

Passing the point of no return

(Credit: *Looney Tunes* featuring Wile E. Coyote. © Warner Bros.)

Runaway Climate: The Point of No Return

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Runaway climate has a new meaning: a climate system pushed beyond the point of no return, when devastating consequences for young people are locked in, impossible to avoid. Below is the latest draft of Chapter 10 of *Sophie's Planet*, which will be published in *Green Energy Times*. For context, it includes the last paragraph of Chapter 9 of *Sophie's Planet*.

Meanwhile, as our instrument for the Venus mission was being built, we became involved in investigations of changes in our own planet's atmosphere. Eventually, our desire to understand those changes overwhelmed our interest in other planets. However, before leaving the planets, let us see what the Goldilocks planets can tell us. That topic is addressed in my first book, *Storms of My Grandchildren*,¹ where I stumbled and did not distinguish between the Venus Syndrome and runaway climate. For the sake of a coherent scientific explanation, in the next chapter I commit three writer's sins by: (1) disclosing an event out of chronological order, (2) showing a graph, and (3) including a simple equation. You may choose to skip lightly over a chapter heavy in technical science. However, runaway climate has a new meaning: a climate system pushed beyond the point of no return, with devastating, unavoidable consequences. We must learn from lessons of the past to avoid handing young people a situation out of their control.



Fig. 10.1. Greenhouse warmings on Mars, Earth, and Venus: about 5°C, 33°C, and 500°C.

Chapter 10. The Venus Syndrome & Runaway Climate

Mars, Venus and Earth are the Goldilocks planets – too cold, too hot, and just right. These planets reveal how a planet’s surface temperature depends on atmospheric gases as well as the planet’s distance from the Sun. The physics is energy balance: a planet sends back to space, as (infrared) heat radiation, the solar energy that it absorbs. The amount of absorbed sunlight depends on the Sun’s irradiance,¹ the planet’s distance from the Sun, and the fraction of incident sunlight that the planet absorbs (the remainder being reflected). The planet’s surface temperature is given by the Stefan-Boltzmann law² (physical principle), if the planet has no atmosphere.

If the planet has an atmosphere that partly blocks heat emission, the surface must be warmer than given by the Stefan-Boltzmann equation for emission to space to match absorbed solar energy.³ This “greenhouse” warming depends on the mass of the atmosphere and its infrared opacity. Mars’ atmosphere is thin and transparent, so its surface is only a few degrees warmer than it would be with no atmosphere. Venus has a thick atmosphere (96% CO₂) with sulfuric acid clouds and water vapor that absorb at wavelengths where CO₂ absorption is weak. Resulting greenhouse warming on Venus is about 500°C. Earth has greenhouse warming of about 33°C, enough to change Earth from an ice ball at –19°C (–2°F) to a hospitable +14°C (57°F).

How did these planets get to this situation? Can Earth end up like Venus, a lifeless hothouse?

Venus was doomed to permanent climatic hell once it lost its ocean. On a planet with an ocean, CO₂ injected into the air by volcanoes (or humans) is put back into the crust² on a time scale of millennia, which is geologically rapid. Removal from the air occurs due to weathering. Rainfall is slightly acidic (from dissolved atmospheric CO₂) and plants and animals release acidic compounds, which speed weathering of rocks. Streams and rivers carry chemicals to the ocean, where CO₂ is deposited on the ocean floor as limestone. Ocean-free Venus, in contrast, has no mechanism to rapidly return volcanic CO₂ to the crust. So much CO₂ is now “baked” (outgassed from)⁴ the Venus crust and mantle that the surface pressure is 90 times that on Earth, enough to crush any human visitors, if they were not already fried to a cinder.

Why the big difference between neighboring planets? The Sun and planets were made from approximately the same material, as they all formed 4.6 billion years ago from gravitational

¹ Irradiance is the flux of radiant energy per unit area normal to the direction of radiation flow.

