

Risk Analysis of Climate Change, and Potential SPS Contribution to Global Warming or Global Cooling Mitigation

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Abstract

Although the mass media have for several years treated the theory of "global warming" caused by humans' emissions of CO₂ as proven fact, the direction of future climate change and its causes are the subject of heated controversy within the scientific community. In particular, geologists, palaeontologists and others have recently drawn attention to the apparently much more serious threat of "global cooling", which has been largely ignored to date. Solar Power Satellites (SPS), originally proposed as a means of supplying continuous solar energy, have recently been advocated as a "low-carbon" energy source which could mitigate said "global warming". The present paper also considers the opposite possibility, that of using microwave power beaming satellites, or Snow-Melt Satellites (SMS), to mitigate the onset of the next Ice Age, which poses a huge threat to northern countries at some time in the future.

Key Words: Solar Power Satellite (SPS), Global Warming, Global Cooling, Ice Age Mitigation, Snow-Melt Satellite (SMS)

1. Introduction: Risk Analysis and Climate Change

Energy policy makers are generally not climate scientists, but they must nevertheless make certain judgements about climate change. Risk Analysis is an essential tool for this work: it involves analysing, as far as possible, different problems that may arise in future, and assessing how costly they could be, the probability of different outcomes, the costs and effects of different possible mitigating strategies, and comparing these with each other. The "Downside Risk", the worst foreseeable outcome from a particular threat, is a particularly important concept in policy-making, since it provides at least a rough estimate of the potential scale of counter-measures that may be appropriate.

1.1. Downside Risk of Global Warming

Having been promoted for more than a decade by the UN's Inter-governmental Panel on Climate Change (IPCC) as "established science", supposedly accepted by the great majority of relevant experts, the theory that "anthropogenic global warming" (AGW) caused by industrial emissions of CO₂ and other so-called "greenhouse gases" is a threat to humanity, and even to life on Earth, has recently become highly controversial. Every aspect of the AGW theory is now severely criticised by experienced scientists in many related fields: physicists, meteorologists, palaeontologists, geologists, archaeologists, statisticians, engineers, economists, ecologists, agronomists and others, as well as by leading climatologists.

For example, the very "Greenhouse Effect" theory itself, first proposed late in the 19th century, was seemingly disproved as long ago as 1909 by American physicist Robert Wood, who built a greenhouse with panes made of rock salt instead of glass. Since rock salt is permeable to infra-red, it should not show a "greenhouse effect": however, the temperature was not significantly different from a glass greenhouse. The accepted explanation is that the theory of "infra-red trapping" is not the reason why greenhouses are warm: the physical trapping of warm air is quantitatively far more important [1].

Moreover, the IPCC's procedures over the past decade and more have also been demonstrated to be far from scientific, with numerous cases of IPCC reports citing work as reliable scientific evidence which has never even been peer-reviewed (such as the highly one-sided and therefore essentially worthless "Stern Report" [2]), and even baseless speculations from Internet web-sites. Recently a team of 43 concerned scientists checked all 18,531 supposedly scientific references from the IPCC's 2007 report, and found that 5,587 of these references - ie more than 30% - were not even refereed as had been falsely claimed [3]. While some non-refereed work can

surely be valuable if treated correctly, for the IPCC to have claimed that these referenced documents were refereed in order to bolster the apparent authority of its conclusions is a mockery of the scientific method. The importance of this is that these IPCC reports have already been cited as scientific justification for billions of USD of government expenditure and taxation around the world!

Specific criticisms now raise profound doubts about whether increased CO2 concentration in the atmosphere can even warm it, whether the Earth's atmosphere is in a warming or a cooling trend, what fraction of the measured rise in atmospheric CO2 is due to industrial emissions, whether the beneficial effects of a rise in atmospheric CO2 and/or in overall global temperatures will outweigh the negative effects, whether reducing human CO2 emissions would exert a cooling effect on the atmosphere, whether computer simulation of climate change can ever be scientific, and others.

