A short review on Geo-engineering proposals to fight against climate change

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Since the beginning of the industrial era, the atmosphere content in greenhouse gases has rapidly increased. In its 4th assessment report (AR4), the Intergovernmental Panel on Climate Change (IPCC, 2007) points out the impact of human's activities and its responsibility for a large part of the changes recently observed in the Earth's climate: increase in global temperature, sea level rise, melting of glaciers and ice-caps...

As expected consequences can become dramatic before the end of the 21st century, numerous geo-engineering proposals have been developed to try fighting against these disturbances.

The average global temperature on our Planet depends both on the quantity of energy received from the Sun, on its absorption by the Earth's surface and on the actions of greenhouse gases preventing a part of the energy emitted by the Earth to escape into the outer-space.

To prevent global warming, the alternatives are therefore either to limit the solar radiation absorbed by the Earth's surface or to reduce the amount of greenhouse gases in the atmosphere. Many of the geo-engineering proposals concern modification in cloud characteristics and are directly linked with weather modification applications.

1. Reducing the solar radiation absorbed at the surface of the Earth

Warming associated with increasing greenhouse gas concentrations could be offset by a reduction of a few percent of the solar radiation that is absorbed by the Earth's surface.

Thus, many ideas have been advanced to develop screens between the Sun and the Planet or to increase the reflective power of the ground.

1.2. Injecting Sulphur in the stratosphere

It has been observed in the past that large volcanic eruptions were accompanied by a fall of a few tenths of a degree in global average temperature; a fall which could last for a few years. Volcanic eruptions eject large amounts of dust and aerosols that reduce solar radiation reaching the Earth's surface. In the troposphere, these aerosols remain only a few days before being leached by precipitations. But those that reach the stratosphere can remain there for several years. As an example, in 1991 the eruption of Mount-Pinatubo, in the Philippines, injected 10 to 20 million tonnes of sulphur dioxide into the stratosphere and, as a consequence, the climate of the Planet underwent cooling of nearly 0.5 °C for more than a year.

To exploit this phenomenon, W.R. Cotton (2008) suggests stimulating volcanic activity in order to encourage eruptions that could inject aerosols in the stratosphere. However, he recognizes the difficulty of the task and the need to first study the feasibility, the impact and the side-effects of such an undertaking.

On the same basis, in 1974, Mr. Budyko, of the Observatory of Saint-Petersburg, in Russia, suggested to inject sulphur or sulphate aerosols directly into the stratosphere.

Later on, the idea has been taken again by P. Crutzen (2006), a Nobel Prize in chemistry, who proposed to drop a few million tonnes of sulphur or hydrogen sulphide by using stratospheric balloons at altitudes between 15 and 50 km. At this level, these compounds are converted into tiny sulphate particles that reflect a part of the solar radiation. P. Crutzen noted that the proposed amounts are not exceptional as we already send about 55 million tonnes of sulphur dioxide in the atmosphere each year. To compensate for a doubling of the carbon dioxide concentrations, he estimated the cost of operations to US $25–50 billion per year.

However, sulphur aerosols are very harmful; they cause acid rain that deteriorate forests and are responsible each year, according to the World Health Organization, for hundreds of thousands premature deaths. Furthermore, the method cannot compensate for the local impact of greenhouse gases. Indeed, it would limit radiation, and therefore temperature, but only on the sunlit areas while greenhouse gases warm the whole Planet, on days and nights, and more strongly the Polar Regions that spend six months a year in the dark. The reduction of global warming in the Polar Regions is considered to be an important aspect of the fight against climate change because when highly reflective ice melts it uncovers soil or ocean surfaces (of smaller albedos) which absorb more solar radiation, amplifying the global Earth warming.

A comprehensive study realised by Tilmes et al. (2008) also shows that the proposed method would destroy part of the stratospheric ozone layer that protects us from highly carcinogenic ultraviolet radiations from the Sun. This concern has to be taken is full consideration while for many years we were looking for ways to restore the ozone layer that is destroyed by impact of chlorofluorocarbons used in aerosol and as refrigerant gases. Other objections have been raised since such an approach could permanently give a milky colour to the sky and have significant effects on our quality of life and on the development of vegetation.

1.3. Making more reflective clouds

The reflecting power of a cloud is a function of its droplet concentration. A higher concentration corresponds to a stronger reflection of the solar energy. Thus, the clouds developing in polluted areas better prevent the ground from solar radiation. Their high concentrations in droplets are due to the presence of numerous aerosols, providing support to the condensation of water vapour.

Conversely, because of the low number of aerosols, clouds over oceans have far less droplets. One could then consider increasing their reflective power by seeding them with hygroscopic nuclei.

Measurements also highlight that, in the track of the ships, the clouds often have higher droplet concentrations than clouds observed in the surrounding areas. This perspective seems to be rather interesting since low clouds such as marine stratocumulus regularly cover about one-quarter of the ocean surface.

