AGENDA

IDAHO WATER RESOURCE BOARD

Cloud Seeding Committee Meeting No. 2-23

Wednesday, September 6, 2023
1:00 p.m. (MT) / Noon (PT)
Water Center
Conference Rooms 602 C&D / Online Zoom Meeting
322 E. Front St.
BOISE

Board Members & the Public may participate via Zoom
Click here to join our Zoom Meeting
Dial in Option: 1(253) 215-8782
Meeting ID: 897 1599 8383 Passcode: 478824

1. Introductions and Attendance
2. Cloud Seeding Bear River Analysis*
3. Other Items
4. Adjourn

Committee Members: Chair Marc Gibbs, Jeff Raybould, Al Barker, and Pat McMahon.

Finance Committee Meeting No. 9-23

Upon Adjournment of Cloud Seeding Committee Meeting

Board Members & the Public may participate via Zoom
Click here to join our Zoom Meeting
Dial in Option: 1(253) 215-8782
Meeting ID: 876 9616 9579 Passcode: 150385

1. Introductions and Attendance
2. Loan Program Requests*
    a. Blaine County Canal Company*
    b. Weiser Irrigation District*
    c. Barber Pool Hydro*
3. Other Items
4. Adjourn

Committee Members: Chair Jo Ann Cole-Hansen, Jeff Raybould, Dale Van Stone, Dean Stevenson, and Marcus Gibbs.

* Action Item: A vote regarding this item may be made at this meeting. Identifying an item as an action item on the agenda does not require a vote to be taken on the item.

Americans with Disabilities: The meeting will be held in person and online. If you require special accommodations to attend, participate in, or understand the meeting, please make advance arrangements by contacting Department staff by email jennifer.strange@idwr.idaho.gov or by phone at (208) 287-4800.

Memorandum

To: Idaho Water Resource Board

From: Kala Golden, Cloud Seeding Program Manager

Date: September 5, 2023

Re: Cloud Seeding in the Bear River Basin

ACTION: Determine next steps

Background

In July of 2021, the Idaho Water Resource Board (IWRB) directed staff to conduct a cloud seeding feasibility and design (F/D) study of the Bear River Basin (BRB). Staff contracted the National Center for Atmospheric Research (NCAR) to conduct this investigation. NCAR was directed to evaluate the potential for seeding in the BRB, focusing on regions that contribute towards the fill of Bear Lake and stream reaches within the Bear that supply water to users in Idaho. The F/D study looks at seeding potential for both ground and airborne seeding opportunities, based on where seedable conditions tend to exist in the atmosphere. Included in this evaluation is an investigation of the potential for shared infrastructure with the Upper Snake River Basin (USRB). Sharing cloud seeding infrastructure between adjoining river basins has been demonstrated to be cost-effective and provides for increased operational efficiency. Sharing infrastructure with the USRB provides an opportunity to enhance the USRB cloud seeding project, while simultaneously supporting the development of cloud seeding operations in the BRB.

NCAR will provide a presentation on the results of the BRB F/D study at the IWRB's Cloud Seeding Committee meeting on September 6, 2023.

Recommendations

- Focus on airborne seeding operations, as it has a higher frequency of seeding opportunities and is less limited by flow blocking and inversions.
    - Aircraft can reach higher elevations, which will be crucial during climatically warm periods.
- For ground-based operations, NCAR recommends pursuing higher elevations sites to avoid limitations from inversions and mountain-blocked flow conditions.
    - Generator sites used to conduct this assessment were primarily done above 6500 feet elevation, though there were a couple generators in group C around 5500 feet.

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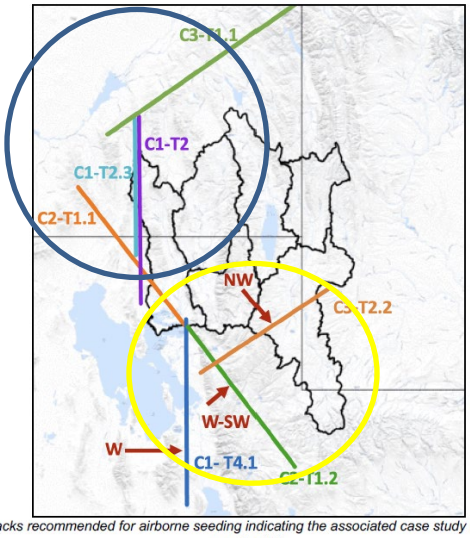
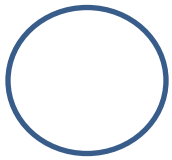
Aircraft



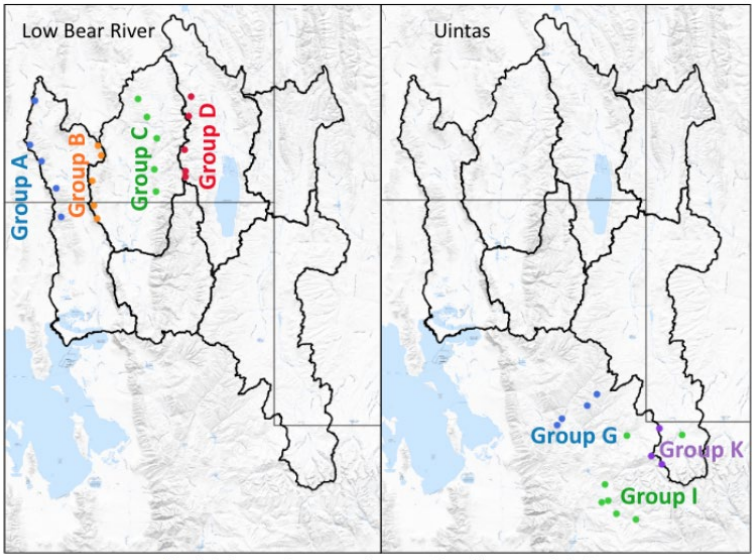
Flight tracks recommended for airborne seeding indicating the associated case study (C) and track number (T).



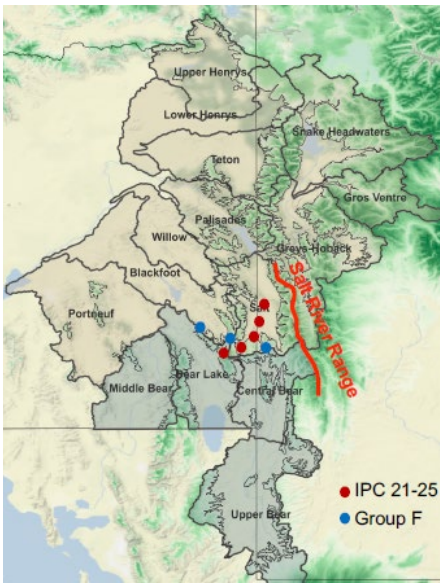
A shared aircraft could be used to target the NW region of the BRB and the USRB, *prioritizing either basin at the IWRB's discretion*.

The addition of a third aircraft could be used to target this region of the BRB. The State of Utah is currently working to implement aircraft seeding operations in this region.

Ground



Simulated generator groups for ground seeding cases 1 to 5.



- For the Lower Bear River Basin, designed to target stream reaches within the BRB that supports fill of the lake and water use in Idaho, NCAR recommends the following design configuration, listed in order of maximum seeding potential. These recommendations are made to reflect optimum seeding potential, based on how many generators the IWRB would like to invest in.
    - For a total of 15 new generators, use either Groups B,D,A or Groups B,D,C
    - For a total of 10 new generators, use Groups B and D
    - For a total of 5 new generators, use Group B

- For the Bear River headwaters out of the Uintas, designed to target the main stem of the Bear River and fill of Bear Lake:
    - Given the limited spatial extent of the BRB headwaters that come out of the Uintas Mountains, targeting this region of the basin will be very challenging, and will additionally show enhanced impact to other river basins fed by the Uinta's mountains.
        - For this reason, partnering with the State of Utah to utilize the existing Group I generators when winds are favorable, is likely more cost effective than attempting to establish new infrastructure in this region.
- For shared infrastructure to optimize seeding potential in both the USRB and BRB:
    - A total of 3 new remote ground generators, use Group F (combined with IPC existing, denoted as gens # 21-25)

ESTIMATED COSTS

It should be noted that estimated costs are based on what staff have determined to be logistically feasible under a continued partnership with Idaho Power Company. Estimated costs were provided by IPC as a courtesy to the IWRB and should not be construed as a formal commitment by IPC to support operations in this basin.

- There would exist significant challenges trying to coordinate a new shared aircraft with existing aircraft operations in the USRB, should another operator be considered for this program.
    - Utilizing another operator would result in duplicate costs for regional forecasting, as it is already being done for the Collaborative Program in this region.
    - No other operator currently has the modeling capabilities or licensures to operate the existing WRF models the IWRB and IPC have invested in and designed for use in Idaho.
    - Existing generator sites 21-25 are already part of the Collaborative Program, owned by IPC.
    - There are no current, off the shelf manufacturers of cloud seeding generators. IPC has designed and manufactured all existing remote ground generators that currently support the Collaborative Program. Costs for devices are based on IPC's cost to develop. Staff are working to identify potential alternative sources for securing generators and develop estimated costs.

- Costs provided reflect:
    - 1 aircraft and a contract meteorologist (required) to support a shared aircraft targeting the NW region of the BRB and USRB as needed.
    - 5 Remotely operated Ground generators (first year, full build out TBD)
    - Weather Instruments needed to support operations and forecasting.
    - WRF model updates to support BRB forecasting and operations were authorized by the IWRB in July of 2023 (approximately $250,000 for both the Lemhi River and Bear River Basins).

Aircraft

WY 2025		
	Initial Year	**Ongoing**
Aircraft	**$ 669,339.30**	**$ 669,339.30**
Fixed	*$ 456,756.30*	*$ 456,756.30*
Variable	*$ 212,583.00*	*$ 212,583.00*
Contract Met	**$ 116,865.00**	**$ 116,865.00**
IPC Contract Admin	$ 3,792.01	$ 3,792.01
Total for Aircraft/Met	**$ 789,996.31**	**$ 789,996.31**

Generators (5 GGENs)

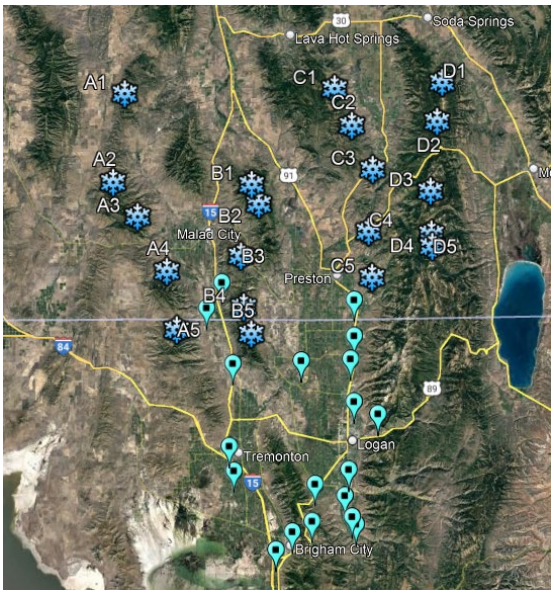
WY 2025		
Ground Seeding	**Initial Year**	**Ongoing**
RCNG units, purchase	$ 250,000.00	
Leases	$ 12,500.00	$ 12,500.00
Site selection	$ 11,552.02	
Installation	$ 10,266.42	
Train State Field Crew	$ 7,113.18	
IPC support and maintenance support	$ 3,754.97	$ 1,877.48
Solution	$ 18,750.00	$ 18,750.00
Total Generators	**$ 313,936.59**	**$ 33,127.48**

Instrumentation

WY 2025		
Instrumentation	**Initial Year**	**Ongoing**
Wx Balloon	$ 12,650.00	$ 10,650.00
Radiometer	$ 207,329.72	$ 10,975.00
Precip gage		$ 2,400.00
Mini-Rad	*$ 1,500.00*	
Ice Rate Sensor	*$ 150.00*	
SWEDAR	*N/A*	*N/A*
Radar	*N/A*	*N/A*
IPC support and maintenance support	$ 3,754.97	$ 1,877.48
Total Instrumentation	**$ 225,384.69**	**$ 25,902.48**

Total	**Initial Year**	**Ongoing**
	$1,329,317.59	**$ 849,026.28**

Additional References



- For ground-based operations, NCAR's evaluation recommended pursuing higher elevations sites to avoid limitations from inversions and mountain-blocked flow conditions.
- Generator sites used to conduct NCAR's assessment were primarily done above 6500 feet elevation, though there were a couple generators in group C around 5500 feet.

State of Utah Existing Manual Generators sites.