In this situation, for policy-makers who are required to make decisions, even in the face of such enormous uncertainty, the perspective of risk analysis is very helpful. Without requiring politicians to try to decide what scientists cannot, risk analysis provides the useful insight that the threat from AGW is not urgent: in particular, even in the worst case, serious costs to society would apparently take decades to materialise. This implication is strengthened by the fact that the Earth's atmosphere, as measured by the research centres used by the IPCC, has apparently not been warming for the past decade [4]. In the absence of any reliable prediction that a warming trend is about to start again soon, any dangerous outcome from AGW would seem to be at least decades away. Policy makers therefore have plenty of time in which to decide what, if any, counter-measures may be justified.

1.2. Downside Risk of Global Cooling

Given this situation, it is perhaps not surprising that the opposite possibility, namely that the recent trend towards longer and colder winters may be the beginning of either another "Little Ice Age" or even the next full "Ice Age", is now considered a greater risk than AGW by a growing number of climate scientists. This view is based on detailed understanding of the long geological record of past Ice Age cycles, driven by variations in terrestrial insolation. For example, Professor Habibullo Abdussamatov, head of space research at the Pulkovo Astronomical Observatory in St Petersburg, has stated:

" . long-term variations in the amount of solar energy reaching the Earth are the main and principal reasons driving and defining the whole mechanism of climate changes . ." and
" . . what lies ahead in the coming decades . . is not catastrophic warming, but a global and very prolonged temperature drop" [5].

Professor George Kukla, micro-palaeontologist and Special Research Scientist at the Lamont-Doherty Earth Observatory, Columbia University, has stated:

"We are certain now that changes in the Earth's orbital geometry caused the ice ages.
The evidence is so strong that other explanations must now be discarded" [6].

The possibility that the climate is going to cool significantly is particularly interesting from the point of view of risk analysis, since as far as public health is concerned, more people reportedly die of cold each year than from heat. Moreover, there is no controversy about the Downside Risk of global cooling: the next Ice Age will be a catastrophe for human civilisation. If one kilometre-deep ice once again covers the northern half of Europe, Asia and America, as it has repeatedly in the past, it will destroy much of the cumulative product of humans' labour over the past thousand years, including much of the most valuable scientific, industrial, educational and cultural infrastructure. This is understood because the cyclical pattern of Ice Ages has been well analysed over the past century, and there is little doubt that the Earth is now heading towards the next Ice Age. Only the timing is uncertain: whether it will begin within 10 years or 1,000 years is not known.

Disturbingly, researchers have recently understood that at least some Ice Ages have started suddenly - with metres of snow falling every day for months on end [7]. This has clarified the downside risk of global cooling: the worst foreseeable outcome would be "rapid onset" of the next Ice Age. If this occurs over the areas of the northern hemisphere which have been ice-bound during earlier Ice Ages, it would kill hundreds of millions of people, roughly from Moscow to Seattle, within just a week or two!

That is, a metre or more of snow falling in a day in northern districts causes considerable disruption. But with modern snow clearing equipment and effective emergency services, within a few days humans' activities return more or less back to normal, except in relatively isolated places, or where old buildings collapse, and so on. By contrast, if a metre or more of snow continued to fall every day, the emergency services would be unable to keep even major roads clear, and local supplies of food and fuel, including in cities, would soon run out. Inhabitants would become unable to leave buildings. Once electricity supply networks failed, which could not be repaired

during continuing heavy snowfalls, large numbers of people would start to die of cold. Within a few weeks there would be only isolated pockets of survivors under tens of metres of snow.

Considering the probability of such a "rapid onset" occurring in the near future, in the absence of better information, the recent several years of record-breaking long and snowy winters in America, Europe and elsewhere, suggests that such a rapid onset could start at any time.

2. Implications for Climate Change Policy

Faced with this vigorous scientific controversy, it might seem impossible for policy makers to do their work. However, even in the face of this uncertainty, policy-makers can nevertheless draw some provisional conclusions.

First, the continuing scientific controversy clarifies the fact that the Earth's climate system is extremely complex, and there are still major gaps in our understanding - including even such critically important features as cloud cover, and the Earth's magnetic field and its variation! This is corroborated by Dr John Theon, one-time Chief of the Climate Processes Research Program at Nasa:

“... the models do not realistically simulate the climate system, because there are many very important sub-grid scale processes that the models either replicate poorly or completely omit. Furthermore, some scientists have manipulated the observed data to justify their model results. In doing so, they neither explain what they have modified in the observations, nor explain how they did it. They have resisted making their work transparent so that it can be replicated by other scientists. This is clearly contrary to how science should be done. Thus there is no rational justification for using climate model forecasts to determine public policy” [8].

