AGENDA

IDAHO WATER RESOURCE BOARD

Cloud Seeding Committee Meeting No. 1-25
May 14, 2025
1:00 p.m. (MT) / Noon (PT)

Water Center
Legacy Pointe Conference Room
322 E. Front St.
First Floor
BOISE

Livestream available at https://www.youtube.com/@iwrb

1. Introductions and Attendance
2. Cloud Seeding Season Update
3. Cloud Seeding Informational Presentations
4. Public Comment—In Person Only—Not to Exceed 30 Minutes
5. Committee Recommendations *
2. Other Items
3. Adjourn

Committee Members: Chair Marc Gibbs, Jeff Raybould, Al Barker, and Pat McMahon.

All public meetings are moderated. The Chairman will allow participants to speak in an orderly fashion. Please be patient and respectful of others while testifying. We reserve the right to stop the meeting if participants are not respectful during the meeting. Public comments at committee meetings should be limited to topics pertinent to that committee. Comments will be recorded and be part of the public record.

* Action Item: A vote regarding this item may be made at this meeting. Identifying an item as an action item on the agenda does not require a vote to be taken on the item. **Americans with Disabilities:** The meeting will be held in person and online. If you require special accommodations to attend, participate in, or understand the meeting, please make advance arrangements by contacting Department staff by email jennifer.strange@idwr.idaho.gov or by phone at (208) 287-4800.

322 East Front Street • P.O. Box 83720 • Boise, Idaho 83720-0098
Phone: (208) 287-4800 Fax: (208) 287-6700 Website: idwr.idaho.gov/IWRB/

Idaho Water Resource Board
Cloud Seeding Program

Cloud Seeding in the State of Idaho

Kala Golden, Program Manager

IWRB Cloud Seeding Committee | May 14, 2025

Photo Courtesy of Idaho Power Company

Overview

- Background
- Operations in Idaho
- Current Projects
- Technical Presentations

What is Cloud Seeding?

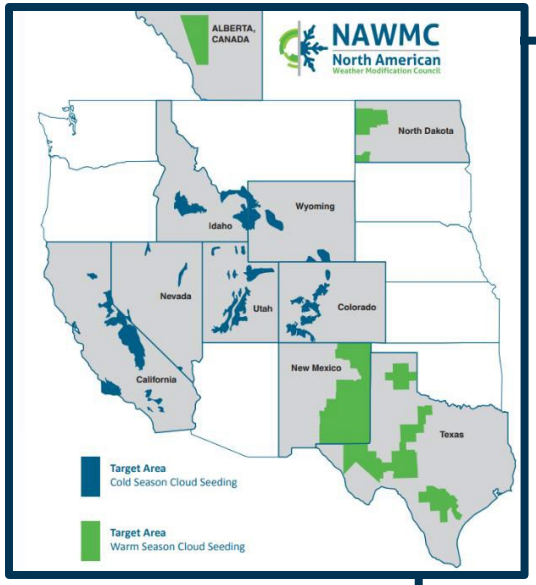
- **Cloud seeding** is a method of introducing aerosol particles into an ***existing*** cloud to generate ice formation.

- **Precipitation enhancement** is a form of cloud seeding used in Idaho to augment winter snowpack, our primary water storage reservoirs.

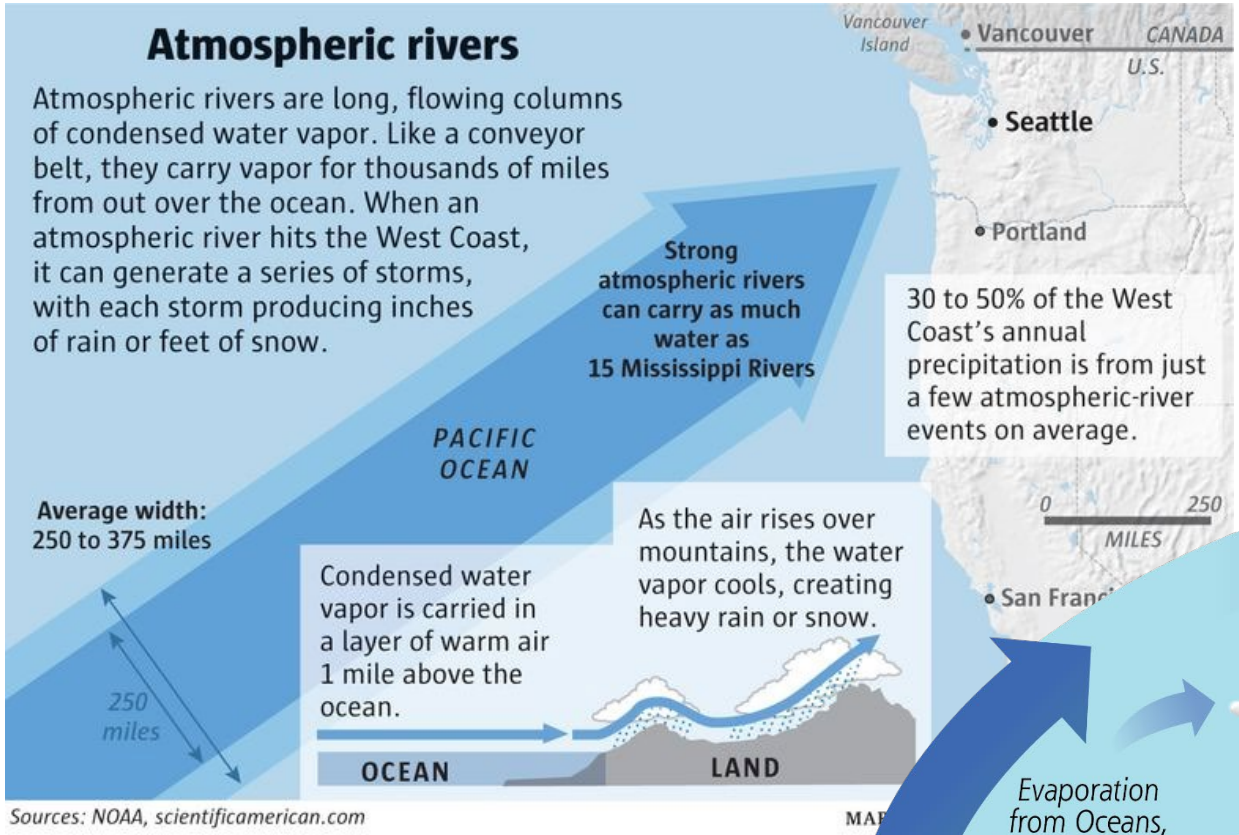
- The ***Objective*** of precipitation enhancement, is to support long term water sustainability for the State of Idaho.

Photo Courtesy of Joel Zimmer, WMI

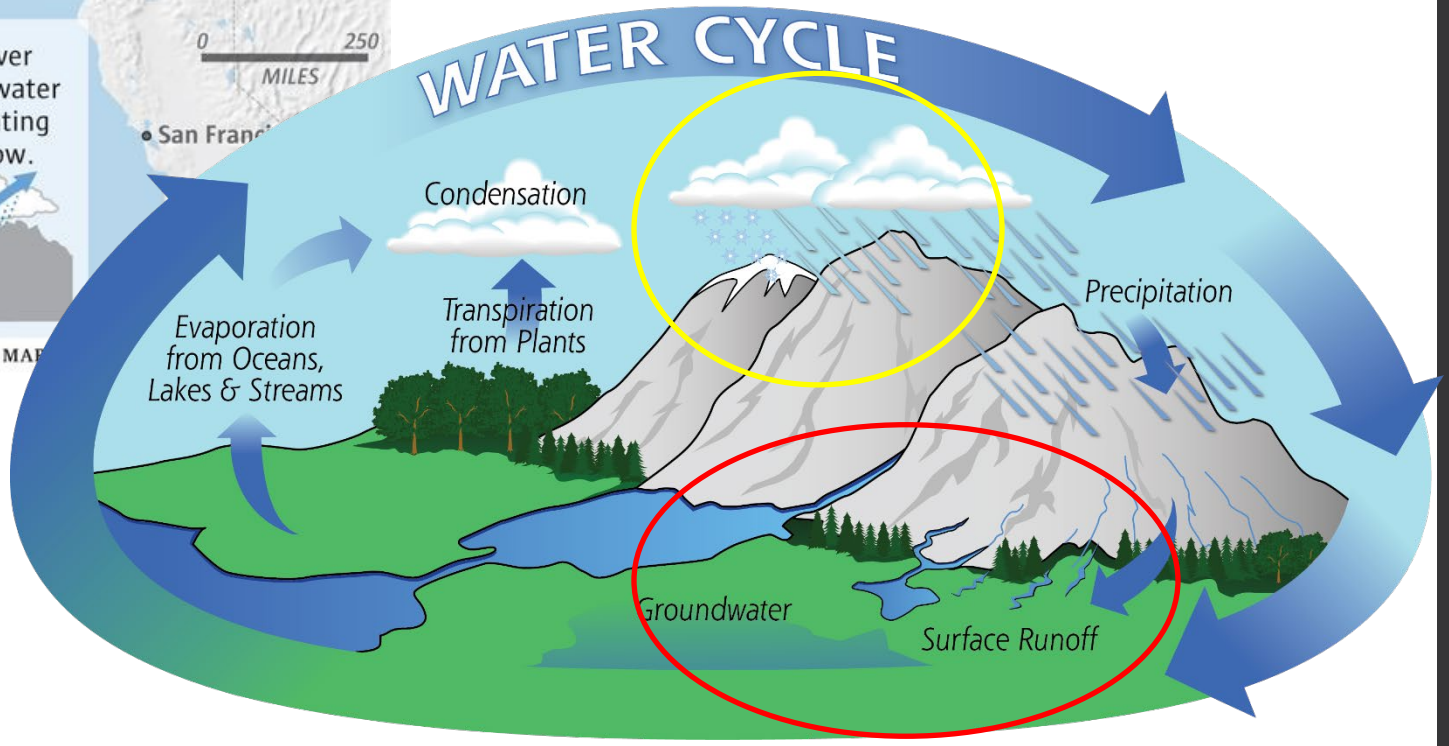
Water Use in the United States



Water Supply Sustainability



Far more fresh water available in the atmosphere HERE…. Then on or in the ground HERE



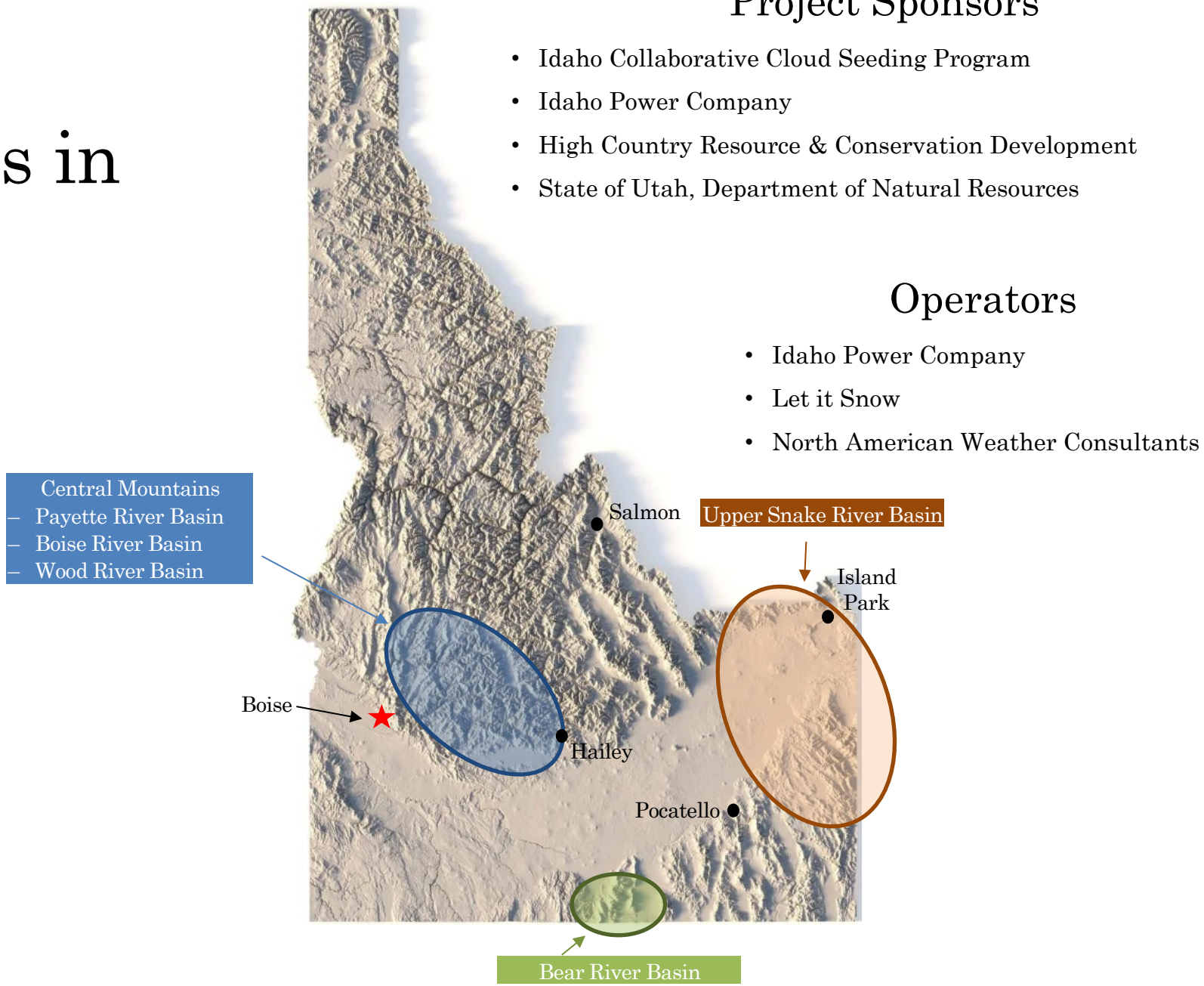
Cloud Seeding Operations in Idaho

Project Sponsors

- Idaho Collaborative Cloud Seeding Program
- Idaho Power Company
- High Country Resource & Conservation Development
- State of Utah, Department of Natural Resources

Operators

- Idaho Power Company
- Let it Snow
- North American Weather Consultants



Cloud Seeding Infrastructure & Equipment

Remotely Operated Ground Generators

Photos Courtesy of Idaho Power Company

Wing-mounted Flares

Photos Courtesy of Weather Modification International

Photos Courtesy of Let It Snow

Manual Ground Generators

Belly-mounted Ejectable Flares

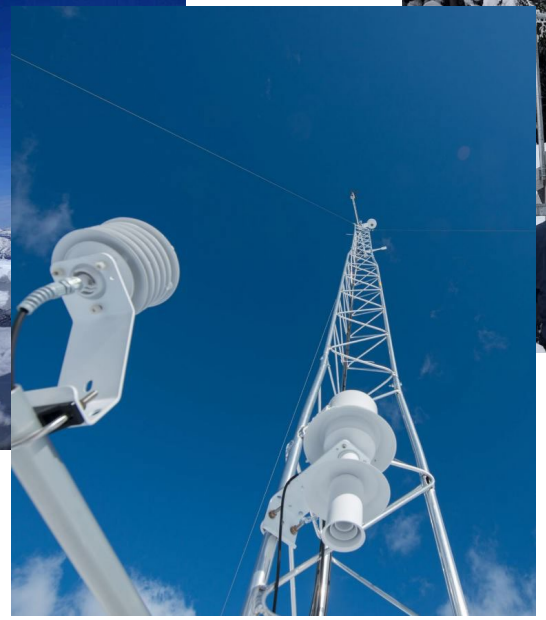
Cloud Seeding Weather Instrumentation

Weather Ballons

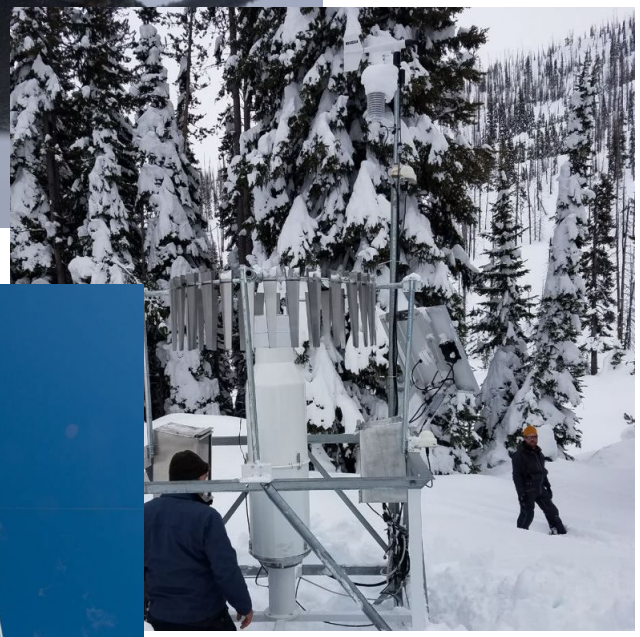
Icing Rate Sensors

Radiometers

Webcam

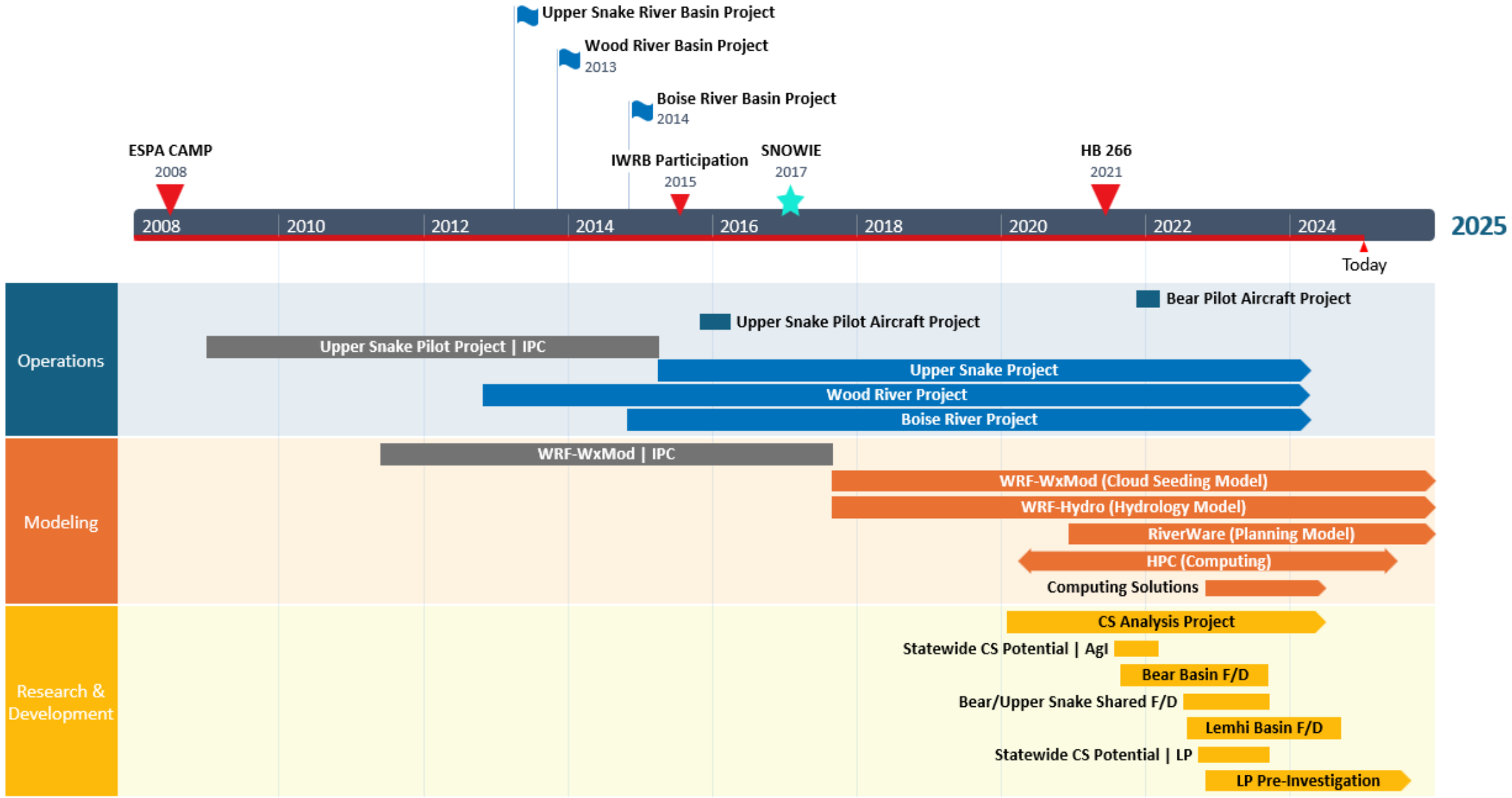


Surface Stations



Precipitation Gages

Idaho Collaborative Cloud Seeding Program Timeline



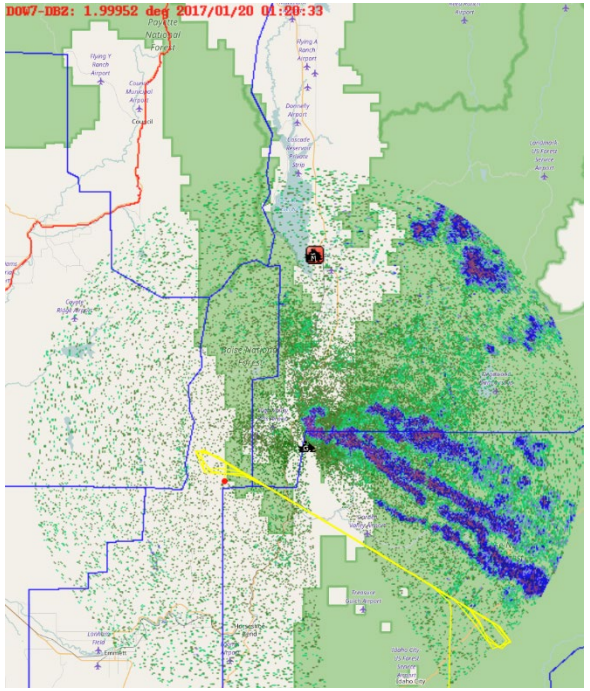
Cloud Seeding Analysis

Objective: Determine how cloud seeding effects water supply

Fundamentally, we know that:

- More precipitation will generally result in increased snowpack → increase streamflow
- Cloud seeding (CS) increases winter precipitation (*SNOWIE, 2017*)

1. *How much additional precipitation was produced?*
2. *How much water did the increase in precipitation add to the system?*
3. *Where does the increase in supply go to?*



