Synthesis of Breakout Group Responses

This document represents a synthesis of the topics discussed across three breakout sessions. Each session featured 6 groups made up of approximately 8 to 15 attendees. Prompts were provided for each session, but groups were encouraged to steer the discussion as they saw fit. Volunteer note-takers provided a recap of each breakout session, which have been combined and edited for ease of reading below.

Session 1 - What are the most pressing high-level research questions?

Discussions for Session 1 both focused specifically on research questions for MCB and SAI, as well as overarching research questions for SRM in general. The approach-specific considerations are presented first, followed by broader considerations.

MCB Considerations

If we break the MCB roadmap into the six challenges as in Diamond et al. (2022) [listed below], the most easily solvable question is probably the Generation and Delivery of particles to clouds. Generation is a non-trivial technical challenge, but progress is being made, and if largescale MCB is undertaken, we might simply have to live with non-optimal particle sizes, provided brightening (as opposed to darkening) conditions exist frequently enough and over large enough areas. We also understand enough about the marine boundary layer (MBL), and could have near real-time observations, to gauge when seeded particles will actually mix up into clouds.

The six challenges/exit ramps are:

I. Generation and delivery
II. Local cloud adjustment
III. Scale of susceptible clouds
IV. Detection
V. Impact on marine ecosystems
VI. General circulation response

We have experience with Detection from satellite-based studies of ACI and their radiative impact. The challenge will be to speed up the detection time. (ii) and (iii) are challenging because they depend on meteorology in non-trivial ways. Very little work has been done on the impacts of sea-water haze on marine ecosystems (v)

The biggest challenge is (vi) General circulation response. It stems from the multiscale nature of MCB – the need to understand how local perturbations scale-up to the global scale, and how this influences general circulation and changes to T and Precip regional patterns. Because models are our only tool for assessing the global influence of MCB they have to be able to adequately represent aerosol-cloud interactions (ACI) at the cloud scale as well as regional/global impacts. No such model exists. A first order priority is improving the representation of target clouds (stratocumulus) in climate models. Improving model resolution down to the km scale may not be good enough to capture cloud adjustments to aerosol perturbations. Instead of trying to represent ACI, it makes sense to apply radiative perturbations over regions where seeding is planned.

The need for robust regional/global responses to MCB is not only the biggest challenge, but it is also the one that carries the largest risks because it affects human populations and ecosystems. Until we reach broad consensus on how multiple Earth System Models will respond to MCB in the major stratocumulus decks, we should not be pursuing MCB.

All six challenges listed above have their uncertainties and all have to be studied in parallel and revisited as the state of knowledge evolves.

SAI Considerations

Current models perform reasonably well in terms of imposing the forcing and investigating the consequences. Several issues remain:

- How well do models represent stratospheric aerosols?
- Model output is very different from what we have measured because most of the model development has focused on reproducing aerosol optical depth shown in satellite observations. Models tend to ignore the aerosol variation in altitude and type. It is crucial to understand how injected aerosol gas/particles will form and populate to make impacts.
- Is the imposed forcing rational and how can it be properly constrained?
- How can we achieve the imposed forcing and what are the controlling processes for the success of the forcing, which is the area that models struggle most with?
- Do models simulate the outcome for the perturbations provided by volcano eruptions at various scales?
- What are the key characteristics of the forcing critical for the success of SAI?
- What is the minimum set of observations for validating the climate models to see if they simulate the response correctly?

Broader SRM Considerations

Both MCB and SAI require the knowledge of background aerosols and an understanding of the background aerosol budget and characteristics through observations.

- What: Do we have a good, comprehensive understanding of background aerosols in the stratosphere; size distribution, composition across the hemispheres? (The stratosphere is always changing so what does "background state" imply?)
- How: Leverage better, more recent measurement of small particles. More field campaigns, including support for post-mission analysis. Especially in the tropics. Observations need both targeted deployments during events and ongoing monitoring for understanding baseline and impacts. WB-57 barely reaches where we need to go, need more ER2 involvement. Balloons enable good vertical distribution.