Second, in view of this, it is clear that government-funded research and policy-making about climate change over the past decade has been excessively one-sided. Tens of billions of USD have already been spent researching, promoting and implementing preliminary counter-measures and policies, although it is now extremely doubtful whether this burden on the economy has had any beneficial influence on the climate at all. It has, however had serious costs: for example, analysis of the Spanish government's generous subsidy programme for wind and solar-photovoltaic power shows that it has cost some 15 billion USD to date, and has reduced employment in Spain by 100,000 or more [9]. Governments' support for AGW counter-measures have also unjustly enriched companies such as Climate Exchange Plc, based in the Isle of Man, which owns the European Climate Exchange, the Chicago Climate Exchange and the Chicago Climate Futures exchange, and has already earned millions of Euros of profits on which it pays no tax [10].

Third, there has been a serious lack of research on global cooling, and especially on the possibility and implications of rapid onset of the next Ice Age. This lack is being tackled in a number of volunteer-run, scientific web-sites, such as [11] and [12].

Fourth, the interface between science, politics, business and volunteer groups concerning the topic of AGW has been shown to be very unsatisfactory. In particular, many irrelevant pressures have been applied to those responsible for scientific research - both financial and political, as well as personal abuse and defamation. This failure has seriously distorted the performance of science, including even the behaviour of leading scientific bodies such as Britain's "Royal Society", which has recently had to retract earlier unscientific statements supporting the AGW theory endorsed by its successive presidents Lord May and Lord Rees. This problem is discussed in detail in [13] and [14], as well as in [15] which describes the distorting influence of long-term, large-scale funding by the EU of environmental NGOs, whose pamphlets were cited by the IPCC as scientific evidence of "global warming".

Anything that distorts the process of scientific research is dangerous and unacceptable, because the role of science in policy-making is clear and vital: to provide factual evidence for government policy-makers to use to decide good policies. Hence it is essential that the "Climategate", "Amazongate", "Himalayagate", "Kiwigate", "Satellitegate" and related scandals concerning the operation of the UN's IPCC and the sources of data it uses should now lead to serious reorganisation of climate change research as a whole, so as to guarantee more balanced funding of different possibilities, and to ensure free and open discussion in the tradition of free speech, and transparency, including of editorial and other forms of control.

2.1 Value of Improved Energy Efficiency

In this context it is noteworthy that whether anthropogenic CO₂ emissions are significant or not, reducing energy use, through improving efficiency of utilisation and other means, could be beneficial in mitigating both climate warming and climate cooling. Other things being equal, reducing energy use reduces emissions of many pollutants (as well as of CO₂). It also reduces waste of thermal energy, which will become a precious resource in the event of significant climate cooling. There is already an extensive body of knowledge about means of reducing energy use sharply: for example, new buildings' net energy consumption can be reduced to near zero if appropriate decisions are made at the initial design stage. Policies to encourage this could therefore be valuable.

3. Potential Contribution of SPS to Climate Stabilisation

The uncertainties about the true potential of SPS are still so large that there are both optimists and pessimists concerning whether SPS could or should become a major new energy source. There are also advocates of many different SPS system architectures and sub-systems. The potential of SPS of course depends not only on its technology and costs, but also on its competitiveness with other future energy sources, including other alternatives that could be developed with the use of tens of billions of dollars of funding over the same decades-long time-frame. This is very hard to evaluate with any certainty today.

Technical progress to date suggests that if multiple, large-scale, microwave-power beams delivering power from space to the Earth's surface are acceptable from the environmental point of view, then SPS could become a major new energy source. However, it is surely still too early to decide this, before a first demonstrator satellite - which will be just 1 millionth the size of proposed commercial units! - has even been built.

However, in the following we assume that delivering solar-generated power from space to Earth using high-power microwave beams and/or lasers will become feasible and economically competitive. Based on this assumption, we consider the potential of such a system for mitigating both global warming and global cooling.

3.1 Climate Warming Mitigation

The argument that SPS could be a good "low-carbon" energy source has been used for some years. From this point of view, a good example of research on the potential of SPS for mitigation is the environmental impact analysis using Input-Output tables led by Professor Kanji Yoshioka: this work showed clearly that SPS would emit very little CO₂ - less even than nuclear power [16].

