DRI
Desert Research Institute

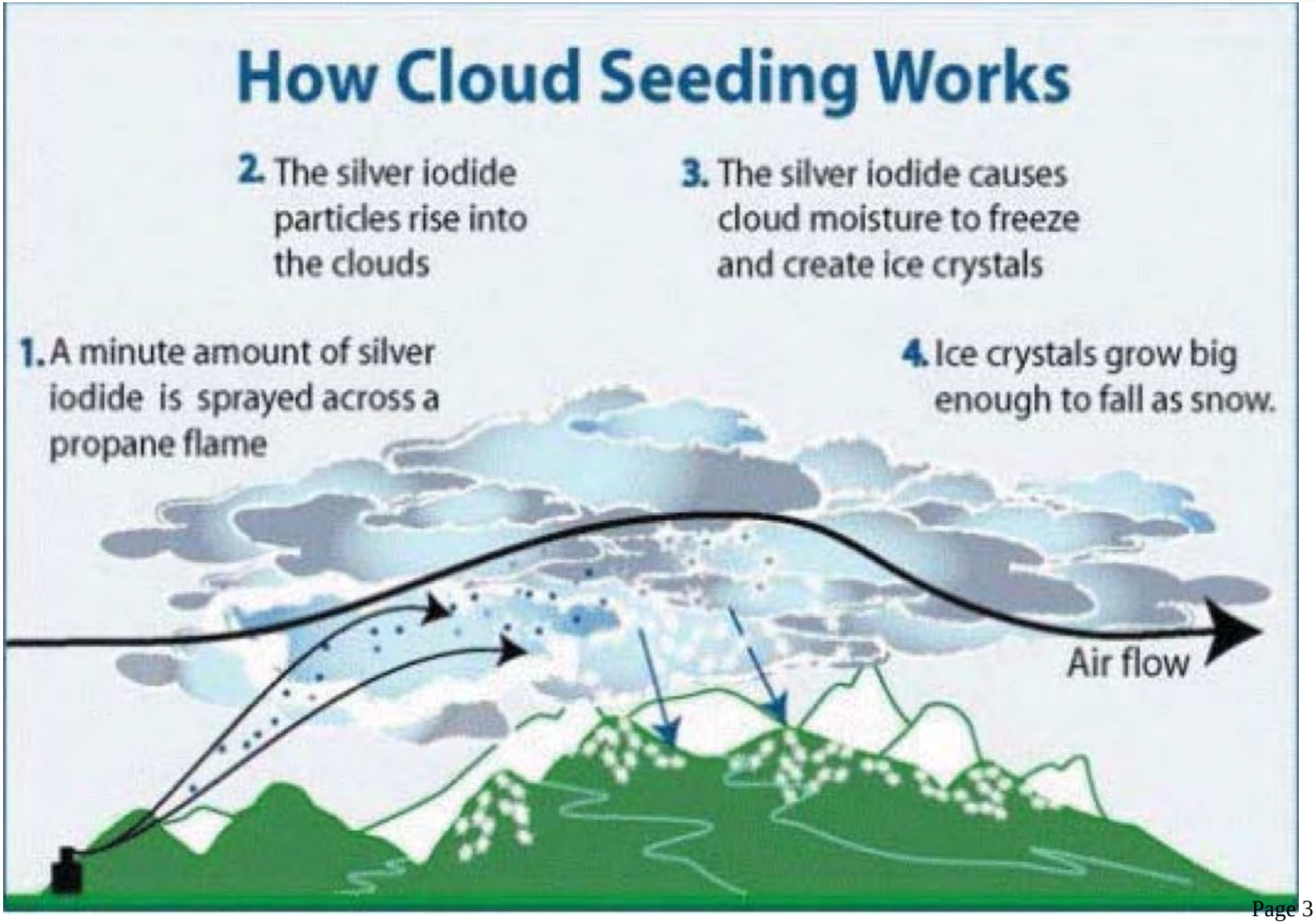
Cloud Seeding

Presented by: Frank McDonough – Meteorologist

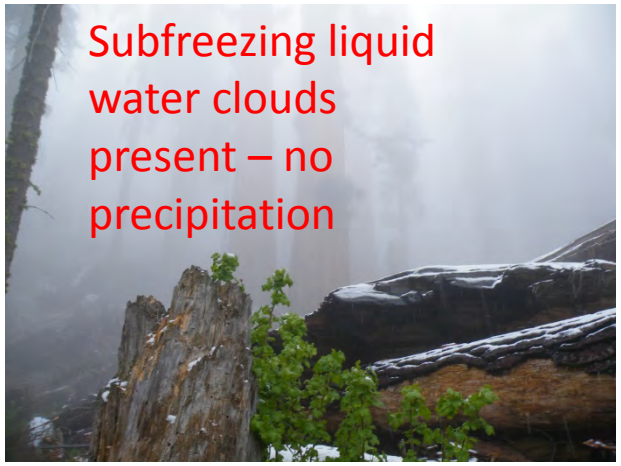
Outline

- Background
- Brief Tahoe Summary
- Cloud seeding technology (table)

Background


How Cloud Seeding Works
2. The silver iodide particles rise into the clouds
3. The silver iodide causes cloud moisture to freeze and create ice crystals
1. A minute amount of silver iodide is sprayed across a propane flame
4. Ice crystals grow big enough to fall as snow.
Air flow

Background



Create small ice crystals through seeding

Crystals grow in presence of tiny subfreezing drops

Crystals grow into large crystals which fall as snow and add to snowpack

Snow melts into runoff

CA/NV cloud seeding projects

West Coast operational cloud seeding projects over the past 20 years.

Currently active in 11 to 14 watersheds

Aircraft and ground-based

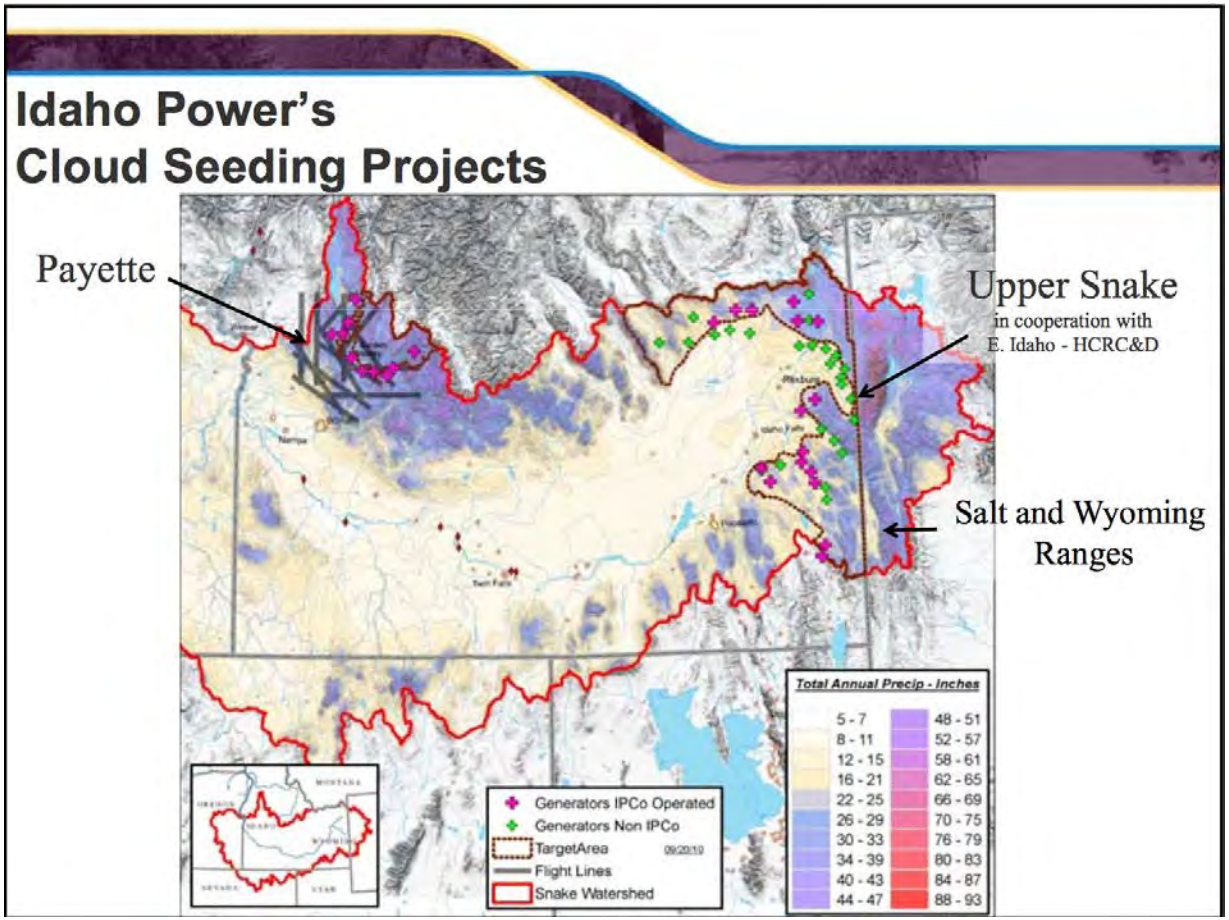
Source: Department of Water Resources. California Water Plan Update 2009. Vol. 2: Resource Management Strategies.