What can we learn from natural analogs such as volcanic eruptions and pyrocumulonimbus clouds (PyroCbs)? Effusive volcanoes and volcanic eruptions in the troposphere impact CCN around the globe, with implications for MCB. Can we model these smaller events together? What size event is 'enough' to justify a rapid response? Diversity of volcanic eruptions. Why do different eruptions impact stratospheric aerosols in different ways? Do any make a useful polar analog? By sampling stratospheric PyroCbs, can we model these plumes? How do injection heights and composition compare to SAI? Combining existing satellite data and natural experiments to get at variability.

Improving model representation of aerosols and processes and reducing uncertainty in simulating the Earth system response to SRM.

What:

- Better understanding of uncertainty in models. Can we use natural experiments (e.g. Honga-Tonga) in an intercomparison to help solve?
- E.g., simulating the response of large-scale circulation
- Models struggle with stratospheric-tropospheric exchange and age of air.
- Robustness of responses in models. Can we get models to look independently to understand mechanism of response? Is there consistency there? Could make progress by using reasonable/physically rationale forcings rather than improving small scale models. Should be done in parallel with CPT working on different scales
- Role of machine learning / AI?
- Resolution is not high enough right now in simulations, but you can couple regional and large-scale…force from large scales, regional high-resolution nesting…

How:

- Utilize existing observations to improve simulations, particularly with respect to transport, dispersion, and sedimentation.
- Prioritize improvements to physics over resolution
- Standardized data files for ease of use and accessibility.

- Improved experimental process understanding that translates into improved process representation in global simulations.
- It will be an iterative process. As we learn more, the models will change.
- Combining observations with models (opportunities like Hunga Tonga or the Chemistry-Climate Model Initiative (CCMI) to bring the community together)
- Coordinating model development

Improved understanding of atmospheric dynamics. In the exchange between the stratosphere and troposphere, how many aerosols get entrained and mixed back down into the troposphere?

Improved and maintained instruments, especially for rapid response. Are the logistics in place for rapid response to natural events? How can we leverage existing deployments, such as increasing the frequency of ozone sondes with additional instruments (e.g. POPs on an AirCore glider?)

Sustain satellite observations. Satellite data are increasingly important for understanding aerosols (e.g. CALIPSO). Are there planned follow-ups and stand-in coverage (balloons) for soon-to-be decommissioned satellites?

Understanding the impact of different intervention strategies. How much does injection location, duration, and/or season matter? e.g. SAI have their own impact to intervene e.g. use of aircrafts/mining/petrol. If it offsets CO_2, should we care? E.g. injection at 50 km = rockets. How many interventions, size of fleet.

Reliable representation of the fate of injected matter in the stratosphere. Stratospheric transport, dispersion, microphysical development, sedimentation, and interaction with radiation are all factors. Questions to study include determining diffusion in regards to disbursing injection material; how to decrease the disconnect between injection at the plume-scale and larger (global) modeling scales; modeling injection microphysics.

Impacts of various SRM scenarios on ecosystems and human systems and attribution of those impacts. Including impact from SRM onset and termination. How do you attribute changes in the climate to SRM actions vs. natural variability? What are the worst possible outcomes?

What role should field experiments (aka outdoor experiments) play? E.g., For MCB, use Large Eddy Simulation (LES) models to inform field experiments (50 - 300 km scale events) to characterize and quantify the response and the processes that mediate the response. What is the risk of waiting? Do we lose options if we observe the changing base state for another decade before OKing outdoor experiments? What is the tipping point for action, and at what timescales? What technology developments (e.g. injection nozzles) and lab work (e.g. aerosol generation) will be necessary for these types of experiments? Value of perturbed physics experiments vs intermodel comparison experiments?

What does SRM look like in a changing world? How do relevant processes operate in the future-based state? IPCC scenarios assume forcing won't change aerosol-cloud interactions or response of marine clouds to increasing SST, for example. Do we need to revisit this assumption? What about MCB during a Super El Nino? Do we care about flux of other metals/particles in the stratosphere? Are there other changes to the stratosphere (e.g. Pinatubo-sized eruption) that could impact SRM deployment decisions? What about the risks measured against taking no deliberate action?

How well do we understand clouds? Determining the spectrum of meteorological conditions for producing clouds, base state of clouds, why do some brighten and others don't? The impact of climate change on cloud brightening, will it brighten or not? Are there fundamental constraints on cloud systems that we don't understand?
Improved representation of the microphysical, dynamical, and radiative response of clouds in global models, and statistically representative observations of the microphysical, dynamical, and radiative response of clouds.

