Does solar radiation management save us from climate change?

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Supervisor: Susanne Burri

Introduction
Solar radiation management (SRM), also referred to as solar geoengineering (SG) is a vividly discussed strategy to prevent global warming. Part of SRM are several measures that enhance the albedo of planet earth and thereby reduce the warming effect of incoming sunlight (MacMartin & Kravitz, 2019). As global warming is considered to bring devastating consequences, ways to uncouple increasing CO₂ concentrations from their effect on the global temperature seem promising to maintain the current state. The fascinating idea behind this strategy is that a temperature overshoot can be prevented with fast actions, while new and more measures to reduce the CO₂ concentration are implemented with reduced time pressure. (IPCC 2018)

So far SRM is not a globally applied principle yet, so current research focuses on small scale experiments and models.

Questions
• What measures are called solar radiation management and what are their limitations?
• What are the main benefits and possible risks?
• Can air pollution help us to estimate solar radiation management effects?

Results
What measures are called solar radiation management and what are their limitations?

1) Space mirrors
This physical approach aims to reflect solar radiation by installing giant mirrors or parasols that circle the planet like satellites. The atmosphere would not be chemically modified. This is a rather clean approach, but the technology is not developed enough to be applied in the near future. (Swiss Academies, 2018)

2) Aerosols in the stratosphere
The release of small particles in an altitude of 15 to 20 km aims to increase the planetary albedo by backscattering (and absorbance). Much research work has been put into this approach already, so it may be applied soon. There are no apparent limits in application, but the negative side-effects might be severe. The applied aerosols may lead to depletion of the ozone layer and can also change the current precipitation patterns, leading to regional droughts and floods. (Irvine at al., 2019)

3) Cloud brightening
Addition of sea salt particles into marine clouds in 3 to 5 km altitude would lead to the formation of smaller water droplets inside the cloud, thereby increasing the ability of the cloud to reflect sunlight. This measure could already be applied today. Unfortunately, the effect of this measure is limited by cloud availability and the brightness of clouds cannot be infinitely increased. (Swiss Academies, 2018)

4) Surface brightening
While the two previous measures aim to modify the outer atmosphere, there is also the possibility to target the planet’s surface. This can be done by applying white paint on roofs and facades in cities or by creating microbubbles on the ocean surface. These strategies can be applied and maintained relatively easily, but their expected cooling effect is small. (Swiss Academies, 2018)

5) Cloud thinning
This approach is very different from cloud brightening. To perform cloud thinning, little ice cores are injected into cirrus clouds at a height of 10 to 15 km. The aim is not to reflect sunlight, but to allow long-wave radiation (e.g. IR) to leave the atmosphere and thereby decreasing the natural and
anthropogenic greenhouse effect to cool the planet. As this is a serious intervention into the atmosphere and climate of the planet, it is discussed very controversially. For example, chemical intervention in this altitude might have a negative impact on the ozone layer and cause increased UV radiation damage on the surface. (Swiss Academies, 2018)

What are the main benefits and possible risks of solar radiation management?

All five SRM approaches have some core aspects in common. They aim to reduce the temperature on earth by reducing the warming effect of solar radiation. While having the potential to prevent global warming, they do not solve the problem of a rising CO₂ concentration in the atmosphere. Therefore, issues like ocean acidification remain. However, keeping the temperature at a low level while having a high CO₂ conc. may also have beneficial effects, for example on plant growth. (Dagon & Schrag, 2019)

The SRM strategy that is discussed in most detail is the application of aerosols in the stratosphere. Usually the applied aerosols are sulfur based, the most prominent chemical being SO₂. SO₂ is emitted in gaseous form and must first be oxidized before nucleation and coagulation can occur to create particles. An alternative could be H₂SO₄ which is applied as aqueous droplets. Based on the global aerosol-chemistry-climate model SOCOL-AER, Vattioni at al. (2019) could show that H₂SO₄ shows a 37 % larger radiative forcing than SO₂. H₂SO₄ brings the big advantage of a better-defined particle size distribution which results in a more effective sulfur use. As H₂SO₄ also has less effect on the ozone layer, it is recommended as the preferred choice.

While SRM does not solve all climate issues, it may even cause additional ones. Changed precipitation patterns due to cloud brightening, cloud thinning and aerosol release can lead to local droughts or floods. By cloud thinning and aerosol release the ozone layer can be depleted and the application of cloud thinning may also lead to stronger UV radiation on the surface. (Irvine et al., 2019)

Hence, these negative effects are most likely to occur by the measures cloud thinning and aerosol release, but at the same time these also are the most promising candidates regarding warming prevention. (Swiss Academies, 2018)

Additionally to the possible risks, there is another problematic aspect about SRM: The measures have to be continued until the CO₂ concentration has decreased, as the climate will quickly react if the measures are stopped. (MacMartin & Kravitz, 2019)

Can air pollution help us to estimate solar radiation management effects?

SRM is always discussed based on model results, as getting real data in this field is problematic. Global measures need to be coordinated internationally and should be carried out for a minimum time of a month to show first cooling effects. (Parker et al., 2018)

Models like SOCOL-AER and HiFLOR are based on observations from volcano eruptions. A different way to uncover the effects of aerosols on the atmosphere is to look at air pollution (Kunyal & Guleria, 2019). In a way, we are applying SRM already at low altitudes. As mentioned above, aerosols can interact with solar radiation in two ways: backscattering (reflection) and absorbance. Feng et al. (2019) have shown that in cold regions the cooling effect of the backscattering of air pollution dominates. However, in warm regions, the absorbance dominates and leads to an even increased temperature which would be contrary to what SRM is aiming at.

With increasing overall temperature, the effect of aerosols at low altitude may shift towards warming by absorbance worldwide, so air pollution cannot be regarded as a beneficial SRM measure. For aerosols at high altitudes the situation is different, though. There, backscattering and absorbance both help to avoid that sunlight increases the temperature close to the ground. (Kunyal & Guleria, 2019)

Conclusion

Solar radiation management covers several approaches to limit global warming. As the intensity of possible negative side effects is hard to predict, it is difficult to conclude whether SRM should be used or not. SRM measures have to be continued until the CO₂ concentration has decreased, as the climate will quickly react if the measures are stopped. So even if applied in a beneficial and well-coordinated way, SRM cannot be the only answer to climate change. Additional measures to reduce CO₂ emissions and to reduce the atmospheric CO₂ concentration are necessary. To make this work, a huge organizational effort must be made by politics on global scale.
References