An Introduction to Cloud Seeding

Cloud Seeding Overview: How It Works

Understanding Water in the Atmosphere

The Pacific Northwest National Laboratory:

It is surprisingly difficult for water to freeze just below its melting point: water resists freezing unless it has something to get it started, like dust or some other solid to cling to. In pure water, it takes an **energetic nudge** to jostle the molecules into the special arrangement needed to freeze.

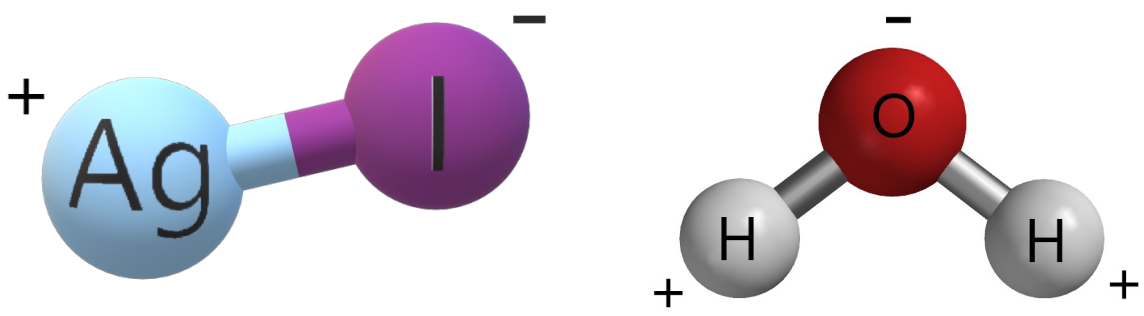
Formation of Precipitation

- Water in a cloud deck can remain a liquid until it reaches temperatures as low as -15^{o} C.
- Precipitation occurs when water freezes and forms ice crystals that congregate to form snowflakes.
- Eventually the snowflakes grow heavy enough to fall.
- ***Nucleating agents*** expedite the formation of snowflakes by providing the necessary energetic nudge.
- Nucleating agents can be **natural** (fine dust particles), **circumstantial** (pollution and smog) or **intentional** (cloud-seeding).

