Climate Engineering Teaching Module

Lesson 2 – Cloud in a Bottle Experiment

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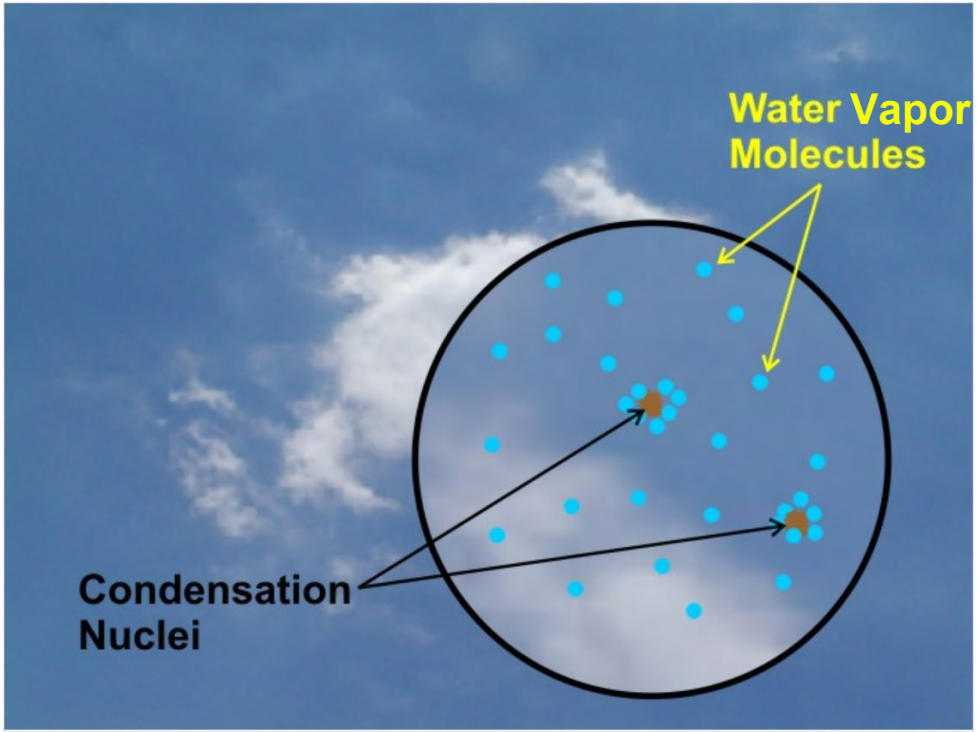
Pre-Experiment

Question 1: What are the main components of a cloud?

Question 1: Components of a Cloud



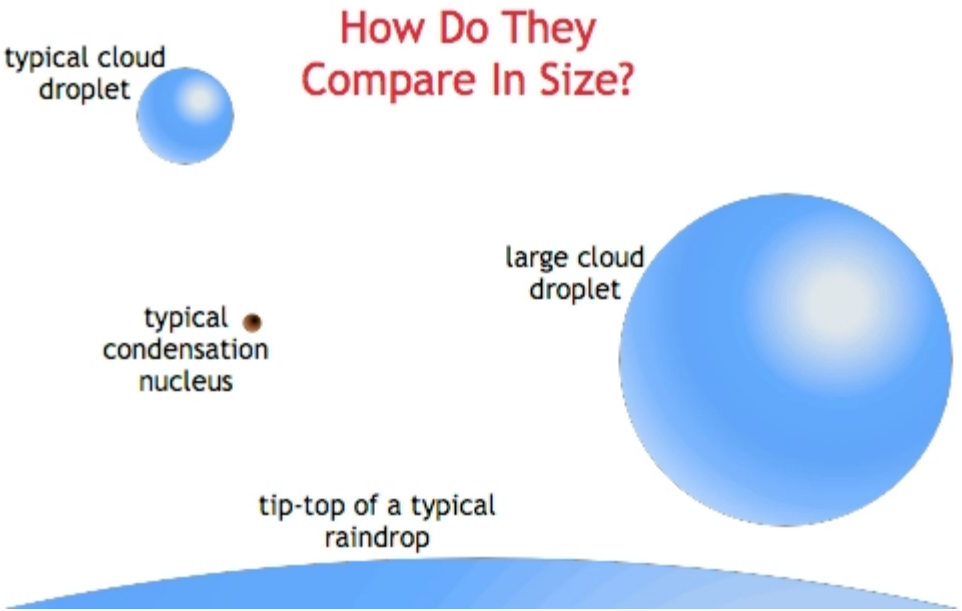
Condensation nuclei in the atmosphere provide surfaces on which water vapor molecules can condense.

Credit: David Babb

Clouds are made from water vapor condensing on very small aerosol particles, called cloud condensing nuclei, or CCN.

Definition: An aerosol is simply a very small particle suspended in air

Question 1: Components of a cloud



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https://blogs.agu.org/wildwildscience/files/2014/04/droplets1.jpg

Pre-Experiment

Question 2: What is *albedo*?

