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The Greenhouse Connection

OF this much we're sure: global climate flip-flops have frequently happened in the past, and they're likely to happen again. It's also clear that sufficient global warming could trigger an abrupt cooling in at least two ways -- by increasing high-latitude rainfall or by melting Greenland's ice, both of which could put enough fresh water into the ocean surface to suppress flushing.

Further investigation might lead to revisions in such mechanistic explanations, but the result of adding fresh water to the ocean surface is pretty standard physics. In almost four decades of subsequent research Henry Stommel's theory has only been enhanced, not seriously challenged.

Up to this point in the story none of the broad conclusions is particularly speculative. But to address how all these nonlinear mechanisms fit together -- and what we might do to stabilize the climate -- will require some speculation.

Even the tropics cool down by about nine degrees during an abrupt cooling, and it is hard to imagine what in the past could have disturbed the whole earth's climate on this scale. We must look at arriving sunlight and departing light and heat, not merely regional shifts on earth, to account for changes in the temperature balance. Increasing amounts of sea ice and clouds could reflect more sunlight back into space, but the geochemist Wallace Broecker suggests that a major greenhouse gas is disturbed by the failure of the salt conveyor, and that this affects the amount of heat retained.

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In Broecker's view, failures of salt flushing cause a worldwide rearrangement of ocean currents, resulting in -- and this is the speculative part -- less evaporation from the tropics. That, in turn, makes the air drier. Because water vapor is the most powerful greenhouse gas, this decrease in average humidity would cool things globally. Broecker has written, "If you wanted to cool the planet by 5°C [9°F] and could magically alter the water-vapor content of the atmosphere, a 30 percent decrease would do the job."

Just as an El Niño produces a hotter Equator in the Pacific Ocean and generates more atmospheric convection, so there might be a subnormal mode that decreases heat, convection, and evaporation. For example, I can imagine that ocean currents carrying more warm surface waters north or south from the equatorial regions might, in consequence, cool the Equator somewhat. That might result in less evaporation, creating lower-than-normal levels of greenhouse gases and thus a global cooling.

To see how ocean circulation might affect greenhouse gases, we must try to account quantitatively for important nonlinearities, ones in which little nudges provoke great responses. The modern world is full of objects and systems that exhibit "bistable" modes, with thresholds for flipping. Light switches abruptly change mode when nudged hard enough. Door latches suddenly give way. A gentle pull on a trigger may be ineffective, but there comes a pressure that will suddenly fire the gun. Thermostats tend to activate heating or cooling mechanisms abruptly -- also an example of a system that pushes back.

We must be careful not to think of an abrupt cooling in response to global warming as just another self-regulatory device, a control system for cooling things down when it gets too hot. The scale of the response will be far beyond the bounds of regulation -- more like when excess warming triggers fire extinguishers in the ceiling, ruining the contents of the room while cooling them down.

Preventing Climate Flips

THOUGH combating global warming is obviously on the agenda for preventing a cold flip, we could easily be blindsided by stability problems if we allow global warming per se to remain the main focus of our climate-change efforts. To stabilize our flip-flopping climate we'll need to identify all the important feedbacks that control climate and ocean currents -- evaporation, the reflection of sunlight back into space, and so on -- and then estimate their relative strengths and interactions in computer models.

Feedbacks are what determine thresholds, where one mode flips into another. Near a threshold one can sometimes observe abortive responses, rather like the act of stepping back onto a curb several times before finally running across a busy street. Abortive responses and rapid chattering between modes are common problems in nonlinear systems with not quite enough oomph -- the reason that old fluorescent lights flicker. To keep a bistable system firmly in one state or the other, it should be kept away from the transition threshold.

We need to make sure that no business-as-usual climate variation, such as an El Niño or the North Atlantic Oscillation, can push our climate onto the slippery slope and into an abrupt cooling. Of particular importance are combinations of climate variations -- this winter, for example, we are experiencing both an El Niño and a North Atlantic Oscillation -- because such combinations can add up to much more than the sum of their parts.

We are near the end of a warm period in any event; ice ages return even without human influences on climate. The last warm period abruptly terminated 13,000 years after the abrupt warming that initiated it, and we've already gone 15,000 years from a similar starting point. But we may be able to do something to delay an abrupt cooling.

Do something? This tends to stagger the imagination, immediately conjuring up visions of terraforming on a science-fiction scale -- and so we shake our heads and say, "Better to fight global warming by consuming less," and so forth.

