HISTORICAL MATERIALISM 30.4 (2022) 3–53

historical materialism
research in critical marxist theory

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Editorial Perspective

The Future Is the Termination Shock: On the Antinomies and Psychopathologies of Geoengineering. Part One

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Abstract

As capitalist society remains incapable of addressing climate breakdown, one measure is waiting in the wings: solar geoengineering. No other technology can cut global temperatures immediately. It would alleviate the symptoms of the crisis, not its causes. But might it be combined with radical emissions cuts? This essay, the first instalment of two, scrutinises the rationalist-optimist case for geoengineering: the idea that soot planes in the sky can shield the Earth from the worst heat while society rids itself of fossil fuels. A more likely outcome is that they encourage business-as-usual to continue, while negative side-effects from geoengineering itself pile up. The logic of the enterprise points in the direction of a catastrophic termination shock. A subsequent, second instalment will subject geoengineering to a materialist psychoanalysis and argue that it represents a fantasy of repression, setting itself up for a dreadful return of the repressed.

Keywords

geoengineering – climate change – Marxism – symptom

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Things bad begun make strong themselves by ill.
Macbeth

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1 Fighting a Symptom by Forming One

When crises break out in contemporary capitalist societies, they are seldom treated below the level of symptoms. The financial crash of 2008 was papered over with trillions of dollars from central banks. The Covid-19 pandemic of 2020 could have been an occasion to deal with the drivers of zoonotic spillover, notably tropical deforestation, but gazes were fixed on the holy grail of vaccines, and nothing was done to reign in the logging: instead it soared to new heights.[1] When migrants try to cross into the EU in 'waves', as they are usually referred to, the invariable response is further fortification of the borders. The misery that propels people onto boats and treks is left to fester. When the chronic hyper-crisis in the Gaza Strip erupts into open conflict and the resistance emerges from the tunnels to fire projectiles towards the occupier's territory, one reflexive reaction is the switching on of the Iron Dome: an advanced technological system for detecting and intercepting rockets in the troposphere, plucking them like fruits fizzing in the air. The blockade, as a matter of course, remains in force, the Palestinians pushed ever deeper into despair. Examples could be multiplied without end. What, within this pattern, is a likely capitalist response to accelerating climate breakdown?

Solar geoengineering – that is, shooting aerosol particles into the stratosphere to block some of the incoming sunlight and thereby cool the Earth – sits in the back of the consciousness of climate politics like an Iron Dome to be rolled out if the fire becomes unbearable. It has done so since 2006, when Paul Crutzen published the editorial in *Climatic Change* that famously broke the taboo on the topic.[2] Yet it would be very wrong to say that geoengineering

1 Harvey 2021.

2 Crutzen 2006. On the rise of geoengineering research and the role of Crutzen's article, see e.g. Kintisch 2010, pp. 1–99; Goodell 2010, pp. 2–16; Hamilton 2013, pp. 14–19; Belter and Seidel 2013; Caldeira and Bala 2017; Möller 2021. With 'geoengineering', we hereafter mean 'solar geoengineering' a.k.a. 'solar radiation management'. More precisely, unless otherwise stated, we mean sulphate aerosol injection.

is now on everyone's lips. Almost two decades after Crutzen, no government is openly championing the measure. Neither ExxonMobil nor Saudi Aramco nor any other fossil fuel corporation of note is promoting it, as a vulgar Marxist would perhaps expect.[3] There have been predictions that climate denialists will somersault into geoengineering advocacy, but this has not transpired, which is somewhat remarkable, given the salience of (anti-)climate politics on the far right: parties like the AfD and Vox and former presidents such as Jair Bolsonaro and Donald Trump have shown considerable interest in the issue, but they have yet to call for the planes to take off.[4] Much as for fossil fuel corporations, carbon dioxide removal has gained far more traction; figures like Trump and Nigel Farage have toyed with the idea of planting trees to reverse the climate change they don't believe in, while Shell and Occidental Petroleum fund ventures for sucking carbon out of the air.[5]

So far, the imperative of geoengineering has not been based on shrill sponsorship. It is structural in nature. In the arsenal of possible climate policies, there is a single one with a known capacity to reduce average temperatures on Earth within months: while the benign effects of emissions cuts would play out over decades, geoengineering alone could work wonders virtually overnight. The cost would be negligible in the larger scheme of things. Imagine, then, that the climate crisis is left untreated at its roots. One day it reaches a pitch of intensity and mass lethality that makes the inert order of capitalist

3 Vulgar or not, this is the expectation expressed by Ott 2018, p. 6; it is presented as an already fulfilled fact in Gunderson, Stuart and Petersen 2020, p. 399. The latter interpretation rests on exceedingly flimsy evidence. It could of course still be the case that this *might* happen in the near or distant future, but that is a different empirical question. ExxonMobil appears to have provided some funding for one report in the early 2000s that advocated geoengineering. Hamilton 2013, p. 78. In 2012, CEO Rex Tillerson claimed that climate change 'is an engineering problem and there will be an engineering solution', but this is too general a statement to count as an endorsement of geoengineering specifically (although we cannot rule out that this is what he had in mind). AP 2012.

4 For such predictions, see e.g. Morton 2015, pp. 158–9, 351; McLaren 2016, p. 598; Ott 2018, pp. 7–10; Markusson, Tyfield, Stephens and Gjefsen 2021, pp. 208–9 (and for an empirical study demonstrating that denialists in the general British population were positive toward geoengineering and hence suggesting a link: Corner and Pidgeon 2014); again, by means of cherry-picking of secondary data, this is presented as an already-fulfilled fact in Gunderson, Stuart and Petersen 2019, p. 704; Gunderson, Stuart and Petersen 2020, p. 399. For the persistence of denialism on the far right, see Malm and the Zetkin Collective 2021. If anything, so far, the denialist far right – at least in the US – has become *less* present in the geoengineering debates over time, the cause moving rather to the centre. Cf. Kintisch 2019, pp. 194–6; Surprise and Sapinski 2022. But again, it cannot be ruled out that the denialist far-right might make a somersault of this kind in the future: see further the second part of this article.

5 For Trump and Farage, see e.g. Friedman 2020; Twidale 2021; for oil companies and DAC, see Malm and Carton 2021.

society snap: something has to be done, immediately, to get this situation under control.[6] What are the options? Only one, it seems. As it happens, this imperative – even if unsaid or muffled – gains force for every passing year of unrestrained business-as-usual and exacerbated climate impacts, a combination that shows no sign of weakening. There is a sense that every season of disaster brings geoengineering one step closer to the stage. How many more summers of extreme wildfires, how many more deadly heatwaves or hurricanes, droughts or floods, before someone calls it up? Geoengineering is a – the – *deus ex machina* waiting in the wings.

But it certainly has its share of proponents. One of the more influential is neither a scientist nor a legislator, but a novelist: Kim Stanley Robinson, whose *The Ministry for the Future*, arguably the greatest and probably the best selling cli-fi novel so far, features geoengineering as part of the plot. It gets off the ground after a heatwave kills 20 million people in a fortnight in India in the year 2025. In the first chapter, Robinson describes with harrowingly credible realism how the electricity goes out in an Indian village, AC systems break down and people seeking refuge from 'the blazing furnace' roast on rooftops or boil in a nearby lake. India can't take it anymore. The government authorises a fleet of planes to circle through the stratosphere and pump out plumes of soot so as to form a sunshade, thin but potent enough to slash average temperatures on Earth by three degrees for five years. The Indian population is spared more carbon holocausts. After half a decade of round-the-clock soot injection, the flights are discontinued, but – a most questionable scenario, as we shall see – temperatures only gradually, slowly creep back to prior levels.[7] The reprieve is a feat of humanitarian intervention.

The most significant predicate about geoengineering in *The Ministry*, however, may be another: in no way does it conflict with attacking the causes of the catastrophe. It is but one response to the Indian heatwave. After this tipping-point into total crisis, all kinds of actors strive to stem the heating at its sources with all manner of methods, from carbon taxes and rewilding via square occupations and direct air capture (DAC) to, crucially, armed struggle. Through causal pathways not always clear, the latter is the motor of the long overdue transition away from fossil fuels. In the wake of the heatwave – and in tandem with the stratospheric aerosol injection – there arise the Children

6 Cf. e.g. Markusson, Ginn, Ghaleigh and Scott 2014; Horton 2015, pp. 147–9; Buck, Geden, Sugiyama and Corry 2020, pp. 2–3; Reynolds 2021, p. 5.

7 The Indian operation is said to have suppressed average temperatures by one degree even during the decade *after* termination; only after 2040 does a return to 'pre-intervention levels' set in. Robinson 2020, p. 356.

of Kali, an outfit initially based in India but rapidly spreading across the globe to hack and wreck coal-fired power-plants, torpedo oil tankers and superyachts, shoot down airplanes, assassinate fossil fuel executives and drone-bomb enclaves of the ultrawealthy. The campaign is so effective that the eponymous Ministry for the Future of the UN picks up sabotage and possibly killings too. Under violent onslaught from all corners of the globe, fossil capital begins to crumble.

In this panorama of edifying scenarios, geoengineering is one weapon for defending people against heat death – not necessarily the most important; just one among many. Robinson has struck the same note in interviews. He has argued that a five-year run of injections would give the planet much needed relief, as in his novel. The notion that this would deflect attention from the sources of the problem is mistaken – geoengineering is

> no longer a get-out-of-jail-free card for capitalism going on the way it is. Nobody who has proposed it is discussing it that way. And if you think of them as snidely twirling their mustaches, the corporations might say that this will allow them to burn all the rest of our fossil carbon. No, it won't.[8]

On this view, geoengineering is not a facile palliative, but an indispensable part of a battery of solutions.

A similar argument has been made by Holly Jean Buck, the leading social scientist in the field; in an essay for *New York Magazine*, she has suggested that geoengineering may be a force for peace. More precisely, it could clinch 'a truce' with the fossil fuel interests that block climate action. 'In its best case form, solar geoengineering would buy time for decarbonization and carbon removal, as a temporary program that ramps up during the transition, then ramps down again over a century or so – "shaving the peak" off climate impacts', while the substitution of renewables for fossil energy unfolds *pari passu*.[9] Geoengineering has similarities to the lockdown measures of the Covid-19 pandemic, but 'the root causes must not be forgotten', and there is apparently

8 Cohen 2021. In this interview, Robinson sticks to the scenario of his novel where a five-year dose of aerosols has an enduring impact: 'You don't have to do it permanently forever in order to keep the temperature from increasing. In fact, you would plan to do it just once in a hundred years, to avoid getting caught in that trap, and see what the effects are over five years.' The usually so well-informed Robinson is here on thin ice: there is zero climate modelling or other evidence to suggest that five years of sulphate aerosol injection could suppress temperatures for many decades afterwards. See further below. For other interviews where he has put forth similar arguments, see Kaufman 2018; Canavan 2019; Baker 2021.

9 Buck 2022.

little reason to fear they would be: in Buck's view, the best-case scenario is not only desirable, but eminently plausible.[10] This technology has 'tremendous potential for security and peace'.[11]

Call this the *rationalist-optimist* position on geoengineering. It holds that solar radiation management can and will be activated *in combination* with mitigation – that is, with closing down the sources of CO_2 emissions. Few if any would classify it as a cure for global warming at the level of causes; rather, the contention is that symptomatic treatment of this kind would not subtract from any such cure, but go hand in hand with it, assist and smooth it out. It would not trigger a mechanism by which capitalist society sweeps the problem under the rug of a pseudo-remedy. This belief can come in a strong form – no such risk exists – and a weak – the risk is manageable and no more cause for concern than any other risk in the risk-saturated climate crisis – and in various intermediate gradations. Furthermore, geoengineering would be a *temporary* procedure, wound up and down like a thermostat as needs dictate. It would be deployed merely to 'shave off the peak' of the most disastrous curves and then retired. The mission would not be permanent or self-sustaining. No demand for ever-increasing volumes of soot would arise. All of this is because – and here is the fundamental wager – geoengineering would be implemented *in a rational fashion*.