Pre-Experiment

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Scientists defined the term *albedo* to quantify the percentage of incoming sunlight that is reflected by an object. For example, viewed from space the Earth has an albedo of about 0.30, meaning that 30% of incoming sunlight is reflected back to space. Given this information, what do you think is the albedo of a forest, of the ocean, of a desert, of snow, of a cloud?

Question 2: Albedo of Common Earth Surfaces

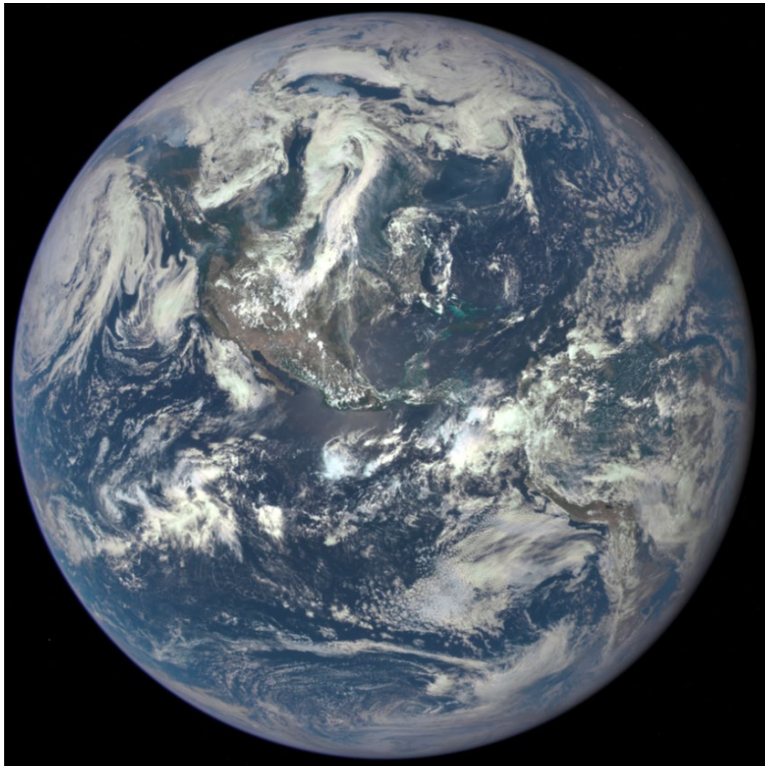
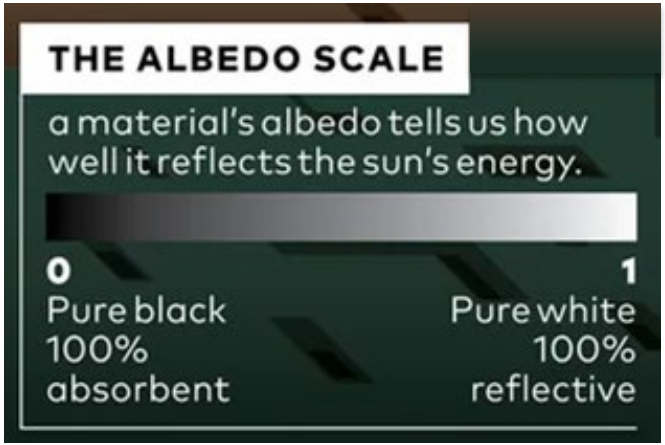


Image Credit: NASA



Question 2: Albedo of Common Earth Surfaces

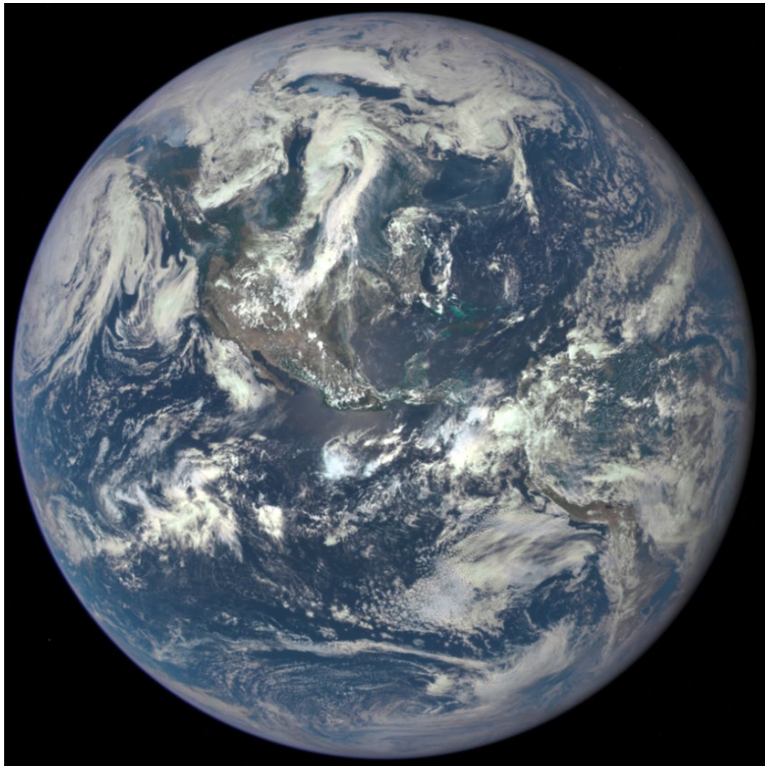


Image Credit: NASA

Reflectivity values of various surfaces

Surface	Albedo
Sand	0.30
Grass	0.21
Cropland	0.21
Forest	0.15
Water	0.07
Fresh Snow	0.90
Sea Ice	0.40
Land Ice	0.30
Clouds - Thick	0.75
Clouds - Thin	0.40
Avg. Earth Surface	0.31

Sources: Oke, 1992; Ahrens, 2006

Research Question:
Can we engineer brighter clouds?

