

Wyoming Weather Modification Pilot Program (WWMPP)

Colorado River Water User's Association
Annual Meeting
Las Vegas, Nevada



Barry Lawrence

Wyoming Water Development Office
Cheyenne, WY

Roy Rasmussen

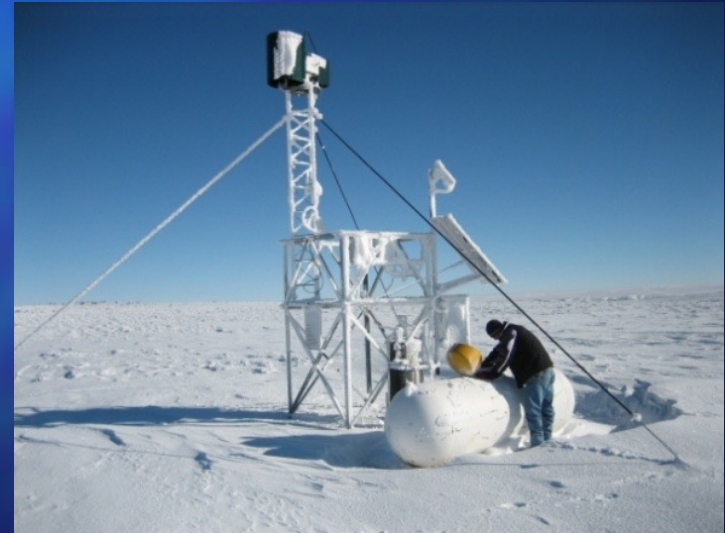
National Center for
Atmospheric Research
Boulder, CO

December 11, 2014



Presentation Overview

- Results of the WWMPP Study
- Next Steps: Collaborative Weather Modification



Wyoming Weather Modification Pilot Program Funding Acknowledgements

Wyoming State Legislature

Legislative Select Water Committee
Wyoming Water Development Commission

Additional Funding

- University of Wyoming Office of Water Programs
- Central Arizona Project
- Colorado Water Board of California –
Six-Agency Committee
- Southern Nevada Water Authority



The **WYOMING**
Weather Modification Pilot Program

WWMPP consistent with the 2003 National Research Council Report:



- High resolution computer modeling of the clouds and airflow should be used to support both operations and evaluations.
- Remote-controlled ground-based seeding generators should be used to optimize targeting.
- **Program evaluation should be independent** and use both physical and statistical methods.
 - Physical studies that examine processes important to the seeding concepts.
 - Randomized experiment: quantitative assessment.

Operations ...



- Weather Modification, Inc.
– Fargo, ND



- Heritage Environmental, Denver, CO

Research & Evaluation ...



NCAR

- National Center for Atmospheric
Research – Boulder, CO



- Desert Research Institute, Reno, NV

Program Components



Weather Balloon Launches (Saratoga, WY)



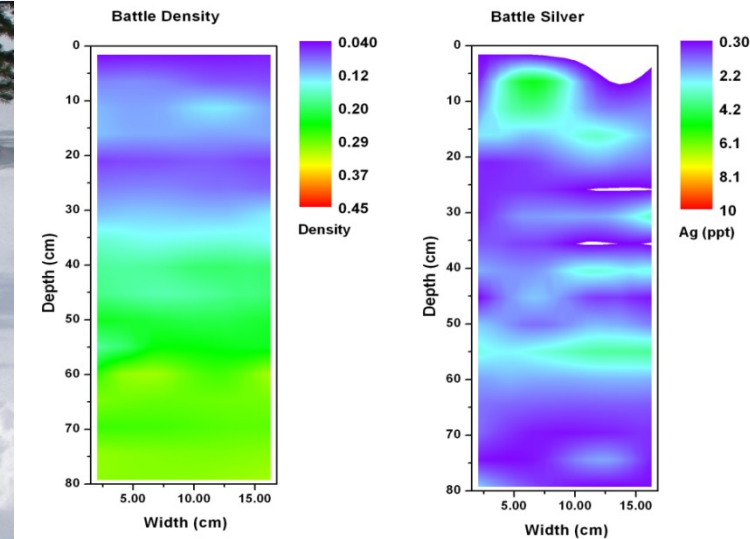
Radiometers

Units deployed near:

- Boulder, WY
(Wind River Range)
- Saratoga, WY
(Medicine Bow Range)
- Savery, WY
(Sierra Madre Range)

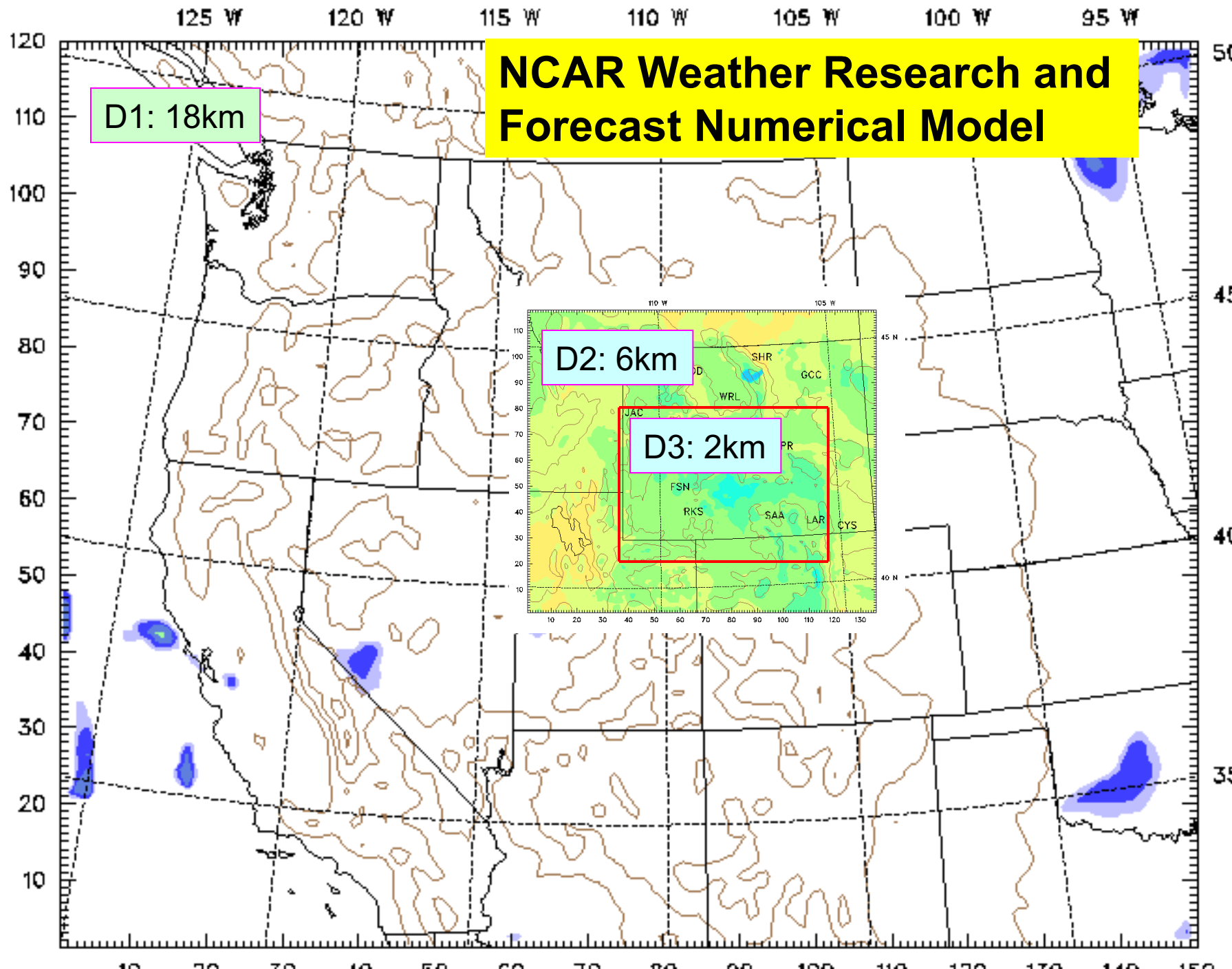


Targeting – “Detailed” profile snow samples



Trace chemistry snow sample collection

NCAR Weather Research and Forecast Numerical Model



High Resolution Precipitation Gauge Sites



**Three gauges per site
(Two different style gauges)**



Education & Outreach Efforts

Saratoga Middle/High School

WWMPP Target Areas

● Cody

● Gillette

● Worland

Wind River Range

Operations were conducted annually from 15 November through 15 April, barring suspension.

