

2. The Physics of a Crisis

Earth and Space

In spite of the differences and controversies about recent warming trends, there is one common denominator that ought not to garner any disagreement from anyone. Despite often heard claims that the Sun is not the cause of warming, in fact, just a little thought soon makes clear that actually it is present in *every* scenario, no matter how we look at things. It is indeed responsible for all but the minutest energy from other distant sources in the galaxy, or from the even remoter cosmic microwave background (Fig. 2.1). Thus, one way or another the Sun is always part of any climate scenario, whether directly, indirectly, or by any other less obvious means. If it were not for its energy, life could not exist. And we need to recognize that climate change can mean cooling instead, depending on the larger principles governing it. Things do not always have to get hotter.

Of the cosmic microwave background, precise measurements of extremely slight radiant energy allows us to peer deep into the farthest observable universe at the true remnants of the Big Bang itself, akin in layman's terms to glowing embers in a long extinguished fire. From this, we can readily determine the fractional energy spectrum remaining from any part; the colors of the illustration here are not actually true to the temperatures themselves, as the maximum shown represents a "tropical" 2.725 K, which is close to absolute zero. So marshmallows would likely take a while to toast...

At these temperatures there is, of course, no visual light as it appears here in this mapped image, but it helps to make the point. Interesting, too, is the remarkable unevenness of the distribution of energy, but that is a story for another book.

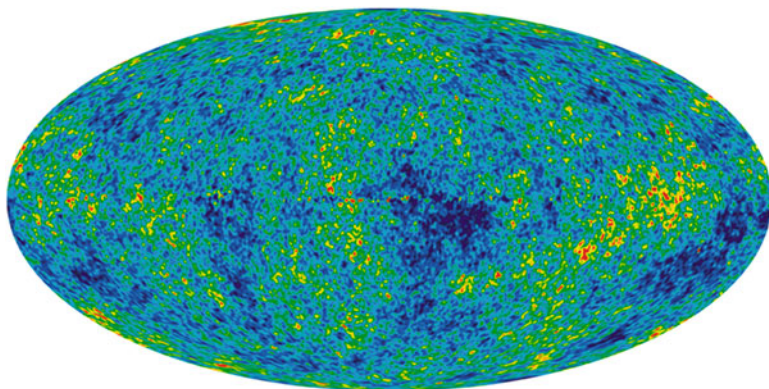


FIG. 2.1 The cosmic microwave background temperature fluctuations from the 7-year Wilkinson Microwave Anisotropy Probe data seen over the full sky (Image courtesy NASA/WMAP Science team)

Climate Mechanics

It will not be possible to proceed in any meaningful way unless we have some background of the principles underlying the mechanics of mainstream climate change. It is necessary to understand these theories to understand how they align or contrast with the various astronomical scenarios that are the focus of this book, and if presented in isolation would be almost meaningless. This chapter also offers some comparisons of different positions, since confusingly, there are often numerous interpretations of the same components.

The foundations laid, later chapters can focus on matters that some readers might not have been aware exist at all, perhaps having already concluded that there was nothing left to discuss or examine in broader detail. This involves substantial legitimate alternate, or differently oriented research into all aspects of climate change science.

The Greenhouse Effect

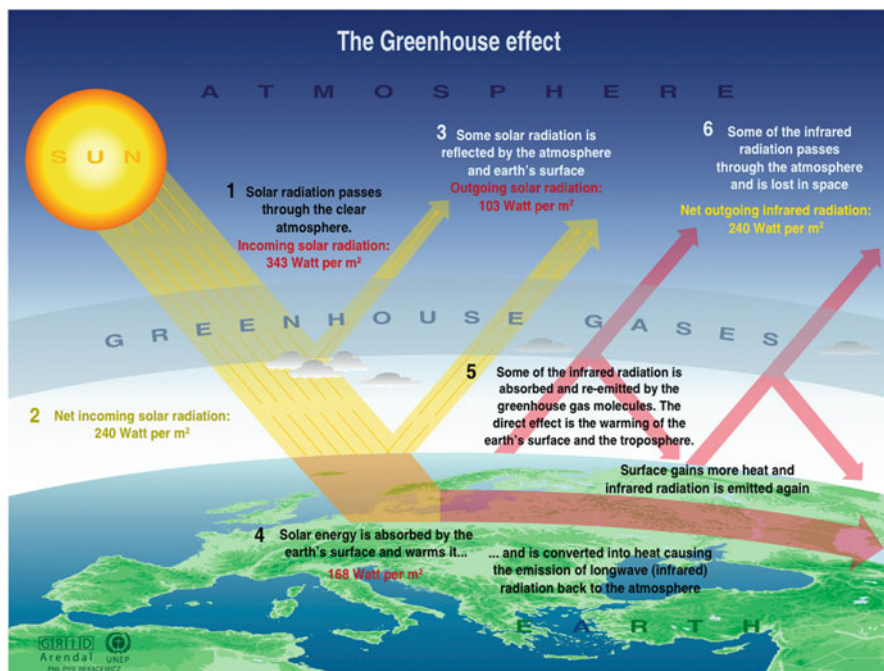
A starting point is to understand how electromagnetic energy from the Sun interacts with Earth and its surrounding atmosphere. What is not reflected is absorbed, re-radiated and compounded in a sequence of events known as the greenhouse effect. We should first understand what this actually is, as it is much misunderstood and usually only implies a negative phenomenon.

Inviting a parallel with glass greenhouses, the analogy has always been incorrect. Glass buildings derive their warming effect from the elimination of convection, and thus the literal trapping and heating of air confined to a small volume of space is responsible for the true greenhouse warming effect. Because this air is warmed by heat radiated directly from the ground below, it cannot re-radiate heat to the air all around it on the outside – actually, an entirely different process to that underlying that of the misnomer.

A common misconception is that the greenhouse effect is a recent phenomenon, caused entirely by increasing concentrations of carbon dioxide. In fact, we depend on it for our survival. Its largest constituent, water vapor, has ensured that the temperature of our environment stays within a livable range. The entire disagreement on climate change revolves around whether humans are artificially increasing Earth's greenhouse temperatures to unlivable levels.

What is not directly reflected back into space is absorbed and re-radiated by Planet Earth and its atmosphere. Only about 6% of the total solar energy absorbed is re-radiated directly back into space in the form of infrared wavelengths. The atmosphere absorbs the majority of the re-radiated energy, adding to the basic warming through a process of the subsequent continued re-radiation of infrared energy to molecules of surrounding atmospheric gases. Energy is thus re-radiated back and forth between molecules in an almost endless chain until all is eventually lost to space. However, more solar radiation continues to enter the environment. A balance is achieved when the lag between absorption and total loss keeps Earth at a habitable temperature. Despite this circular process, obviously, if further incoming radiation were to be blocked, all existing energy eventually would be dissipated away from Earth.

Earth's overall temperature is not a given constant and can change as a result of a variety of factors. Some might well be avoidable, and others not. The concern today is that warmth is being absorbed faster than it can be re-radiated to maintain a livable environment, because of additional greenhouse gas contributions. Figure 2.2 illustrates the basic mechanisms of the greenhouse effect, minus the influence of some variables, such as clouds and aerosols.



Sources: Okanagan university college in Canada. Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995. The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

FIG. 2.2 The greenhouse effect (Image courtesy of UNEP/GRID-Arendal Maps and Graphic Library (2002). Retrieved from <http://maps.grida.no/go/graphic/greenhouse-effect>)

Forcings and Feedback

In climate change science some other specific terms come with the turf. “Forcings” and “feedback” are perhaps the most common of these. We can have both positive and negative forms of both, depending on whether the net result is an addition or a loss of temperature. Generally speaking, positive forcings are those primary factors that initially add to the total energy equation, opposed to the secondary effects of positive feedback as existing matter re-radiates absorbed energy to other matter. Positive feedback is thus a secondary process, whereby matter that has been warmed via the primary forcing agent then radiates energy to other surrounding matter, only to return it back to the original matter in a circular fashion. This process compounds the warming effect.

The subject is somewhat diffusely defined, since many feedback gases, such as water vapor, also have forcing properties. Thus, gaining a precise understanding of the differences between both types of effects may be confusing. The IPCC has defined a forcing, technically, as:

a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism Radiative forcing values are for changes relative to pre-industrial conditions defined at 1750 and are expressed in watts per square meter (W/m^2).

Additionally, the IPCC's definition of feedback is:

an interaction mechanism between processes in the climate system ... when the result of an initial process triggers changes in a second process that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it.