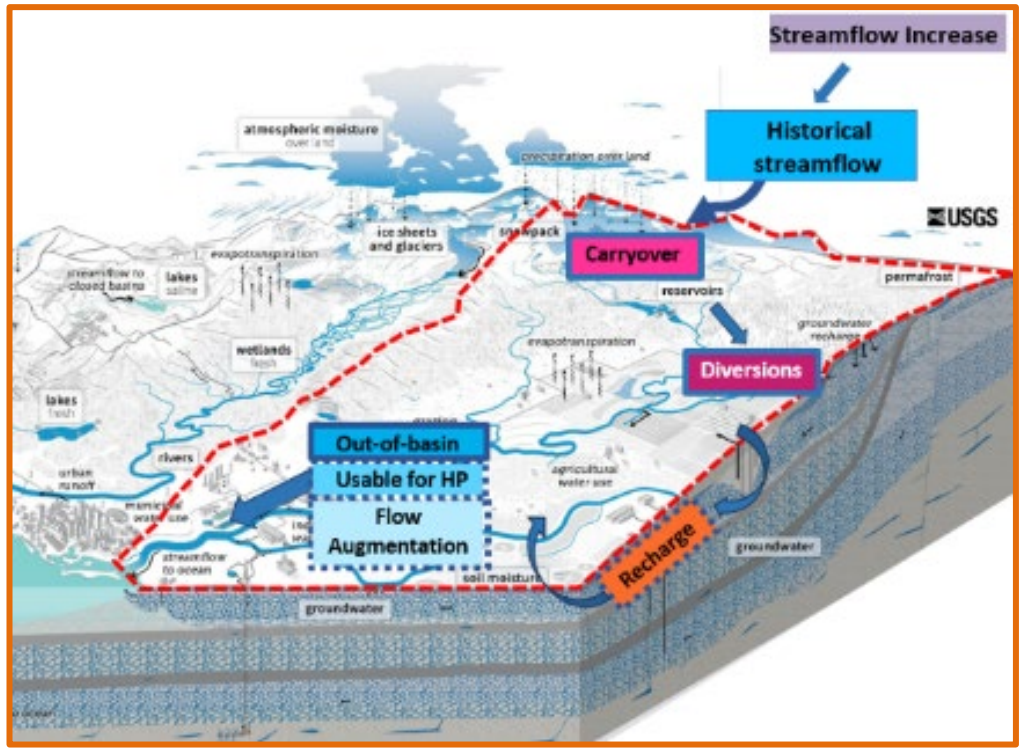
(*SNOWIE | DOW Radar Image, 2017*)

Cloud Seeding Analysis

Objective: Determine how cloud seeding effects water supply

- *How much did cloud seeding increase the precipitation?* *Cloud Seeding Model (WRF-WxMod)*
- *How much water does increased precipitation add to the system?* *Hydrologic Model (WRF-Hydro)*
- *Where does the increase in supply go to?* *Planning Model (RiverWare)*

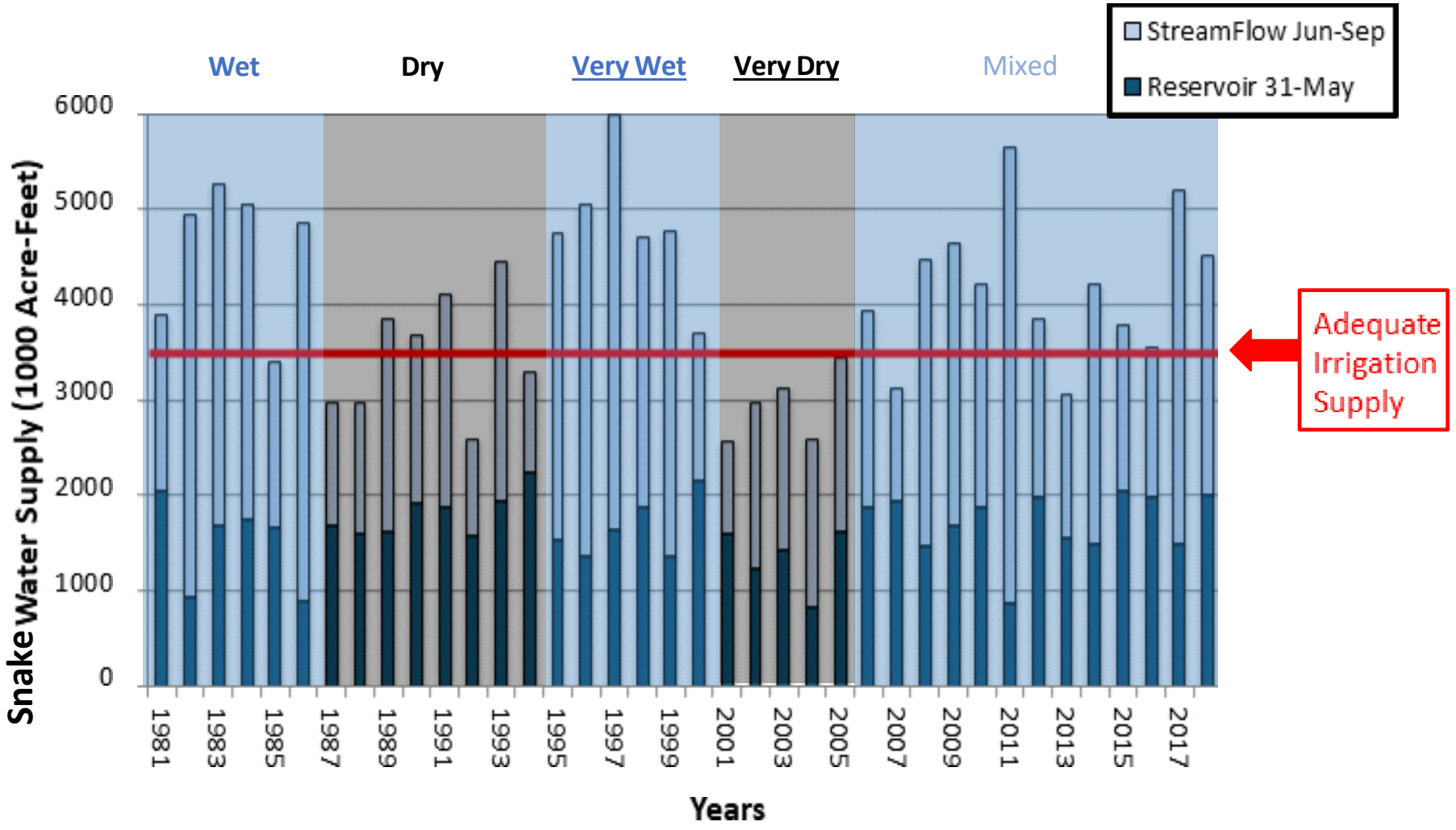
1. How does the hydrologic system work <u>before</u> inputs from cloud seeding?
2. How sensitive is the hydrologic system to change?



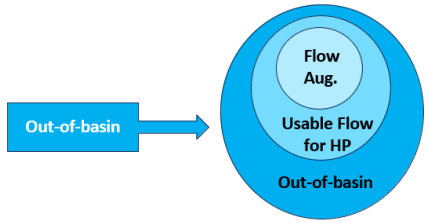
Snake River Basin Planning Model

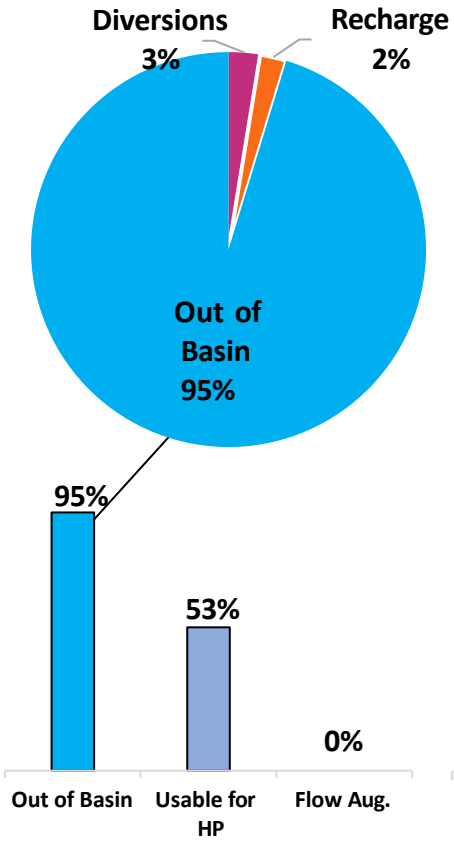
- Model developed based on organizational needs
- Bureau of Reclamation
  - Developed original Snake River model for planning purposes
- Idaho Power Company
  - Integrated Middle Snake reservoir operations & recharge for IRP and analysis
- Idaho Department of Water Resources
  - Integrated diversions; cloud seeding and recharge analysis
- Useful tool for collaboration on water management

Wet and Dry Periods (Short-term)

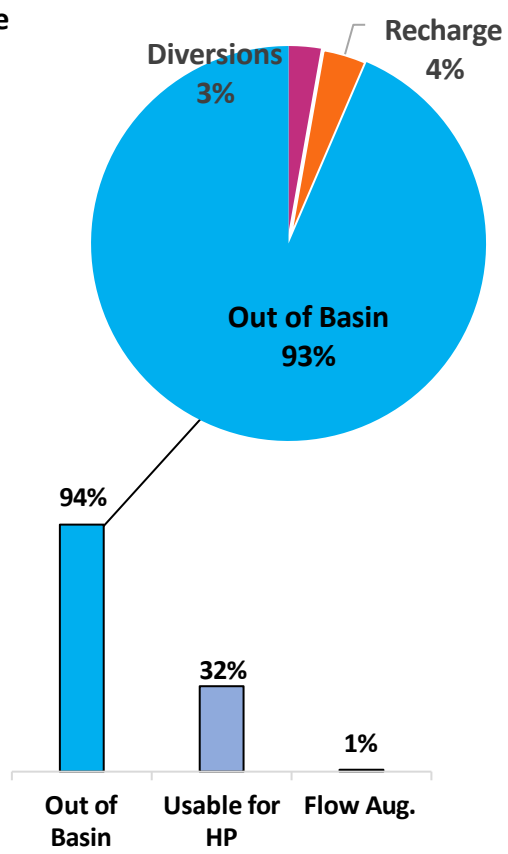


Wet and Dry Periods- Upper Snake Basin

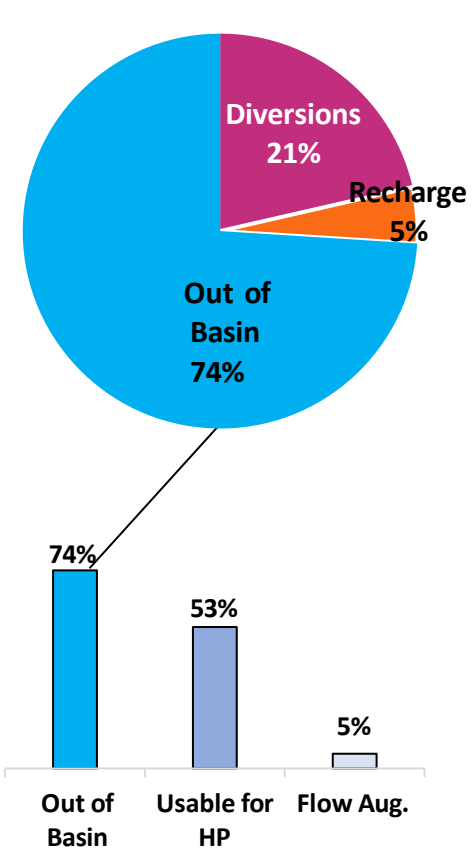




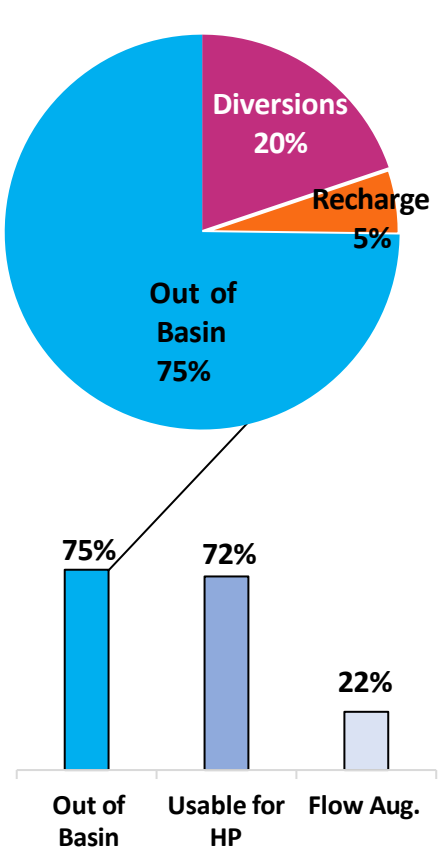
1995-2000
(5 years)



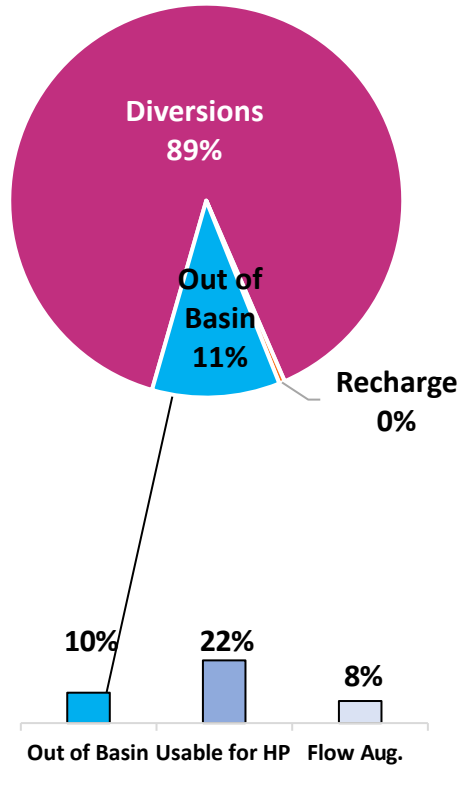
1981-1986
(5 years)



2006-2018
(12 years)



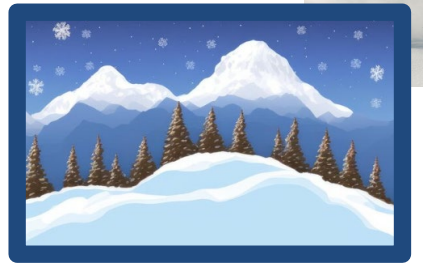
1987-1994
(6 years)

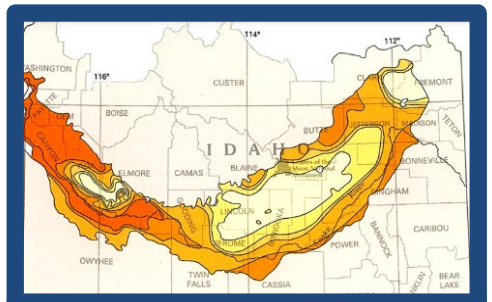


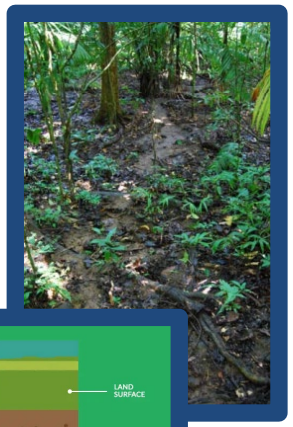
2001-2005
(4 years)

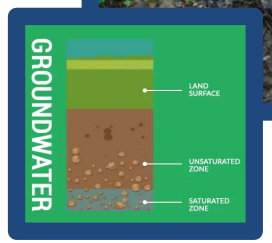
Very wet → **Very dry**

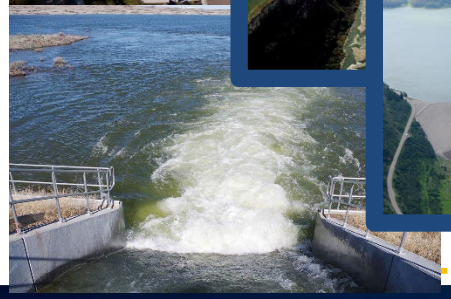
What are the benefits of increased snowpack and subsequent streamflow?

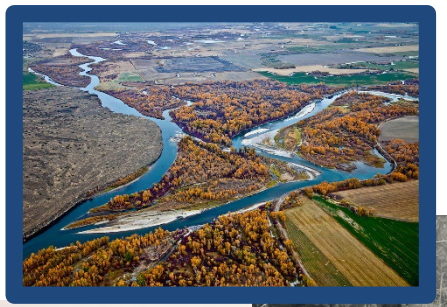


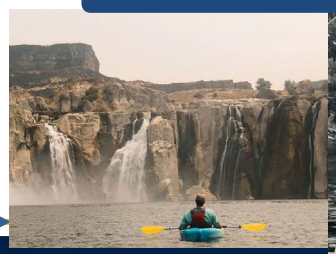


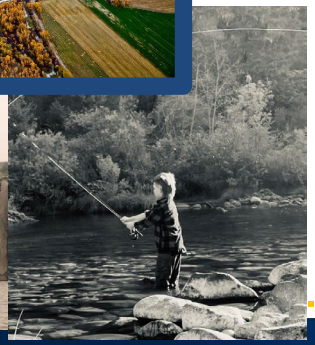


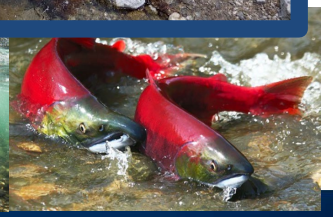


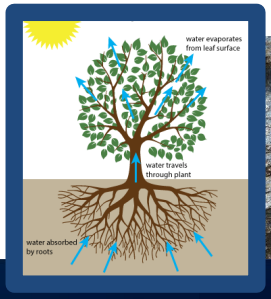




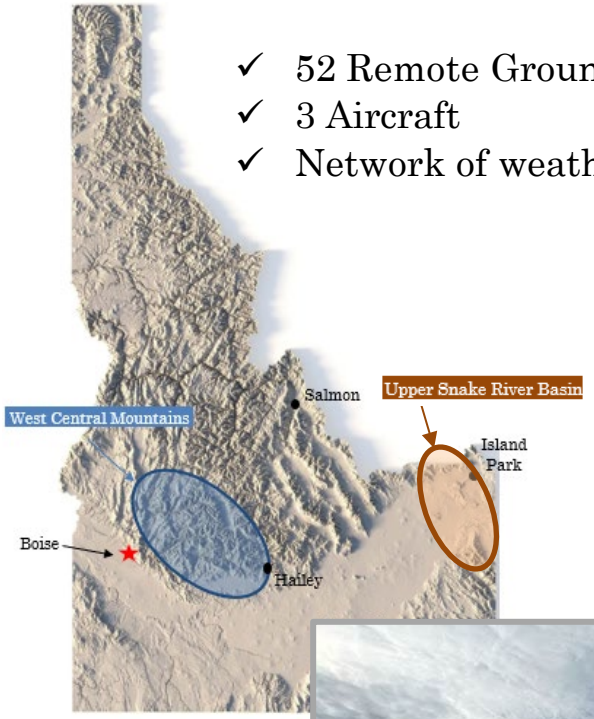








Idaho Collaborative Cloud Seeding Program | Payette*; Boise, Wood, Upper Snake River Basins



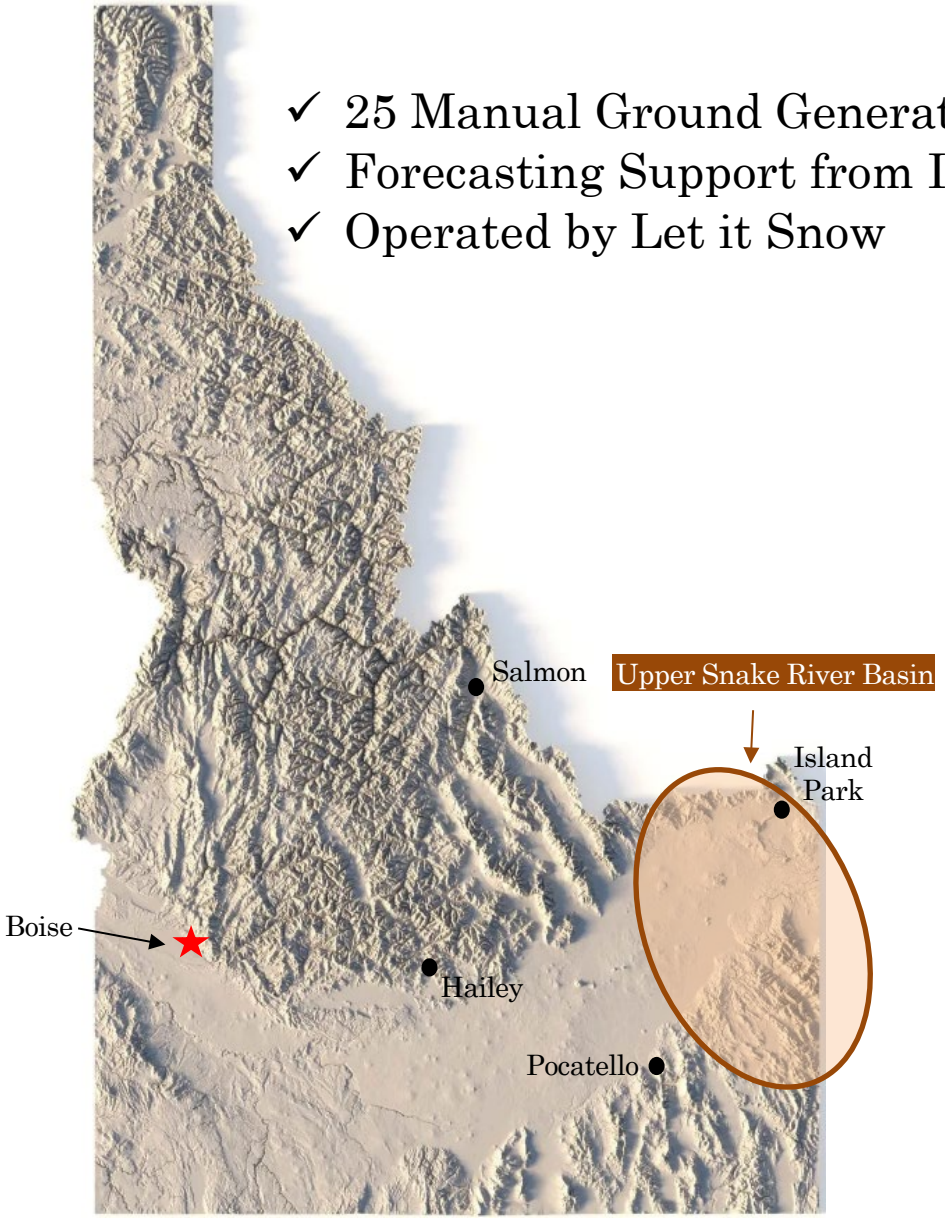
- ✓ 52 Remote Ground Generators
- ✓ 3 Aircraft
- ✓ Network of weather instrumentation

November 2024- April 2025

		AgI GGENS (hrs)	Aircraft (hrs)	BIPs & EJs (#)	Total AgI (kg)
Central Mountains	2025	1818	70	1193	41
	Average	2322	124	3958	63
Upper Snake	2025	1210	40	1031	27
	Average	1595	52	1163	37

HCRCD Cloud Seeding Program

- ✓ 25 Manual Ground Generators
- ✓ Forecasting Support from IPC
- ✓ Operated by Let it Snow



