WORKSHOP

Cloud Seeding as a Water Management Tool

Sponsored by the North American
Weather Modification Council

8 AM (MST)
Wednesday November 15, 2023

Idaho Water Center

322 E Front St

Boise, ID

&

ONLINE

NAWMC

North American

Weather Modification Council

Welcome

Sean Collier, *President* | North American Weather Modification Council

NAWMC North American Weather Modification Council

Mission: To advance the proper use of weather modification technologies through education, promotion

Members

California Department of Water Resources

Central Arizona Water Conservation District

City of Grand Junction Water Enhancement Authority

Colorado River District

Colorado Water Conservation Board

Desert Research Institute

Heritage Environmental Consultants

Idaho Power Company

Idaho Water Resource Board

Metropolitan Water District of Southern California

North Dakota Atmospheric Resource Board

North Dakota Weather Modification Association

Salt River Project

San Luis Obispo County Public Works

Santa Ana Watershed Project Authority

Santa Barbara County Water Agency

Six Agency Committee

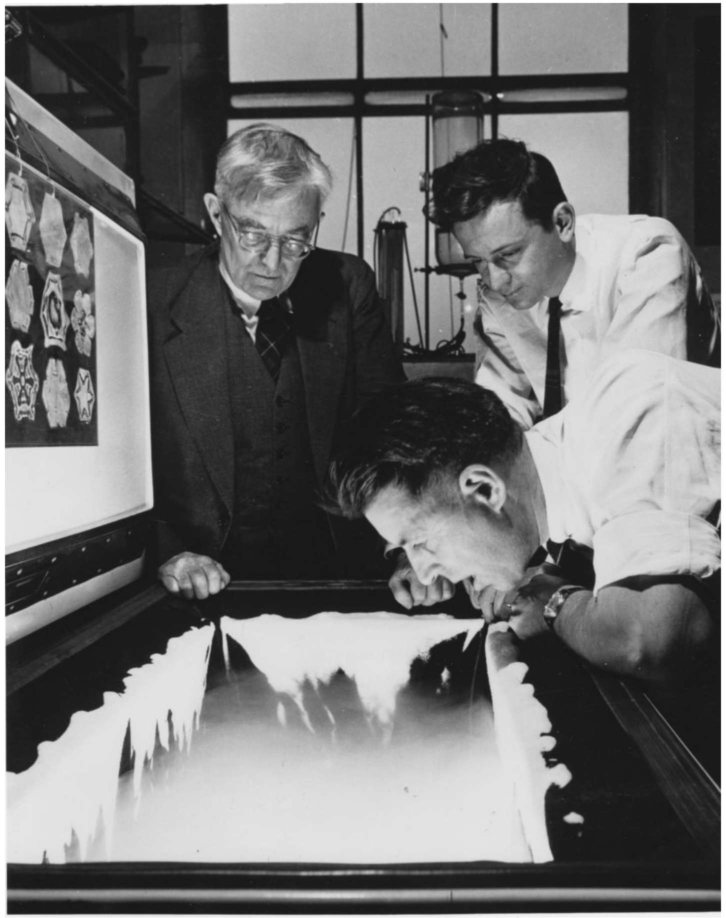
Southern Nevada Water Authority

University of Wyoming Office of Water Programs

Utah Division of Water Resources

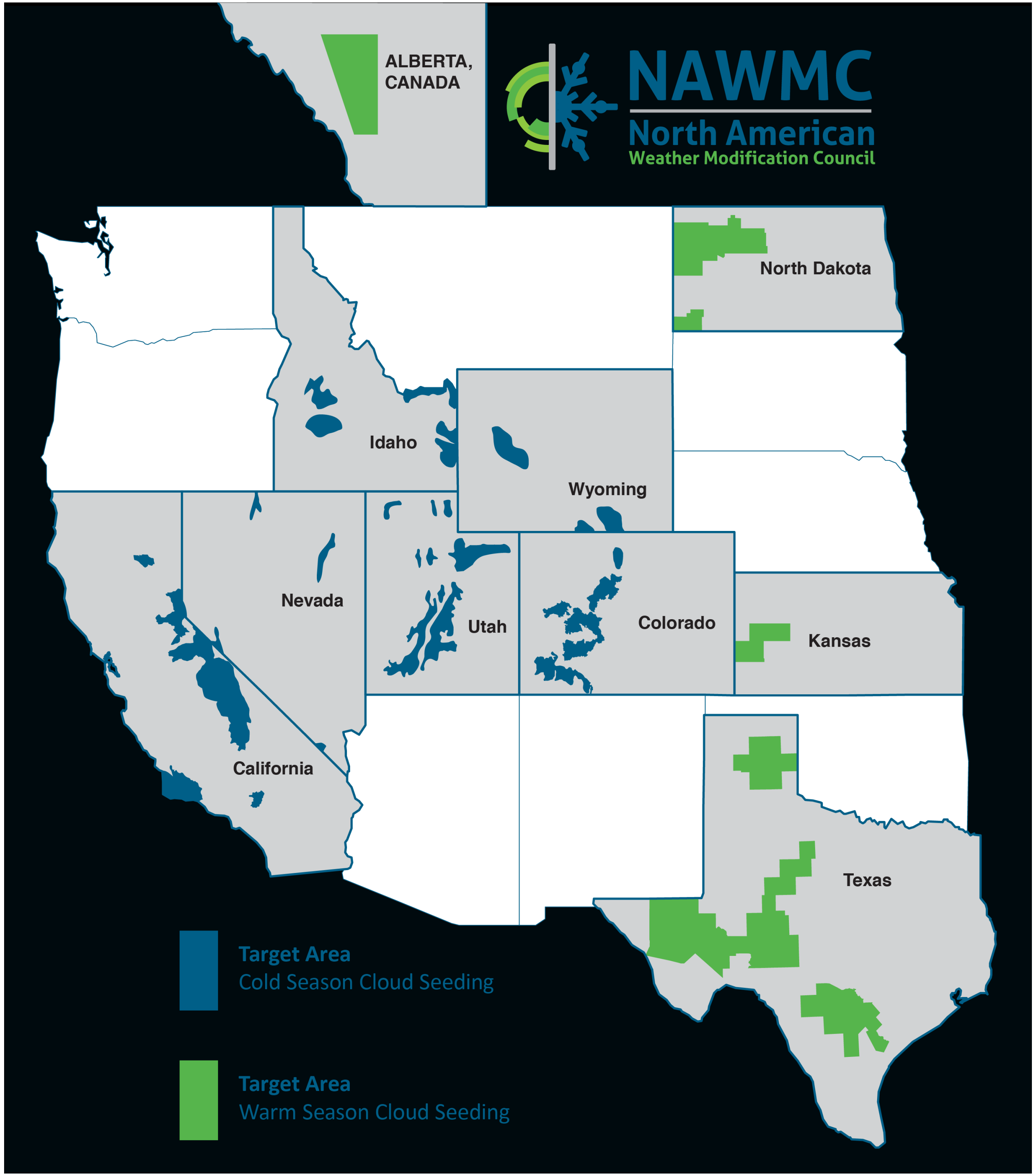
Wyoming Water Development Office

Origins of Cloud Seeding



Purposes for Cloud Seeding

- Warm Season Cloud Seeding
  - Increased Precipitation (rain)
  - Hail Suppression
  - Fog Abatement
- Cold Season Cloud Seeding
  - Increased Precipitation (snow)



WORKSHOP AGENDA

08:00 AM | Welcome & Introduction

08:15 AM | Overview & Housekeeping

08:20 AM | Cloud Seeding 101
Cloud Physics, State of the Science, Operations

10:15 AM | Break

10:30 AM | Cloud Seeding 101, *continued*
Environmental topics, Panel Q/A

11:15 AM | Developing a Program
Breaking Ground, Feasibility & Design

12:00 PM | Lunch

01:00 PM | Developing a Program, *continued*
Program Implementation, Monitoring & Analysis, Panel Q/A

02:00 PM | Current Programs
North Dakota, Colorado River Basin, Colorado, Nevada

03:00 PM | Break

03:15 PM | Current Programs, *continued*
California, Utah, Idaho

04:15 PM | Final Q/A & Discussion

05:00 PM | End

Workshop Housekeeping

❖ Reverences | Kindly, please exercise courtesy for both speakers and attendees

❖ Questions | will be addressed at the end of each panel

❖ Workshop Recording |

- This workshop is being recorded; to view the recording, please visit http://www.nawmc.org/.
- Recordings will be posted by panel.

❖ Online Participants |

- There is no audio available for this workshop.
- Participants may exit and rejoin the meeting at any time.
- Questions may be submitted at any time by clicking the Q&A box located on the bottom right of the meeting screen.

Cloud Seeding 101

Cloud Physics | Dr. Jeffrey French, University of Wyoming

State of the Science | Dr. Sarah Tessendorf, National Center for Atmospheric Research

Operations | Derek Blestrud, Idaho Power Company ; Bruce Boe, Weather Modification International

Environmental | Patrick Golden, Heritage Environmental

NAWMC North American Weather Modification Council

Cloud Physics

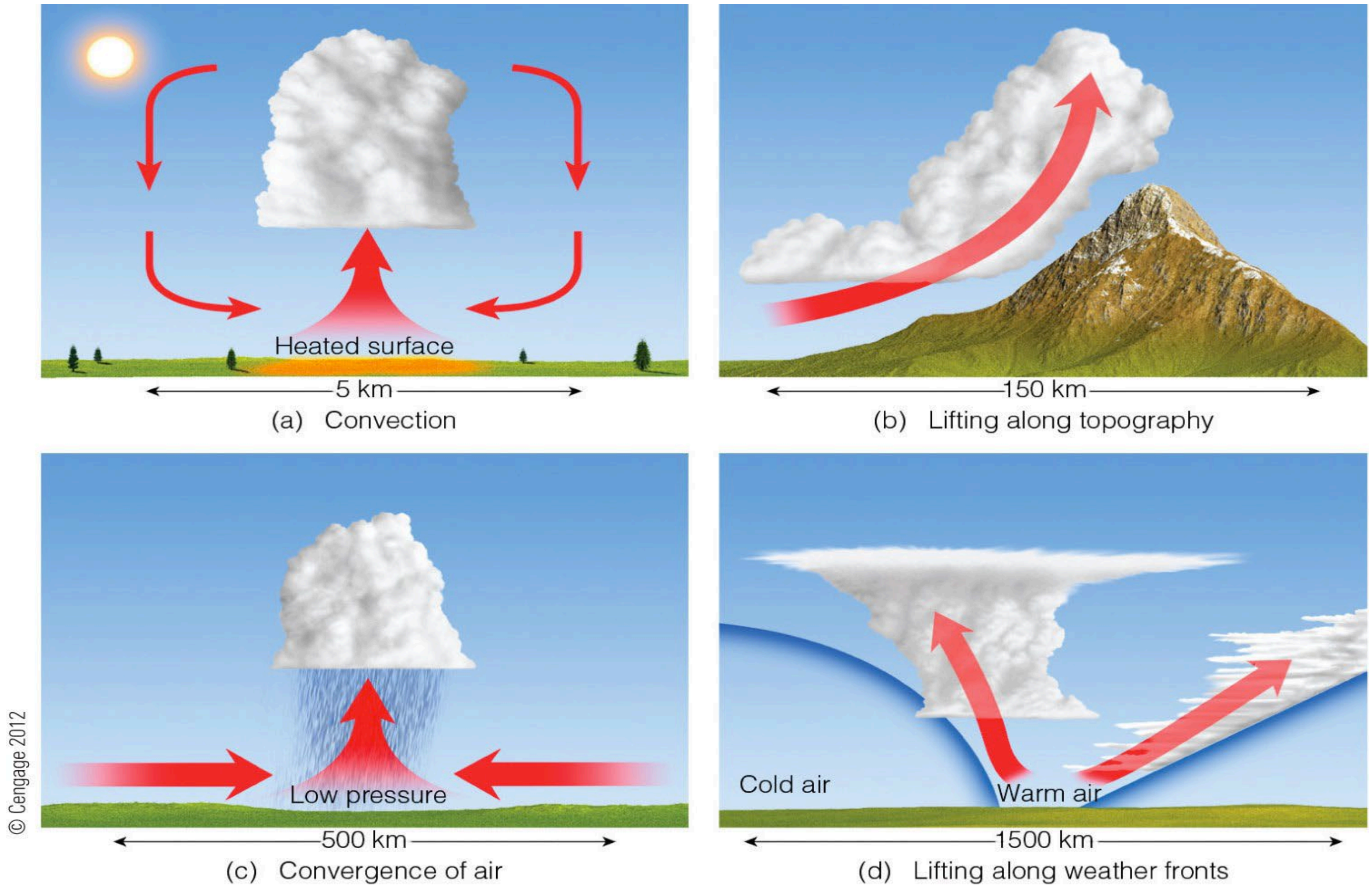
Dr. Jeffrey French, *Associate Professor and Head, Dept. of Atmospheric Science*
University of Wyoming

What is a cloud? What is it made of?

When we look at a cloud, what do we 'see'?

Are these two clouds made up of the same things?

How do clouds form? Why do clouds form?



How do clouds form? Why do clouds form?

Why is rising air important?

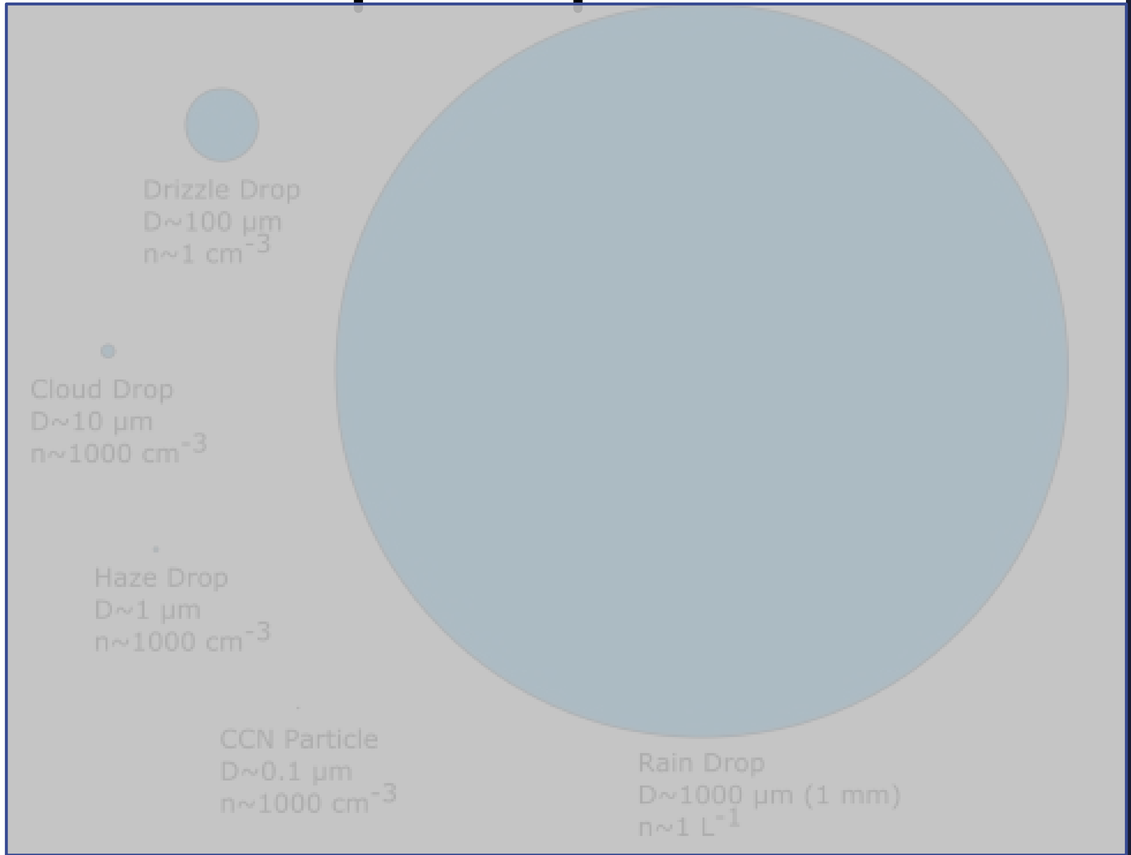
1. When air rises, it expands. When it expands it cools (temperature drops)
2. As the temperature drops the relative humidity (RH) increases
3. When/If the RH reaches 100% then water vapor (a gas) in the air condenses and VOILA….A CLOUD IS BORN!

(c) Convergence of air

(d) Lifting along weather fronts

Big deal….most of us probably already knew that clouds were made up of tiny water droplets or ice particles anyway….

The real question is how do we get from small drops/ice crystals in the cloud to precipitation on the ground?



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The real question is how do we get from small drops/ice crystals in the cloud to precipitation on the ground?

There are roughly 1000 cloud drops in a drizzle drop

And roughly 1000 drizzle drops in a raindrop

We need to know *something* about processes to go from cloud drop to raindrop!

Lets take a couple of steps back…

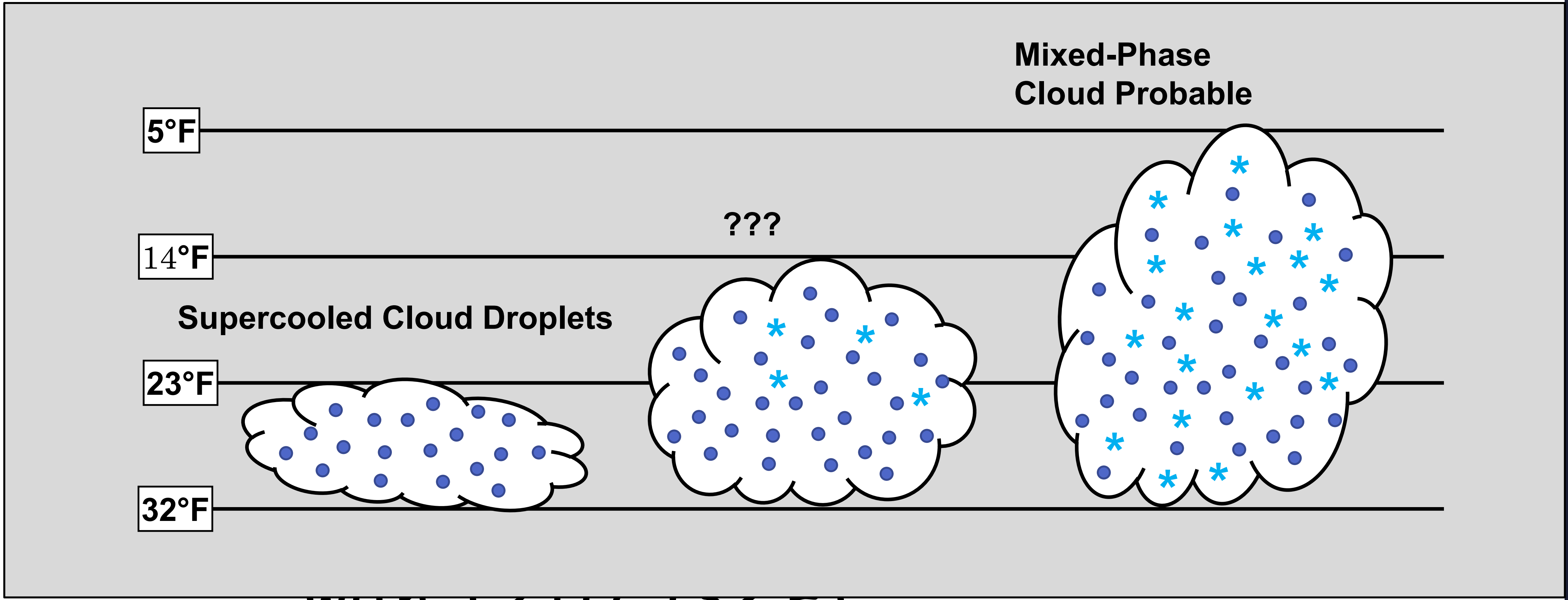
Consider two types of clouds:

1. **All <u>Liquid</u> Clouds**
   → these clouds generally include clouds that exist entirely T > ~-5 to -10 C (14 to 23 F)

2. **Clouds made up of <u>Liquid AND Ice [MIXED-PHASE]</u>**
   → these clouds have some portion with there T < -5/-10 C and include all regions with T < 0 C (32 F)
   [These are HARD!!!!]

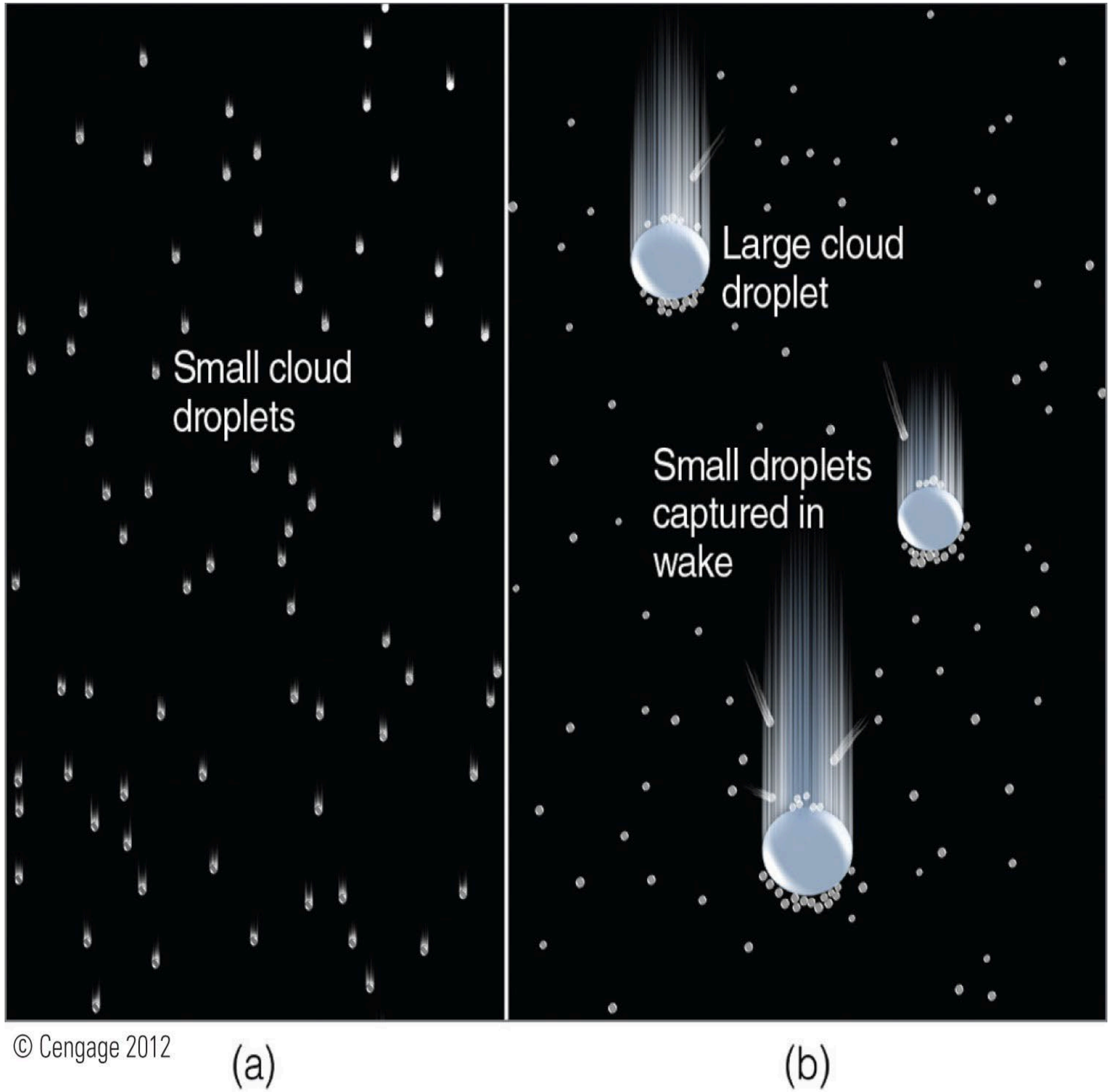
Lets take a couple of steps back…

Consider two types of clouds:



First considering all liquid clouds (because these are easiest!!!!)

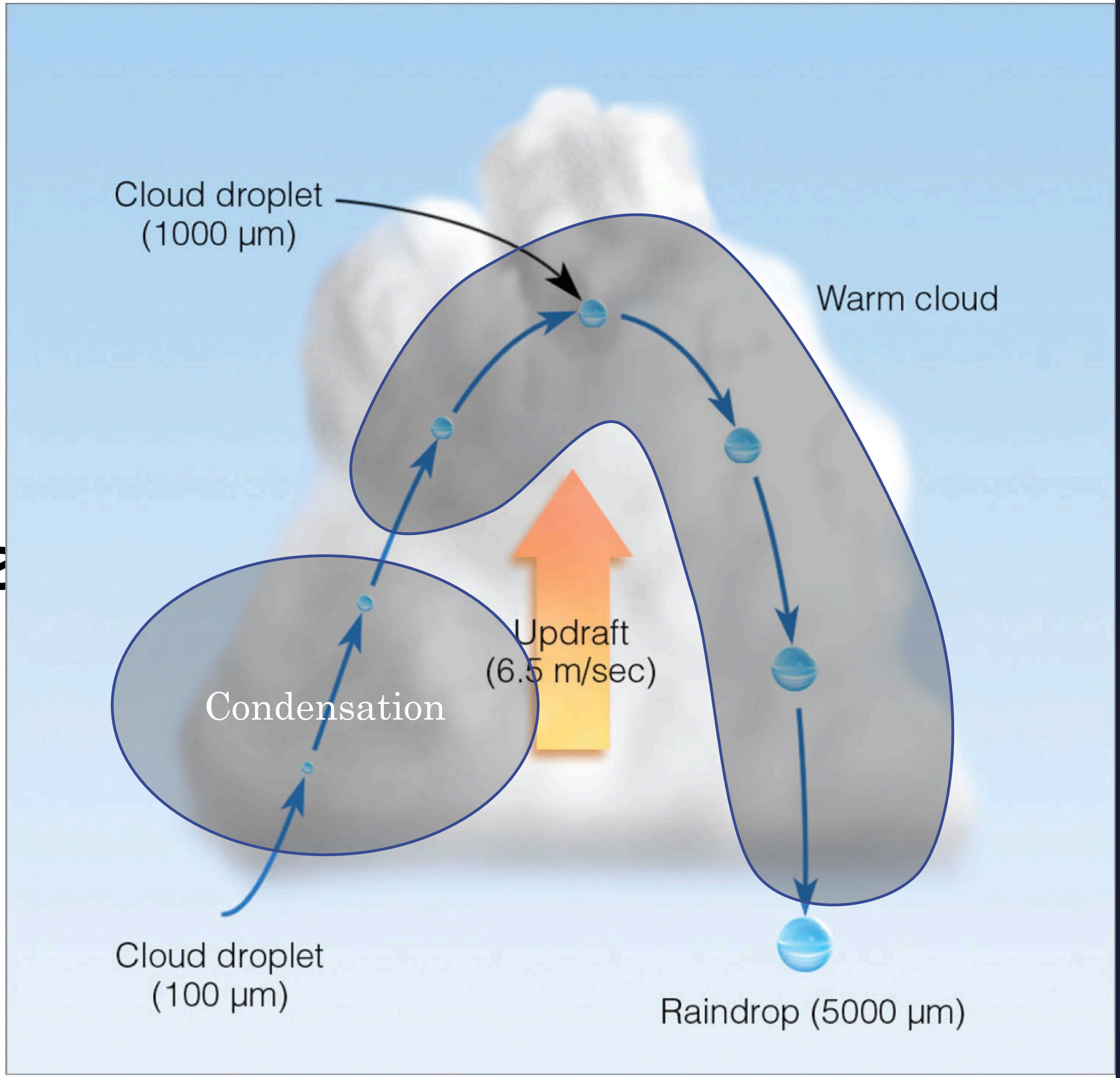
A. Begin with a field of many cloud droplets
B. Droplets of different sizes fall at different speeds
C. These different sized droplets **collide and coalesce** into larger drops
D. A typical raindrop can fall 600X faster than a cloud droplet



First considering all liquid clouds (because these are easiest!!!!)

A. Cloud drops first grow by **condensation**

B. When they are big enough they begin growing more rapidly by **collision and coalescence**



First considering all liquid clouds

Condensation followed by Collision/Coalescence can be a slow/inefficient process

- It works 'best' in very warm clouds that contain LOTS of liquid water
- In colder clouds, where less liquid is available, there often is not enough liquid to grow drops large enough to fall and produce precipitation (here ice is more important)
- In addition to the amount of liquid water, how many droplets are present and their relative size, also impacts the effectiveness of collision/coalescence

Now let's talk about clouds that contain ice

this is when things get real!

Everyone knows that ice will melt (and turn into liquid water) at 0 degC (or warmer T).

But…it is less well known that liquid water does not necessarily freeze (and turn into ice) at 0 degC (or colder T)

In Fact….in the atmosphere liquid water drops often exist at much lower temperature…

Now let's talk about clouds that contain ice

At temperatures warmer than -40 *degC* (!!!!), liquid drops will not freeze without some type of particle to initiate t the freezing process (dust, smoke particle, etc)

These particles are relatively *rare*....thus clouds at cold temperatures (for example: -15 *C*) often contain both liquid and ice

WHY DO WE CARE?????

Now let's talk about clouds that contain ice

WHY DO WE CARE?????

1. Many/most of cloud at mid- and high-latitudes are too cold to produce precipitation from liquid alone

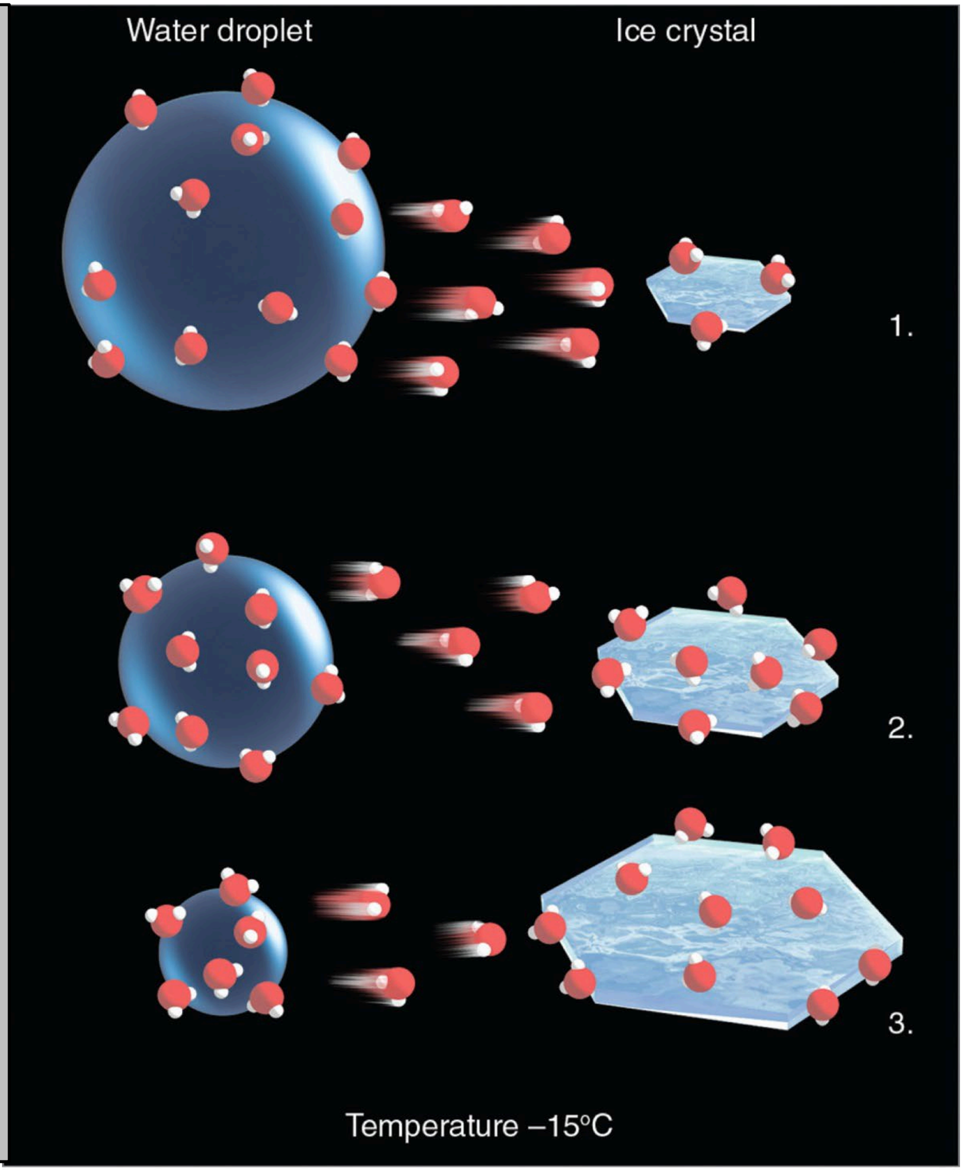
2. These same clouds are often mixed-phase (containing both liquid and ice)....in such clouds ice has an advantage compared to liquid in growing to precipitation sizes.

Now let's talk about clouds that contain ice

In mixed-phase regions ice crystals grow at the expense of liquid water drops.

We call this the ***Wegener-Bergeron-Findeisen*** ice growth process (or Bergeron process for short)

This is the primary mechanism by which precipitation forms in the midlatitudes.



The Bottom Line....

1. Colder clouds (at mid- and high-latitudes) are often unable to produce precipitation through liquid alone.

2. Ice particles are relatively rare in these clouds....at least compared to liquid water drops.

3. If ice does form....those (few) ice crystals can grow rapidly and very efficiently transform into falling precipitation (and eventually fall to ground).

The Bott

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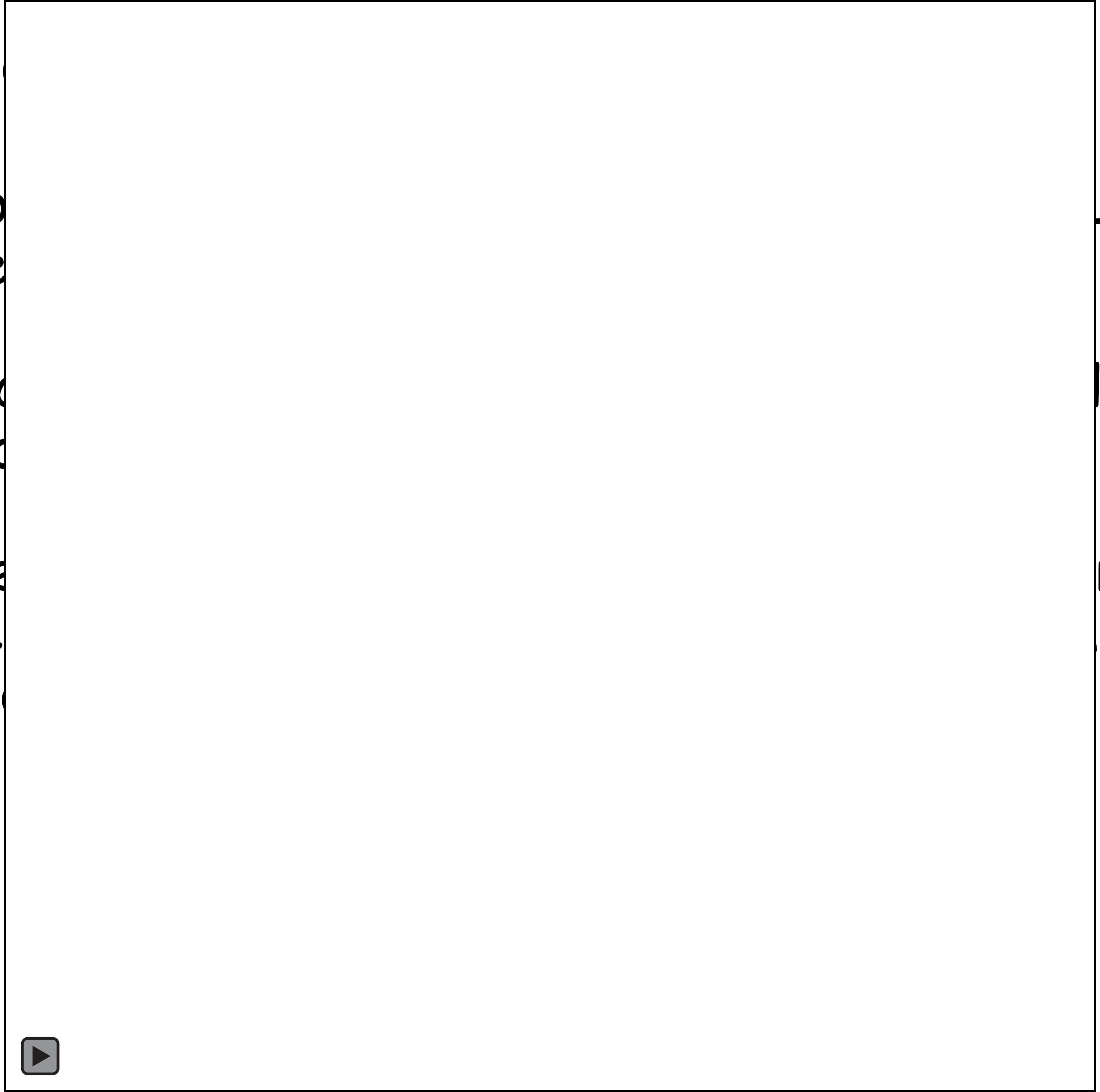
2. Ice parti least compared to

3. If ice doe rapidly and very efficie d eventually f



State of the Science

Dr. Sarah Tessendorf, *Project Scientist* |National Center for Atmospheric Research, RAL

The Science of Cloud Seeding

How it works and recent advances

Dr. Sarah Tessendorf
National Center for Atmospheric Research, Boulder, CO

November 15, 2023

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Key Messages

Recent studies have proven that cloud seeding works to enhance precipitation in winter orographic clouds

Recent advances in modeling are enabling innovative research and improved understanding of cloud and precipitation processes, and cloud seeding impacts

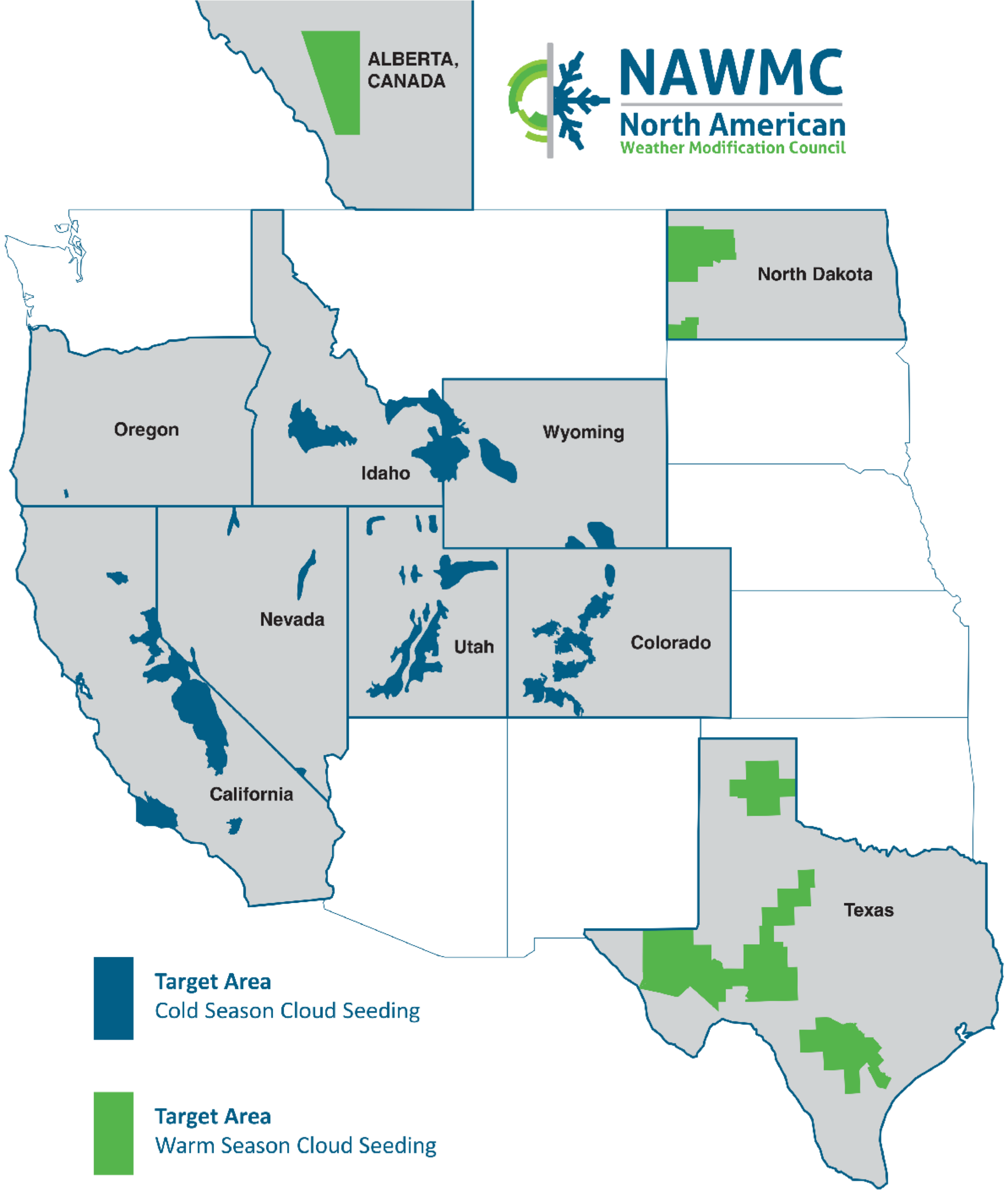
More research is needed to advance our understanding of cloud seeding in summer clouds

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

Cloud Seeding Introduction

Cloud Seeding is a technology typically used to enhance precipitation

- Cloud seeding occurs across the western U.S. and also in countries outside of North America, such as (but not limited to):
  - Australia
  - United Arab Emirates
  - China
  - Israel



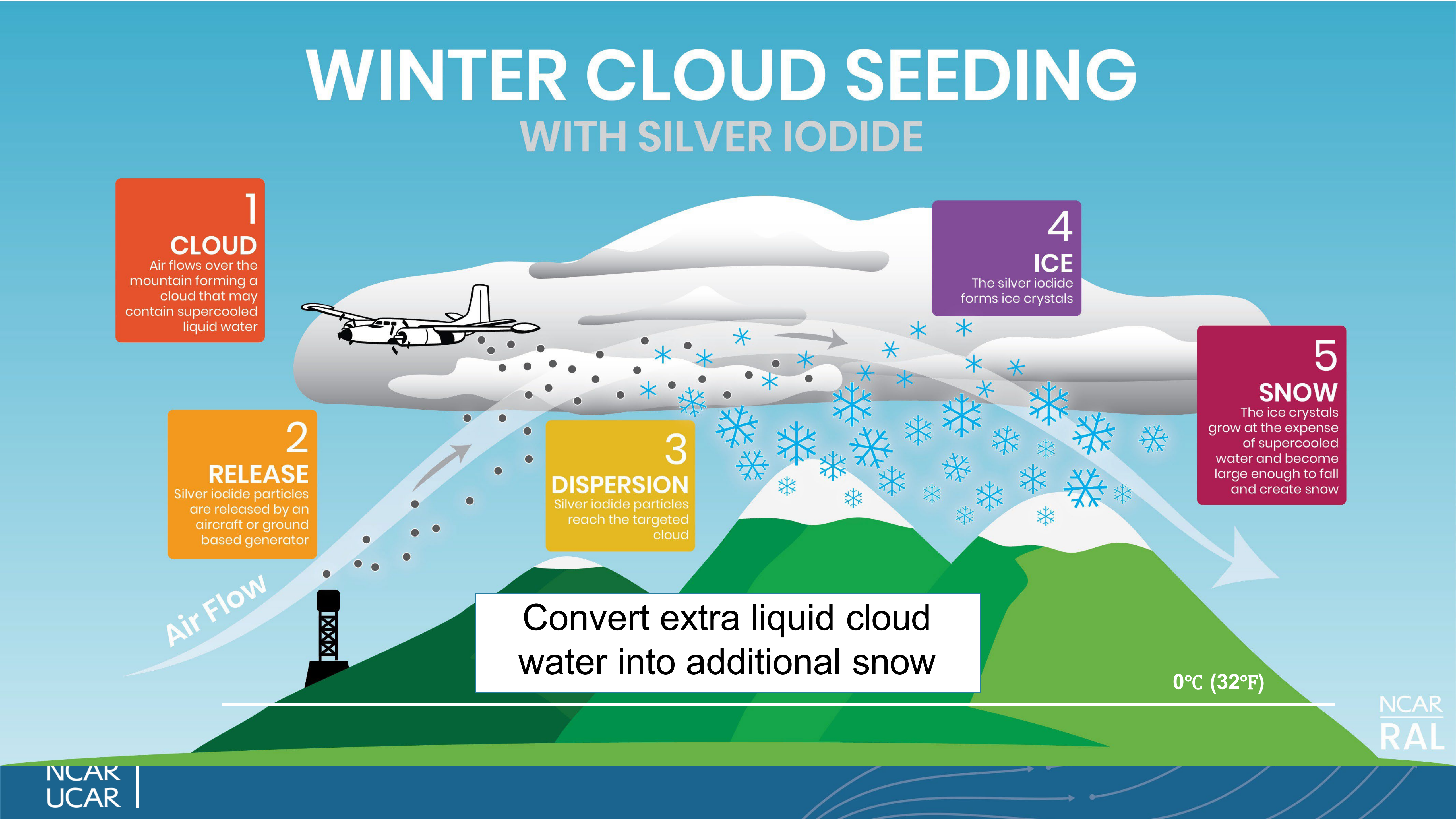
Two modes for seeding winter storms

Insert ice nucleating particles

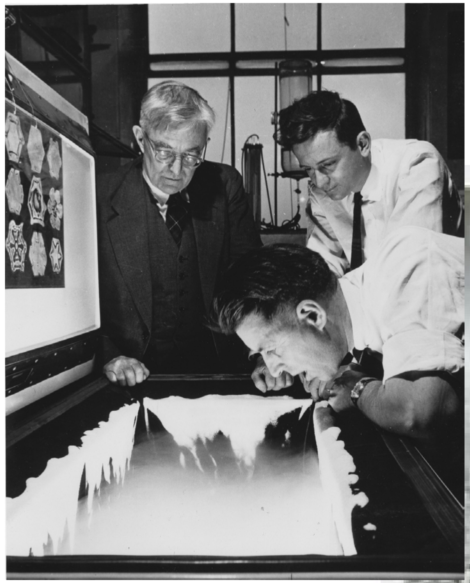
Silver iodide (AgI) is common

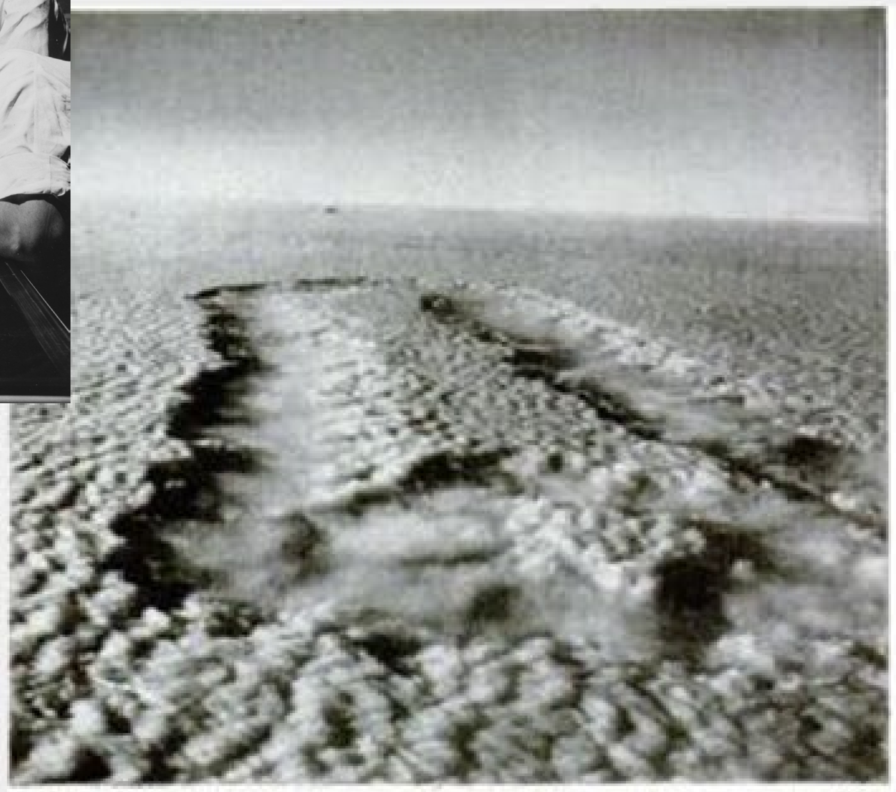
Create a supercooling effect to nucleate ice

Dry ice or liquid propane


WINTER CLOUD SEEDING
WITH SILVER IODIDE
1
CLOUD
Air flows over the mountain forming a cloud that may contain supercooled liquid water
2
RELEASE
Silver iodide particles are released by an aircraft or ground based generator
3
DISPERSION
Silver iodide particles reach the targeted cloud
4
ICE
The silver iodide forms ice crystals
5
SNOW
The ice crystals grow at the expense of supercooled water and become large enough to fall and create snow
Air Flow
Convert extra liquid cloud water into additional snow
0℃ (32℉)
NCAR
RAL
NCAR
UCAR

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—

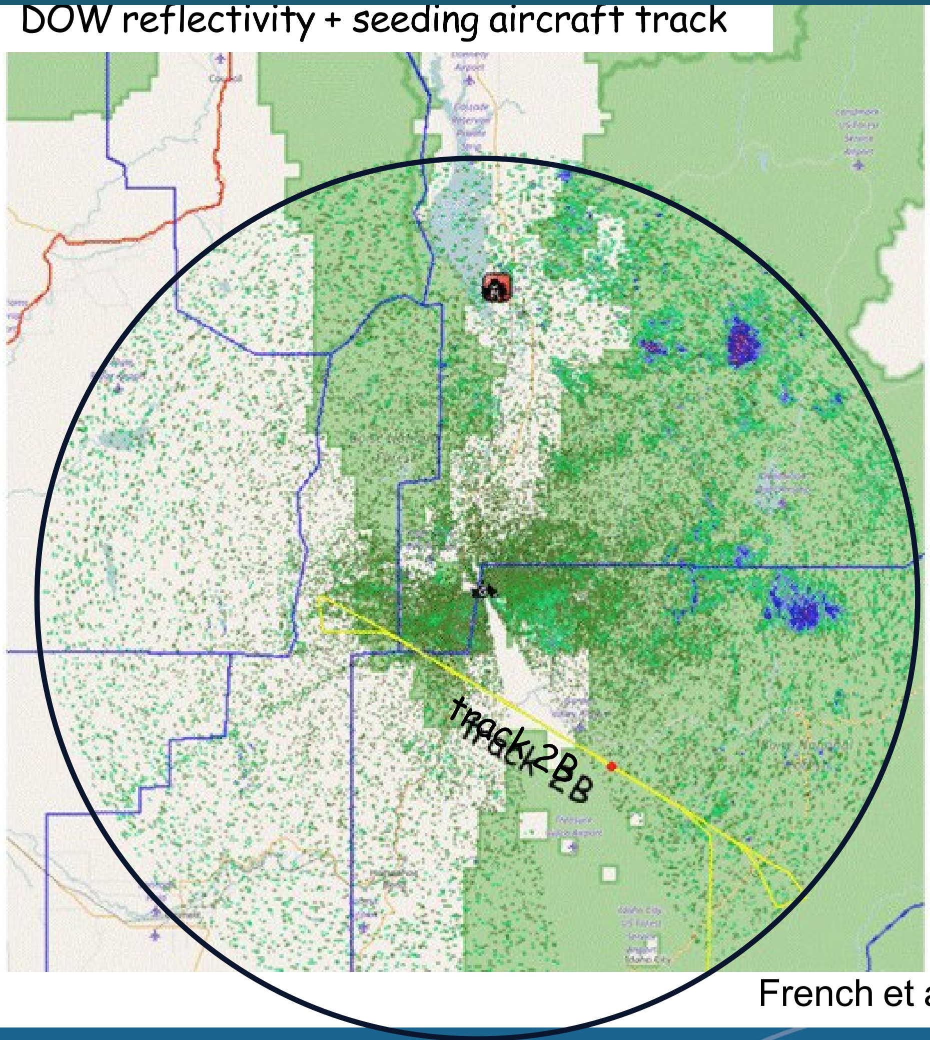
Proof of concept that liquid clouds could be seeded to produce ice, which would deplete the liquid cloud

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

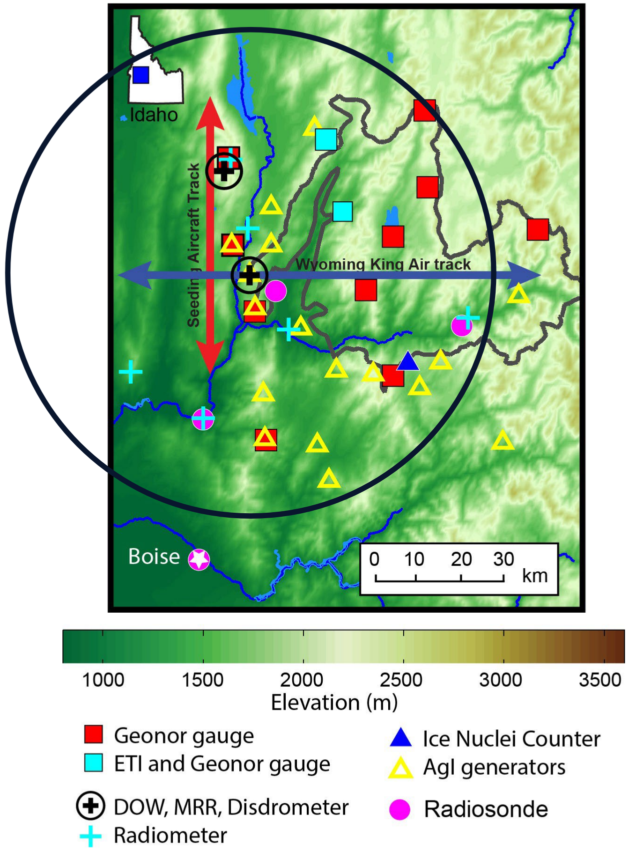
Cloud seeding produces ice and snow

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

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

Where does winter cloud seeding research go next?

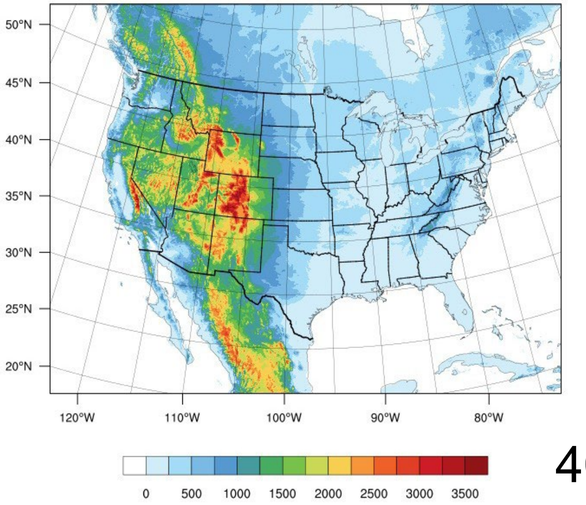
- Where and when does cloud seeding with silver iodide **work most effectively**?
- How effective is cloud seeding with **liquid propane**?
- How do we confidently **quantify the impacts** of cloud seeding?
- How does cloud seeding impact snowmelt-driven **streamflow**?
- How **cost effective** is cloud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

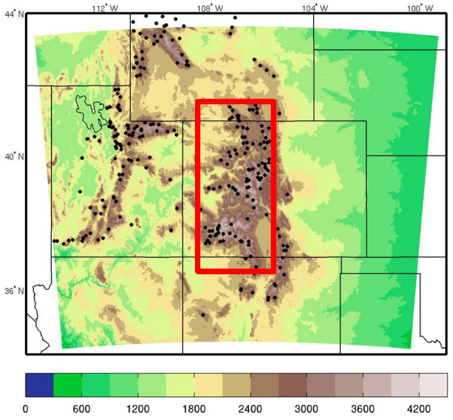
We are working to address these questions (and more) with new advances in computer modeling and observational capabilities

Breakthroughs in modeling orographic precipitation

Able to **realistically simulate natural precipitation** in regions of complex terrain Ikeda et al. (2010), Rasmussen et al. (2011), Liu et al. (2017)

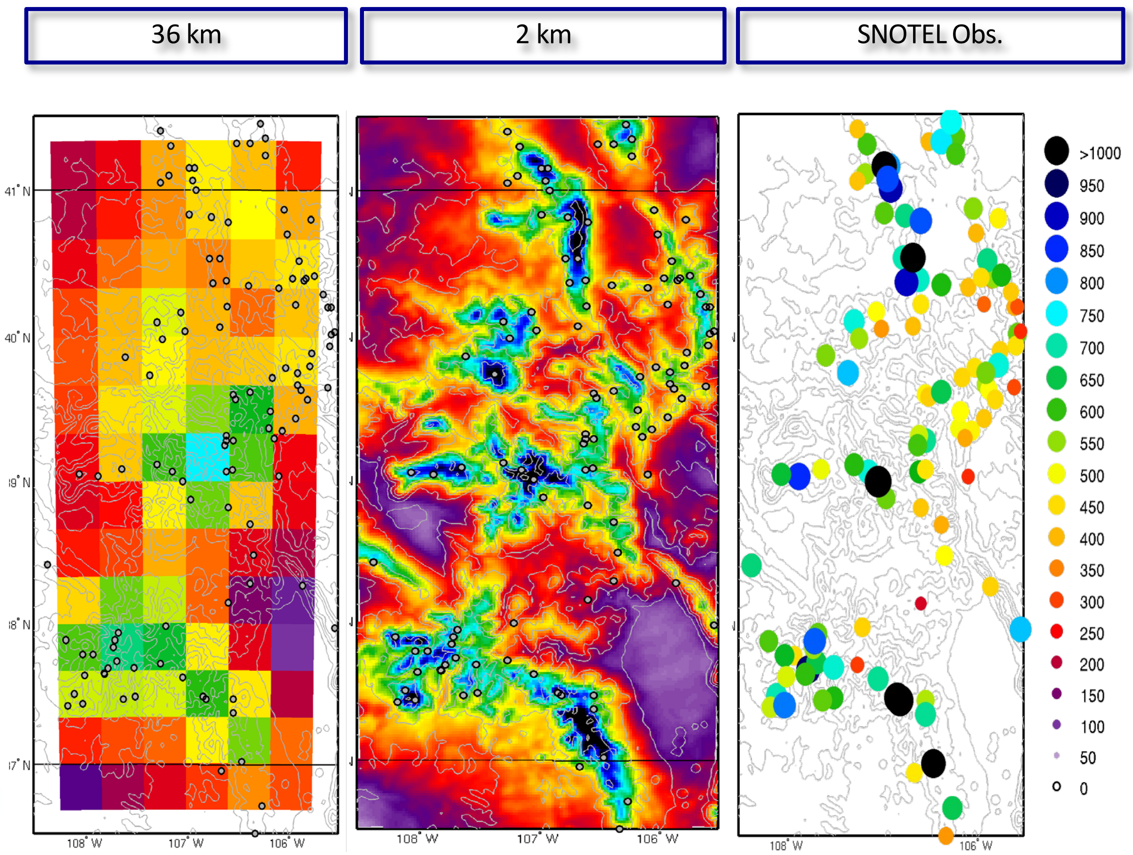
CONUS404 Simulation





40 years at 4 km!

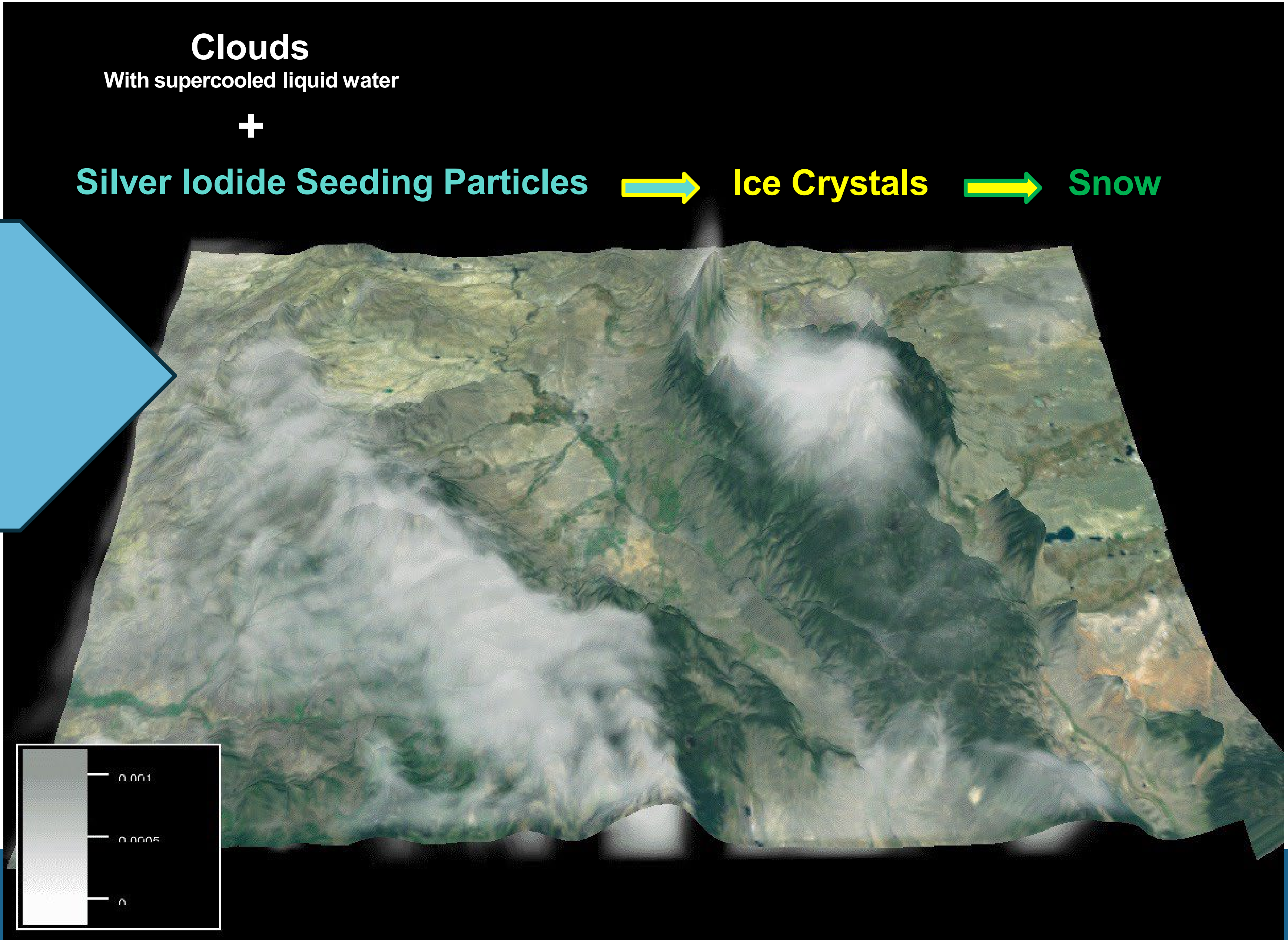
Precipitation accumulation over one water year



Colorado Headwaters Region

Breakthroughs in modeling the impacts of cloud seeding

Developed a **parameterization to simulate cloud seeding** in WRF (WRF-WxMod®) Xue et al. (2013)



Coupled modeling to quantify impacts of cloud seeding

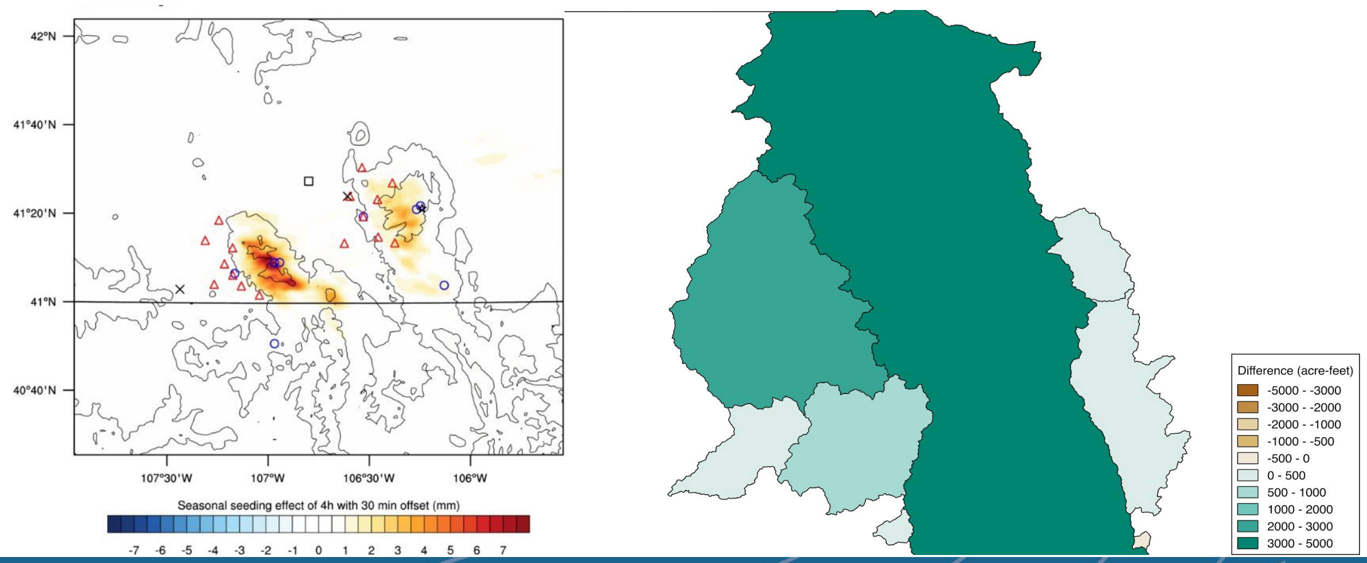
Able to **realistically simulate natural precipitation** in regions of complex terrain
Ikeda et al. (2010), Rasmussen et al. (2011), Liu et al. (2017)

Developed a **parameterization to simulate cloud seeding** in WRF (WRF-WxMod)
Xue et al. (2013)

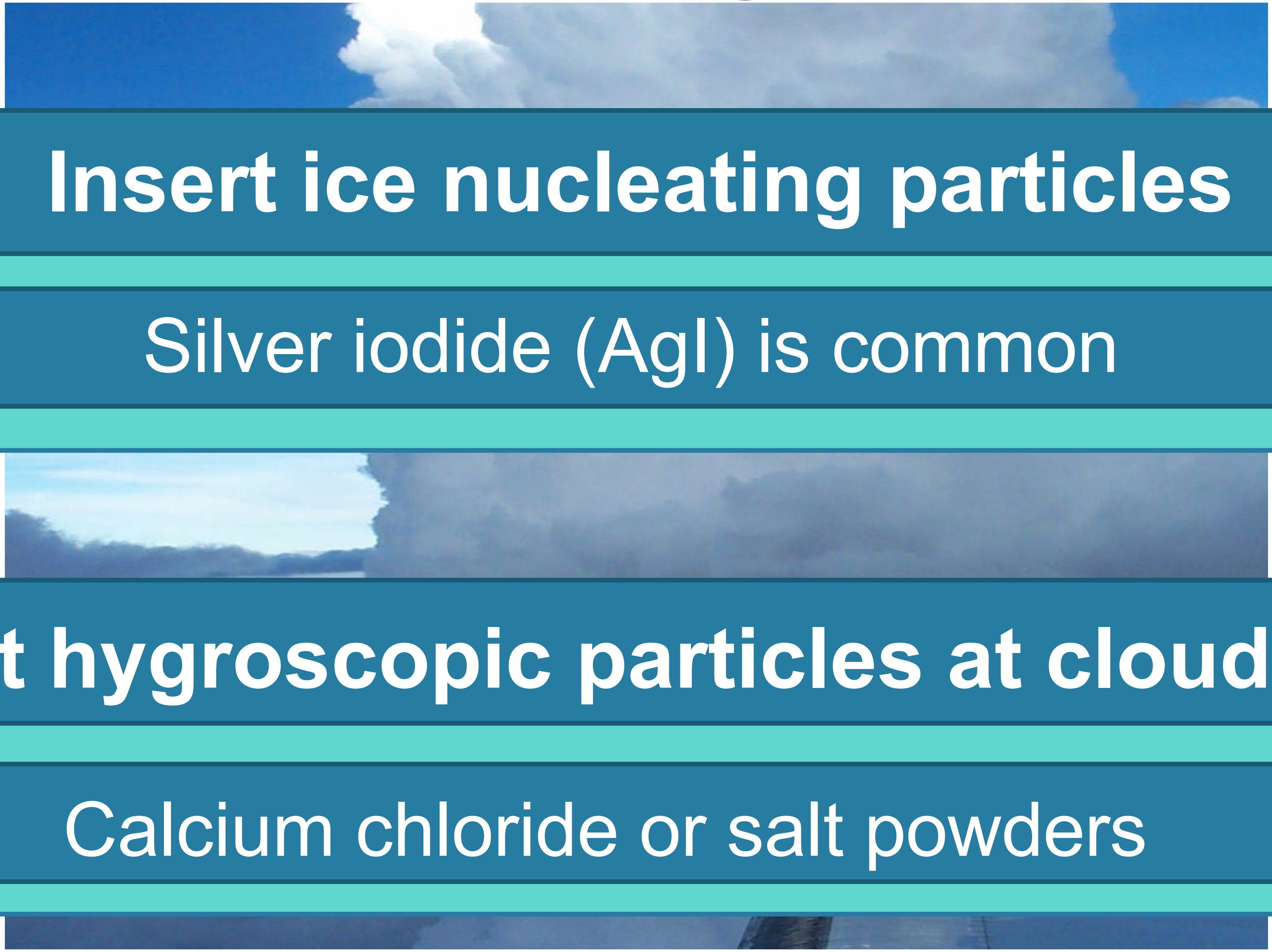
Developed WRF-Hydro® model that simulates spatially-distributed runoff and streamflow driven by WRF output
Gochis et al. (2018)

Building a capability to **simulate cloud seeding impacts on precipitation and streamflow**

Simulated change in precipitation and streamflow



Two modes for seeding summer storms



Insert ice nucleating particles

Silver iodide (AgI) is common

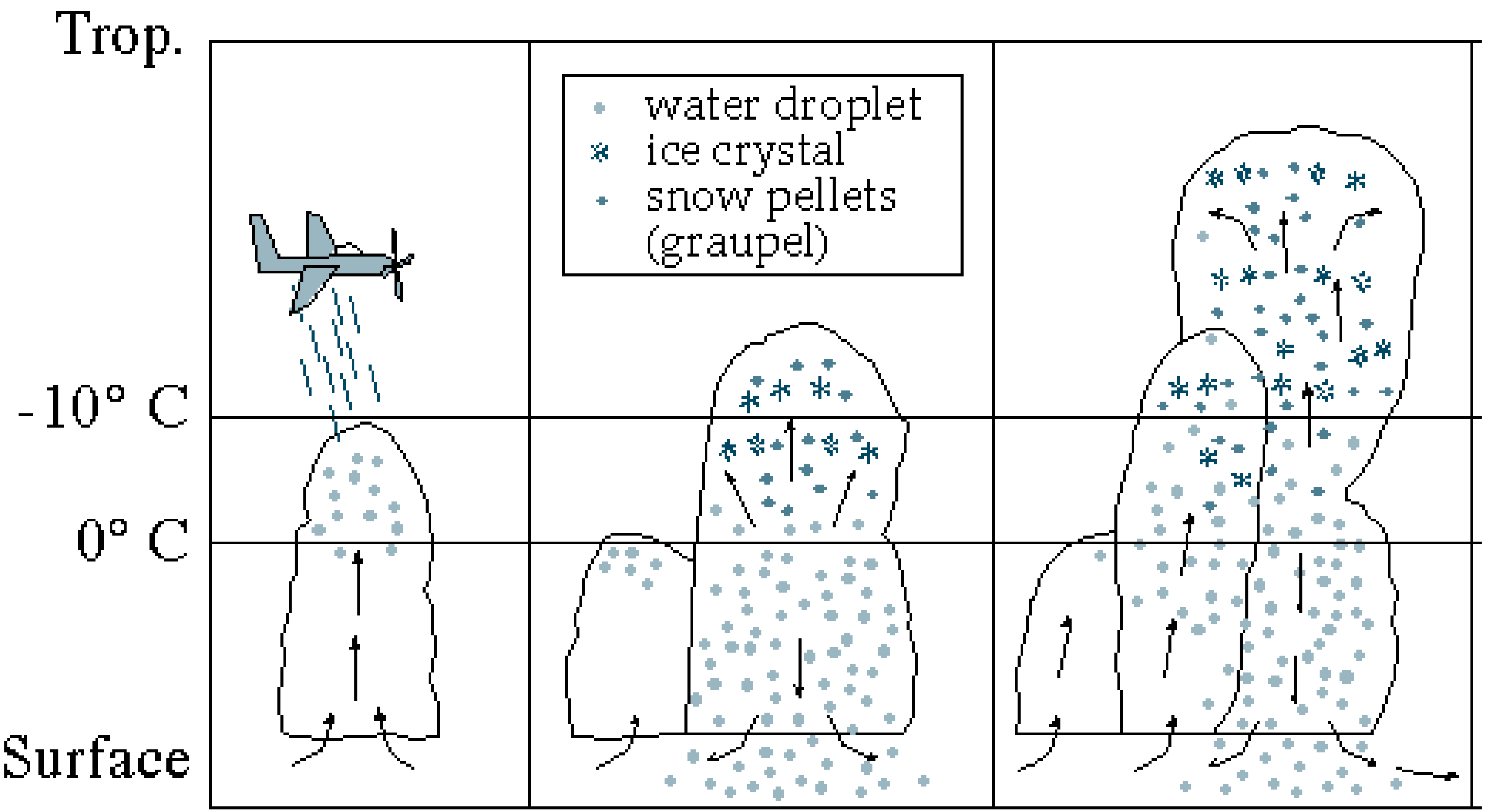
Insert hygroscopic particles at cloud base

Calcium chloride or salt powders

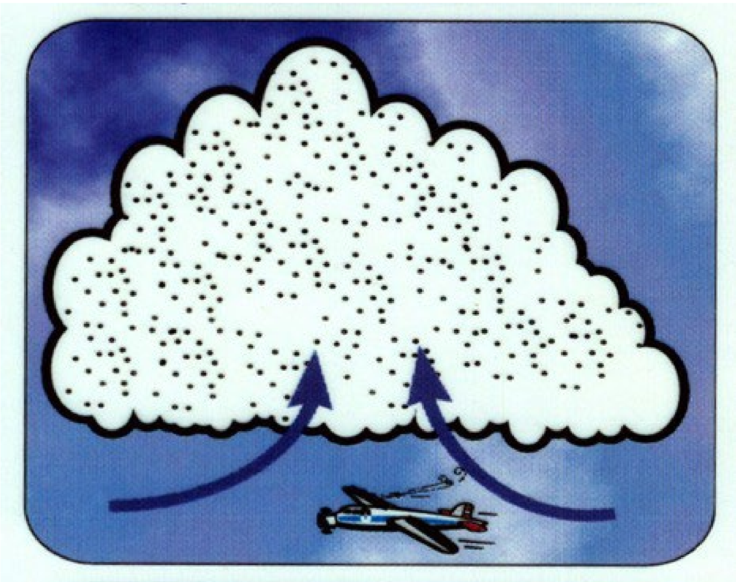
Seeding summer storms with AgI

Convert more liquid water into ice to enhance precipitation

- Not well proven



Hygroscopic Seeding

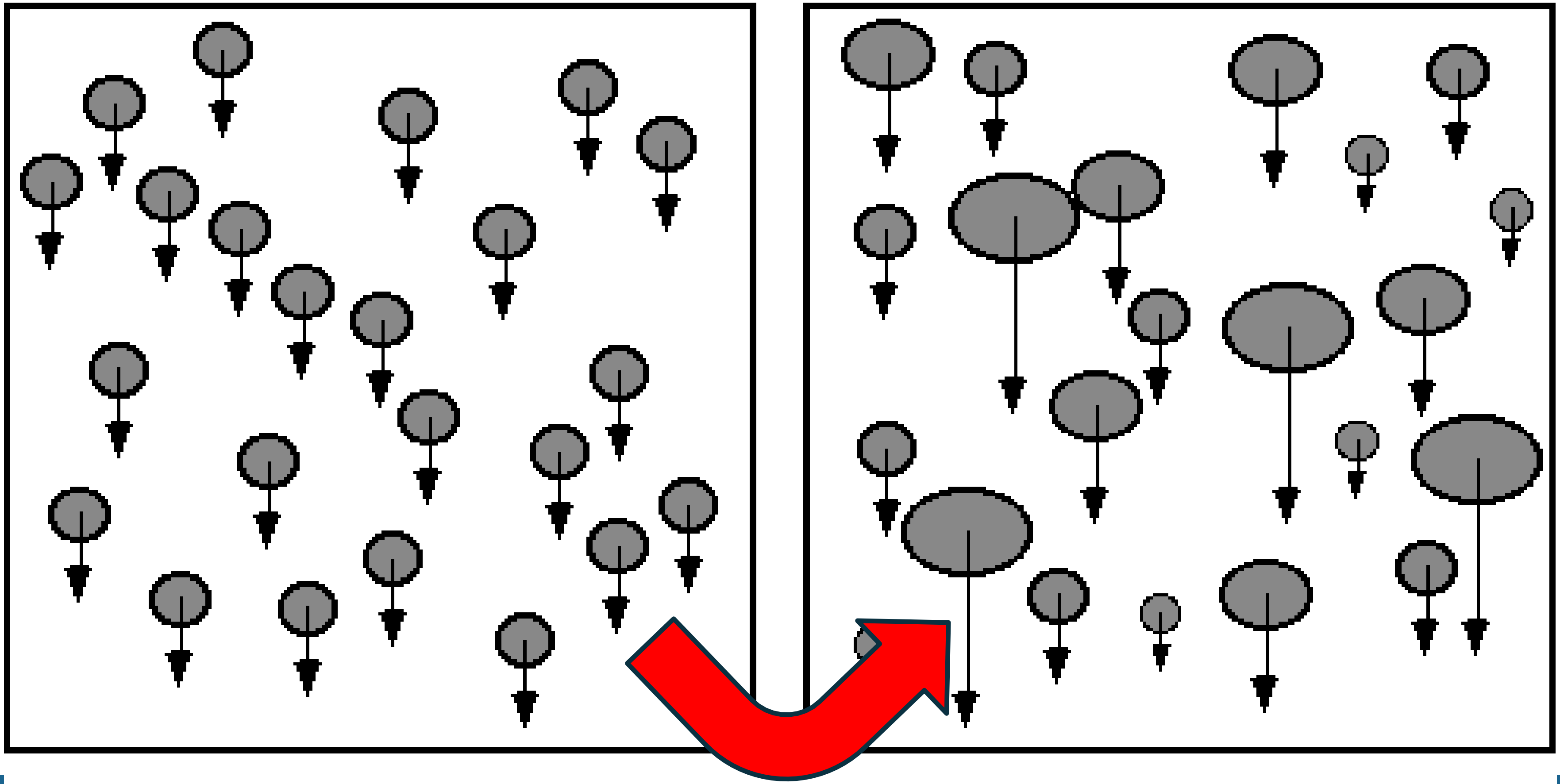


Less efficient

Uniform distribution of droplets

More efficient

Non-uniform distribution



Try to add larger droplets that will initiate coalescence

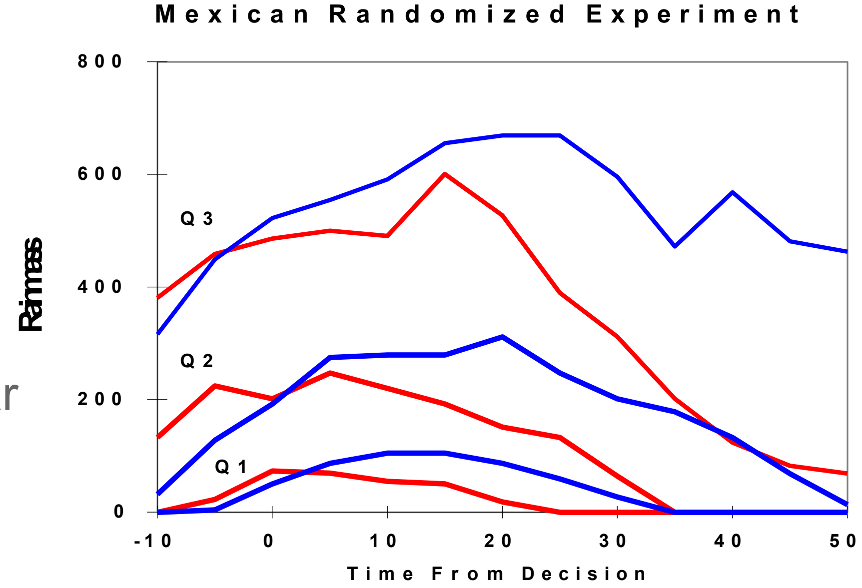
Partial evidence of hygroscopic seeding impacts

