Wintertime Cloud Seeding

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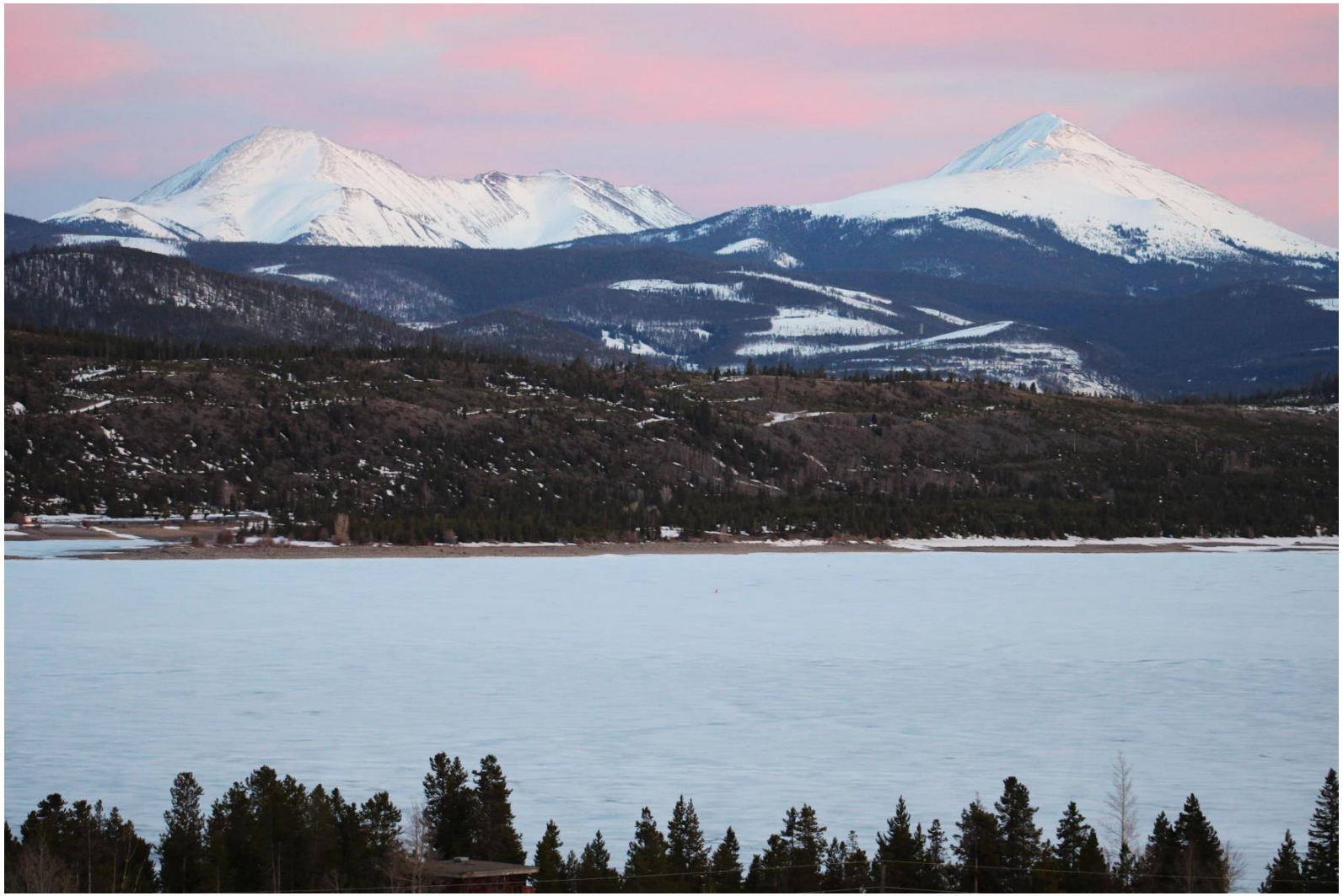
ATSC 252
Applied Weather Modification



Snowy mountains loom over Colorado's Lake Dillon reservoir

Learning Objectives

- Need for Wintertime Orographic Cloud Seeding
- Conceptual Basis of Wintertime Orographic Cloud Seeding - Fundamental Hypothesis
- Ground-Based Generators
- Seeding with an Aircraft
- Relative advantages and disadvantages of both methods
- Recent Field Campaigns – SPERP, SNOWIE

Need for Wintertime Cloud Seeding

- **U.S. population more than doubled from 1950 to 2010** - shifted from rural to urban (U.S. Census Bureau, 2010), with greatest population increase in **Southern and Western states**, leading to strained public water supply systems
- **Water scarcity is expected to worsen** due to continued population growth and climate change impacts on mountain snowpack
- **Winter mountain snowpack acts as a natural water reservoir**, supplying spring and summer water through snowmelt
- **Enhancing snowfall through wintertime orographic cloud seeding can increase snowpack and improve water availability in arid regions**
- **Cloud seeding** offers a potential tool for supplementing water resources alongside conservation efforts

Western U.S. snowpack is worth trillions of $$$$$!!

Gross Reservoir, southwest of Boulder, Colorado (Oct, 2019)