November 2024- April 2025

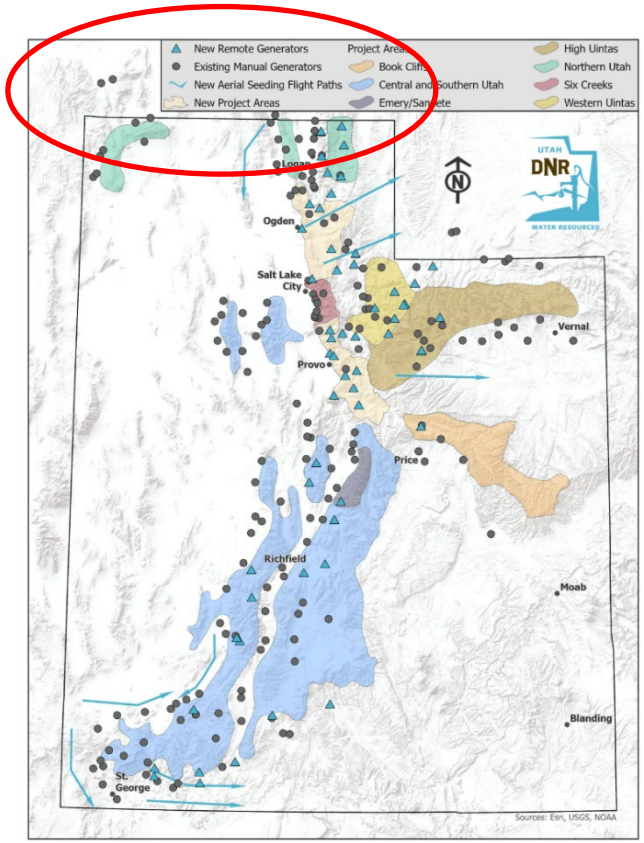
Total Hours of Operation:

Manual Generators: **1415.75**

Victor site Feb. 2025

Northern Utah Cloud Seeding Program

- ✓ 3 Manual Ground Generators in ID
- ✓ Operated by North American Weather Modification Consultants



November 2024- April 2025

Total Hours of Operation:

- Manual Generators: **1985.5**
- Remote Generators: **1715.7**

Liquid Propane Investigation

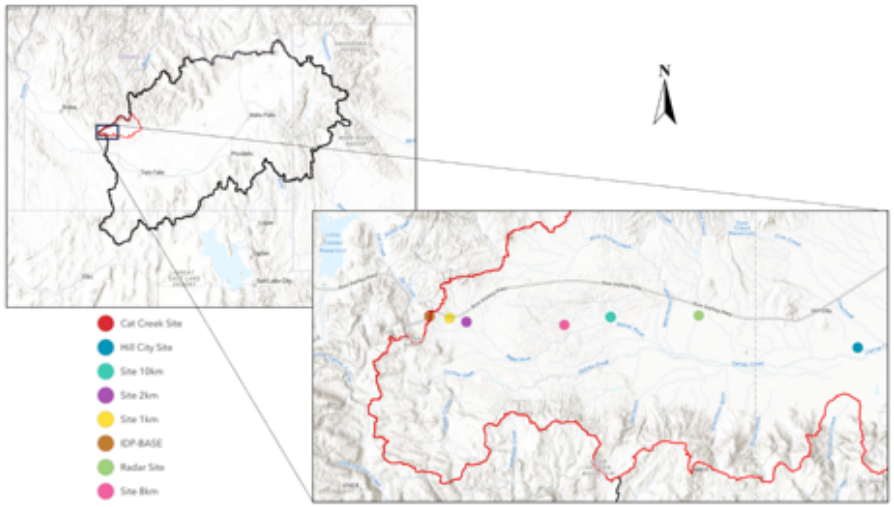


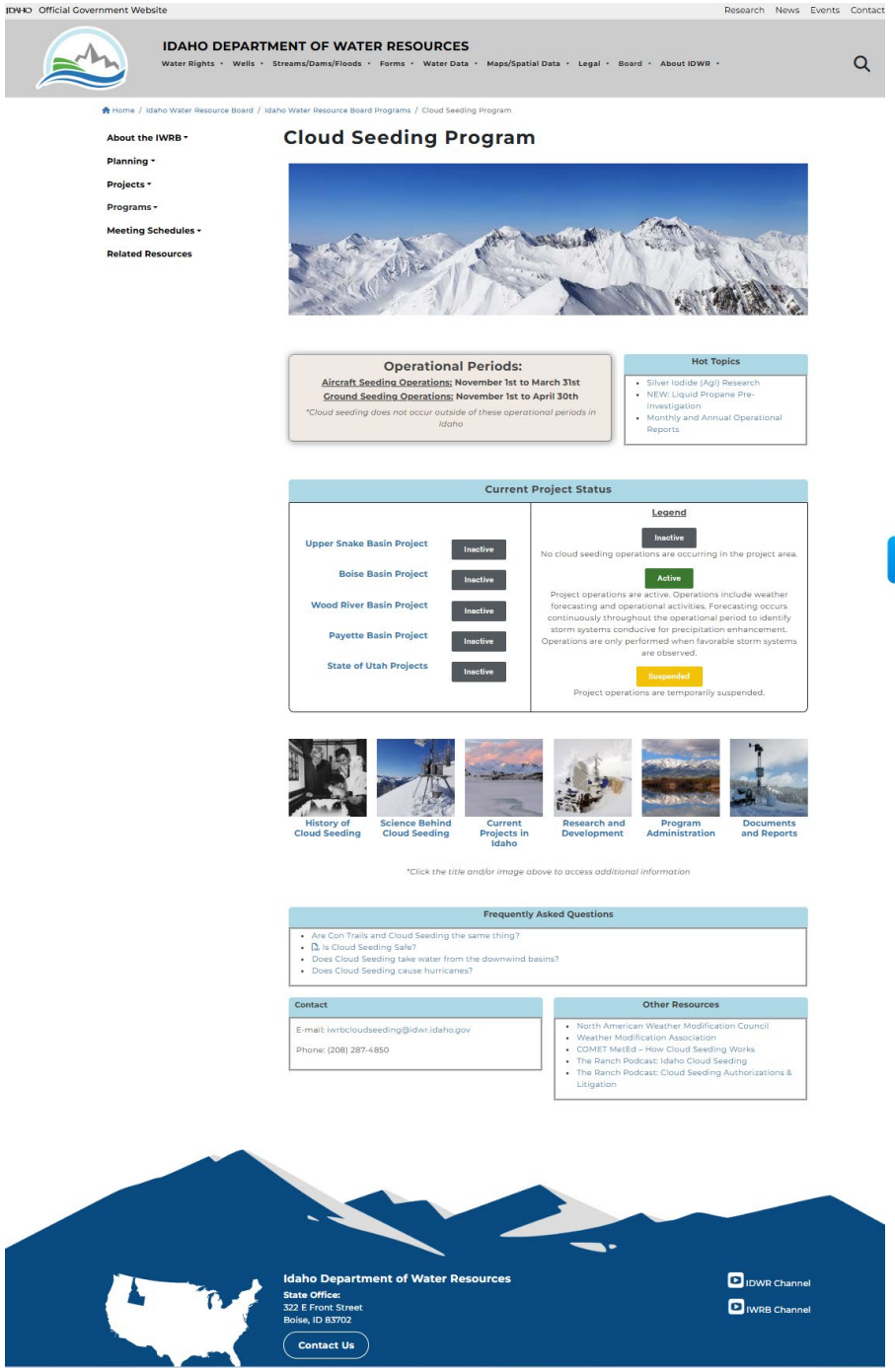
Figure 1. Map of study area. The black outline is the Upper Snake Basin, and the red outline is the Camas Basin. Cat Creek and IDP-BASE overlap with each other.

Data Collected:

- Radar (MRR and x-band) horizontal and vertical scans
- Drone aerial surveys
- Snowmobile surveys
- Snowboard snowfall amount
- Snow pit information
- Precipitation amount (7-days worth)
- Meteorological observations (air temperature, dew point, wind speed/direction)
- Radiometer integrated liquid water
- Icing rate

Seeding Operations

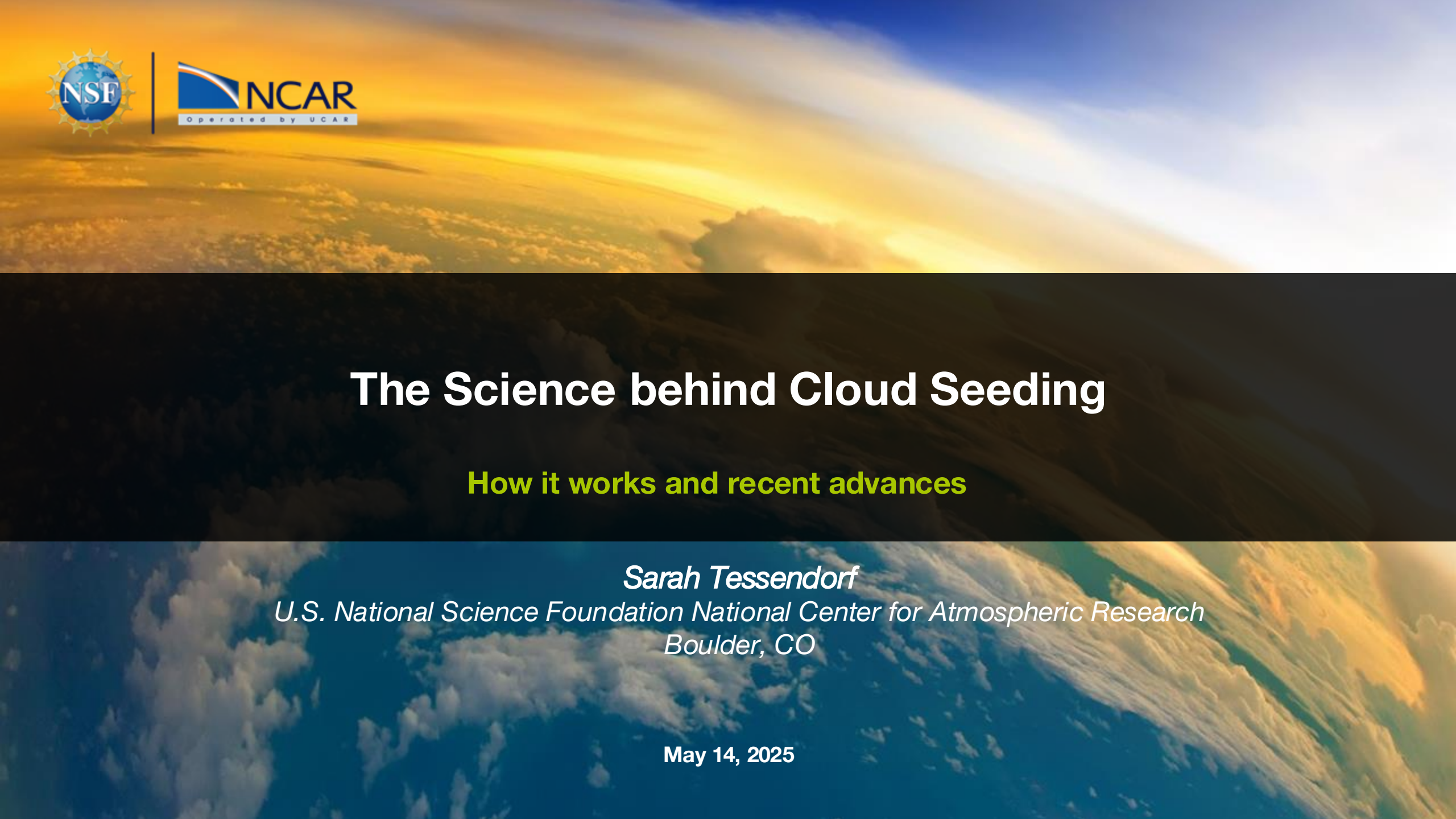
- 11 Total events Dec 2024 – Mar 2025
- 9 Seeded storms
- 1 Dry Run
- 1 Natural Conditions
- Three IOPs exhibited possible seeding signatures based on X-band radar imagery



https://idwr.idaho.gov/iwrb/programs/cloud-seeding-program/

208-287-4850

IWRBCloudSeeding@IDWR.Idaho.Gov



The Science behind Cloud Seeding

How it works and recent advances

Sarah Tessendorf
U.S. National Science Foundation National Center for Atmospheric Research
Boulder, CO

May 14, 2025

Key Messages

Cloud seeding aims to enhance precipitation

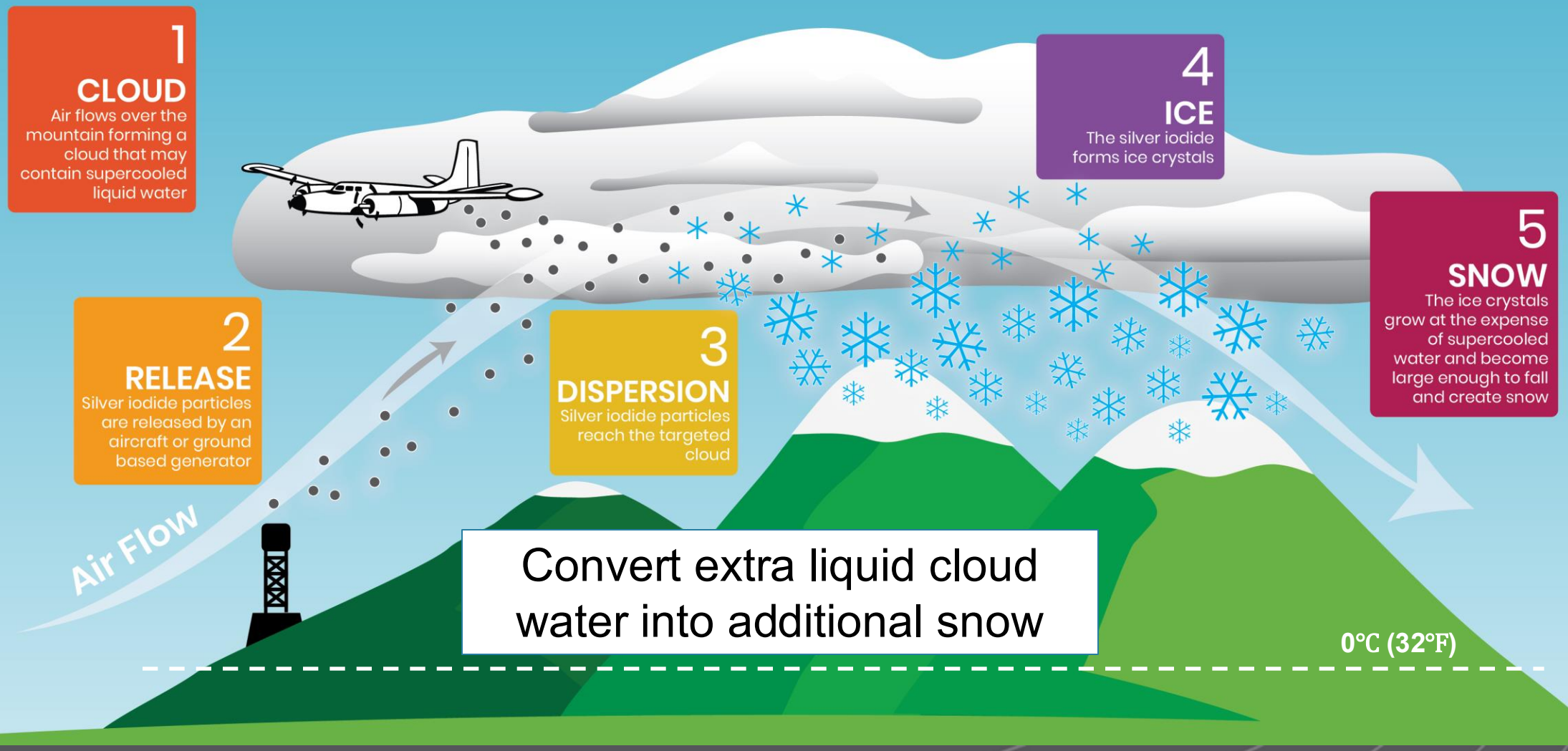
Recent scientific studies have proven that cloud seeding works to enhance snowfall in winter storms over the mountains

Advances in computer models help quantify the impacts of cloud seeding on precipitation and streamflow

Cloud seeding effectiveness varies by storm and location—feasibility studies are needed

WINTER CLOUD SEEDING

WITH SILVER IODIDE



NCAR RAL

NSF | NCAR

The Origins of Cloud Seeding

DRY-ICE SEEDING cut race-track pattern into clouds over Rome, N.Y. Dropping dry ice from plane was first successful way of making rain artificially.

New York dry ice seeding 1946 (Life Magazine)

Early work in cloud seeding by Schaefer and Langmuir in 1946

—1946—

Proof of concept that liquid clouds could be seeded to produce ice, which would deplete the liquid cloud

It has taken over 70 years to prove the entire seeding conceptual model

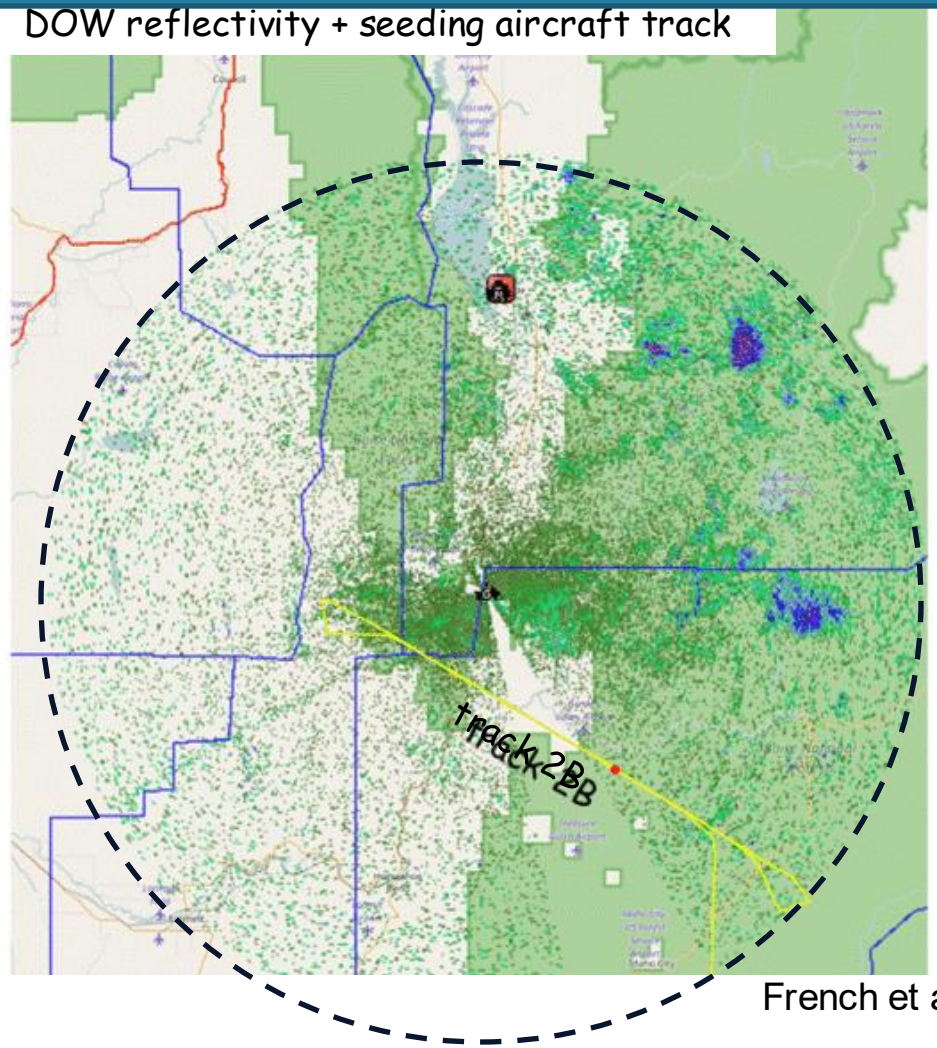
- Challenges with large natural variability of weather made it hard to isolate effects due to seeding
- Limited observations and computer modeling capabilities

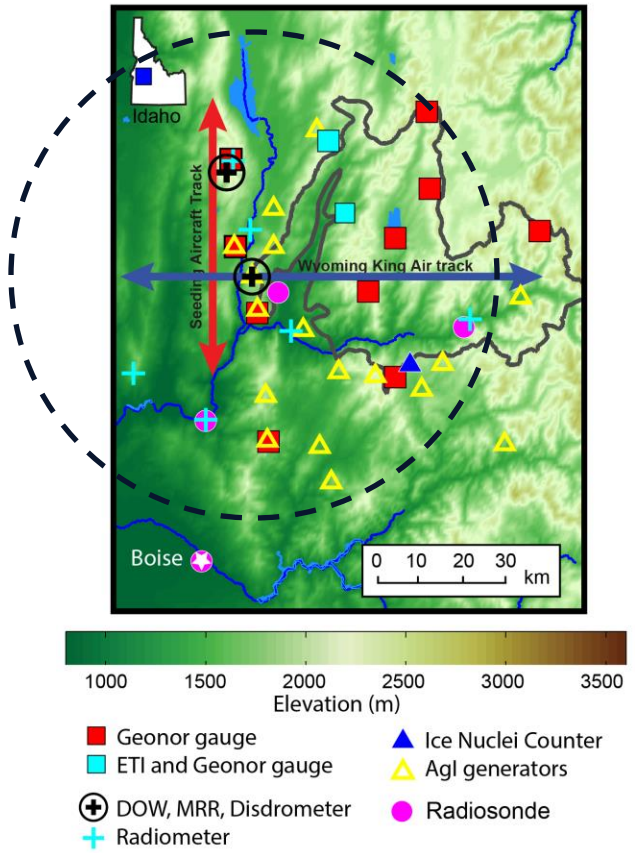
Cloud seeding produces ice and snow in SNOWIE

Seeded and **N**atural **O**rographic **W**intertime clouds: the **I**daho **E**xperiment
January 7–March 17, 2017

- Silver iodide (AgI) produces ice
- Ice grows into snow that falls to the ground

The "zig zag" pattern is an unambiguous seeding signature from airborne seeding



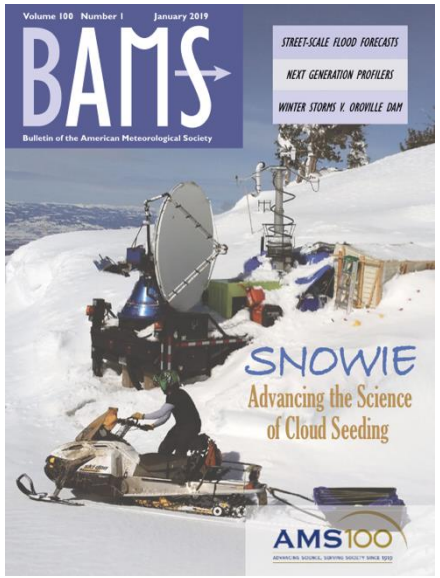


French et al. (2018) PNAS, Tessendorf et al. (2019) BAMS

Where does the science go next?

