Idaho Power Company's Cloud Seeding Program

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Background

- IPC started evaluating cloud seeding based on a shareowner inquiry in 1993
- Literature review – 1993 - 1994
- Data collection -1995 (climatology and background silver levels)
- One year program in winter 1996-97
- Operational program started in late winter 2003
- Included two year assessment

Presentation Overview

- What is cloud seeding?
- How we know cloud seeding works…
- IPC's history with cloud seeding…
- IPC's cloud seeding program…

What is cloud seeding?

- The term cloud seeding has been used to describe:
  - Fog suppression (airports)
  - Hail suppression (reduce crop and property damage)
  - Rainfall enhancement (water supply augmentation)
  - Snowpack enhancement (snowpack augmentation)
- Our focus is **snowpack** enhancement
- First, some overview of precipitation process

Precipitation…

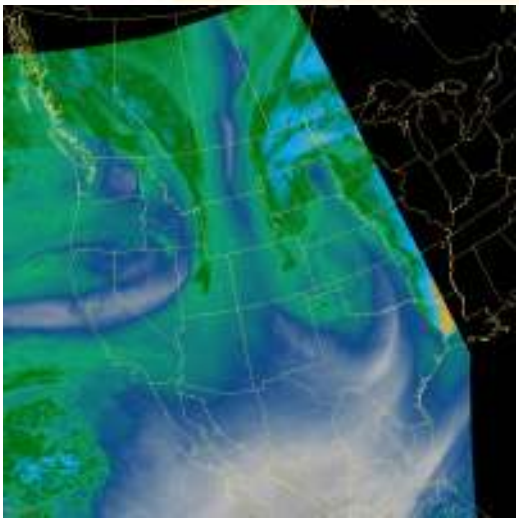
- A given column of air has a limited amount of water vapor it can hold
- For precipitation to occur, the air column must be at or near saturation (i.e. relative humidity ≈ 100%)
- Relative humidity is a function of temperature (warm air can hold more water vapor than cold air)
- However, saturation alone does not lead to precipitation
- Ice nuclei are required for water vapor to convert to ice crystals
- Ice nuclei are found naturally in the atmosphere, but may be limited relative to available water vapor
- This limitation can provide an opportunity….

Precipitation…

Can we get a little more?

Atmospheric Water Vapor

- There is a lot more water vapor in the atmosphere than we can see.
- Not all water vapor is visible as clouds.



Cloud Seeding

The key is super cooled liquid water…

Water that is in a vapor state, but below freezing.

Cloud Seeding

- Cloud seeding provides mother nature with ice nuclei
- But, it is only effective when ice nuclei are limiting and nature is performing the other required precipitation processes
  - cloud seeding doesn't create clouds to seed – it will not cure a drought!
- Effectiveness depends on:
  - temperatures,
  - available water vapor,
  - ice nuclei properties,
  - cloud droplet and natural ice distributions
- Several agents can be used as ice nuclei, with silver iodide (AgI) being the most common used in commercial cloud seeding.

Cloud Seeding

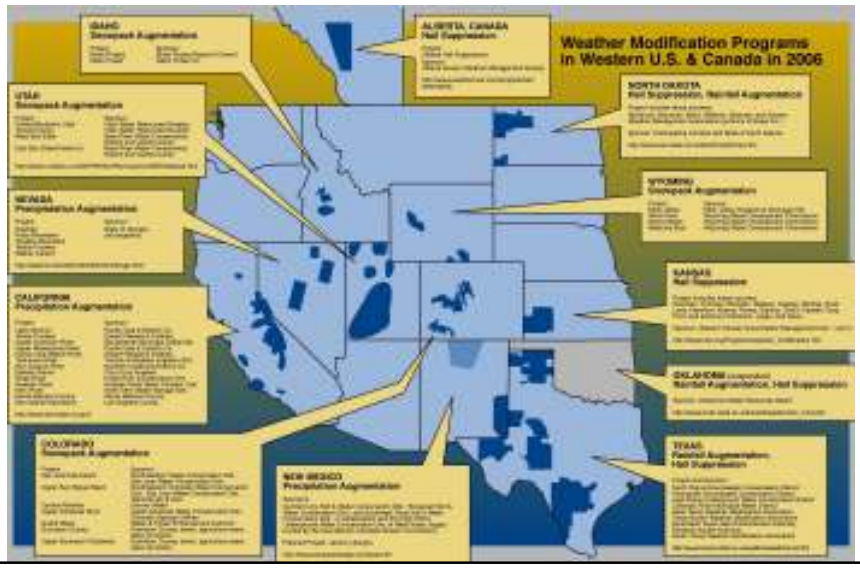
Where did it get started?

