(54) Title of the Invention: A cloud of sub-micron particles having a refractive index greater than 1.4

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Figure 1: Radiation Scattering by Aerosol Cloud in Lower Stratosphere
Figure 2: Ship + conduit + dirigible
Figure 3: Local Circulation Patterns Induced by Aerosol Cloud
Figure 4: Multiple Ship Arrangement to provide a broad cooling effect

Note: Ships and Dirigibles not shown to scale
Figure 5: Ensuring a well dispersed aerosol
Figure 6: Ship or Land based Slurry Preparation
Figure 7: Conduit Construction and Arrangement

Not to scale
Title: A cloud of sub-micron particles having a refractive index greater than 1.4

Technical field

The present invention relates to a cloud of particles at an elevated location, e.g. in the earth’s stratosphere, particularly to achieve a local or regional cooling effect.

Background to the invention

Many authors now agree there is a significant possibility of abrupt discontinuities in the earth’s climate, e.g. by global warming, through rising atmospheric greenhouse gas levels which in turn may cause significant positive feedback, such as release of methane from melting arctic tundra or loss of rainforest through changed precipitation patterns. Such discontinuities might lead to a serious impact on ocean levels, and agriculture.

However, emissions of greenhouse gases such as CO₂, are intimately connected to the economies of the world. An abrupt reduction in the levels of these gases over effective timescales may be difficult to achieve.

Various methods of reducing the levels of solar radiation incident upon the earth have been proposed, for example, space mirrors, cloud seeding and stratospheric sulphate aerosols. The effects of significant stratospheric sulphate aerosol injection have been demonstrated to reduce mean global temperatures by around half a degree centigrade over a period of two years with the eruption of Mount Pinatubo in the Philippines in 1991.

Reducing incident solar radiation to counteract the trapping of heat by rising greenhouse gas emissions leaves ocean acidities rising due to increased levels of absorbed carbon dioxide. However it may reduce rising temperatures generating
more greenhouse gas emissions through the melting of arctic permafrost exacerbating the ocean acidity problem.

The particular method of stratospheric sulphate aerosols suffers from a number of drawbacks: the choice of particle diameter is determined by natural processes in the stratosphere if precursor materials such as Sulphur Dioxide or Hydrogen Sulphide are used, and the generation of stable aerosols with defined characteristics presents many difficulties. Furthermore their effect on stratospheric chemistry, particularly the ozone concentration may cause concern. In addition the possibility of generating local ‘shadows’ does not arise since it takes a significant time (days at least) after injection of Sulphur Dioxide for Sulphuric Acid or Ammonium Sulphate particles to be generated by the natural processes (hydration and reaction with UV atmospheric Nitrous Oxides), by which time any high local concentration will be well dispersed by even moderate stratospheric winds.

There is therefore a need for more effective solutions to the problem of global warming with less alarming side effects.

Summary of the invention

By transporting particles into the earth’s atmosphere, such particles can be dispersed to influence the incident solar radiation and provide a local or regional cooling effect. If sufficient quantities of particles are dispersed, then a cloud of such particles can form, providing the local, regional or global cooling effect. Additionally, as the particles are solid their size can be controlled to provide optimum results.

The lifetime of such a cloud is largely determined by the rate of depletion of particles from the cloud.

The exact rate of depletion is influenced by several factors, including particularly the size of the particles. For sub micron particles, when the settling rates are very low, the losses from the stratosphere to the troposphere are determined by the relatively small amount of mixing between the stratosphere and troposphere. It is estimated that
as many as half of any sub micron particles in the stratosphere may leave the stratosphere per year. In addition, particle-to-particle collision by Brownian motion will cause sub-micron particles to agglomerate and become larger particles, greatly increasing their settling rates.

The invention relates to a cloud of solid particles located in the earth’s atmosphere at an elevated location, wherein the cloud comprises at least 1,000 tonnes (preferably at least 5,000 tonnes, or even at least 10,000 tonnes) of solid particles, wherein substantially all of the solid particles are sub-micron having a refractive index in excess of 1.40, over a region of at least 1,000 square kilometres. Such clouds will typically extend over a region of at least 3,000 square kilometres, preferably at least 30,000 square kilometres, e.g. from 50,000 to 300,000 square kilometres.

Depletion rates below the stratosphere will be significantly greater due to the increased turbulence and mixing in the tropopause and the troposphere. Thus, the elevated location is preferably at an altitude of at least 5,000m, more preferably at least 10,000m, and most preferably in the stratosphere, in order to minimise particle depletion rates.

For local or regional cooling such a cloud is typified by being able to scatter at least 10% of incident solar radiation, thus providing a local cooling effect.

In one arrangement the cloud may be generated during daylight hours to provide an effective local or regional cooling effect, but disperses over night.