Thus, in the loosest and simplest terms, radiant responses from water vapor, already part and parcel of the natural atmospheric environment, are considered overall as feedback, even when the primary effect may be partially that of a forcing. Depending on climatic conditions at the time, water vapor comes and goes rapidly. Thus, it is a highly variable and volatile component, unlike carbon dioxide (CO_2), and this goes to the crux as to why it is treated differently. Similarly, one might argue that although CO_2 exists in a natural state throughout the world (most CO_2 is, in fact, natural) and has been warmed partly by water vapor, that it should be considered feedback instead.

Water Vapor *Not* a Forcing Agent?

A German website, Allianz.com, declares that although water vapor is not a forcing agent, it amplifies existing warming.

Regardless of this confusing description or how one categorizes it, water vapor is responsible for 21 K of the total (33 K) natural greenhouse warming effect. Thus, Allianz's position illustrates the difficulties of separating forcings from feedback.

One could also argue that many activities of modern humans, such as the combustion of fossil fuels, lead to more water vapor in the atmosphere, and thus, it should be more accurately categorized as a forcing agent. It does absorb infrared radiation from Earth, albeit at different frequencies to CO_2 , and subsequently re-radiates it to other adjacent matter, which may result in the formation of more water vapor! So perhaps the easiest way to consider the primary difference between them really is to consider just the time of residence in the atmosphere. Since CO_2 resides in the atmosphere for a much longer period of time (more about this later), and mostly is increased by manmade emissions and activities (as opposed to by naturally occurring processes), it is considered a forcing agent.

Needless to say, the confusion may remain for many readers! The distinction between them still remains a fine line. For anyone wanting a more detailed description of these somewhat esoteric distinctions, an excellent and very readable analysis may be found online at RealClimate.org [1].

Beyond the warmth that we depend on for life itself, we need to know, therefore, how the various natural and anthropogenic forcings and feedbacks

- Interact with each other.
- Counteract each other.
- May result from the presence of another, and to what degree.
- Are counterbalanced, decreased or enhanced by aerosols (atmospheric particulates, solid or droplet).
- Are affected by varying degrees of Earth's albedo (the diffuse reflective properties of incident radiation by such a body of matter).

We could expand this short list almost limitlessly. More to the point, though, have we yet reached runaway status, whereby a chain of unstoppable forcings and feedbacks will take place in a cascade? Conversely, is there anything we can do – or should do – to mitigate these effects? Perhaps most significantly, is it all our fault, or at least partly so?

Black Bodies in Space

In addition to the fundamental mechanisms of Earth's "greenhouse," we need also to understand something of the physical

process whereby matter absorbs electromagnetic energy and re-radiates it at different wavelengths. This process is central to the principles involved in maintaining Earth's climate.

Let us consider first what is termed a "black body" (something existing only in the purest theoretical sense) – a hypothetical object that absorbs all electromagnetic radiation that falls upon it and re-radiates all of it as thermal radiation. At low temperatures, such objects, were they to exist, would appear perfectly black – invisible, in fact. Increasing temperatures of re-radiated thermal energy would cause spectral emissions ranging from red to white, with pure white objects (the hottest) emitting a substantial portion of energy in the ultraviolet part of the spectrum, depending on the level of extreme temperature at the upper end.

Let us imagine a black body of identical size, round shape and spectral makeup to the Sun. If it were to re-radiate all of the energy that it absorbs, what we would see would appear much the same as the Sun, having virtually the identical radiant power and spectrum. This scenario makes for an interesting and remarkably close comparison [2], also having a temperature of approximately 6,000°C, and would exhibit the pure white of the upper end of the spectrum, including ultraviolet wavelengths. Although the Sun itself isn't a black body, of course, since it generates its own radiation internally, the visual comparison is instructive, nevertheless.

For another example in the Solar System, let us look at Earth. Since it re-radiates a good portion of the energy it receives from the Sun in the form of low frequency invisible infrared waves, Earth is acting like a partial black body at the lower, cool end of the electromagnetic spectrum. It is partial because some of the Sun's radiation (in all wavelengths) is reflected back to space.

Initially, about 30% of incoming solar energy (including light wavelengths) is reflected (as well as scattered) directly back to space from the top of the atmosphere, by layers of clouds and Earth itself, which is what renders our world visible! What remains is absorbed by Earth and its atmosphere and re-radiated at low frequency infrared wavelengths into the surrounding atmosphere, land, oceans, and space.

Instinctively, even if the term is new to us, we already know about the concept of black bodies, since we think regularly in terms of "red-hot" and "white-hot" objects. Even if we have never considered it, though, we realize instinctively that with

increasing temperatures objects re-emit absorbed energy at higher wavelengths. We can envisage already how black bodies at low temperatures would appear by thinking of familiar things such as optical blacking, soot, black felt, velvet and the like, even though the latter examples would hardly survive any radical increasing temperature! The opposite, of course, to a black body would be a mirror-like object and other very shiny (reflective) surfaces that absorb very little energy.

Although electromagnetic energy cannot be destroyed, it can be transformed into energies of different wavelengths. The portion of solar energy that is intercepted by Earth must be accounted for in an energy equation. The total incoming radiation is measured at 342 watts per square meter (abr. 342 W/m²). Whether absorbed and retransmitted at lower wavelengths or reflected back into space, it represents a simple concept, although it is very complex in practice. Regardless, it all must add up and be accounted for.

Continuing to look at Earth as a partial black body, approximately 16% of incoming radiation is absorbed by the atmosphere and clouds, and the remaining 54% or so by the surface. Of the remaining 30%, that which is reflected is dependent on the specific planetary albedo, as well as the reflectivity and amount of cloud. The fraction that is scattered is dependent on the molecules of the atmosphere (a function of Rayleigh scattering) and aerosols, which may even include water droplets in the atmosphere (a function of the anomalous diffraction theory).

The 1971 NASA study called “Earth Albedo and Emitted Radiation” [3], summarized its conclusions with the following:

- Reflectance tends to increase with increasing solar angle.
- Continental areas have higher albedo values than ocean areas.
- Albedo increases with latitude due in part to the decreasing solar elevation angle, snow and ice near the poles, and increased cloud cover associated with large scale weather activity.
- Regions of dense cloud cover have higher albedo values.
- Albedo values for any region vary seasonally, primarily because of changes in cloudiness, vegetation and snow and ice cover (Fig. 2.3).

All in all, it is daunting to produce any realistic computation of the combined effect.

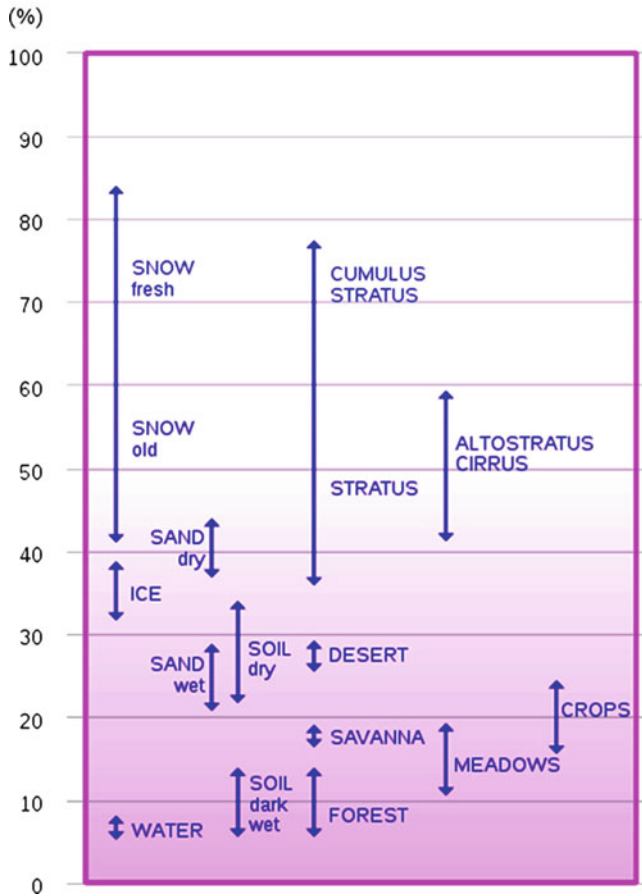


FIG. 2.3 Earth's albedo, in percentages according to surface and atmospheric conditions (Graphic by Hannes Grobe)

The albedos of different terrestrial surfaces, vegetation or clouds vary greatly. More specifically, desert and arid surfaces are reflective to some degree, but snow is almost entirely so; cold water is moderately reflective, warm water much less. The densest, lowest clouds tend to be the most reflective (by as much as 75% in some cases) and high cirrus clouds the least. However, the continuing variability of clouds as a whole makes exact measurements of their reflective properties among the most problematic components in the entire study of climate change.