- In 1946 at GE labs in Schenectady, NY, it was discovered that various materials can initiate the formation and growth of water droplets and ice crystals (leading to **cloud seeding**).

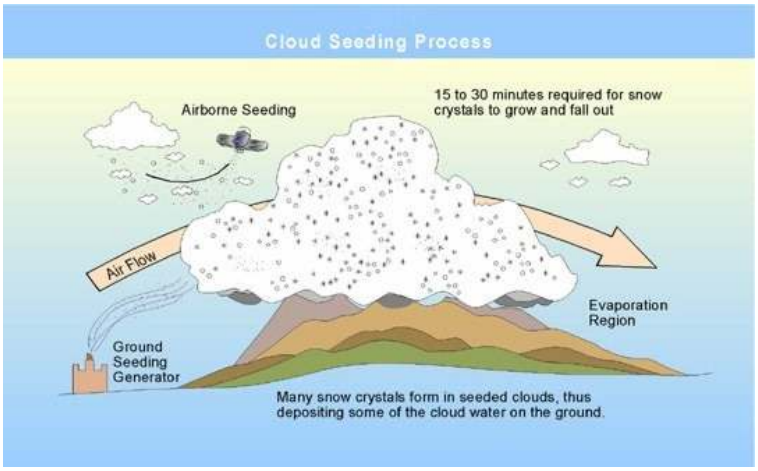
Building on those early discoveries,

- Cloud seeding is conducted in over 40 countries
- Numerous projects in US, including some dating to the 1950's

Cloud Seeding Programs - WMA



Cloud Seeding –
Wintertime Orographic



Silver Iodide Distribution

- In commercial programs, silver iodide is burned to release silver iodide particles (ice nuclei) of an appropriate size to the atmosphere.
- Ground generators - Acetone – silver iodide solution is burned in a propane flame.
- Aircraft - silver iodide is incorporated into a flare, or solution is burned.

Ground-based Generators

Ground-based Generators

Beech King Air C90

- Turboprop
- Known performance in icing conditions
- Pressurized
- Oxygen
- Weather Radar
- GPS Navigation

