenous (or autonomous) adaptation. For example, the vast majority of studies of global warming impacts on water resources do not incorporate *any* allowance for adaptive measures that might be taken to reduce those impacts, despite the fact that steps of this nature have been taken since time immemorial.^{164,165} For instance, the world’s oldest functioning dam, at Lake Homs in Syria, dates back to 1319 BC,¹⁶⁶ and *qanats*, underground canals to convey water for human settlements and irrigation, were built in Persia as long ago as the first millennium BC.¹⁶⁷ Similarly, of the many studies used by the IPCC to estimate future impacts on crop yields, 63% did not consider improvements in the agricultural sector’s adaptive capacity.¹⁶⁸

Moreover, specific adaptive measures used in many global warming impact studies are based on surveys of available technologies from the 1990s. However, today suitable adaptation measures are both more numerous and cheaper.¹⁶⁹ And because we are wealthier, these options are even more affordable.¹⁷⁰ Consequently, our ability to adapt has improved markedly just in the past few decades or so.¹⁷¹ As proof, consider the previously noted global increases in, for example, crop yields, access to safer water, and life expectancy on one hand, and reductions in poverty and mortality from vector-borne diseases and extreme weather events on the other. These examples suggest that neglecting adaptive capacity and technological change can, over the course of several decades, lead to estimates of impacts that are too pessimistic by an order of magnitude or more.¹⁷²

Another factor that is ignored in impacts assessments is the tremendous increase in our interconnectedness due to the internet, e-mail, text messages, and cell phones. As a result, the dissemination of knowledge is today far faster and wider than what was possible two or three decades ago. This increase in connectivity alone has considerably enhanced humanity’s adaptive capacity.¹⁷³

Also ignored is the array of technologies that are collectively called ‘precision farming’: the growing ability to monitor plant growth, nutrient deficiencies and the environmental conditions at finer scales, combined with techniques that use GPS and drones to more precisely deliver nutrients and water to crops. Today these technologies can be afforded by wealthy farmers in rich countries. Over time, they should,

like all other technologies, also diffuse around the world as their costs drop and as rising incomes make them more affordable. Such techniques should reduce agriculture's demand for water. Because agriculture is responsible for about 70% of global water consumption, this ought to free up water for other human uses and substantially reduce water stress.¹⁷⁴ A 20% increase in global agricultural water-use efficiency should, for example, translate into a global increase of 39% in water available for non-agricultural use.

Failure to fully account for benefits of carbon dioxide Although some studies of the impacts of global warming on agricultural production and food security include limited technological change, most do not include the beneficial impacts of carbon dioxide on photosynthetic rates or water-use efficiency. The IPCC AR5 synthesis of modelled estimates of the impact of recent climate trends on yields for major staple crops notes in a remarkable understatement that '[s]ome included effects of positive carbon dioxide trends...but most did not'.¹⁷⁵ In fact, only 2 of 56 studies considered carbon dioxide increases.¹⁷⁶ For this reason alone the IPCC's claim that the impacts of global warming to date on agricultural productivity and food security are likely negative is suspect. In fact, Lobell et al. (2011), which is one of the few studies that has attempted to estimate the 'historical' (i.e. present-day) impact of warming on agricultural productivity, notes that had their study incorporated the direct effects of carbon dioxide from 1980 to 2008 their results would have shown 'the net effects of higher carbon dioxide and climate change since 1980 have likely been slightly positive for rice and soybean, and negative for wheat and maize'.¹⁷⁷

Failure to account for benefits of warming Finally, assessments of climate change impacts usually give short shrift to the potential positive impacts of anthropogenic global warming. The first part of this paper attempted to provide a partial corrective by focusing on the benefits that increases in atmospheric carbon dioxide concentrations might bring. Note that the analysis and discussion here is focused on the global scale, and only on carbon dioxide increases rather than on warming itself. The benefits of warming, in terms of human health – notably reductions in winter deaths – longer growing seasons and other benefits could be substantial, particularly given that warming is predicted to occur disproportionately in winter, and at night.

Mortality data from several countries, regions and cities with cold, temperate, sub-tropical and even tropical climates show that average daily mortality is substantially higher in cold months than in warm months.^{178,179,180,181,182,183} Figure 8 displays the results of a systematic evaluation of the risk of mortality from non-accidental causes as a function of daily mean temperature for 306 communities in 12 countries.¹⁸⁴ Since additional deaths from exposure to hot or cold temperatures are known to accumulate for several days subsequent to actual exposure, the mortality rate was based on cumulative deaths over 21 days following (and including) exposure. The period over which these deaths accumulate is longer for cold temperatures than for hot

ones.¹⁸⁵ The methodology also apparently accounted for ‘mortality displacement’ or ‘harvesting’, which is the phenomenon that temperature-related deaths immediately following the temperature exposure are partially offset by fewer deaths in following weeks.¹⁸⁶ The graphs in Figure 8 show that for each country:

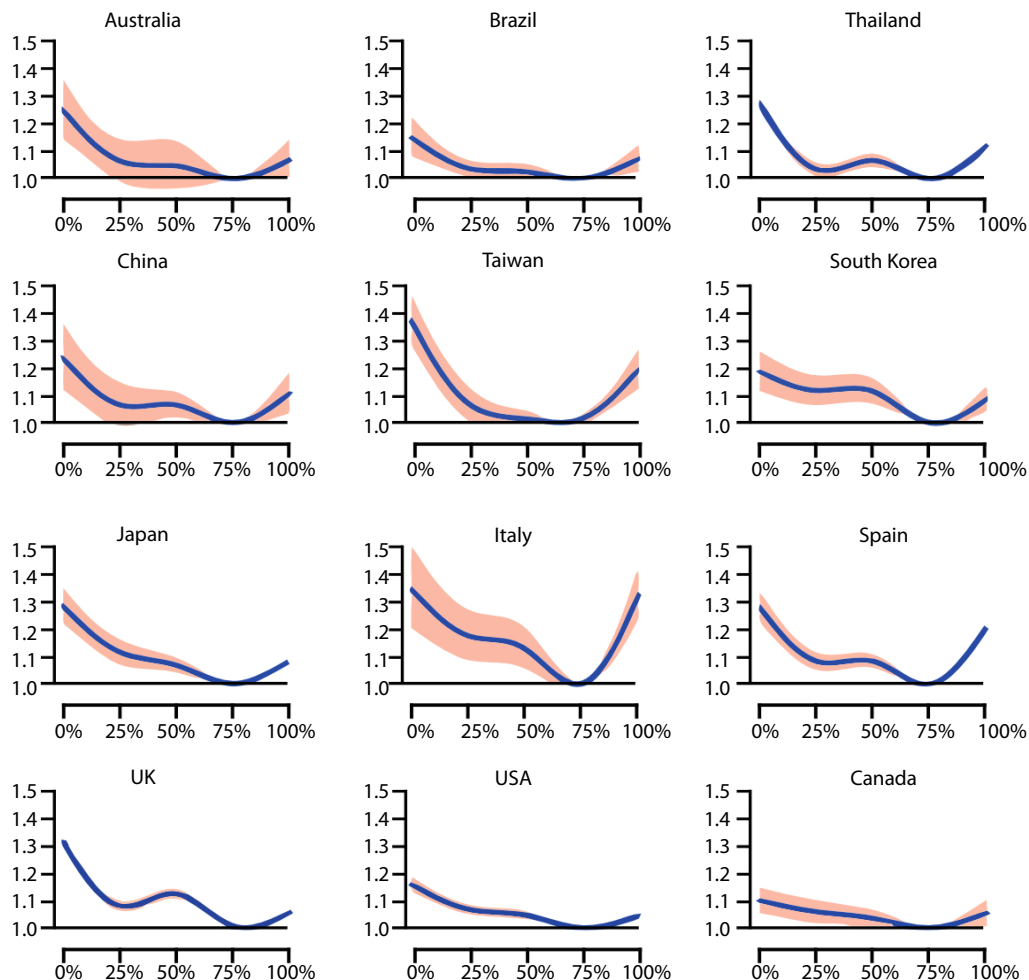


Figure 8: The risk of higher temperatures

Relative risk of mortality (y-axis) as a function of mean daily temperature plotted as the percentile of the entire temperature data. Data for each country was pooled. Source: Guo et al. (2014).

- The relative mortality risk is at a minimum between the 66th and 80th percentile of mean temperature. Nine of the twelve countries have an ‘optimum’ temperature between the 72nd and 76th percentiles.

- Relative mortality risk is substantially higher at the 1st percentile temperature (cold end) than at the 99th percentile (hot end).

Because (a) there are more days during the year that are cooler than the optimum, and (b) relative risk is higher at the cold end than the warm end, more deaths should be associated with temperatures that are colder than optimum than those that are warmer. Hence, if global warming merely slides each curve to the right wholesale, total mortality during the year should drop. This drop should be further magnified by the fact that global warming is supposed to warm winters more than summers, and nights more than days; the latter are nearly always warmer to begin with.

Remarkably, Figure 8 indicates that the risk of death is higher in the winter not only in countries in cold climates, but also in Thailand and Brazil. It also confirms human beings' general preference for warmer temperatures, something that is also manifested in the migration of retirees to warmer areas (e.g. the US 'Sun Belt' for North Americans or the South of France for the British). In these areas, the seasonal phenomenon of 'excess winter mortality' (EWM) – calculated as the increase in deaths during the four coldest months above what would have occurred had daily death rate stayed at the average level for the remainder of the year – is substantially higher than either deaths from extreme cold or extreme heat. For example, excess winter mortality claimed 89,300 people annually in the US from 2003–12, whereas extreme heat and cold annually on average killed 550 and 1 100 people respectively in 2006–2010.^{187,188}

Notably, the US EWM alone exceeds the total average annual deaths over the same 2003–12 period attributed *worldwide* not only to extreme temperatures (both cold *and* hot) – 14,400 – but to *all* extreme weather events – 35,200.¹⁸⁹ It is almost certainly also true for the European Union and Japan.¹⁹⁰ Consequently, because of global warming, a small decrease in global EWM could overwhelm any net increase in mortality from changes in the frequency and magnitude of extreme weather events.

The pattern of a higher death rate in the colder months also holds for all-cause mortality in tropical and subtropical areas in China,^{191,192} Bangladesh,¹⁹³ Kuwait,¹⁹⁴ and Tunisia.¹⁹⁵ Mortality rates apparently also peak in winter in Sao Paulo, Brazil; Mexico City and Monterrey, Mexico; Santiago, Chile, Cape Town, South Africa; and Nairobi, Kenya (see Figure 9).^{196,197} It is also the case for the southern US states of Florida, Texas, California and even Hawaii.¹⁹⁸ In addition, in Cuba, deaths from heart diseases and cerebrovascular diseases, which account for 37% of all deaths, peak in the colder (winter) months.¹⁹⁹

In summary

The approach used in impacts assessments therefore suffers from three fundamental flaws. Firstly, they rely on climate models that have failed the reality test. Secondly, they do not fully account for the benefits of carbon dioxide. Thirdly, they implicitly

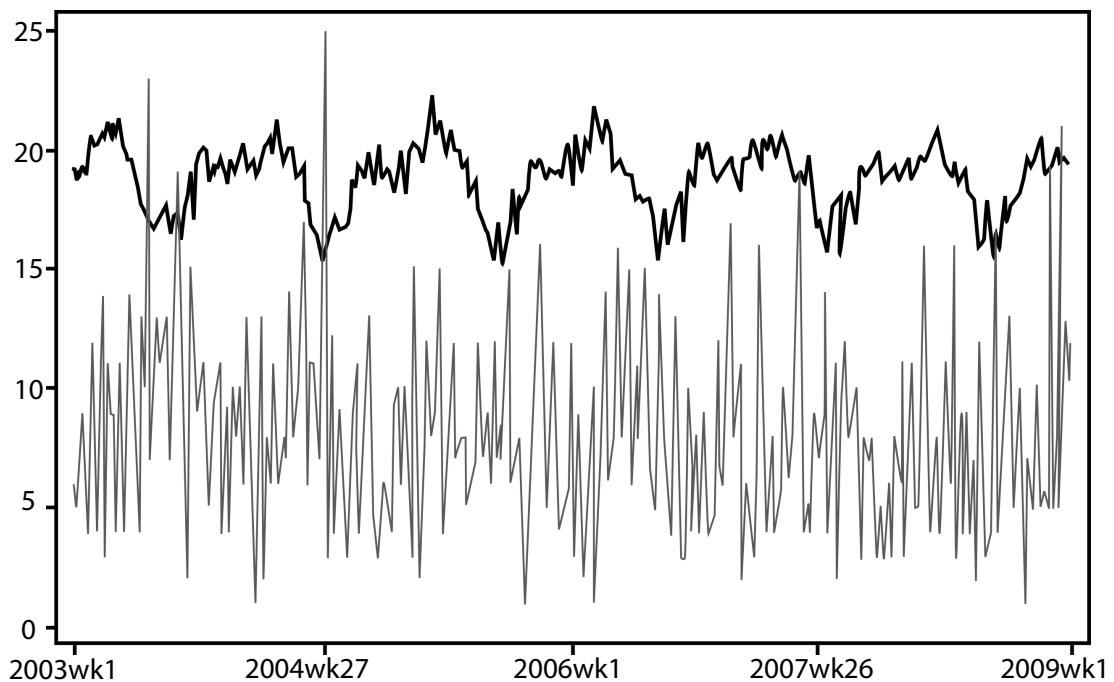


Figure 9: Cold risk in a warm country

Time series for all-cause (weekly) mortality and temperature ($^{\circ}\text{C}$) in Nairobi, Kenya. The highest rates of death occur during periods of relative cold, which coincides with high amounts of rainfall. Source: Egondi et al. (2012).

