CCIS Webinar 3: Solar Radiation Management
May 27, 2020

The purpose of the webinar was to identify existing national and international SRM research activities in particular focusing on modeling challenges and uncertainties and future research needs. The webinar mostly focused on two most discussed SRM approaches, Stratospheric Aerosol Interventions (SAI) and Marine Cloud Brightening (MCB). This webinar presented four speakers that addressed these questions.

Jim Hurrell, Colorado State University, started with a broad introduction into several different SRM proposals. He gave a convincing argument that limiting the global mean temperature increase through emission reductions or adapting to the impacts of a greater-than 2°C (3.6°F) warmer world is severely challenging; thus, is it important to explore additional measures designed to reduce climate change impacts through climate intervention. Bearing that in mind, he argued that additional research is needed to understand the impacts of such approaches. Neither MCB nor SAI are well enough understood, especially in terms of injection locations and sensitivity to different particle types. Applications of SAI would have global effects and regional impacts have to be still understood. Jim pointed out that SAI model approaches are becoming more sophisticated, and highlighted the Geoengineering Large Ensemble as one example that uses a feedback algorithm to meet several climate goals. However, even with those advanced strategies, additional changes in the atmosphere and especially regional climate occur in response to SAI and need to be further investigated.

Jim Haywood, University of Exeter, addressed the question on what we have learned from a decade of coordinated GeoMIP and stand-alone-SRM geoengineering simulations. Jim talked about SRM approaches in terms of effectiveness, readiness, costs, and safety, which have to be considered in deciding on these approaches. SAI and MCB are the most studied approaches because of their largest potential effectiveness. The Geoengineering Model Intercomparison project (GeoMIP) was started in 2011 to assess inter-model differences of SRM experiments of different complexity. The project has led to a large international modeling participation and currently 86 publications. Early GeoMIP activities encouraged participation from modeling centers by designing simple experiments such as reducing the solar constant. Some consistency was identified between models for those simplified experiments, including uneven cooling and global precipitation changes. More complex sulfur injection experiments showed that stratospheric dynamics controls the aerosol movement and therefore requires injection strategies to achieve uniform forcing reductions. Jim also discussed the "termination effect," whereby a very rapid warming occurs when large scale SRM is suddenly ceased; the rapid change could have devastating impacts on terrestrial ecosystems. The so-called peak-shaving approach, where SAI or other measures are implemented temporarily to slow warming, potentially reduces these risks. Jim pointed out that regional extremes need to be investigated, but those are strongly dependent on the type of application. As an example of this dependence, a point of discussion was that purposely cooling one hemisphere can lead to large shifts in tropical rainfall, underscoring the need for well-designed strategies and careful evaluation. GeoMIP6 is moving now to more complex, policy-relevant experiments that require comprehensive models and he stressed the need for multi-model comparison studies and larger ensembles of simulations.

Sarah Doherty, University of Washington, explained the idea of MCB, and the well-known effect that added aerosols will increase the droplet number in clouds and therefore increase the cloud albedo. This phenomenon has been well observed in ship tracks. However, these effects depend on various variables such as background aerosols, size and concentration of injected aerosols, water availability above and below clouds and if they are or have been precipitating, and behavior of adjacent clouds. Injection of aerosol under different conditions could result in an albedo increase or decrease. Sarah described the new MarineCloud-brightening project, which will cover testing and optimizing injections of sea-salt, modeling of regional and global forcing effects, and process understanding, as well as human systems and social science. Particular focuses being given to producing the “right” aerosol size, developing a spray system, and performing modeling and field tests. Sarah stressed that aerosol-cloud interactions need to be studied in more diverse meteorological conditions in high resolution models in order to inform field studies. Stratocumulus regions will be targeted. Finally, climate interactions have to be studied using modeling, observational analogues and machine learning approaches.

Jean-François Lamarque, NCAR, addressed current understanding and challenges in stratospheric aerosol modeling of SRM. He provided an overview of the aerosol lifecycle, including natural and anthropogenic emissions of aerosol precursors at the surface, transport to the stratosphere, and formation processes. Microphysical processes govern the evolution of the aerosols. Jean-François pointed out that the fundamentals of stratospheric aerosols have been studied since the 1940s, and that there is relatively good understanding of the processes involved, but much more work is needed. In particular, he noted that measurements from volcanic eruptions have been used to study the aerosol lifecycle. Jean-François described Earth System Models, emphasizing that they are founded on basic physical and chemical principles, but that to make computation feasible, models have coarse resolution and depend on parameterizations to describe complicated processes. A number of challenges of using Earth System Models in simulating SRM were presented. One was the challenge of resolution, as increasing resolution allows more processes to be resolved explicitly, but at the cost of more expensive models and greater output data volumes. Another challenge is to better capture the size distribution and composition of stratospheric aerosols and interactions with chemistry; this was identified as both a modeling challenge and also an observational one. Further challenges include identifying forced signals embedded within internal variability, and also realistically representing internal variability. He also pointed out that many processes are still missing in models and unknown effects cannot be included.

