GLOBAL TEMPERATURE STABILIZATION VIA CLOUD SEEDIING

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SUMMARY

The escalating global warming resulting from the burning of fossil fuels seems likely to have an ever-increasing number of adverse, irreversible and possibly catastrophic consequences. The establishment of some technique for holding the Earth's temperature constant until a clean form of energy is developed to take over from oil, gas and coal is therefore an urgent requirement. We are examining the possibility of seeding maritime clouds with large quantities of small seawater particles to make them reflect more sunlight, thus producing a cooling, which computations employing world-class global climate models suggest could balance predicted global warming for perhaps 50 or 100 years. We need to engage in further studies of all relevant scientific and technological aspects of this idea – and also identify and assess all likely ramifications of its possible global deployment – in order to determine unequivocally whether or not it can play the crucially important role of suppressing global warming. Currently, no funding is available for the pursuance of these necessary studies.

THE GLOBAL COOLING TECHNIQUE.

It appears increasingly unlikely that the major countries of the world will reduce their carbon dioxide emissions rapidly enough to prevent disastrous consequences. It has therefore become imperative to examine 'geo-engineering' ideas for suppressing warming for several decades, until clean-energy sources can be fully deployed.

Colleagues and I are examining one such idea, which involves seeding low-level marine clouds to make them more reflective to incoming sunlight, thereby producing a cooling adequate to balance global warming. This idea has been published in a number of peer-reviewed articles. It has received a strongly positive response internationally (conferences, workshops, seminars etc) and been the subject of TV documentaries (BBC and Discovery Channel). We have been invited to write 2 papers (one on the science – Latham et al. 2008 - and the other – Salter et al. 2008, on the technology of our global cooling idea) for a special issue of the prestigious and venerable UK journal, *The Philosophical Transactions of the Royal Society*, devoted entirely to global warming mitigation ideas. This issue will constitute the most up-to-date, comprehensive and authoritative assessment of such projects.

The two scientists with most time to devote to this work are Latham (formerly Head of the Atmospheric Physics Research Group and Professor of Physics at the University of Manchester, UK: and now holding the honorary position of Senior Research Associate at the National Center for Atmospheric Research (NCAR), Boulder, Colorado), and Dr Stephen Salter, Emeritus Professor of Engineering Design at the University of Edinburgh, UK. Other scientists have been very helpful to us but their regular duties have prevented them from being able to devote a major fraction of their time to this work. They include: Dr Tom Choularton (University of Manchester, UK), Dr Alan Gadian & Ms Laura Kettles (University of Leeds, UK), Drs Jack Chen & Phil Rasch (NCAR). Optimal furtherance of this work leading to an authoritative assessment of the operational validity our scheme will require the provision of significant funding.

Our basic idea (proposed by Latham, *Nature,* 1990) is to increase the reflectivity (albedo) of the Earth to incoming sunlight, thus producing a cooling. Our calculations (Latham, 1990, 2002; Bower et al. 2006, Latham et al. 2008), indicate that cooling sufficient to hold the Earth's temperature constant for 50 to 100 years could be achieved by increasing the albedo of low-level shallow maritime stratocumulus clouds - which cover about a quarter of the oceanic surface - by seeding them with sea-water droplets, (typically about 1 micrometer in size). These act as centers for additional droplet formation, causing the clouds – for well-established physical reasons - to become more reflective. This process occurs naturally, but not sufficiently strongly to produce adequate cooling. Plans – spearheaded by Salter - are well advanced for dealing with the crucial engineering problems of the production and dissemination of seawater droplets at the rates and on the geographical scales required. Our current thinking is that these particles will be disseminated from unmanned, satellite-controlled, wind-powered vessels.

This global cooling technique has the advantages that: (1) the only raw materials required are wind and seawater; (2) the amount of global cooling could be adjusted by switching on or off, by remote control, aerosol generators mounted on the unmanned, satellite-guided vessels; (3) if necessary, the entire system could be immediately switched off, with conditions returning to normal within a few days.

WORK PLANNED FOR THE NEAR FUTURE

We now describe several specific areas of work emanating from the research described above, which in our view represent the top-priority requirements over the next 12months or so. We also provide cost estimates associated with each of these tasks. It is difficult to predict the exact costs of each of the six high-priority goals, since very useful, but more limited, work can be initiated for appreciably less than the fully optimal figure. We feel, however, that considerable progress could be made in each of the 6 categories in the next 12months, for the itemised amounts listed opposite each goal on the final page of this document.