Major Orographic Cloud Seeding Projects in Western US

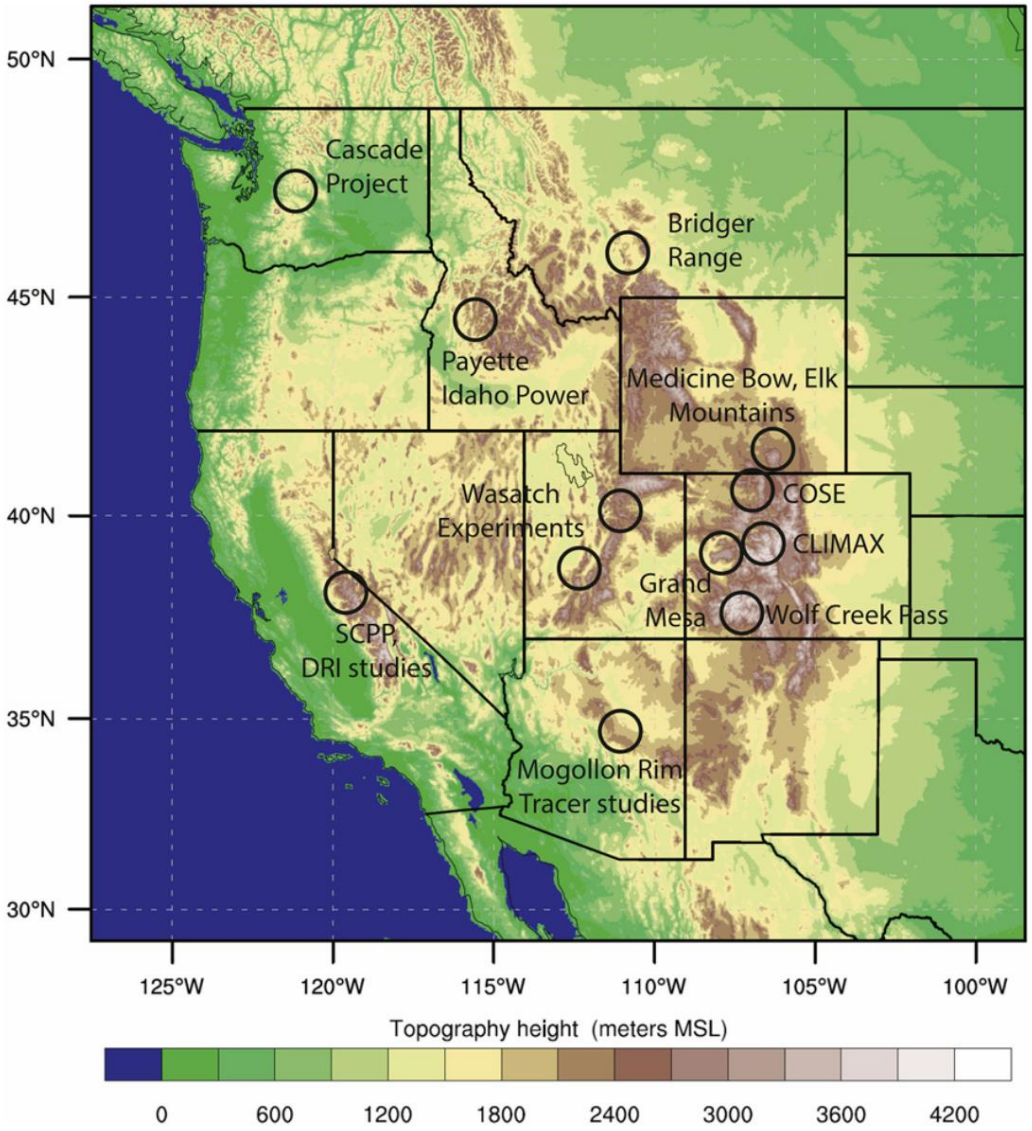


TABLE 1. Summary of the seven randomized seeding experiments studying the effect of winter orographic precipitation enhancement using silver iodide.

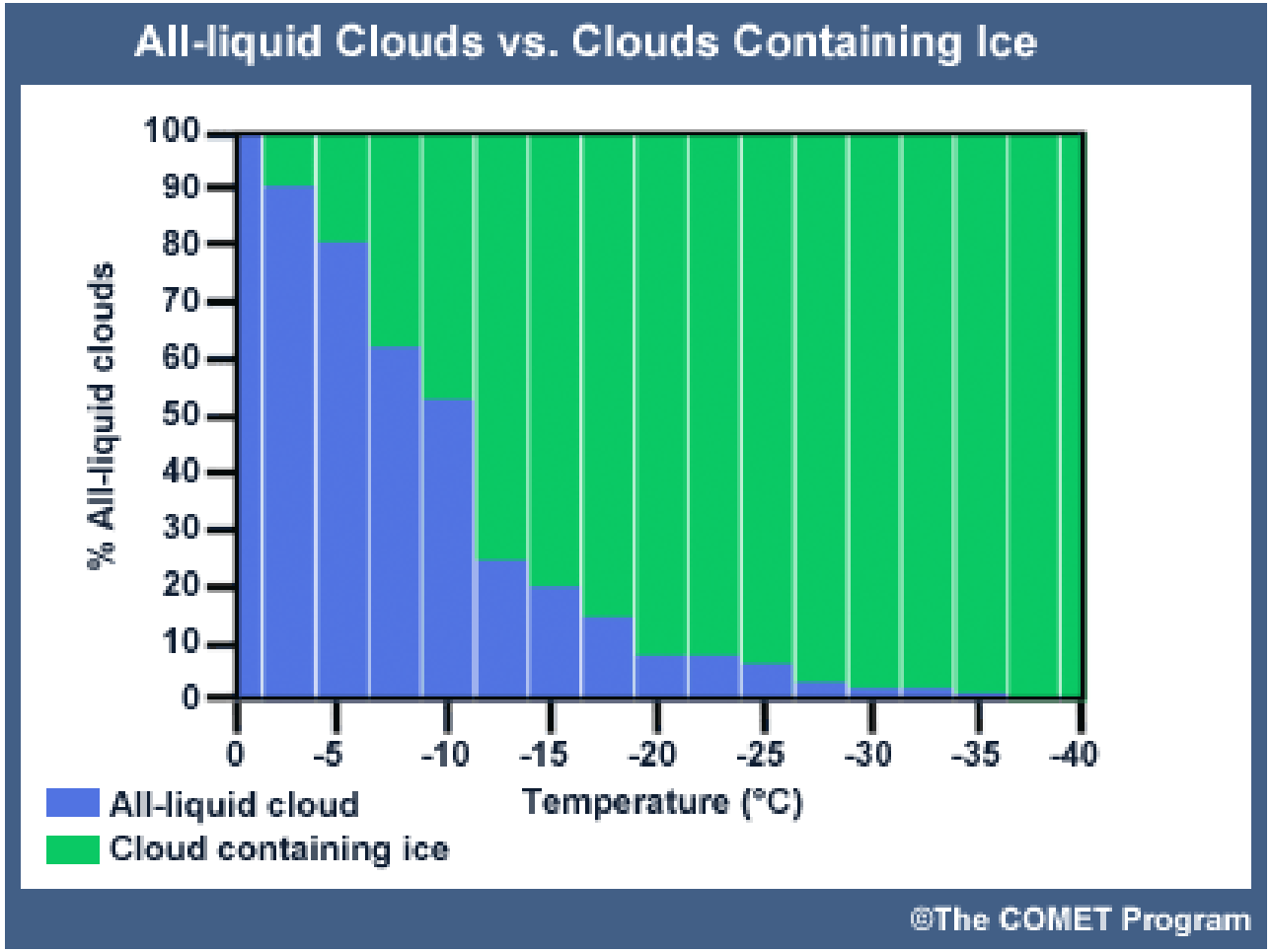
Project Name	Location	Years	Type of expt
Climax I; Climax II	Climax, CO	1960–65; 1966–70	Exploratory; confirmatory
Wolf Creek Pass	Wolf Creek Pass, CO	1964–70	Exploratory
Elko, NV	Northeast Nevada Range, NV	1961–67	Exploratory
Colorado River Basin Pilot Project (CRBPP)	San Juan Mountains, CO	1970–75	Exploratory
Bridger Range Experiment	Bridger Range, MT	1970–72	Exploratory
Wyoming Weather Modification Pilot Project (WWMPP)	Medicine Bow/Sierra Madre Ranges, WY	2008–13	Confirmatory
Snowy Precipitation Enhancement Research Project (SPERP1; SPERP2)	Snowy Mountains, Australia	1955–63; 2005–09; 2010–13	Exploratory; confirmatory; confirmatory