The forcing and feedback effects of such large and variable amounts of potential cover and reflectivity are large, but the process may be a lot more complex than previously realized, as

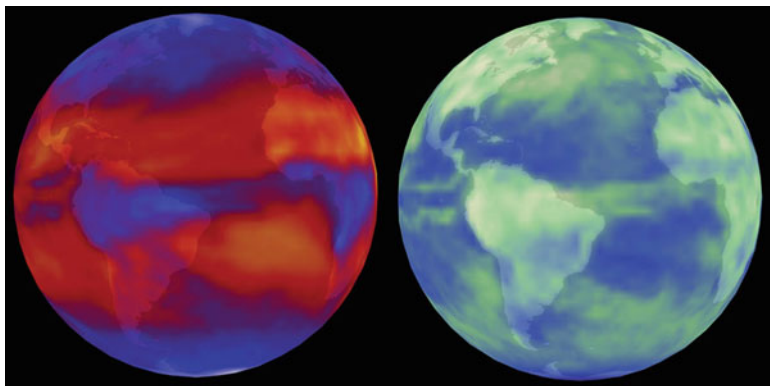


FIG. 2.4 The radiative properties of Earth. (*Left*) Heat given off by Earth's surface and atmosphere and radiated to space. (*Right*) Sunlight reflected out into space by land, oceans, clouds and aerosols (Data provided by the Atmospheric Sciences Data Center and CERES Science Team at NASA Langley Research Center; Image courtesy of Todd Bridgman, NASA Goddard Space Flight Center Scientific Visualization Studio)

shown in the study by Timothy Andrews and Piers M. Forster [4]. Although Earth's albedo determines how incident radiation is reflected, the remainder is absorbed, to be re-radiated at low frequencies. This is clearly demonstrated in Fig. 2.4.

Theoretically, at least by calculation, the direct effects of the Sun should warm Earth from absolute zero (0 K, or -273.15°C) to 270 K. Because Earth does not absorb all the incident energy, its actual direct warming is estimated to be only approximately 254 K. Again, by calculation, scientists have deduced the total warming due to greenhouse gases to be approximately 33 K, to give a total average global temperature of approximately 287 K, or 13.85°C .

The Atmosphere and Interactions with Solar Radiation

During the forcing process, radiation absorbed by Earth and its atmosphere is re-radiated in all directions to adjacent molecules. In greenhouse warming, it is mostly the absorption by the constituent gases of the atmosphere that creates the effect. In turn the process continues as these molecules re-radiate to other molecules during the feedback process.

CO₂ would seem to be the only changing factor measured with certainty over the past 40 years. Changing concentrations of, say, water vapor have been much harder to determine. Depending on the source for exact amounts, the total amount of CO₂ in the atmosphere today stands about ± 100 ppmv higher than it did before industrial times, or approximately 32%. Different estimates shade this amount up or down a little, but it is a good reference point for our purposes.

Perhaps surprisingly, most of the minor constituents of the atmosphere exist essentially in uniform concentrations throughout its volume, regardless of altitude; carbon dioxide occupies surprisingly little of it at $\pm 0.0388\%$, although next to water vapor it is the leading greenhouse gas. Ozone concentrations and water vapor, however, unlike all the trace greenhouse gases, are *not* evenly distributed throughout the atmosphere. They are both variable in amount, producing a less predictable greenhouse effect.

Although water vapor is an invisible greenhouse gas, upon condensing into clouds it becomes more a reflective cooling component than an absorptive one – a negative feedback. Low atmospheric ozone is produced as a result of solar photochemical reactions with vehicle emissions, a direct byproduct of fossil fuel burning. It is common in urban areas, acting as a forcing agent. However, ozone is present higher in the stratosphere, where it acts reflectively as a negative feedback! Thus, ozone depletion from chlorofluorocarbons (CFC's) in this part of the atmosphere results in additional warming potential. It is easy to see why the total effects of ozone and water vapor remain something of a wildcard (Fig. 2.5).

We should be sure to note again the actual proportion of CO₂ in the atmosphere. Since its concentration is 380 ppmv (precise readings depend on the source), or only 0.0380% of the total atmosphere, we are certainly far from suffocating in this gas. Such popular misconceptions should not, however, lead us to dismiss increasing concentrations lightly. In 1750 CO₂ concentrations were approximately 0.0288 ppmv [5]. Despite what appears to be a minimal concentration in the atmosphere – both in 1750 and today – the effect of carbon dioxide must not be discounted, because regardless of the amount of warming it causes, it has fairly strong forcing capabilities compared to many other atmospheric gases. Increased concentrations also persist in the atmosphere for a substantial amount of time, and lie at the very heart of the present controversy.

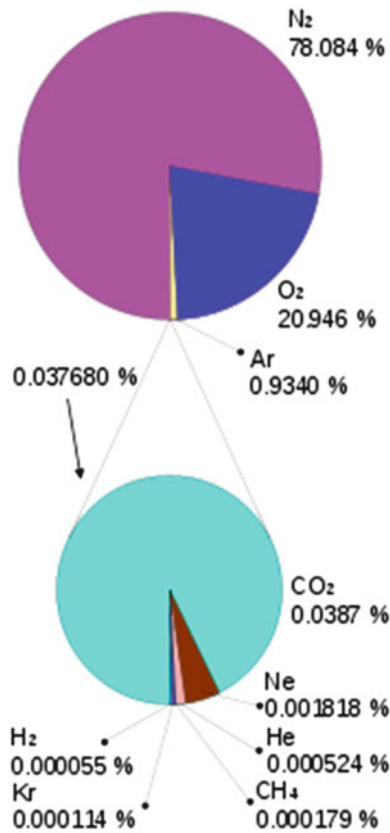


FIG. 2.5 Proportions of gases of the atmosphere (not including water vapor)
(Graphic by Mysid)

More specifically, we can now analyze energy being re-radiated from Earth over any time frame, and it is clear how events in the climate can influence it. The NASA graph (Fig. 2.6) shows variations in Earth’s long-wave (infrared) radiation from tropical latitudes averaged over more than two decades. Variations in its amplitude can clearly be seen, caused by different events at or near the surface. They are most readily apparent, due to atmospheric aerosols, following volcanic eruptions, as well as during El Nino years. The former may be identified by strong dips during volcanic eruptions, and distinctive radiative spikes during the latter. Aerosols not only prevent a portion of solar radiation from reaching Earth (contributing to an overall cooling effect) but also leaving it (adding to warming). Overall, however, their effect is of a negative forcing.

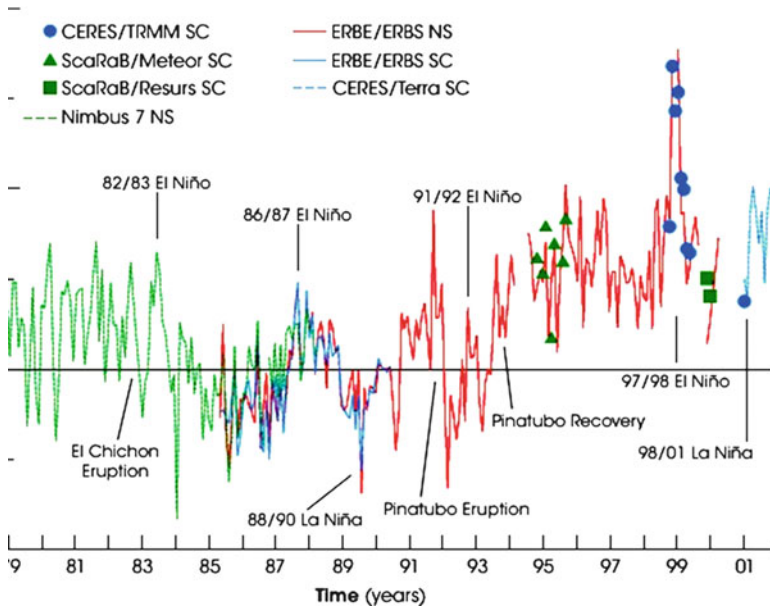


FIG. 2.6 Long-wave radiation leaving Earth (*the horizontal dividing line representing the mid-point between reductions in radiated infrared energy below the line up to 0 W/m^2 , and increases in radiated energy (above the line up to 10 W/m^2)* (Graph courtesy of NASA)

The sharp upwards spike of 1997/1998 is remarkable, not only due to its strength but also because after this event there was a marked step upwards in global average temperatures of 0.25°C that has persisted since in the baseline average global temperature [6]. Thus, claims of *gradual* temperature increases in step with CO_2 increases over the period do not appear to be substantiated. It will be interesting to see if the substantial Icelandic and Indonesian volcanic eruptions of 2010 can be tied to any decreases in radiation or temperature. It has already been remarked by some, however, that climate models projected far greater temperature declines after sizeable volcanic eruptions over the past half-century than actually were observed.