ID	Site Name	Elevation (ft)
BE-1	Trout Creek	5070
BE-2	Oakley	4570
BE-3	Grouse Greek	5334
BE-4	Grouse Creek N	5484
BE-5	Lynn	5930
BE-6	Almo	5340
BE-7	Yost	5986
BE-8	Rosette	5640
BE-9	Standrod	5811
CV-1	Malad South	4450
CV-2	Portage	4500
CV-3	Plymouth	4417
CV-5	Newton	4662
CV-6	Cove	4577
CV-7	Richmond	4600
CV-8	Smithfield	4694
CV-9	Logan	4580
CV-10	Logan Canyon	4971
CV-11	Tremonton	4295
CV-12	Bear River City	4265
CV-13	Perry	4404
CV-14	Brigham City	4690
CV-15	Mantua	5200
CV-16	Wellsville	4884
CV-17	Hyrum	4816
CV-18	Paradise	4875
CV-19	Avon	5059
CV-20	Avon South	5079
CV-21	Liberty	5107
CV-22	Huntsville	5066
CV-23	Red Rock Ranch	5473

NCAR *Proposed* Remote Ground Generator

Generator	Elevation Modeled
A1	6627
A2	6480
A3	6890
A4	7513
A5	6824
B1	7726
B2	6627
B3	6463
B4	6316
B5	6988
C1	7218
C2	6660
C3	5807
C4	5906
C5	5479
D1	9137
D2	8333
D3	9121
D4	8990
D5	8530

Attachments: NONE

Bear River Basin Feasibility and Design Study

Results, Recommendations, and Shared Infrastructure Opportunities

Sarah Tessendorf, Courtney Weeks, Maria Frediani, Amy DeCastro, Jamie Wolff, Lulin Xue, Kyoko Ikeda, Amanda Siems-Anderson

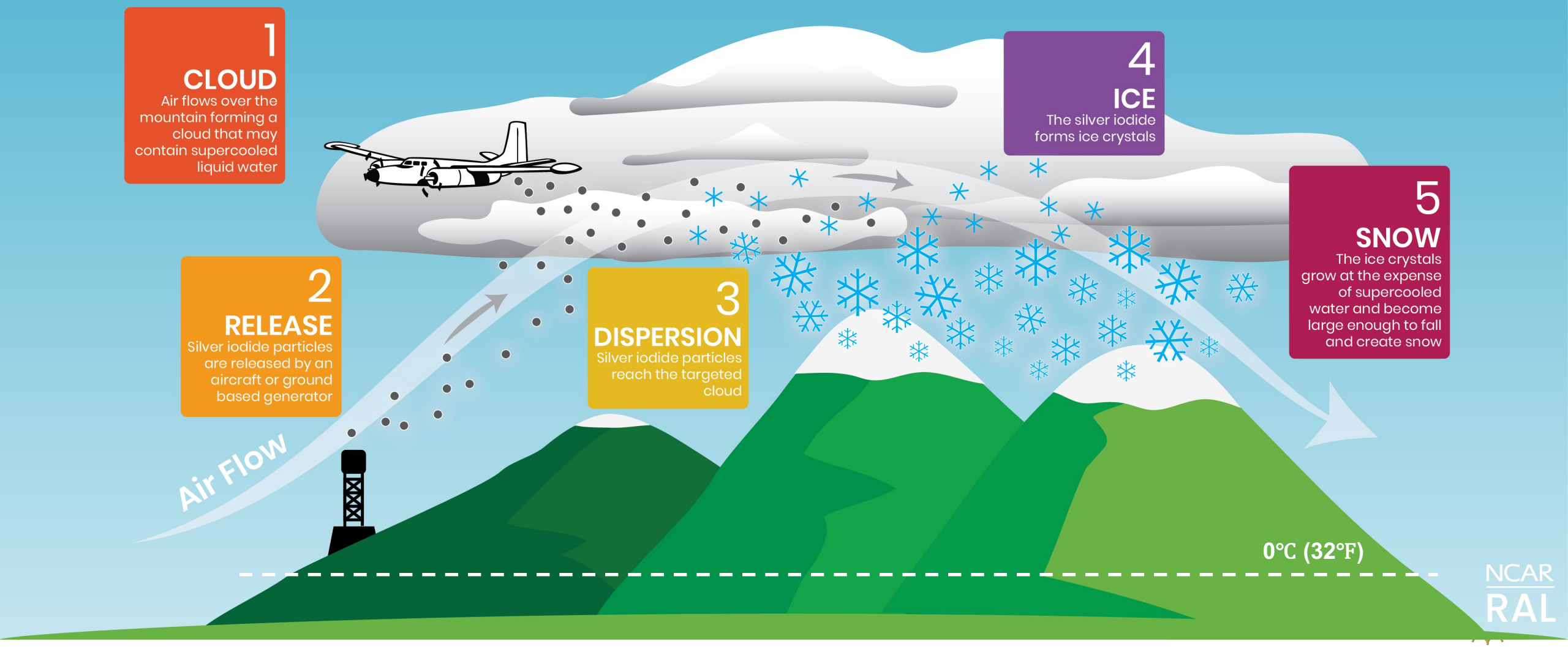
Research Applications Laboratory

National Center for Atmospheric Research, Boulder, CO

September 6, 2023

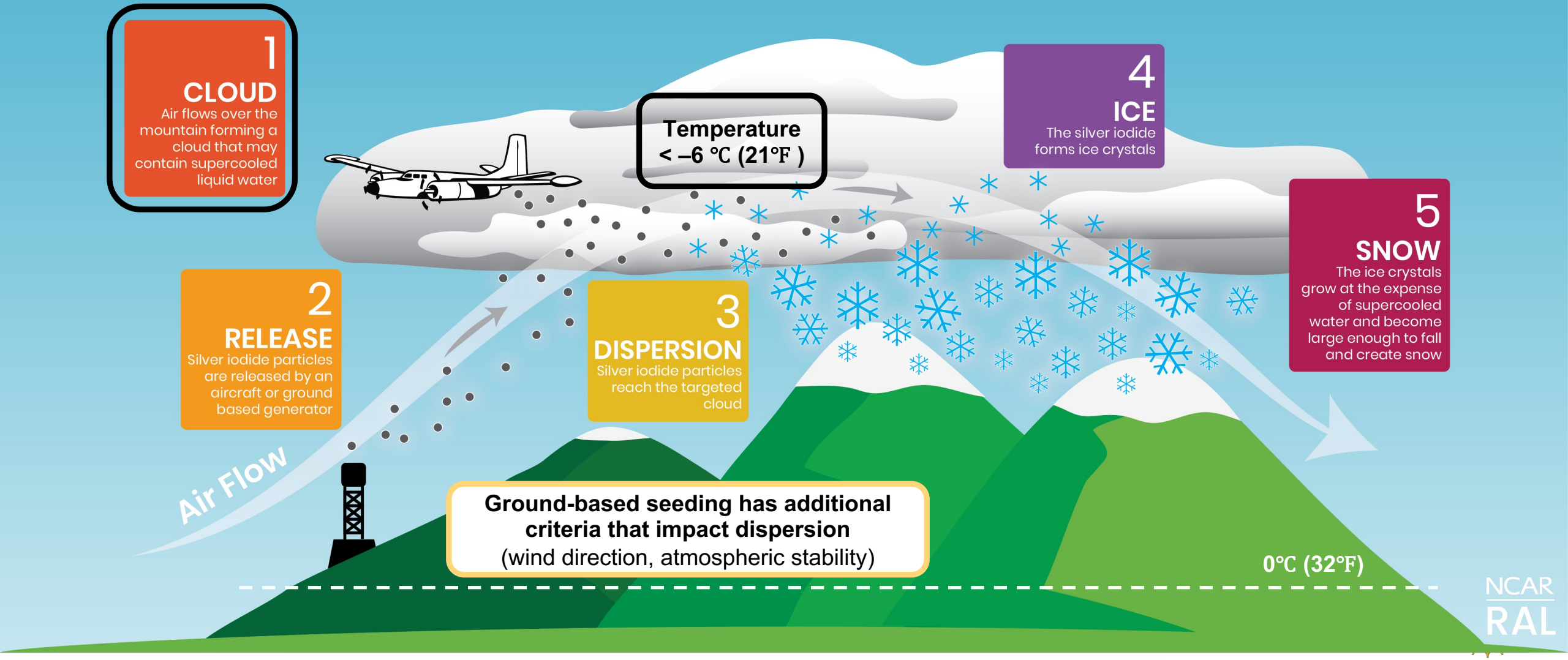
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

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



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.

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

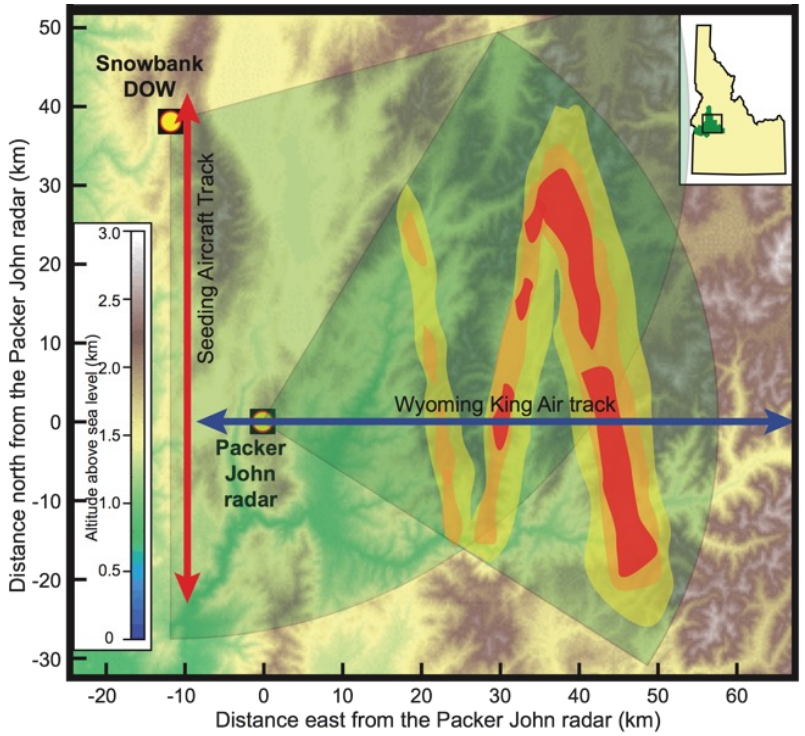


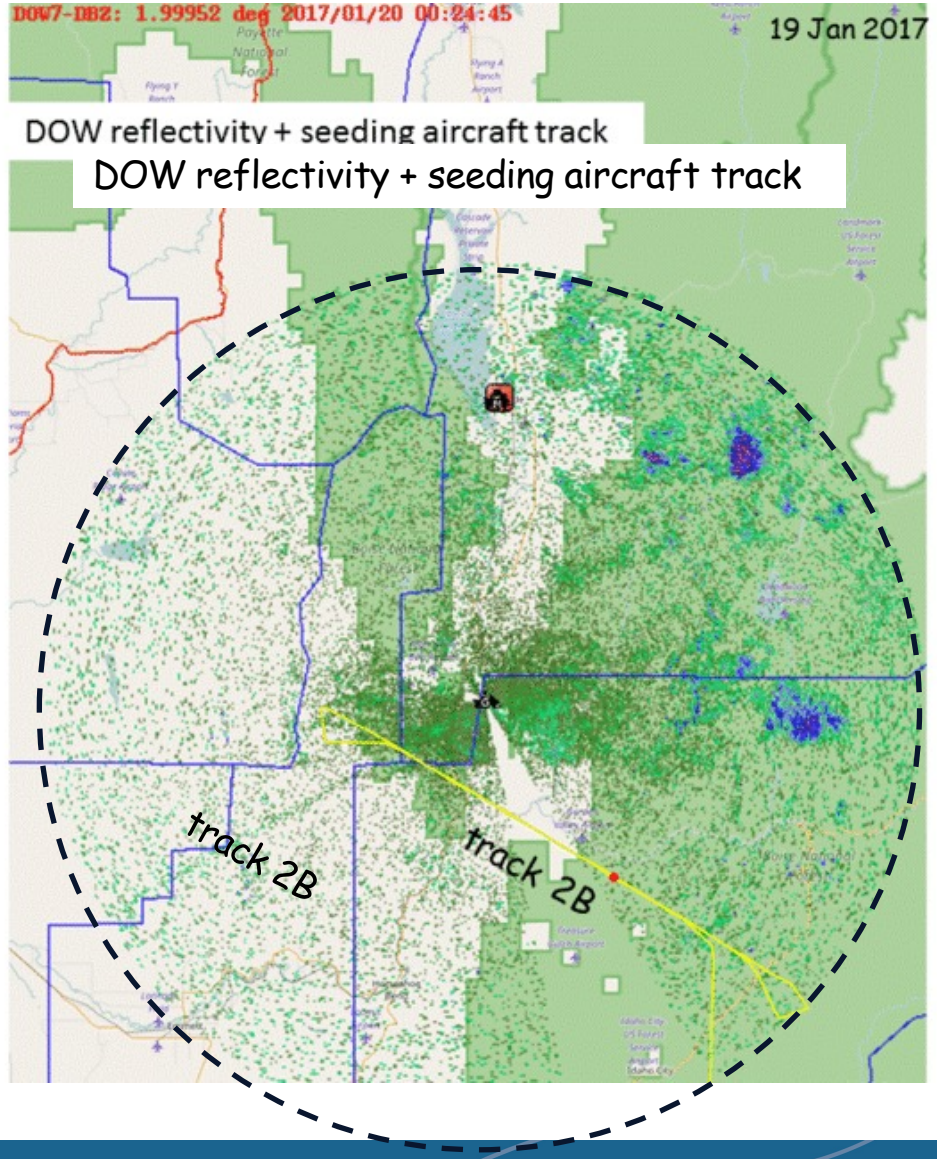
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