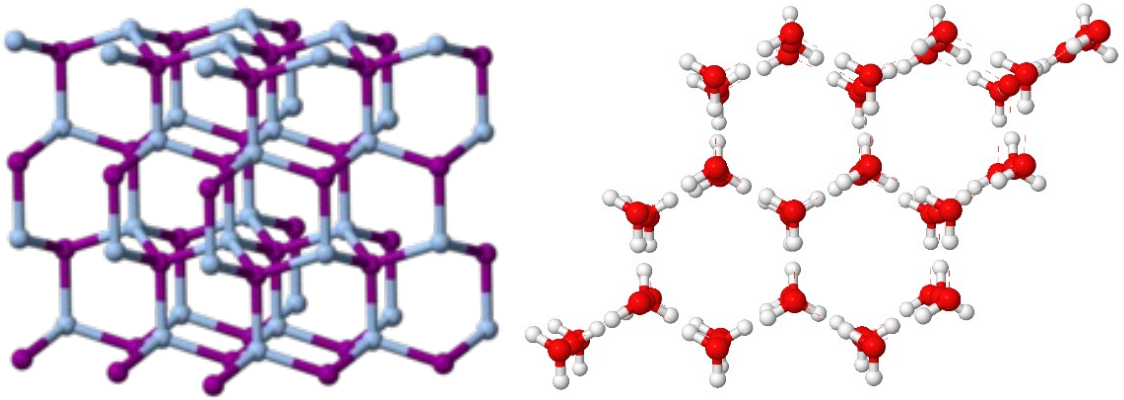
Putting this Together

Silver Iodide as a Seeding Agent

Silver Iodide molecules exhibit strong electrical polarity

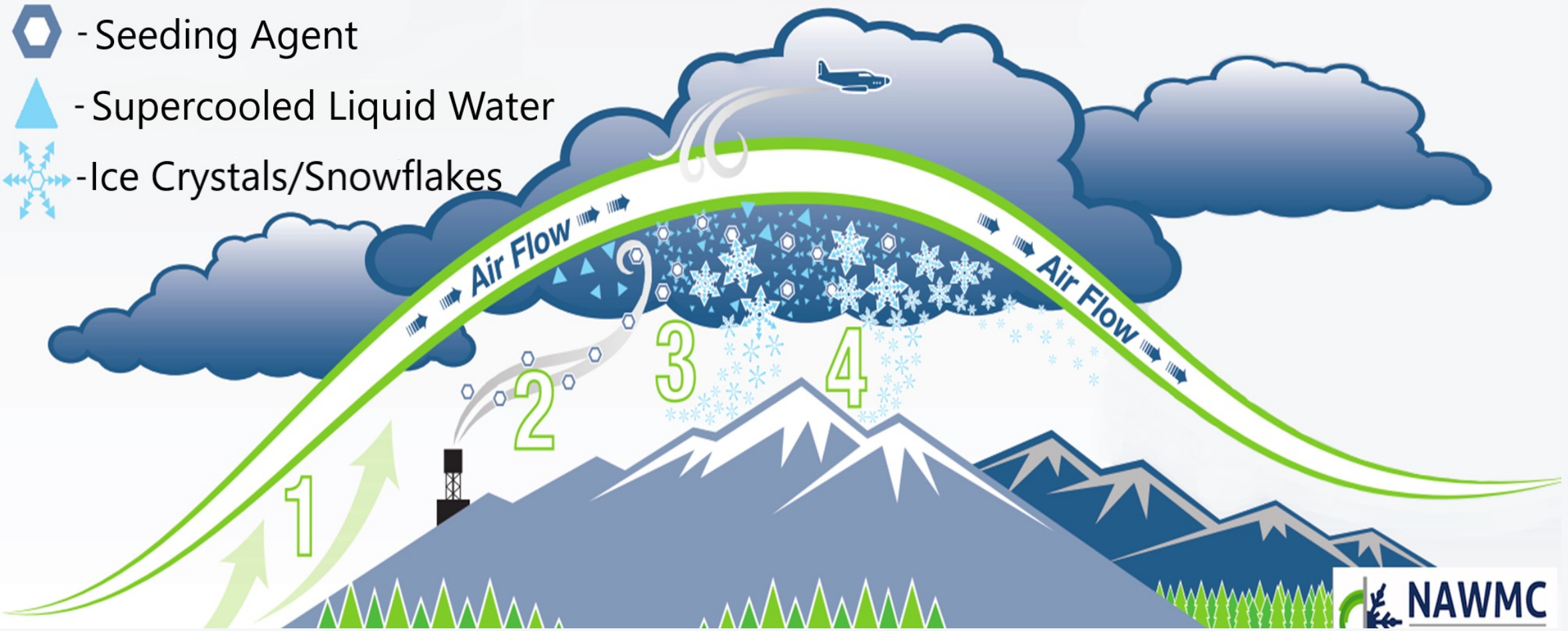


Silver Iodide crystals have a shape similar to ice crystals.



Seeding Methods & Design

Artificial Induction of Nucleating (Seeding) Agents



Ground Seeding

Advantages:

- Create a continuous plume of seeding agents
- Inexpensive to install and efficient to operate for extended periods of time

Limitations:

- Require a lifting mechanism (orographic or convection)

Aerial Seeding

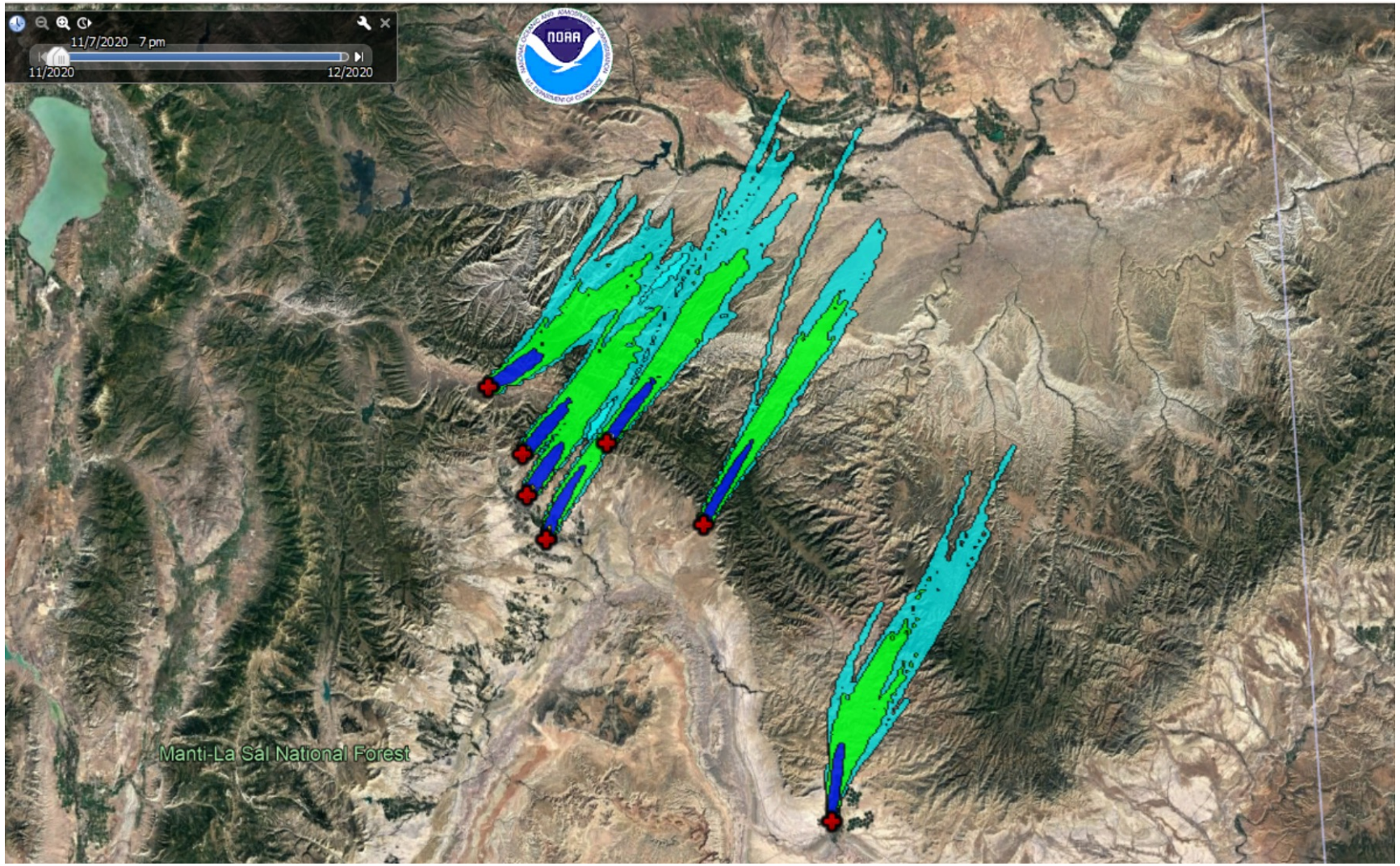
Advantages:

- Seeding agents dispersed directly into the cloud – precise targeting
- Can be performed over flat terrain – no lifting mechanism required

Limitations:

- More expensive than ground based methods
- Seeding dispersed from a single point source

Modeling Seeding Dispersion



Safety

Seeding Materials

Primary Seeding Agent – Silver Iodide

- When exposed to sunlight Silver Iodide quickly deconstructs to silver and molecular iodine.
- Silver is biologically inert.
- Molecular Iodine is a critical building block of human hormones.
- Iodine is a common food additive, often found in household staples like table salt and baby formula.

INGREDIENTS: NONFAT MILK, LACTOSE, HIGH OLEIC SAFFLOWER OIL, SOY OIL, WHEY PROTEIN CONCENTRATE, COCONUT OIL, FRUCTOOLIGOSACCHARIDE (FOS), **LESS THAN 1%:** CRYPTHECODINIUM COHNII OIL[3], MORTIERELLA ALPINA OIL[4], 2'-FUCOSYLLACTOSE (2'-FL)[1], BETA-CAROTENE, LUTEIN, POTASSIUM BICARBONATE, CALCIUM CARBONATE, ASCORBIC ACID, SOY LECITHIN, MONOGLYCERIDES, CALCIUM CHLORIDE, CALCIUM HYDROXIDE, MAGNESIUM CHLORIDE, FERROUS SULFATE, CHOLINE BITARTRATE, ASCORBYL PALMITATE, SODIUM CITRATE, TAURINE, INOSITOL, ZINC SULFATE, MIXED TOCOPHEROL CONCENTRATE, VITAMIN E (*dl*-ALPHA TOCOPHERYL ACETATE), NIACINAMIDE, CALCIUM PANTOTHENATE, L-CARNITINE, VITAMIN A PALMITATE, CUPRIC SULFATE, THIAMINE HYDROCHLORIDE, RIBOFLAVIN, PYRIDOXINE HYDROCHLORIDE, FOLIC ACID, MANGANESE SULFATE, VITAMIN K_1 (PHYTONADIONE), BIOTIN, SODIUM SELENITE, VITAMIN D_3, CYANOCOBALAMIN, POTASSIUM PHOSPHATE, POTASSIUM IODIDE, POTASSIUM HYDROXIDE, NUCLEOTIDES (ADENOSINE-5'-MONOPHOSPHATE, CYTIDINE-5'-MONOPHOSPHATE, DISODIUM GUANOSINE-5'-MONOPHOSPHATE, DISODIUM URIDINE-5'-MONOPHOSPHATE). **CONTAINS:** MILK AND SOY.