The conceptual model has been proven for winter orographic cloud seeding with silver iodide in the SNOWIE field project

- Where and when does cloud seeding with silver iodide **work most effectively**?
- How effective is cloud seeding with **liquid propane**?
- How do we confidently **quantify the impacts** of cloud seeding?
- How does cloud seeding impact snowmelt-driven **streamflow**?
- How **cost effective** is cloud seeding to augment water resources?



We are working to address these questions (and more) with new advances in computer modeling and observational capabilities

Further Training Opportunities

Free Online Training Module:

Produced by the COMET Program
https://www.meted.ucar.edu/USBR/cloud_seeding/

You will be asked to create an account to access this training module and any others in the catalog

Key Messages

Cloud seeding aims to enhance precipitation

Recent scientific studies have proven that cloud seeding works to enhance snowfall in winter storms over the mountains

Advances in computer models help quantify the impacts of cloud seeding on precipitation and streamflow

Cloud seeding effectiveness varies by storm and location—feasibility studies are needed

Summary of Common Questions

- **How does seeding with silver iodide impact the environment?**
  - Silver is naturally occurring in water and soil and the amount from cloud seeding is hard to detect and since it is insoluble, it does not pose a health hazard

- **What about extra area effects (are we "Robbing Peter to pay Paul")?**
  - The impact of cloud seeding on water vapor in the atmosphere is very small, and the atmosphere recharges water vapor over time as well

- **Could cloud seeding lead to hazards like flooding?**
  - Suspension criteria are used by operational cloud seeding programs to not conduct cloud seeding in certain situations, to mitigate real or perceived hazards like flooding and avalanches
  - The impact of cloud seeding on precipitation is small relative to the natural variability of precipitation, so cannot change a cloud that would not create a flood and turn it into a flood producing storm

Condensation trails (Contrails)

FlightAware 5/12/2025

- **Ingredients for a cloud**: 1) cooling, 2) moisture, and 3) aerosol particles for water vapor to condense on
- Human activities create clouds under special atmospheric conditions
  - When the atmosphere is cold and humid (1) and (2)
  - Adding moisture (2) and/or aerosol particles (3) to the air creates clouds, called condensation trails (contrails) when behind a jet or car

Jet Contrails

Photo of sky with contrails from UCAR Sci Ed

Image (Courtesy J. Thomissen) on NASA Earthdata

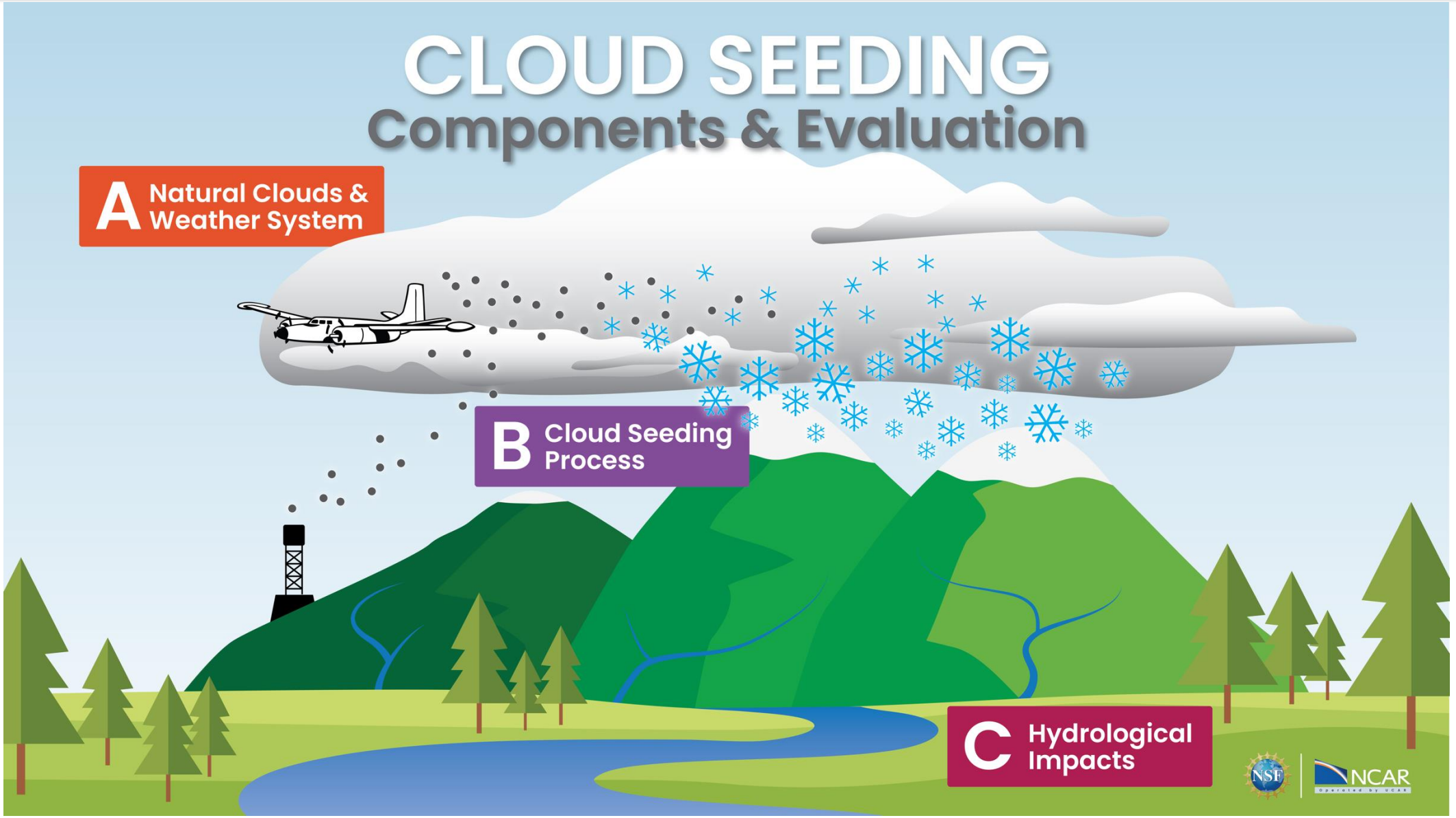
Contrails from a car

https://www.pa.uky.edu/~straley/THE/heat/puff.htm

Industrial Exhaust Clouds

NOAA Research webpage

Idaho Ongoing Evaluation Efforts



Operational Cloud Seeding in Southern Idaho

Shaun Parkinson

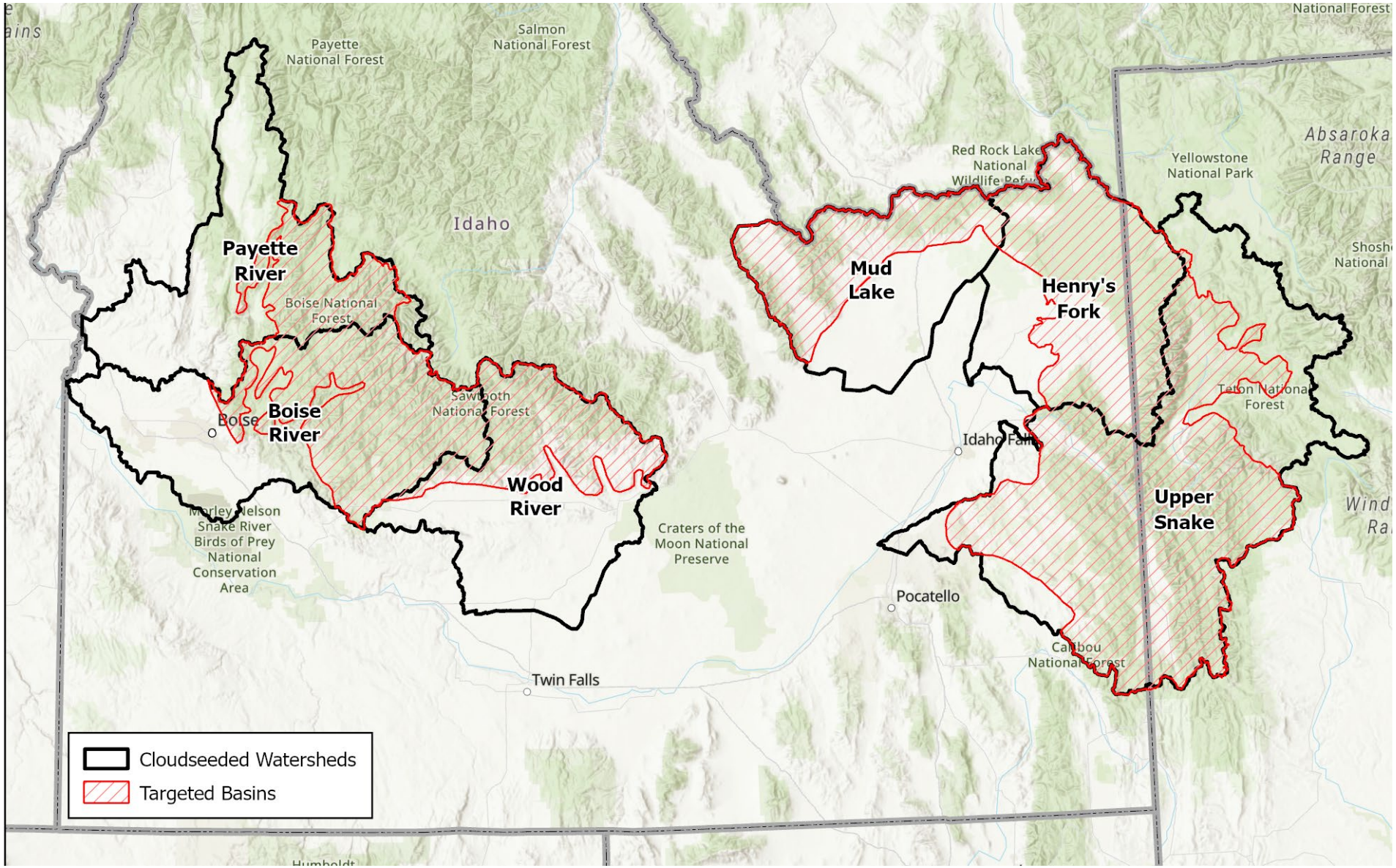
Meteorology and Cloud Seeding Leader

May 14, 2025

Operational Cloud Seeding In Idaho – Why?

- High-elevation snowpack is a natural ‘reservoir’ in the Snake River watershed
  - High-elevation snow is the last to melt.
  - This snow enhances river flows into and through the summer.
- Cloud seeding in Idaho increases high-elevation snowpack
- Benefits of the additional water include:
  - Improved aquatic ecosystem (water quality and fish habitat)
  - Irrigated agriculture
  - Municipal
  - Industry
  - Recreation
  - Hydropower

Cloud Seeding in Snake River Basins



Definitions

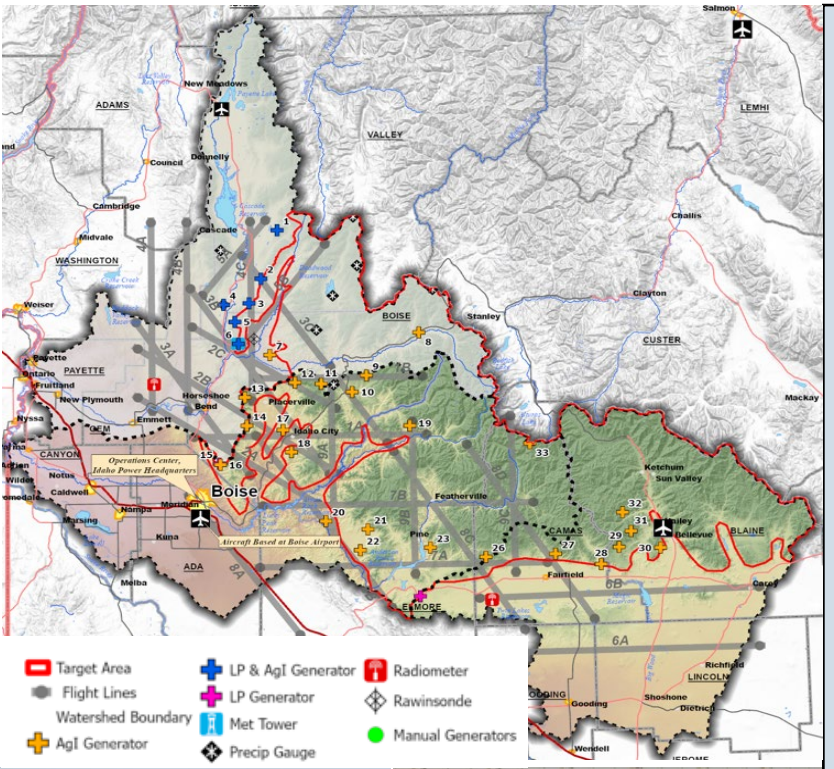
Weather Models

- **GFS** – Global Forecast System. A global computer weather model, run by National Weather Service.
- **NAM** – North American Mesoscale. A computer model of North America run by National Center for Environmental Prediction.
- **WRF** – Weather Research and Forecast model. A numerical weather forecasting model that is widely used for high resolution weather forecasting, evaluations and research.
- **WRF NAM** – WRF downscale (higher resolution) of a NAM forecast
- **WRF GFS** – WRF downscale (higher resolution) of a GFS forecast
- **WRF-WxMod** – a numerical model based on WRF that is capable of simulating cloud seeding (introduction of additional ice nuclei)

General

- **NWS** – National Weather Service
- **NRCS** – Natural Resource Conservation Service
- **RFC** – River Forecast Center
- **KAF** – Thousands of Acre-Feet
- **SNOTEL** – network maintained by NRCS, SWE
- **SWE** – Snow Water Equivalent
- **AgI** – Silver Iodide
- **BIP** – Burn In Place (flare)
- **EJ** – Ejectable (flare)
- **GGEN** – Ground Generator – ground instrument that releases silver iodide

Cloud Seeding in Snake River Basins



Water Year 2025

Central Mountains

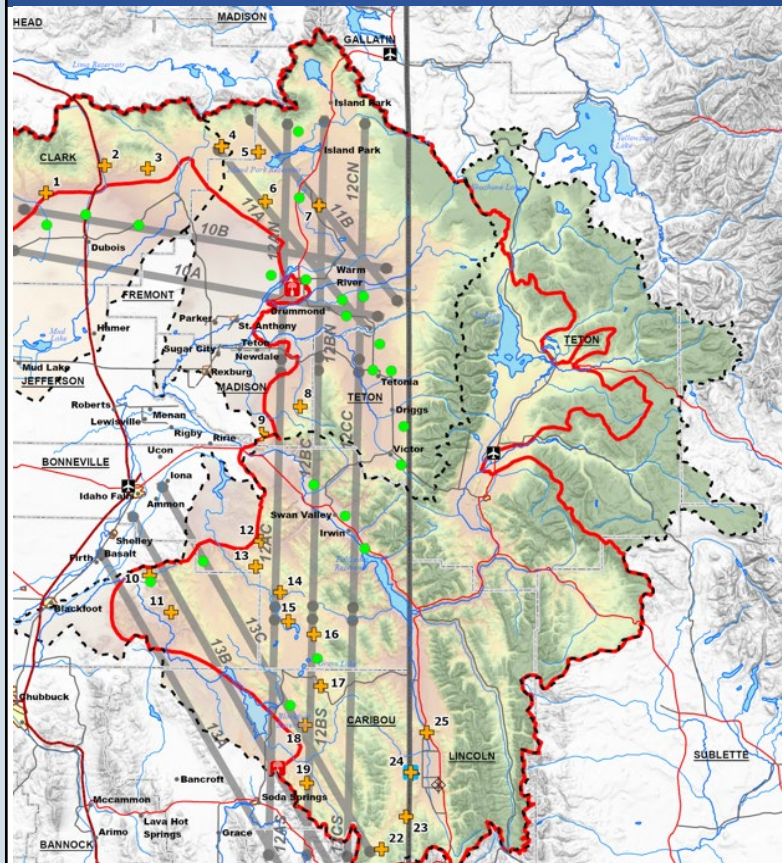
- 39 Idaho Power Remote Ground Generators
  - 24 Payette
  - 15 Boise/Wood
- 2 Aircraft

Upper Snake

- 25 Idaho Power Remote Ground Generators
- 1 Aircraft
- 25 Let It Snow Manual Ground Generators

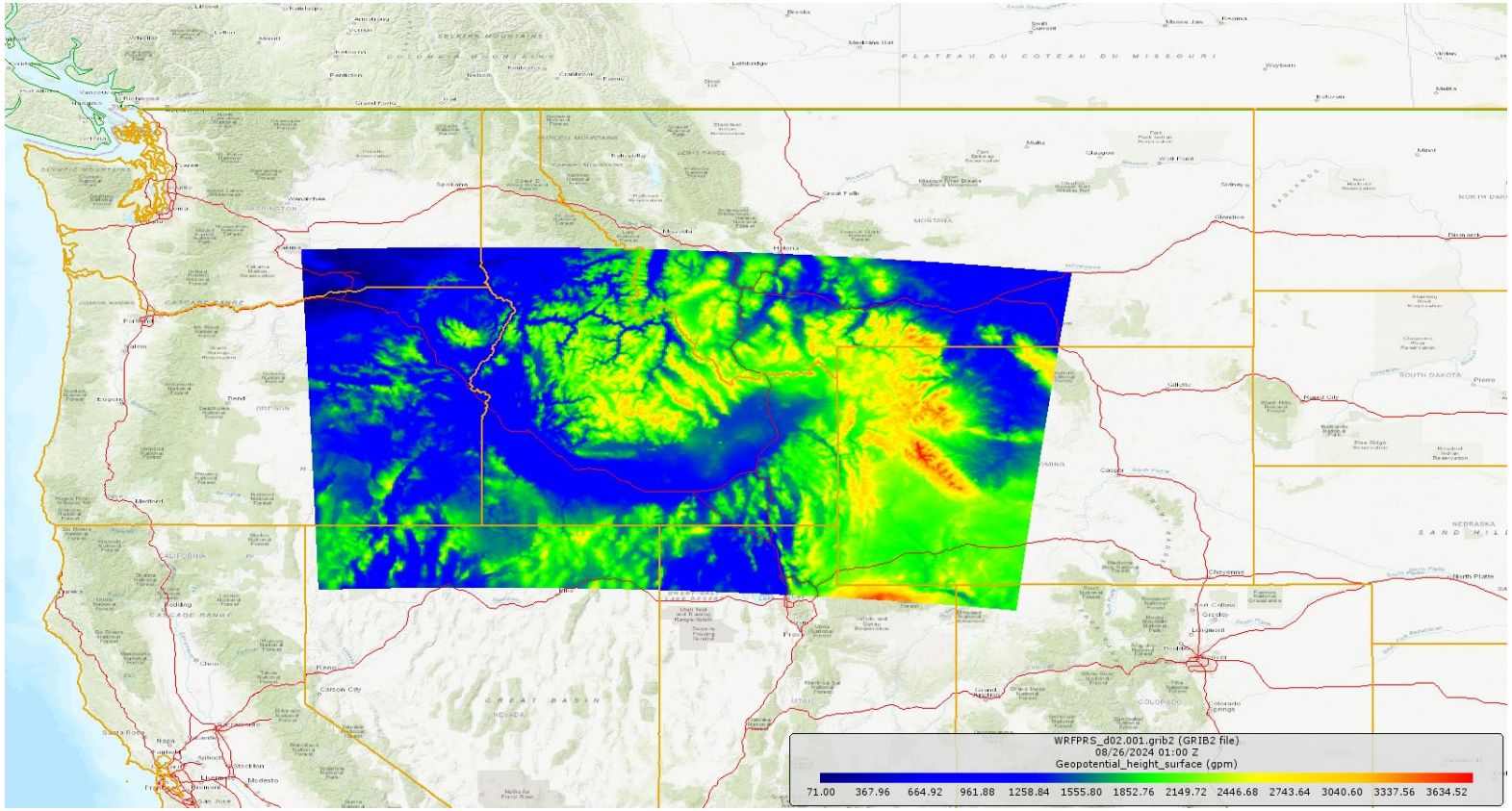
Across the Program

- High Performance Computing System
- High Resolution WRF Weather Model
- WRF-WxMod Module
- High Resolution weather instrumentation
- Cameras



Weather Forecasting - WRF

- Outer domain 5.4 km
- Inner domain 1.8 km
- 48 layers
- WRF GFS
  - Initialized with GFS
  - Two times per day at 00Z & 12Z 240 hours into the future
  - Two times per day at 06Z & 18Z 120 hours into future
- WRF NAM
  - Initialized with NAM
  - Runs four times daily
    - 00, 06, 12, 18Z
  - Runs 84 hours into the future
- WRF WxMod
  - Initialized by WRF NAM
  - Runs four times daily
  - Runs 48 hours into the future



Forecasting – Observations

Cloud Seeding Operations

Though Water Year 2025

		AgI GGENS (hrs)	Aircraft (hrs)	BIPs & EJs (#)	Total AgI (kg)
Central Mountains	**2025**	1818	70	1193	41
	Average	2322	124	3958	63
Upper Snake	**2025**	1210	40	1031	27
	Average	1595	52	1163	37

Context:

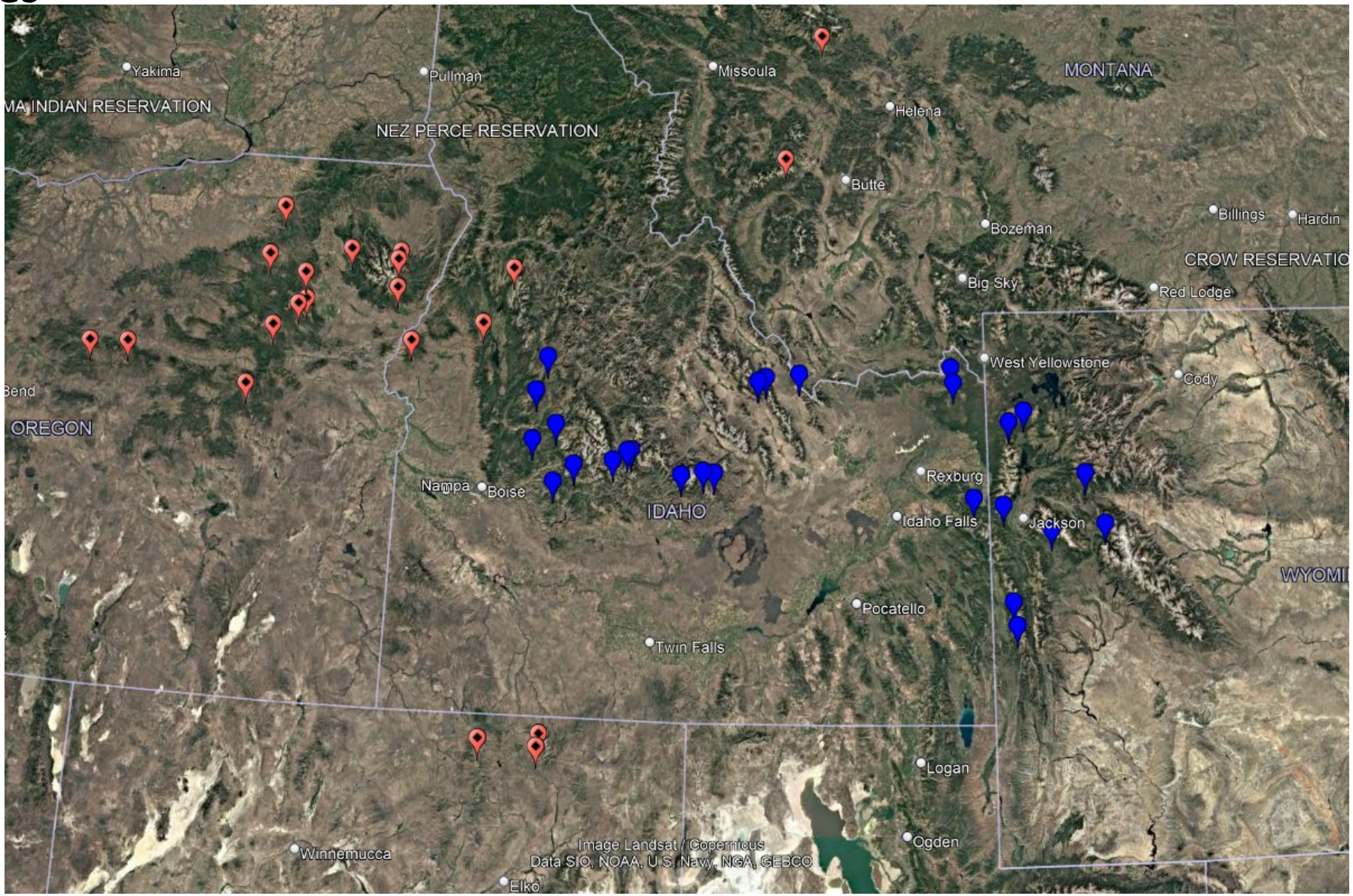
- On average, 100 kg AgI released each year,
- Total target area is approximately 14,000 sq-miles,
- If 100% of AgI released falls in target area (unrealistic),
- That is less than 1 tablespoon of AgI per sq-mile per year.

