Bear River Basin Feasibility and Design Study

Results, Recommendations, and Shared Infrastructure Opportunities

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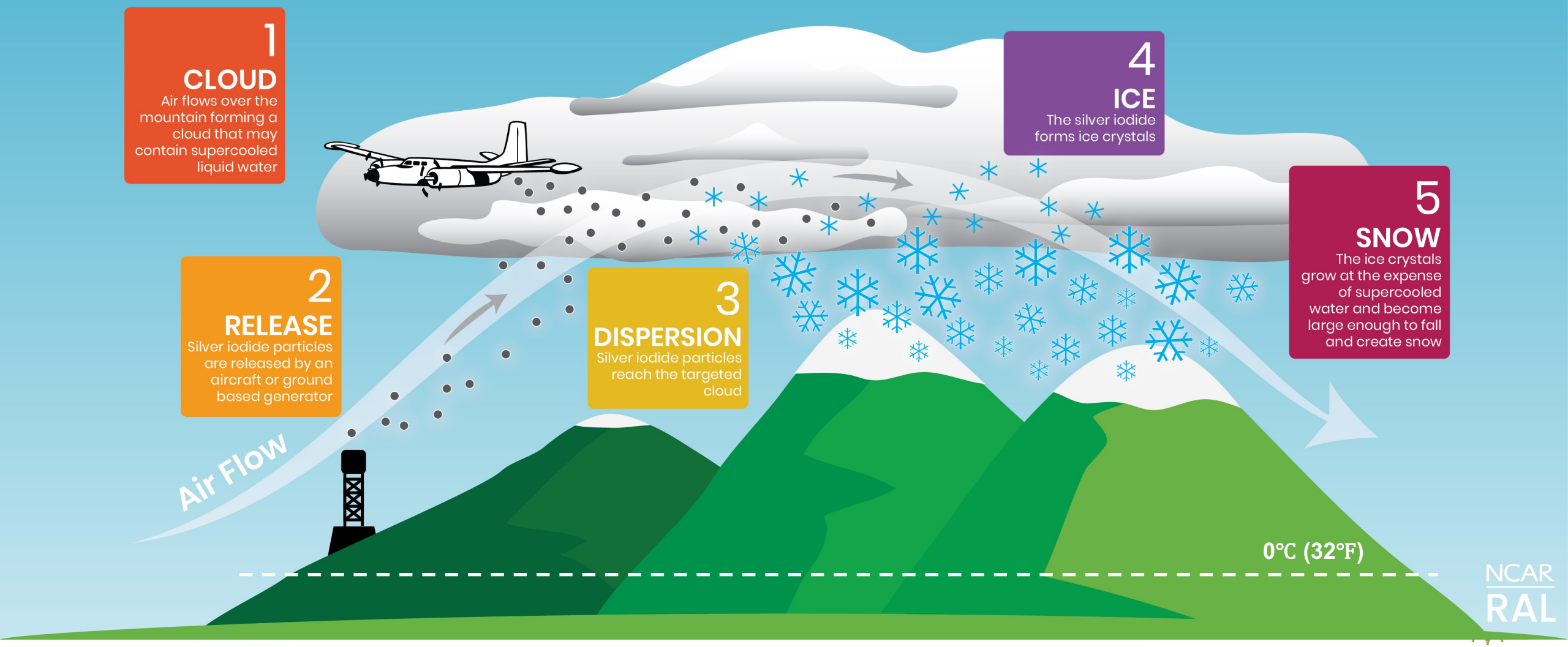
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

The goal of winter orographic cloud seeding is to increase snowpack (and subsequent streamflow)



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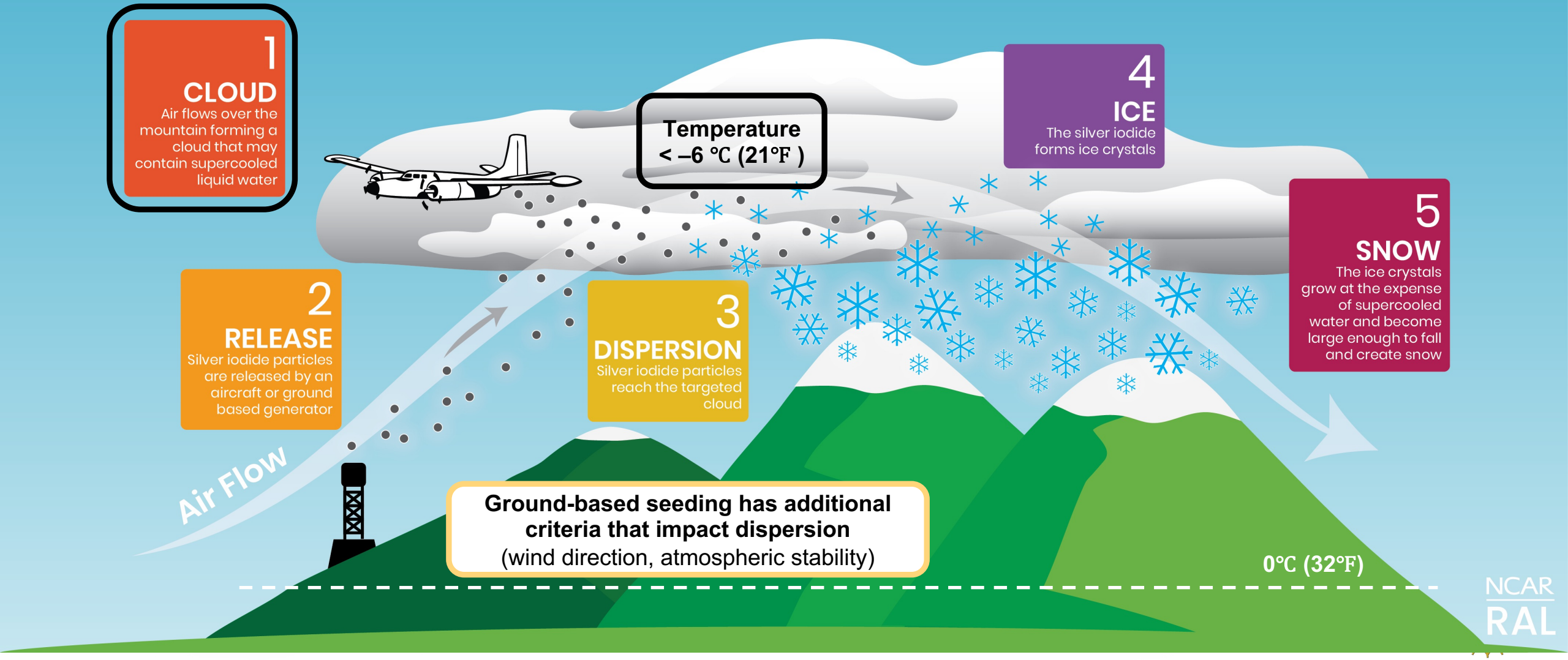
Two key criteria : 1) Supercooled liquid water (SLW) 2) Temperature for silver iodide to nucleate ice



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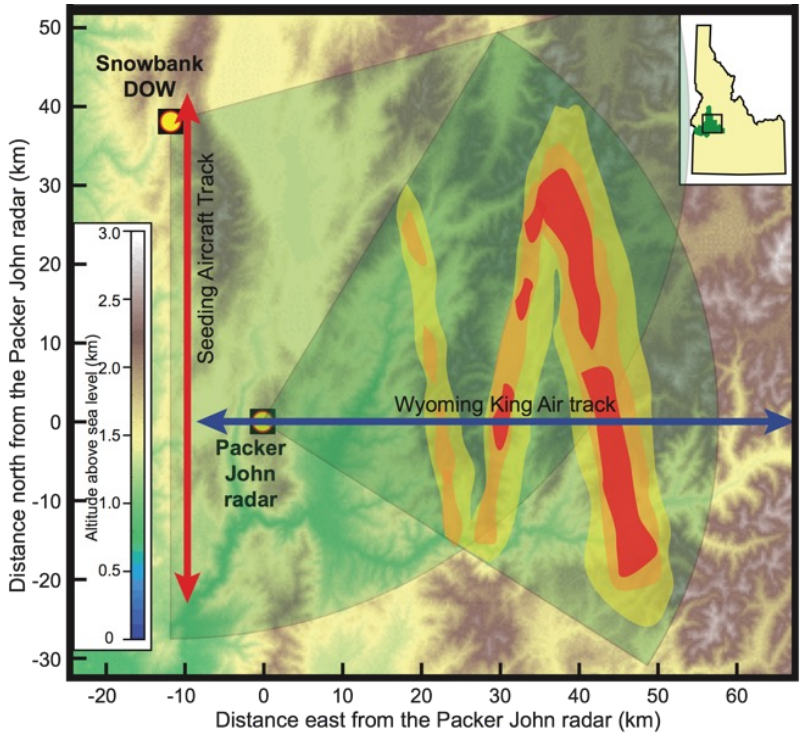
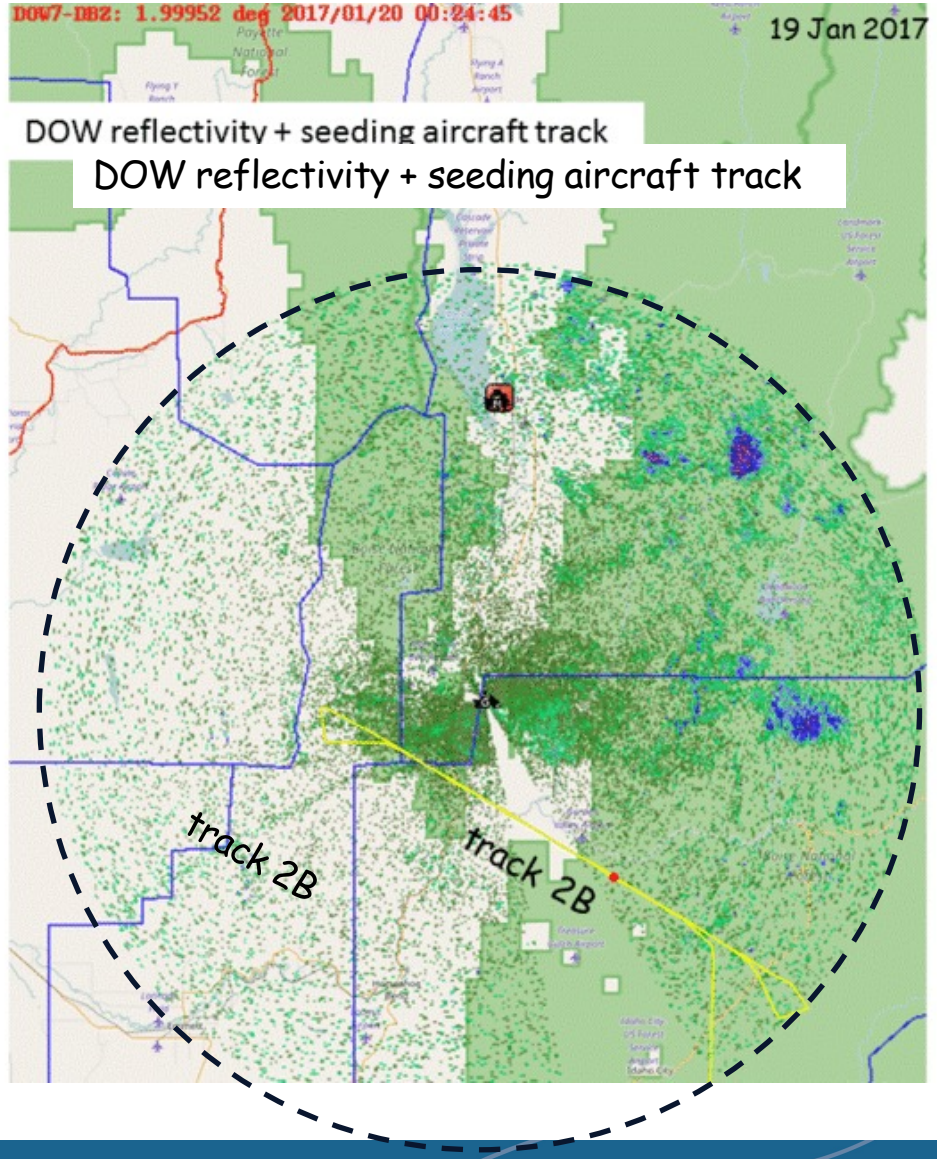
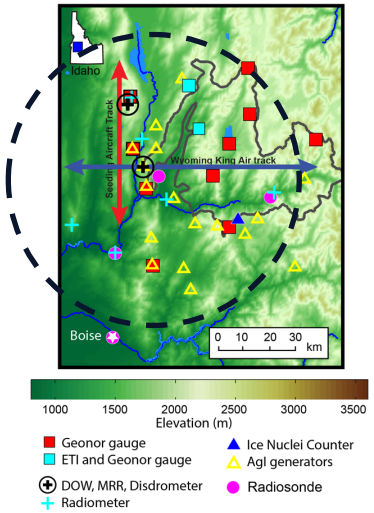
Recent study proves seeding produces snow

Wind

Hypothesized seeding plume dispersion







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:

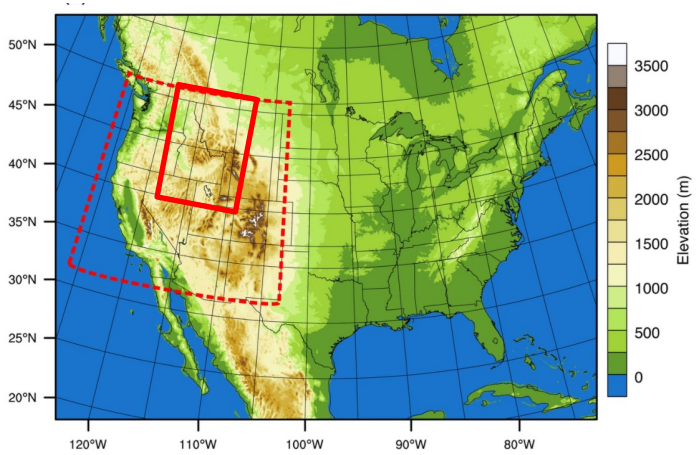
- Temperature
- Supercooled liquid water (SLW)
- Precipitation
- Winds
- Atmospheric stability

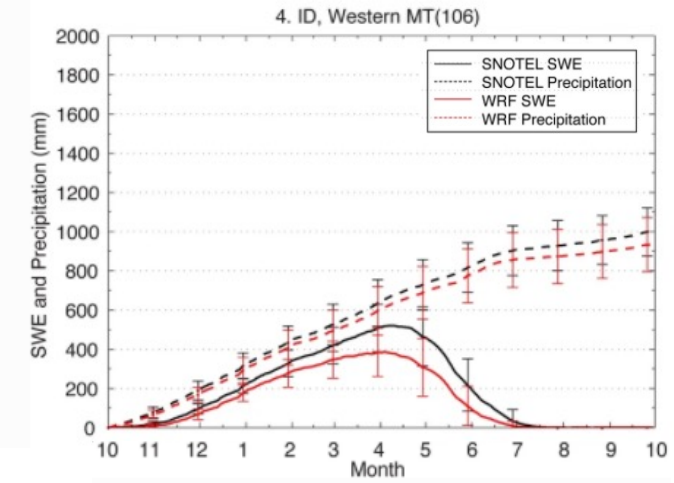
Approach for Climatology Analysis

Analysis of Historical Data

- Observations required for assessing the potential for cloud seeding are not routinely collected
  - Weather balloons provide vertical profiles of temperature (limited)
  - No routine measurements of SLW
- High-resolution, long-term model simulations provide a new opportunity
  - 13-year (2000-2013) 4-km grid spacing WRF model simulation over the CONUS
  - Shown to realistically reproduce precipitation observations
  - Includes 3D information on temperature, SLW, winds, etc.

Weather Research and Forecasting (WRF) model CONUS Simulation Domain

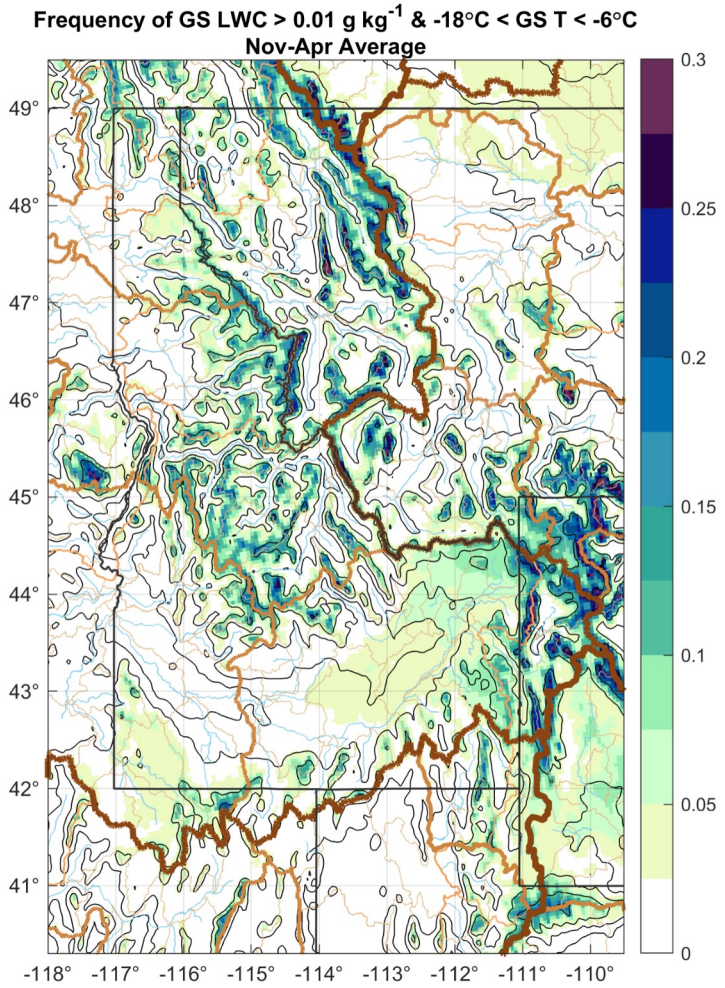




Ikeda et al. (2021)

Goal: Identify areas in the state of Idaho with potential for cloud seeding to conduct more detailed feasibility and design

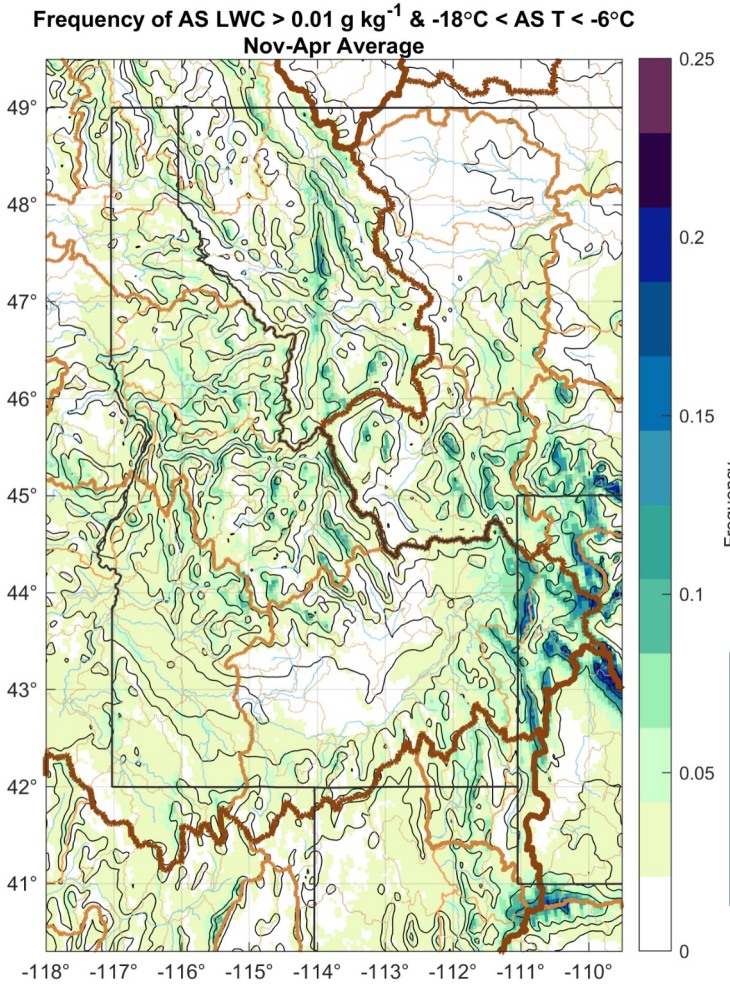
Ground seeding layer (0-1 km AGL)



This maps shows the frequency that temperature and SLW conditions are met, but not the additional dispersion criteria that are specific to each mountain barrier.

More detailed analysis by basin or mountain barrier is needed

Airborne seeding layer (3.5-4.5 km MSL)



This layer was determined based upon minimum safe flight altitudes over most of the state. Regions with lower altitude mountains may have more potential than shown here since SLW decreases with altitude.

More detailed analysis by basin or mountain barrier is needed

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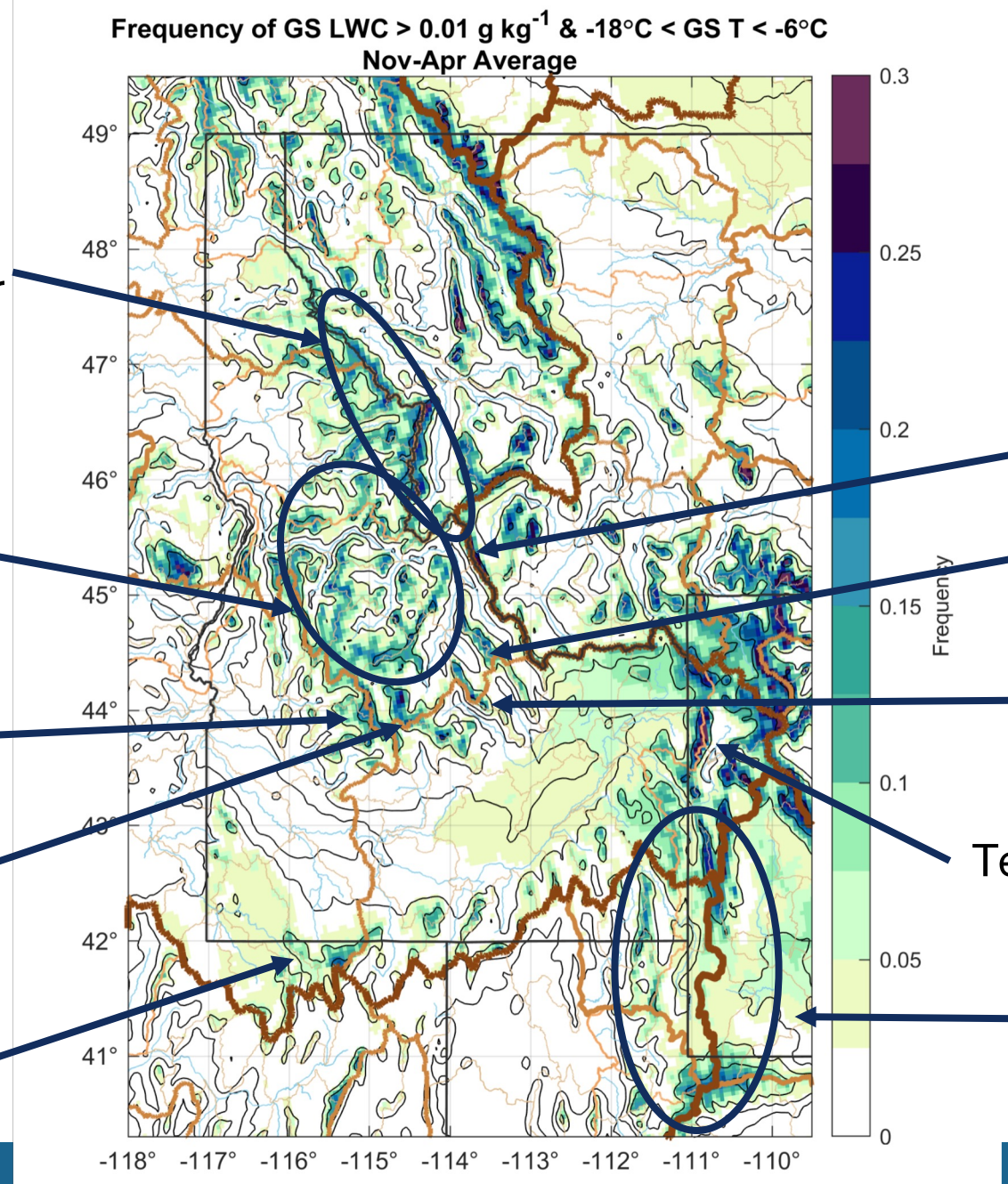
We recommend focusing on basins with some ground-seeding potential to investigate both ground and airborne seeding potential with a more detailed analysis approach



Bitterroot Mountains/Some parts of Clearwater

Salmon River Mountains

Boise/Sawtooth Mtns

Boulder/White Cloud Mtns

Independence Mountains (flows into ID)

Beaverhead Mtns (on divide)