DILUTED: EACH 5 FL OZ (150 mL) CONTAINS 100 CALORIES

NUTRIENTS PER 100 CALORIES:

PROTEIN g	2.07	BIOTIN mcg	4.6
FAT g	5.6	VITAMIN C (ASCORBIC ACID) mg	9
CARBOHYDRATE g	10.7	CHOLINE mg	24
WATER g	133	INOSITOL mg	24
LINOLEIC ACID mg	1000	**MINERALS:**	
VITAMINS:		CALCIUM mg	82
VITAMIN A IU	300	PHOSPHORUS mg	44
VITAMIN D IU	75	MAGNESIUM mg	6
VITAMIN E IU	1.5	IRON mg	1.9
VITAMIN K mcg	8	ZINC mg	0.79
THIAMINE (VITAMIN B_1) mcg	100	MANGANESE mcg	5
RIBOFLAVIN (VITAMIN B_2) mcg	160	COPPER mcg	95
VITAMIN B_6 mcg	63	IODINE mcg	15
VITAMIN B_{12} mcg	0.26	SELENIUM mcg	2
NIACIN mcg	1100	SODIUM mg	25
FOLIC ACID (FOLACIN) mcg	16	POTASSIUM mg	110
PANTOTHENIC ACID mcg	470	CHLORIDE mg	68

Material Concentrations and Consumption

Seeding Agents

- For a typical program, the total amount of silver iodide released during a season would equate to 1-2 sand bags or salt bags. This scattered over the breadth of the seeding area

CO2 Emissions

- For a typical program, CO2 emissions from all ground based equipment for a full seeding season will be similar to burning roughly 500 gallons of gasoline (less CO2 than a single fleet vehicle). Seeding does not release any NOx or SOx emissions.

Tracking the Impact

Measuring Seeding Impact - SNOWIE

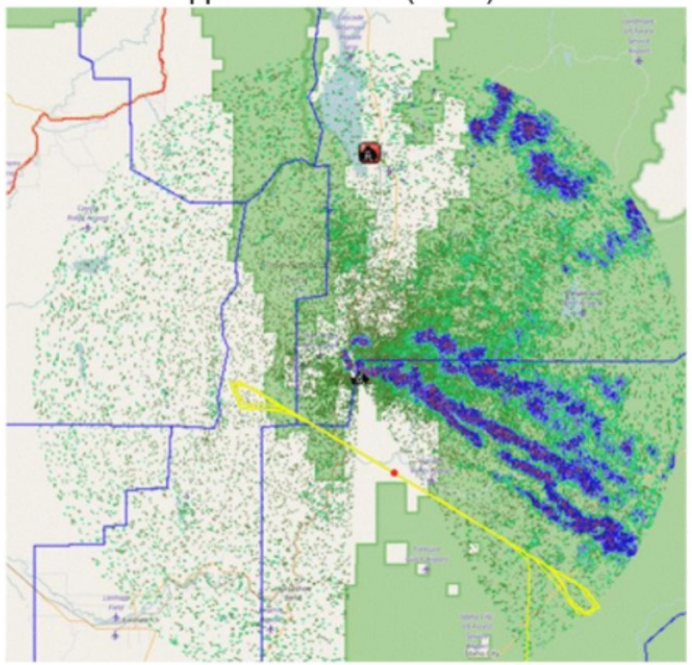
Using recent advancements in instrumentation and computer modeling, the SNOWIE project (**S**eeded and **N**atural **O**rographic **W**intertime Clouds: the **I**daho **E**xperiment) observed the microphysical response from seeding orographic clouds addressing the critical questions about using cloud seeding to enhance precipitation.