Target-Control

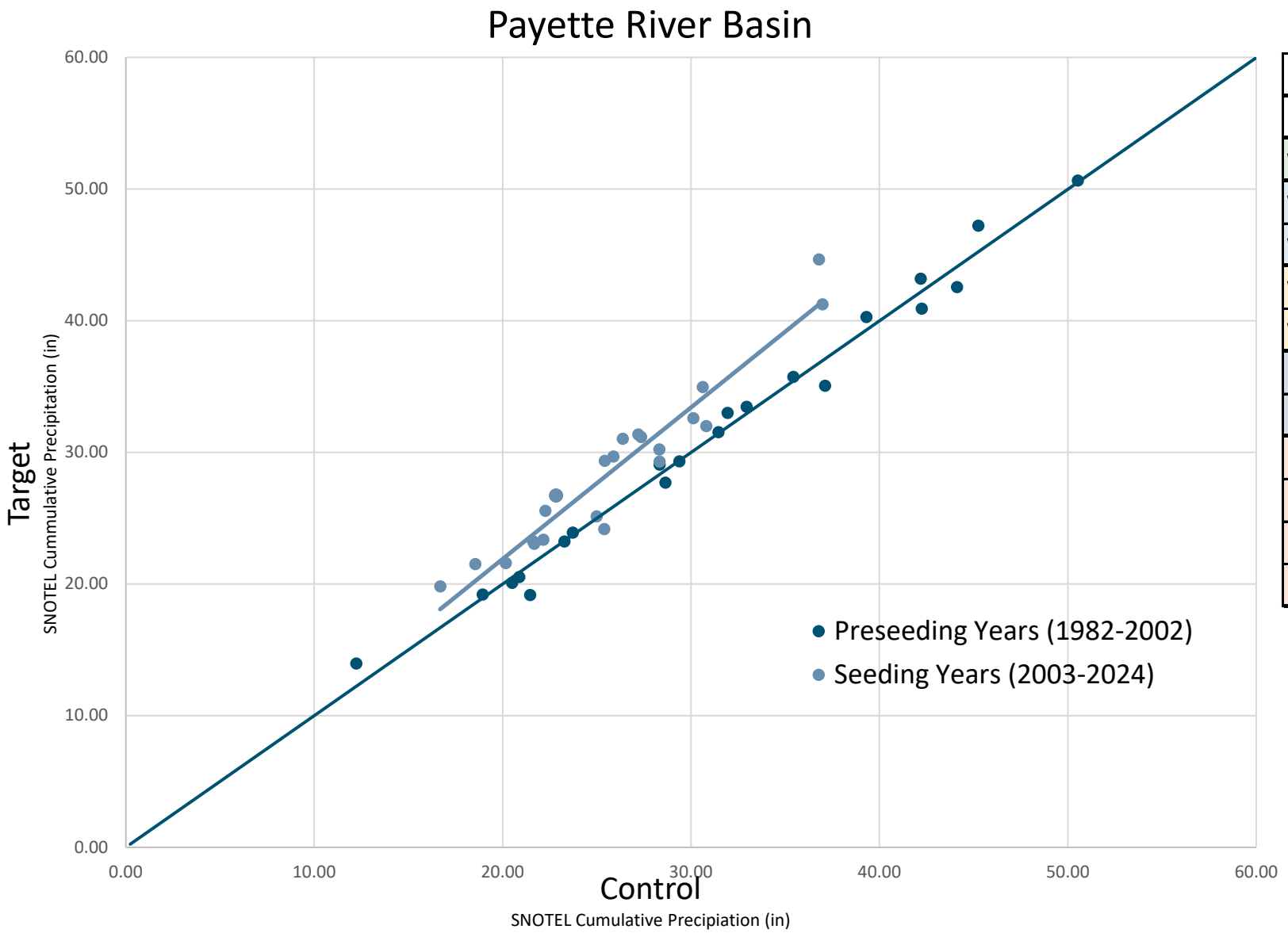
Precipitation Gages

Targets

Controls



Target-Control Analysis



November 1 - April 1			
Zones	**Basin**	**Years**	**Average Benefit**
WP1	Payette	2003-2024	10.7%
WP2	Boise	2013-2024	11.0%
WP3	Boise	2013-2024	10.4%
WP4	Wood	2013-2024	9.3%
WP5	Wood	2013-2024	9.7%
EP1	Henry's Fork	2008-2024	4.8%
EP2	Henry's Fork	2008-2024	6.4%
EP3	Upper Snake	2008-2024	10.0%
EP4	Upper Snake	2008-2024	8.8%
EP5	Upper Snake	2008-2024	8.9%
EP6	Upper Snake	2008-2024	7.8%

Central Mountains 10%

Upper Snake

- Henry's Fork 5.5%
- Upper Snake 9%

Benefit Estimates from Other Projects*

- **King's River Basin, Sierra Nevada Mountains, Calif.**

  Streamflow **5.1% increase**, 90% confidence (*Silverman 2007*)

- **Kern River Basin, Sierra Nevada Mountains, Calif.**

  Streamflow **6.4% increase,** 90% confidence (*Silverman 2008*)

- **Vail Basin in Gore Mountain Range, Colorado**

  Streamflow **6.3% to 28.8%** increase (*Silverman 2009*)

- **Bridger Range, Montana**

  Snow Water Equivalent ~**15% increase** (*Super & Heimbach 2009*)

- **Snowy Mountains, SE Australia**

  Precipitation **14% increase**, 97% confidence (*Manton and Warren 2011)*

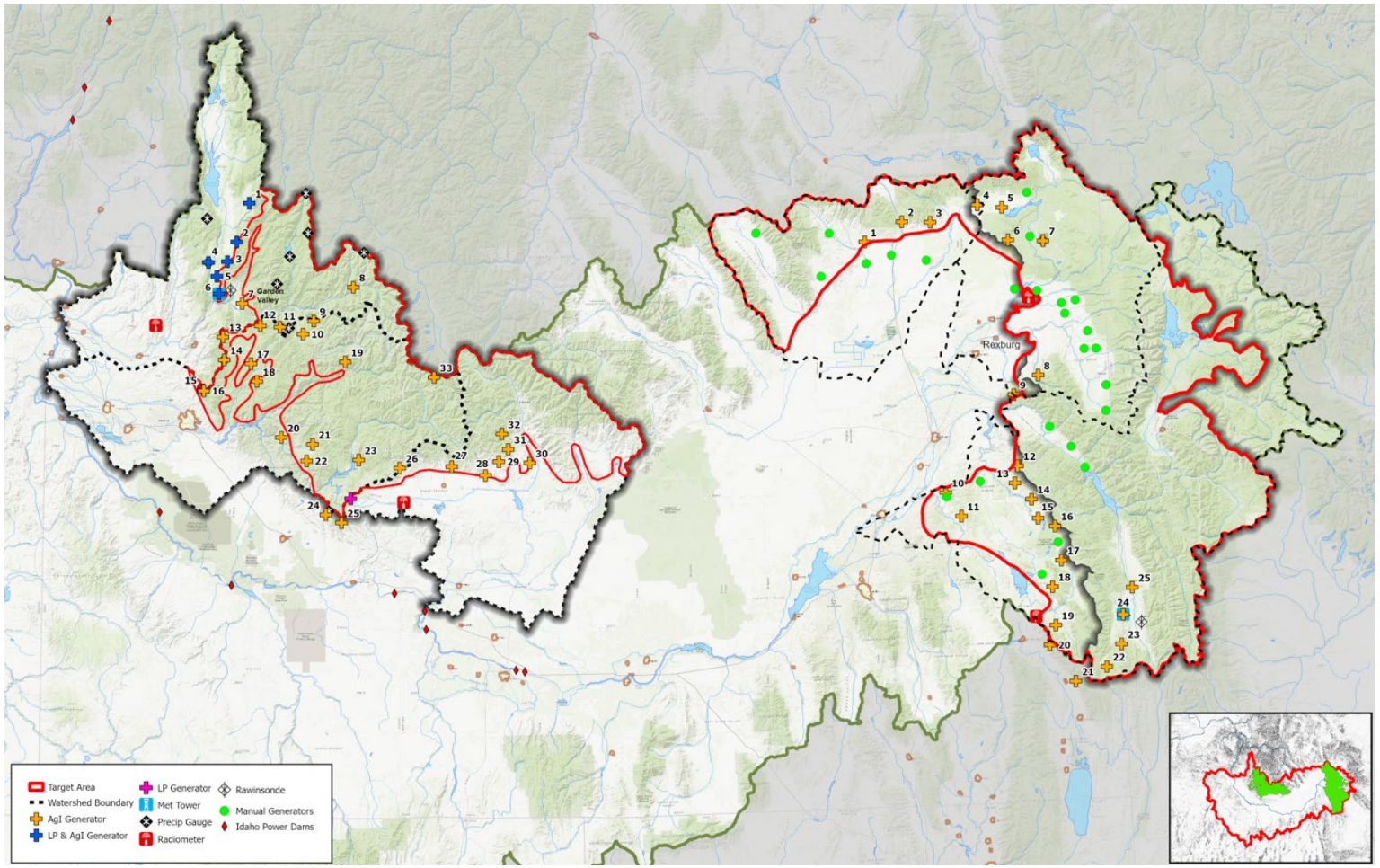
**These projects used ground seeding only*

Estimated Runoff Benefits

Average Additional Runoff
(Natural flow)

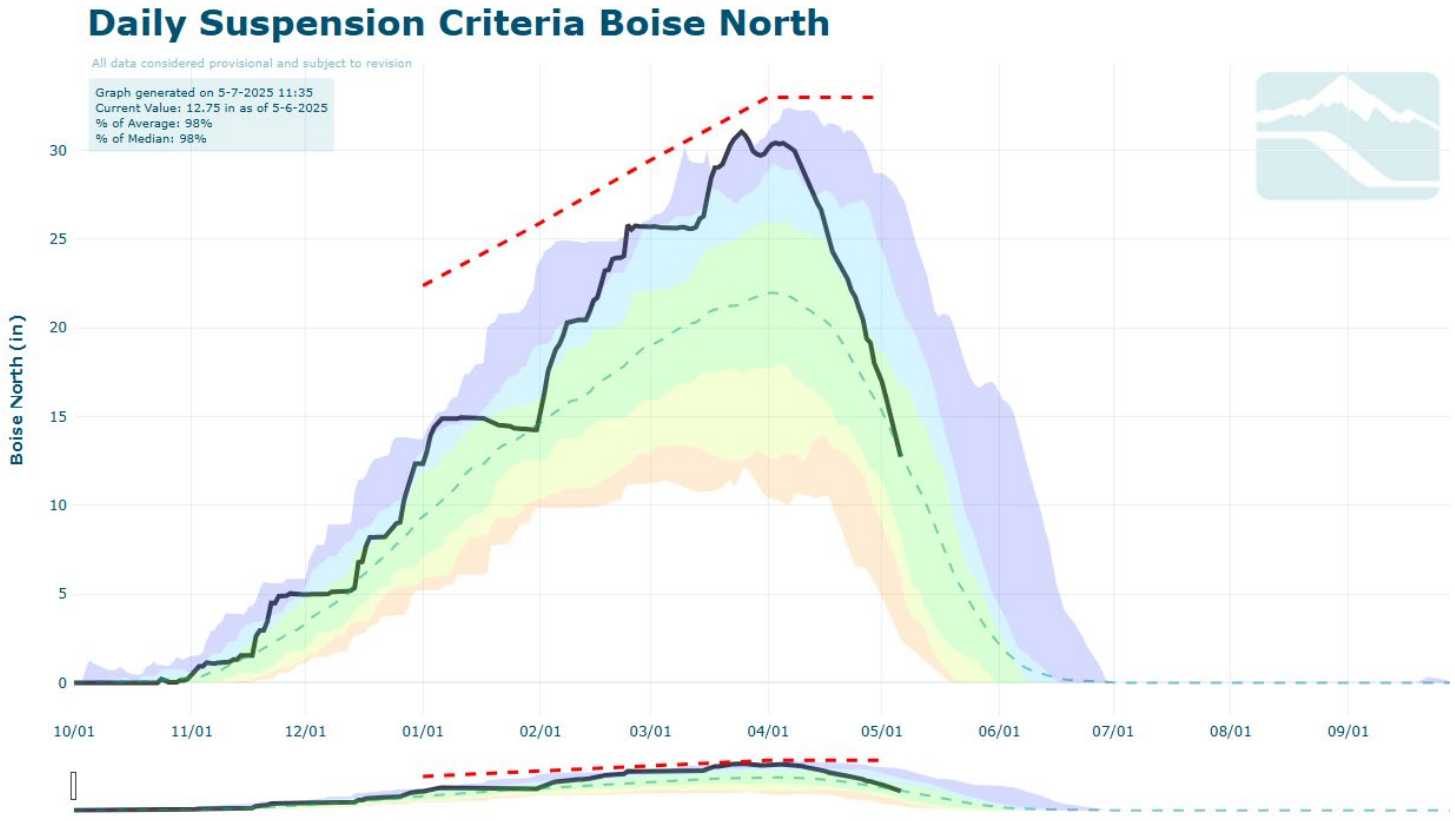
- Payette: 193 KAF
- Boise: 239 KAF
- Wood: 101 KAF
- Upper Snake: 613 KAF
  - Above Palisades: 450 KAF
  - Henry's Fork: 163 KAF

Total: 1,147 KAF



Suspension

- Snowpack - SWE from NRCS SNOTEL
- Flood potential
  - RFC
  - NWS flood warning, rain on snow, etc.
- Avalanche Conditions
  - Extreme
- Severe weather
  - Locally heavy precipitation, strong or damaging winds, hail, lightning
- Special circumstances



An Overview of Winter Orographic Cloud Seeding

"How It's Done"

Bruce A. Boe
Weather Modification International
Fargo, North Dakota USA

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Cloud Seeding in the Western U.S.

This map, from the North American Weather Modification Council, www.nawmc.org, shows the locations and seasons of cloud seeding programs ongoing in Western North America.

Cold season programs target winter orographic storm systems as in Idaho.

Warm season programs target convective clouds and storms.

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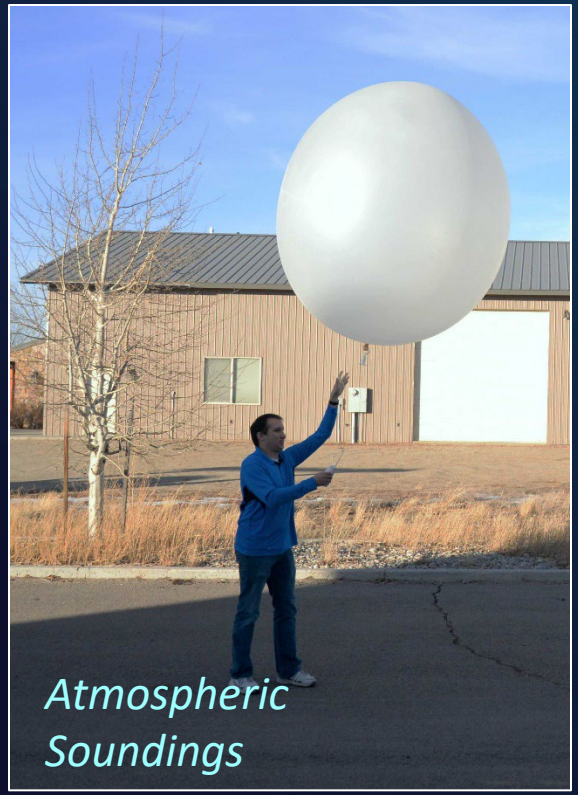
When to Seed: Opportunity Recognition



Atmospheric Soundings

- Cloud seeding programs are supported by meteorologists well-trained in the science.
- These persons leverage their experience, numerical weather prediction (computer models), soundings, remote sensing (satellite, radar, and radiometers), and real-time observations.
- When seedable clouds are identified, they go into action.

Left, a technician prepares to release a weather balloon. Above, the receiver acquires and processes the data from the sonde, carried by the balloon.

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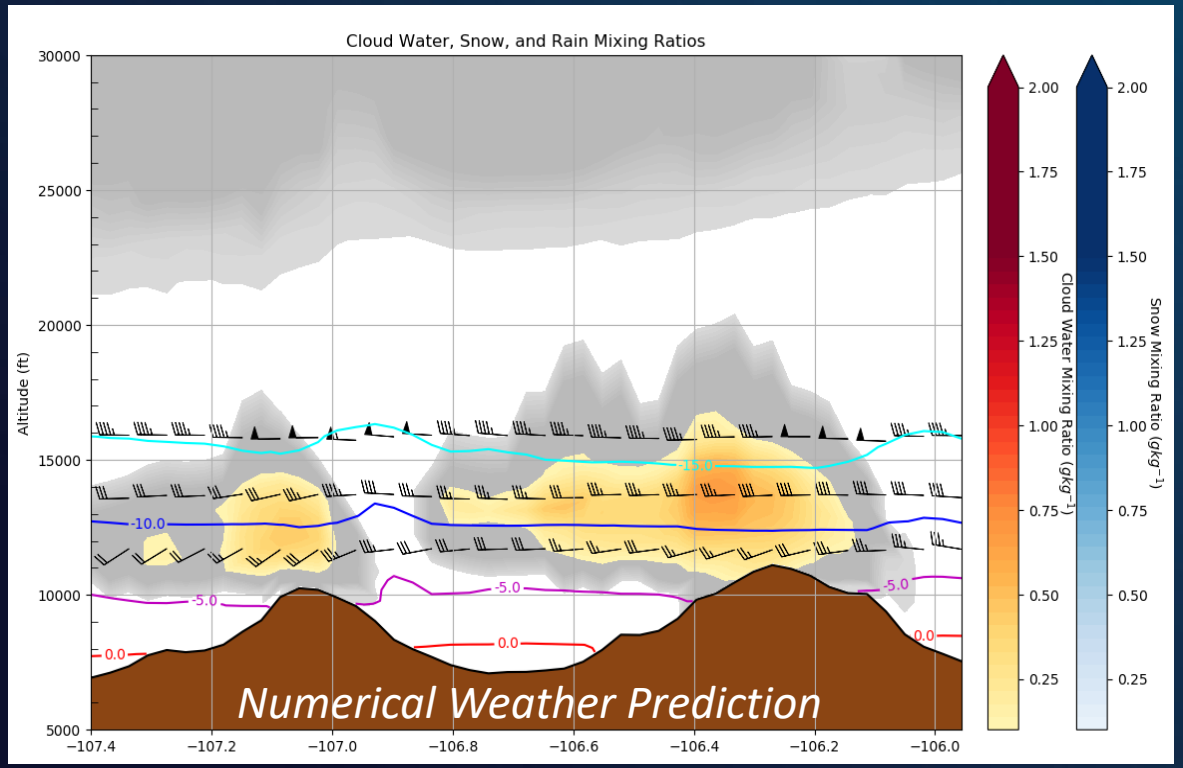
When to Seed: Opportunity Recognition



- Many programs utilize advanced computer models to identify seeding opportunities.
- Here we see a vertical cross section above a two target ranges.
- The temperature is cold enough, and the yellows and oranges predict the presence of supercooled liquid water.