Reflectivity values of various surfaces

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Image Credit: NASA

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Research Question:
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Answer Question 3 in Worksheet

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Experimental Design & Methods

Experimental Design & Methods

How would you design an experiment to brighten clouds?

Experimental Design to Answer the Research Question: Create a Cloud-in-a-Bottle and Vary the Cloud Components

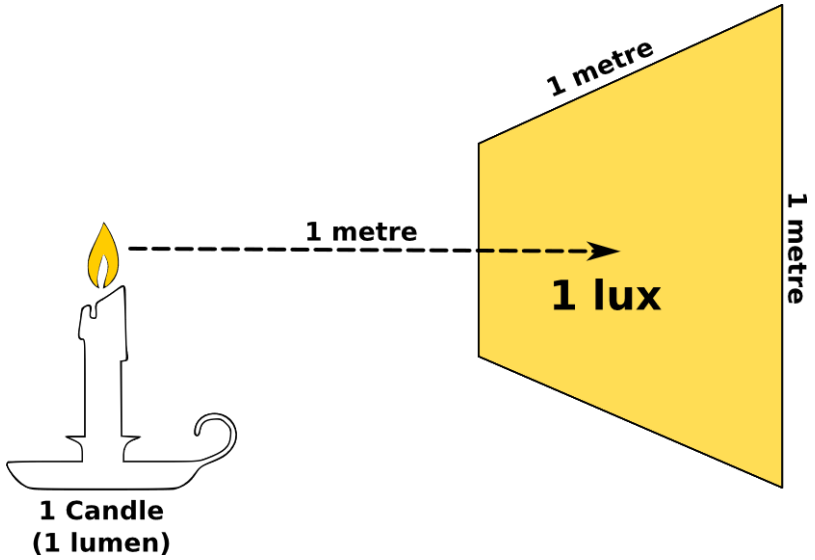
Record the reflectance (brightness) of a cloud using a lux meter.

Experiment Videos

Experiment Video – Materials and Set-Up	https://drive.google.com/file/d/13gS2LMqGwDXbPaPAF9BQuCbdf51GzzHY/view?usp=sharing
Experiment Video – Low-aerosol trials	https://drive.google.com/file/d/1sMgcZq1RiaCJkklNZEHtrNE0zPUUXXY3/view?usp=sharing
Experiment Video – High-aerosol trials	https://drive.google.com/file/d/18LpOGMESVKUkdocbuplMplV9J3-bphT7/view?usp=sharing

What is a lux?

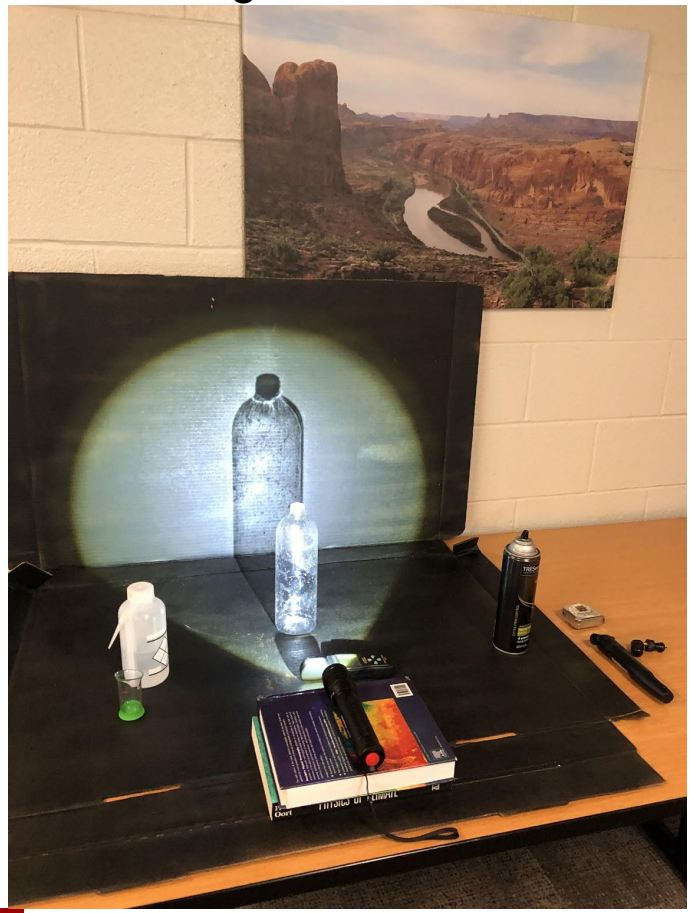
A measurement of 1 lux is equal to the illumination of a one-meter square surface that is one meter away from a single candle.