assume that the world of 2100 will not be much different from that of the present – except that we will be emitting more greenhouse gases and the climate will be much warmer.²⁰⁰ In effect, they assume that for the most part our adaptive capacity will not be any greater than today. But the world of 2015 is already quite different from that of 1990, and the notion that world of 2100 will be like that of the baseline year verges on the ludicrous. Moreover, this assumption directly contradicts

- (a) the basic assumption of positive economic growth built into each of the underlying IPCC scenarios
- (b) the experience over the past quarter millennium, of relatively rapid technological change and increasing adaptive capacity.

It is also refuted by any review of the changes that have taken place in the human condition and the ordinary person's life from generation to generation, at least as far back as the start of the Industrial Revolution.^{201,202}

9 Conclusions to Part II

Carbon dioxide levels have risen inexorably since the 1700s. Yet despite this, climate-sensitive indicators of human and environmental wellbeing that carbon dioxide affects directly, such as crop yields, food production, prevalence of hunger, access to cleaner water and biological productivity, and those that it affects indirectly, such as living standards and life expectancies, have improved virtually everywhere. In most areas they have never been higher, nor do they show any sustained signs of reversing.^{203,204}

10 Acknowledgements

I am grateful to Matt Ridley for his encouragement in undertaking this work, and for letting me use him as a sounding board. This work is immeasurably improved because of his reviews and comments on previous drafts. I am also grateful to Craig Idso, Will Happer, and other reviewers, for their insightful and constructive comments, , and to Andrew Montford for his careful editing of the manuscript. Any shortcomings in this paper, however, are my responsibility.

Notes

1. Svante Arrhenius *Worlds in the Making: The Evolution of the Universe*, Harper & Bros, New York, 1908, p. 56. The two quotes are found on pp. 56 and 63 respectively.
2. <http://thinkprogress.org/person/joe/>.
3. For example Gillis J (2014), <http://www.nytimes.com/2014/08/27/science/earth/greenhouse-gas-emissions-are-growing-and-growing-more-dangerous-draft-of-un-report-says.html>.
4. See, for example, Freedman A (2008), http://voices.washingtonpost.com/capitalweathergang/2008/01/ground\protect_truth.html.
5. For example, http://www.huffingtonpost.com/margie-alt/time-for-climate-deniers-\protect_b\protect_5768168.html?utm\protect_hp\protect_ref=green.
6. For example, Gillis J (2014), <http://www.nytimes.com/2014/08/27/science/earth/greenhouse-gas-emissions-are-growing-and-growing-more-dangerous-draft-of-un-report-says.html>.
7. For example, Freedman A (2008), http://voices.washingtonpost.com/capitalweathergang/2008/01/ground\protect_truth.html.
8. <http://www.weather.com/news/science/environment/10-signs-global-warming-happening-now-20130618>.
9. Press Release, Office of Sen. Ed Markey, Bicameral Task Force on Climate Change Applauds President Obama's Commitment to Climate Change Resilience Preparation (Nov. 1, 2013), <http://www.whitehouse.senate.gov/news/release/-bicameral-task-force-on-climate-change-applauds-president-obamas-commitment-to-climate-change-resilience-preparation>.
10. DARA (2012), *Methodology Note: Methodological Documentation for the Climate Vulnerability Monitor*, 2nd edn. Available at www.daraint.org/cvm2/method.
11. Global Humanitarian Forum (2009), *Anatomy of a Silent Crisis: Human Impact Report – Climate Change*, Geneva. Available at <http://www.ghf-ge.org/human-impact-report.pdf>.
12. In *Recherches chimiques sur la végétation* (1804; *Chemical Research on Vegetation*), Saussure proved Steven Hales's theory that plants absorb water and carbon dioxide in sunlight and increase in weight. He was thus one of the major founders in the study of photosynthesis. He further demonstrated that plants are dependent upon the absorption of nitrogen from soil. (*Encycl. Britannica*, <http://www.britannica.com/EBchecked/topic/525589/Nicolas-Theodore-de-Saussure>). 'Saussure, Nicolas-Théodore de', in *Complete Dictionary of Scientific Biography*, 2008. Encyclopedia.com, 25 Apr. 2014.
13. Mortensen LM (1987), Review: carbon dioxide enrichment in greenhouses: crop responses. *Scientia Horticulturae* 33:1–25.
14. Tisserat B and Vaughn SF (2003), Ultra-high carbon dioxide levels enhance loblolly pine seedling growth, morphogenesis, and secondary metabolism, *HortScience*,

38(6), 1083–1085.

15. Tisserat B, Vaughn SF, and Berhow MA (2008). Ultrahigh CO₂ levels enhances cuphea growth and morphogenesis. *industrial crops and products*, 27 (1), 133–135.
16. Frantz JM (2011), Elevating carbon dioxide in a commercial greenhouse reduced overall fuel carbon consumption and production cost when used in combination with cool temperatures for lettuce production. *Hortechonology* 21: 647–651.
17. Idso C (2013), *The positive externalities of carbon dioxide: Estimating the monetary benefits of rising atmospheric carbon dioxide concentrations on global food production*. Center for the Study of Carbon Dioxide and Global Change, 2013.
18. Reyes-Fox M, Steltzer H, Trlica MJ et al. (2014), Elevated carbon dioxide further lengthens growing season under warming conditions, *Nature* 510: 259–262, doi:10.1038/nature13207.
19. Taub DR (2010), Effects of rising atmospheric concentrations of carbon dioxide on plants. *Nature Education Knowledge* 1. Available at: <http://www.nature.com/scitable/knowledge/library/effects-of-rising-atmospheric-concentrations-23of-carbon-13254108>. Last accessed 1 October 2011.
20. IPCC AR5 WGI (2013), p. 502; citations omitted.
21. 277 ppm in 1755. IPCC AR5 WGI (2013), Annex II, p. 1401.
22. IPCC AR5 WGI (2013), Annex II, p. 1401.
23. IPCC AR5 WGI (2013), p. 502.
24. Goklany IM (2007), Is a richer-but-warmer world better than poorer-but-cooler worlds? *Energy & Environment* 18: 1023–1048.
25. Goklany IM (2012), Is climate change the number one threat to humanity? *Wiley Interdisciplinary Reviews: Climate Change* 3: 489–508, p. 499.
26. Goklany IM (2002), From precautionary principle to risk-risk analysis, *Nature Biotechnology* 20: 1075.
27. Bloom AJ, Burger M, Asensio JSR, and Cousins AB (2010), Carbon dioxide enrichment inhibits nitrate assimilation in wheat and Arabidopsis. *Science* 2010, 328: 899–903.
28. Kant S, Seneweera S, Rodin J et al. (2012), Improving yield potential in crops under elevated carbon dioxide: integrating the photosynthetic and nitrogen utilization efficiencies, *Frontiers in Plant Science*, 3: 162.
29. Bloom AJ, Burger M, Kimball BA, and Pinter PJ, Jr. (2014), Nitrate assimilation is inhibited by elevated carbon dioxide in field-grown wheat. *Nature Climate Change* 4: 477–480.
30. Bloom AJ, Burger M, Kimball BA, and Pinter PJ, Jr. (2014), Nitrate assimilation is inhibited by elevated carbon dioxide in field-grown wheat. *Nature Climate Change* 4: 477–480.
31. Kant S, Seneweera S, Rodin J et al. (2012), Improving yield potential in crops under elevated carbon dioxide: integrating the photosynthetic and nitrogen utilization