Surprisingly, it may prove possible to prevent flip-flops in the climate -- even by means of low-tech schemes. Keeping the present climate from falling back into the low state will in any case be a lot easier than trying to reverse such a change after it has occurred. Were fjord floods causing flushing to fail, because the downwelling sites were fairly close to the fjords, it is obvious that we could solve the problem. All we would need to do is open a channel through the ice dam with explosives before dangerous levels of water built up.

Timing could be everything, given the delayed effects from inch-per-second circulation patterns, but that, too, potentially has a low-tech solution: build dams across the major fjord systems and hold back the meltwater at critical times. Or divert eastern-Greenland meltwater to the less sensitive north and west coasts.

Fortunately, big parallel computers have proved useful for both global climate modeling and detailed modeling of ocean circulation. They even show the flips. Computer models might not yet be able to predict what will happen if we tamper with downwelling sites, but this problem doesn't seem insoluble. We need more well-trained people, bigger computers, more coring of the ocean floor and silted-up lakes, more ships to drag instrument packages through the depths, more instrumented buoys to study critical sites in detail, more satellites measuring regional variations in the sea surface, and perhaps some small-scale trial runs of interventions.

It would be especially nice to see another dozen major groups of scientists doing climate simulations, discovering the intervention mistakes as quickly as possible and learning from them. Medieval cathedral builders learned from their design mistakes over the centuries, and their undertakings were a far larger drain on the economic resources and people power of their day than anything yet discussed for stabilizing the climate in the twenty-first century. We may not have centuries to spare, but any economy in which two percent of the population produces all the food, as is the case in the United States today, has lots of resources and many options for reordering priorities.

Three Scenarios

FUTURISTS have learned to bracket the future with alternative scenarios, each of which captures important features that cluster together, each of which is compact enough to be seen as a narrative on a human scale. Three scenarios for the next climatic phase might be called population crash, cheap fix, and muddling through.

The population-crash scenario is surely the most appalling. Plummeting crop yields would cause some powerful countries to try to take over their neighbors or distant lands -- if only because their armies, unpaid and lacking food, would go marauding, both at home and across the borders. The better-organized countries would attempt to use their armies, before they fell apart entirely, to take over countries with significant remaining resources, driving out or starving their inhabitants if not using modern weapons to accomplish the same end: eliminating competitors for the remaining food.

This would be a worldwide problem -- and could lead to a Third World War -- but Europe's vulnerability is particularly easy to analyze. The last abrupt cooling, the Younger Dryas, drastically altered Europe's climate as far east as Ukraine. Present-day Europe has more than 650 million people. It has excellent soils, and largely grows its own food. It could no longer do so if it lost the extra warming from the North Atlantic.

There is another part of the world with the same good soil, within the same latitudinal band, which we can use for a quick comparison. Canada lacks Europe's winter warmth and rainfall, because it has no equivalent of the North Atlantic Current to preheat its eastbound weather systems. Canada's agriculture supports about 28 million people. If Europe had weather like Canada's, it could feed only one out of twenty-three present-day Europeans.

routes. The only reason that two percent of our population can feed the other 98 percent is that we have a well-developed system of transportation and middlemen -- but it is not very robust. The system allows for large urban populations in the best of times, but not in the case of widespread disruptions.

Natural disasters such as hurricanes and earthquakes are less troubling than abrupt coolings for two reasons: they're short (the recovery period starts the next day) and they're local or regional (unaffected citizens can help the overwhelmed). There is, increasingly, international cooperation in response to catastrophe -- but no country is going to be able to rely on a stored agricultural surplus for even a year, and any country will be reluctant to give away part of its surplus.

In an abrupt cooling the problem would get worse for decades, and much of the earth would be affected. A meteor strike that killed most of the population in a month would not be as serious as an abrupt cooling that eventually killed just as many. With the population crash spread out over a decade, there would be ample opportunity for civilization's institutions to be torn apart and for hatreds to build, as armies tried to grab remaining resources simply to feed the people in their own countries. The effects of an abrupt cold last for centuries. They might not be the end of *Homo sapiens* -- written knowledge and elementary education might well endure -- but the world after such a population crash would certainly be full of despotic governments that hated their neighbors because of recent atrocities. Recovery would be very slow.