Idaho Cloud Seeding

$1 million/ year

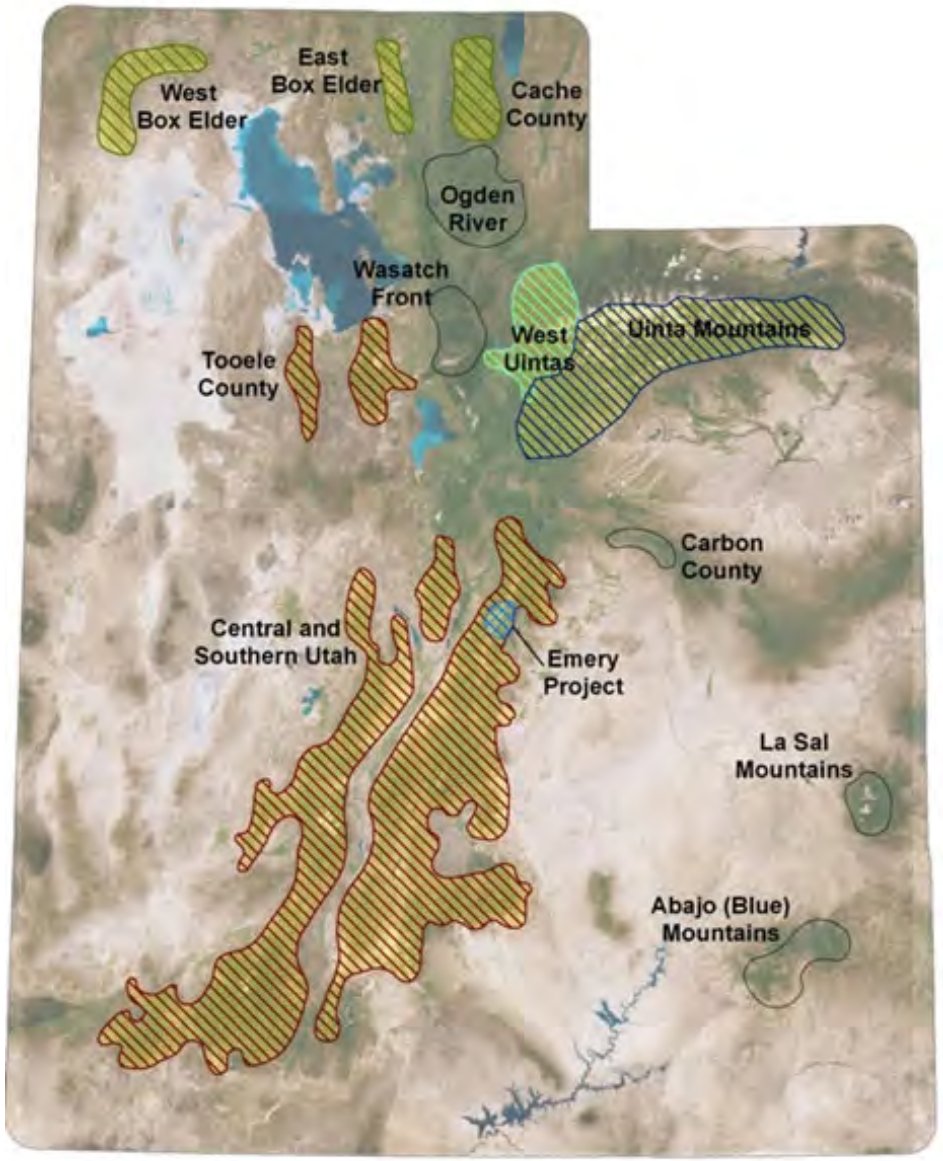
Aircraft cloud seeding warmer winter storms

Ground-based and aircraft cloud seeding for colder storms

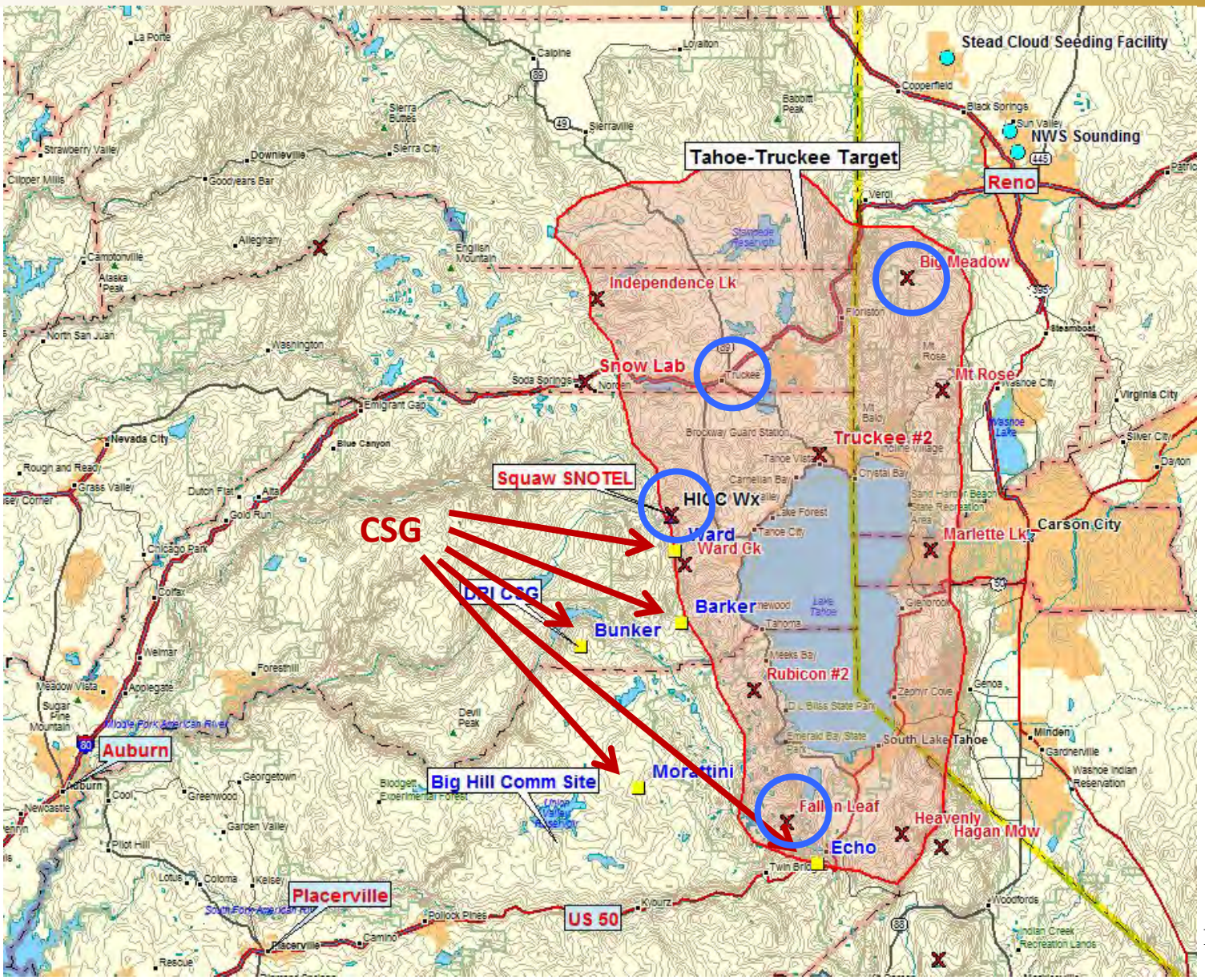


Utah cloud seeding projects

Most of the higher terrain in the state is targeted.