² The crust is the outer layer of a terrestrial planet, like the skin of an apple. The continents on Earth are part of the crust – slabs of solid rock with some soil on top – that are mobile, riding on top of the viscous mantle, the mantle being a layer of silicate rock, about 1800 miles (2900 km) thick between the crust and Earth’s iron-nickel core.

collapse of a swirl of gas, ice, and dust in a spiral arm of our Galaxy, the Milky Way. Original atmospheres of the four inner planets were blown away by a hot solar wind because of the weak gravity of small planets and proximity to the Sun. The atmospheres of Venus and Earth today are secondary³ gases released on geologic time scales from the materials that compose the mantle and crust. Thus, Venus must have had an ocean once, even though Venus is dry today.⁵

How do we know that Venus had an ocean? Why does Earth still have an ocean, while Venus does not? The key process is escape of hydrogen to space. Ultraviolet solar radiation breaks up (dissociates) molecules in a planet's upper atmosphere. The lightest constituent, the hydrogen atom, can readily escape the gravity of an inner planet, traveling off into space. Thus, water (H₂O) loses its hydrogen and the oxygen combines with other atoms. Great overabundance today of deuterium (heavy hydrogen) on Venus relative to protium, the main hydrogen isotope, confirms the initial presence of water on Venus.⁴ Thus, Venus once had a lot of water, and surely some ocean, but the hydrogen escaped to space. Venus spiraled into hellish conditions, the Venus syndrome, as carbon dioxide was baked from the crust into the atmosphere.

The question becomes: why has Earth not followed in the footsteps of Venus? Will Earth suffer the Venus syndrome in the future? This was a big issue when I was a post-doc, as the Soviet Union's Venera spacecraft series revealed the extreme conditions on Venus.

Andy Ingersoll, in a landmark paper,⁶ raised the issue of possible “runaway” global warming. What does that mean exactly? Climate change is so complex that persuasive analysis demands solution of the fundamental equations that describe atmospheric structure and motion, in other words, the use of a global climate model (GCM). GCMs were still in their infancy in the 1970s, when I had a small research group, a few scientists supported by planetary science funding. However, because of a series of curious developments, described in the next few chapters, I was able to hire three exceptional young scientists in 1978. These scientists broadened our group's capabilities and made it possible for us to develop our own climate model.

Gary Russell, one of the three scientists, became the chief architect and programmer of our climate model. Gary's Ph.D. was in mathematics, but he could understand and program the physics of the entire model. This gave us the potential to pursue an unusual goal: a model that was valid for a wide range of planets and planetary evolution. That goal requires the model to correctly include the effect of changing atmospheric mass as the amounts of water vapor and carbon dioxide change, an effect that is ignored in most climate models. However, our first climate simulation was based on more limited changes to a conventional weather model. Before our first long simulation with that model was complete, we were asked to provide results for a National Academy of Sciences study of climate change. Our interest in a “planetary” climate model was thus preempted by a rush of events described in following chapters.

Gary did not forget the early objective and years later produced a model⁷ viable for climate from snowball Earth to a prelude of the Venus syndrome (Fig. 10.2). This model helps clarify the “cold trap” effect that limits hydrogen escape. The temperature profile in Earth's atmosphere

³ Earth's atmosphere now can be described as tertiary because it has been altered by the development of life.

⁴ Overabundance is relative to the Sun or Jupiter, where abundances should be close to their initial values because of the strong gravity of those bodies. Energy for hydrogen escape is provided mainly by the thermal energy of gases.

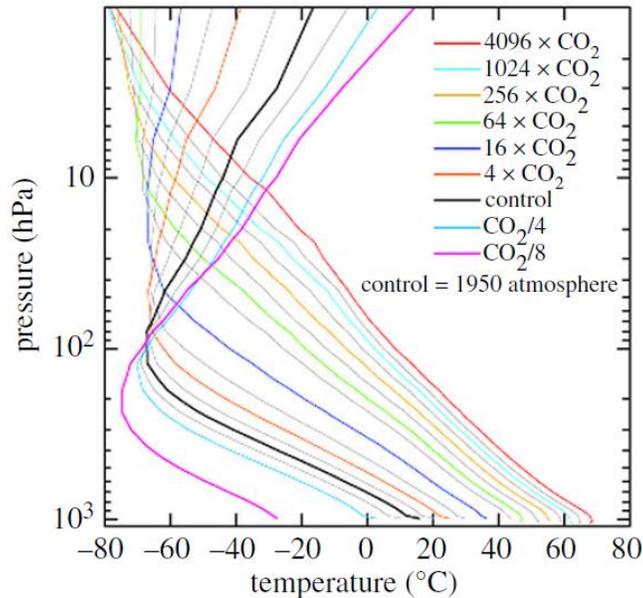


Fig. 10.2. Simulated global temperature profiles in Earth's atmosphere for alternative atmospheric carbon dioxide (CO₂) amounts relative to a 1950 control run (312 ppm).⁸

today is near that in 1950 (black curve, Fig. 10.2), ~15°C at the surface and colder than -60°C at the tropopause (temperature minimum near the 100 mb⁵ pressure level). Extreme cold at the tropopause “wrings out” almost all water in upward moving air. Thus, little water makes it to the upper atmosphere above the 1 mb level, where it can be dissociated by extreme ultraviolet radiation. As a result, negligible water is escaping from Earth today.