Although the IPCC has stated that the long cooling trend from around 1940 into the 1970s can be largely attributed to the total of aerosols from all origins (including volcanoes), this also appears to be hard to reconcile with the volcanic record and assessments of present warming trends. However, even if we accept that in theory volcanic aerosols could cool the climate, it might be seen

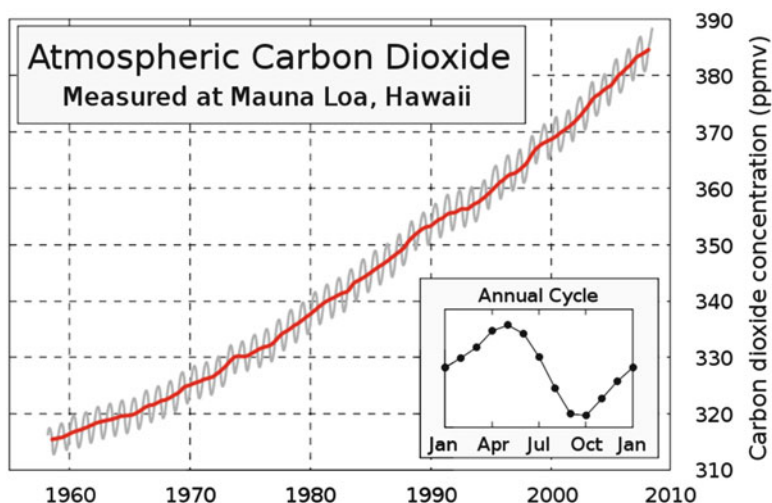


FIG. 2.7 The rise in atmospheric CO₂ since 1960 (Graph by Sémhur)

as unlikely that any scientist would suggest the possible release of aerosol particulates into the atmosphere as a means to offset present day warming, even less to actually recommend such actions. Remarkably, though, this is not the case at all.

A program in the United Kingdom with the acronym SPICE (Stratospheric Particle Injection for Climate Engineering) has proposed to do just that! Although recently placed on hold for some months, it promises to test the concept with fine water-sprayed droplets from a high altitude balloon, with the hope of graduating to full-scale sulfur-type particle injection later. The researchers believe that up to 2°C cooling could be achieved artificially, but naturally, many geopolitical and legal factors have yet to be ironed out.

With the majority opinion within the IPCC that present-day climate change is human induced, apparently it is no longer seeking other underlying causes. However, its position regarding the period between 1940 and 1970 remains a sticking point, even though climate models have been adapted to reflect this scenario. The gradual, virtually monotonic, upward curve in CO₂ over the past 100 years or so bears no resemblance to the wildly uneven global temperature footprint at all, even proportionately. Other than showing a total rise in both from the beginning of the century to the end, there are few other visible parallels (Fig. 2.7).

Anthropogenic Greenhouse Gases

Despite the apparent clarity of the various AGW greenhouse gas contributions shown in the next graphic (Fig. 2.8), greater understanding is needed of variables, including:

- The enormous complexity of Earth's changing albedo.
- Changes in water vapor.
- Possible yet unrecognized consequences.
- Possible repercussions of changes in the output of any gas, or its proportion.
- The precise role that increasing concentrations of carbon dioxide and other greenhouse gases might play.

Such factors remain undetermined, especially since we can only speculate on most of them. We can see in this chart

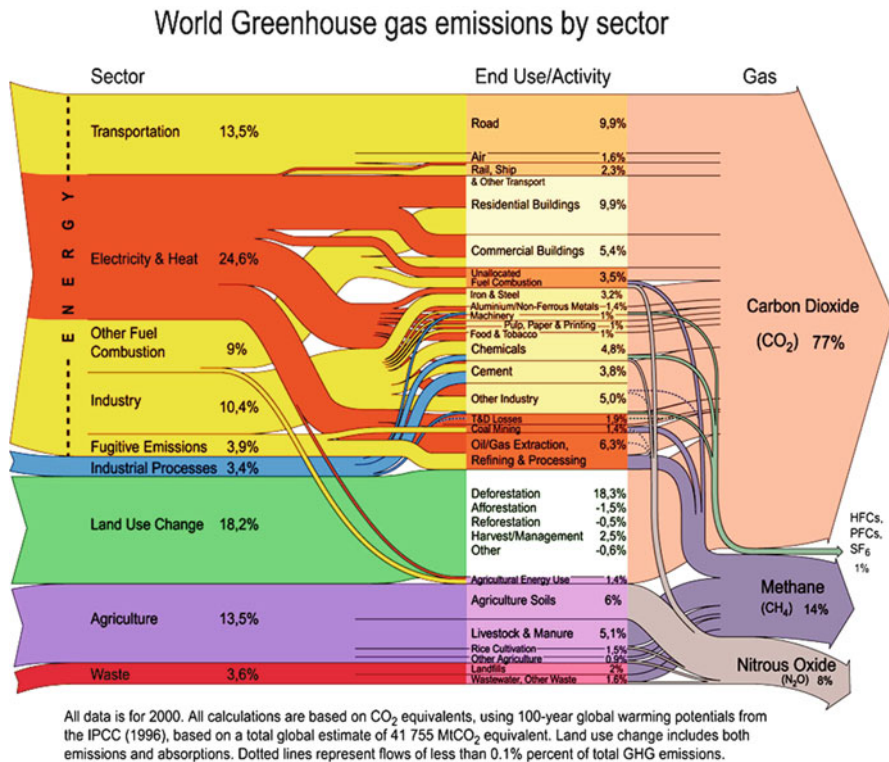


FIG. 2.8 Greenhouse gases due to humans (anthropogenic gases) (Image courtesy of Emmanuelle Bournay, UNEP/GRID-Arendal; available at: <http://maps.grida.no/go/graphic/world-greenhouse-gas-emissions-by-sector>)

the breakdown of things as they stand at the present time but should be cognizant of the uncertainties dictated by evolving circumstances.

On AGW CO₂

From the NRDC (National Resources Defense Council):

“Carbon dioxide and other air pollution that is collecting in the atmosphere like a thickening blanket, trapping the sun’s heat and causing the planet to warm up. Coal-burning power plants are the largest U.S. source of carbon dioxide pollution – they produce 2.5 billion tons every year. Automobiles, the second largest source, create nearly 1.5 billion tons of CO₂ annually.”

And:

How can we cut global warming pollution?

A: It’s simple: By reducing pollution from vehicles and power plants.

It is hard to forgive so many scientific misconceptions and transgressions within just one sentence, since

- Anthropogenic carbon dioxide is not a pollutant in the normal sense of the term, despite the absence of the 14C signature in naturally occurring CO₂.
- It does not *collect* in the atmosphere like a thickening blanket, since it is essentially evenly distributed throughout the atmosphere relative to volume.
- CO₂ does not *trap* the Sun’s heat.
- CO₂ has not yet been conclusively demonstrated to *cause the planet to warm up*.
- Automobiles are not the second largest source of CO₂. Look again, even at the IPCC’s own analysis (Fig. 2.8), in which *all* transportation accounts for just 13.5% of all human-produced CO₂, of which automobiles account for just 9.9%.

It is clear that increasing temperatures will also result in increasing water vapor. It is generally considered that the natural water vapor balance, as well as its effect, can be rapidly affected by its response to increases in the amounts of any other greenhouse gas emissions. However, there is a continuing controversy about exactly how much warming is caused by increased greenhouse forcing gases, and thus how much water vapor results from them. This is in addition to the measurement of extra forcing and feedback that might result from the increased water vapor itself in the atmosphere.