● Lander

● Casper

Evaluation – modeling studies

● Rawlins

Medicine Bow Range

● Green River

Sierra Madre Range

● Laramie
Cheyenne ★

Randomized Seeding Experiment

Scientific Evaluation of the Wyoming Weather Modification Pilot Project (WWMPP)

Roy Rasmussen, Sarah Tessendorf, Courtney Weeks, Lulin Xue, Kyoko Ikeda, Scott Landolt and Dan Breed

National Center for Atmospheric Research

Approach to the Evaluation

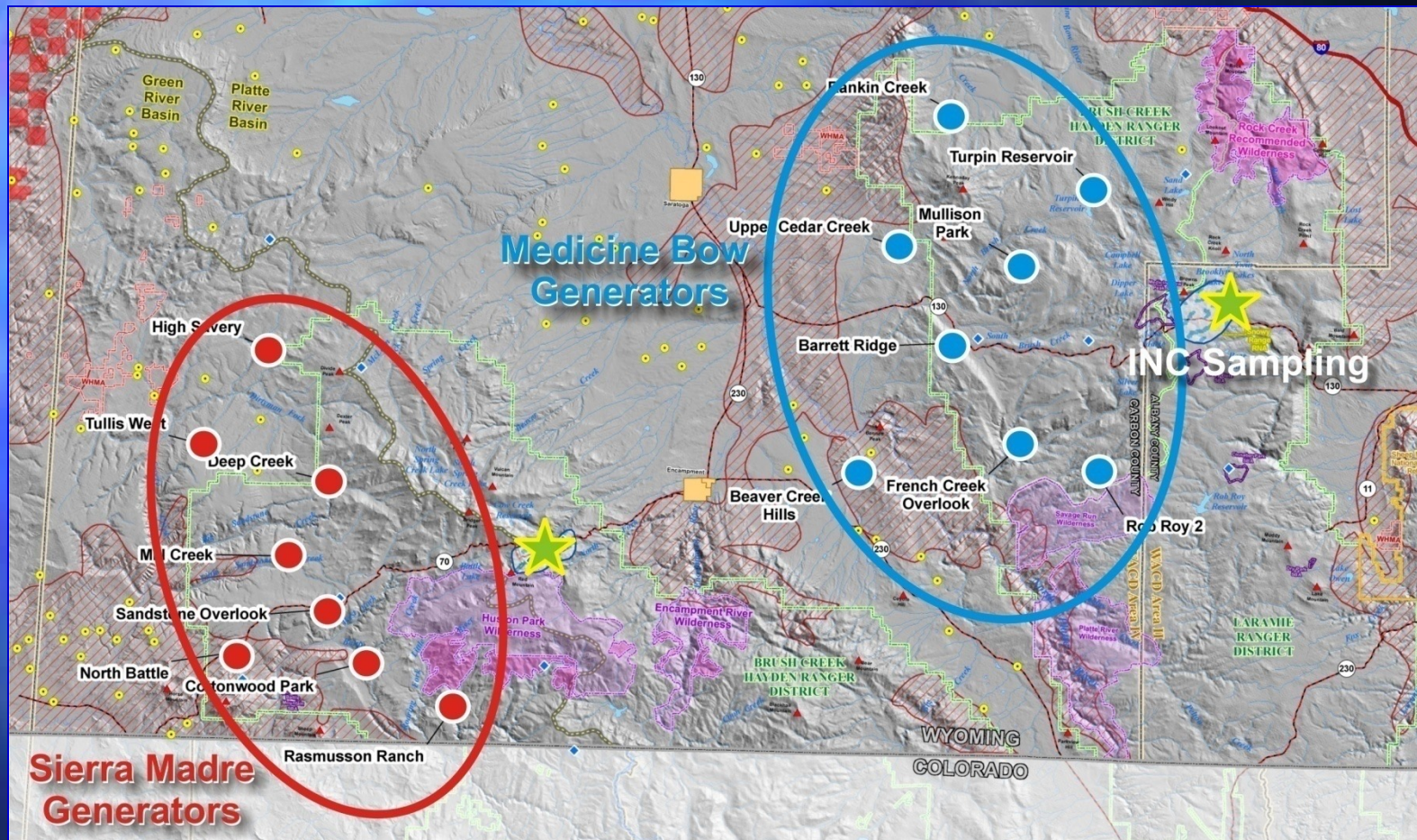
- Will apply the accumulation of evidence approach to evaluation recommended by National Research Council 2003 report on Weather Modification focused on the following areas:
 1. Statistical
 2. Physical
 3. Modeling



2003 National Research Council Report:

- Program evaluation should be independent and use both physical and statistical methods.
- High resolution computer modeling should be used to support both operations and evaluations.

Randomized Crossover Experimental Design



Similarity in storm conditions affecting both ranges allow for the possibility of a “cross-over” design resulting in paired data (seeded and control cases), and statistically is the most efficient design to conduct and evaluate.

What variable used to evaluate the program?

4 hour
precipitation
accumulation
from
snowgauges



Three gauges per site
Two different style gauges (ETI, Geonor)
Resolution: 1-min, 0.1 mm

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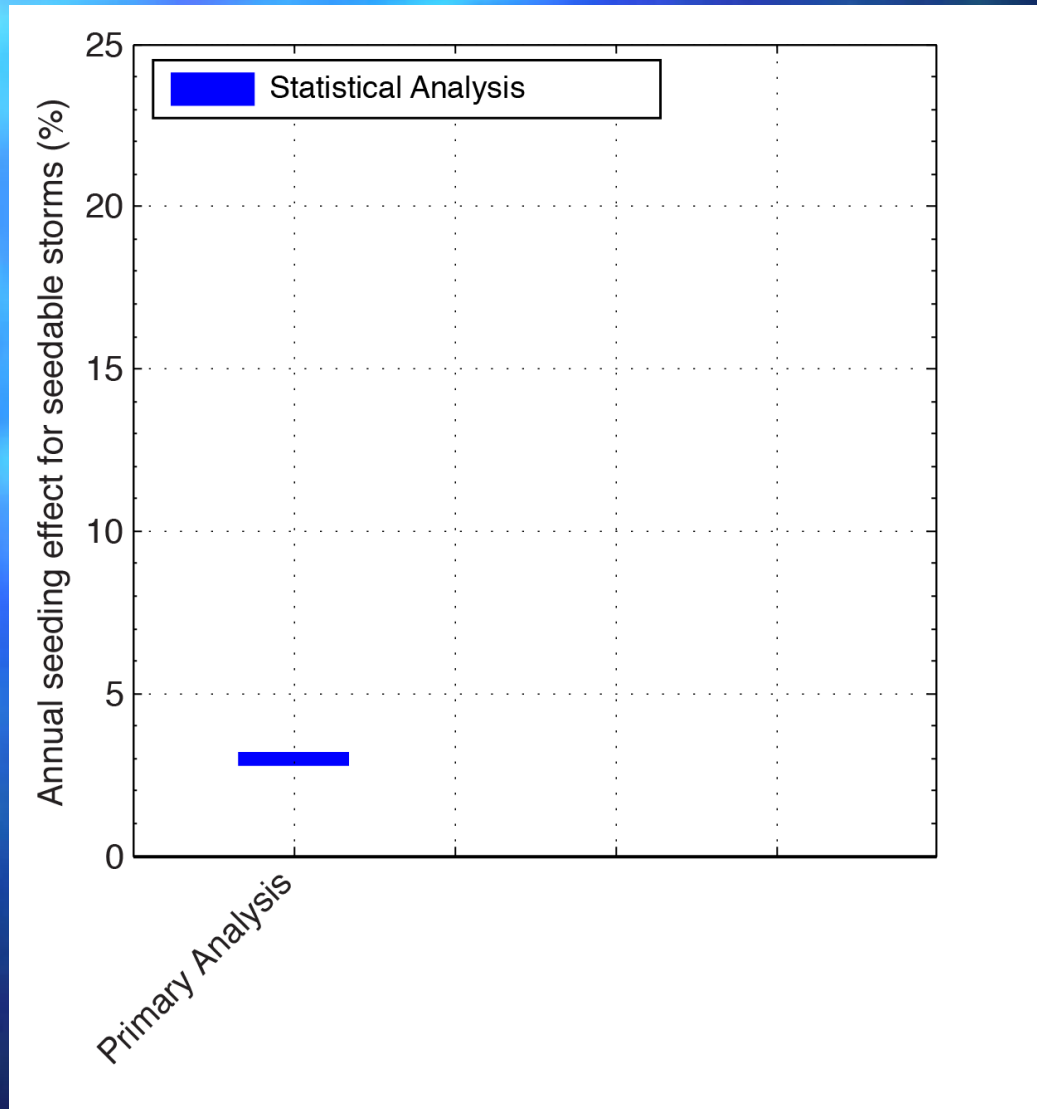
Primary Statistical Results