Rauber et al., 2019

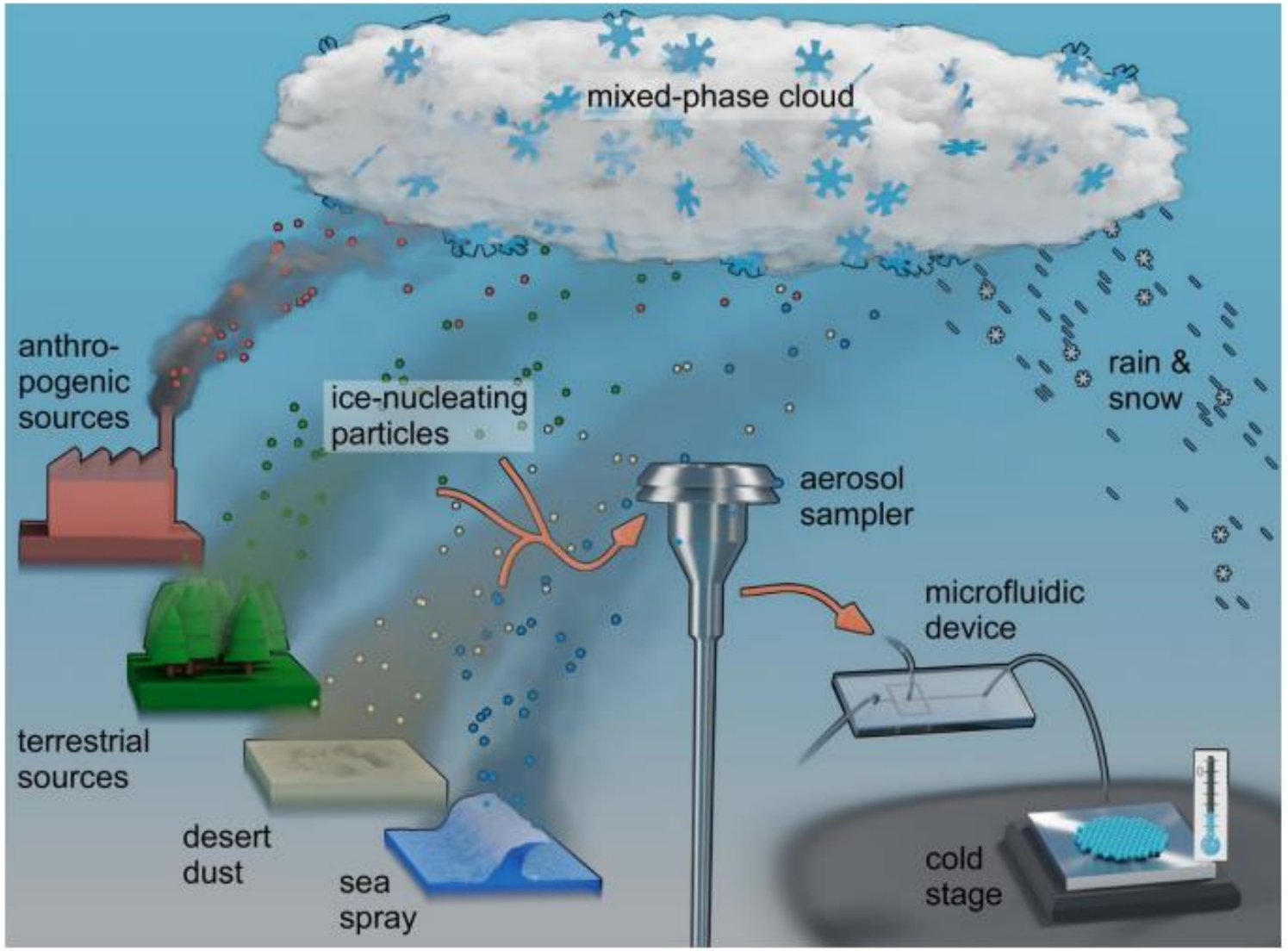
Physical Mechanisms

Does water always freeze right at the "freezing point" of 32°F (0°C)?

No!!



Physical Mechanisms



Between **0°C and -37°C,** supercooled water needs foreign Ice-Nucleating Particles **(INPs)** to freeze.