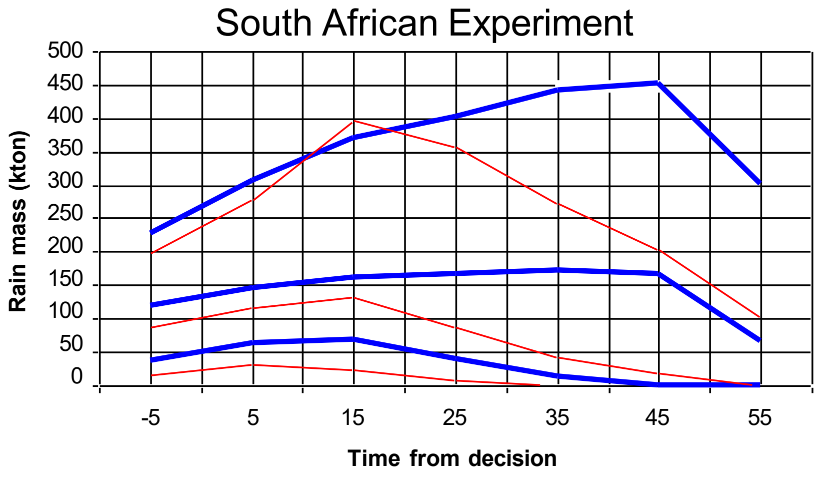
First step in conceptual model confirmed, but depends on background aerosol

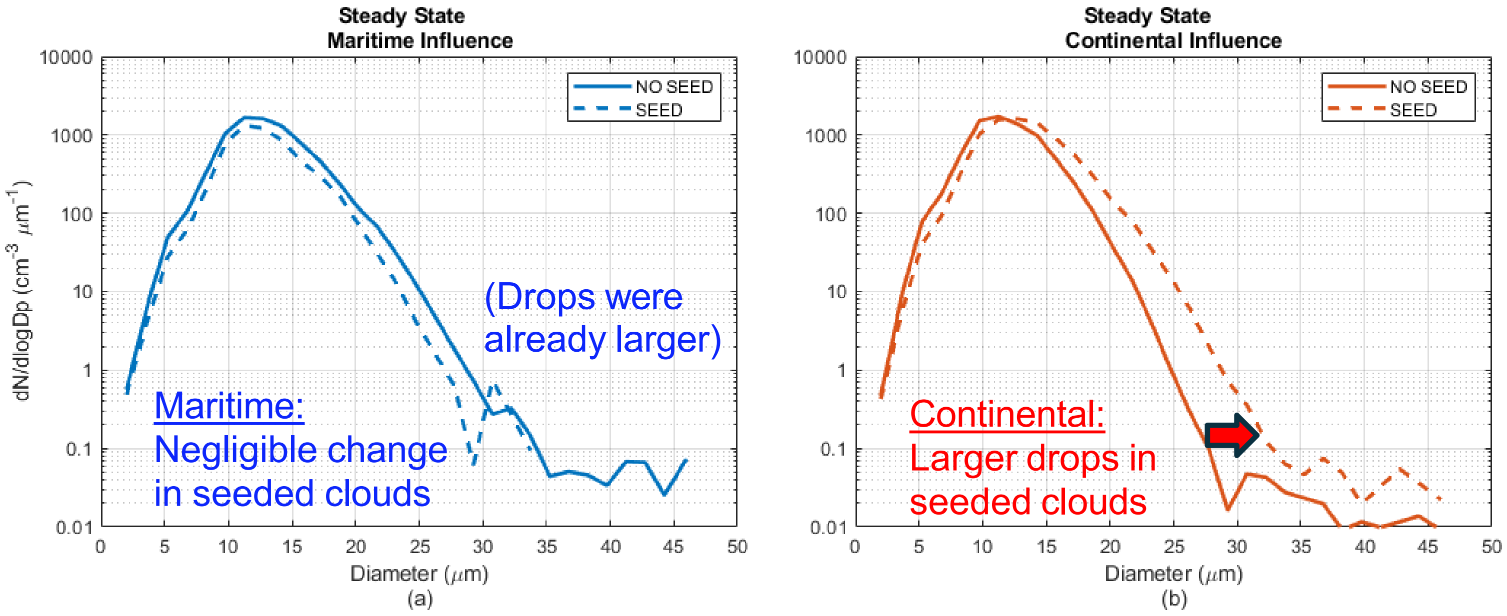
- Larger drops are produced in clouds with continental aerosol
- Less of an impact in clouds with maritime (already large drops)

Impact on precipitation unclear

- Potentially flawed methods using radar



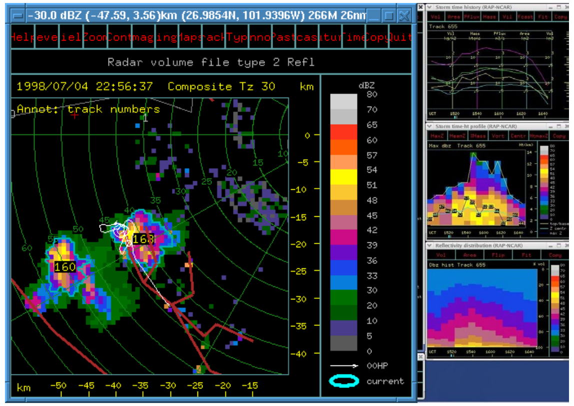




Tessendorf et al. (2021)

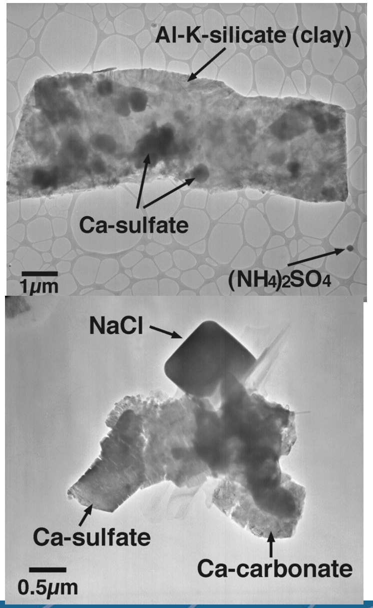
From R. Bruintjes

Scientific challenges of summer cloud seeding



- **Short-lived convective storms with vigorous updrafts**
  - Challenge in timing seeding appropriately
  - Challenge in detecting impacts of seeding
  - Large natural variability in how convective storms evolve

- **Model simulations of convection struggle** to represent and/or resolve exact size, strength, and location of storms



- **Limited understanding the background aerosol** conditions
  - This is also still a challenge in winter cloud seeding, but hygroscopic seeding is reliant on this, because if collision-coalescence is naturally effective, hygroscopic seeding will not be viable

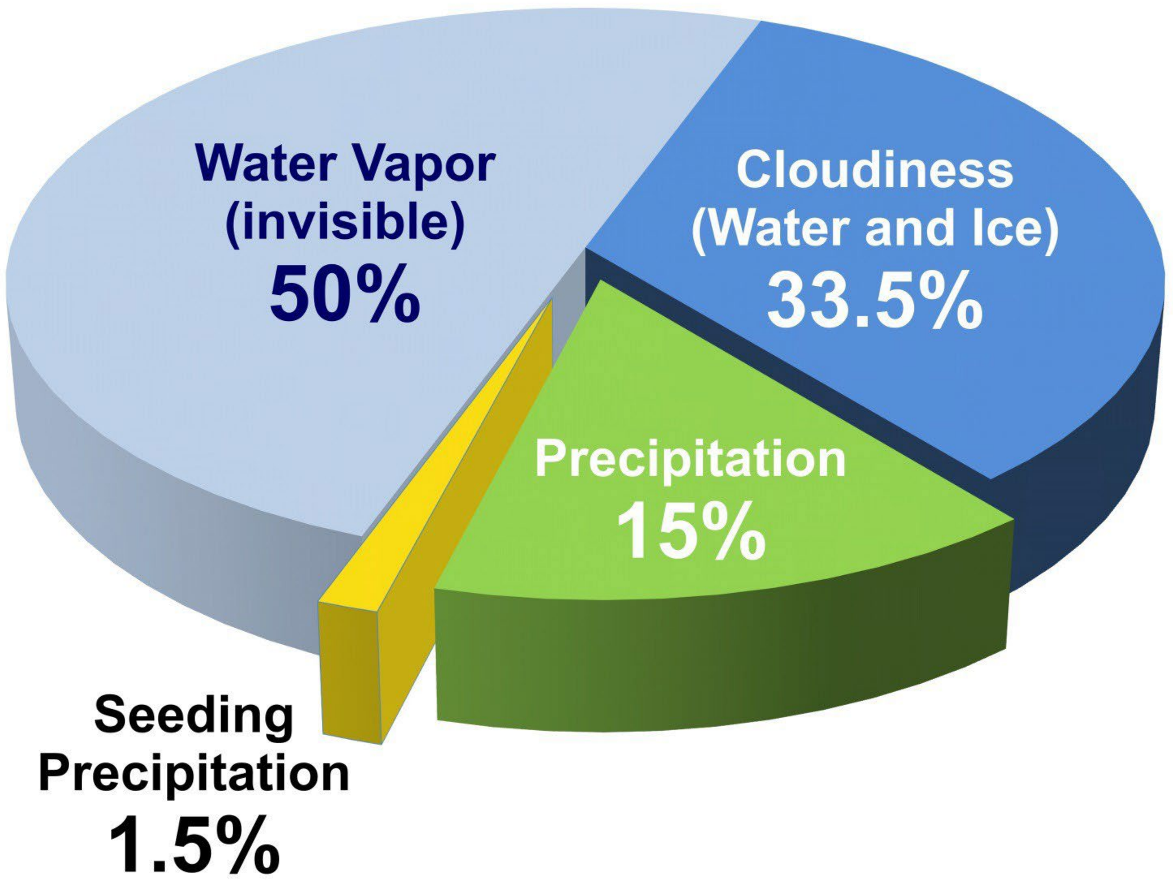
Cloud Seeding Feasibility

- **Clouds can contain supercooled liquid water (SLW)**
  - Clouds with SLW are candidates for cloud seeding to enhance the efficiency of ice and snow formation processes, notably in winter storms
- **Opportunities to seed will vary from place to place**; some locations or mountain ranges are more amenable to cloud seeding than others
  - Important to study the climatology of weather and aerosol conditions to determine when, where, and how to seed
- **Not every storm is the same**; some storms are more amenable to seeding than others
  - Some winter storms are better targeted by ground-based seeding than airborne seeding, and vice versa

What are the extra area effects of cloud seeding?

- Conceptually, the **effect outside of the target area is estimated to be very small**
  - Challenging to detect the intended effect, extra area effects may be even more diffuse
- New modeling capabilities present new opportunities to better address this question

Conceptual Water Vapor Budget

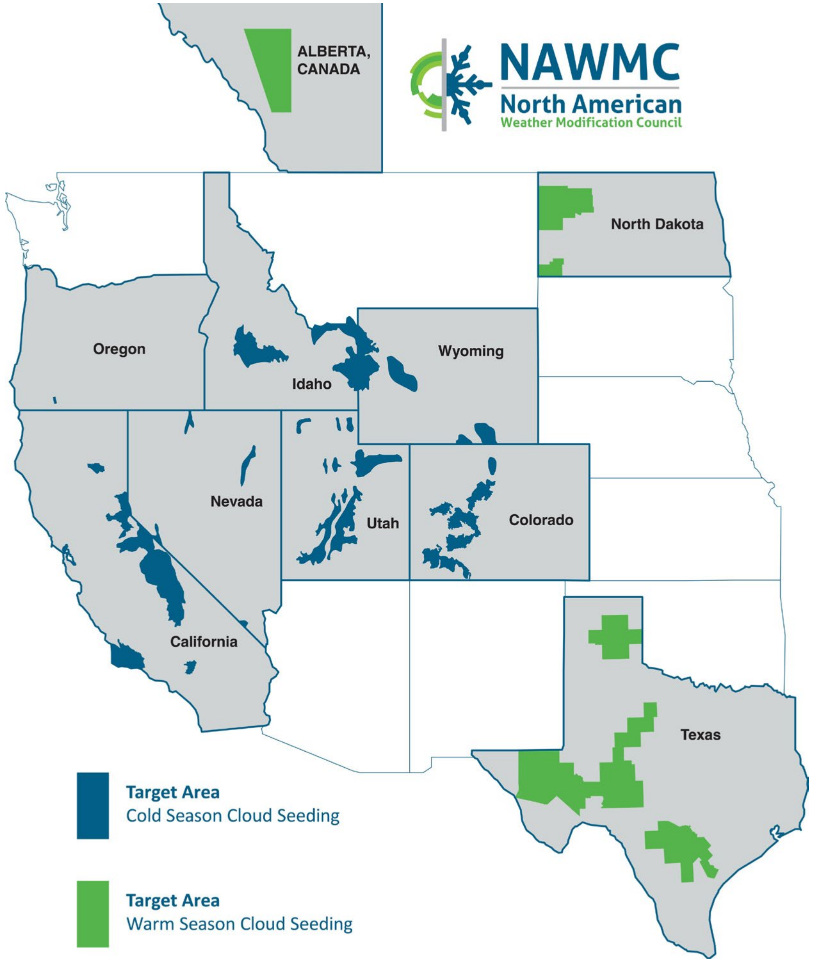


Coordinated and Collaborative Science is Needed

- Weather modification research in past decade has focused on the local and state level
  - ► A great example of research being coproduced by researchers and stakeholders
  - ► Engagement of local stakeholders to address needs unique to each state and local region
  - ► Ensures useful and useable outcomes to meet stakeholder needs

- Research coordinated across states can address regional and larger scale questions

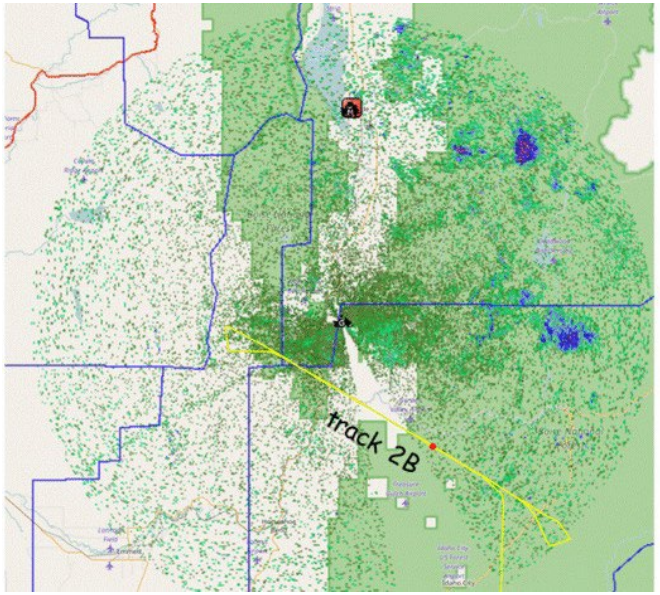
NAWMC
North American
Weather Modification Council

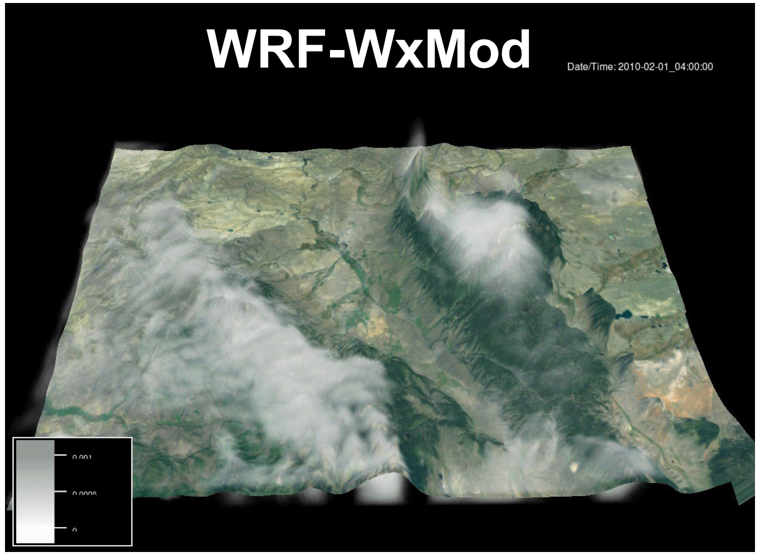


Summary of Advances in the Science

- **SNOWIE data proved the conceptual model that cloud seeding can enhance precipitation in winter orographic clouds**
- **Modeling capabilities have advanced**
  - Realistically represent precipitation and atmospheric conditions in the mountains
  - WRF-WxMod can simulate the impacts of cloud seeding on precipitation
  - WRF-Hydro can simulate spatially distributed precipitation and streamflow

SNOWIE Radar Data





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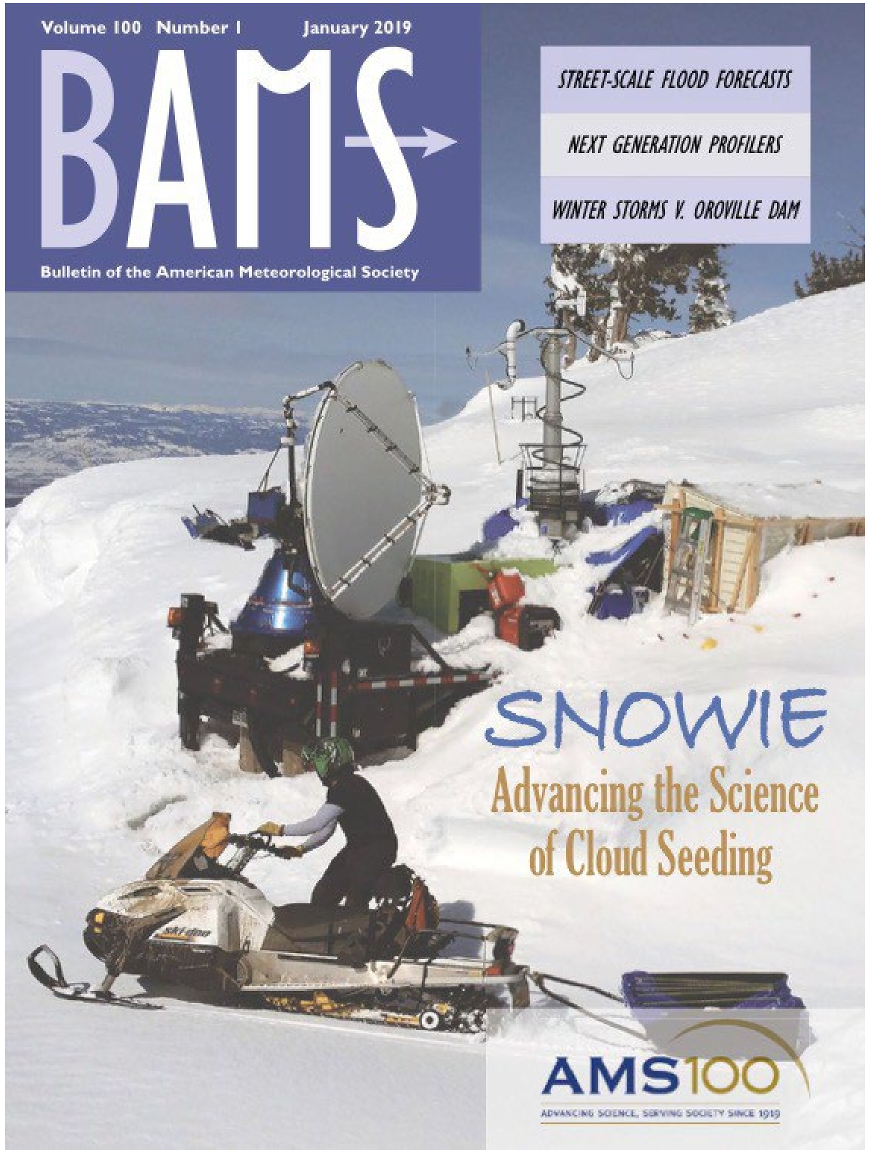
Thank you!

Questions?

Contact me at sarahT@ucar.edu



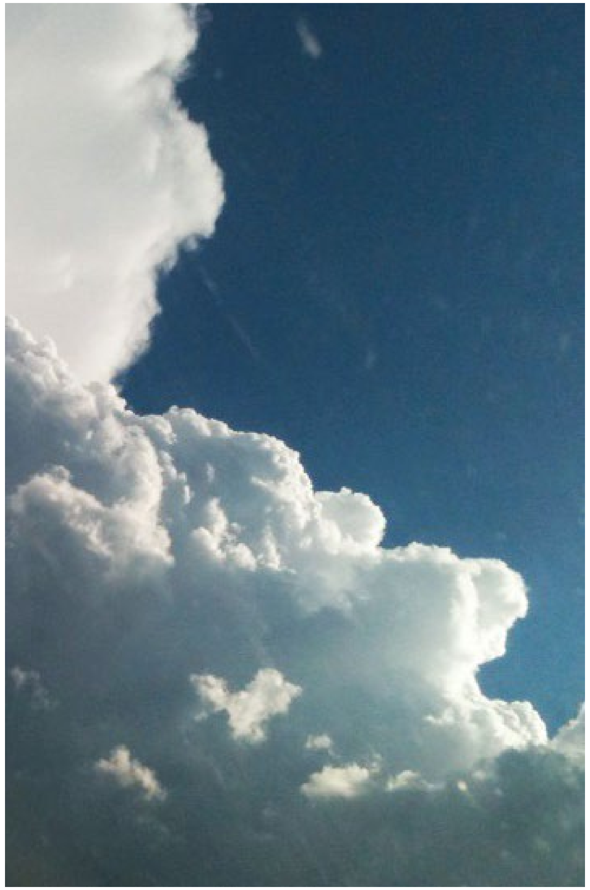
Tessendorf, S.A., and co-authors, 2019: **A transformational approach to weather modification research: The SNOWIE project**. *Bull. Amer. Meteor. Soc.*, **100**, 71–92, doi: 10.1175/BAMS-D-17-0152.1

Cloud Seeding Operations

Summer Precipitation Enhancement & Hail Mitigation

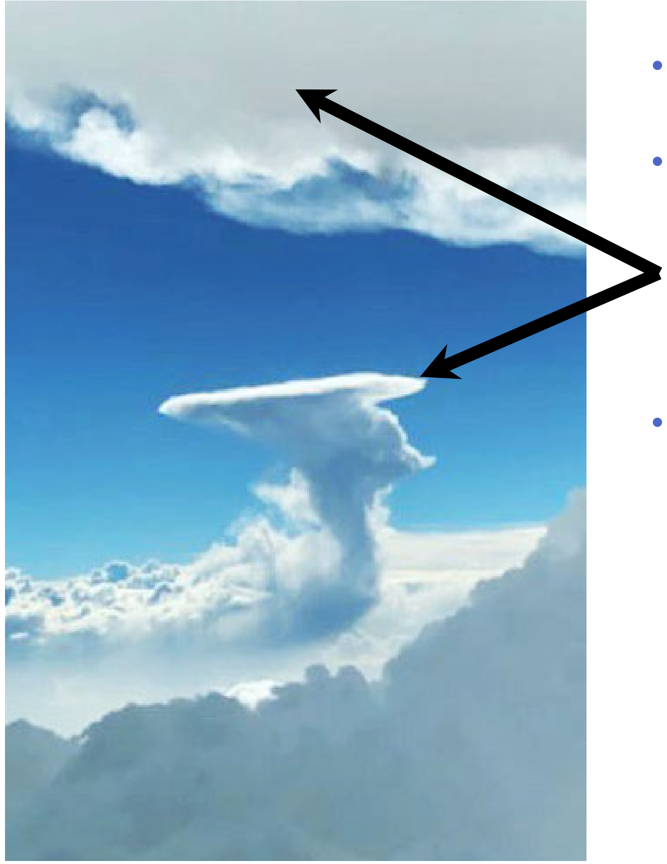
Bruce Boe, *Vice President of Meteorology* |Weather Modification International

Warm Season Cloud Seeding



- Bruce Boe, VP Meteorology, WMI
  bboe@weathermod.com
- "Warm season" typically is taken to mean ***convection***, clouds of vertical development.
- Purposes
  - Precipitation (rainfall) increases
  - Hail Damage Mitigation (hail suppression)
- Today, we will focus on precipitation enhancement.

Premise

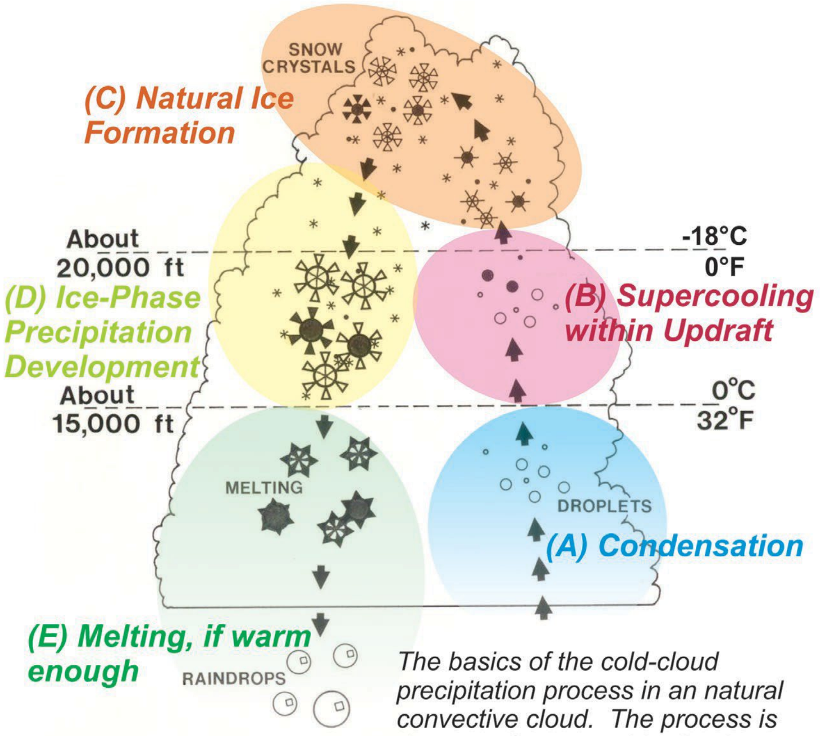


- Nature is not always efficient in converting cloud condensate to precipitation.
- Efficiency = precipitation divided by condensate.
- When we observe rain showers and storms, the parent cloud never ends up entirely on the ground. The residual cloud left behind is condensate, unconverted to precipitation.
- Warm season cloud seeding works when we are able to:
  - Identify inefficient clouds having potential, and
  - Target such clouds appropriately.

Avenues

- Identifying "modifiable" clouds.
- Such clouds are:
  - Certain "cold" clouds capable of supporting mixed-phase precipitation processes that have not developed ice, and
  - Those "warm" clouds comprised of cloud droplets too small to effectively coalesce into precipitation.
- Let's examine each.

Cold Clouds



The basics of the cold-cloud precipitation process in an natural convective cloud. The process is the same in orographic clouds, except for the lifting mechanism.

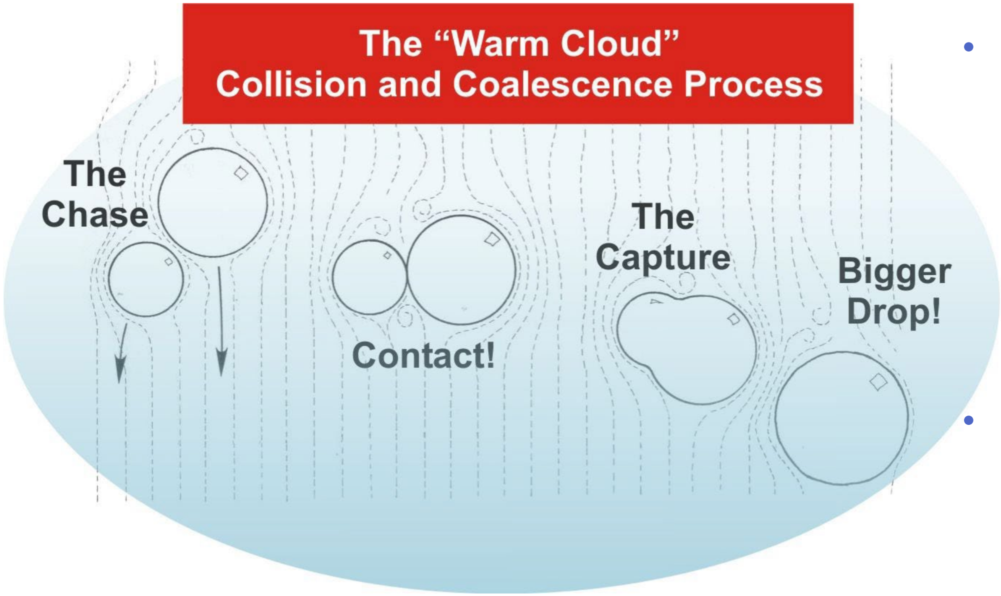
Natural ice-nucleating particles (INP) generally don't produce cloud ice until the cloud gets quite cold, typically around +5°F, (-15°C), sometimes much colder.

We have environmentally-friendly seeding agents available that can create cloud ice at much warmer temperatures, beginning at +23°F (-5°C).

If the seeding agent can be delivered to the cloud when it is younger (warmer), but cooled to +23°F, we can accelerate the mixed-phase precipitation process.

This will give the cloud more time to develop precipitation.

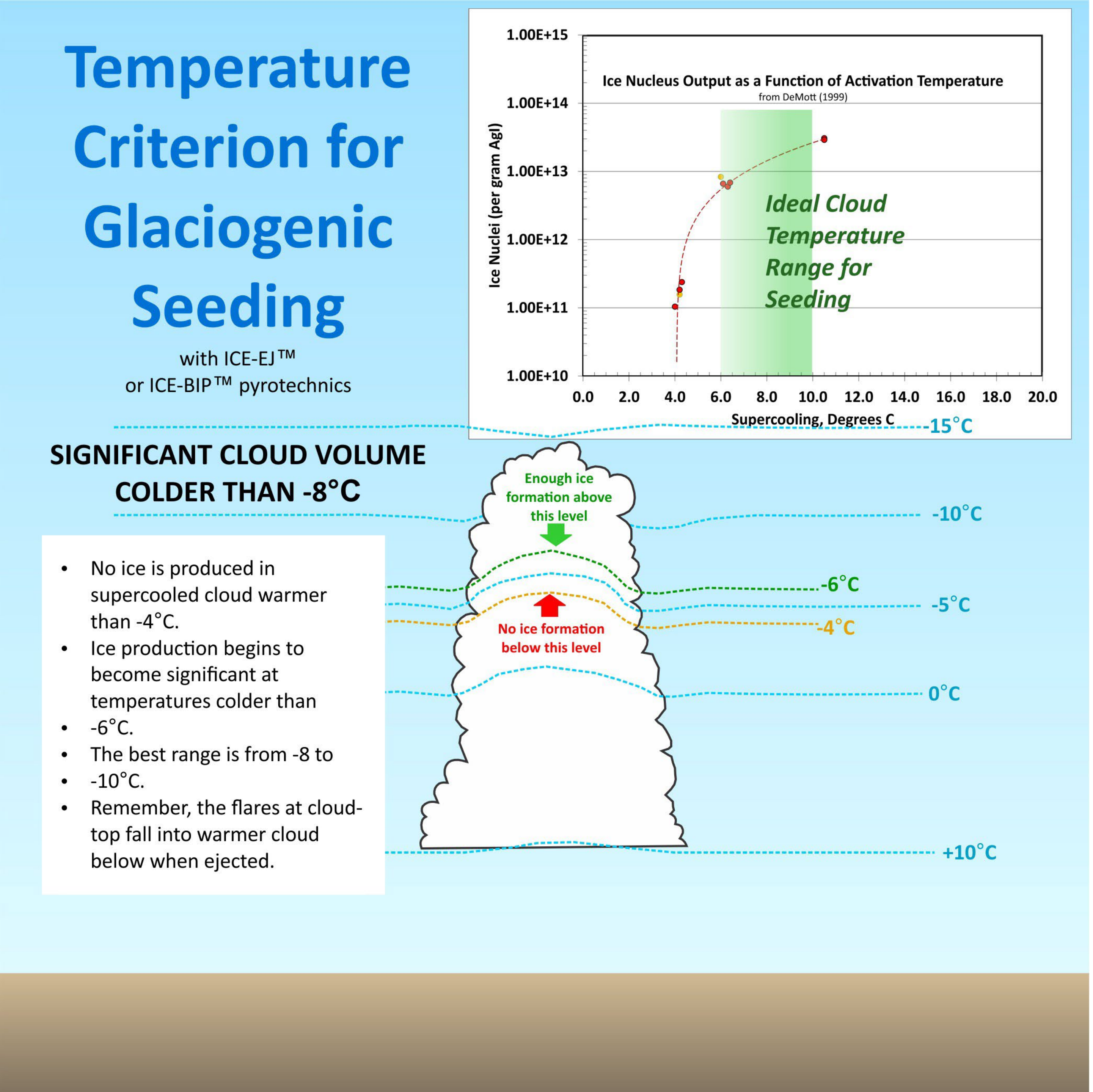
Warm Clouds



- The sizes of cloud droplets formed at cloud base, where water vapor is condensed into liquid water droplets, is determined by character of the particles on which the vapor condenses. These are the cloud condensation nuclei (CCN).
- When the natural CCN result in mostly small cloud droplets, precipitation development is impaired, and the warm rain process is inefficient.
- If we can provide enough large, hygroscopic (water-attracting) CCN at cloud base, we can create much larger cloud droplets, enhancing the warm rain (collision-coalescence) process.

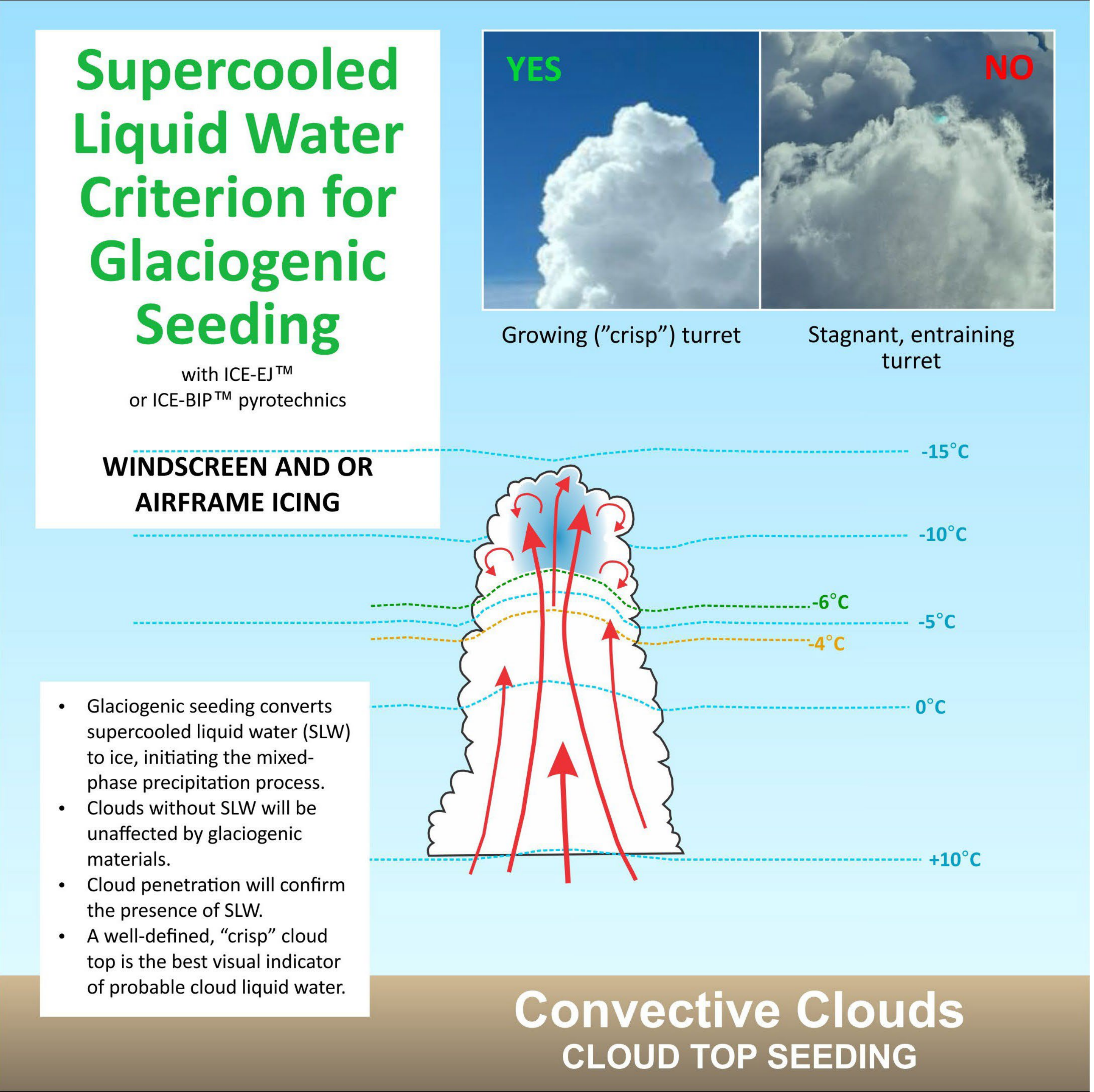
How it Works: Cold Clouds

- Viable candidates for glaciogenic (ice-forming) treatment are clouds having the following characteristics:
  - An updraft.
  - A lack of natural cloud ice.
  - Supercooled cloud top.
- There are other ancillary considerations as well, but we'll save those (mostly) for another workshop.



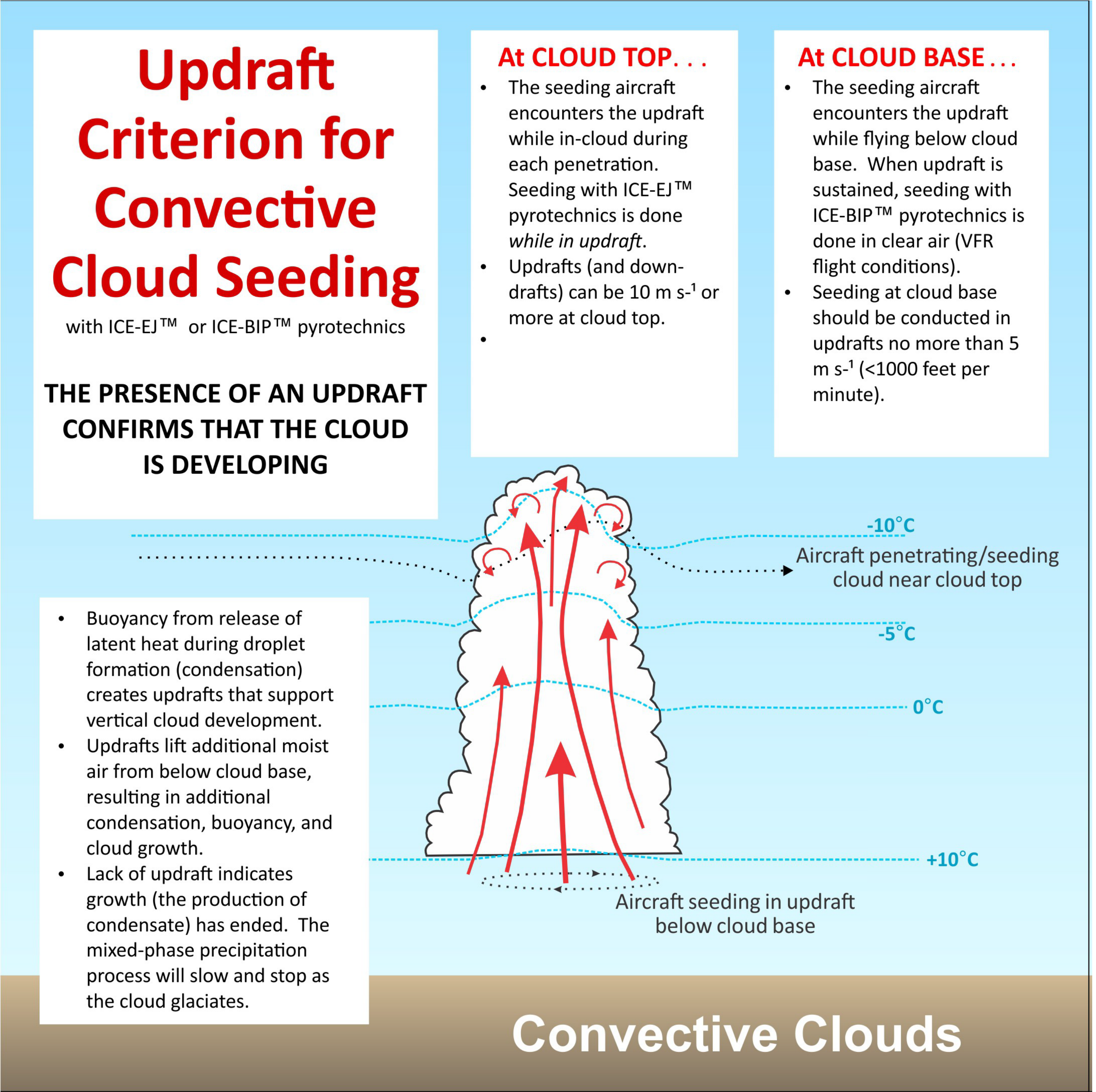
Supercooling

- **Supercooling**. We need clouds cold enough to respond to our seeding agents.
- Flares can make a little ice at +23°F, but 100-times more at +16°F.
- Dry ice can make cloud ice at +28°F!
- Liquid propane anything below +32°F! (but ground-based only).
- Dry ice and liquid propane produce ice via extreme, very localized supercooling, and do not produce ice-nucleating particles.



Cloud Water

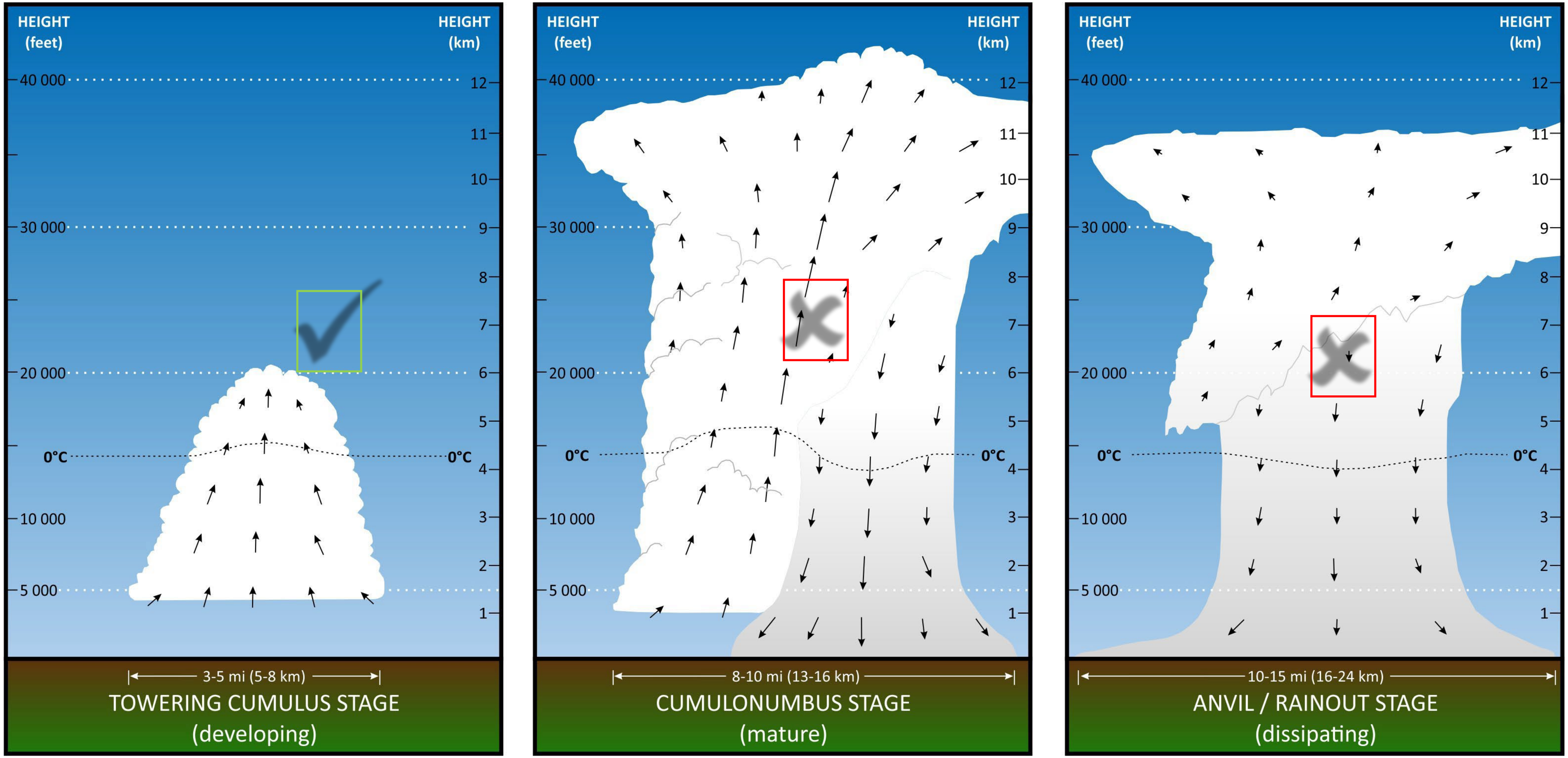
- A supercooled cloud top ***without*** detectable liquid water won't have anything much to freeze!
- A supercooled cloud top ***with*** cloud water will result in ice on the airplane!

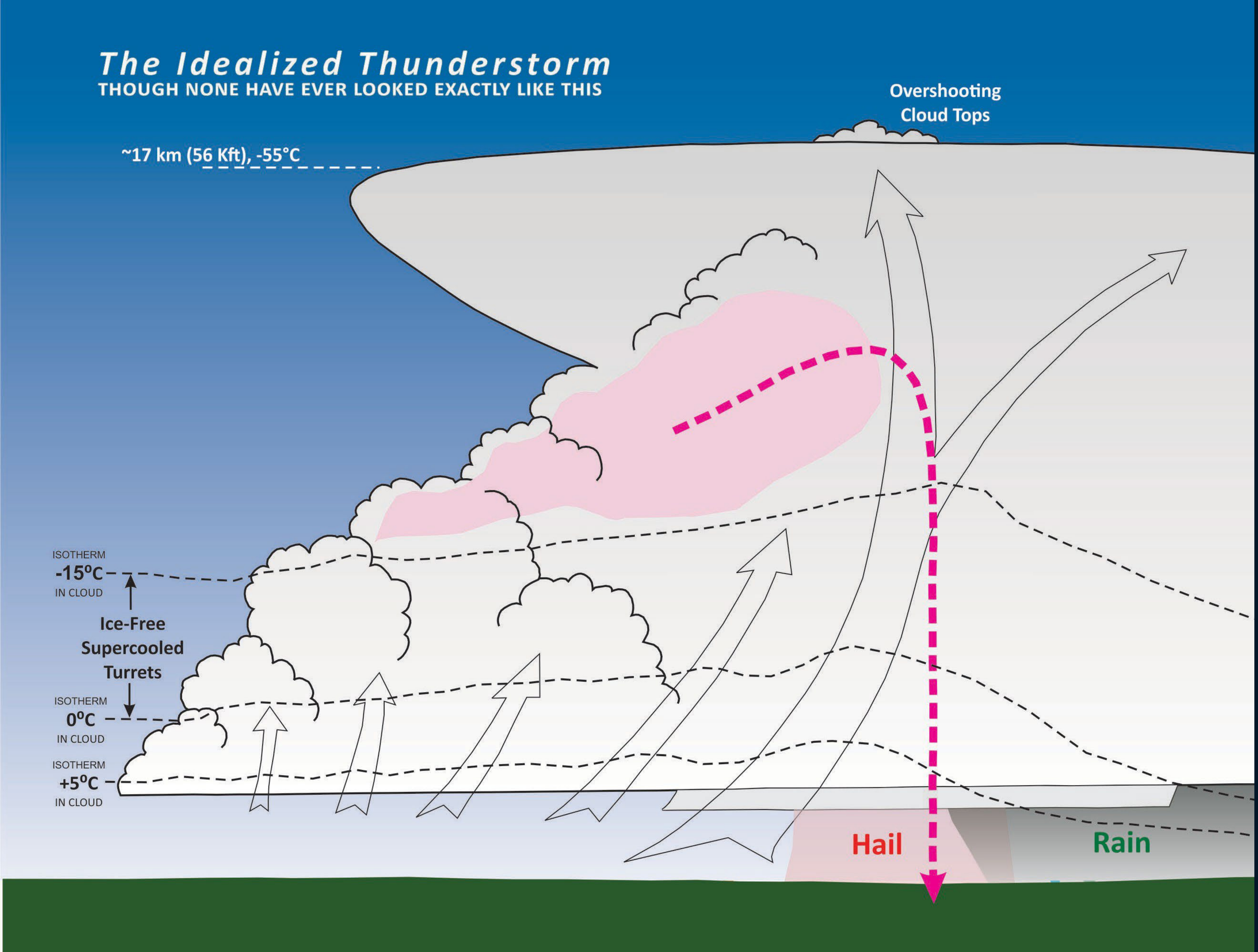


Updrafts

- Updrafts reflect buoyancy and produce cloud condensate.
- Seeding a cloud top should be done by penetration, which verifies updraft and liquid water. Such penetrations are often exciting.
- Seeding at cloud base is done by flying close to cloud base (not in cloud) in updraft. In multicell storms updrafts associated with mature cells can be strong but are to be avoided, as such cells have grown tall/cold enough to produce ice naturally.

The Convective Life Cycle





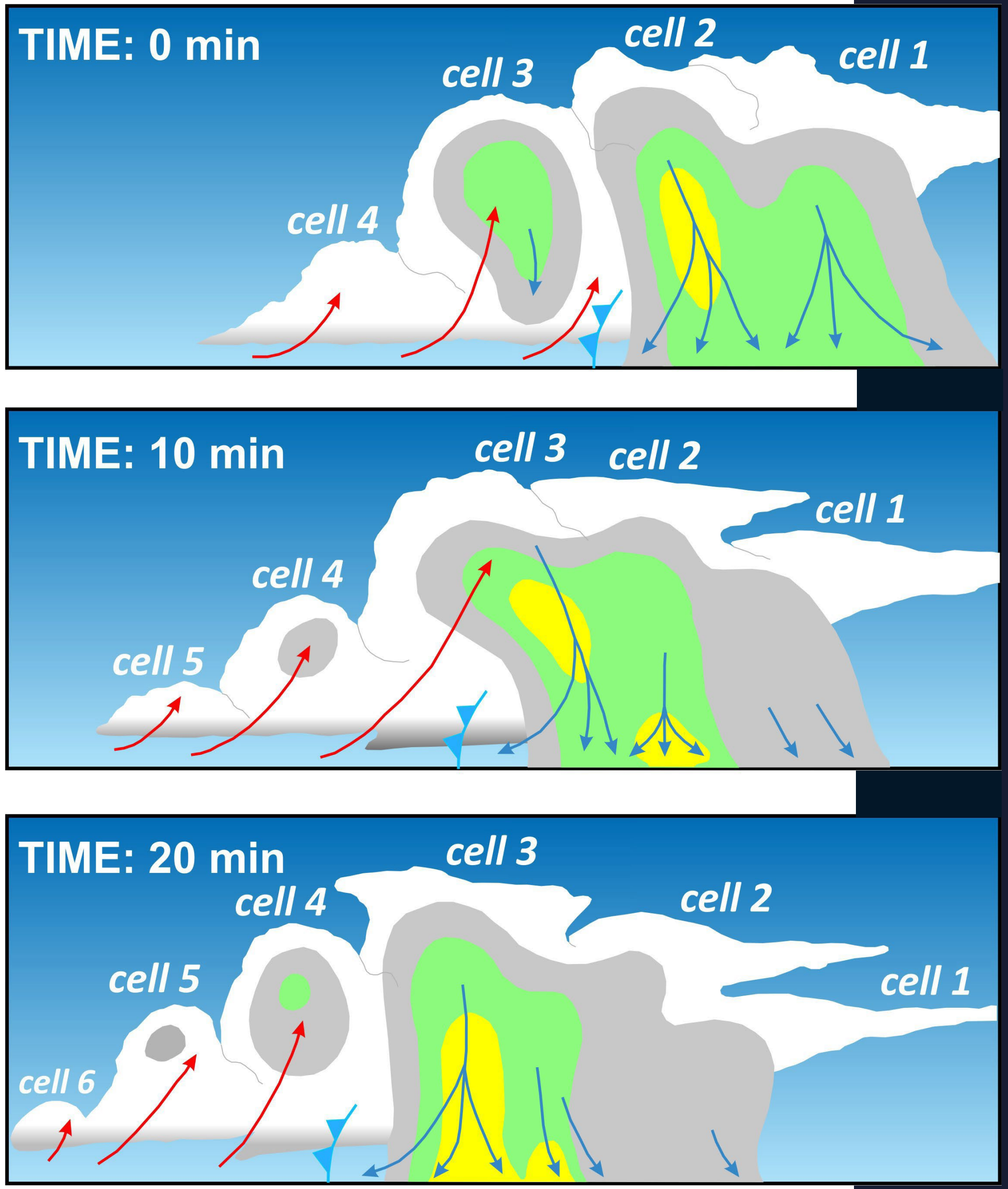
Multicell Concepts

In sheared environments series of convective cells often develop in sequence, adjoining each other.

This is illustrated here, with the oldest (dissipating) cells on the right, and the youngest, developing cells on the left.

What is seen . . .
By Radar? By Eyes?

- A series of multicell storm snapshots at ten-minute intervals is shown.
- As in the previous slide, older cells are on the right, younger on the left.
- The white portions reflect what is seen by the human eye.
- The gray, green, and yellow portions reveal what a weather radar sees.



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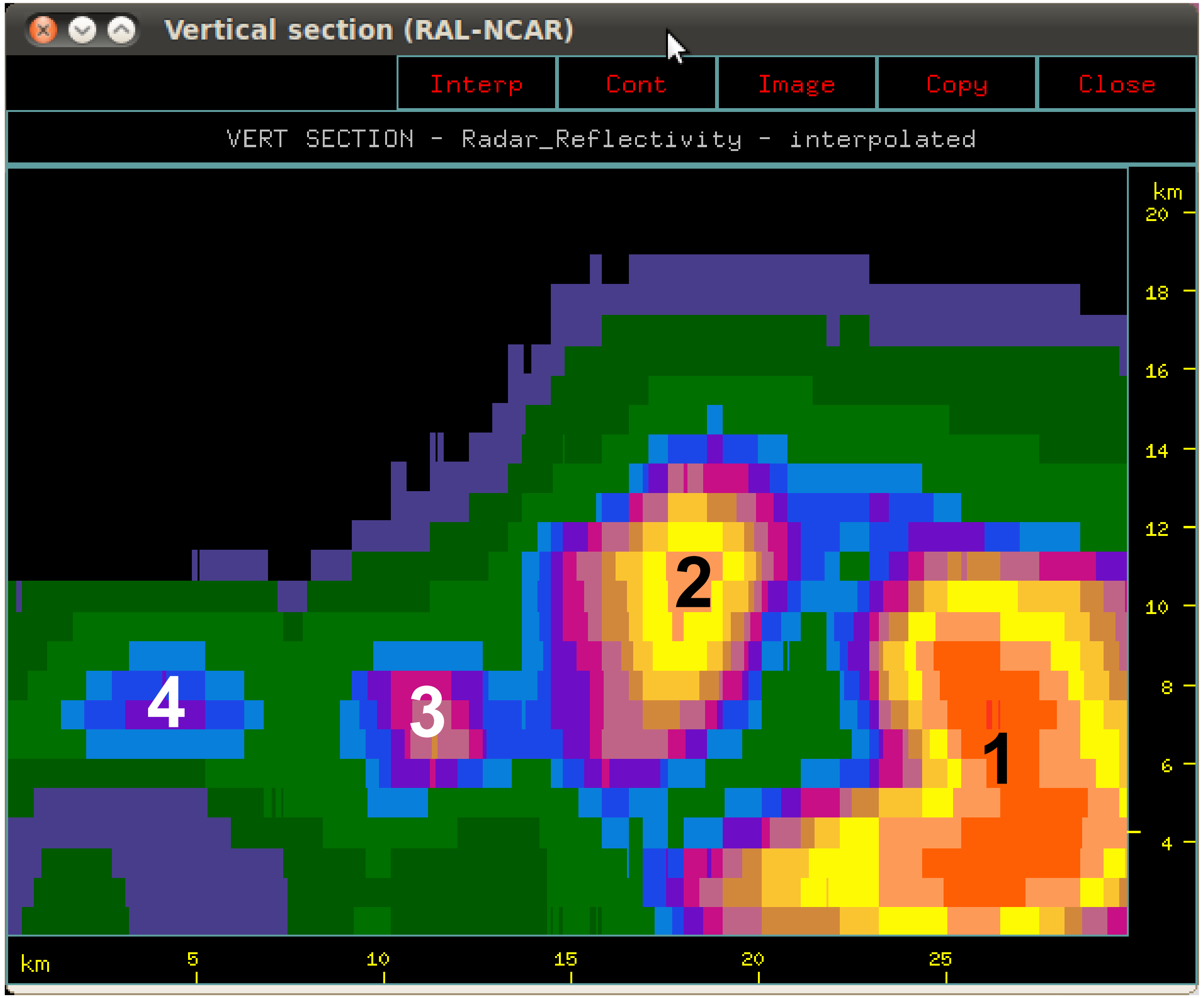
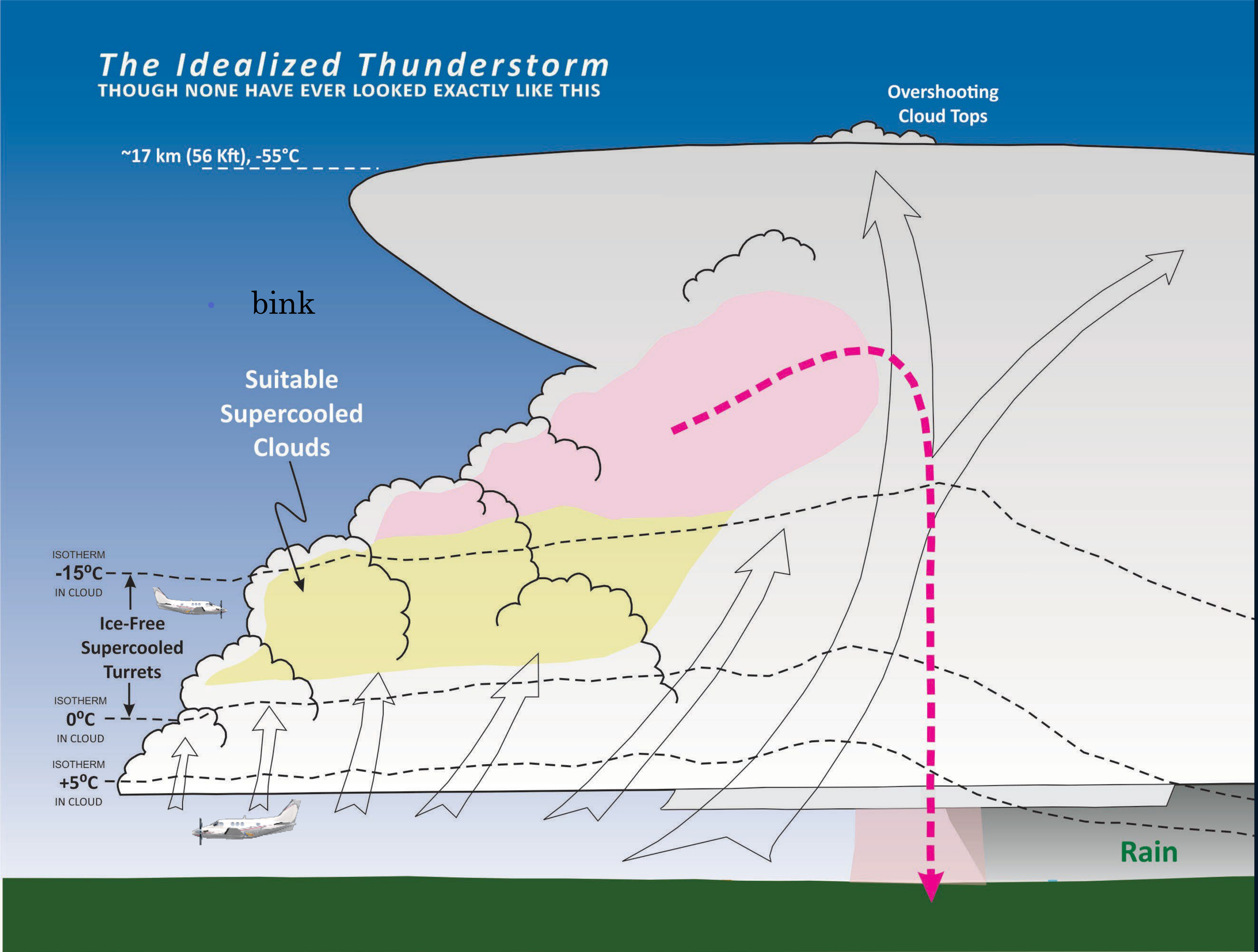




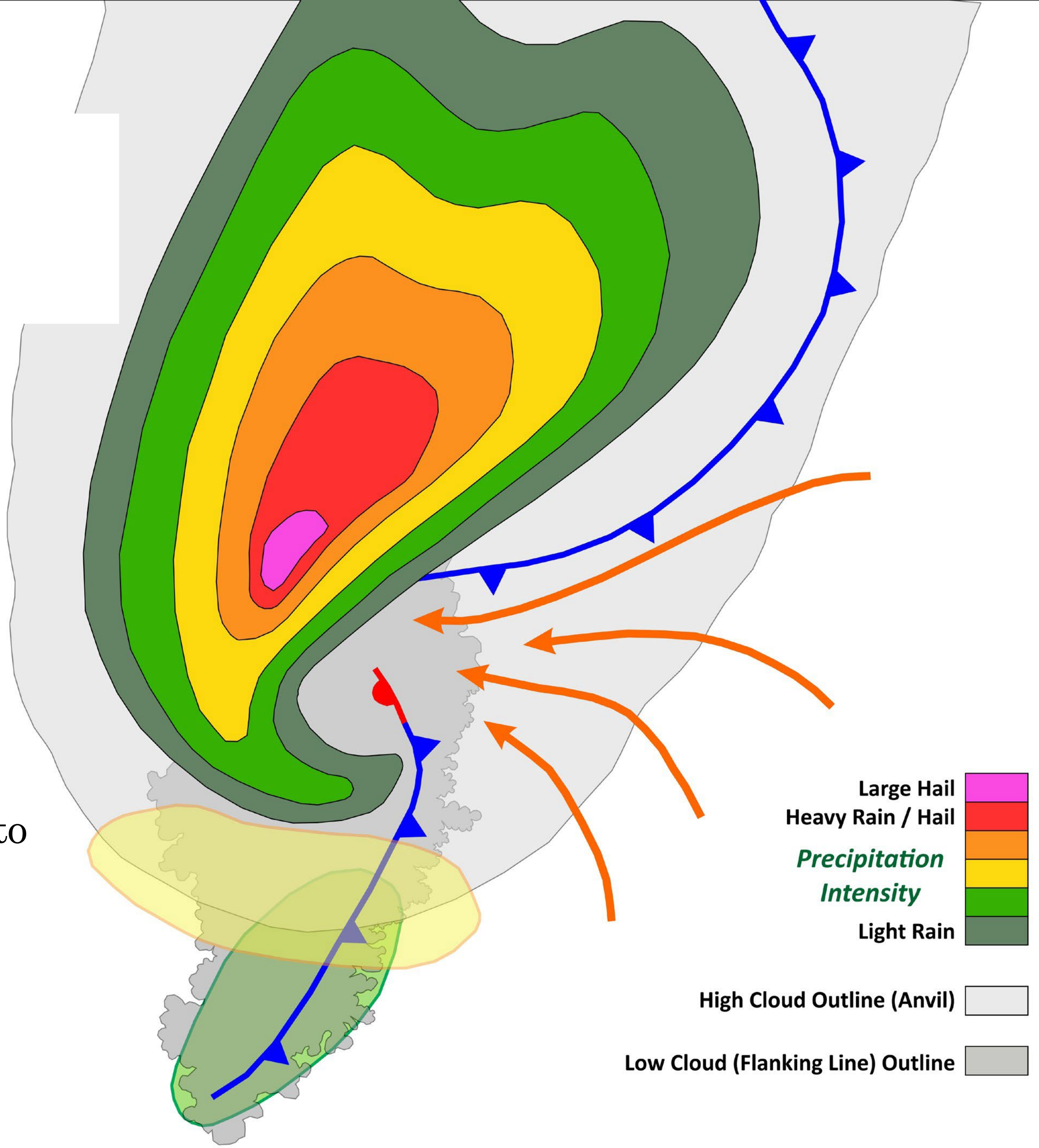
Multicell Concepts

The cloud volume shaded in yellow shows the probable locations of supercooled, ice-free cloud.

We would want to target only those younger clouds on the left, as they have not yet produced ice, and have a greater fraction of their lifetimes remaining.

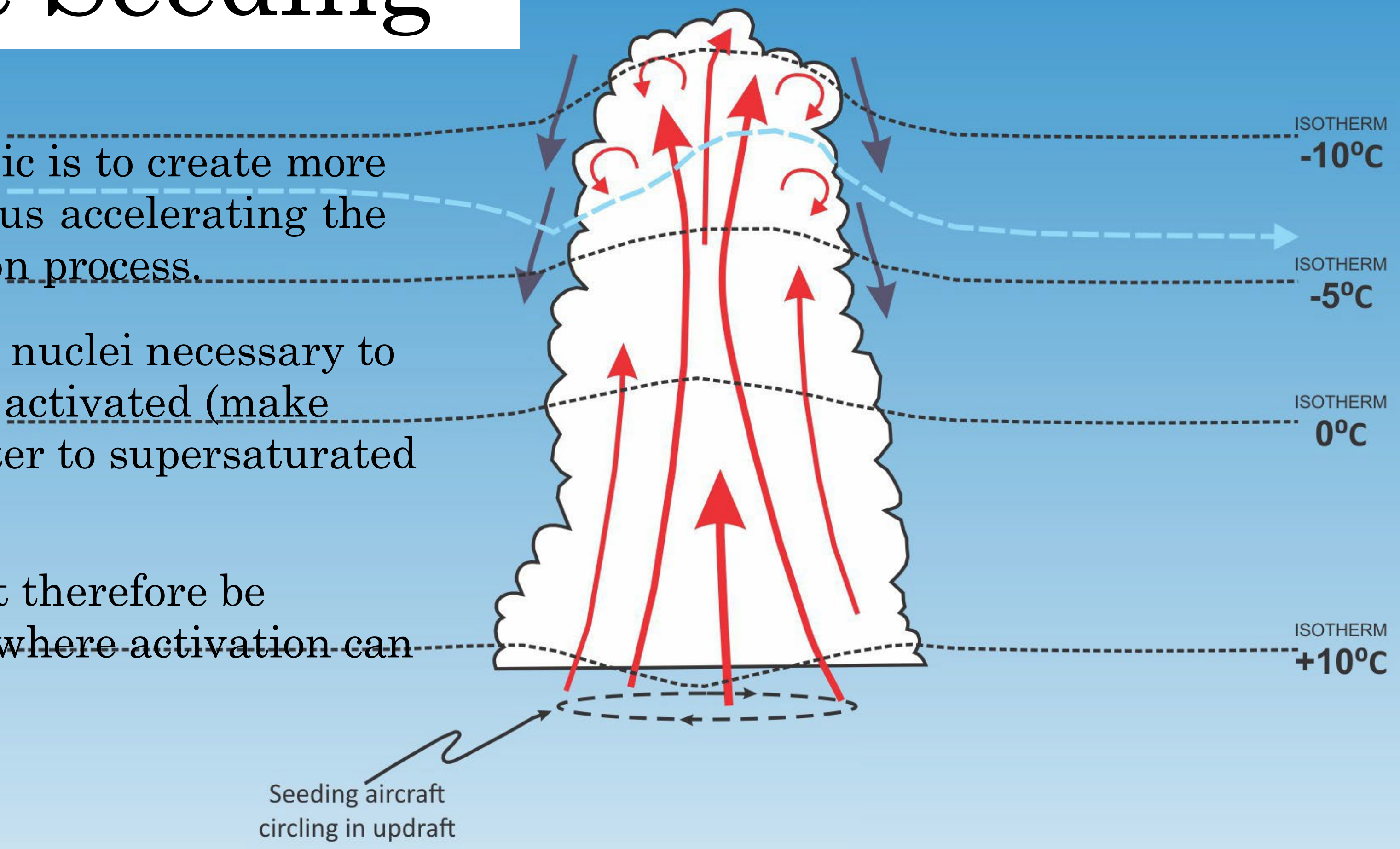
From above . . .

- The numbers of seedable turrets may vary considerably from storm to storm.
- *Generally*, cloud top seeding opportunities will be closer to the location of the radar echoes than seeding at cloud base (yellow).
- It takes time for seeding agent released at cloud base to be lifted to supercooled cloud, so it makes sense to target younger cloud. These are farther out (green).

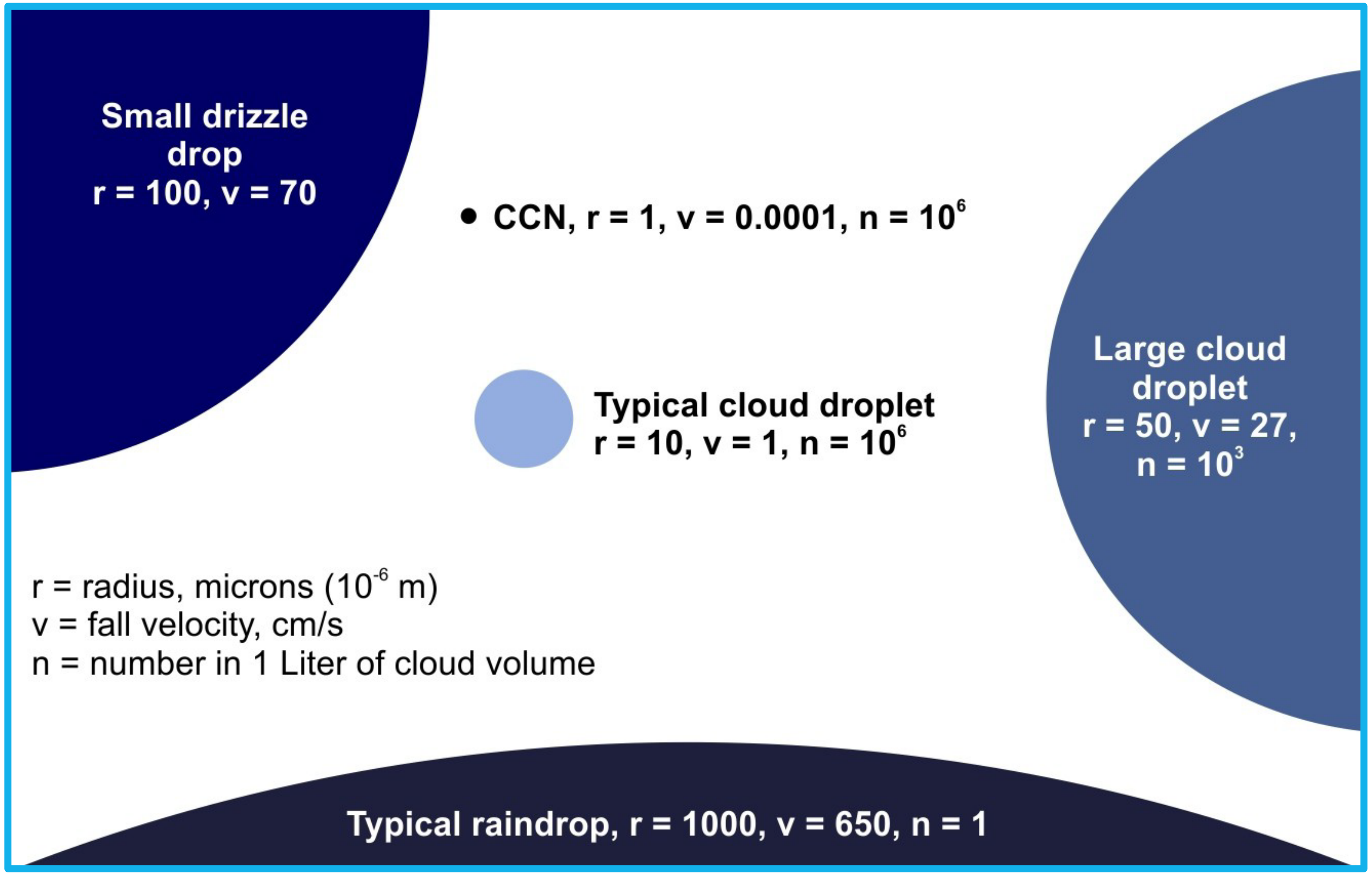


Hygroscopic Seeding

- The intent of hygroscopic is to create more large cloud droplets, thus accelerating the warm cloud precipitation process.
- The cloud condensation nuclei necessary to form cloud droplets are activated (make droplets) when they enter to supersaturated cloud at cloud base.
- Our seeding agent must therefore be released at cloud base, where activation can occur.