The primary statistical results (confirmatory analysis) using the snowgauge data with a randomized cross-over statistical design are:

RRR = 1.03	(3% increase in precipitation)
P-value = 0.28	(28% chance that occurs by chance)

Since the p-value is greater than 0.05, the statistical test does not reject the null hypothesis that there is no effect of cloud seeding.

Primary statistical analysis



Further Exploratory Statistical Analysis

Further analysis of the data suggested two primary physical effects impacting the statistical analysis of the 4-hr precipitation data:

1. Down-wind seeding of the Med Bow Range by the Sierra Madre generators
2. Minimum number of generator hours per case (or coverage of the cloud with silver iodide).

Downwind Seeding of Med Bows by Sierra Madre

Examination of the potential
of downwind seeding of the
Medicine Bows by Sierra
Madre

Downwind Impacts

Ice Nuclei Plume Detection and Snow Sampling



Mountain Meadows Cabins, Medicine Bow Range, December 2008

Downwind Impacts

- The ground-based AINC measurements indicated that silver iodide reached the Medicine Bow target in 21 Sierra Madre seeding cases.
- Eliminating these 21 cases from the 118 snow gauge cases increased the RRR from 1.03 to 1.04.

An AgI cloud seeding parameterization implemented into the Weather Research and Forecast NCAR model

Xue et al., 2013: Implementation of a silver iodide cloud seeding parameterization in WRF. Part I: Model description and idealized 2D sensitivity tests. *JAMC*.

Xue et al., 2013: Implementation of a silver iodide cloud seeding parameterization in WRF. Part II: 3D simulations of actual seeding events and sensitivity tests. *JAMC*.