The rationalist-optimist position has a solid base – or so it would seem – in an advanced research frontier. Public intellectuals like Kim Stanley Robinson stand on the shoulders of a cohort of scientists who painstakingly develop the case, and we may as well name the top names: David Keith, Gernot Wagner, Wake Smith, Jesse Reynolds, Douglas MacMartin, Ben Kravitz, Peter Irvine, Joshua Horton – all white men, all active in the US, circumstances that cannot be brushed off as trivial.[12] But to portray them as reactionary bigots fronting for fossil capital would – and here Robinson is right – be unfair. Nor are they maniacs or Pollyannas. Rather, they go out of their way to distance themselves from the stereotype of the mad scientist. An upfront awareness of the risks of geoengineering is integral to their project. More often than not, they are liberal

10 Buck, Geden, Sugiyama and Corry 2020, p. 2. Buck is a most prolific writer; for her book-length treatment of the subject, see Buck 2019. Her pronouncements on the matter have varied over time, from critical analyses to the most sanguine accounts, e.g. a paper written together with the leading rationalist-optimists, arguing that geoengineering could 'ultimately *enhance* democracy.' Horton, Reynolds, Buck *et al.* 2018, p. 10. Emphasis in original.

11 Buck 2022.

12 On this demographic bias and its implications, see e.g. Biermann and Möller 2019; Stephens and Surprise 2020; Sikka 2021. The problem is recognised in NASEM 2021, p. 37. Ken Caldeira seems to sit on the fence of the rationalist-optimist compound.

and progressive, in the American senses of the terms, wary of any association with more irrational currents. 'In some ways the thing we fear most is a tweet from Trump saying, Solar geoengineering solves everything! It's great! We don't need to bother to cut emissions', Keith, the maven of rationalism-optimism, a furiously productive scientist and efficient communicator, whose centre at Harvard is the avant-garde of the enterprise, acknowledged in 2017.[13] No such tweet was posted, presumably to the relief of Keith *et al.*, their self-image as the consummately cautious and prudent scientists surviving the Trump presidency intact.

And then they received a fillip, in March 2021, in the form of a report from the National Academies of Sciences, Engineering, and Medicine, or NASEM. A 300-page dossier from the highest scientific institution in the US, *Reflecting Sunlight* gave the imprimatur to rationalism-optimism, while stopping short of endorsing it outright. The vistas opened up by Keith *et al.* appear to have inspired NASEM to recommend not deployment, but – no small thing – a national research programme on geoengineering to learn more about what could be done.[14] No major scientific body in the world had made a similar call before.[15] To Keith, it was 'thrilling' news; for him and his colleagues, a federally funded research programme would make a qualitative difference.[16] They would no longer be at the mercy of the private sources that have bankrolled their work so far. Contrary to expectations, again, fossil fuel companies and denialist think-tanks have shown scant interest; the funding has come from the ecomodernist, high-tech, Silicon Valley fractions of the US capitalist class. Charitable billionaires have owed their fortunes to Microsoft – Bill Gates the emblematic patron – Google or Skype, not Chevron or Peabody.[17] But a shift from these philanthropic props to the (Democratic) government would boost

13 Keith in Orcutt 2017. An early profile and mini-biography of Keith – 'A Planetary Cooler' – can be found in Goodell 2010, pp. 23–46; cf. Kintisch 2010, pp. 7–8.

14 The rationalist-optimist position is summarised in NASEM 2021, pp. 114–15, 120. For a rapid-response critique of the report and its mainstreaming of geoengineering, see Stephens, Kashwan, McLaren and Surprise 2021.

15 *Nature* 2021.

16 Keith in Voosen 2021; cf. the excitement expressed in Smith 2022, pp. 328–30, 339.

17 See the superb study by Surprise and Sapinski 2022. It is marred, however, by the belief that there is an ongoing 'decline of fossil capital' and the rise of something called 'climate capital'. Surprise and Sapinski 2022, pp. 4, 11. Low costs of renewable energy are said to tilt the latter against the former; US military power is likewise on the wane. If these propositions were possible to make before 2022, they are conspicuously erroneous after the events of this year. The point, rather, is to study how geoengineering, even if not directly animated by fossil capital, is articulated with its unbroken ascendancy. On Gates as patron, see Hamilton 2013, pp. 74–7.

the financial resources and the enlightened reputation of the geoengineering laboratories in equal measure.

So, are we getting ready for judicious piloting of the planet through the coming decades or even centuries of climatic turbulence? In the best of all possible worlds, perhaps. But in the best of all possible worlds, we would not, of course, be facing this breakdown to begin with. And here we encounter the first and most basic antinomy of the geoengineering enterprise. If rationality had been a reasonable assumption about the way the world is run, the rationalist-optimists would have no quest to pursue: geoengineering would be nowhere on the agenda. Only the most profoundly irrational forces could have placed the Earth in the trajectory it is currently in.[18] What Keith and his cohort propose to do is to enter the cockpit and take us out of the danger zone, at just the right time with just the right amount of steering. But is such a scenario probable? In what follows, we shall inspect a series of interlocked antinomies that suggest it is not. The possibility rather appears that, for all their appeals to reason, scientists and others who advocate geoengineering – including leftist intellectuals like Robinson and Buck – provide a kind of cover for the working out of *un*reason. That cover is more likely than not to find itself blown. Put differently, it is precisely because capitalist society has long since taken leave of the reality principle that geoengineering can amass the structural imperative on which the rationalist-optimists ride. Much as a cloud of sulphur would mask the cumulative emissions, so their rationality puts a veil on systemic irrationality: and neither is truly soothing or sustainable.

When examining scenarios of this sort, one would be best served by access to several Earths. One would then engineer the atmospheres on some of them and not on others and compare the results. Unfortunately, the universe does not allow for such testing, which means that any advance knowledge we can acquire about geoengineering will be theoretical. Here is a key difference vis-à-vis carbon dioxide removal: a DAC machine can be assembled and studied as it does the actual work of sucking CO_2 out of the air; if promising, it can be copied and improved in the next generations of plants. But to inject sulphate aerosols into the stratosphere is to switch on a machinery that would encompass the Earth as a whole from the outset. There is no way to learn how it would work by gradually scaling up small modules; outdoor experiments are certainly possible (and recommended by NASEM) – say, a sack of particles unloaded into the stratosphere – but merely to enable limited observations. The only field trial at scale would be full implementation. It is for this reason that scientists are restricted to running climate models in computers and other

18 Cf. McKinnon 2020, p. 592.

roundabout exercises for approximating the contours of the phenomenon.[19] (We might say, then, that the ideology of geoengineering has a lower degree of materiality than that of carbon dioxide removal.)

By the same token, a futurological, necessarily speculative study of the irrational and potentially highly destructive forces that could be unleashed by geoengineering cannot be based on site visits or similar fieldwork. It is the corpus of scientific output itself that comes closest to a crystal ball. Solar radiation management does not (yet) have a significant presence in the sphere of politics *sensu stricto*, and even less so in capital accumulation. Unlike DAC, it promises no new lines of commodity production; whereas the former boasted many dozens of start-ups as of 2022, the number of private companies in the business of aerosol injection was zero.[20] Instead, the imperative of geoengineering is working its way towards the surface of the conscious primarily by means of scientific research. There is no better material at hand than the texts the rationalist-optimists themselves produce.

By reading them, we might learn how they prefigure or even partake in symptom formation, in the psychoanalytical sense of the term. A classic example of a symptom is compulsive hand-washing. Lady Macbeth is its tragic heroine. Once her husband has stabbed the king to death, she launches an operation for removing the stain of the crime: 'Go get some water / and wash this filthy witness from your hand. […] A little water clears us of this deed.' But, of course, the drama does not stop with one act of killing. As Macbeth struggles to seize and hold on to the throne, the murders multiply, the substance of blood attaching to sundry surfaces of the usurper and his queen: blood on their daggers, their faces, their hands. The washing of Lady Macbeth takes on the character of a continuous obsessive ritual. In the fifth and final act, a doctor observes that 'it is an accustomed action with her to seem thus washing her hands: I have known her continue in this a quarter of an hour', and the Lady is caught in the act speaking to herself: 'Out, damned spot – out I say. One, two – why then 'tis time to do't – Hell is murky.'[21] There is some *prima facie* resemblance between Lady Macbeth and a capitalist society that sends planes into the furthest reaches of the sky to undo the deed that has been done – although, of course, the physical sign would be the opposite: pollution not ablution. If geoengineering begins as the urgent treatment of a symptom, it might well slide into *symptom formation*. (The blurring of the lines between the two was incidentally highlighted during

19 Cf. e.g. Hamilton 2013, pp. 67–8; Robock 2020, p. 63; NASEM 2021, pp. 50–1, 117, 245–50.

20 As pointed out – and we are aware of no change to the figure since then – by Smith and Henly 2021, p. 7.

21 Shakespeare 2008, pp. 128–9, 194.

the Covid-19 pandemic, when compulsive hand washing became compulsory and the most classical symptom of neurotic disorder proliferated; Lady Macbeth's 'Out, damned spot' became a meme.)[22]

The passage from treatment to formation would seem to be triggered by reactions to a crisis. For the Macbeth couple, the crisis is at once moral, legal and psychic: 'I have done the deed', the husband confesses to his wife, who responds: 'These deeds must not be thought / After these ways: so, it will make us mad.'[23] Hence the washing. It might seem sensible in the first instance; it does, after all, remove the evidence of guilt. But it is the escalated washing that marks the descent of Lady Macbeth into utter madness. We may posit that a crisis is a moment of acutely intensified contradictions – in this case, between the avarice of the Macbeths and their perception of themselves and the world around them; between their desire to take the throne and their decency, legitimacy, even sense of reality itself – which ushers in a primary symptom – a surfeit of blood – combatted so as to neutralise the danger. But through that very defence, a secondary symptom is formed. 'Symptoms are created in order to remove the ego from a situation of danger', writes Freud.[24]

Whatever individual event might tip the scales into a sudden crash-like climate emergency, that crisis, all but certain to come, would manifest the contradiction between capital accumulation based on fossil fuels as its material substratum – in short, fossil capital – and the climate system of the Earth. It would be the moment when the refusal of capitalist society to countenance the boundaries and thresholds of reality no longer works. The danger would have become unignorable. The rationalist-optimists prepare for a timely rescue operation, in the belief that it can be a discreet and politic stopgap measure. But another twist can be divined: the washer/injector becomes unable to detach or desist from the act, bound to repeat it, fearful that the unmitigated underlying danger will otherwise explode into the open. The operative mechanism here would, of course, again in the psychoanalytical sense, be repression.

At this point, we have come some distance from rationality. Neither Macbeth nor his Lady is a model of sanity; from the beginning, rather the contrary. Their endeavours to cover up their crimes send them on a downward spiral and eventually prove futile. The tyrant king is slain. His queen kills herself. If

22 For some studies of the causal links between exhortations to hygienic measures during the pandemic and exacerbation of obsessive-compulsive disorders, see Dennis, Radnitz and Wheaton 2021; Hassoulas, Umla-Runge, Zahid *et al.* 2021; Jelinek, Moritz, Miegel and Voderholzer 2021; Sulaimani and Bagadood 2021; on the Shakespearean meme, see Smith 2020.