The Importance of Droplet Size

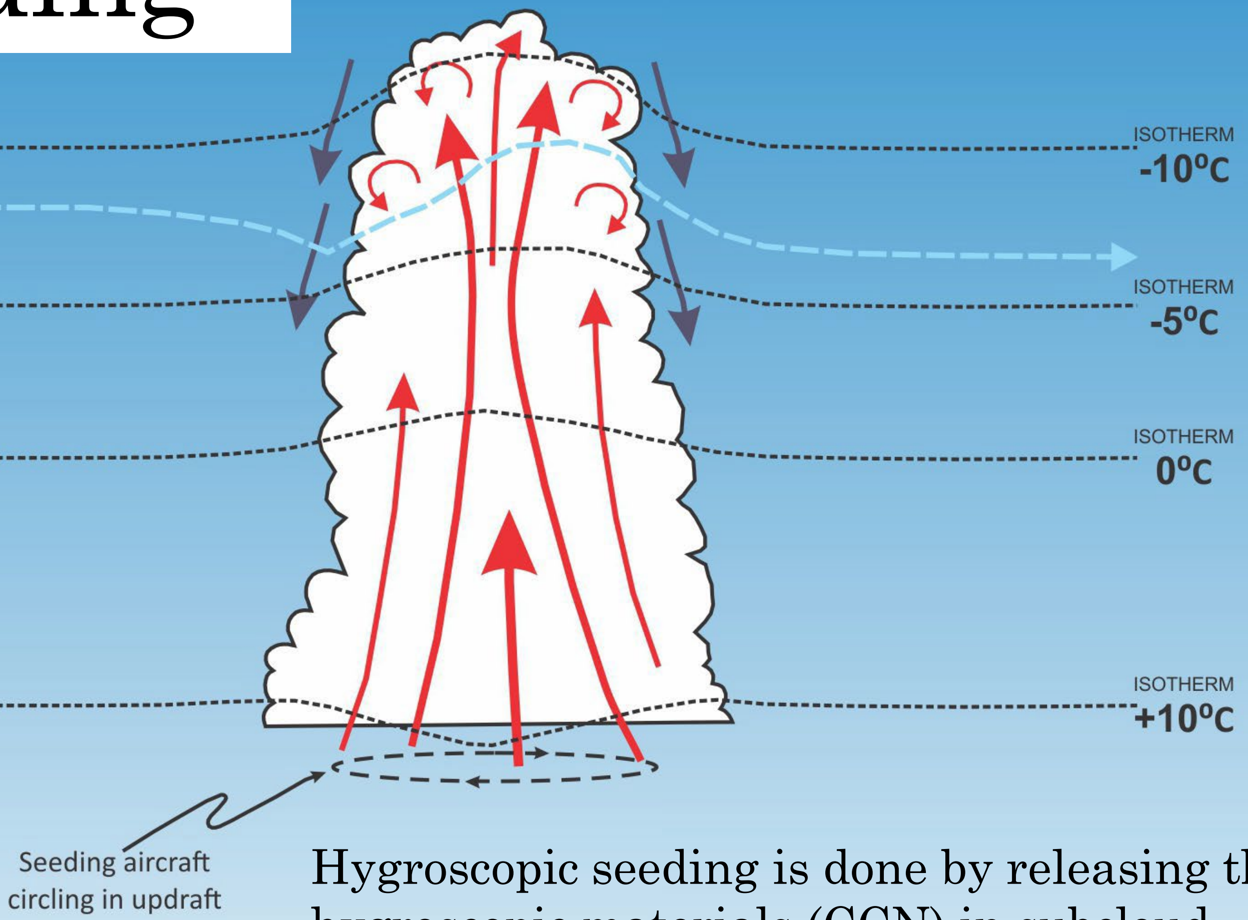


Hygroscopic Seeding

- Seeding locations for hygroscopic seeding are the same as for glaciogenic cloud-base seeding:
  - In updraft
  - At cloud base
  - At WARM cloud bases!

- Successful hygroscopic seeding requires a “wet” cloud, that is, clouds with lots of water. The best indicator of this is the cloud-base temperature.

- Clouds with bases of +10°C have the best chance of responding favorable to hygroscopic seeding.



Hygroscopic seeding is done by releasing the hygroscopic materials (CCN) in subcloud updraft. The updraft carries it into the supersaturated cloud, where formation of larger cloud droplets immediately occurs.

Cloud Seeding Operations

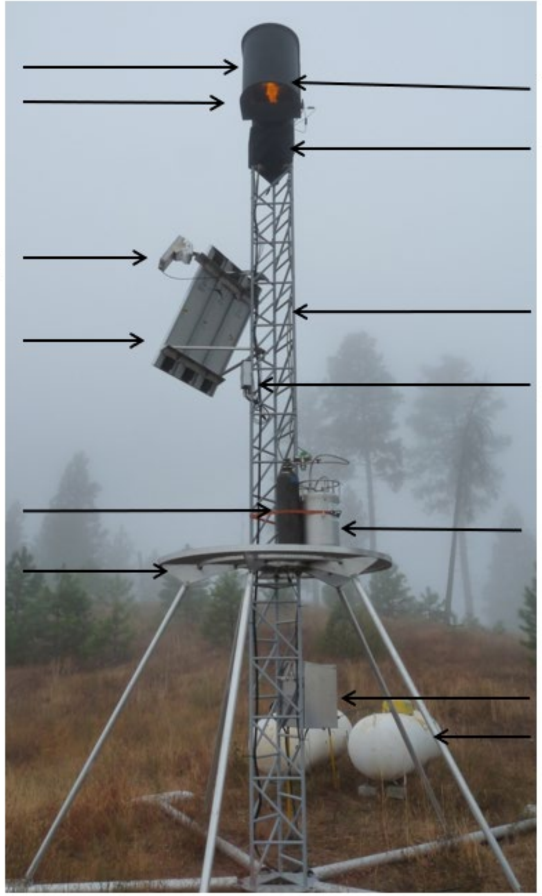
Winter Precipitation Enhancement

Derek Blestrud, *Senior Meteorologist* | Idaho Power Company

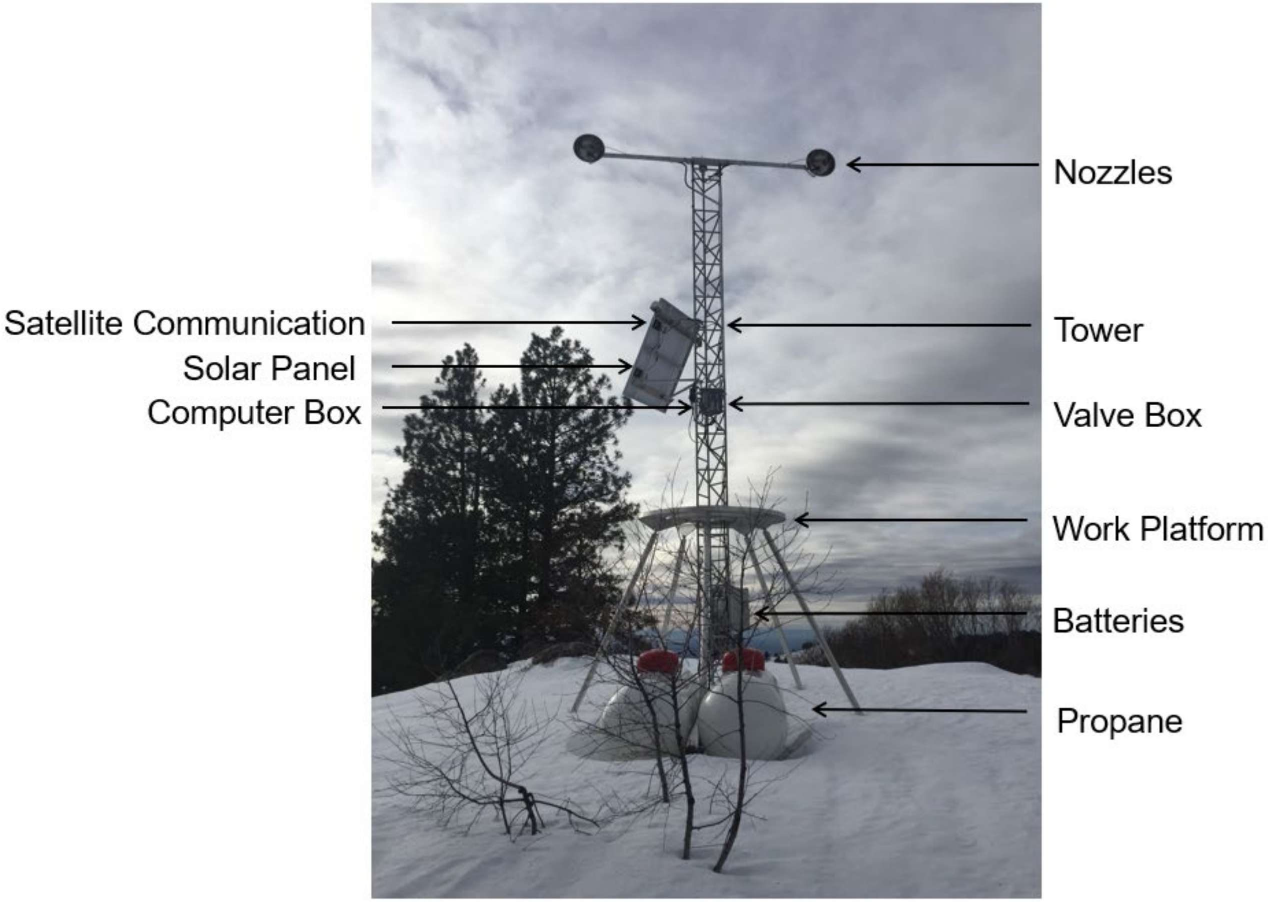
Cold Season Seeding Apparatus

- Generators
  - Remote – Silver Iodide (AgI)
  - Remote - Liquid Propane (LP)
  - Manual – Silver Iodide (AgI)
- Aircraft
  - Flares (AgI)
    - Burn In Place (BIP)
    - Ejectable (EJ)
  - Wingtip Generator (AgI)

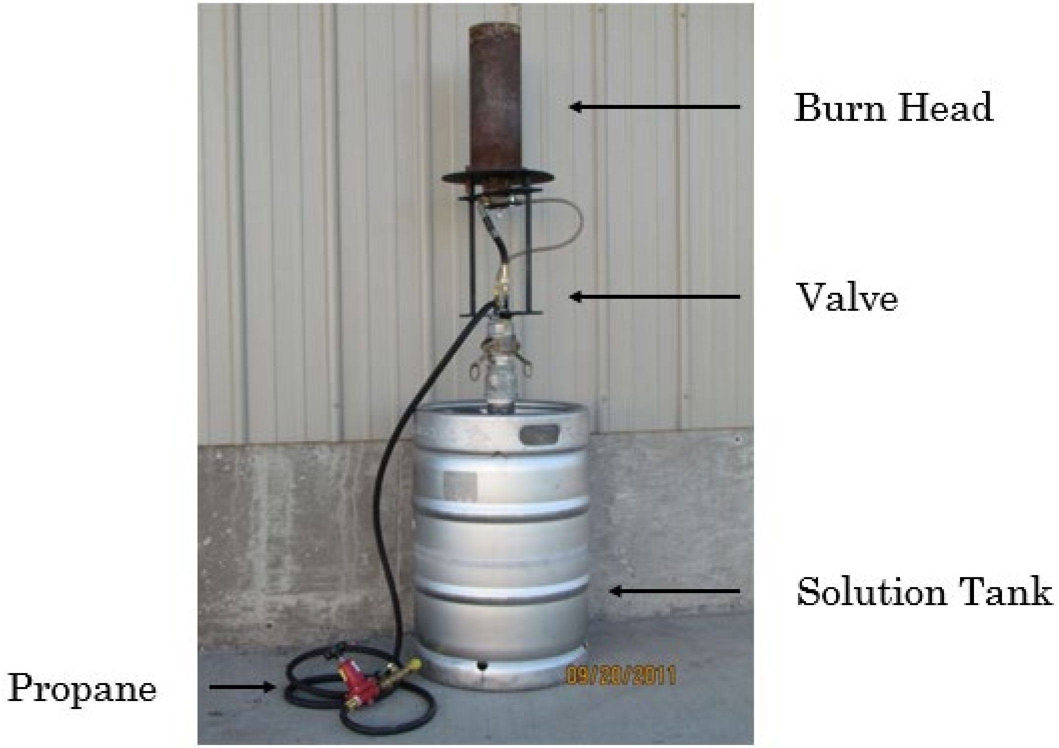
Remote Cloud Seeding Generator - AgI



Remote Cloud Seeding Generator - LP



Manual Cloud Seeding Generator - AgI

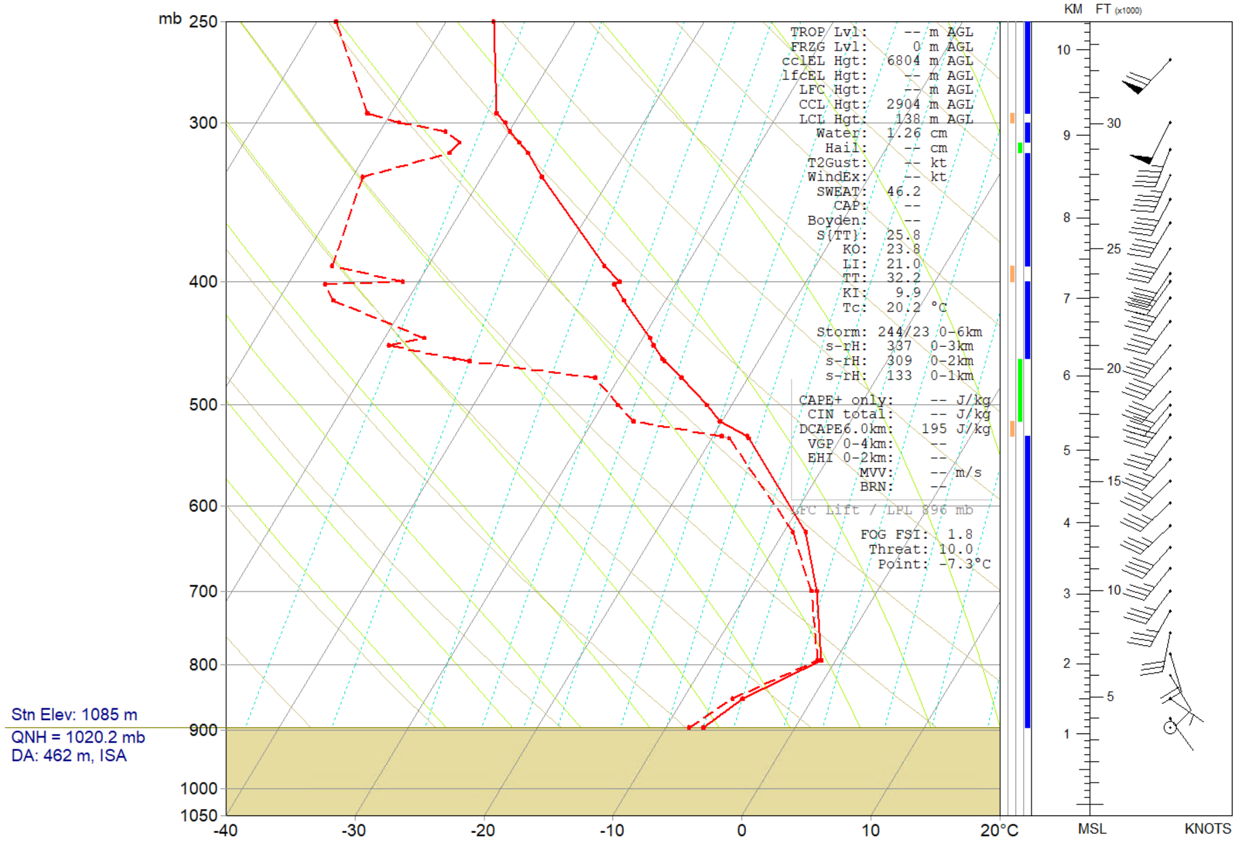


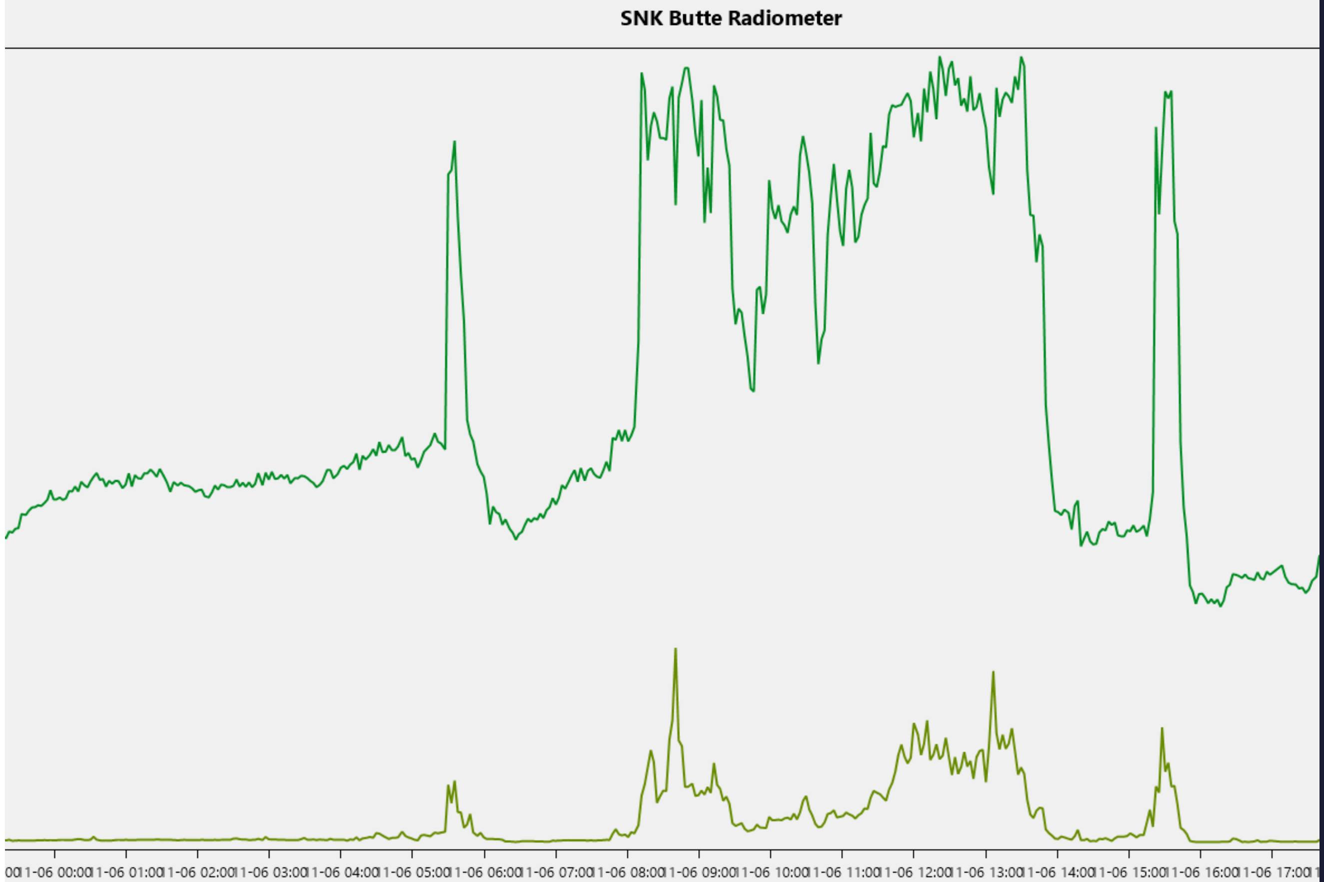
Aircraft - AgI

Weather Instrumentation

- Designed to answer **<u>THREE</u>** primary cloud seeding questions
  1. Is there liquid water available?
  2. Is the temperatures cold enough for ice nucleation?
  3. Is the wind flow correct for additional snowfall to fall out over the designated target area?

Weather Balloons



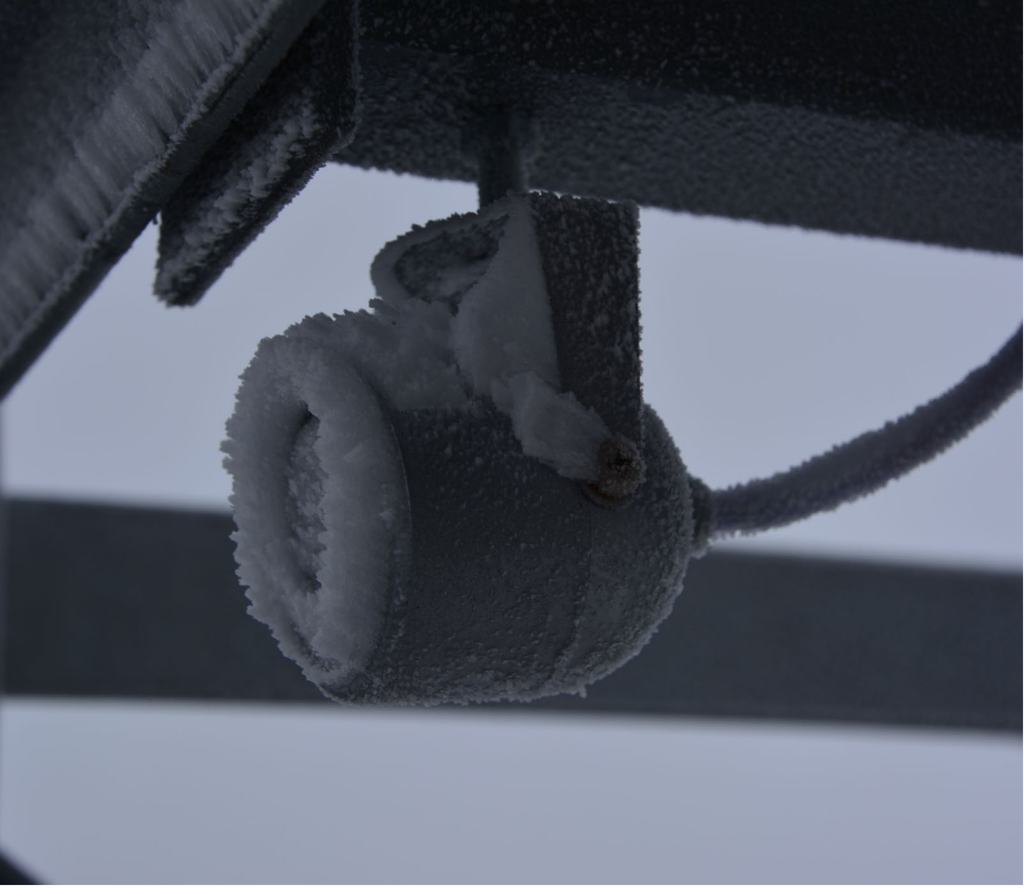


Radiometer

- Provides meteorologist with real-time atmospheric water values

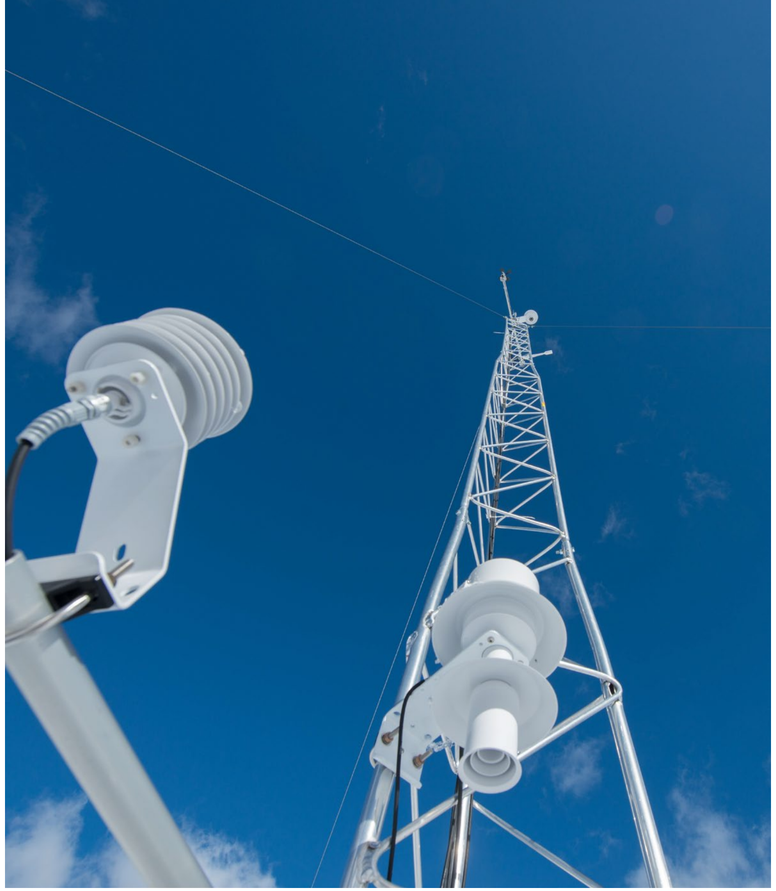
Ice Rate Sensors

- Provides Meteorologists with real-time observations of liquid water at a point location



Web Cameras

- Provides visual confirmation of current conditions

Other Surface Data

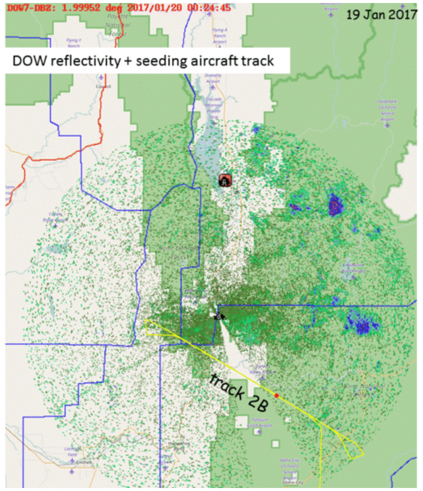
- Temperature
- Wind
- Dew Point

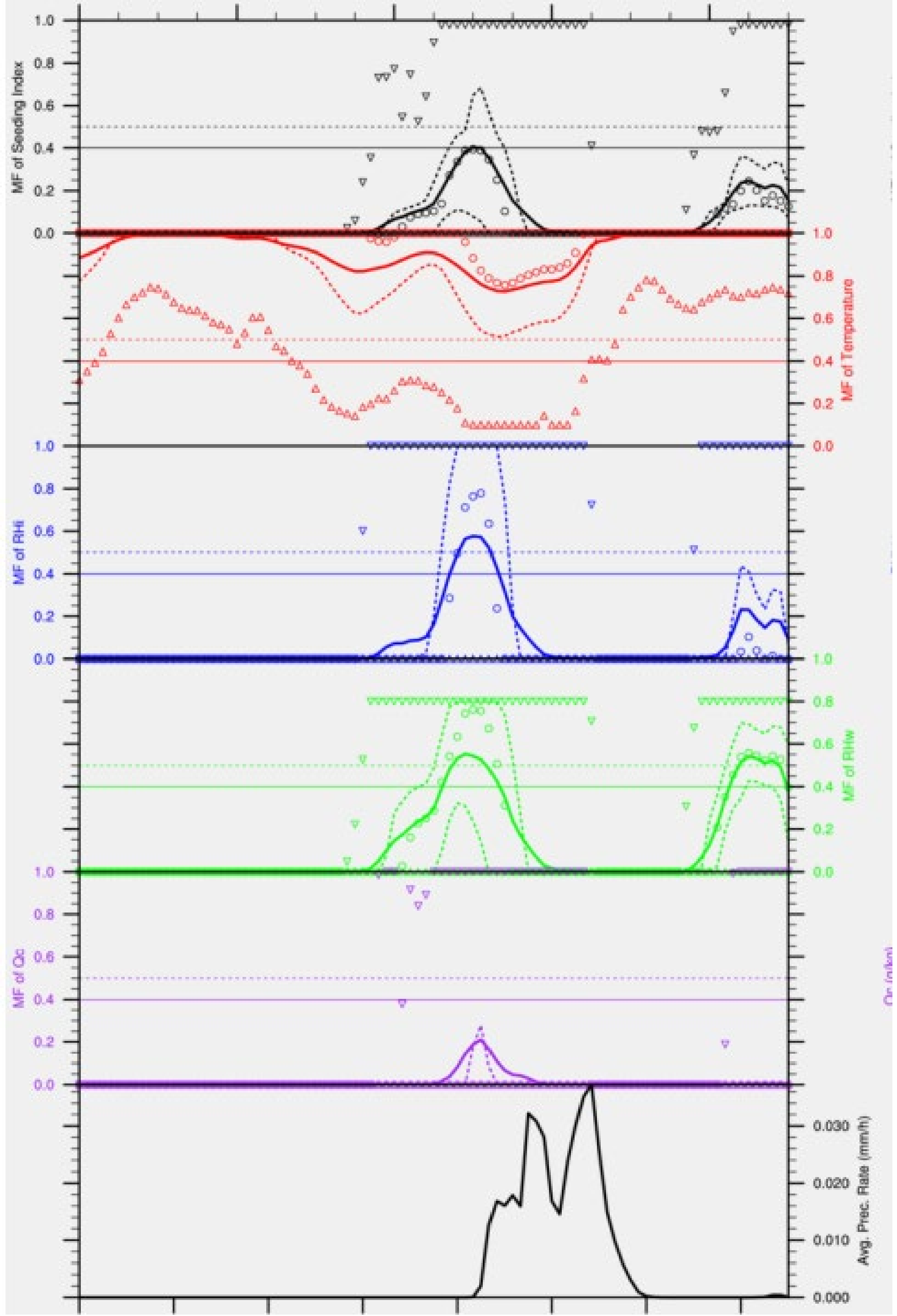
Precipitation Gauges

- Near real-time, high resolution, snow and rainfall rates and quantities.


DOW 7

Radars


DOW7-DBZ: 1.99952 deg 2017/01/20 00:24:45
19 Jan 2017
DOW reflectivity + seeding aircraft track
track 2B

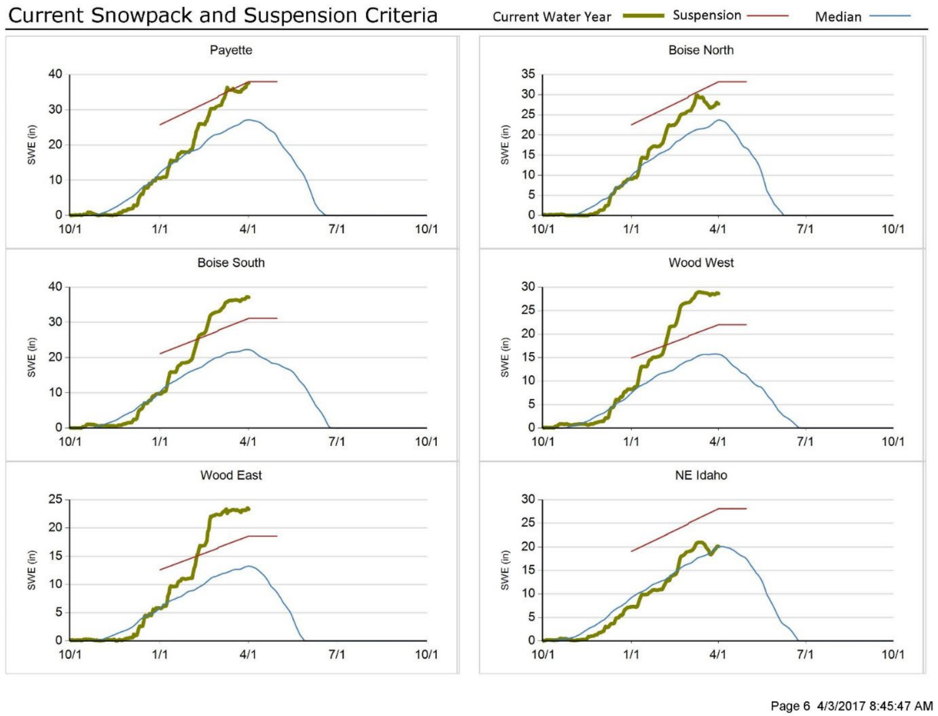


Numerical Modeling

- High resolution modeling (not available from publicly available data sources)
- Provides case calling
- Used for forecasting and operational planning
- Potential for benefit analysis

Suspension Criteria - Flooding

- Cloud seeding has raised concerns about flooding from early on
  - Rain-on-snow
  - Excessive snowpack
- Well-designed and responsibly conducted programs include suspension criteria



Suspension Criteria – Other

- Avalanche
- Flooding (USGS Gauge flood stage)
- Search and Rescue
- Severe weather
  - Lightning
  - Local heavy precipitation
  - Strong or damaging winds
  - Tornadoes
  - Special circumstances

Environmental Considerations

Pat Golden, *Owner & Principal Biologist* | Heritage Environmental Consultants

Environmental Considerations Associated with Cloud Seeding

Patrick Golden
Principal Lead Biologist

Heritage Environmental Consultants, LLC

Silver in the Environment

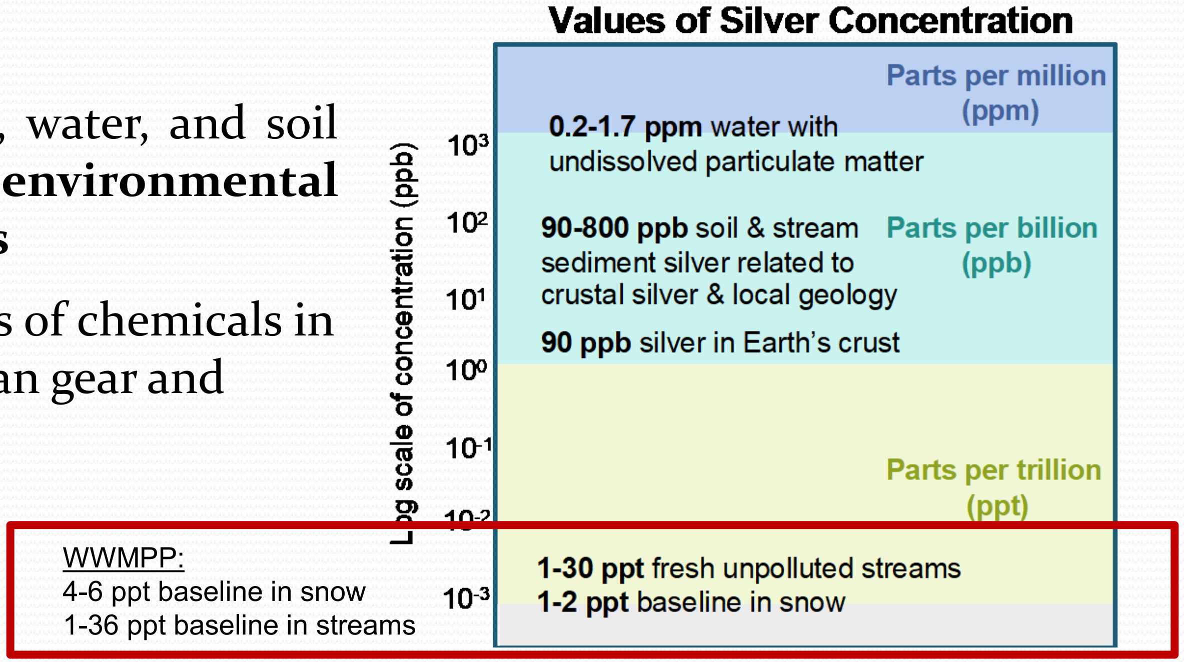
- Silver (Ag) is a rare metal present at concentrations averaging 100-1,000 ppb in soil, and 0.002-0.03 ppb in freshwater environments.
- Stream sediments are 0.2-1.7 ppm.
- Freshwater concentrations are commonly between 1 ppt – 30 ppt, though concentrations of 50 ppt are not uncommon. Ppt is 3 orders of magnitude (1,000 times) less than ppb.
- Silver concentrations in snow vary between 1-20 ppt after seeding events.
- 5,000-50,000 times more Ag in soil compared to seeded snow with 20 ppt of silver.
- Localities exceeding these concentrations tend to be a result of anthropogenic releases (mines, photographic industry, urban refuse combustion, sewage treatment facilities).

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

Localities exceeding these concentrations tend to be a result of anthropogenic releases (mines, photographic industry, urban refuse combustion, sewage treatment facilities).



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

Silver Speciation/Toxicity

- Free silver ion (Ag^+) is extremely toxic in aquatic environments (fish, plankton).
- Silver iodide (AgI) is an insoluble salt and does not dissociate in water.
- Ag^+ is much less toxic to humans and terrestrial species (wildlife, plants).
- World Health Organization, EPA and most state government water quality standards is 100 ppb total silver.
- Worst case (and impossible) scenario – if silver iodide (AgI) were in solution with unlimited time to react, a solution of 0.984 ppb of free silver (Ag^+) would result. This concentration is below every U.S. silver toxicity guideline (100 ppb).
- Toxicity levels – rats = 95 ppb of free silver; germinating plants = 750 ppb; adult plants = 14,000-120,000 ppb.

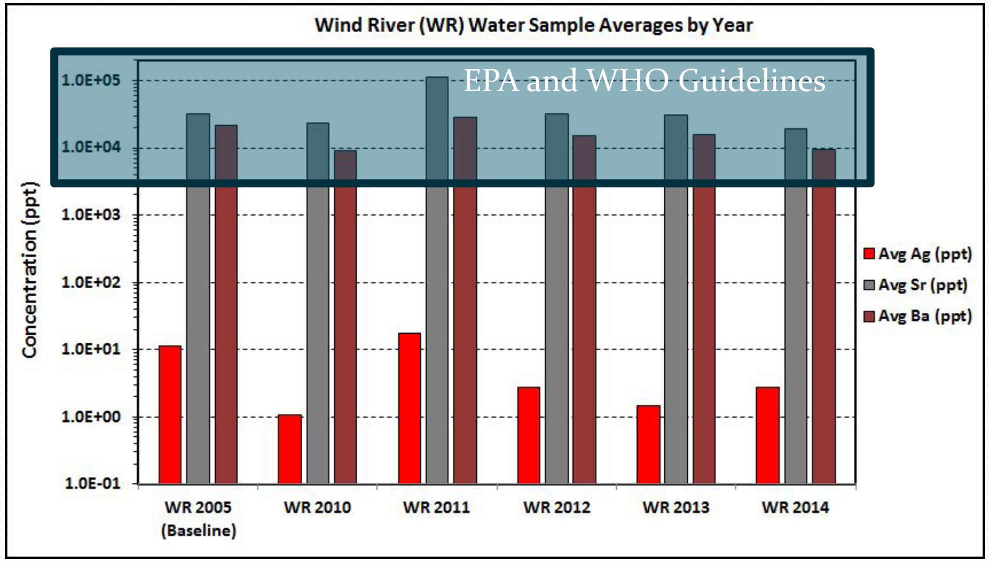
Silver Accumulation and Trace Chemistry

- Silver iodide 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 silver iodide are dispersed over large areas after cloud seeding are orders of magnitude lower than naturally occurring background levels of silver; trace 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

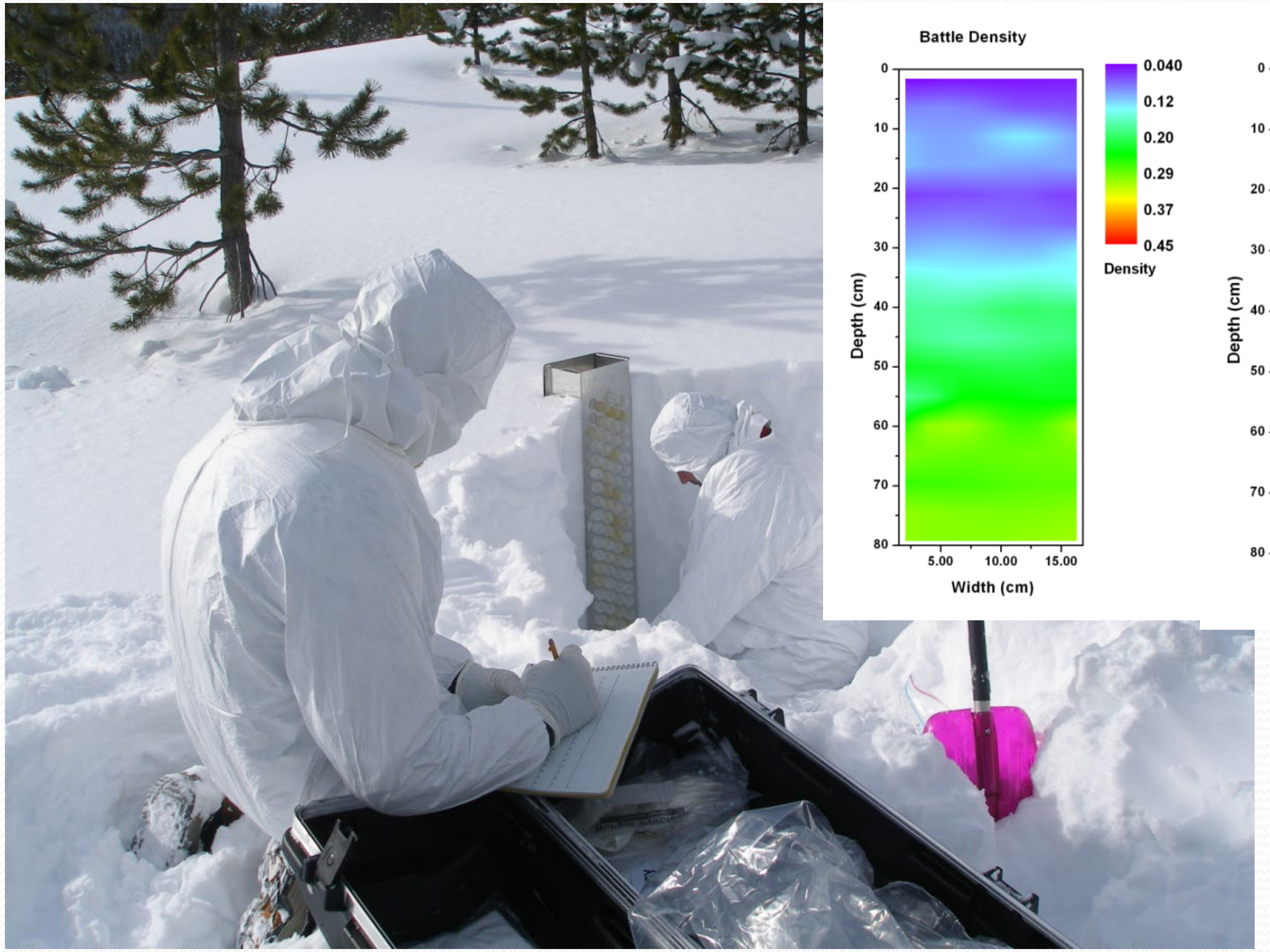
- Total silver in water measured during seeding operations was the same order of magnitude as the baseline from years before seeding started.
- Several orders of magnitude less than values considered hazardous to the environment or human health.

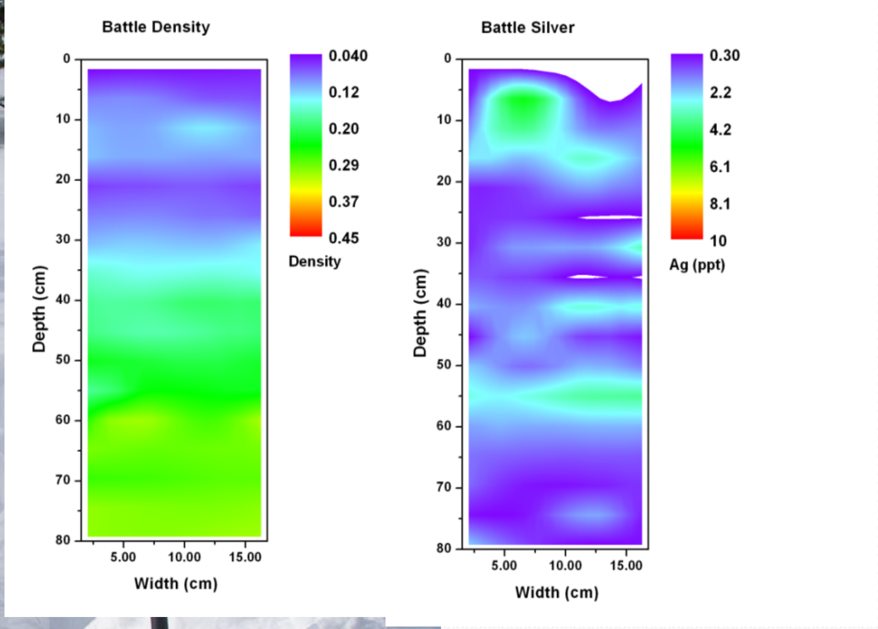
Silver in Water Samples from WWMPP



From the WWMPP

Targeting Silver Iodide





Trace chemistry horizontal snow sample collection

Bioaccumulation (Food Chain)

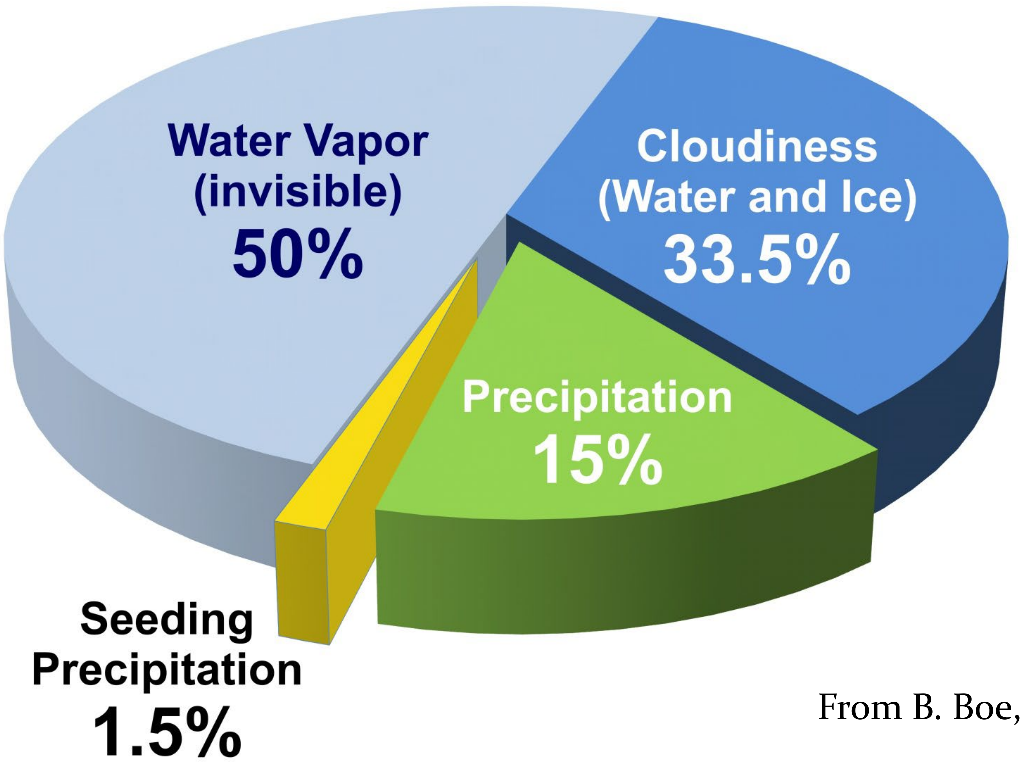
- Bioaccumulation is the buildup of a substance as it moves up the food chain.
- Toxicity depends on the concentration of active, free Ag+ ions in water.
- Silver iodide is insoluble, stable, and does not break down into Ag+.
- Soil, sediment, and water silver toxicity is very low even at high total 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.

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.

Downstream Effects

The Atmosphere's Water Budget

When Cloud Seeding Increases Precipitation By 10%



From B. Boe, WMI

Extra Area Effects Summary

- The conceptual model suggests small impact on the total atmospheric water vapor budget.
- The seeding material will be diluted in extra areas so the effects outside of the intended area is also diluted (negligible, difficult to detect and have been shown to be beneficial downstream of target areas due to residual positive effects from AgI).

Noise Impacts

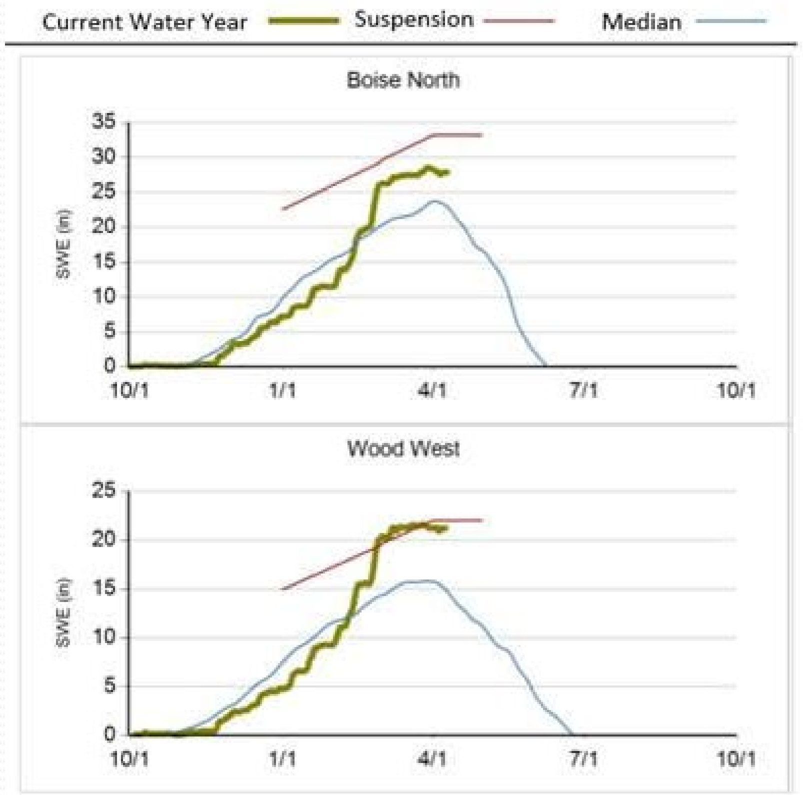
- Chevy ¾ ton diesel idling, radio and fans off 67 db.
- Remote cloud seeding generator - average noise level is 65 decibels (db) at the generator.
- Noise reduced to 60 db at 25 feet; 54 db at 50 feet; 50-52 db at 100 feet; noise dissipates rapidly with distance.
- 20-25 mph winds produce 72-78 db.
- 10-15 mph winds produce 54-60 db.
- Sounds like a forced-air furnace or high-pressure gas stove.
- Very few, if any, impacts to terrestrial wildlife or nearby residences.

Ground generators are often quieter than the ambient noise level during operation because it is often windy (54-78 db) when they are operating.

Suspension Criteria to Minimize Hazards (Floods/Avalanches)

- Most operational cloud-seeding programs establish suspension criteria to suspend seeding when hazardous conditions are likely.
- Reasons for suspension include, but are not limited to:
  - Unusually heavy snowpack in the target area
  - Extreme avalanche danger
  - Unusually severe winter storms, as forecast by the National Weather Service or project meteorologists.
  - Insufficient reservoir capacity for expected runoff
  - Seeding can also be suspended at anytime at the direction of the water management agency, utility, and/or program sponsor

Snow Water Equivalent (SWE) Accumulation



Courtesy Idaho Power Company

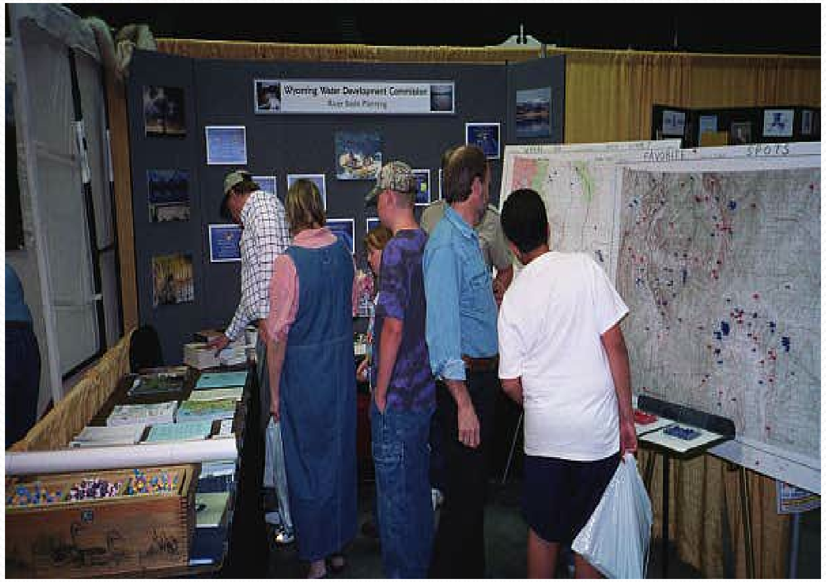
Permitting

- 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 (state) trigger environmental review. State permits are much easier to obtain, so siting on state land is wise.
- Laws – National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA), Endangered Species Act (ESA).
- Aerial operations must submit annual reports to NOAA describing hours operated, amount of seeding agent used, etc.

Common NEPA Scoping Comments

- Potential downwind effects
- Effects of silver iodide on the environment
- Streamflow monitoring requirements
- Consultation for listed wildlife and plant species
- Tower design/avian and raptor protection
- Crucial wildlife winter range concerns (AgI and snowpack)
- Flooding potential
- Concern for public water supply intake (AgI)
- Seeding wildfire burn areas, erosion.

Building Stakeholder Support/Public Involvement



Continuous ongoing dialogue with stakeholders through public hearings, special presentations, basin advisory group meetings, etc.

Technical Advisory Team

Bureau of Land Management
Natural Resources Conservation Service
National Weather Service

- Riverton and Cheyenne offices

University of Wyoming - Atmospheric Science
U.S. Forest Service

- Medicine Bow, Bridger-Teton, Shoshone
- Rocky Mtn Research Station

U.S. Geological Survey
Wyoming Dept. of Environmental Quality
Wyoming Dept. of Transportation
Wyoming Game & Fish Department
Wyoming State Engineer's Office

Summary

- Total silver concentrations from seeding are orders of magnitude lower than naturally occurring background levels of total silver.
- Silver iodide (AgI) is stable, insoluble, does not dissociate in water and is not toxic.
- Although silver ions (Ag^+) from soluble silver salts have been shown to be toxic to aquatic species, <u>this is not the case with insoluble silver salts such as AgI</u>.
- 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

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Heritage Environmental Consultants, LLC
Environmental Consulting, Permitting and Strategy

Question/Answers?

NAWMC
North American
Weather Modification Council

Developing a Program

Breaking Ground

Feasibility & Design

Program Implementation

Monitoring & Analysis

NAWMC North American Weather Modification Council

“Breaking Ground”

Case Study: Idaho Power Company

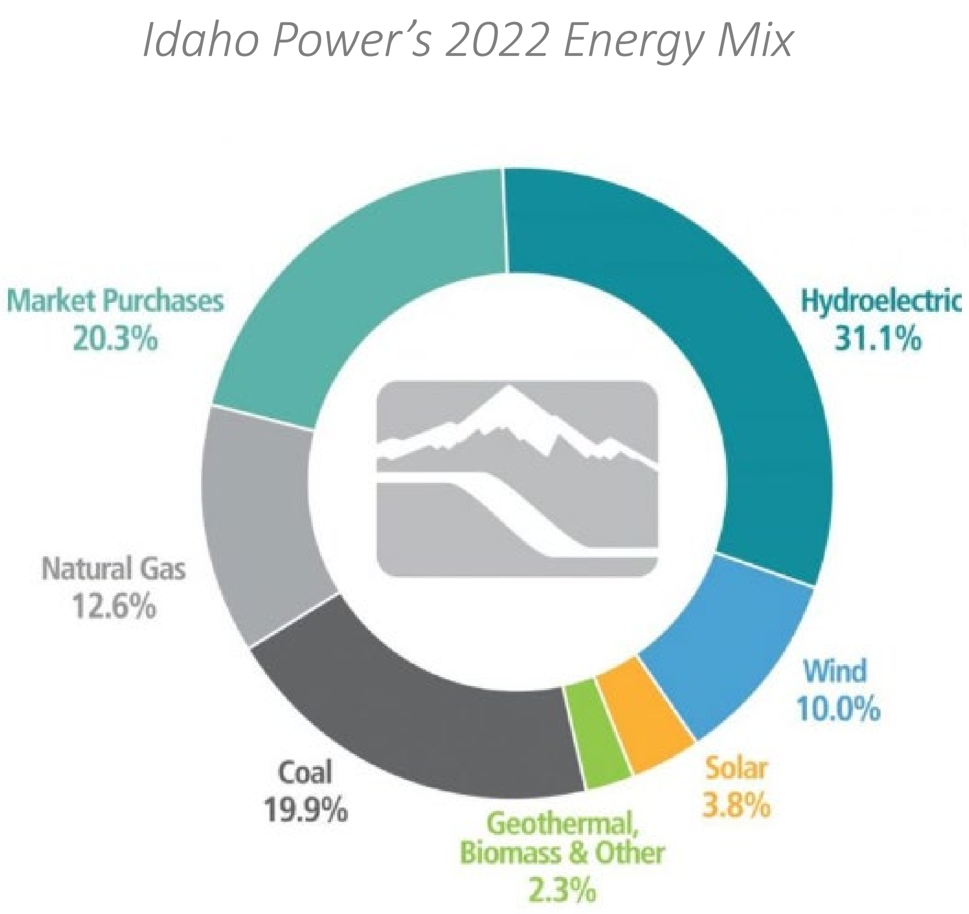
Shaun Parkinson, PhD, P.E., *Meteorology and Cloud Seeding Leader* |Idaho Power Company

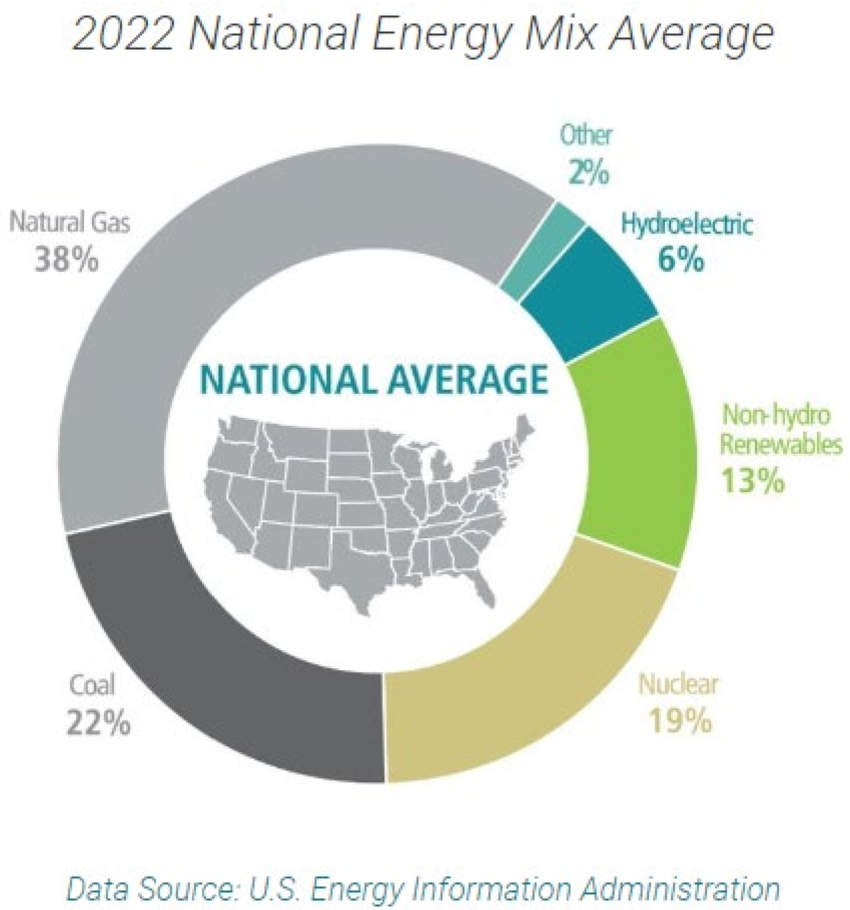
The Payette CS Program
-a case study-

IPC Background

- Investor-owned electric utility
- Hydropower is largest generation resource
  - IPC owns & operates 17 hydroelectric projects on the Snake River
  - When the concept of the Payette Cloud Seeding project started, hydro was ~**70%** of annual generation (varies with water supply)
  - Hydropower is IPC's lowest cost generation
- A typical electric utility 'model' for rates passes power supply costs to the customer
  - as the cost of generating or acquiring power to meet customer needs go up or down, rates will follow.
- For an IPC customer, more water equates to lower cost electricity - good for customers!
- The IPUC played a key role in the formation of the Payette cloud seeding project
  - For a sustainable project, there needed to be an equitable share of program costs and benefits.

Clean Energy





Snake River Tributaries and Hydro

The Kickoff for the Payette project

- A new program typically starts with a question…
- The start of the Payette cloud seeding project
  - In the late 80's and early 90's there was an extended drought in Southern Idaho
  - A shareowner posed the following question in 1992:

    '…why IPC doesn't have a cloud seeding program to augment snowpack for its hydroelectric system?' (1992)
- For a sustainable program, it is important to know the question that is being addressed
  - Over time, it will be important to refer to the original question/intent when educating new stakeholders.
  - A project that doesn't have a specific purpose for stakeholders to support will be much harder to defend over time.

Initial Education

What is Cloud Seeding?

This is an important step for the project advocate or stakeholders to go through

- For me in 1992, this consisted of about a 2-year literature review effort
- Fast forward, workshops like this, or there are some online education options that streamline the cloud seeding 101 process
- Allow for a common understanding of what is being pursued, and what's both feasible and realistic.

Is the watershed a candidate for Cloud Seeding??

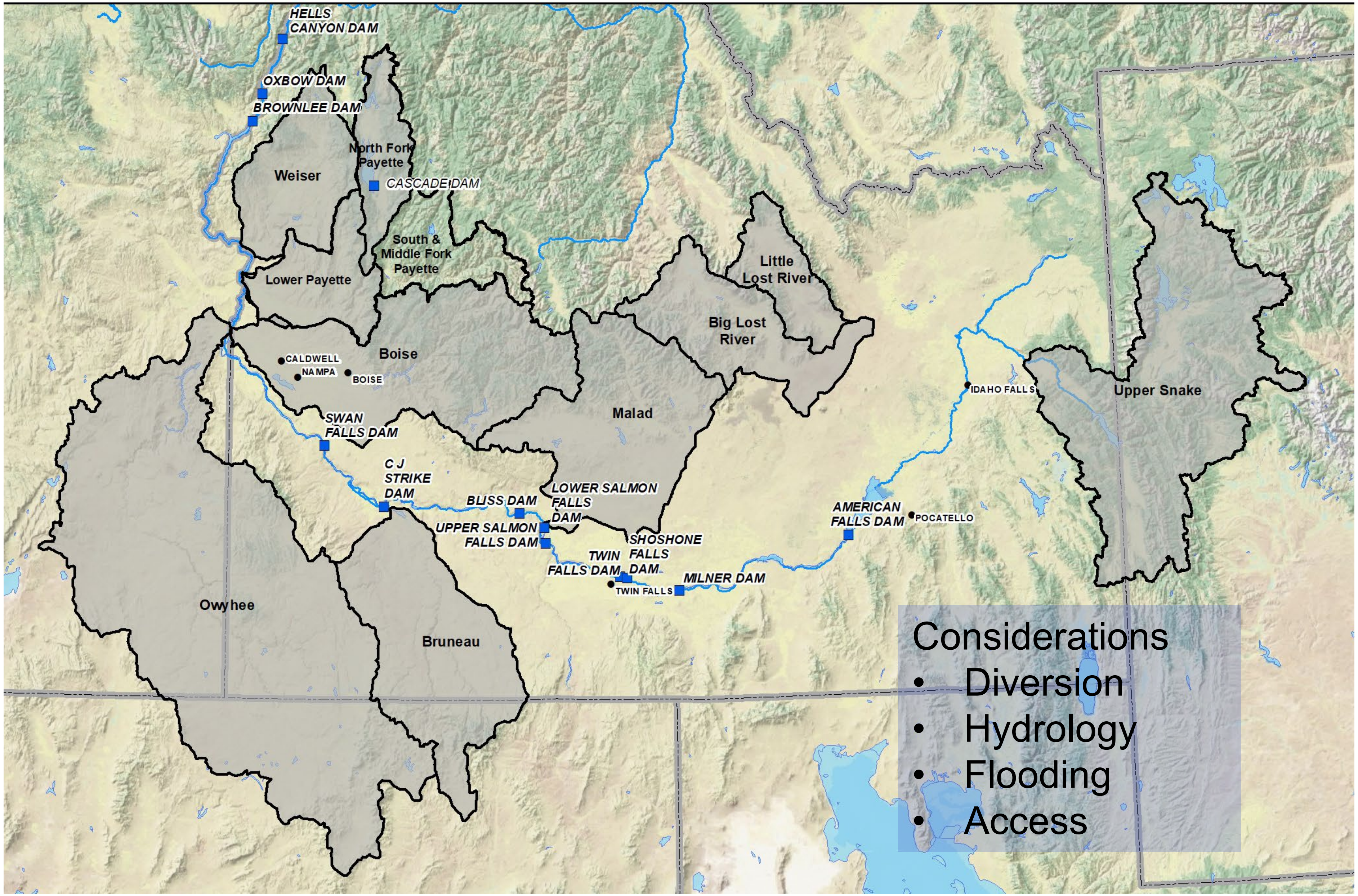
The question is defined, there is interest, but is the watershed a good candidate??

Considerations include:

- Climate and terrain
  - Unfavorable temperatures, lack of precipitation, or inversions all limit seeding opportunities.
- Hydrology – will additional water from the mountains reach the place of benefit?
  - Ex. storage, diversion, or losses can reduce the amount or change timing which could reduce benefit
- Does the watershed tend to flood?
- Access - roadless and primitive areas can have ideal terrain, but access and permitting are more complicated.
- Politics?

Where to start?

Need to narrow the options



Considerations

- Diversion
- Hydrology
- Flooding
- Access

Preliminary Program Design

A watershed is identified – initial program design.

This step will require a number of assumptions – it is just a starting place!

Considerations include:

- Aircraft
  - Proximity to airport and hanger facilities (think 24/7 access)
    - Don't want to spend all the time getting to/from flight tracks – time needs to be seeding
  - Terrain will influence where aircraft can fly
  - Can flight tracks be oriented to allow aircraft seeding over a wide range of storm conditions?
- Ground
  - Access is important – preferably road access. Winter can make access.
  - Ability to site equipment on public land varies.
  - If private land exists, permitting can be easier, however, property sales have their own issues
- Equipment and Instrumentation
  - What already exists, and what may be needed? (weather stations, radar, radiometer, weather balloons, SNOTEL, etc.)

Initial Feasibility - Payette

- Assessing if program benefits likely exceed costs. Lots of assumptions!
- Estimate operating costs based on preliminary design assuming combined air and ground seeding
    - 1 aircraft, 15 +/- remote ground generators for the Payette
    - Worked with industry experts for high level cost estimates
- Estimate benefits
    - This can be tricky…avoid getting too far into the weeds!
    - What already exists to estimate additional runoff??
        - For Payette, initially used USBR regression models
        - Adjust snowpack to estimate a difference in runoff.
            - We initially used published estimates of 10% increase (pursing ground & air)
        - What is the energy value of the additional water?
    - Consider sensitivity analysis?
- Do the benefits outweigh the cost??

Confirm some assumptions

- Climatology –
  - Needed to understand how many seeding opportunities the Payette would have
- DRI placed a 2-channel radiometer and weather station in the target area (Lowman)
- Collected weather data over the WY1995 winter. Found an abundance of seeding opportunities.
  - Lucked out that 1995 was a 'normal' water year for the Payette
  - The Payette has lots of seeding opportunity!
  - Data provided the basis for following detailed benefit analysis and operating strategies
- Today, climatology's exist that reduce the need for some of the time consuming and expensive data collection IPC did in the Payette
  - Drawbacks include models don't capture inversions as well as weather balloons and liquid water as well as a radiometer
  - A model-based effort will benefit from some observations for confirmation.

Ready for a deeper dive!

- Climatology study found that the Payette is a great candidate for seeding from both ground and air
- The rough terrain that provides seeding opportunity also required remote seeding equipment – manual seeding equipment was not a viable option.
- The terrain allows a lot of flight track options to cover many storm conditions.
- Refined cost estimates from contractors improve estimates for ground operations and to provide aircraft operations
- More elaborate benefit estimates – better hydrologic and energy modeling.
- Benefit estimates included sensitivity analysis of assumptions.

Ground Equipment

- Remote seeding equipment –
  - Options were and are limited
  - Idaho Power initially purchased remote generators
  - Ended up with a complete redesign and now manufactures its own variety.
  - A generator may run ~100 hrs per season – it is critical that they run when conditions present. Reliability is critical!
- What is needed for instrumentation?
  - Weather stations
  - Radiometers
  - Weather balloons
  - Precipitation gages
- Where does this equipment need to go? Who owns the land?
- Learn the lease or permit process for your watershed early. It may be necessary to initiate securing sites early!

Aircraft Seeding

- Idaho Power has always contracted for aircraft, flares and flight crew.
- Considerations
  - Backup pilots
  - Backup aircraft and aircraft maintenance
  - Aircraft type – performance, station time
  - Aircraft instrumentation
  - Hangar
  - Flare performance
  - Flight tracks
  - Flight communications between mets and pilots
- In a decent 5 month season, an aircraft may seed ~75 hrs – for an effective seeding program, aircraft availability is critical!
- Aircraft are much quicker to put in place
- Our experience in the Payette, over time aircraft contribute about half the benefit.

Who will operate the program??

Early in IPC's investigation, coaching from many fronts was for the owner (IPC) to be very involved with operations if possible.

- Who forecasts for seeding operations?
- Who monitors suspension criteria?
- Who owns the ground equipment?
- Who services ground equipment and instruments?
- Who turns seeding equipment on/off, calls for aerial seeding?
- Who communicates with stakeholders and public?

Stakeholders & Funding

- In the Payette, IPC was the only advocate for a program. Which is simpler than most programs
- However, there were complications.
- The electric utility industry was facing deregulation in 1990's…the uncertainty made it important to work with the IPUC to find a balance to share costs and benefits between IPC and its customers.
- The IPUC desired an assessment – 2 years of intensive data collection.
- Payette
  - The question was posed in 1992,
  - Investigation started in 1993.
  - Assessment 2003-2005.
  - Operational 2005 (limited: 7 remotes, 1 aircraft)
  - Build out took several more years.

Closing considerations

- Getting a program off the ground will be an iterative process
- Cloud seeding is a long-term water management tool – most beneficial if it is operated year in and year out. A funding mechanism needs to support that
- There will be lots of interest for a program - more water is good, right? **But**, everyone will want 'the other guy' to pay for it!
- Cloud seeding projects will have different stakeholder, regulatory and funding relationships. It is important to recognize and address them upfront.
- Understand the question, or the issue(s) to be addressed. Stakeholders may have different or conflicting desires.
  - Is the program to show that 'we are doing something?'
  - Or is the program to apply the best science, equipment, technology and information to make as much water as feasible?
  - There is a difference in cost

“Breaking Ground”

Case Study: State of Nevada

Frank McDonough, *Associate Research Scientist |Desert Research Institute*

Spring Mountains Cloud Seeding

Breaking Ground

Frank McDonough

Desert Research Institute

What are the Water Issues in the Spring Mountains?

Order #1293A remains in effect, leaving area developers and property owners with no choice but to obtain two acre-feet of water rights for any new well they wish to drill on land that has not previously had said water rights relinquished in support of the new well.

State Engineer prevails in Pahrump water order case

Special to the Pahrump Valley Times The Nevada State Engineer's Office has won its appeal over Order #1293A and the requirement to have two acre-feet of water relinquished for each new domestic well drilled in Pahrump stands.

What are the Water Issues in the Spring Mountains?

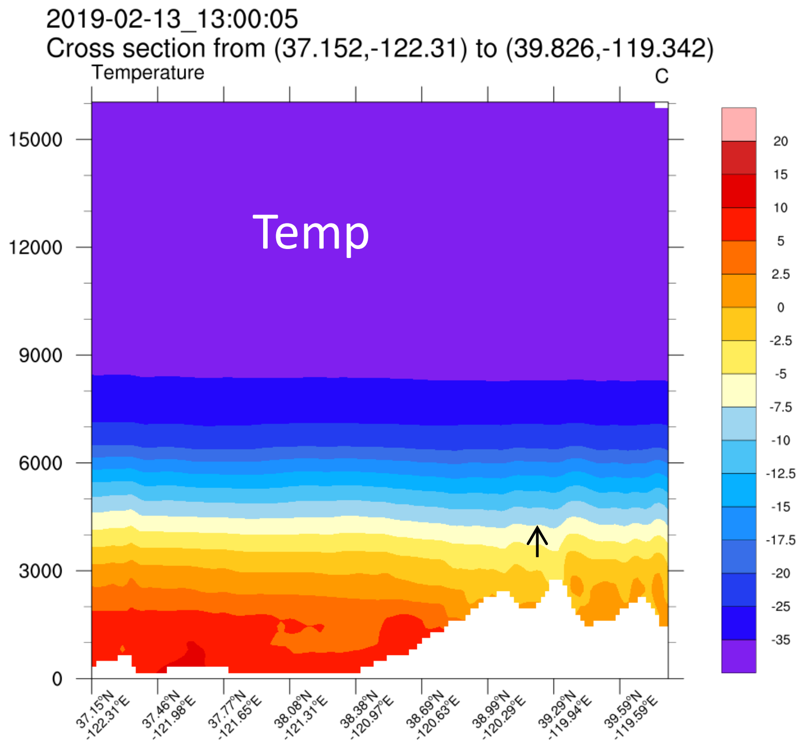
"If we don't do something, we're going to be looking at a landscape of dead trees in our national park," said Pauline Van Betten with the nonprofit organization Save Red Rock. The megadrought gripping the Western U.S. for the last two decades has dried out the canyon.

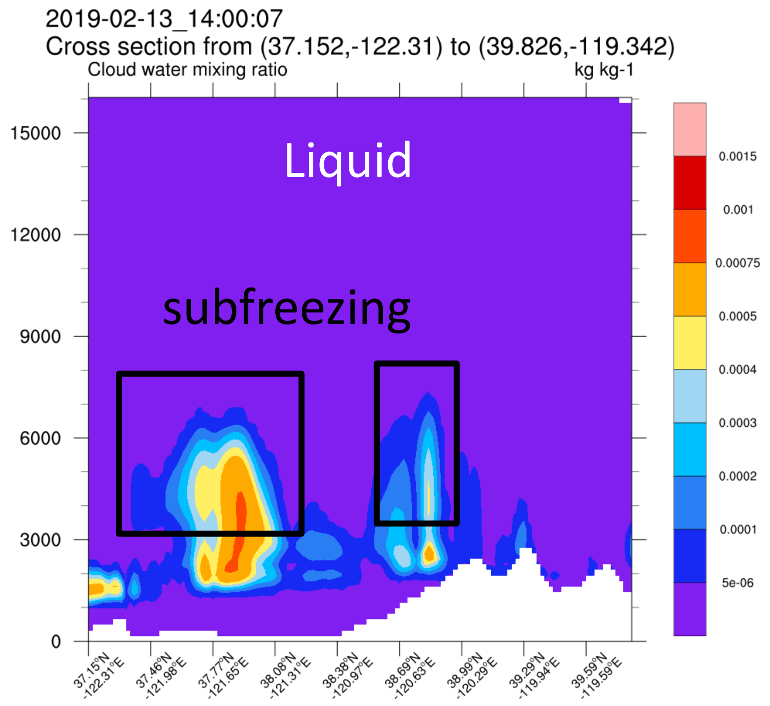
The fear is the canyon's ecosystem may not survive the drought either. The marsh lands, natural spring and aquifer have dried up.

Cloud Seeding May Help Sustain Ecosystem In Nevada's Red Rock Canyon

Scientists are trying to create snow in the mountains to save the plants and animals in the dried-out canyon.

Is Cloud Seeding Feasible in the Spring Mountains? Yes





Most storms have seeding conditions

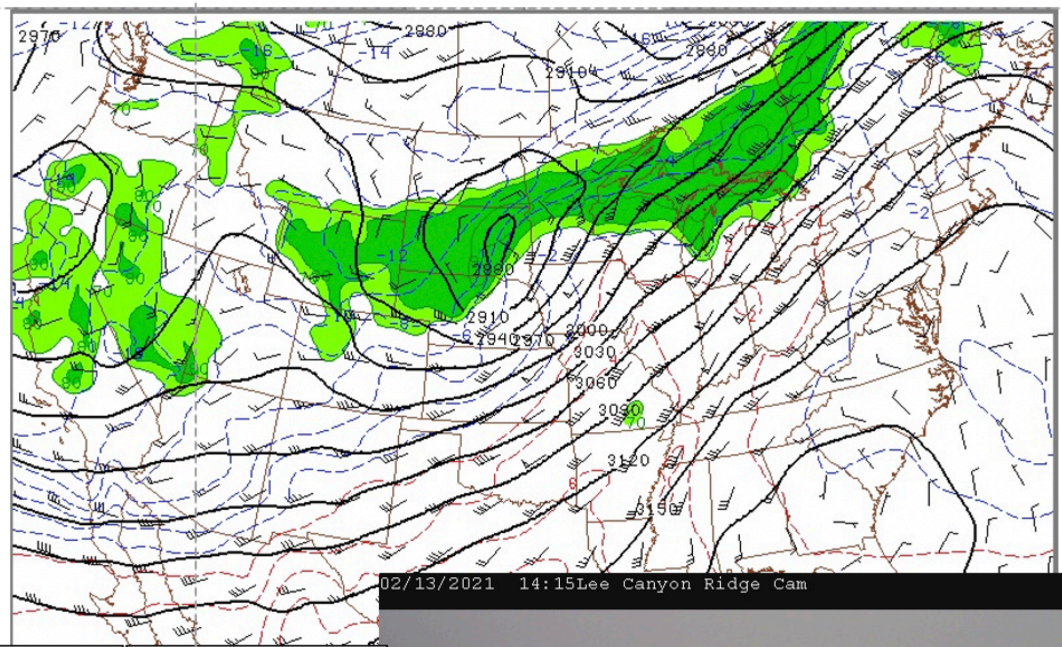
Spring Mountains Cloud Seeding Weather (based on climatological analysis of winter storms)

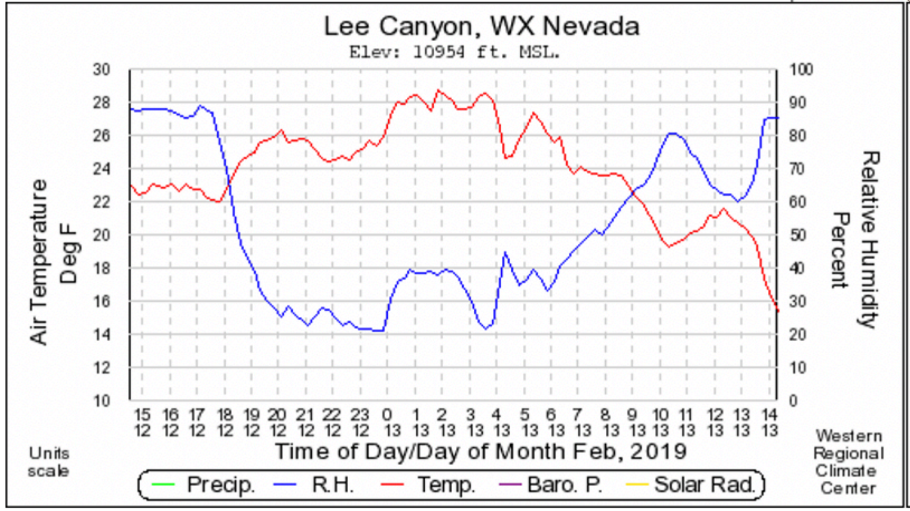
Cloud bases below mountain top level.