The other curves in Fig. 10.2 are computed for successive doublings of atmospheric CO₂. Each CO₂ doubling is a “forcing” equivalent to a 2% increase of solar irradiance, as discussed in later chapters. Our Sun is an ordinary star, “burning” hydrogen via nuclear fusion, with solar irradiance increasing 10% per billion years, equivalent to 5 CO₂ doublings (32×CO₂) in 1 billion years. The 20% increase of solar irradiance in two billion years produces a climate forcing equivalent to 1024×CO₂. By then, upwelling circulation in Earth's atmosphere has a clear path to pump water directly into the upper atmosphere (Fig. 10.2). As the Sun's irradiance continues to grow, Earth will lose its ocean, probably within 3 billion years, and our own Venus syndrome will commence. There is no need to be concerned about that. Three billion years is 100 million human generations in the future. If humanity still exists, it likely will have technology to move a livable environment to a safer distance from the Sun.

Runaway climate change can occur, if climate feedbacks are large enough. Global warming caused by 2×CO₂ or a 2% increase of solar irradiance would be only 1.2°C, if there were no climate feedbacks, because 1.2°C warming increases radiation to space enough to restore planetary energy balance. However, observations and modeling reveal three main feedbacks – increased atmospheric water vapor, decreased cloud albedo (reflectivity), and decreased sea ice albedo – and all are amplifying. The net feedback effect is described by a simple equation,⁶ $\Delta T =$

⁵ The unit mb (millibar) has been supplanted by hPa (hectopascal) in scientific literature. These units are numerically identical. I prefer mb, which helps keep scientific discussion connected to the educated public.

⁶ Imagine that water vapor increase caused by increased CO₂ causes a forcing half as large as that from the CO₂ increase (thus gain = 0.5). That warming from water vapor, half that from CO₂, adds still more water vapor. This

$1.2^{\circ}\text{C}/(1 - g)$, where ΔT is climate sensitivity for $2\times\text{CO}_2$ and g is the feedback “gain” in our feedback parlance.⁹ Climate system gain today (sum of all feedbacks) is likely between $g = 0.7$ (thus $\Delta T = 4^{\circ}\text{C}$) and $g = 0.75$ ($\Delta T = 4.8^{\circ}\text{C}$), as we will show in later chapters.

Runaway climate occurs if g approaches unity. Runaway happened several times when the Sun was weaker, Earth was cooler, and sea ice was extensive. Atmospheric CO_2 varies due to the level of volcanic emissions and other processes associated with movement of continental plates. When decline of CO_2 caused enough cooling for sea ice to expand toward the tropics, g reached unity and runaway to snowball Earth occurred.¹⁰ Eventually, volcanoes increased atmospheric CO_2 enough for sea ice near the equator to melt, and runaway global warming ensued. Warming then was likely rapid until the “fuel” for the sea ice feedback (sea ice area) was small enough for total gain, g , to subside to less than unity. Since the most recent snowball event, 600 million years ago, the Sun’s irradiance has increased 6%, making another snowball Earth implausible.

Earth’s paleoclimate history contains remarkable data on climate change¹¹ that is still being converted into knowledge. “Hyperthermal” events, rapid global warming of a few degrees Celsius,¹² are helpful for understanding the potential for limited runaway warming. The larger episodic hyperthermal events are separated by at least a million years; they coincide with, and are likely triggered by, extreme eccentricity⁷ of Earth’s orbit.¹³ These rapid warmings are marked by changes of the carbon isotopes in ocean sediments that imply release of hundreds or thousands of gigatons of isotopically depleted carbon.⁸ Most interpretations are that extreme summer heat and drought due to the eccentric orbit lead to oxidation of the carbon in peat, permafrost, and/or methane hydrates. Rapid warming caused by the increased atmospheric CO_2 then speeds depletion of carbon reservoirs.

In *Storms of My Grandchildren*, I painted a scenario in which all fossil fuels are burned rapidly – within the next 1-2 centuries -- including unconventional ones (hydrofracturing to extract gas and oil, tar sands, heavy oil). Total fossil fuel resources are huge, far exceeding proven reserves, which expand as technology improves. That extreme scenario yields a forcing, including other greenhouse gases, of $8\times\text{CO}_2$. Visitors to Earth in 2525 found a devastated planet. Is that possible? Land temperature rises about 1.5 times more than global average, and this scenario could bring into play feedbacks such as melting permafrost and/or methane hydrates.