General Questions and Discussion:

General discussion focused on details about feasibility, impacts, and modeling of different SRM schemes as well as connections to governance:

Question: There is currently a negotiation underway of a treaty that will introduce new governance of activities on the high seas, where at least some geoengineering/cloud brightening/SRM activities might take place. How would you see this community engaging with the negotiation and what would you like to see in such a treaty? (Disclosure: I've been involved in the negotiation as legal advisor to IUCN).
Answer: Science and research is still in its early stages and besides modeling, small scale experiments are needed to advance our understanding of the feasibility of these approaches. Engagement of the scientific community is needed to guide the negotiations and development of treaties.

Question for modelers: Would a Geoengineering DECK experiment help address some of the issues around Jim's point about more modelling studies being needed and if so what should that experiment be so that it provides as much bang for its buck?
Answer: GeoMIP has developed such experiments that were mostly performed to understand the effects of SRM on the climate system. Now, GeoMIP experiments move towards policy relevant and more complex experiments that require the development of more comprehensive models. Identifying a new set of core GeoMIP experiments is needed. In addition, the Geoengineering Model Research Consortium has performed targeted model experiments to understand processes that lead to certain climate impacts, as well as studies that help understanding the effectiveness of stratospheric aerosol interventions.

We also received a comment by Leslie Field on a regional SRM approach called Ice911 Research, that works on testing and evaluation safe methods for Arctic ice restoration. This topic as well as the earlier presentations raised the question on the efficiency and side effects of regional methods and general questions regarding the Arctic.

Questions: Is it possible to use SRM specifically to cool the Arctic? Do models tell us enough to know whether SRM can be employed to refreeze the Arctic? We know the Arctic is seriously threatened at the moment.
Answer: The climate modeling is showing that global SRM applications can be done and are effective to refreeze the Arctic. But clearly more modeling must be done in the area. Regional approaches have to be tested in much more detail but solar dimming studies in one hemisphere have shown to introduce global side effects including shifts in precipitation, that have to be carefully investigated. A substantial problem with trying to refreeze the Arctic using a local radiative forcing (such as glass beads) is that you are working against both the atmosphere and the ocean: the primary role of circulation in both is to transfer heat from the equator to the poles. Ensemble studies of small sea ice perturbation impacts both regionally and globally across most variables of interest are planned.

Detailed questions for the speakers:

Questions for Jim Haywood:

Question: Do we have a good handle on to what degree single-model studies suffer from not sampling lots of potential natural variability (response differs with PDO, AMO, etc.) versus the differences in single-model studies being due to structural differences?

Answer: We have a handle on some, but not all of the differences owing to natural variability. Just as different models show different climate sensitivities, different strengths of feedback and different spatial distributions of climate change under global warming scenarios, there can be similar differences in responses to SRM geoengineering. However, SRM geoengineering does not suffer from the same levels of the impacts of variability as volcanic eruptions, where e.g. the phase of the QBO and the local weather at the time are of critical importance to the pattern of dispersion of the resulting aerosol, because the emissions are generally over a prolonged period of time. While there are some take home messages from the GeoMIP simulations, such as the over-cooling of the tropics and continued warming at polar regions, that are common to all models, the detailed response when it comes to regional impacts is much less clear.

Questions for Sarah:

Question: Could you talk about the biology of marine cloud brightening: the role of airborne microbes in cloud formation and how that might be affected by this process; the air/water surface interactions; and the impacts on ocean biodiversity of this technique (recognizing that you are using salt water, which is presumed to itself be neutral in effect)

Answer:

Airborne microbes play a very small role in cloud formation in low marine clouds. As for the impact of MCB on ocean biota, the expectation is that impacts would be small because a) the reductions in sunlight in a given location would be relatively small and, more important b) the regions where we would be likely to implement MCB is the open ocean where biological productivity is lower (relative to the coastal environment). Having said that, this is a completely open area of research. We are starting right now to do some initial modeling runs at Univ of Washington as part of the Marine Cloud Brightening Project to explore just this question.

Question: How much energy is required for these efforts and what would energy source be?

Answer: I assume you're meaning for implementation and not for research purposes. This is really an engineering question, and the exact answer would depend on this final design of the spray system and deployment platform (e.g. ships/USVs). First-order calculations, however, show that the next CO_2-equivalent effect of implementing MCB would be to cool climate because it operates through such a powerful lever arm on climate: cloud reflectivity. Assuming we are able to figure out the aerosol-cloud science of how to predictably and reliably increase cloud albedo I don't think it's a question of whether an implementation system could be designed that would produce significant net climate cooling when the CO_2 emissions of the deployment system is accounted for, but rather just how energy-efficient/low-carbon you could make that system.