23 Shakespeare 2008, pp. 126–7.

24 Freud 2001b, p. 144. Cf. p. 129; Freud 2001a, p. 123.

Shakespeare is any guide, this story – would it be told without interruption – ends in insanity and death, and in the field of geoengineering, there is in fact a very concrete and specific chain of causation for bringing such an end about. It goes by the name of the termination shock. We shall argue, in what follows, that the inherent logic of the geoengineering enterprise points in precisely that direction. The first instalment of this essay provides an overview of the basic science and identifies structural antinomies working their way towards the shock. A subsequent, second part will sketch a materialist psychoanalysis of the phenomenon. It will inspect the contradictions, inconsistencies, elisions, evasions and other symptomatic tensions in the rationalist-optimist corpus and make a more elaborate case for analysing geoengineering itself as a symptom in formation. More precisely, it now represents a *fantasy of repression* – a daydream about suppressing the real contradictions capitalist society is incapable of resolving. As such, if it is ever realised, it is bound to end badly.

2 A Most Unusual Technology

The basic physics are well understood. Aerosols suspended in the atmosphere stand in the way of rays from the sun. They scatter the incoming sunlight, down, to the sides and back into space. It happens all the time; the air naturally contains aerosols – dust, organic matter – and economic activity by humans supplement them with effluents, such as soot.[25] It follows that if more particles of this kind are lofted from the ground and into the atmosphere, more solar insolation will be intercepted. Temperatures on Earth will fall. This was the 'kill mechanism' for the fifth mass extinction, the K-T event that wiped out the dinosaurs: an asteroid 10 kilometres in diameter smashed into the Yucatan peninsula with such force that a cloud of dust, ash, sulphur and other aerosols rose into the atmosphere, encompassed the globe, shut out sunlight and sent temperatures plunging. The ensuing 'impact winter' eradicated the habitats where dinosaurs could live.[26] More contemporarily, the notion of a 'nuclear winter' hinges on similar cause and effects: atomic bombs would set a giant match to cities and industrial areas and entire landscapes, black sooty smoke would shoot into the air, particulate matter would linger in the stratosphere, temperatures would plummet, the dark and the cold would kill crops, food supplies for humanity would collapse. The use of a fraction of the world's nuclear arsenal

25 Smith 2022, p. 218.

26 Chiarenza, Farnsworth, Mannion *et al.* 2020.

would be enough to inaugurate such a season.[27] In other words, a nuclear war caused by inter-imperialist rivalry or some other geopolitical antagonism – between the US and Russia, or India and Pakistan, or Israel and Iran – would go some way to suspend the results of fossil capital. Ironically, the lead author of the first scientific paper warning about the climatic implications of atomic warfare in 1982 was Paul Crutzen; not inaptly, a very early paper on geoengineering referred to it as 'a controlled "nuclear winter"'.[28]

The favoured analogue, however, is volcanos. A large enough eruption will spew out sulphur into the stratosphere – picture a billowing pyroclastic cloud – where it might stay for a year or so. The most recent incident of size is still the outbreak of Mt Pinatubo in the Philippines in 1991: some 20 million tons of sulphur suppressed global temperatures by half of a degree for about a year afterwards. Geoengineering has thus been colloquially known as 'the Pinatubo option'. Volcanos get close to live demonstrations of what can be achieved with a mountain of sulphur, but the analogy is imperfect, because aerosols drizzle back to Earth within months. Eruptions come in single pulses. In geoengineering, by contrast, the sulphur – the default candidate for a substance, following the volcano prototype – would have to be replenished through continuous injections, or else the effect would slip away like water between one's fingers.[29]

Temperatures on Earth are a function of the amount of solar radiation striking its surface and the amount of departing radiation trapped in the atmosphere. Greenhouse gas emissions change the latter variable – more heat in transit is held up for longer – while solar radiation management, as the term indicates, tinkers only with the former. It is 'not anti-CO_2', as rationalist-optimists readily admit.[30] It bypasses the greenhouse gases and leaves them in peace. Instead, it intervenes with a force that alone has the power to break the causal link between temperatures on the one hand and atmospheric concentrations of CO_2 and its lesser peer gases on the other: and in this, it is virtually guaranteed to have effect. The science leaves little doubt that injection of sulphates into the stratosphere would indeed accomplish a temperature drop. Taking out one or two per cent of sunlight would be enough to undo the effects of the past two centuries of large-scale fossil fuel combustion; while such combustion

27 Robock 2010; Robock 2011; Coupe, Bardeen, Robock and Toon 2019; Xia, Robock, Scherrer *et al.* 2022.

28 Crutzen and Birks 1982; Mautner 1991, p. 135.

29 E.g. Kintisch 2010, pp. 58–67; Robock, MacMartin, Duren and Christensen 2013; Plazzotta, Séférian, Douville *et al.* 2018; Robock 2020, p. 64; NASEM 2021, pp. 34, 38, 66–7; Smith 2022, pp. 219, 225. Put differently, a controlled nuclear winter would have to be perpetually renewed.

30 E.g. Keith and Irvine 2016, p. 551; Belaia, Moreno-Cruz and Keith 2021, p. 4.

continues, the hit rate might have to increase, but the accuracy would still be there for the taking.[31] One can imagine how irresistible the promise could become.

And it is fairly easy to do: airplanes suited for the task are within reach. To tuck the sulphate into the stratosphere and have it stay there for as long as possible – preferably a year – it needs to be transported some 20 km above Earth; lower down, it will drop to the surface within weeks. Existing business jets cannot fly that high. But some spy planes and other military jets have routinely done so. One leading rationalist-optimist, Wake Smith, has a former career as a CEO of sundry aviation companies and president of the training division of Boeing; to see what can be done, he called up his pals in the latter corporation (and others in the business, of which more below). The team came up with a customised design for high-flying sulphate planes. It will have abnormally long and large wings so it can cruise in the thin air. The fuselage will be narrow, filled not with passengers who need space but with chemicals: a payload of molten sulphate, combusted onboard and released into the winds. These will be specialised single-purpose machines – like 'water bombers that are used to fight forest fires', a metaphor with several connotations. They will scream up to their intended altitudes within ten minutes, above the tropics, from which the sulphate will slowly make their way towards the poles; then back to base and up again, with the next load.[32]

The challenge to build a workable fleet of this kind could be met by private industry within 'several years'.[33] A military crash programme could churn it out faster. This would not be cost-free. The design effort would command resources, although not too many: no major technological breakthroughs are called for; rather the injection vehicles would synthesise already-existing features of planes. Airliners and air forces could afford the mission.[34] But what other costs might there be? The sulphate itself is currently 'dirt cheap' – geoengineering would augment demand, but not render the material scarce; from Vesuvius to India, volcanos and limestone hold it in abundance.[35] Instead fuel is thought to be the main cost factor (or, if one prefers, circulating capital). It will, of course, be fossil. The price of jet fuel and thereby the geoengineering fleet might, somewhat perversely, skyrocket if mitigation were to occur – say, carbon rationed or rigorously taxed. And then there is the labour, which, in the

31 Kravitz and MacMartin 2020, p. 64; Wagner 2021, p. 15; NASEM 2021, pp. 31, 35, 52, 66, 206; Smith 2022, p. 202.

32 Smith and Wagner 2018; Smith 2022, pp. 220, 231–40. Quotation from Smith 2022, p. 235.

33 Smith and Wagner 2018, p. 8. Cf. e.g. Lockley, MacMartin and Hunt 2020, pp. 6–7.

34 Smith 2020, p. 11; Smith 2022, pp. 225–6.

35 Smith 2020, p. 7; cf. Smith 2022, p. 220.

form of aircrews, would have a fantastically strong bargaining position: strikes could put civilisation itself in peril, as more aerosols would trickle down to Earth for every week or month of work lost. One can imagine a kind of class struggle that would turn the geoengineering pilots into the cream of a labour aristocracy or, perhaps more likely, induce a round of automation that would issue in unmanned, remote-controlled, drone-like planes (which, however, would still necessitate service crews on the ground). Sustained technological development might reduce costs further.[36]

It would surely be an industrial undertaking of massive proportions: many millions of tons of sulphate extracted from underground deposits and ferried to hundreds of planes taking off from a network of bases, all integrated in extensive supply chains and surveillance systems. Even so, the consensus holds that total costs for the technical apparatus would easily be within the means of an advanced capitalist country. Smith derives a ballpark figure of 30 billion dollars for the global geoengineering operation in the year 2100 and points out that it equals the sum currently spent on pet food in the US. If that sounds paltry, it would also – a mathematical equality perhaps denoting a certain irrationality – consume every military budget of the world save for the ten largest. This would put geoengineering beyond the reach of poor countries. It would even exhaust the fortunes of individual billionaires (at their present levels of net worth) and instead demand the involvement of at least one 'major economy'.[37] But when compared with the costs of runaway warming, geoengineering might be a bargain; the price tag for it is it unlikely to be a decisive factor in the decision to deploy. Symptomatic treatment can come on the cheap. Measured in cost per degree of suppressed temperatures, the economics of geoengineering does indeed appear 'incredible'.[38]

Other delivery systems have been mooted. One could use guns to shoot aerosol shells into the stratosphere. Balloons tethered to the Earth or an armada of free-floating balloons might possibly do the trick. Some have envisioned the construction of the world's tallest tower with an inbuilt hose to pump sulphate into the sky, or an elevator taking the stuff to a satellite, but all of these

36 Smith and Wagner 2018, pp. 4, 6; Smith 2020, pp. 3, 7; Smith 2022, p. 241. Or, employees in this sector might be given a role analogous to policemen: a repressive function that would conform to geoengineering as repression in the Freudian sense (see the forthcoming second part of this essay).

37 Smith 2020, pp. 10–11. Cf. Smith 2022, p. 243. Technological developments cutting the cost of the fleet would, however, make it more widely affordable, as pointed out by Rabitz 2016, pp. 105–6.

38 Robock *et al.* 2009, p. 7; Smith and Wagner 2018, pp. 8–9; Smith 2020, pp. 2, 10–11; Wagner 2021, pp. 9, 17–18, 24–5. 'Incredible': as first suggested by Barrett 2008.

alternatives have drawbacks: guns do not distribute soot as evenly as planes; balloons are unreliable; towers of the required length would hardly withstand the ferocious winds of the jet stream.[39] But future marvels cannot be ruled out. In the same vein, aerosols other than sulphates are on the table: salts, alumina, calcite, diamonds, the latter two being solid minerals that would be ground to powder and sent skywards.[40] We might pause briefly and reflect on what is going on here. Scientists steeped in the instrumental rationality of bourgeois civilisation are seriously discussing whether to use guns and diamonds to offset the effluvium from a process of capital accumulation they (and many others) cannot imagine being brought under control.

It gets fancier still when we consider astrophysical variants of geoengineering. Three decades ago, a scientist from New Zealand mooted the idea of using lunar dust to build a reflective film belt in space and position it around the waist of the Earth.[41] In early 2022, an Iranian scientist proposed to hitch our planet to asteroids and harness their force to nudge it out of orbit, away from the sun, advertising it as 'an alternative' to the apparently insurmountable task of 'decreasing fossil fuel consumption'.[42] Of greater stature, a team at MIT publicised a plan for manufacturing frozen silicon bubbles in space and placing them halfway between the sun and Earth, where they would stay fixed like a slender curtain.[43] Earlier proposals also include refractors manufactured from lunar glass, a superfine mesh of aluminium threads, a swarm of mirror-like disks to reflect sunlight – but as of 2022, these have all fallen by the wayside.[44] None has entered the handbooks of the rationalist-optimists. It remains to be seen if the MIT bubbles fly.