Tahoe/Truckee seeding network



DRI cloud seeding

Sited at locations that maximize seeding effectiveness

Remote 24/7 operations by expert cloud seeding meteorologists

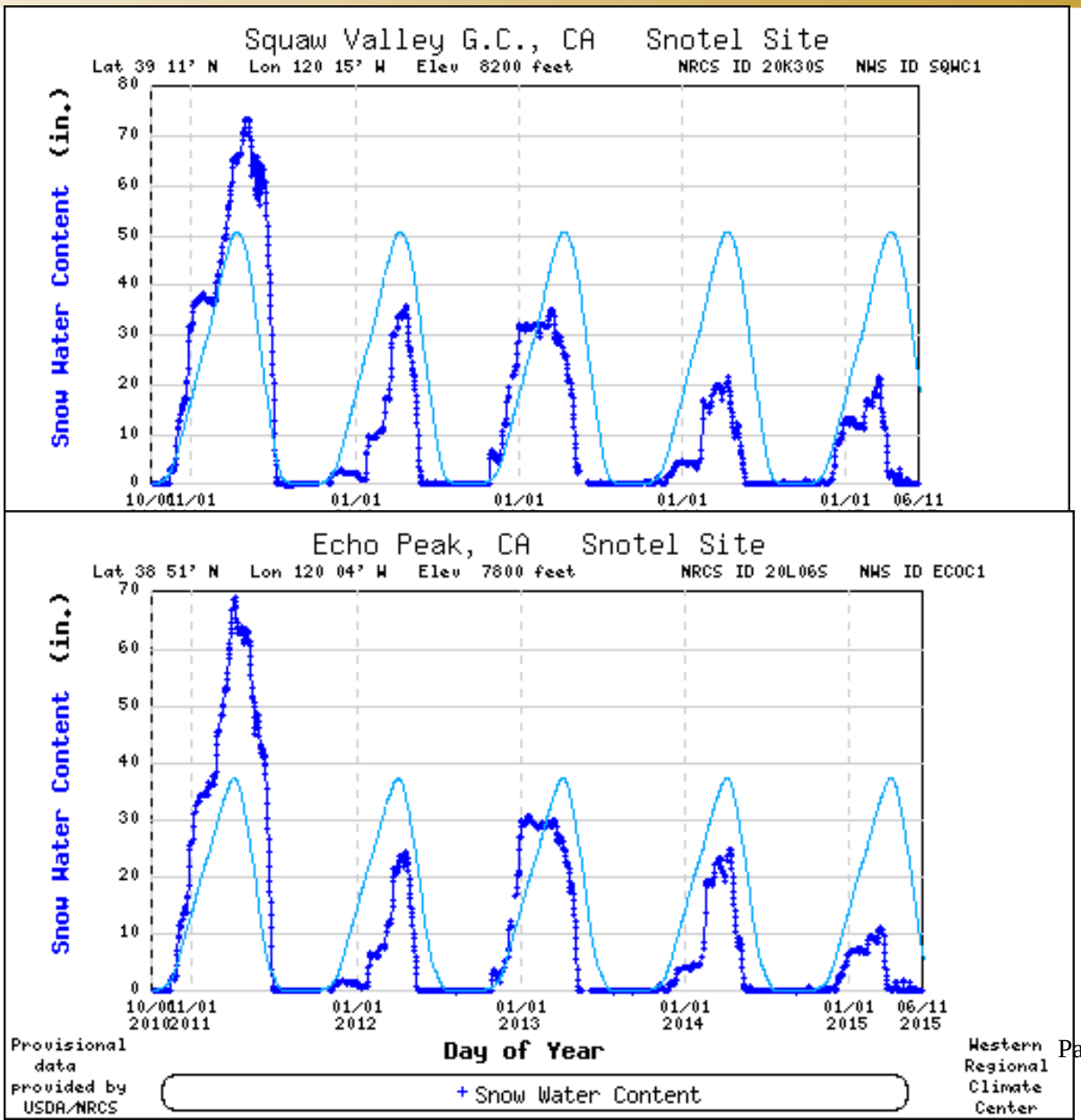
Generators and communications equipment are reliable and serviced by experienced technicians

Tahoe/Truckee – 5 year SWE

Sierra Crest

Squaw (8,200’)

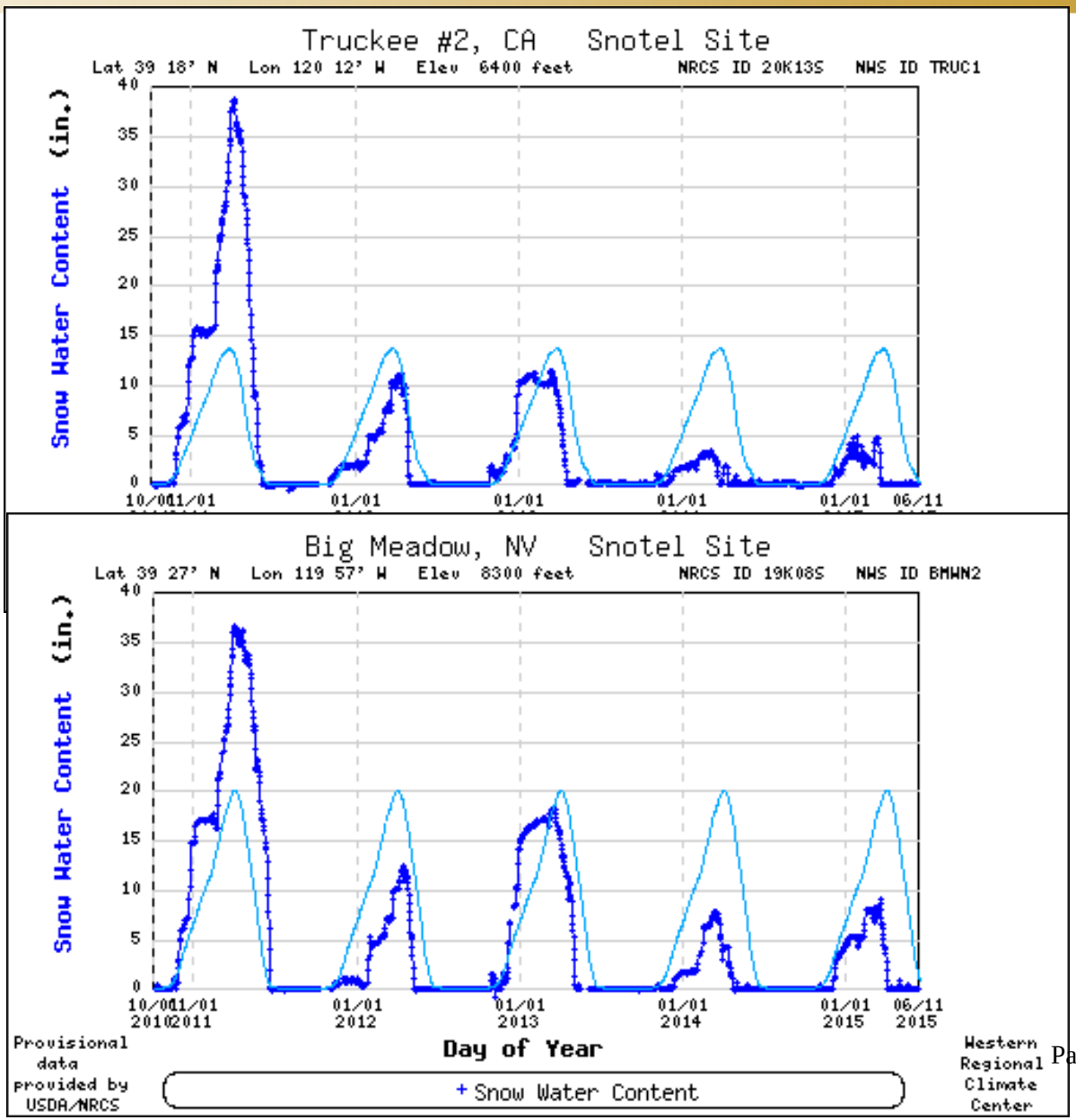
Echo Pk (7,600’)



Tahoe/Truckee – 5 year SWE

Truckee (6,400')

Big Meadow (8,300')



Cloud Seeding Truckee/Tahoe WY 2015

Summary of season

- 19 events year to date

Nov 2014 – 4 events
Dec 2014 - 6 events
Jan 2015 - 1 event
Feb 2015 - 2 events
Mar 2015 - 2 events
Apr 2015 - 4 events