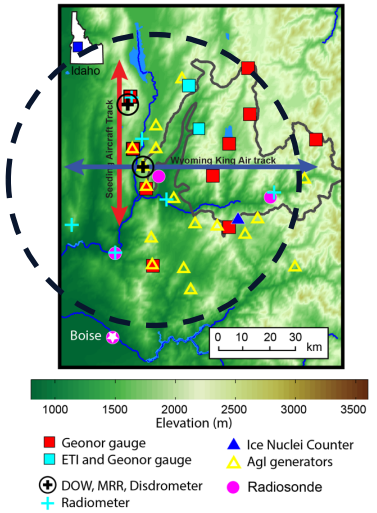
Recent study proves seeding produces snow

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:

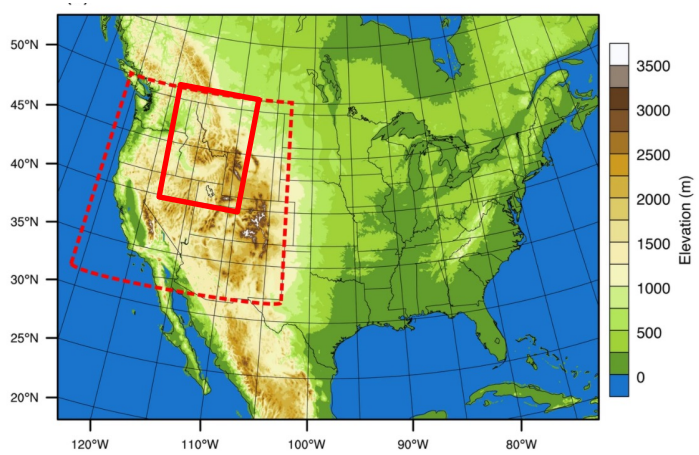
- Temperature
- Supercooled liquid water (SLW)
- Precipitation
- Winds
- Atmospheric stability

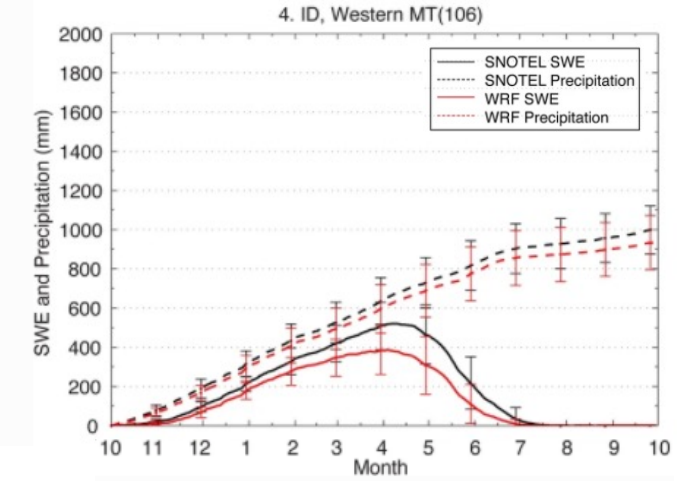
Approach for Climatology Analysis

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

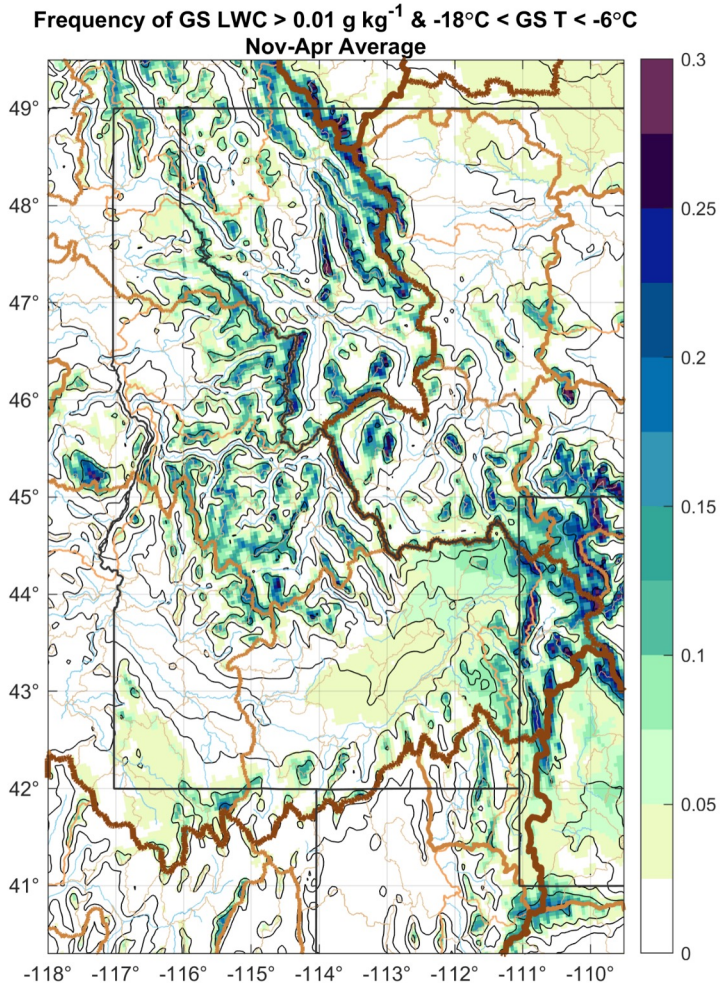




Ikeda et al. (2021)

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

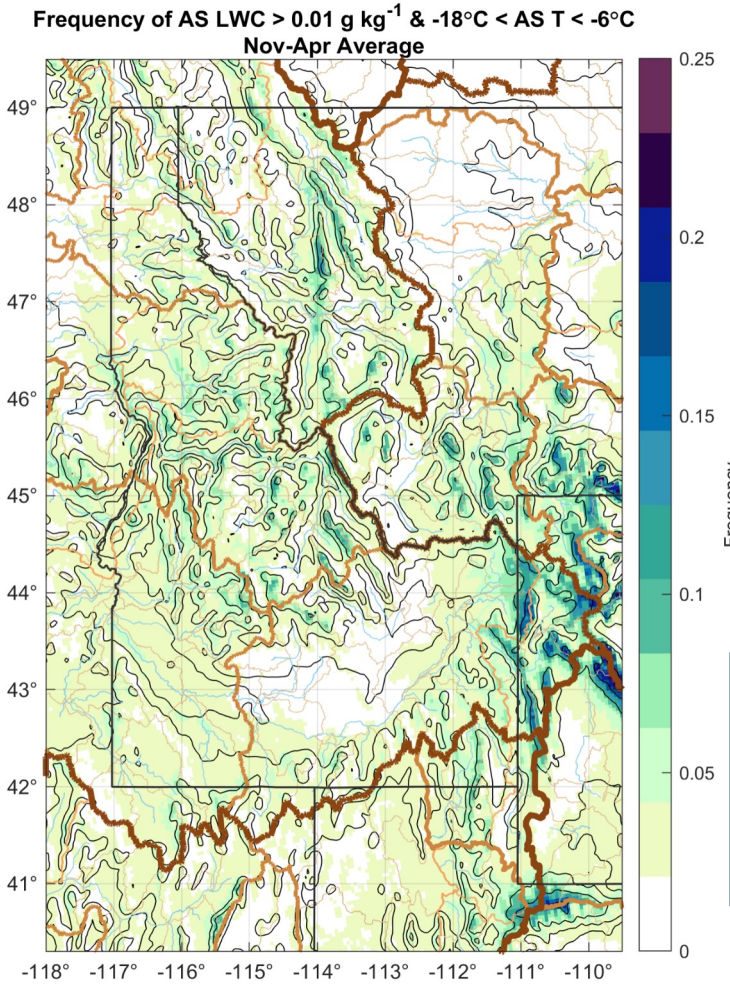
Ground seeding layer (0-1 km AGL)



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)

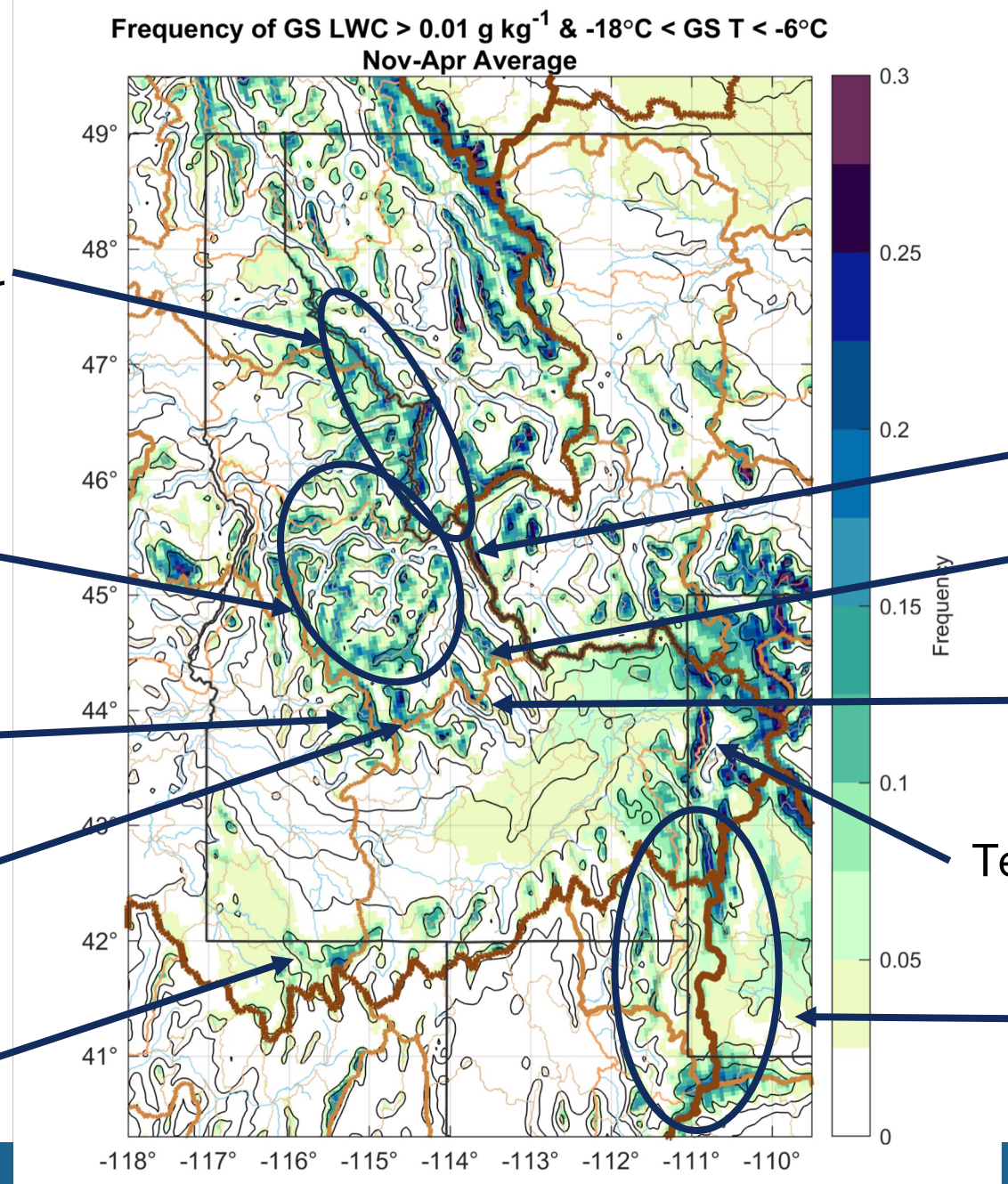


This layer was determined based upon minimum safe flight altitudes over most of the state. Regions with lower altitude mountains may have more potential than shown here since SLW decreases with altitude.