Clouds containing subfreezing water drops.

12,000' MSL temperatures less than 23°F

Winds blowing from the south-southeast through southwest





Current Values

Date/Time
Feb. 13, 2021
14:15 PST

Air Temperature
15.4 F HI: 28.7 F LO: 15.4 F

Relative Humidity
85 % HI: 89 % LO: 21 %

Precipitation
-999 in. Past 24h 0.00

Solar Radiation
-999 Kw/m2

Barometric Pressure
NA

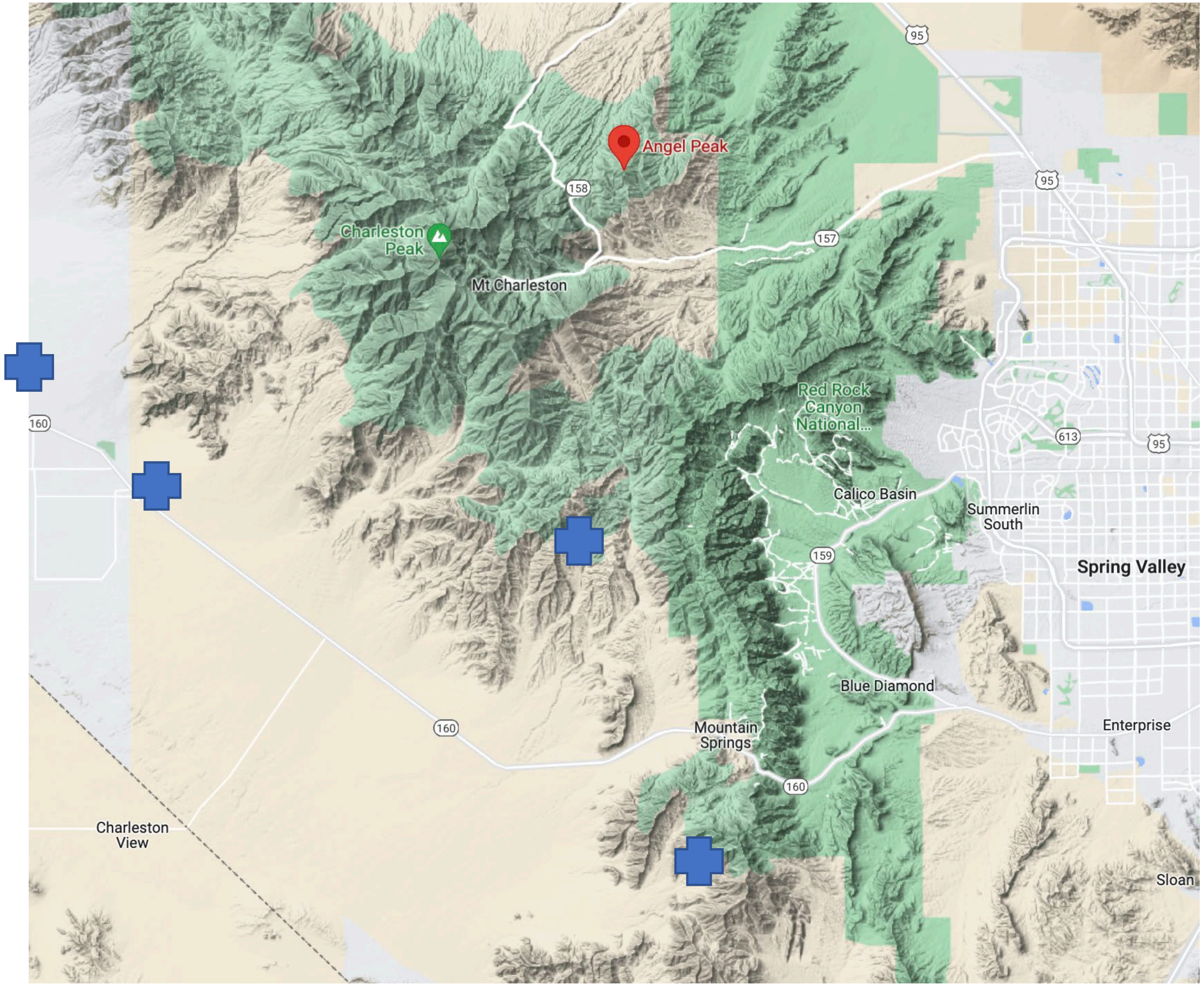
Spring Mountains mountain top weather station

Spring Mountains mountain top webcam

Spring Mountains Cloud Seeding Project

4 – DRI generators
- Mesquite
- Manse
- Lovell
- Potosi

Operated under southeast through west winds (majority of storms)



Spring Mountains Project Sponsors

Nye County Water District — Protecting Water Resources in Nye County, Nevada

Southern Nevada Water Authority

The Great Seal of the State of Nevada — All For Our Country

Feasibility & Design Studies

Winter Precipitation Enhancement

Dr. Sarah Tessendorf, *Project Scientist* |National Center for Atmospheric Research, RAL

Feasibility and Design Studies

What research is needed to design a cloud seeding program?

Dr. Sarah Tessendorf
National Center for Atmospheric Research, Boulder, CO

NCAR

November 15, 2023

NSF

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Feasibility and Design Components

Climatology Analysis

How often are there opportunities for seeding clouds in this region?

What are the characteristics of clouds in this region?

→

Preliminary Design

What methods of cloud seeding might target the clouds in this region most effectively?

→

Test and Refine Design

How effective are each design option at targeting and enhancing precipitation in this region?

Which combination of design options is recommended?

Analyze historical data:

- Temperature
- Supercooled liquid water (SLW)
- Precipitation
- Winds
- Atmospheric stability

Observational Data for Feasibility Study

Surface Station Data

- Temperature, moisture, winds
- Precipitation gauges
- SNOTEL sites in western U.S. mountains

Weather Balloons

- Vertical profiles of temperature, moisture, winds
- Every 12 hours
- In select FEW locations

Radar

- Good for summer storms
- Not good coverage over mountains

Missing Data:

Supercooled liquid water content, aerosols

Limited Data:

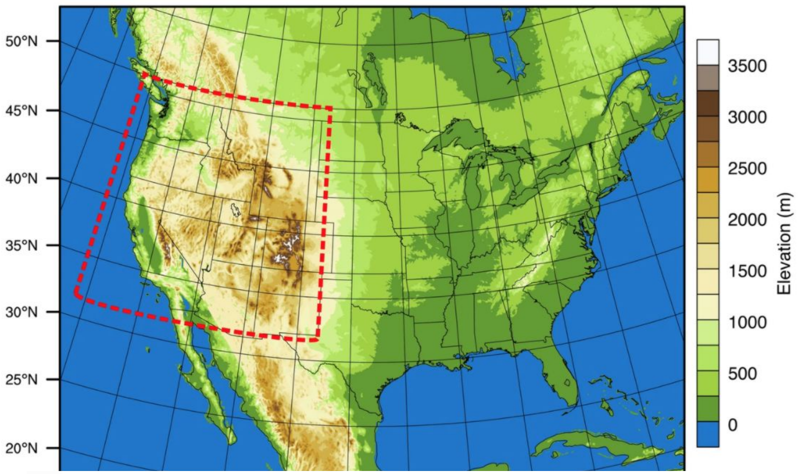
Vertical profiles of temperatures, moisture, winds where and when you want it
Spatial precipitation patterns

New Approach for Climatology Analysis

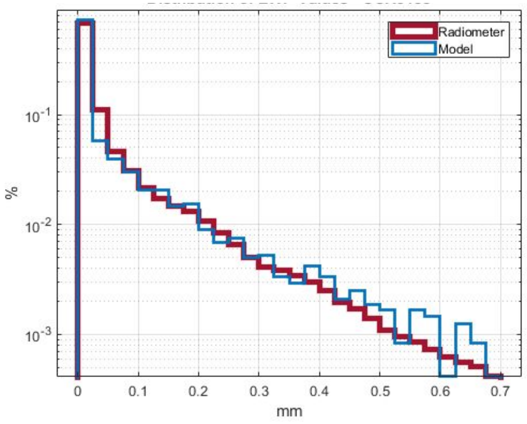
Multi-year high-resolution model simulations

- 4-km grid spacing WRF model simulation over the CONUS, up to 40 years of simulated data with latest "CONUS404" simulation
- Includes 3D information on temperature, supercooled liquid water, winds, precipitation, etc.

Weather Research and Forecasting (WRF) model
CONUS Simulation Domain

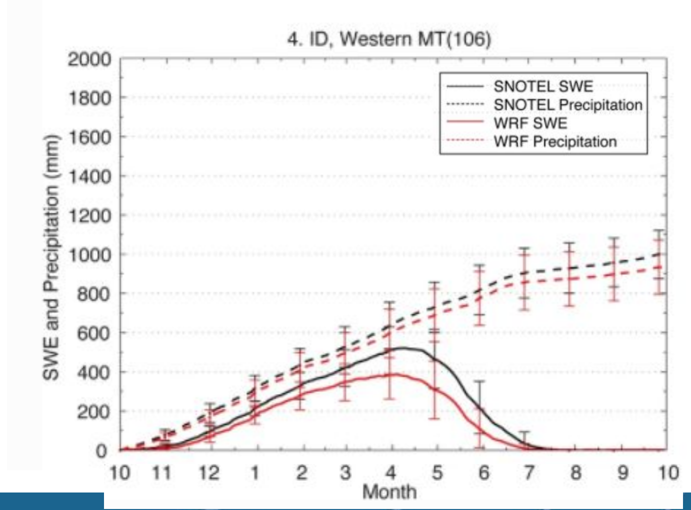


Liquid Water Path Distribution
Radiometer observations vs CONUS model



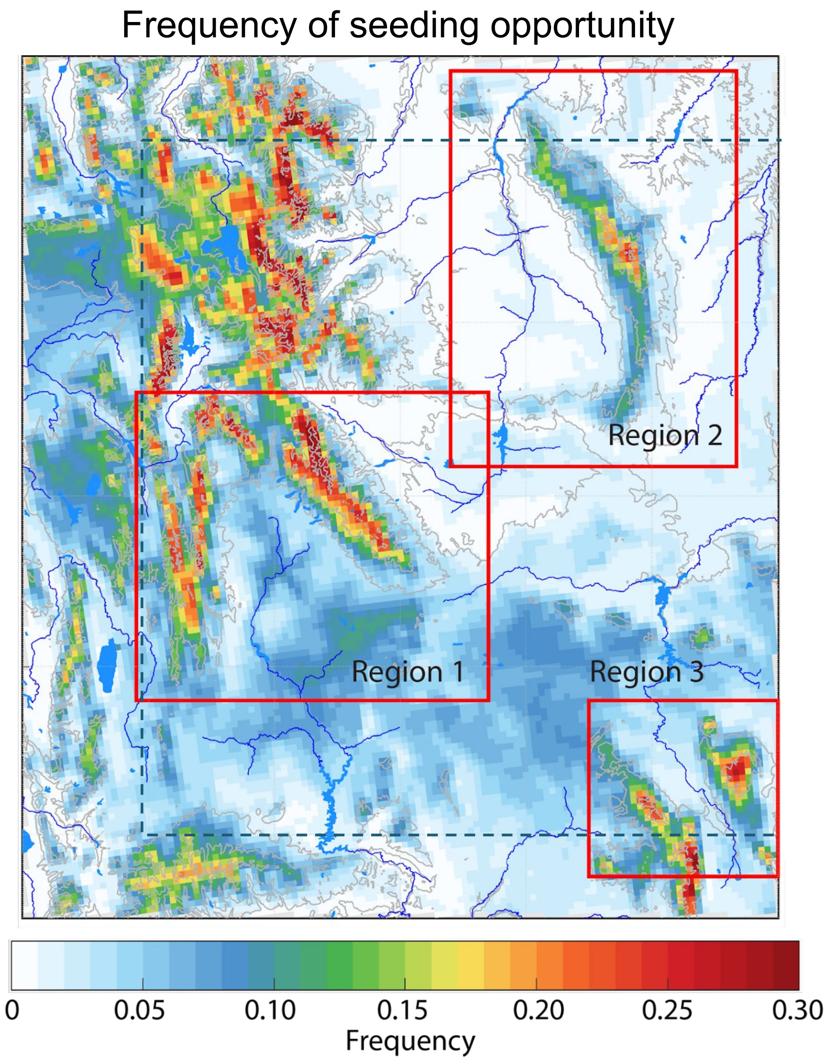
Shown to realistically reproduce liquid water path observations

Shown to realistically reproduce precipitation observations



Ikeda et al. (2021)

Model-based analysis of cloud seeding climatology



- Spatial map of where and when cloud seeding opportunities occur
  - More detailed analysis for each mountain range or local region of interest
- Used to guide design of how to target the region of interest

Important tool to identify opportunities for cloud seeding!

Tessendorf et al. (2020)

Feasibility and Design Components

Climatology Analysis

How often are there opportunities for seeding clouds in this region?

What are the characteristics of clouds in this region?

Preliminary Design

What methods of cloud seeding might target the clouds in this region most effectively?

Test and Refine Design

How effective are each design option at targeting and enhancing precipitation in this region?

Which combination of design options is recommended?

Analyze historical data:

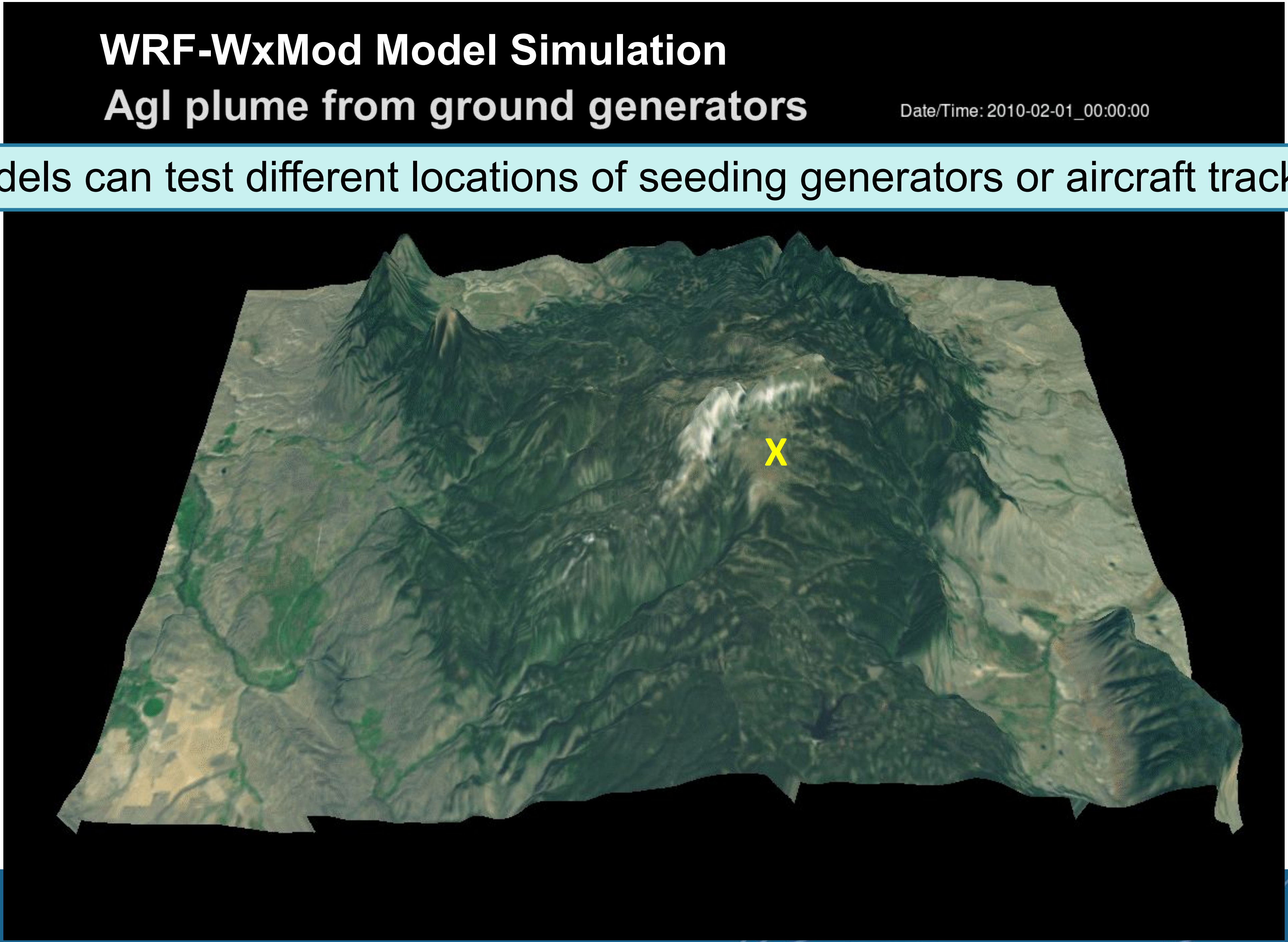
- Temperature
- Supercooled liquid water (SLW)
- Precipitation
- Winds
- Atmospheric stability

Review climatology results

- Place hypothetical ground-based generator locations
- Identify possible aircraft tracks

Simulations of cloud seeding

- Test each group of generators or flight tracks individually and combined
- Identify the options with optimal simulated results



Models can test different locations of seeding generators or aircraft tracks

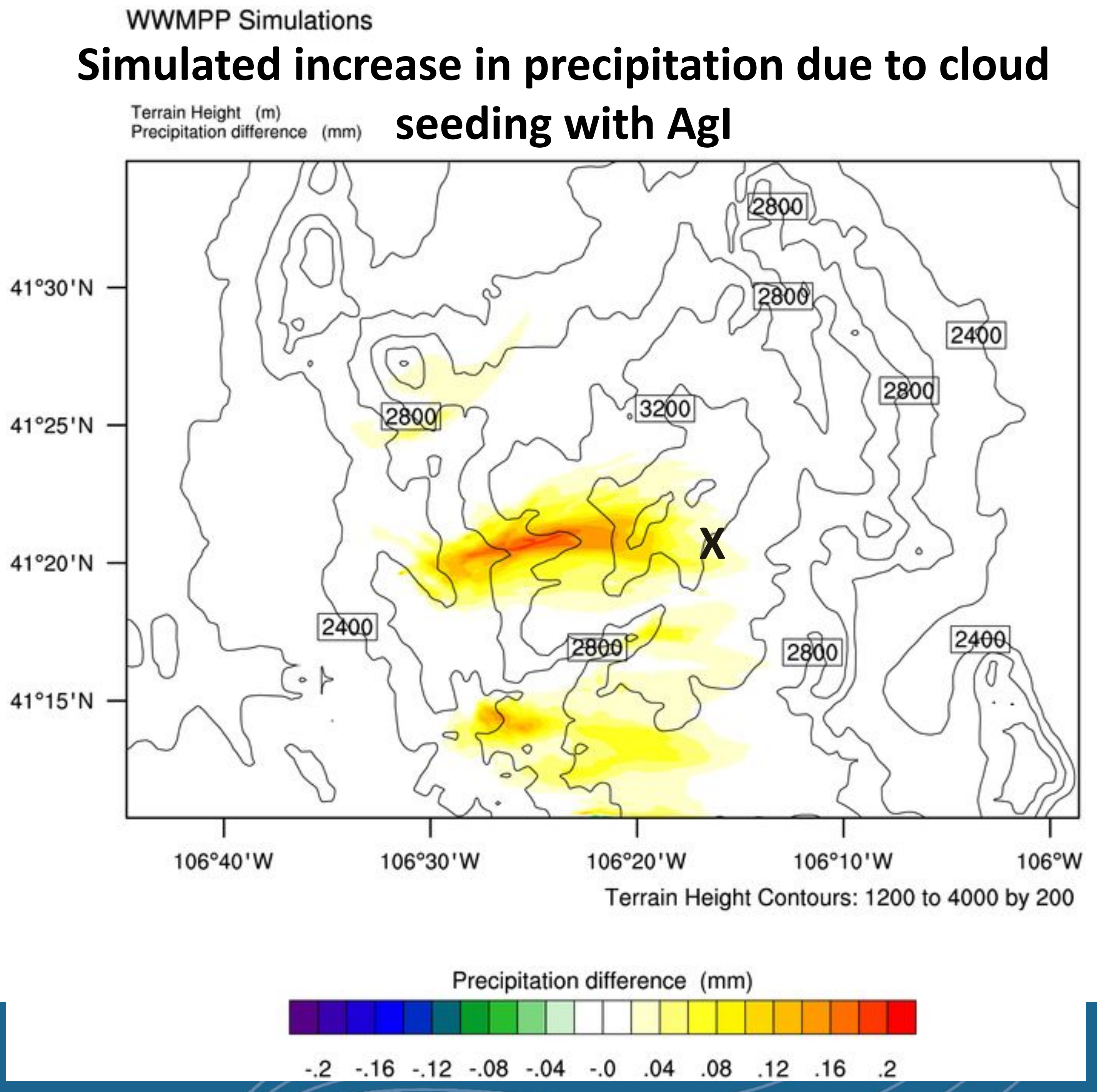
Simulated seeding effect:

P seeded – P not seeded

Where P = simulated precipitation accumulation

WRF-WxMod model simulations can be used to:

- test program design
- evaluate impacts of cloud seeding



Feasibility and Design Components

Research Components

Climatology Analysis → Preliminary Design → Test and Refine Design

Operational Components

Public engagement

Forecasting data

Communications

Operational criteria/procedures

Suspension criteria

Data management

Feasibility & Design Studies

Summer Precipitation Enhancement & Hail Mitigation

Bruce Boe, *Vice President of Meteorology* |Weather Modification International

Feasibility and Design

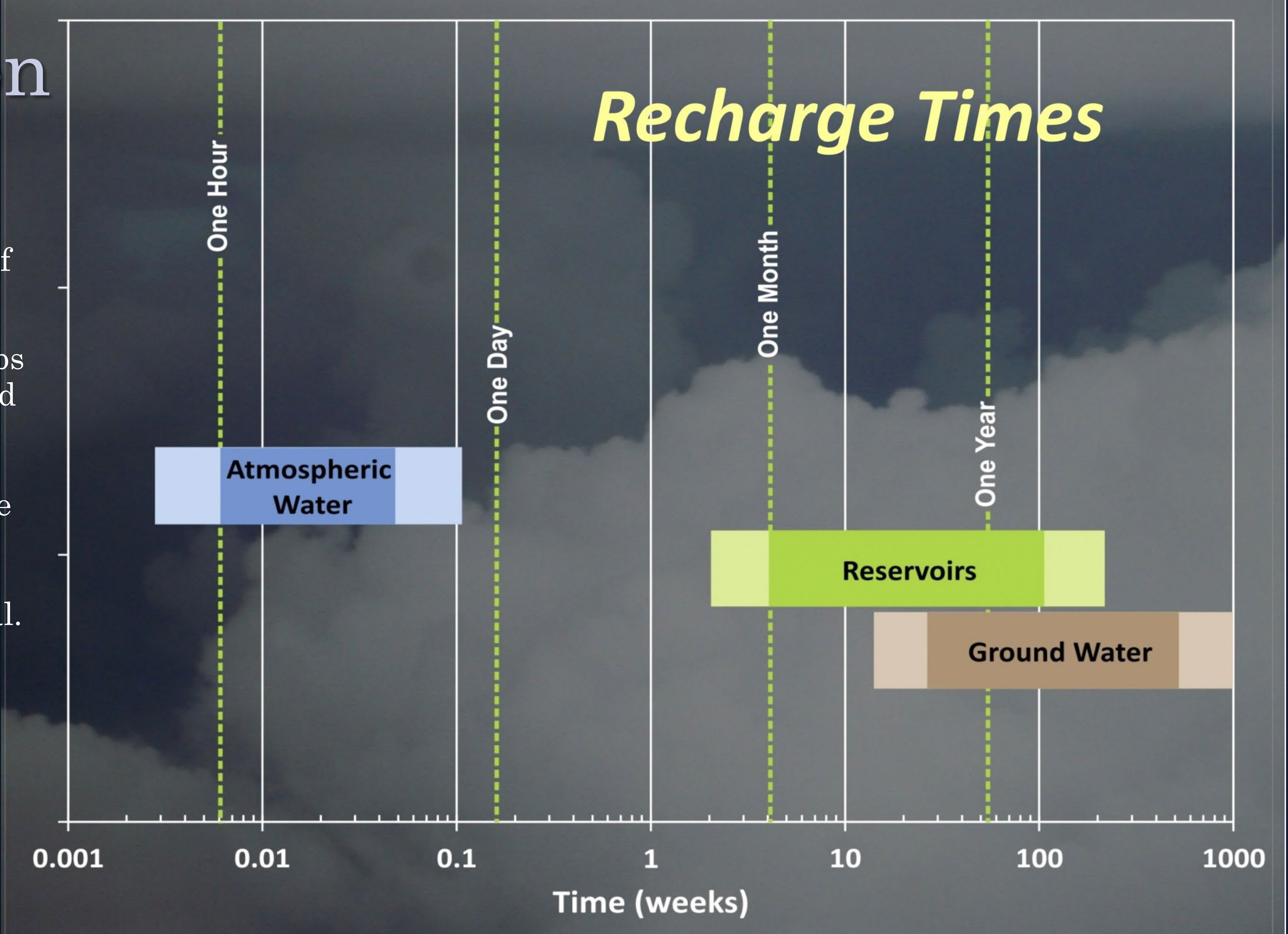
- You’ve just seen how climatology and research can support the development of cloud seeding programs.
- Now, we’re going to consider why and how such programs get going, and some of the DOs and DON’Ts.

Bruce Boe – Weather Modification International bboe@weathermod.com

Intuition

We all know the value of rain: freshwater that comes from out of the “blue”.

This graphic helps explain how cloud seeding, a technology that let’s us access the water in the atmosphere, has so much potential.



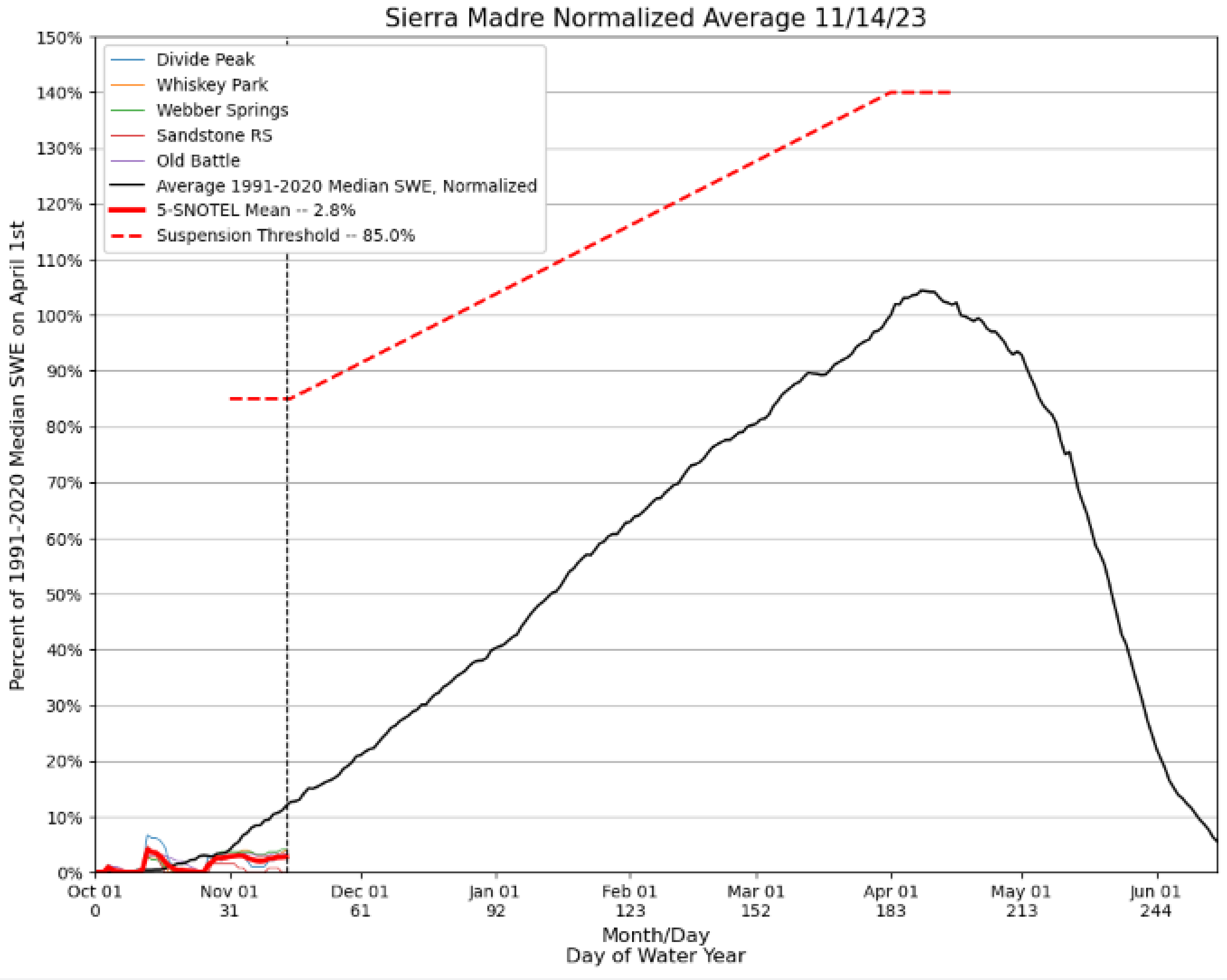
Cloud seeding works better in some places than others.

- Sometimes the potential can be assessed in a straightforward way, without time-consuming analysis.
- *Williams County, North Dakota, snowpack enhancement.*
- Sometimes the potential is less certain and requires a deeper dive.
- *Big Horn Mountains, Wyoming.*
- Geography, latitude, elevation, and other factors all can influence the potential program efficacy.

- The “stakeholders” are those persons having an interest in the program.
- For some, it may be direct benefit from increased crop yields, a longer irrigation season, or more sales.
- For others, benefits may be secondary. The implement dealer may sell more equipment. Increased crop yields result in increased tax revenue.
- For still others, interest in a program might come solely from knowing it is publicly-funded by their tax dollars.
- All of these viewpoints should be respected.

Public Information

- Full disclosure and transparency is always the best path.
- Understanding of the technology's limitations is essential.
- Cloud seeding should be considered as a tool available to water managers, never a stand-alone or short-term solution.



Do all projects need a feasibility study before they begin?

- The short answer is, “Yes”.
- The depths of such studies may vary, however.
- At the very least, an assessment should be made of the program’s objective(s) and local climate. Such will afford an initial idea if a program *could* be successful.
- A feasibility study establishes a baseline for expectations. Findings also play a significant role in project design.
- Feasibility and design studies also lay the groundwork for eventual evaluations.

Value

- The value of water determines program feasibility.
- Analysis of the cloud/rainfall climatology provides an estimate of how often seeding opportunities could occur.
- Assumptions must be made about how large a subset of those opportunities can be effectively targeted.
- An estimation of the additional rainfall resulting from seeding can then be applied to the intended target and scope, and a preliminary estimate pf the net precipitation gain projected.

Benefits

- Additional precipitation may be beneficial when:
- SHORT TERM - It supplements natural rainfall/snowfall, allowing additional growth/increased yields of agricultural commodities.
- MEDIUM TERM - It adds to soil moisture, building reserves for drier days to come.
- LONG TERM - It permeates deep, and recharges aquifers.
- There can also be benefits to wildlife, reservoir storage, and general water supplies, which benefit municipal and industrial uses as well.

Evaluations

- Programs that are purely operational, do not survive long-term because at some point the need to know how well it works (or doesn't) gets asked by too many stakeholders.
- It is best to plan with evaluations in mind, even if it is acknowledged that multiple seasons' data will be required for such to be meaningful.
- Independent evaluations? Whenever possible, program evaluations should be conducted by qualified persons other than those running the program.

Design

- If the proposed program appears to have promise, the design should include:
  - Means by which the cloud development and evolution can be monitored spatially and temporally. This means weather radar for warm seasons, and radiometers and/or cloud radars for cold season programs.
  - Surface precipitation measurements. The more, the better. The more often, the better.
    - There are ways to ground-truth radar-estimated precipitation with surface precip observations, especially helpful in warm-season programs.
  - Project communications infrastructure must be well defined.
  - Suspension criteria.
  - Public information and outreach.

Data Management

- Detailed records should be kept of the times, locations, amounts, and types of seeding agents dispensed.
- Such data, combined with physical observations (radar, precipitation), can be the basis for evaluation.
- Forecasts should be verified and retained.
- Numerical weather prediction (NWP) in support of operations, both warm- and cold-season, are proving to be very helpful. These records, at least some subset of the graphical output, should be archived.

Questions?

Bruce Boe – Vice President of Meteorology
Weather Modification International
Fargo, ND USA
bboe@weathermod.com

Program Implementation

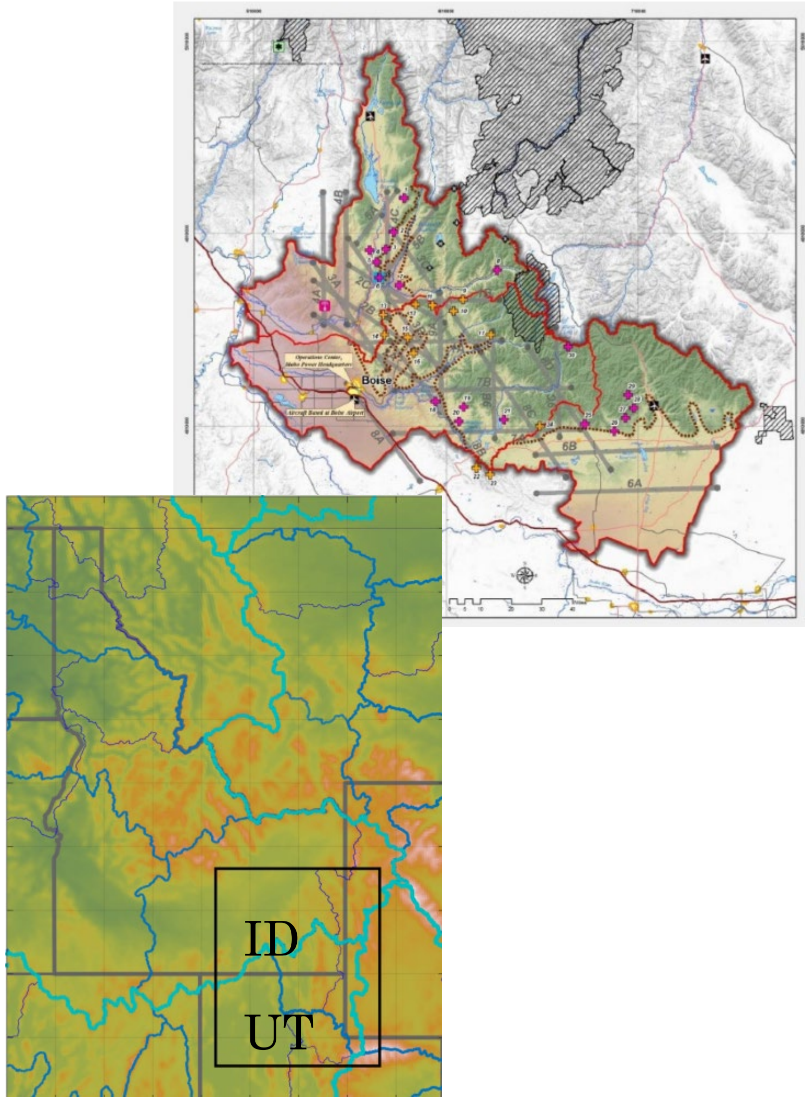
Budget Development | Program Commitments | Supporting Policy

Kala Golden, *Cloud Seeding Program Manager* | Idaho Water Resource Board

Budget Development

- Feasibility & design study will determine potential
  - Budget will constrain size of program

    → **Leveraging funds**
- Coordinating stakeholder groups
- Coordinating with other projects/programs



Program Commitments

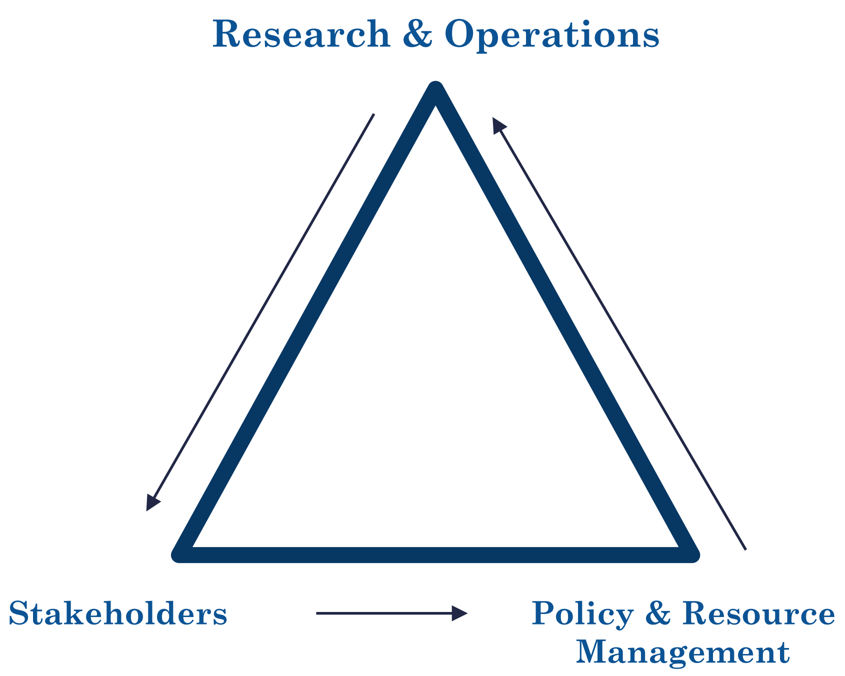


- Cloud seeding (CS) is a long term water management tool
  - Operationally and cost inefficient to stop and start
  - CS should be viewed as an “insurance policy”
- Long term program commitments: Who will maintain the program long term?
  - Multi-year program agreements vs annual

    → often based on legislative appropriations when public funds are involved
  - Contracting/statutory limitations? *i.e.* public bodies committing future funds

Supporting Policy & Development

- Answering policy questions = Research & Complex Analysis
  - *How well does it work? How (and when) does the increase in supply impact the hydrologic system? Is it safe? Are we "Robbing Peter to Pay Paul"?*
  - **Data** (*if available*) → **Tools** (*models*) → **Analysis** = $$$
    who will fund the development of tools & research?
- Demonstrating benefits: "*Why should I support this program?*"
  - Modeling & Analysis to solicit funding from various entities



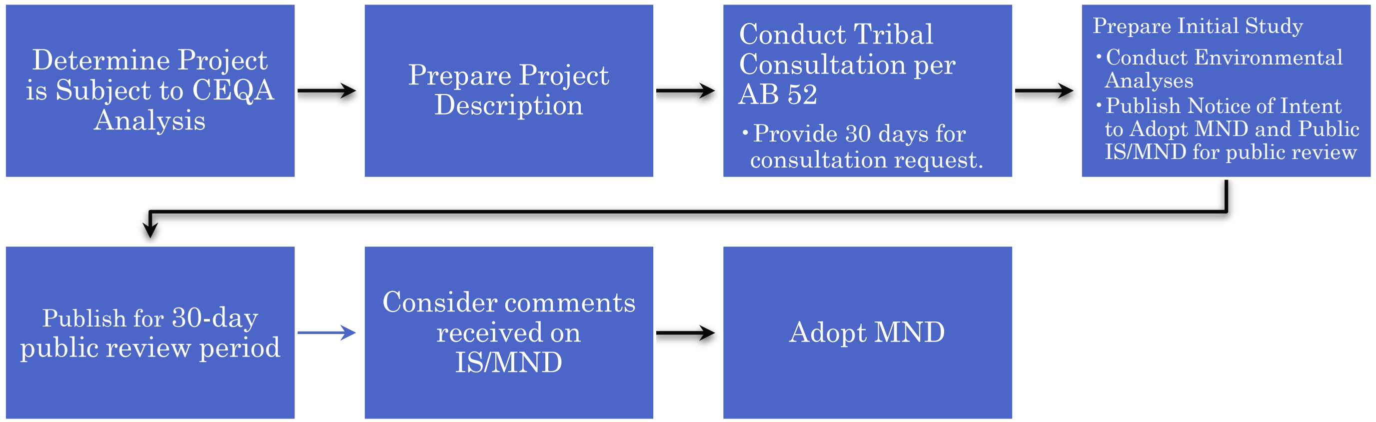
Program Implementation

Regulatory Considerations

Rachel Gray, *Water Resource & Planning Manager* | Santa Ana Watershed Project Authority

California Environmental Quality Act

- Compliance with the California Environmental Quality Act (CEQA) requires state, local, and other California public agencies to evaluate and disclose to the public and other agencies the potential environmental impacts of their projects before implementation.
  - CEQA requires California public agencies to avoid or reduce impacts where feasible.
  - 8-10-month process.
  - Implement Mitigation Monitoring and Reporting Plan



- Aesthetics
- Agriculture and Forestry Resources
- Air Quality
- Biological Resources
- Cultural Resources
- Energy
- Geology and Soils
- Greenhouse Gas Emissions
- Hazards and Hazardous Materials
- Hydrology and Water Quality
- Land Use and Planning
- Mineral Resources
- Noise
- Population and Housing
- Public Services
- Recreation
- Transportation
- Tribal Cultural Resources
- Utilities and Service Systems
- Wildfire
- Growth Inducing Impacts

Site Access Agreements/Insurance

Site access and operator agreements with public and private entities: legal review.

Commercial general liability insurance – site sponsors requiring contractors to have up to $4M general liability insurance

Pollution Liability – the minimum recommended limit is $2M/$4M; if there is high risk of environmental exposures, a higher limit should be considered.

Auto Liability: owned, hired, and non-owned autos coverage.

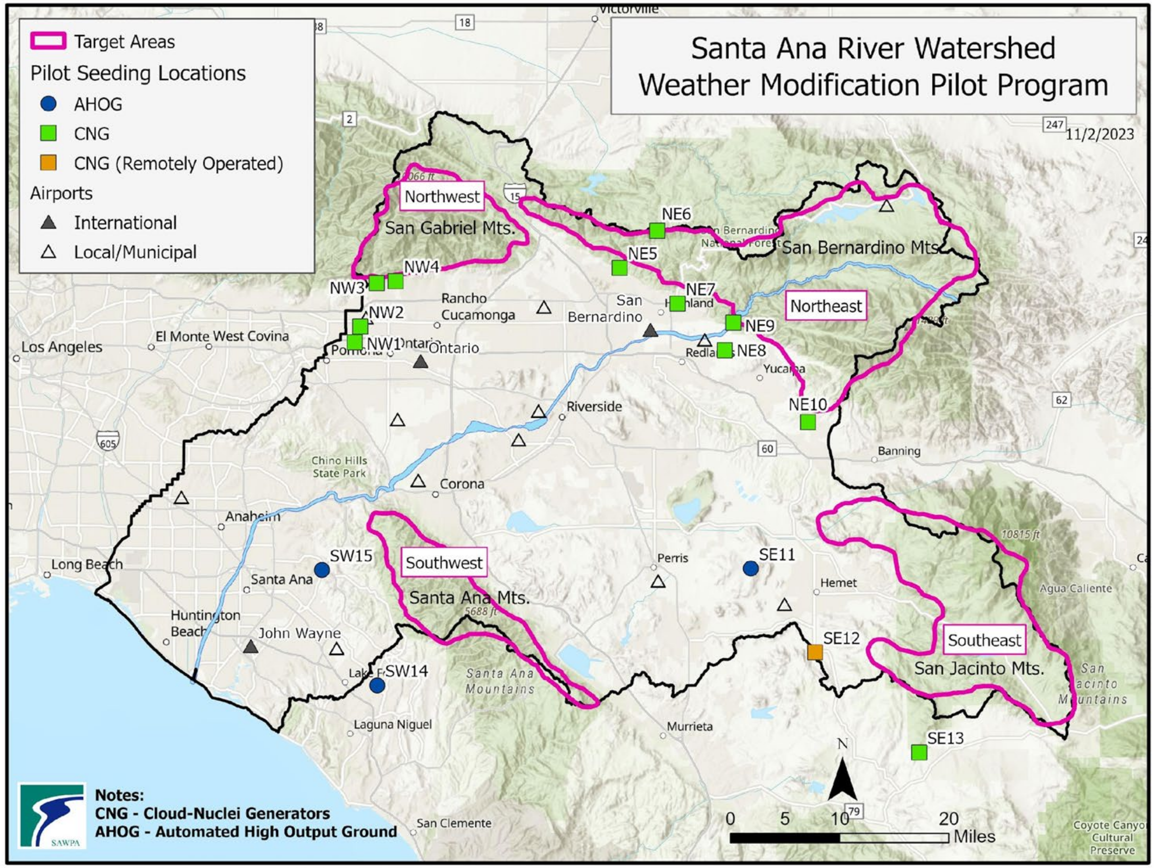
Indemnification from and against all actual and alleged damages, claims, lawsuits, administrative and judicial proceedings, liabilities, settlements, penalties, fines, costs, expenses, losses, or attorney and consultant fees and costs.

Hazardous materials indemnity.

Remediation in event of any release on or contamination.

Federal Aviation Administration

- The decision to allow a seeding aircraft to occupy the same airspace in a watershed for an extended period, during intense storm activity, lies largely in the hands of air traffic control.
- Even with all the proper permits, waivers and licenses, a plane may still be grounded during critical seeding periods, if the tower is concerned about air traffic, or if the pilot is concerned about the safety of the flight.
- In particular, areas in and around major airports or densely populated regions can pose challenging for airborne seeding operations.



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Environmental (CEQA)

- Ground Seeding Emissions: The primary long-term impact to operating a program is the release of CO_2
- Across an entire program over the course of an entire season, including all operational sites, it is estimated that CO_2 release would be less than a single vehicle in SAWPA's vehicle fleet over the same time period (1000 gallons of propane = 631 gallons of gasoline or about 500 gallons of diesel fuel).

  → *Consequently, one would assume the insurance carrier would deem a vehicle be uninsurable due to a vehicles potential impact on climate change.*
- Silver Iodide: concentrations of silver measured in the environment before (background) and after cloud seeding event are not toxic to humans and are over 1,000 times lower than the USEPA's secondary drinking water standard.
- Comprehensive reviews of cloud seeding programs have shown that there is no evidence of harm to humans or the environment from the use of silver iodide (Cardno ENTRIX 2011, Fisher et al. 2015). Therefore, operation activities for the proposed Project would not expose sensitive receptors to substantial pollutant concentrations. As such, impacts associated with operations would be less than significant.

Suspension Criteria

➢ Flooding Situations

- In addition to the possibility of flooding due to extreme rainfall, the potential also exists for wintertime flooding from rainfall on existing snowpack, especially if a lower elevation snowpack exists.
- The objective of suspension under these conditions is to eliminate the perceived impact of weather modification when any increase in precipitation has the potential of creating or contributing to a significant flood hazard.
- When a significant rain on snow event is expected, the forecast will be monitored closely to flag the potential for warm storm rain on snow, and coordination between the meteorologist and SAWPA will be appropriate in circumstances where the freezing level is >8,000 feet and the quantitative precipitation forecast (QPF) is > 3 inches in 24 hours.

➢ Burn Scars

After a wildfire is contained, a burn scar will form in the impacted area. According to the National Weather Service (NWS), the length of time the burn scar remains a threat for debris flow "depends on the severity of the wildfire that occurred as well as how much erosion occurs. It could take many years for vegetation to become reestablished and this is the main factor in slowing the precipitation run off that creates flash flooding and debris flows. Most burn areas will be prone to this activity for at least two years."*

➢ Severe Weather

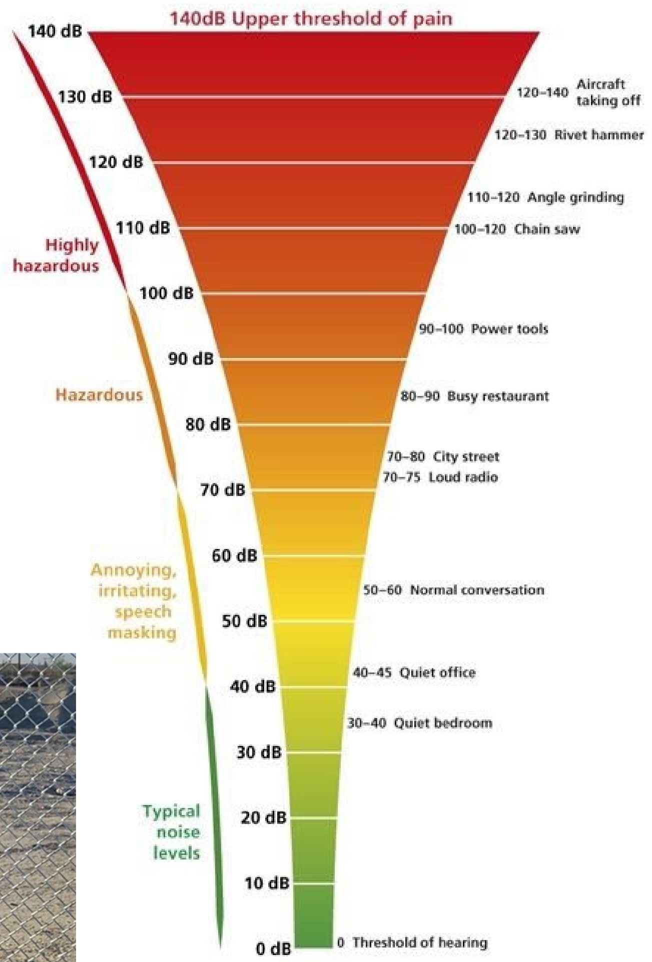
During periods of hazardous weather phenomena associated with both winter orographic and convective precipitation systems it is sometimes necessary for the NWS to issue special weather bulletins advising the public of the weather phenomena. Each phenomenon is described in terms of criteria used by the NWS in issuing special weather bulletins. Those of concern while conducting winter cloud seeding programs include the following:

- Winter Storm Warnings – issued by the NWS when it expects heavy snow, along with strong winds/wind chill or freezing precipitation.
- Flash Flood Warnings – issued by the NWS when flash flooding is imminent or in progress, or a dam break is imminent or occurring.
- Severe Thunderstorm Warnings – issued by the NWS when a thunderstorm is expected to produce strong winds more than 58 miles per hour (mph) or hail larger than one inch in diameter.

*Acquired on 10/12/2023 from - https://www.weather.gov/riw/burn_scar_flooding.

Sound Rating

- SAWPA had a test conducted of the sound rating.
    - Measured sound ratings for deployment 1 foot away from generator
    - Result: upon ignition there is a pop at 105 dB (instantaneous), similar to the sound of a clap or book dropping flat on the ground.



Vandalism

- Equipment vulnerable to tampering.
  - Propane tank
  - Copper tubing
  - CNG
  - Fencing
- Unhoused Community.

Collaboration

Regulatory Agencies:

- Department of Water Resources
- Regional Water Quality Control Board
- The State Clearinghouse in the Governor's Office of Planning and Research

Cities/Public Agencies:

- Elected Officials
- Water Districts
- Water Conservation Districts
- Flood Control Districts

Public:

- Watershed stakeholders
- General public

Public Perception

Toxicity of silver iodide	Allergic reactions to acetone	Cloud seeding does not work
Weather manipulation	Chemical trails	Wildfires
Flooding	Debris flows	High wind areas

Contracting for Operations

- Limited operations pool (firms).
- RFP process yielded very limited responses due to the specialized nature of operating a cloud seeding program.
    - RFP process:
        - Prepare RFP: scope of work and deliverables.
        - Approval from boards/commissions to release RFP.
        - Respond to questions.
        - Obtain proposals from potential contractors.
        - Review proposals and select a qualified contractor.
        - Obtain approval from boards/commissions to select contractor.
        - Contractor agreement and submittals
        - Time intensive: 6-9 months
- Ground-Based Unit Operators:
    - Public agency versus private contractors.
    - Site sponsor’s willingness to operate seeding units.
    - Compensation.

Program Implementation

Deploying Infrastructure

Jake Serago, P.E., *Cloud Seeding Program Manager* | Utah Division of Water Resource

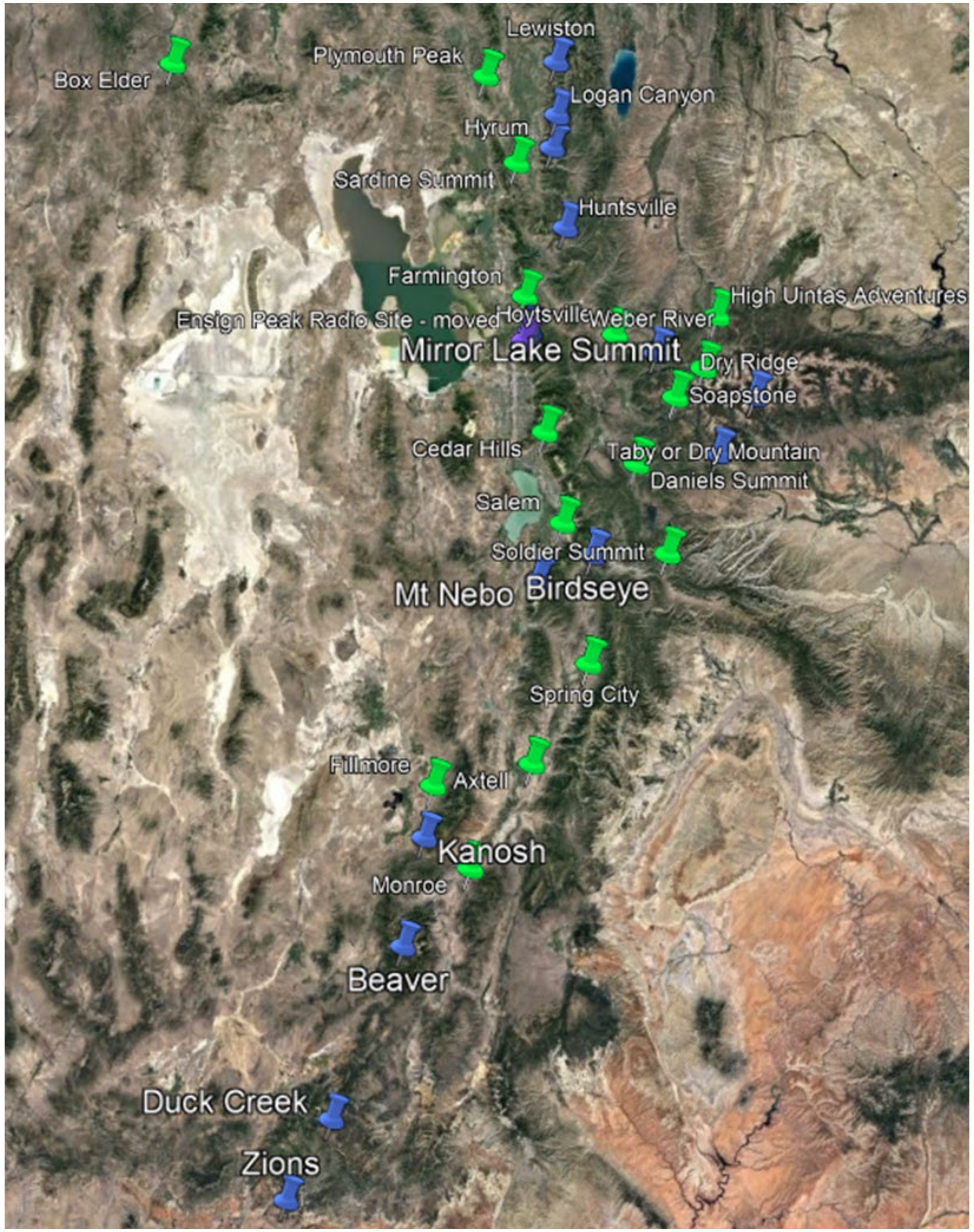
Infrastructure

- Ground-based generators
    - Manually operated
    - Remotely operated
- Aerial seeding
    - Aircraft
    - Equipment
- Weather monitoring equipment

Example: Remote Generators

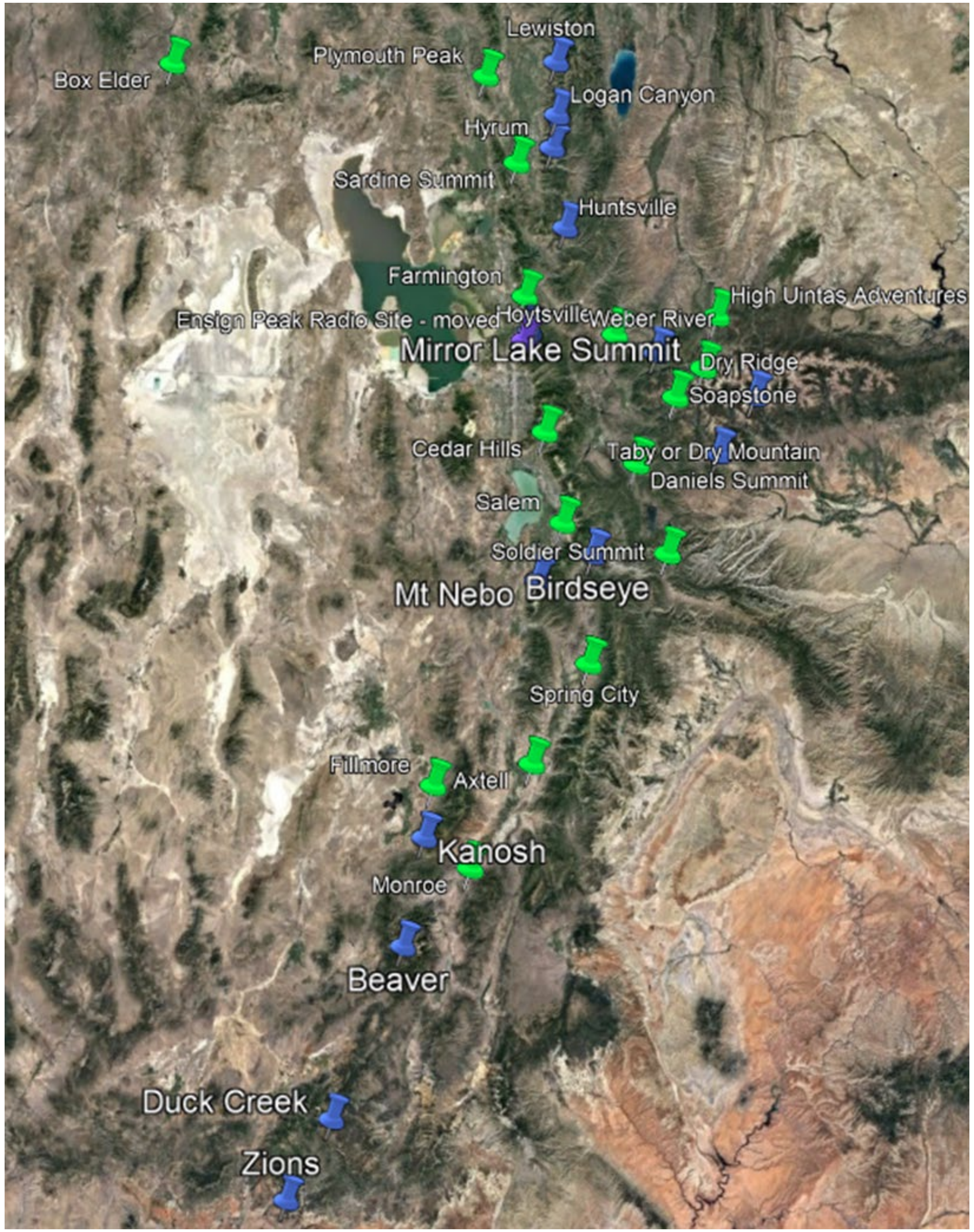
Goal:
Deploy remote generators using previous studies which identified suitable areas

120 sites identified using previous and new studies



Example: Remote Generators

- Limited number of vendors
- Considerations
  - Geographical proximity
  - Relationship
  - Ability to customize
  - Processing capacity
  - Contracting/Purchasing
- Lease or purchase?
  - Maintenance
  - Storage
  - Set-up/take down
- Siting
  - 1. Private - logistics
  - 2. State - limited area
  - 3. Federal - permitting



Monitoring & Analysis

Program Validation

Dr. Roy Rasmussen, *Senior Scientist, Section Head* | National Center for Atmospheric Research, RAL

Evaluating winter orographic cloud seeding

Roy Rasmussen, NCAR

Outline of talk

1. Need for Observations and High-Resolution Models
- Radiometers to measure SLW
- Gauges and radar to measure precipitation
- Mesoscale models at sufficiently high resolution

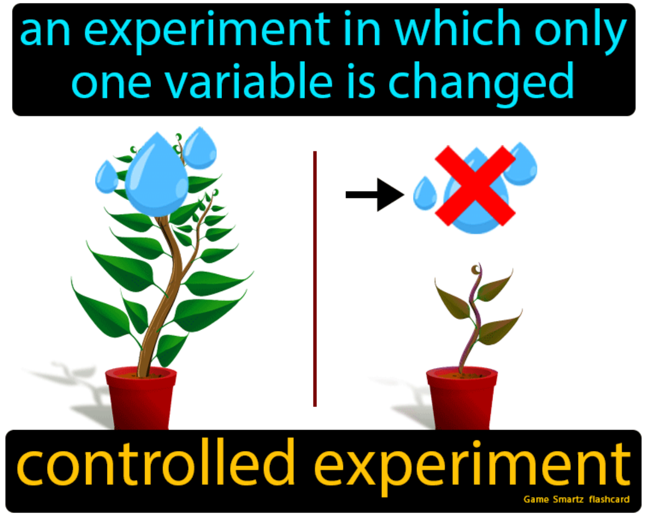
2. Use Verified models to Perform the Evaluation
   Rasmussen et al. (2018) JAMC paper

3. Evaluators should be independent of operators.

Challenges in Cloud Seeding Evaluation

Once you seed a cloud, you do not know what it would have done otherwise

- Randomized statistical trials were utilized, similar to a pharmaceutical trial
- However, these approaches have often been inconclusive
  - Hard to get large enough number of cases to get "statistically significant" results
  - Signal is small relative to the variability of natural weather

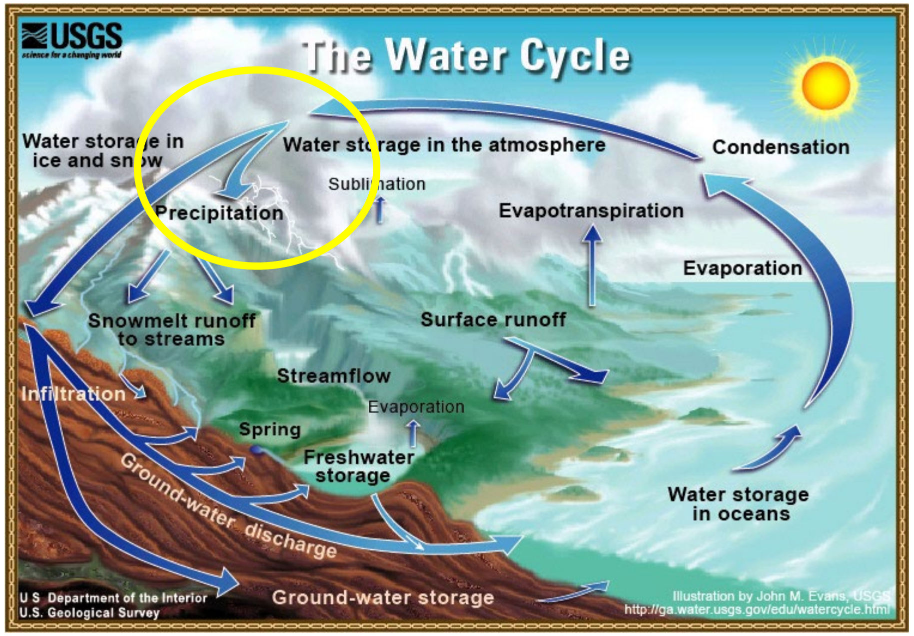


Cannot control all of the variables in cloud-seeding experiments

Challenges in Cloud Seeding Evaluation

The water cycle is a system of complex processes

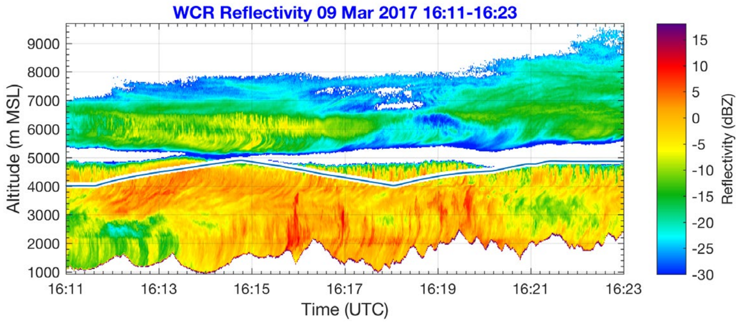
- Difficult to measure all its components



How much additional precipitation?

Simplified schematic

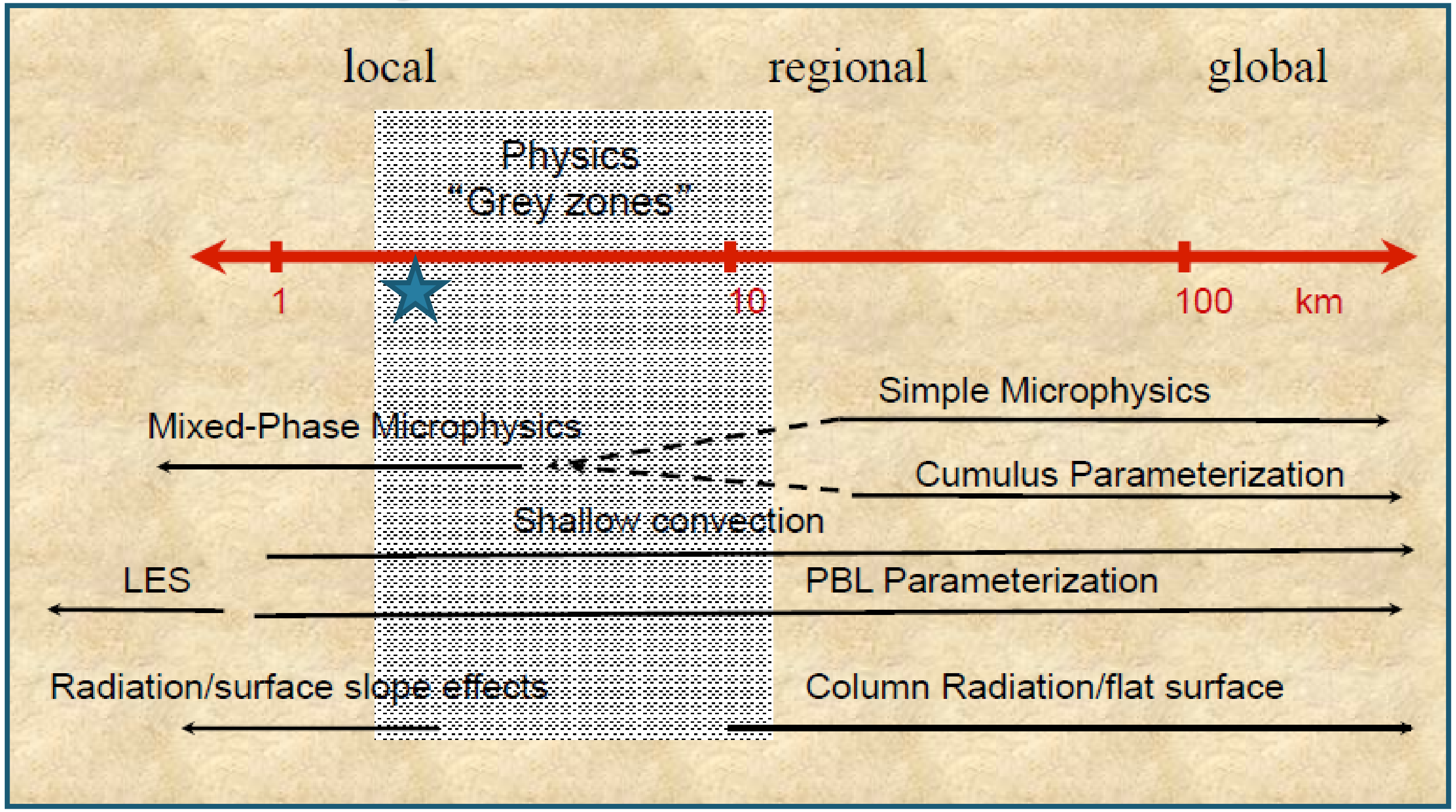
Reality



And then, how much additional streamflow?