Agl plume from ground generators

Date/Time: 2010-02-01_00:00:00

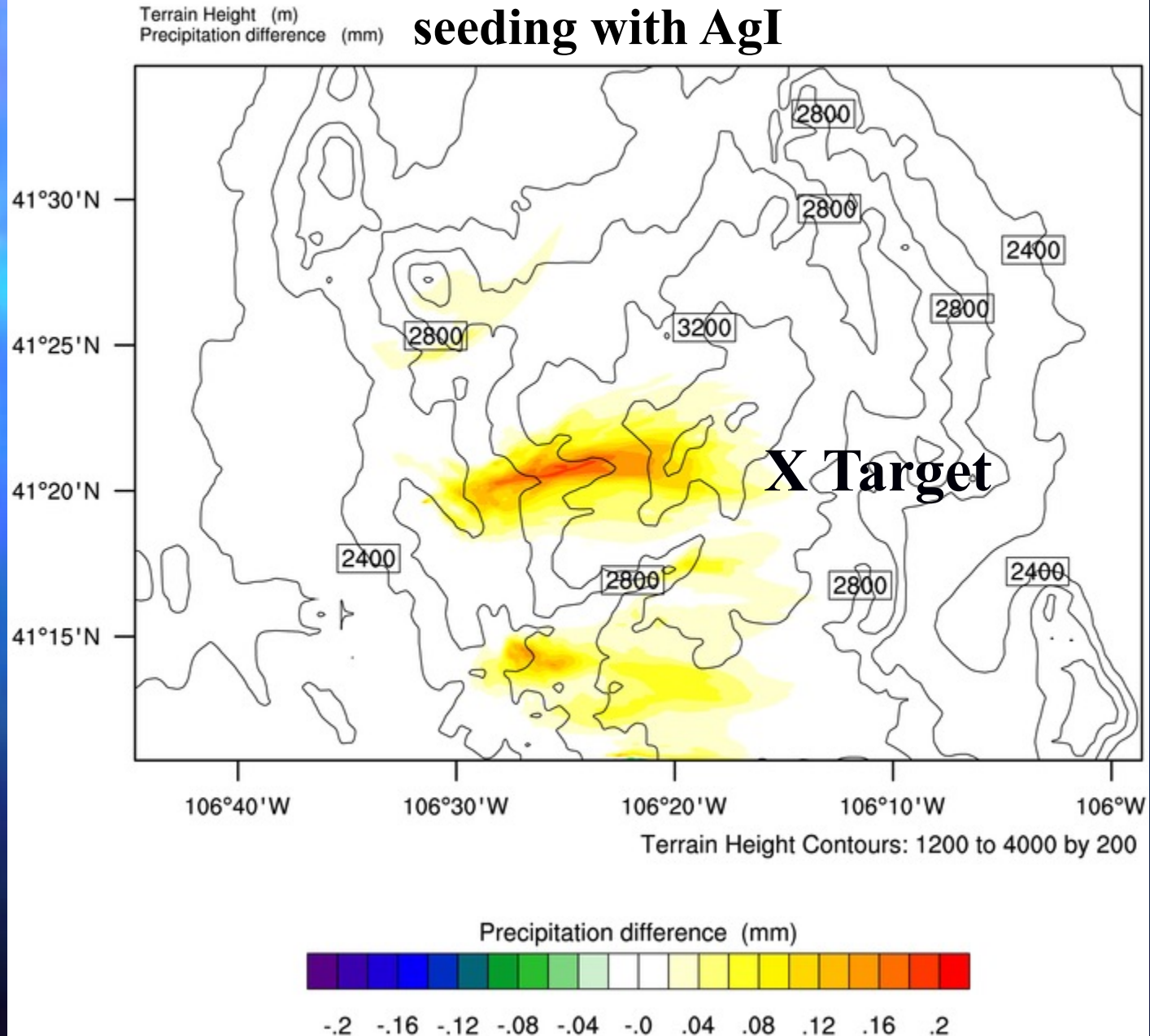


Simulated precipitation from nucleation of AgI

Date/Time: 2010-02-01_00:00:00



Simulated increase in precipitation due to cloud seeding with AgI

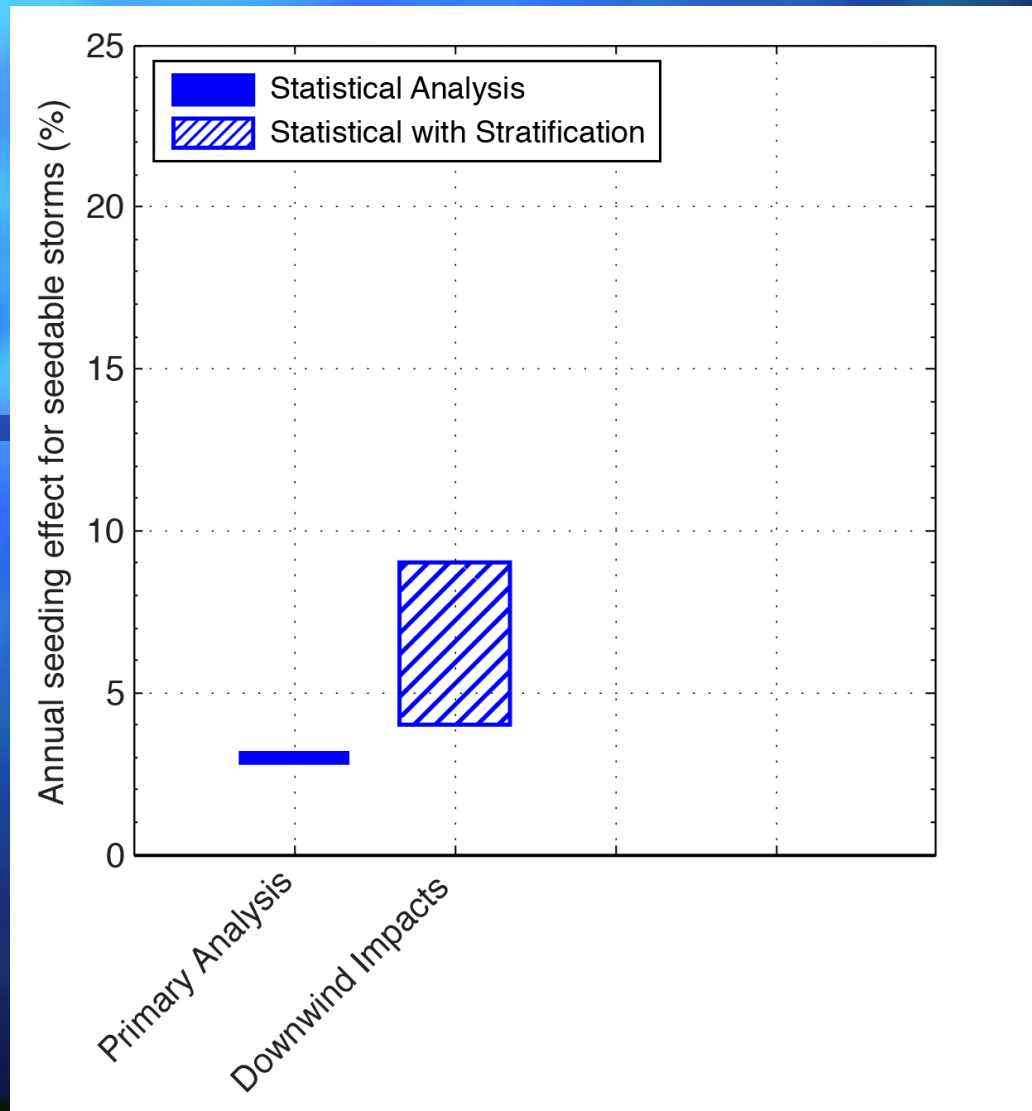


Downwind Seeding of the Medicine Bow by the Sierra Madre

The model estimated 18 cases of enhanced precipitation in the Medicine Bow target during Sierra Madre seeding cases (for 2009/2010, 2011/2012, 2013/2014).

Eliminating these 18 cases from the 118 snow gauge cases increased the RRR from 1.03 to 1.09.

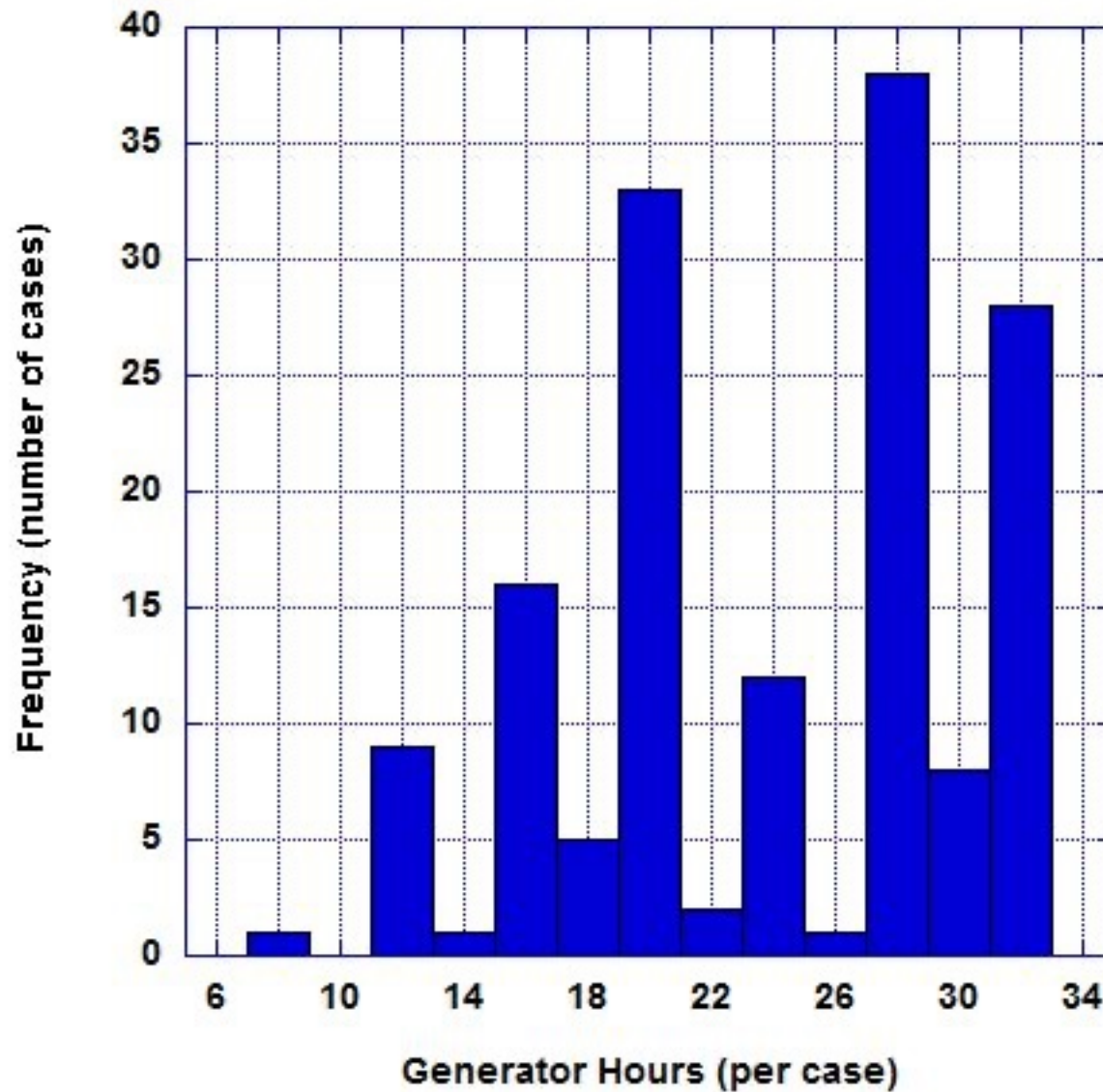
Eliminating cases of **downwind** seeding of the Med Bows by Sierra Madre seeding from silver iodide ground based measurements and model estimates of seeding precipitation and applying the statistical analysis results in values of RRR from 1.04 to 1.09.