SNOWIE RESULTS

Doppler on Wheels – Composite Reflectivity

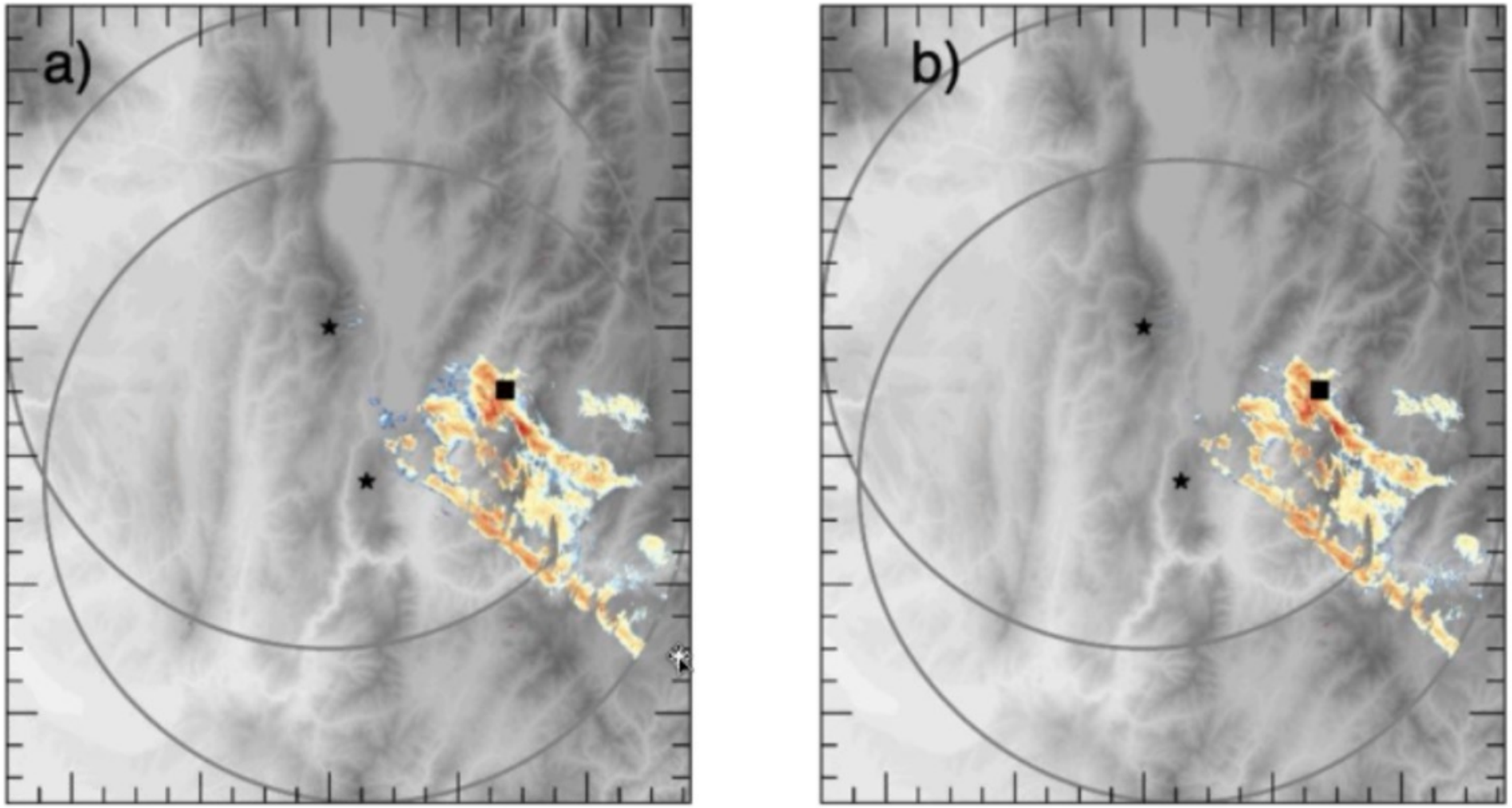
- High resolution Doppler on Wheels was used to measure composite reflectivity. Much like long range satellites measure cloud composition and predict precipitation.
- During the SNOWIE experiment the DoW validated lab and wind-tunnel tests, proving the impact of cloud seeding in orographic storm systems.