J. Latham (2004) rather suggests using particles in solution. To this end, he proposes to construct a fleet of vessels equipped with long chimneys used to send fine sea water particles into the atmosphere.

If they do not reach directly the clouds, these droplets will evaporate and release the salt crystals they contain. This increased number of condensation nuclei present in the atmosphere would then promote the formation of a greater number of droplets in the developing clouds. J. Latham estimated to 1,500 the number of boats necessary to compensate for a doubling of atmospheric carbon dioxide concentrations.

Studies are still needed to estimate the feasibility, cost, and possible side effects of such a project. Clouds with high droplet concentrations being less efficient to produce large drops, the implementation of such a technique could, in particular, lead to a decrease in precipitation watering coastal regions.

1.4. Making a cloud of parasols

R. Angel (2006) imagines covering the space that separates the Earth from the Sun with a multitude of small discs playing the role of umbrellas.

There is a region, at an altitude of about 1.5 million kilometres, where the force of attraction of the Sun is equal to that of the Earth and where small objects can stay in equilibrium. Angel proposes placing in this region small discs, 60 cm in diameter, equipped with a navigation system.

To get a significant effect, it would be necessary to create a 100,000 km long cloud consisting of several thousands billion discs. Even if each disk is very light, the whole set would weight about 20 million tonnes. At the rate of one million disks per minute, it would take about thirty years to implement this cloud.

1.5. Painting deserts in white

Surfaces reflecting light warm less than surfaces absorbing it. The distribution of more or less reflective surfaces that cover the Earth has a significant effect on its temperature.

Thus, when glacier melting replaces white and highly reflective surfaces by dark and more absorbent surfaces, it results both an increase of the absorbed energy and of the surface temperature. As a consequence, several projects aim at increasing the reflective power of the Earth (its albedo) in considering for example painting deserts in white.

However, a simple calculation shows that this type of action can only have very insufficient and limited effects.

On a smaller scale, there are also studies that suggest painting urban buildings in white in order to reduce temperature in urban heat islands that are associated with the absorption of solar radiation by bricks and concrete.

2. Reducing the greenhouse effect

Several methods have also been proposed to reduce the greenhouse effect which maintains a high temperature on the Planet, by dissipating some clouds or by extracting a part of the carbon dioxide from the atmosphere.

As an example, Lackner et al. (1995), at the University of Colombia, in the United States, propose to build "artificial trees" able to collect carbon dioxide from the air and to reduce it in powder that is directly stored in the ground.

2.1. Dissipating cirrus veils and contrails

Cirrus, cirrostratus and condensation contrails produced by aircraft reduce the passage of solar radiation and retain a portion of terrestrial radiation. Considering their overall contribution, it is believed that they participate in the greenhouse effect and thus to the global warming of the Earth (Minnis et al, 2004).

W.R. Cotton (2008) suggests seeding them with carbonaceous aerosols and soot in order to absorb a portion of solar radiation and thus to warm them up sufficiently to evaporate ice particles and to dissipate them.

However, such operations could have an impact on rainfall and on the global water cycle. Moreover, side effects, associated with the presence of large quantities of soot in the atmosphere, remain to be considered.

2.2. Favouring the growth of algae that gobble up the carbon dioxide

The Ocean has a very strong capacity to absorb carbon dioxide. However, only a small part of the waters are in contact with the atmosphere and surface waters are thus quickly saturated. Major transfers take place in the regions of surface cold water diving (or subduction) and in the growth of microorganisms fed with carbon dioxide before pouring into the depths of the oceans.

Lovelock and Rapley (2007) suggest stirring the water to stimulate the growth of phytoplankton, a microscopic marine alga that consumes large amounts of carbon dioxide.

To achieve this, they propose installing in the oceans thousands large tubes (approximately 100 metres long and 10 metres in diameter) which, like elevators, would move up the deep waters to the surface.

As the growth of phytoplankton is favoured by the presence of iron, J.H. Martin (1990) suggests seeding the oceans with iron fillings. Among all of the actual projects envisaged to cool the planet, it is certainly the simplest to implement.

Operations were thus conducted, in 1993 and 1995, off the coast of the Galapagos Archipelago.

Unfortunately, Boyd et al. (2004) show that this technique has no scientific basis and present a non-negligible risk because, before sinking to the depths, the plankton would absorb a portion of the oxygen that fishes need to live. In addition, the absorption of large amounts of carbon dioxide would acidify the ocean leading to the dissolution of a large part of the plankton, a result opposite to that which is looked for.

It should also be noted that the reproduction of plankton produces toxins that are fatal to many organisms that would then be in danger.