Impact of the number of generators active per case

Impact of the number of generators
active per case on the snowguage
statistics

Distribution of Generator Hours



Procedure: Simulate three years of the RSE using the exact seeding timing and conditions (57 cases)

Seasons

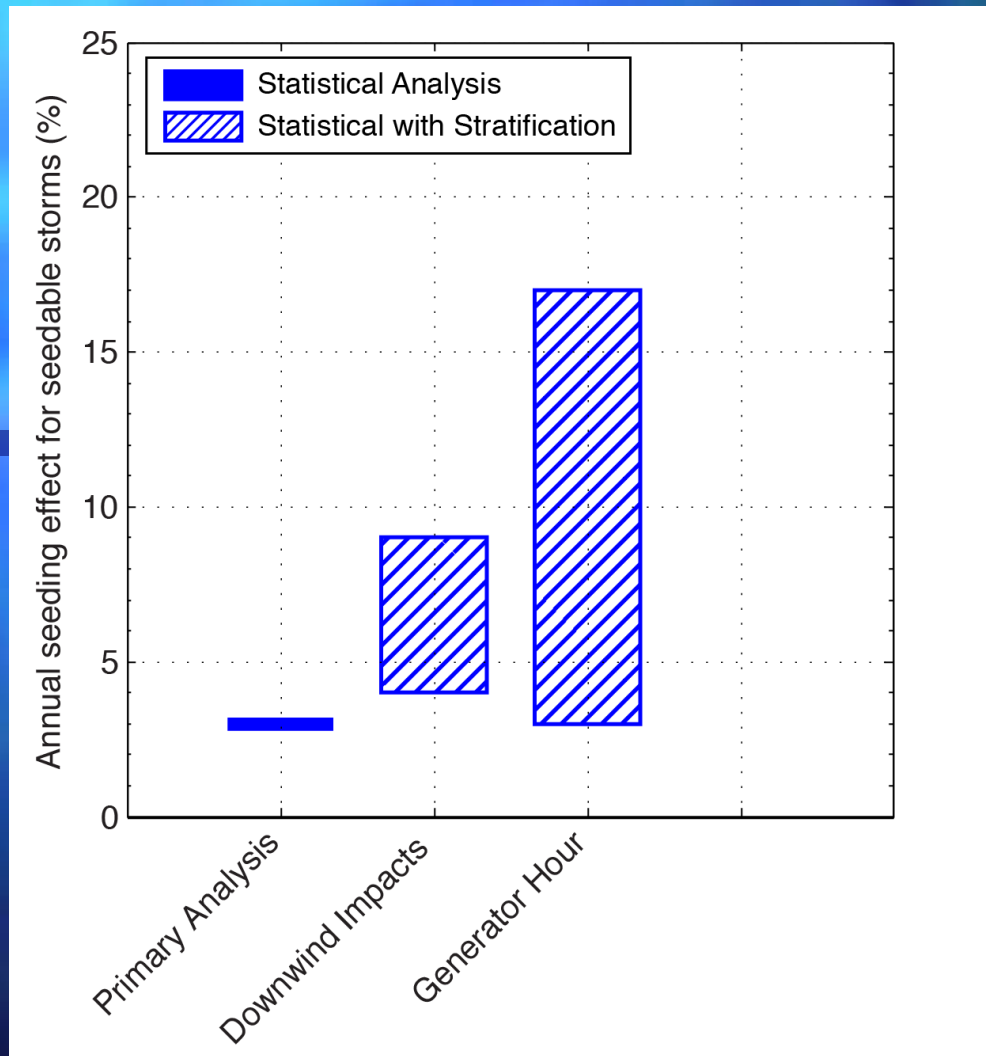
2009/2010

2011/2012

2013/2014

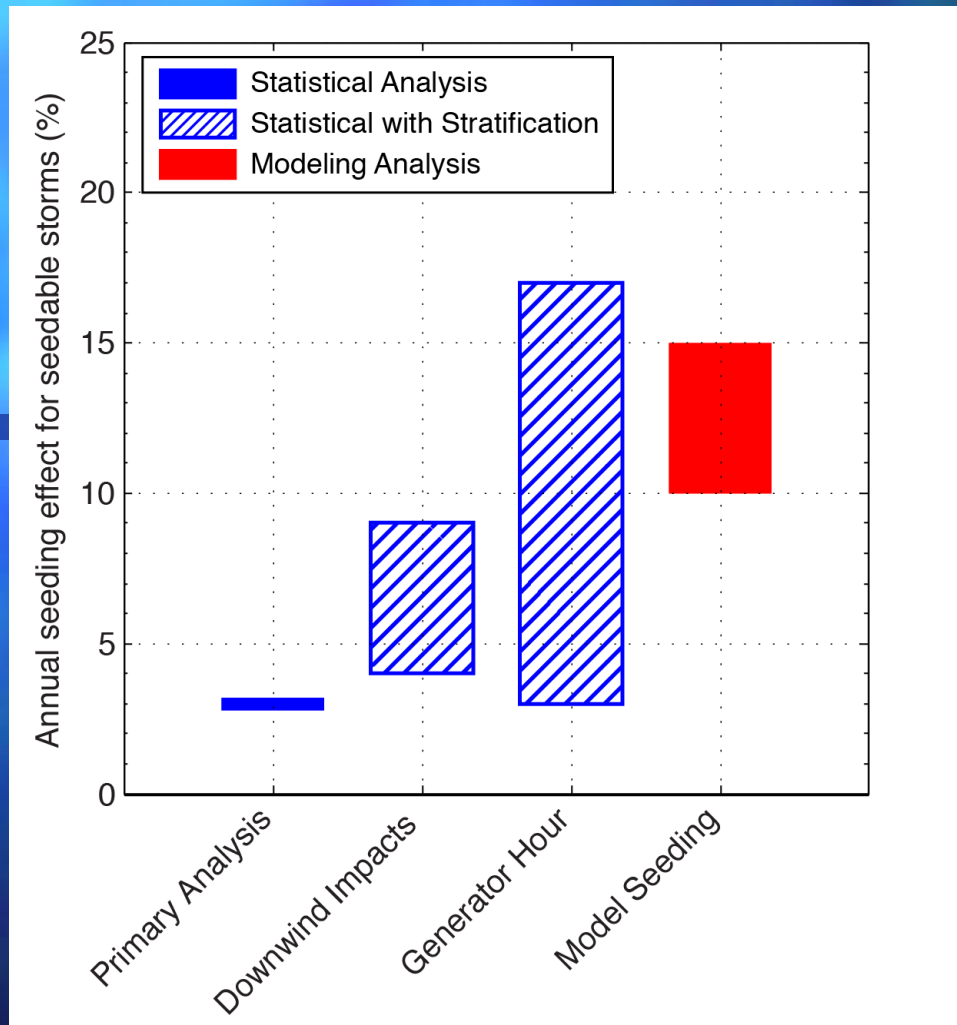
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Eliminating cases with generator hours per case of less than 21 hours and applying the statistical analysis results in values of RRR from 1.03 to 1.17.



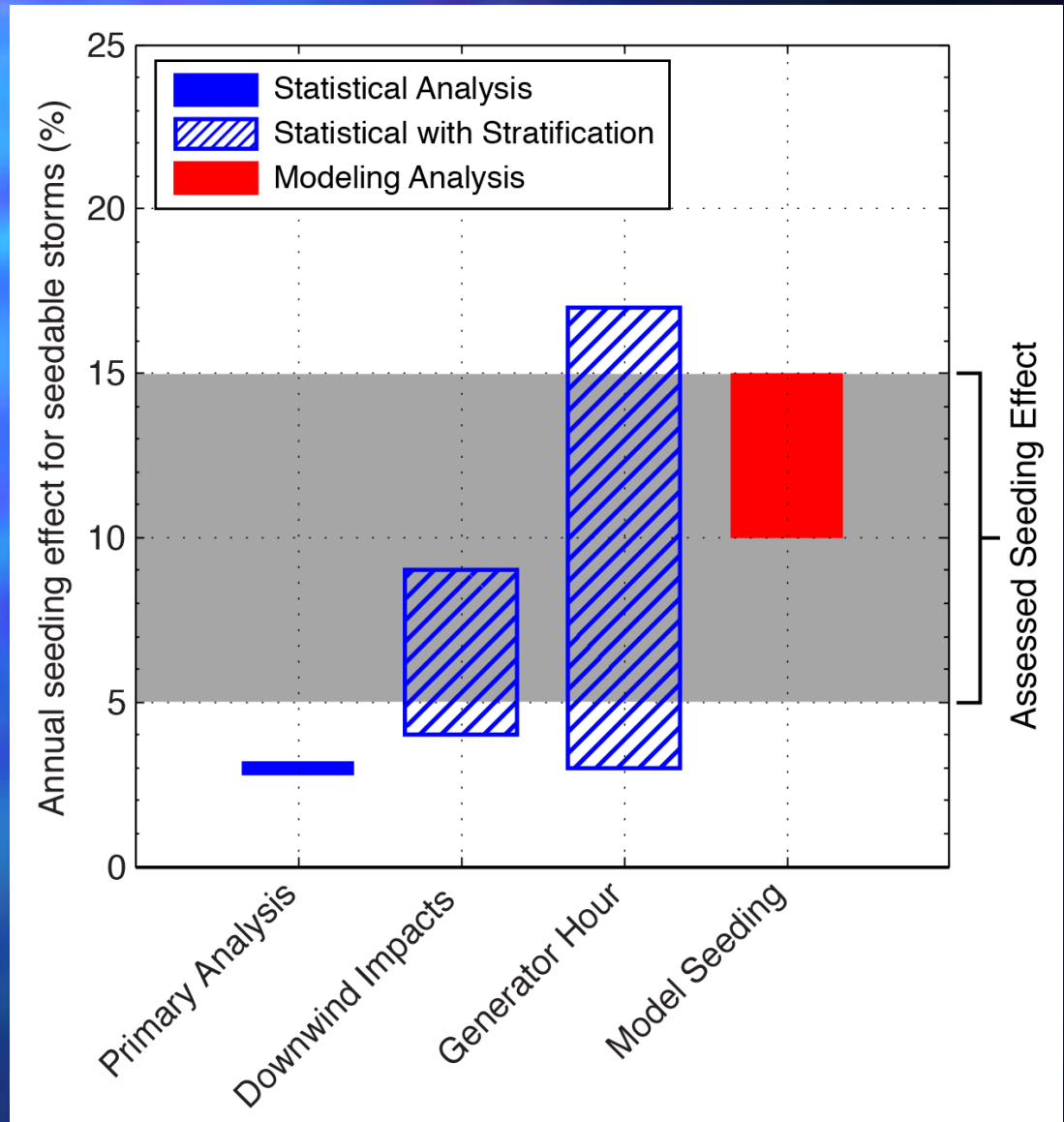
Simulation of the impact
of AgI seeding with the
WRF model shows 10-15% increase in
precipitation