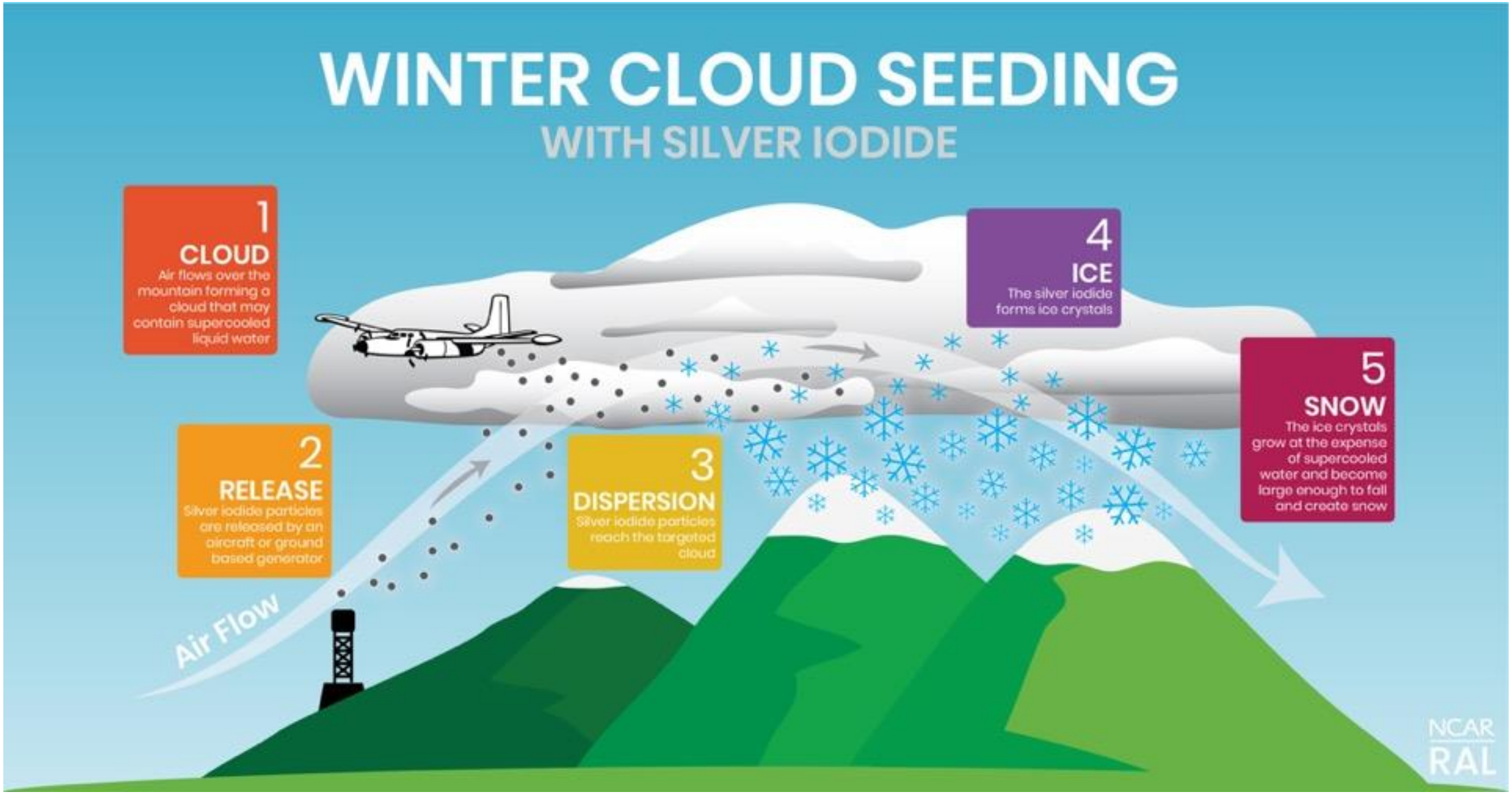
Tarn et al., 2018

Physical Mechanisms

- Various INPs become “active” at specific temperatures. **Silver iodide (AgI)** can activate at temperatures as warm as -4° C.
- Most cloud-seeding programs use a temperature criterion of **-5°C or colder** to indicate the cloud is suitable for cloud seeding.
- INPs can be placed in the cloud via **aircraft or a ground generator.**

Ice crystals growing at the expense of supercooled liquid droplets within a cloud