We should also bear in mind that although these gases, together with man's own additional contributions of CFC's may be seen in Fig. 2.8, water vapor accounts for almost all of the atmosphere's greenhouse gas, as well as the warming, followed by other gases, which trail far behind. By many calculations (see later), of the 33°C total natural greenhouse warming of Earth, that from water vapor amounts to at least 95% of it. This is exclusive to the present climate change discussion, since we are only referring to Earth's natural greenhouse. There is no universally accepted ratio, however.

Thus we can readily see that CO₂ and other trace component gases fall into controversial territory. Of the group of remaining greenhouse gases (not including water vapor), CO₂, being a moderately strong absorber and source of re-radiation, accounts for at least 77% of the warming. Despite its relatively minute proportion by mass compared to atmospheric water vapor, it is a more significant greenhouse gas, and responsible for the higher ratio of the warming itself than might be expected.

The degree that carbon dioxide versus water vapor is responsible for warming the lower atmosphere has been the ongoing subject of dispute throughout all of the present climate controversy. Depending on the source, the numbers are surprisingly different. When one logically thinks through some of the higher estimates for CO₂ warming, they might seem unnecessarily alarmist. Although they could be accurate, it is hard to find coherent explanations for these conclusions – at least in searches one can readily conduct oneself. This does nothing to calm the controversy.

Adding It Up: The CO₂ Equation

T. J. Nelson, a research scientist with a Ph.D. in biophysics, works in the field of biomedical research. He has found a passion for climate issues, although we should be aware that his self-published views on climate, while solidly conceived, do not constitute “peer-reviewed” study. However, they seem worthy of our attention, particularly with the dearth of readily available similar analyses. In his online article “Cold Facts on Global Warming” [7], Nelson shows how he calculated by formula the specific warming due to CO₂ to be between 4.2% and 8.4% of the total greenhouse warming effect.

On the face of it at least, this puts into perspective what we are actually dealing with. Other sources, including the IPCC, put the influence of CO₂ at a much higher number; for example, Wikipedia lists its warming influence at 9–26%, and water vapor at 36–72%. Thus we have possible total temperature increases from 1750 until the present, and those caused by greenhouse gases, (excluding water vapor) ranging from 1.39°C (Nelson), to 6.4°C (IPCC AR4), and to 8.6°C (Wikipedia). All in all, this allows for quite a wide berth in the margin of error. Of the trace gases, according to Nelson, carbon dioxide warming counts for 84% of the total.

Most sources inform us that the total warming on Earth since 1900 is about 1°C; some shade it up or down a little. Regardless, the lack of agreement on the effects of CO₂ on temperature causes us considerable difficulties if we try to do the math. The answers produce seemingly irreconcilable conclusions based on previous atmospheric concentrations. If we take the upper figure for the effect of CO₂ (i.e., that of Wikipedia), none of the natural ratios of warming relative to those of recent times seems to make any sense at all.

Nelson does take issue with a “pro-consensus” website, www.realclimate.org, and its estimate that actual CO₂ warming is closer to five times his final projection of ~5% of the total (a number based on what he terms “most credible sources”). In the equation he presents, the IPCC’s projection simply is not possible, given past history and the makeup of existing atmospheric warming. He argues that if we use the projected inputs and responses of IPCC models to retroactively calculate present-day temperatures, they should have reached what he terms “preposterous heights.” Thus, in his view, such models have been made to fit what has actually taken place.

Since we know how some of the variables in Earth's complex system affect climate, nothing can be taken at face value. However, perhaps the most interesting and provocative point made in Nelson's paper is his analysis that shows that the atmosphere already is sufficiently laden with CO_2 (and is effectively transparent to incoming solar infrared radiation of higher wavelengths) to have absorbed most of the low wavelength infrared radiation being re-emitted from Earth's surface. Accordingly, additional amounts of the gas would generate differences from the added concentrations only. Therefore, these would not compound the warming in a multiplying manner. Any increases would follow a logarithmic curve, whereby the amount of heating already produced by the total would only be added to incrementally. Even if atmospheric CO_2 were doubled (to 760 ppmv!), the worst-case scenario he projects would be a temperature increase only of between 1.02°C and 1.85°C . Similar temperature increments would be the case with *each subsequent doubling*.

At the present rate of increase, Nelson deduces it would take a couple of centuries to reach those levels. Additionally, increases or decreases in anthropogenic production CO_2 would be immediately felt, since the atmosphere cannot store it for long (5–10 years). This figure is in direct conflict with other claims (50–200 years, and more!) that we have heard.

Debate continues over the “shelf life” of CO_2 and other greenhouse gases in the atmosphere. Clearly, this is a significant part of any argument, since projections of a lengthy existence of anthropogenic greenhouse gases residing in the atmosphere color any discussion about their potential to affect climate. If we accept the low estimate of only 5–10 years, a remedy for any proven ill effects of the gases on climate ought to be the most straightforward to find.

CO_2 Residence Time

The website skepticalscience.com has claimed that excess human emissions of CO_2 will remain resident in the atmosphere for over 100 years.

Again, such approximations of fact do this website grave injustice, not only in the simplistic and imprecise picture painted but by implication that only *human* CO₂ emissions have a long residence time.

Of course, increased temperatures would increase water vapor, which, being a greenhouse gas, would also add some amount to the warming; Nelson does not appear to build this aspect into his math. He does, however, take us through a projected scenario that includes Earth's responses to increased warming (its albedo from increasing or decreasing clouds and snow cover, etc.) and once again demonstrates, by his carefully laid-out logic, that total warming is still well within the basic 1.85°C range – his maximum estimate. Even with numerous other potential and actual factors, his logic seems consistent, providing some very insightful food for thought, whether or not one regards his view as being the last word.

In contrast, if we accept the IPCC's position, things look a lot more serious. Should anthropogenic greenhouse gases be the root of modern climate change, the IPCC maintains that, even if emissions stopped completely: "About 50% of a CO₂ increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries. The remaining 20% may stay in the atmosphere for many thousands of years," in which case, it is already too late to remedy some damage that has already been done.

Also, the atmospheric lifetime of water vapor is quite transitory at only about 10 days, something that is not disputed. Thus, it is primarily CO₂ that is our concern. Apparently, the fear exists that this gas may tip the scales of compounding greenhouse warming conditions, leading to a runaway crisis. A study, by Arindam Samanta et al. [8], concurred with the more pessimistic findings. Considering the limited warming potential of these gases, as well as far lesser concentrations, not everyone agrees with this line of reasoning. It would probably be fair to state that most researchers believe that the true warming potential of any gaseous compound depends most critically upon its total ability to absorb and re-radiate heat efficiently, as well as its residence time in the atmosphere. Settling this argument would do much to resolve some key disputes behind the AGW theories.

More typical of articles and papers in defense of the theory of carbon dioxide driven warming is "Atmospheric CO₂: Principal Control Knob Governing Earth's Temperature," by Andrew A. Lacis et al. [9]. Assessments easily drawn from articles such as these only serve to keep the controversy alive. The article states that CO₂ accounts for 20% of the warming from greenhouse gases. By that line of reasoning, most casual readers will deduce different outcomes on a number of levels:

- If the total warming prior to 1850 accounts for thus 20% of 33°C (the calculated average natural global warming above simple solar warming), it would equate with a total warming effect from natural CO₂ to have been 6.6°C.
- By the same line of reasoning, should not the 92 ppmv of CO₂ that has been added since then have produced an additional warming of 2.17°C: $6.6 - 280 \times 92 = 2.17^\circ\text{C}$, and not just the ~0.8% recorded? However, the 0.8°C temperature increase since 1850, give or take a few fractions of degrees by various authorities, is hardly in dispute.
- Perhaps the implication meant was that 20% of the actual measured warming is the result of the approximately 92 ppmv of CO₂ added since 1850. However, if this should be the case, 0.16° of warming would be all that the added CO₂ is directly responsible for! Since with such a result it could hardly be claimed that there is an environmental problem, this cannot be the authors' meaning.
- Or, are the authors possibly referring to the feedback warming effect beyond the primary greenhouse foundation to be at a different ratio of 20%? If so, they certainly do nothing to dispel the notion that radical warming of this magnitude could result from just small CO₂ increases.

We shouldn't have to guess what the article means, and ultimately, whose facts to believe. Despite coming from such eminent scientists, the article illustrates exactly the kind of confusing positions that have become all too common in discussions about climate. How could such wide disparities in estimates have occurred? Even the IPCC itself seems to consider that a doubling of CO₂ by itself would only increase temperatures by 1°C, despite the different stated percentages they have provided of its warming effect.