-Total Generator hours – 590 gen-hours

-Initial estimate of increase in snow water equivalent (SWE) ~9,000 acre-feet

Tahoe/Truckee – February 2015

3 Storms:

Feb 6-7

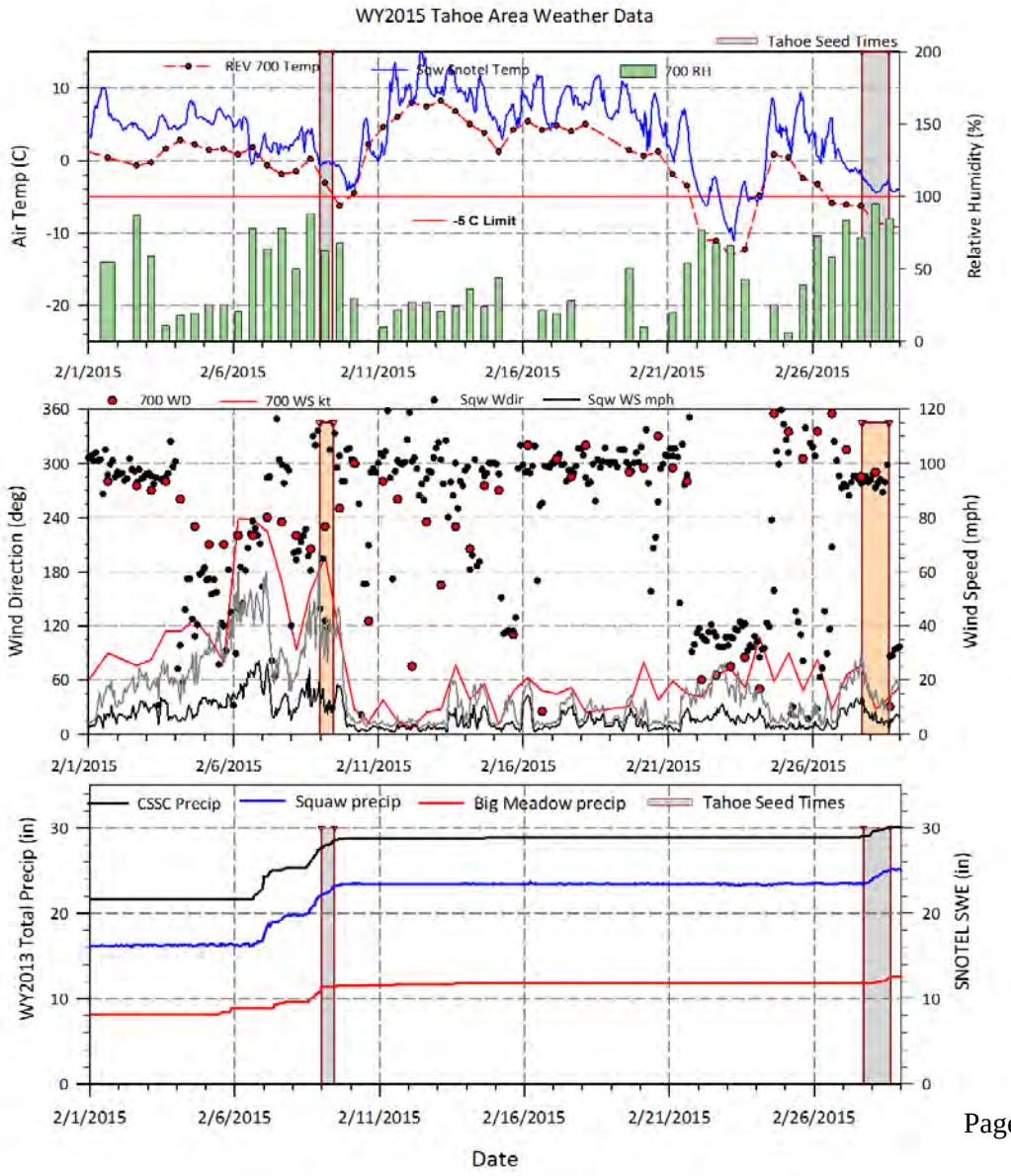
4” SWE
T -2C
Winds (SW/80MPH)
No Seed

Feb 8-9

4” SWE
T 0C -> -6C
Winds (SW-W/60MPH)
Seed 2nd half of storm (unstable)

Feb 27-28

1.7” SWE
T -8C
Winds (W/15MPH)
Seed entire event



Cloud Seeding Truckee/Tahoe WY 2015

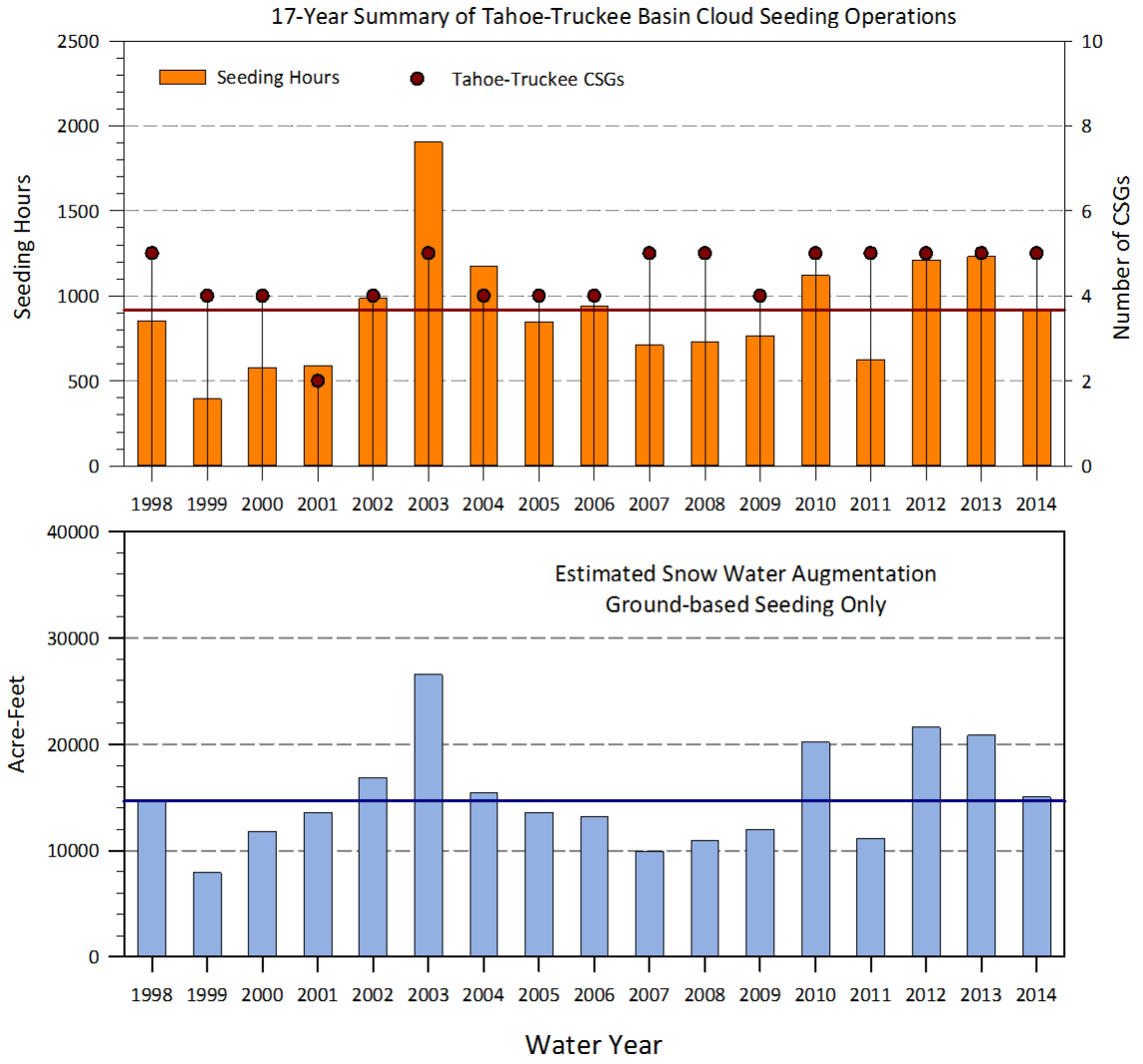
WY 2015 compared to previous years

Mean generator hours
Historic: 917 gen-hours
WY2015: 590 gen-hours

Mean seeding water augmentation
Historic: 14,600 acre-feet
WY2015: ~9,000 acre-feet*

Median cost per acre-ft.
Historic: < $20

*9,000 acre-ft. is enough water for 21,000 Truckee Meadows households.



Cloud Seeding Truckee/Tahoe WY 2015

Tahoe Summary

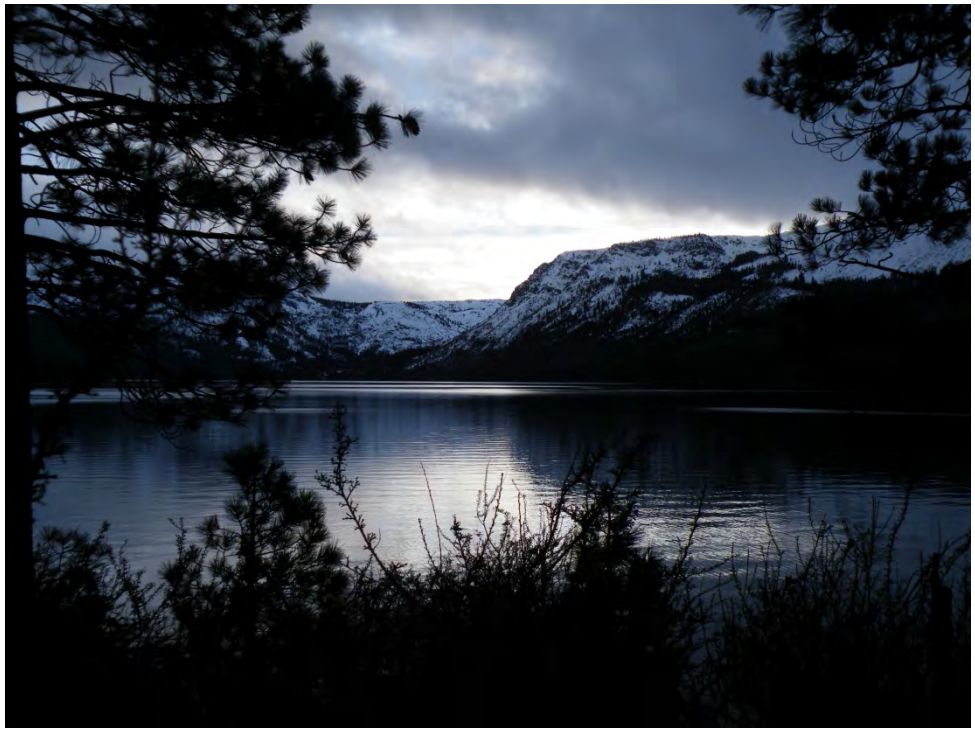
- Very warm and dry winter overall

- All seedable storms were seeded

- Equipment worked well when needed

- Estimated 9000 acre-feet (3 billion gallons) of water added to snow pack

- Several big storms (Pineapple express) were too warm to cloud seed from ground using AgI
    - Aircraft
    - Liquid Propane