Conceptual Diagram

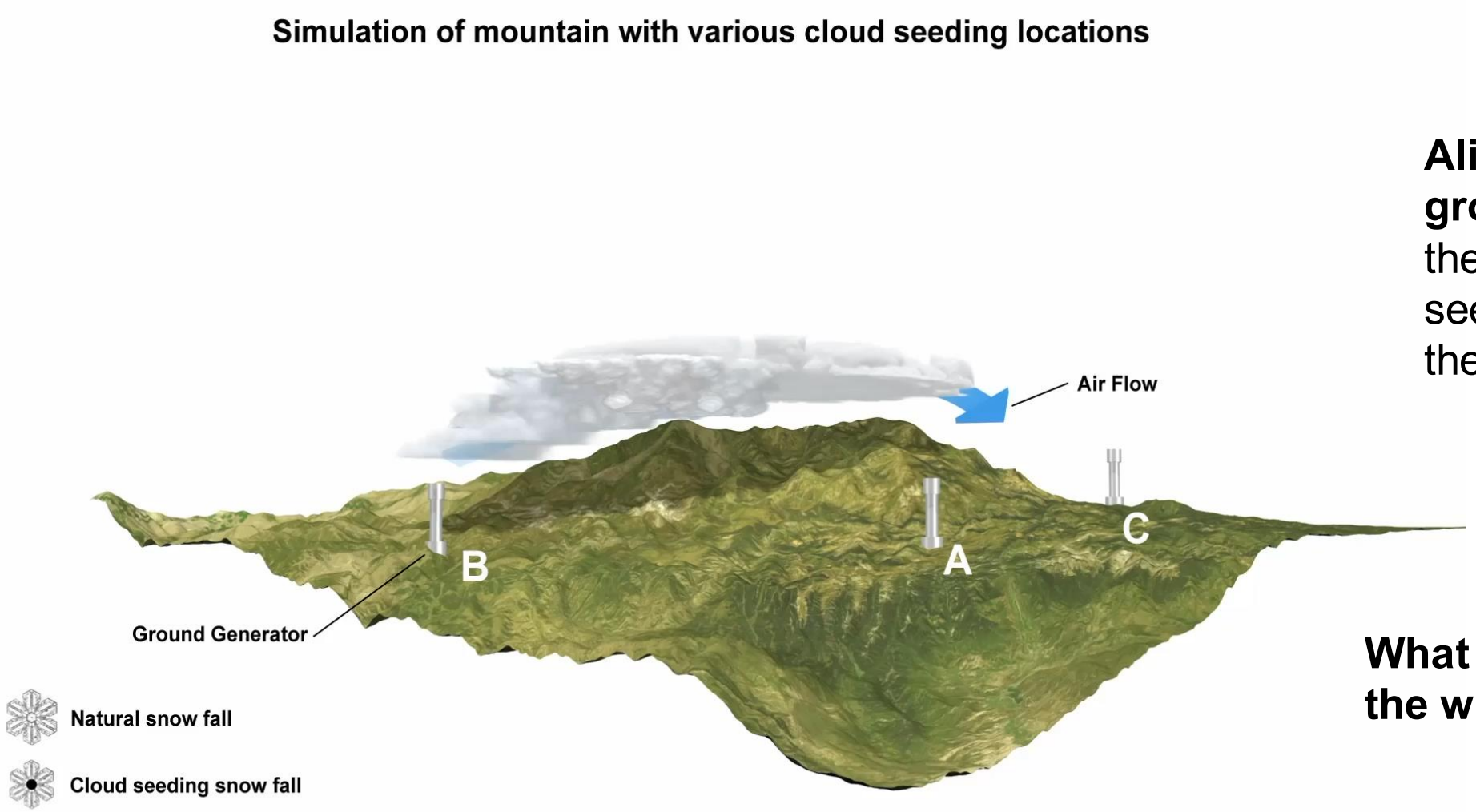


Cloud Seeders

Above: A DRI cloud-seeding generator and maintenance truck in a wintery, mountain-top setting.
Credit: Jesse Juchtzer/DRI

https://www.youtube.com/watch?v=veOlftZp-44 (Courtesy: Desert Research Institute or DRI)

Ground-based Generator locations



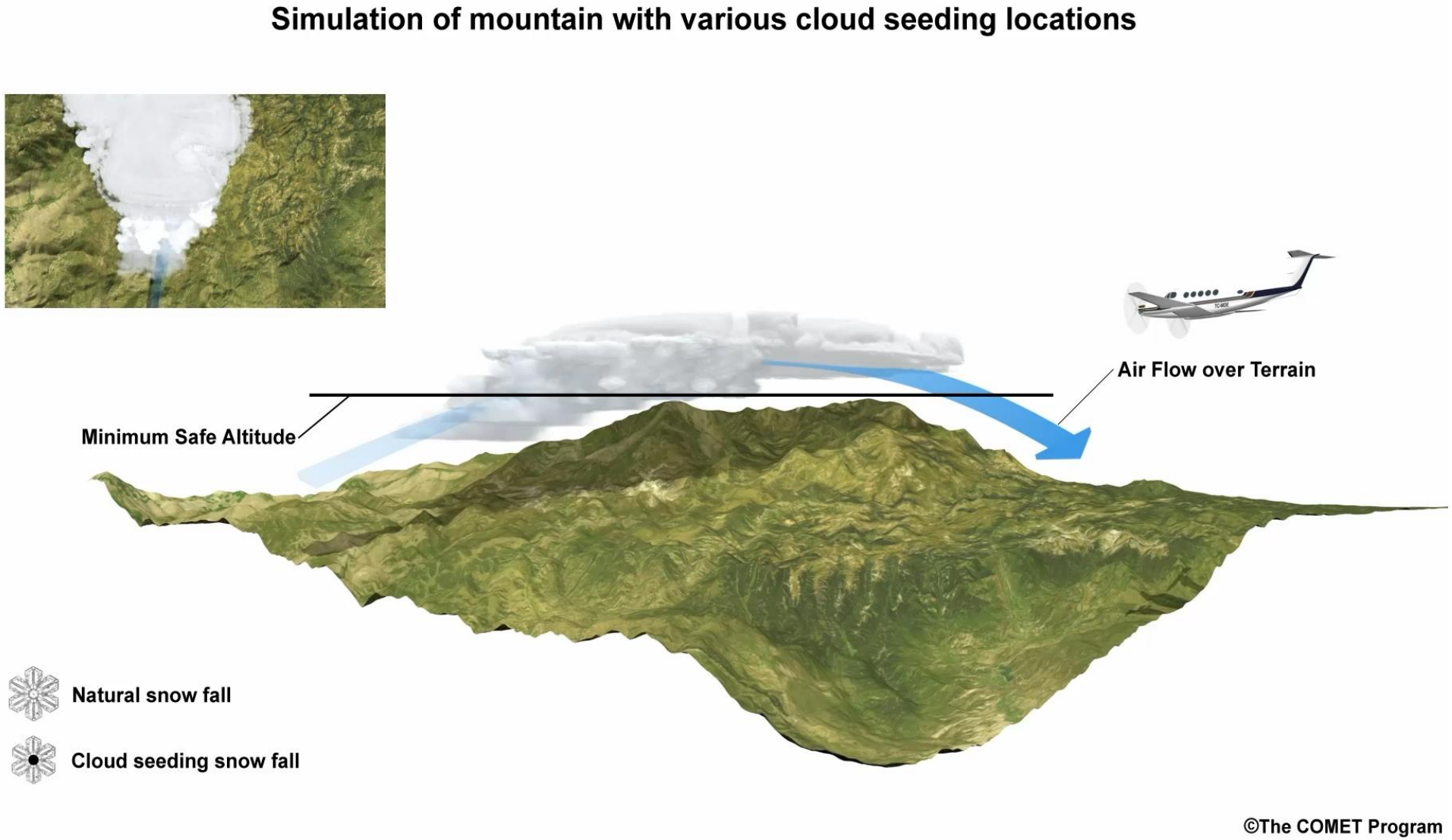
Alignment of the ground generators so the wind transports the seeding particles into the cloud is **important.**

What happens when the winds are weaker?