The IPCC also concedes that 0.12°C of the total increase since 1900 can be attributed to what is known as the Urban Heat Island Effect, where zones of densely populated areas have been theorized by some to produce misleadingly high readings. It becomes ever clearer that the science of climate change is so complicated, laden with theories, studies, projections, statistics, findings, contradictions and disagreements, that any newcomer to the topic will likely reach sensory overload very quickly. Regardless, it further demonstrates how much remains to be settled, and how unsupported – or unexplained – statistics continually lead us into trouble.

In contrast, the IPCC summed up this effect differently: “However, over the Northern Hemisphere land areas where urban heat islands are most apparent, both the trends of lower-tropospheric temperature and surface air temperature show no significant differences. In fact, the lower-tropospheric temperatures warm at a slightly greater rate over North America (about $0.28^{\circ}\text{C}/\text{decade}$ using satellite data) than do the surface temperatures ($0.27^{\circ}\text{C}/\text{decade}$), although again the difference is not statistically significant.”

TAR, 2001

It is interesting to note that statistician Thayer Watkins of San José State University Department of Economics deduced virtually the same degree of inaccuracies in IPCC projections of CO_2 warming – apparently by coincidence in his own independent and carefully constructed study [10]. However, once again, as a representation of his views only, it is not a peer-reviewed paper. His conclusion that the IPCC’s projection is ~ 2.5 times reality hits about same note as we have just illustrated. More controversial, though, will be his conclusion that the IPCC uses such projections to “generate scary projections,” although he is not the first to make such claims.

Among other scientists who have taken up the issue of carbon dioxide, Jeffrey A. Glassman (an applied physicist and engineer), in another independent paper posted on his own website [11], approaches the issue a little differently, although it is closely related to that of Nelson’s approach. Using the same basic principles of physics outlined by Nelson, Glassman compares them to the record taken from the Vostok ice core. This core was found and

extracted in 1988 and was the deepest ice core ever found and recovered (3,623 m), extending back through history some 400,000 years. This is an excellent proxy record, providing invaluable information on past climate cycles, along with the trace gas composition of the atmosphere. In this case, especially, the record of atmospheric carbon dioxide concentration appears clear.

Glassman also discusses oceanic respiration (outgassing) of CO_2 , that is reabsorbed back into cold ocean waters and transported down into the deepest, most highly saturated regions. Increases in atmospheric CO_2 have always accompanied increasing temperatures, but delayed in time. As Nelson similarly observed, if global temperatures had followed the projected warming that would accompany such increased CO_2 concentrations as in the ice cores, the consequences already would have been disastrous. Glassman's final take, however, is a little different. He concludes that increased CO_2 must have always been reabsorbed into the oceans before such events could take place, an interesting hypothesis. He also considers increased CO_2 quite likely to be the result of warming by some yet undetermined process of outgassing and not the other way around.

Greenhouse Gases as a Shield

The components of the atmosphere shield us from some of the Sun's rays, including those that are especially harmful. We can also see (Fig. 2.9) that the specific wavelengths of solar radiation absorbed by the various atmospheric components differ quite significantly. Thus, the absorptive function of one does not necessarily overlap, or necessarily enhance (or detract), that of another. This is another reason that the equation is so complex. We can see from this graph (averaged for different regions) how the various atmospheric components determine the degree to which different wavelengths of the solar spectrum are absorbed.

Different trace gases also absorb energy and re-radiate infrared wavelengths most efficiently at specific temperatures. For example, carbon dioxide absorbs and radiates heat to the maximum extent at low temperatures in the region of 220 K. The altitude this corresponds to is 40–50 km. At lower altitudes, increasingly warm

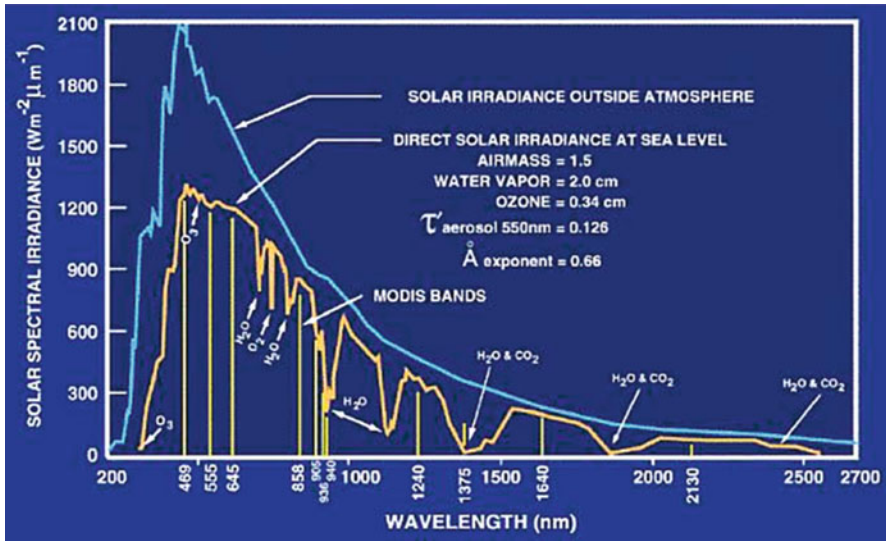


FIG. 2.9 Atmospheric transmissions (Image courtesy of NASA)

temperatures make that part of the atmosphere less able to radiate energy back to space. In order to maintain equilibrium of energy absorbed versus energy lost, more infrared energy will be transmitted back to space from the altitude where the temperature for re-radiation is most efficient for that gas. Increasingly cold temperatures at high altitudes will be the result, and warmer ones will be closer to the surface – a chain reaction of forcing and feedback. Because the total incoming energy is effectively measurable, many researchers consider that confirmation of cooling temperatures in the upper atmosphere would be significant in showing the influences of anthropogenic gases. There is some evidence – admittedly not conclusive or overwhelming – that this could indeed be taking place (see Chap. 4, Fig. 3.19?).

Carbon Sinks

Closely related to this topic, and indeed part of it, are the natural “sinks” of Earth, and their ability to mitigate the increased concentrations of heat and CO_2 by absorption. By far the largest

reserves of carbon dioxide reside in the oceans and landmasses. An interesting history by Richard Mackay about the work of pioneer Rhodes Fairbridge raised the issue of CO_2 outgassing from the oceans – the opposite action to absorption. He concluded that increased outgassed CO_2 from Earth's "sinks" might have contributed a portion of the increased temperatures since 1850 [12]. However, Mackay did not speculate on how much of the increase can be ascribed to this natural process, presumably feeling this was beyond the realm of the paper, perhaps even his particular expertise despite his considerable credentials.

The mechanics of outgassing are simple. Because increasing temperatures reduce the solubility of CO_2 in water especially (or in soils), this causes increased natural reductions of CO_2 . However, even though the added CO_2 in the atmosphere is very small, it is again the increasing concentrations that have come under the microscope, because most researchers do not believe they have been induced naturally.

Although increased anthropogenic emissions may be responsible for the majority of CO_2 increases, there is an ongoing recycling of CO_2 by the oceans and land. Some have questioned whether the observed changes in atmospheric concentrations are due to some not yet understood processes [13] but many "skeptics" have argued that increased temperatures are the sole cause of increased carbon dioxide, especially in the last 100 years – that greenhouse gases are the outcome of natural warming variations. However, this does not appear to be credible, at least according to the laws of physics and chemistry Nelson outlined with such clarity. The increased CO_2 concentrations under discussion are far greater than could have been released by the oceans following the recorded temperature rise, in which the amount of outgassed CO_2 would be a mere 4.4 ppmv following an increase of 0.6°C . For the actual average temperature increases usually mentioned since 1900, this would amount to about 5.9 ppmv, a far cry from the amount we have actually seen.