More detailed analysis by basin or mountain barrier is needed

NCAR | UCAR

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

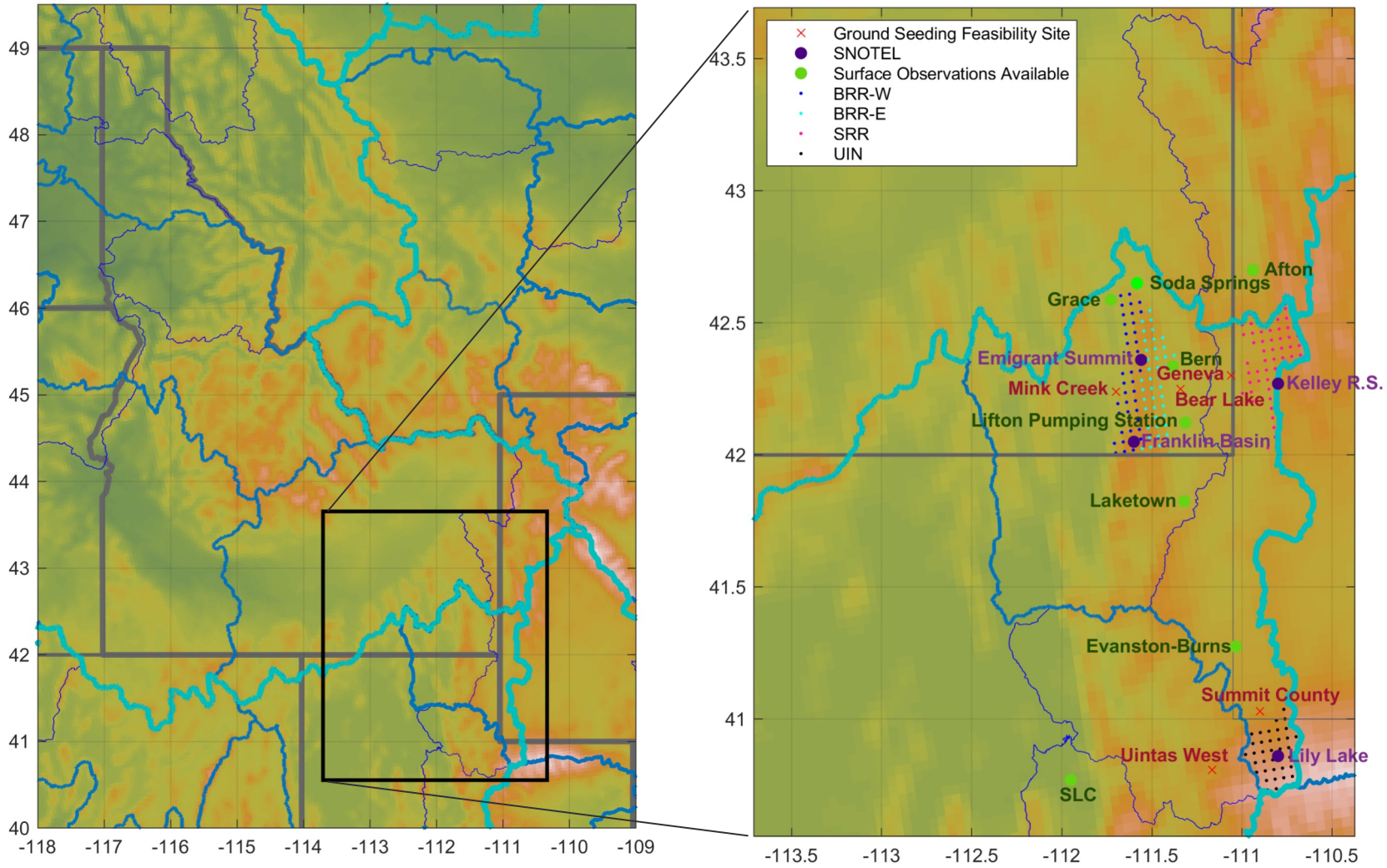
Current Study Area (incl. Bear River Range, Salt River Range, Uintas)

Bear River Basin: Region of Study

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

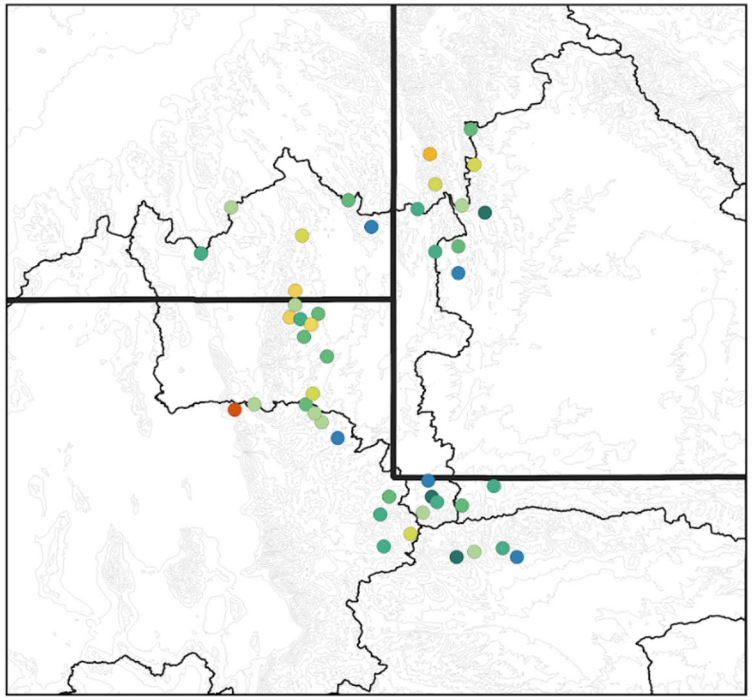
Focus on Bear River Basin:

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

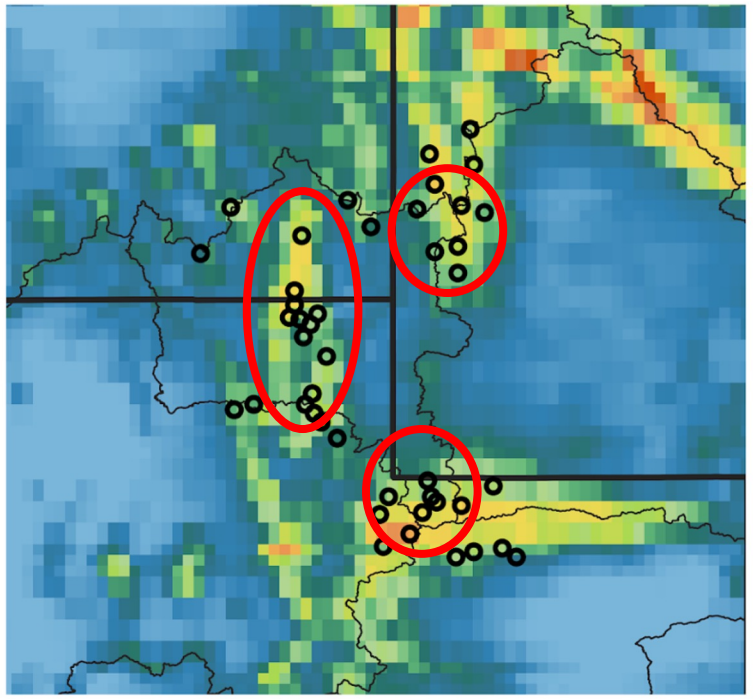


Average Annual Precipitation in the Bear River Basin

SNOTEL Observations



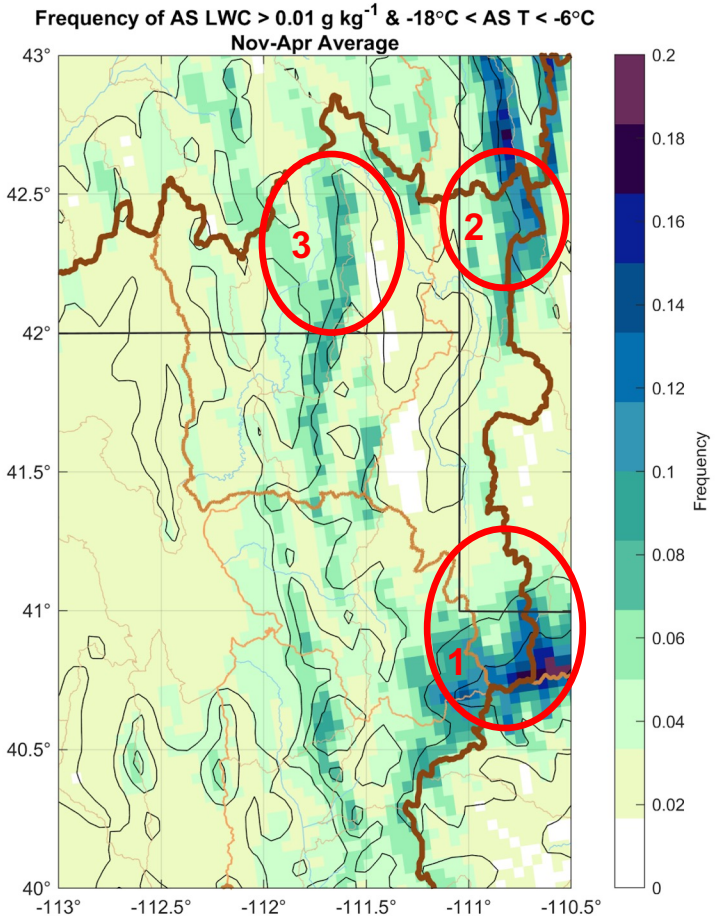
CONUS Model Simulation



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

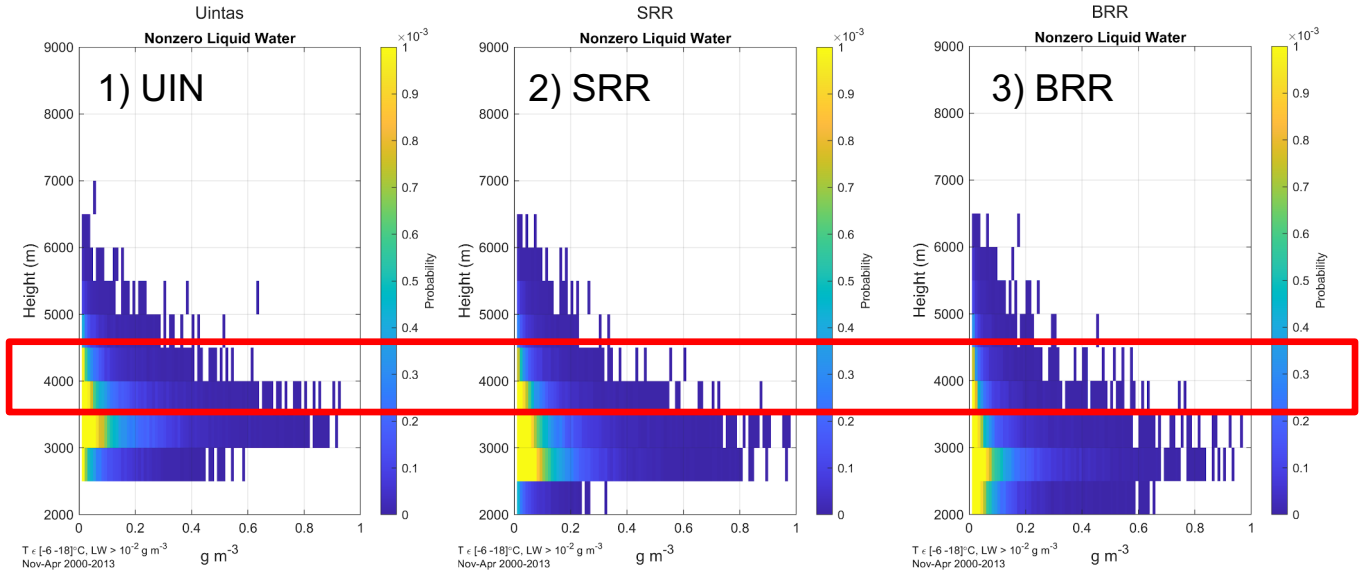
Frequency of Airborne Seeding Opportunities



Three regions feed the Bear River Basin:

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

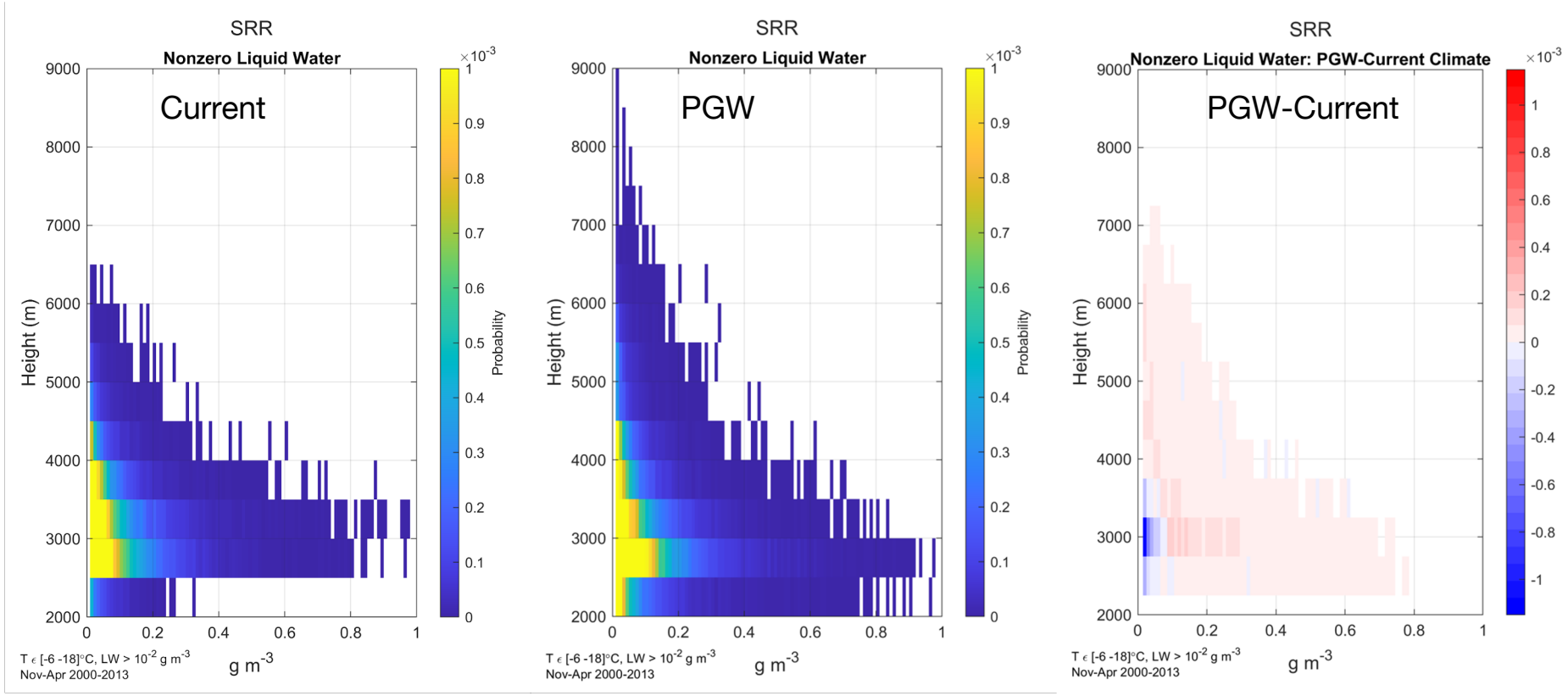
Airborne seeding opportunities between Nov-Apr, peak in late winter



Flight level 3.5-4.5 km MSL

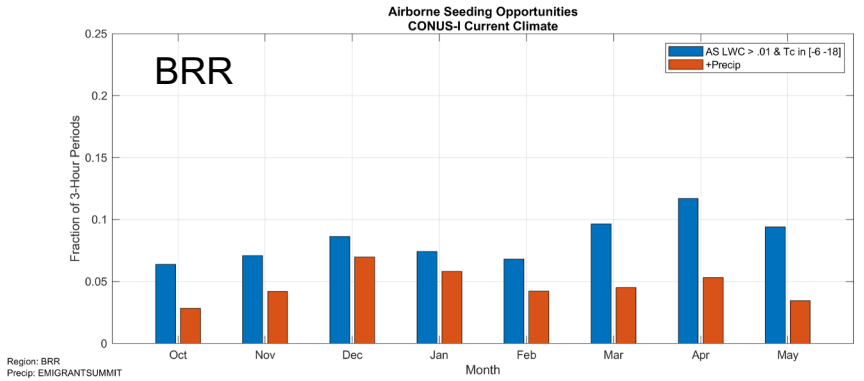
Future Climate Analysis for the Bear River Basin

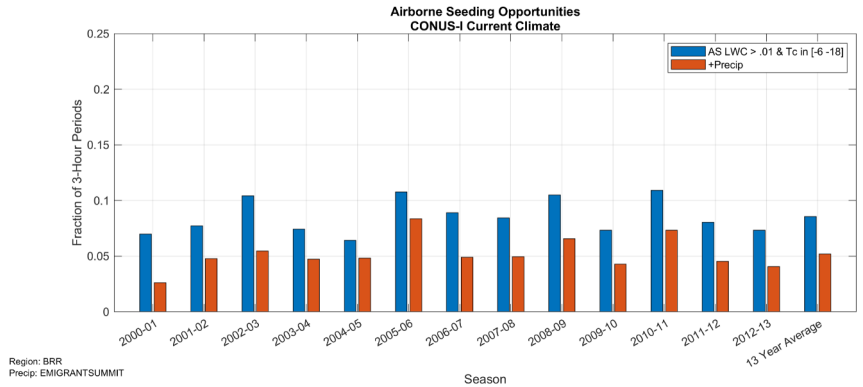
- Increased SLW and warmer temperatures reduces ground seeding opportunities and offsets airborne at the 3.5-4.5 km MSL layer, however SLW extends to higher altitudes in PGW so aircraft could fly at higher altitudes to be in ideal temperatures with SLW

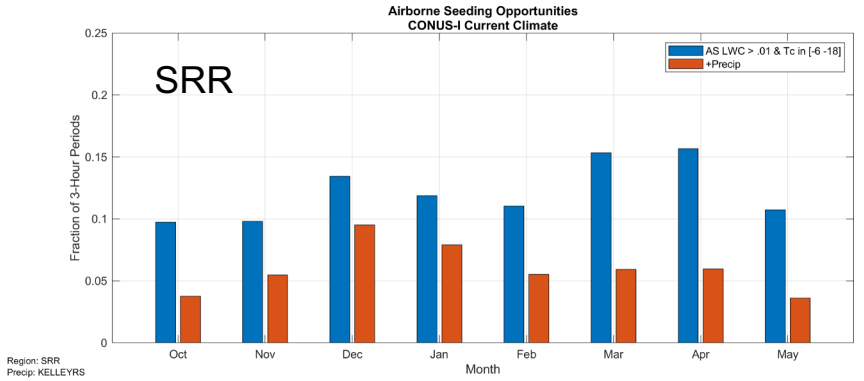


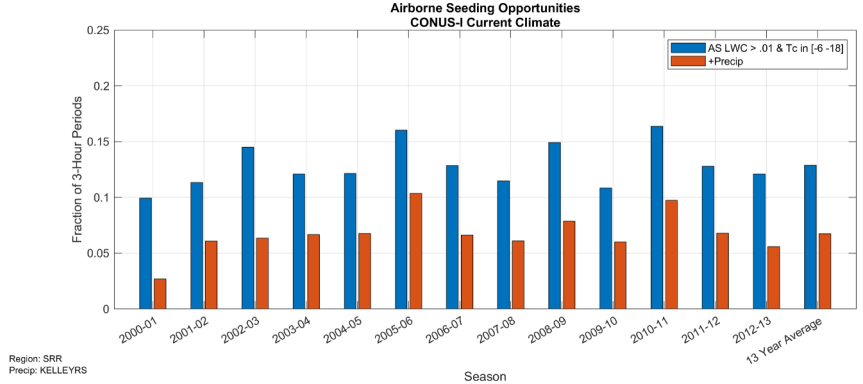
Airborne Seeding: CONUS-I Current Climate

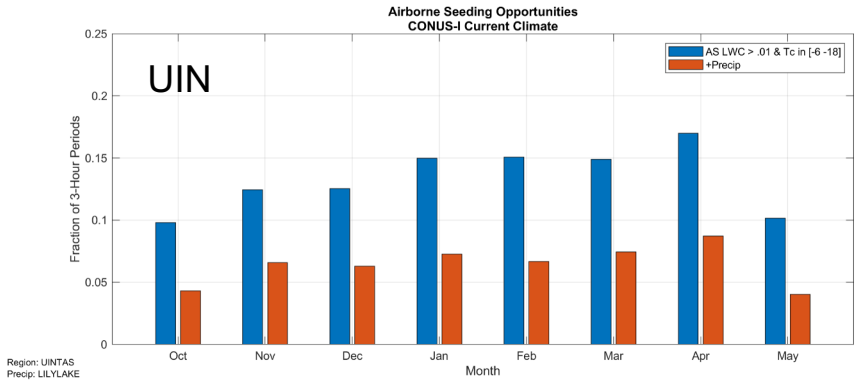
- Salt River Range and Unitas have most frequent opportunities for airborne seeding
- Season between Oct or Nov through April

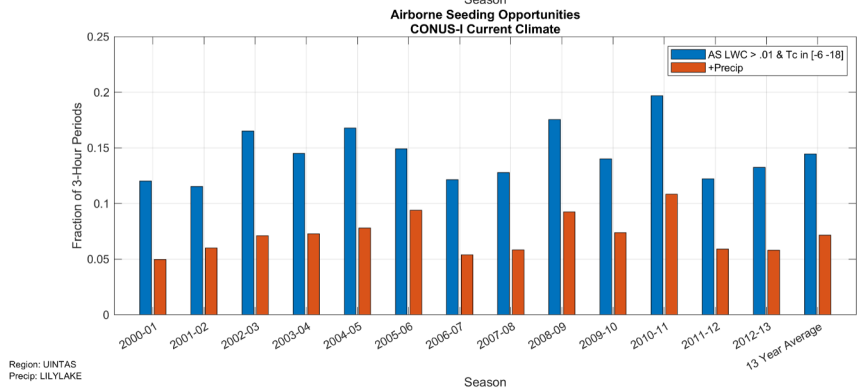












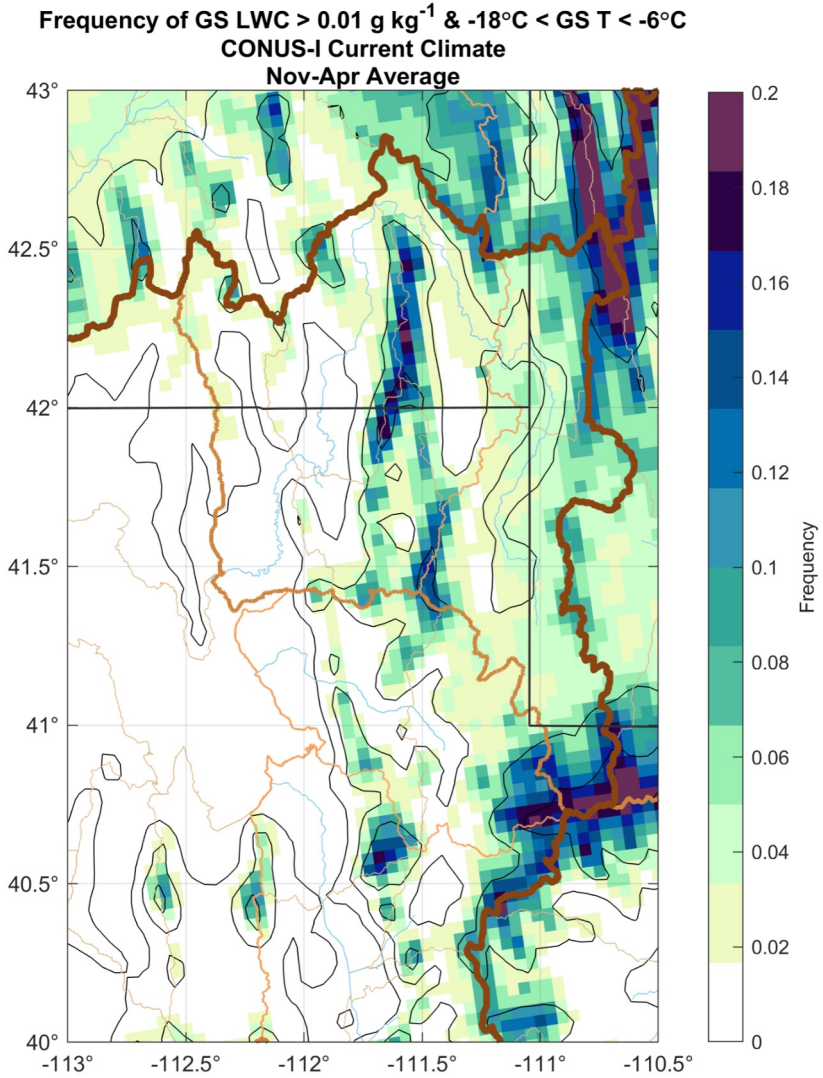
Frequency of Ground-based Seeding Opportunities