1. Cloud Modelling.

More cloud modelling will enable us to examine quantitatively important questions concerning the ascent - from ocean-level to the clouds - of the disseminated seawater aerosol. In particular, estimates will be made of the fraction of aerosol particles that successfully make this journey. Values of this fraction will be sensitive to the prevailing meteorological conditions in ways we need to assess. We will also examine suggestions in the scientific literature that in special circumstances increasing the cloud droplet concentration in a cloud can reduce its reflectivity. This can result from interactions between droplets in the clouds and undersaturated air drawn into the cloud from its environment, a process known as entrainment. We also need a better quantitative understanding of the effect of seeding the clouds on the formation and development of drizzle within them. Drizzle acts to shorten the lifetimes of the clouds: and so they reflect solar radiation back to space for a shorter time, reducing the amount of cooling. The above questions need to be fully answered before we can assess definitively the viability of our technique.

2. Global Climate Modelling.

More global climate modelling will be performed in order to improve our estimates of the level of cooling that our scheme can produce. Such computations will also permit us to produce seasonally variable global maps of the cooling produced by the seeding of clouds with seawater aerosol. It is not necessarily the case that maximum cooling will occur in regions of most frequent cloud and maximum solar radiation. Indeed, the greatest cooling is likely to occur in remote oceanic regions minimally influenced by pollution. We also need to explore further the seasonal variability of the susceptibility of clouds to seeding. This will allow us to determine the best regions to seed at any part of the year. This factor underlines our provisional decision to utilise mobile disseminators for the seawater particles. We will also need at some fairly early stage to improve the accuracy of our GCM computations by using a model in which the oceans and the atmosphere are coupled. To date, we have used atmosphere-only models.

3. Assessment of Possible Negative Ramifications

GCM modelling is also expected to be the principal tool in examining the meteorological and other ramifications of the possible global deployment of our scheme. For example, we need to determine the likely impact of our scheme on global patterns of wind and rainfall. It is absolutely crucial that all such possible ramifications are thoroughly examined before any decision to deploy our system globally is taken. Only if such ramifications are found to be non-existent or small in comparison with the advantages associated with deployment of our technique, can the latter be justified. It may well prove advantageous that our scheme does not require fully global seeding, so that – to a significant degree – we could choose to modify clouds which are a long way from sensitive areas. It is crucial for this aspect of our work to utilise a good atmosphere/ocean coupled model, as wind and rainfall patterns are strongly influenced by oceanic temperatures and flows.

4. Technological and Laboratory Work.

Continuing work is required on technological issues, especially regarding the optimisation, construction and testing of the spray disseminators. Some features of the unmanned, satellite guided vessels also need further attention. . Current plans for the aerosol dissemination system are based on micro-fabrication lithography. Sea-water will be forced through a matrix of about 20 billion nozzles of 0.8 micrometer diameter. The speed of the seawater jet from each nozzle is set by pressure and will be about 4 metres per second. We should be able to spray about 30 kg of seawater per second. More work is required to optimally resolve the important question of seawater filtration prior to reaching the nozzles. Some small laboratory tests and experiments will probably be desirable, in order to examine technological and scientific problems.

5. Preparatory Work for Localised Area Field Experiment.

A vital requirement of our work programme is to conduct a limited area field experiment, in a carefully chosen extensive region of marine stratocumulus clouds. The plan of operation would be to select a central region (perhaps circular, of diameter about 200km) and seed the cloud throughout this region but not outside it. Comparisons would be made (directly) between the reflectivities of the seeded and unseeded regions, probably using satellite measurements: and (indirectly) by making passes through the seeded and unseeded clouds at a variety of levels with a research aircraft carrying particle-measuring devices; and calculating the albedo-differences between the seeded and unseeded regions. In these ways estimates can be made of the amount of cooling associated with the seeding. This experiment will involve ground-based, airborne and satellite measurements, as well as specially tailored major computations. Decisions will need to be made about instrumentation, models, flight patterns etc. We feel it important to start preparatory work now, on this crucial part of our overall program, so that we are poised to move swiftly to a full experiment when funding for it is procured.