efficiencies, *Frontiers in Plant Science*, 3: 162.

32. IPCC AR5 WGI (2013), p. 1401.

33. Attavanich W, McCarl BA (2014), How is carbon dioxide affecting yields and technological progress? A statistical analysis, *Climatic Change* DOI 10.1007/s10584-014-1128-x.

34. Idso C (2013), The positive externalities of carbon dioxide. Center for the Study of Carbon Dioxide and Global Change.

35. Oliveira da Silva CE and Ghini R (2014), Plant growth and leaf-spot severity on eucalypt at different carbon dioxide concentrations in the air. *Pesquisa Agropecuária Brasileira* 49: 232–235.

36. Guo H, Sun Y, Ren Q, Zhu-Salzman K, Kang L, et al. (2012) Elevated carbon dioxide reduces the resistance and tolerance of tomato plants to *Helicoverpa armigera* by suppressing the JA signaling pathway. *PLoS ONE* 7(7): e41426.

37. Jwa NS and Walling LL (2001). Influence of elevated carbon dioxide concentration on disease development in tomato, *New Phytologist* 149: 509–518.

38. Watling JR and Press MC (2000). Infection with the parasitic angiosperm *Striga hermonthica* influences the response of the C3 cereal *Oryza sativa* to elevated carbon dioxide. *Global Change Biology* 6: 919–930.

39. Goufo P, Pereira J, Moutinho-Pereira J et al. (2014). Rice (*Oryza sativa* L.) phenolic compounds under elevated carbon dioxide (carbon dioxide) concentration. *Environmental and Experimental Botany* 99: 28–37.

40. Zeng Q, Liu B, Gilna B et al. (2011), Elevated carbon dioxide effects on nutrient competition between a C3 crop (*Oryza sativa* L.) and a C4 weed (*Echinochloa crusgalli* L.). *Nutrient Cycling in Agroecosystems* 89: 93–104.

41. von Caemmerer S, Quick WP, and Furbank RT (2012). The development of C4 rice: Current progress and future challenges. *Science* 336 (6089): 1671–1672.

42. Brutnell TP, Wan L, Swartwood K, Goldschmidt A et al. (2010), *Setaria viridis*: a model for C4 photosynthesis. *The Plant Cell Online*, 22(8), 2537–2544.

43. Bacastow RB, Keeling CD and Whorf TP (1985). Seasonal amplitude increase in atmospheric carbon dioxide concentration at Mauna Loa, Hawaii, 1959–1982. *Journal of Geophysical Research* 90: 529–10, 540.

44. Graven HD, Keeling RF, Piper SC et al. (2013), Enhanced seasonal exchange of carbon dioxide by northern ecosystems since 1960. *Science* 341: 1085–1089.

45. IPCC (2013), AR5 WG1, pp. 1401–2.

46. Zhu Z and Myneni RB (2014), A greener Earth (?) Global vegetation monitoring and modelling, Avignon, France, February 3 to 7, 2014.

47. Luo Y, Su B, Currie WS et al. (2004), Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide, *Bioscience* 54: 731–739.

48. Reich, PB and Hobbie SE (2013). Decade-long soil nitrogen constraint on the carbon dioxide fertilisation of plant biomass. *Nature Climate Change* 3(3): 278–282.

49. Dijkstra FA, Pendall E, Mosier AR et al. (2008), Long-term enhancement of N availability and plant growth under elevated carbon dioxide in a semi-arid grassland, *Functional Ecology* 22(6): 975–982.
50. Austin EE, Castro HF, Sides KE et al. (2009), Assessment of 10 years of carbon dioxide fumigation on soil microbial communities and function in a sweetgum plantation, *Soil Biology & Biochemistry* 41: 514–520.
51. Menge DNL, Hedin LO, Pacala SW (2012) Nitrogen and phosphorus limitation over long-term ecosystem development in terrestrial ecosystems. *PLoS ONE* 7(8): e42045. doi:10.1371/journal.pone.0042045
52. Ellsworth DS, Thomas R and Crous KY (2012), Elevated carbon dioxide affects photosynthetic responses in canopy pine and subcanopy deciduous trees over 10 years: a synthesis from Duke FACE, *Global Change Biology*, 18(1), 223–242.
53. Drake BG (2014). Rising sea level, temperature, and precipitation impact plant and ecosystem responses to elevated carbon dioxide on a Chesapeake Bay wetland: review of a 28-year study. *Global Change Biology* 20: 3329–3343.
54. Warren JM, Jensen AM, Medlyn BE, Norby RJ and Tissue DT (2015). Carbon dioxide stimulation of photosynthesis in *Liquidambar styraciflua* is not sustained during a 12-year field experiment. *AoB plants* 7: plu074.
55. FAOSTAT
56. Zeng N, Zhao F, Collatz GJ et al. (2014), Agricultural Green Revolution as a driver of increasing atmospheric carbon dioxide seasonal amplitude, *Nature* 515: 394–397.
57. Pan Y, Birdsey RA, Fang J et al. (2011). A large and persistent carbon sink in the world's forests. *Science* 333: 988–993.
58. Pretzsch H, Biber P, Schutze G et al. (2014), Forest stand growth dynamics in Central Europe have accelerated since 1870, *Nature Communications* 5, DOI: 10.1038/ncomms5967.
59. Keenan TF, et al. (2013), Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise, *Nature* 499.7458: 324–327.
60. Donohue RJ, Roderick ML, McVicar TR and Farquhar GD (2013) Carbon dioxide fertilisation has increased maximum foliage cover across the globe's warm, arid environments. *Geophysical Research Letters* 2013; DOI: 10.1002/grl.50563.
61. Fogel RW (1995), The contribution of improved nutrition to the decline in mortality rates in Europe and America. In: Simon JL (ed), *The State of Humanity*, Cambridge, MA: Blackwell, pp.61–71.
62. Goklany IM (2007), The improving state of the world: why we're living longer, healthier, more comfortable lives on a cleaner planet. Cato Institute.
63. This is in the same ball park as estimated by: Krausmann F et al. (2013), Global human appropriation of net primary production doubled in the 20th century. *PNAS* 110: 10324–10329.