Environment	Typical Lux
Hospital Theatre	1,000
Supermarket, Sports Hall	750
Factory, Workshop	750
Office, Show Rooms, Laboratories, Kitchens	500
Warehouse Loading Bays	300 to 400
School Classroom, University Lecture Hall	250
Lobbies, Public Corridors, Stairwells	200
Warehouse Aisles	100 to 200
Homes, Theatres	150
Family Living Room	50

https://greenbusinesslight.com/resources/lighting-lux-lumens-watts/

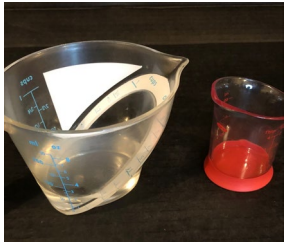
Experimental Design & Methods



In this experiment, we explore how/whether different amount of aerosol affect the brightness of the cloud.

In this experiment,
Independent variable is____
Dependent variables is_____
The constants are_____

Materials and tools



Water & measurable units

Hand air pump

Picture of plug in the bottle

Aerosol hairspray

Lux meter

Rubber stopper & valve plug

Picture of hand air pump with valve plug attached

Clear 1-liter plastic bottles

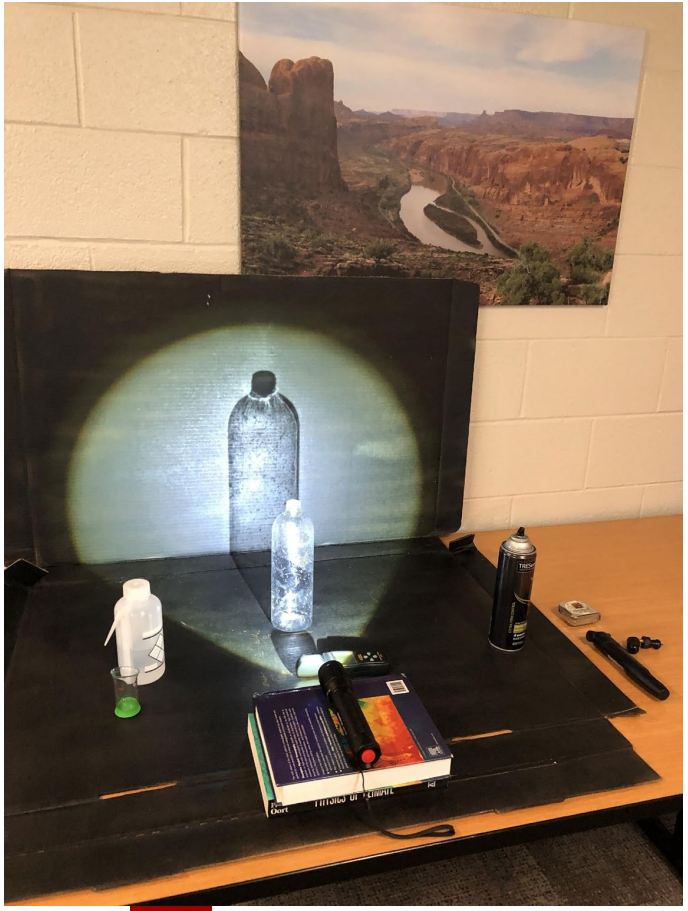
Light source

Materials and tools

OR:
“Fizz Keeper”

Picture of
fizz keeper
on the bottle

Setting up apparatus



15 by 15 by 15 set up

Set the flashlight 15 cm above surface

Set the lux meter 15 cm in front of light source, point sensor at the middle of the bottle

Set the plastic bottle 15 cm in front of the lux meter

Experiment One: Low-Aerosol Environment

1. Add 20 ml water to the bottle. Swish around to cover inner surface.
2. **Spray 3 times** with the aerosol hairspray into the bottle (Wear a mask).
3. Quickly cap with the rubber stopper and valve plug.
4. Use the air pump 15x (CAUTION – Do not over pressurize). **OR:** Use the "Fizz Keeper and squeeze air into the bottle until you can not add any more air.
5. Immediately pull out the stopper (make sure bottle remains 15 cm from lux meter).
6. And ….

Experiment One: Low-Aerosol Environment

… Clouds!

8. Capture the lux meter reading ASAP and record the value.
9. Wait until the cloud fully dissipates (1-2 minutes), record the lux meter reading
10. Repeat Experiment One for at least 4 trials (up to 10).

Record Data

Record the lux meter reading for each trial on the worksheet

Experiment One: Low-Aerosol Environment 3 Sprays of Hairspray			
	Lux Meter Reading (lx)		
Trial #	Bottle w/ Cloud	Bottle w/o Cloud	Difference
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Following the same procedure, run at least 4 trials for Experiment Two in which **10 sprays** of hairspray are used.