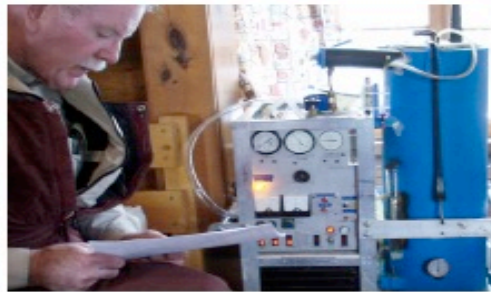
Model estimate of seeding effect by direct simulation of seeding and natural cloud for 1/2 of the RSE cases shows 10-15% increase over a season



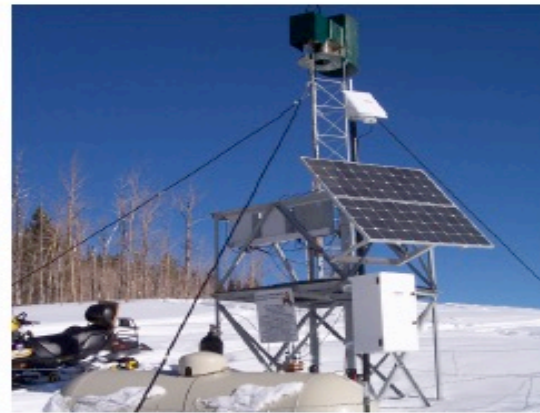
Conclusion:

The accumulated evidence from the statistical, modeling, and physical studies suggests a positive orographic seeding effect, over a winter season, between 5 and 15% in the Medicine Bow and Sierra Madre Ranges, for seedable cases based on the RSE criteria and for which sufficient ground-based silver iodide seeding was achieved