Lemhi Mtns

Lost River Range

Teton Range

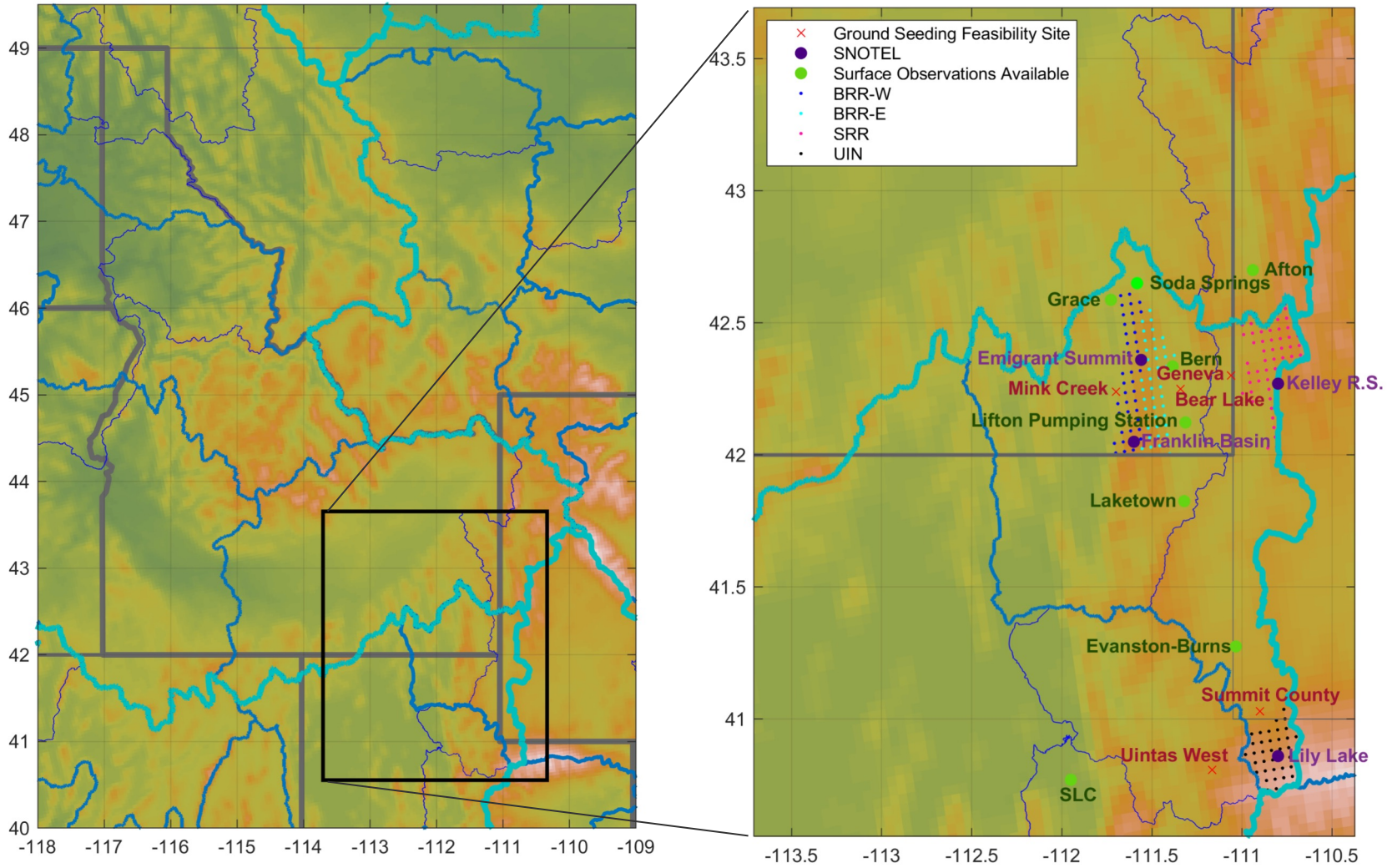
Current Study Area (incl. Bear River Range, Salt River Range, Uintas)

Bear River Basin: Region of Study

- State- and basin-wide maps of seedable conditions (based upon SLW and T)

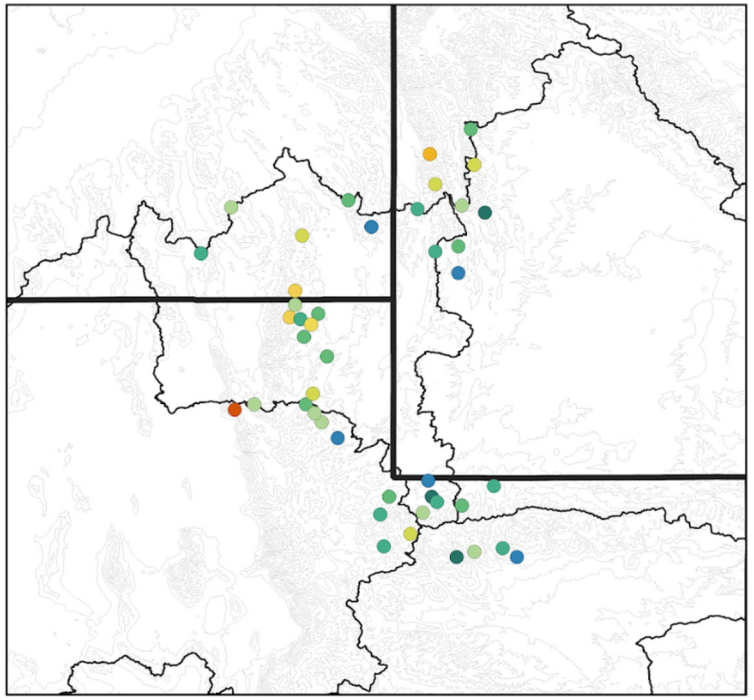
Focus on Bear River Basin:

- 700-hPa conditions at representative sites along each range for wind and stability
- Frequencies of seedable conditions area averaged over identified target regions

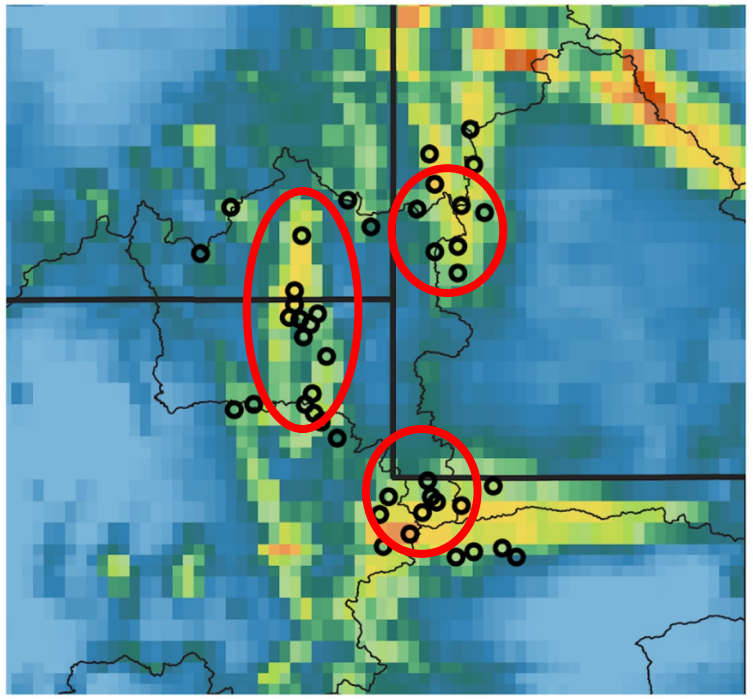


Average Annual Precipitation in the Bear River Basin

SNOTEL Observations



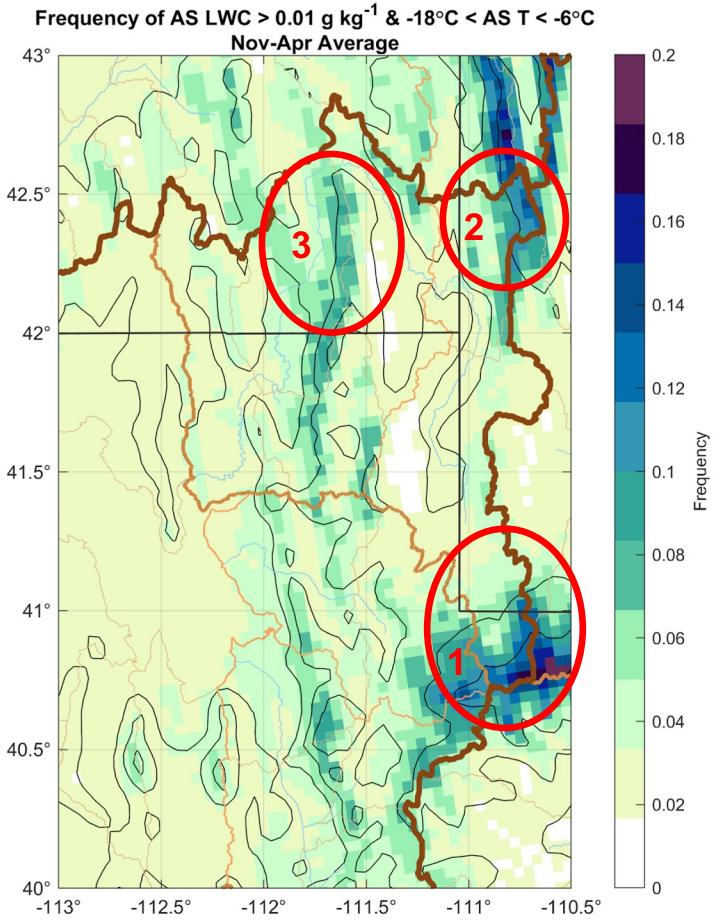
CONUS Model Simulation



precipitation (mm)

- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1000
- 1000 - 1100
- 1100 - 1200
- 1200 - 1300
- 1300 - 1400
- 1400 - 1500
- 1500 - 1600
- 1600 - 1700
- 1700 - 1800
- 1800 - 1900

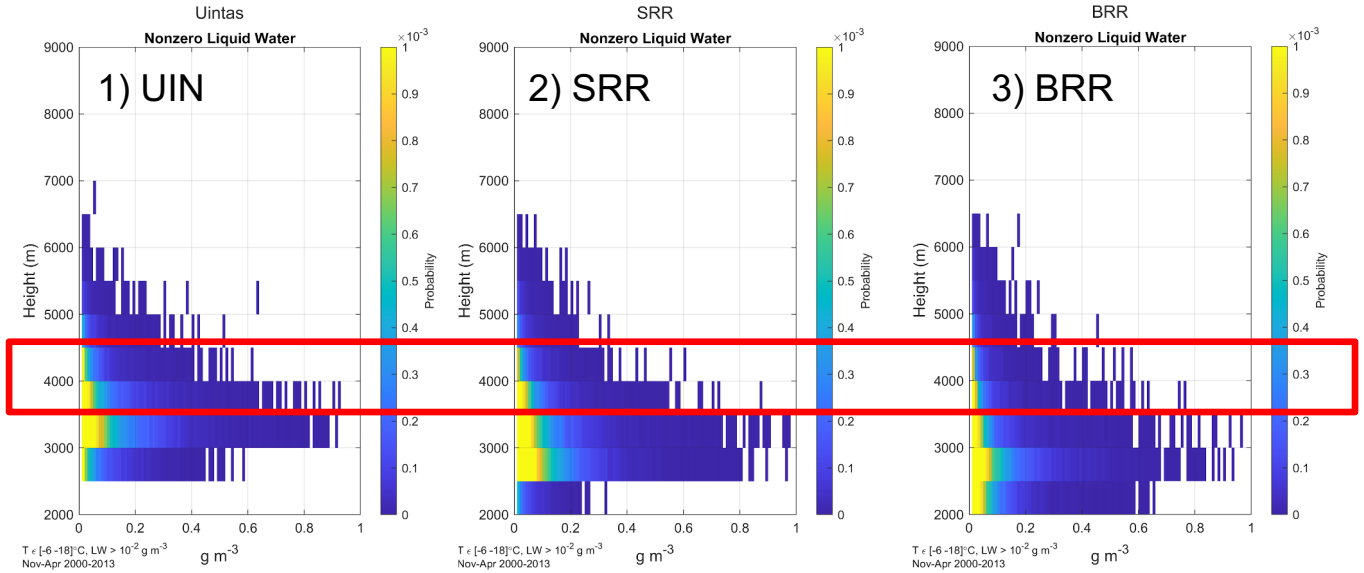
Frequency of Airborne Seeding Opportunities



Three regions feed the Bear River Basin:

1. Uintas (UIN)--Bear River headwaters
2. Salt River Range (SRR)
3. Bear River Range (BRR)

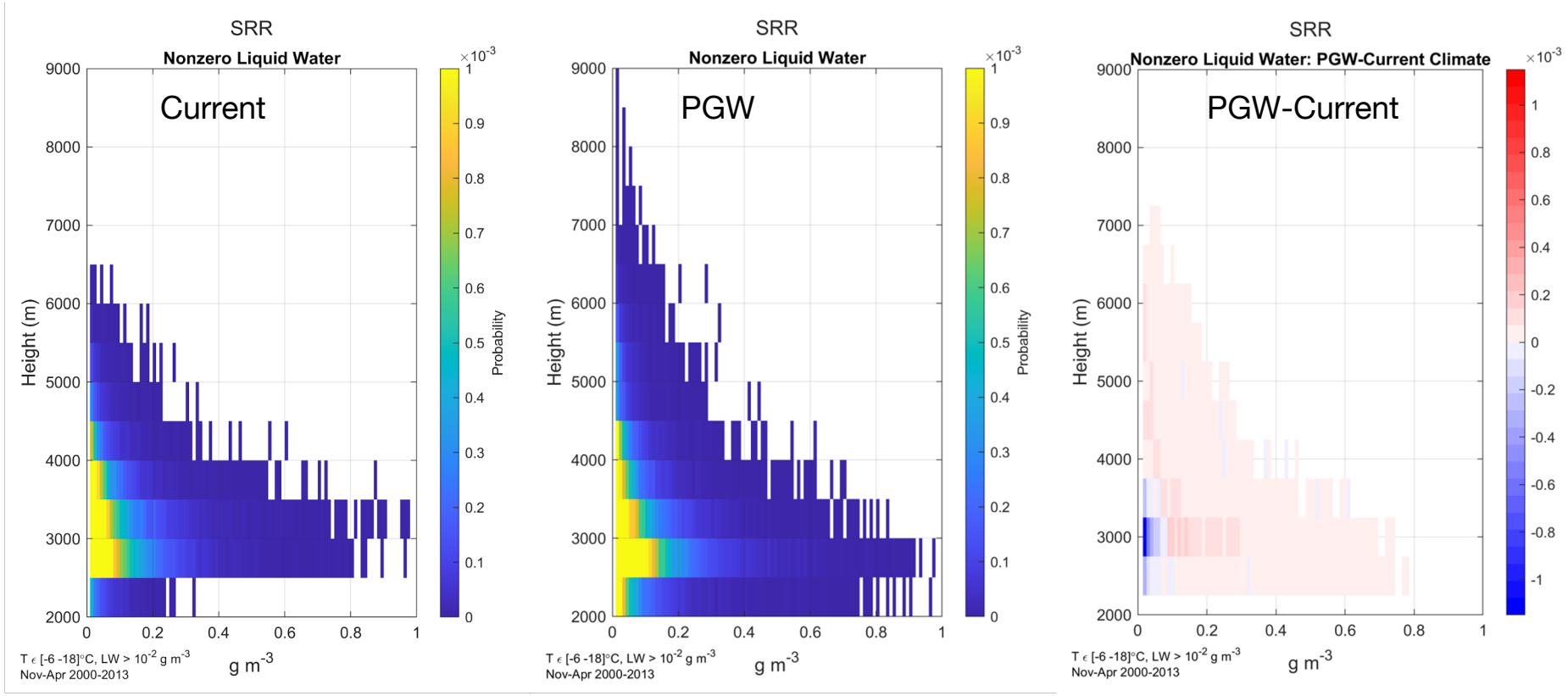
Airborne seeding opportunities between Nov-Apr, peak in late winter