Weather and climate responses to SRM. Globally? Regionally? Short- vs. long-term? What are the regional impacts on precipitation patterns and are our global models skilled enough to resolve them? For MCB, is there co-variability between meteorological conditions and aerosols?

Better understanding of chemistry in the marine boundary layer. How will MCB affect the sulfur budget? How much NOx is coming out of the ocean? What microscale processes matter?

For CCT, the most pressing research questions revolve around efficacy. (1) surface cooling and its dependence on latitude and season, and (2) changes in geopotential height (GPH) and the resulting impacts on the general circulation. That is, the radiative impact (CRE in W/m2) of CCT often affects the atmosphere more than the surface, and the corresponding atmospheric GPH changes are likely to affect the general circulation.

How to prioritize research questions? Use a risk matrix approach, where the dimensions to consider include SRM type, difficulty, importance, cost, effectiveness. Also acknowledge that even if we can never fully reduce global model uncertainty, stakeholders and decision makers will still form opinions and put forward ideas. Something to organize the community around such as more frequent assessments or a Grand Challenge like WCRP or an annual meeting at the IGAC level.

Larger issues. Unknown timescale for disastrous consequences of climate change vs. slow process of advancing science. How can the scientific community work more quickly? Understanding the impacts of the most-likely SRM scenarios may be most useful to policy makers. Do we learn anything from 'worst case' scenarios? Ownership of action; 'who' gets to take action? Climate intervention science involves the whole climate community, more than that, social science areas of expertise, e.g., attitudes of different populations towards intervention approaches. Governance discussion and framework needed.

Session 2 - What tools are missing or underutilized?

For MCB…groups discussed what would be the minimum set of observations for addressing the research questions. In terms of surface-based instruments, lidar was identified as a key instrument for characterizing boundary layer structure and aerosol properties. Simple lidars like ceilometers (lower sensitivity) would be very useful; High Spectral Resolution Lidar (higher sensitivity) would provide aerosol extinction under ambient conditions. In addition to lidar, surface broadband radiation measurements and spectral flux measurements provide essential downwelling shortwave radiation and can also be used for retrieving aerosol and cloud properties. In terms of surface platforms, 'ships of opportunity' (instrumented fleets of ships), routine UAS measurements at the fixed ARM Graciosa site, offshore deployment, or oil rig platforms (e.g., North Sea oil rigs), dedicated routine flights (e.g., 3–4 times a week with stacked aircrafts sampling below-, in-, and above clouds) would allow measurements for various conditions. This will help identify the conditions that lead to optimal brightening. To improve process representation in models we require sounding data for initializing models, and in-situ turbulence, and radiation measurements for intercomparisons. Note that unattended instruments on board ships should not require a lot of care, and the platforms should be stabilized. Additionally, since many candidate instruments are vertically pointing, and do not provide a 3-D view, sufficient data is needed to derive robust statistics to reduce the uncertainties associated with the column view.

Satellite-based observations will continue to play a key role in quantifying both the radiative and microphysical responses to ACI, and if deployed, MCB. There are some concerns about future satellite-based measurement capabilities, particularly regarding radiation measurements on polar orbiters. (NASA's future AOS is lacking in this regard.) Larger UASs in lower orbit might fill the gap – e.g., by hovering over seeded and non-seeded areas for periods of days at a time.

Model weaknesses for understanding MCB impacts are discussed above.

For SAI…improved knowledge and robust statistics of background stratospheric aerosol properties, including aerosol composition and size distribution, are needed to study their response to forcing. Current observations suffer from various issues, e.g., in-situ data were not collected at high enough altitudes; satellite retrievals were not sufficiently frequent and often based on predefined aerosol models; and lidar may not be operated most of the time. In general, the group considered that lidar measurements are crucial but the quality, frequency, and quantity of lidar measurements all need to be improved to provide sufficient information on background aerosols and to resolve the variability/uncertainty of regional impacts due to SAI. It was suggested to use detailed field campaign data to improve satellite retrievals and their interpretation to fulfill this need. The group stresses that satellite measurements are extremely important.