Question: What is the relative effectiveness (in terms of level of effort, greater flexibility, lifetime of injected particles, etc.) of MCB versus increasing sulfate in clear air over remote, dark ocean areas? Has a

comprehensive comparison been done? We have a sulfate effect now, but is concentrated near industrial areas rather than spread widely and thinly over a dark surface.
Answer: This can be addressed through a first-order calculation of how much aerosol you'd need to put in the atmosphere to cool climate through direct scattering versus through cloud brightening; it doesn't require, e.g., an in-depth modeling study. First: The aerosols that would be most effective at directly scattering sunlight would be larger than those needed to effectively brighten clouds, and that alone would mean a spray system that uses significantly more energy. Second, the sheer number of (larger) aerosol you'd need to generate in order to directly scatter sunlight would be orders of magnitude greater than the number of (smaller) aerosol you'd need to generate to brighten clouds to produce an equivalent increase in sunlight reflection. As in the answer above, this is because a relatively small increase in aerosol concentrations can have a large impact on cloud albedo when added to otherwise clean low marine clouds -- i.e. the aerosol has a very large lever arm on affecting reflectivity through this mechanism.

Question: Might an analog for MCB's potential influences (global and regional) be the shift of major emissions of SO_2 from North America/Europe in the mid to late 20th century to now being in China, India and related areas? What, if any, was the influence on the circulation of this regional shift in tropospheric forcing of changes in the regional patterns of SO_2 emissions?
Answer: This is an imperfect analogue, in that the clouds downstream of the regions most strongly affected by these emissions trends are not the clouds that you'd primarily target with MCB, and because we have very imperfect knowledge of how much of this aerosol is mixed into the clouds in this region. More problematic is that it will be difficult to quantitatively distinguish changes in clouds in these regions that are attributable to a) natural variability, b) changes driven by climate change in general, and c) changes driven by aerosol trends. The reality is that it will likely take quite long time-series of observations to pull these apart. This is absolutely worthwhile research for reasons beyond MCB, but for gaining insights to the potential efficacy of MCB there are better analogues: specifically, looking at how ship emissions and trends in ship emissions and in some cases how volcanic plumes affect low marine clouds (especially in stratocumulus and stratocumulus->cumulus transition regions).

Question: Is MCB ultimately seen more as a regional or targeted approach (albeit with global side effects) or as an imperfect global approach?
Answer: Neither :-) It may be no less of an "imperfect" global approach than other forms of solar radiation management. Initial studies (e.g. Jones et al. 2009) indicate that significant cooling across the globe could be achieved through brightening clouds in just three targeted regions (the stratocumulus regimes off the west coasts of N. America, S. America and central Africa). MCB could *also* specifically be used to try and cool targeted regions, such as for cooling ocean temperatures around coral reefs that are susceptible to bleaching due to ocean warming, but no, it is not primarily seen as a regional or targeted approach.

Question: What impact might a simultaneous SRM portfolio of both MCB and SAI deployment have on the efficiency of MCB at lower altitudes?
Answer: I can't think of any reason why co-implementation of SAI and MCB would affect the efficacy of MCB, since the mechanisms by which MCB operates would not be directly affected by a slight reduction in sunlight through SAI.

A separate but related question is about exploring what the climate and ecosystem impacts might be of different implementation scenarios that combine SAI and MCB. This would be a useful area to explore through modeling work; to date, almost all modeling studies have looked at only either one or the other.

Question:
Getting a license for experiments can be hard. Is there any merit is using changes in the fuel mix from various forms of transport (ships?) for periods of time to assist with increase in knowledge?
Answer:
There has been some work in this area on the impacts of past changes in ship fuel mix and of course with the large reductions in ship emissions starting this year it's expected that cloud impacts will be measurable. However, based on, e.g., recent work out of our group looking at the cloud impacts of ship emissions in one region where MCB might be implemented (the west coast of Africa; https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019AV000111) we'll need at least 3-5 years of observations to pull out a robust signal from these changes, due to the "noise" of the natural variability of these clouds. Because we don't (and won't) have a good measure of the actual emissions from ships (the amount of aerosol, its size, and how much of it actually mixes into clouds) such analyses, while absolutely worthwhile and informative, are not a replacement for controlled perturbation experiments with the full suite of needed observations.

Question for Jean-Francois:
Question: Injecting is the major problem, what are the costs?
Answer: this was not the topic of my presentation. I would refer to publish studies.

Question: Interesting that you highlight COS in the stratospheric aerosol layer. What do you think of the COS to enhance the stratospheric aerosol layer...... a non-starter because its toxic and a greenhouse gas? How much COS can make it into the stratosphere?
Answer: Model simulations indicate that increases in OCS over the historical period is responsible for most of the increase of the background aerosols, especially prior to the 2000s. After that, a collection of small volcanoes injected SO_2 in sufficient amount to generate a trend.