Weak Winds

The particles **may not reach the cloud**, more likely to flow around the mountain (known as **flow blocking**)

Seeding with an Aircraft



Which of the following positions of the aircraft track will produce snow over the mountains?

a) Flying high above the clouds
b) Flying near the top of the clouds
c) Flying under the clouds

Advantages/Disadvantages

Based on the previous information on ground generators and aircraft seeding methods,

what are the advantages and disadvantages of cloud seeding via each method?

a) Aircraft can disperse particles directly into the cloud
Advantage
b) Aircraft are costly to operate and fly for limited periods of time
Disadvantage
c) SLW in clouds can coat aircraft wings and cause loss of lift
Disadvantage
d) Ground generators can run continuously for many hours or days
Advantage
e) Ground generators need to be located where they will align with the predominant airflow
Disadvantage

Cloud Seeding Efficacy

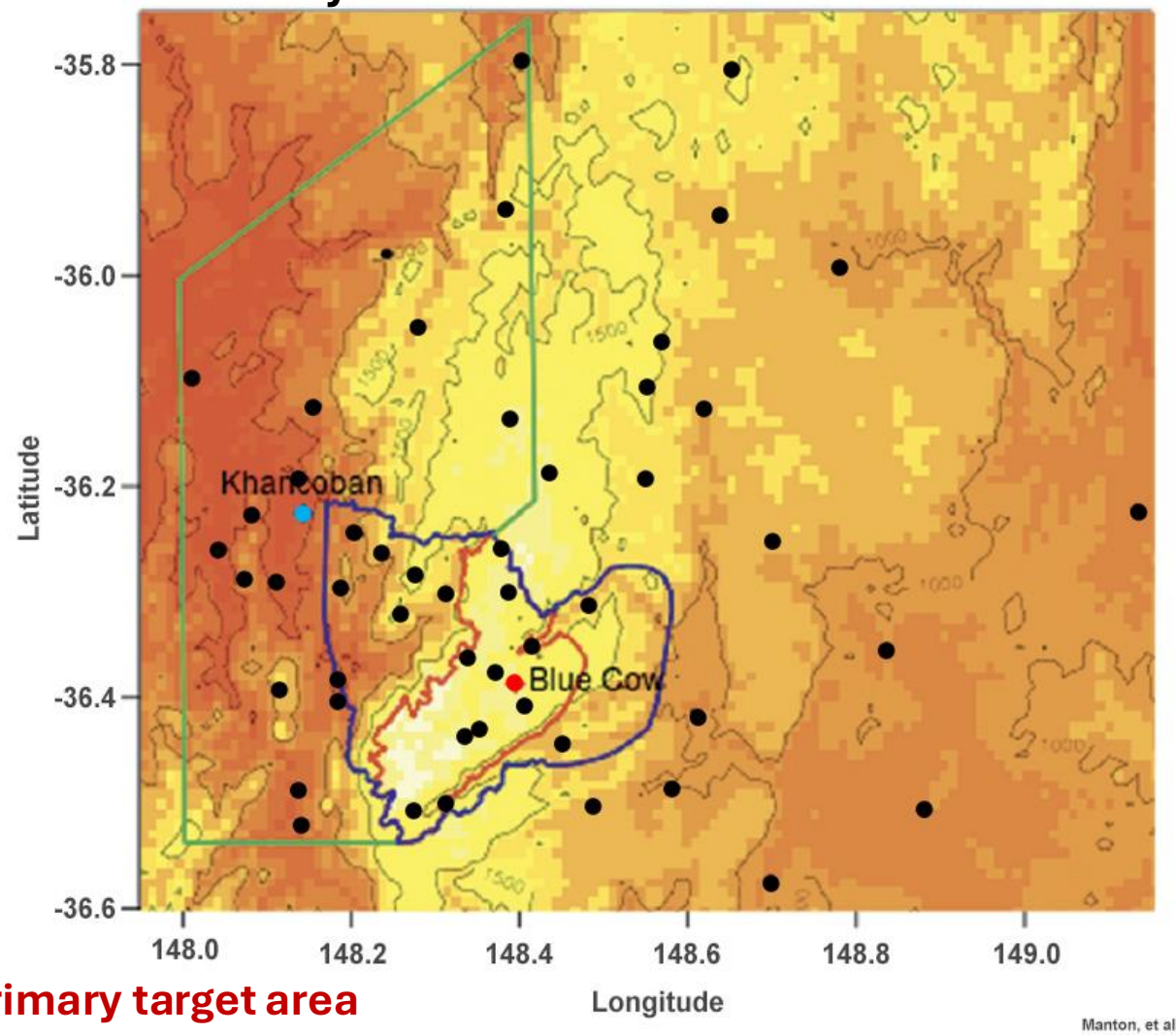
How much snow is cloud seeding likely to generate?

- Observational studies such as **Snowy Precipitation Enhancement Research Project (SPERP)** statistically examined seeding effects using a network of **13 ground generators** and **44 precipitation measuring gauges** at various locations along Snowy Mountains in Australia (Manton et. al. 2011a,b)

- 53 instances of seeding periods compared with 31 similar unseeded cases

- **Total fractional increase in precipitation above natural precipitation level** in the overall target area was found to be 14% with 3% risk (chances of observed precipitation differences due to inadequate sampling, much larger natural variability, etc)

Snowy Mountains of southeastern Australia



Primary target area

Overall target area

Control area

Black dots – **Precipitation gauges**

contours at 500, 1000, and 1500 m

SNOWIE

SNOWIE (Seeded and Natural Orographic Wintertime Clouds: The Idaho Experiment)