Already underway, however, is another subset of geoengineering. In Australia, the bleaching and dying of the Great Barrier Reef has prompted the government to funnel money to scientists with an antidote: equipping boats with nozzles for shooting nano-sized droplets into clouds. The clouds would then become brighter and function as enhanced parasols for the heat-stressed corals underneath. This is 'marine cloud brightening', a method for manipulating the albedo, or reflectivity, of a cloud cover; a form of geoengineering that targets not the climate system, but some regional ecosystem to be desperately saved. But the logic is similar. The scientists behind the pioneering project aim to

39 Robock *et al.* 2009, pp. 6–7; Lockley, MacMartin and Hunt 2020. Airships and rockets are also discussed.

40 Weisenstein, Keith and Dykema 2015; Keith, Weisenstein, Dykema and Keutsch 2016.

41 Mautner 1991.

42 Rahvar 2022 (quotation from p. 1).

43 MIT 2022.

44 Keith and Dowlatabadi 1992, p. 293; Kintisch 2010, p. 59.

'significantly reduce damage to the Great Barrier Reef from coral bleaching in the short term, while waiting for viable long-term solutions to save the reef.'[45] The latter is presumably an allusion to phasing out fossil fuels – something the Australian government and dominant class, profiting from the world's largest exports of coal, have ostentatiously refused to do. The waiting could be long. The ongoing experiment might be considered a test for some key elements of the rationalist-optimist hypothesis: will successful geoengineering, if only at a provincial scale, provide an incentive or disincentive to rid economies of fossil fuels? Imagine scientists do in fact manage to relieve the Great Barrier Reef of bleaching, for a time. They have reported positive results from their first forays in the summer of 2021.[46] But any effects on Australian climate and energy policies have, as of this writing, yet to register.

If the options for geoengineering are variegated, however, none is as realistic, in the narrowly technical sense of the term, as stratospheric injection of sulphate aerosols by means of modified airplanes. This remains the core of the rationalist-optimist programme for the foreseeable future. The most certain outcome would be average global re-cooling – or, depending on the level of ambition, decelerated or annulled warming – and by dint of this achievement, geoengineering would also slam the brakes on some of the worst consequences of the prior trend, notably heatwaves.[47] There would be fewer hot spells than in a world where the CO_2 concentration rises supremely, without countermeasures. Model simulations likewise predict that the melting of glaciers and ice sheets would slow down.[48] Sea level rise would taper off.[49] With less heat entering the oceans, hurricanes would be less frequent and powerful than under untreated business-as-usual, and we can expect studies to continue identifying an array of local disasters to be averted – for instance, the 'Day Zero' droughts that would deprive Cape Town of all water.[50] It follows, by plain logic, that positive feedback mechanisms would be abated too. If the sulphate planes curb overall warming, smaller areas of forest will burn, a greater

45 Sydney Institute of Marine Sciences n.d.

46 On the experiment, see Tollefson 2021; on marine cloud brightening in general, NASEM 2021, pp. 34–5, 44–9.

47 Curry, Sillmann, Bronaugh *et al.* 2014; Aswathy, Boucher, Quaas *et al.* 2015; Jones, Hawcroft, Haywood *et al.* 2018; Pinto, Jack, Lennard *et al.* 2020. For overviews of all the climate impacts geoengineering would – on optimist expectations – stop in their tracks, see MacCracken 2009; Svoboda *et al.* 2019, pp. 359–60; Kravitz and MacMartin 2020, p. 64.

48 Govindasamy, Caldeira and Duffy 2003, pp. 164–6; Irvine, Lunt, Stone and Rigwell 2009; Applegate and Keller 2015; Moore, Yue, Zhao *et al.* 2019.

49 Moore, Jevrejeva and Grinsted 2010.

50 Moore, Grinsted, Guo *et al.* 2015; Jones, Haywood, Dunstone *et al.* 2017; Ji, Fang, Curry *et al.* 2018; Odoulami, New, Wolski *et al.* 2020.

share of permafrost will stay frozen, microbes decomposing organic matter in the soil and releasing it as CO_2 will calm down: more carbon will stay in its sinks than in a world where no water is poured on the fire.[51] But then there are also the potentially very negative side effects. And they are legion.

2.1 *The Law of the Tendency of Side Effects to Rise*

On the way out from Earth, infrared radiation bumps into the greenhouse gases. We might think of them as an invisible halo, sitting everywhere at the same distance from the globe, warming the troposphere below, day and night. Their effect is even. Disregarding local anomalies, the atmospheric concentration of CO_2 will be roughly as high over the Antarctic as over Ankara. Incoming sunlight is another matter: it strikes the surface as shortwave radiation, but not at all uniformly. More of it reaches the equator than the poles; more arrives in summer than in winter, while it does not materialise at night. Now if a sheet of substances is wrapped around the globe to obstruct this incoming sunlight, the effects will be uneven in space and time: during polar winter, for instance, close to none. No sunlight would have struck the Arctic in mid-January anyway. It would be like a solar eclipse in the darkest hour. But a stratospheric layer of sulphate will make an appreciable difference at noon in the sun-bathed tropics. All modelling demonstrates that average cooling would translate into comparative 'overcooling' of the tropics and 'undercooling' of the poles; or, in other words, the former would get a lot cooler, the latter just a little. Now it so happens that the steep temperature gradient between equator and poles drives much of the weather systems on Earth, those awesome conveyors of warm and cold air that regulate the routes of trade winds and jet streams, the location of rain-belts and deserts, the alternation between wet seasons and dry – what is locally experienced as rain, storm, calm, thunder.[52] How would they fare if the gradient tends to flatten out? We shall presently see that geoengineering might wreak havoc on patterns of precipitation in particular.

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51 Cao and Jiang 2017; Dagon and Schrag 2019; Chen, Liu and Moore 2020; Yang, Hoffman, Ricciuto *et al.* 2020; Xia, Robock, Tilmes and Neely 2016, pp. 1480–1, 1485; Tjiputra, Grini and Lee 2016, pp. 20–3; Keith, Wagner and Zabel 2017.

52 E.g. Govindasamy and Caldeira 2000, pp. 2141–2; Matthews and Caldeira 2007, p. 9950; Kintisch 2010, p. 60; Irvine, Kravitz, Lawrence and Muri 2016, p. 817; Russotto and Ackerman 2018; Kravitz, MacMartin, Tilmes *et al.* 2019, p. 7901; Kravitz and MacMartin 2020, p. 69; Malik, Nowack, Haigh *et al.* 2020, e.g. pp. 15461, 15466, 15480; NASEM 2021, pp. 51–3; Cheng, MacMartin, Kravitz *et al.* 2022. There is also another mechanism generating the tropical overcooling and polar undercooling, which has to do with a different vertical transport of energy and temperature change – or 'lapse rate' in the meteorological jargon – under geoengineering: see Henry and Merlis 2020.

An analogous levelling effect applies to seasons. Because there is more sunlight to reflect in summer than in winter, the sunshade would be more consequential for the former: overcooling summers and undercooling winters, the more so the higher the latitude. The amplitude of the seasons in Scandinavia could diminish sharply. Summer – as registered in temperatures, snow cover, the extent of sea ice – would appear less different from winter and vice versa.[53] An additional mechanism of this seasonal equalisation is the paradoxical fact that extra amounts of sulphate aerosols would cool the surface of the Earth, but warm the stratosphere: like soot flakes hanging high, they would absorb radiation and turn up the heat of the air some 20 kilometres above. Such upper-atmosphere heating would react on the weather below and push air currents off their tracks and further blur the seasons.[54]

But to add to the complications, flattening is already an element of global warming. When snow and ice melt in the Arctic, they leave behind dark surfaces that absorb more heat, fuelling further melt, and so on – the albedo feedback now throwing northern ecosystems out of gear. Polar regions heat up much faster than the tropics, closing the latitudinal gap. Geoengineering would counter this trend with the opposite one: the tropics would cool down faster and approach the poles from the south, as it were. Which one is worse? The upshot depends on how much the gap has been closed by warming once geoengineering is launched, how aggressive the injections are, how much the preceding trend is pushed back, how the baselines shift over the decades from extreme warming to more or less extreme cooling: chances are that abrupt changes will set off a seesaw of levelling. However, modelling suggests that the albedo feedback in the poles will be too strong for geoengineering to bring to an end; by the time the planes are in the sky, it will be self-acting, residual Arctic (and Antarctic) warming unstoppable.[55] In that case, a geoengineered world would affect its own levelling (overcooling the tropics) on top of the inherited trend (overwarming the poles) – the worst of two possible worlds, less a seesaw than a squeeze. Seasons in the north would narrow correspondingly.

Diurnal cycles would go the same way: less contrast (but only marginally less).[56] Land would cool faster than the heat-storing seas. Because there is

53 Jiang, Cao, MacMartin *et al.* 2019; NASEM 2021, p. 53.

54 Heckendorn, Weisenstein, Fueglistaler *et al.* 2009; Tilmes, Garcia, Kinnison *et al.* 2009, pp. 5–7; Aquila, Garfunkel, Newman *et al.* 2014; Simpson, Tilmes, Richter *et al.* 2019; Jiang, Cao, MacMartin *et al.* 2019, pp. 154, 160; NASEM 2021, pp. 53–4. Conversely, greenhouse gases warm the troposphere but cool the stratosphere.

55 Fasullo, Tilmes, Richter *et al.* 2018; Henry and Merlis 2020. But different modelling results are reached in the older study of Govindasamy, Caldeira and Duffy 2003, p. 162.

56 Govindasamy and Caldeira 2000, p. 2142; Govindasamy, Caldeira and Duffy 2003, pp. 157–8.

more land in the northern hemisphere than in the southern, it would depart on its own path of cooling, and this would be merely a beginning.[57] The climate system could come apart at the seams. The *ex ante* knowledge we have of geoengineering points to its capacity to scramble regional climates and send them off like rafts on a swirl of eddies, their courses and ultimate destinations impossible to foretell. It follows that heating the Earth by emitting greenhouse gases and then cooling it down by injecting aerosols are two disparate processes, whose fingerprints on the climate do not match – very unlike a thermostat turned up and down in a four-wall room. There can be no geoengineered return to the *status quo ante*.[58]

Rainfall is perhaps the most precarious parameter. In a warming world, the hydrological cycle – the perpetual circulation of water, from rain or hail or snow to river runoff and evaporation and back to the clouds – is intensified, there being more energy in the system, more water evaporating due to the heat, more water vapour held in the warmer air: hence the torrential downpours and floods. Geoengineering would reverse the trend. With some of the sun blocked out, the cycle, one might say, would be starved of fuel. It would slacken, meaning a decline in overall precipitation.

Volcano eruptions have brought in their wake lower levels of rainfall, less water discharged from rivers, looming aridity: how would a permanent Pinatubo play out? If it is turned up to a degree where it compensates for all global warming, it would, simulations suggest, dampen the hydrological cycle more than it had previously been amplified – that is, the countereffect would be larger, bringing the Earth back not to the pre-industrial point of departure but to some unknown state. The advantage would be fewer deluges. In a warming world, already wet regions tend to get wetter and dry regions drier; in a geoengineered world, apparently, the wet would get drier and the dry wetter – a redistribution, if you will, but not without risks. Evaporation would also subside in cooler climes. Soils would not necessarily desiccate. Where the balance between precipitation and evaporation would end up is a question open to innumerable concrete factors and swings; in the informed assessment of Keith and Irvine, geoengineering would, on the whole, 'exacerbate water stress' around the world.[59]

57 Jones, Haywood, Boucher *et al.* 2010, p. 6002; Kintisch 2011, p. 68; Kravitz, MacMartin, Tilmes *et al.* 2019, p. 7901.

58 E.g. Hulme 2014, pp. 48–52, 105; Jones, Hawcroft, Haywood *et al.* 2018; NASEM 2021, pp. 35–6, 50, 59; Belaia, Moreno-Cruz and Keith 2021, p. 4.