Flight level 3.5-4.5 km MSL

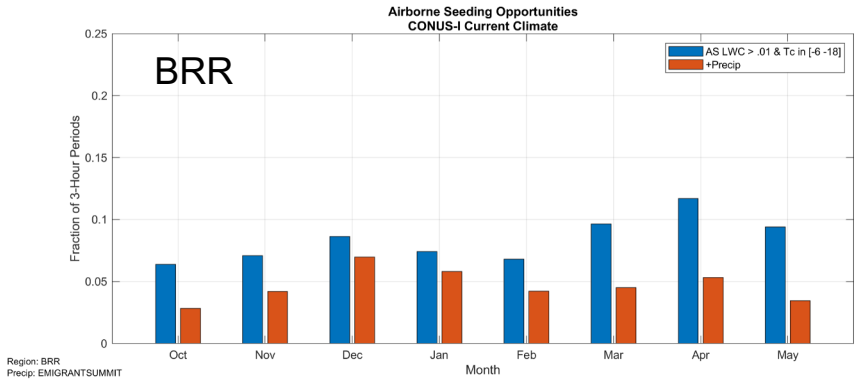
Future Climate Analysis for the Bear River Basin

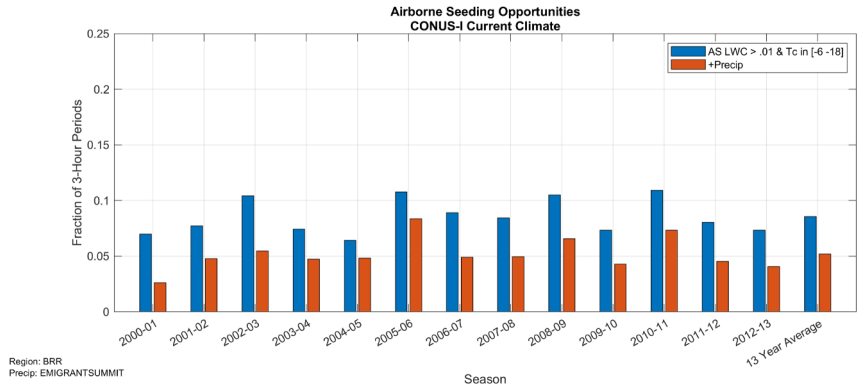
- Increased SLW and warmer temperatures reduces ground seeding opportunities and offsets airborne at the 3.5-4.5 km MSL layer, however SLW extends to higher altitudes in PGW so aircraft could fly at higher altitudes to be in ideal temperatures with SLW

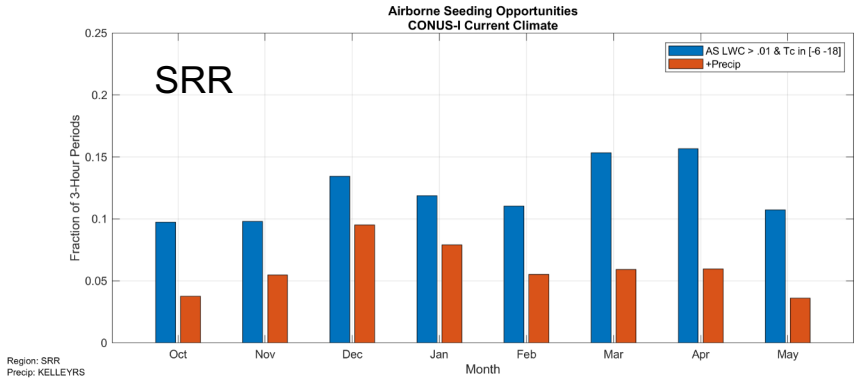


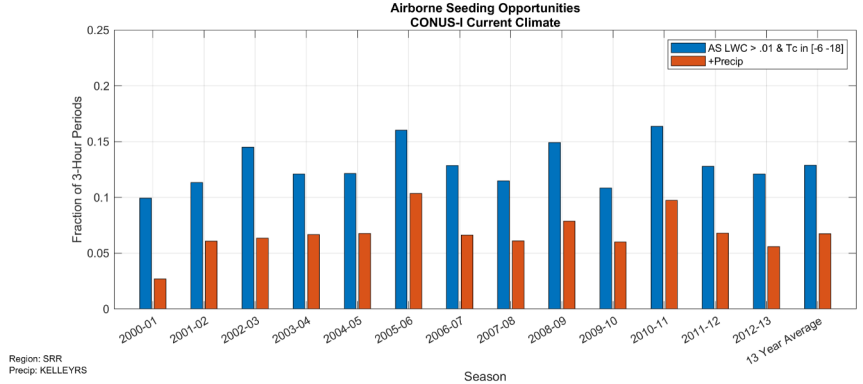
Airborne Seeding: CONUS-I Current Climate

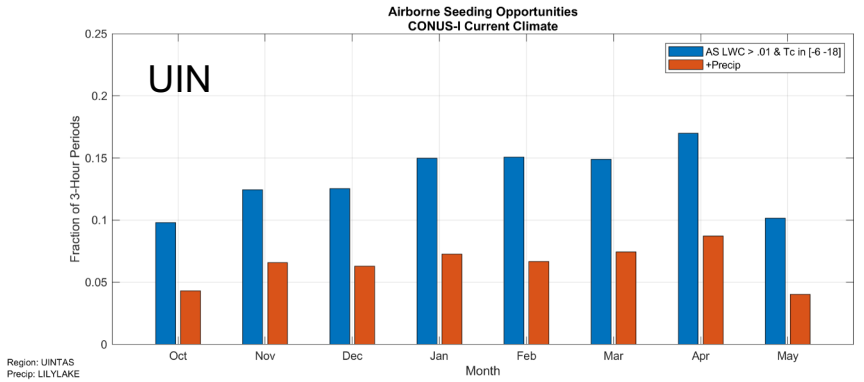
- Salt River Range and Unitas have most frequent opportunities for airborne seeding
- Season between Oct or Nov through April

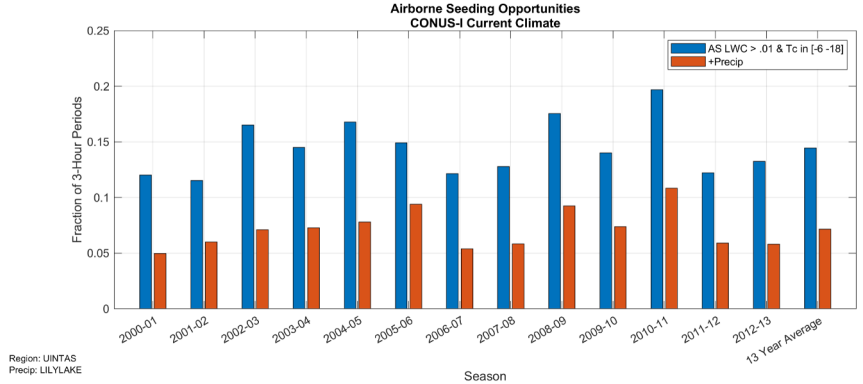












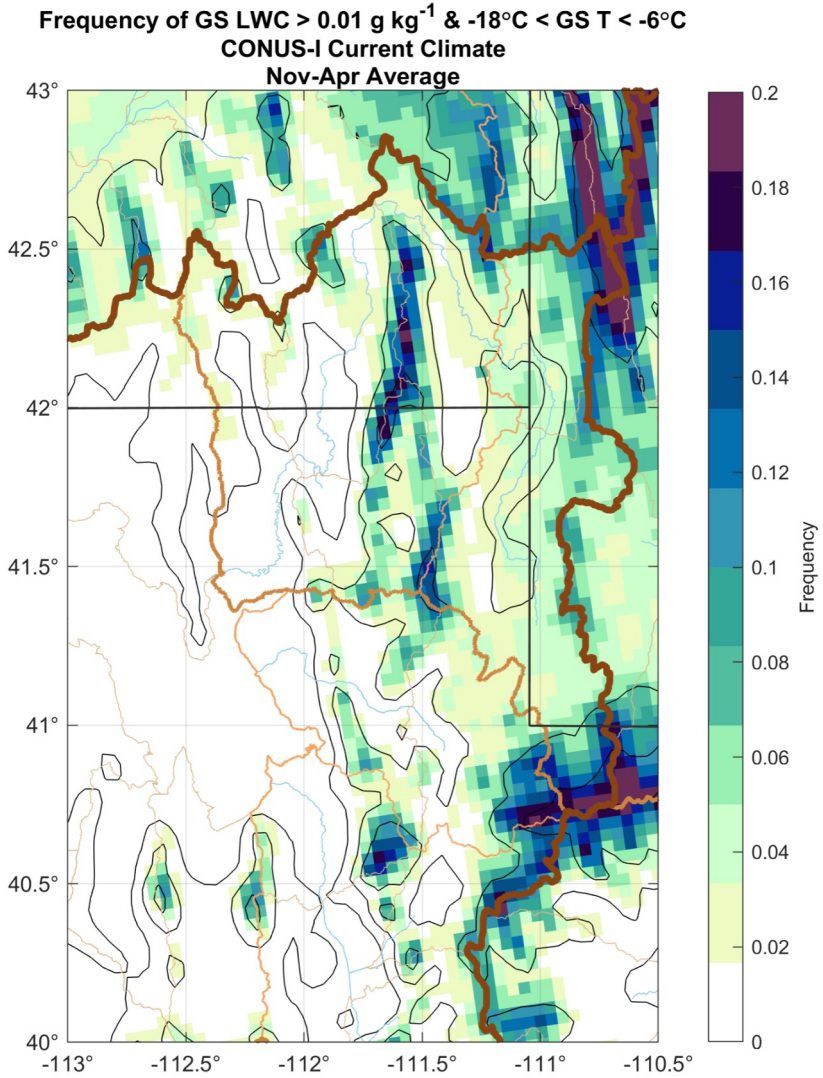
Frequency of Ground-based Seeding Opportunities

- Most of the SLW is in the ground-based seeding layer, which explains the higher frequencies here
- These are based upon SLW and temperature only

Additional criteria need to be analyzed for ground-based seeding to ensure the seeding material released from the ground reaches the targeted cloud over the mountains

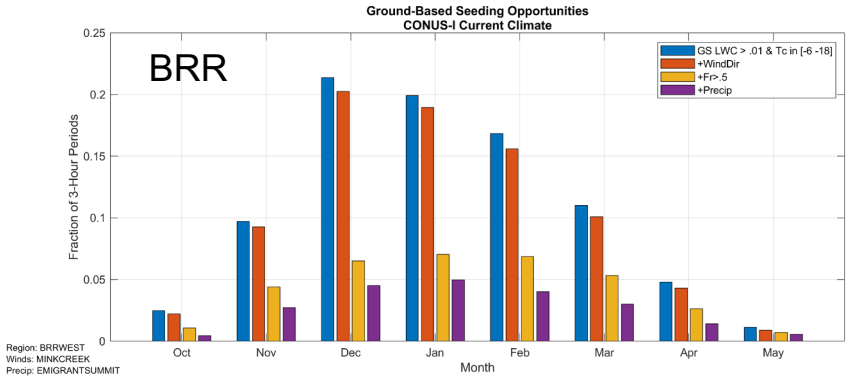
<u>Additional criteria include:</u>

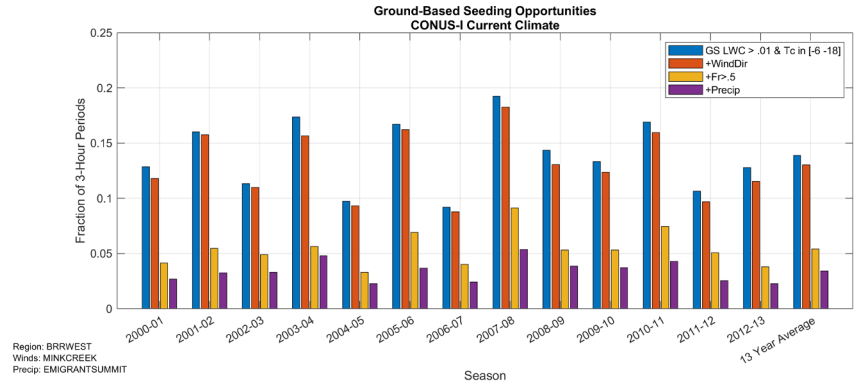
- Wind direction
- Wind Speed
- Atmospheric Stability