64. Barnosky AD et al. (2012) Approaching a state shift in Earth's biosphere. *Nature* 486: 52–58.
65. Brown JH (2014) Why are there so many species in the tropics? *Journal of Biogeography* 41: 8–22.
66. Brown JH (2014) Why are there so many species in the tropics? *Journal of Biogeography* 41: 8–22.
67. This is qualitatively analogous to the notion of the velocity of money in economics. The faster money circulates the greater the economic growth, the wider the types of jobs, and more the number of jobs. Similarly, the faster the metabolic rate, the greater the number of species and their representatives.
68. Graven HD et al. (2013). Enhanced seasonal exchange of carbon dioxide by northern ecosystems since 1960. *Science* 341(6150): 1085–1089.
69. Roderick ML, Hobbins MT and Farquhar GD (2009). Pan evaporation trends and the terrestrial water balance. I. Principles and observations. *Geography Compass* 3(2): 746–760.
70. Royer DL (2001). Stomatal density and stomatal index as indicators of paleoatmospheric carbon dioxide concentration. *Review of Palaeobotany and Palynology* 114.1: 1–28.
71. Köhler, IH, Macdonald A and Schnyder H (2012). Nutrient supply enhanced the increase in intrinsic water-use efficiency of a temperate seminatural grassland in the last century. *Global Change Biology* 18.11: 3367–3376.
72. Gagen M et al. (2011) Evidence of changing intrinsic water-use efficiency under rising atmospheric carbon dioxide concentrations in boreal Fennoscandia from sub-fossil leaves and tree ring $\delta^{13}\text{C}$ ratios. *Global Change Biology* 17.2: 1064–1072.
73. Keenan TF et al. (2013) Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. *Nature* 499.7458: 324–327.
74. Hietz P, Wanek W and Dunisch O (2005) Long-term trends in cellulose $\delta^{13}\text{C}$ and water-use efficiency of tropical *Cedrela* and *Swietenia* from Brazil. *Tree Physiol* 25: 745–752. doi:10.1093/treephys/25.6.745
75. Loader NJ et al. (2011) Recent trends in the intrinsic water-use efficiency of ringless rainforest trees in Borneo. *Philosophical Transactions of the Royal Society B: Biological Sciences* 366.1582: 3330–3339.
76. Maseyk K et al. (2011) Increase in water-use efficiency and underlying processes in pine forests across a precipitation gradient in the dry Mediterranean region over the past 30 years. *Oecologia* 167.2: 573–585.
77. Gagen M et al. 2012 Evidence of changing intrinsic water-use efficiency under rising atmospheric carbon dioxide concentrations in boreal Fennoscandia from sub-fossil leaves and tree ring $\delta^{13}\text{C}$ ratios. *Global Change Biology* 17.2: 1064–1072.
78. Lévesque M, Siegwolf R, Saurer M, Eilmann B, and Rigling, A. (2014). Increased water-use efficiency does not lead to enhanced tree growth under xeric and mesic

conditions. *New Phytologist* 203(1): 94–109.

79. Peñuelas, J, Canadell JG and Ogaya R (2011) Increased water-use efficiency during the 20th century did not translate into enhanced tree growth. *Global Ecology and Biogeography* 20.4: 597–608.

80. Zhu Z and Myneni RB (2014), A greener Earth (?) Global vegetation monitoring and modelling, Avignon, France, February 3 to 7, 2014.

81. Donohue RJ, Roderick ML, McVicar TR and Farquhar GD (2013) carbon dioxide fertilisation has increased maximum foliage cover across the globe's warm, arid environments. *Geophysical Research Letters*. DOI: 10.1002/grl.50563.

82. IPCC AR5 WG2, Box CC-VW, p. 158.

83. Haworth, M, Elliott-Kingston C and McElwain JC (2013) Co-ordination of physiological and morphological responses of stomata to elevated [carbon dioxide] in vascular plants. *Oecologia* 171: 71–82.

84. Ukkola AM and Prentice IC (2013) A worldwide analysis of trends in water-balance evapotranspiration. *Hydrol. Earth Syst. Sci.* 17: 4177–4187.

85. Dai A, Qian T, Trenberth KE and Milliman JD (2009) Changes in continental freshwater discharge from 1948 to 2004. *Journal of Climate* 22(10): 2773–2792.

86. Ukkola AM and Prentice IC (2013) A worldwide analysis of trends in water-balance evapotranspiration. *Hydrol. Earth Syst. Sci.* 17: 4177–4187.

87. Saurer, M et al. (2014) Spatial variability and temporal trends in water-use efficiency of European forests. *Global Change Biology* 20.12: 3700–3712.

88. IPCC AR5 WG2, Box CC-VW, p. 158.

89. Gerten D et al. (2011) Global water availability and requirements for future food production. *Journal of Hydrometeorology* 12(5): 885–899.

90. Konzmann M, Gerten D and Heinke J (2013) Climate impacts on global irrigation requirements under 19 GCMs, simulated with a vegetation and hydrology model. *Hydrological Sciences Journal* 58(1): 88–105.

91. Wiltshire, Andrew, et al. "The importance of population, climate change and carbon dioxide plant physiological forcing in determining future global water stress." *Global Environmental Change* 23.5 (2013): 1083–1097.

92. Wiltshire, A et al. (2013) The importance of population, climate change and carbon dioxide plant physiological forcing in determining future global water stress. *Global Environmental Change* 23.5: 1083–1097.

93. Hofmann GE, Smith JE, Johnson KS, Send U, Levin LA, et al. (2011) High-frequency dynamics of ocean pH: A multi-ecosystem comparison. *PLoS ONE* 6(12): e28983. doi:10.1371/journal.pone.0028983

94. Iglesias-Rodriguez MD et al. (2008). Phytoplankton calcification in a high-carbon dioxide world. *Science* 320(5874): 336–340.