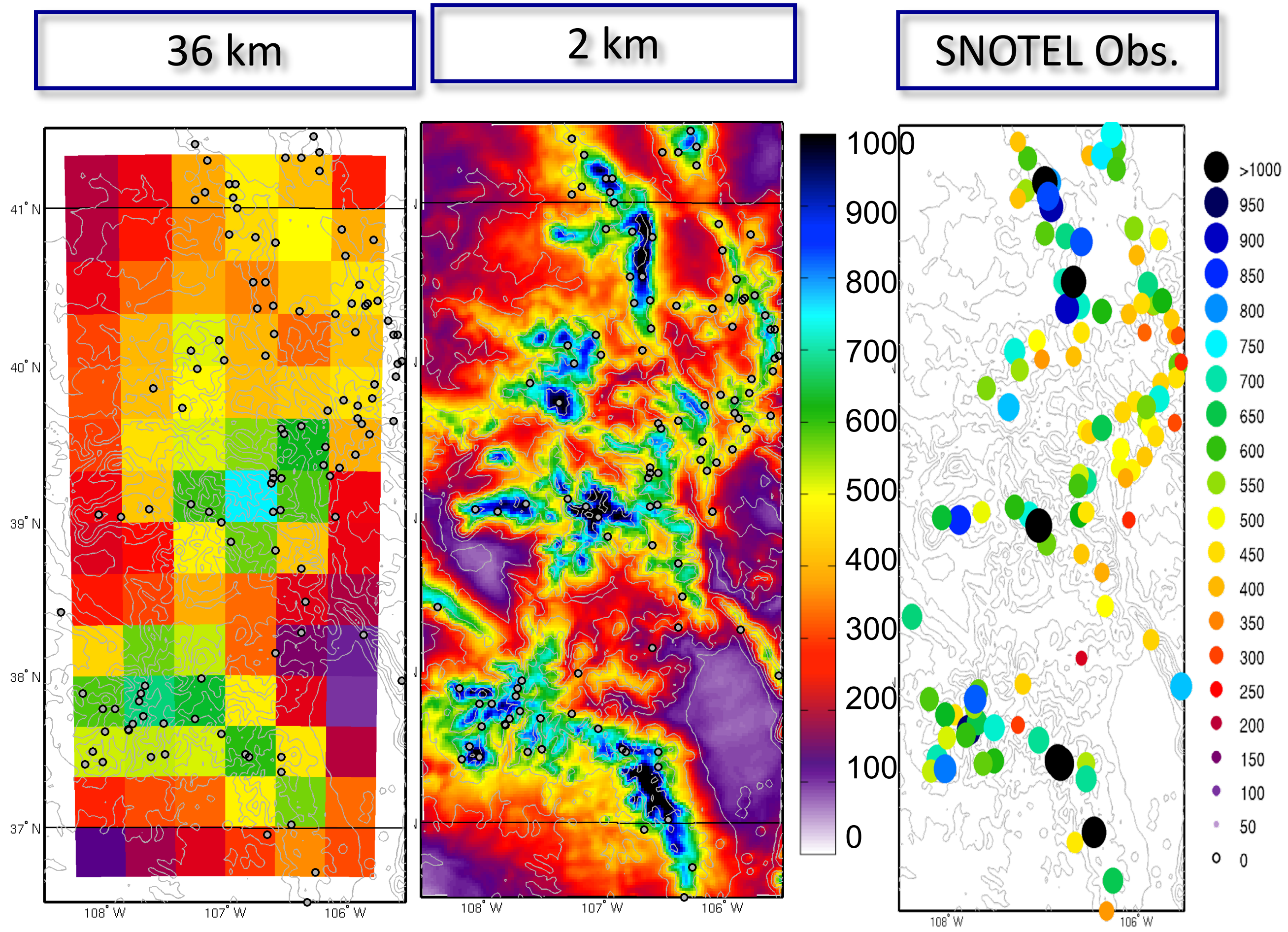
Computer models provide new opportunities to evaluate cloud seeding

Physics in Multiscale Model



WRF model able to reproduce the amount and spatial distribution of snowfall and snowpack over a winter season over the Colorado Headwaters at spatial resolutions less than 6 km

NCAR



6-mo. Total Precipitation (mm) Comparison
1 Nov. 2007-1 May 2008

SNOTEL Precip gauge

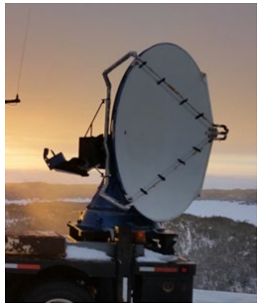
Observations useful for evaluation

Better observational networks to optimize forecasting for cloud seeding and evaluation of the impacts:

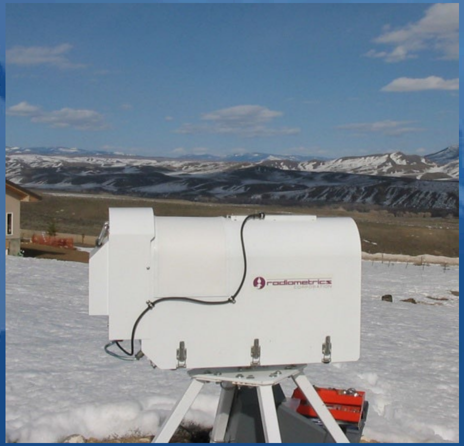
- Multi-channel radiometer to measure vertically integrated supercooled liquid water
- Snow gauges with high temporal resolution
- Atmospheric sounding(s)

Cloud seeding evaluation and provide benefits to other stakeholders:

- Gap-filling X-band radars



radiometers



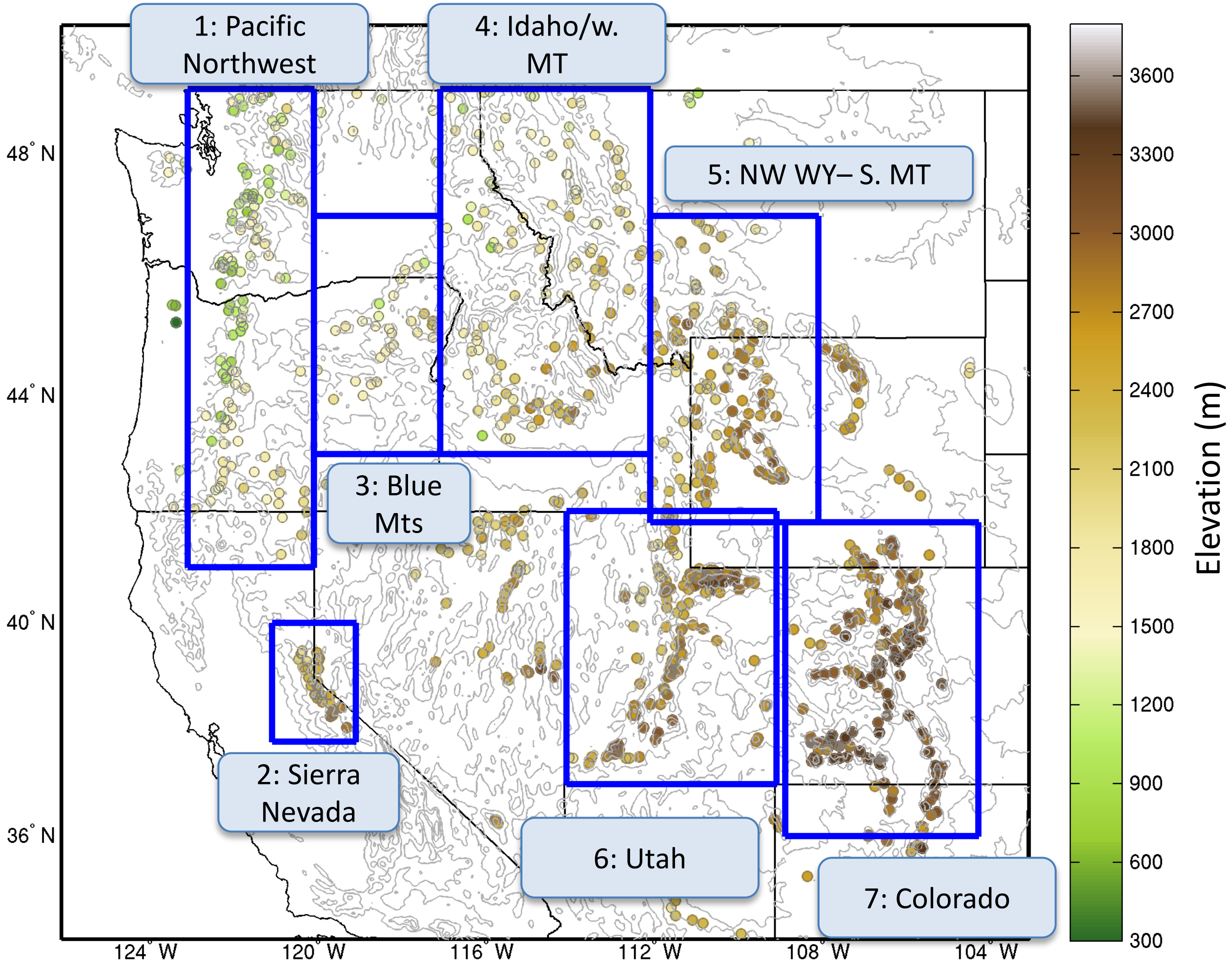
Barret Ridge

Model Evaluation at SNOTEL Sites

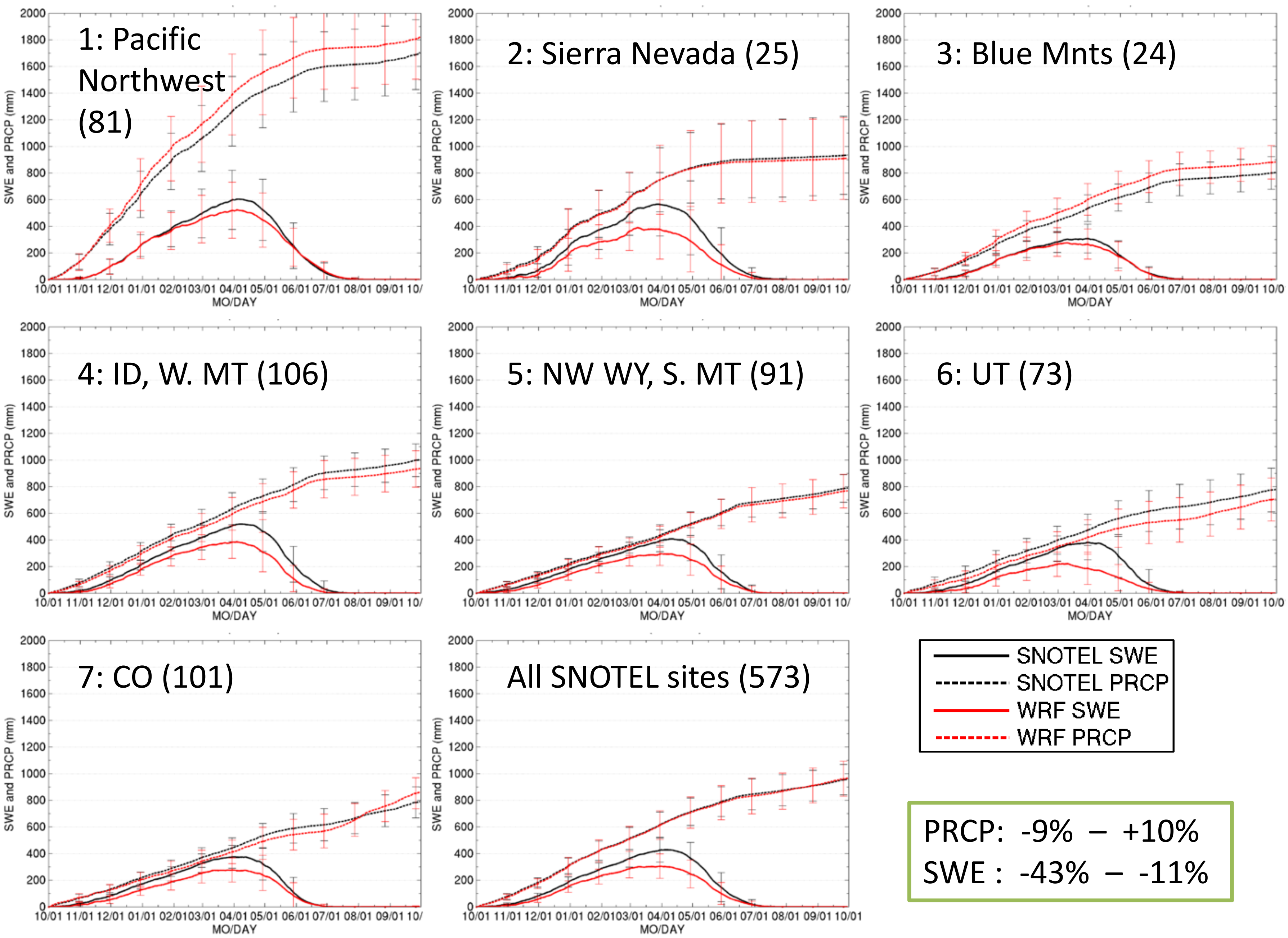
SNOTEL site at Brooklyn Lake, WY

Snow gauge

Snow pillow



SNOTEL vs WRF at SNOTEL sites: 13-year climatology



PRCP: -9% – +10%
SWE : -43% – -11%

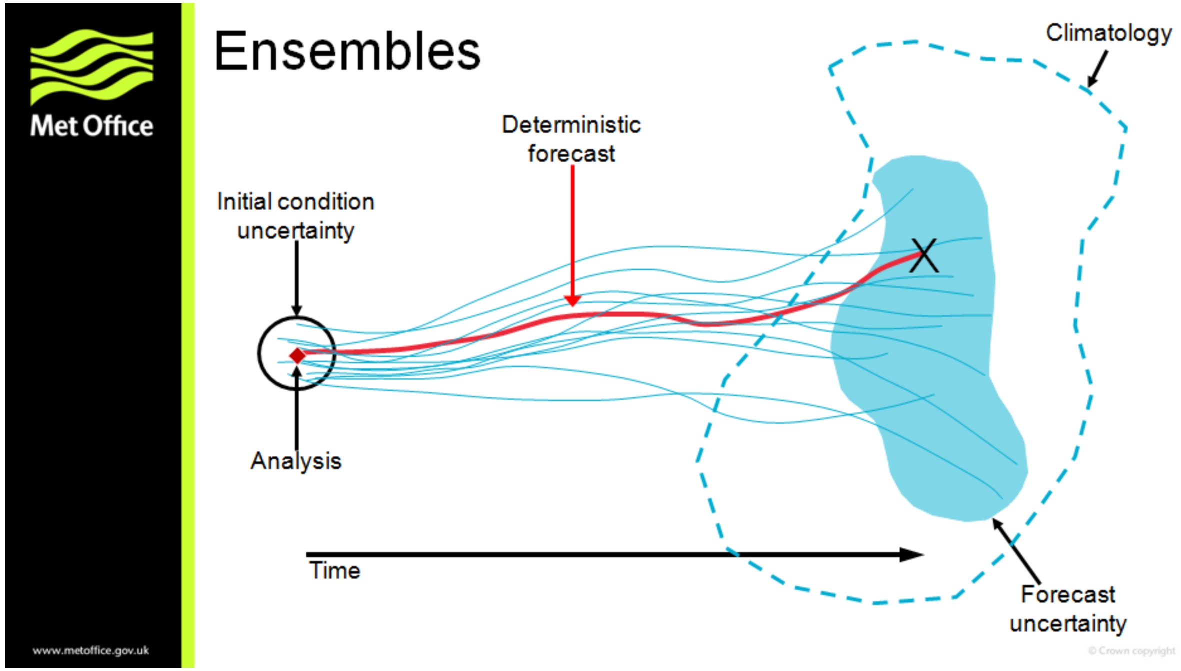
WWMPP Approach (Rasmussen et al. 2018)

- Ensemble members (model simulations with different configurations) need to cover a wide range of initial condition and model based uncertainties:
  - Large scale environment (Driving re-analysis)
  - Natural cloud evolution (land surface physics, PBL physics, and cloud and precipitation microphysics)
  - Seeding processes (PBL physics for AgI dispersion, land surface physics, and seeding microphysics)

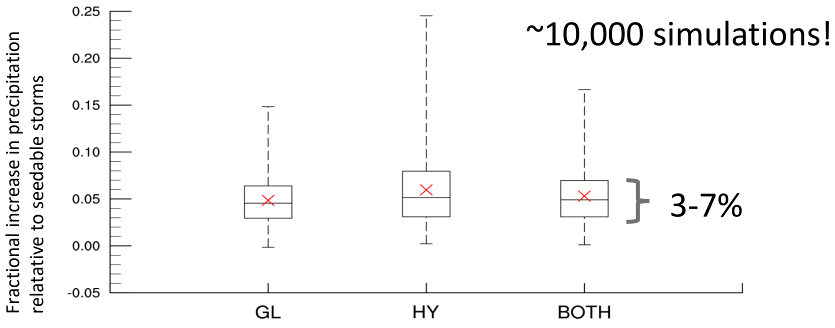
Ensemble modeling to evaluate cloud seeding

An ensemble approach to modeling captures:

1. Initial condition uncertainty
2. Model uncertainty



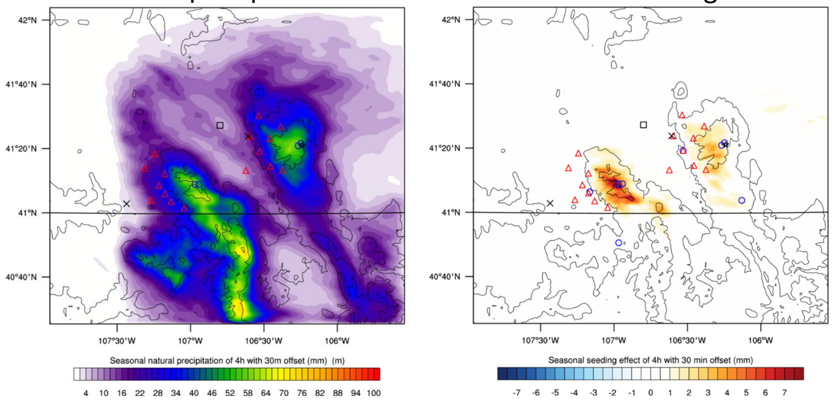
Spread of simulated seeding effects from ensemble for Wyoming Weather Modification Pilot Program (WWMPP)



Rasmussen et al. (2018)

<u>Ensemble Mean Effect of Seeding</u>

Natural precipitation | Simulated seeding effect



Summary

1) Computer modeling methods are the future of cloud seeding evaluation

2) Observations are important to verify the models and can help optimize cloud seeding forecasting operations

3) Evaluation should be done independently from operations

(Wyoming Pilot Project, Barry Lawrence)

Monitoring & Analysis

Methods to estimate annual precipitation enhancement from cloud seeding

Mel Kunkel, *Senior Atmospheric Scientist* | Idaho Power Company

Two Primary Methods

1. Target-Control Analysis

2. NCAR Weather Forecasting and Research (WRF) Weather Modification Module (WxMod).

Target Control Analysis

1. Simple statistical approach used historically to estimate benefits from cloud seeding operations. Developed prior to the readily availability of high-performance computing to support cloud seeding operations analysis.
   - Best described by Arnett S. Dennis in his 1980 book **Weather Modification by Cloud Seeding** a report published by the Utah Water Research Laboratory a part of Utah State University. Numerous other reports/articles are also available.
2. Uses a regression methodology comparing target and control precipitation based upon a preseeding statistical relationship (regression).
   - Provides an estimate of the difference between the observed precipitation in the targeted basin and what would have occurred if seeding had not occurred.
   - Does not historically provide uncertainty estimates.
   - Relationship can be impacted by changes in gage location, climate change, etc.
   - Upwind seeding can impact the control relationship.

A Priori guidance for development

1. Data must have a long history of precipitation accumulation that existed (typically at least 10 years, preferable much longer) prior to the beginning of Cloud Seeding that occurs within the target area and outside of the target area.

Commonly used data

- SNOTEL data
- National Weather Service Station data
- COOP Weather Station data
- RAWS Weather Station data
- Many other types of precipitation are possible to use, but many do not receive adequate quality control.

2. Target data must exist within designed basins of interest

3. Control data must come from stations not previously influenced by cloud seeding, by any organization.

A Priori guidance for development

4. Control stations must be within an upwind weather flow (S-W-N)

5. Individual sites (target and or control sites) do not have to be strongly correlated but some correlation does help

- The combined (pooled) target and control data should (normally) show a strong correlation.

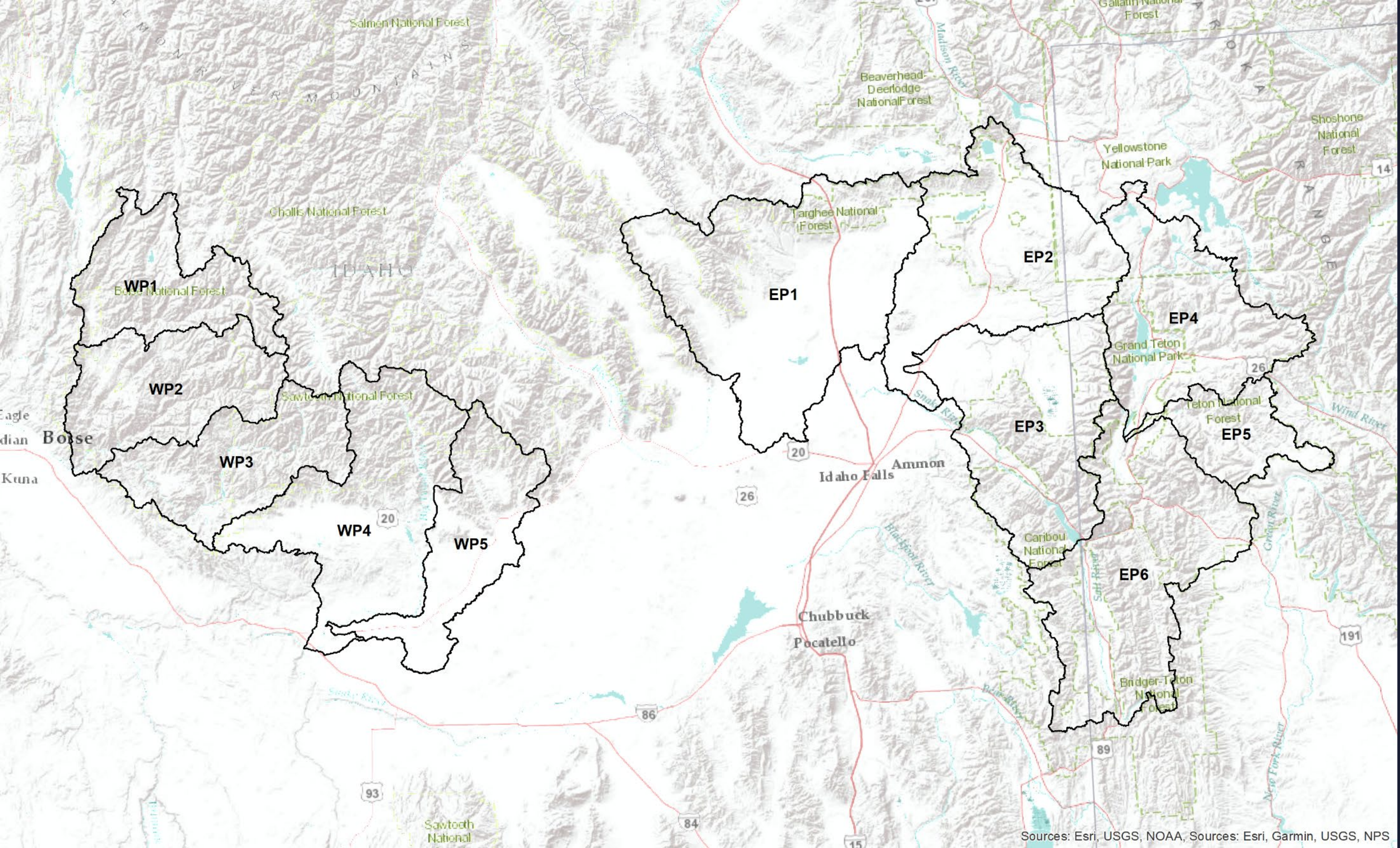
6. Expected benefit range 0.0% – 25.0% for benefit (precipitation) estimates and have reasonable variability based upon literature review.

- Some reports have indicated higher benefit estimates for individual storms

Process (as IPC does it)

1. Target sites selected based upon sub basin division (8-Digit HUC) for regions of interest
Interactive Map (usda.gov)

2. Control sites based upon excluding target areas and surrounding areas that have likely/possibly been impacted by cloud seeding. This is getting harder and harder each season as more and more basins are seeded in the western United States.


WP1
WP2
WP3
WP4
WP5
EP1
EP2
EP3
EP4
EP5
EP6
Salmon National Forest
Challis National Forest
Boise National Forest
Sawtooth National Forest
Targhee National Forest
Beaverhead-Deerlodge National Forest
Yellowstone National Park
Shoshone National Forest
Grand Teton National Park
Teton National Forest
Caribou National Forest
Bridger-Teton National Forest
IDAHO
Boise
Eagle
Kuna
Idaho Falls
Ammon
Chubbuck
Pocatello
Madison River
Snake River
Blackfoot River
Salt River
Wind River
Green River
New Fork River
20
26
86
84
93
89
191
14
15
Sources: Esri, USGS, NOAA, Sources: Esri, Garmin, USGS, NPS

Process (as IPC does it)

1. Target sites selected based upon sub basin division (8-Digit HUC) for regions of interest
Interactive Map (usda.gov)

2. Control sites based upon excluding target areas and surrounding areas that have likely/possibly been impacted by cloud seeding.

3. Collect precipitation data for Control and Target sites from SNOTEL
-- Download both the Water Year (WY) Nov 1st and Apr 1st precipitation data.

4. Using downloaded data, develop the cloud seeding precipitation accumulation amounts for each site.
-- CSprecip = Apr 1st precip - Nov 1st precip (or whatever other period is chosen).

Process (Cont)

5. Combine Control and Target data sets. Identify years to remove from analysis based upon previous years seeded in that zone.

6. Identify number of years remaining in development and analysis periods.

7. Select most representative target sites and control sites using a combined bootstrap/regression approach based on A Priori guidance.

Process (Cont)

7. Select most representative target sites and control sites using a combined bootstrap/regression approach based on A Priori guidance.

EX: In the early 2010s we redid the WP1 (Payette) T/C and it had 5 possible SNOTEL target sites (Banner, Big Creek Summit, Cozy Cove, Deadwood Summit and Jackson Peak) and 73 possible SNOTEL controls sites.
- if doing 3x3 there are 10 possible target combinations and 60,198 possible control combinations (if looking at 3x4, there are 1,088,430 possible control combinations).
--- There were 13,780 combinations that give regression R^2 of 0.94 or higher
--- There were 69 that give R^2 of 0.97 or higher
--- Of those 69, 29 produce results that fell between 0% and +50% benefit estimates
--- Of those 29, 2 produce results that fell between 0% and +32.
--- Of those 2, none produce results that fall between 0% and +25.

* Completed using a 3x4 combination that fell within the A Priori guidelines.

Process (Cont)

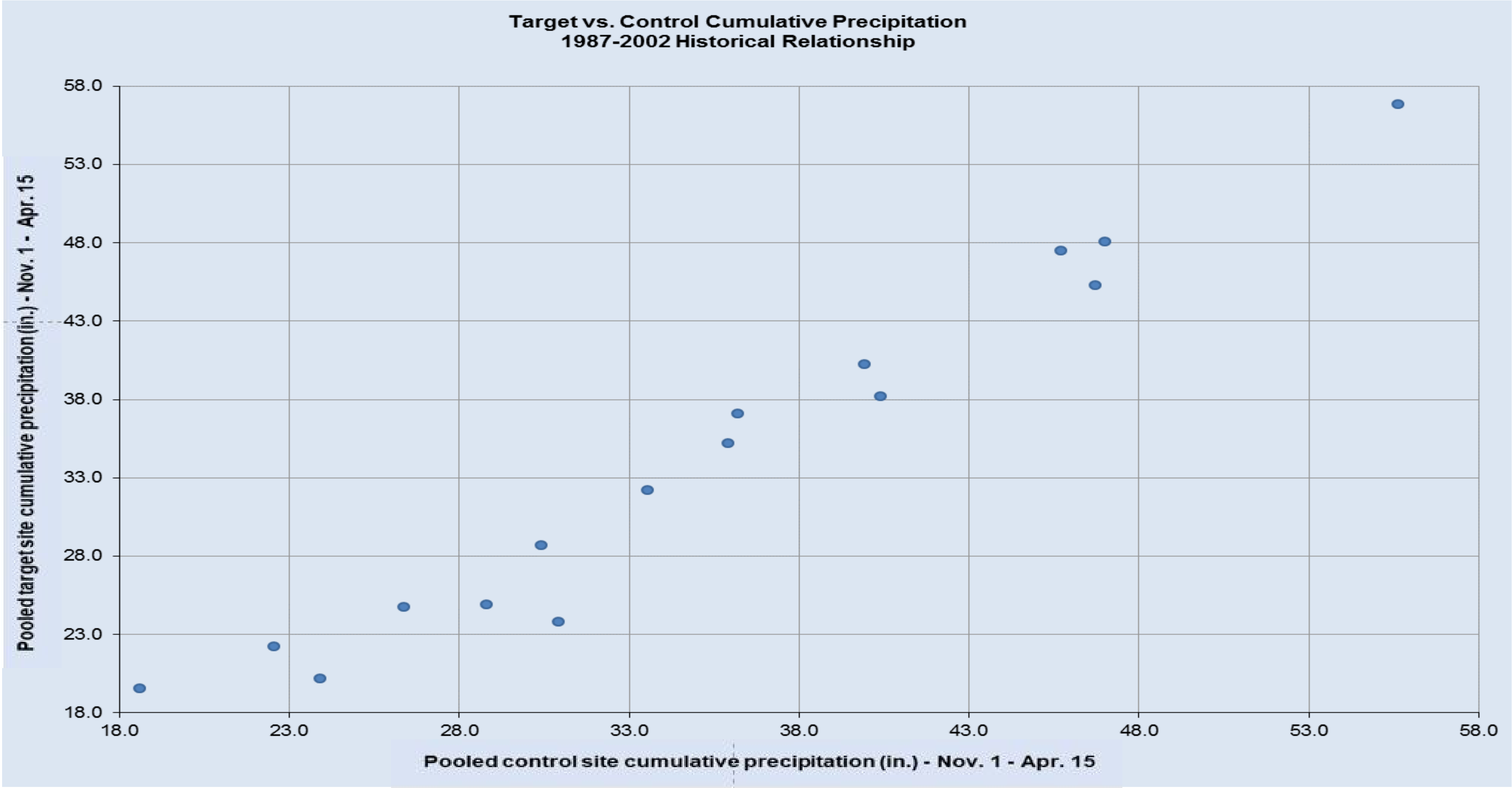
5. Combine Control and Target data sets. Identify years to remove from analysis based upon previous years seeded in that zone.

6. Identify number of years remaining in development and analysis periods.

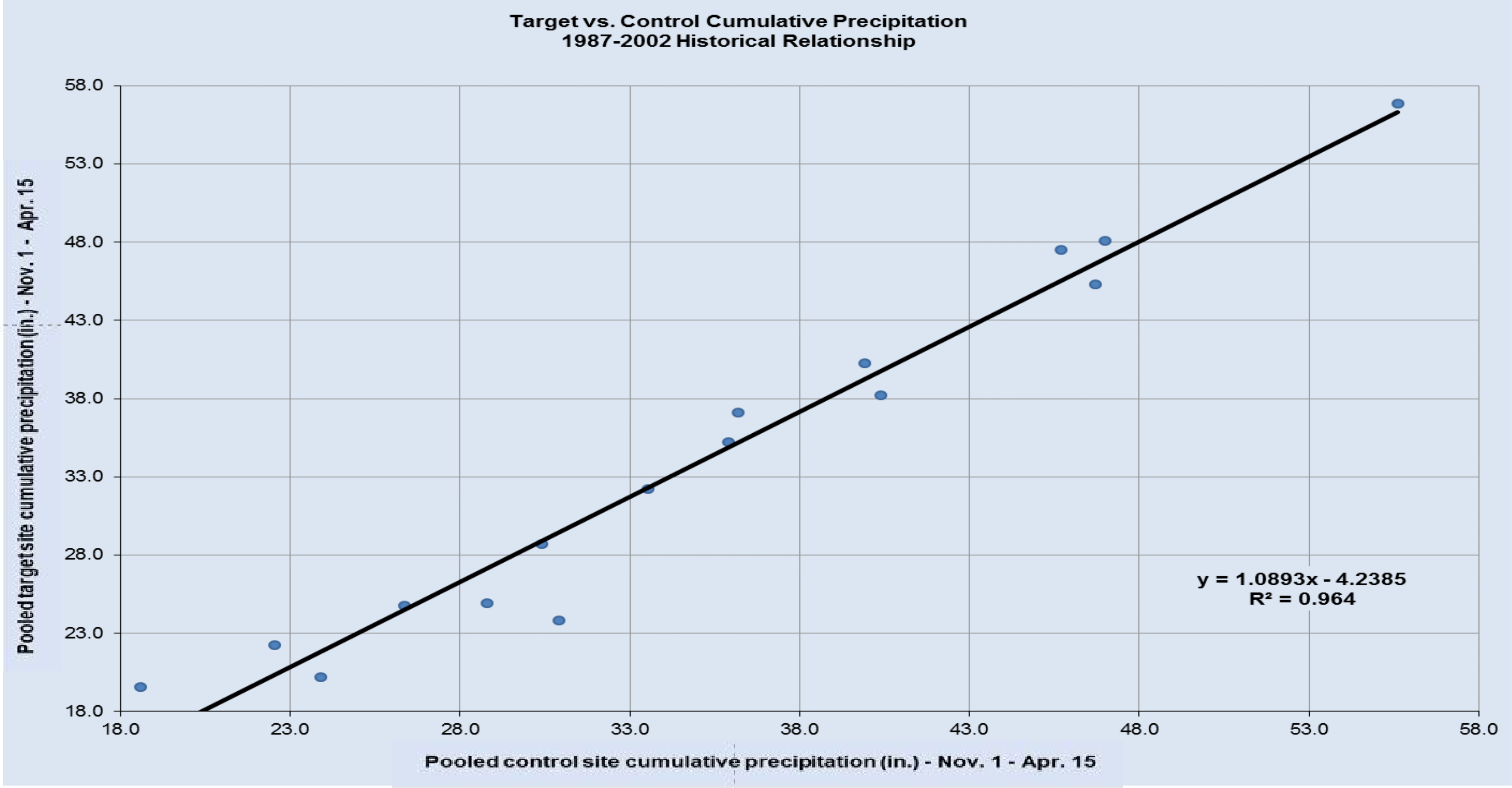
7. Select most representative target sites and control sites using a combined bootstrap/regression approach based on A Priori guidance.

8. Develop a final regression based upon full data sets (not subsetted) after selecting the best combination of Target and Control stable sites from the analysis, develop a table and figure.

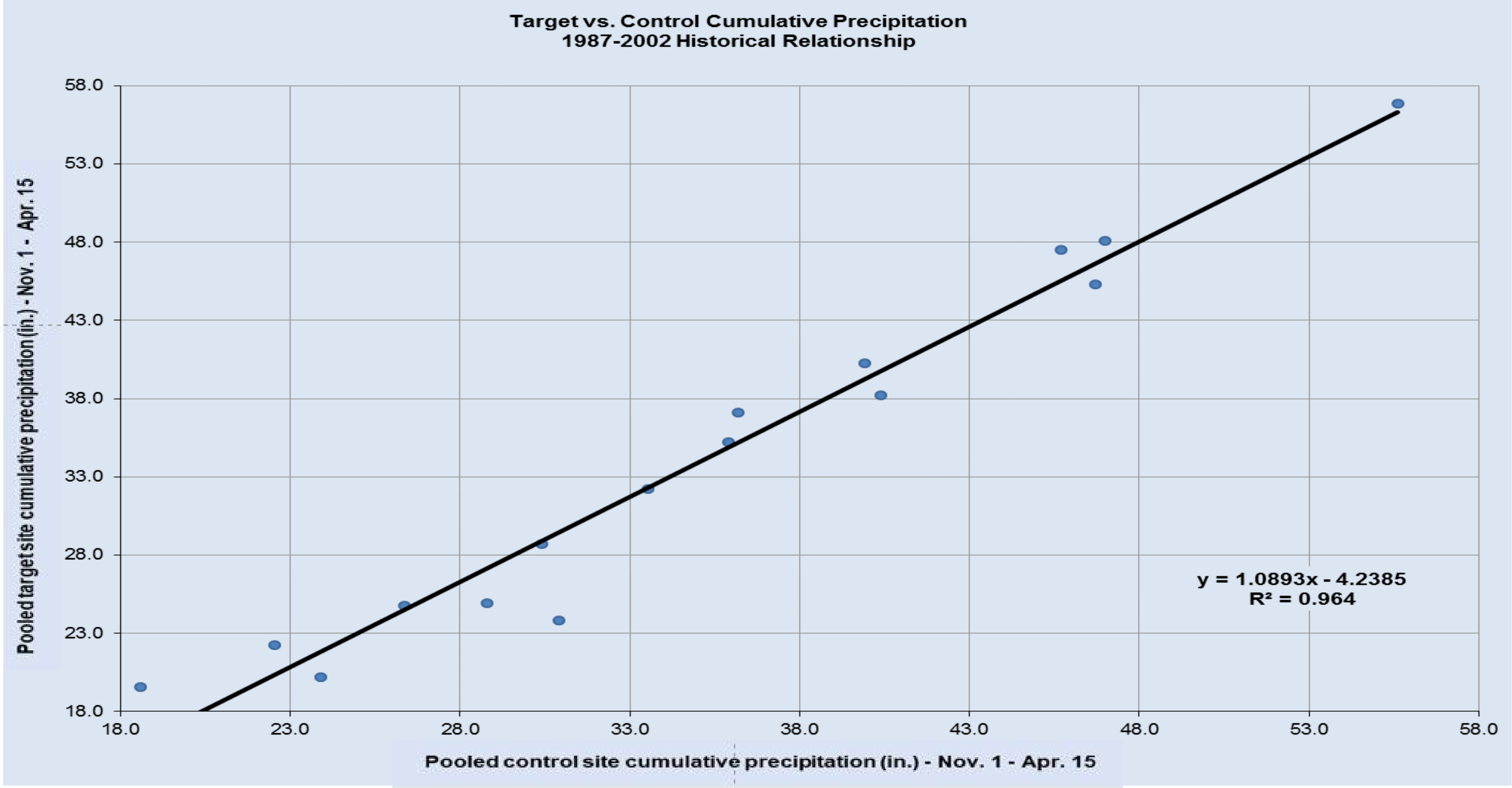
Target/Control - Development



Target/Control - Development



Target/Control - Development



Target Control - Concerns

- TC depends upon near stationarity of conditions at the target and control sites throughout the control and seeding periods.
  - This is seldom the case
- Any upwind seeding (either of the target or control site) reduces the effectiveness of the TC relationship.
  - More and more areas are no longer suitable for control sites
- Using the results of an individual year are risky because of the uncertainty within the statical approach, the precipitation measurements and conditions at the individual sites.
  - More suitable to look at the trend in the average/median

NCAR WRF-WxMod

- Provides a physically based approach to estimating changes in precipitation within a storm for cloud seeding operations.

- Uses High Resolution WRF data (1.8km for IPC) to identify atmospheric conditions and determines if they are suitable for cloud seeding, either by aircraft or ground generator.

- Two different modes operation
  - Case Calling to support operations
  - Benefit estimates

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- Uses High Resolution WRF data (1.8km for IPC) to identify atmospheric conditions and determines if they are suitable for cloud seeding, either by aircraft or ground generator.
- Two different modes operation
  - Case Calling to support operations
    - Control WRF run is ingested by the WRF-WxMod Case-calling Algorithm
      - Algorithm identifies cases for cloud seeding that have the right parameters for successful seeding (i.e. temperature, moisture, winds (speed & direction), etc..)
      - Provides text files of potential seeding events and time series plots of seeding criteria (membership function and meteorological condition values)
    - Has been proven very effective in operations
    - Was used during the 2017 SNOWIE experiment and verified against meteorological conditions reported by both seeding and research aircraft as well as Doppler on Wheels radar systems

Example: WRF-WxMod Output (partial)

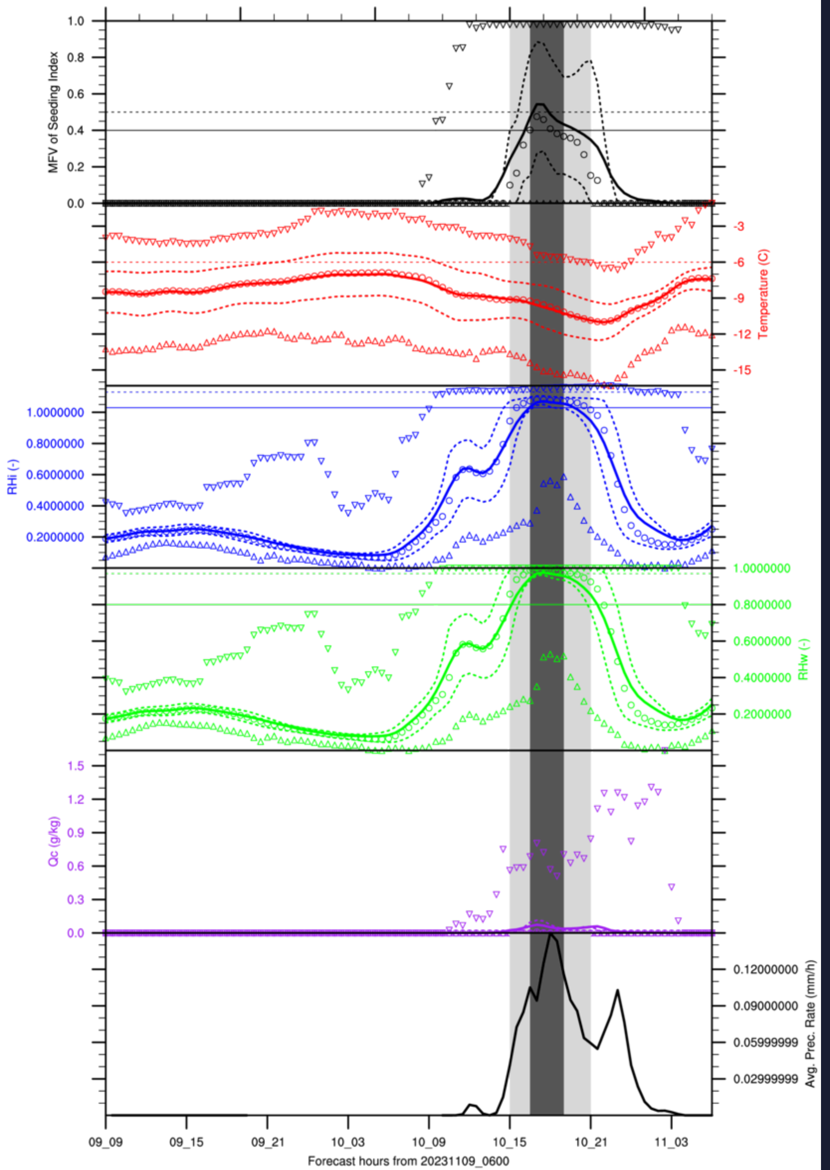
No ground seeding for PAY

For PAY, number of suitable airborne seeding period[s]: 1

Period 1 ranges from 2023-11-10_13:00:00 to 2023-11-10_21:30:00

Best case of period 1 seeds from 2023-11-10_15:30:00 to 2023-11-10_18:00:00 at track 4B

No higher airborne seeding for PAY



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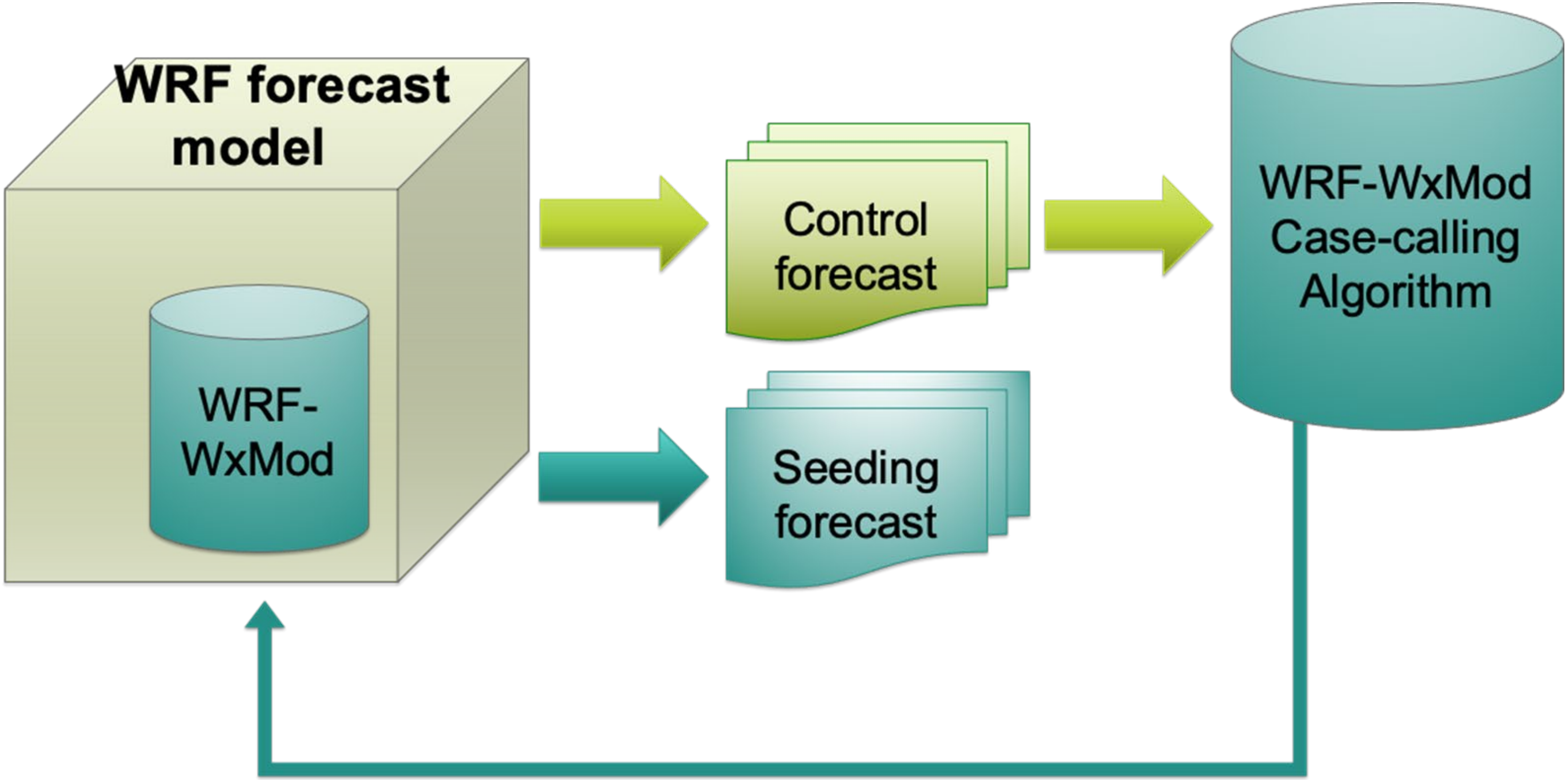
- Uses High Resolution WRF data (1.8km for IPC) to identify atmospheric conditions and determines if they are suitable for cloud seeding, either by aircraft or ground generator
- Two different modes operation
  - Case Calling to support operations
  - Benefit estimates
    - Control WRF run is ingested by the WRF-WxMod Case-calling Algorithm
      - Control WRF run simulates natural precipitation amounts
      - Seeded WRF tun simulates precipitation amounts in the basin if seeding activities were conducted
      - "Seed – Control" provides a simulated seeding effect
    - WRF-WxMod takes identified periods where seeding conditions are favorable for seeding and simulates seeding activities resulting precipitation as if seeded.
      - Run the actual seeding activities with reanalysis data to complete an annual seeding estimate

NCAR WRF-WxMod



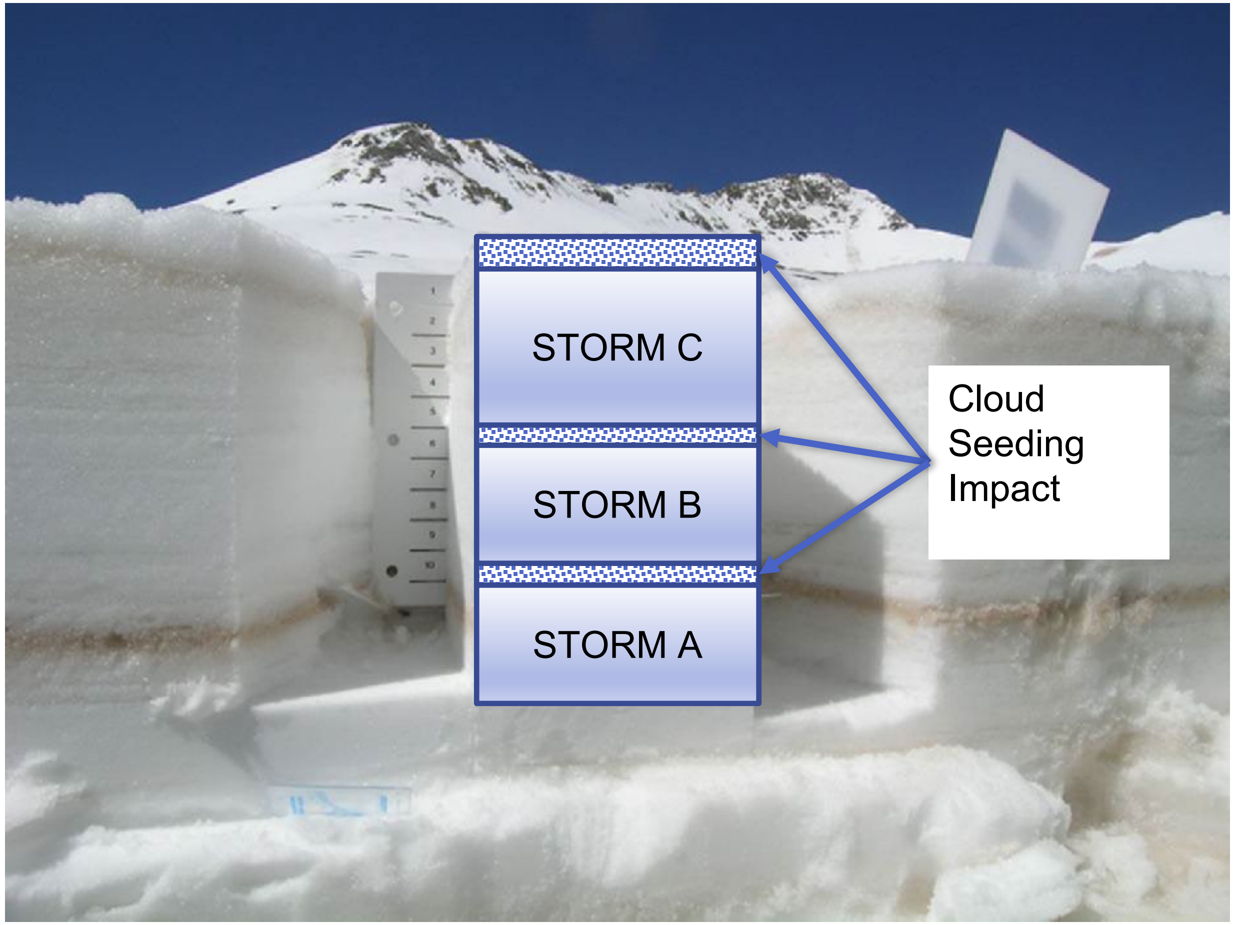
Monitoring & Analysis

Analysis | Hydrology

Frank Gariglio, *Operations Hydrology Leader* | Idaho Power Company

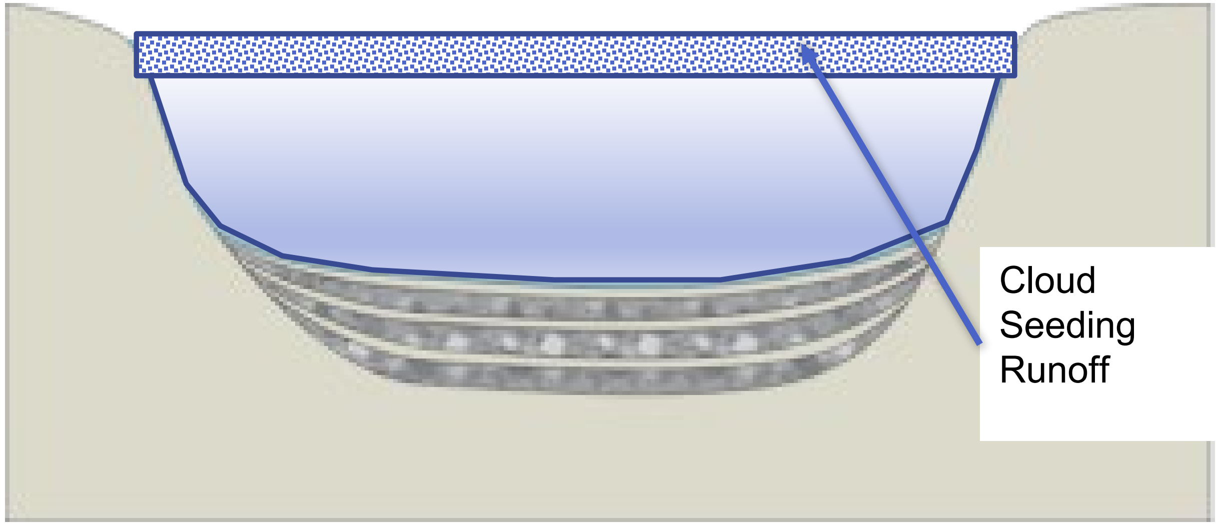
In a Perfect World…

- Generally, models only “see” what has occurred
- Ideally, we would be able to perfectly partition the snowfall that would have occurred without cloud seeding from what occurred due to cloud seeding
- If we could we could go from this…



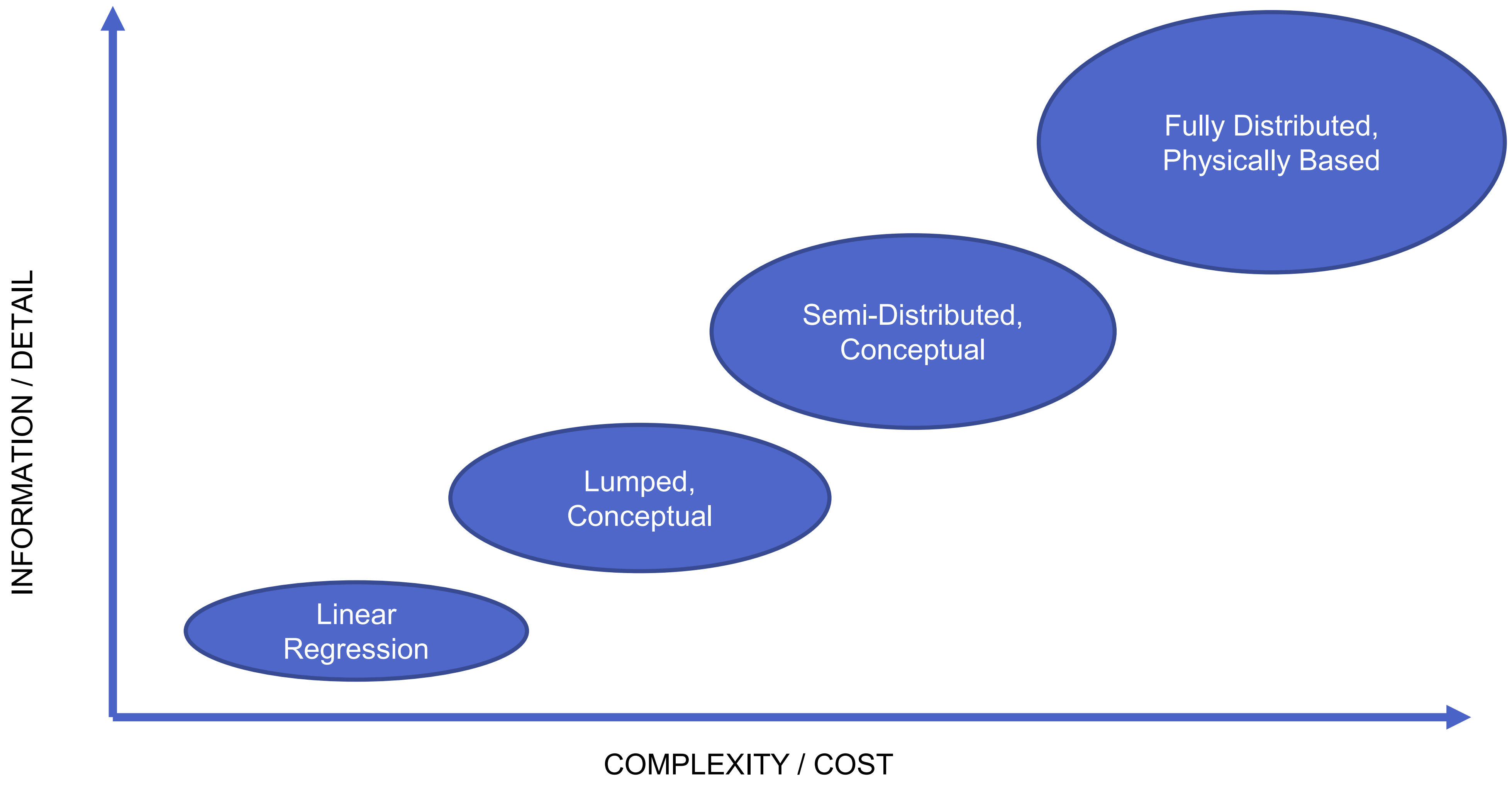
In a Perfect World…

- To this…
- Like the snowpack example, our models are typically set up to "see" what has occurred, making it difficult to separate out the cloud seeding contribution
- Ultimately, it is often desired to develop some estimate of how the cloud seeding precipitation benefit impacts streamflow and water supply



Know the Needs

Hydrologic Modeling Options



Example Data Requirements

- Regression
  - Input – Observed SWE
  - Output – Seasonal Water Supply Volume
- Pros
  - Simple
  - Computationally inexpensive (Excel®)
  - Readily understood by stakeholders
- Cons
  - Little to no spatial or temporal information
  - Marginal predictive capabilities
  - Could be influenced by other factors
  - Difficult to ask "What If" questions

Example Data Requirements

- Semi-Distributed, Lumped Parameter Model (e.g. NWS River Forecasting System)
  - Inputs – Mean Areal Temperature, Mean Areal Precipitation
  - Outputs – general area-averaged snow & soil states, sub-basin hydrograph

- Pros
  - Related to physical processes
  - Computationally inexpensive
  - Intuitive

- Cons
  - Calibrations can be “over-tuned” without physical justification
  - Sub-basin dynamics are not well-represented
  - Difficult to ask sophisticated “What If” questions
  - Pushing models outside of calibrated ranges can be worrisome

Example Data Requirements

- Fully Distributed Physically Based Model (e.g. WRF-Hydro)
  - Inputs – Gridded suite of meteorologic variables (temperature, wind speed, humidity, radiation fluxes, precipitation, etc.)
  - Outputs – Gridded snowpack, soil, land surface, streamflow, and flux variables (hundreds of output parameters)
- Pros
  - Physically based
  - Highly granular in space and time
  - Well calibrated models can be widely applied and forced under different scenarios (climate change, seeding program changes, etc.)
- Cons
  - Challenging to gather enough observed data for a good calibration
  - Computationally expensive (high performance computers)
  - Availability of forcing data
  - Specialized skillsets to develop, maintain, and run these models

Final Thoughts

- Let the program needs and questions drive the model and process selection
- Don’t build a Ferrari if a Camry will do the job
- Consider the uncertainties in the modeling chain, and whether the tools can reasonably show confidence in the program impacts

Monitoring & Analysis

Analysis | Regulation

David Hoekema, *Hydrologist* | Idaho Department of Water Resources

IDAHO Department of Water Resources

IDAHO DEPARTMENT OF WATER RESOURCES

Cloud Seeding Regulation: Where does the water go?

David Hoekema, Hydrologist, IDWR

11/15/2023

What is the goal of Cloud-Seeding?

- Increase general water supply
- Irrigation Supply
- Hydropower Generation
- Aquifer Recharge
- Increase Baseflows for habitat

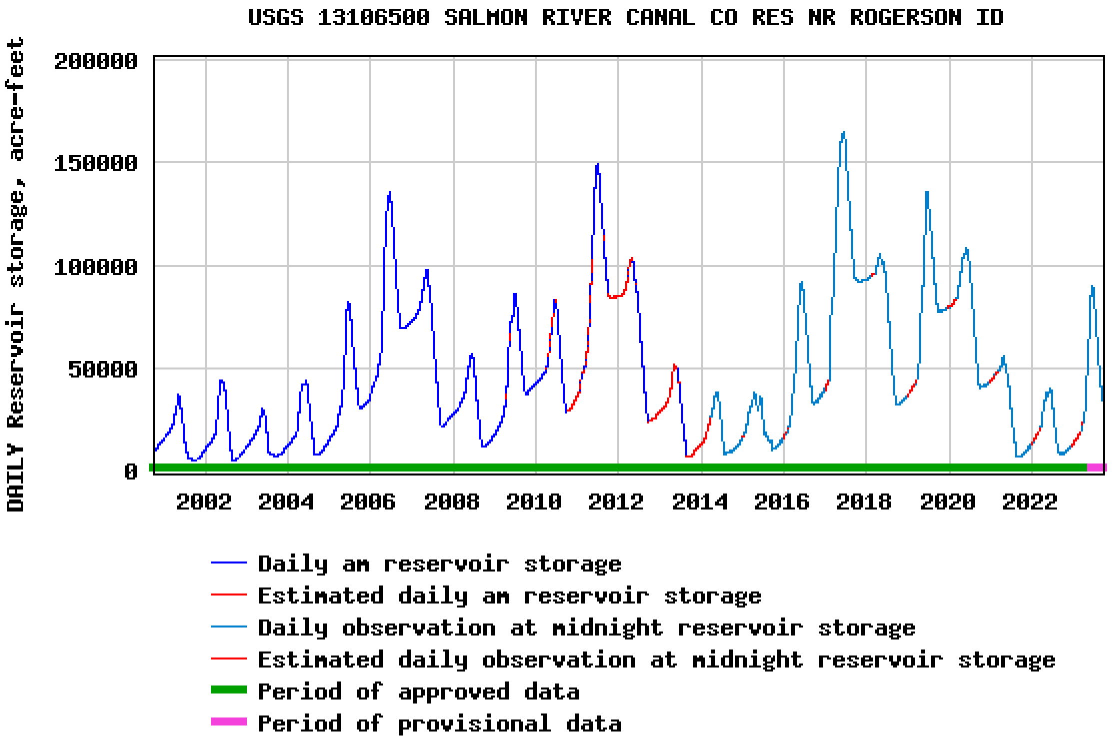
Where Does the Water Go?

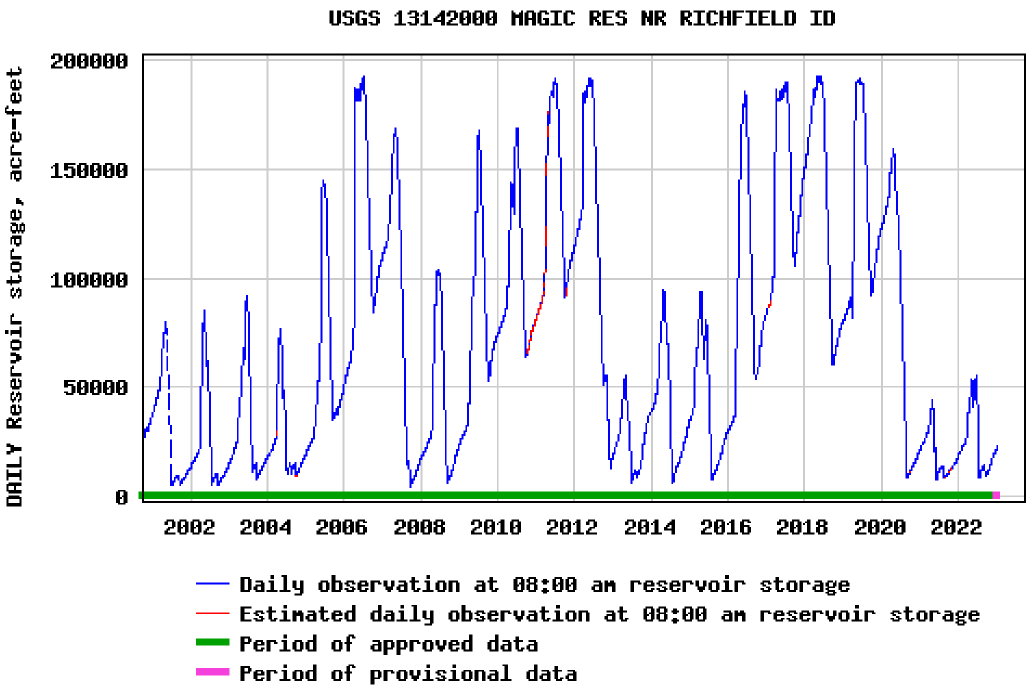
- Accounting for Uncertainty
- View historic Hydrographs
- Diversions
- Hydropower
- Recharge

Accounting for Uncertainty?

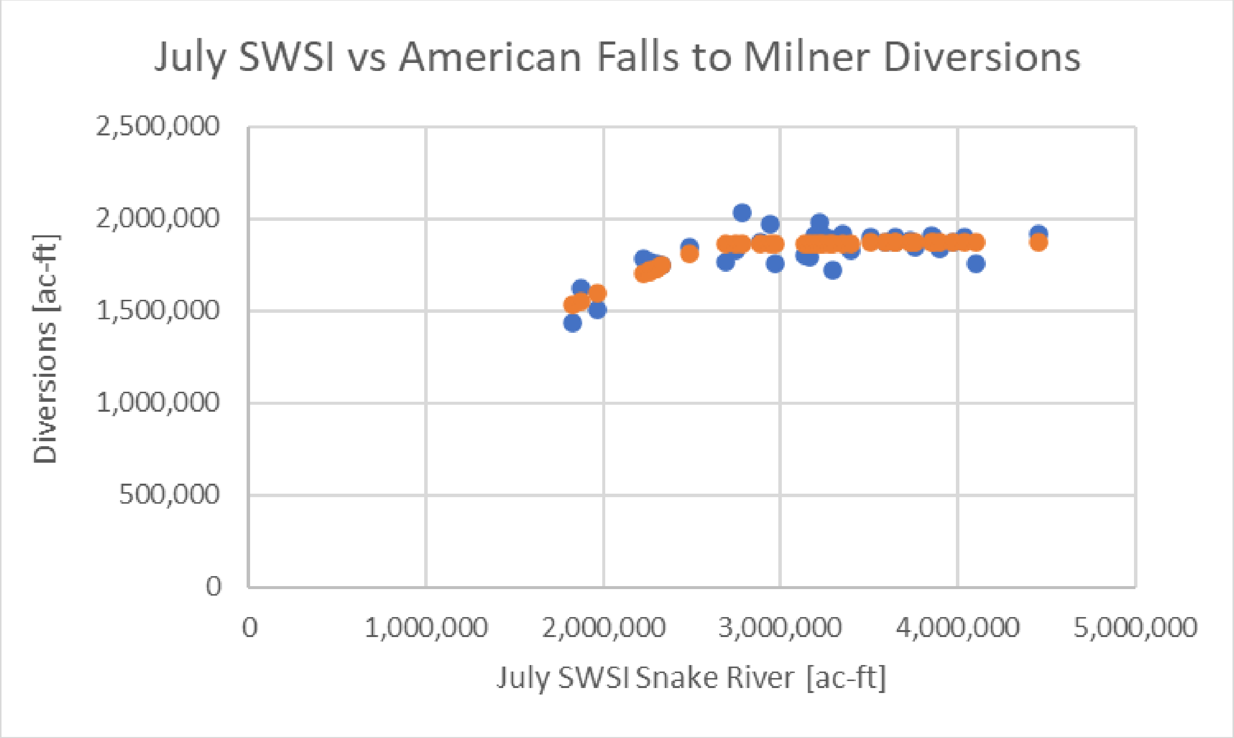
- Change in Streamflow and/or change in precipitation
  - Model a range of precipitation/streamflow changes
  - Consistent percent change over multiple years
  - How does the hydrograph change?

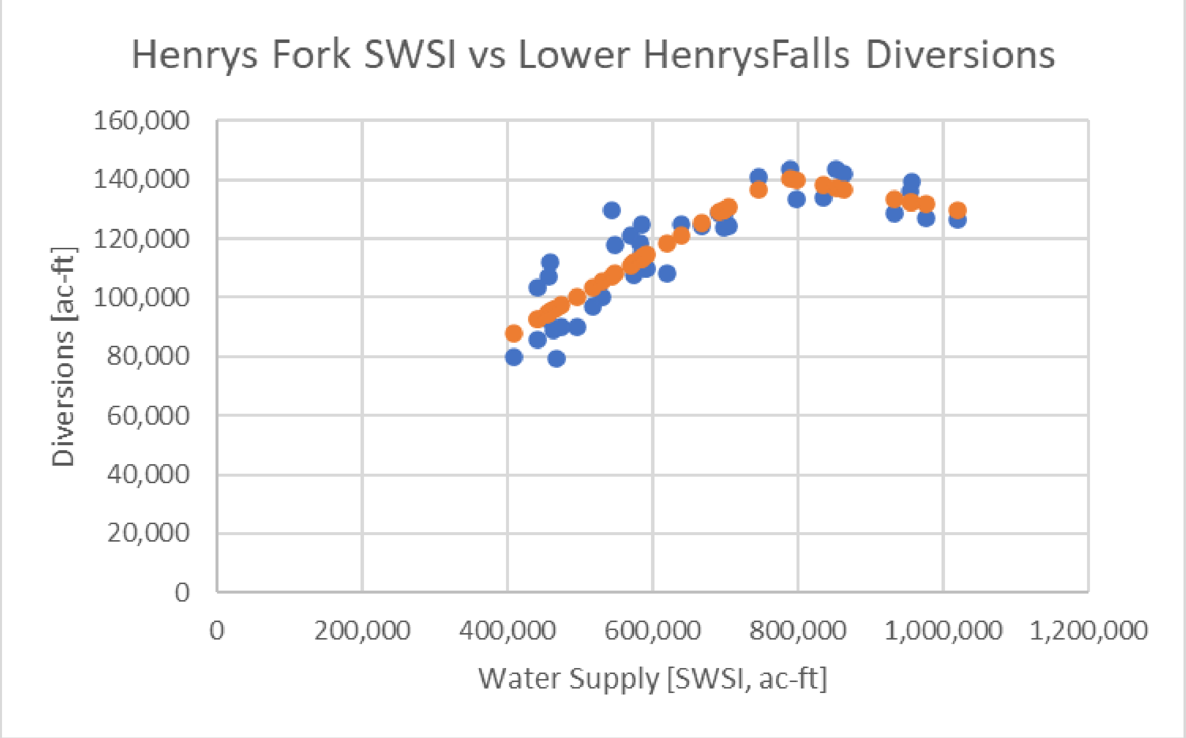
View Hydrographs





Diversions





Hoekema, D. J., & Sridhar, V. (2011). Relating climatic attributes and water resources allocation: A study using surface water supply and soil moisture indices in the Snake River basin, Idaho. *Water Resources Research*, *47*(7).

Hydropower: Run-of-the-River vs Storage

- Run-of-the-River, runoff may exceed capacity when and where does excess capacity occur

- Storage—increases in both cfs and head need to be considered.

- Is Storage for Hydro, Irrigation, other use?

Recharge

- Groundwater Responses should be considered if changing diversions results in significant increase in incidental recharge or managed recharge occurs

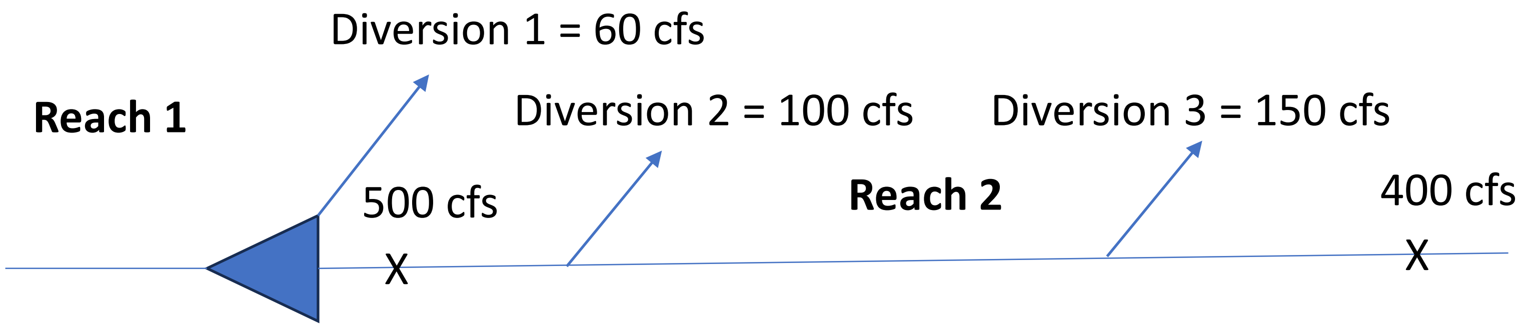
- Response Functions can be used if aquifer is modeled as a single layer unconfined aquifer.

Johnson, G. S., Sullivan, W. H., Cosgrove, D. M., & Schmidt, R. D. (1999). RECHARGE OF THE SNAKE RWER PLAIN AQUIFER: TRANSITIONING FROM INCIDENTAL TO MANAGED 1. *JAWRA Journal of the American Water Resources Association*, *35*(1), 123-131.

How do add water

- By reach were seeding occurs
- Percent increase = % of precipitation
- Percent increase comes from calibrated hydrologic model

Reach Gain



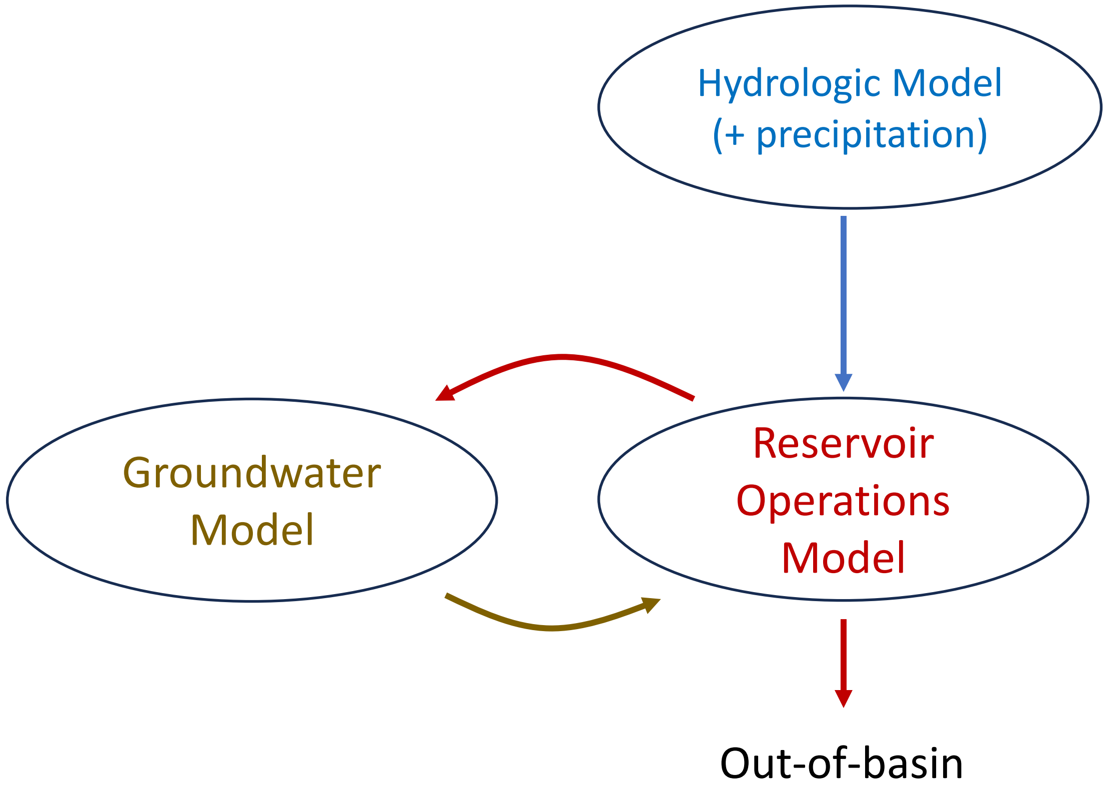
Δstorage = -300 ac-ft or -150 cfs

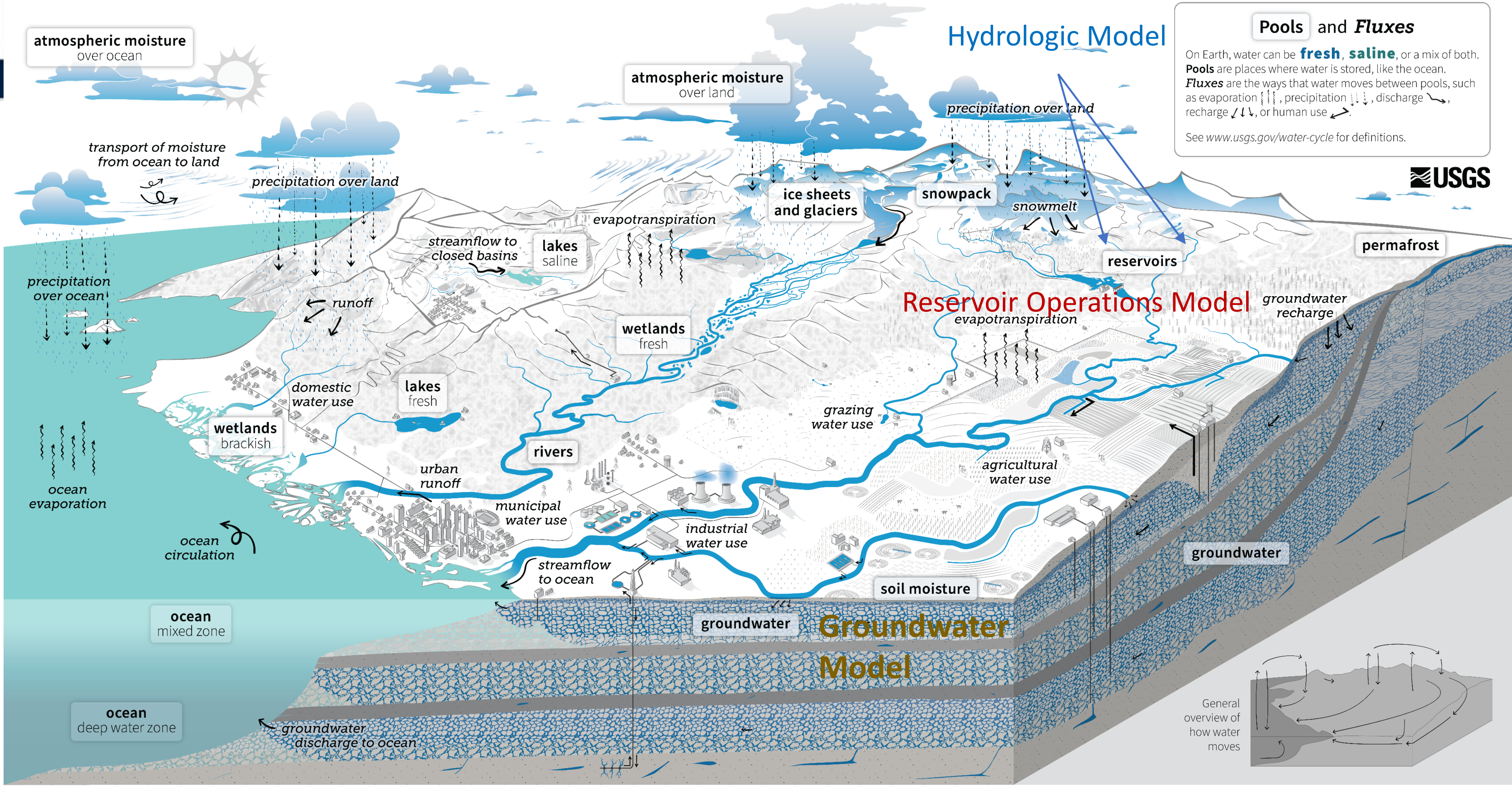
Reach Gain = Downstream – Upstream + Diversion + Δstorage

Reach 1 = 500 cfs – 0 cfs + 60 cfs +(-150 cfs) = 410 cfs

Reach 2 = 400 cfs – 500 cfs + 250 + 0 cfs = 150 cfs

A Possible Modeling Framework





The Water Cycle

The water cycle describes where water is found on Earth and how it moves. Water can be stored in the atmosphere, on Earth's surface, or below the ground. It can be in a liquid, solid, or gaseous state. Water moves between the places it is stored at large scales and at very small scales. Water moves naturally and because of human interaction, both of which affect where water is stored, how it moves, and how clean it is.

Liquid water can be fresh, saline (salty), or a mix (brackish). Ninety-six percent of all water is saline and stored in **oceans**. Places like the ocean, where water is stored, are called **pools**. On land, saline water is stored in **saline lakes**, whereas fresh water is stored in liquid form in **freshwater lakes**, artificial **reservoirs**, **rivers**, **wetlands**, and in soil as **soil moisture**. Deeper underground, liquid water is stored as **groundwater** in aquifers, within the cracks and pores of rock. The solid, frozen form of water is stored in **ice sheets**, **glaciers**, and **snowpack** at high elevations or near the Earth's poles. Frozen water is also found in the soil as **permafrost**. Water vapor, the gaseous form of water, is stored as **atmospheric moisture** over the ocean and land.

As it moves, water can transform into a liquid, a solid, or a gas. The different ways in which water moves between pools are known as **fluxes**. **Circulation** mixes water in the oceans and transports water vapor in the atmosphere. Water moves between the atmosphere and the Earth's surface through **evaporation**, **evapotranspiration**, and **precipitation**. Water moves across the land surface through **snowmelt**, **runoff**, and **streamflow**. Through infiltration and **groundwater recharge**, water moves into the ground. When underground, groundwater flows within aquifers and can return to the surface through **springs** or from natural **groundwater discharge** into rivers and oceans.

Humans alter the water cycle. We redirect rivers, build dams to store water, and drain water from wetlands for development. We use water from rivers, lakes, reservoirs, and groundwater aquifers. We use that water (1) to supply our **homes** and **communities**; (2) for **agricultural** irrigation and **grazing** livestock; and (3) in **industrial** activities like thermoelectric power generation, mining, and aquaculture. The amount of available water depends on how much water is in each pool (water quantity). Water availability also depends on when and how fast water moves (water timing), how much water is used (water use), and how clean the water is (water quality).

Human activities affect **water quality**. In agricultural and urban areas, irrigation and precipitation wash fertilizers and pesticides into rivers and groundwater. Power plants and factories return heated and contaminated water to rivers. Runoff carries chemicals, sediment, and sewage into rivers and lakes. Downstream from these types of sources, contaminated water can cause harmful algal blooms, spread diseases, and harm habitats. **Climate change** is also affecting the water cycle. It affects water quality, quantity, timing, and use. Climate change is also causing ocean acidification, sea level rise, and extreme weather. Understanding these impacts can allow progress toward sustainable water use.

Questions?

Contact:

David Hoekema
Hydrologist, IDWR
714 697-3203
David.Hoekema@idwr.Idaho.gov

Current Programs

North Dakota | Colorado River Basin | California

NAWMC North American Weather Modification Council

North Dakota

Darin Langerud, *Director*
North Dakota Atmospheric Research Board

WEATHER MODIFICATION IN ND

Darin Langerud, Director, NDARB

NORTH Dakota
Be Legendary.™

CLOUD SEEDING IN NORTH DAKOTA

- First seeding attempts in 1948
- Project areas established, ground-based seeding in 1951
- Aircraft become preferred seeding method in 1960
- State Legislature creates the ND Weather Modification Board in 1975 to provide regulatory functions, operational support, conduct research and evaluations and provide State cost-share funding

NORTH DAKOTA PILOT PROJECT

- NDPP conducted from 1969-72
  - Randomized (3:1) proof of concept cloud seeding project in McKenzie County. Mountrail and Ward included in 1972
    - 67 rain gauges, radar observations
- Findings:
  - Statistically significant increases in (1) the number of rain events, (2) average rainfall per event, and (3) total rainfall in the target area (~10%). Published in AMS Journal of Applied Meteorology by Dennis *et. al*, 1975

NORTH DAKOTA PILOT PROJECT

- Findings:
  - Analysis of cloud seeding on hail indicated the ratio of average rainfall to hail energy was greater on seeded days and crop-hail insurance losses lower. Due to smaller sample size, results weren’t statistically significant. Published in AMS JAM by Miller *et. al*, 1975.