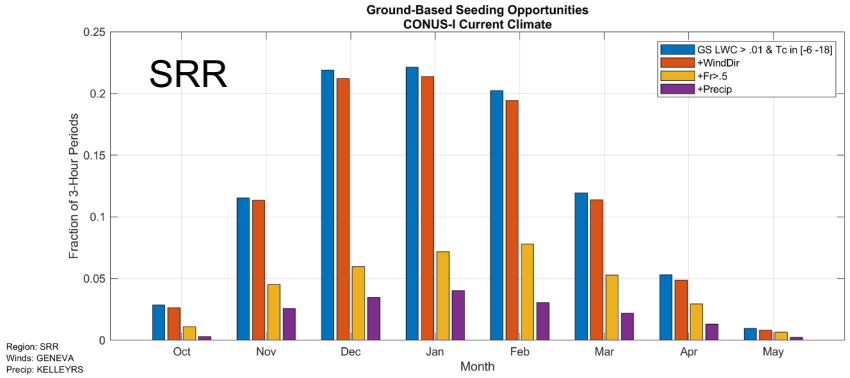


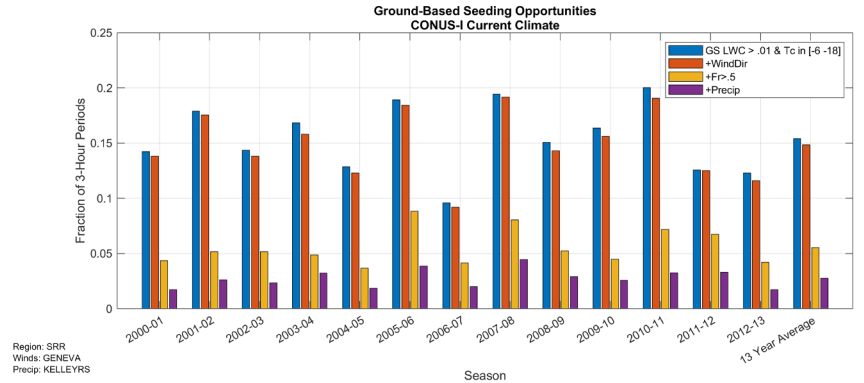
Frequency of Ground-based Seeding Opportunities

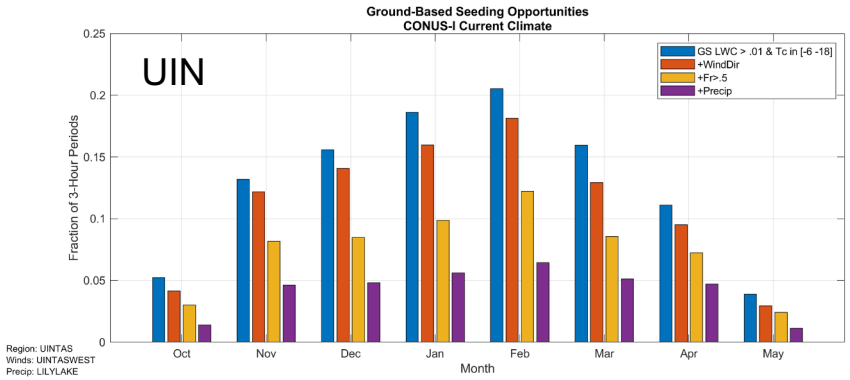
- Flow blocking limits ground seeding opportunities the most, especially in BRR and SRR
  - *Suggests that low level generator placement would not be effective*
- Season peaks Dec-Feb or Nov-Mar in Uintas

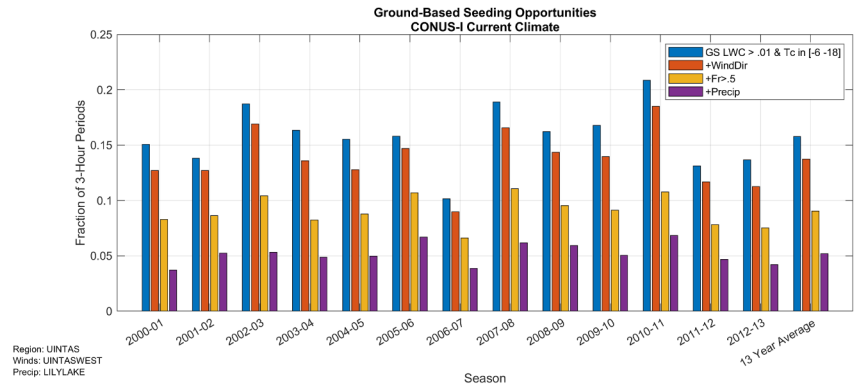












Bear River Basin Climatology Analysis
Summary and Recommendations

- 10-15% of winter season may be targetable for ground-based seeding or airborne seeding (varies by target region)
  - Nov-Apr season with Dec-Feb most frequent for ground-based
  - Future climate shows airborne seeding as more promising
- 30-50% of precipitation falls under seedable conditions
- Ground-based seeding opportunities may be limited by flow blocking, therefore best to look for higher altitude sites

Recommendations:

- Focus on airborne seeding since it has more frequent opportunities and is less limited by flow blocking
  - Aircraft can also fly higher for future climate scenario indication of higher SLW altitudes
- If ground-based seeding is pursued, higher elevation sites would be recommended to overcome flow blocking issues
  - Future climate opportunities for ground-based seeding may be reduced, unless another seeding agent is used

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?

Analyze historical data:

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

Preliminary Design

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

Review climatology results

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

Test and Refine Design

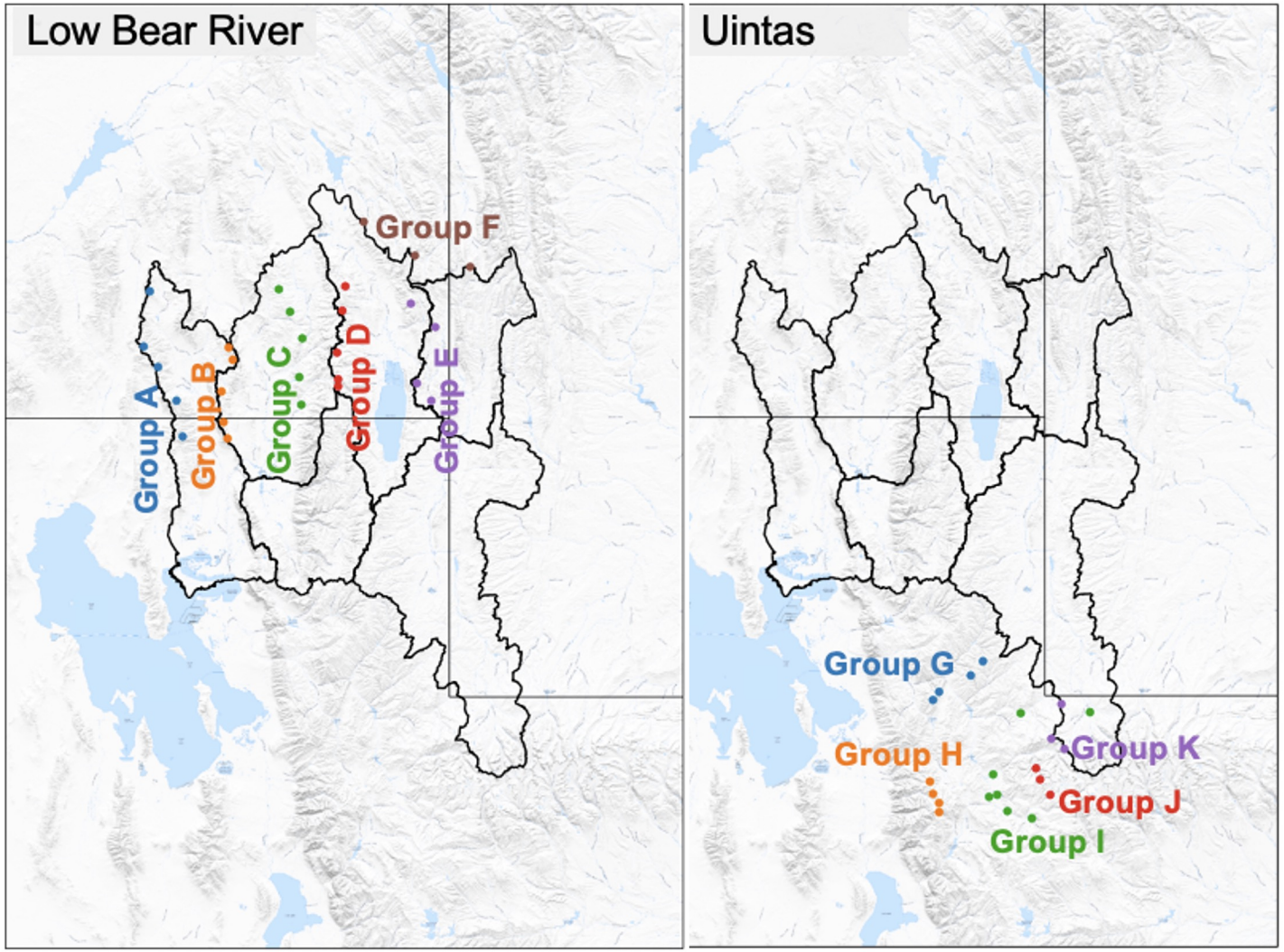
How effective are each design option at targeting and enhancing precipitation in this region?

Which combination of design options is recommended?

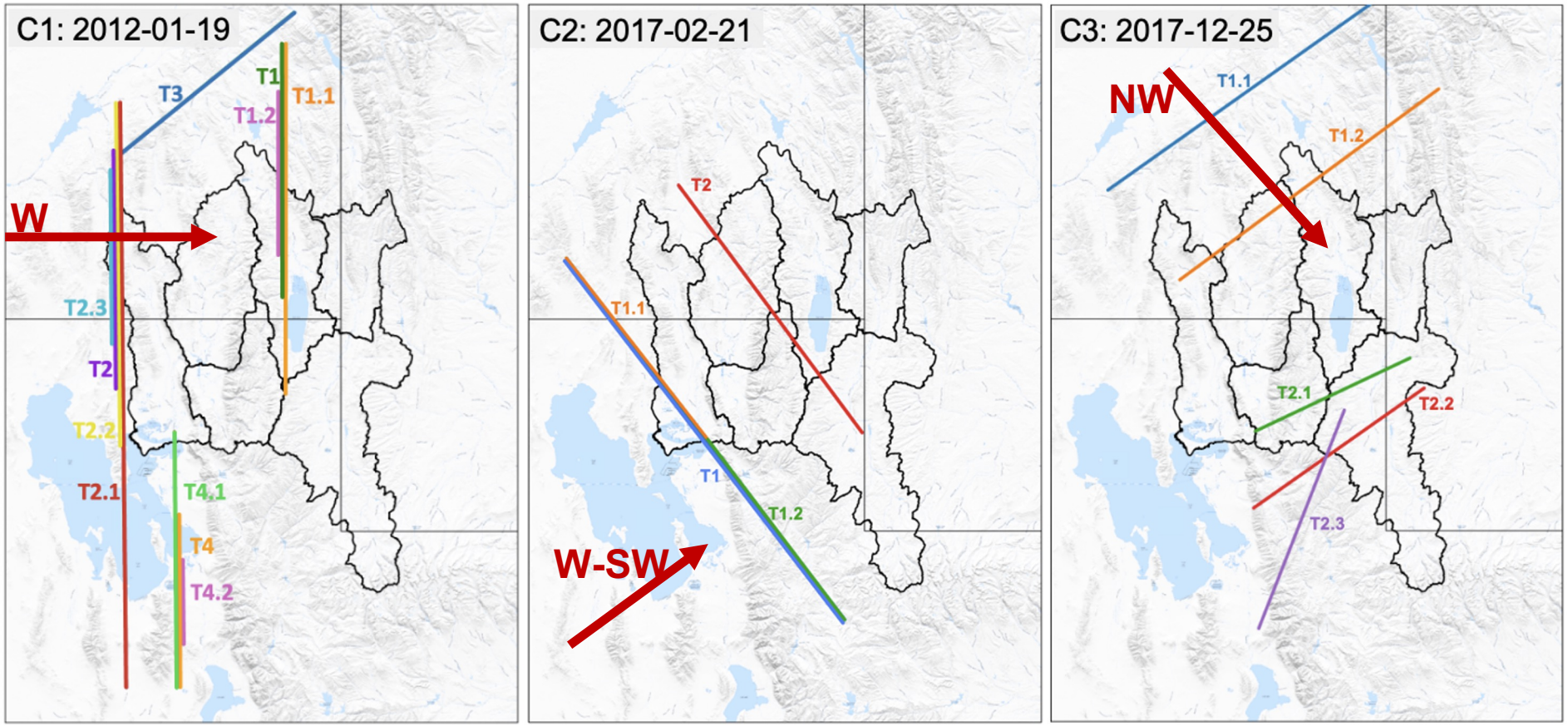
Ground Generator Design Options

<u>5 cases tested:</u>
W, NW, and N winds

- 1 impacted Lower Bear
- 3 impacted Uintas (varying wind direction)
- 1 impact both regions