Seeding Method	Description	Pro's	Con's	Productivity	Cost
Remote: Ground based (AgI*)	Use AgI plume released from surface to seed clouds	- Continuous operation - Low Cost - Solar powered - In or below cloud base - Proven technology	- Colder than -6°C (21°F) - Requires specific set of atmospheric conditions	10000 – 20000 acre-ft season	$60,000/generator: includes install/full, forecasting and seeding operations, reporting
Aircraft (AgI*)	Release AgI from aircraft flares directly into clouds	- Max increase in precipitation - Warmer storms - More seeding options (winds)	- Higher cost - No continuous operations (pilot rest/refuel) - Aircraft Icing	~200+ acre-ft/hr (in ideal conditions)	$20,000 mo aircraft/crew, $800/hr seeding operations $ forecasting/flight guidance

Remote: Propane	Create ice crystals at nozzle use crystals to seed cloud	-Warmer storms -2°C (29°F)
		- Low Cost
		- Solar Powered
			- In cloud operations
			- High elevation sites (access)
			- Experimental
				Expected to be significant (Utah study) but requires further study after operations	$13,000 to build and fill,
					$ id site and install (variable)
					$ operations

*AgI – silver iodide

Thank You !

Any questions/comments?

Extra slides

Silver Iodide (AgI)
-Insoluble in water (remains a solid at high and low temperatures)
-No molecular charge
-Less than 1 oz released per hour by DRI generators – dispersed over 35 sq. miles
-Not bioavailable (is not biologically available to the ecosystem)
-The amounts found in the seeded snow < 10 pts trillion (10/1000000000000) (Huggins 2015)
-Not detectable in soil/runoff or water bodies even after 50 years of cloud seeding (Mokelumne; Stone 2006)

Is cloud seeding effective?

Cloud seeding can increase snowfall by up to 15% (peer reviewed scientific publications)

- Climax Experiments Colorado (central Colorado Mountains) (Mielke et al. 1981; Grant 1986)

- Bridger Range Experiments (15%) (southwestern Montana) (Super and Heimbach 1983)

- Snowy Precipitation Enhancement Research Project (14%) (Snowy Mountains, Australia) (Manton et al. 2011)

- Wyoming Weather Modification Pilot Project (5 to 15%) (Medicine Bow/Sierra Madre, WY) $15M, 10 years (Breed et al. 2014)

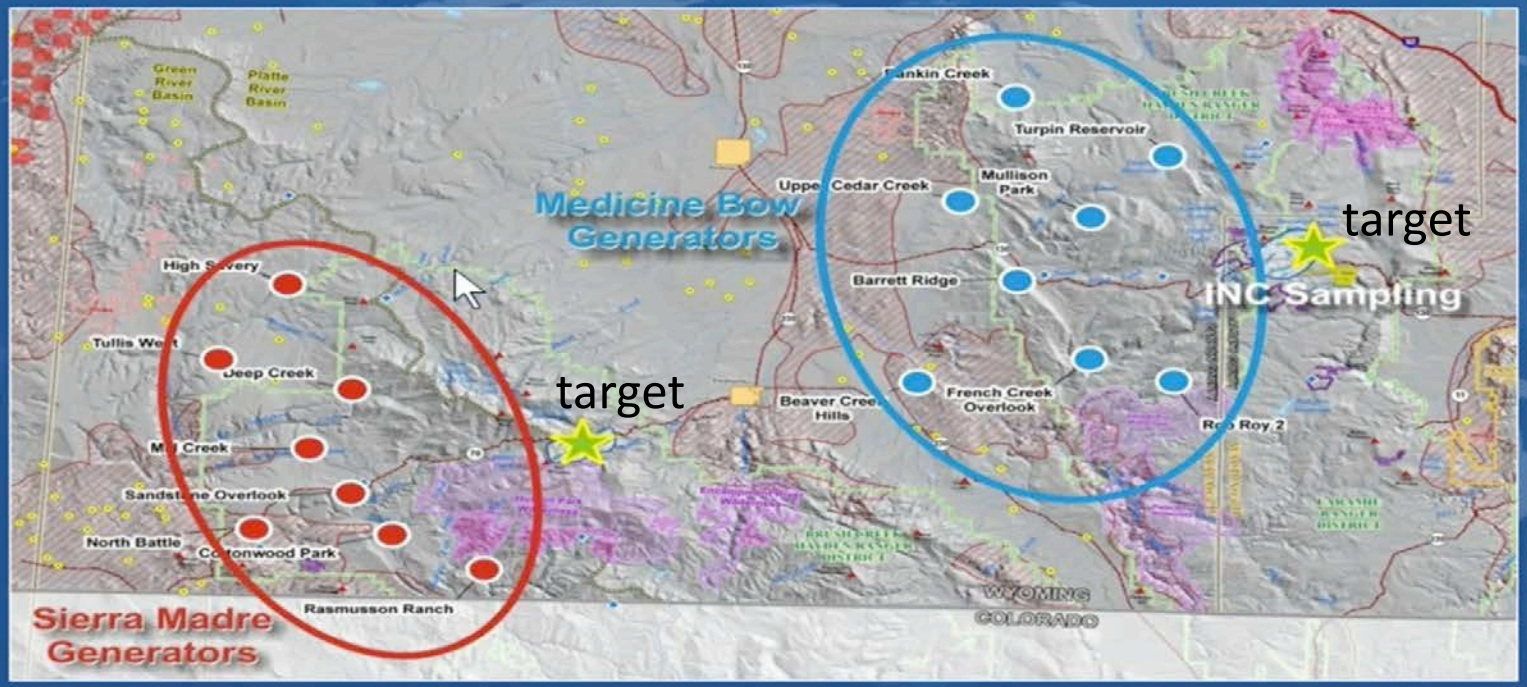
Wyoming Weather Modification Pilot Program

summarized from Roy Rasmussen's 2015 AMS presentation
presented by Frank McDonough

Wyoming WMPP - Summary

Experiment Area

Randomized Crossover Experimental Design

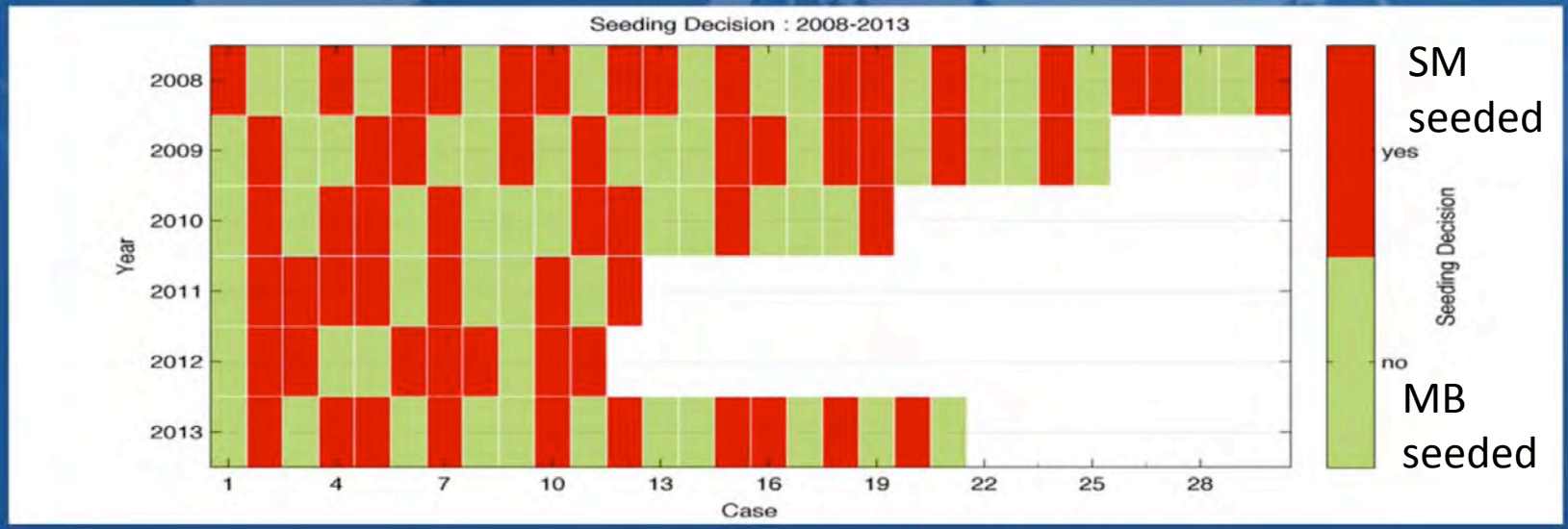


Similarity in storm conditions affecting both ranges allow for the possibility of a "cross-over" design resulting in paired data (seeded and control cases), and statistically is the most efficient design to conduct and evaluate.