PROGRAM SETUP

- Governed through N.D.C.C. Chapter 61-04.1
- County participation through petition or public vote
  - Creates 10-year authority, or
  - Temporary (up to 4 year) authority created via public hearing and resolution of the county commission
- Authority must be renewed every 5 years

PROGRAM SETUP

- County Comm. appoints 5 members to “Weather Modification Authority”, which oversees project
- Authority contracts with State to provide cloud seeding operations
- Authorities provide 66% of ops funding, State 34%

PROGRAM SETUP

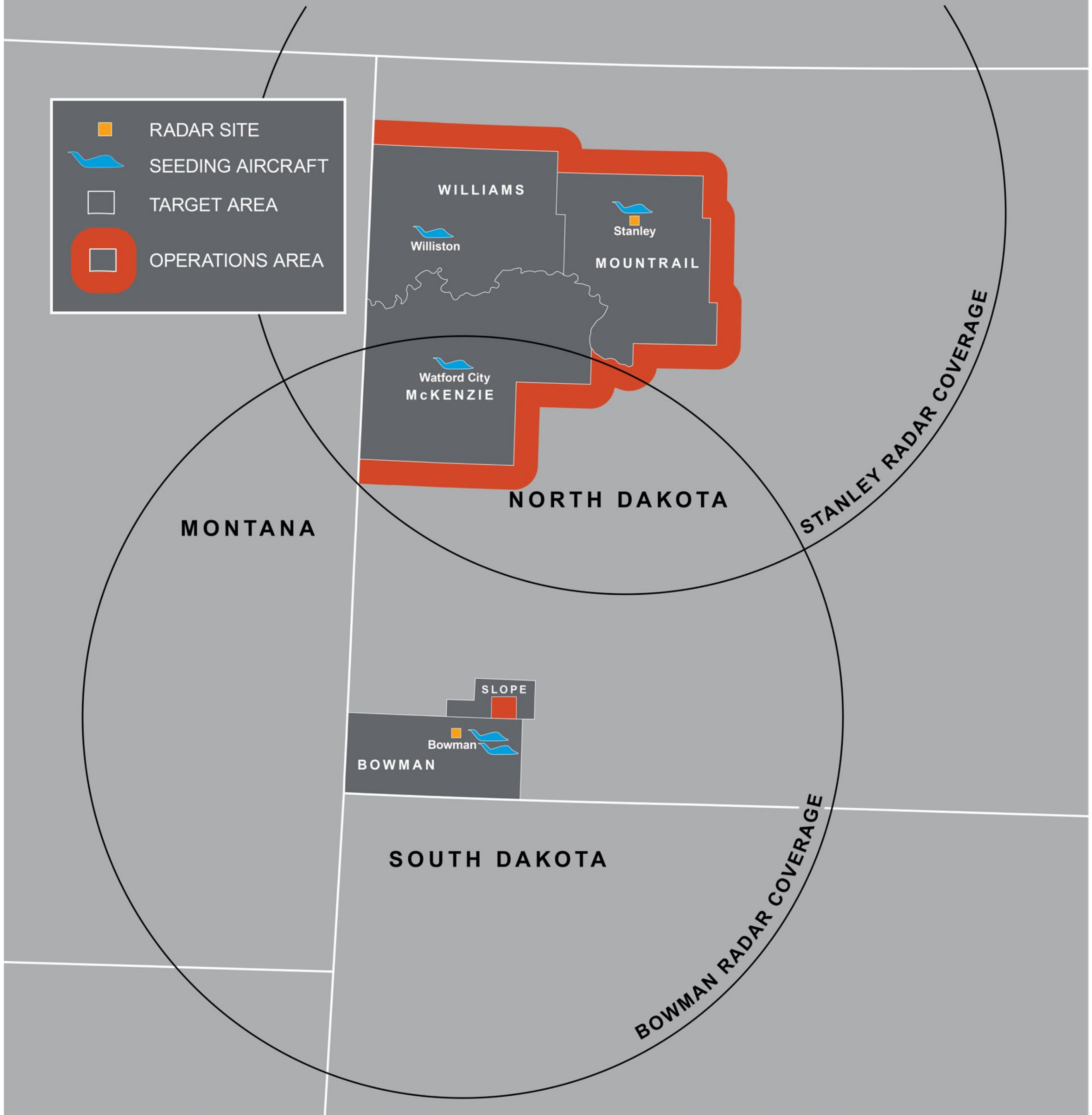
- Permits are issued annually
  - Require public notice and 20-day comment period
  - ARB must approve prior to issuance to contractor
- Contractors conducting seeding operations must be state licensed

ND CLOUD MODIFICATION PROJECT

- NDCMP goals are hail suppression and rain enhancement
- NDCMP is primarily designed to benefit agricultural production
- Operations from June 1 – August 31 each year
  - Extension into September is optional depending on crop conditions and harvest progress
- Convective clouds are seeded by aircraft in the updraft below cloud base, or directly at cloud top
- Glaciogenic seeding materials and methods are employed

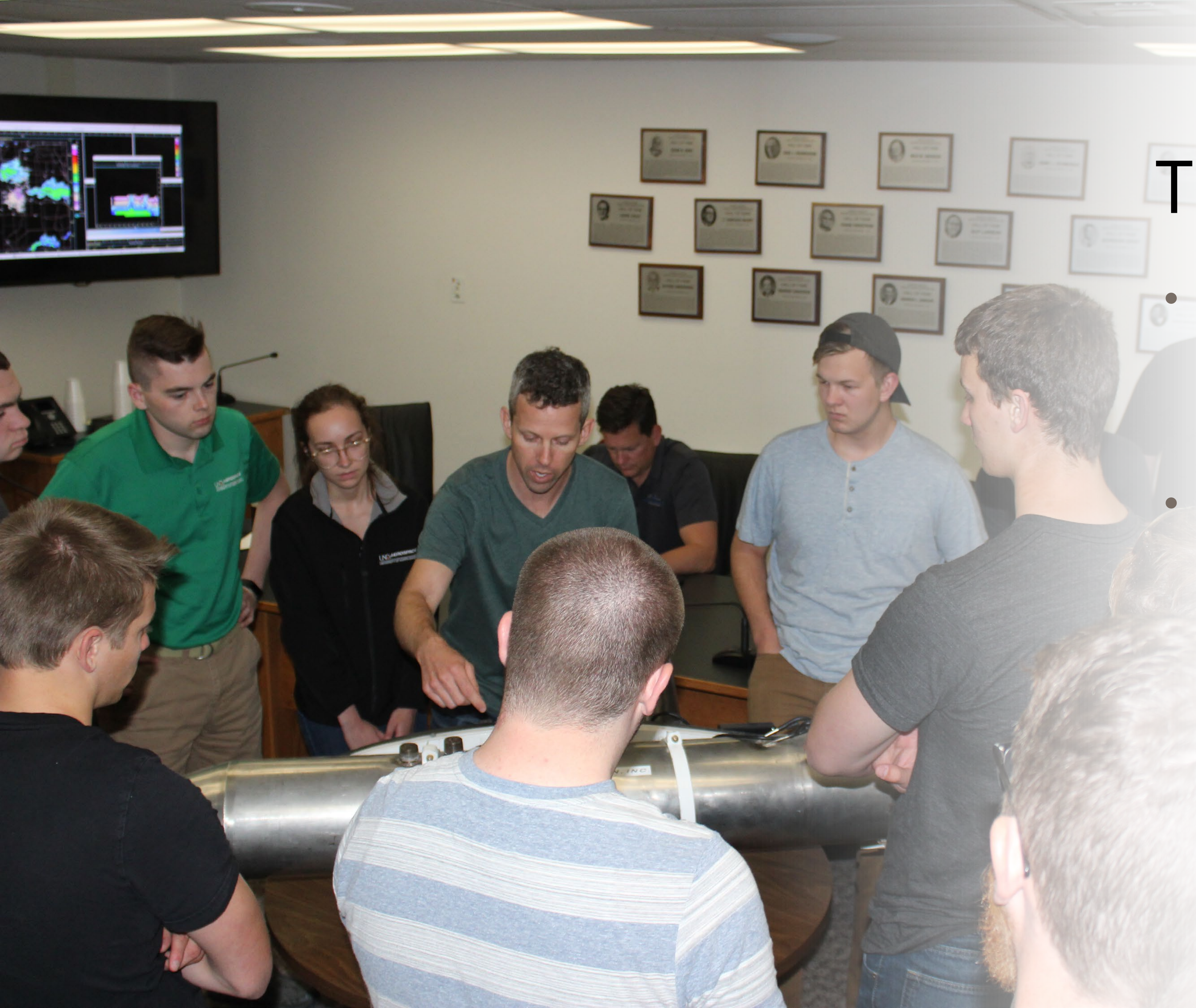
2023 NDCMP

4.1 M acres, or 6,400 mi^2



INTERN PROGRAMS

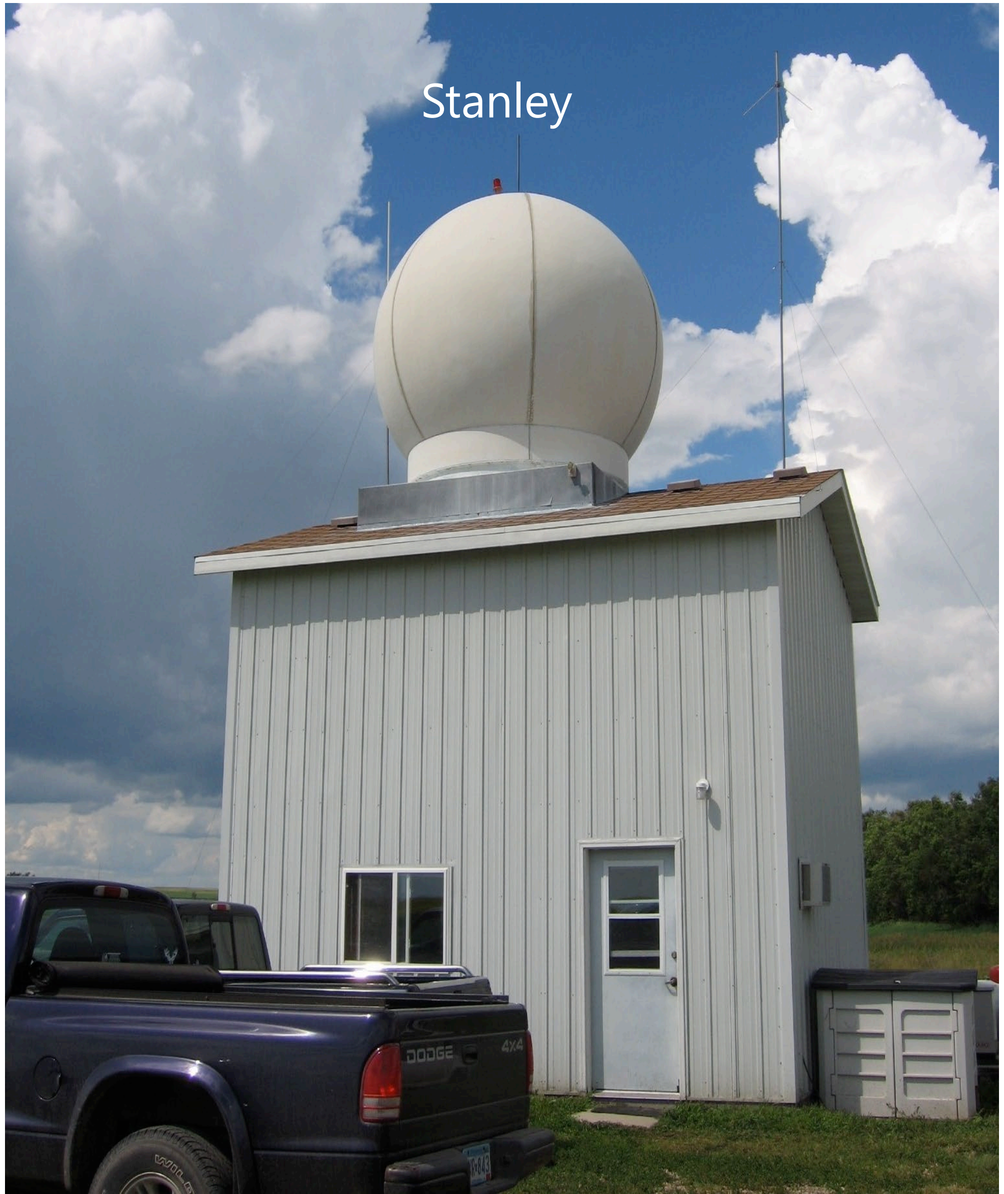
- ARB & UND MOU to provide Intern Pilot training since 1975
  - Since then, 407 pilot interns have participated
- ARB's meteorology intern program began in 1996 and has provided training for 73 students



TRAINING

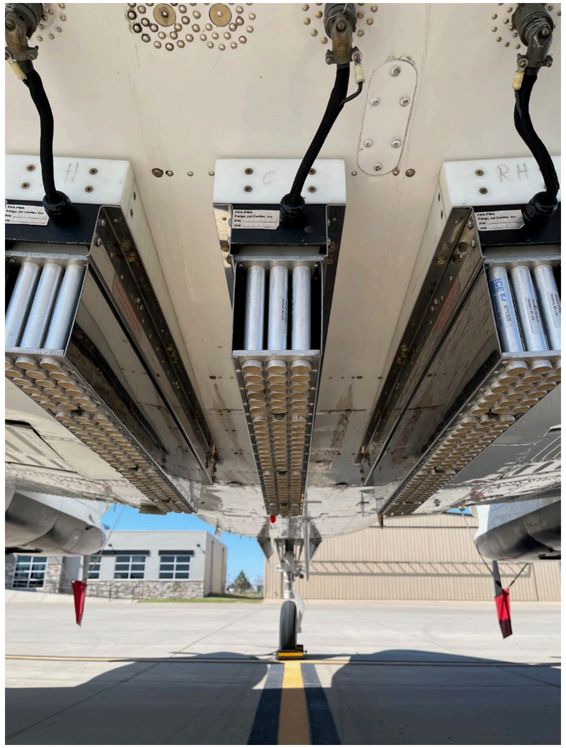
- NDCMP personnel participate in a pre-project ground school prior to startup
- Topics covered include:
  - Safety
  - Seeding operations
  - Forecasting
  - Scientific concepts
  - Public relations
  - Administration

NDCMP RADARS



NDCMP AIRCRAFT

- Piper Seneca II
  - Base seeding
- Beechcraft King Air C90
  - Top seeding



NDCMP SEEDING EQUIPMENT

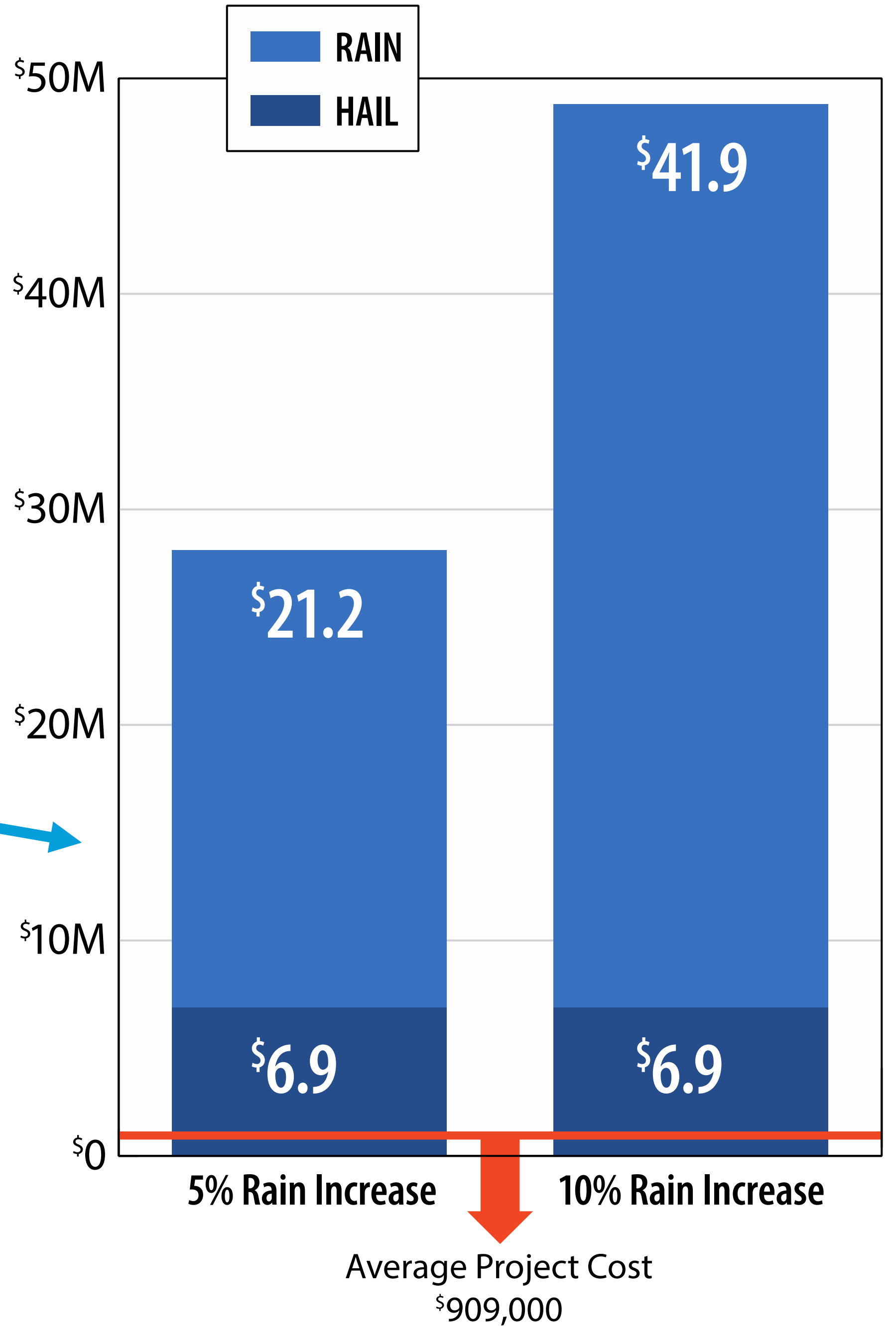
INDEPENDENT EVALUATIONS

- Crop insurance analysis over a 13-year period found **45% lower crop-hail losses** in seeded counties vs. upwind control (JAM, Smith *et al.*, 1997)
  - Prior study of crop insurance in 1987 found 43.5% reduction
  - Nodak Insurance study found 43% lower incidence of hail claims in seeded counties versus unseeded ND counties (K. Pifer, personal comm.,1995)
- Several rainfall studies using varied datasets have indicated percentage increases from the low single digits to the low teens, with **typical results in the 5-10% range** (Eddy & Cooter, 1979, Johnson, 1985, Smith *et al.*, 2004, Wise, 2005)

INDEPENDENT EVALUATIONS

- Wheat yields were found to be **5.9% higher** on average in the seeded counties versus an adjacent control area (JAM, Smith *et al.*, 1992)
- Downwind effects show a slight ***increase*** in rainfall (Wise, 2005), which is consistent with findings from other programs in the U.S. and around the world (DeFelice *et al.,* 2014)

Economic Impacts of Cloud Seeding on Agricultural Crops in ND



Total combined benefits of **$28.1 Million** with a Benefit to Cost ratio of 31 to 1.

Total combined benefits of **$48.8 million** with a Benefit to Cost ratio of 53 to 1.

Bangsund & Hodur, (2019) NDSU Agribusiness and Applied Economics

INDEPENDENT EVALUATIONS

- Knowles and Skidmore (2021) analyzed results of wheat and barley yields from 1989-2018 in the NDCMP seeded and adjacent unseeded areas
- Results of the crop analysis showed annual wheat yields were higher by 3.87 bushels/acre, statistically significant at 0.05
- Crop insurance loss ratios were lower in the seeded areas
- Economic benefits exceeded costs in every year, with an average annual benefit-to-cost ratio exceeding 36 to 1
  - *Cloud Seeding Crops and Yields: Evaluation of the North Dakota Cloud Modification Project. AMS Weather, Climate and Society. https://doi.org/10.1175/WCAS-D-21-0010.1*

NORTH DAKOTA
DWR

THANK YOU

701.328.2750

dwr@nd.gov

dwr.nd.gov

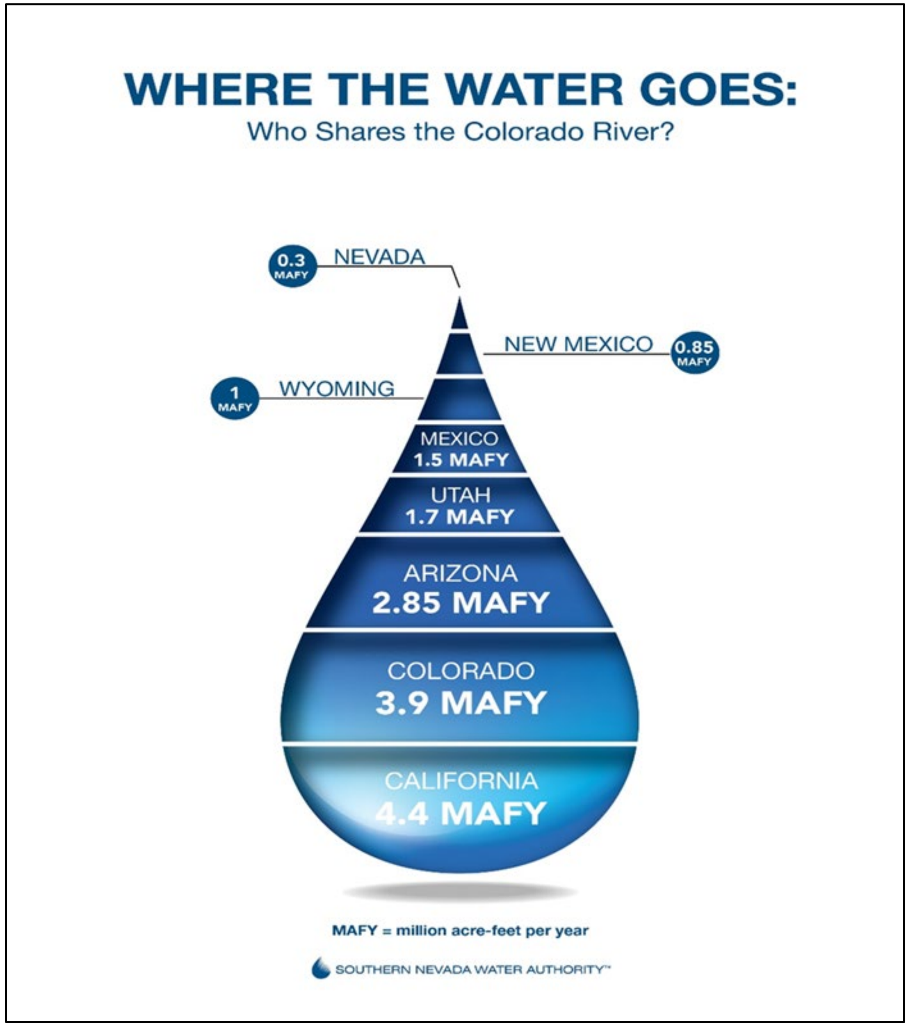
/NDWaterResources

NORTH Dakota | Water Resources
Be Legendary.

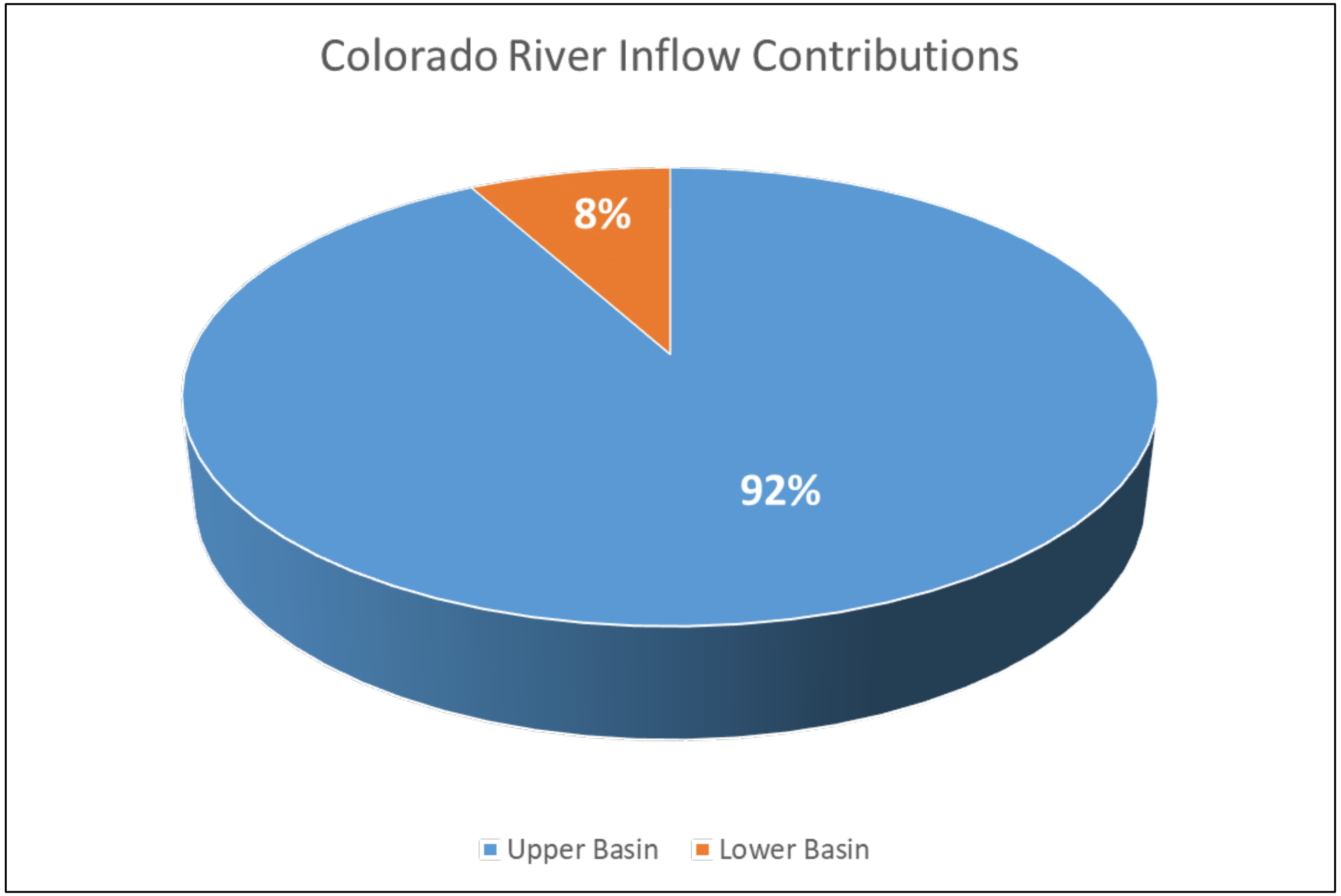
Colorado River Basin

Sean Collier, *Hydrologist*
Southern Nevada Water Authority

Colorado River Basin

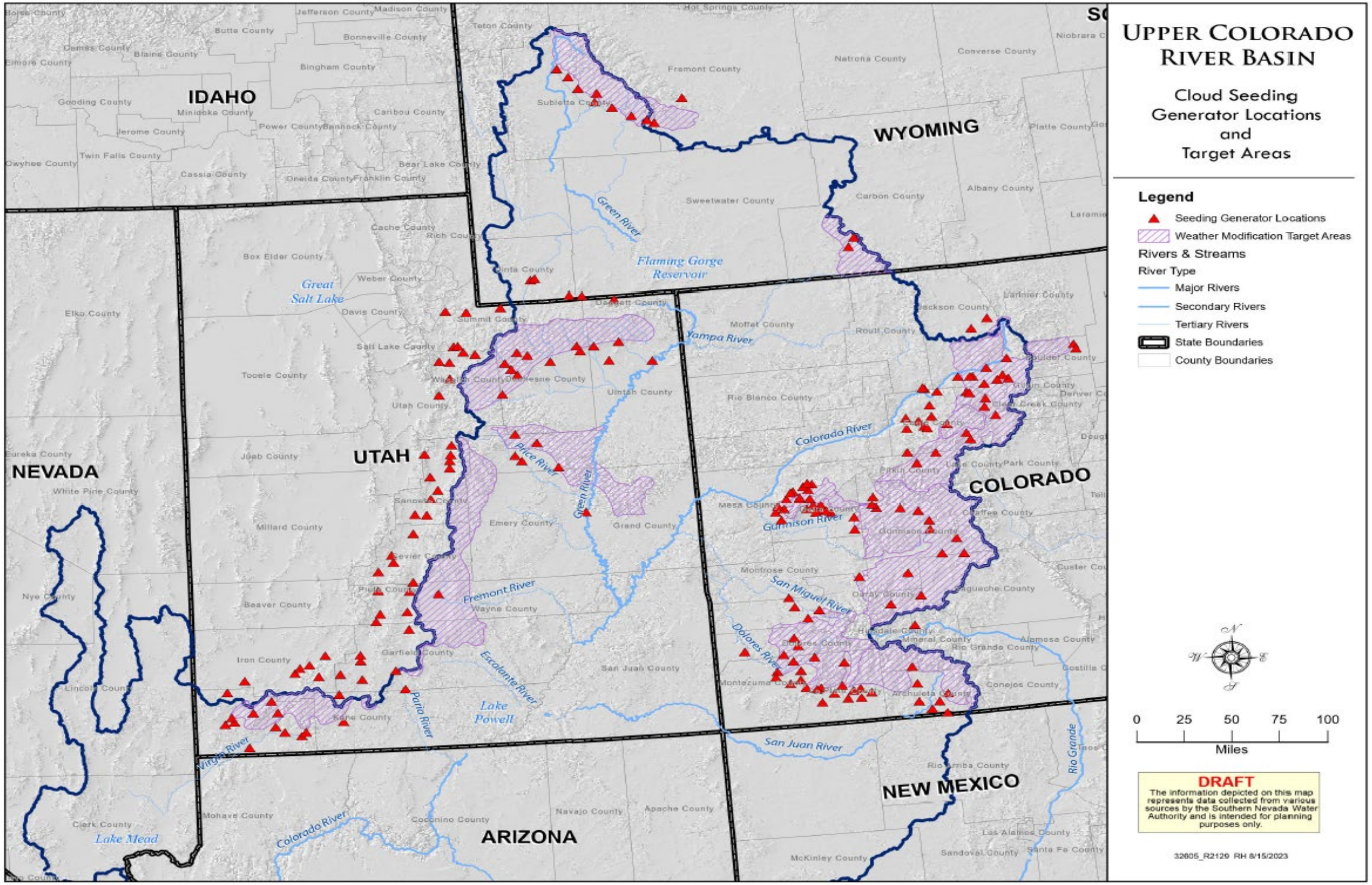


Inflows into the Colorado River



Cloud Seeding in the Colorado River Basin

- Central Arizona Water Conservation District (CAWCD)
- Southern Nevada Water Authority (SNWA)
- Six Agency Committee of California (SAC)
- New Mexico Interstate Stream Commission (NIMISC)
- Wyoming Water Development Office (WWDO)
- Colorado Water Conservation Board (CWCB)
- Utah Division of Water Resources (UDWRe)



Highlights of Reclamation Grant

- $2.4 million that can be spent over 2 years (through CY 2024)
- Source of funds Bureau of Reclamation Lower Colorado River Operations Program (LCROP)
  - Money appropriated for operations at Boulder City Office of Reclamation
  - Will be in addition to the Programmatic Agreement funds committed in 2018 Agreement

NOTICE OF AUTHORIZATION

1. DATE ISSUED MM/DD/YYYY 03/01/2023

1a. SUPERSEDES AWARD NOTICE dated except that any additions or restrictions previously imposed remain in effect unless specifically rescinded

2. CFDA NO. 15.560 - SECURE Water Act – Research Agreements

3. ASSISTANCE TYPE Project Grant

4. GRANT NO. R23AP00118-00 Originating MCA #

4a. FAIN R23AP00118

5. TYPE OF AWARD Other

5a. ACTION TYPE New

6. PROJECT PERIOD MM/DD/YYYY From 04/01/2023 Through MM/DD/YYYY 01/31/2025

7. BUDGET PERIOD MM/DD/YYYY From 04/01/2023 Through MM/DD/YYYY 01/31/2025

NOTICE OF AWARD

AUTHORIZATION (Legislation/Regulations)

Public Law 111-11, Omnibus Public Land Management Act of 2009, Subtitle F, Secure Water, Section 9509.

8. TITLE OF PROJECT (OR PROGRAM) Colorado River Basin Cloud Seeding

9a. GRANTEE NAME AND ADDRESS
SOUTHERN NEVADA WATER AUTHORITY
1001 S Valley View Blvd
Las Vegas, NV, 89107-4447

9b. GRANTEE PROJECT DIRECTOR
Kathy Flanagan
1001 South Valley View Boulevard
Las Vegas, NV, 89107-4447
Phone: [NO PHONE RECORD]

10a. GRANTEE AUTHORIZING OFFICIAL
Mr. John Entsminger
1001 South Valley View Boulevard
Las Vegas, NV, 89107-4447
Phone: 702-875-7080

10b. FEDERAL PROJECT OFFICER
Mrs. Leslie Walker
P.O. Box 61470
LCB-10101
Boulder City, NV, 89006
Phone: 702-293-8369

ALL AMOUNTS ARE SHOWN IN USD

11. APPROVED BUDGET (Excludes Direct Assistance)
I Financial Assistance from the Federal Awarding Agency Only
II Total project costs including grant funds and all other financial participation II

a. Salaries and Wages	$	0.00
b. Fringe Benefits	$	0.00
c. Total Personnel Costs	$	0.00
d. Equipment	$	0.00
e. Supplies	$	0.00
f. Travel	$	0.00
g. Construction	$	0.00
h. Other	$	0.00
i. Contractual	$	2,400,000.00
j. TOTAL DIRECT COSTS	$	2,400,000.00
k. INDIRECT COSTS	$	0.00
l. TOTAL APPROVED BUDGET	$	2,400,000.00
m. Federal Share	$	2,400,000.00
n. Non-Federal Share	$	0.00

12. AWARD COMPUTATION

a. Amount of Federal Financial Assistance (from item 11m)	$	2,400,000.00
b. Less Unobligated Balance From Prior Budget Periods	$	0.00
c. Less Cumulative Prior Award(s) This Budget Period	$	0.00
d. AMOUNT OF FINANCIAL ASSISTANCE THIS ACTION	$	2,400,000.00
13. Total Federal Funds Awarded to Date for Project Period	$	2,400,000.00

14. RECOMMENDED FUTURE SUPPORT
(Subject to the availability of funds and satisfactory progress of the project):

YEAR	TOTAL DIRECT COSTS	YEAR	TOTAL DIRECT COSTS
a. 2	$	d. 5	$
b. 3	$	e. 6	$
c. 4	$	f. 7	$

15. PROGRAM INCOME SHALL BE USED IN ACCORD WITH ONE OF THE FOLLOWING ALTERNATIVES:
a. DEDUCTION
b. ADDITIONAL COSTS
c. MATCHING
d. OTHER RESEARCH (Add / Deduct Option)
e. OTHER (See REMARKS)

e

16. THIS AWARD IS BASED ON AN APPLICATION SUBMITTED TO, AND AS APPROVED BY, THE FEDERAL AWARDING AGENCY ON THE ABOVE TITLED PROJECT AND IS SUBJECT TO THE TERMS AND CONDITIONS INCORPORATED EITHER DIRECTLY OR BY REFERENCE IN THE FOLLOWING:
a. The grant program legislation
b. The grant program regulations.
c. This award notice including terms and conditions, if any, noted below under REMARKS.
d. Federal administrative requirements, cost principles and audit requirements applicable to this grant.
In the event there are conflicting or otherwise inconsistent policies applicable to the grant, the above order of precedence shall prevail. Acceptance of the grant terms and conditions is acknowledged by the grantee when funds are drawn or otherwise obtained from the grant payment system.

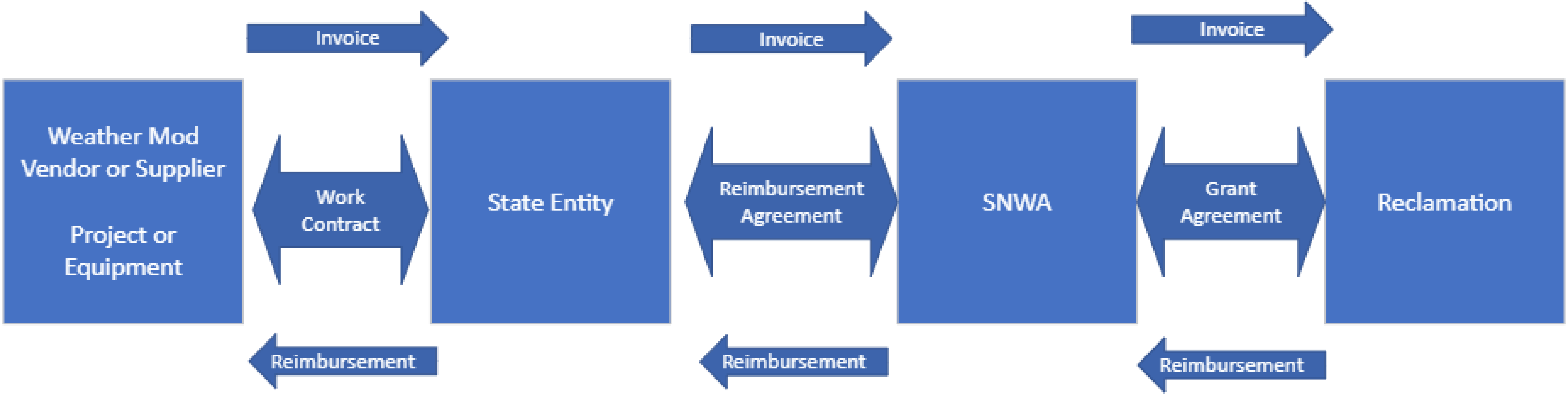
REMARKS (Other Terms and Conditions Attached - ● Yes ○ No)

GRANTS MANAGEMENT OFFICIAL:
Leslie Walker, Grants Management Specialist
P.O. Box 61470
LCB-10101
Boulder City, NV, 89006
Phone: 702-293-8369

17. VENDOR CODE 0070159896 | 18a. UEI SM1CPB4X7E88 | 18b. DUNS 135965650 | 19. CONG. DIST. 01

LINE#	FINANCIAL ACCT	AMT OF FIN ASST	START DATE	END DATE	TAS ACCT	PO LINE DESCRIPTION
1	0051031554-00010	$2,400,000.00	04/01/2023	01/31/2025	0680	Base Agreement

Grant Reimbursement Workflow



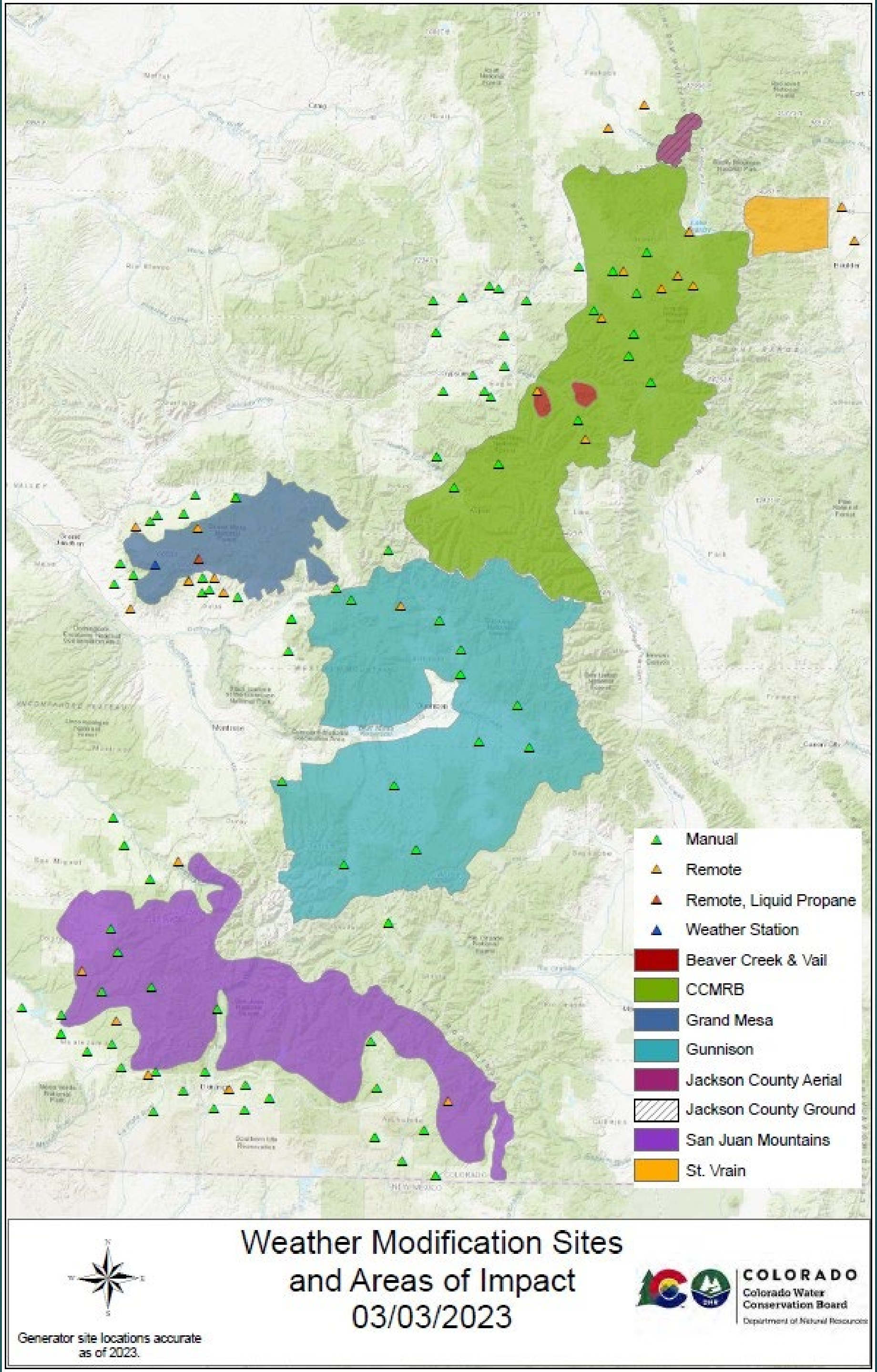
State of Colorado

Andrew Rickert, *Title**
Colorado Water Conservation Board

Colorado Weather Modification Programs

ANDREW RICKERT – CWCB
ERIK SKEIE - CWCB
INTERSTATE, FEDERAL, & WATER INFORMATION SECTION

COLORADO
Colorado Water Conservation Board
Department of Natural Resources


Manual
Remote
Remote, Liquid Propane
Weather Station
Beaver Creek & Vail
CCMRB
Grand Mesa
Gunnison
Jackson County Aerial
Jackson County Ground
San Juan Mountains
St. Vrain
Weather Modification Sites
and Areas of Impact
03/03/2023
Generator site locations accurate
as of 2023.
COLORADO
Colorado Water
Conservation Board
Department of Natural Resources

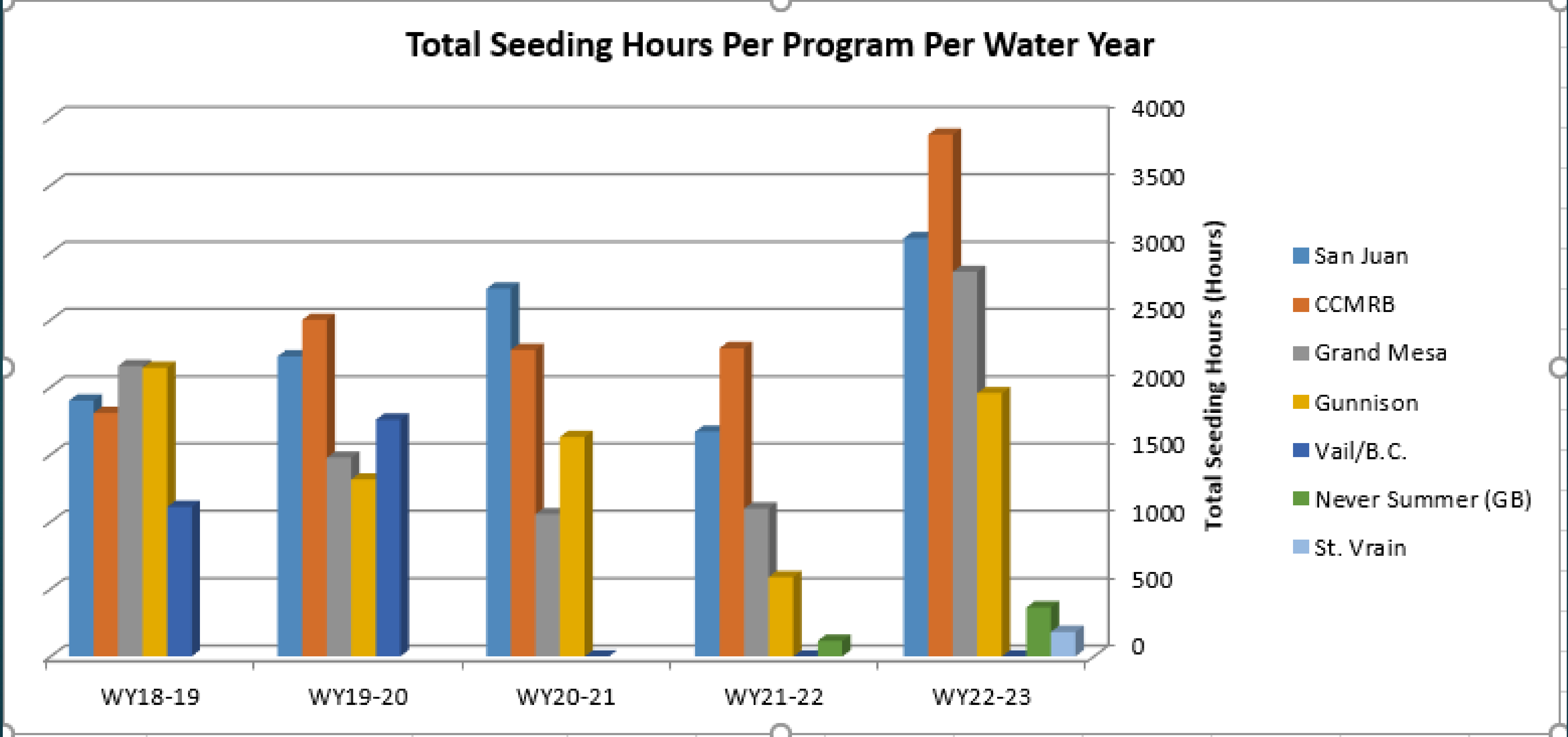
Colorado Weather Mod. Overview

- CWCB (State) doesn't operate programs but supports local initiative with grants to:
  - Extend operations
  - Support program upgrades
  - Conduct studies and modeling
  - Conduct periodic evaluations of programs

Camp Hale site
Upper Eagle River Basin
8500 feet elevation
targets Breckenridge and Keystone

Funding for Colorado's Weather Mod. Programs

- CWCB Projects Bill: $500,000
- Local Funds (40+ Participants): $480,000
- Lower Basin: $475,000
  - Southern Nevada Water Authority: $151,666.67
  - Central Arizona Water Conservation District: $151,666.67
  - California Six Agency Committee: $151,666.67
  - New Mexico Interstate Stream Commission: $20,000

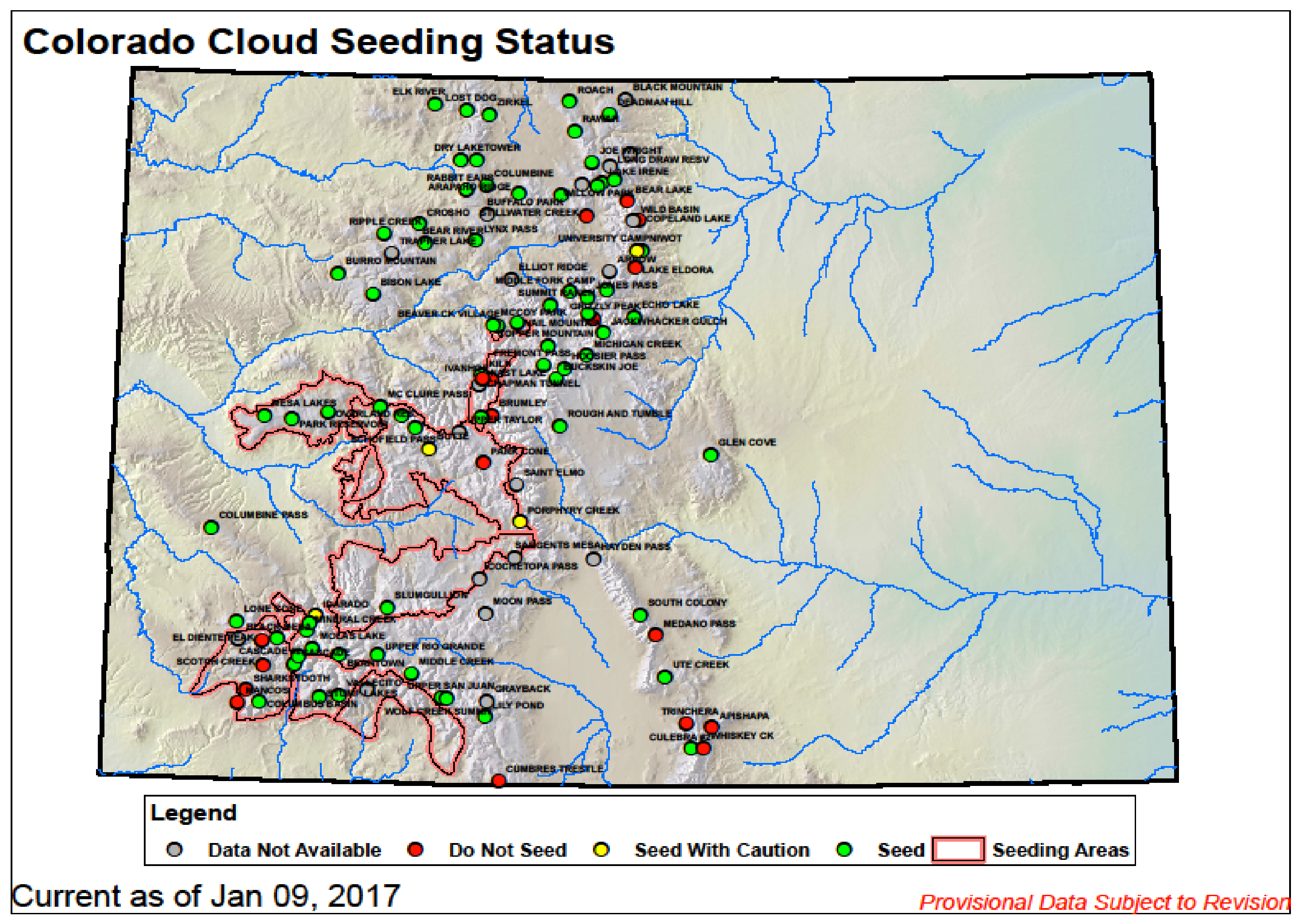


Total Seeding Hours Per Program Per Water Year
4000
3500
3000
2500
2000
1500
1000
500
0
Total Seeding Hours (Hours)
WY18-19
WY19-20
WY20-21
WY21-22
WY22-23
San Juan
CCMRB
Grand Mesa
Gunnison
Vail/B.C.
Never Summer (GB)
St. Vrain

Colorado Suspension Criteria

- Suspension of cloud seeding operations occurs following certain conditions:
  - Flood advisory
  - Blizzard warning
  - Avalanche hazard
  - Severe thunderstorm
  - Exceedance of Snow Water Equivalent (SWE) thresholds

NRCS SNOTEL Tool (right): Developed for the CWCB to aid in suspension decisions and is updated daily (This snapshot is from January 9, 2017)



Questions?

State of Colorado

Dave "DK" Kanzer, M.E., P.E, *Director of Interstate Matters*
Colorado River District

Cloud Seeding as a Water Management Tool

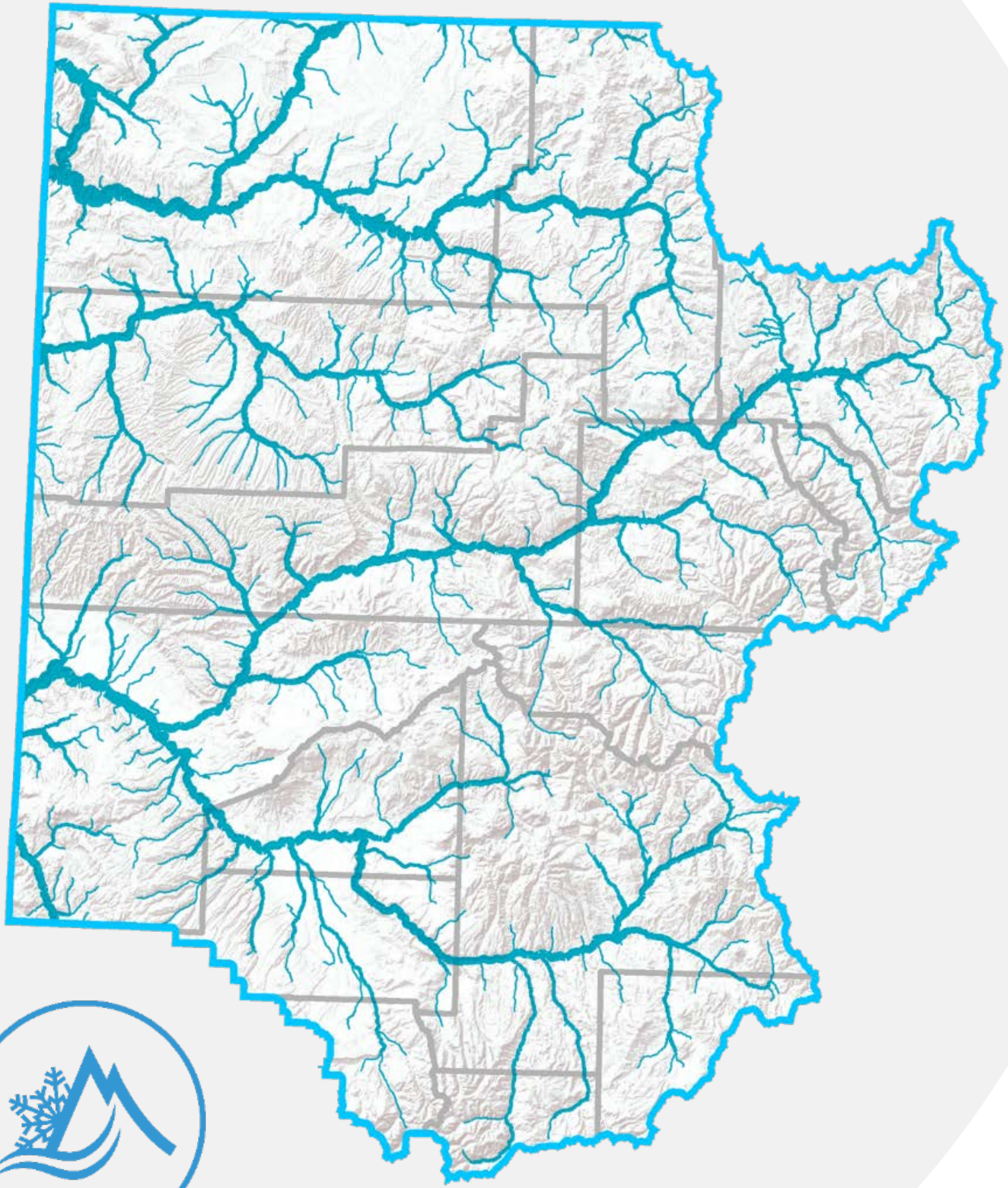
North American Weather Modification Council & Idaho Division of Water Resources

November 13, 2023 - Boise, ID

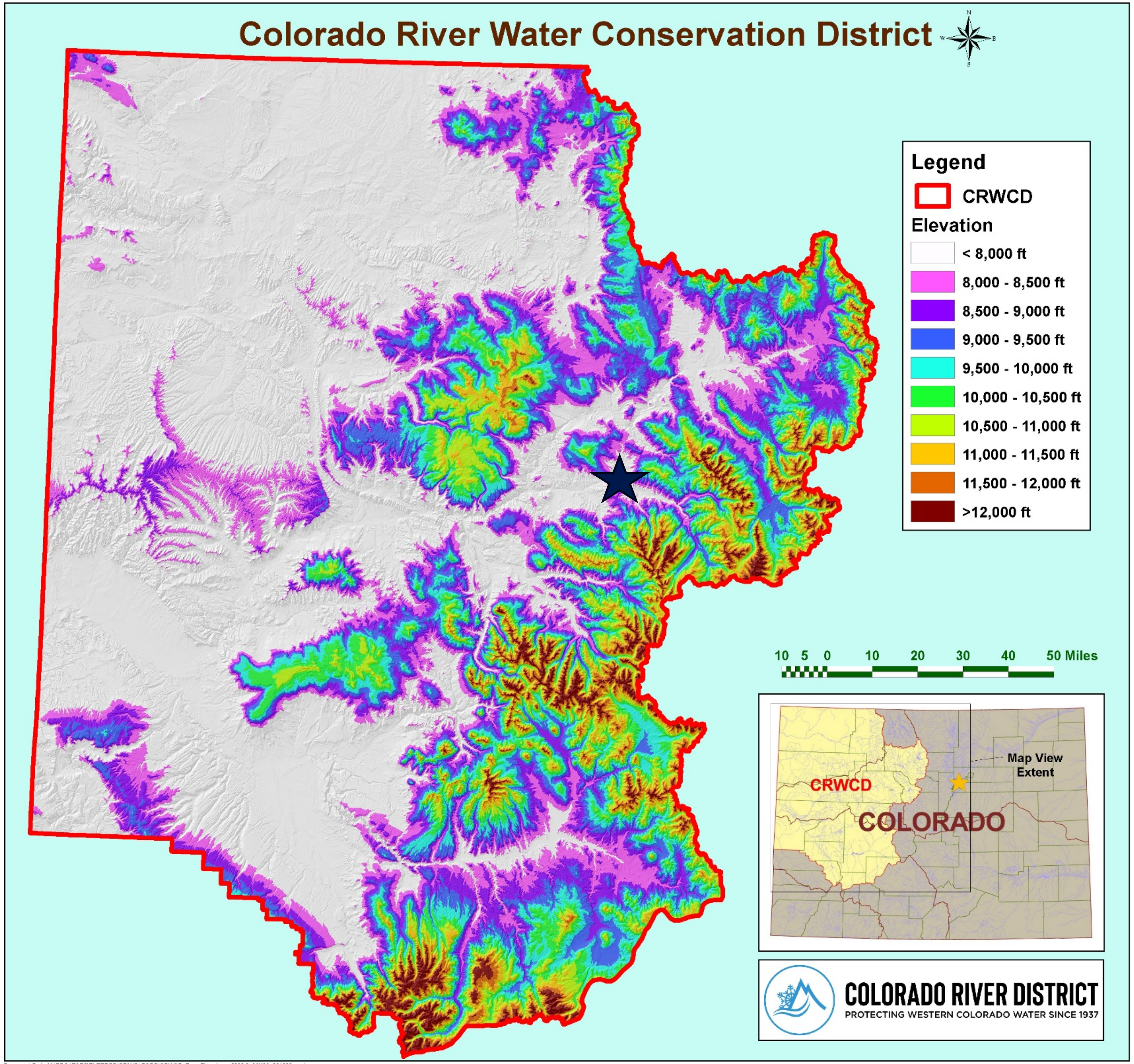
Dave "DK" Kanzer, P.E.
Director of Science and Interstate Matters

COLORADO RIVER DISTRICT
PROTECTING WESTERN COLORADO WATER SINCE 1937

The Colorado River Basin



To lead in the **protection, conservation, use,** and **development** of the water resources of the Colorado River basin.



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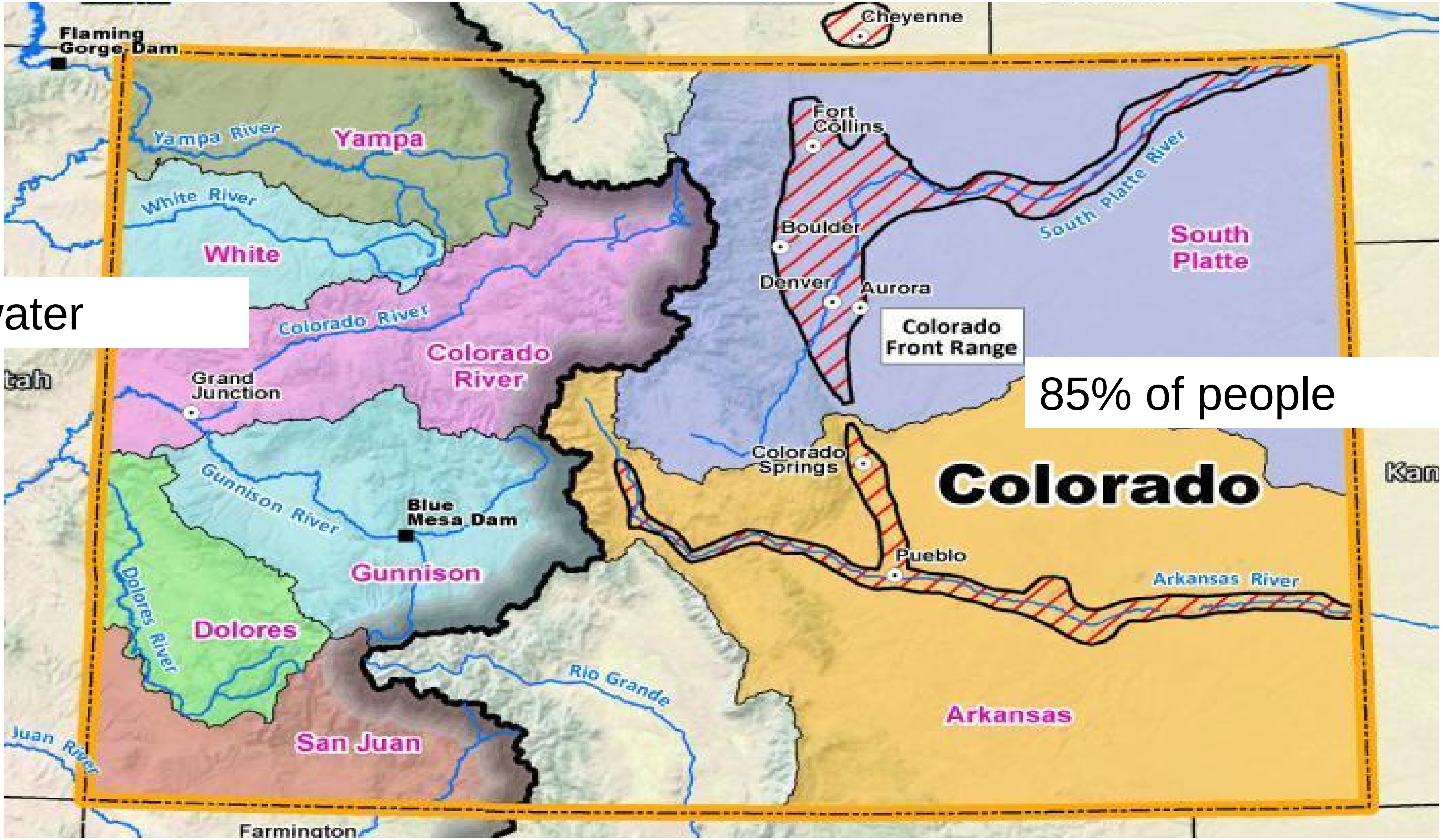
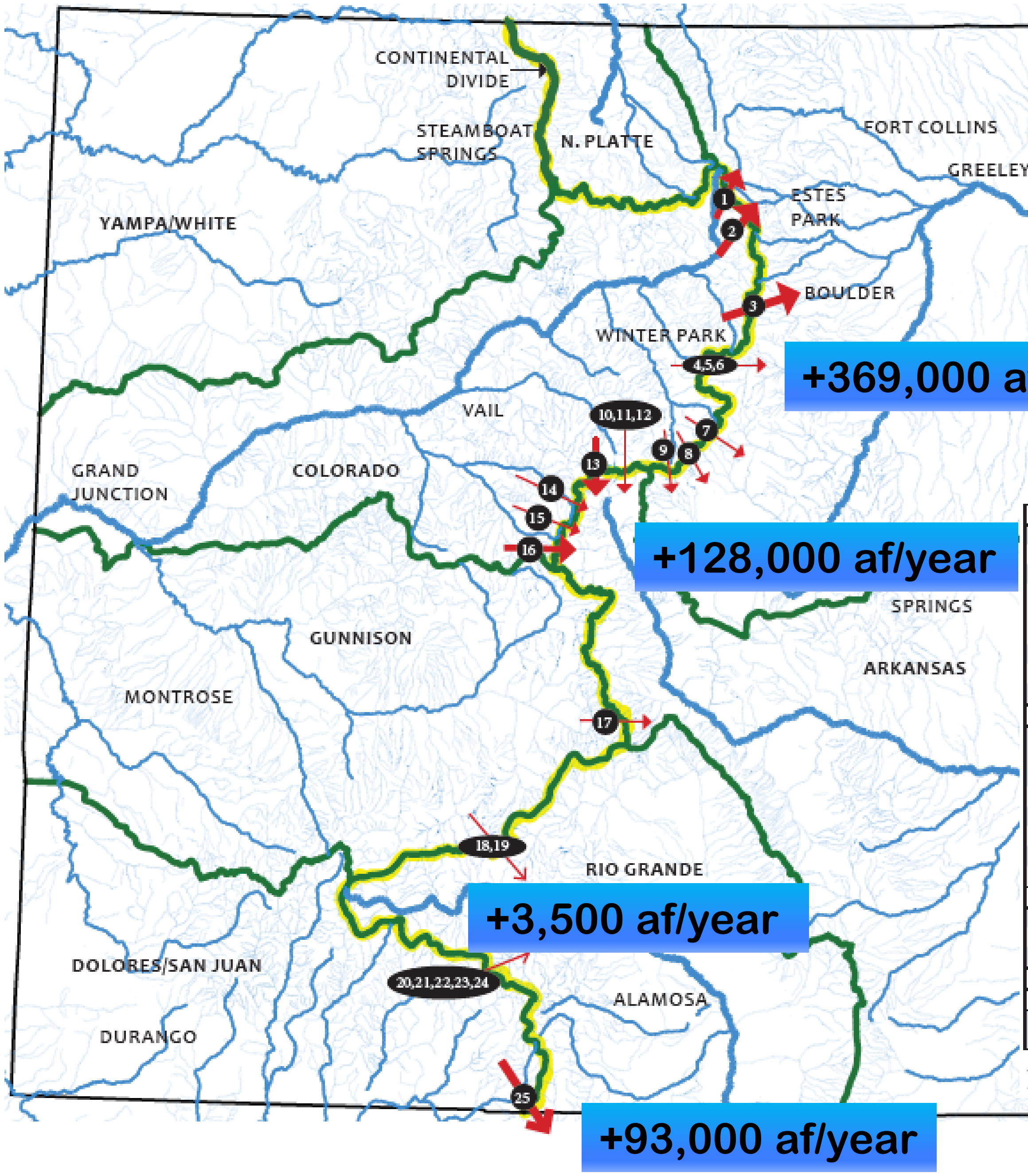
Hydro-Social & Climatic Divide



80% of water

85% of people

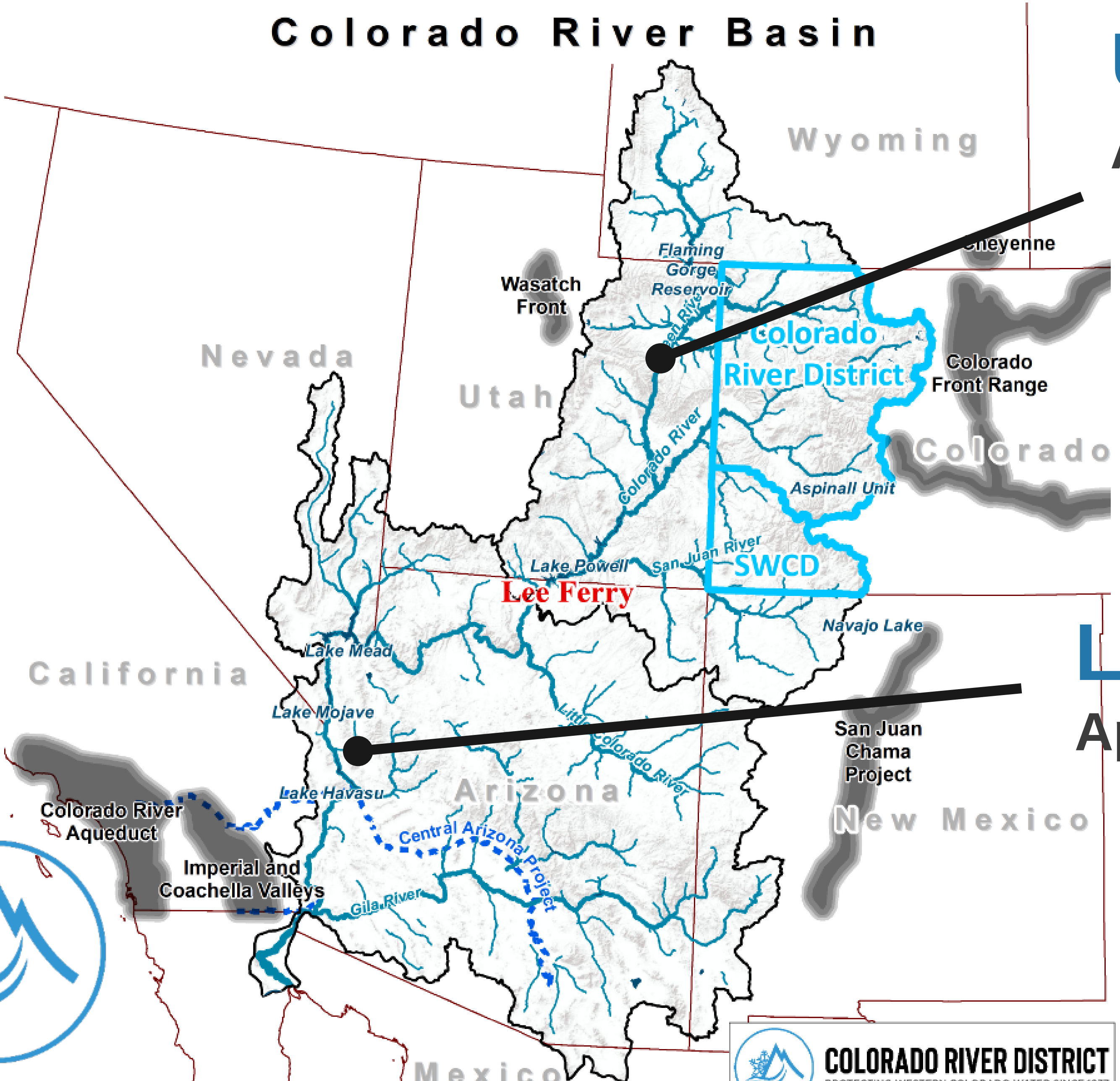
Colorado's Transmountain Diversions



Map #	Divsersion	Mean AF/YR*
1	Grand River Ditch	17,462
2	Adams Tunnel	230,500
3	Moffat Tunnel	52,390
4	Berthoud Pass Ditch	664
5	Straight Creek Tunnel	311
6	Vidler Tunnel	518
7	Roberts Tunnel	58,426
8	Boreas Pass Ditch	117
9	Hoosiers Pass Tunnel	8,375
	South Platte Imports	**368,763 AF**
10	Columbine Ditch	1,431
11	Ewing Ditch	1,027
12	Wurtz Ditch	2,508
13	Homestake Tunnel	25,286
14	Boustead Tunnel	52,013
15	Busk-Ivanhoe Tunnel	5,108
16	Twin Lakes Tunnel	40,005
17	Larkspur Ditch	190
	Arkansas Imports	**127,568 AF**
18	Tarbell Ditch	432
19	Tabor Ditch	703
20-24	Weminuche Pass Ditch/others	2,451
	Rio Grand Imports	**3,586 AF**
	Total TM Import	**499,917 AF**
25	Rio Grand Imports (New Mexico) San Juan Chama (New Mexico)	92,789 AF

*Source: Colorado Division of Water Resources. *Figure is based upon the period of record available in electronic form for each division*

Another Hydro-Social & Climatic Divide

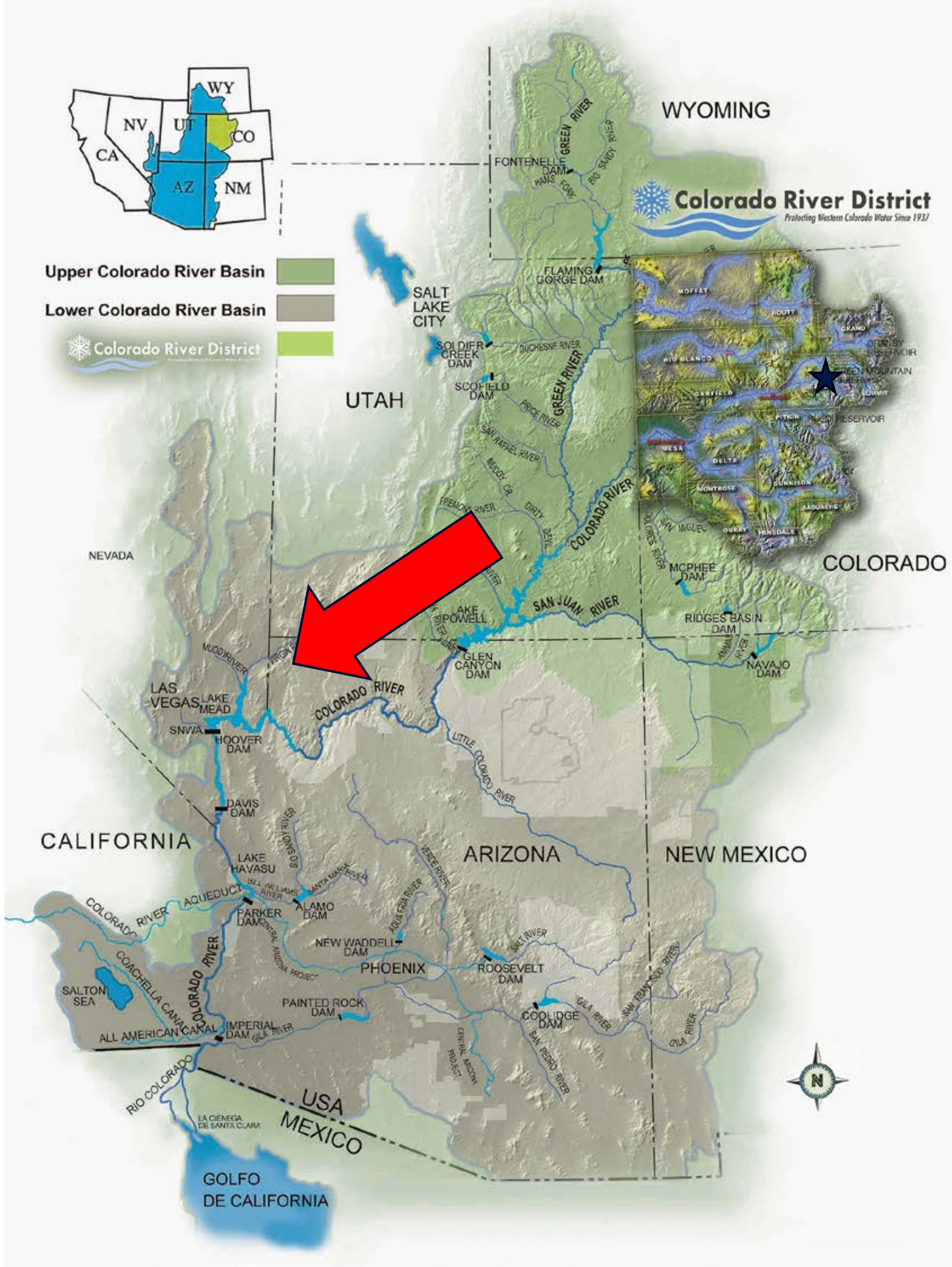


Upper Basin (supply)

Approximately 90% of the water

Lower Basin (demand)

Approximately 90% of the people


WY
NV
UT
CO
CA
AZ
NM
Upper Colorado River Basin
Lower Colorado River Basin
Colorado River District
WYOMING
Colorado River District
Protecting Western Colorado Water Since 1937
FONTENELLE DAM
GREEN RIVER
FLAMING GORGE DAM
SALT LAKE CITY
SOLDIER CREEK DAM
SCOFIELD DAM
UTAH
GREEN RIVER
COLORADO RIVER
NEVADA
COLORADO
MCPHEE DAM
SAN JUAN RIVER
LAKE POWELL
RIDGES BASIN DAM
GLEN CANYON DAM
NAVAJO DAM
LAS VEGAS
LAKE MEAD
SNWA
HOOVER DAM
COLORADO RIVER
LITTLE COLORADO RIVER
DAVIS DAM
CALIFORNIA
LAKE HAVASU
ARIZONA
NEW MEXICO
AQUEDUCT
PARKER DAM
ALAMO DAM
COLORADO RIVER
NEW WADDELL DAM
PHOENIX
ROOSEVELT DAM
SALTON SEA
COLORADO RIVER
PAINTED ROCK DAM
COOLIDGE DAM
ALL AMERICAN CANAL
IMPERIAL DAM
RIO COLORADO
USA
MEXICO
GOLFO DE CALIFORNIA

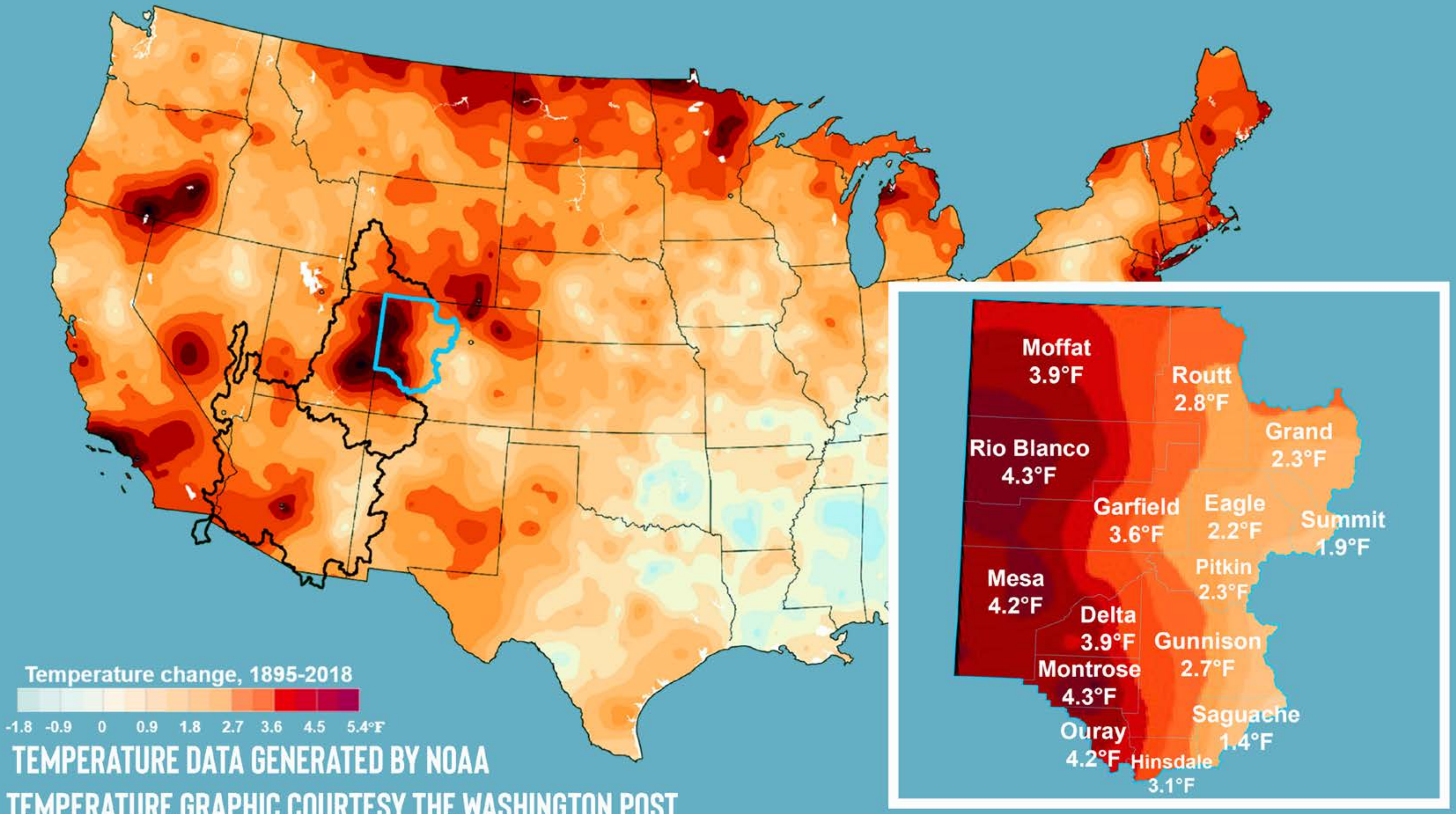
Water supply and demand imbalance

It is all about: where, when and how

- Decreasing demands and use
- Increasing supplies

- **Tools**:
  - conservation (storage when wet, release when dry)
  - Investment
    - efficiency (less loss)
    - demand management (less use)
    - ***augmentation (create more via cloud seeding)***

A HOTTER, DRIER FUTURE IN THE COLORADO RIVER DISTRICT



TEMPERATURE DATA GENERATED BY NOAA

TEMPERATURE GRAPHIC COURTESY THE WASHINGTON POST

Law of the River based upon long-term stable water supply

- Climate and human impacts
  - Warmer, longer growing season
  - Higher evapotranspiration
  - Increasing surface and groundwater depletions
  - Lower volume of reliable water supplies
  - Greater variability


COLORADO RIVER DISTRICT
coloradoriverdistrict.org
Colorado River District
@ColoradoWater
ColoradoRiverDistrict

State of Nevada

Frank McDonough, *Cloud Seeding Program Director, Research Meteorologist*
Desert Research Institute

Nevada State Cloud Seeding Program

Frank McDonough

Desert Research Institute

Background – NV driest state in US

The significant water resources that serve humans and wildlife in Nevada originate from winter storms crossing the highest portions of states mountain ranges.