IOP6 Doppler on Wheels (DOW) radar

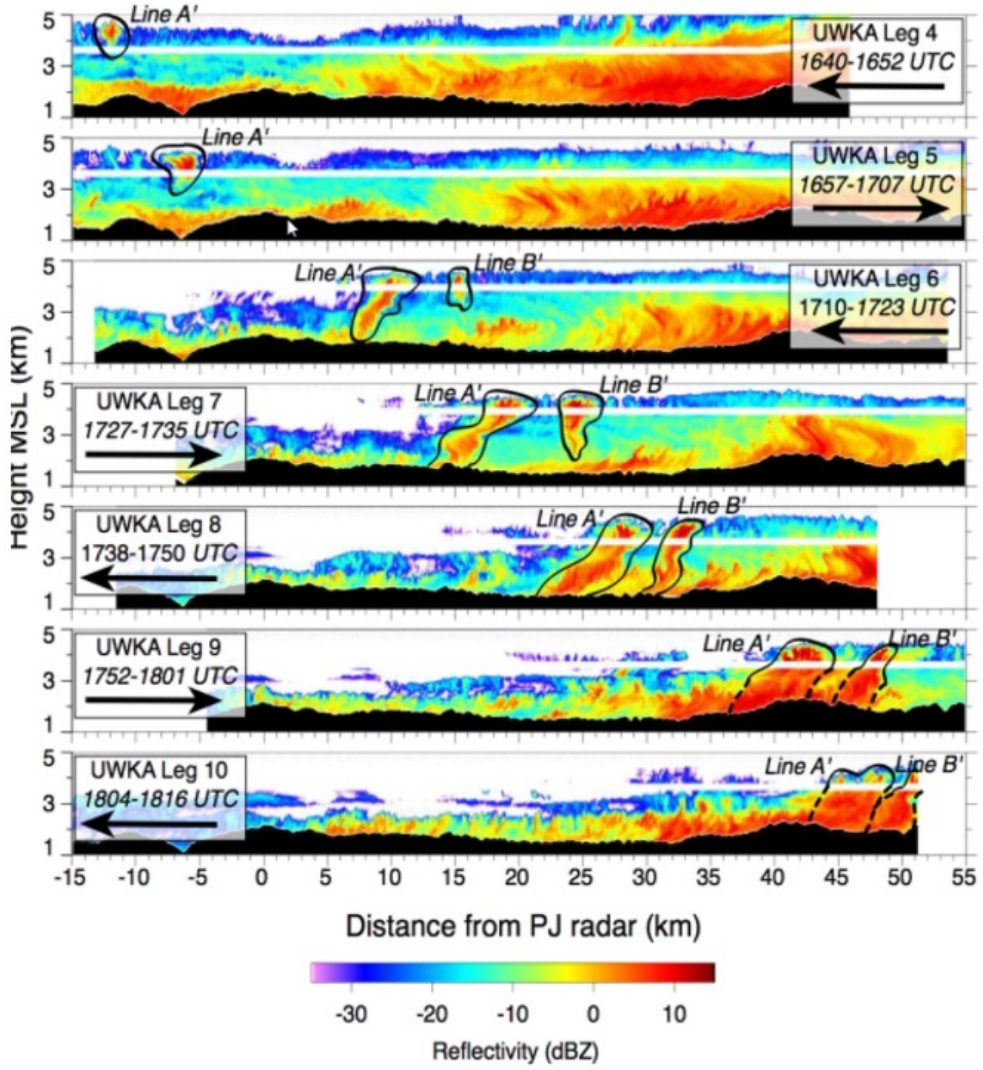


- In 3 Intensive Observing Periods (IOPs) during SNOWIE, unambiguous lines attributed to seeding were observed by the DOW radar
- These IOPs have allowed us to study the microphysical response to cloud seeding using both in situ measurements and radar observations
- We have also quantified the snowfall reaching the ground in these cases
- These cases are also ideal for evaluating and improving numerical modeling of cloud seeding impacts