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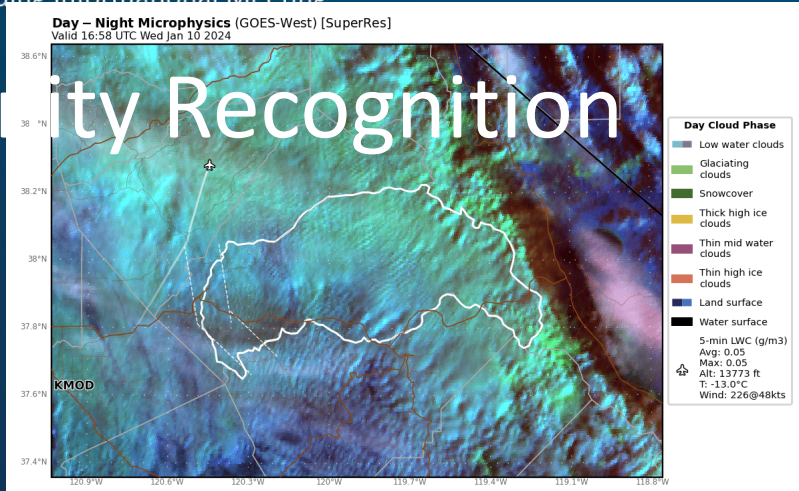
Case 1: Zig-zags observed | California | Time 0
10-Jan-2024 17Z

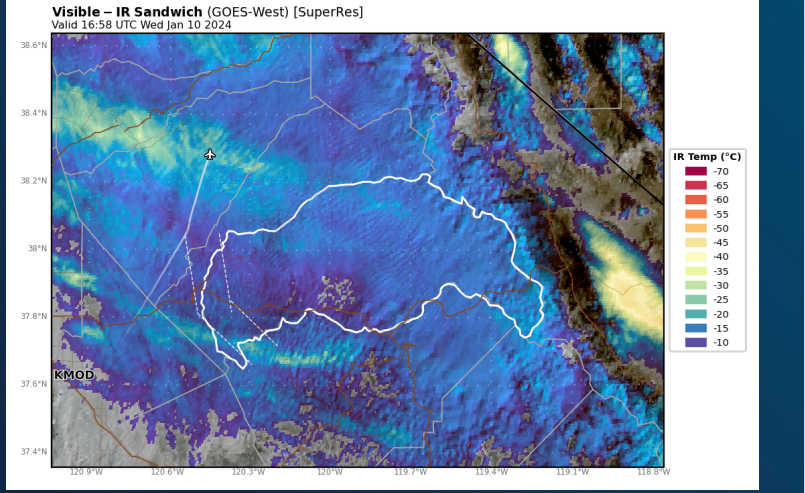
When to Seed: Opportunity Recognition

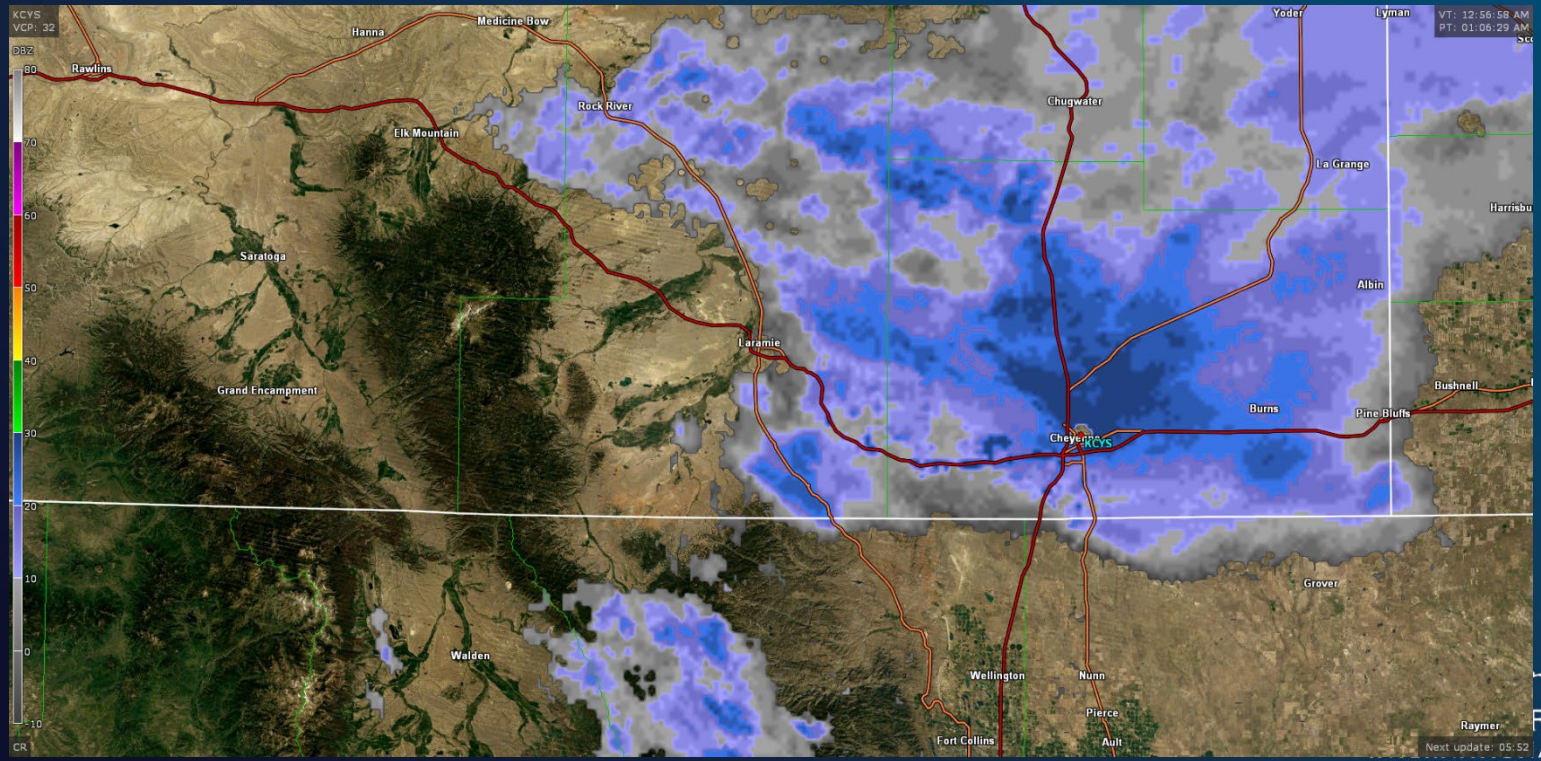
This case features observed “zig-zag” seeding lines in both satellite and radar imagery, confirming both a suitable cloud and effective delivery.

West-northwest flow is creating upslope snow in the central-southern Sierra Nevada. The Day Cloud Phase multispectral imagery from GOES-16 indicates much of this is supercooled water, while channel 13 indicates most of this is warmer than -20°C, even -15°C. Bands of thin cirrus with colder cloud tops can occasionally be seen through these images, with a generally WNW-ESE orientation.

This slide, excepted from a scientific conference presentation, shows how satellite data can reveal cloud characteristics suitable for seeding (supercooled liquid water) and the effects of seeding (the development of ice/precipitation).



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Elk Mountain
Saratoga
Grand Encampment
Laramie
Yoder
Lyman
Chugwater
La Grange
Albin
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Bushnell
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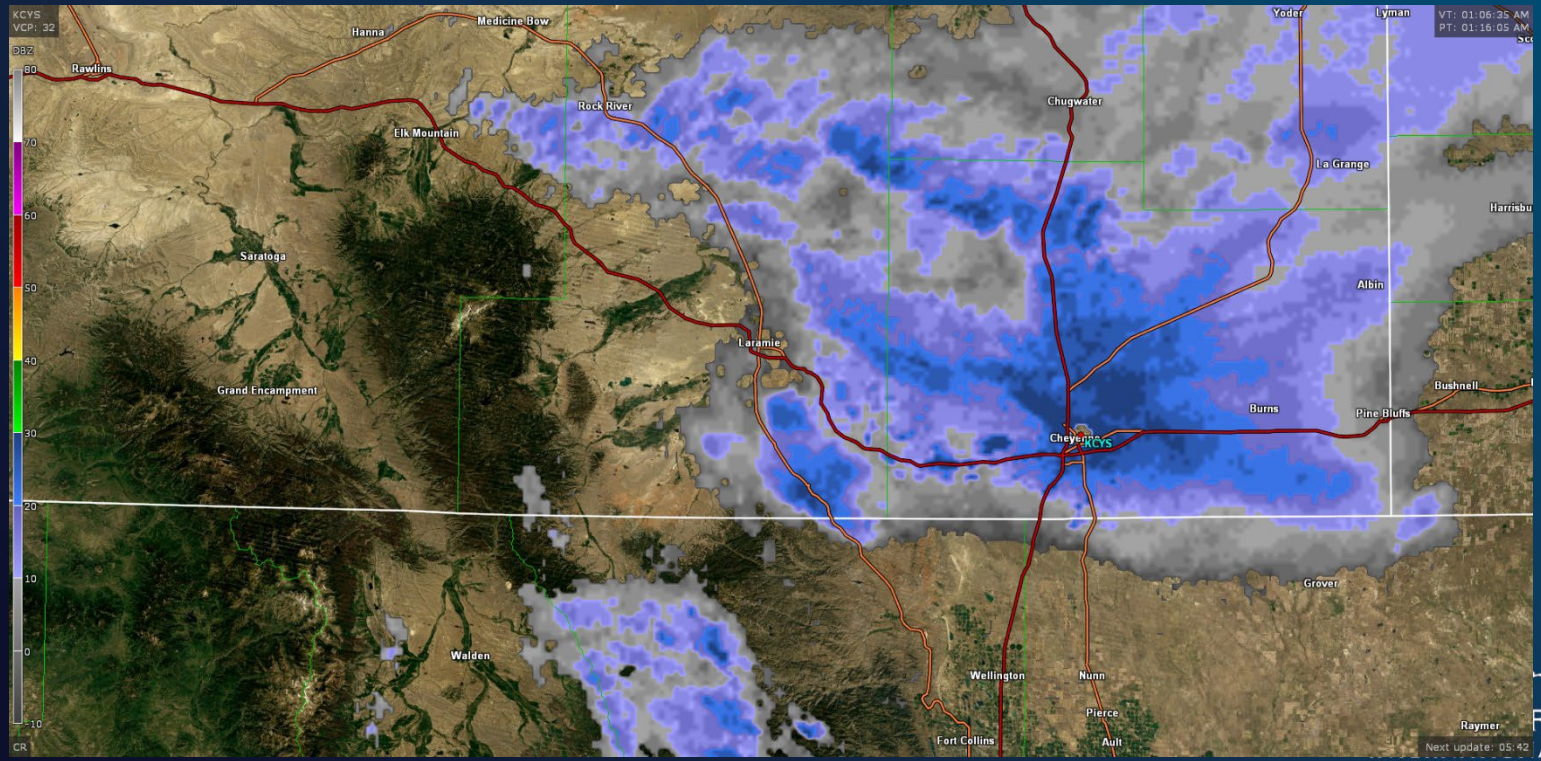
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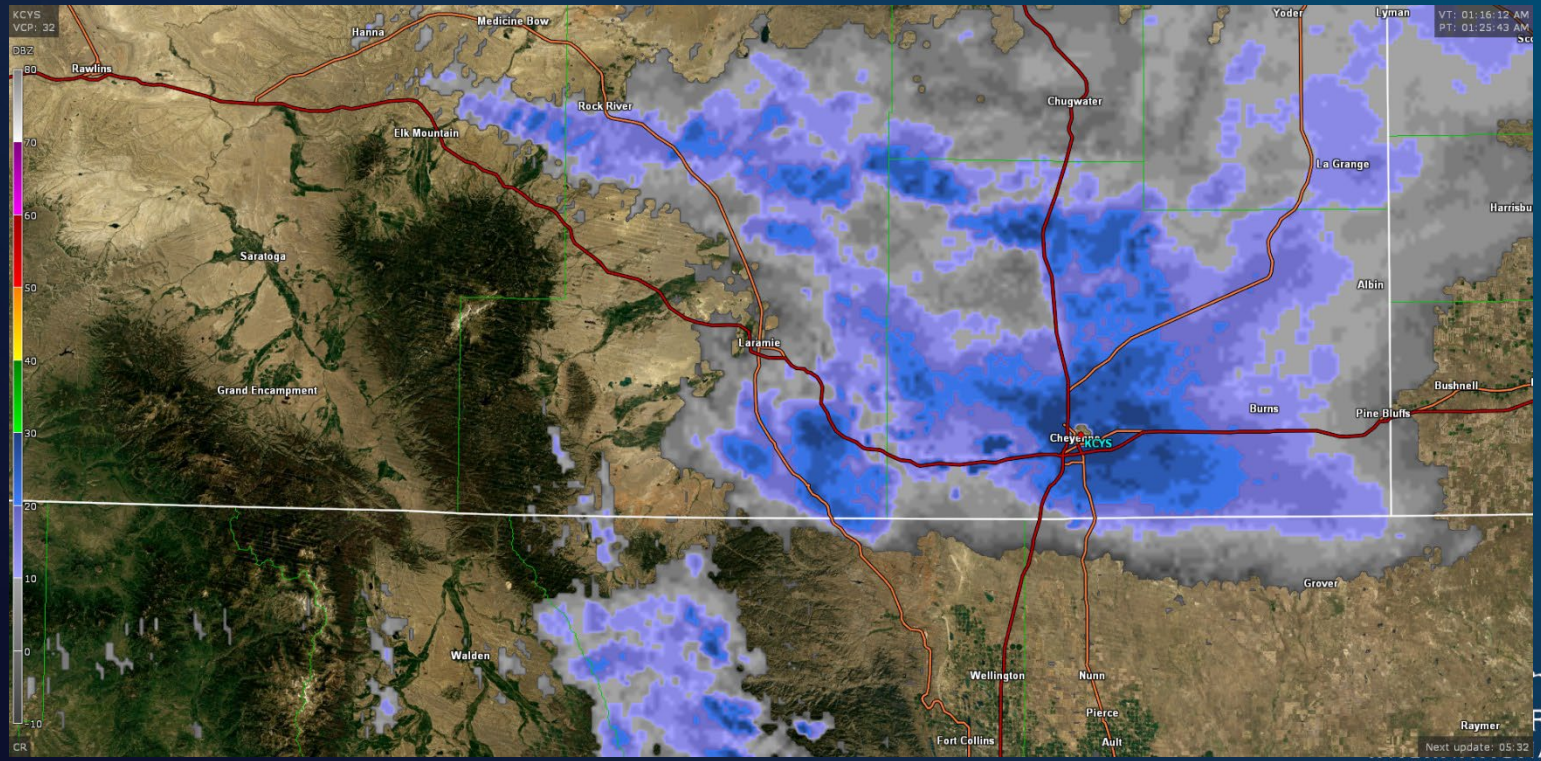
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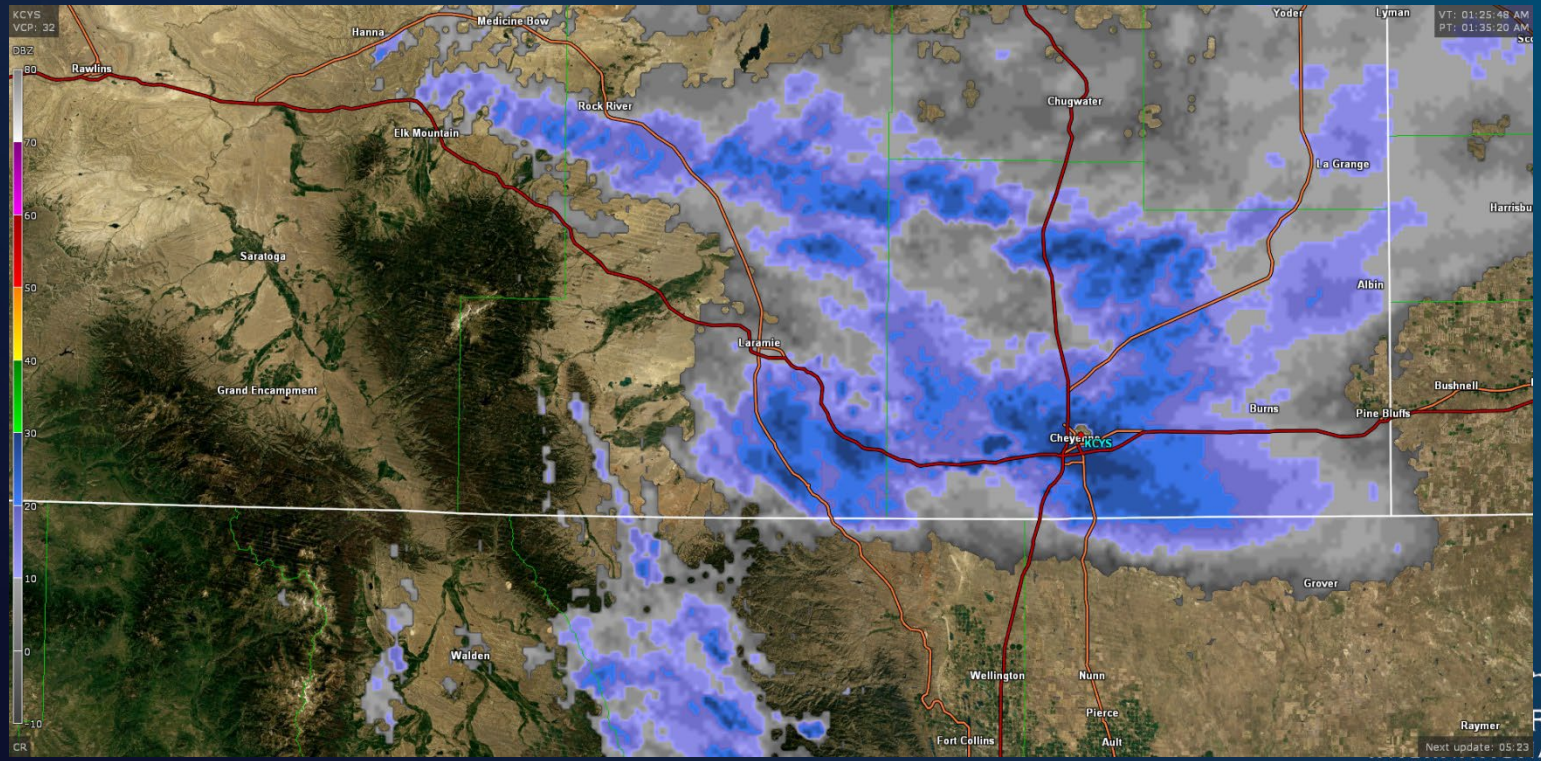
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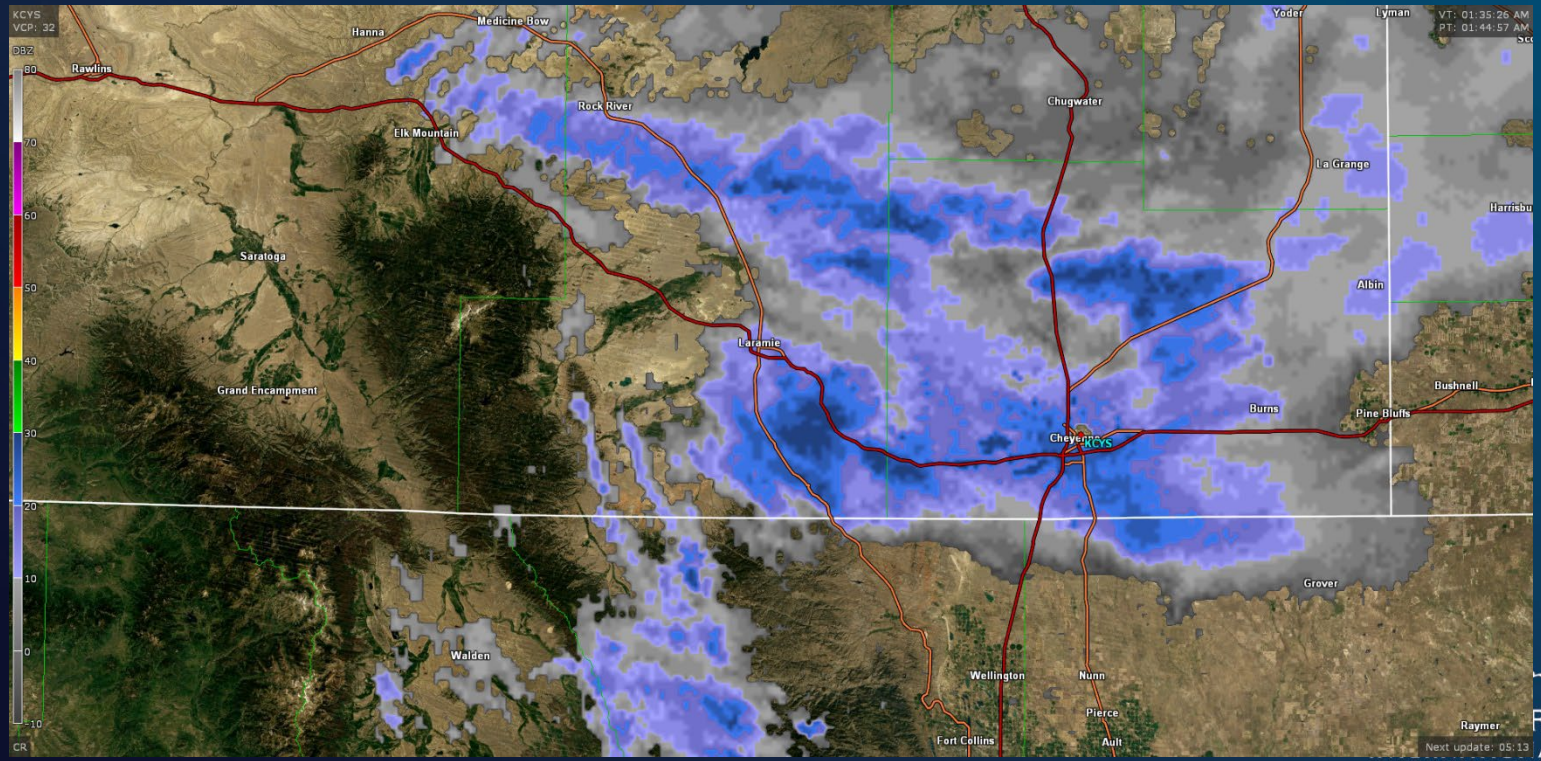
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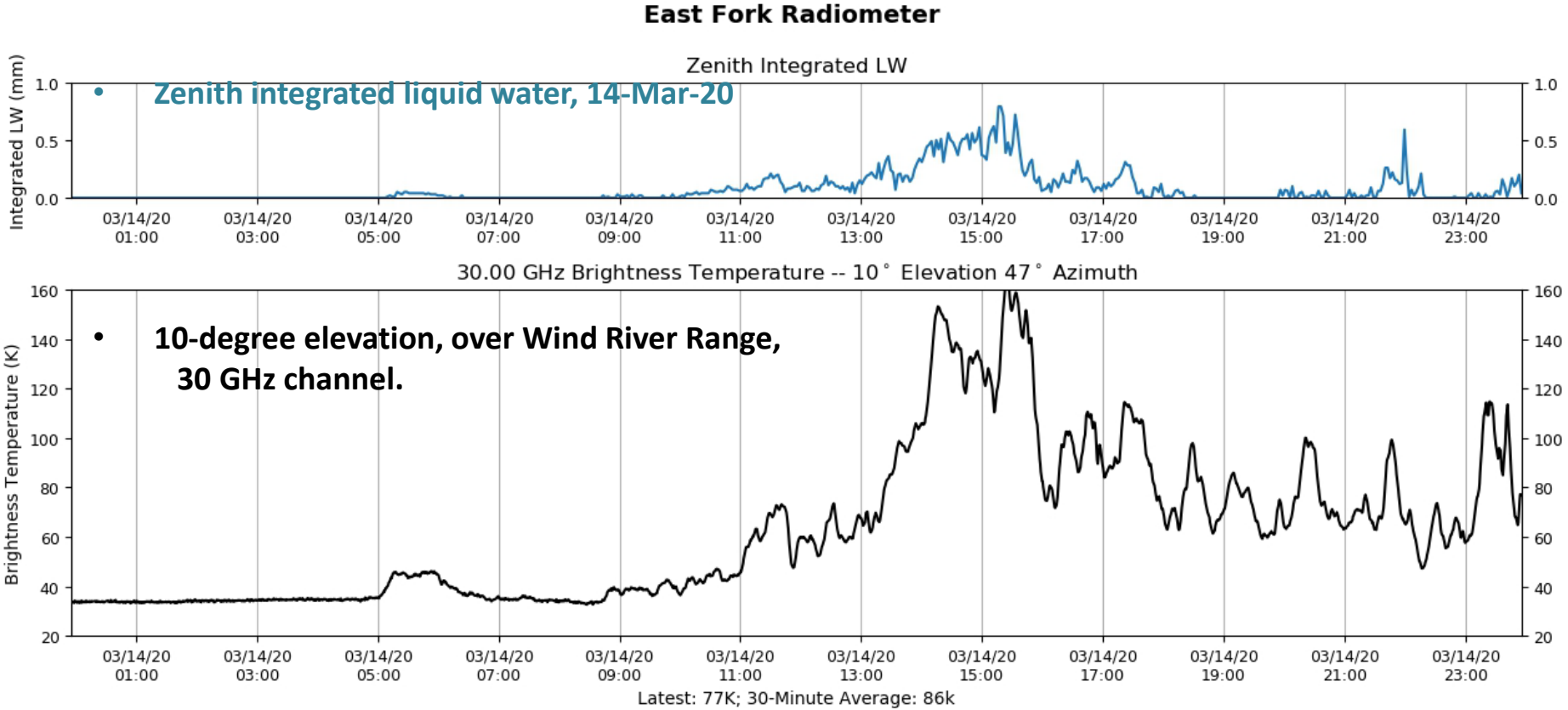
Radiometers

- Microwave radiometers measure incoming radiation at specific wavelengths. (The do not transmit.)
- It turns out that water vapor absorbs radiation at a specific wavelength.
- Even more helpful, liquid water, even supercooled, absorbs radiation at a slightly different wavelength.
- If we measure the radiation changes at these two wavelengths, we can detect the presence of water vapor and liquid water—and the latter is a requisite for seeding operations. Helpful indeed.