Sierra Nevada Snowpack

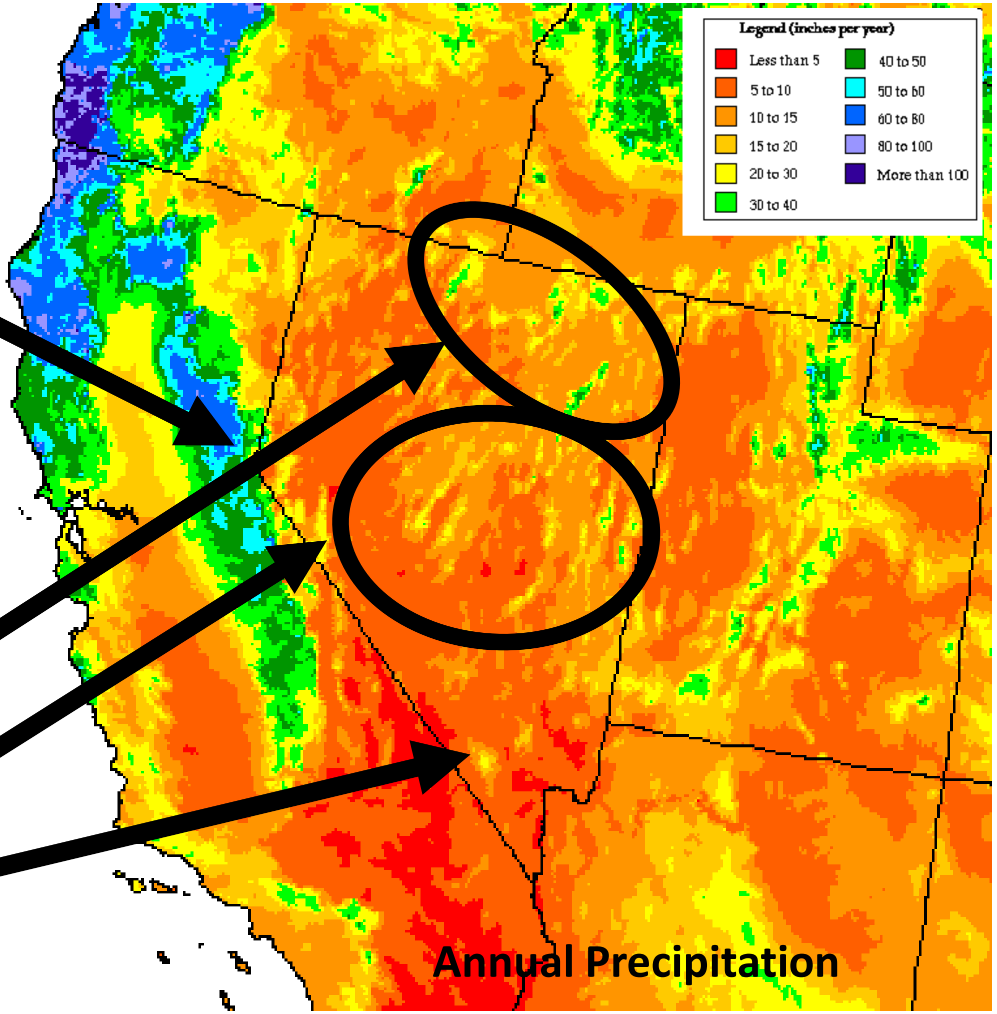
- Truckee River (Reno/Farming)
- Carson River (Carson City/Farming)
- Walker River (Farming, few smaller towns)

Ruby, Santa Rosa, Jarbidge Mtns

- Humboldt River (Ranching, Farming, several smaller cities/towns)
- Ground water

Isolated Great Basin Ranges and Spring Mountains

- Ground water



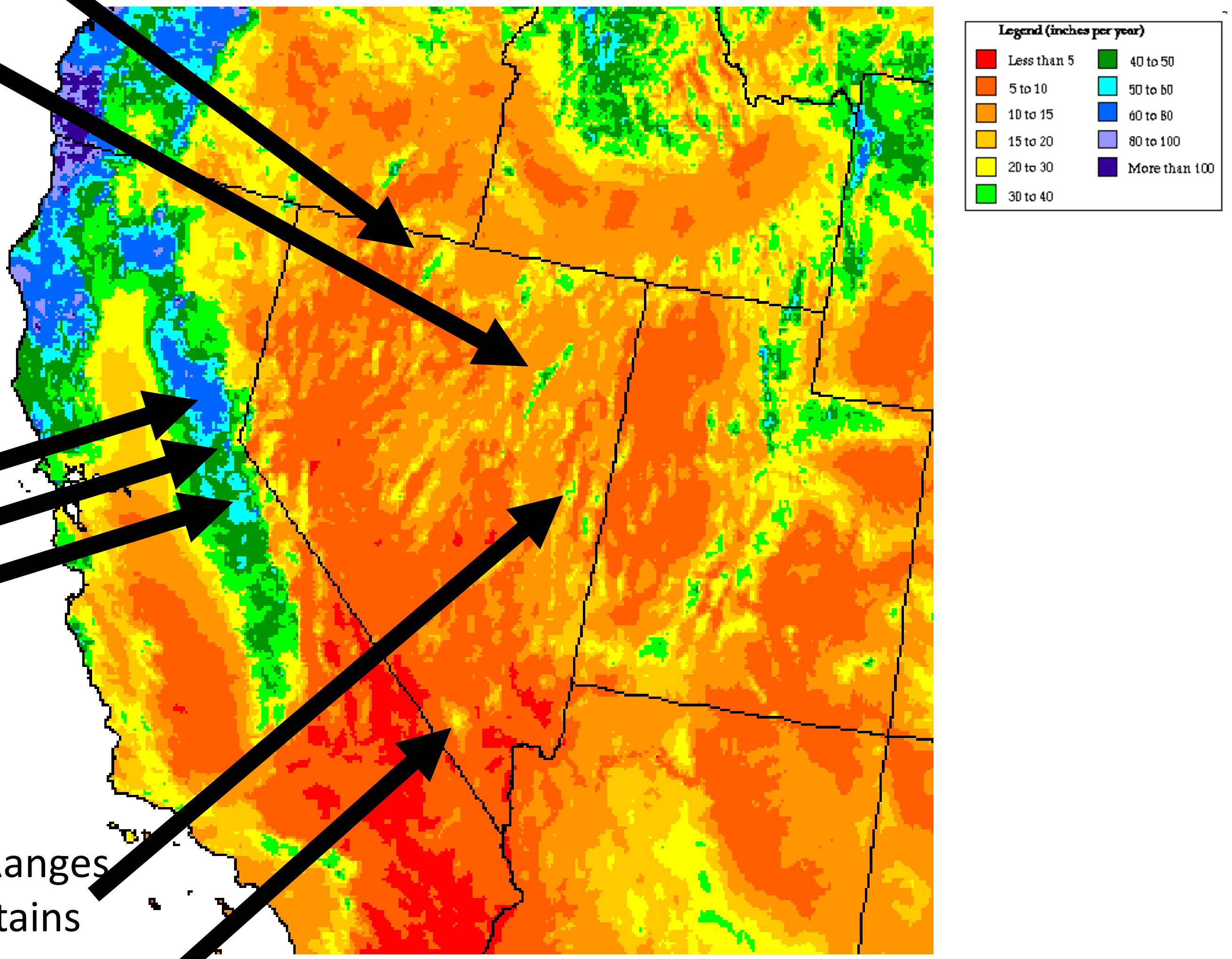
Background – Primary Storm Tracks (wind direction)

Santa Rosa (NW)

Ruby (NW)

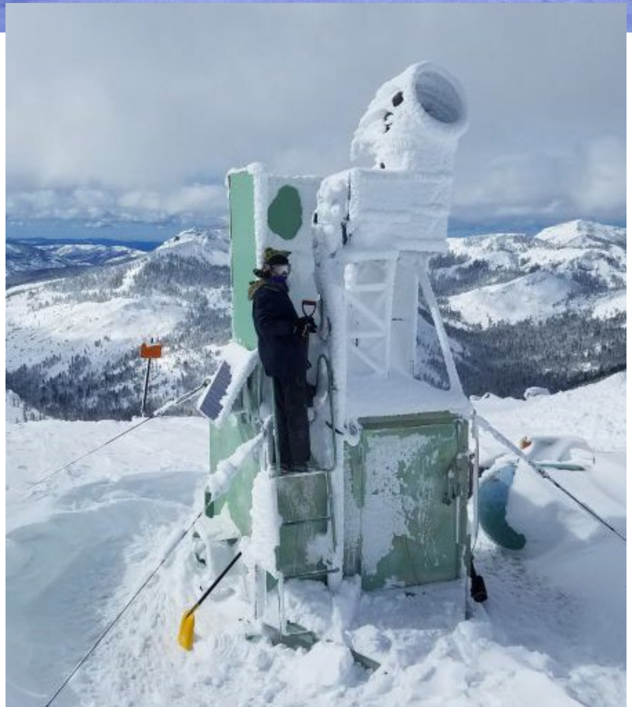
Sierra Nevada
(SW)

Great Basin Ranges
Spring Mountains
(SW)



History of Cloud Seeding in Nevada

- Aircraft experiments over the Sierra and Ruby Mountains as early at 1962 by UNR/DRI.
- Research by DRI continued into the 1970s with ground seeding also introduced in the research programs.
- Research results suggested snowfall was being enhanced but many challenges quantifying results remained.



Research Programs Suggested the Chain of Events are Required

- Cloud seeding material must be successfully and reliably produced
- Seeding material must be transported into a region of cloud that has supercooled liquid water (SLW)
- Seeding material must be dispersed sufficiently in the SLW cloud so that a significant volume is affected.
- Temperatures must be cold enough for substantial new ice production
- The new ice must remain in the SLW cloud long enough to gain significant mass and fall out as snow in the target area

History of Cloud Seeding in Nevada

- Severe drought during the 1975-1977 winters.
- Governor of Nevada asked DRI (state resource) if they believed cloud seeding could potentially help to help boost water supplies. DRI thought an operational cloud seeding program was feasible.
- DRI established the Nevada State Cloud Seeding Program which was both an operational and research program.
- Programs designed using the Chain of Events

History of Cloud Seeding in Nevada

- State Program research-operational program continued for 30+ years through the 2009-2010 winter, when it was suspended due to state budget shortfalls from the Great Recession.
- State funding was $500K for the last seeded winter in winter 2009-2010.
- State funds supported the entire program.

Accomplishments of the NV State Program

- Estimated 50,000 – 75,000 acre-feet* of additional snow water equivalent to targeted NV watersheds at $10/acre-foot.
- Pioneered the development of the DRI remote controlled cloud seeding generator. Technology passed on to Idaho Power, and Snowy Australia and allowed generators to be placed in ideal locations.
- New cloud seeding aerosol AgI-NaCl allowed for much more efficient ice nucleation
- Pioneered the use a trace chemistry for cloud seeding validation.

*acre-foot of water enough for 2 landscaped houses.

State Program 2011-present

- With the State Program suspended stop gap funding needed to be acquired from local sources.

*The Tahoe-Truckee Program was able to continue through the period with local funding, and the Ruby Mountains Program was able to continue until 2012 when no funding sources could be found.

State Program 2023-2025

- The 2023 State Legislature and Governor passed a bill providing $600K for the next 2 years to reinstate the State Research-Operational Cloud Seeding Program.

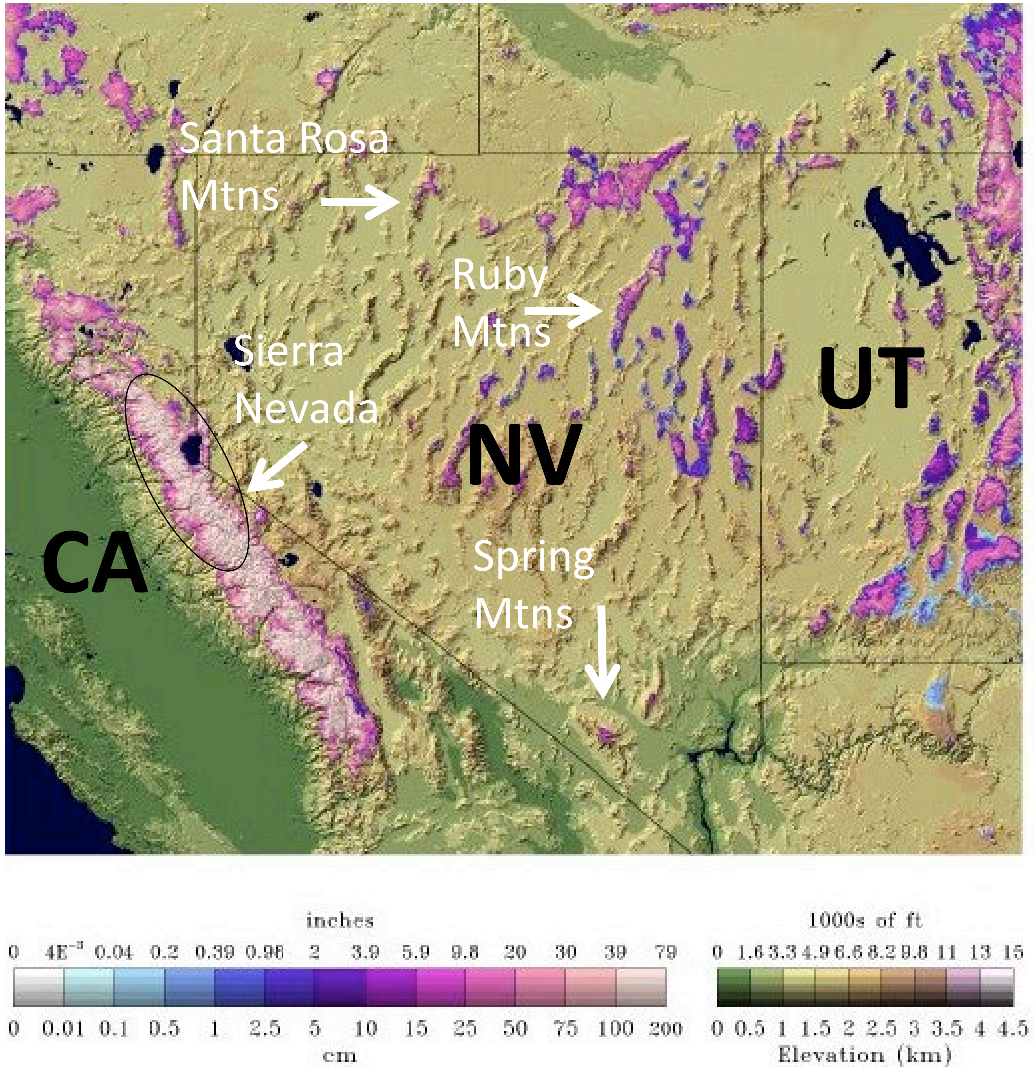
State Program 2023-2025

- The program will conduct operations in:

- Sierra Nevada
- Ruby Mountains
- Santa Rosa
- Spring Mountains

Additional Research in:

- Diamond Mountains
- Jarbidge Mountains



Matching Funds 2023-2025 (not 1:1)

- Nevada Gold Mines
- NV Energy
- Save Red Rock Canyon
- NOAA
- Humboldt River Basin Water Authority
- Humboldt County
- Elko County
- Pennington Foundation
- Nye County Water District
- Eureka County
- Pershing County Conservation District
- Lee Canyon Ski Area

Summary

- Cloud Seeding has been done in Nevada since the early 1960s.

- State operational-research programs started in 1976 and continued into 2010.

- Nevada state investments in cloud seeding has allowed for many advancements in the science and in the technology currently used in the field.

- State program reinstated in 2023 at $600K per year.

- Partner funding (not required) can be used to expand programs or be used for research (i.e. precip gauges, ice detectors, ice crystal collection field work, snow chemistry, hydrology …)

Current Programs

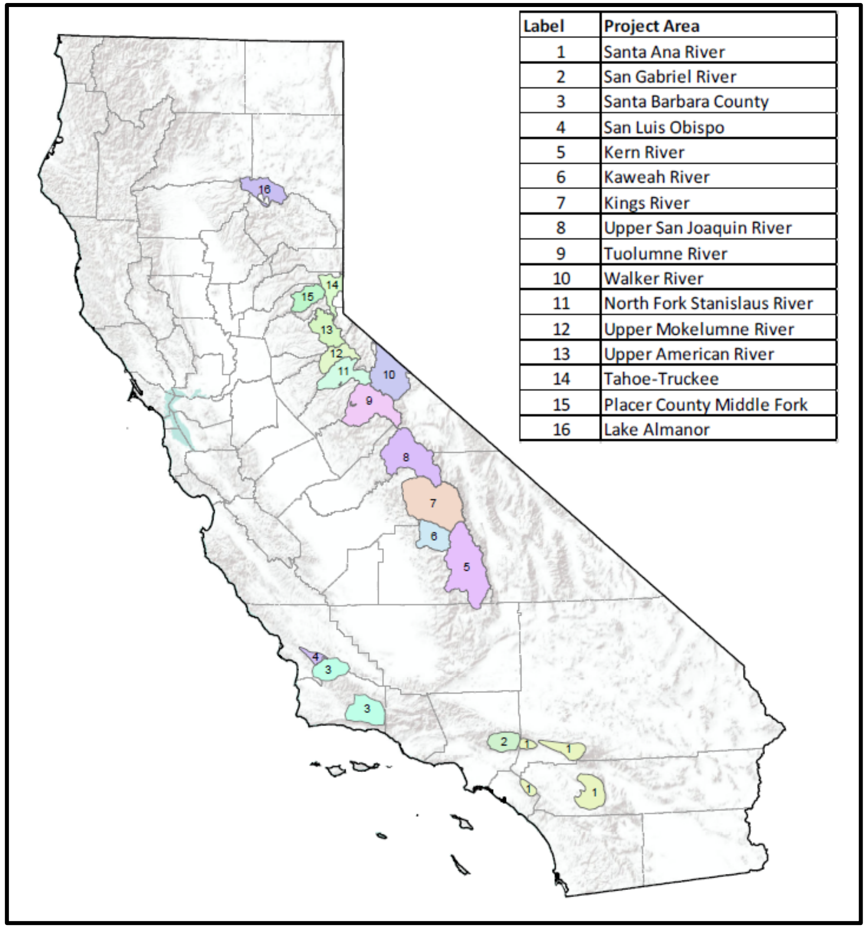
Wyoming | Utah | Idaho

NAWMC
North American
Weather Modification Council

Santa Barbara County Program

Matthew Scrudato, *Senior Hydrologist*
Santa Barbara County Water Agency

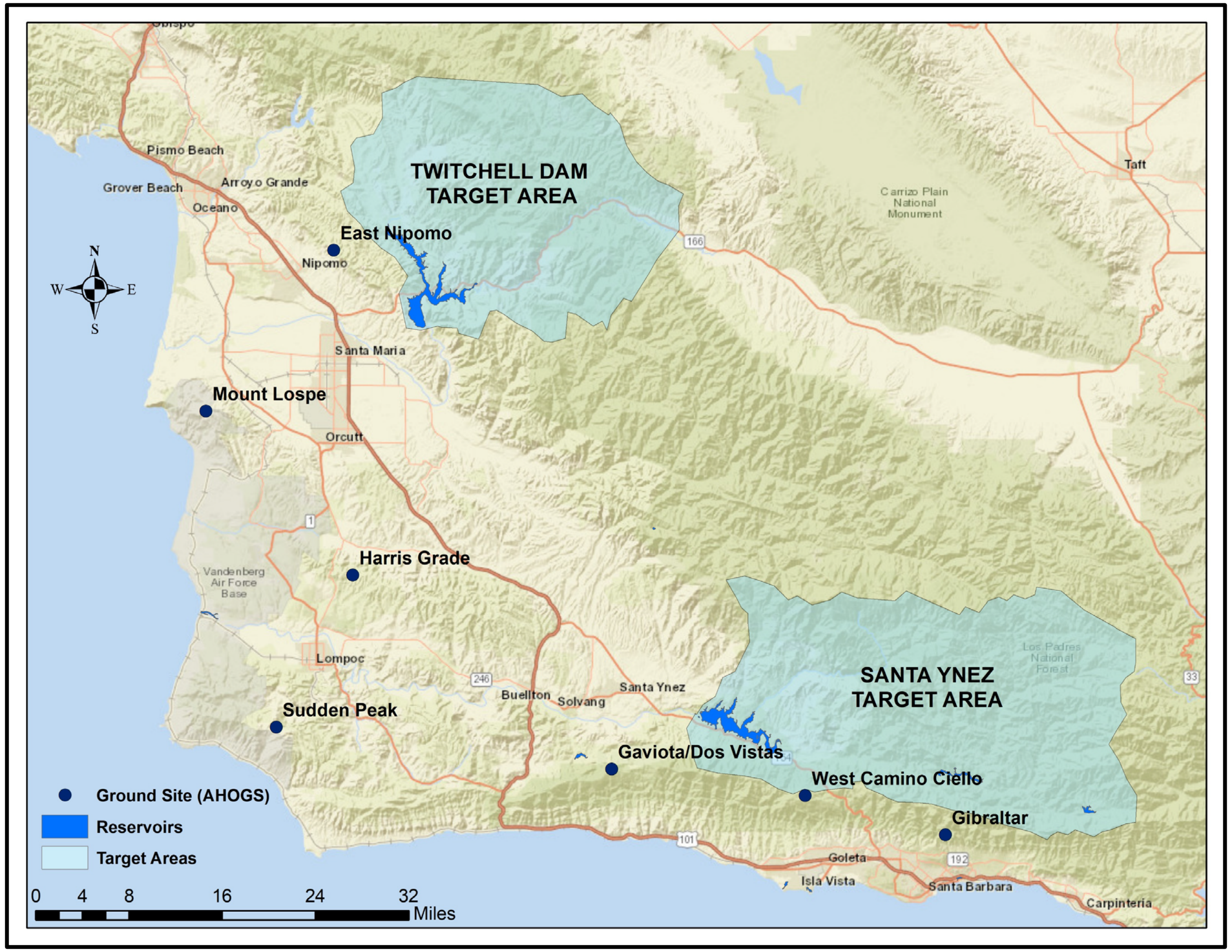
Active Programs in California



Label	Project Area
1	Santa Ana River
2	San Gabriel River
3	Santa Barbara County
4	San Luis Obispo
5	Kern River
6	Kaweah River
7	Kings River
8	Upper San Joaquin River
9	Tuolumne River
10	Walker River
11	North Fork Stanislaus River
12	Upper Mokelumne River
13	Upper American River
14	Tahoe-Truckee
15	Placer County Middle Fork
16	Lake Almanor

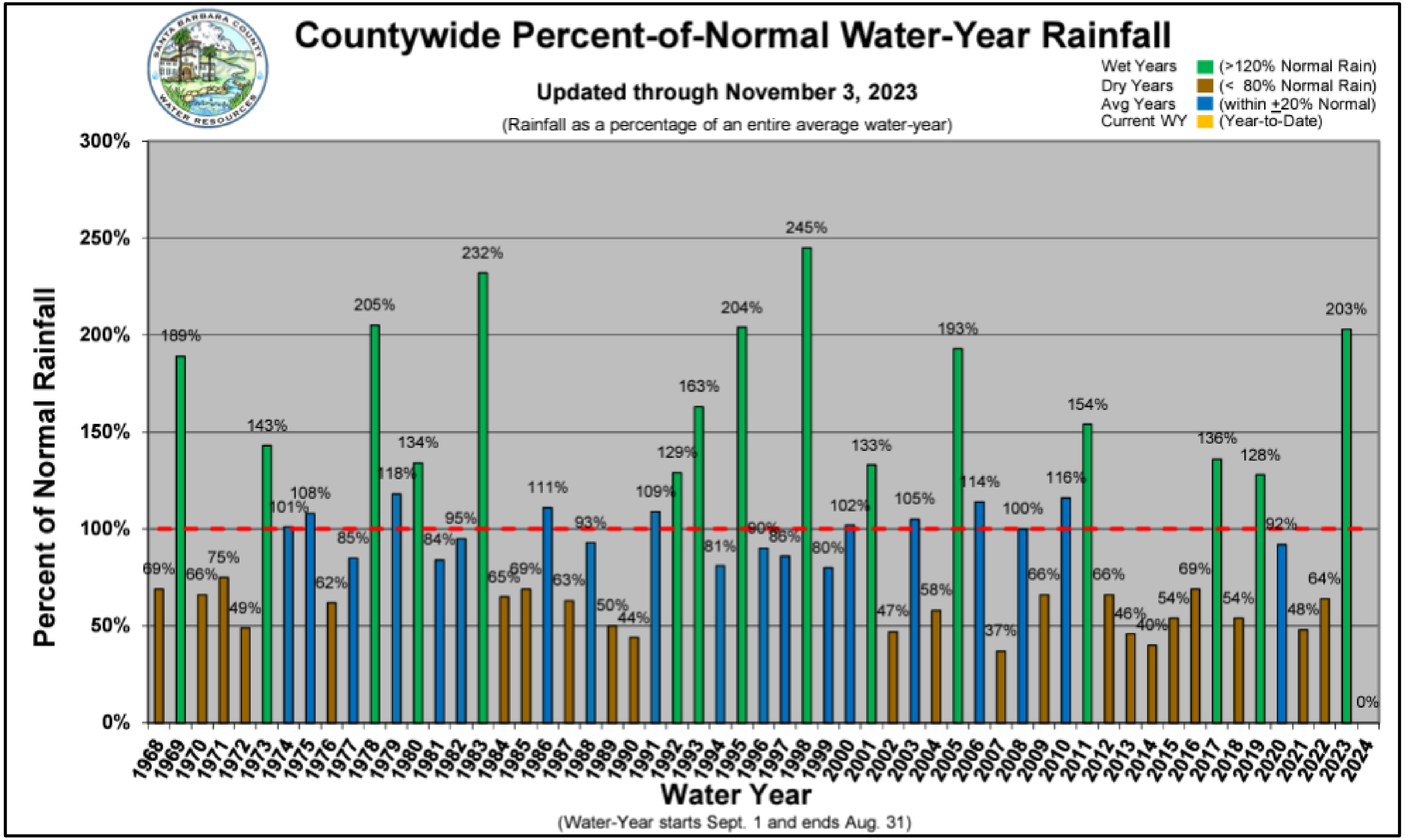
- Currently 16 +/- programs
  - Power utilities
  - Water resources / supply agencies
  - Conservation districts
  - Irrigation districts
  - Research institutes
  - Ski areas

Santa Barbara County Program

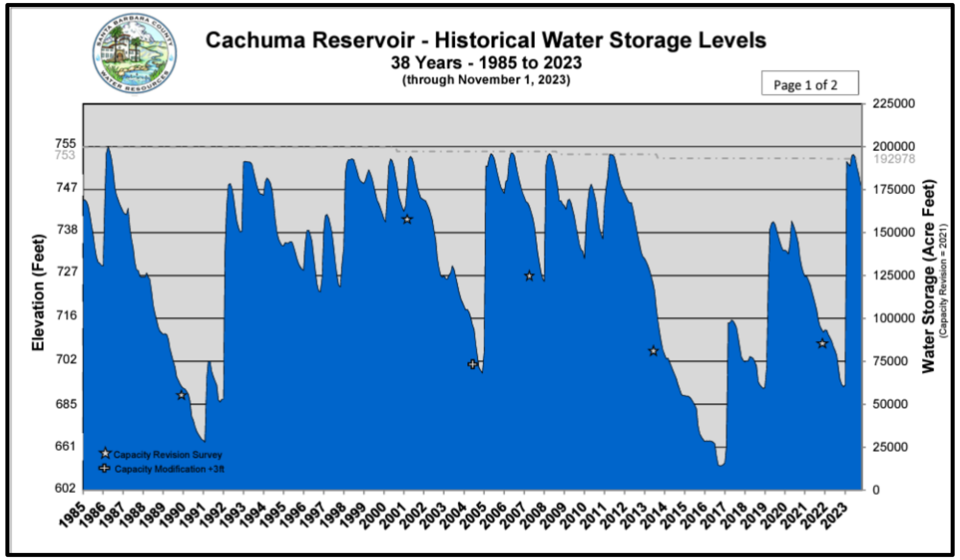


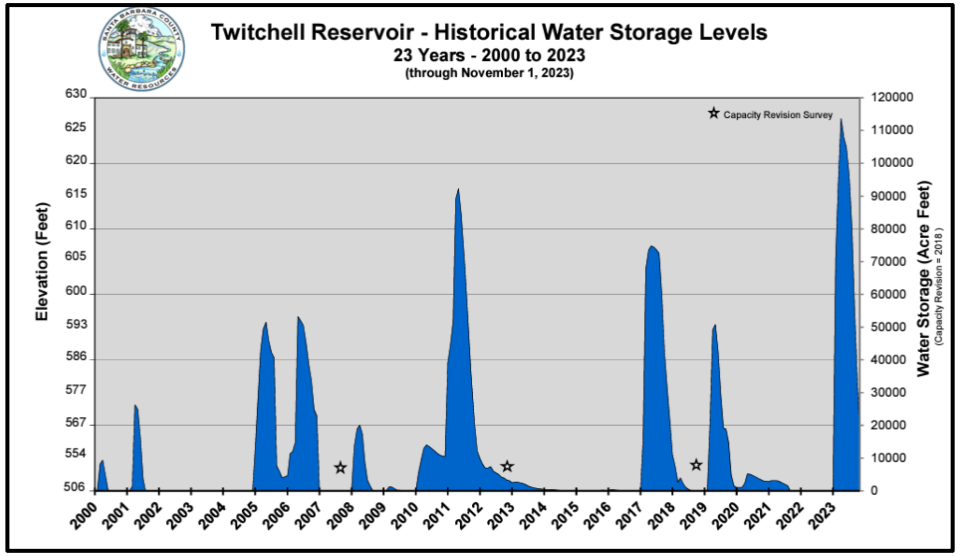
- Contract with North American Weather Consultants.
- Operational program since 1981.
- Airborne and/or ground based seeding modes to target convective bands
  - Ground from 12/1 to 4/15
  - Air from 1/1 to 3/30
- Criteria
  - Wind direction
  - Temperature
  - Presence of supercooled liquid water

Highly Variable Precipitation



Major Reservoir Storage





- Two or three high precipitation events will usually determine if the county will have a wet, dry, or normal year.

- Events typically occur between January and March

- Cloud seeding can help augment between these large rainfall events, building up a “savings account” in reservoirs for a dry year (or many dry years).

Program Research

- **Cloud seeding Santa Ynez (1950 to 1955)**
- **Santa Barbara 1 (1957 to 1962)**
  - State of CA and University of CA
  - Randomized seeding experiment using ground based silver iodide generators.
  - RESULT – Increases of precipitation up to 45%
- **Water Balance of Orographic Clouds and Convective Band Study** (1960 to 1963)
  - Winter storm analysis
- **Santa Barbara II (Phase I and II)** (1967 to 1974)
  - Naval Weapons Center China Lake
  - Randomized seeding of convective bands with ground (phase I) and aircraft (phase II)
- Results of Santa Barbara II showed significant increases in convective band precipitation
  - Program foundation which started in 1981

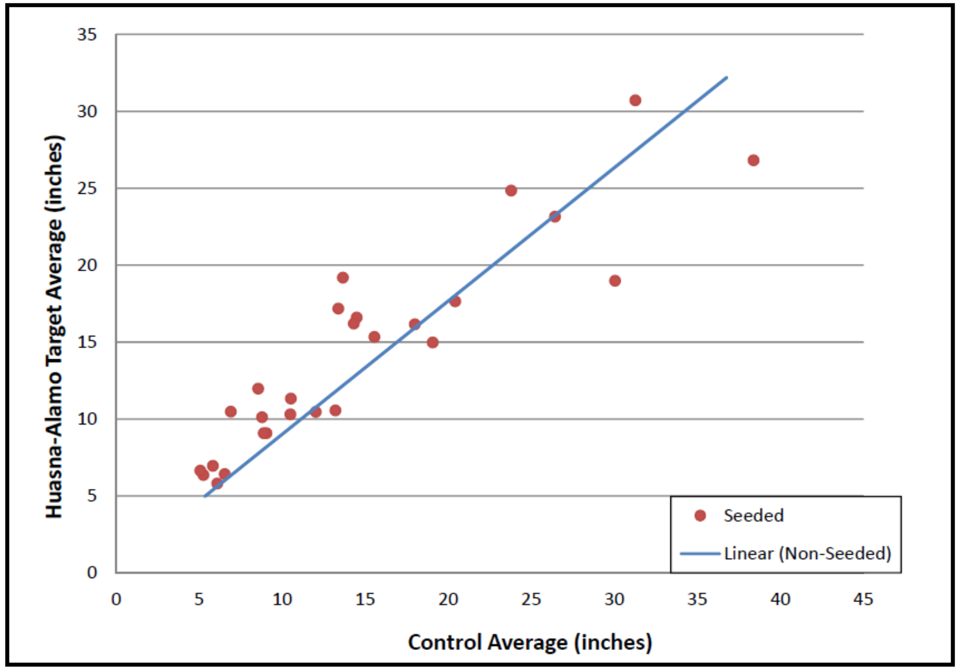
2015 Statistical Analysis

- **Upper Santa Ynez Target Area:**
  - Estimated increases of 20%
  - 24 seeded seasons
- **Huasna-Alamo Target Area:**
  - Estimated increases of 9%
  - 27 seeded seasons

10 JOURNAL OF WEATHER MODIFICATION VOLUME 47

TARGET/CONTROL ANALYSES FOR SANTA BARBARA COUNTY'S OPERATIONAL WINTER CLOUD SEEDING PROGRAM

Don A. Griffith, David P. Yorty, Stephanie D. Beall
North American Weather Consultants



Detailed Model and Program Evaluation (current study)

Desert Research Institute

- **OBJECTIVE**
  - Analyze the efficiency of the current program
  - Recommendations for future program design optimization
- **QUESTIONS TO EXPLORE**
  - Is the weather regime underpinning current operations and program design still relevant?
  - How effective is the current program design relative to the maximum potential increase in precipitation?
    - What is the current estimated increase in precipitation?
    - What are the limitations of the current program design (ie- frequency of inversion)?
  - Are the number and placement of ground seeding sites adequate?
  - Have the program results diminished without the use of airborne seeding? If so, how?
  - Will the use of remote ground generators, aircraft, or aerial seeding provide opportunity for further precipitation enhancement relative to the current program design?
  - What is the estimated increase in precipitation that could be reasonably expected with an optimized program design?

Seeding Methods

GROUND SITE

AIRPLAN
E

Program Funding

- Varies each season (length, ground, air, fire, etc.)
- Water Agency 50%
- Additional 50% distributed between 9 agencies who benefit from increased precipitation
- Based on agency production.
- Shared cost with San Luis Obispo County (Lopez Lake)

Program Information

CLOUD SEEDING

Cloud Seeding (Precipitation Enhancement)

The Santa Barbara County Water Agency (SBCWA) conducts a precipitation enhancement program, also known as "cloud seeding," to augment natural precipitation to increase surface water runoff in watersheds behind the major water reservoirs. These reservoirs include Cachuma Reservoir, Gibraltar Dam, and Jameson Reservoir on the Santa Ynez River and Twitchell Reservoir on the Cuyama River near Santa Maria. The Department of Water Resources outlines the benefits of precipitation enhancement in the Resources Management Strategies of the California Water Plan.

The operational program has been in existence since 1981 and is based on research conducted between 1957 and 1974 which showed that significant increases in rainfall could be achieved by seeding convective bands during winter storm events. View the Summary of the Early Research (PDF).

Cloud Seeding Process

Most storms in Santa Barbara County are abundant in moisture but limited in condensation nuclei. Water droplets or ice particles form on microscopic condensation nuclei, which are extremely small particles of dust or dirt in the atmosphere. Research has shown that many of these storms have embedded convective bands with super-cooled water vapor. Super-cooled water vapor exists below the freezing point but does not freeze due to extremely low atmospheric pressure. Cloud seeding injects artificial hydroscopic material into the convective bands and cloud mass, providing a mechanism to move the moisture from the cloud mass to the surface of the earth where it is needed.

Seeding in Santa Barbara County is accomplished by using a combination of ground-based sites and at times aircraft. There are currently seven land-based sites being utilized. These sites are referred to as Automated High Output Ground Sites (AHOGS) and are illustrated in the map above. AHOGS located at Berros Peak (East Nipomo), Mount Lospe, Harris Grade, and Sudden Peak are used for the Twitchell Dam target area, while AHOGS located at Refugio Pass, West Camino Cielo and Gibraltar Road are used for the Santa Ynez target area. A video of an operational AHOGS and air seeding event can be viewed below by clicking on the photo.

Implications

SBCWA shares the cost of the operational program with local water purveyors throughout the County. The design of the program may change each year to reflect watershed and hydrologic conditions. Additionally, program modifications may be implemented based on storm severity, or the program may be completely suspended as a result of fire and erosion potential.

The practice of precipitation enhancement in Santa Barbara County has proven to be a cost-effective and positive addition to water resources management goals and objectives. A historical target/control analysis was completed in 2015 which showed that the cloud seeding program plays a valuable role in increasing water supplies and protecting groundwater resources by increasing rainfall in seeded storms by approximately 20% in the Santa Ynez target area, and 9% in the Twitchell Dam target area.

Cloud seeding programs are conducted throughout California and are common throughout the world. The SBCWA recognizes cloud seeding as a safe and cost-effective means of enhancing water supplies. The California Department of Water Resources labels cloud seeding a "safe and effective means of augmenting local water supplies." The American Society of Civil Engineers (ASCE) recognizes cloud seeding and has produced an operations guidelines manual. The Weather Modification Association and the North American Weather Modification Council provide excellent information on international programs, studies, methodology, and seeding material. Santa Barbara's program is in compliance with the California Environmental Quality Act and conducted in accordance with

- Annual Cloud Seeding and Evaluation Report, Twitchell and Upper Santa Ynez Watersheds, 2021-2022 Winter Season (PDF)
- Artificial Hydroscopic Material (DOC)
- Seeding Material (PDF)
- Santa Barbara County Cloud Seeding Program Mitigated Negative Declaration (PDF)
- Cloud Seeding, The Environment & The Climate (PDF)
- Understanding Cold Season Cloud Seeding (PDF)
- Material Safety Data Sheet for Silver Iodide (PDF)
- North American Weather Modification Council
- Weather Modification Association
- A Resource Management Strategy of the California Water Plan (PDF)
- CNET: Cloud Seeding Site Walk-Through and Demonstration

REPORTS AND DOCUMENTS

Cloud Seeding (Precipitation Enhancement)

Yearly Operations & Evaluation Reports

THE CURRENT OPERATIONAL PROGRAM BEGAN IN 1981

- 2021 to 2022 Operational Program (PDF)
- 2020 to 2021 Operational Program (PDF)
- 2019 to 2020 Operational Program (PDF)
- 2018 to 2019 Operational Program (PDF)
- 2017 to 2018 Operational Program (PDF)
- 2016 to 2017 Operational Program (PDF)
- 2015 to 2016 Operational Program (PDF)
- 2014 to 2015 Operational Program (PDF)
- 2013 to 2014 Operational Program (PDF)
- 2012 to 2013 Operational Program (PDF)
- 2011 to 2012 Operational Program (PDF)
- 2010 to 2011 Operational Program (PDF)
- 2009 to 2010 Operational Program (PDF)
- 2008 to 2009 Operational Program (PDF)
- 2007 to 2008 (**NO PROGRAM** - Zaca Fire)
- 2006 to 2007 Operational Program (PDF)
- 2005 to 2006 Operational Program (PDF)
- 2004 to 2005 Operational Program (PDF)
- 2003 to 2004 Operational Program (PDF)
- 2002 to 2003 Operational Program (PDF)
- 2001 to 2002 Operational Program
- 2000 to 2001 Operational Program (PDF)

Research and Publications

- Feasibility/Design Study for a Winter Cloud Seeding Program in the Upper Cuyama River Drainage, California (PDF) 2016
- Target/Control Analyses for Santa Barbara County's Operational Winter Cloud Seeding Program (PDF) 2015
- Santa Barbara County Cloud Seeding Program Mitigated Negative Declaration (PDF) 2013
- The Santa Barbara Cloud Seeding Project in Coastal Southern California, Operations and Research Spanning More Than 50 Years (PDF) 2005
- Precipitation Augmentation Potential From Convection Band Cloud Seeding in Santa Barbara County (PDF) 1988
- An Examination of the Effects of Cloud Seeding in Phase II of the Santa Barbara Convective Band Seeding Test Program (PDF) 1980
- Potentials For Yield Augmentation Through Weather Modification (PDF) 1977
- Santa Barbara Convective Band Seeding Test Program (PDF) 1975
- Santa Barbara Pyrotechnic Cloud Seeding Test Results 1967-70 (PDF) 1971
- Physical Studies of the Santa Barbara Cloud Seeding Project (PDF) 1962
- Statistical Evaluation of the Santa Barbara Randomized Cloud Seeding Experiment (PDF) 1960

Related Publications

- Department of Water Resources, Precipitation Enhancement, Resource Management Strategy (PDF) 2016
- A Review of Cloud Seeding Experiments to Enhance Precipitation and Some New Prospects (PDF) 1999
- Weather Modification by Cloud Seeding (PDF) 1980

Santa Ana River
Weather Modification Pilot Program

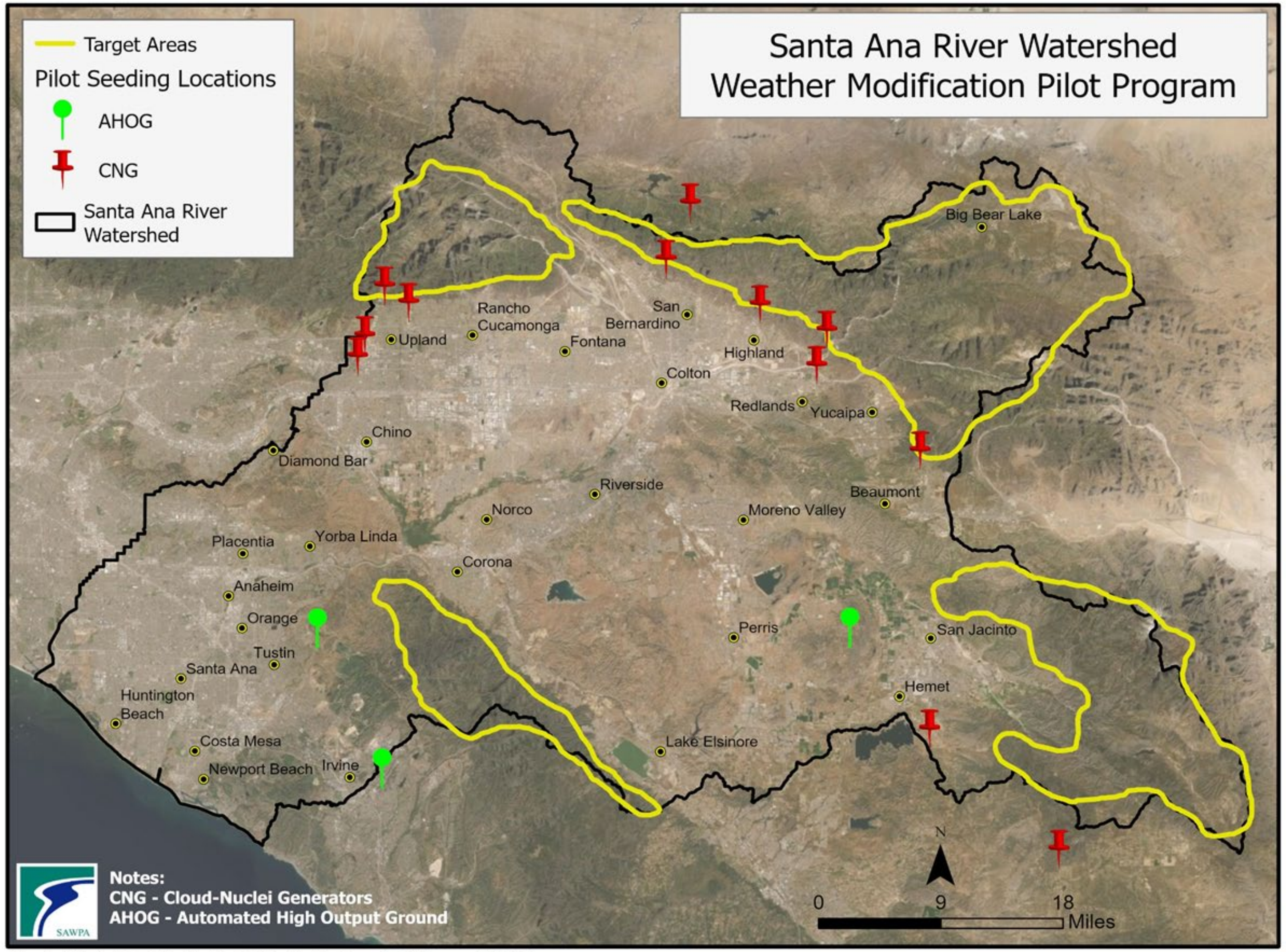
Rachel Gray, *Water Resource & Planning Manager*
Santa Ana Watershed Project Authority

Santa Ana River Weather Modification Pilot Program

Rachel Gray
Water Resources and Planning Manager

Pilot Project Overview

- Feasibility Study (2020)
- Pilot Program Proposal (2022)
  - North American Weather Consultants (NAWC) selected
- Pilot Program
  - 4-year study
  - 4 Target Areas (NW, NE, SW, SE)
  - Use of ground-seeding units (15)
  - Use of Validation Study to assess increases in precipitation
  - Communications Plan



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Agency Funding Partners

SAWPA Member Agencies	Big Bear City Community Services District	Big Bear Lake Department of Water & Power
Chino Basin Water Conservation District	City of Corona Utilities Department	City of Santa Ana Municipal Utility Services
Lake Elsinore and San Jacinto Watersheds Authority	San Antonio Water Company	San Gorgonio Pass Water Agency

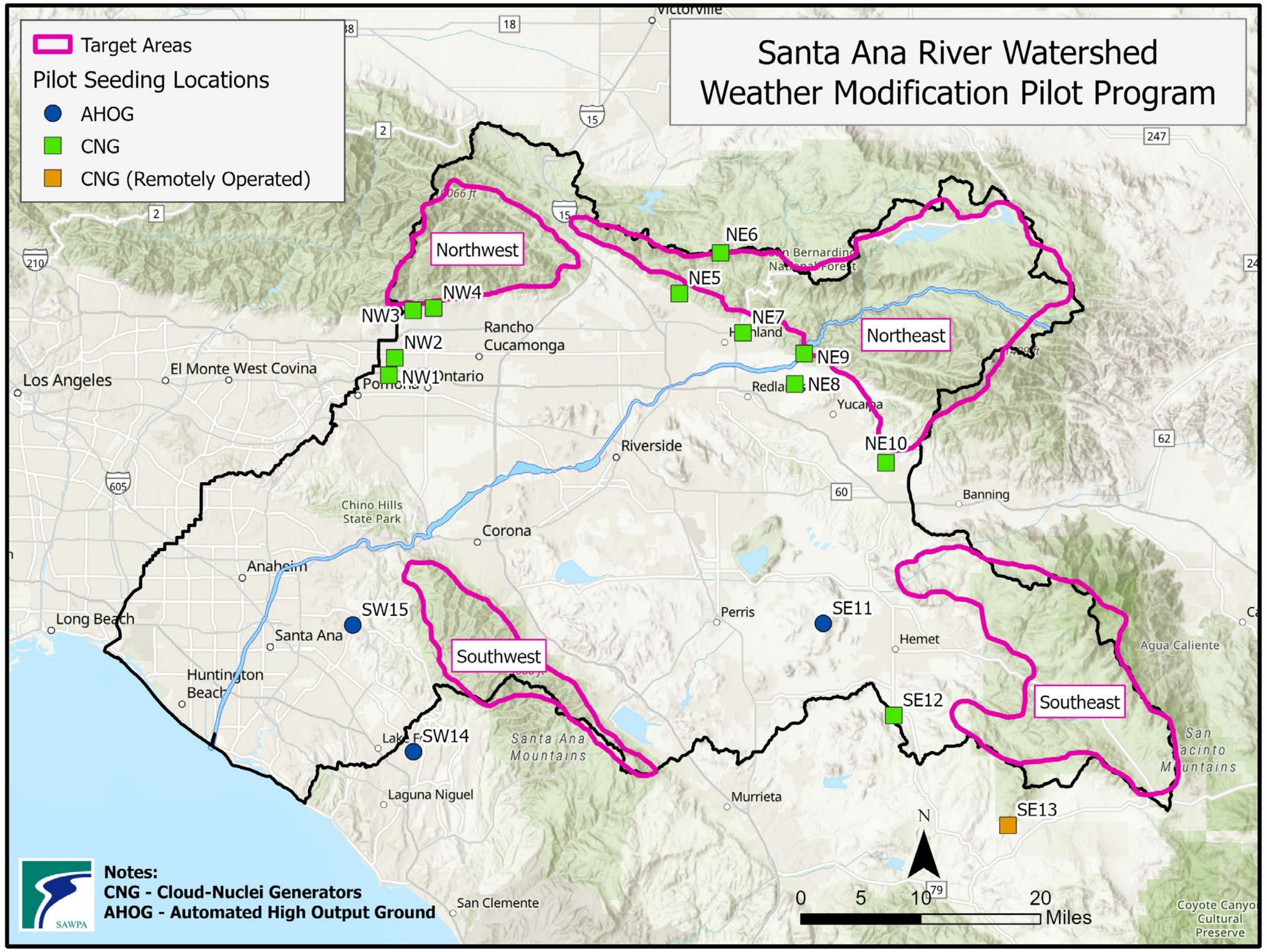
DWR Funding

Proposition 1 Round 2 Grant

In April 2023, SAWPA was notified by the Department of Water Resources (DWR) that the Pilot Program will receive a grant valued at $861,400 under the Proposition 1 Round 2 funding program.

Cloud Seeding Ground-Based Unit Locations

Site (15)	Sponsors (11)
Northwest	
NW1	Chino Basin Water Conservation District
NW2	
NW3	San Antonio Water Company
NW4	
Northeast	
NE5	City of San Bernardino MWD
NE6	Private Landowner
NE7	San Bernardino Valley MWD
NE8	San Bernardino Valley Water Conservation District
NE9	
NE10	San Gorgonio Pass Water Agency
Southeast	
SE11	Eastern Municipal Water District
SE12	
SE13	Private Landowner
Southwest	
SW14	El Toro Water District
SW15	East Orange County Water District



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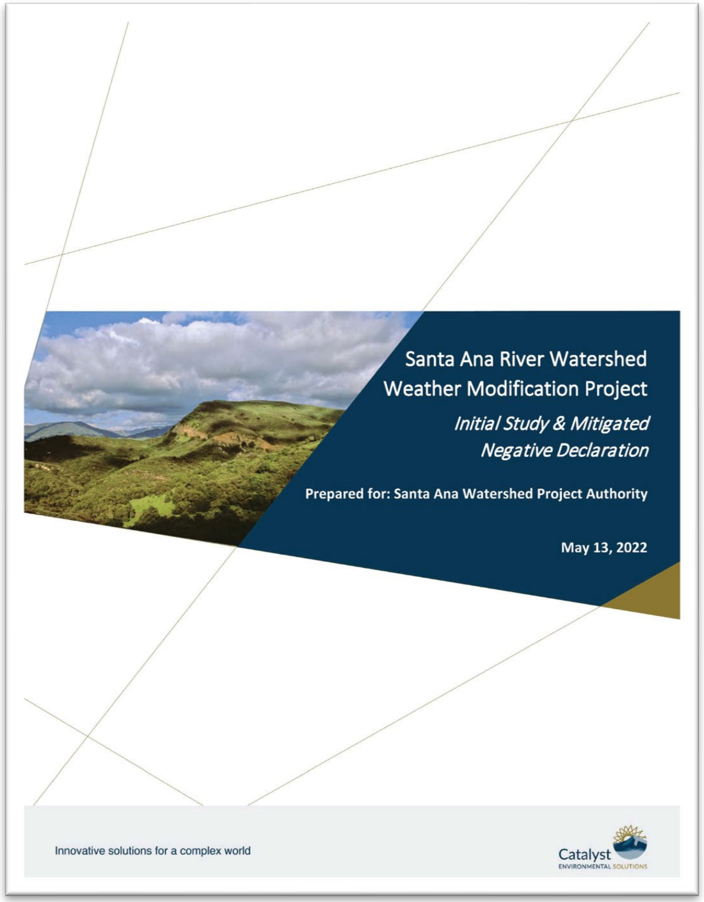
CEQA Requirements

Mitigation Measures:

- **BIO-1.** A qualified botanist will conduct pre-construction clearance surveys within 10 days prior to the start of construction.
- **BIO-2.** The nesting season generally occurs from February 1 to September 15. Pre-construction nesting bird surveys will be conducted by a qualified biologist no more than 14 days before initiation of any construction activities.
- **CUL-1.** In the event that any archaeological features are discovered during installation, all work shall stop within a 60-foot buffer of the find, and a qualified archaeologist shall be notified.
- **TCR-1.** SAWPA shall prepare and implement an Unanticipated Discoveries Plan prior to installing any of the cloud seeding units.



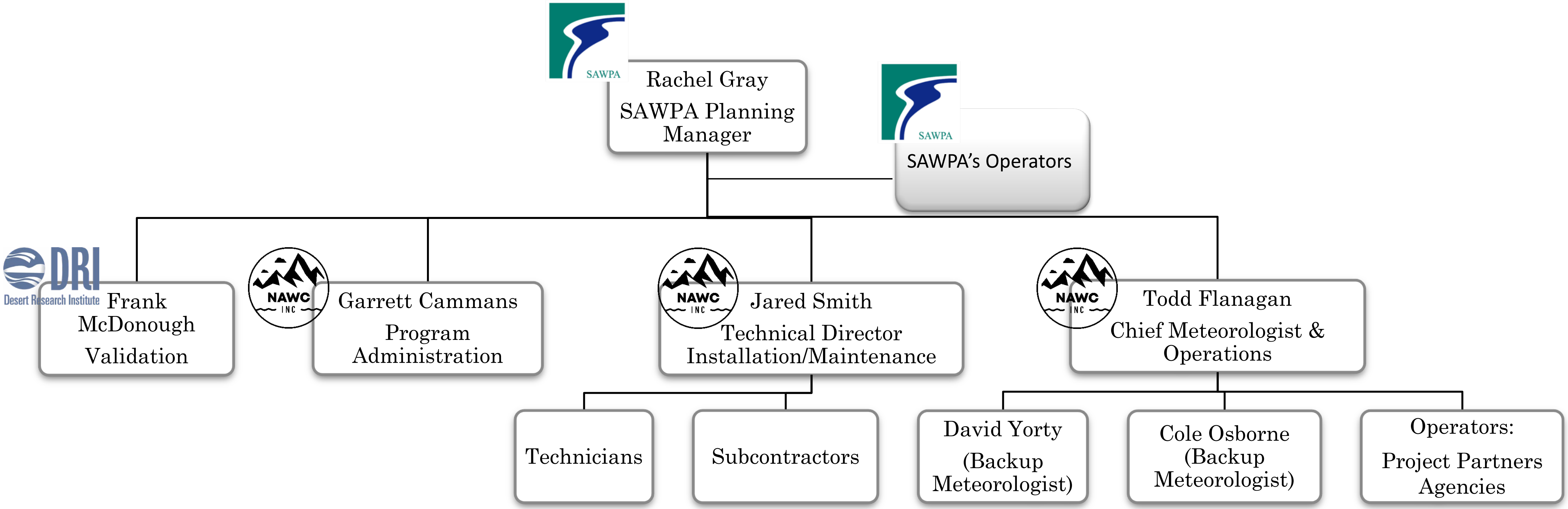
Preliminary Biological Review Results

- Preliminary Biological Survey
  - Conducted by Blue Consulting Group (July 2023)
  - No significant findings were identified
- Comments provided:
  - No special status plant species were observed
  - All locations were classified as disturbed or developed
  - SE-11 (EMWD northern site): adjacent to Chaparral but site is disturbed
  - SE-12 (EMWD southern site)
    - Original location had Coastal Sage Scrub on slope on south side of the water tank
    - Location relocated to the north side of the water tank

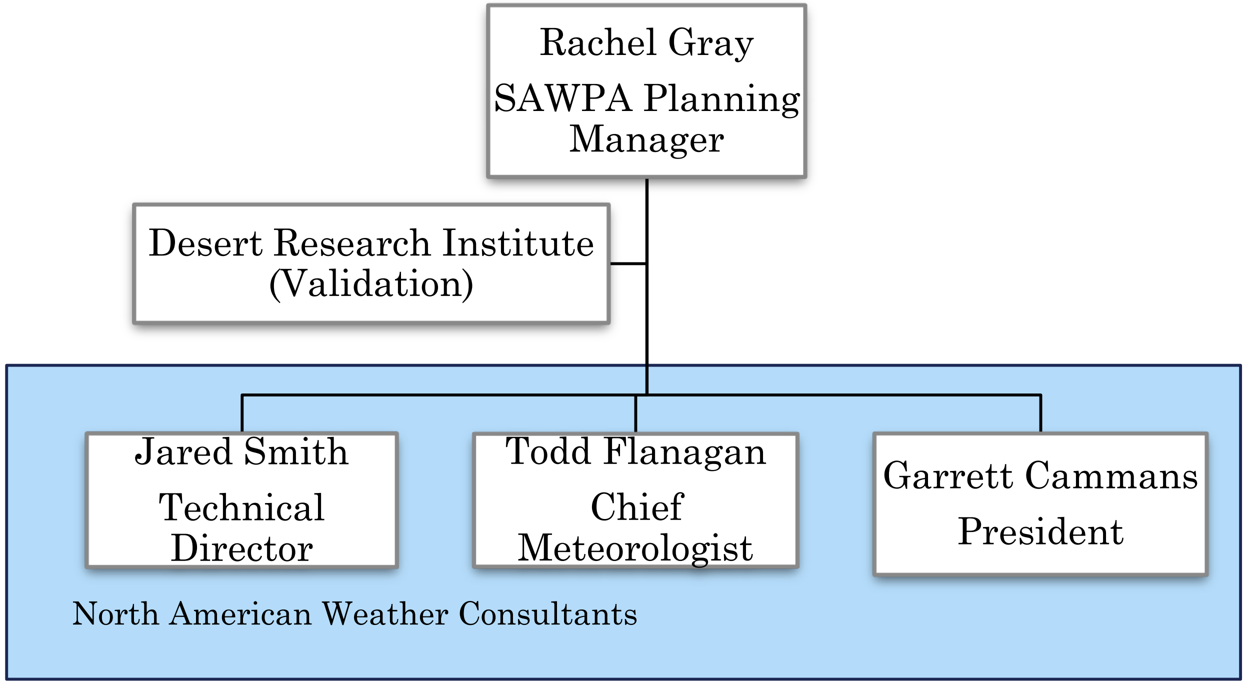
Final Biological Review Results

- Final Biological Survey
  - Conducted by Blue Consulting Group (October 2-3, 2023)
  - No significant findings were identified
- Comments Provided:
  - No special status plant species were observed.
  - No sensitive habitat was observed within the footprint of the proposed weather stations.
  - No potential impacts to sensitive plants/animal species will occur.

Project Team



NAWC Operations Plan



OPERATIONS PLAN FOR:

Weather Modification Pilot Program for the Santa Ana River Watershed

PREPARED FOR:

Santa Ana Watershed Project Authority

11615 Sterling Avenue
Riverside, CA 92503

SAWPA

PREPARED BY:

North American Weather Consultants, Inc.

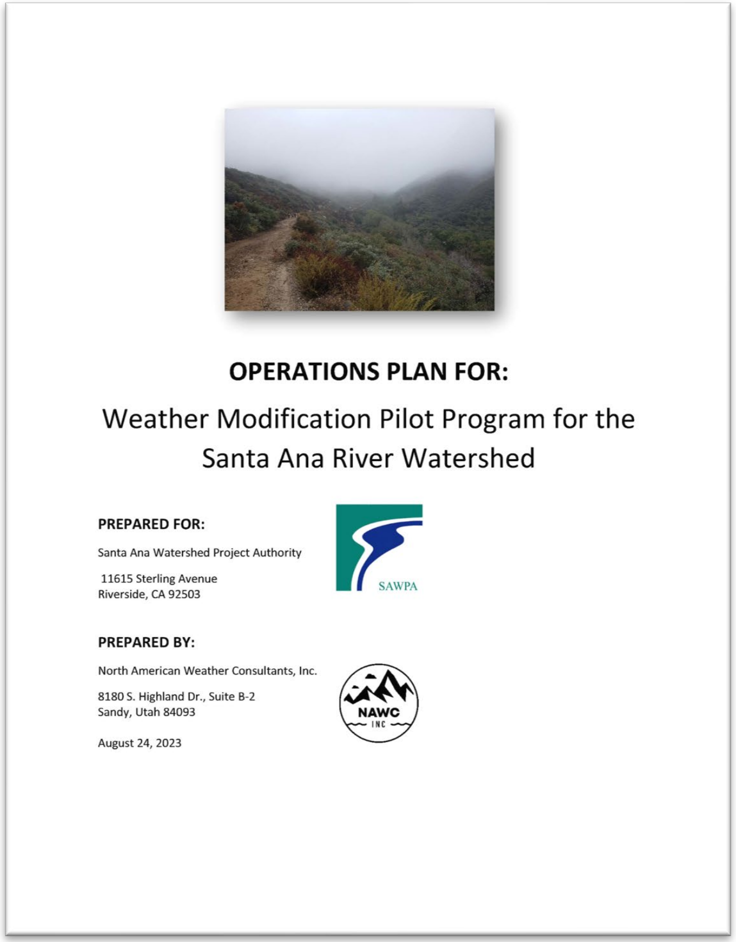
8180 S. Highland Dr., Suite B-2
Sandy, Utah 84093

NAWC INC

August 24, 2023

NAWC Operations Plan – Topics

- Operational Criteria
  - Generalized Cloud Seeding Criteria: Storm Conditions
  - Site-specific Seeding Criteria
  - Meteorological Data and Computer Modeling Data to Assess Criteria
- Seeding Suspension Criteria
  - Flooding
  - Severe Weather
  - Burn Areas
- Project Communication
  - NAWC/SAWPA
  - NAWC/Site Operators



OPERATIONS PLAN FOR:

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SAWPA

PREPARED BY:

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8180 S. Highland Dr., Suite B-2
Sandy, Utah 84093

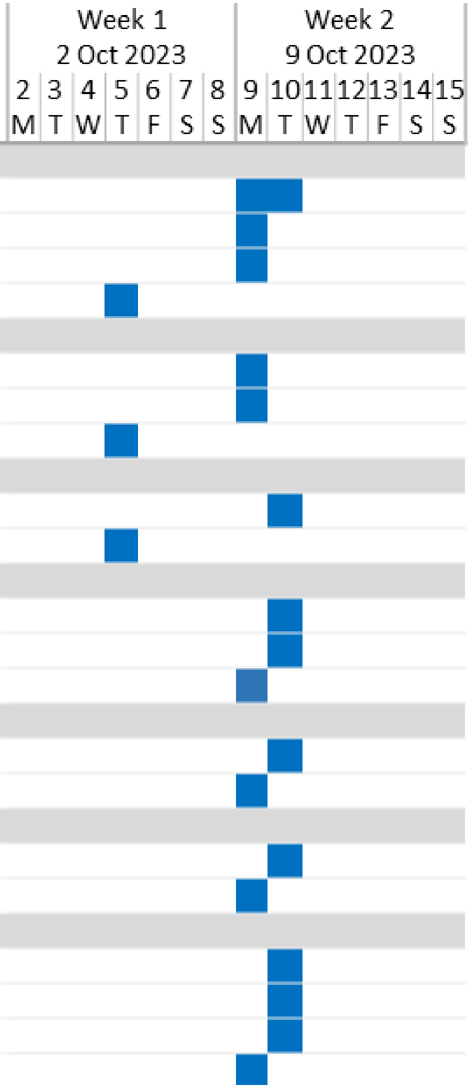
NAWC INC

August 24, 2023

Schedule: Site Improvements and Installation

Project Start Date	10/5/2023 (Thursday)
Project Lead	Jared
Display Week	1

SITE	TASK	Team	START	END	DAYS	% DONE	WORK DAYS
1 & 2	**NW1 & NW2 - Chino Basin Water Conservation District-CNG**			-			-
	NW1 Chain Link Fence Install with concrete	1	Mon 10/09/23	Tue 10/10/23	5	0%	2
	NW1 Combo Lock install/daisy chain	1	Mon 10/09/23	Mon 10/09/23	5	0%	1
	NW1 Equipment Install	1	Mon 10/09/23	Mon 10/09/23	4	0%	1
	NW1 Biologist Review		Thu 10/05/23	Thu 10/05/23	4	0%	1
3 & 4	**NW3 & NW4 - San Antonio Water Company-CNG Friday Access**						-
	NW3 Install Combination lock on Entry Gate	1	Mon 10/09/23	Mon 10/09/23	4	0%	1
	NW3 Equipment Install	1	Mon 10/09/23	Mon 10/09/23	3	0%	1
	NW3 Biologist review		Thu 10/05/23	Thu 10/05/23	3	0%	1
5	**NE5-SBMWD-CNG**						-
	NE5 Equipment Install	1	Tue 10/10/23	Tue 10/10/23	1	0%	1
	NE5 Biologist Review		Thu 10/05/23	Thu 10/05/23	1	0%	1
6	**NE6-Rim Forest-CNG**						-
	NE6 Equipment Install	1	Tue 10/10/23	Tue 10/10/23	1	0%	1
	NE6 Install Fence with privacy screen	1	Tue 10/10/23	Tue 10/10/23	1	0%	1
	NE6 Biologist Review		Mon 10/9/23	Mon 10/09/23	1	0%	1
7	**NE7-SBVMWD-CNG**						-
	NE7 Equipment Install	1	Tue 10/10/23	Tue 10/10/23	1	0%	1
	NE7 Biologist Review		Mon 10/09/23	Mon 10/09/23	1	0%	1
8	**NE8-SBVWCD Maintenance Yard-CNG**						-
	NE8 Equipment Install	1	Tue 10/10/23	Tue 10/10/23	1	0%	1
	NE8 Biologist review		Mon 10/09/23	Mon 10/09/23	1	0%	1
9	**NE9-SBVWCD Santa Ana Diversion Structure-CNG Friday access**						-
	NE9 Chain Link Install	1	Tue 10/10/23	Tue 10/10/23	1	0%	1
	NE9 Combination lock installed	1	Tue 10/10/23	Tue 10/10/23	1	0%	1
	NE9 Equipment Install	1	Tue 10/10/23	Tue 10/10/23	1	0%	1
	NE9 Biologist Review	1	Mon 10/09/23	Mon 10/09/23	1	0%	1



Schedule: Site Improvements and Installation

Project Start Date 10/5/2023 (Thursday)
Project Lead Jared
Display Week 1

Week 1 — 2 Oct 2023; Week 2 — 9 Oct 2023

SITE	TASK	Team	START	END	DAYS	% DONE	WORK DAYS
10	**NE10-San Gorgonio Pass Water Agency-CNG**						-
	NE10 Install chain Link Fence	2	Tue 10/10/23	Thu 10/12/23	1	0%	3
	NE10 10x10 Concrete pad installed	2	Tue 10/10/23	Thu 10/12/23	1	0%	3
	NE10 Install combination lock/daisy chain	2	Tue 10/10/23	Tue 10/10/23	1	0%	1
	NE10 Install equipment	2	Thu 10/12/23	Thu 10/12/23	1	0%	1
	NE10 Biologist Review		Mon 10/09/23	Mon 10/09/23	1	0%	1
11	**SE11-Eastern Municipal Water District-AHOG Friday access**						-
	SE11 Install combination lock/daisy chain	2	Thu 10/12/23	Thu 10/12/23	1	0%	1
	SE11 Install Chain Link fence enclosure with Privacy Screen	2	Thu 10/12/23	Thu 10/12/23	1	0%	1
	SE11 Install equipment	2	Thu 10/12/23	Fri 10/13/23	1	0%	2
	SE11 Biologist Review		Tue 10/10/23	Tue 10/10/23	1	0%	1
12	**SE12-Eastern Municipal Water District-Remote CNG**						-
	SE12 Combination lock/daisy chain	1	Wed 10/11/23	Wed 10/11/23	1	0%	1
	SE12 Install chain link fence enclosure	1	Wed 10/11/23	Wed 10/11/23	1	0%	1
	SE12 Install equipment	1	Wed 10/11/23	Wed 10/11/23	1	0%	1
	SE12 Biologist Review		Tue 10/10/23	Tue 10/10/23	1	0%	1
13	**SE13-Mary Lea Garginer-CNG**						-
	SE13 Install equipment	1	Wed 10/11/23	Wed 10/11/23	1	0%	1
	SE13 Biologist review	Jared	Tue 10/10/23	Tue 10/10/23	1	0%	1
14	**El Toro Reservoir Water District-AHOG**						-
	SW14 Install equipment	2	Wed 10/11/23	Thu 10/12/23	1	0%	2
	SW14 Biologist review		Tue 10/10/23	Tue 10/10/23	1	0%	1
15	**SW15-East Orange County Water District-AHOG - cut asphalt**						-
	SW15 Install Equipment	2	Wed 10/11/23	Thu 10/12/23	1	0%	2
	SW15 Biologist Review		Tue 10/10/23	Tue 10/10/23	1	0%	1

Timeline of Key Tasks

Task	Completion Date or Time Period
Preliminary Biological Surveys	July 31, 2023
45 Day Public Notice Submission	September 14, 2023
Biological Surveys Before Equipment Set Up	October 2 and 3, 2023
Propane Tank Placement	October 3 – October 9, 2023
Equipment Set Up and Testing	October 5 - October 31, 2023
Operator Training	October 31, 2023
Seasonal Program Kick Off Meeting	November 13, 2023
Seasonal Program Start	November 15, 2023
Seasonal Program Operational Period	November 15, 2023 – April 15, 2024
Seasonal Program End	April 15, 2024
Seasonal Equipment Collection Deadline	May 30, 2024
Draft Seasonal Report Delivered	June 1, 2024

Cloud Seeding Independent Validation

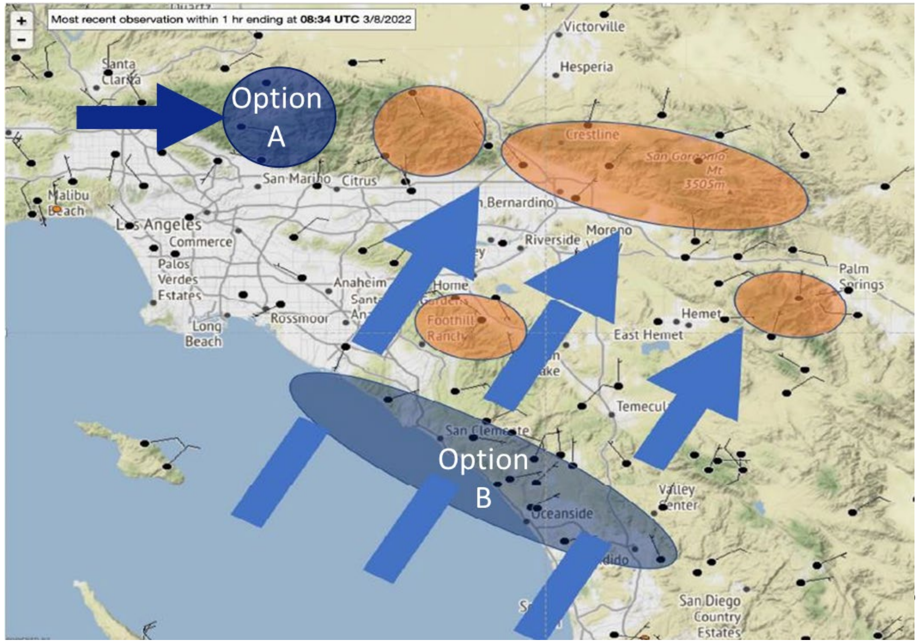
- Validation Consultant
  - Desert Research Institute (Reno, NV)
  - Frank McDonough, Associate Research Scientist
- Purpose
  - Verify deposition of silver iodide
  - Verify increases in precipitation and stream flows
  - Evaluate increases by target areas in watershed
  - Review of operations
  - Review of suspension criteria

DRI
Desert Research Institute

Validation Study Approach (4-Year Study)

- Verify deposition
  - Measure elemental **silver** in snow before and after cloud seeding
- Verify increases in precipitation
  - Compare “Target Areas” to “Control Areas”
  - Two options: A and B
- Outcomes
  - Estimated precipitation increases
  - Estimated stream flow increases
  - Assess benefits/costs

Control Area Options:



SAWPA’s Pilot Program Communications Plan

- Communications with Project Stakeholders
  - Internal SAWPA communications
  - Member Agencies
  - Funding Partners
- Materials
  - Fact Sheet
  - Brochure
  - External FAQ
  - Webpage on SAWPA’s website
- Outreach and Engagement
  - Certain neighborhoods (such as door hangers)
  - Public agencies
  - General public
  - Media


SAWPA

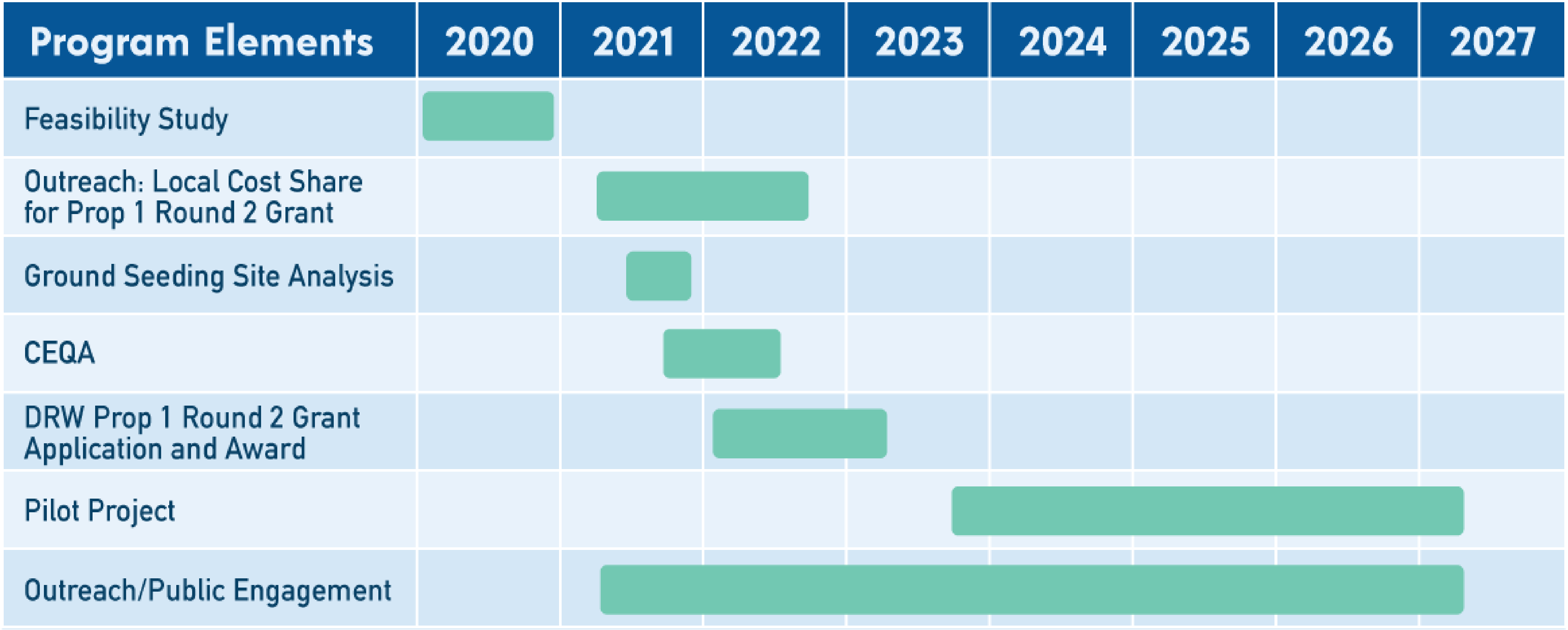
Santa Ana Watershed Project Authority
Santa Ana River Watershed Weather Modification Pilot Program