The **WYOMING**
Weather Modification Pilot Program • LEVEL II STUDY

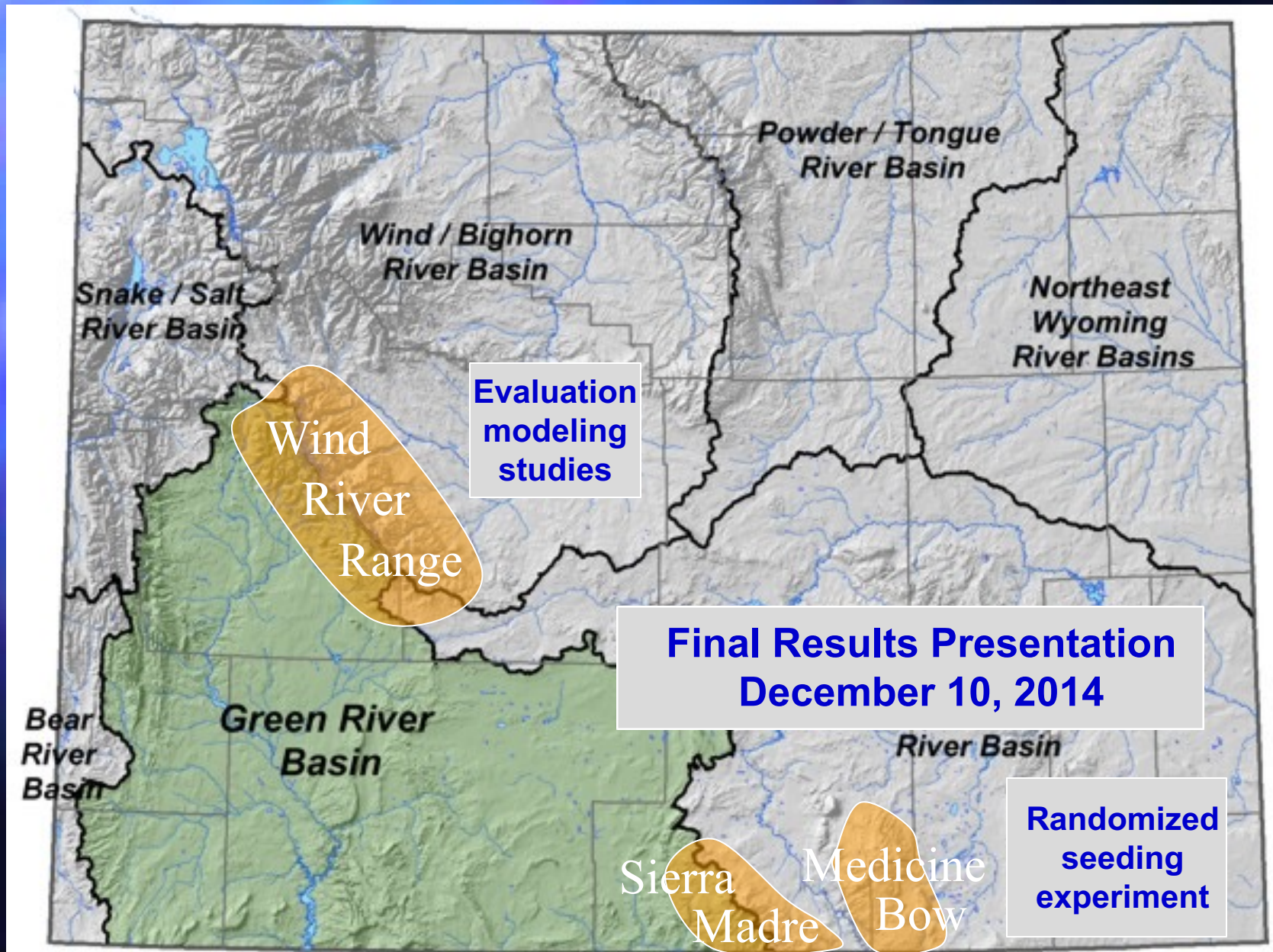


<http://wwdc.state.wy.us>

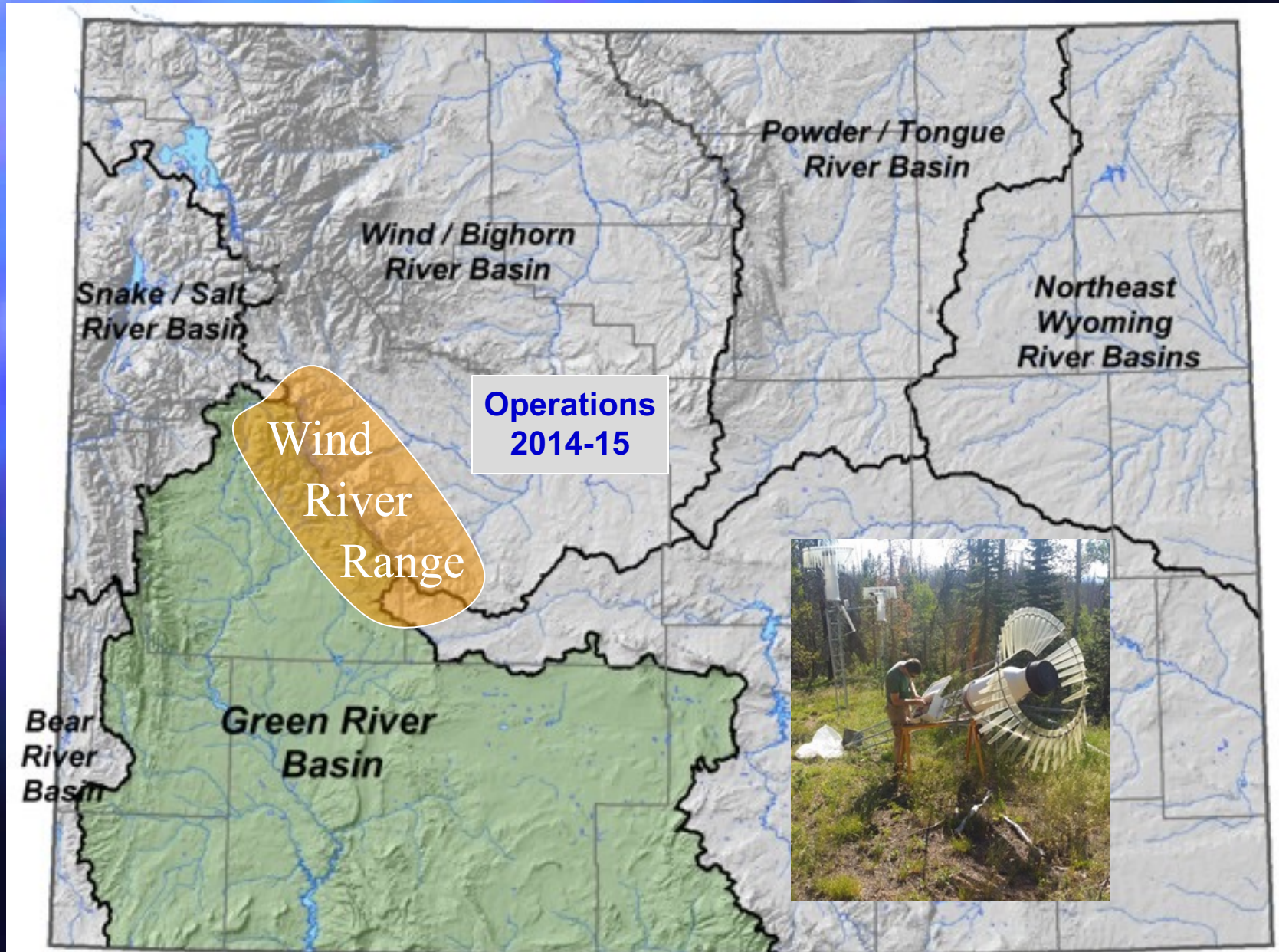
Next Steps: Collaborative Weather Modification



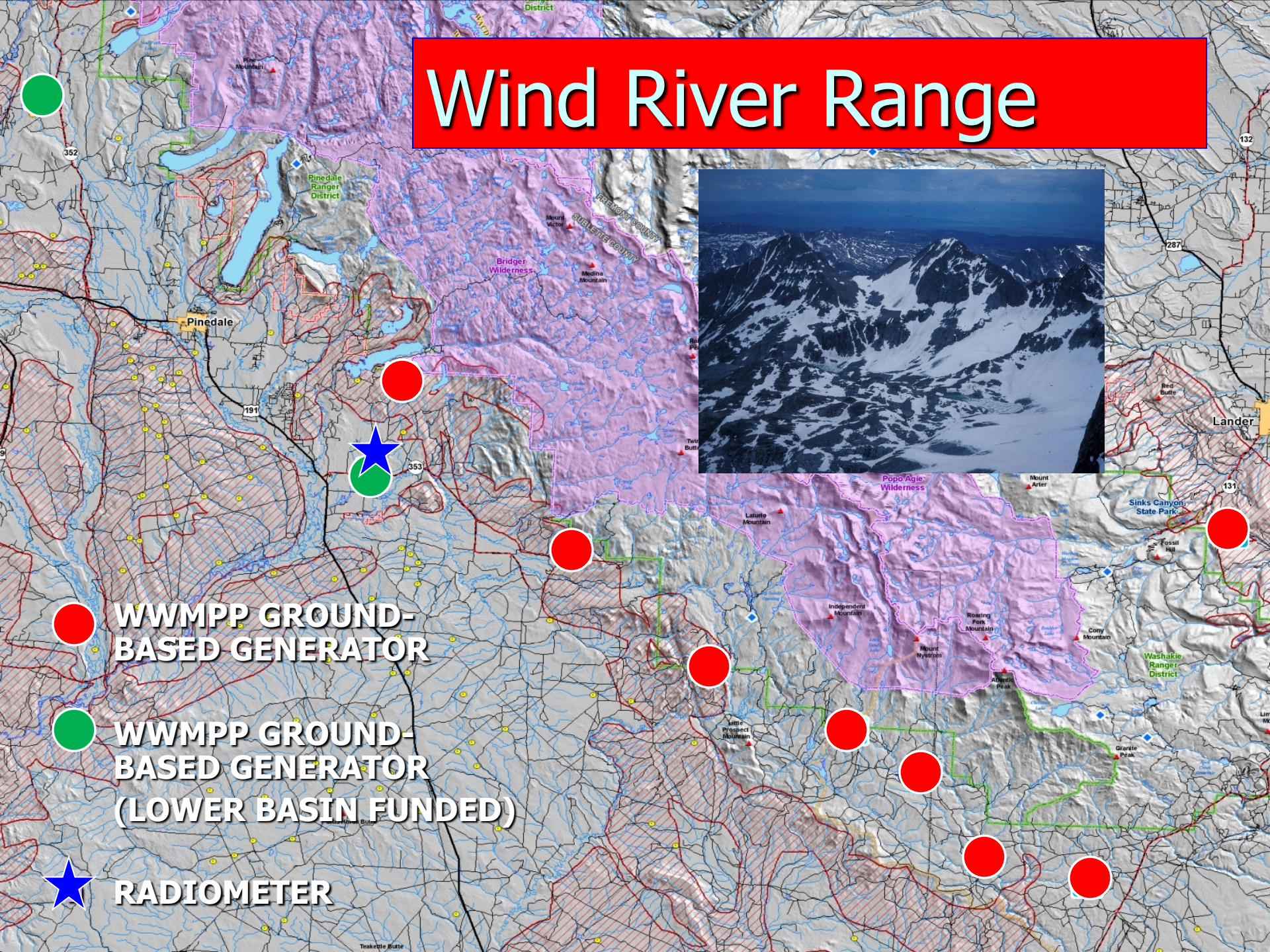
Wyoming Weather Modification Project



Wyoming Weather Modification Project



Wind River Range



WWMPP GROUND-BASED GENERATOR

**WWMPP GROUND-BASED GENERATOR
(LOWER BASIN FUNDED)**

RADIOMETER

2014 Wyoming Legislative Session

Omnibus Water Bill - Construction

- Included \$240K cost share funding for continued operations in the Wind River Range for Winter '14/15 with a total project cost of \$930,000.
- State of Wyoming's participation capped at 25% to reflect:
 - Historical participation of three Lower Basin funding partners
 - Acknowledgement of other States' programs
 - Believe majority of benefits will be accrued downstream

Wind River Range Winter 2014-15

Funding Partners

Operations:

- Southern Nevada Water Authority
- Central Arizona Project
- Colorado Water Board of California –
Six-Agency Committee
- Arizona Dept. of Water Resources
- Utah Division of Water Resources

Modeling and Evaluation:

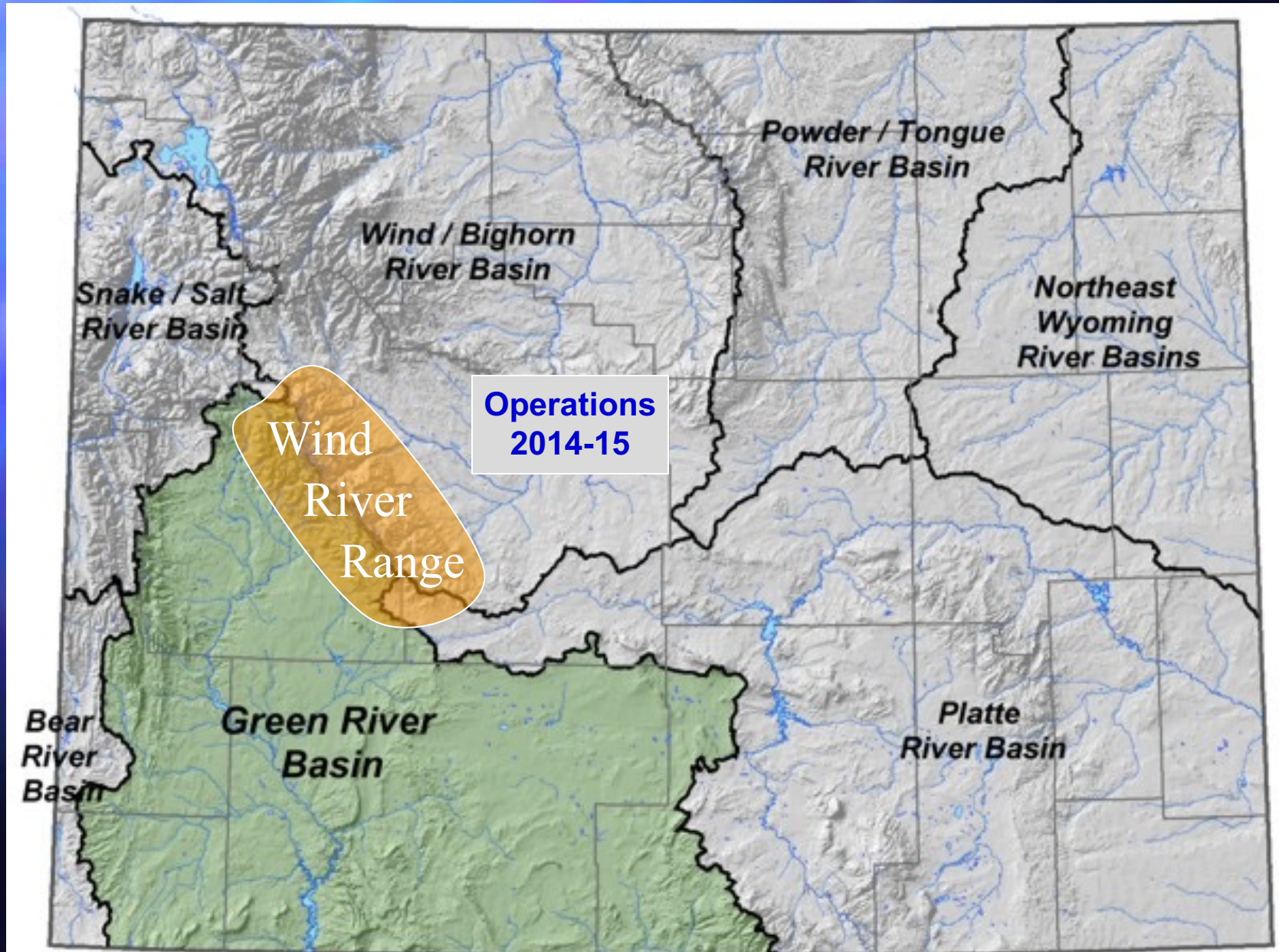
- US Bureau of Reclamation



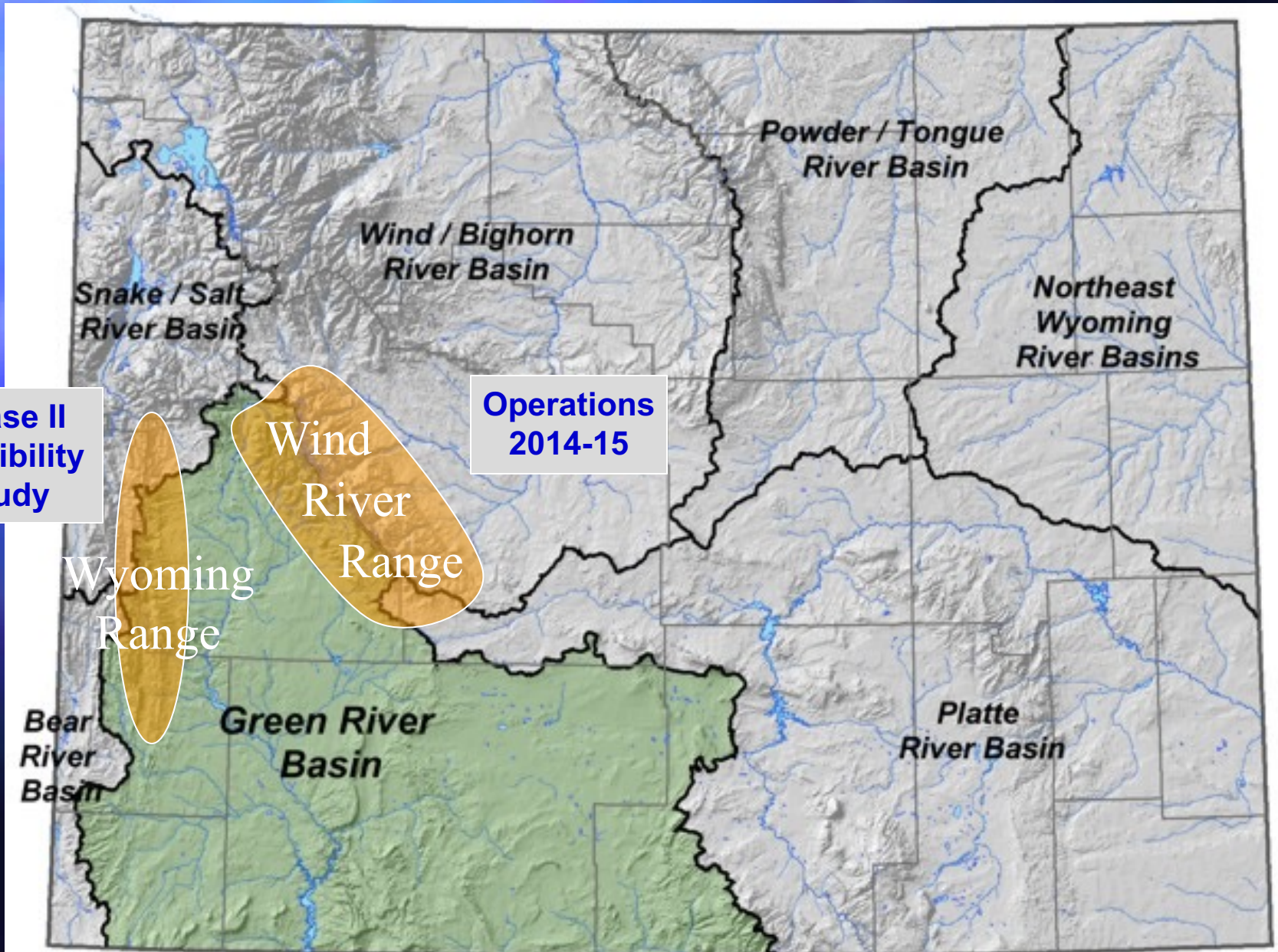
Basic Tenets of Program

- No ownership of any additional water produced is implied.
- No expectation of a certain amount of water being delivered downstream.
- Treated as a natural event.
- Subject to Wyoming Water Law.
- **An effort to improve system conditions.**

Wyoming Weather Modification Project



Wyoming Weather Modification Project



Flow Augmentation in the Upper Colorado