Thus, the invention can provide local shade effects, which, if over a significant body of water can (a) cool the water surface by a few degrees centigrade thereby reducing the motive force of local tropical storms and (b) allow the creation of onshore winds laden with water to promote irrigation of coastal lands.

As discussed, over time the cloud will disperse, and if it was located in the stratosphere, will produce a rarefied cloud without clearly defined boundaries, extending over a significant fraction of the earth’s surface. When quantities are
sufficient, such a rarefied cloud may only scatter a few percent of incident solar radiation but may provide a global cooling effect.

To maintain such a local or regional cloud in a steady state, emission rates of at least 500 metric tonnes of particles per 12 hours, preferably at least 1000 metric tonnes, more preferably at least 2000 metric tonnes, or more preferably at least 4000 metric tonnes, or most preferably at least 10,000 metric tonnes per 12 hours may be required.

Such throughputs may be provided by a single conduit or by a plurality of conduits. In the case where there is a plurality of conduits, each may be independent of the other or they may be combined into a single apparatus.

Releasing the solid particles into the stratosphere utilising a dispersal means will result in a cone of particles whose cross-section downstream of the injection point is very broad compared to its vertical span, and from which a cloud according to the invention results. This is because the turbulent intensity in the vertical direction is less than in the horizontal direction in the stratosphere.

It has been found that particles having a refractive index in excess of 1.40 are able to effectively scatter incoming solar radiation so that less radiation impinges on the earth.

Preferably the particles have a refractive index of greater than 2.0, more preferably greater than 2.3. Preferably, substantially all of the solid particles are of titanium dioxide, sodium chloride, silicon or mixtures thereof. A highly preferred material is titanium dioxide. However, sodium chloride may be preferred as it can be readily obtained from sea water.

Titanium dioxide exists in several material forms, the primary ones used for scattering being rutile and anatase. All of these forms have refractive indices in excess of 2.4 and so make excellent materials for use in the present invention. Additionally titanium dioxide is stable in air and not toxic. Anatase crystal may be preferred as it has relatively lower abrasion properties than the rutile crystal form.
In a preferred embodiment the present invention involves the Mie scattering of incident solar radiation. Mie scattering occurs when the size of the particles is comparable with that of the wavelength of incident light and preferably with the particle diameter being within a factor of 10, more preferably a factor of 3, of the wavelength of the incident light.

The particles preferably have a mean particle size in the range of from 0.01 to 0.5 μm, more preferably in the range of from 0.02 to 0.5 μm. This size range straddles the ultra violet and visible regions of the electromagnetic spectrum and therefore will be effective at scattering these dominant regions of the incident solar radiation.

In a particularly preferred embodiment, the particles may have a bimodal size distribution with peaks in the visible and ultra violet wavelengths respectively. For example peaks at from 0.1 to 0.3 μm and at from 0.02 to 0.06 μm are particularly effective.

At such small particle sizes, agglomeration of the particles presents a significant difficulty. For titanium dioxide the interparticle forces are particularly high because of the high polarisability of oxygen in the particles. Agglomeration will inhibit the ability of the particles to be involved in Mie scattering of the incident radiation due to the increase in effective particle size that results from agglomeration. It is therefore highly desirable to be able to deagglomerate the particles at the stratospheric location.

In a preferred embodiment, the solid particles are coated with one or more materials, different to the material of the particles.

Coatings can be selected from a range of options, for example to reduce chlorine concentrations present in the stratosphere, to reduce the tendency of ice or nitrogen oxides to coat the surface, to reduce ozone depletion, promote ozone generation in the stratosphere, to mitigate the possibility of electrical discharge near the dispersal means. For example, alkaline (metal and earth) coatings involving oxides,
hydroxides, aluminates, silicas and combinations thereof can be used to scavenge chlorine from the stratosphere, thus preventing it from destroying ozone.

Hydrophobic coatings can also be chosen to reduce the tendency for water vapour to condense on the particles and form ice. Ice can have a highly deleterious effect on the destruction of ozone, particularly in the polar regions. In a preferred embodiment, the coatings comprise siloxanes or a variety of other hydrophobic coatings.

It is also possible to use a the coating material to produce either a positive or a negative charge on each particle, leading to mutual repulsion of likely charged particles and reduced agglomeration.
The invention will now be illustrated, by way of example, and with reference to the following figures, in which:

Figure 1 is a diagram showing the effect of a cloud according to the present invention on incoming solar radiation to the earth’s surface.

Figure 2 is a schematic representation of an apparatus for forming a cloud according to the present invention.

Figure 3 is a schematic representation of the effect of a cloud according to the present invention on local weather conditions.

Figure 4 shows a schematic representation of three apparatuses working together to alter the local weather conditions.