95. Duarte CM, et al. (2015), Reconsidering ocean calamities. *BioScience* 65(2): 130–139.

96. Li W, Gao K and Beardall J (2012). Interactive effects of ocean acidification and nitrogen-limitation on the diatom *Phaeodactylum tricornutum*. *PLOS ONE* 7: e51590.
97. Vogel N and Uthicke S (2012). Calcification and photobiology in symbiont-bearing benthic foraminifera and responses to a high carbon dioxide environment. *Journal of Experimental Marine Biology and Ecology* 424–425: 15–24.
98. Palacios SL and Zimmerman RC (2007). Response of eelgrass *Zostera marina* to carbon dioxide enrichment: possible impacts of climate change and potential for re-mediation of coastal habitats. *Marine Ecology Progress Series* 344: 1–13.
99. Hendriks IE, Duarte CM and Alvarez M (2010). Vulnerability of marine biodiversity to ocean acidification: a meta-analysis. *Estuarine, Coastal and Shelf Sciences* 86: 157–164.
100. Idso SB, Idso CD and Idso KE (2000). Carbon dioxide, global warming and coral reefs: Prospects for the future. *Technology* 75: 71–94.
101. Muscatine L et al. (2005). Stable isotopes ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) of organic matrix from coral skeleton. *Proceedings of the National Academy of Sciences USA* 102: 1525–1530.
102. Kleypas JA, Anthony KRN and Gattuso J-P (2011). Coral reefs modify their sea-water carbon chemistry—case study from a barrier reef (Moorea, French Polynesia). *Global Change Biology* 10.1111/j.1365–2486.2011.02530.x.
103. Findlay HS et al. (2009). Calcification, a physiological process to be considered in the context of the whole organism. *Biogeosciences Discussions* 6: 2267–2284.
104. Thomsen J et al. (2013). Food availability outweighs ocean acidification effects in juvenile *Mytilus edulis*: laboratory and field experiments. *Global Change Biology* 19(4): 1017–1027.
105. Castillo KD et al. (2014) The reef-building coral *Siderastrea siderea* exhibits parabolic responses to ocean acidification and warming. *Proceedings of the Royal Society B: Biological Sciences*. DOI: 10.1098/rspb.2014.1856
106. Silverstein RN, Correa AMS and Baker AC. 2012. Specificity is rarely absolute in coral–algal symbiosis: implications for coral response to climate change. *Proceedings of the Royal Society B* 279: 2609–2618.
107. Hendriks IE, Duarte CM and Alvarez M (2010). Vulnerability of marine biodiversity to ocean acidification: a meta-analysis. *Estuarine, Coastal and Shelf Sciences* 86: 157–164.
108. Lough JM, and Cantin NE (2014), Perspectives on massive coral growth rates in a changing ocean, *Biological Bulletin* 226: 187–201.
109. International Coral Reef Initiative (2014), Status of and threat to coral reefs: Why are coral reefs threatened? <http://www.icriforum.org/about-coral-reefs/status-and-threat-coral-reefs>, visited September 9, 2014.
110. Vega Thurber RL et al. (2014). Chronic nutrient enrichment increases prevalence and severity of coral disease and bleaching. *Glob. Chang. Biol.* 20: 544–554. 10.1111/gcb.12450.

111. See: <http://climate.nasa.gov/effects/#ft7> and <http://bit.ly/18ltQnO> and <http://huff.to/1pSWN4y>.
112. FAO (2013) Food security indicators, <http://bit.ly/14FRxGV>.
113. Goklany IM (2011) Could biofuel policies increase death and disease in developing countries? *Journal of American Physicians and Surgeons* 16(1): 9–13.
114. Gregory JM et al. (2013), Twentieth-century global-mean sea level rise: is the whole greater than the sum of the parts? *J. Climate* 26: 4476–4499.
115. Jevrejeva S, Moore JC, Grinsted A et al.(2014) Trends and acceleration in global and regional sea levels since 1807, *Global and Planetary Change* 113: 11–22.
116. See also <http://hockeyschtick.blogspot.com/2013/11/new-paper-finds-sea-level-rise-has.html>.
117. IPCC AR5 WG1 (2013), Chapter 13, p. 1150.
118. Chen X, Feng Y and Huang NE (2013). Global sea level trend during 1993–2012. *Global and Planetary Change* 112: 26–32.
119. Cazenave A, Dieng H-B, Meyssignac B et al. (2014), The rate of sea-level rise, *Nature Climate Change*. doi:10.1038/nclimate2159.
120. Haigh ID, Wahl T, Eelco JR and Price RM (2014), Timescales for detecting a significant acceleration in sea level rise. *Nature Communications* 5. DOI: 10.1038/ncomms4635.
121. University of Southampton. 'Back to the future to determine if sea level rise is accelerating.' *ScienceDaily*, 9 May 2014. www.sciencedaily.com/releases/2014/05/140509074116.htm.
122. NOAA/GFDL (2007) Will the wet get wetter and the dry drier? <http://www.gfdl.noaa.gov/will-the-wet-get-wetter-and-the-dry-drier>.
123. Lau WKM, Wu HT and Kim KM (2013), A canonical response of precipitation characteristics to global warming from CMIP5 models, *Geophys. Res. Lett.* 40: 3163–3169. doi:10.1002/grl.50420.
124. IPCC AR5 WG2 (2013), Chapter 3, p. 240.
125. Sun F, Roderick ML and Farquhar GD (2012), Changes in the variability of global land precipitation, *Geophys. Res. Lett.* 39: L19402. doi:10.1029/2012GL053369.
126. Greve P, Orłowsky B, Mueller B et al. (2014) Global assessment of trends in wetting and drying over land, *Nature Geoscience*. doi:10.1038/ngeo2247.
127. Pielke R, Jr, Statement to the Committee on Environment and Public Works, United States Senate hearing on climate change: It's happening now, 18 July 2013, available at <http://1.usa.gov/1oadXsM>.
128. IPCC SREX: IPCC (2012), Managing the risks of extreme events and disasters to advance climate change adaptation, pp. 6, 7.
129. IPCC WGI AR5 (2013), pp. 162, 163, 214, 215.
130. Hao Z, AghaKouchak A, Nakhjiri N and Farahmand A (2014), Global integrated drought monitoring and prediction system. *Scientific Data*. doi:10.1038/

sdata.2014.1.

131. Kundzewicz ZW, Kanae S, Seneviratne SI et al. (2014), Flood risk and climate change: global and regional perspectives, *Hydrological Sciences Journal* 59: 1–28. DOI: 10.1080/02626667.2013.857411

132. Maue R (2014), <http://polclimate.com/tropical/>, visited August 21, 2014.

133. See <http://www.ncdc.noaa.gov/climate-information/extreme-events/us-tornado-climatology/trends> and also <http://www.spc.noaa.gov/climo/online/monthly/newm.html>, visited August 21, 2014. Note that the count of strong-to-violent tornadoes is less likely to be affected by improvements in detection and measurement techniques over time.