A slightly exaggerated version of our present know-something-do-nothing state of affairs is know-nothing-do-nothing: a reduction in science as usual, further limiting our chances of discovering a way out. History is full of withdrawals from knowledge-seeking, whether for reasons of fundamentalism, fatalism, or "government lite" economics. This scenario does not require that the shortsighted be in charge, only that they have enough influence to put the relevant science agencies on starvation budgets and to send recommendations back for yet another commission report due five years hence.

A cheap-fix scenario, such as building or bombing a dam, presumes that we know enough to prevent trouble, or to nip a developing problem in the bud. But just as vaccines and antibiotics presume much knowledge about diseases, their climatic equivalents presume much knowledge about oceans, atmospheres, and past climates. Suppose we had reports that winter salt flushing was confined to certain areas, that abrupt shifts in the past were associated with localized flushing failures, *and*that one computer model after another suggested a solution that was likely to work even under a wide range of weather extremes. A quick fix, such as bombing an ice dam, might then be possible. Although I don't consider this scenario to be the most likely one, it is possible that solutions could turn out to be cheap and easy, and that another abrupt cooling isn't inevitable. Fatalism, in other words, might well be foolish.

A muddle-through scenario assumes that we would mobilize our scientific and technological resources well in advance of any abrupt cooling problem, but that the solution wouldn't be simple. Instead we would try one thing after another, creating a patchwork of solutions that might hold for another few decades, allowing the search for a better stabilizing mechanism to continue.

We might, for example, anchor bargeloads of evaporation-enhancing surfactants (used in the southwest corner of the Dead Sea to speed potash production) upwind from critical downwelling sites, letting winds spread them over the ocean surface all winter, just to ensure later flushing. We might create a rain shadow, seeding clouds so that they dropped their unsalted water well upwind of a given year's critical flushing sites -- a strategy that might be particularly important in view of the increased rainfall expected from global warming. We might undertake to regulate the Mediterranean's salty outflow, which is also thought to disrupt the North Atlantic Current.

Perhaps computer simulations will tell us that the only robust solutions are those that re-create the ocean currents of three million years ago, before the Isthmus of Panama closed off the express route for excess-salt disposal. Thus we might dig a wide sea-level Panama Canal in stages, carefully managing the changeover.

Staying in the "Comfort Zone"

STABILIZING our flip-flopping climate is not a simple matter. We need heat in the right places, such as the Greenland Sea, and not in others right next door, such as Greenland itself. Man-made global warming is likely to achieve exactly the opposite -- warming Greenland and cooling the Greenland Sea.

A remarkable amount of specious reasoning is often encountered when we contemplate reducing carbon-dioxide emissions. That increased quantities of greenhouse gases will lead to global warming is as solid a scientific prediction as can be found, but other things influence climate too, and some people try to escape confronting the consequences of our pumping more and more greenhouse gases into the atmosphere by supposing that something will come along miraculously to counteract them. Volcanos spew sulfates, as do our own smokestacks, and these reflect some sunlight back into space, particularly over the North Atlantic and Europe. But we can't assume that anything like this will counteract our longer-term flurry of carbon-dioxide emissions. Only the most naive gamblers bet against physics, and only the most irresponsible bet with their grandchildren's resources.

To the long list of predicted consequences of global warming -- stronger storms, methane release, habitat changes, ice-sheet melting, rising seas, stronger El Niños, killer heat waves -- we must now add an abrupt, catastrophic cooling. Whereas the familiar consequences of global warming will force expensive but gradual adjustments, the abrupt cooling promoted by man-made warming looks like a particularly efficient means of committing mass suicide.

We cannot avoid trouble by merely cutting down on our present warming trend, though that's an excellent place to start. Paleoclimatic records reveal that any notion we may once have had that the climate will remain the same unless pollution changes it is wishful thinking. Judging from the duration of the last warm period, we are probably near the end of the current one. Our goal must be to stabilize the climate in its favorable mode and ensure that enough equatorial heat continues to flow into the waters around Greenland and Norway. A stabilized climate must have a wide "comfort zone," and be able to survive the El Niños of the short term. We can design for that in computer models of climate, just as architects design earthquake-resistant skyscrapers. Implementing it might cost no more, in relative terms, than building a medieval cathedral. But we may not have centuries for acquiring wisdom, and it would be wise to compress our learning into the years immediately ahead. We have to discover what has made the climate of the past 8,000 years relatively stable, and then figure out how to prop it up.

> Those who will not reason
> Perish in the act:
> Those who will not act
> Perish for that reason.
>
> -- W. H. Auden

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