However, this idea was not part of the original justification for SPS research - which was as a way to use solar energy to supply continuous electric power on Earth, thereby overcoming one of the major drawbacks of solar energy. Even in Spain, a country with strong insolation, photovoltaic systems were found to generate only 700 kWh of electrical energy per kW of capacity per year - a utilisation factor of less than 8% [9]. Hence, even if the lack of urgency of the AGW threat reduces the need to develop low-carbon energy sources, if SPS can become economically competitive it could still make a major contribution to 21st century energy supply.

The strong endorsement given to space-based solar power (SBSP) by the US Department of Defence's National Security Space Office (NSSO) [17] as a promising means of avoiding "Resource Wars" in the 21st century, is further recent evidence of the potentially major benefits of SPS as an effectively inexhaustible energy source for Earth. If every member of a population of 10 billion is to reach a standard of living similar to the rich countries today, humans will need to build about 10,000 GW of electricity generation capacity through the 21st century. Even allowing for great progress in other energy technologies, the possibility of space-based solar energy systems supplying perhaps 1,000 GW may well make an important contribution to preventing energy shortages that might lead to international friction.

For Japan, a particularly attractive result of successfully developing SPS is that Japan could thereby become an energy-exporting country. That is, microwave power supplied to other countries from satellites built by Japanese companies would count as exports in the national accounts. This might grow to a larger business than supplying power domestically, because Japan's limited land area makes siting of rectennas within Japan difficult. Such a development would help remedy the greatest strategic weakness of the Japanese economy: its dependence on imports of energy.

In considering a scenario involving development of SPS it is also necessary to include likely "spin-offs". These include particularly the development of large-scale manufacturing in Earth orbit and on the lunar surface. The logic of such developments was understood even decades ago: if some hundreds of GW of SPS capacity are

to be assembled in geo-stationary orbit (GEO), this will involve delivering millions of tons of aluminium, silicon and other minerals to GEO. This scale of activity is so large that it could enable recovery of the initial costs of establishing mining activities, processing plants and factories on the lunar surface, from where the cost of delivering aluminium and other materials to geo-stationary orbit could be considerably lower than delivery from the Earth's surface. Similar arguments apply to asteroidal and other extra-terrestrial resources. Such developments will depend on entrepreneurial companies planning how to deliver lunar-derived materials to GEO at prices competitive with the cost of delivery from Earth [18]. Although it is not possible to predict this in detail, the overall business opportunity is easy to understand.

Another example of the spontaneous industrial development that can be expected if SPS-generated electricity becomes competitive with other electricity supplies on Earth, is that the cost of using electricity in orbit will then be roughly one quarter that on the Earth's surface. (This is because the space-to-Earth power transmission system is expected to lose about 50% of the power, and its cost, including both transmitting and receiving antennas, is likely to be about half of the total cost of an SPS.) This fact alone will create numerous business opportunities for companies to perform industrial activities that use large quantities of electric power in orbital factories. Starting with products for use in space, such as components of SPS units, and orbiting facilities such as research stations and space hotels, made from aluminium, silicon, glass, etc, the range of products will presumably grow steadily to include products for use elsewhere, as well as products that use the unique properties of space, such as "metal foam" structures that can only be made in weightlessness.

If this longer-term effect of gradually moving energy-consuming industries off Earth is considered, it is clear that developing SPS will represent a major change, a new industrial revolution, with great potential to reduce humans' overall environmental impact. That is, even if reduction of CO₂ emissions is not itself required, SPS could make a unique contribution to reducing other forms of pollution resulting from energy production and use, including progressively removing energy industries from the Earth's surface, which could bring many benefits, environmental, economic and social.

4. Climate Cooling Mitigation

As described briefly above, the prospect of the next Ice Age is so dramatic, and the scale of the climatic change so huge, that it is tempting to conclude that any attempt made by humans to mitigate such a large-scale natural process would be futile. However, we must at least recognise that the feasibility of mitigation depends on how much time humans have to prepare before the Ice Age arrives. For example, if onset of the next Ice Age was confidently understood to take more than 100 years, many counter-measures may become feasible that are not possible today. By contrast, if it was likely within a few years, little could be done to prevent it. Consequently, genuinely scientific research on the onset of past Ice Ages, on precursor events that may enable more precise prediction, and on current weather and climate trends in different regions, are clearly all very important for evaluating the threat humans face from global cooling.