Airborne Seeding Flight Track Options



Tested with 3 different cases, representing W, W-SW, and NW winds

Feasibility and Design Components

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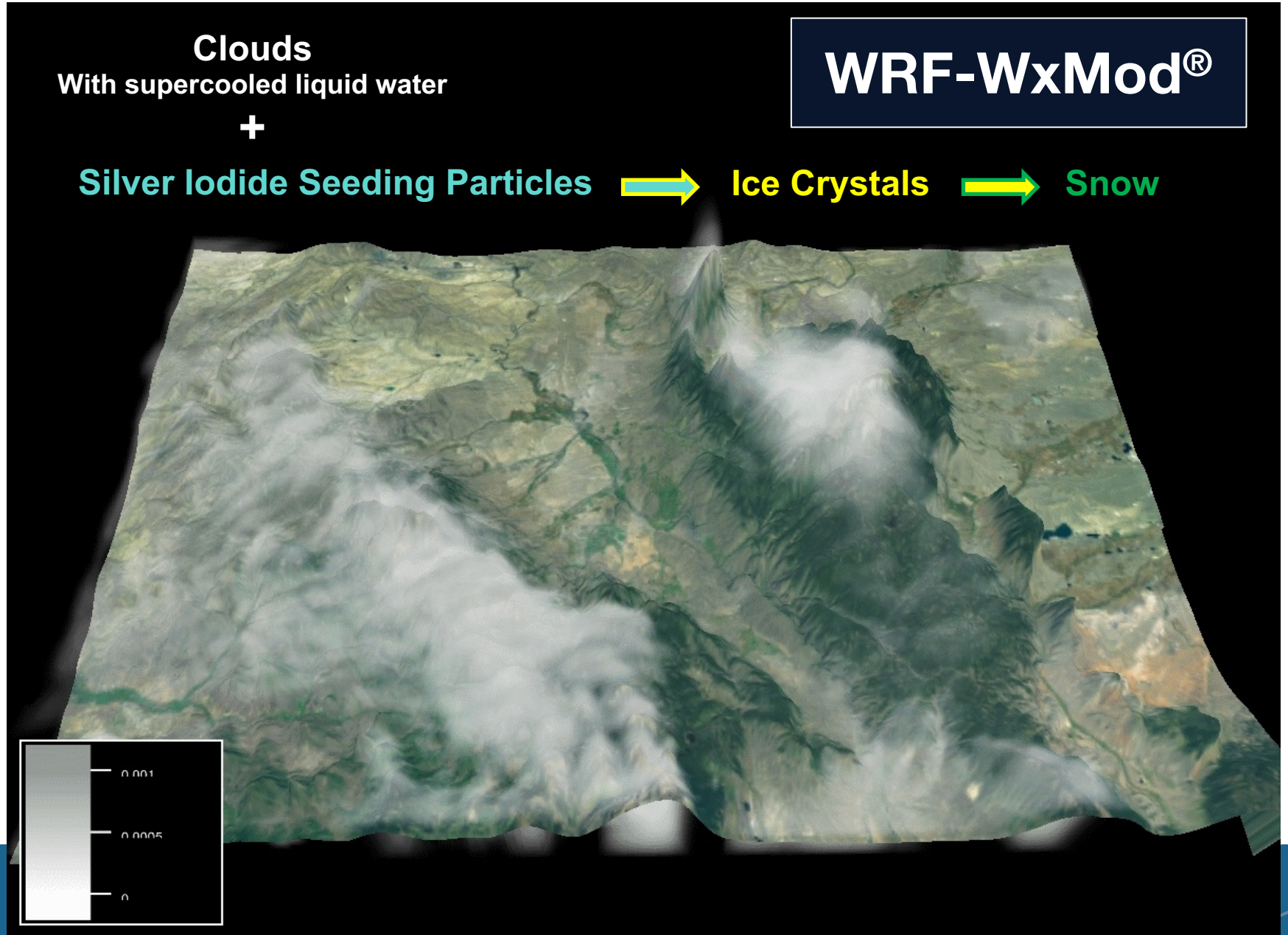
Simulations of cloud seeding

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

Simulations of Cloud Seeding



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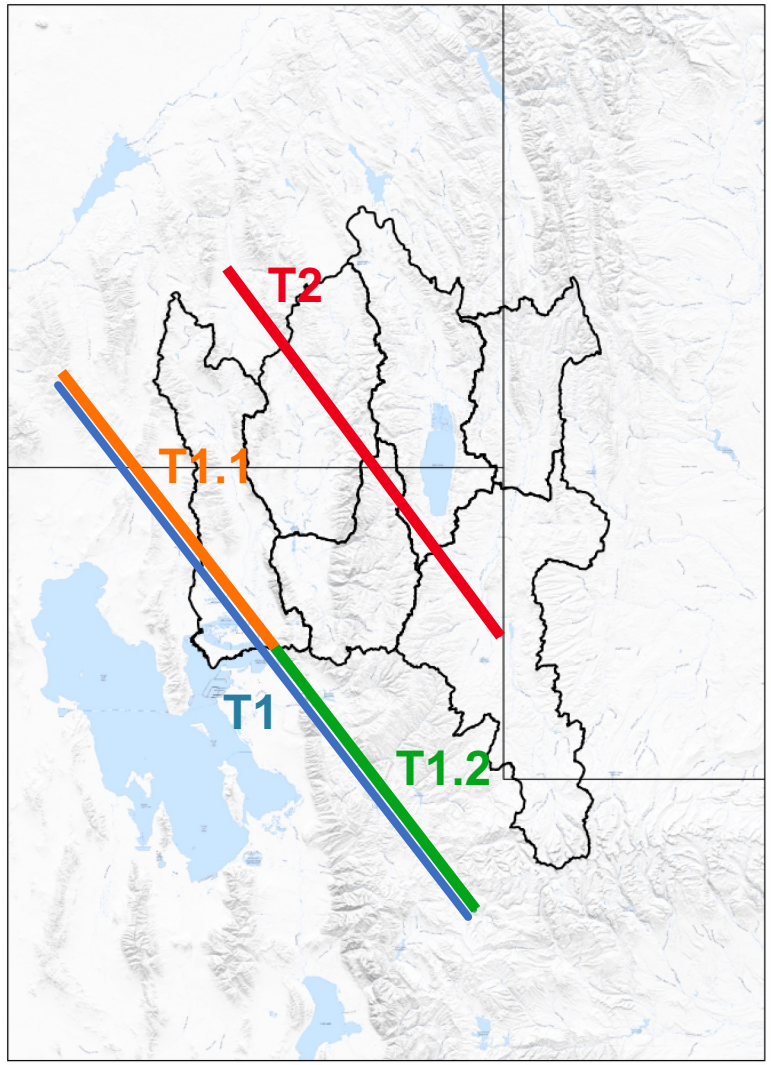
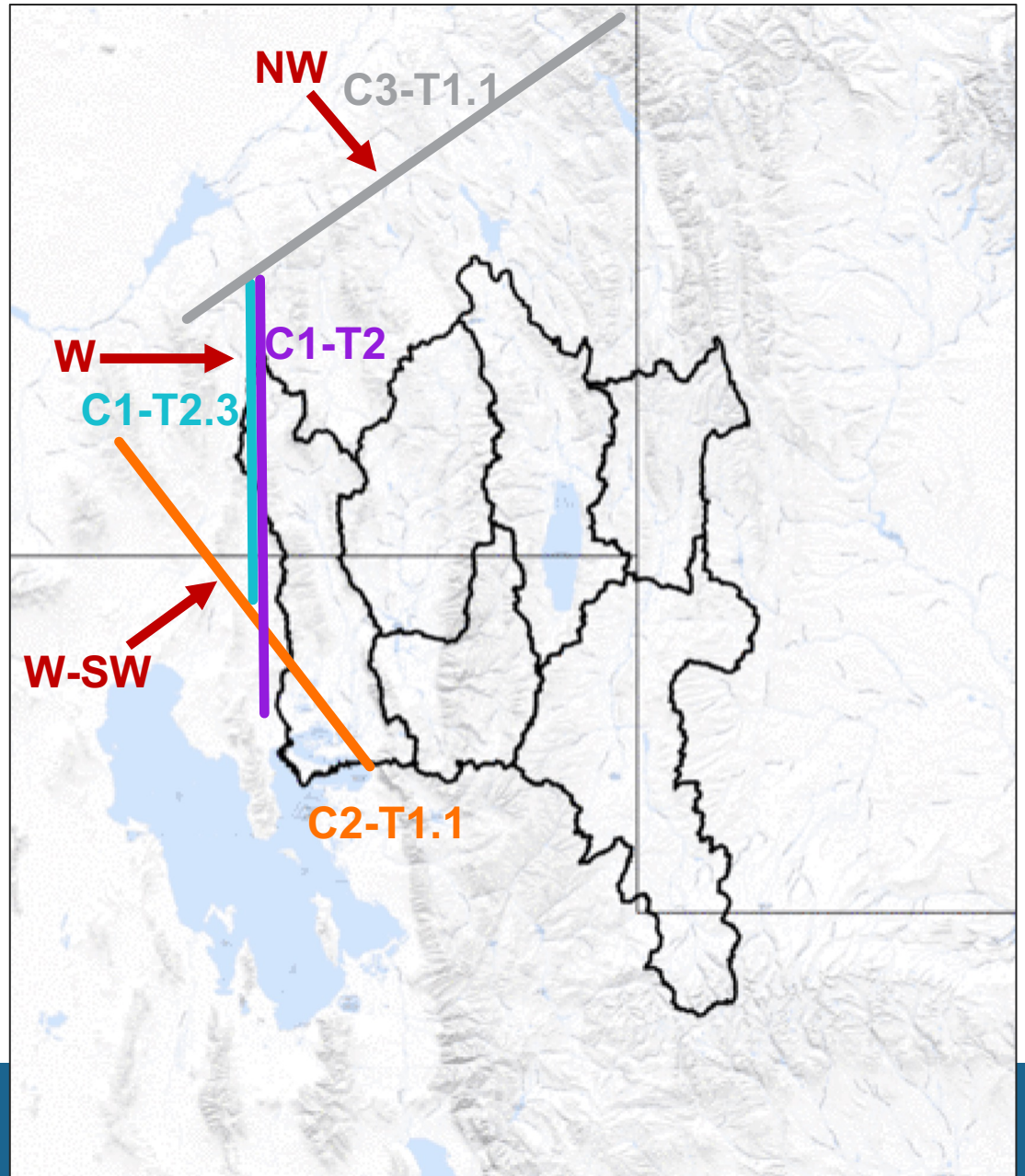
Xue et al. (2013)

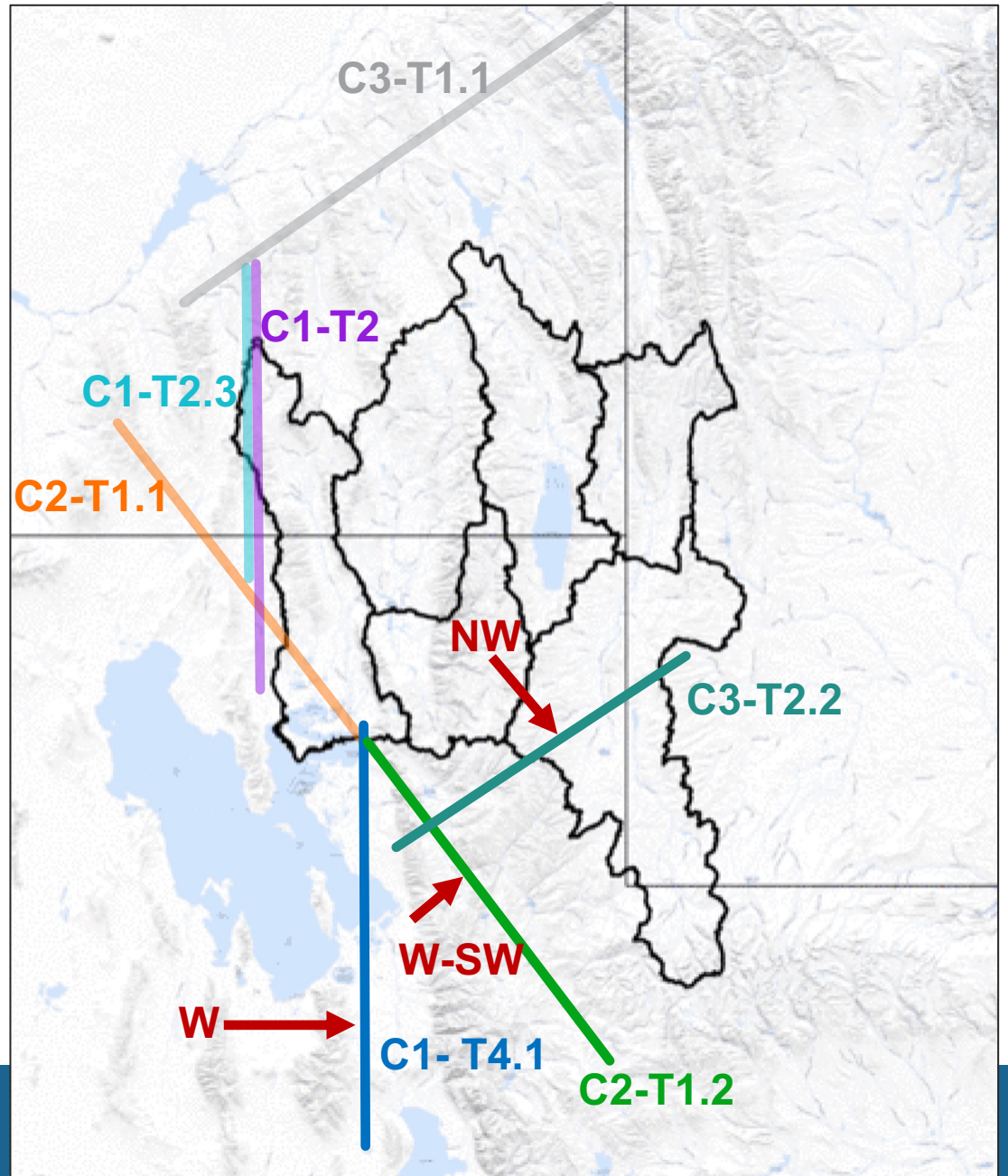
Simulated Seeding Effect Overview

- Shorter tracks were more effective when compared to an equivalent longer track attempting to target both Lower Bear and Uintas (**T1** x **T1.1**)
- Targeting Lower Bear River basin as a whole was consistently more effective than targeting the BRR or SRR (**T1.1** x **T2**)
- Targeting solely Uintas was less effective than seeding Lower Bear (up to 38% of the amount obtained in Lower Bear) due to area of Headwaters
- In the cases studied, tracks at higher altitude (4250m) indicated a slightly higher effect, likely at more optimal temperature