- 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

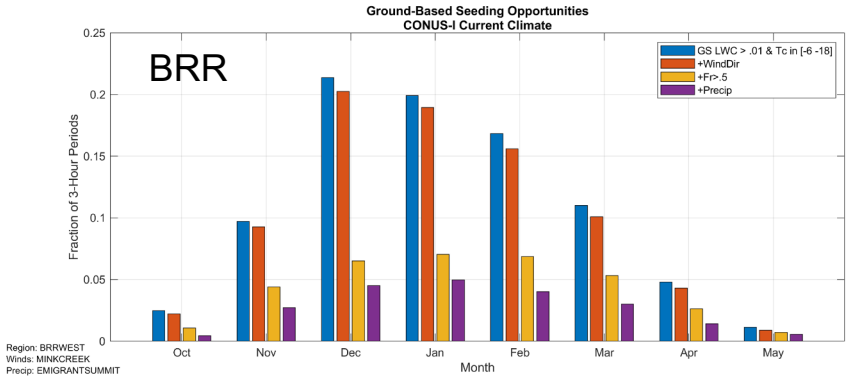
<u>Additional criteria include:</u>

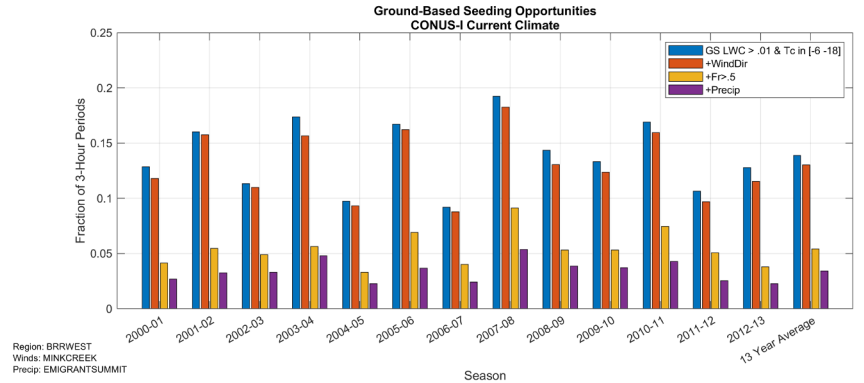
- Wind direction
- Wind Speed
- Atmospheric Stability

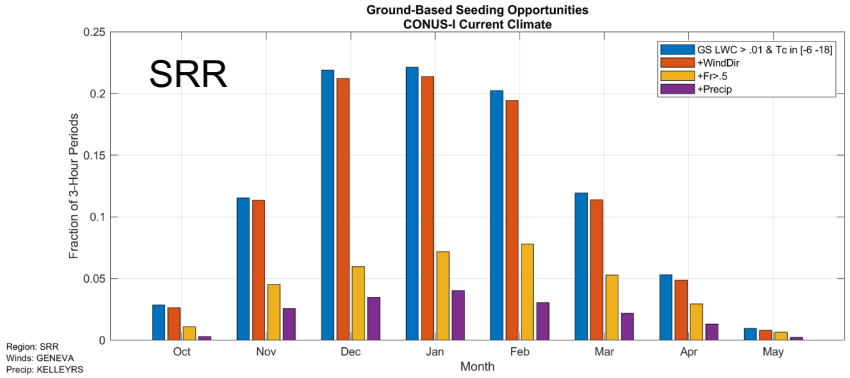


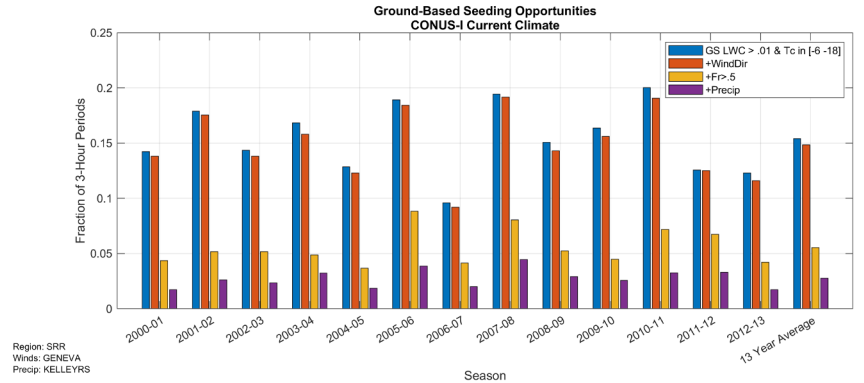
Frequency of Ground-based Seeding Opportunities

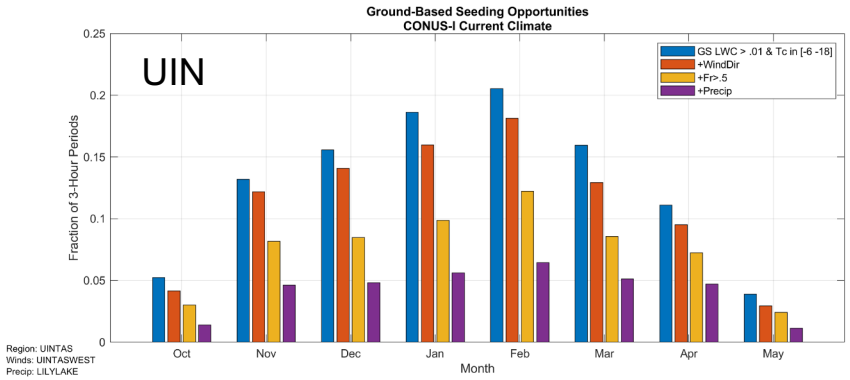
- Flow blocking limits ground seeding opportunities the most, especially in BRR and SRR
  - *Suggests that low level generator placement would not be effective*
- Season peaks Dec-Feb or Nov-Mar in Uintas

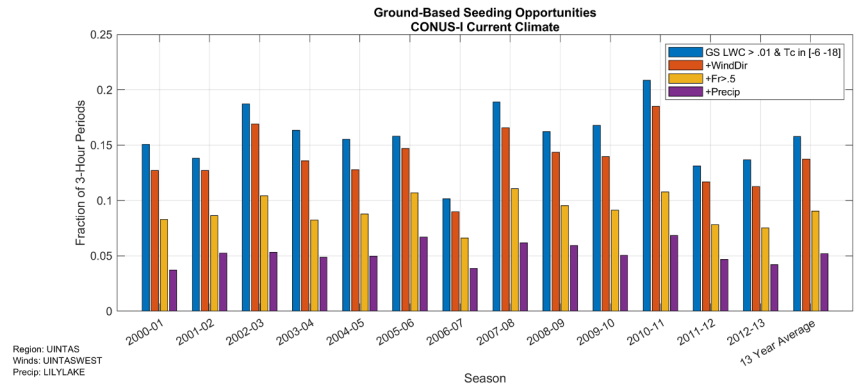












Seedable Precipitation

	Precipitation (mm)			
Region, Precip. Site	**Season Total**	**GS: T+LWC**	**GS: All criteria**	**AS: T+LWC**
BRR*, Emigrant Summit	626.0	181.2 (29%)	110.2 (18%)	235.8 (38%)
SRR, Kelley R.S.	405.7	104.8 (26%)	54.7 (13%)	194.7 (48%)
UIN, Lily Lake	452.2	143.9 (32%)	83.2 (18%)	175.1 (39%)

"Seedable precipitation" = Ratio of modeled wintertime precipitation falling during seedable conditions to total modeled wintertime precipitation

- ~30% of wintertime precipitation is seedable by ground-based seeding when considering the basic criteria of temperature and LWC
  - dropping to ~10–20% when including wind direction and stability
- ~40–50% of wintertime precipitation fell during conditions suitable for airborne seeding

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?

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?

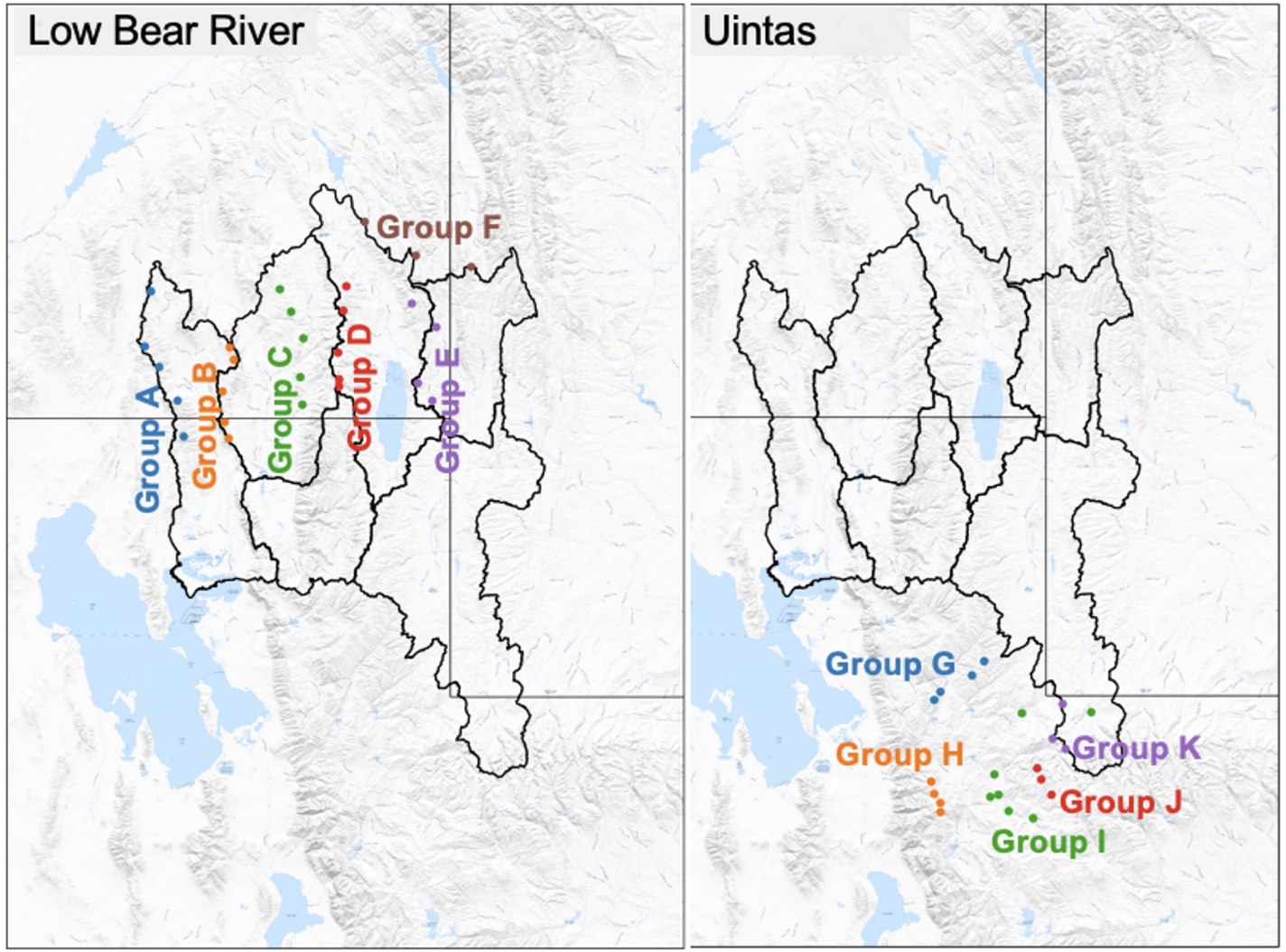
Analyze historical data:

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

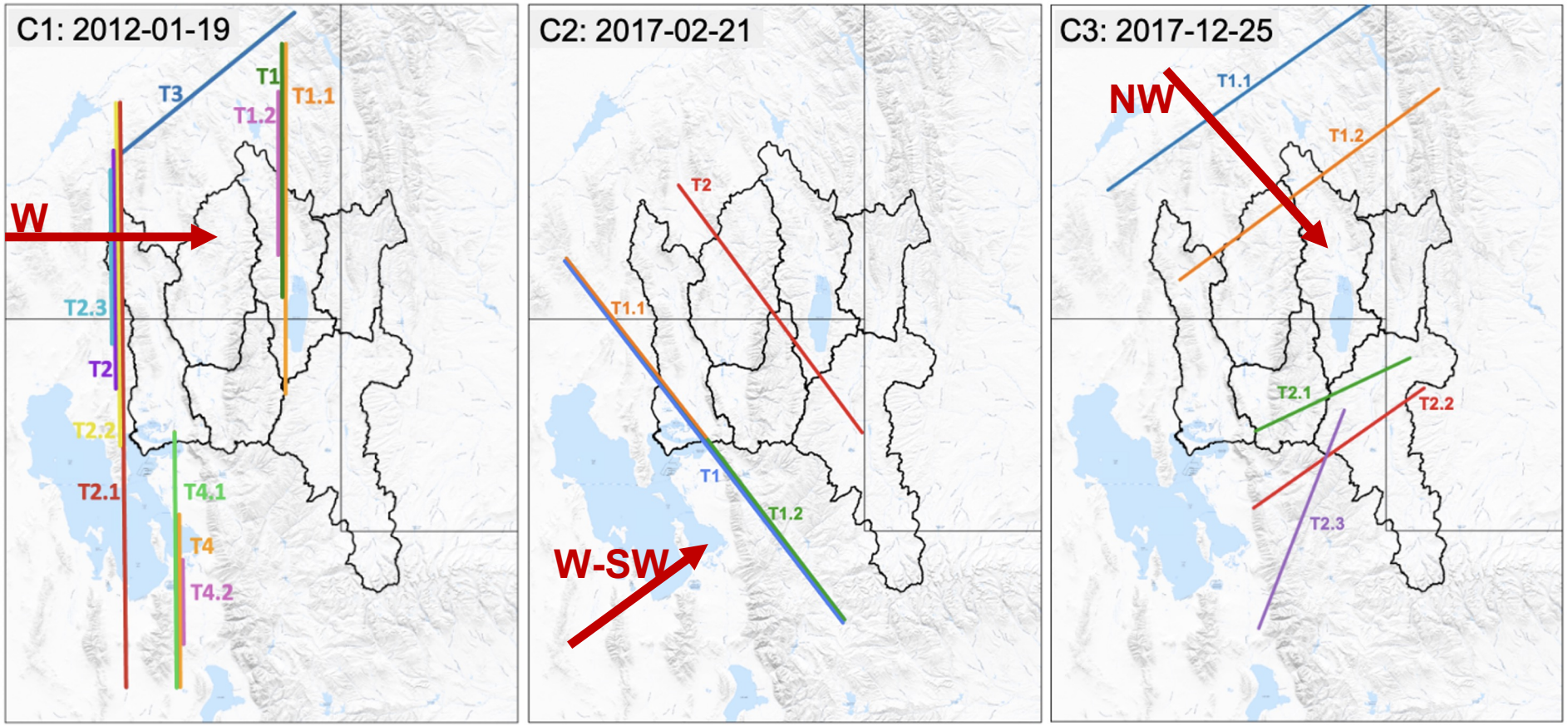
Review climatology results

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

Ground Generator Design Options



Airborne Seeding Flight Track Options



39 seeding simulations

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

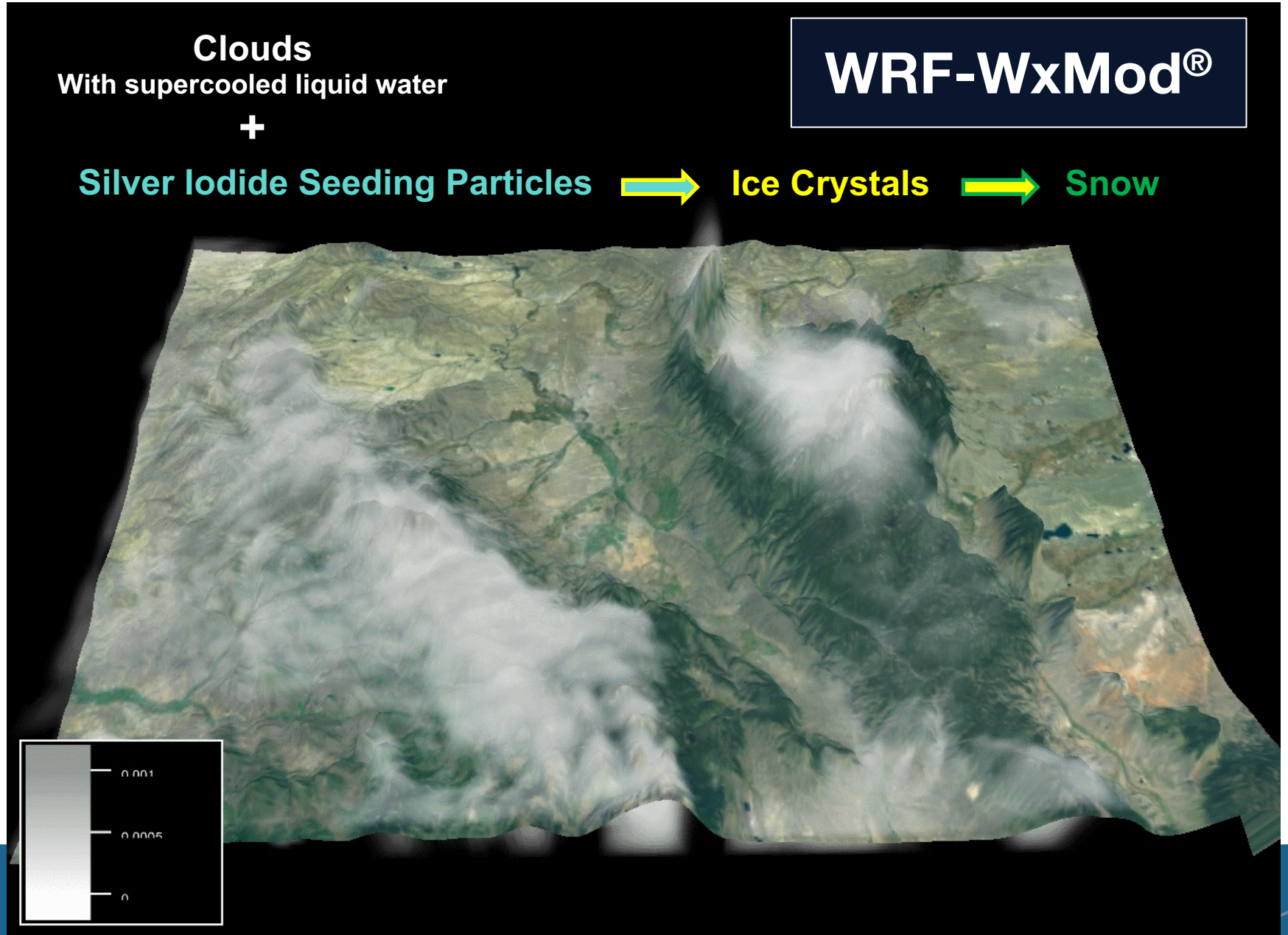
Review climatology results

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

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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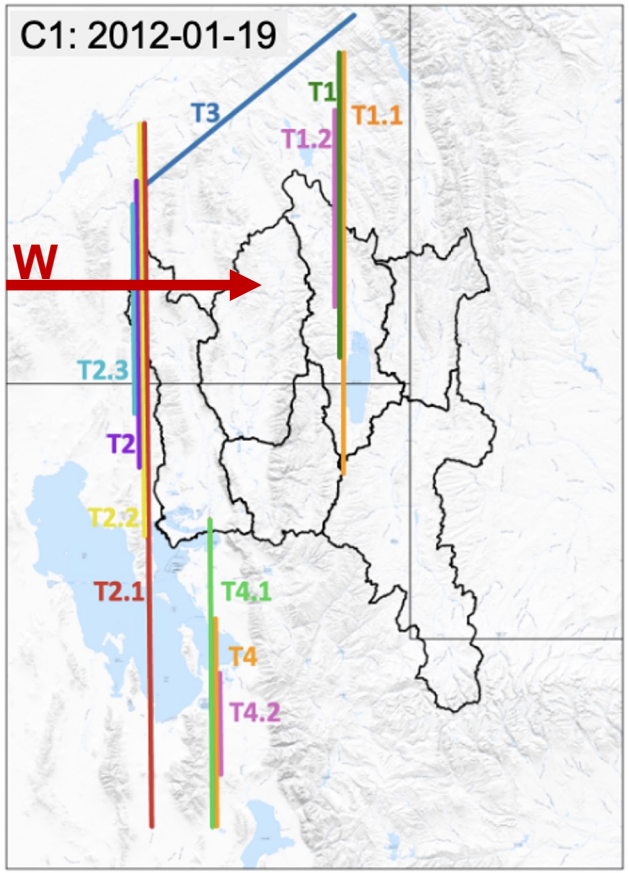
Xue et al. (2013)

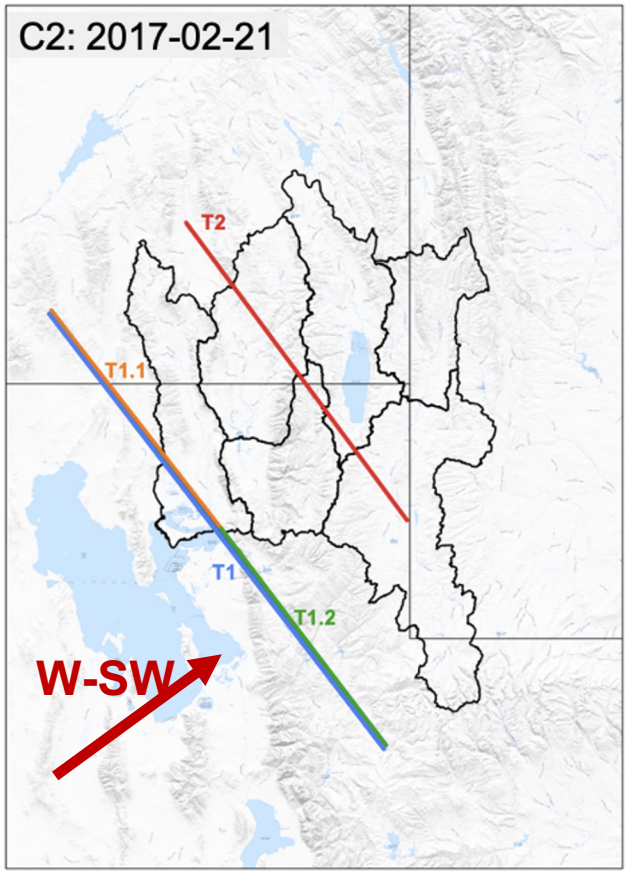
Airborne Seeding Simulation Experiments

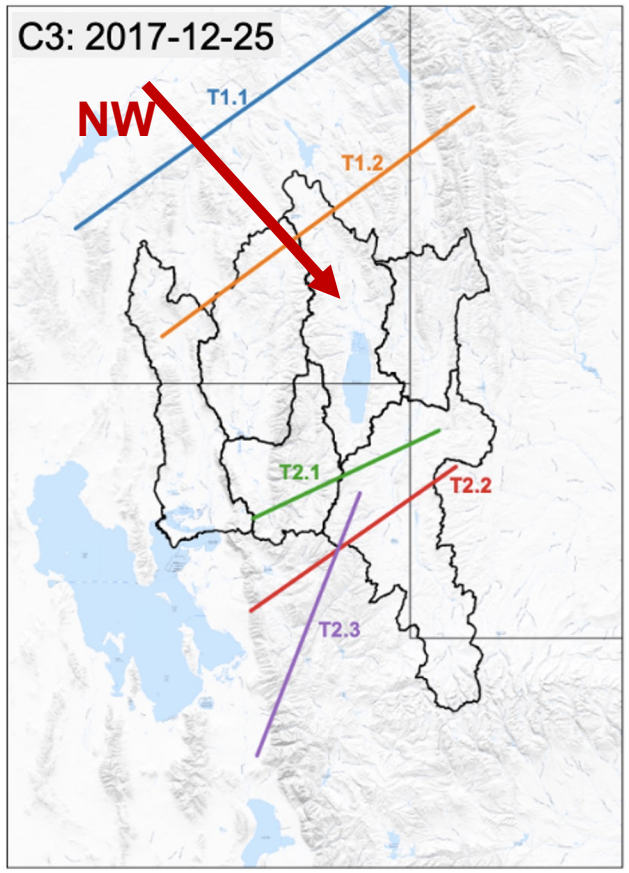
- 3 cases were studied to examine the simulated impacts of various aircraft track options under different weather conditions