However, what is of particular interest for SPS researchers is that SPS-like systems may be the only means by which humans may be able to significantly mitigate the coming Ice Age, by melting snow over very wide areas. Consequently it is interesting to at least review the scale of activity that could be required: some simple calculations show the magnitude of the task.

4.1. Quantitative Estimates of Ice Age Mitigation using "Snow-Melt Satellites"

In order to evaluate the feasibility of counteracting the progressively longer and wider snow cover that will inaugurate the next Ice Age, a key figure is the latent heat of melting of snow. The latent heat of melting of ice is 333.6 kJ/kg. The ratio between snow and ice depends on how heavily packed the snow is. Varying from 7% for fresh snow in cold air to 50% for old snow [19], we assume a density of 10%. Hence, melting 10 cm depth of snow would require the same quantity of heat as melting 1 cm of ice (and would produce 1 cm of water).

The effectiveness of a microwave at melting snow will also depend on the efficiency of coupling between microwaves and snow. (NB this depends on the microwave beam frequency, which for SPS is selected in order not to be absorbed by water vapour in the atmosphere. In order to melt snow, a different wavelength will likely be chosen for which absorption is high.) For the present estimate we assume 100% absorption, because most of the microwave energy that was not absorbed by the snow would presumably reach the ground, where it would turn to heat and tend to melt the overlying snow. In this case, 1 MJ would melt 3 kg of snow, and so 1 GW of microwave power could melt 3,000 kg of snow/second, or approximately 260,000 Tons/day. (NB This is an

upper limit, which would need to be reduced if, for example, it was considered necessary to also raise the temperature of the resulting water.)

The overall quantity of microwave power needed to keep a given area clear of snow would depend on the rate of snow fall. Normal snowy winter conditions see snowfall of some 30 cm/day, in which case 1 GW of microwave power could keep some 8 square km clear of snow. (Alternatively, if focused on just 1 square km, it could melt 0.25 m of ice, or heavy snowfall of 2.5 metres of snow/day.) If the area over which snow was to be melted was 1 million square km (a small fraction of the Ice Age Zone), this would require some 120,000 GW of microwave power, or roughly 1 million square km of solar panels in orbit. Although the individual units of such a dedicated "Snow-Melt Satellite" (SMS) system would be considerably easier to build than units intended for electricity supply to Earth, since there would be no need for rectennas nor retro-directive control of the microwave beam, it seems reasonable to conclude that this is not a feasible strategy during the 21st century.

4.2. Solar cell production potential

For comparison, as a result of rapid growth in recent years, terrestrial solar cell production reached some 9GW, or some 60 square kilometres in 2009, and is currently growing at about 20%/year. If this growth rate were to continue, it could reach 50 GW/year in about 2020, when it would take 20 years to produce 1,000 GW of solar panels, with an area of about 6,000 square kilometres. That is, a gigantic industrial effort duplicating that of the entire terrestrial solar cell industry over 3 decades would produce barely 1% of the quantity of space-qualified solar cells needed to keep 1 million square km clear of snow.

4.3 "Soletta" concept

In view of this problem, it is noteworthy that it would be physically far easier to produce aluminium foil than solar cells on the huge scale that seems to be needed. Kraft Ehrlicke called the idea of using lightweight solar reflectors, ie thin aluminium foil, to reflect solar energy directly down to the Earth's surface for various purposes such as lighting and improved agriculture, "Soletta". However, this approach faces an insurmountable problem: most visible light is reflected by snow and clouds. Thus, for the particular application of melting snow, this potential benefit is entirely lost because of the poor absorption of visible light due to the high albedo of both clouds (0.4 - 0.9) and snow (0.77 - 0.88).