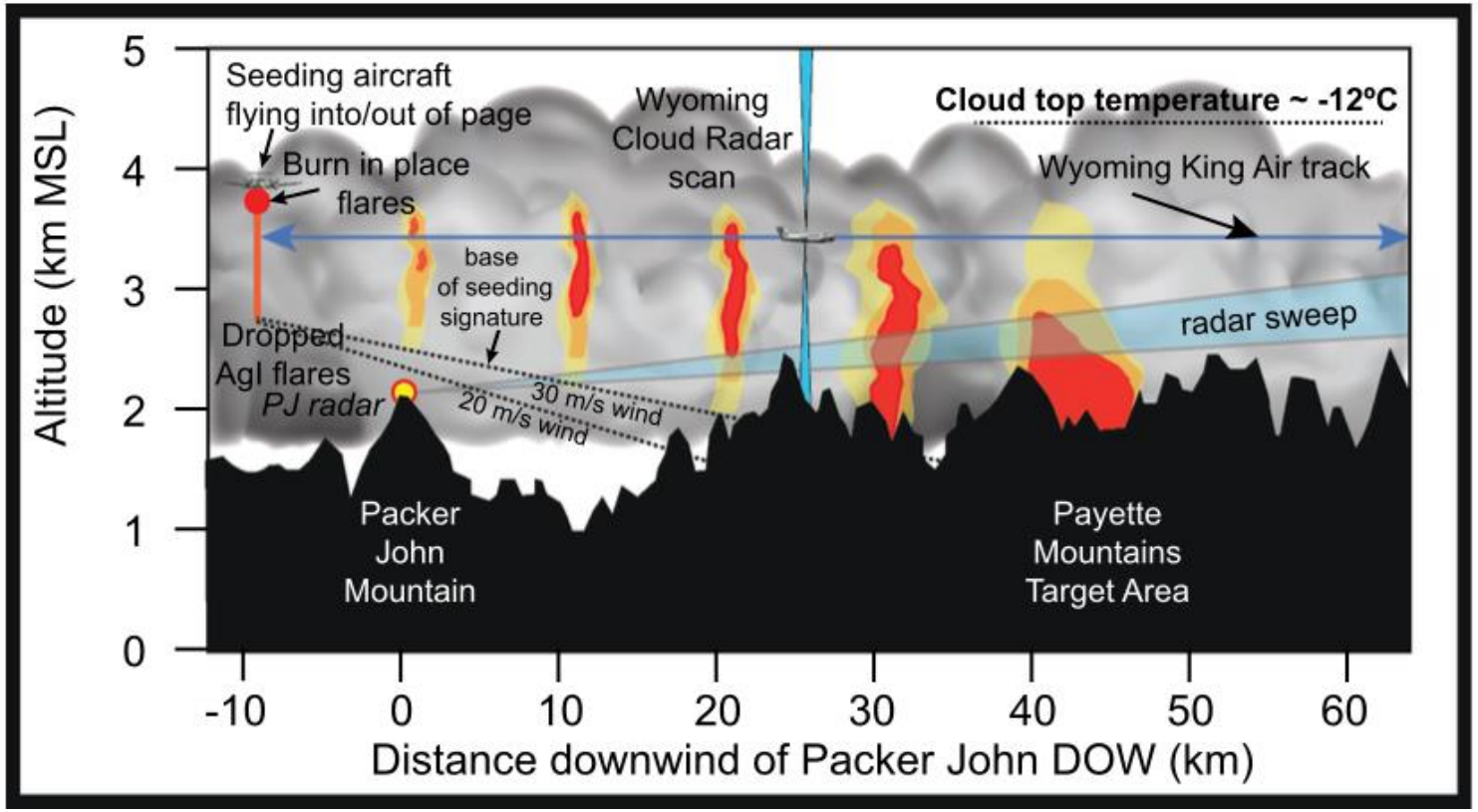
- to understand **natural dynamical and microphysical processes** by which precipitation forms and evolves within orographic winter storms

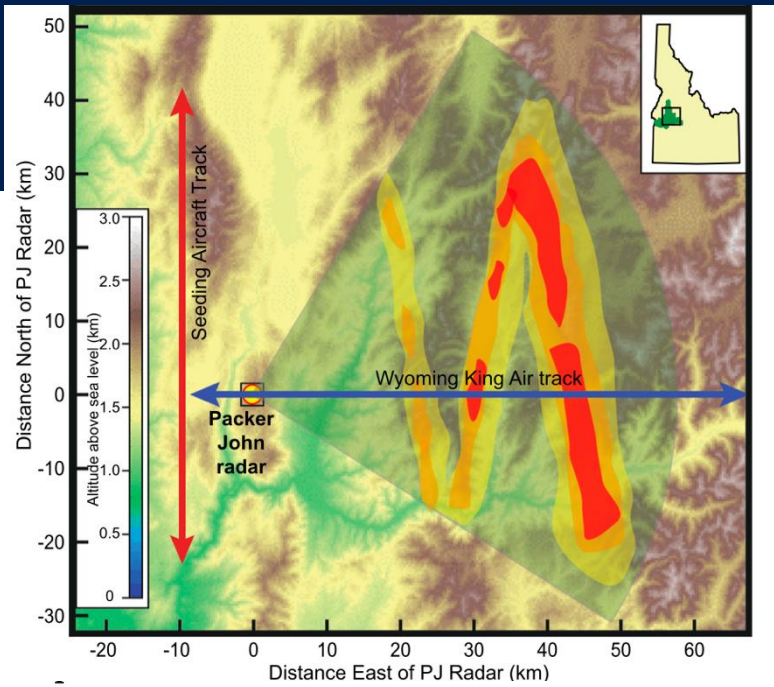
- to determine the **physical processes by which cloud seeding with silver iodide (AgI),** either from ground generators or aircraft, impacts the amount and spatial distribution of snow falling across a river basin

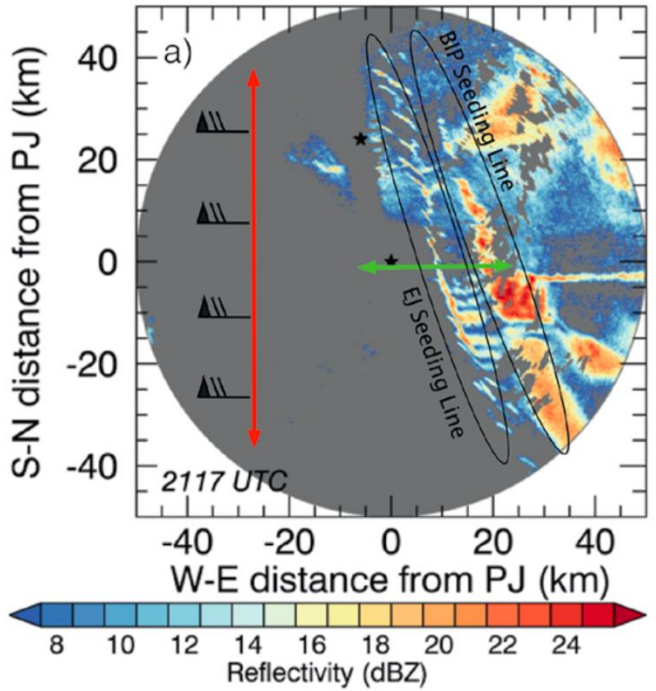
The study reported **increases in liquid equivalent snowfall** of **0.05 mm to 0.28 mm** and snowfall rates of **0.04 mm/hr to 1.2 mm/hr** as a result of cloud seeding in three cases.

FIG. 1. Photos of (a) the UWKA aircraft (courtesy L. Oolman, University of Wyoming) and (b) the DOW-7 radar located at Packer John at sunset (courtesy J. Aikins, University of Colorado Boulder).