Experiment Two: High-Aerosol Environment 10 Sprays of Hairspray			
	Lux Meter Reading (lx)		
Trial #	Bottle w/ Cloud	Bottle w/o Cloud	Difference
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Post-Experiment

Answer Questions 4-9

Review Question 7

Explain why more aerosol particles (10 sprays vs. 3 sprays of hairspray) created a cloud that reflects more light?

Review Question 7

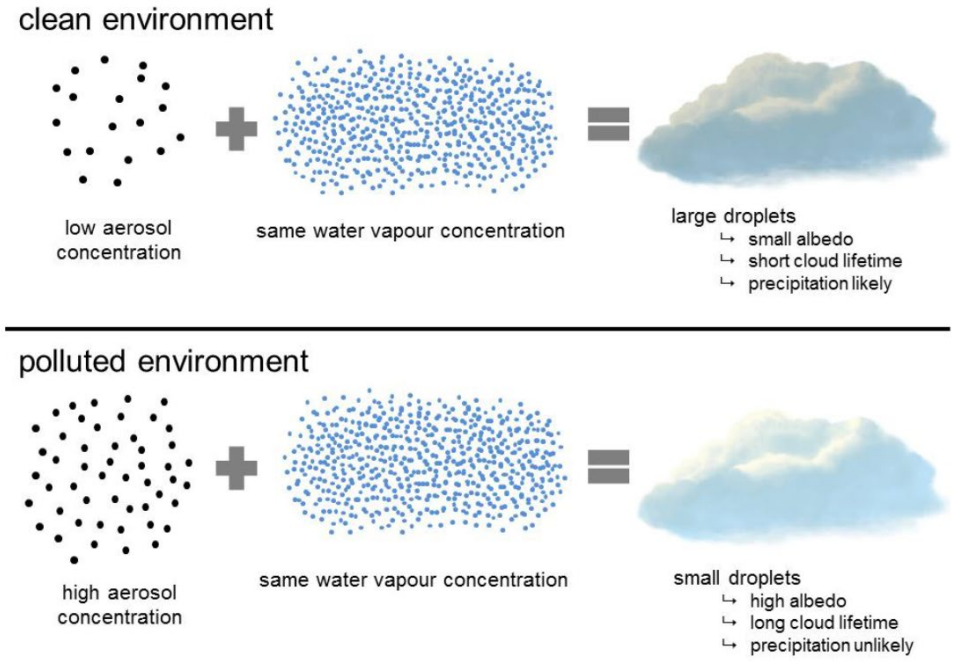


Figure 1. A simple schematic of the indirect effect of aerosols on climate.

The greater the number of cloud condensing nuclei (sea salt aerosols) the higher the cloud albedo, and thus greater reflectively of the cloud.

https://helda.helsinki.fi/bitstream/handle/10138/154682/lifecycl.pdf?sequence=1&isAllowed=y

Review Question 8

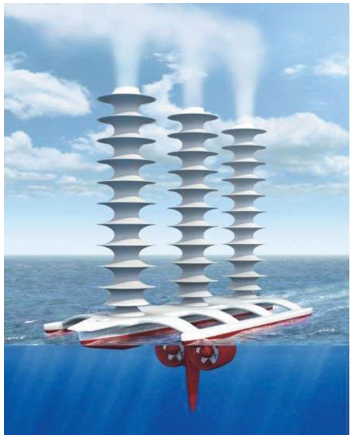
How could we implement this climate engineering technology to brighten clouds on a larger scale, in the real world?

Review Question 8

We have evidence that introducing aerosols into a marine environment will create and brighten clouds. Here is a picture of ‘ship tracks' above the northern Pacific Ocean. These patterns are produced when fine particles from ship exhaust float into a moist layer of atmosphere. The particles seed new clouds or attract water from existing cloud particles.

Image taken by the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA’s Aqua satellite on July 3, 2010.