(from Rasmussen et. al. 2015)

Random Seeding Experiment (RSE)

Summary of Cases and Seeding Decisions at the Sierra Madre Range



RRR equation – Statistics

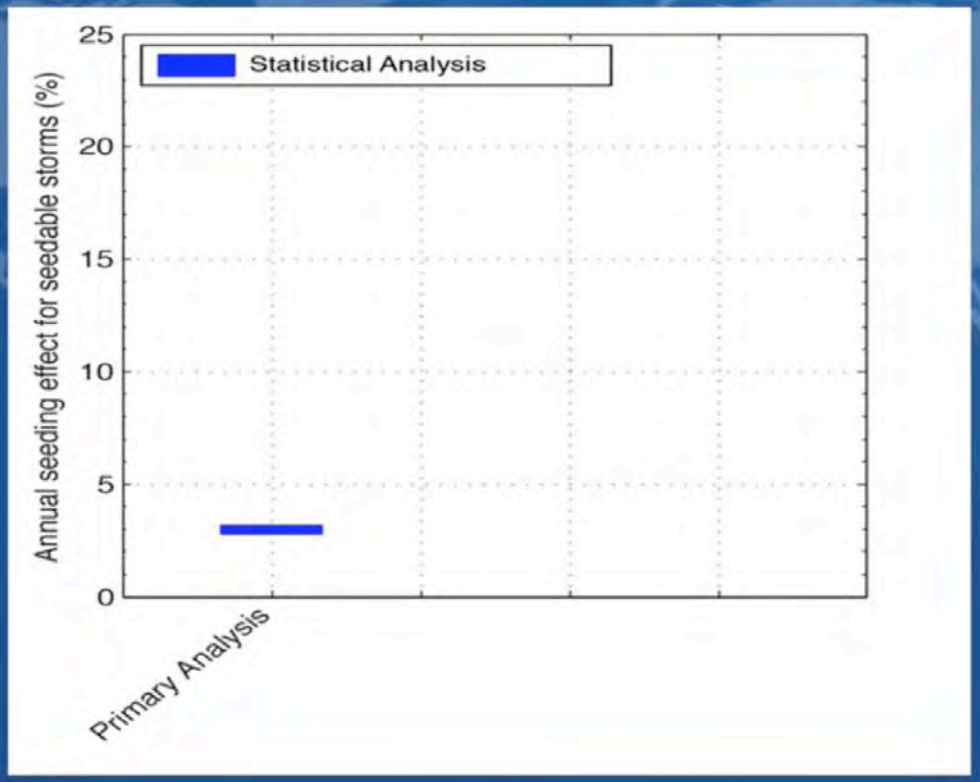
Primary Test Statistic for the Statistical Evaluation
Root Regression Ratio (RRR)

RRR = (Seeded Snowfall/Unseeded Snowfall)

with adjustments using controls which would provide an estimate of snowfall that would have occurred naturally

Primary Results

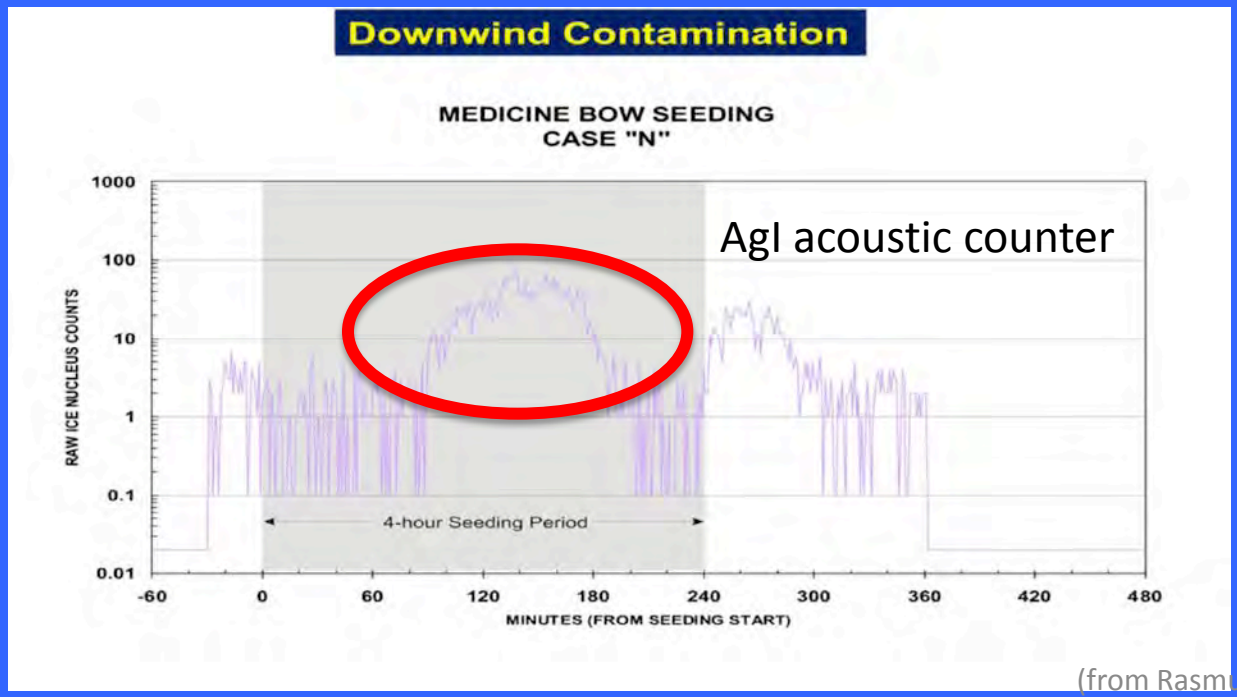
Primary statistical analysis



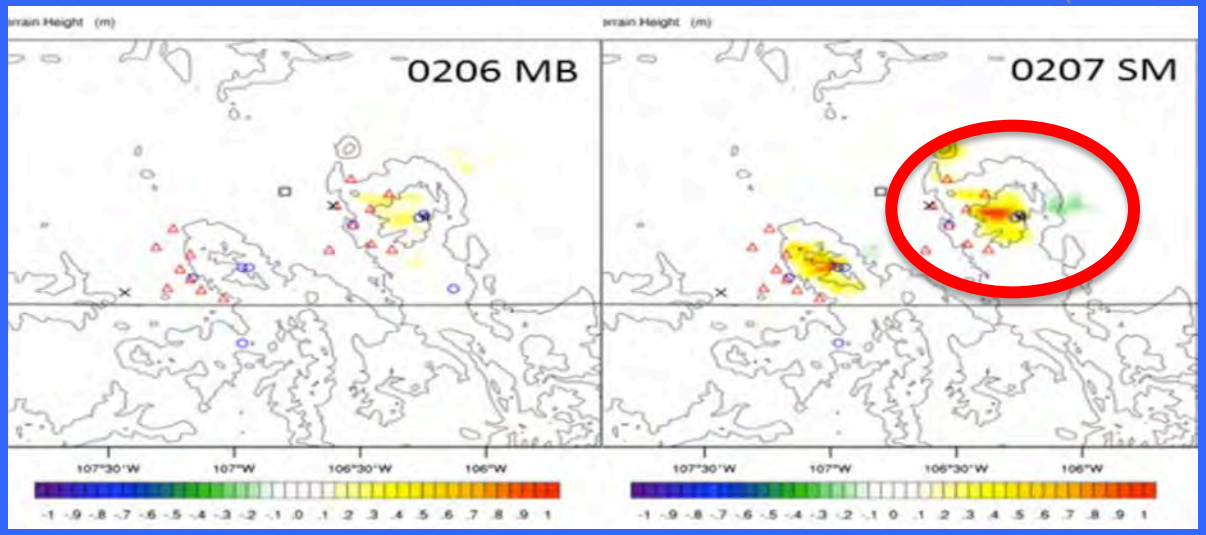
(from Rasmussen et. al. 2015)