SNOWIE


Seeding aircraft
flying into/out of page
Burn in place
flares
Wyoming
Cloud Radar
scan
Cloud top temperature ~ -12°C
Wyoming King Air track
base
of seeding
signature
radar sweep
Dropped
AgI flares
PJ radar
30 m/s wind
20 m/s wind
Packer
John
Mountain
Payette
Mountains
Target Area
Altitude (km MSL)
Distance downwind of Packer John DOW (km)


Seeding Aircraft Track
Wyoming King Air track
Packer
John
radar
Altitude above sea level (km)
Distance North of PJ Radar (km)
Distance East of PJ Radar (km)


a)
BJP Seeding Line
EJ Seeding Line
2117 UTC
S-N distance from PJ (km)
W-E distance from PJ (km)
Reflectivity (dBZ)

SNOWIE

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https://movie-usa.glencoesoftware.com/video/10.1073/pnas.1917204117/video-1

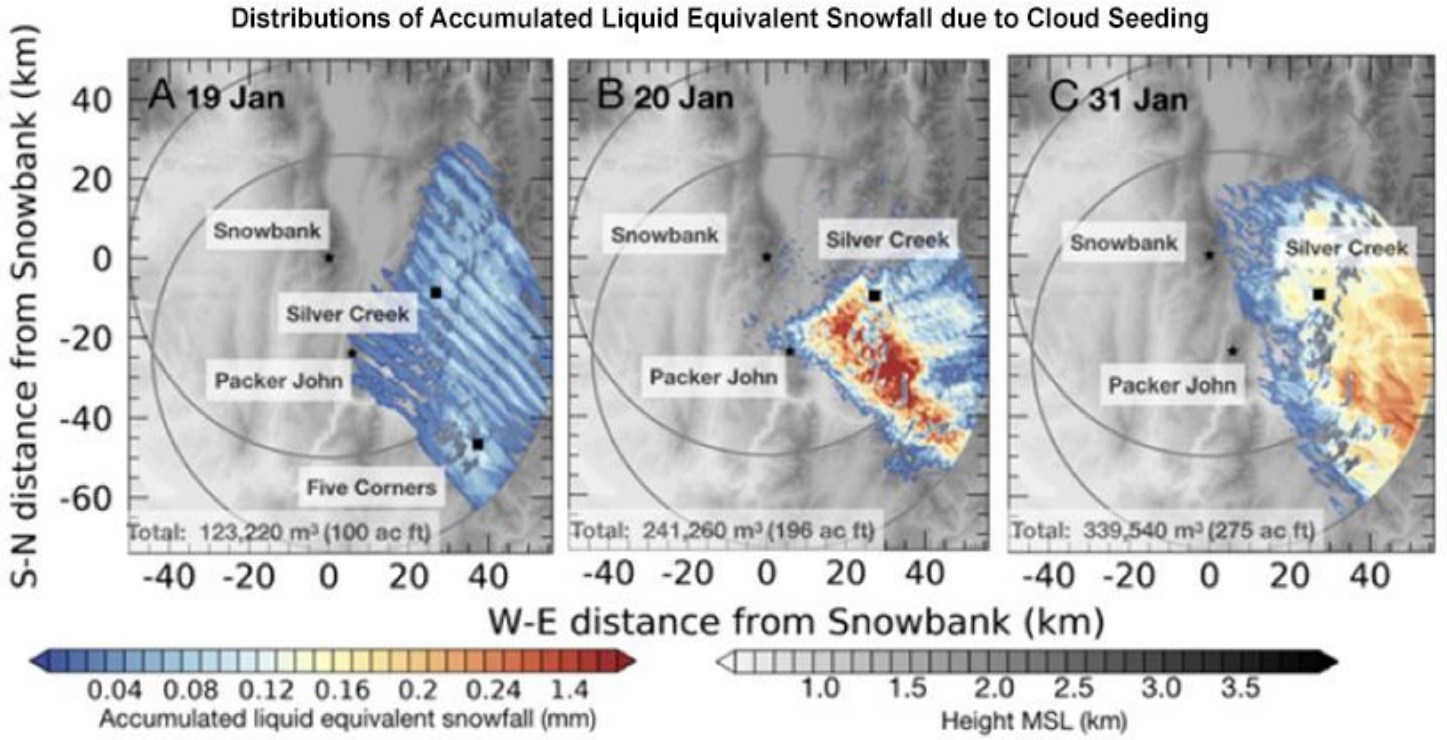

Fig. 3. Distribution of accumulated liquid equivalent snowfall (*S*) attributed to cloud seeding over the observational period between (*A*) 1705 and 1806 UTC on 19 January; (*B*) 0042 and 0315 UTC on 20 January; and (*C*) 2117 and 2151 UTC on 31 January 2017 using the best-match Z_e–*S* relationship for that day. Data are shown on a 100 × 100 m grid. Total accumulations over the entire domain and observational period are highlighted. Corresponding Z_e are shown in *SI Appendix*, Movies S1–S3.

Friedrich et al, 2020

How much snow is likely to be generated?

- **Challenging to quantify** amount of precipitation over a specific target area attributed to seeding efforts

- Past observational studies have used statistical experiments (similar to how pharmaceutical companies trial new medicines). Given there is **so much natural variability in weather** and **sample of clouds that could be seeded for some of the trials was too low** to gain statistical significance, a lot of these studies have not proven how much snow was produced by cloud seeding. For those studies that have been able to claim significant or less ambiguous results, such as finding a **14% increase** from the statistical experiment in Australia, **those results do not apply everywhere.**

- **Each individual cloud-seeding program needs to do their own evaluation** in order to estimate what the impacts in that region are.

- **Modeling Studies:**

New computer models like **WRF** simulations of WWMPP cases in Rasmussen et al., 2018 are showing promise in being able to simulate how much additional snow from cloud seeding may be falling, and where it is falling. Those **models could eventually be coupled with hydrological models to project streamflow impacts of cloud seeding.**

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- Recent Field Campaigns

Further Reading Suggestions

1. **How Cloud Seeding Works – UCAR COMET Program**
2. Yau, M. K., & Rogers, R. R. (1996). A short course in cloud physics. Elsevier.
3. Friedrich, K., Ikeda, K., Tessendorf, S. A., French, J. R., Rauber, R. M., Geerts, B., ... & Dawson, N. (2020). Quantifying snowfall from orographic cloud seeding. Proceedings of the National Academy of Sciences, 117(10), 5190-5195.
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