Review Question 8



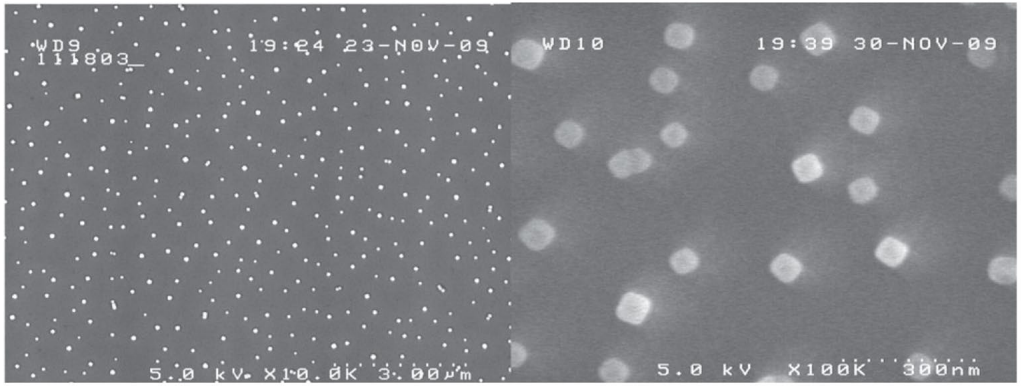
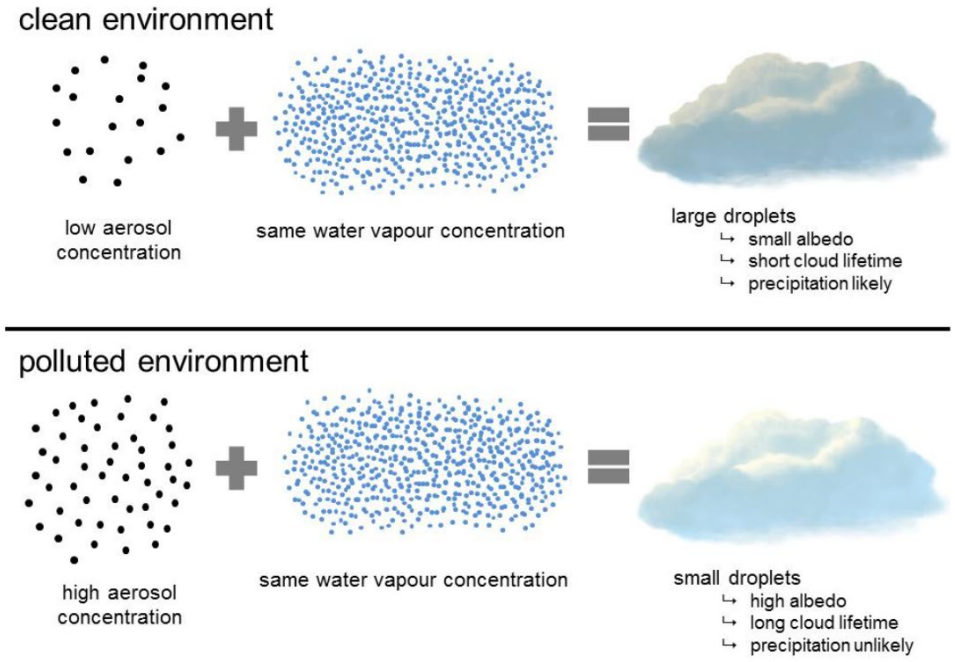


Figure 8. SEM images of salt particles from salt-water cone-jets at different magnifications.

By using seawater sprayers on ships or autonomous marine vehicles, we can inject tiny sea salt particles into the lower atmosphere. These sea salt particles increase the cloud condensing nuclei. (Unlike ship exhaust, the sea salt particles are not accompanied by GHGs)

Image Credits: Daniel Harrison & Alejandro Tagliafico / SIMS and Southern Cross University. John MacNeill. Latham et al., 2012.

Review Question 8



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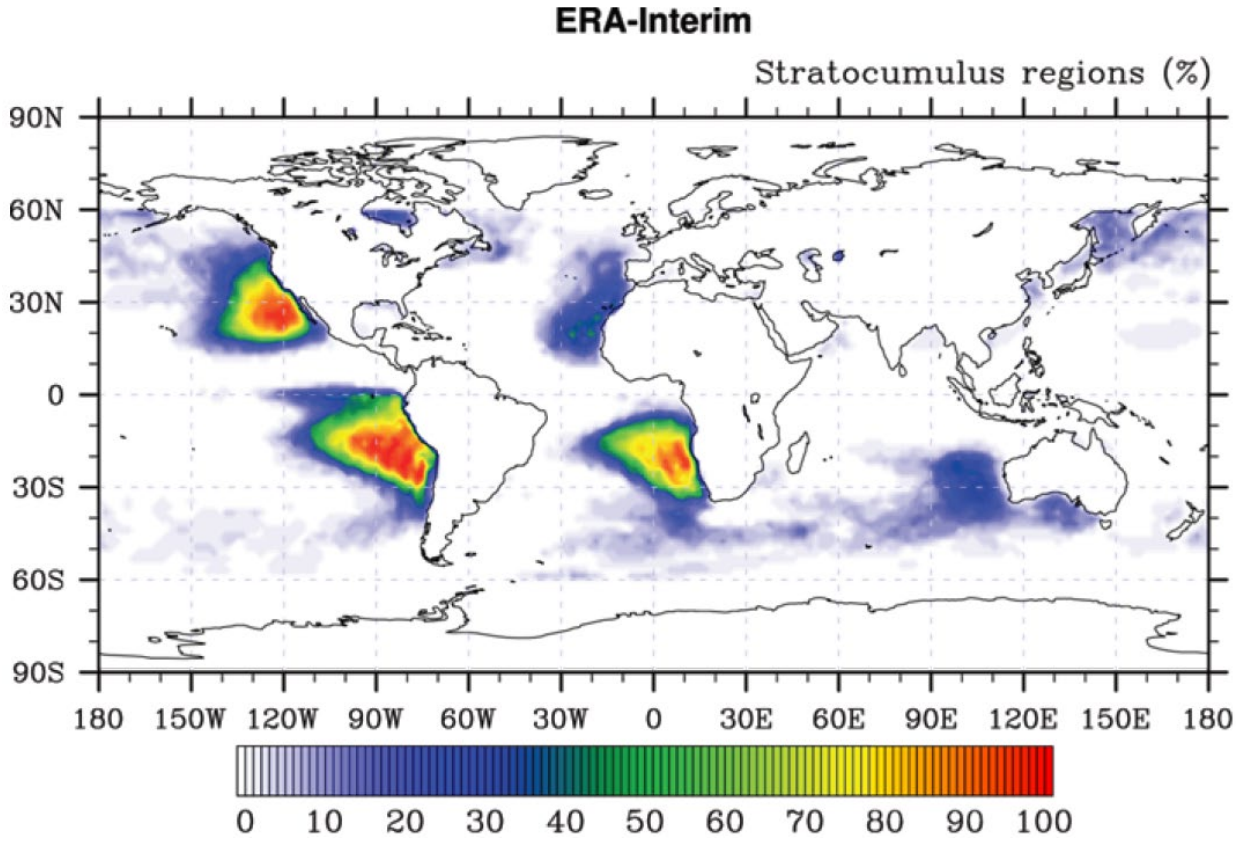
Review Question 8