Current global circulation models (GCMs) do not have aerosol modules and prescribe aerosol properties in their simulations, but major upgrades are in progress. Field campaign data are useful for testing models and nailing certain aerosol/chemical processes. Additionally, it may be good for the modeling and observational community to work more closely to see what the most effective aerosol properties and processes would be for modelers to incorporate, and to understand whether some known model deficiency (e.g., no organic aerosols at all in the stratosphere) matters or not in SAI applications.

For both MCB and SAI…groups proposed an integrated measurement, modeling effort – similar to NOAA's Climate Process Teams for both MCB and SAI applications. SAI simulation efforts at smaller scales are lacking. It is crucial to ensure that the simulated co-variability of aerosol properties with other geophysical variables is consistent with observations.

The imposed perturbations associated with MCB and SAI are anticipated to be large (if we are to achieve a measurable impact) and will occur in a warmer climate (a different set of atmospheric base states). Hence, observationally-based correlation models will be extrapolating relationships in the existing observational space (spanning the range of conditions of the current climate) to infer responses to large aerosol perturbations under new atmospheric states. Given the nonlinearity of the Earth system, we should consider dedicated field perturbation experiments to measure the responses under a range of conditions and not rely only on model experiments. We should also consider building data-driven causal inference models, instead of correlation models, in order to infer the responses to large perturbations.

A. What observations are still missing and are missing for what application?

a. Regular aerosol composition profiles
b. Water vapor detection in the stratosphere/troposphere.
c. Higher density of uncrewed aerial vehicle (UAV), balloon and glider measurements.
    i. Wish list: buoy based UAV that does autonomous flights.
d. Chemistry and size distributions in the marine boundary layer
e. Direct measurements of aerosols over the ocean
f. Vertical distributions of aerosols - boundary layer and stratosphere are stable
g. Combinations of instruments in a self-consistent dataset for models to use
h. Existing perturbations, like rocket plumes
i. Tracer correlations to diagnose stratospheric dynamics
j. Cloud droplet number concentration (CDNC) is used as a proxy for aerosols
k. Aerosol composition and size distribution (not just total mass)
l. Is there interesting science occurring > 35 km?
m. Knowing what happens when inject at high altitudes, how Brewer Dobson circulation changes, impact on ozone.
n. We need tools to understand upper troposphere/lower stratosphere (UTLS) pathways for aerosols and water vapor
    i. In UTLS how water vapor gets transported to the troposphere, strat can have intrusion in the troposphere. It's not that we don't have observations, it's the quality: uncertainty is large and cannot answer actually what's going on.

o. Monitoring is not just baselining but also is important when you are looking at perturbations.
p. Aircraft campaigns:
   i. More campaigns like SABRE that give us in situ measurements of aerosols and chemistry in the upper atmosphere
   ii. We're using airplanes that were largely developed in the 1950s so represent risk for future deployments
   iii. Better communication system so data doesn't 'drop out' on important flights and resources to send enough data packets up/down (issue in Alaska with lack of satellites). Communications between aircraft and ground crew to properly direct aircraft platforms mid flight.
q. Accessible satellite datasets:
   i. Everything our current satellites are doing if there is no replacement plan
   ii. More products from geostationary satellites, especially over the ocean
   iii. Satellite observations of upper troposphere lower stratosphere, including water vapor and aerosols
   iv. Satellite observations of stratosphere (LIDAR) – targeted towards SRM. Equalize importance of monitoring strat vs trop. Currently low signal to noise ratio for aerosols in stratosphere, while looking at troposphere at the same time.
   v. No guarantee of measurements of Earth Radiation budget when current satellite programs end.
r. Balloon observations:
   i. Large gondola balloon measurements
   ii. Balloon-borne payloads for specific measurements
   iii. More balloon launches to cover gaps, where it's tough to model, use data to better constrain models. Multiple sites at different latitudes, need an equatorial site – takes time and money. Rely on field campaigns now to understand places where there is not a regular site.
s. Process scale -perturbation field campaigns:
   i. Experiments to induce a change and observations. Initial dispersion of the plume, chemistry in different stages of experiment, understand and measure the processes. Appropriate for MCB and SAI, potentially CCT.
   ii. Dust events, engineering mixed phase cirrus cloud experiments.
   iii. MCB/SAI technology already on the table, other experiments for more unknown