Communication Work Plan

In Partnership With:

Sponsored By:

Pilot Program Schedule



State of Utah

Jake Serago, P.E, *Water Resource Engineer, Cloud Seeding Program Manager*
Utah Division of Natural Resources

jserago@utah.gov
801-538-7283

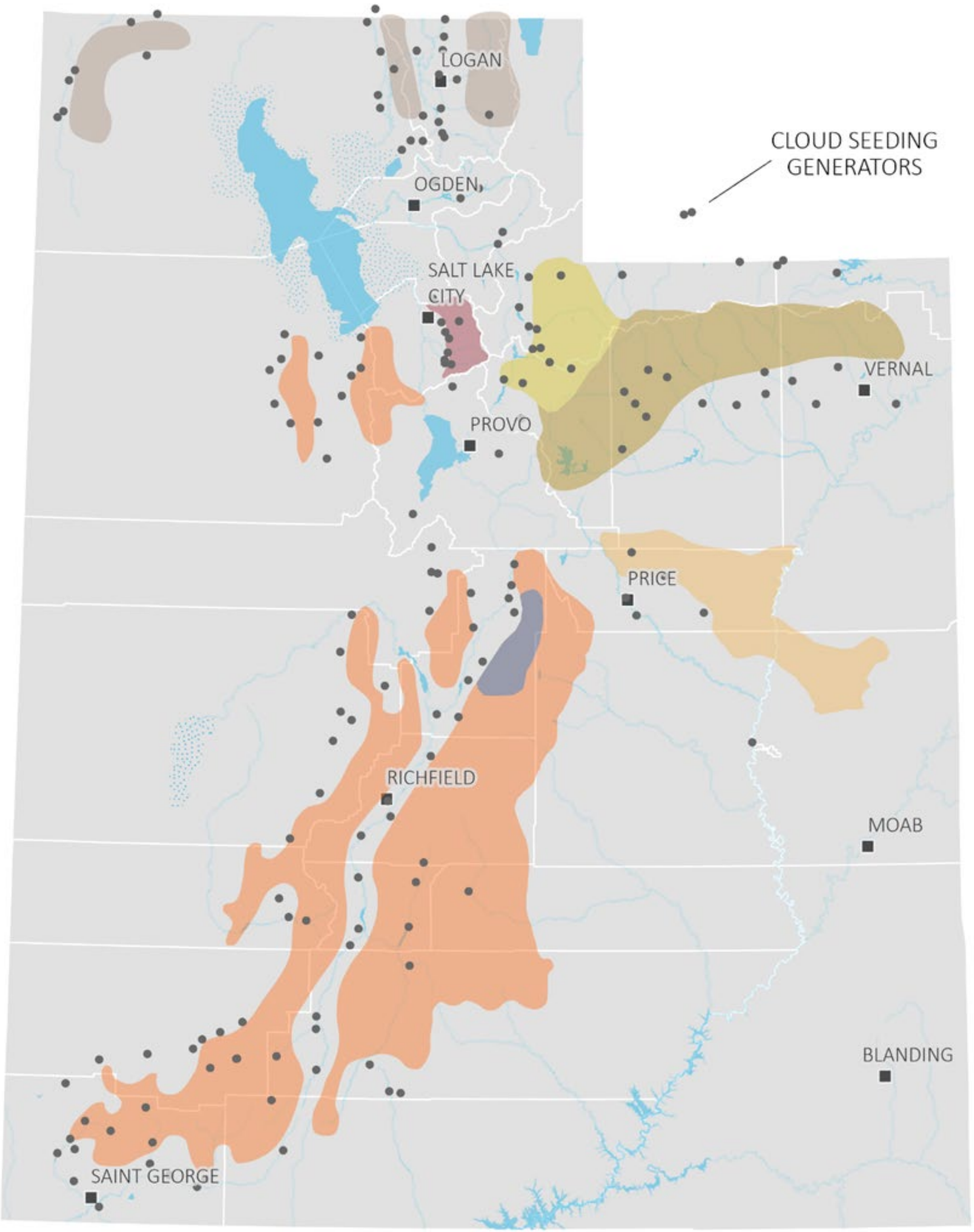
Utah Program History

- 1951 – First cloud seeding project
- 1953 – First legislation
- 1955 – End of first cloud seeding project
- 1973 – Cloud Seeding Act
    - Determined ownership of water
    - Authorizes UDWRe to permit and organize projects
    - UDWRe regulates all cloud seeding activities in Utah
- 2007 – Agreement with Lower Colorado River states
- 2017 – Research partnership with Utah Climate Center
- 2021 – First remote generator from LB
- 2023 – Budget increase; first aerial program

Procedure

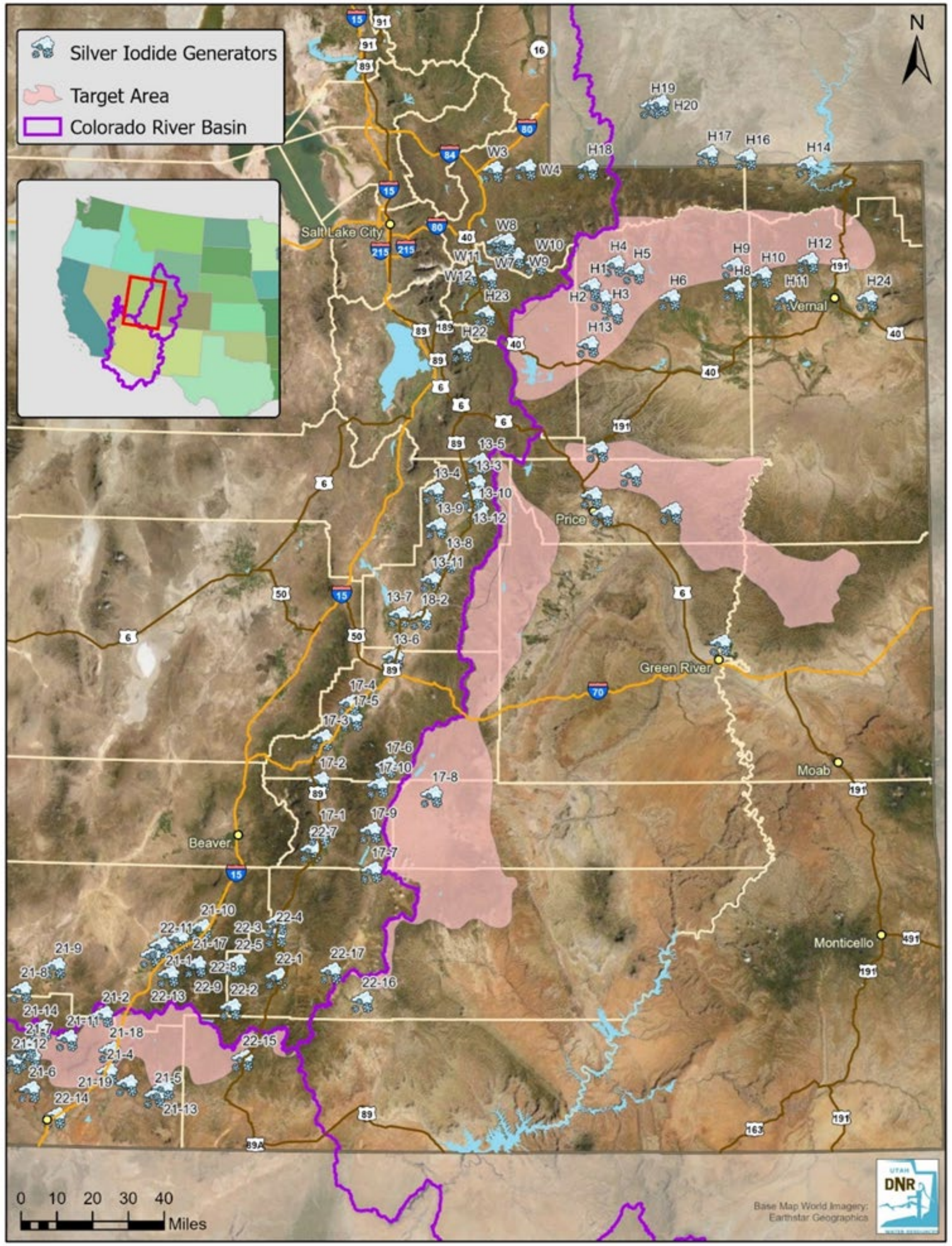
- Inquire interest of (potential) sponsors
- Contract with local program sponsor
- Licensing and permitting
- Monitor activity and snow levels
    - Suspension criteria
- Reimburse sponsors
- Celebrate a massive snow year

Cloud Seeding Project Areas



Local Sponsors

- Cache Water District
- Bear River Water Conservancy District
- Weber Basin Water Conservancy District
- Provo Water Users Association
- Central Utah Water Conservancy District
- Salt Lake Public Utilities
- Emery Water Conservation District
- Utah Water Resource Development Corp.
- Duchesne County Water Conservancy District
- Range Valley Ranch

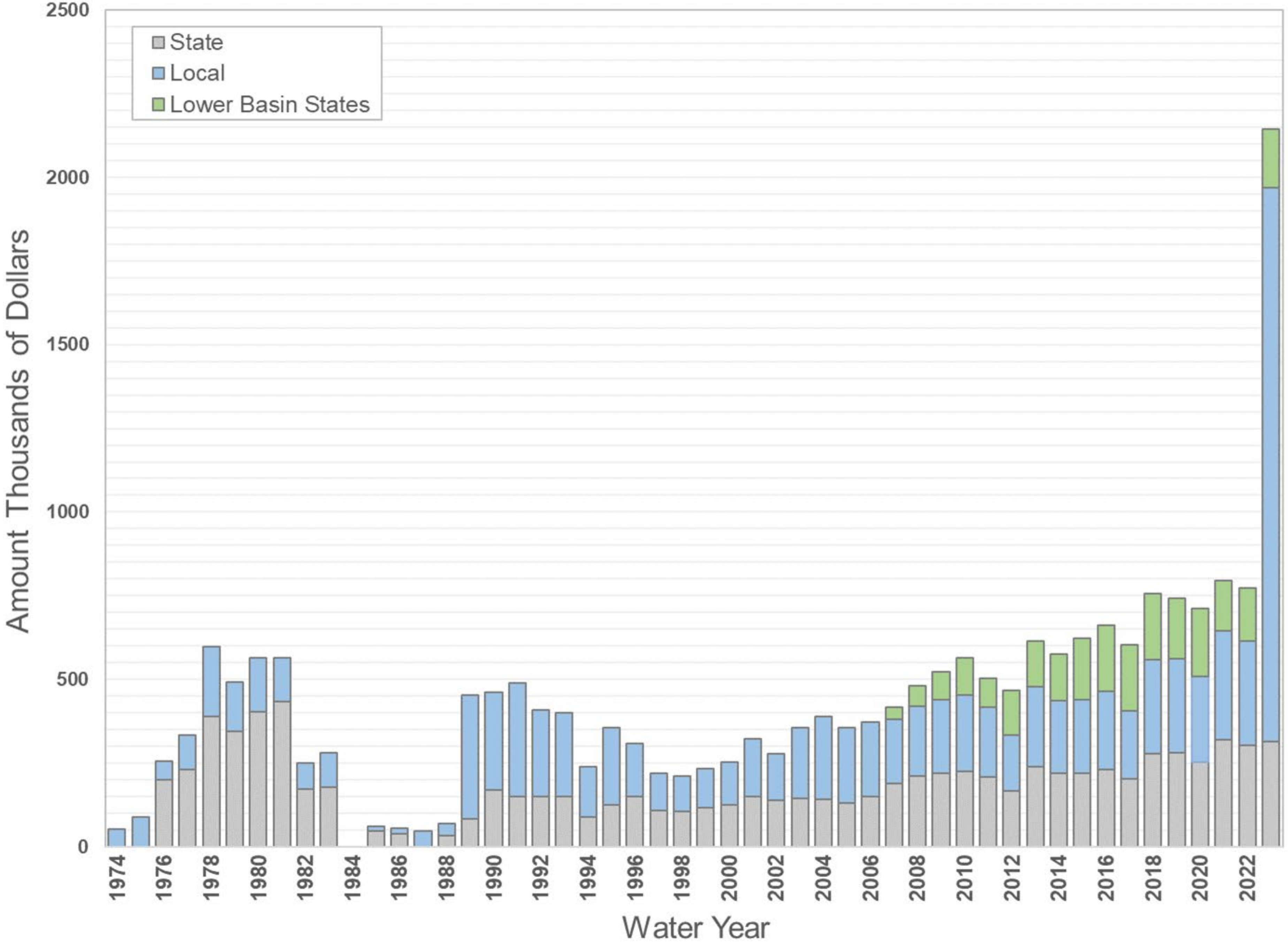


Regional Sponsors

- Southern Nevada Water Authority
- Central Arizona Water Conservation District
- Six Agency Committee of California
- Extensions in Colorado River Basin
- Instrumentation
- Research

2020-2021 CLOUD SEEDING PROGRAM EXPENSE

Program and Sponsor	Program Costs ($)				
	Board	Sponsor	Utah Total	Lower Basin States	
Central	97,790	102,720	200,510	54,980	
Utah Water Resource Development Corp.					
Northern	45,990	45,990	91,980		
Cache County	22,995				
Bear River Water Conservancy District	22,995				
Western Uinta	41,370	41,370	82,740		
Weber Basin Water Conservancy District	20,685				
Provo Water Users Association	10,343				
Central Utah Water Conservancy District	10,343				
High Uinta	49,280	49,280	98,560	18,170	
Central Utah Water Conservancy District	24,640				
Duchesne County Water Conservancy District	12,320				
Uintah Water Conservancy District	12,320				
Six Creeks	41,690	41,690	83,370		
Salt Lake Public Utilities					
Book Cliffs	20,070	20,070	40,140		
Range Creek Properties					
Emery	24,220	24,220	48,450	10,000	
Emery Water Conservation District					
SubTOTAL	**320,410**	**325,340**	**645,750**	**83,150**	
Remote Generator				30,000	
Icing meters				38,000	
SubTOTAL		**0**	**0**	**68,000**	
TOTAL	**320,410**	**325,340**	**645,750**	**151,150**	**796,900**



State
Local
Lower Basin States
Amount Thousands of Dollars
2500
2000
1500
1000
500
0
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Water Year

Cloud Seeding evaluation

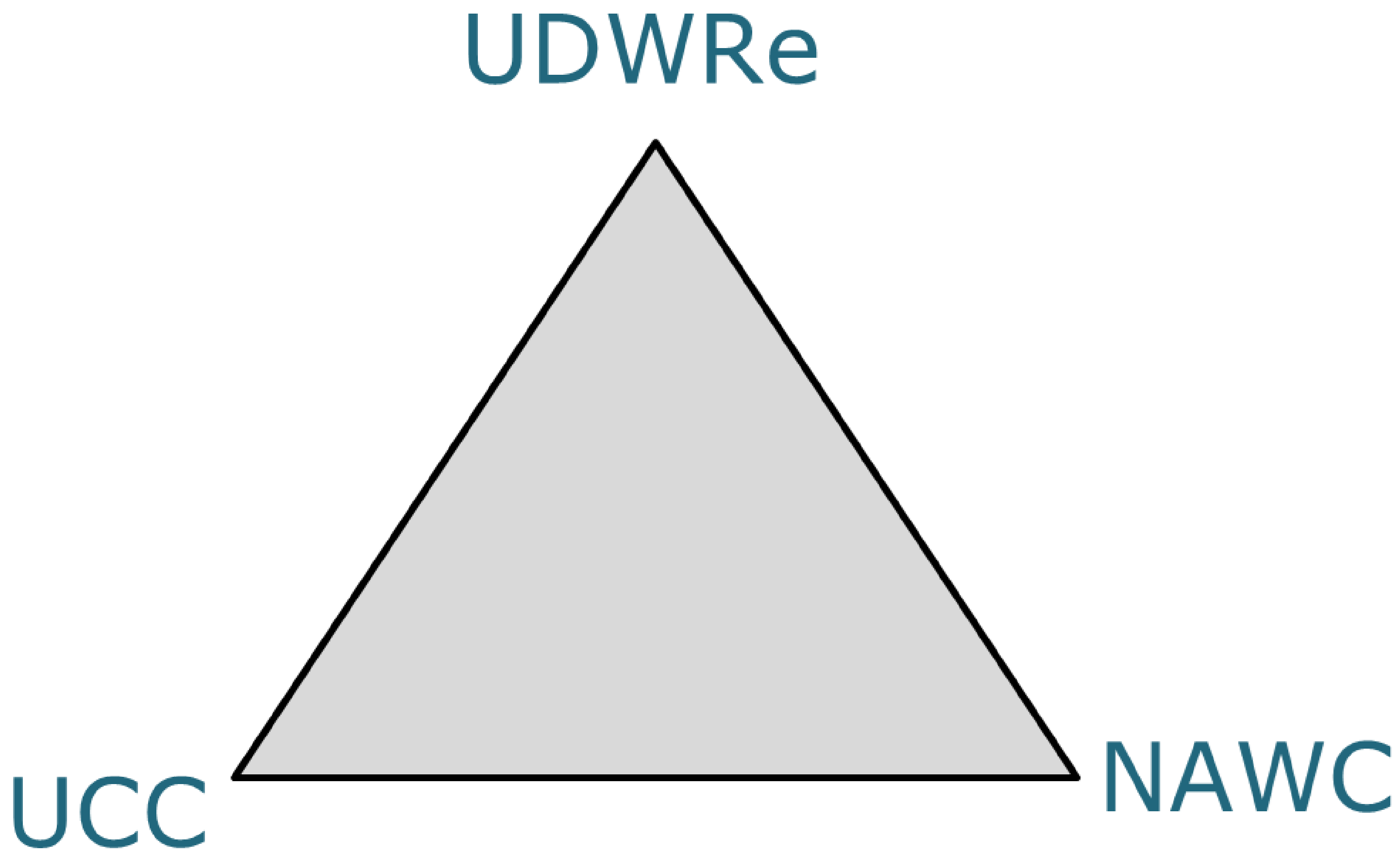
Estimated average annual increase in SWE

Program Area	Seasons Seeded	April 1 SWE Increase
Central/Southern	41	10%
Northern	31	7%
West Uinta	26	6%
High Uinta	32	1%
Six Creeks	3	8%
Statewide		**6%**

Estimated cost per unit increase in runoff volume

Program Areas	Increased Runoff (ac-ft)	Cost	
		$	$/ac-ft
Central/Southern Utah	83,654	169,359	2.02
Northern	50,698	81,929	1.62
West Uintas	22,364	69,753	3.12
South Slope Uinta Mountains	29,947	86,758	2.90
Statewide	**186,663**	**407,799**	**2.41**

Public-Private-University Partnership



2024 Expenditures

- Feasibility study of new target areas
- 40 new remote generators
- Installation of 30 remote generators
- 2 aerial programs
- Upgrade propane program
- New state coordinator
- 60 new manual generators
- Additional cost share

Beyond 2024

- Multi-year field research campaign
- 120 remote generators
- 220 manual generators
- 2+ aerial programs
- All feasible areas
    - GSL drainage basin

State of Idaho

Kala Golden, *Project Manager, Cloud Seeding Program Manager*
Idaho Water Resource Board

Idaho Collaborative Cloud Seeding Program

IDAHO WATER RESOURCE BOARD

Overview

- Water Management in Idaho
- History of Cloud Seeding in Idaho
- Current Projects
- Program Budget
- Priorities & Next Steps

Photo Courtesy of Joel Zimmer, WMI

Water Management in Idaho

Idaho Department of Water Resources

MISSION
To serve the citizens of Idaho by ensuring that water is conserved and available for the sustainability of Idaho's economy, ecosystems, and resulting quality of life.

- Adjudication
- Water Rights
- Floodplain Management
- Groundwater Protection
- Stream Channel Protection
- Water Distribution
- Hydrology
- Geospatial Technology
- Planning & Water Projects
- Regional Operations | Northern, Southern, Eastern, and Western Offices
- Field Offices | Salmon, ID and Preston, ID

IDAHO DEPARTMENT OF WATER RESOURCES

Idaho Water Resource Board

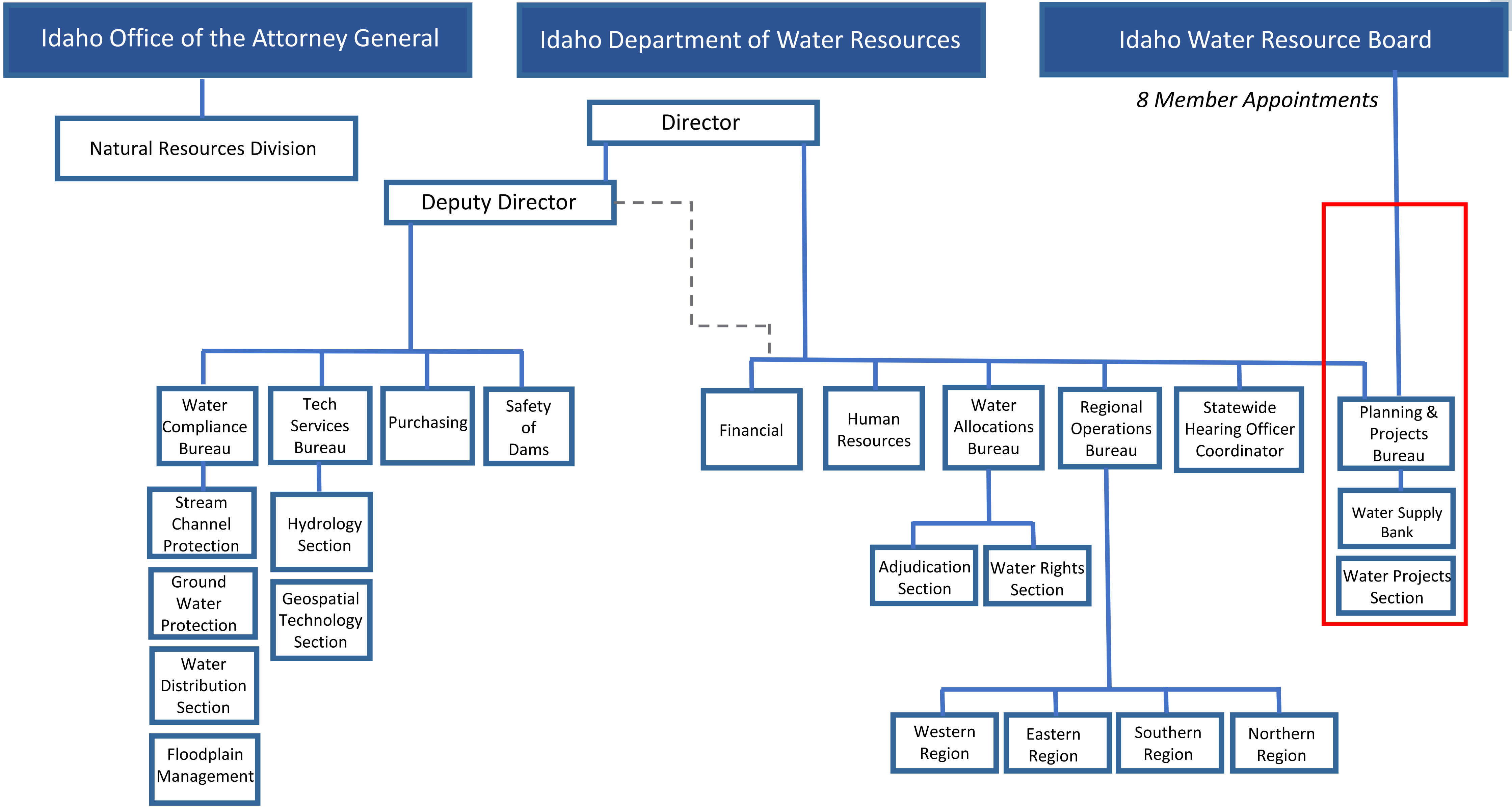
MISSION
Develop and implement actions that promote water sustainability; defined as the active stewardship of Idaho's water resources to support current and future use, in accordance with State law and policy.

- Formulation and implementation of the State Water Plan
- Implementation and financing of large water projects
- Operation of programs that support sustainable management of Idaho's water resources

  - Water Supply Bank
  - Managed Aquifer Recharge
  - Cloud Seeding
  - Water Transactions
  - Financial Programs

IDAHO WATER RESOURCE BOARD

IDAHO DEPARTMENT OF
WATER RESOURCES



History of Cloud Seeding in Idaho

Water Year	Northern Idaho	Southwestern Idaho	Southern Idaho	Southeastern Idaho
1950	-	-	-	-
1951	*	-	-	-
1952	-	-	-	-
1953	*	-	-	-
1954	*	-	*	*
1955	*	*	*	*
1956	*	*	-	*
1957	*	-	-	*
1958	*	-	-	*
1959	*	-	-	*
1960	*	*	-	*
1961	-	*	-	*
1962	-	*	-	*
1963	-	-	-	*
1964	-	-	-	*
1965	-	-	-	*
1966	-	-	-	*
1967	*	-	-	*
1968	*	-	-	*
1969	*	-	-	*
1970	*	-	-	*
1971	*	-	-	-
1972	-	-	-	-
1973	-	-	-	-
1974	*	-	-	-
1975	-	-	-	-
1976	-	-	-	-
1977	-	-	-	-
1978	-	-	-	-
1979	-	-	-	-
1980	-	-	-	*
1981	-	-	-	*
1982	-	-	-	*
1983	-	-	-	-
1984	-	-	-	-
1985	-	-	-	-

Water Year	Payette	Boise	Wood	Northern Upper Snake	Southern/Eastern Upper Snake
1986	-	-	-	-	-
1987	-	-	-	-	-
1988	-	-	-	-	-
1989	-	-	-	*	*
1990	-	-	-	-	*
1991	-	-	-	-	-
1992	-	-	-	-	*
1993	-	*	-	*	*
1994	-	*	-	-	-
1995	-	*	-	-	*
1996	-	*	-	-	-
1997	*	-	-	* | LIS, $	-
1998	-	-	-	* | LIS, $	-
1999	-	-	-	* | LIS, $	-
2000	-	-	-	* | LIS, $	-
2001	-	-	-	* | LIS, $	-
2002	-	*	-	* | LIS, $	* | LIS, $
2003	* | IPC	*	-	-	* | LIS, $
2004	* | IPC	*	-	* | LIS, $	* | LIS, $
2005	* | IPC	*	-	-	* | LIS, $
2006	* | IPC	-	-	* | LIS, $	-
2007	* | IPC	-	-	* | LIS, $	-
2008	* | IPC	*	-	* | LIS, IPC, $	* | LIS, IPC, $
2009	* | IPC	*	-	* | LIS, IPC, $	* | LIS, IPC, $
2010	* | IPC	-	-	* | LIS, IPC, $	* | LIS, IPC, $
2011	* | IPC	*	-	* | LIS, IPC, $	* | LIS, IPC, $
2012	* | IPC	*	-	* | LIS, IPC, $	* | LIS, IPC, $
2013	* | IPC	-	* | IPC, $	* | LIS, IPC, $	* | LIS, IPC, $
2014	* | IPC	*	* | IPC, $	* | LIS, IPC, $	* | LIS, IPC, $
2015	* | IPC	* | IPC, $	* | IPC, $	* | LIS, IPC, $	* | LIS, IPC, $
2016	* | IPC	* | IPC, $	* | IPC, $	* | LIS, IPC, $	* | LIS, IPC, $
2017	* | IPC	* | IPC, $$	* \| IPC, $$	* | LIS, IPC, $$	* \| LIS, IPC, $$
2018	* | IPC	* | IPC, $$	* \| IPC, $$	* | LIS, IPC, $$	* \| LIS, IPC, $$
2019	* | IPC	* | IPC, $$	* \| IPC, $$	* | LIS, IPC, $$	* \| LIS, IPC, $$
2020	* | IPC	* | IPC, $$	* \| IPC, $$	* | LIS, IPC, $$	* \| LIS, IPC, $$
2021	* | IPC	* | IPC, $$	* \| IPC, $$	* | LIS, IPC, $$	* \| LIS, IPC, $$
2022	* | IPC	* | IPC, $$	* \| IPC, $$	* | LIS, IPC, $$	* \| LIS, IPC, $$
2023	* | IPC	* | IPC, $$	* \| IPC, $$	* | LIS, IPC, $$	* \| LIS, IPC, $$

* Cloud Seeding Ops; Idaho Power Company (IPC); Let it Snow (LIS) ; $ Stakeholder Funding ; $ State Funding

What is Idaho's Collaborative Cloud Seeding Program?

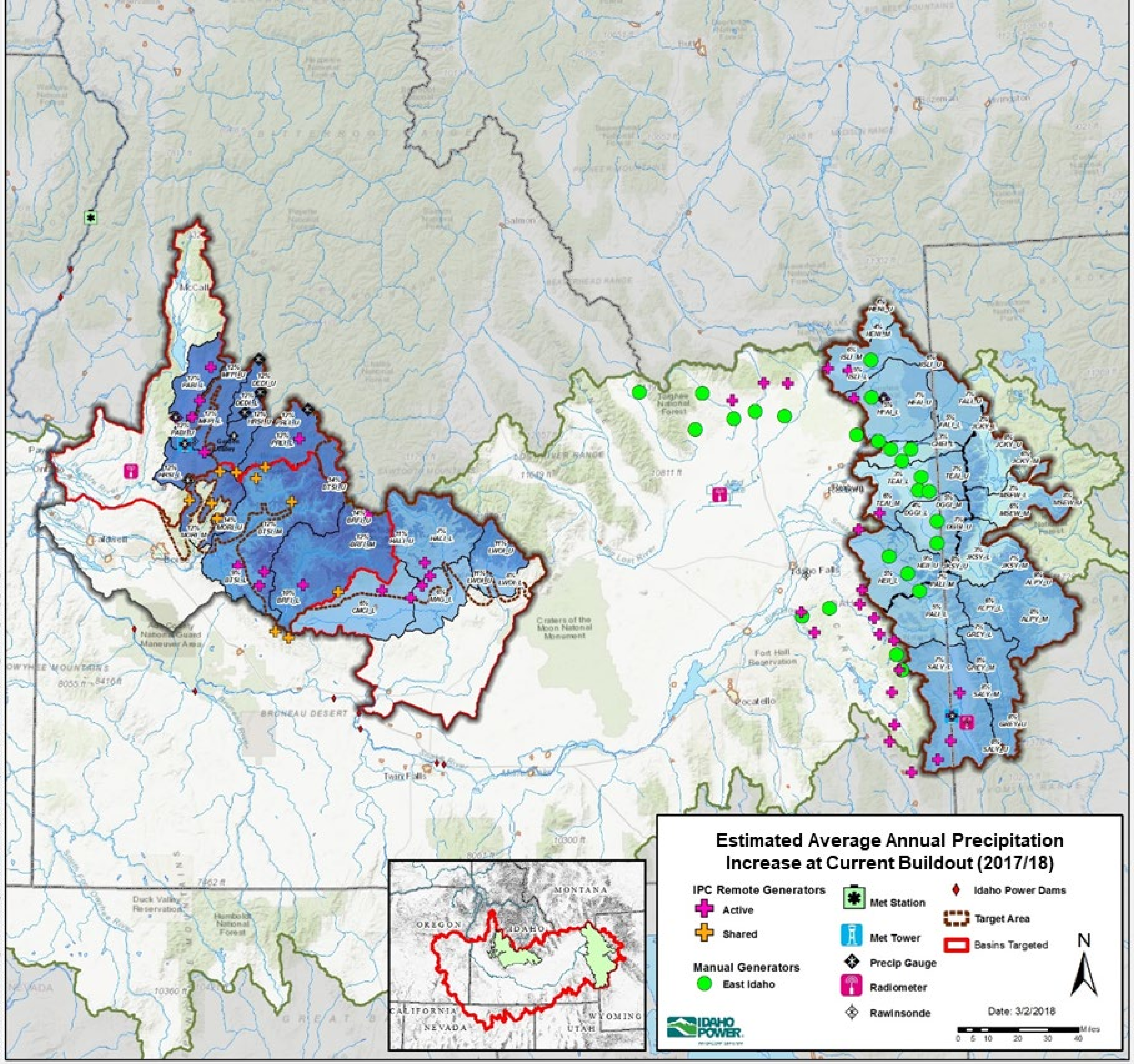
- Unique partnership between:
  - Idaho Water Resource Board (IWRB)– State of Idaho
  - Idaho Power Company (IPC)
  - Stakeholders/Local water users in basins of operation
- IPC operates the program, the State and local water users participate in program funding
- Currently includes the Boise, Wood, Upper Snake River Basins of Idaho
- IPC operates independent project in the Payette River Basin, in coordination with the collaborative program.

History of the Collaborative Program

- 1990's, Idaho Power Company (IPC) began investigating cloud seeding to support hydropower
- 2003, first operational program in the Payette River Basin– IPC
- 2008, ESPA CAMP → implementation of 5-year pilot project in the Upper Snake Basin– IPC
- Water users in the Wood and Boise River Basins partnered with IPC to begin new projects
- 2014, the IWRB began participation in program funding with capital for new infrastructure
- 2016, the IWRB began contributing towards program operations and modeling
- 2019, program reached existing build-out (3 aircraft, 57 remote generators, network of weather instrumentation)

Idaho Collaborative Cloud Seeding Program

- 57 Remote Ground Generators
- 3 Aircraft
- Network of Weather Instrumentation
- Sophisticated Modeling technologies
- Atmospheric Science Team



Cloud Seeding Infrastructure

Remote Ground Generators

Aircraft

Burn-in-Place (BIP) flares are released in cloud

Ejectable (EJ) flares are released above cloud

Images Courtesy of Idaho Power Company and Ice Crystal Engineering

Cloud Seeding Infrastructure

Weather Instrumentation

Wind Direction?

Wind Speed?

SLW Content?

Temperatures?

Atmospheric?

Pressure?

SWE?

More…

Images Courtesy of Idaho Power Company

Program Operations

- Guidelines for the operation of cloud seeding– American Society of Civil Engineers (ASCE)
- Annual Operational Planning
  - When, Where, How, Communications
  - Suspension Criteria to mitigate risks for flooding/avalanche or other hazards
- Forecasting & Analysis
  - Weather Instrumentation (precipitation gages, balloons, radiometers, etc.)
  - High Resolution modeling, WRF Models
- Supported by team of atmospheric scientists, 24-7

West Central Mountains Projects

Estimated Average Additional Runoff (unregulated) &

Current Project Costs (Annually)

Boise River Basin– 273 KAF | $910K

Wood River Basin – 112 KAF | $670K

Payette River Basin* – 223 KAF | $870K

WCM Total: 608KAF |$2.45M

**Independent project operated by Idaho Power Company in coordination with the Collaborative. 100% Funded by IPC.*

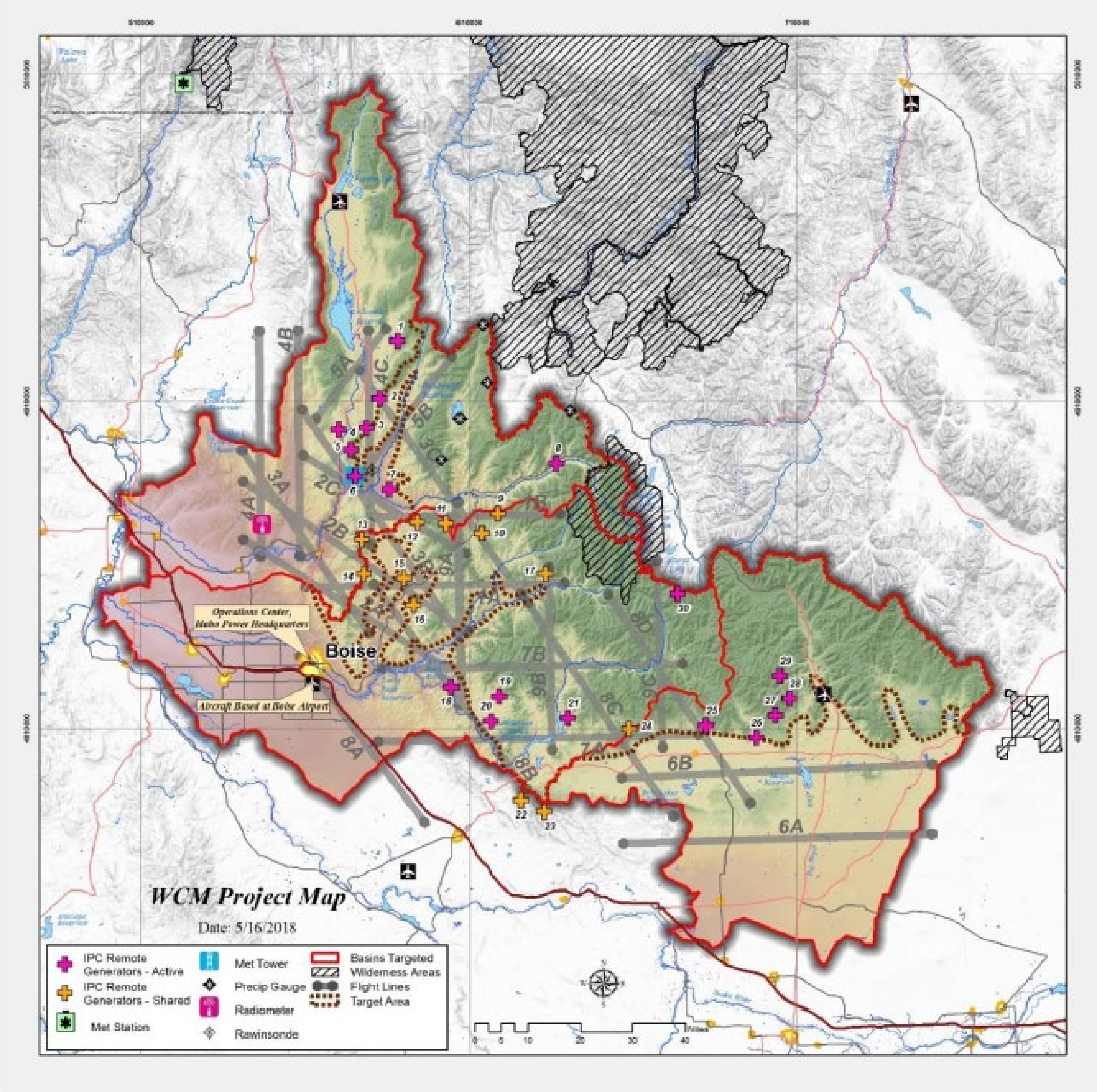
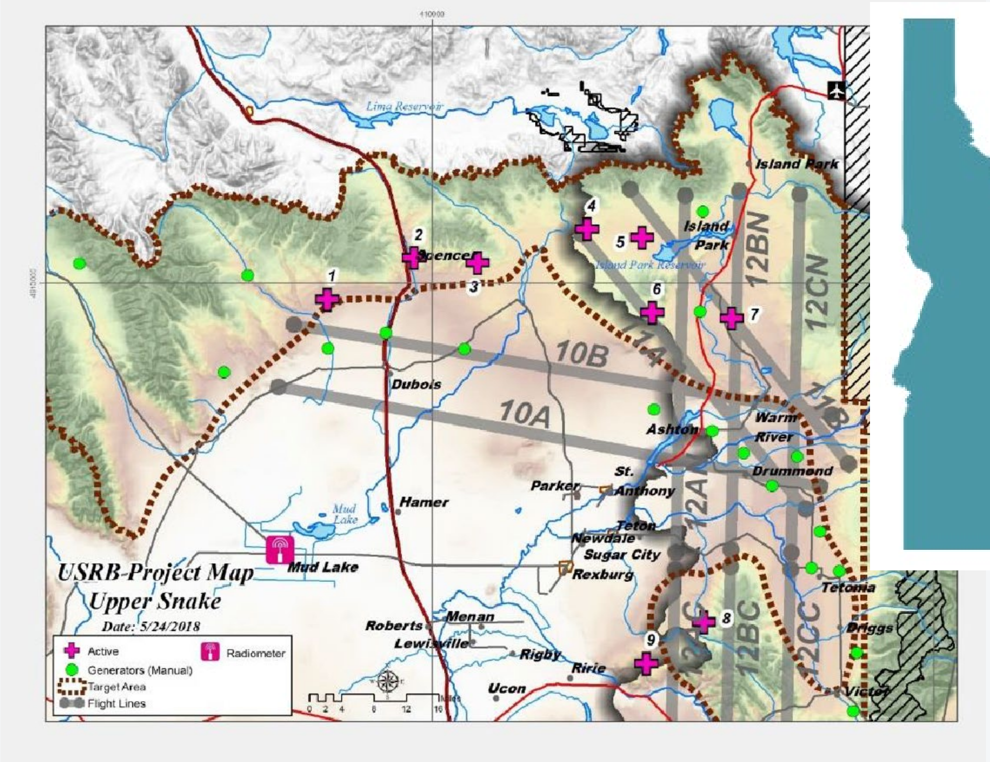


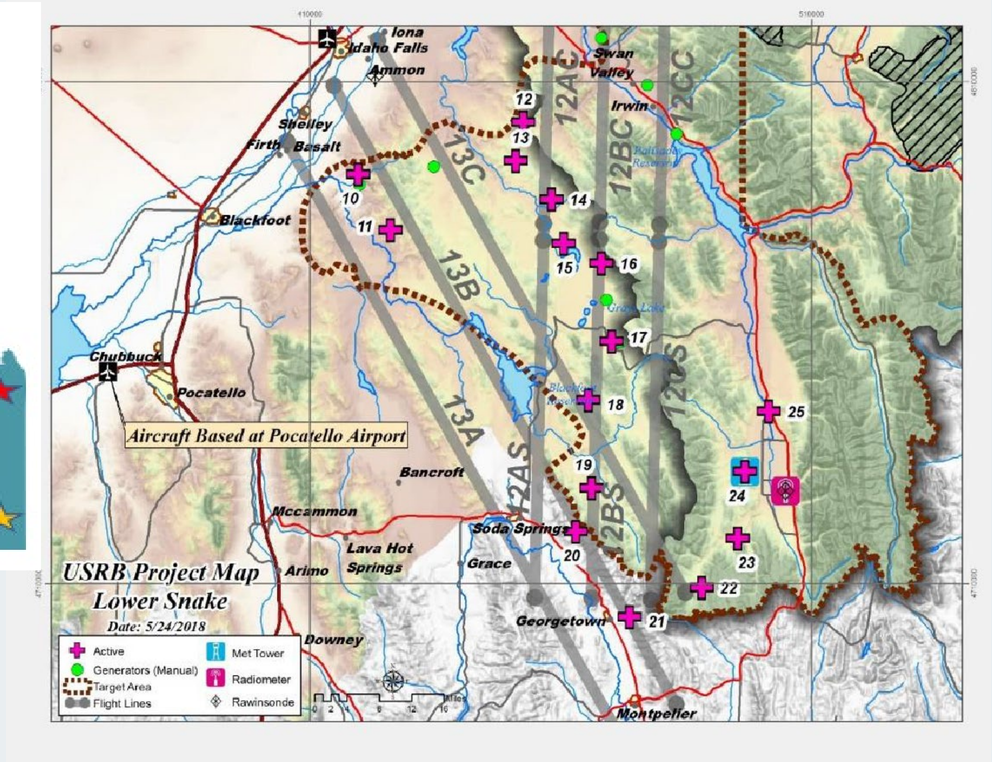
Figure 5: Central Mountains Cloud Seeding Project

Upper Snake River Basin Projects

Northern Upper Snake | 168 KAF Avg Annual



Southern Upper Snake | 464 KAF Avg Annual



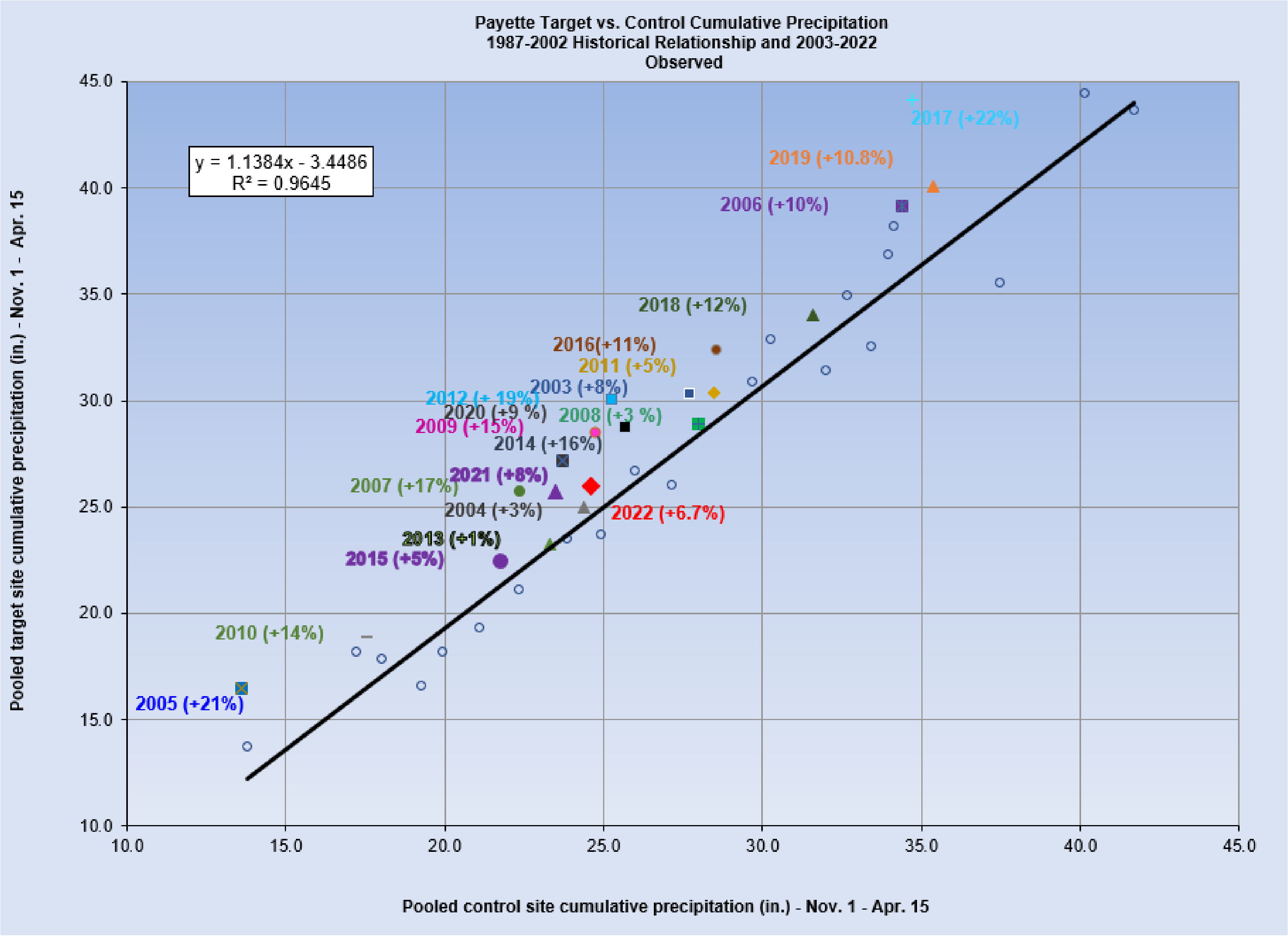
Upper Snake River Basin | 632 KAF | $1.54M

Target/Control Analysis

How do we know the amount of precipitation that was increased?

- Target/Control analysis compares historical data between 2 areas with similar climatology
  - TARGET area: Seeded area; location where seeding impacts are intended to occur
  - CONTROL area: non-seeded area; location just outside target area, with historically similar climatology
- A statistical relationship is developed between the 2 areas → used to compare % change in the target area

Target/Control Analysis



Average Estimated % Increase

	Payette	Boise		Wood		Henrys Fork		Upper Snake			
Year	WP1	WP2	WP3	WP4	WP5	EP1	EP2	EP3	EP4	EP5	EP6
2003	8%										
2004	3%										
2005	19%										
2006	12%										
2007	14%										
2008	4%					2%	3%	3%	3%	3%	3%
2009	16%					6%	8%	12%	10%	11%	9%
2010	16%					3%	4%	13%	13%	13%	9%
2011	7%					6%	7%	9%	8%	8%	8%
2012	18%					3%	4%	14%	14%	14%	9%
2013	1%	4%	3%	10%	9%	2%	3%	8%	7%	8%	5%
2014	15%	24%	22%	11%	10%	3%	5%	11%	10%	11%	8%
2015	5%	15%	14%	13%	12%	3%	4%	12%	10%	11%	7%
2016	14%	8%	7%	8%	8%	4%	6%	5%	5%	5%	6%
2017	21%	21%	19%	16%	15%	9%	11%	12%	10%	11%	11%
2018	15%	12%	11%	9%	8%	6%	9%	8%	7%	8%	8%
2019	15%	10%	9%	11%	10%	6%	8%	17%	14%	15%	11%
2020	6%	7%	7%	7%	6%	5%	8%	10%	9%	9%	8%
2021	8%	10%	9%	9%	7%	4%	5%	9%	8%	9%	7%
2022	6.6%	6.5%	5.7%	6.1%	7.1%	5.1%	4.0%	5.8%	5.9%	6.4%	5.4%
Average	11.2%	11.7%	10.8%	10.0%	9.3%	4.5%	5.9%	9.9%	8.9%	9.4%	7.6%

Collaborative Program Summary

Current Annual Operations Cost: $4,200,000

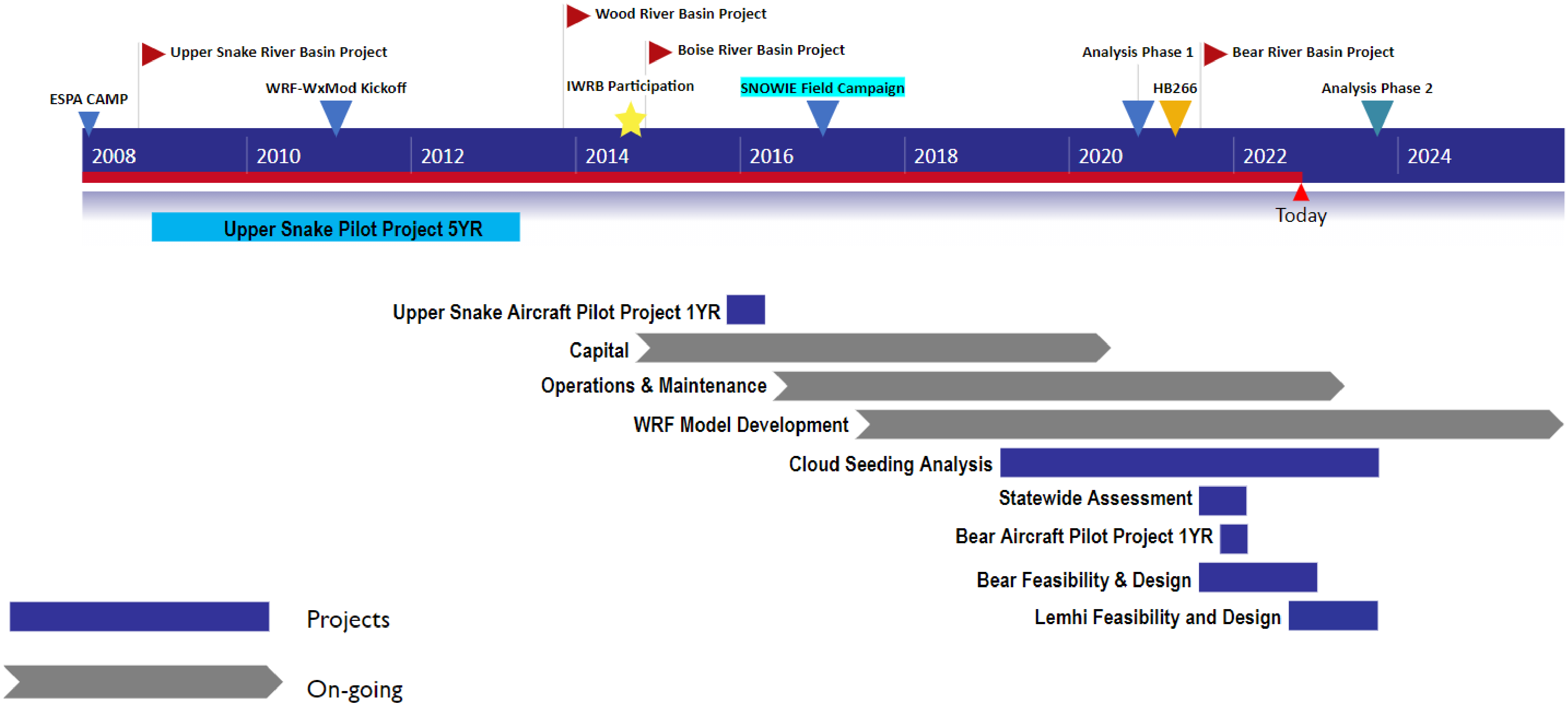
Average Annual Runoff Generated: 1,240,000 AF

Estimated Cost Per Acre Foot: $3.4/AF

Current Priorities

- **Develop Program Structure–** *What is the State's roll? The roll of stakeholders?*
- **Secure long term collaborative agreements–** *How will the program be funded long term?*
- **Assess opportunities for program expansion or enhancement–** *Can we grow the program/be more effective?*
- **Ongoing monitoring and analysis–** *How will we ensure the programs continued effectiveness?*

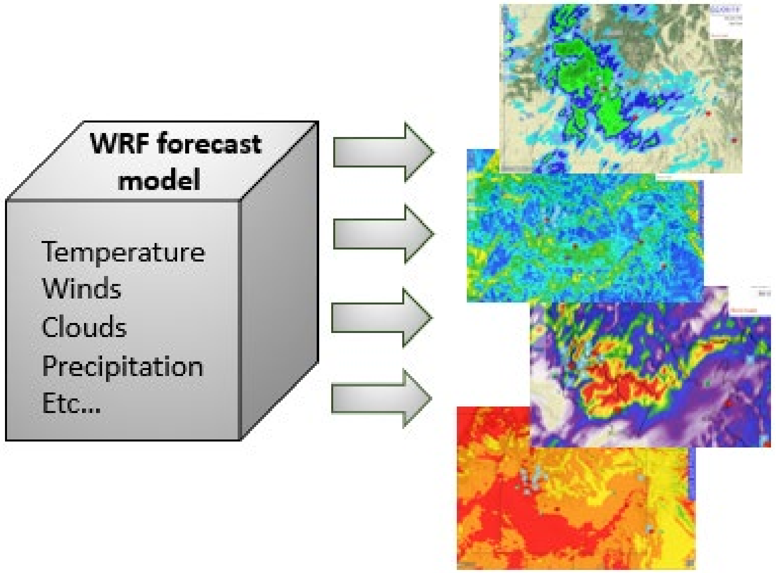
Idaho Cloud Seeding Program Development



Modeling

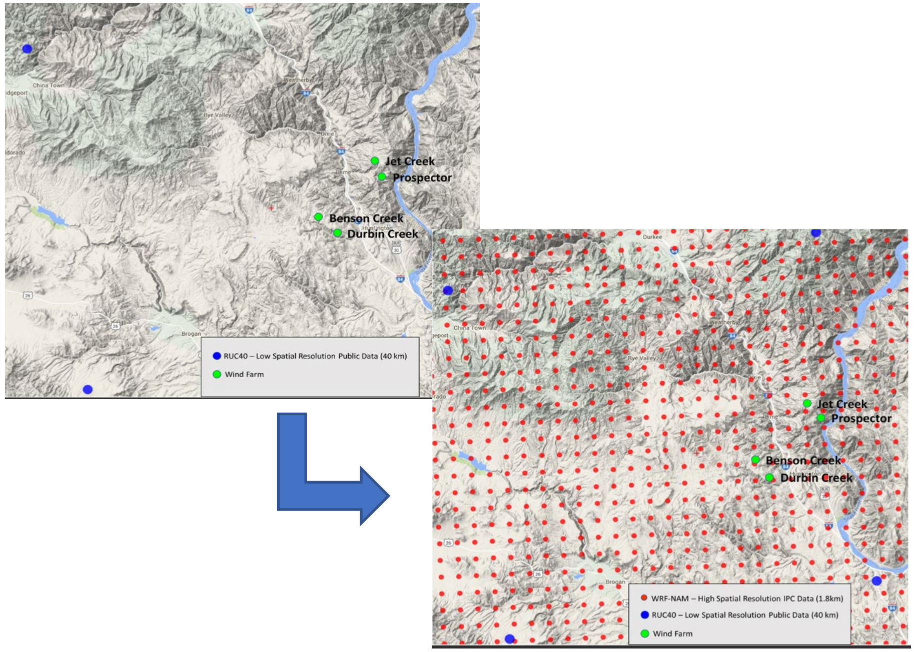
Sophisticated modeling technologies are necessary for:

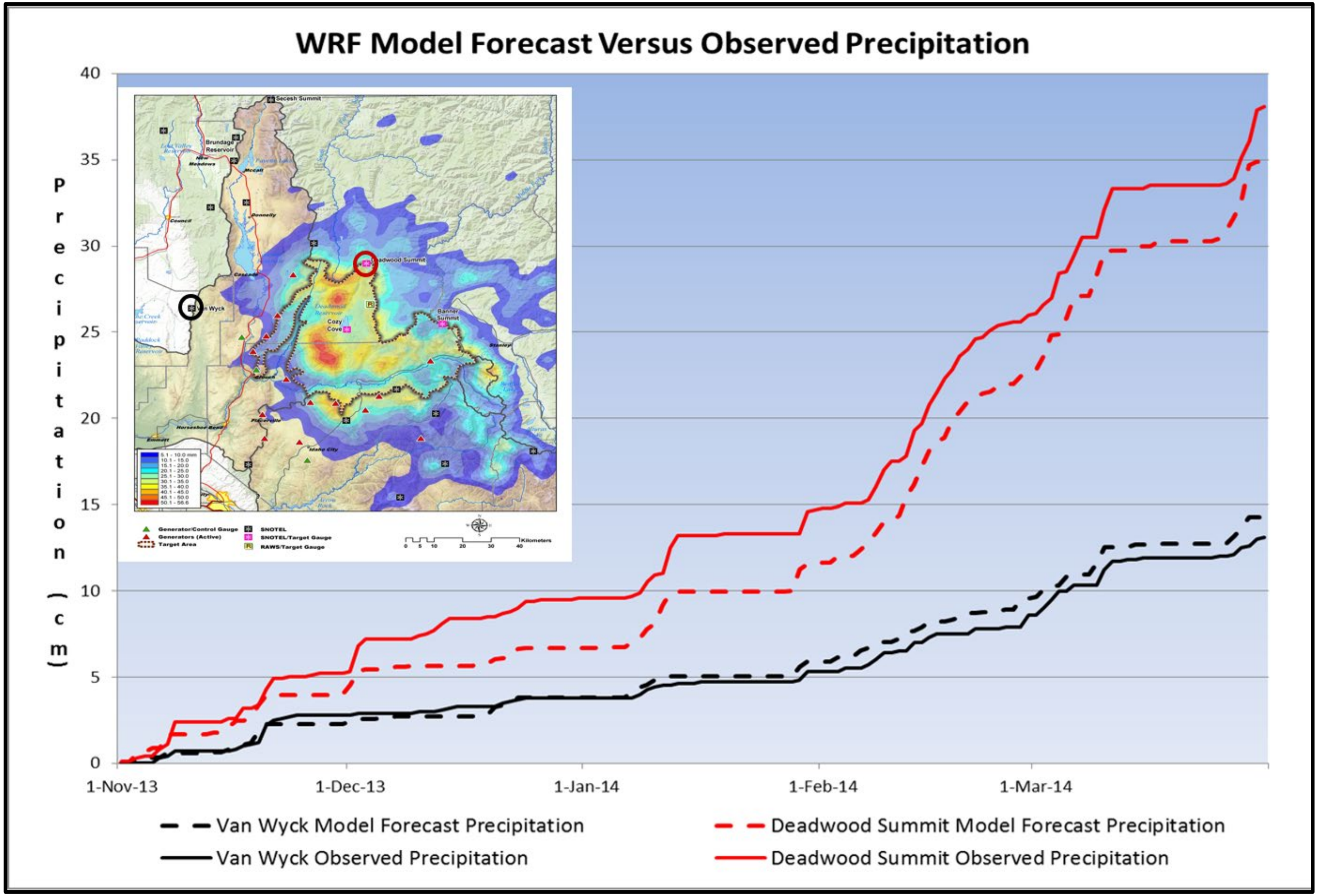
- Planning & Development of new projects
- Forecasting & Guiding Operations
- Analysis



<u>Weather Research & Forecasting (WRF) Models</u>

- **WRF** | Designed for atmospheric research and operational forecasting
- National WRF model struggles to resolve mountainous terrain, need for development of region-specific model
  - ~40km grid size → 1.8km
- **WRF Cloud Seeding Model (WRF-WxMod)**
- **WRF Hydrologic Model (WRF-Hydro)**





WRF Model Forecast Versus Observed Precipitation
Precipitation (cm)
40
35
30
25
20
15
10
5
0
1-Nov-13
1-Dec-13
1-Jan-14
1-Feb-14
1-Mar-14
Van Wyck Model Forecast Precipitation
Van Wyck Observed Precipitation
Deadwood Summit Model Forecast Precipitation
Deadwood Summit Observed Precipitation
Secesh Summit
Brundage Reservoir
McCall
Donnelly
Council
Cascade
Deadwood Summit
Van Wyck
Cozy Cove
Banner Summit
Stanley
Idaho City
Generator/Control Gauge
Generators (Active)
Target Area
SNOTEL
SNOTEL/Target Gauge
RAWS/Target Gauge
Kilometers

Modeling

Weather Research & Forecasting (WRF) Models

- IPC & IWRB partnered with NCAR to develop WRF models for Idaho
    - 2011 | IPC Initiated model development w/NCAR
    - 2017 | IWRB began partnering for model development
- WRF Cloud Seeding Model (WRF-WxMod)
    - Initial Development Costs: $5,000,000 ($1.5M IWRB|$3.5M IPC)
    - Continued model development using data from SNOWIE
        - $2.05M cost share from IWRB/IPC (50/50); $300K WaterSmart Grant
    - July 2023 | IWRB authorized $210,000 to expand WRF-WxMod to support Bear and Lemhi River basins
- WRF Hydrologic Model (WRF-Hydro)
    - Initially calibrated to existing collaborative program basins
    - July 2023 | IWRB authorized funding for statewide calibration of model, $750,000

Computing

Lots of modeling = Lots of computing power

- High Performance Computing (HPC) is required to run sophisticated modeling technologies
- 2019 | IWRB & IPC Partnered w/Boise State University (BSU) and Idaho National Laboratory (INL) for purchase of the "Borah" HPC System
  - Capital: $1.47M IWRB/IPC funding (50/50)
  - Annual administration: $80K (50/50)
  - IPC/IWRB share computing space (CS Operations & Research)
  - Quickly outgrown → IWRB currently exploring options (cloud based, new equipment, leased space, etc)

Cloud Seeding Impacts Analysis

Objective: *Estimate how cloud seeding operations impact hydrology in the Payette, Boise, Wood, Upper Snake River Basins*

- Phase 1 (2019-2020)
  - Designed to approximate benefits to water use categories
  - Simplified analysis (No Operations Model)
  - Models "present conditions"

- Phase 2: RiverWare modeling (2020-Present)
  - Implements reservoir operations & calibrated hydrologic modeling
  - Groundwater and recharge feedbacks
  - Model sensitivity analysis – Testing the model

How much additional precipitation (%) was generated?

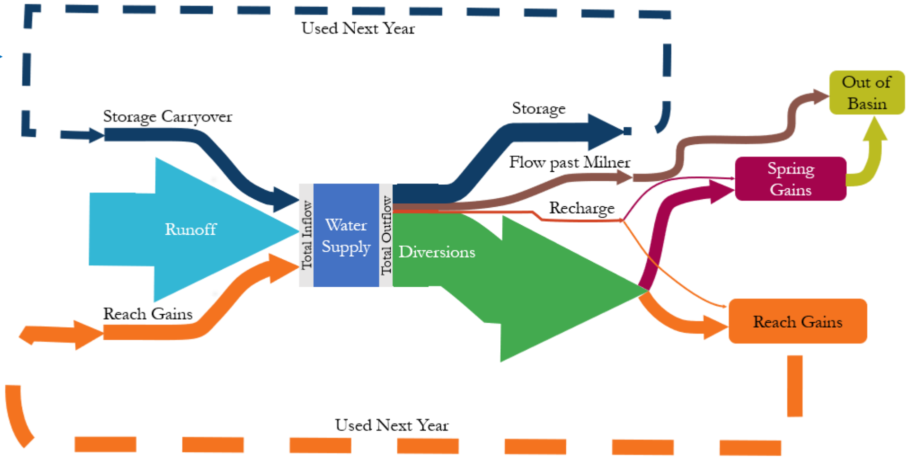
WRF-Hydro

How does that translate to water on the ground?

Project work conducted by NCAR

- Calibrate model & assess estimated impacts
- $620K (IWRB/IPC)

RiverWare



How does the system change with increased supply?

Cloud Seeding Impacts Analysis (Next Steps)

How much additional precipitation (%) was generated?

<u>WRF-WxMOD</u>
(WRF Cloud Seeding Model)

WRF-Hydro

- Must be calibrated to each region of operation
- July 2023 | IWRB authorized funding for statewide calibration of model, $750K
  - 2 Years | Statewide tool w/training
  - Use beyond CS could include forecasting streamflow in regions w/o gaging

RiverWare

- Initial Snake River model developed by USBR for Columbia River planning purposes
- Collaboration between IDWR and IPC to update model with new improvements
- Improvements include:
  - Reservoir operations
  - Groundwater response
  - Diversions
  - Flow augmentation
  - Recharge
- Requires sensitivity analysis to understand how model responds to basic inputs

Legislation

Idaho House Bill 266 (*HB266, 2021*)

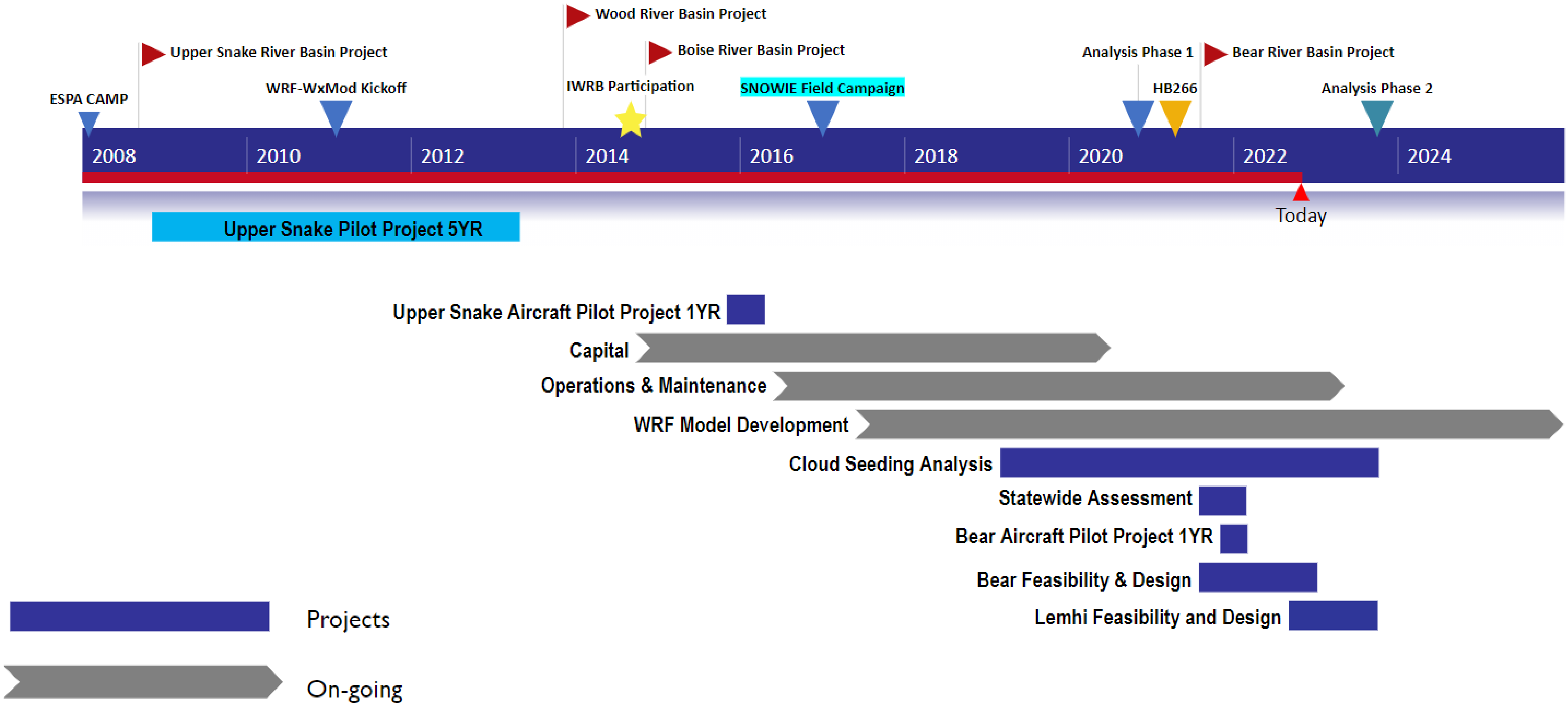
Directed the IWRB to:

1. Continue analysis of existing cloud seeding projects
2. Complete an assessment of opportunities for cloud seeding in other basins
3. Authorize cloud seeding programs in Idaho

Provides the IWRB authority to:

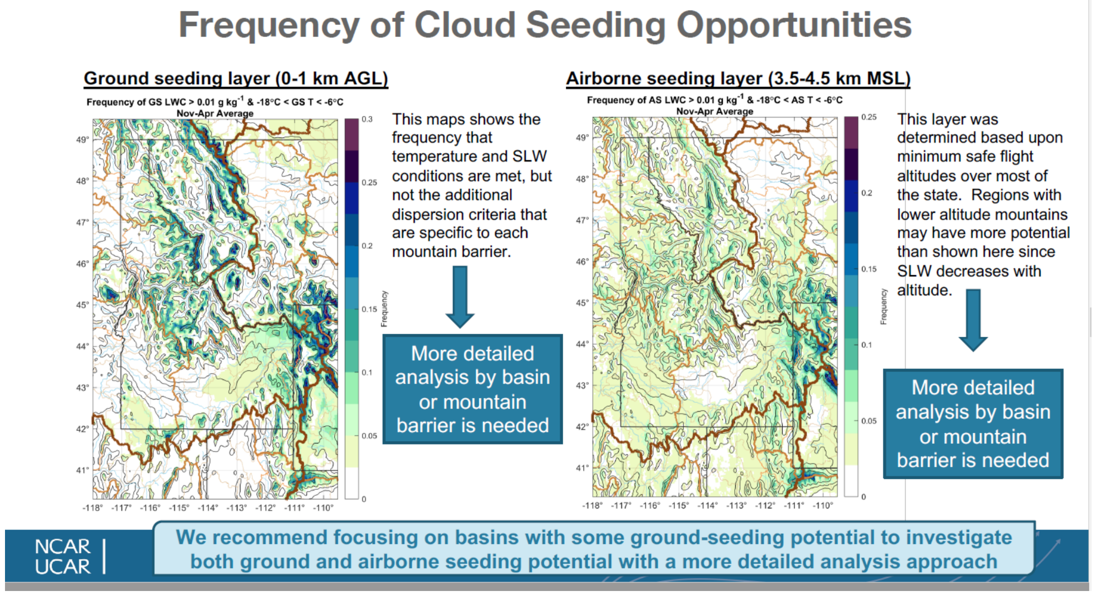
- Sponsor or develop local or statewide cloud seeding programs
  - *State funds may only be used in basins where the IWRB finds that existing water supplies are insufficient to support existing water rights, water quality, recreation, or fish and wildlife*

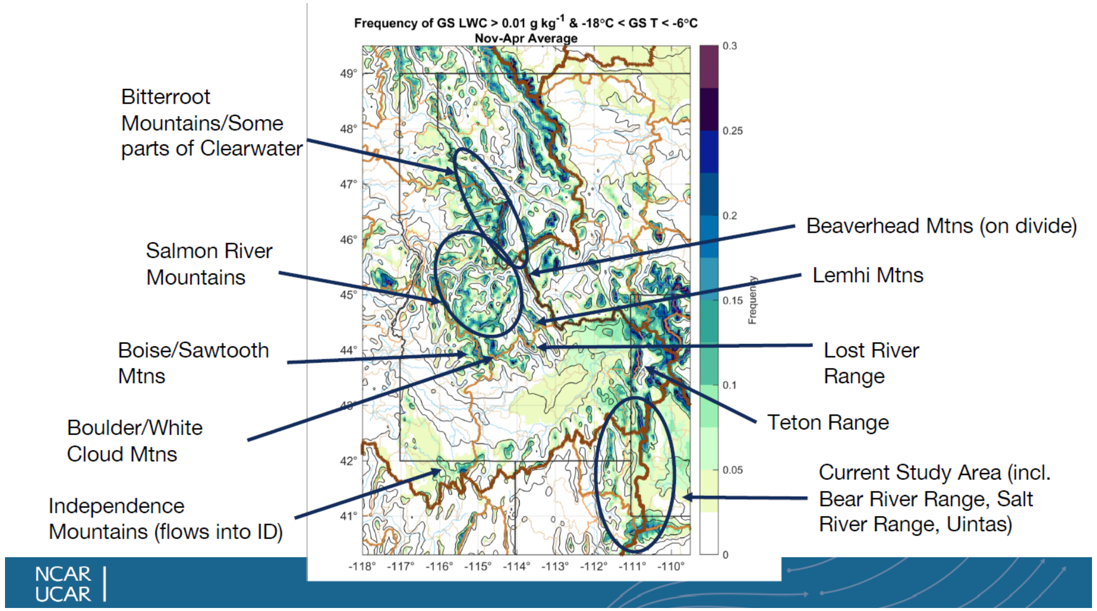
Idaho Cloud Seeding Program Development



Statewide Assessment

- July 2021– Contracted with the National Center for Atmospheric Research (NCAR) to look at opportunities for cloud seeding across the State of Idaho
- Provides initial look, more detailed feasibility required for basins of interest
- Looks for ground and airborne seeding opportunities (AgI)
- Opportunities for seeding with propane
- $30,000 Project Cost





Feasibility & Design Studies

Current Investigations:

- Bear River Basin, Completed Dec 2022 | $390K
  - Includes investigation of opportunities for shared infrastructure w/ Upper Snake River Basin
  - Results presented to IWRB Sep 2023 → IWRB working to determine next steps
- Lemhi River Basin, *est completion* Sep 2024 | $370K
  - Includes Cost/Benefit Analysis
  - Potential shared infrastructure w/State of Montana

Research & Development

Current Efforts

Seeding Agents

- **Liquid Propane (LP) Research** | LP has been demonstrated to nucleate ice in lab settings at warmer temperatures than AgI and at a reduced cost– *Can LP be used to effective seed clouds in an operational setting?*
  - Working towards development of a comprehensive investigation (similar to SNOWIE and AgI)
  - Winter 2022-2023 field investigations | $100,000 + In-Kind
  - Winter 2023-2024 field investigations | $100,000 + In-Kind
  - LES Modeling | $450,000
  - Identifying project partners

Instrumentation

- **SWEdar Development** | Gaps in available weather data contribute to reduced efficiency in planning, operations, and analysis. Implementation of SNOTEL sites is expensive and difficult to implement.
  - Potential "Micro-SNOTEL" sites will provide necessary data at reduced cost and with reduced footprint

IWRB Cloud Seeding Program Budget | FY2024

CLOUD SEEDING PROGRAM			
			FY24 Approved
Operations & Maintenance	**Collaborative Program**	(B/W/US) 2023-2024 operations; IWRB cost share 2/3 Program Total	$2,300,000
	Bear River Basin	N/A for 2023-2024 operations	$0
	Technology	Model and computing administration, device support	$50,000
		TOTAL	**$2,350,000**
Capital	**Weather Instrumentation**	Replacement/Enhancement/Upgrade, existing	$200,000
		New Devices (statewide)	$1,000,000
	Modeling	Modeling, computing, device support	$1,000,000
	Infrastructure	Equipment for new basins (Bear/US shared/Lemhi/Other... for season Nov 2024-25)	$750,000
		TOTAL	**$2,950,000**
Research & Development	**Technology**	Development of instrumentation and modeling, data support	$0
	Investigations	Analysis, assessments, cost share in research to support policy questions	$1,000,000
	Reserve	Additional Program Costs	$700,000
		TOTAL	**$1,700,000**
CLOUD SEEDING PROGRAM TOTAL			**$7,000,000**

Program Priorities & Next Steps

- **Develop Program Structure**– *What is the State's roll? The roll of stakeholders?*
- **Secure long term collaborative agreements**– *How will the program be funded long term?*
- **Assess opportunities for program expansion or enhancement**– *Can we grow the program/be more effective? How can we support other regions of the state?*
- **Ongoing monitoring and analysis**– *How will we ensure the programs continued effectiveness (validation)? How will we address public concerns regarding environmental considerations or extra area effects?*
- **Research and Development**– *How will we support policy questions? How will we fund R/D? Who are other potential partners?*

NAWMC

North American Weather Modification Council

Thank you

For more information, please visit us online at: http://www.nawmc.org/