This climate engineering technology, known as Marine Cloud Brightening, is currently being researched by scientists and engineers using laboratories and computer models to assess the benefits and risks.

https://www.youtube.com/watch?v=cgJyw2cTrW4

How MCB Could Work:



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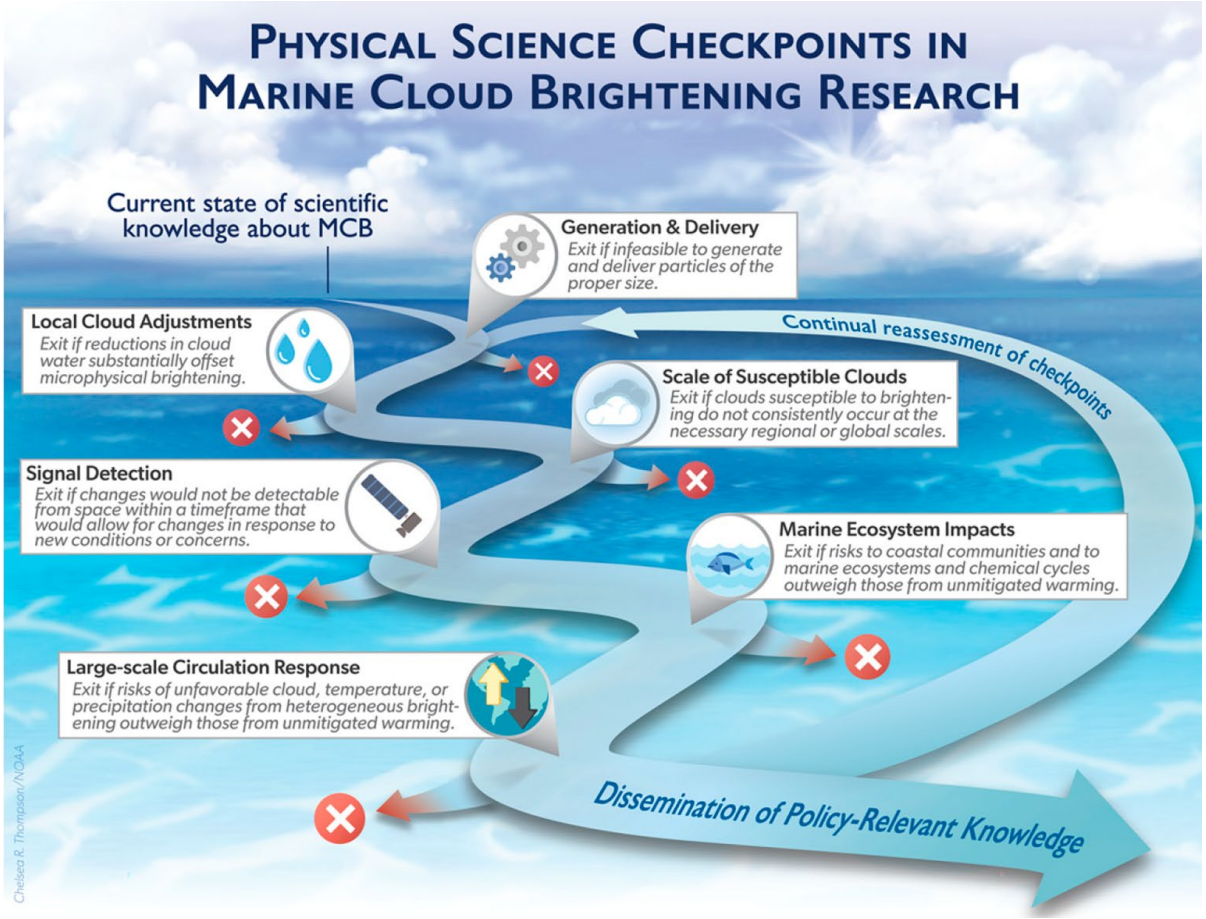