However, it should be noted that Nelson says nothing about the involvement of landmasses, which also have large reserves of CO_2 , especially from ongoing or old decaying vegetation from deforestation. The omission seems perhaps sound, since Earth's

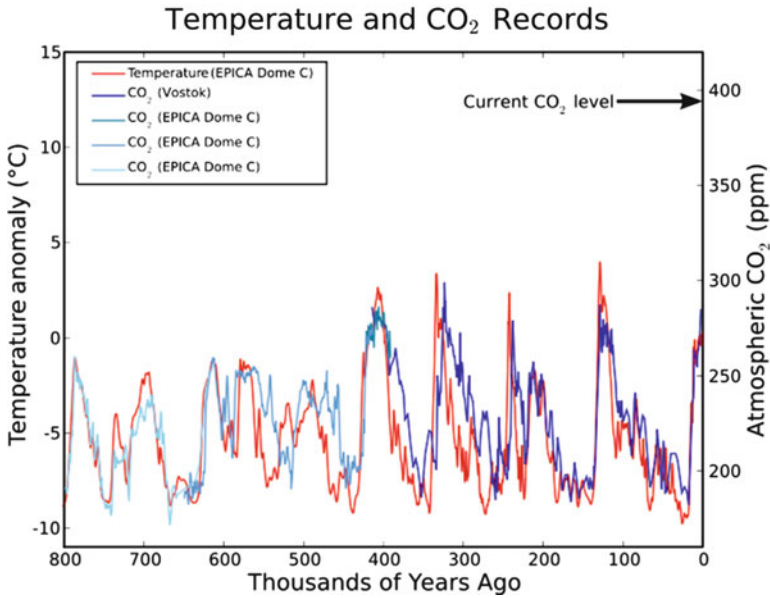


FIG. 2.10 Historic temperatures and CO₂ correlation (Graphic by Leland McInnes)

landmasses represent a far smaller CO₂ sink than the oceans. However, the present day clearing of forests across large continental landmasses, with the subsequent increased volumes of carbon emissions, may play a larger role than Nelson's paper suggests. This is even after we bear in mind that landmasses would still encompass hugely less CO₂ than the oceans.

Only in the last 100 years or so do we find no obvious correlation between increasing concentrations of CO₂ and the historic record. Prior to this, the ratio of carbon dioxide relative to temperature can be seen to be consistently predictable, where substantial and proportional temperature increases apparently have always followed elevated CO₂ atmospheric concentrations (Fig. 2.10). The ~12°C swings in temperature that follow CO₂ concentrations are striking, but do not appear to correspond to:

- Possible amounts of outgassing from such temperatures.
- Any existing theory of comparable warming resulting from CO₂ increases.

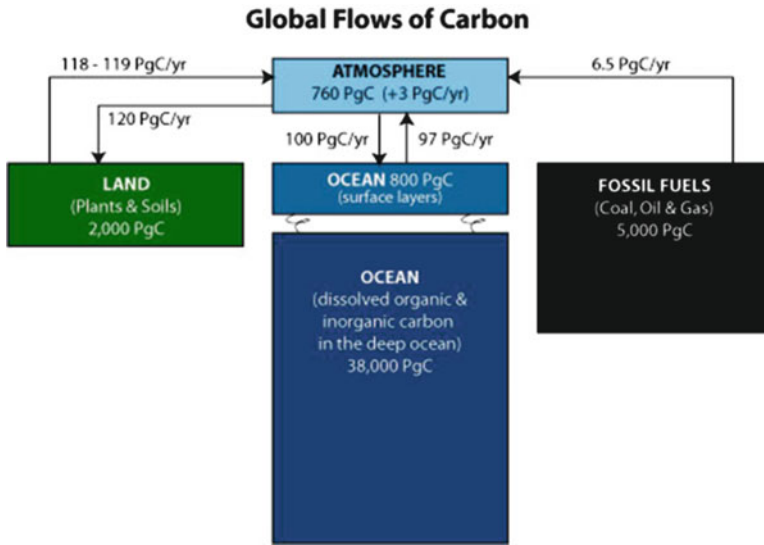


FIG. 2.11 The carbon cycle (Graphic courtesy of NASA)

Therefore, it is reasonable to assume that both of these synchronized swings must have been caused by one or more other stimuli external to any direct relationship. Measurements from hundreds of millions of years ago reveal CO_2 concentrations 10–20 times present-day levels, contrary to claims by some that they have never been as high as they are now. Some might reference this to suggest that similar undetermined forces might have produced the rise in CO_2 seen during the last 100 years.

Regardless, some researchers have suggested that the naturally occurring carbon sinks can more than absorb all of the increasing greenhouse gases, as well as any increasing temperatures. Thus, presumably these sinks could have always acted as long-term regulators in some way.

A study by Joseph G. Canadell et al. [14] rated the amount of natural absorption of anthropogenic CO_2 into natural sinks at 57%, which is not inconsiderable. This seems to indicate that CO_2 lifespan in the atmosphere could indeed be short, despite many claims to the contrary. It also tells us that the maximum we would need to reduce emissions by would be just 43% of the total. In other words, according to the time at which the chart (Fig. 2.11) was made, and using the most superficial estimate, less than

2.8 GT a year – assuming this could finally be agreed upon by all concerned as being a necessity and solution.

If such absorption does not produce serious changes to the chemical composition of the oceans alone (a “sink” so large, at 38,000 GT, it is hard to conceive that in the short term an annual increase of 2.8 GT could statistically alter it in a meaningful way), the fact remains that, according to Canadell et al., just 2.8 GT represents the probable *total amount* that CO₂ levels are out of balance. It is argued that the cumulative effect will build over time, but with amounts such as these, perhaps there will yet be a way found to equalize atmospheric conditions to pre-1750 levels, again if that were to be determined as the remedy to additional warming.

If we are looking to know the length of time it would take to reach equilibrium again (of both CO₂ levels and temperature), this remains undetermined, so the conundrum continues. However, we do know that the oceans, and biosphere, have been absorbing large quantities of anthropogenic CO₂ all along, and that levels of the gas in the atmosphere would have been hugely greater than they are at this time. It could be argued that the sinks have already been tested under extreme conditions through history, and proven an effective shield against climate change, but this is pure conjecture at this stage.

A bigger question is whether corrective actions would produce any effect at all, according to the so-called “skeptical” scientists, since they do not accept the AGW theory in the first place. Regardless, if we do accept them, we know that without anthropogenic contributions, at 1750 temperature levels apparently the balance was reasonably stable.

The process of ocean CO₂ storage is interesting. Acidic carbon dioxide oxide gas (CO₂) dissolves in seawater to form carbonate and bicarbonate ions in reactions with calcium rock deposits on the ocean floor, resulting in reduced alkalinity (of 0.1 units, per the IPCC) and greater ocean acidity. Because the oceans are warmest near the surface, they are less able to hold as much CO₂, which is thus increasingly outgassed into the atmosphere, according to the degree of ocean warmth.

The denser, more acidic waters drop to ever greater depths, producing a very highly carbon saturated liquid of ever colder

temperatures. Of the total Earth reserves, anthropogenic annual CO_2 contributions amount to approximately 6.5 GT (see Fig. 2.11 [15]; GT is termed in the NASA graphic as Pg C). This is quite a small percentage of the estimated total that is exchanged back and forth in the biosphere. The total CO_2 in play is close to 1,000 GT per year.

A good guide to the amounts of carbon dioxide believed to exist naturally in the environment may be seen in the previous graphic. The proportion of anthropogenic CO_2 needs to be weighed into consideration relative to naturally occurring reservoirs. We should take note that the general mood created in the media and elsewhere relies on what may seem to be a tiny proportion of the total CO_2 residing in the atmosphere at any time – that representing human activities' carbon additions. According to this chart, we should consider the following:

- Earth's landmasses absorb an average of 1.5 GT of excess CO_2 per year.
- The atmosphere absorbs approximately 3 GT excess CO_2 per year.
- Anthropogenic CO_2 contributions total 6.5 GT per year.
- Total CO_2 exchange each year is 222 GT.
- Anthropogenic CO_2 represents $6.5 - 222 \times 100 = 2.9\%$.
- Actual net CO_2 : $6.5 - 1.5 - 3 = 2$ GT.
- Net annual total percent of added anthropogenic atmospheric $\text{CO}_2 = 0.93\%$.

Despite the common impression by the populace that human activity is responsible for most atmospheric carbon dioxide, in fact, by our estimate above, only 2.9% of the total global CO_2 exchange (see later in this chapter) is attributable to the combustion of fossil fuels. In other words, it aligns fairly closely with the findings of Canadell et al. Others shade this figure upwards a little; for example David J. C. MacKay puts it at 3.27% [16], while some place it beyond this, but generally we don't find estimates of fossil fuel CO_2 to far exceed 5% of the total amount exchanged.

However, because it is this portion that is being added on an ongoing basis to the total that occurs naturally, it is this, therefore, that is a source of concern. Thus, in essence, the basis for the continuing disagreements about people's influence on climate can

be further traced to this one statistic alone, and by what degree, if any, changes at this level have on the climate.