B. What role do different types of observations play? Field campaigns vs. satellite retrievals, etc?

a. *We need all types.* Different types of observations and different instruments retrieve differently. Multi-method is to make sure we are doing the right thing. Relying on one method is risky.
b. *Satellites* give spatiotemporal coverage. Satellites provide monitoring as well as data to understand some processes. Benefits from continuous measurements of

past satellite records. Geostationary gives you temporal evolution, but liquid water path (LWP) measurements are not trustworthy at night. Geostationary satellites – geo color maps of composition.

i. CCT: Our work in satellite remote sensing of cirrus clouds…new relationships have been discovered that would probably not have been discovered using only observations from aircraft field campaigns. This is primarily due to the enormous increase in cloud sampling during different seasons yielding statistically robust results for each season. Using only data from field campaigns, the statistics are arguably not robust enough for establishing such seasonal-dependent relationships. For example, to explain our CALIPSO observations, a new theory of cirrus cloud formation process was developed.

c. *Field campaigns* give you process-level details. The only reliable aerosol measurements we have (that capture relevant heterogeneity and small scales) are from aircraft campaigns and ships. High-resolution field observations give data to understand processes. Field campaigns give process info. How albedo of clouds changes due to difference in cloud microphysics. Continuous sampling.

d. Things to Consider?

i. The tools you have to observe things are much smaller than the questions you apply them to.
ii. Are we measuring in the right places (location, vertical profile) to constrain satellites?
iii. What is the process for incorporating these measurements into models?
iv. Attribution not detection is an issue.
v. What power calculation are you building your detection system around? For different kinds of detections you would build it differently. If we consider SAI as different from all the other sources of sulfate, then we would need a different detection mechanism.

C. What models still need to be developed? Are there priorities when thinking about funding new avenues vs. continuing current work? E.g., How to balance developing missing processes with new models?

Two avenues: refining existing models or developing new ones.

Using existing models for SAI comes with a lot of uncertainties; the models lack physics representation, volcanic plume transport currently doesn't track which implies something is missing in the models since transport cannot be modeled as observed.

a. *What's still missing?*

i. Cloud interaction is missing in the model. Cloud forcing is one of the biggest forcing for radiative transfer.
ii. Integrated assessment models (IAMs). IAMs would put together whole sequences of processes.

   iii. Interactions between all methods, inclusions of three techniques (SRM, MCB, CCT) in model scenario.
   iv. Comparison between models specifically for SRM.

b. *Challenges?*
   i. Including droplet size in global models – too computationally expensive.
   ii. Global climate models with refined meshes
   iii. LES initialized with aerosol conc but what value, LES with reanalysis value. Realistic initialization parameters, these need improvement.
   iv. GCM models need a lot of improvements, need it to be good enough for MCB approach etc. MCB models can't inject salt particles in without needing an existing route, develop parameterizations for manmade injection.
   v. So many things we are not confident about, starting from the first step by injecting aerosols in the stratosphere.
   vi. Spatially heterogeneous parameterizations and parameter values, scale awareness
   vii. Plume-scale modeling in the stratosphere
   viii. Turbulence
   ix. Coupled physics/chemistry at fine scales - capturing feedbacks and emergent properties
   x. How much mass needs to be injected? What frequency?
   xi. Difficult to put different aerosol modes into global model, needs more funding
   xii. Vertical resolution above 30 km.
   xiii. Initialization parameters for LES models.
   xiv. Simplification in CSM can cause issues/ pre existing ice.
   xv. Nd-ice retrievals need improvement, more usage, better retrievals.
   xvi. Continuation of nd products, don't just stop updating after paper.
   xvii. Really high resolution cloud models to determine small scale/regional cloud processes (i.e. few cm, for 1 – 3 days).

c. *Suggestions for improvements?*
   i. Regional model of cloud resolving capability, with really high resolution for modeling supersaturation/turbulence/fluxes over a few day timescales. Focus on processes that larger scale LES don't do brilliantly.
   ii. Between coordination between groups using LES, maybe an intercomparison and do for MCB.
   iii. Lot of efforts in the modeling community are going for high resolution, but physics is something we should spend more effort on.
   iv. Building up a core group of models that have ontological differences and a small number to do intercomparison is important.
   v. Process-level: Using targeted observation sets to address specific questions about models
   vi. Cleaning up model code would be useful.
   vii. Adaptive grids applied over larger scales.