SNOWIE RESULTS



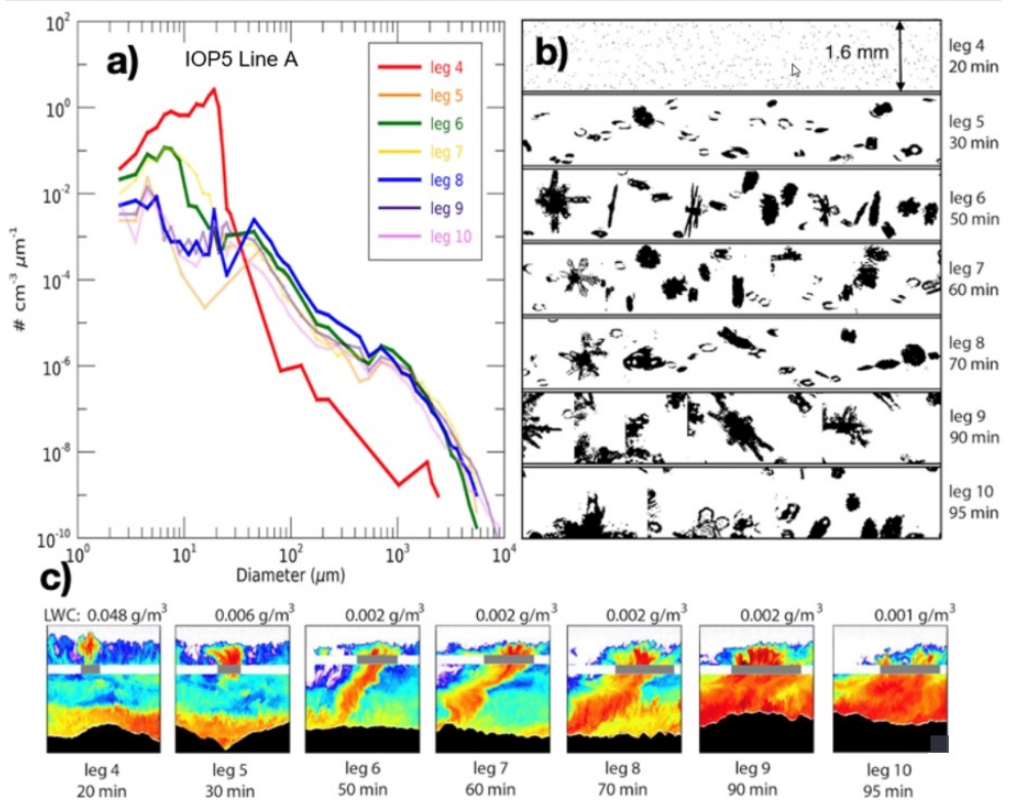
SNOWIE RESULTS



SNOWIE RESULTS

Ice Crystal Observations

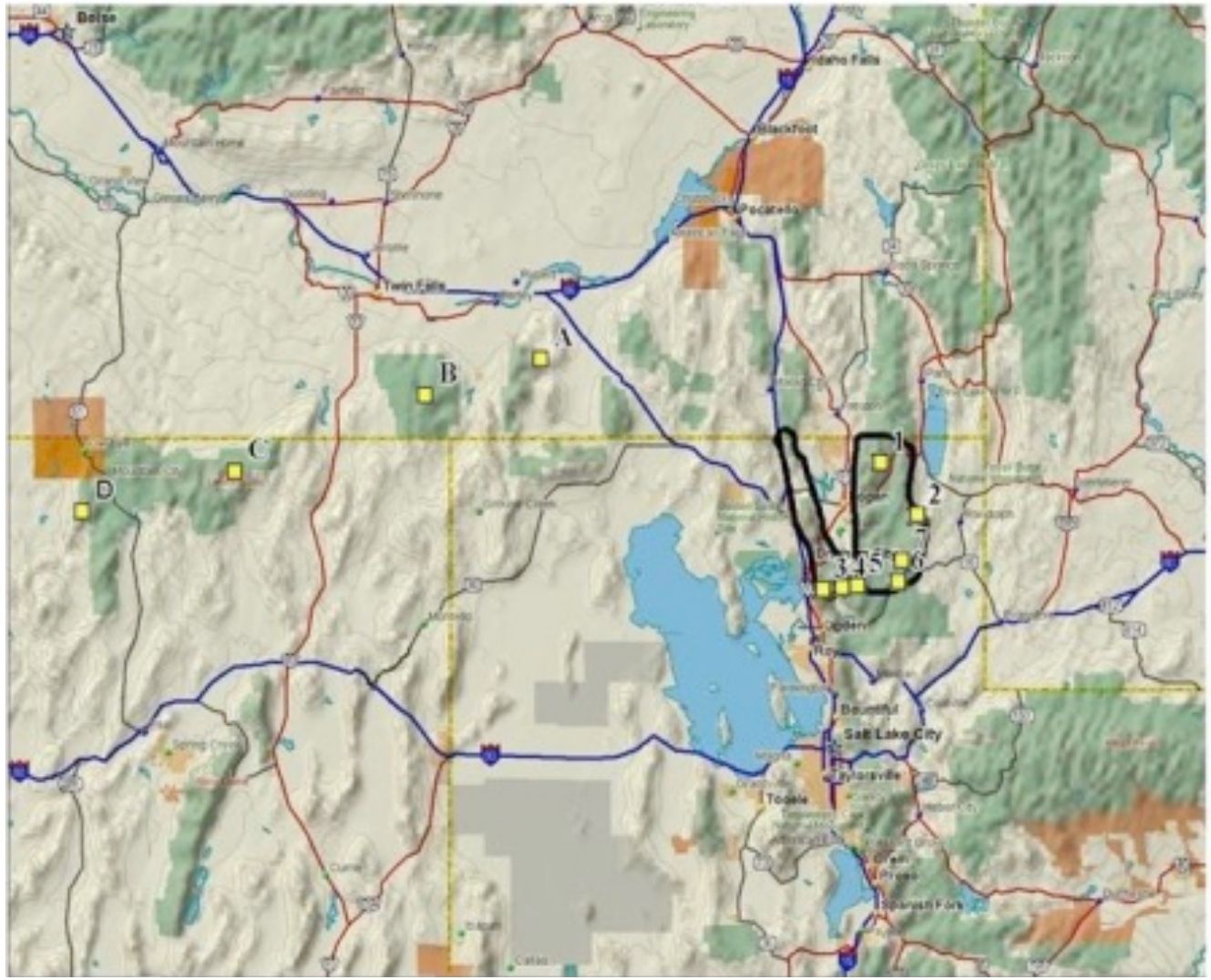
- Prior to seeding, there was little-to-no ice in the cloud.
- After seeding, ice depleted nearly all of the liquid.
- Dendrite structures were observed in the cloud.