Airborne Seeding Equipment

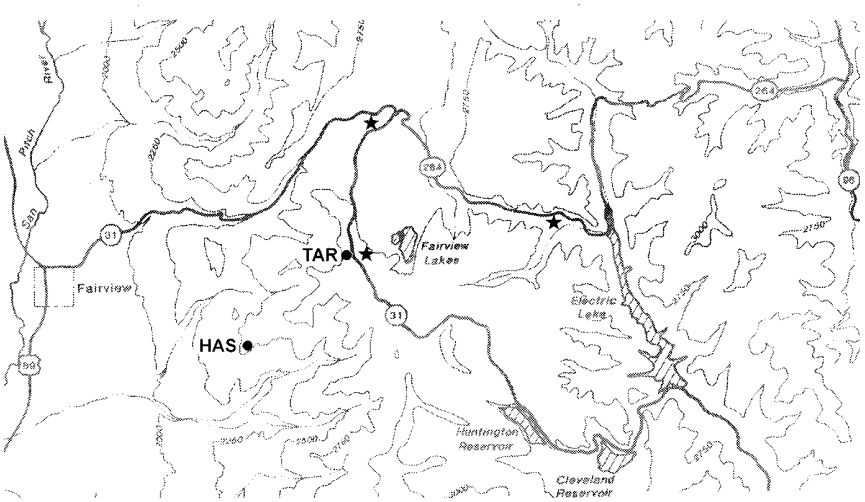
Cloud Seeding

How we know it works…

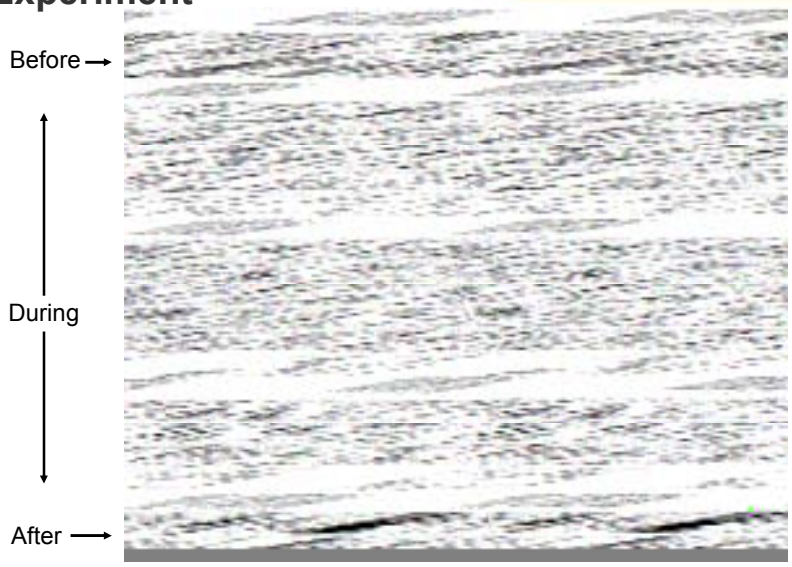
Cloud Seeding

- Lots of evidence that it works in laboratory and controlled conditions.
- The big question – how do we know it puts snow on the ground?
- Plume tracing – UT pulsed seeding experiment
- Trace chemistry (IPC's dual tracer)
- Aircraft data collection

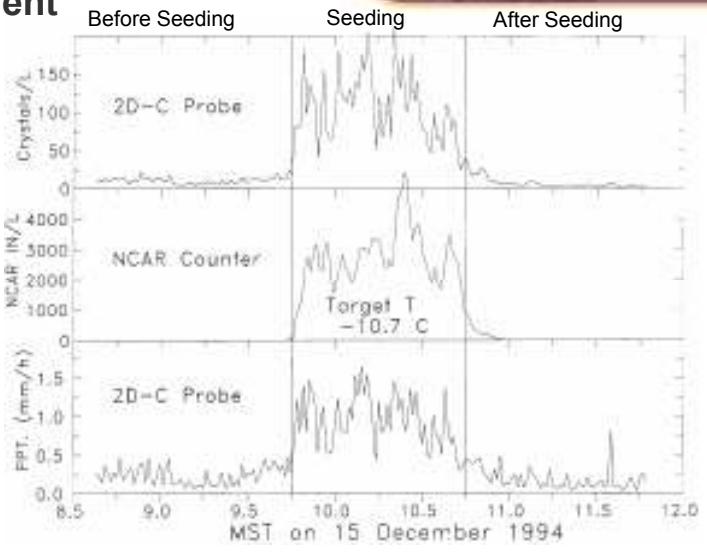
Pulsed Seeding Experiment



Pulsed Seeding Experiment



Pulsed Seeding Experiment



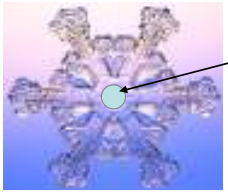
IPC's Dual Tracer Assessment

Approach

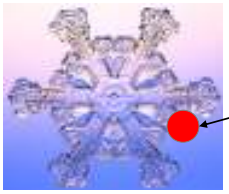
- IPC needed to demonstrate that project can effectively put seeding material in target area, and that seeding increases snowpack as expected.
- Independent contractors performed assessment
- Co-located seeding and tracer generators
  - Release seeding and tracer at same rate
- Silver iodide (AgI) released from both ground and aircraft generators.
- Silver incorporated into snowpack through ice nucleating (seeding) process or scavenging
- Inert tracers (non-nucleating) incorporated in snowpack through scavenging process only.

Co-located Generators

Ice Nucleation vs. Scavenging



Silver Iodide nano-particles actively cause ice crystal formation (seeding)



Indium oxide nano-particles are passively incorporated into snow crystals (scavenged).

IPC's Dual Tracer Assessment

Approach (cont.)