4.4 Geographically selective melting

AGW theorists have proposed a vicious circle of progressive global warming resulting from shrinking areas of snow cover leading to increased absorption of solar energy, due to the lower albedo of soil, and hence ever warmer weather. By the same mechanism, the opposite vicious circle resulting from extended snow cover, both in area and over time, leading to reduced absorption of solar energy due to higher albedo, and to progressively colder winters may also operate. However, many uncertainties remain, and such a vicious circle of terrestrial cooling may not be quantitatively so significant. This is because, even where the ground is not snow-covered, northern regions are typically cloudy for long periods during the winter, and the intensity of solar radiation is also very weak in the far north, due to the low inclination of sunlight - and zero within the Arctic circle.

The brief review above of the scale of the problem suggests that a "brute force" approach - keeping the entire Ice Age Zone snow-free - is not feasible in the foreseeable future. However, a much smaller plan, to keep certain, relatively small, critical zones snow-free could be feasible. EG in southern parts of the Ice Age Zone, cloud cover is relatively less, and insolation is relatively stronger, so snow cover has relatively strong cooling effect, and melting it would have a relatively strong warming effect. The density of cultural and industrial assets, especially those concentrated in cities, is also higher in the southern part of the Ice Age Zone.

Such a proposal raises many detailed questions about how effective such a plan could be over what timescale, which merit research in order to understand the feasibility of planning a system to protect selected areas. For example, though unfair in some sense, it is logical that centres of economic activity could pay more for protection from heavy snow than more sparsely populated areas. Another potential source of heat for melting snow is power station waste heat, which is typically more than the delivered electric power: this could presumably be used to melt snow in the vicinity of thermal power stations, a 1 GW power station being able to keep several square kilometres free of snow, in principle.

As seen above, in order to melt snow sufficiently fast, the average microwave intensity would need to be 1GW per 8 square km, or 125 Watts/sqm - or even 1 kW/sqm for heavy snow. Although the latter intensity of microwave radiation is generally not considered satisfactory in a permanent power source near to human

habitation, it seems likely that it could be acceptable in a disaster-mitigation system. This is because protecting the body from microwave radiation of this intensity is not difficult in principle: a person needs to be inside a Faraday cage. Radar workers typically achieve this by wearing overalls with conducting threads in the cloth, and helmets and goggles with conducting layers. In addition, if snow-melting in cities was carried out at night-time it would perhaps be possible to protect the population from radiation using a "curfew" during times when microwave radiation would be used for snow melting.

4.5 Alternative Approach to Mitigation

It also seems possible that there may be more effective means than the "brute force" approach of melting snow (and thereby causing floods). For example, there might be a means of coupling microwave energy with clouds sufficient to either disperse the clouds, or to produce rain instead of snow, possibly depending on the exact wavelength used. Excessive rain would of course cause heavy flooding, but this may well be a lesser evil than than prolonged and massive snowfalls.

This possibility is a form of weather modification, which is well-known to face serious legal and political difficulties. Notably, changing weather in one area is likely to affect it also in other areas, and so victims of bad weather can reasonably require compensation from those benefiting from the modification. Ideally, one would wish to prevent precipitation over land, diverting it over the sea or to uninhabited regions further north. A unique advantage of space-based systems for this application is the flexibility of targeting: a microwave (or laser) beam could follow selected weather patterns accurately over thousands of kilometres. However, the uncertainties inevitably involved due to the statistical variability of weather make the issue legally complex. Clearly more research is needed, as discussed and recommended elsewhere [20].

5. Conclusion: Need for Balanced Climate Change Research Funding

To date, essentially no government funding has been provided for research on the dangers of global cooling, and specifically concerning the risk of "rapid onset" of the coming Ice Age. Necessary policy responses include both research on improving prediction of such weather trends, and contingency planning for counter-measures.

The possibility of using microwave-generating Snow-Melt Satellites (SMS) to melt snow over selected areas, and/or to disperse snow-bearing clouds, and thereby to possibly mitigate a vicious circle of increased snow-cover leading to further cooling, seems to deserve detailed investigation.

In view of the evidence that north American and northern European winters are currently in a cooling trend, it is clearly more urgent to start this research than adding even more to the already heavy investment made in policies to reduce CO₂ emissions, of which the value seems highly doubtful.

For SPS researchers, measures to mitigate climate cooling may offer the greatest promise of funding to develop large-scale SPS systems as rapidly as possible. In any case, even the end of concern about CO₂ emissions is clearly no reason to reduce efforts to develop space-based solar power systems.

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