59 Bala, Duffy and Taylor 2008; Lunt, Ridgwell, Valdes and Seale 2008; Tilmes, Garcia, Kinnison *et al.* 2009, p. 10; Tilmes, Fasullo, Lamarque *et al.* 2013; Dagon and Schrag 2016; Irvine, Kravitz, Lawrence and Muri 2016, pp. 818–19; Fasullo, Tilmes, Richter *et al.* 2018,

The effect, again, is likely to be strongest in the tropics. That is where the rains would most often absent themselves.[60] For the past 5,000 years, a belt of clouds known as the Intertropical Convergence Zone has hovered around the equator, encircling the globe where trade winds from north and south meet, keeping the land underneath muggy, regularly pouring out torrents. This zone is pulled towards the heat. If the northern hemisphere cools more than the southern, it would migrate southwards; if this cooling is more pronounced in summertime, the push would be seasonally boosted. The result could be a devastating absence of rain in the Sahel.[61] Extreme El Niño and – especially, because it is the cold phase of the oscillation – La Niña events might become more frequent.[62] But most sensitive of all is the Indian monsoon. Every major volcanic eruption over the past three centuries has caused a failed or feeble monsoon, due to reduced polarities in temperature.[63] Keeping the artificial eruption going could double the risk of failure and threaten central India with chronic drought; indeed, this is the part of the world – incidentally the location of Robinson's heatwave – that stands to lose most water from geoengineering.[64] Damned if you do and damned if you don't? All that can be known for a relative certainty is that geoengineering will throw regional climates into confusion.

The sunlight would be more diffuse. This could be good for some plants. Direct light hits the canopy, but diffuse radiation penetrates it and spreads like a glowing blanket over the shaded leaves. An opaque stratosphere would stimulate photosynthesis in the understory, which would, in turn, contribute to carbon sequestration. Cooling would by definition lessen heat stress.[65] As for edible plants, however, the benefits are not so straightforward: for maize, rice, soy, wheat – staples all – the hazy light would be detrimental and any yield

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pp. 910–11; Simpson, Tilmes, Richter *et al.* 2019; Irvine and Keith 2020, pp. 1–2, 6; NASEM 2021, pp. 51–4; quotation from Keith and Irvine 2016, p. 556.

60 Ferraro, Highwood and Charlton-Perez 2014; Lunt, Ridgwell, Valdes and Seale 2008, p. 4; Pinto, Jack, Lennard *et al.* 2020, pp. 8–9; Malik, Nowack, Haigh *et al.* 2020.

61 Haywood *et al.* 2013; cf. e.g. Jones, Haywood, Boucher *et al.* 2010, pp. 6003–4. Some modelling indicates that global warming would drive the Zone northwards and geoengineering restore it to its original place: Malik, Nowack, Haigh *et al.* 2020, p. 15480. Most models, however, seem to suggest a dislocation: Cheng, MacMartin, Kravitz *et al.* 2022, pp. 6–7.

62 Malik, Nowack, Haigh *et al.* 2020.

63 Robock, MacMartin, Duren and Christensen 2013, pp. 447–8.

64 Simpson, Tilmes, Richter *et al.* 2019; e.g. pp. 604, 611, 613. Another modelling exercise suggests an effect of the same kind but smaller in magnitude: Bhowmick, Mishra, Kravitz *et al.* 2021, pp. 8, 9.

65 Xia, Robock, Tilmes and Neely 2016; Ito 2017; Zarnetske, Gurevitch, Franklin *et al.* 2021, p. 6. One study expects the stimulus on photosynthesis to be very small, due to limitations on nitrogen: Tjiputra, Grini and Lee 2016.

gains from cooling nullified.[66] Nor would the scattering be beneficial for solar power. Photovoltaic systems – solar panels, in common parlance – can just as well run on diffuse sunlight, but concentrated solar power – the huge installations for capturing rays and beaming them onto a turbine, with the largest potential for mass production of electricity – needs the direct variety. Shading the sky with sulphates could cut off some 6 per cent of their output.[67] While this might sound like a limited loss, there is surely irony in geoengineering throwing a spanner into the exploitation of solar energy, an essential replacement for fossil fuels.

The blue sky would take on a milky, white hue. In cities already wrapped in smog the difference might hardly be perceptible, but the sky in rural areas would come to look like inside them.[68] This particular side effect has become something of a poster child for geoengineering, thanks to Elizabeth Kolbert entitling her popular science best-seller on the topic *Under a White Sky: The Nature of the Future*.[69] And for the human eye, this might indeed be the most momentous change: the heavens blue since time immemorial, no more. On the upside – possibly – sunsets would become more spectacular, flashing up in the warm crimson colours familiar to inhabitants of Tehran or Beijing.[70] But stars would be more difficult to make out. The telescopes astronomers use to train their eyes on distant celestial bodies would face a new obstacle.[71] The sulphates would, as we have seen, return to Earth before long and there pollute the air: there would be more fine particulate matter in people's lungs, more acid rain, differences again most noticeable in pristine areas.[72]

Ozone depletion would speed up. It does so after volcanic eruptions, because sulphate aerosols *per se* and stratospheric heating both accelerate the cycle destroying that molecule. The recovery of the Antarctic ozone hole could be delayed until the end of the twenty-first century, geoengineering thereby negating one of the few triumphs of environmental protection – the Montreal

66 Proctor, Hsiang, Burney *et al.* 2018. Another study, again, reaches opposite results, because of different background assumptions: the worst-case business-as-usual scenario allowing for a greater cooling effect – hence relief from heat stress in the geoengineered scenario – and an enduring fertilisation effect from extremely high atmospheric concentrations of CO_2: Fan, Tjiputra, Muri *et al.* 2021.

67 Smith *et al.* 2017.

68 Kravitz, MacMartin and Caldeira 2012.

69 Kolbert 2021.

70 Cf. Zerefos, Gerogiannis, Balis *et al.* 2007.

71 Robock *et al.* 2009, p. 2.

72 Effiong and Neitzel 2016; Eastham, Weisenstein, Keith and Barrett 2018; Visioni, Slessarev, MacMartin *et al.* 2020.

Protocol – under late capitalism.[73] This is the main motivation for scientists to explore alternative aerosols, such as calcites or diamond powder; but they would come with adverse reactions of their own, largely unknown, since they do not exist naturally in the atmosphere (not to mention diamonds driving the costs to preposterous heights).[74] And this is still not the end of it. There seem to be potential side effects without number, from aerosol clouds corroding the planes themselves to them interfering with the nucleation of cirrus clouds; from a rearrangement and extension of malaria habitats to stimuli for cholera, meningitis, yellow fever, arboviruses. There could be a worrisome footprint of the very infrastructure for sulphate extraction and delivery.[75] And if not airplanes, what of the noise from guns or the litter from balloons?[76]

To that should be added the inherent limitations of geoengineering, all that it cannot achieve. We have seen that it might not beat back the albedo feedback cycle in the Arctic. If the ice caps pass their tipping points for irreversible melting, the only way to refreeze them would be for the re-cooling to be so drastic as to plunge the planet into excessive temperature drops.[77] If CO_2 concentrations keep rising, it does not matter how much they are counterbalanced by aerosols: the oceans will continue to acidify. The seawater will swallow a rising surplus of CO_2 from the air, the pH level fall and shells and corals and food chains dissolve, possibly even at a higher rate, because lower temperatures increase the solubility of the gas.[78]

In all of this, uncertainty appears to be the rule rather than the exception. The biosphere is so coupled and chaotic, so deeply complex, so overdetermined a totality as to defy any predictions about how geoengineering would unfold, beyond the broadest contours. The potentials for splintering effects and ricochets and chain reactions are plainly incalculable. This is due not to

73 Robock, MacMartin, Duren and Christensen 2013, p. 448; Tilmes, Müller and Salawitch 2008; Heckendorn, Weisenstein, Fueglistaler *et al.* 2009; Tilmes, Garcia, Kinnison *et al.* 2009, pp. 11–21; NASEM 2021, pp. 42–4, 65.

74 Keith, Weisenstein, Dykema and Keutsch 2016; Dai, Weisenstein, Keutsch and Keith 2020; Weisenstein, Keith and Dykema 2015, p. 11854; Kravitz and MacMartin 2020, p. 67.

75 Robock *et al.* 2009, p. 5; Kuebbeler, Lohmann and Feichter 2012; Carlson and Trisos 2018; Carlson, Colwell, Hossain *et al.* 2022; and for the classic catalogue of side effects, Robock 2008.

76 See Lockley, MacMartin and Hunt 2020.

77 Sillmann, Lenton, Levermann *et al.* 2015, p. 291; Applegate and Keller 2015; Irvine, Lunt, Stone and Rigwell 2009, p. 7. Cooling of a similar kind – as precipitous as worst-case business-as-usual warming – might be needed to stop sea level rise in general; since oceans respond only slowly to forcing, the shove would have to be all the greater. See Irvine *et al.* 2012.

78 Williamson and Turley 2012; Tjiputra, Grini and Lee 2016, pp. 14–17, 21; NASEM 2021, p. 60.

impaired science, but to the nature of the system in question. From the largest planetary mechanisms down to the tissue of leaves, geoengineering would have unforeseeable repercussions that could cascade across scales; the chance that the last side effect will have been discovered in advance is nil.[79] 'Unknown unknowns', that gift from Donald Rumsfeld to the scientific lexicon, are bound to proliferate – or, 'unnatural deeds / Do breed unnatural troubles', as a doctor observes in *Macbeth*.[80] With metabolic rift theory, we might say that geoengineering merely covers up an original rift, as capitalist society is wont to do, and shifts it elsewhere, into derivative rifts that open up one after the other.[81] Surely the scanty political uptake of geoengineering thus far has something to do with (the expert knowledge of) this ubiquity and near-infinity of side effects. If so, the rationality assumed by the rationalist-optimists might be a reason for them being frustrated in their quest. But it cannot be counted on to last.

Amid this clutter of uncertainties, however, one certainty can be laid down as a virtual iron law, and it is of the greatest moment. *Every negative side effect from geoengineering will worsen the longer it goes on and the larger the quantities of sulphates injected.* In the beginning, they may not be that much of a problem. After the first year of flying rounds, the accomplishments are likely to overshadow any by-products on the horizon, but if the mission goes on, if CO_2 continues to build up in the atmosphere – that is, unless the launch coincides with a slashing of emissions to zero – and the injections come in larger doses, then the side effects will start to kick in. Flattening of latitudinal gradients, levelling of seasons, precipitation collapse, monsoon failure, withered crops, starved solar plants, whitened skies, air pollution, ozone depletion – all are hardwired to escalate with the duration and magnitude of the operation.[82] None might be detectable in the first instance.

To this law is appended a problem of coagulation: unlike a one-off volcanic eruption, continuous addition of sulphate aerosols into the stratosphere makes them attach to one another and form blobs. They will then fall faster to the Earth, so that more aerosols will have to be injected to maintain the cooling

79 See in particular Zarnetske, Gurevitch, Franklin *et al.* 2021; and cf. e.g. Robock 2008, p. 17; Hulme 2014, e.g. pp. 98–100, 104; Irvine, Kravitz, Lawrence and Muri 2016, p. 824; Kravitz and MacMartin 2020; NASEM 2021, p. 117; Wagner 2021, pp. 70–1.

80 Shakespeare 2008, p. 196.

81 Cf. York 2021, p. 182. This analysis was sketched by Holly Jean Buck in her first paper on the topic: Buck 2012, p. 255.