2.3. Storing carbon dioxide

Capture and storage of carbon dioxide produced by industry or thermal power plants are part of the methods envisaged to reduce their atmospheric emissions. According to the Intergovernmental Panel on Climate Change (ICCP, 2007), this method could contribute for 10 to 15% of the greenhouse gas reduction efforts.

Several companies, especially in the oil field, work on this subject. The simplest technique is to produce a concentrated carbon dioxide at high pressure that can be easily sent to a place of storage in order to isolate it from the atmosphere. The main proposed techniques of storage are: industrial fixation in inorganic carbonates, deposition in the deep layers of the ocean or injection into the substratum.

Under specific conditions of temperature and pressure, the peridotite, the main rock of the Earth's mantle, reacts with carbon dioxide (CO_2) to form calcites, magnesites or dolomites.

From research developed at Columbia University, this crystallization would allow to store several gigatons (or billion tonnes) of carbon dioxide every year.

However, most of the peridotite, formed by the crystallization of magma, is located at about 30 km depth and only the countries where it is close to the Earth's surface (Oman, Papua, New Guinea, Caledonia, California…) could benefit from such a method.

It seems also possible to directly inject the trapped CO_2 in the oceans, at more than 1 000 metre depth, where most of it could be isolated from the atmosphere for centuries. The retention may be increased by forming solid hydrates or liquid CO_2 lakes at the bottom of the oceans.

However, the possibility to proceed at ocean storage has not yet been demonstrated. It would change significantly the chemistry of waters and their acidity and could be detrimental to marine organisms (lower rates of calcification, breeding...). It is not yet very well known how the species and ecosystems will adapt to such changes in their environment.

Other proposed storage sites are exhausted oil and gas fields, unworkable coal mines and underground salted water tables.

But the implementation of such solutions still presents several technical, economical and societal difficulties. As it is reminded by the tragedy that happened in 1986 in Cameroon during a natural degassing, at high dose of carbon dioxide is lethal. More than 1,000 people have died. Then, because of the risks of leakage, many associations are opposed to massive storage of carbon dioxide near inhabited areas.

3. Conclusions

If, ideas to cool the Planet are flourishing, most of them still rely on fiction and, at this stage of understanding, their effects are still uncertain. All the possible consequences are not known yet, and some of them could be uncontrollable and far more serious and damageable than the fought effects. Research should therefore be continued. Solutions sometimes arrive when they are the less expected. However, today we should not forget that there is no acceptable solution yet. Reflection on geo-engineering techniques should not prevent us from developing safer and more effective methods to modify our energy consumption and reduce both pollution and the quantity of carbon dioxide we produce on a daily basis.

References

Angel, R., 2006: Feasibility of cooling the earth with clouds of small spacecraft near the inner Lagrange point. *Proceedings of the National Academy of Sciences*, USA, vol 103, 46, pp. 17184-17189, 2006.

Boyd PW, Law CS, Wong CS, Nojiri Y, Tsuda A, Levasseur M, Takeda S, Rivkin R, Harrison PJ, Strzepek R, Gower J, Mckay RM, Abraham E, Arychuk M, Barwell-Clarke J, Crawford W, Crawford D, Hale M, Harada K, Johnson K, Kiyosawa H, Kudo I, Marchetti A, Miller W, Needoba J, Nishioka J, Ogawa H, Page J, Robert M, Saito H, Sastri A, Sherry N, 2004 : The decline and fate of an iron-induced subarctic phytoplankton bloom. *Nature*, 2004 1 April; 428(6982): pp. 549-553, 2004.

Cotton, W.R., 2008: Weather and climate engineering. *17th planned and inadvertent weather modification Conference*. Weather Modification Association, 2008.

Crutzen P., 2006: Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma? *Climatic Change*. Springer, 77(3-4), pp. 211-220, 2006.

IPCC, 2007: 4th assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). www.ipcc.ch. 2007.

Lackner, K. S, C. H. Wendt, D. P. Butt, E. L. Joyce, and D. H. Sharp, 1995: Carbon Dioxide Disposal in Carbonate Minerals. *Energy*, 20, pp. 1153-1170, 1995.

Latham, J., 2004: John Latham ponders a plan to counter global warming. UCAR Staff note, May 2004.

Lovelock, J.E. and C.G. Rapley, 2007: These ocean pipes could help the Earth to cure itself. *Nature* 449, p. 403, 2007.

Martin, J. H., 1990: Glacial-interglacial CO2 change: the iron hypothesis, *Paleoceanography*, 5, pp.1-13, 1990.

Minnis, P., J.K. Ayers, R. Palikonda, and D. Phan, 2004 : Contrails, cirrus trends and climate. *Journal of Climate*, 17, pp.1671-1685, 2004.

Tilmes, S., R. Müller, R. Salawitch, 2008: The Sensitivity of Polar Ozone Depletion to Proposed Geo-engineering Schemes. *Science*, 30, Vol. 320, n°5880, pp. 1201–1204, 2008.