134. Goklany IM (2011), Wealth and safety: the amazing decline in deaths from extreme weather in an era of global warming, 1900–2010. Reason Institute.

135. IPCC SREX: IPCC, 2012. Managing the risks of extreme events and disasters to advance climate change adaptation, p. 7.

136. WHO (1999), Roll back malaria. *World Health Report 1999*.

137. WHO (2013), *World Malaria Report 2013*, Annex 6B.

138. Gething PW, Smith DL, Patil AP et al. (2010), *Climate change and the global malaria recession*. *Nature* 465: 342–345.

139. Updated from Goklany IM (2011), ‘Economic development in developing countries: advancing human wellbeing and the capacity to adapt to climate change,’ in: Michaels PJ, ed., *Climate Coup: Global Warming’s Invasion of Our Government and Our Lives*. Washington, DC: Cato Institute, pp. 157–184, using World Development Indicators, visited August 18, 2014.

140. World Bank (2014), *PovcalNet*, at <http://iresearch.worldbank.org/PovcalNet/index.htm?1>, visited August 18, 2014.

141. World Bank (2014), *World Development Indicators*, 18 August 2014.

142. Demand for food and the prevalence of hunger and malnutrition depend as much on consumer incomes as on food prices which are constantly modulated by the opportunity to trade.

143. Fyfe JC, Gillett NP and Zwiers W (2013), Overestimated global warming over the past 20 years. *Nature Climate Change* 3: 767.

144. The number following the $\pm$ sign indicates the 95% confidence interval. Thus, a trend of $0.30 \pm 0.02^\circ\text{C}$ per decade informs the reader that the researchers are 95% confident that the decadal trend is between 0.28 and 0.32°C .

145. IPCC AR5 WG1 (2013): 769.

146. IPCC AR5 WG 1 (2013): 769

147. IPCC AR5 WG1 (2013), Annex II: 1435.

148. See, for example Yang J, Gong P, Fu R et al. (2013), The role of satellite remote sensing in climate change studies. *Nature climate change* 3(10): 875–883.

149. Goklany IM (2009), *Trapped between the falling sky and the rising seas: the imagined terrors of the impacts of climate change.* Prepared for University of Pennsylvania Workshop on Markets and the Environment, 13 December 2009.
150. Remote Sensing Systems (2014), at <http://www.remss.com/measurements/upper-air-temperature>, visited June 11, 2014; University of Alabama, Huntsville, MSU data, at <http://bit.ly/1Km1blX>. These data are for the temperature of the lower troposphere, which is slightly higher than the surface temperature. Therefore, the divergence between the model results and reality at the surface is greater than the numbers suggest.
151. IPCC 1992: 6.
152. IPCC WGI 1995: 6.
153. McNider R, and Christy J (2014), 'Why Kerry is flat wrong on climate change', *Wall Street Journal*, February 19.
154. <http://350.org>.
155. NOAA ESRL, <http://1.usa.gov/1EZDKaE>, visited 17 October 2014.
156. World Bank, World Development Indicators, <http://databank.worldbank.org/data/databases.aspx>, visited 18 October 2014.
157. World Bank, Povcalnet, <http://iresearch.worldbank.org/PovcalNet/index.htm?1>, 18 October 2014.
158. See for example McMichael A et al. (2004) Climate change. In: *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors* (Ezzati M et al. (eds). Geneva:World Health Organization, pp. 1543–1649.
159. DARA (2012), *Methodology Note: Methodological Documentation for the Climate Vulnerability Monitor*, 2nd edn. Available at: <http://www.daraint.org/cvm2/method>.
160. Global Humanitarian Forum (2009), *Anatomy of a silent crisis: Human impact report – climate change*, Geneva. Available at <http://www.ghf-ge.org/human-impact-report.pdf>.
161. Goklany IM (2009), *Trapped between the falling sky and the rising seas: the imagined terrors of the impacts of climate change*. Prepared for University of Pennsylvania Workshop on Markets and the Environment, draft, 13 December 2009: 12–13.
162. Goklany 2012: 491.
163. Pierce DW, Cayan DR, Das T et al. (2013), The key role of heavy precipitation events in climate model disagreements of future annual precipitation changes in California, *J. Climate*, 26: 5879–5896.
164. Goklany IM (2007), pp. 1034–35.
165. Goklany IM (2012), p. 499.
166. The world's oldest dams still in use. Water Technology website, October 21, 2013. <http://www.water-technology.net/features/feature-the-worlds-oldest-dams-still-in-use/>.

167. Qanats. WaterHistory.org website, <http://www.waterhistory.org/histories/qanats/Qanats>,
168. IPCC AR5 WG2, Chapter 7, p. 506, Figure 7–7. According to this figure, yields considering adaptation are marginally worse than yields without adaptation in tropical areas. Similarly, Figure 7–4, p. 498, indicates that maize yields in tropical areas would on average be lower with adaptation. Fortunately, Chapter 7 recognizes that such adaptations are unlikely to be implemented. See p. 516, Figure 7–8. However, such absurd results – and the amount of ink devoted to them in the chapter – do not inspire confidence in the impacts assessment.
169. Goklany IM (2012), 498–99.
170. Goklany IM (2007), Is a richer-but-warmer world better than poorer-but-cooler worlds? *Energy & Environment* 18: 1023–1048.
171. Goklany, IM (2007) Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development. *Mitigation and Adaption Strategies for Global Change* DOI 10.1007/s11027–007–9098–1. <http://goklany.org/library/Goklany-IAM2007.pdf>.
172. Goklany, IM (1996). *Factors affecting environmental impacts: the effects of technology on long term trends in cropland, air pollution and water-related diseases*. *Ambio* 25: 497–503.
173. Goklany, IM (2012). Is climate change the number one threat to humanity? *Wiley Interdisciplinary Reviews: Climate Change*. 3: 489–508.
174. Goklany IM (2007), The improving state of the world: why we’re living longer, healthier, more comfortable lives on a cleaner planet. Cato Institute, Washington, DC.
175. IPCC AR5 WG2, Chapter 7, p. 492, Figure 7–2.
176. Ibid. Remarkably, according to Figure 7–2, the studies that considered carbon dioxide suggest that the carbon dioxide effect reduces yields.
177. Lobell DB, Schlenker W and Costa-Roberts J (2011) Climate trends and global crop production since 1980. *Science* 333(6042): 616–620.
178. Guo Y, Gasparrini A, Armstrong B et al. (2014), Global variation in the effects of ambient temperature on mortality: a systematic evaluation. *Epidemiology*, 25 (6), 781–789.
179. Vardoulakis S, Dear K, Hajat S, Heaviside C and Eggen B (2014). Comparative assessment of the effects of climate change on heat-and cold-related mortality in the United Kingdom and Australia. *Environmental Health Perspectives* 122: 1285–1292.
180. Wu W et al. (2013) Temperature–mortality relationship in four subtropical Chinese cities: A time-series study using a distributed lag non-linear model. *Science of the Total Environment*, 449: 355–362.
181. Yi W and Chan AP (2014) Effects of temperature on mortality in Hong Kong: a time series analysis. *International Journal of Biometeorology*, 1–10.