Downwind Contamination

18 of 118 cases found to have downwind contamination

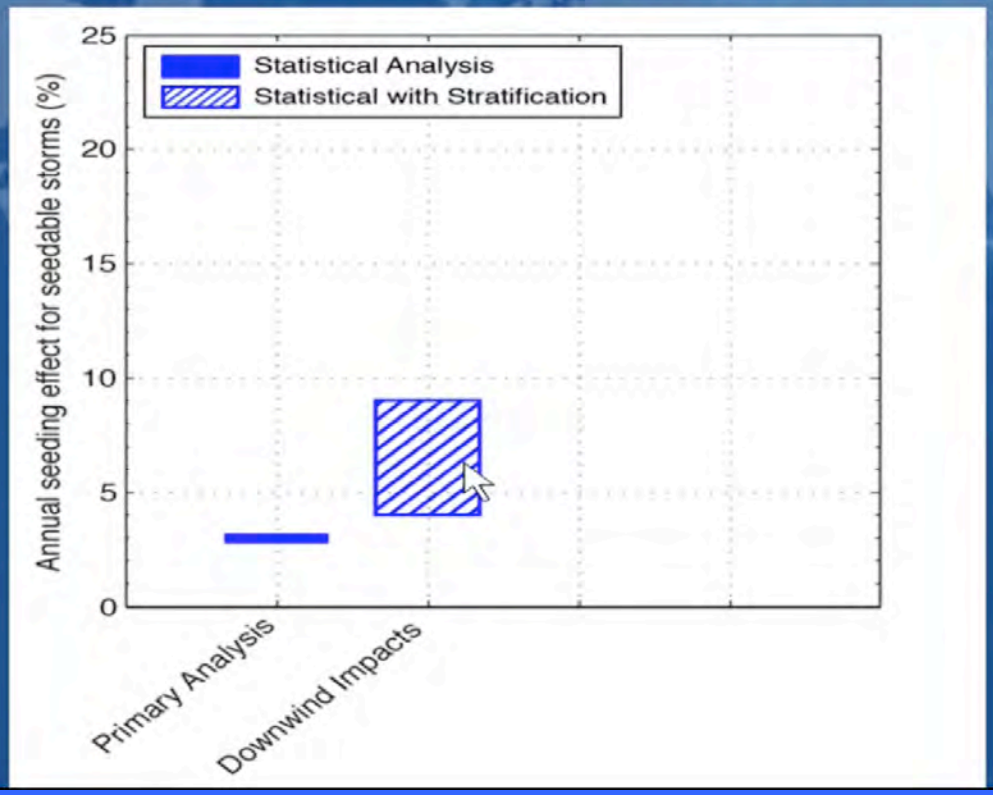


(from Rasmussen et. al. 2015)



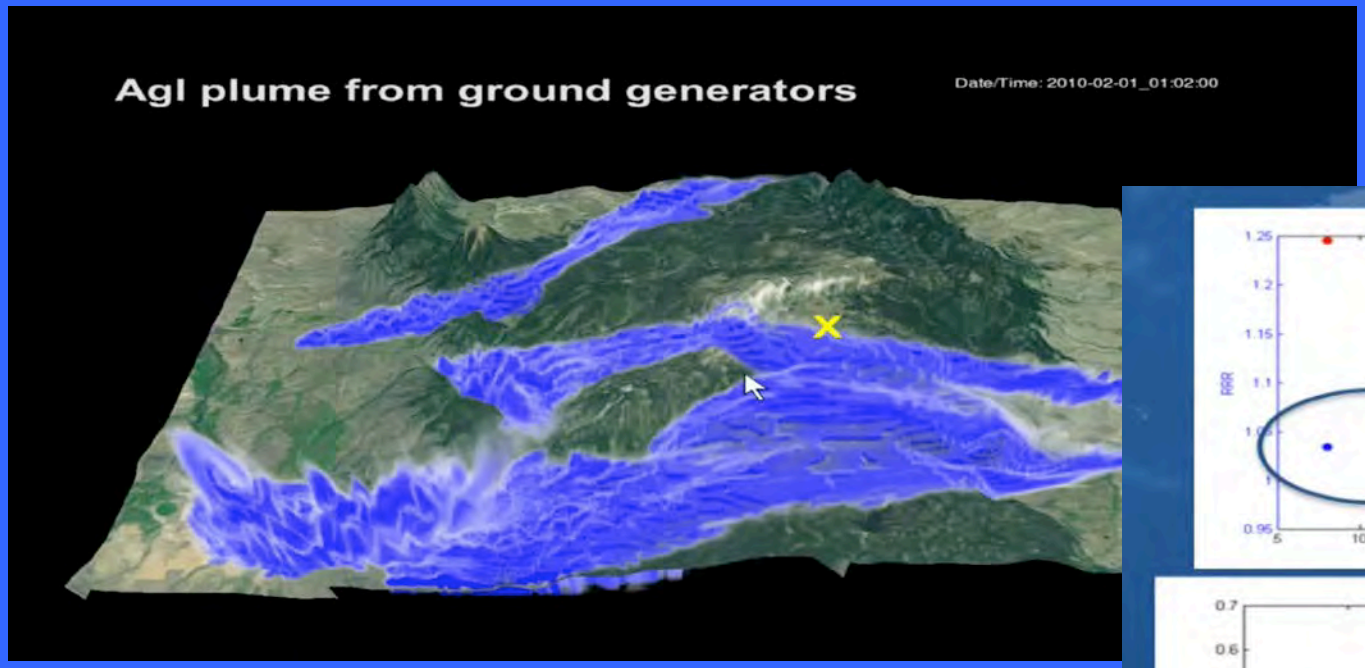
Downwind Contamination

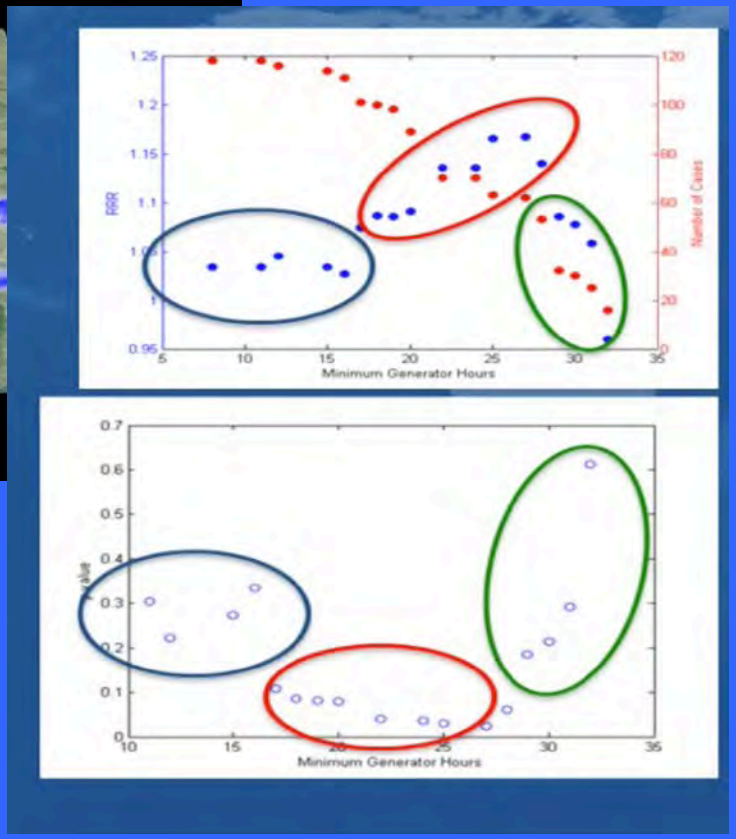
Eliminating cases of **downwind** seeding of the Med Bows by Sierra Madre seeding from silver iodide ground based measurements and model estimates of seeding precipitation and applying the statistical analysis results in values of RRR from 1.04 to 1.09.



(from Rasmussen et. al. 2015)

Generator Hours



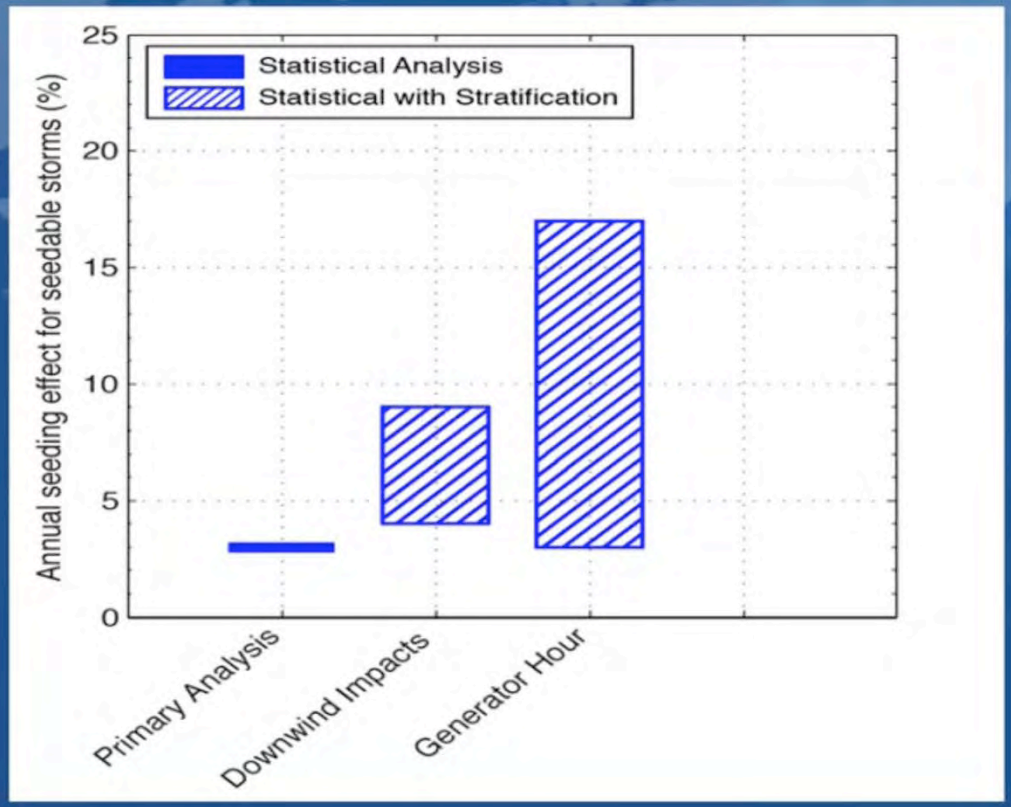


Not all generators operated for all cases.
Leads to target area not getting seeded.
Remove cases when generators-hours
less than 21-hr of 32-hr possible.