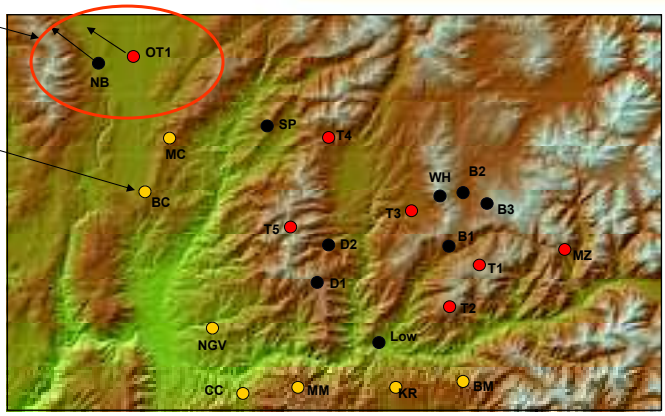
- Following seeding, sample snowpack for evaluation of trace levels of silver, indium, and cesium as well as snowpack density
- Ratio of silver to tracer (ex. Indium) in the snow pack gives an indication of how much silver deposited by ice nucleating vs. scavenging processes.

Snow Sampling and Ground Generator Sites

Control Sites

Ground Generators

- 2003-2004 Sites
- 2004-2005 Sites



New sites were sampled in 2004 -2005 due to access problems in 2003-2004.

Sampling Snow Pack

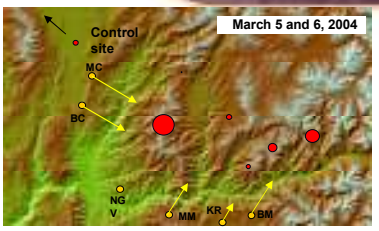
- Snow samples collected using ultra-trace 'metal clean' techniques and acid cleaned equipment.

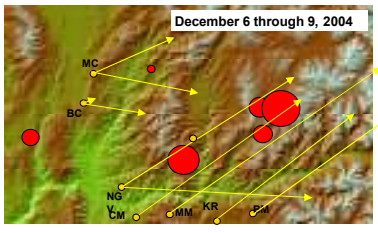
Analytical Methods

- Samples acidified with ultra-pure nitric acid in class 100 clean room.
- Analysis by High Resolution Inductively Coupled Plasma Mass Spectrometry.
- Detection limits of ~ 300 parts per quadrillion for silver
  - 300 / 1,000,000,000,000,000 (10^{15})
- Think of it as a single drop of water in a sports arena like the Idaho Center (Nampa, ID)

Targeting from Chemistry Data

- Targeting of the seeding operations was assessed by integrating the silver found in the snow over a given storm period to estimate the total amount of silver deposited during the storm.





Ground-generator Site

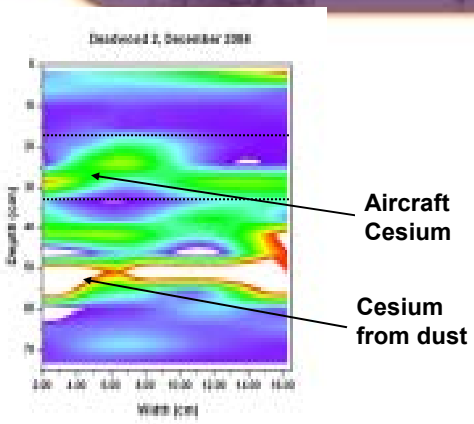
= silver deposited 100 x 10^{-12} g

= silver 100 g released

Example Targeting Maps for the March 2004 and December 2004 storm periods

Aircraft Targeting

- Aircraft seeding identified by using a cesium tracer.
- Identification of aircraft tracer was complicated by dust – cesium, which was also deposited in the snow .

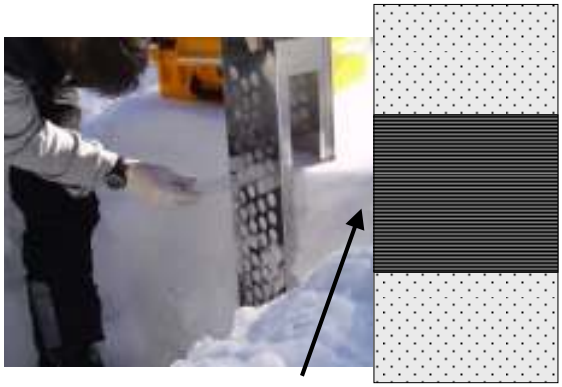


2D profile of snow cesium

Targeting Results

- The amount of silver deposited downwind of active ground generators was much greater than that found at the control sites.
- Silver deposition maps show that the center of the target area was affected by the seeding operations.
- Indium concentrations were generally very low
  - Silver not from scavenging
- Evidence for targeting by aircraft was found in the center of the target area in December 2004.
- The project layout and operations can effectively hit the target area with **both** ground generators and aircraft.
- Determining precipitation increases…