182. Falagas ME, Karageorgopoulos DE, Moraitis LI, Vouloumanou EK, Roussos N, Pappas G and Rafailidis PI (2009). Seasonality of mortality: the September phenomenon in Mediterranean countries. *Canadian Medical Association Journal* 181: 484–6.
183. Goklany IM (2012), Global warming policies might be bad for your health. Global Warming Policy Foundation, London. ISBN: 978–0-9566875–7-9.
184. Guo Y et al. (2014) Global variation in the effects of ambient temperature on mortality: a systematic evaluation. *Epidemiology* 25(6): 781–789.
185. Deschenes O (2014) Temperature, human health, and adaptation: A review of the empirical literature, *Energy Economics* 46: 606–619.
186. Deschenes O (2014) Temperature, human health, and adaptation: A review of the empirical literature, *Energy Economics* 46: 606–619.
187. U.S. data updated from Goklany IM (2012), Global warming policies might be bad for your health. Global Warming Policy Foundation, London. ISBN: 978–0-9566875–7-9.
188. Berko J et al. (2014). Deaths attributed to heat, cold, and other weather events in the United States, 2006–2010. *National Health Statistics Reports* 76; 1–16.
189. EM-DAT (2014). The OFDA/CRED International Disaster Database. Université Catholique de Louvain. Available at <http://www.em-dat.net>. Data downloaded on 21 December 2014.
190. Goklany IM (2012), Global warming policies might be bad for your health. Global Warming Policy Foundation, London. ISBN: 978–0-9566875–7-9.
191. Wu W et al. (2013) Temperature–mortality relationship in four subtropical Chinese cities: A time-series study using a distributed lag non-linear model. *Science of the Total Environment* 449: 355–362.
192. Yi W and Chan AP (2014). Effects of temperature on mortality in Hong Kong: a time series analysis. *International journal of biometeorology*, 1–10.
193. Burkart K et al. (2011). Seasonal variations of all-cause and cause-specific mortality by age, gender, and socioeconomic condition in urban and rural areas of Bangladesh. *Int J Equity Health* 10(1): 32–32.
194. Douglas AS, al-Sayer H, Rawles JM and Allan TM (1991). Seasonality of disease in Kuwait. *Lancet* 337(8754): 1393–7.
195. Woodhouse, P.R. (1993). Why do more old people die in winter? *Journal of the Hong Kong Geriatric Society* 3: 23–29.
196. McMichael AJ et al. (2008). International study of temperature, heat and urban mortality: the 'ISOTHURM' project. *International Journal of Epidemiology* 37(5): 1121–1131.
197. Egondi T et al. (2012). Time-series analysis of weather and mortality patterns in Nairobi's informal settlements. *Global Health Action* 5: 23–32.
198. CDC, WONDER Database, Underlying cause of death, detailed mortality. Available at <http://wonder.cdc.gov/>.

199. Marie GC, González RT and Palanco IM (2009). Seasonal Variation in mortality for five main death causes. Cuba, 1996–2006. *The Internet Journal of Epidemiology* 6(2). Available at <http://bit.ly/1HjUDhG>, visited 6 May 2011.
200. The present is generally taken to be 1990, although some newer studies employ baselines in the early 2000s. See e.g. IPCC AR5 WG2 (2014), p. 498: ‘Some of the studies have associated temporal baselines, with centre-points typically between 1970 and 2005.’ Caption for Figure 7–4.
201. Ridley, *The Rational Optimist*.
202. Goklany IM, *Humanity Unbound*.
203. Ridley, *The Rational Optimist*.
204. Goklany, *The Improving State of the World*.

GWPF REPORTS

1	Montford	The Climategate Inquiries
2	Ridley	The Shale Gas Shock
3	Hughes	The Myth of Green Jobs
4	McKittrick	What Is Wrong With the IPCC?
5	Booker	The BBC and Climate Change
6	Montford	Nullius in Verba: The Royal Society and Climate Change
7	Goklany	Global Warming Policies Might Be Bad for Your Health
8	Hughes	Why Is Wind Power So Expensive?
9	Lilley	What Is Wrong With Stern?
10	Whitehouse	The Global Warming Standstill
11	Khandekar	The Global Warming-Extreme Weather Link
12	Lewis and Crok	Oversensitive
13	Lewis and Crok	A Sensitive Matter
14	Montford and Shade	Climate Control: Brainwashing in Schools
15	De Lange and Carter	Sea-level Change: Living with Uncertainty
16	Montford	Unintended Consequences of Climate Change Policy
17	Lewin	Hubert Lamb and the Transformation of Climate Science
18	Indur Goklany	Carbon Dioxide: The Good News

The Global Warming Policy Foundation is an all-party and non-party think tank and a registered educational charity which, while openminded on the contested science of global warming, is deeply concerned about the costs and other implications of many of the policies currently being advocated.

Our main focus is to analyse global warming policies and their economic and other implications. Our aim is to provide the most robust and reliable economic analysis and advice. Above all we seek to inform the media, politicians and the public, in a newsworthy way, on the subject in general and on the misinformation to which they are all too frequently being subjected at the present time.

The key to the success of the GWPF is the trust and credibility that we have earned in the eyes of a growing number of policy makers, journalists and the interested public. The GWPF is funded overwhelmingly by voluntary donations from a number of private individuals and charitable trusts. In order to make clear its complete independence, it does not accept gifts from either energy companies or anyone with a significant interest in an energy company.

Views expressed in the publications of the Global Warming Policy Foundation are those of the authors, not those of the GWPF, its trustees, its Academic Advisory Council members or its directors.

Published by the Global Warming Policy Foundation

For further information about GWPF or a print copy of this report, please contact:

The Global Warming Policy Foundation
40 Bank Street, London E14 5NP.
T 020 3059 4547
M 07553 361717

www.thegwpf.org

Registered in England, No 6962749
Registered with the Charity Commission, No 1131448