82 Likewise, the stimulus on understory photosynthesis will only continue up to a point, after which it turns into its opposite: Xia, Robock, Tilmes and Neely 2016, p. 1482.

effect, further promoting coagulation, and so on.[83] Needless to say, all of this would add to the financial burden. A growing operation – a second generation of planes, more bases, spare parts, back-up systems, security; a larger quantity of aerosols to be lofted – would incur greater costs, as would, of course, if taken into account, any mounting side effects.[84] The possibility cannot be excluded that the price for geoengineering will eventually become a drag. This too has a strict temporal logic. Call it *the law of the tendency of side effects from geoengineering to rise*. No countervailing factors so far uncovered, the science points to it as an absolute law. It is of central importance for any speculation about how this process might develop over time and whether a terminal breakdown is to be expected.

2.2 *Return of the Repressed Fire*

Of all the risks with geoengineering, none is as frightening as the prospect of its sudden termination.[85] Imagine it is the year 2130 and the operation has been going on for a century. In the meantime, fossil fuel combustion has not ceased; suppose, for example – a mid-range scenario, far from the worst – that annual net CO_2 emissions over these one hundred years have averaged half the level in 2030. That means that a whole lot of carbon has been deposited into the atmosphere, there to cause global warming – if it were not for the layer of sulphate aerosols, thickening in lockstep so as to mask the radiative forcing. Then in 2130, something happens: geoengineering is terminated. The mask is ripped off, all the accumulated carbon set free to do its work. Temperature-wise, the effect would be similar to that of standing before the glass door of an oven inside which a fire is roaring and raging: and suddenly the glass shatters and the flames leap out without hindrance.

This is the termination shock, a risk inherent in the constitution of the technology. Because aerosols naturally drift back to Earth, and insofar as their function is to undo the damage of the underlying emissions, any interruption to the injections would set the shock off.[86] There would be a pulse of liberated warming. Its severity would, of course, be a function of the span and scale of the operation: the longer it has lasted, the more aerosols it has kept afloat and – crucially – the higher the concentrations of greenhouse gases it

83 Heckendorn, Weisenstein, Fueglistaler *et al.* 2009, pp. 1, 6–7, 11; Robock, MacMartin, Duren and Christensen 2013, p. 450; Robock 2020, p. 61.

84 Smith 2020, e.g. pp. 5, 10–11; cf. Reynolds, Parker and Irvine 2016, p. 565.

85 This has become something like common knowledge, accepted by e.g. NASEM 2021, p. 4.

86 E.g. Boucher, Lowe and Jones 2009, p. 269; McCusker, Armour, Bitz and Battisti 2014, p. 1; Rabitz 2019, p. 503.

has cancelled out, the greater the impact.[87] If, come 2130, emissions have not only been reduced to zero, but carbon dioxide removal has also cleaned the atmosphere of the historical accumulation and returned the CO_2 concentration to, say, 350 ppm, termination would not set off any roasting. If the net sum – behind the frail engineered glass door – is rather a doubling or quadrupling of that concentration, the result could be exceedingly cataclysmic. It follows that *inasmuch as geoengineering exerts an effective temptation upon capitalist society to keep business-as-usual in place, the risk of a severe termination shock rises*.[88]

How bad could it be? It would not be gradual or smooth, as in Robinson's storytelling. If injection is called off from one year to the next, the ensuing spike in temperatures is likely – on the premise of non-ideal background conditions – to be abrupt. The heating would be several times faster than any pre-sulphatic business-as-usual could achieve on its own. For obvious reasons, simulations have thrown up a range of estimates: heating twice that of the maximum rate under business-as-usual, or five or 16 times greater, or 20 times greater than early twenty-first century warming.[89] We are here talking about average temperatures on Earth jumping by maybe half a degree per year, or four degrees per decade – whatever the exact figure, a heating so precipitous that it would have 'no precedent in the geological history of climate'.[90] Only the K-T impact winter of the dinosaurs would provide a meaningful parallel. Carbon stored in sinks during the period of geoengineering would be exhaled in concentrated fumes.[91] Precipitation would rebound and the hydrological cycle go into overdrive over the course of a few years; the kind of storms that would flare up can best be left to some sublime (or twisted) imagination.[92]

To a shock of this size, no ecosystems and precious few species could adapt. For that to be possible, the climate must change at a reasonably slow pace, so that plants and animals have a chance to keep up and follow the envelopes to which they are evolutionarily adapted: the Arctic fox might be able to track its chilly habitat if it retreats by two kilometres per year, but not if

87 Here assuming that the termination would be practically instantaneous and not a phase-out protracted over decades; for the latter scenario, see further the second part.

88 Cf. e.g. Matthews and Caldeira 2007; Jones, Haywood, Alterskjaer *et al.* 2013; McCusker, Armour, Bitz and Battisti 2014, p. 7; Halstead 2018, p. 69.

89 McCusker, Armour, Bitz and Battisti 2014; Irvine *et al.* 2012, p. 97; Ross and Matthews 2009, p. 3; Matthews and Caldeira 2007, p. 9949. See further e.g. Burns 2011, pp. 47–8; Jones, Haywood, Alterskjaer *et al.* 2013; Aswathy, Boucher, Quaas *et al.* 2015, pp. 9604–6; Bhowmick, Mishra, Kravitz *et al.* 2021, pp. 2, 4, 9.

90 Brovkin, Petoukhov, Claussen *et al.* 2009, p. 255.

91 Keller *et al.* 2014, p. 6; Ito 2017, p. 60.

92 Bhowmick, Mishra, Kravitz *et al.* 2021, p. 9.

it caves in and disappears at four or seven times that speed. Birds, fish, reptiles, mammals – none would have experienced climate dislocation at anything near post-termination velocity; all but a minority of species would avoid extinction.[93] Human life would be marginally easier. Planting crops when temperatures shoot up from one season to the next is a well-nigh pointless endeavour. In a world of two, three, four degrees of warming per decade, food supplies would dwindle.[94] Smith has referred to geoengineering as 'climatic morphine'.[95] That substance is known for its addictive properties; going cold turkey on it would be vastly more dangerous than the original disease. Indeed, alongside nuclear winter and hothouse Earth, this is the scariest scenario known to climate science.[96]

Now, rationalist-optimists like to point out that the scare is overblown, because under the protection of the veil, the world will have time to not only end all fossil fuel use but also scrub the atmosphere of the CO_2 added during the industrial centuries. Termination would then present no problem: the fire would have gone out by the time the glass door breaks.[97] We shall presently inspect how plausible this scenario is, but for now, let us just note that the optimism about a shock-free termination is overblown. Even if CO_2 concentration is back to 350 ppm in 2130, a stop would throw the planet out of its ruts. During the preceding century, regional climates would have settled into some kind of novel state, under regimes of precipitation, evaporation, radiation and loads of other factors determined by the continuous injections. Upon their cessation, the jerk would be violent, even in the absence of heat flashing up: there would be a reshuffling of climates. Societies that would presumably have adapted to the geoengineered century and grown accustom to knowing it as the normal modern would face the unknown realities of a post-geoengineered future – not as bad as being grilled, surely, but still bad. We may thus introduce a distinction between two types of termination shock: roasting and reshuffling.[98] In what follows, however, we shall focus on the former, as it is functionally related to the continuation of business-as-usual – a not implausible scenario, as we shall soon see.

Triggers of termination also fall into two categories. Most discussions have assumed that they would be exogenous. Terrorists could shoot down the planes.

93 Trisos, Amatulli, Gurevitch *et al.* 2018. Cf. e.g. Ross and Matthews 2009, pp. 4–6.
94 Baum, Maher Jr. and Haqq-Misra 2013, p. 175.
95 Smith 2020, p. 11.
96 Cf. Tang and Kemp 2021, p. 10. The seminal paper on hothouse Earth is Steffen, Rockström, Richardson *et al.* 2018.
97 E.g. Reynolds, Parker and Irvine 2016, p. 563; Belaia, Moreno-Cruz and Keith 2021, p. 18.
98 This point is owed to Wim Carton.

A war, a pandemic, a total crash of the world-economy, a series of unheard-of natural disasters – earthquakes, asteroids – a wave of revolutions or perhaps even (though it would seem a self-destructive form of proletarian action) a general strike that sweeps up the pilots could knock out the just-in-time infrastructure for keeping catastrophe at bay. One team of scientists has considered a scenario of 'double catastrophe': first there is a nuclear war, causing temperatures on Earth to tumble. Then comes the second blow, when said war disables the system for stratospheric aerosol injection and temperatures bounce back.[99] 'It would be global frost followed by global furnace.'[100] The one-two punch would leave humanity down and out. Some would surely label this 'collapse porn'.[101] But, as we have seen, the termination shock is not some outlandish fantasy, but a threat intrinsic to the technology; the question is rather what sort of trigger is most concerning.

The second type is endogenous: an end caused not by some monster that enters, but rather by the unfolding of geoengineering itself. And this too is a recognised potentiality. If the side effects become too overwhelming, 'a possible decision would be to terminate the deployment altogether'.[102] It follows that the law of the tendency of side effects to rise *points in the direction of the termination shock*. Or, in other words: all that would be needed in the year 2130 would be for one actor, powerful enough to switch off injection, to perceive some number of side effects as more pressing than the prospect of global heating, the memory of which would by then have been suppressed for a century. Seen from this vantage point, the shock appears logically immanent to the set-up of the technology.[103]

99 Baum, Maher Jr. and Haqq-Misra 2013.

100 Tang and Kemp 2021, p. 7.

101 Phillips 2015.

102 MacMartin, Irvine, Kravitz and Horton 2019, p. 1332. There can also be mixtures of endogenous and exogenous triggers: geoengineering causes a pandemic or nuclear conflict that accidentally shuts the system down. Tang and Kemp 2021, pp. 7–9.

103 Researchers in 2020 uncovered a new twist on this scenario. If emissions were to incessantly rise in a geoengineered world and the CO_2 concentration hit as high as 1,700 ppm, the whole operation would come undone, even if actual temperatures on Earth had not risen at all in the interim. This is because, at such elevated concentrations, the molecules of carbon dioxide break up stratocumulus clouds – swathes of rounded, wavey clouds that cool the Earth – not gradually, but suddenly. Instant heating of five degrees would ensue. From this shock – a late result of the law of the tendency of side effects to rise – geoengineering would be unlikely to survive, and so the termination shock would add another few degrees, the planet doubly fried in a geological split second. Schneider, Kaul and Pressel 2020.

Conversely, however, a thoroughly and enduringly geoengineered world could be aware of the 'Sword of Damocles' hanging over it and thereby induced to keep going.[104] Knowledge of the shock would deter the parties from termination.[105] By the same token, it would reinforce the tendency of the side effects to rise, further heightening the ultimate risk, motivating another round of prolongation … and so on. From this downward spiral, there would be no way out; if emissions steadily continue, the planes might have to fly – more sorties, delivering larger loads – for several centuries or even millennia to hold the furnace shut, keeping the spiral in place. But even a brief masking of an excess of CO_2 might lock in a lasting commitment. Some modelling suggests that a period of one to four decades of increasing emissions under a geoengineered sky would be enough to necessitate that the operation runs for several centuries, lest the built-up extra heat bursts forth – with the attendant risk of just that happening.[106] The planet would then still be held captive to the dialectic of the law of the rise and the risk of the shock. And it is precisely the weight of these two factors, pressing in on the very idea of geoengineering, that has compelled the rationalist-optimists to formulate their position in an attempt to save some sanity for this enterprise.