Diamond et al., 2022

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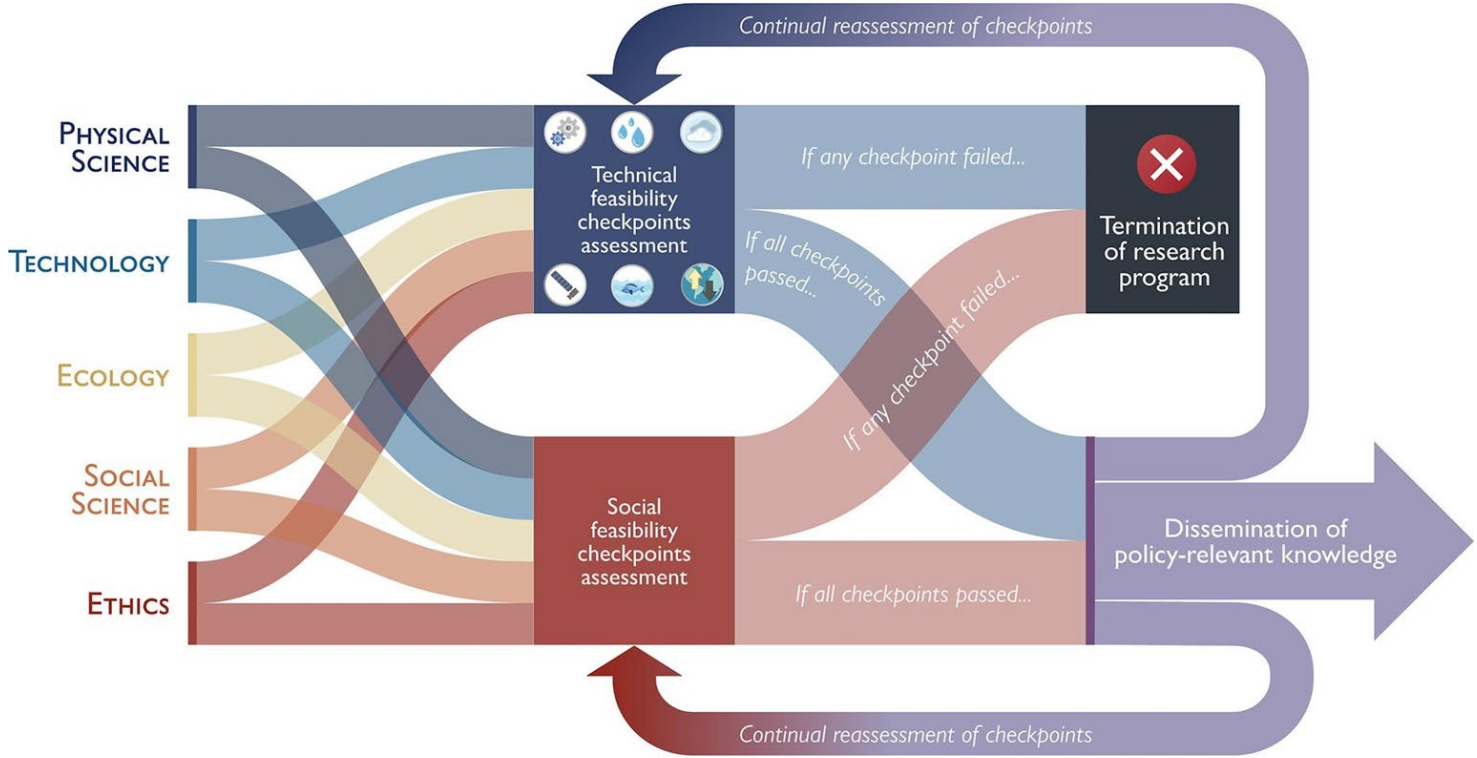

Diamond et al., 2022

Review Question 9

What are some possible limitations and risks to scaling this technology to use in the real-world?

Review Question 9

Limitations:

- Cost
- Preferred ocean environment (low clouds, low background aerosols, far from land)
- Will greatly benefit from global cooperation and support
- Does not address increasing atmospheric greenhouse gases nor ocean acidification

Risks:

- Regional to global changes in precipitation amounts and patterns
- Regional changes to atmospheric and oceanic chemistry
- Impacts on biology and ecosystems
- Potential for rapid change if abruptly terminated

Conduct a similar exercise regarding SAI with students which will help prepare them to critically evaluate their climate engineering designs

Limitations:

- _____
- _____
- _____
- _____

Risks:

- _____
- _____
- _____
- _____

Prepare for Lesson 3

In summary, Marine Cloud Brightening is a promising climate engineering strategy. Nonetheless, it is important that scientists and engineers continue to improve this technology and to address its limitations and risks.

In the next lesson, how can you improve your climate engineering design to address its limitations and risks?

Questions/Comments/Thoughts/Ideas welcome!

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