Figure 5 is a schematic representation of the components of an apparatus forming a cloud according to the present invention located at a stratospheric location.

Figure 6 is a schematic representation of the components of an apparatus located at a substantially ground-level location.

Figure 7 is a schematic representation of the conduit construction for forming a cloud according to the present invention.

Detailed description of the figures
Figure 1 shows a diagram of the effect of a cloud 100 according to the present invention located in the earth’s stratosphere. The cloud 100 comprises titanium dioxide having a unimodal distribution with a peak at 0.25 micrometres or a bimodal particle size distribution with peaks at 0.15 micrometres and at 0.04 micrometres.

Incoming solar radiation 102 impinges upon the cloud 100. Due to the particle size of the titanium dioxide particles in the cloud, Mie scattering of the incoming solar radiation occurs causing a proportion of the incoming solar radiation 102 to be reflected away from the earth as scattered radiation 104. Thus, a significant proportion of the ultra violet and visible light of the incoming solar radiation 102 is prevented from reaching the earth’s surface. A reduced level of solar radiation 106 passes through the cloud to impinge upon the earth’s surface.

Infrared radiation 108 is emitted from the earth’s surface, which largely passes through the cloud 100 without being scattered due to the wavelength of the infrared radiation being significantly greater than the particle size of the titanium dioxide particles. Thus, the cloud 100 according to the present invention is able to reduce the level of incoming solar radiation without significantly inhibiting the emission of infrared radiation to space, and thus is able to cause a local or regional cooling effect.

Figure 2 shows an apparatus for forming a cloud according to the present invention comprising a conduit 210 connecting a substantially ground-level location on a ship 200 to a stratospheric location at a dirigible 220. Dirigible 220 comprises a deagglomeration means (not shown) and a dispersal means (not shown). Also shown is the tropopause 240, signifying the boundary between the troposphere below and stratosphere above.

In use, particles typically of sub-micron high refractive index particles, such as titanium dioxide, are transported from the ship 200 by means of a particle transport means, such as a pressurisation of a carrier fluid, so that the particles travel along the conduit 210 to the stratospheric location 220. As the particles of the titanium dioxide are sub-micron, some agglomeration will have occurred during transport through the conduit, and so the particles are passed through a deagglomeration means (not shown)
before passing to dispersal means (not shown) such as a fan or jet engine. Once the particles have passed through dispersal means, they begin to form a cloud 230 according to the present invention.

Figure 3 shows a schematic representation of how local weather patterns may be influenced by the action of a cloud 360 according to the present invention. Incoming solar radiation 370 is scattered by cloud 360, as discussed above, resulting in a region of cooled water surface 300 in the shadow of the cloud 360. The cooled water surface 300 has the effect of cooling the air above it, which has the effect of inducing a down draught of air 310 which is cooler and therefore denser than adjacent air. The down draught 310 causes an increase in horizontal wind speed at the water surface 320 which has the effect of increasing the water vapour uptake of the air 320 and cooling the water surface, before rising. The rising air column 330 results in the formation of clouds and ultimately precipitation. Rising air 330 is drawn back into the cloud’s shadow by moving horizontally 340 and it begins its descent once more.

The formation of the clouds has the effect of further reducing incident radiation to extend the region of cooled water surface 300 to an extended cooled water region 380.

Thus, it can be seen that a cloud according to the present invention can be employed to cool the water surface by a few degrees and allow the creation of onshore winds laden with water to promote irrigation of coastal lands.

Figure 4 shows the effect of using three apparatuses for forming a cloud according to the present invention together to generate a more substantial cooling effect. In this embodiment, three ships 400 each with their own conduit 410 attached to dirigible 420 are employed. Three separate clouds of high refractive index particles are generated, having the effect of cooling an extended region of water surface 460.

In the embodiment shown, a significant spacing is left between the clouds, so that circulation patterns between the clouds are generated. Thus, cooled water causes a cooling of the air above resulting in descending air 440 and horizontal wind 430 picking up additional water vapour. Airstreams 430 rise 450 and form clouds and
eventually precipitation to subsequently be drawn back into air stream 440. However, it can be advantageous to have multiple sources without a significant spacing.

Figure 5 shows in more detail suitable equipment of an apparatus for forming a cloud according to the present invention located at a stratospheric location. The equipment comprises the upper end of conduit 500 wound around spool 510 which is driven electrically by motor 525 with active damping control to dampen oscillating in the conduit 500, and connected to a pipeline via rotational seal 520. The particles in the conduit are carried by a supercritical water carrier and remain in a supercritical state at the stratospheric location, despite the loss in pressure head and frictional pressure drop during transport from a substantially ground-level location (not shown). The particles carried in this supercritical water pass through a turbine and/or reducing valve 530 to flash-off steam and bring the carrier fluid out of a supercritical state.