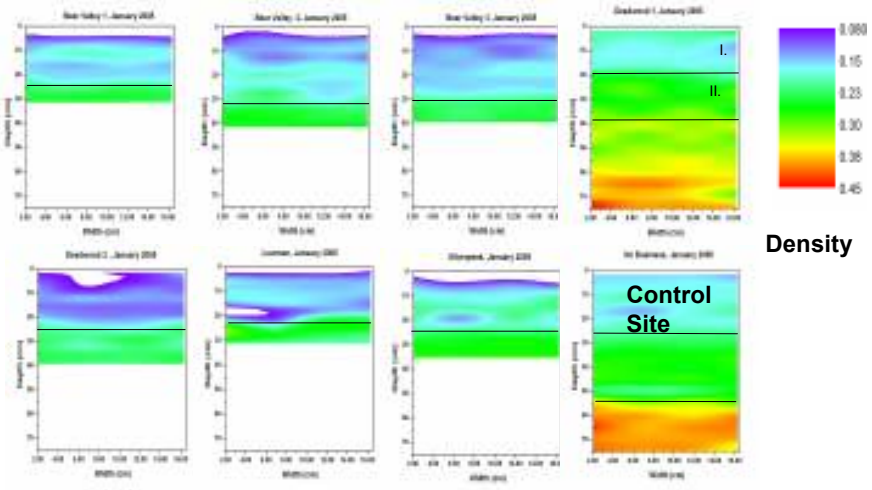
Snow Pack Density



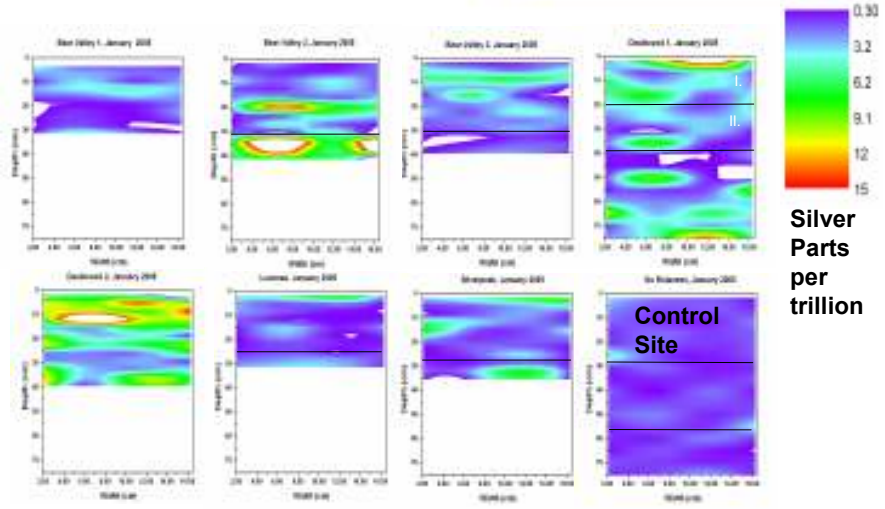
Unseeded snow

Seeded snow

Example 2D Snow Pack Density Profiles



Example 2D Snow Pack Silver Profiles

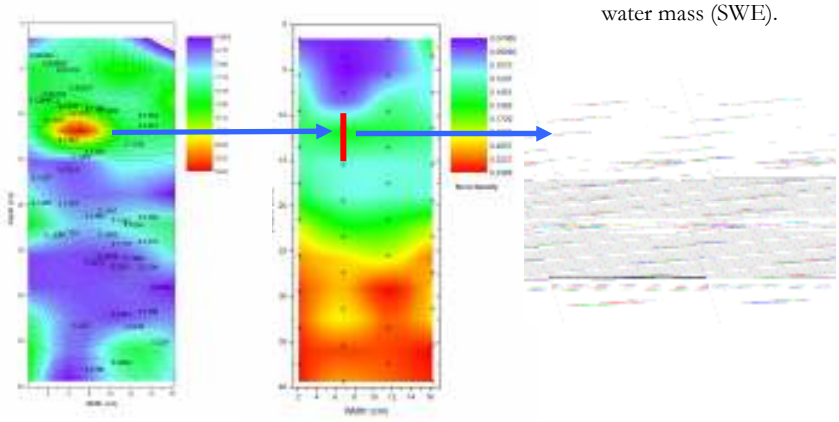


Trace Chemistry Interpretation

Trace Chemistry

Snow Pack Density

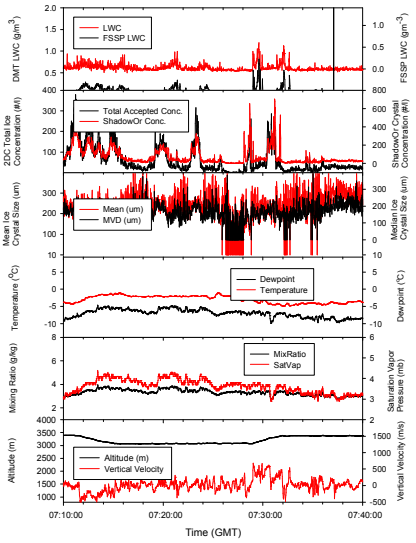
13% increase in integrated water mass (SWE).



2004 Cloud Physics

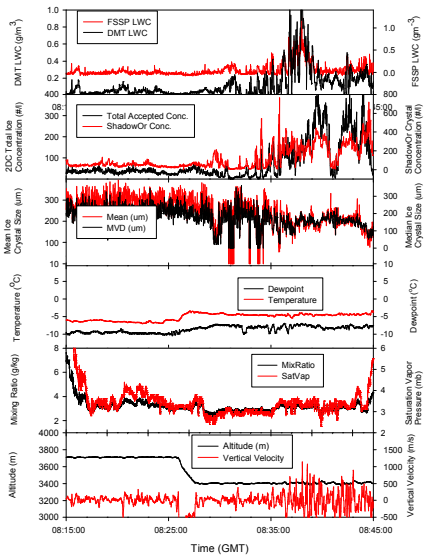
- Two planes – seeding and research aircraft.
- Research aircraft fitted with a number of probes to measure parameters important to precipitation

2004 Cloud Physics



Cloud physics data collected just prior to the onset of airborne seeding. In particular, note the second and third frames, and compare them to the following diagram.

2004 Cloud Physics



The same data as in the previous figure, but shortly after the initiation of airborne seeding. Note that the total ice mass increases dramatically about 20 minutes after the onset of seeding while at the same time, the mean ice crystal size decreases.

Indicative of conversion of supercooled liquid water into new ice crystals that can then grow into snowflakes.

Trace Chemistry Summary

- Due to compaction of the snow pack, water increases could not be estimated for the 2003-2004 season.
- During 2004-2005, DRI concluded cloud seeding revealed an average increase of 7%. Individual storm events ranged between 7 and 35% increases.
- Under favorable conditions, greater increases may be obtained through longer seeding periods.
- Moving to flares significantly increases seeding potential from the aircraft.

How do others view cloud seeding?

- During California energy crisis while PG&E was facing bankruptcy, the CA PUC advised PG&E that they would continue their cloud seeding programs during reorganization.
- PG&E is working to expand their project

Idaho Power's Cloud Seeding Project

- At the request of shareholders – began investigating cloud seeding in 1993
- Literature review 1993 and 1994
- Climatology study water year 1994-95
- Contracted operational program in 1996-97
- Planned to perform internal program in 1997-98
  - canceled do to no mechanism to recover project expenses and share benefits
- Reinstated in Feb 2003.
- Operational including assessment in fall of 2003
- Completed second year of assessment and third year of operations in May 2005.
- Currently in final stages of 5th operational year

Idaho Power's Cloud Seeding Project

IPC views cloud seeding as a long-term water management tool.