When to Seed: Opportunity Recognition



- Zenith integrated liquid water, 14-Mar-20

- **10-degree elevation, over Wind River Range, 30 GHz channel.**

When to Seed: Opportunity Recognition

- Eyes are invaluable.
- The human eye is a remarkable tool, very helpful in assessing cloud coverage.
- To the right, cloud coverage is beginning to increase, and the cloud base getting a little lower . . .
- Hmm. I wonder what the radiometer is seeing?

Another useful tool is the webcam.
Today's models can't yet see in the dark, but many do amazingly well in low light.
If it can see stars, the clouds are too thin (or don't exist).

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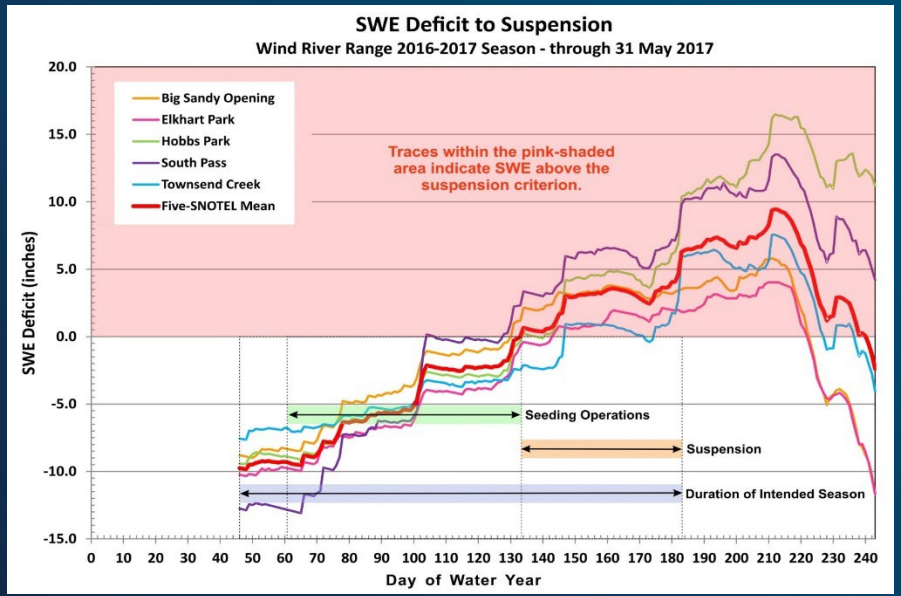
Starting and Stopping

- The tools just listed give us a good understanding of how clouds are developing, and when they become seedable.
- Operations begin when the conditions are right, when targetable supercooled clouds are present in locations that will produce snow in the target.
- Operations end when those conditions cease to exist, or when seeding resources are no longer available.

Suspension

- Programs always have “suspension criteria”, which, when satisfied, result in the cessation of seeding (if ongoing), and the prohibition of seeding (if not underway).
- These criteria typically include the snow water equivalent of the snowpack in the target area, available reservoir storage capacities, and other factors such as emergencies affected by weather (search and rescue).
- Regulatory agencies typically reserve the authority to implement suspensions for other reasons as well.



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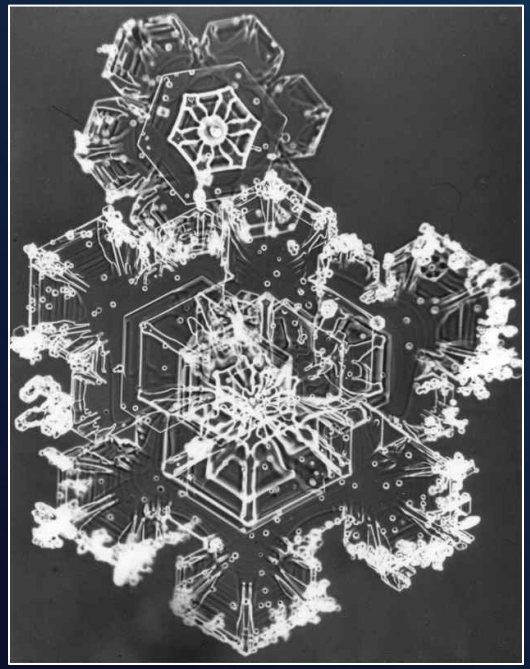
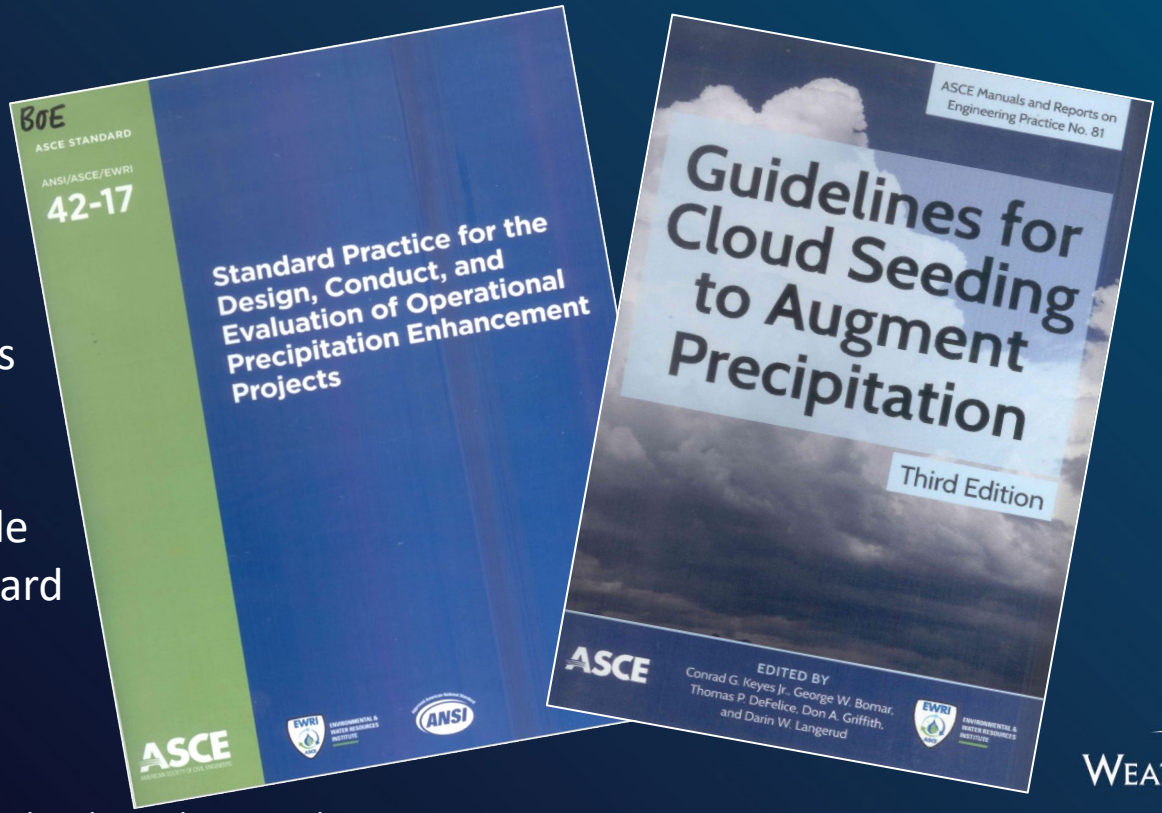
How to do it



- Cloud seeding is applied cloud physics.
- Cloud seeding procedures, protocols, and safeguards have been developed over decades.
- These are published in documents produced through the American Society of Civil Engineers (ASCE) and its Environmental Water Resources Institute (EWRI).
- Refinements (improvements) occur as knowledge increases.
- These documents are updated every few years and again subjected to scientific and public review.

https://ascelibrary.org/doi/book/10.1061/9780784414118

How to do it



These documents are regularly reviewed and updated, available for purchase in hard copy or digital format.

https://ascelibrary.org/doi/book/10.1061/9780784414118

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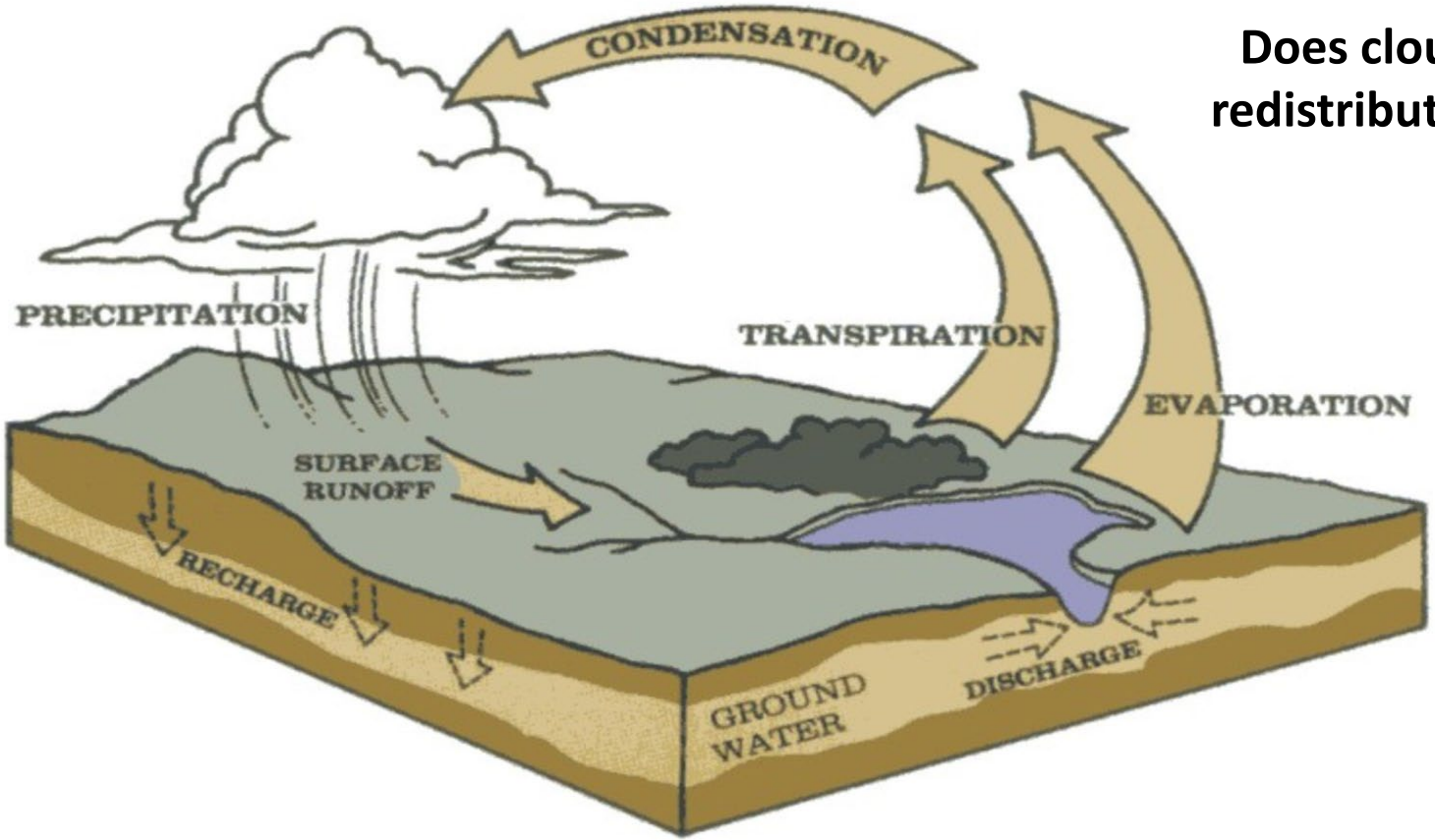
Thank you for your attention.
More to come.
bboe@weathermod.com

Seeding & the Hydrologic Cycle

It is important to remember that cloud seeding makes an incremental increase in natural precipitation. Net precipitation remains well within the bounds of natural variability.

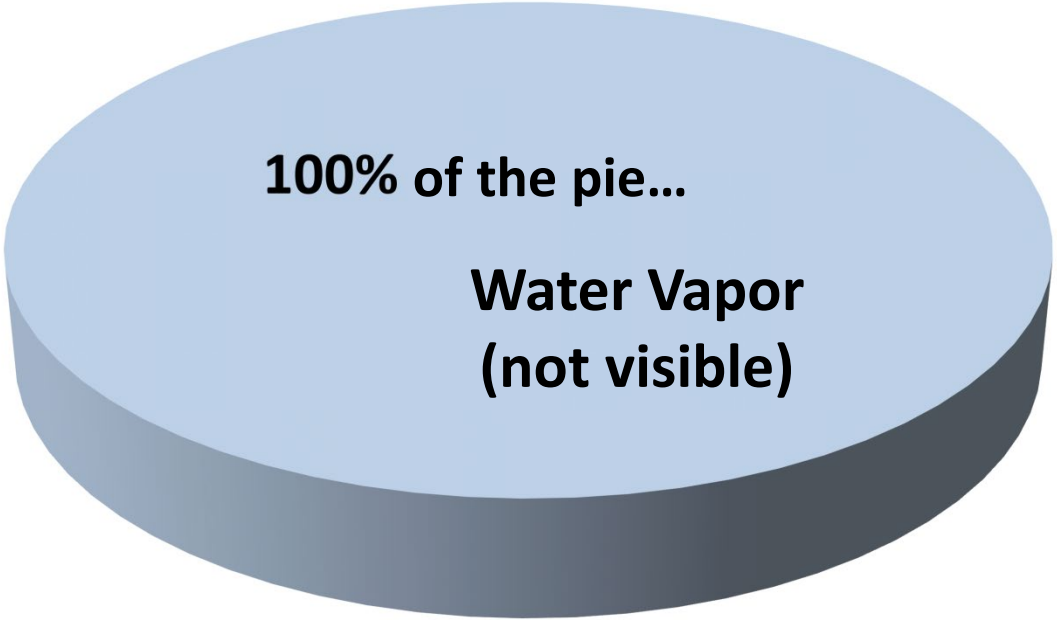
Next, we'll look at a few slides that help us better understand the natural water budget, and the impacts of cloud seeding.

The Hydrologic Cycle

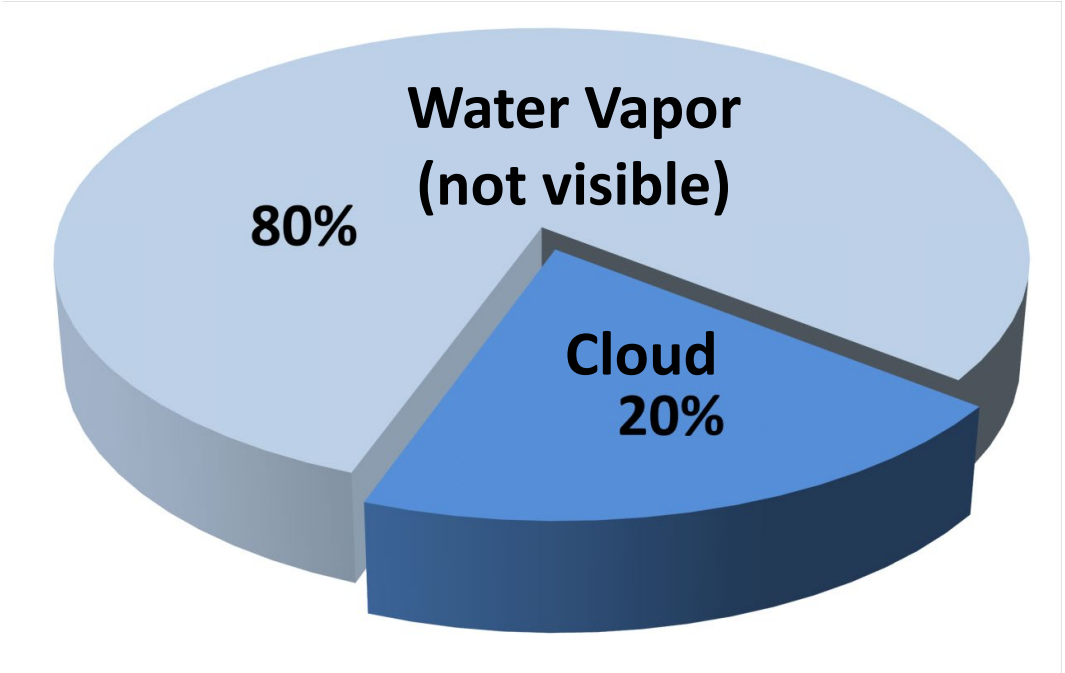


Does cloud seeding just redistribute precipitation?