Thus, the conclusion that burning all fossil fuels rapidly would lead to extreme climate change and pose an existential threat to humanity may be right, but the discussion in *Storms* was flawed. First, I did not distinguish between and explain well the Venus Syndrome and runaway climate. Second, I inferred runaway warming based on simulations with our GCM that found an uptick in climate sensitivity between $4\times\text{CO}_2$ and $8\times\text{CO}_2$ and GCM breakdown for $16\times\text{CO}_2$. The model breakdown, however, was only an indication that one or more of the scores of processes in the complex GCM was pushed outside its range of validity. Once we had the model version developed by Gary Russell – stripped of all unessential processes so that it could be used to

continues ad infinitum, so the total warming is $1+0.5+0.25+0.125\dots$ times larger than the direct CO_2 warming. The sum of this infinite series is obviously 2, but a much easier way to sum the series for any value of $g < 1$ is $1/(1-g)$.

⁷ Earth’s orbit is perturbed over tens and hundreds of thousands of years by the gravitational tug of other planets. The eccentricity reaches up to about 7%, but presently it is small, 1.67%, so the orbit is nearly circular.

⁸ Isotopically depleted carbon refers to carbon compounds with a high proportion of ^{12}C relative to the heavier isotope ^{13}C . Organic matter, methane hydrates, and volcanic eruptions are sources of isotopically depleted carbon.

investigate climate sensitivity – the effect of limited “ammunition” in most feedbacks was clear. Only water vapor has a practically unlimited source (the ocean). The physics and radiative properties of water vapor are understood, calculated well in the model, and do not yield runaway.

The underlying problem soon became clear. My research in the 20 years before writing *Storms* was focused on GCMs. In 1989, NASA received funding from Congress for “Mission to Planet Earth,” an effort to understand ongoing global change. Our group submitted two proposals: (1) a comprehensive GCM study of the carbon, energy, and water cycles, and (2) a satellite instrument to measure aerosol climate forcing. Remarkably, both proposals were selected.⁹ At the meeting announcing winning proposals, in a gentle mocking of the ambitious objectives of our GCM investigation, NASA summarized its title as “The Theory of Everything.”

That summary epitomizes a problem with GCMs. Global modeling is essential to investigate the simultaneous interactions of all parts of the global system. However, GCMs are imperfect – at best approximating the laws of nature – so there are continual efforts to improve the models and include more physical processes. It is easy to spend most of one’s time on modeling, crowding out alternative ways to investigate a problem. It was my own fault, a self-inflicted error, which I did not recognize until I began to question conclusions of the Intergovernmental Panel on Climate Change (IPCC), specifically IPCC’s downplaying of the threat of sea level rise and shutdown of the overturning ocean circulation.

How could those conclusions be disputed? We needed to go back to a broad research approach, one that placed comparable emphasis on (1) Earth’s climate history, (2) global climate modeling, and (3) modern observations of ongoing climate change, as will be described in later chapters.

The “runaway” climate threat now is the danger that today’s accelerated global warming will push Earth past a “point of no return,” with irreversible consequences for today’s young people and their descendants. I described the danger of rapid ice sheet collapse and sea level rise as the “tipping point” in a December 2005 tribute to Charles David Keeling¹⁴ and Bill McKibben popularized this a month later in an article¹⁵ in the *New York Review*. However, Lenton *et al.*¹⁶ now use “tipping point” for a broad range of climate feedbacks, many of which are reversible when the climate forcing is removed or replaced with global cooling. Therefore, I prefer “point of no return”¹ as terminology for the point of lock-in of unavoidable ice sheet collapse.

The danger of passing the point of no return is taboo with the United Nations Intergovernmental Panel on Climate Change (IPCC), the organization that we should expect to be most protective of the future of young people. This reticence of IPCC is a cause for concern, which deserves to be pointed out and vigorously debated. IPCC relies on models with millennial response times, even when driven by forcings that dwarf any experienced in Earth’s history. Based on paleoclimate data, global modeling, and ongoing ocean and ice sheet observations, we have concluded that shutdown of the ocean’s overturning circulation could occur within decades and this will affect ocean/ice sheet interactions and the rate of sea level rise.¹⁷ We will show in later chapters that up-to-date data support these conclusions. Concern about the danger of passing the point of no return is not a reason to panic. The climate system’s delayed response provides time to take preventive actions, if the science is understood well enough to define effective policy actions.