The particles, now carried in a largely gaseous carrier are then passed to a jet impact mill and microniser 540 via multiple entry points to a microniser of approximately 4 metres in diameter. The jet impact mill and microniser, constituting a deagglomeration means, breaks any agglomerates formed between the particles and ejects the individual particles via nozzle or nozzles 570. Also shown is a fan or jet engine 560 with air inlet 550. The fan or jet engine 560, constituting a dispersal means, generates a significant flow of air. As can be seen, nozzle 570 is located in the flowing gas stream, and the agglomeration means is therefore close-coupled to the dispersal means. This has the effect that the deagglomerated particles do not have an opportunity to reagglomerate and are dispersed into the stratosphere to form a cloud 580 according to the present invention. The particle stream can also be injected into the inlet of the jet, fan or gas turbine to aid dispersion but can lead to particle build-up and particle degradation issues. Also shown is valve 525 which can be opened to allow the ingress of air when it is desired to drain the contents of the conduit 500.

Figure 6 shows in more detail suitable equipment of an apparatus for forming a cloud according to the present invention located at a substantially ground-level location. Shown is a portion of a slurry pipeline or conduit 600 attached to a spool 610 to take the tension force
from the slurry pipeline 600. The spool 610 has active tensioning arrangements 625 to control pipeline oscillations. The pipeline 600 is secured by a pipe release restraint 690 which is secured by an anchor 695 to a ship or to the ground.

Also shown is suitable slurry preparation equipment. Separate streams of high refractive index particles and carrier fluid, e.g. water, are passed to slurry mixing vessels 650. Once mixed, the mixture is passed to pumps 640 which increase the pressure of the mixture to very high levels. Once at high pressure, the mixture is passed to pressure surge vessels 630 in order to smooth out any pressure impulses from pumps 640. As shown, a plurality of streams are employed and combined together to increase the pressure of the slurry still further before being passed to pipeline 600 for transmission to the stratosphere.

Additionally, additives may be included via additive feed pump 670 and a pipe dump tank 680 is conveniently to allow draining of the conduit when the dirigible needs to move location independently of the ground location. Typically, heating apparatus (not shown) will also be employed in order for the carrier fluid to become a supercritical fluid.

Figure 7 shows in more detail the conduit construction and arrangement of its structure. Shown is a former 701, surrounded by a composite pipe 702, insulation 703 and surface protection 704. Fluid is pumped from a ship or ground station 709 via the conduit 708 to a dispersal arrangement 710 at an elevated location.

The former 701 is typically steel but can be a strong non-conducting abrasion-resistant plastic, typically from 0.2 to 2.0 mm thick, providing abrasion resistance and abase on which fibre is wound on or which a braid is stretched. An epoxy or other filler would provide some additional stability to the fibre orientation.

Close-up view 706 illustrates how the elongate fibres or braid are wound around the conduit at a very low angle with respect to a line passing through the fibre and parallel to the central axis. This helps to deal with the very high longitudinal tension forces encountered there due to the weight of the conduit being supported. At the base of the
conduit in close-up view 705, it can be seen that the elongate fibres or braid are wound around the conduit at a greater angle with respect to a line passing through the fibre and parallel to the central axis. This is to provide greater protection for the high hoop stress encountered there due to the high fluid pressure. Although not shown, the angle of winding or braid alters gradually from the top to the bottom to account for the gradually changing nature of the stresses in the conduit. This provides for an efficient use of materials, reducing the size and cost of the conduit.
Claims

1. A cloud of solid particles located at an elevated location wherein the cloud comprises at least 1,000 tonnes, of solid particles wherein substantially all of the solid particles are sub-micron particles having a refractive index in excess of 1.40, over a region of at least a thousand square kilometres.

2. A cloud according to claim 1, at an altitude of at least 5,000m, preferably at least 10,000m, more preferably located in the stratosphere.

3. A cloud according to claim 1 or 2, which extends over an area of at least 3,000 square kilometres, preferably at least 30,000 square kilometres, more preferably from 50,000 to 300,000 square kilometres.

4. A cloud according to any one of claims 1 to 3, wherein the solid particles have a refractive index greater than 2.0, more preferably greater than 2.3.

5. A cloud according to any one of claims 1 to 4 wherein substantially all the solid particles are of titanium dioxide, sodium chloride, silicon or mixtures thereof.

6. A cloud according to any one of claims 1 to 5, wherein the solid particles have a mean particle size in the range of from 0.01 to 0.5 μm, more preferably in the range of from 0.04 to 0.5 μm.

7. A cloud according to any one of claims 1 to 6, wherein the particles have a bimodal size distribution with peaks in the visible and ultra violet wavelengths respectively.