Project Organization

- In literature review, found expert opinions that some commercial programs benefit public relations more than anything else.
- Most long-term programs have an in-house component - representing stakeholders interest.
- Rather than commission entire project, IPC elected to employ key personnel to represent the Company's interest.
- A 3rd party provides aircraft and conducted an assessment.

Current Project Organization

Internal

- Forecasting, project operations (dispatch balloon launches, ground and aircraft seeding), equipment fabrication and maintenance, solution mixing, data (NOAA port), communications and control software.
- Project staff
  - 2 staff meteorologists (forecasting, operations)
  - 2 water resource specialists (ground gens)
  - shared time - administration, data acquisition and communication

External

- Aircraft and pilots
- Weather balloon launches
- Part time forecasting meteorologist

Effective Program

An effective program includes:

- Knowledge of:
  - Water content – is the storm conducive to seed?
  - Temperature profile
  - Wind speed and direction
    - The wrong combination of temperature and water content can easily lead to reduced precipitation.
    - Winds effect targeting
- Flexibility – ability to seed a range of conditions
- Aircraft safety
  - Flying a plane in storm conditions – pilot needs guidance regarding severe ice, lightning, etc.

Both Airborne and Ground-based

- Seeding intended to enhance snowpack at the higher elevations above 4500'
- Target area ~ 938 sq. miles
- ~ 497 mi^2 above the 6000' level

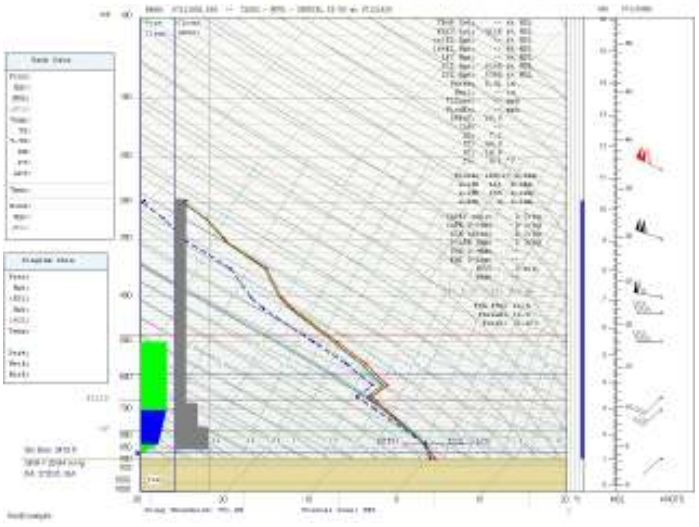
- Combined approach provides more opportunities for addressing storms.
- Complementary
  - Too warm for ground, can still fly, too cold to fly, can still use the ground units, or,
  - Use both at the same time

Weather Balloons

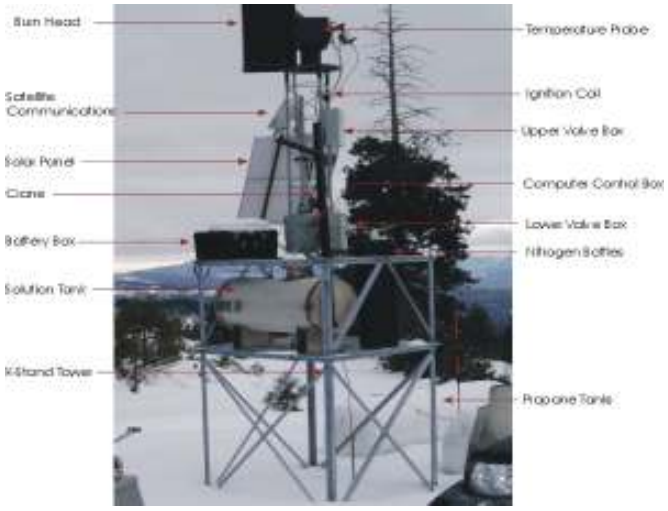
Weather Balloon Data

By Elevation:

- Temperature
- Relative Humitity
- Wind Speed
- Wind Direction



Ground-based Generators



Ground Generator Locations

Getting There…

Ground-based Generators

Ground-based Generators

Generator Components

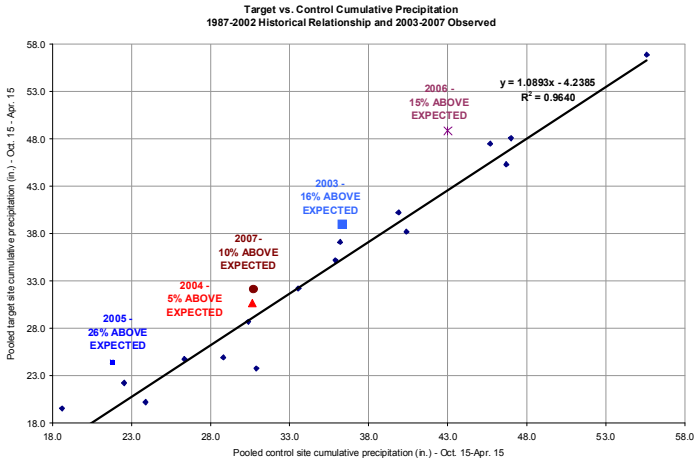
Control Box

Valve Boxes

Burn Chamber

Aircraft Seeding

Target - Control



Operations Summary

WY	WY % Normal	% TC Benefit	Silver Iodide			Hours		Status
			Total	Air	Ground	Air	Ground	
2003	89%	16	33558	23270	10288	15.4	515	start-up (Feb-Apr)
2004	65%	5	21485	2803	18682	11.9	930	assessment
2005	59%	7*	27301	11122	16179	50.5	810	assessment
2006	160%	15	113173	97710	15463	48.5	768	operational
2007	52%	10	106082	76980	29102	51.3	1351	operational

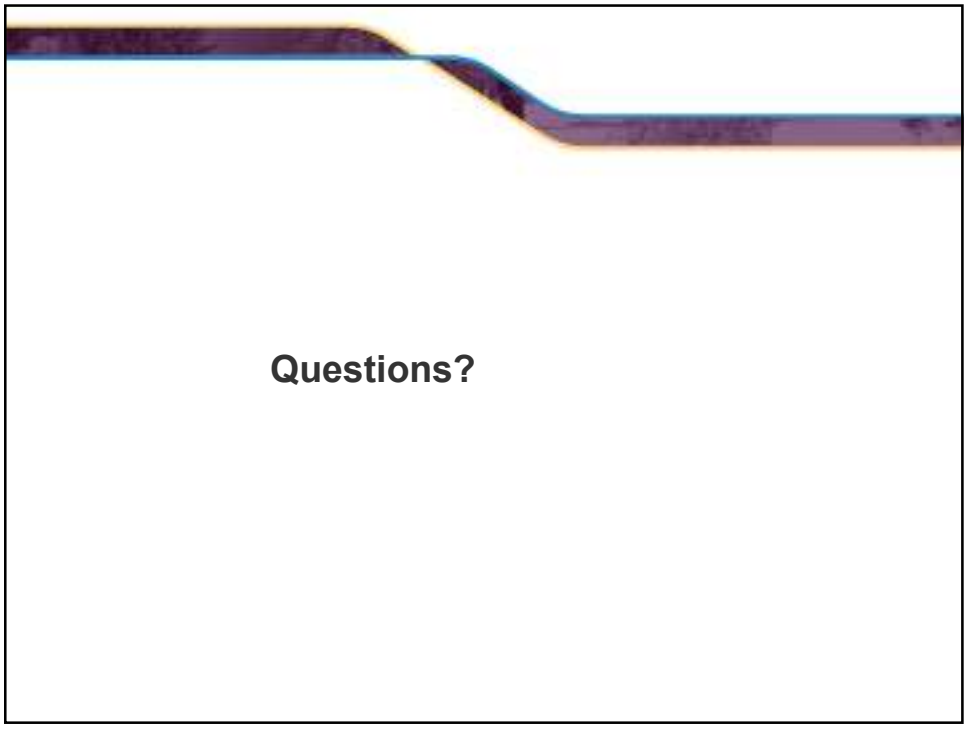
*DRI Trace chemistry average benefit
TC = Target - Control

Benefit Summary

2008 Benefits estimate using:

- USBR regression equation for Payette at Horseshoe Bend
  - Using current 2008 conditions (near normal)
- Precipitation increase of 10% from cloud seeding
- Results in approximately 100 KAF of additional Mar – Jul runoff

Estimated cost per acre-foot of additional water ≈ $8.50


Questions?