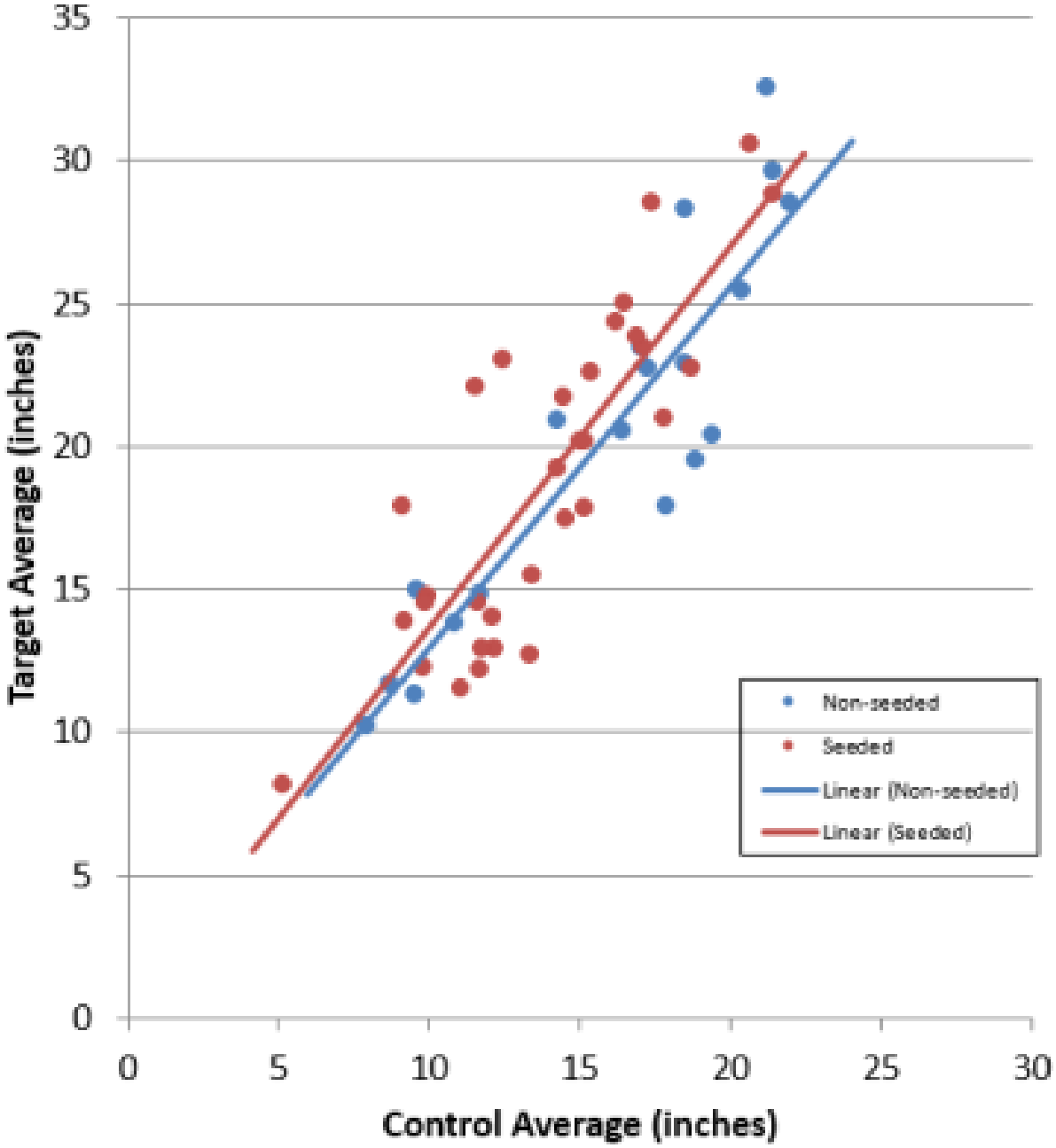


Quantifying the Increase-Target Control Analysis

Target/Control Analysis
Example

- Target verses control analysis is conducted each season to determine the benefit from cloud seeding.
- Control Sites are selected in areas that are upwind from seeding activity
- Target sites are selected at the onset of a new program and represent areas inside the targeted area.




35
30
25
20
15
10
5
0
Target Average (inches)
0
5
10
15
20
25
30
Control Average (inches)
Non-seeded
Seeded
Linear (Non-seeded)
Linear (Seeded)

Target/Control Analysis
Long Term Results

NAWC evaluates each program area independently after each seeded period. Similar evaluations have been performed by third party research groups to validate our own results.

Across all of our program areas (with one exception) over multi-decadal periods, evaluations consistently project an increase in April 1 snowpack of 5-10% for high elevation seeding programs, and precipitation increases in excess of 7-10% for low elevation coastal programs.

Runoff

Increases in program specific runoff generally exceeds snowpack or precipitation increases as the conversion of rainfall or snowpack to runoff improves with additional moisture.

Most program areas therefore experience an estimated 7-15% increase in surface flow resulting from well executed cloud seeding programs.