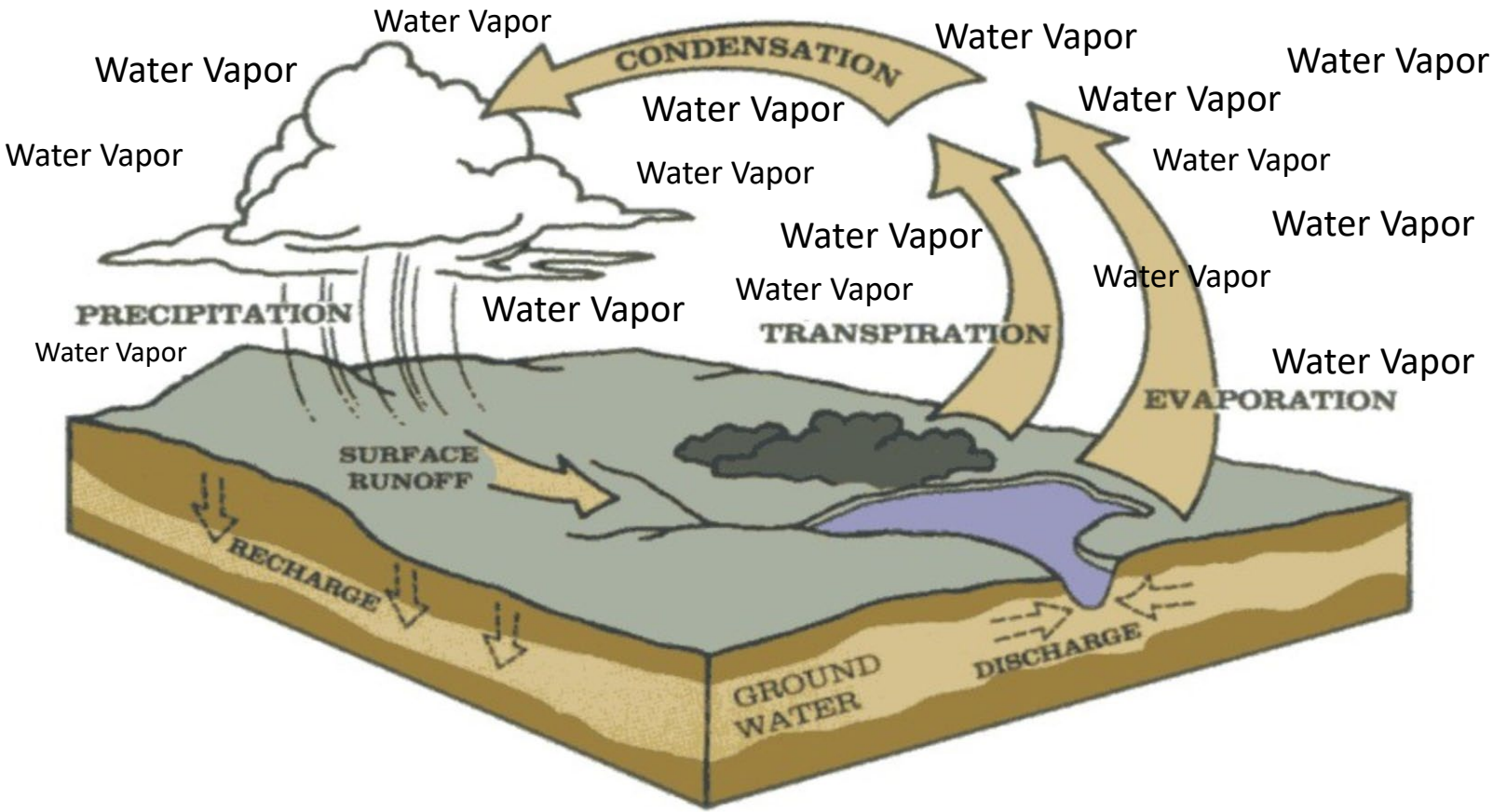
Before Cloudiness



When Clouds Form

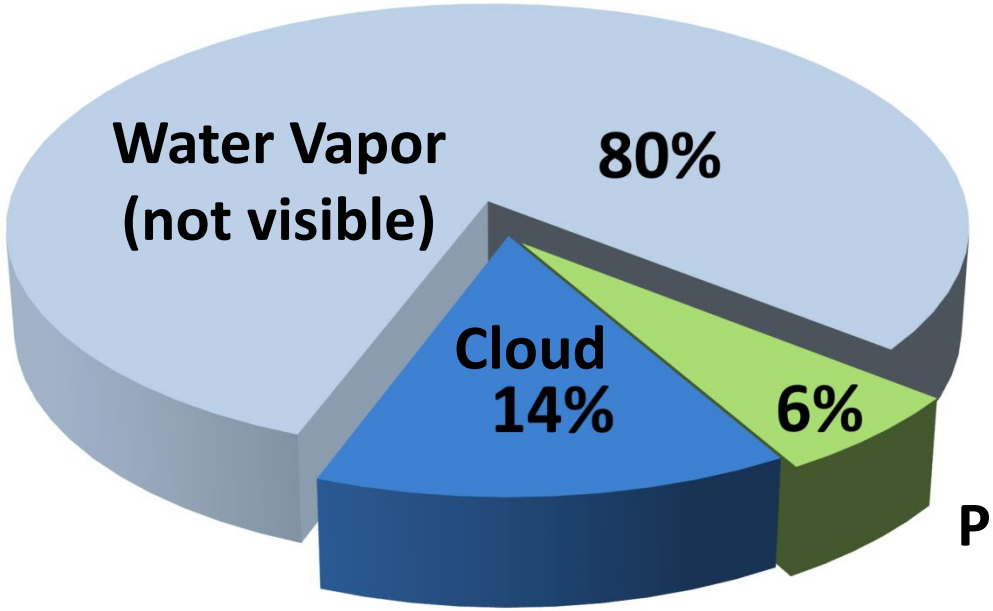


The MORE COMPLETE Hydrologic Cycle



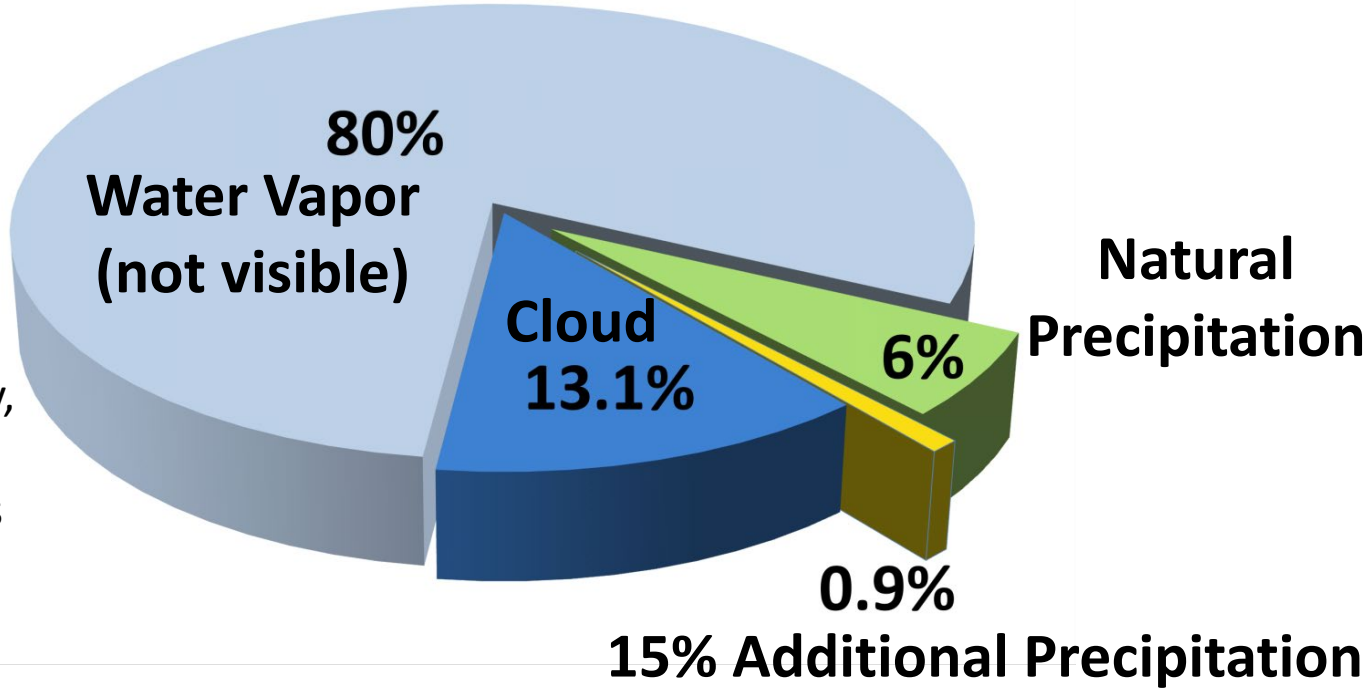
Typical Precipitation Efficiency

30% of the cloud falls out



The Cloud Seeding Slice

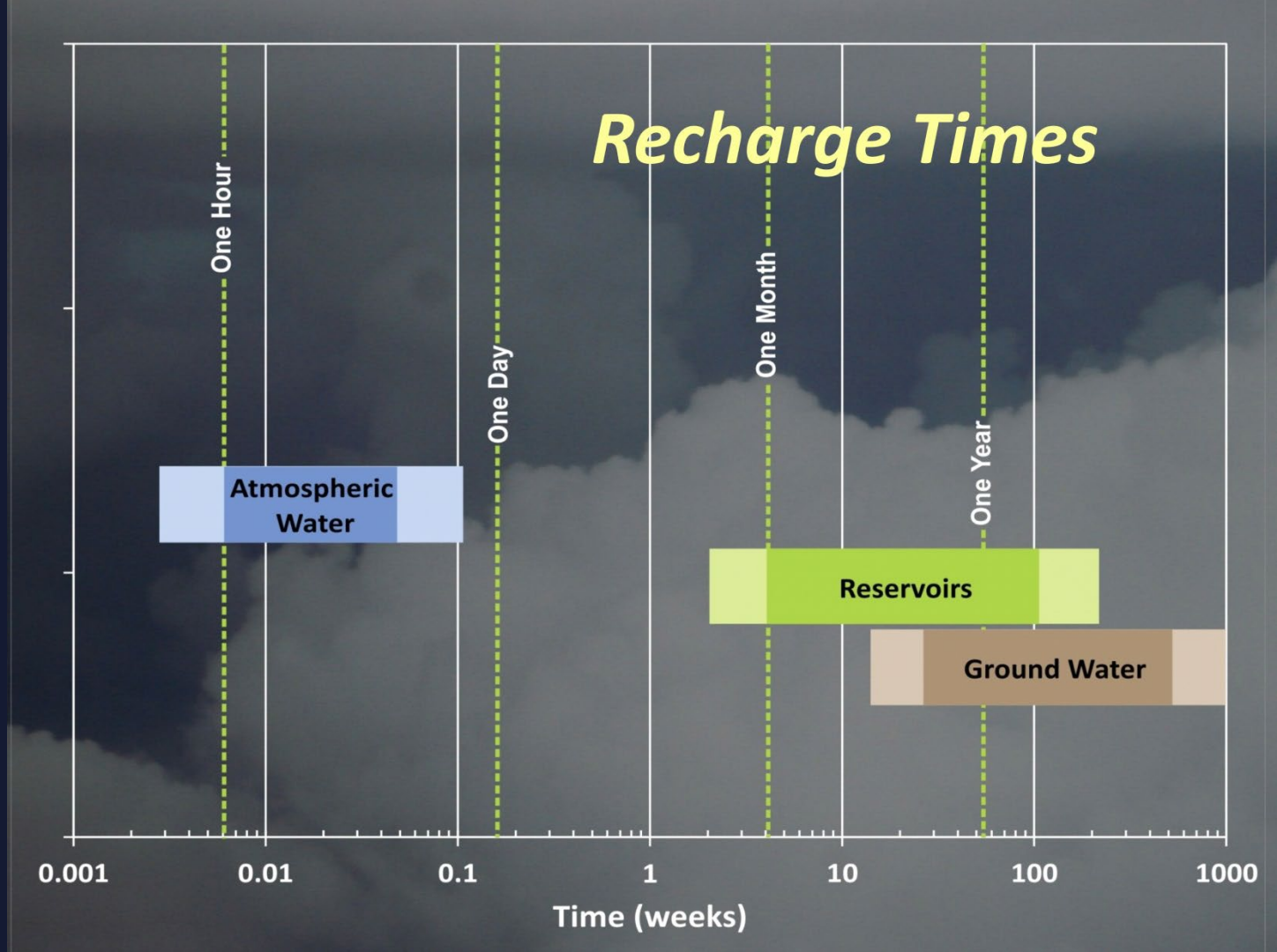
We should also remember:
① seeding occurs only when conditions are right, a small fraction of the time,
② the atmosphere recharges very quickly,
③ the additional precipitation that falls does not vanish.



Perhaps we should think of the atmosphere as a largely untapped reservoir?

It recharges quickly, and the water is of high quality (most of the time).

The question, then, is how we get that water (vapor) to the ground, where we can use it.



What Cloud Seeding *Can* Do

- Increase precipitation, incrementally, above what nature can give us, thus getting more of the atmospheric water to the ground, where we can use it.

Users of the technology can make no claims on any water thus produced. It is considered part of the natural water supply, and it treated accordingly under western water law.

Water managers are using it increasingly to help make systems whole, and to add supply to over-appropriated systems.

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What Cloud Seeding *Cannot* Do

- Break droughts
- Create clouds
- Move clouds
- Change cloudiness, winds, or temperatures.
- Ensure that it won't rain/snow on your wedding/party/rally, etc.

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Thank you for your attention.
bboe@weathermod.com

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Environmental Considerations Associated with Cloud Seeding

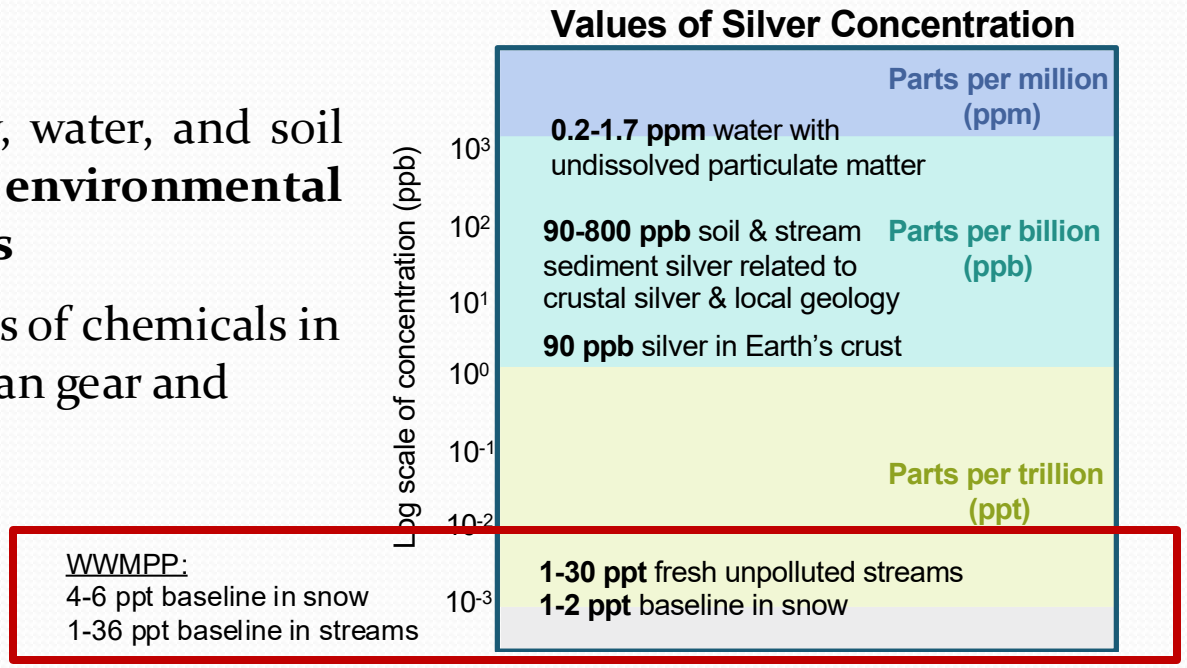
Patrick Golden
Principal Lead Biologist
Dr. Ross Edwards
University of Wisconsin, Madison

Silver in the Environment

Trace chemistry analyses of snow, water, and soil samples have shown a **negligible environmental impact from seeding operations**

Trace chemistry measures amounts of chemicals in such small concentrations that clean gear and clean procedures are required

1 ppt = 1 drop in 20 Olympic-sized swimming pools. If a seeding signature was 20ppt, that is about 1/20 of a drop of water in a pool – it is very hard to find.



Far less than would be expected from other (background) sources of silver

Different Forms of Silver

Silver Salts

Silver nitrate

Silver Chloride

Silver Iodide

Silver metal

Silver sulfide

Most

Silver ion release

Ag+

Less

Ultimately silver released into the environment becomes silver sulfide.

Silver Speciation/Toxicity

- Free silver ion (Ag+) is extremely toxic in aquatic environments (fish, plankton); not harmful to humans or wildlife.
- Silver iodide (AgI) is an insoluble salt and does not dissociate in water.
- AgI is essentially insoluble and doesn't readily produce Ag+.
- World Health Organization, EPA and most state government water quality standards is 100 ppb total silver.
- Worst case (and impossible) scenario – if 1 ppb AgI were in solution with unlimited time to react, a solution of 0.984 ppb of free silver (Ag+) would result. This is the maximum due to saturation. This is well below U.S. total silver toxicity guideline (100 ppb).
- Toxicity levels – rats = 95 ppb of Ag+; germinating plants = 750 ppb; adult plants = 14,000-120,000 ppb.

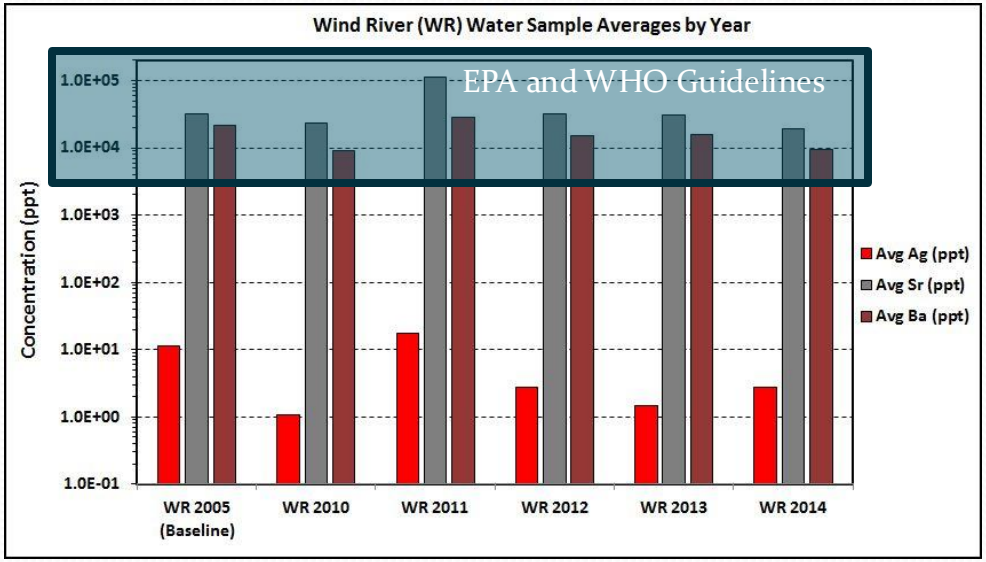
Silver Accumulation and Trace Chemistry

- Silver primarily accumulates in soils or streambed sediments and is found at parts per trillion (ppt) levels in the environment.
- Environmental sampling of cloud seeding operations have found no detectible increase in total silver concentrations above background levels in soil, streams or aquatic species in seeded areas.
- Field studies in the western U.S. for seeded snow found that extremely small amounts of AgI are dispersed over large areas after cloud seeding - orders of magnitude lower than naturally occurring background levels of silver; ultratrace chemistry is required to detect it.
- Snow sampling – clean techniques are required due to contamination issues and low levels of total silver in snow.

Measured Silver from Seeding

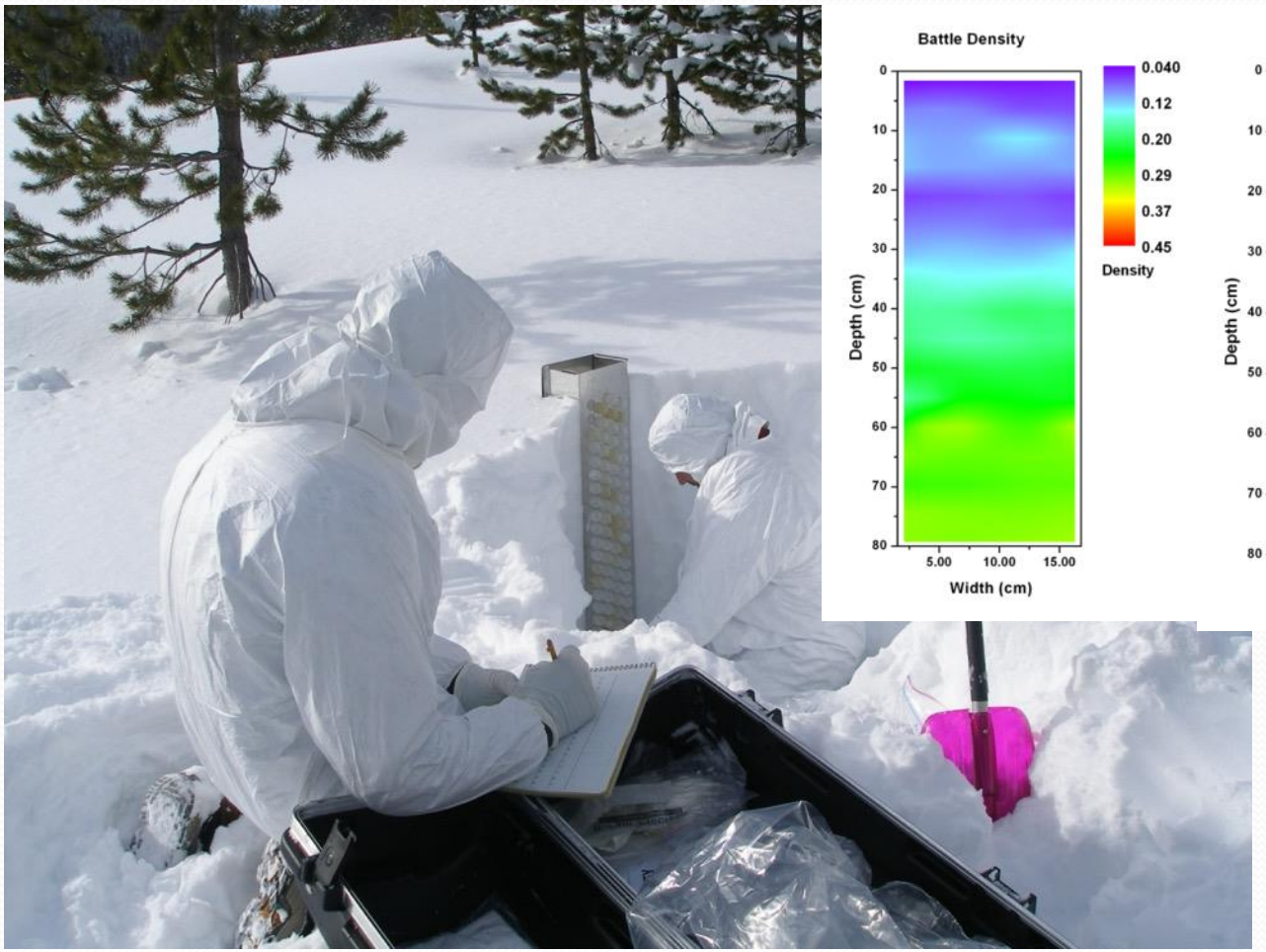
- Total silver in water measured during seeding operations was the same order of magnitude as the baseline from years before seeding started.
- Several orders of magnitude less than values considered hazardous to the environment or human health.

Silver in Water Samples from WWMPP



From the WWMPP

Snowpack Silver Profiling



- Need to account for Ag from dust layers in snowpack.

Trace chemistry horizontal snow sample collection

Weather Mod Silver inputs to Idaho CM and Upper Snake

Cloud seeding Ag

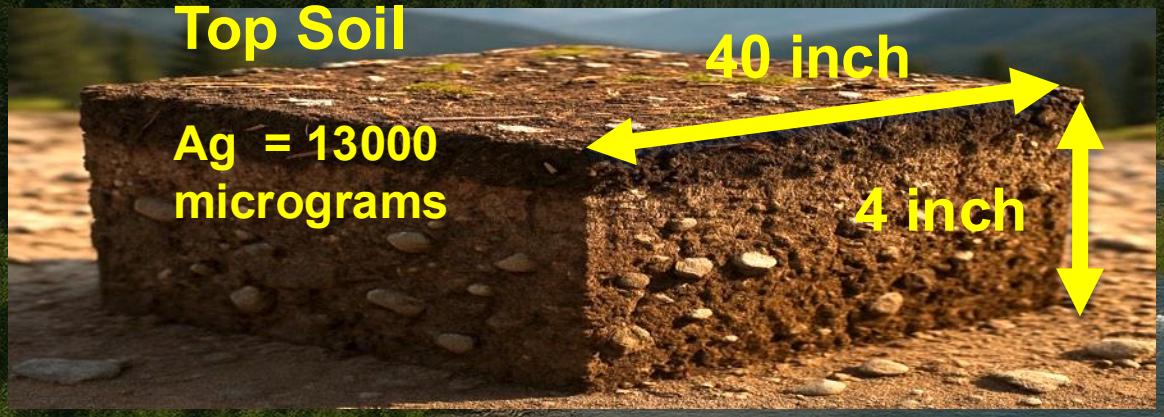
Target Area = 14,000 sq. miles ,
100 Kg silver iodide released per year

Dust Ag

1.27 µg
Ag per year

0.1 to 1 µg
Ag per
year

- Cloud seeding impact on background.
- Background soil levels reached in 10,000 years.
- Conservative estimate.



Background soil silver = 13000 micrograms. Assuming 0.1 mg Ag Kg^{-1}

Bioaccumulation (Food Chain)

- Bioaccumulation is the buildup of a substance as it moves up the food chain.
- Toxicity depends on the concentration of active, free Ag+ ions in water.
- Silver iodide is insoluble, stable, and does not readily break down into Ag+.
- Soil, sediment, and water silver toxicity is very low even at high total silver concentrations – most is bound into a compound and is not available for absorption.
- Accumulation of Ag+ in algae is relatively high but much is bound into stable compounds; macroinvertebrates feed on algae but don't show significant bioaccumulation because less Ag+ ingested. Even lower in fish, ingested silver is passed as waste, also showing no significant bioaccumulation.
- Ultimately, Ag+ becomes locked up as non-toxic silver sulfide (Ag_2S).

Although silver ions (Ag+) from soluble silver salts have been shown to be toxic to aquatic species, this is not the case with insoluble silver salts such as AgI.

Permitting

- Many higher elevation lands in the western United States are targeted or could be targeted for winter orographic cloud seeding projects. These lands are often managed by federal agencies such as the USFS and BLM. Placement of equipment requires permits.
- Permits – Special Use Permits (federal)(CatEx, EA, EIS); Temporary Use Permits may or may not trigger environmental review, depending on the federal agency.
- Laws – National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA), Endangered Species Act (ESA).
- Private or state lands are also suitable and don't trigger NEPA.
- Ground and aerial operations must submit annual reports to NOAA describing hours operated, amount of seeding agent used, etc.

Summary

- Total silver concentrations from seeding are orders of magnitude lower than naturally occurring background levels of total silver.
- Silver iodide (AgI) is not toxic, stable, insoluble, does not readily dissociate in water and does not become toxic.
- Although silver ions (Ag+) from soluble silver salts have been shown to be toxic to aquatic species in laboratory settings, this is not the case with insoluble silver salts such as AgI in the natural environment.
- Environmental sampling of cloud seeding operations have found no detectible increase in total silver concentrations above background levels in soil, streams or aquatic species in seeded areas.
- Extra-area affects – seeding has a small impact on water vapor budget and downstream affects are negligible.
- Suspension criteria minimize the potential for floods, avalanches and overtopping dams.

References

Snowy Hydro (Australian Program)

https://www.snowyhydro.com.au

North American Weather Modification Council

http://www.nawmc.org

Weather Modification Association

https://weathermod.org

Wyoming Water Development Commission (Pilot Program and Operations Reports)

https://wwdc.state.wy.us/weathermod/projects.html

Questions?

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