(from Rasmussen et. al. 2015)

Generator Hours

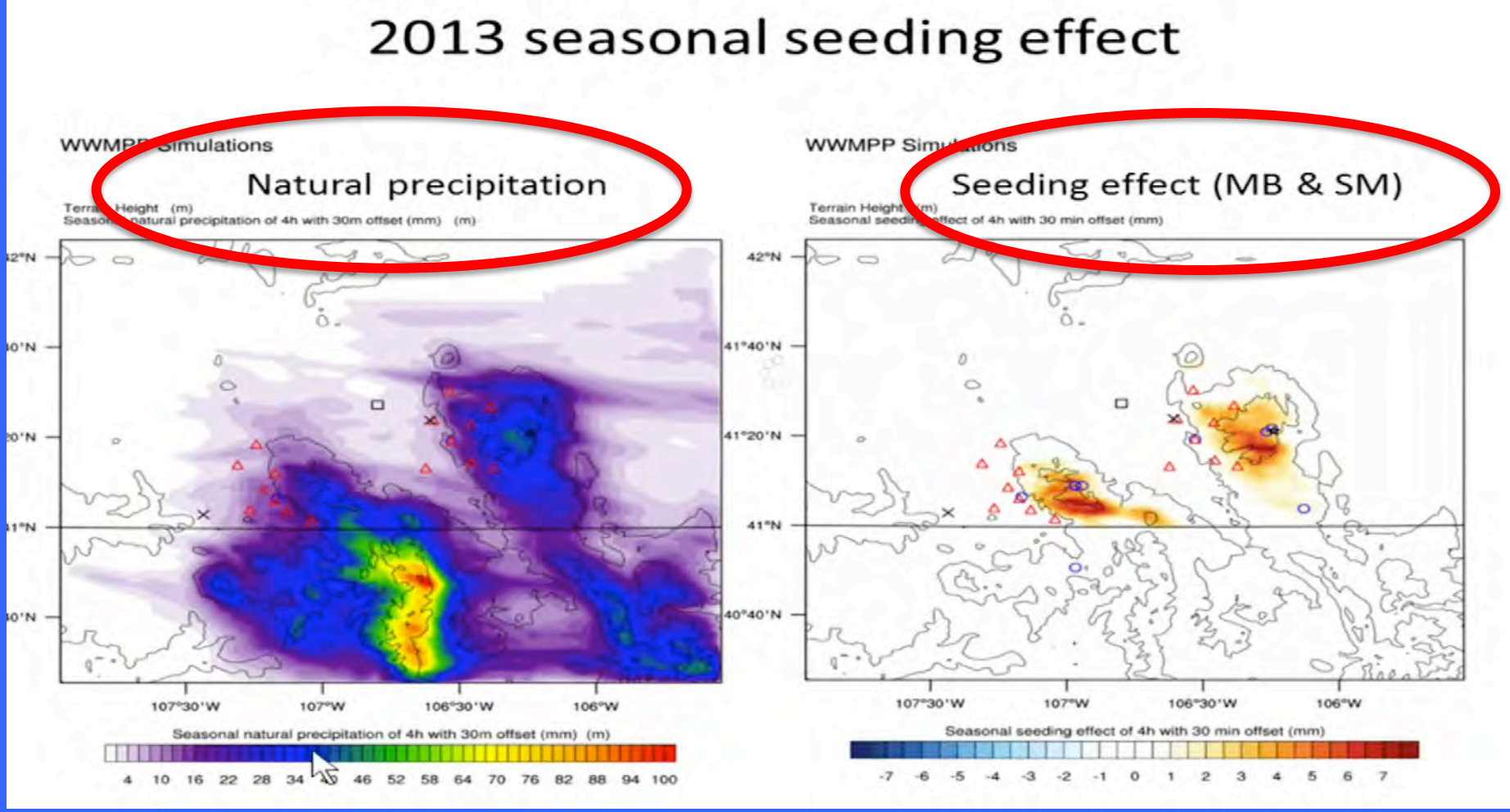
Eliminating cases with generator hours per case of less than 21 hours and applying the statistical analysis results in values of RRR from 1.03 to 1.17.



(from Rasmussen et. al. 2015)

Numerical Model Simulations

High-resolution model run over 3 -winters



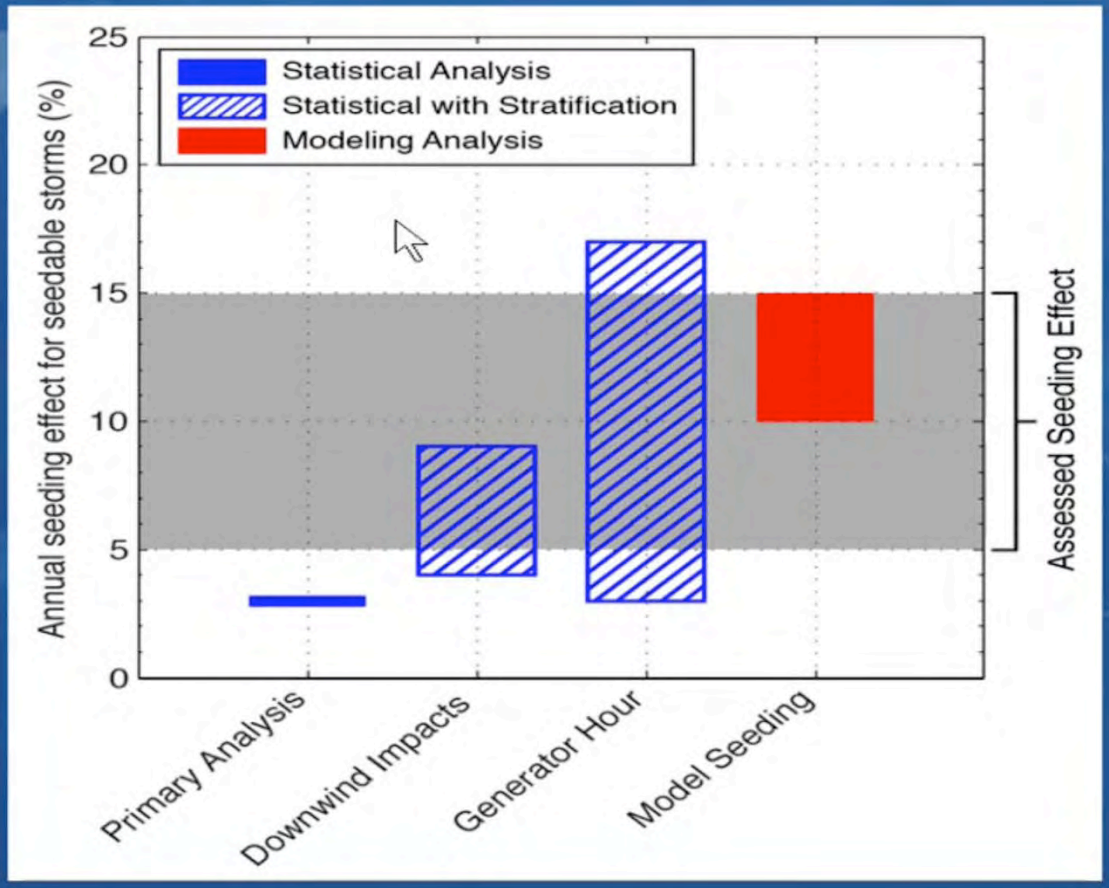
Modeling results of half of cases suggests 10 – 15% increase in seeded model snowfall compared to unseeded model snowfall

(from Rasmussen et. al. 2015)

Conclusion

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



(from Rasmussen et. al. 2015)

Moving Forward

Based on positive results Wyoming investing over $1 million to explore/conduct cloud seeding in other areas of the state