Recommended Flight Tracks

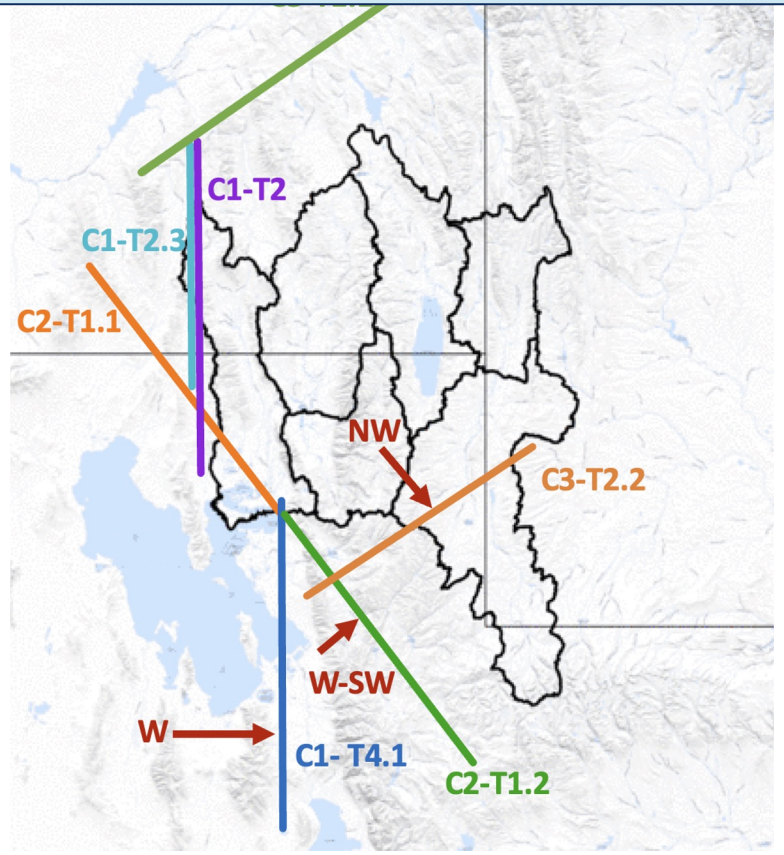




Summary of Recommendations

Airborne Seeding

Seed along the west boundary of the LBR basin
A single aircraft can't effectively seed LBR & UIN

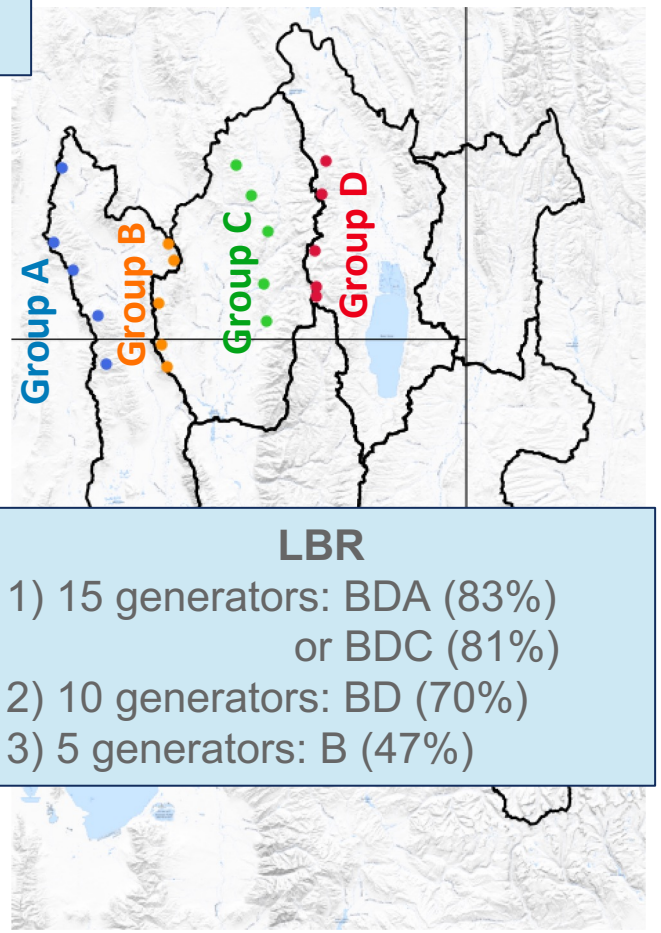


UIN

C1-T4.1: Limited by airspace availability

- Shift track east/west according to wind speed

Ground-based Seeding



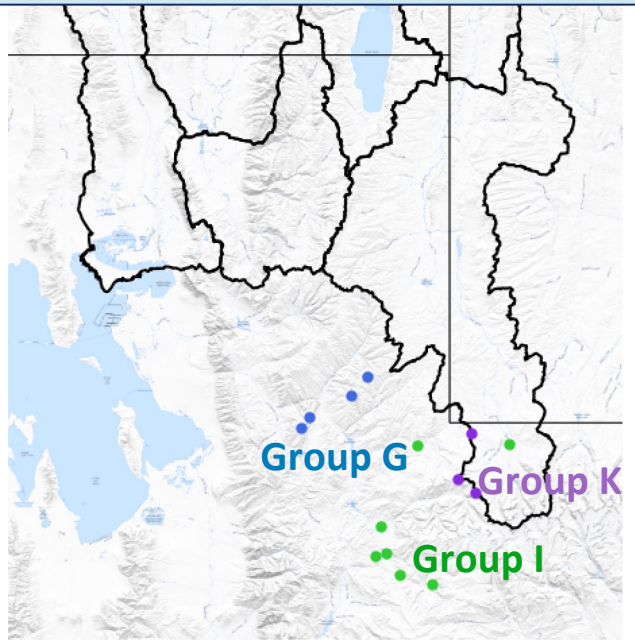
LBR

1) 15 generators: BDA (83%)
   or BDC (81%)
2) 10 generators: BD (70%)
3) 5 generators: B (47%)

UIN

LBR has ~6 times the potential of UIN due to small area of Bear Headwaters

- Shared infrastructure to target all Uintas instead of just headwaters



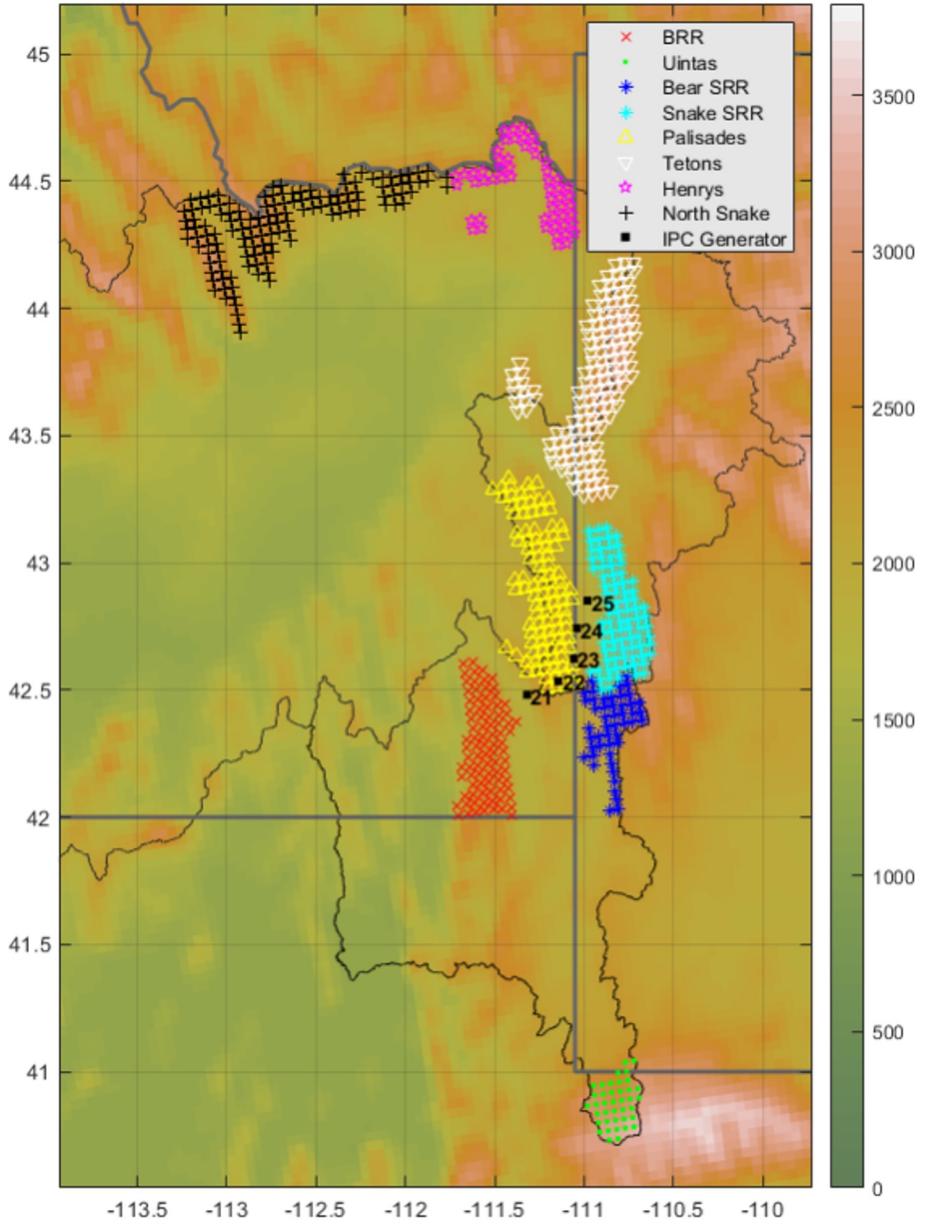
Are there opportunities to partner with Idaho Power's Upper Snake Basin seeding program?

TASK: Identify opportunities for shared infrastructure to be used for ground-based or airborne seeding to benefit both the Upper Snake and Bear River Basins simultaneously

- Shared infrastructure investigation included:
  - Climatology analysis of frequency of opportunities for sharing ground generators or aircraft
  - WRF-WxMod simulations to test the opportunities for sharing infrastructure

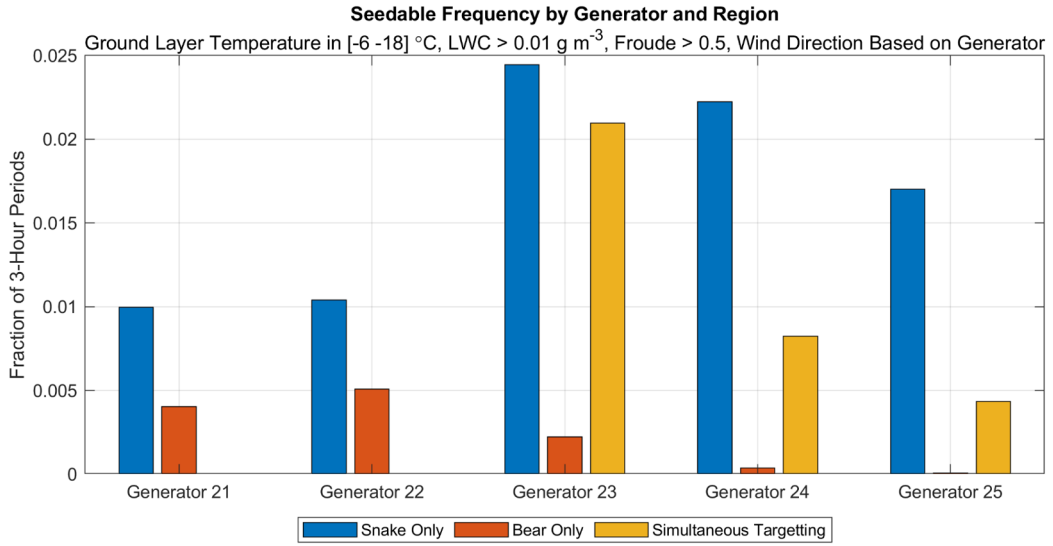
Methods for shared infrastructure analysis

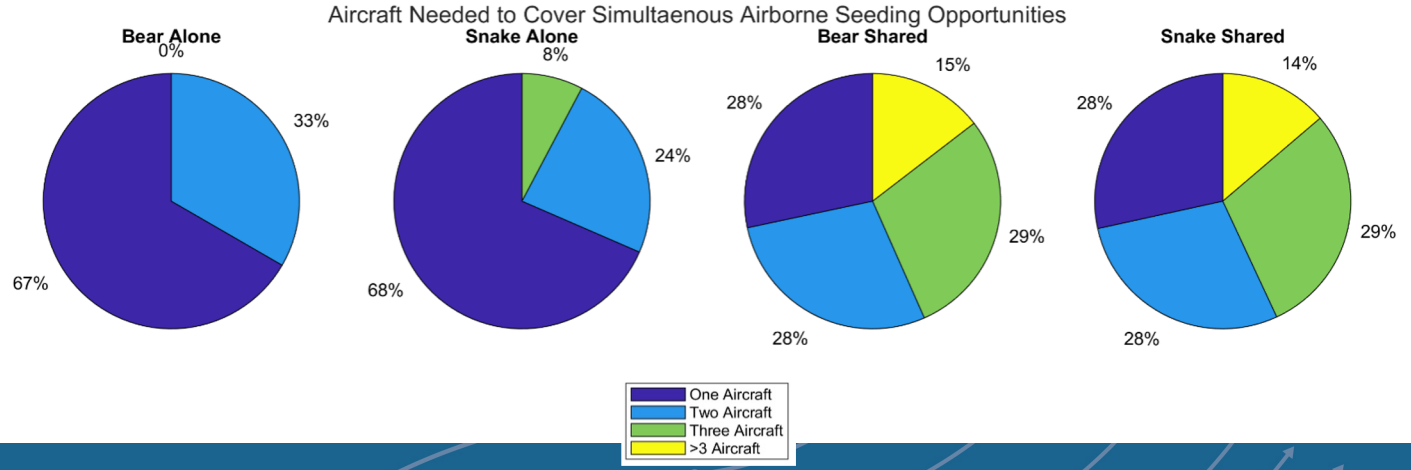
- Climatology analysis uses CONUS model simulation to assess:
  - Frequency of time that a shared aircraft could be used to target one basin or the other, as well as the possibility to target both simultaneously
  - Frequency of time and conditions under which existing generators targeting the Upper Snake could be used to simultaneously or individually target the Bear River Basin