2.3 *From Substitution to Ideal Combination*

During its early career – roughly speaking, until the second decade of this century – one could hear proponents bluntly state that 'geoengineering and emissions reductions are substitutes'.[107] That is, the world could do the one or the other: if the choice fell on one, the other would be redundant. These were but two instruments for achieving an identical goal. As early as 1992, just after the Rio summit, William Nordhaus, the only economist who has won the Nobel prize for his work on climate, published an article to this effect in *Science*. He argued that stabilising the climate by phasing out fossil fuels would gobble up unacceptable amounts of economic growth and so should rank as the worst possible option (hereby providing scientific support to the refusal of the Bush government to back such measures at the summit). Geoengineering would be of 'enormous', indeed 'mind-numbing' superiority. Nordhaus considered it

104 Brovkin, Petoukhov, Claussen *et al.* 2009, p. 255. Cf. e.g. Cairns 2014, p. 651.

105 So would habituation to geoengineered climates: see further below.

106 Boucher, Lowe and Jones 2009.

107 Barrett 2008, p. 46. The year 2013 is quite appropriately identified as the end of this period in Keith and Irvine 2016, p. 550.

'costless' to the world economy, plus far more efficient in providing benefits for the climate than any emissions cuts could ever be: optimisation ensured.[108]

In 2000, David Keith compared mitigation with geoengineering and likewise found the latter to be of superior cheapness.[109] MIT *Technology Review* ran the headline, 'A Cheap and Easy Plan to Stop Global Warming'.[110] In the run-up to COP15 in Copenhagen, Richard Branson mused: 'If we could come up with a geoengineering answer to this problem, then Copenhagen wouldn't be necessary. We could carry on flying our planes and driving our cars.'[111] (Turned out that Copenhagen, as a metonym for cutting down on planes and cars, wasn't necessary anyway, but that's another matter.) The perception spread that this was indeed how authorities on geoengineering regarded it: as an *alternative* to mitigation.

But when the science matured, such a position became untenable. What we have here referred to as the law of the tendency of side effects to rise (widely recognised in substance) and the termination shock (all but universally dreaded) together make it abundantly clear that geoengineering without decarbonisation is a recipe for catastrophe deferred and then ignited with terrible intensity. The core of the rationalist-optimist consensus, then, is the opposite of substitution. It is now repeated with the sincerity and devotion that become a credo: 'Geoengineering complements emissions reductions' (Keith); it 'cannot substitute for emissions mitigation but it may be a useful supplement' (Keith and Irvine); 'optimal use […] is in parallel with mitigation' (Keith and colleagues), the word 'optimal' being key.[112] In his *Geoengineering: The Gamble*, Gernot Wagner seems honestly worried by the possibility that someone would treat it as an alternative and passionate about what comes first: 'Most importantly, we must stop burning fossil fuels and putting CO_2 into the atmosphere. Nothing else will do.'[113] Branson's dream has been punctured; in this, again, Robinson is right.

108 Nordhaus 1992, quotations from pp. 1317–18. This being early in the career of geoengineering, Nordhaus had in mind 'shooting smart mirrors into space with 16-inch naval rifles'. Nordhaus 1992, p. 1317. Thanks to Wim Carton for this reference.

109 Keith 2000, pp. 272–3.

110 Rotman 2013.

111 Revkin 2009.

112 Keith 2013, p. 15 (see further e.g. p. 38); Keith and Irvine 2016, p. 549; Belaia, Moreno-Cruz and Keith 2021, p. 17. For similar statements, see e.g. MacMartin, Ricke and Keith 2018, p. 2; Smith 2020, p. 2; Pasztor 2021, p. 494; Smith and Henly 2021, p. 8. The argument for complementarity and combination was, however, present already in some of the early seminal papers: e.g. Crutzen 2006, pp. 216–17; Wigley 2006, p. 452.

113 Wagner 2021, p. 7; see further pp. 28–9, 74, 99.

And yet some statements in this category have an 'I'm not a racist, but…' whiff to them. 'There is no substitute for aggressive cuts in greenhouse-gas emissions. But the risks and benefits of technologies that could mitigate [a Freudian slip] global warming need to be evaluated', *Nature* opened its editorial commending the NASEM report.[114] That report likewise began with declaring emissions cuts the 'top priority', a ranking performatively contradicted by a long report that says nothing about how it could be achieved.[115] Can geoengineering avoid sliding back into default substitution? Can it be promoted without blunting the urgency of the primary task? That might be the most critical question; what is clear for now, however, is that the rationalist-optimists are engaged in heroic efforts to hold on to their ideal combination.

Here it is not either/or, but both: geoengineering sits like a ceiling over a world economy busy cleansing itself of fossil fuels. That ceiling is constructed so as to keep the space artificially cold *and* remind those below to finish their work on time. 'Ideally', write Buck *et al.*, 'the bought time could be used to decarbonize' – 'ideally', like 'optimally', being the operative qualifier.[116] Geoengineering is kept in place *at the same time as capitalist society maximises its endeavour to phase-out fossil fuels* and finally accomplishes that goal. The hope is for a brief interlude. But some formulations give it away: 'At best', Wagner reasons, geoengineering 'could help shave off the peak of climate impacts, serving as a lengthy bridge from the present to a low-carbon future.'[117] Lengthy? Once again, the combination as a state of exception would seem to be drawn towards extension, leaving the law and the shock close to returning through the back door.

To keep them away, leading rationalist-optimists have specified three precepts for safe and wise geoengineering. A seminal paper appeared in the top climate science journal in 2015, co-authored by Keith and Douglas MacMartin, under the headline 'A Temporary, Moderate and Responsive Scenario for Solar Geoengineering', shorn of the hype and the follies.[118] It began by taking due note of the side effects, which will rise, but not in a linear fashion; there could

114 *Nature* 2021. The slip consisting, of course, in the use of 'mitigation' – normally reserved for emissions reductions – to designate what geoengineering would do.

115 NASEM 2021, p. xi. 'The starting point for the committee is that SG [solar geoengineering] is not a substitute for mitigation, nor does it lessen the urgency for pushing mitigation actions.' NASEM 2021, p. 25. See further e.g. pp. 27, 256.

116 Buck, Geden, Sugiyama and Corry 2020, p. 3.

117 Wagner 2021, p. 99.

118 Keith and MacMartin 2015. A similar argument is made in MacMartin, Caldeira and Keith 2014.

be threshold effects for *inter alia* ozone depletion. Geoengineering therefore ought to be done with moderation. It should not aim to compensate for all anthropogenic warming, but perhaps half of it, a sober choice that has subsequently been fed into the models and whisked away most if not all negative side effects.[119] Likewise, the sole guarantee against the law and the shock is to have the technology somehow programmed for an early expiration: it must have an 'implied commitment to measured wind down'. Keith and MacMartin are silent on how that will be ensured. But they hint at how long a 'temporary' deployment could be: of 'the order of a century'.[120] A more ambitious best-case has it abridged to 'only several decades'.[121] Lastly, the agent conducting geoengineering must not be nonchalant or reckless about side effects, but has to be studiously 'responsive' to any mishaps along the way; we shall return to the implications of this third precept. The gist of the case is that geoengineering must be 'done moderately, modestly, and managed well'.[122] It has to be a wonder of rationality. Otherwise it will succumb, without fail, to its inner demons. The question now to be asked is: does this revised, restrained vision of geoengineering have any claim to plausibility?

3 Terror Begins with a Sigh of Relief

Some rationalist-optimists have argued that it would make most sense to deploy before an all-out emergency. Starting early, with tiny doses, before conditions are agitated, would allow researchers and policymakers to learn to know the force they are about to unleash.[123] But such wishes do seem pious, given the general inertia of capitalist society in the face of the climate crisis, the negligible interest in geoengineering thus far, the cost of the operation and, conscious or unconscious, the widespread perception of it as a last resort. By far the most realistic scenario is one where some singular emergency convinces one or several powerful states to throw caution to the wind.[124] There is a surprising degree of support for it: when 723 climate negotiators and scientists,

119 Irvine, Emanuel, He *et al.* 2019; Irvine and Keith 2020.

120 Keith and MacMartin 2015, pp. 204–5.

121 MacCracken 2009, p. 11.

122 Wagner 2021, p. 40.

123 E.g. Horton 2015, pp. 150–1; Keith and MacMartin 2015, p. 205; MacMartin, Irvine, Kravitz and Horton 2019, p. 1330; Smith 2022, pp. 222, 275.

124 Cf. Rabitz 2016, p. 105, and the recognition of this as the likely scenario in Smith 2022, pp. 277, 310. Further e.g. Shepherd 2012, p. 4171.

working with the UNFCCC and IPCC, were polled in 2019, 52 per cent approved of deployment 'in the event of an approaching climate emergency' (the diplomats and politicians disproportionately eager compared to the academics).[125]

Such a preference might fit the occasion. For all that has been said above, it may still be – or even just appear to be – that unmitigated global warming has worse consequences than geoengineering, *especially* as the two would be experienced and examined in an emergency. That would be the moment when 1) the impacts of the warming strike home with full force, 2) geoengineering turns up as the sole measure for supressing them, and 3) any side effects of the latter are as yet dimly visible (at least to the layperson's eye). The corollary of the law of the rise is that geoengineering will seem fairly innocuous initially – just when climate breakdown has passed some threshold of intolerability. From these temporal tendencies, intersecting in the emergency, we can infer a likely hunger for geoengineering. Will it be satisfied with moderate portions? It is a tautology that geoengineering will make the largest difference if used to counteract large emissions (precisely what will bring the emergency about).[126]

This moment would also be one of conspicuous 'failure', as it is commonly conceived. The average paper on geoengineering has a preamble about how the world continues to fail in mitigation. 'In light of society's *failure* to act concertedly to deal with global warming', geoengineering has imposed itself on our consciousness, we typically read.[127] Critics of the idea are prone to the same phrasing, among them philosopher Stephen Gardiner: 'It is mainly because we have failed – and continue to fail – to do what we should have done, ethically speaking (e.g., seriously decrease emissions), that geoengineering is considered at all.'[128] But this is a slightly odd way of putting it. We would not say that Lady Macbeth considers and then commences washing her hands because of the failure to protect the king's life. Nor does she continue because the guards of various noblemen and families repeatedly fail in their duty: she is covering up *crimes*. Surely the accumulation of capital based on fossil fuels should

125 Dannenberg and Zitzelsberger 2019, p. 771.

126 Cf. McCusker, Armour, Bitz and Battisti 2014, p. 7.

127 Robock 2008, p. 14. Emphasis added. For just a handful more examples, see Crutzen 2006, pp. 211–12; Matthews and Caldeira 2007, p. 9949; Irvine, Lunt, Stone and Rigwell 2009, p. 1; Ross and Matthews 2009, p. 1; Shepherd 2012, p. 4167, Baum, Maher Jr. and Haqq-Misra 2013, p. 168; Parson and Ernst 2013, p. 308; Keller, Feng and Oschlies 2014, p. 2; Reynolds 2019, p. 1; Bhowmick, Mishra, Kravitz *et al.* 2021, p. 1; Parson and Reynolds 2021, pp. 1–2; Schenuit, Gilligan and Viswa 2021, p. 1; NASEM 2021, p. 148.

128 Gardiner 2020, p. 74.

likewise count as a sin of commission, not one of omission. It is first of all a crime, and a crime that feeds itself to boot, degenerating into more serious degrees of villainy for every passing year; the failure is secondary and belongs to those who have tried to stop the culprit. Insofar as rationalist-optimists take their assignment from what they call a 'failure' – and not a crime – we must presume on their part some loyalty to the cause of radical climate action. We might give them the benefit of the doubt. Their gambit, then, is that *failure can and will be transformed into success at the moment of its most glaring manifestations*.