Whether the annual addition of this much CO₂ into the environment can be curtailed to a realistic degree cuts to the heart of the equation, if this should be required. Refer again to Fig. 2.8. It is instructive to pay careful attention to those sectors of the total that produce most of the CO₂ and aerosols; are we paying too much attention to some while largely ignoring others?

For example, if every form of fossil fuel transportation – land, air and sea – were to disappear tomorrow, only 13.5% of all major anthropogenic emissions would be eliminated! In a media sometimes out of touch with reality, you will not hear such a statistic; but you might hear that the automobile is the primary culprit for causing global warming.

Definitive positions to all such questions, so typical of almost everything in climate science, is more likely to encounter multiple answers than one single illuminating answer; they may depend upon whose argument strikes the individual as the most persuasive. Perhaps a more important question is whether we can all finally agree upon whether there are potential hazards awaiting us, and if there is anything we can do to stop them.

Hydrogen Fuel Cells and Electric Cars

“Hydrogen is high in energy, yet an engine that burns pure hydrogen produces almost no pollution.”

– renewableenergyworld.com

“The electric car finally seems to be on the verge of breaking through, offering significant environmental benefits, especially in urban areas. Innovative business models are on the way which should boost consumer acceptance and overcome the remaining barriers, such as high battery costs, green electricity supply and charging infrastructure.”

– European environment Agency

"Much touted as the solution to the automotive byproduct of CO₂, these currently fashionable technologies may not be all that they might seem, since each still requires the generation of electricity. In the case of hydrogen, this gas is generated by electrolysis and thus requires a significant electrical power supply; rechargeable batteries also require charging from the power grid."

"Similarly fashionable solar and wind power technologies are not yet realistic as major suppliers of electricity; as significant sources they are severely limited. Hydroelectric power is, however, a significant source of electricity, representing about 92% of the total green energy production, and about 24% of the world's total electricity, but only 8% of the total in the US."

– (Source: waterencyclopedia.com)

Nuclear electricity generation is still minimal in most countries. Thus the production of electricity mostly requires the burning of fossil fuels. Although at present loads it is possible to take advantage of off-peak hours when electricity might otherwise be wasted, for any large-scale automotive reliance on electric power, the problem brings us right back to where we started. Thus, the dream of entire highways running on these alternate technologies is still far away. Perhaps it never will be a reality.

Heat Sinks

The oceans and landmasses, in addition to being able to store large quantities of carbon dioxide, also have the capacity to act as vast "heat sinks," and much of the excess warmth from the Sun and greenhouse gases can be effectively buried. However, there are consequences from such storage. Because the ocean has far greater heat storage capability than the land, it has some of the most profound influences on much of what happens in Earth's climate. What is buried in the oceans drives the deep ocean currents, with

significant consequences for the climate, all of which we will examine in due course.

Carbon and heat sinks are often linked. One study by S. Sitch et al. [17] proposed that carbon dioxide absorption by Earth's natural carbon sink will be compromised by increased temperatures beyond that which Earth can absorb, leading to greater influences of anthropogenic ozone due to the damage it causes to plant photosynthesis. The EPA (Environmental Protection Agency) has published an extraordinarily detailed analysis of the absorptive capacities of greenhouse emissions by Earth's natural sinks [18].

However, other researchers have come to the opposite conclusion. William Happer, in his paper on greenhouse gases [19], explained that the amount of atmospheric CO_2 was at the low end of what would be tolerable for life on Earth by a factor of at least 14 times the present levels. He also argued that the outgassing of CO_2 from the oceans had always *followed* temperature increases in the distant past, rather than the other way around. Thus, regardless of the formulae he used, this is a simple acknowledgement that Earth's heat sinks cannot simply "bury" all excess heat, any more than carbon sinks can soak up all excess concentrations either.

Happer's main argument was that variations of CO_2 concentrations were a natural reaction to temperature increases and decreases. During historical times, CO_2 concentrations were far greater than today, and, Happer argued, life flourished. Happer also seemed to concur with Nelson's findings on CO_2 warming effects, allowing only a 1°C increase with a doubling of present CO_2 levels (as have other scientists, including Richard Lindzen; see Chap. 6), although his proposed theory of reactive release of CO_2 seems incompatible with what we know.

Nelson had also mentioned the potential of Earth to absorb much of the increased heat in a process termed "masking." However, if he did not seem to take possible unseen detrimental long-term side effects of such processes into consideration, that may not be the correct assessment of his position. Also he did not discuss how much additional CO_2 might be released by the resulting increased ocean temperatures. Nevertheless, perhaps we would need to imagine a considerable absorption, over perhaps hundreds or thousands of years, before the accumulation might appear

significant in comparison to the immense potential reserve of the oceans. The issue remains, in the IPCC's own term, "undocumented," and thus highly controversial at best. However, we must first consider in the next chapter two areas of study, clearly related though often confused with one another. Ultimately they are very different species.

References

1. Water vapor: feedback or forcing? Real Climate. Online: <http://www.realclimate.org/index.php/archives/2005/04/water-vapour-feedback-or-forcing/>
2. Graphic: effective temperature and comparison of the Sun to a black body. 2006. http://en.wikipedia.org/wiki/File:EffectiveTemperature_300dpi_e.png
3. NASA (1971) Earth albedo and emitted radiation. [ntrs.nasa.gov/archive/nasa/casi.ntrs.../19710023628_1971023628.pdf](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19710023628_1971023628.pdf)
4. Andrews T, Forster PM (2008) CO₂ forcing induces semi-direct effects with consequences for climate feedback interpretations. School of Earth and Environment, University of Leeds, UK
5. Data Source: Keeling CD, Whorf TP (1998) Atmospheric CO₂ concentrations (ppmv) derived from in situ air samples collected at Mauna Loa Observatory. Scripps Institute of Oceanography, Hawaii; Neftel A et al (1994) Historical CO₂ record from the Siple Station Ice Core, Physics Institute, University of Bern, Switzerland
6. Global temperatures, from resource of graphs based of numerous satellite measurements. Climate 4 You. 2010. <http://climate4you.com/GlobalTemperatures.html>, <http://climate4you.com/GlobalTemperatures.htm#Outgounlongwave radiation global>
7. Nelson TJ (2011) Cold facts on global warming. Sci Notes. Online: <http://www.randombio.com/co2.html>
8. Samanta A, Anderson B, Ganguly S, Knyazikhin Y, Nemani RR, Myneni RB (2010) Physical climate response to a reduction of anthropogenic climate forcing. *Earth Interact* 14(7):1–11
9. Lacis AA, Schmidt GA, Rind D, Ruedy RA (2010) Atmospheric CO₂: principal control knob governing Earth's temperature. *Sci Mag*. <http://www.sciencemag.org/content/330/6002/356.abstract>
10. Watkins T. Global warming on Venus. Department of Economics, San Jose State University. Webpage: <http://www.applet-magic.com/GWvenus.htm>

11. Glassman JA (2009) The acquittal of carbon dioxide. Online: http://www.rocketscientistsjournal.com/2006/10/co2_acquittal.html
12. Mackay R (2007) Rhodes Fairbridge, the solar system and climate. *J Coast Res* 50
13. Robinson AB, Robinson NE, Soon W (2007) Environmental effects of increased atmospheric carbon dioxide. *J Am Phys Surg*
14. Canadell JG, Le Quere C, Raupach MR, Field CB, Buitenhuis ET, Ciais P, Conway TJ, Gillett NP, Houghton RA, Marland G (2007) Contributions to accelerating atmospheric CO₂ growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proc Natl Acad Sci USA* 104(47):18866–18870. <http://www.pnas.org/content/104/47/18866.abstract>
15. Global flows of carbon. NASA graphic. Online: <http://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-carbon-cycle/>
16. Source: Prof. MacKay DJC, FRS, University of Cambridge, and chief scientific adviser to the UK Department of Energy and Climate Change
17. Sitch S, Cox PM, Collins WJ, Huntingford C (2007) Indirect radiative forcing of climate change through ozone effects on the land carbon-sink. *Nature* 448(7155):791–794
18. 2011 U.S. Greenhouse gas inventory report. Environmental Protection Agency. epa.gov/climatechange/emissions/usinventoryreport.html
19. Happer W (2011) The truth about greenhouse gases. Global Warming Policy Forum, briefing paper #3, 17 Aug 2011

Astronomy and the Climate Crisis

Cooke, A.

2012, XVIII, 280 p. 99 illus., 96 illus. in color., Softcover

ISBN: 978-1-4614-4607-1