Shared Infrastructure Climatology Results

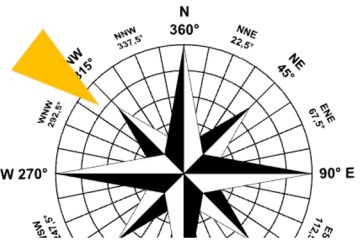
- Generators 21 and 22 can target the Bear portion of the SRR when winds are not favorable to target the Snake, **increasing the generator usage by nearly 150%**
- Generators 23–25 can simultaneously **target both regions 25–45% of the time they'd be operating anyway**
- A shared 2nd or even 3rd aircraft **reduces missed opportunities** compared to both programs operating one aircraft each
  - Extra aircraft could also be used when seedable conditions persist for longer than a single crew could operate one flight

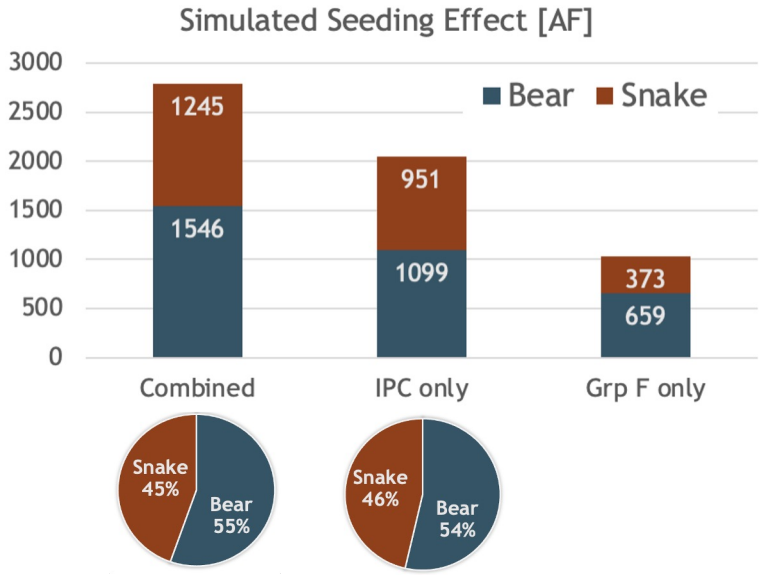


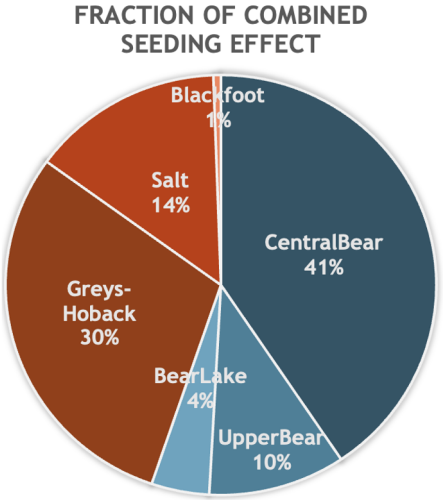


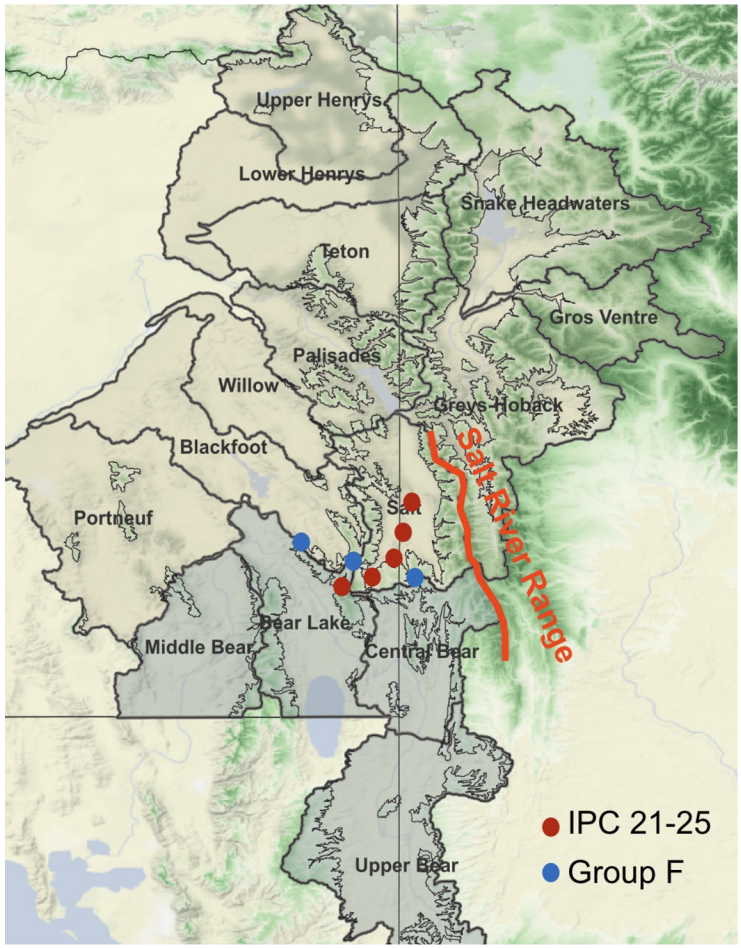
Impact from Cases Selected for Shared Infrastructure

Shared cases:
C1: 2016-01-17
C2: 2020-12-17
C3: 2021-01-17



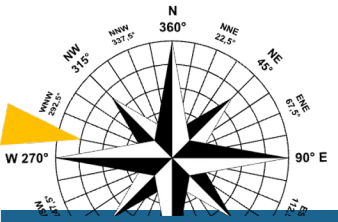


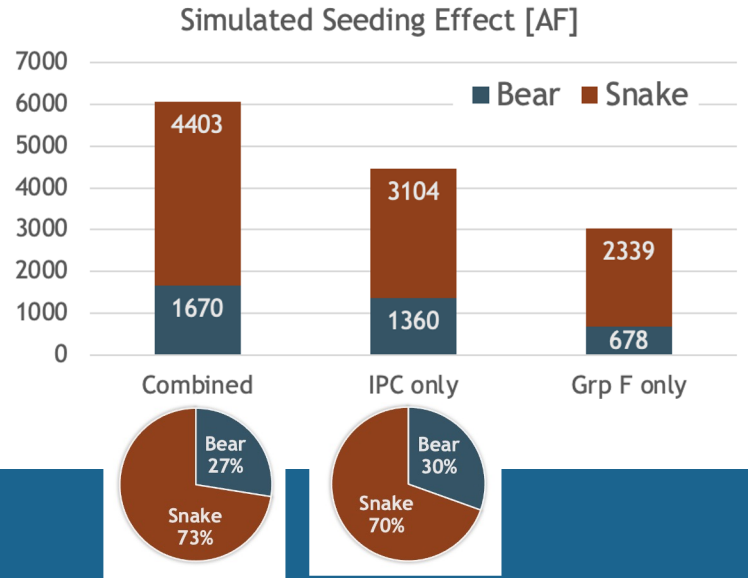


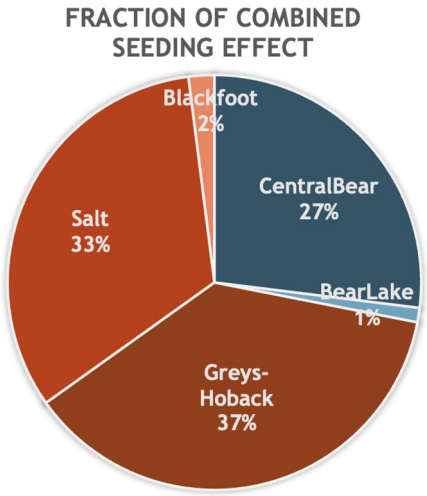


Impact from Cases Selected for Bear River Basin

Bear River cases:
C1: 2016-12-03
C2: 2017-01-20
C3: 2018-02-25







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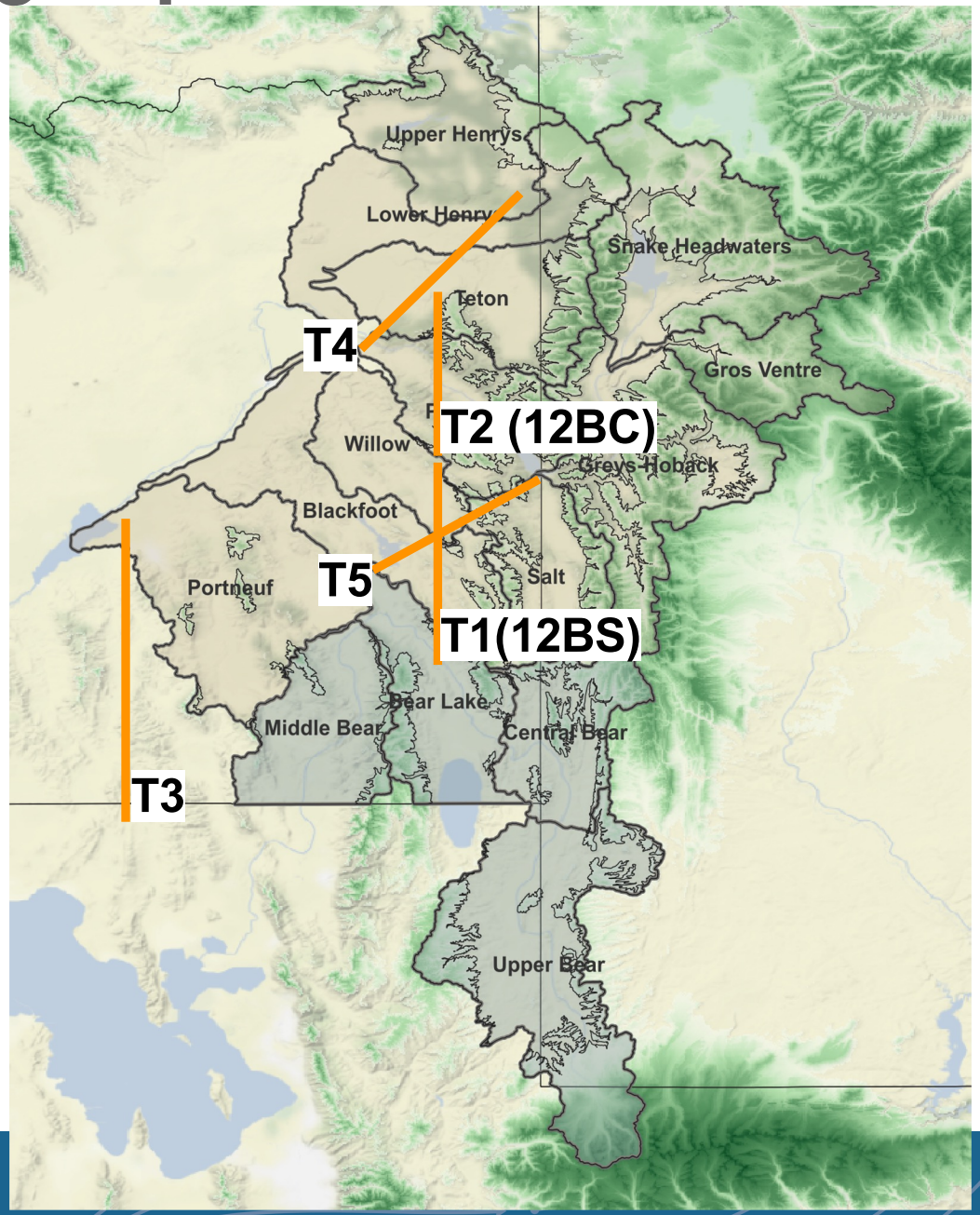
Airborne Seeding Experiment

- One test case was simulated to quantify how existing or new flight tracks could impact each basin
- Under W-NW winds, the existing IPC track 12BS (T1) can yield precipitation that benefit the Snake and the Bear



Key Points

A study was conducted to assess the feasibility for cloud seeding with silver iodide and develop designs to target the Bear River Basin with cloud seeding to enhance precipitation

- Cloud seeding with silver iodide has been shown to produce snowfall
- There are opportunities to use silver iodide cloud seeding to enhance precipitation in the Bear River Basin
- Airborne seeding is recommended over ground-based seeding given flow blocking issues and warming temperatures due to climate change
  - If ground seeding is pursued, higher elevation sites are needed to overcome flow blocking
  - Liquid propane seeding may be an alternative for ground-based seeding in a warming climate, but more research is needed to better understand how effective it can be
- There are opportunities to partner with Idaho Power's Upper Snake seeding program to share ground generators and/or aircraft to also target the Bear
  - Partnerships with Utah may also be useful for targeting the Upper Bear