Once we see this, however, we must also recognise that something similar applies to those who reject geoengineering out of hand as a distraction from the one true calling of mitigation: they assume that the most persistent failure can and will transform itself into success in the precious little time that is left. Who is most given to magical thinking? On this, the jury might still be out. What can perhaps be said is that the magical thinking of the rationalist-optimists run with, not against, the current of the existing order, to the extent that it holds that failing humanity can succeed when its failure is at its grossest and criminal dominant classes, their daggers dripping with blood, metamorphosise into paragons of virtue – moderate, modest, managing their newfound mission with the best of manners.

On the other hand, again, the rationalist-optimist case rests on a realism of sorts. In the preface to the NASEM report, Chris Field, climate scientist at Stanford University and chair of the writing committee, shares his distress: 'As I write this in September 2020, my home in California's Bay Area is experiencing record-breaking temperatures and has been blanketed with wildfire smoke for more than 3 weeks. But despite overwhelming evidence that the climate crisis is real and pressing, *emissions of greenhouse gases continue to increase*' – an acute observation made already by Crutzen.[129] The case is predicated on a lucid appreciation of the seriousness of climate breakdown and, more importantly, of the extreme tenacity of business-as-usual. Signs of the latter again amassed

129 NASEM 2021, p. xi. Emphasis added. Cf. Crutzen 2006, pp. 211–12. For some more cases of similar realism, see Reynolds, Parker and Irvine 2016, p. 562; Jones, Hawcroft, Haywood *et al.* 2018, pp. 230–1; Wagner 2021, p. 126. A still earlier case is the first article on the subject penned by David Keith, which begins by formulating two premises: 'Geoengineering might be needed if climate change is worse than we expect', and: 'It seems very unlikely that world greenhouse gas (GHG) emissions can be kept below ~40% of 1990 levels – a prerequisite for averting climate change in the long term.' Keith and Dowlatabadi 1992, p. 292. The tragedy of geoengineering is the tragedy of capitalist society – in dialectic with the climate system – methodically fulfilling these two premises.

in the post-pandemic period. The snapback in 2021 yielded the largest absolute increase in CO_2 emissions – more than two gigatonnes – ever recorded.[130] Companies producing oil and gas stood under a veritable waterfall of profits, exceeding anything seen in at least a decade. The money – 'more cash than we know what do with', in the words of BP's chief financial officer – was ploughed back into expanded reproduction: the fresh exploration of more fields and the construction of more rigs, more platforms, more terminals, more pipelines.[131]

Meanwhile, the world edged ever closer to 1.5 degrees of global warming.[132] One of the anticipated effects of crossing that boundary is the kind of heatwaves described by Robinson – pushing heat and humidity to wet-bulb temperatures at 35 degrees and above, fatal for even the fittest person – rolling through the tropical zones in which 40 percent of humanity resides.[133] What would it take to respect the boundary? Wealthy nations would have to eliminate all production of fossil fuels by 2034. Or, countries like the US and Norway and Australia and Germany and Canada and Qatar and the UK would need to cut their output by half in six years. If they were to embark on such a descent, the world would retain a 50:50 chance to stay below 1.5 degrees.[134] Not only would there be zero fresh installations for extracting fossil fuels; 40 per cent of already-developed reserves would have to be left in the ground.[135] How likely is that, when the forces of accumulation are again hitting the gas in exactly the opposite direction?

'Overshoot' is becoming the buzzword of climate politics: the 1.5 degree boundary will be breached, quite probably two degrees as well, and the question is how humanity then survives. One paper appearing in the appropriately entitled journal *Climate Risk Management* in late 2021 called for a 'realistic plan' to deal with the overshoot and return to liveable temperatures.[136] Naturally, it concluded that geoengineering alone can shave the peak off the overshoot, and before long, the Paris Peace Forum, a centrist bourgeois outfit aspiring to be the equivalent of the World Economic Forum in the realm of international politics, had formed a 'Global Commission on Governing Risks from Climate

130 International Energy Agency 2022.

131 Murray Auchincloss, quoted in Harvey 2022a. See further e.g. Carrington and Taylor 2022.

132 Carrington 2022.

133 Zhang, Held and Fueglistaler 2021.

134 Calverley and Anderson 2022.

135 Trout, Muttit, Lafleur *et al.* 2022. Cf. the call from the International Energy Agency to desist from any new infrastructure, as reported in e.g. Vetter 2021.

136 Taylor and Vink 2021. Cf. the very similar argument made in MacMartin, Ricke and Keith 2018, pp. 2–4.

Overshoot', headed by Pascal Lamy, former director of the WTO. 'All the ways by which we can alleviate the risk must be evaluated. I think a global effort on geoengineering could work', Lamy told *The Guardian* in May 2022.[137] Serving as scientific advisor of the Commission was David Keith. A few months later, *Foreign Affairs* published a piece that declared: 'The Time for Geoengineering Is Now: Drastic Climate Change Calls for Drastic Measures'; citing emissions trends and the latest sequence of disasters 'from hell', observing that the crisis is far deeper than even the most pessimistic scenarios predicted, rehashing the arguments of Keith and Wagner, the organ of American geopolitics adumbrated a fast-approaching future.[138] Shortly after, an editorial in the *Economist* called for geoengineering to deal with overshoot.[139] 2022 was probably not the year when the avalanche of bourgeois support for geoengineering burst forth. These were merely signs of rapidly moving times.

Such hard-nosed realism of geoengineering advocacy mirrors the structural imperative, but by the same token, it renders the central tenet of rationalism-optimism unrealistic. *If business-as-usual is this extreme in its tenacity, there is no reason to expect it to give way at the moment of deployment*.[140] Why would it? By far the most realistic scenario is one where the emergency is symptomatically treated with an operation that, insofar as it succeeds in cutting temperatures, elicits a big sigh of relief. We've found it! There was, after all, a technology that could shave off the deadly edge of fossil-fuel combustion! This is unlikely to be the moment when dominant classes have a change of heart and give up on their material substratum, because there can be only two reasons for doing so: the manifestations of climate breakdown themselves, or the infliction of serious material costs on fossil capital. The former would be softened or even suspended by geoengineering, insofar as the emergency is precipitated by heatwaves, wildfires, storms, hurricanes, droughts or floods, or some mix thereof. That is the whole point of the exercise: to reduce one of two possible incentives to mitigate.[141] There are moments in the literature when this open secret is leaked. While geoengineering 'cannot substitute for emissions cuts, it *may* substantially reduce the risks of any given GHG [greenhouse gas] emissions pathway', write Keith and Irvine – in plainer terms, emissions would not

137 Harvey 2022b. Cf. Paris Peace Forum n.d.

138 Litan 2022.

139 *The Economist* 2022.

140 This contradiction is identified and formulated in slightly different terms in Neuber and Ott 2020, p. 6.

141 Similar arguments are made in Baatz 2016, pp. 36–7, 41; Neuber and Ott 2020, pp. 2, 4.

be so much of a problem any longer.[142] And that would be the occasion to commit to climate action?

Only, conceivably, if the second incentive were to be ratcheted up at the same time. That concurrence is a pivot of *The Ministry for the Future*. Robinson solves the equation for the realist-optimists by inventing an outbreak of global armed struggle against fossil capital that coincides perfectly with the launch of the injections: this is how the ideal combination is realised in his novel (which he has designated 'a best-case scenario').[143] Here he is the free-wheeling novelist. No research from rationalist-optimists has suggested that armed struggle is the mechanism for enforcing the second element of the combination. In fact, they are deafeningly silent on this issue, vacating a space that instead is occupied by a theorem.

The better geoengineering works, the worse it will be. If scientists and others design a fleet of planes that really does have the intended effects, the allure of going all in will be mighty. If geoengineering does *not* work, then it doesn't work; but if it has the curative properties its inventors ascribe to it and seek to optimise, it will debut as an amazing success, raising in the same proportions the risk of long-term failure: it will instil a sense of security.[144] Geoengineering will be as susceptible to 'lock-in' as carbon has been for two centuries, for epiphenomenal reasons.[145] There will be nothing temporary or reserved about it. Emissions cuts will not be instigated, but further delayed; any other prediction is guilty of underestimating the obduracy of fossil capital and its use of every excuse to continue expanding.[146]

In their more clear-sighted moments, even rationalist-optimists acknowledge that this is how things are liable to pan out in the actually existing social order. 'A balanced approach' – the ideal combination, plus the temporary-moderate-responsive formula – 'may well be wishful thinking. If history – and not just climate history – is any guide, it almost surely is. Fundamental forces hold the world back from doing enough to cut CO_2 emissions. Those same forces push the world to do too much when it comes to solar geoengineering', Wagner

142 Keith and Irvine 2016, p. 551. Emphasis in original.

143 Goodell 2020.

144 Cf. Baatz 2016, pp. 42–3.

145 For other aspects of geoengineering lock-in, primarily pertaining to the research itself causing lock-in effects, see Cairns 2014; McKinnon 2019; Lin 2020. The classic paper on carbon lock-in is Unruh 2000. Another way to conceptualise this risk is to say that the 'stopgap' measure might become permanent, or even the goal itself: Buck, Martin, Geden *et al.* 2020.

146 Cf. Baatz 2016, p. 44; Asayama and Hulme 2019, p. 942; Neuber and Ott 2020, p. 6.

throws up his hands at the end of the introduction to *The Gamble*.[147] And yet he persists in the wishful thinking. In a similar vein, Keith and MacMartin have authored another paper in which they simulate how long geoengineering would have to continue, if it were very modest indeed – merely reducing the *rate* of global warming to 0.1 degree per decade. In a scenario of stringent emissions cuts, such an operation would need to run for 40 years. In the worst-case business-as-usual scenario – the one currently tracked by emissions trends in the real world – it would be extended to 800 years, even without any ambition to cancel let alone reverse the warming.[148]

Such findings should be enough to explode the rationalist-optimist position from within. But this does not happen, of course, because Keith, MacMartin, Wagner and the others are deeply invested in the preparation of a chalice to the world: a remedy that will have its effect for some time, at the critical moment. Then comes the sigh of relief. The side effects come later.[149] And if that is how the story begins, we know – and the rationalist-optimists know too, on some level – how it ends.

Acknowledgements

Many comrades have read and commented on this manuscript. Thanks, first and foremost, to Wim Carton, in dialogue with whom it was conceived. Thanks also to Henrike Elisabeth Kohpeiß, Richard Seymour and Troy Vettese, as well as to the CPS students working on the *Overshoot* project – Ashley Marie Almqvist-Ingersoll, Siri Arvidsson, Jake Ferrell, Rikke Jespersen, Franek

147 Wagner 2021, p. 11.

148 This latter scenario is the one known as RCP8.5; the former is RCP2.6. MacMartin, Caldeira and Keith 2014. The authors of this paper (among whom the fence-sitter Caldeira is included) try to make it seem like 800 years would fall within the realm of 'temporary' geoengineering. But they do eventually admit that such 'time horizons are still long in comparison with most policy commitments' – an understatement if ever there was one. MacMartin, Caldeira and Keith 2014, p. 11. (And the underlying assumption here is that nearly a millennium of future time can be subsumed under the controlling forces of models, so much coming human history ready to conform to how scientists in the present want it to be.) On how actual emissions track RCP8.5, see Schwalm, Glendon and Duffy 2020.

149 As, again, the rationalist-optimists themselves recognise, in more formulaic language: 'the benefits of SRM [solar radiation management] first increase, then saturate and decline'; or, the benefits 'increase more slowly than linear, with the highest marginal benefit accruing initially'; or, the benefits 'have a concave function'. Keith and MacMartin 2015, pp. 203–4.

Korbanski, Nicholas LePage, Hanna Oosterveen, Alexander Perry, Eric Teller, Jonas Winter – and members of the editorial board of *Historical Materialism*. Remaining shortcomings are my responsibility solely. This research was made possible by the research grant FORMAS 2018-01686.

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