⁹ Unfortunately, in a short time, the aerosol instrument was deselected, a story in itself.

Public support will be needed to achieve timely, effective, climate and energy policy, but, as of now, long-term climate change is far down the list of public concerns. However, priorities can change – and have historically¹⁸ – as effects of changing climate on weather increase. What a coincidence! That brings us back to our chronological account, as we had a remarkable opportunity to witness the most exciting development ever in weather prediction.

¹ Hansen J. [Storms of My Grandchildren](#). ISBN 978-1-60819-502-2. New York: Bloomsbury, 2009

² The law says that energy radiated from a solid body is proportional to the 4th power of its absolute temperature, with temperature measured in degrees Kelvin (Kelvin temperature is Celsius temperature plus 273). This Stefan-Boltzmann equation was deduced by Josef Stefan in 1879 from laboratory measurements of the Irish physicist John Tyndall and derived from thermodynamic theory by Ludwig Boltzmann in 1884.

³ Air is warmest at the ground, where most solar energy is absorbed. Added greenhouse gases absorb heat radiated from the ground and radiate at the cooler local temperature, thus temporarily reducing radiation to space. The resulting planetary energy imbalance causes air and surface temperature to rise until energy balance is restored.

⁴ Gillmann C, Way MJ, Avicé G et al. [The long-term evolution of the atmosphere of Venus: processes and feedback mechanisms](#), *Space Sci Rev* 218 (56), <https://doi.org/10.1007/s11214-022-00924-0>

⁵ Marcq E, Mills FP, Parkinson CD et al. [Composition and chemistry of the neutral atmosphere of Venus](#). *Space Sci Rev* 214 (10), 2018

⁶ Ingersoll AP. [The runaway greenhouse: a history of water on Venus](#). *J Atmos Sci* 26, 1191-8, 1969

⁷ Russell GL, Laci AA, Rind DH et al. [Fast atmosphere-ocean model runs with large changes in CO₂](#). *Geophys Res Lett* 40, 1-6, doi:10.1002/2013GL056755, 2013

⁸ Hansen J, Sato M, Russell G et al. [Climate sensitivity, sea level, and atmospheric carbon dioxide](#). *Phil Trans R Soc A* 371, 20120294, 2013

⁹ Hansen J, Laci A, Rind D, et al. [Climate sensitivity: analysis of feedback mechanisms](#). In American Geophysical Union *Geophysical Monograph* 29, 130-63, 1984

¹⁰ Hoffman PF, Schrag DP. [The snowball Earth hypothesis: testing the limits of global change](#). *Terra Nova* 14, 129-55, 2002

¹¹ Zachos, J., M. Pagani, L. Sloan, E. Thomas and K. Billups, [Trends, rhythms, and aberrations in global climate 65 Ma to present](#), *Science* 292, 686-693, 2001

¹² Zachos JC, McCarren H, Murphy B, Rohl U, Westerhold T, Tempo and scale of late Paleocene and early Eocene carbon isotope cycles: implications for the origin of hyperthermals, *Earth Planet Sci Lett* 299, 242-9, 2010

¹³ The PETM (Paleocene Eocene Thermal Maximum) is an exception, coinciding with extensive flood basalt on the floor of the North Atlantic and volcanic CO₂ emissions (Gutjahr M, Ridgwell A, Sexton PF et al. [Very large release of mostly volcanic carbon during the Palaeocene Thermal Maximum](#). *Nature* 548, 573-7, 2017) associated with a sea floor rift as Greenland pulled away from Europe (see discussion in Hansen JE, Sato M, Simons L et al. [Global warming in the pipeline](#), *Oxford Open Clim. Chan.* 3(1), 2023: doi.org/10.1093/oxfclm/kgad008).

¹⁴ Hansen J. [A Tribute to Charles David Keeling](#), 6 December 2005, AGU meeting, San Francisco, California

¹⁵ McKibben B. The coming meltdown, *New York Review*, LIII (no. 1), 12 January 2006

¹⁶ Lenton TM, Held H, Kriegler E et al. [Tipping elements in the Earth's climate system](#), *Proc Natl Acad Sci* 105, 1786-93, 2008

¹⁷ Hansen J, Sato M, Hearty P et al., [“Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2C global warming is highly dangerous,”](#) *Atmos Chem Phys* 16, 3761-812, 2016

¹⁸ Cologna V, Meiler S, Kropf CM, et al. [Extreme weather event attribution predicts climate policy support across the world](#). *Nat Clim Chang* 15, 725-35, 2025, doi:10.1038/s41558-025-02372-4