d. *CCT research* is greatly handicapped by a lack of realism in atmospheric processes as represented in Earth System Models (ESMs), GCMs, etc. In the case of the NCAR models, realistic vertical motions (i.e., orographic gravity waves or OGW) at cirrus cloud levels have only recently been implemented in CAM6 (Lyu et al., 2023, JGR), but such improvements are not yet publicly available. Moreover, this improvement does not appear to render improvements in the treatment of homogeneous ice nucleation (i.e., HOM), perhaps due to the treatment of pre-existing ice in cirrus clouds. For example, the frequency of hom when using the new OGW scheme does not appear greater than the HOM frequency in the control simulation that does not use the new OGW scheme, and this may be due to the treatment of pre-existing ice. In contrast, the study of Barahona et al. (2017, Nature) shows a strong correlation between OGW activity and HOM activity. The reason the pre-existing ice treatment is suspect is that vertical resolution at cirrus cloud levels in ESMs is ~ 700 m (for the ECHAM6 model), and the value for pre-existing ice in the supersaturation development equation is taken as the mean ice mass mixing ratio (qi) for that layer. However, ice nucleation in cirrus clouds occurs at the extreme top of a cirrus layer (e.g., Dekoutsidis et al., 2023, ACP), where qi near cloud top << mean qi. This large overestimation of qi in the primary "ice nucleation zone" (due to vertical resolution in ESMs) may generally prevent the RHi threshold for hom from being reached, greatly underestimating the frequency of HOM.

D. What tools do we need to consider in the context of scenarios? And/or different SRM deployment strategies?

Underutilized tools can be identified by taking inventory. Look at all the monitoring capabilities and see what we can add to different networks. Surveying the existing measurement capabilities and networks for opportunities for expansion, e.g. SHADOZ could use more SO2 instrumentation, we can use more AirCores for aerosols etc. While there is a distinction between monitoring network and field campaigns, they should start being similar. For monitoring, multiple platforms in multiple locations, planes and satellites that will still be functioning in 10 years, altitude range, etc.

Rather than tools, think in terms of expertise needed. Both scenarios and deployment strategies need input from economists, social scientists, etc.

a. What are the minimum set of observations needed to evaluate models and constrain problems?
    i. Ships of Opportunity: minimum set of observations that are automated. Build containers that have the instruments inside them. Contract to add to container ship.
    ii. CARIBIC vs IAGOS model of sampling
    iii. Use of UAV at DOE Azores site
    iv. MAGIC was good experiment to understand considerations

v. Remote sensing – what is the minimum we need?

b. *With regards to SAI…*
   i. Tools could be different processes in the models that need to be figured out with regards to SAI. Learn more about how SAI would work under certain circumstances.
   ii. Scale depends on what you're emitting (H_2SO_4 requires very small scales) and what interactions you care about.
   iii. What can we learn from SAI 'done badly?'

Session 3 - How can we increase collaborations?

A. How can interactions between modelers and observationalists be facilitated to better inform process understanding and model development?

A greatly expanded form of NOAA's Climate Process Team (CPT) as a framework to help facilitate the interactions between the observational and modeling communities and improve the transfer of knowledge from observational and process-oriented research to the model development across scales with common goals. Such a "CPT" would have to be big enough to be able to yield progress but not too big as to become unwieldy. It would need to be backed by significant resources.

Models have their strengths and weaknesses. Climate models capture large-scale circulations well but lack detailed aerosol and cloud microphysical processes; similarly, large eddy simulation represents aerosol-cloud interactions quite well but not the large-scale impacts. Building an integrated modeling framework that bridges these scales is important. In parallel, a multiscale observational tool database is required to test models at a range of scales.

a. More observationalists can participate at NCAR's Atmosphere Model Working Group (AMWG), where they can recommend improvements to the CAM.
b. Have a proposal call that specifies it has to be a collaboration between models and observations.
   i. Funding for targeted questions.
   ii. Incentive structures - require PI team to have collaborations, spreads out the effort to reduce barriers of proposal writing
   iii. Seed funding (smaller proposals, lower effort), or reducing the barrier of proposal writing in general
   iv. Increasing funding, people need money to spend time on intercomparisons.
c. Workshops and Conferences.
   i. Fund dedicated personnel that bridge observationalists list and modelers.
   ii. Workshop session on white paper development breakout groups - giving people time to develop their ideas rather than constantly chasing funding
   iii. Small conferences to build connections.