6. Strengthening/Extending the Collaborative Team: Meeting.
As mentioned earlier, the number of collaborators involved to some significant degree with our cloud-albedo enhancement project has grown steadily, to its great advantage. However, the number of investigators, the time they can devote to the project, and the number of required areas of expertise currently covered, are far from optimum. These deficiencies can be diminished by: (1) inducing scientists with time and relevant skills, to join our team, and (2) employing people to work full-time on the project. Both routes will be pursued as fully as possible, but item (2) of course requires the availability of funds. We wish to devote an appreciable amount of time and energy to pursuing this team-strengthening requirement. Success in this matter, and also in developing plans for the limited-area field experiment, would be greatly assisted, we believe, by holding a meeting (a free-ranging, largely informal workshop, perhaps for 2 or 3 days) in which a specially selected small group of scientists / engineers etc are invited to participate.

We remain convinced that the ideal solution to the global warming problem is for fossil fuel burning to be reduced by the requisite amount to halt further temperature rise, we but we believe that such a massive reduction is highly unlikely to occur in the foreseeable future. If our scheme (or any other reflectivity enhancement or global cooling technique) could successfully be deployed operationally, it would not, of course, reduce the atmospheric and oceanic carbon dioxide levels, whose increase has injurious planetary effects, which will need to be addressed, in addition to temperature rise. However, if it proves feasible to produce a cooling to balance, in a controlled way, the global warming, we could buy time within which to stave off catastrophic warming while clean energy sources are being developed and deployed. In this regard we are strongly encouraged by both the positive reactions to our idea expressed by climate scientists, and also, especially, by our recent GCM results. It seems to us deplorable that resources have so far not been provided at governmental level to enable such geo-engineering ideas to be adequately assessed.

The seven papers emanating from our work to date are:
1. Latham, J., 1990: Control of global warming? Nature 347. 339-340.
2. J Latham and M H Smith: 1990 Effect on global warming of wind-dependent aerosol generation at the ocean surface. Nature, 347, No. 6291, 372-373
3. Latham, J., 2002, Amelioration of Global Warming by Controlled Enhancement of the Albedo and Longevity of Low-Level Maritime Clouds. Atmos. Sci. Letters. (doi:10.1006/Asle.2002.0048)
4. K.Bower, T.W.Choularton, J.Latham, J.Sahraei and S.Salter., 2006. Computational Assessment of a Proposed Technique for Global Warming Mitigation Via Albedo-Enhancement of Marine Stratocumulus Clouds. Atmos. Res. 82, 328-336.
5. J. Latham, 2007. Cooling may be possible, but we need safety data. Nature, 447, 908.
6. J. Latham, P.J. Rasch, C.C.Chen, L. Kettles, A. Gadian, A. Gettelman, H. Morrison, S. Salter., 2008. Global Temperature Stabilization via Controlled Albedo Enhancement of Low-level Maritime Clouds. (Submitted).
7. S. Salter, G. Sortino and J. Latham, 2008. Sea-going Hardware for the Cloud Albedo Method of Reversing Global warming. Phil. Trans. Roy. Soc. (submitted).

Global Cooling 2008 Budget
12 months

Collaborative research travel.		$22,000
Conference registration & fees.		$2,000
1. Cloud Modeling		
Salary, benefits, etc	$39,000	
Travel to conferences, meetings etc	$7,000	
Computer items	$4,000	
		$50,000
2. Global Climate Modeling.		
Salary, benefits etc	$16,000	
Travel to conferences, meetings etc	$6,000	
Computer items	$3,000	
		$25,000
3. Assessment of Possible Negative Ramifications		
Salary, benefits etc	$29,000	
Travel to conferences, meetings etc	$7,000	
Computer items	$4,000	
		$40,000
4. Technological and Laboratory Work.		
Small capital items	$10,000	
Consumable items	$7,000	
Specialised assistance	$8,000	
		$25,000
5. Preparatory Work for Localised Area Field Experiment		
Data analysis	$14,000	
Travel to laboratories etc	$8,000	
Specialised assistance	$8,000	
		$30,000
6. Strengthening/Extending the Collaborative Team: Meeting		
Meetings with individual scientists	$4,000	
Workshop meeting costs	$15,000	
Production of report	$1,000	
		$20,000
Graduate student fellowship.		$25,000
Admin overhead 5%		$11,950
TOTAL		**$250,950**