d. Modelers should have a bigger role in field studies and vice versa (borrow DOE's idea of measurements-to-models)
e. Use LASSO as an example - combining long-term measurements with modeling sensitivity studies around specific case studies
f. Cross-checking validity of results - can be done formally (e.g., AEROCOM), through informal collaborations, requirements of proposals, etc.
g. Figure out how to prioritize (rather than just more)
h. The tools are already here to put modeling and observations together (ex. CPTs). SAI does not present a different challenge; we don't have to fundamentally reimagine atmospheric science, we just have to apply what we already know to this new use case.
    i. One big difference is high urgency and near term climate risk.
    ii. Is there a higher standard in this realm of research, because of the potential impacts of SAI? Don't other climate impact fields have similar standards as well? Decision makers and/or funders may see this differently.

B. What about cross/interdisciplinary expertise?

We may wish to work with sociologists and across other Federal agencies via inter-agency programs such as USGCRP, as well as international groups like the The United Nations Environment Programme (UNEP) and World Climate Research Programme (WCRP), to understand downstream impacts. Interacting with international research teams will help facilitate collaboration and be well-informed about the progress and plan, e.g., the UK SPICE project (Stratospheric Particle Injection for Climate Engineering), UK and the Netherlands ("Refreeze the Arctic").

a. Both scenarios and deployment strategies need input from economists, social scientists, etc. Dedicated data analysts are also needed.
b. Difficult to do well. This type of collaboration needs to be facilitated, not a random walk. Danger in prioritizing such that ideas are reduced to a point that takes away the synergies between these ideas.
c. Sponsoring disciplinary scientists to visit groups in different domains.
d. Partnership with NGOs, who are better at gauging proposals that widely vary
e. USGCRP to endorse cross-agency funding opportunities.
f. Ensure a good balance between labs and universities.
g. NOAA's practice area focuses a lot on climate observations and modeling, instead of expanding scope, focus on bringing others in. Take advantage of the relationships we already have in other areas of our work.
h. Previous conversations on collaborations had to do with making sure we produce outputs that are the most useful to other users in the community.
    i. Don't need super frequent communication to understand each others needs if we have an integrated global modeling system

ii. ALL communities around the globe want the regional information that is relevant to them (halibut fisheries to the people of Greenland vs coral reef conditions to the people of Australia)
iii. Make sure you are providing relevant biogeochemical science for marine ecosystems, don't get pigeonholed

C. Who's not here that we should be talking/interacting with?

a. NCAR scientists who are primarily charged with improving the CESM. NCAR in general.
b. Interaction with NASA seems to be missing. There are topics that should have collaboration...in particular the impacts of the space industry. Incorporation of other models looking at the problem would be useful.
    i. Other space programs.
c. Talking to satellite retrieval people.
d. Relevant people from wider community outside of ERB. Organize more open workshops such as this.
e. Communicator/PR people to communicate scientists' consensus.
f. Social scientists.
g. Interagency discussions, other program managers.
h. Talking about global scale problems but the invitees are only from the US - there are partnerships that allow for international funding.
    i. Relevant work in Australia.
    ii. International collaboration with countries from every continent
    iii. ARIA (UK) and KNMI (Netherlands) projects
i. Entraining local researchers when conducting field campaigns.
j. Remote sensing specialists
k. Ecosystem scientists.
l. Human health scientists
m. Interagency group for managing SRM research overall, coordination between departments.
n. GCM people work with small scale process scientists
o. Sociologists et al. to understand downstream impacts: work with other Federal agencies (DOE ARM), UNEP, WCRP…
p. Lots of opportunities for DOE/NOAA collaboration (DOE measurements are largely ground-based, so useful to collaborate with aircraft efforts) (bringing in different agencies models and modeling expertise)
q. Opportunities to contribute to the development of CMIP7
r. When considering DEI in science, bring in as many qualified stakeholders as possible for a high quality product. There should be no one community who tries to own this topic.
s. The question is not who we should be bringing in, but bringing us out. Sharing ideas at AGU, for example.