Method	Case Id	Date	Period	WSpeed [m/s] LBR, UIN	WDir LBR, UIN	T [C] LBR, UIN	Target
Airborne	A-C1 P1	2012-01-19	00:40-01:40Z	29, 23	W, W	-12, -10	LBR
	A-C1 P2		06-10Z	25, 20	W, W	-10, -9	LBR & UIN
	A-C1 P3		09-11Z	24, 17	W, W	-10, -9	LBR & UIN
	A-C2 P1	2017-02-21	12-16Z	27, 26	W, SW	-9, -8	LBR & UIN
	A-C3 P1	2017-12-25	14-17Z	22, 17	NW, NW	-14, -12	LBR & UIN

Airborne Seeding Simulations Overview







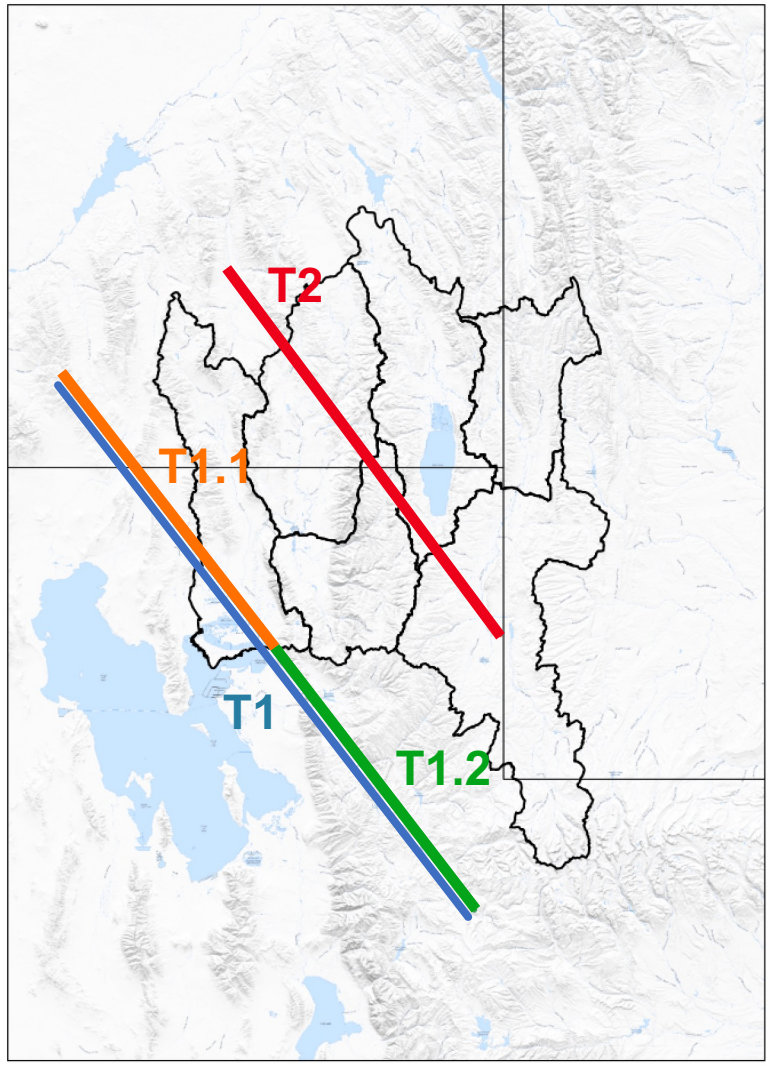
<u>21 track experiments:</u>
3 periods
P1: 3 at 3750m, 1 at 4250m
P2: 4 at 3750m, 3 at 4250m
P3: 7 at 3750m, 3 at 4250m

<u>8 track experiments:</u>
1 period
P1: 4 at 3750m, 4 at 4250m

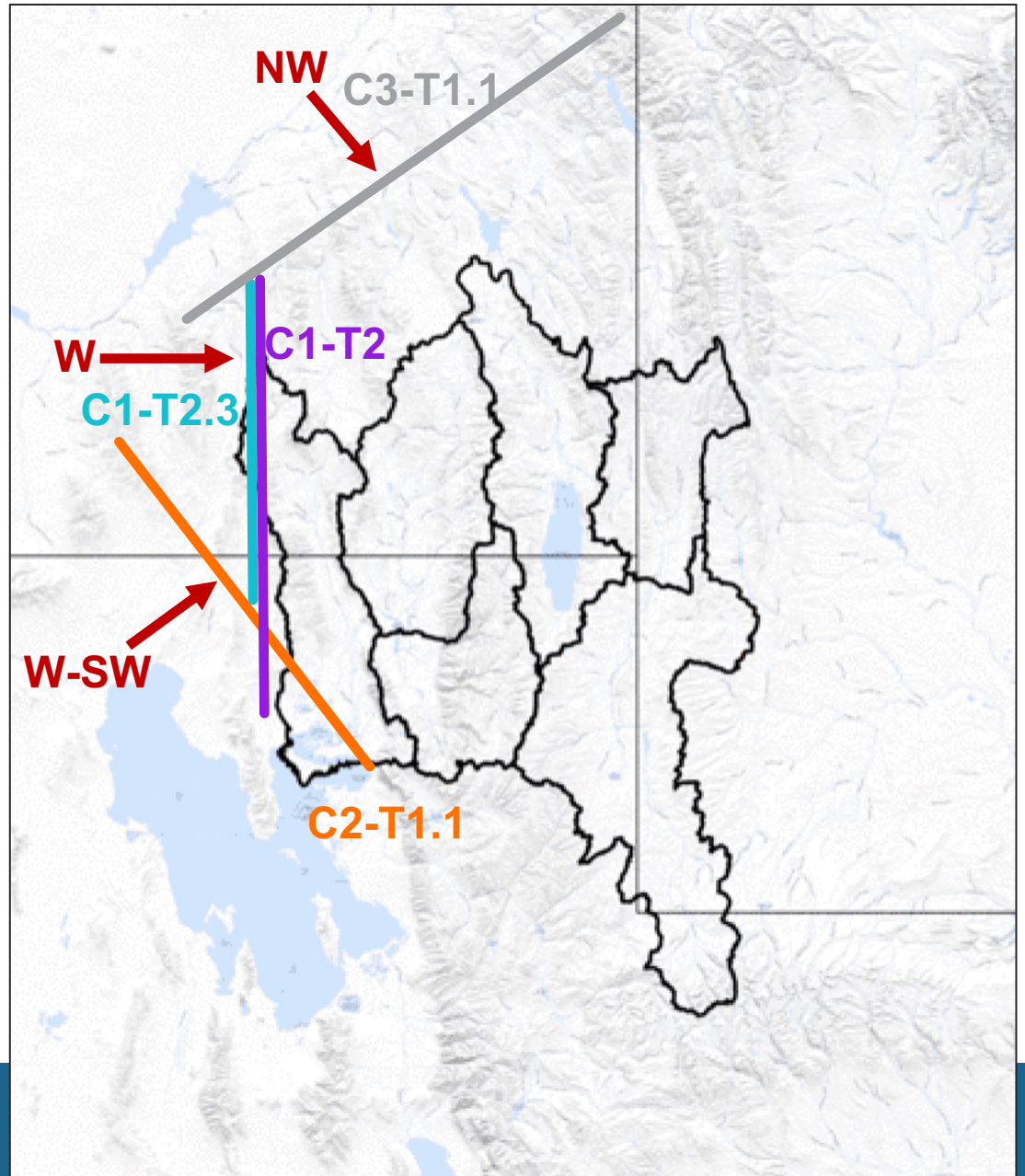
<u>10 track experiments:</u>
1 period
P1: 5 at 3750m, 5 at 4250m

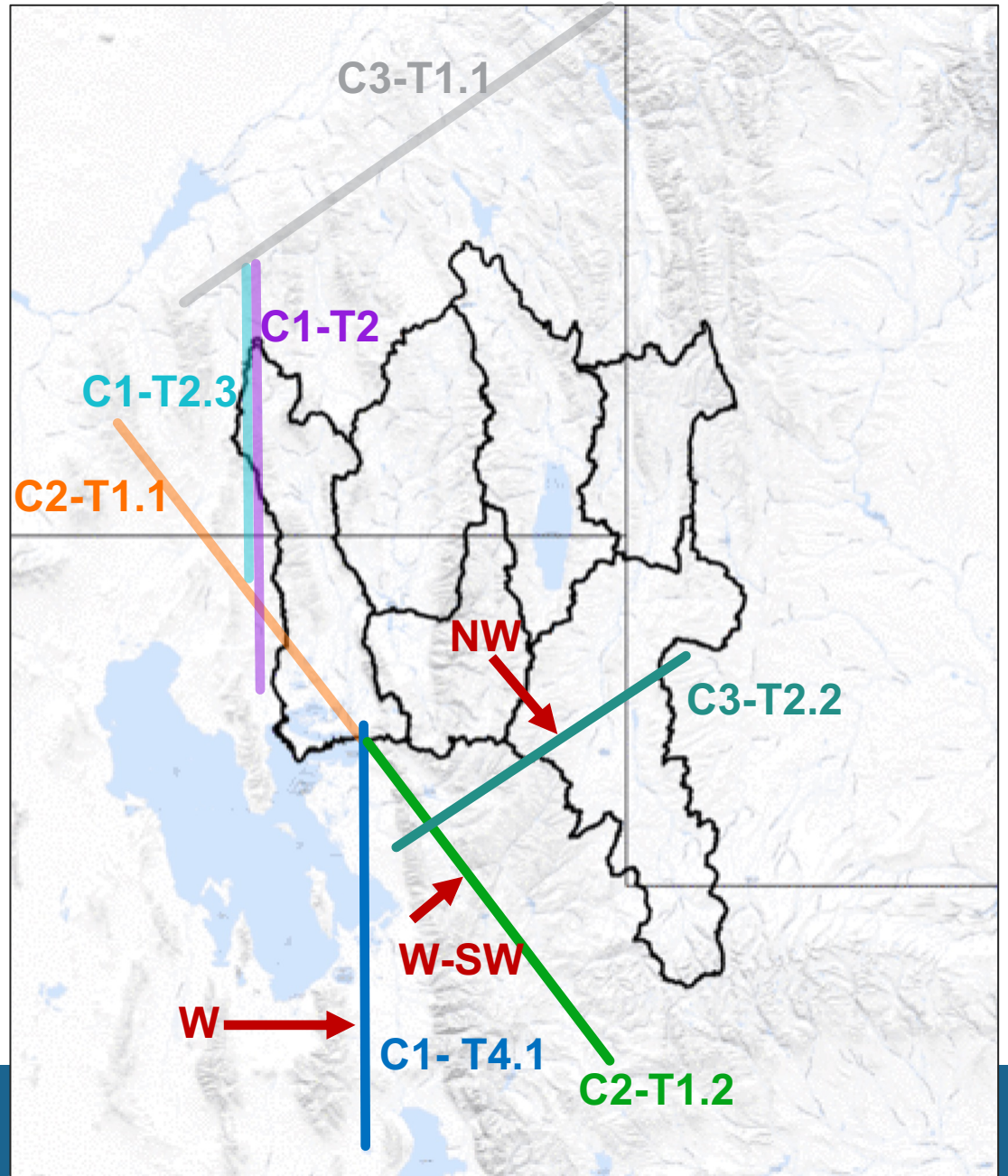
Simulated Seeding Effect Overview

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



Recommended Flight Tracks





Ground Seeding Simulation Experiments

- 5 cases were studied to examine the simulated seeding effects of the ground generator design options
  - 2 cases focused on the Uintas only, 1 focused on Lower Bear only, and 2 included both regions

Method	Case Id	Date	Period	WSpeed [m/s] LBR, UIN	WDir LBR, UIN	T [C] LBR, UIN	Target
Ground	G-C1 P1	2017-01-20	06-16Z	8, 2	W, NW	-14, -14	LBR
	G-C1 P2		11-16Z	8, 1.5	W, W	-15, -14	UIN
	G-C2 P1	2016-12-03	19Z-1d04Z	19, 14	NW, NW	-13, -15	LBR
	G-C2 P2		1d17Z - 2d03Z	27, 20	W, W	-11, -10	LBR
	G-C3 P1	2018-02-25	04-11Z	15, 11	W, W	-22, -22	LBR
	G-C3 P2		09-13Z	16, 12	NW, NW	-23, -23	UIN
	G-C4 P1	2018-03-28	08-14Z	16, 14	NW, NW	-12. -10	UIN
	G-C5 P1	2018-04-13	07-20Z	17, 15	N, N	-17, -18	UIN

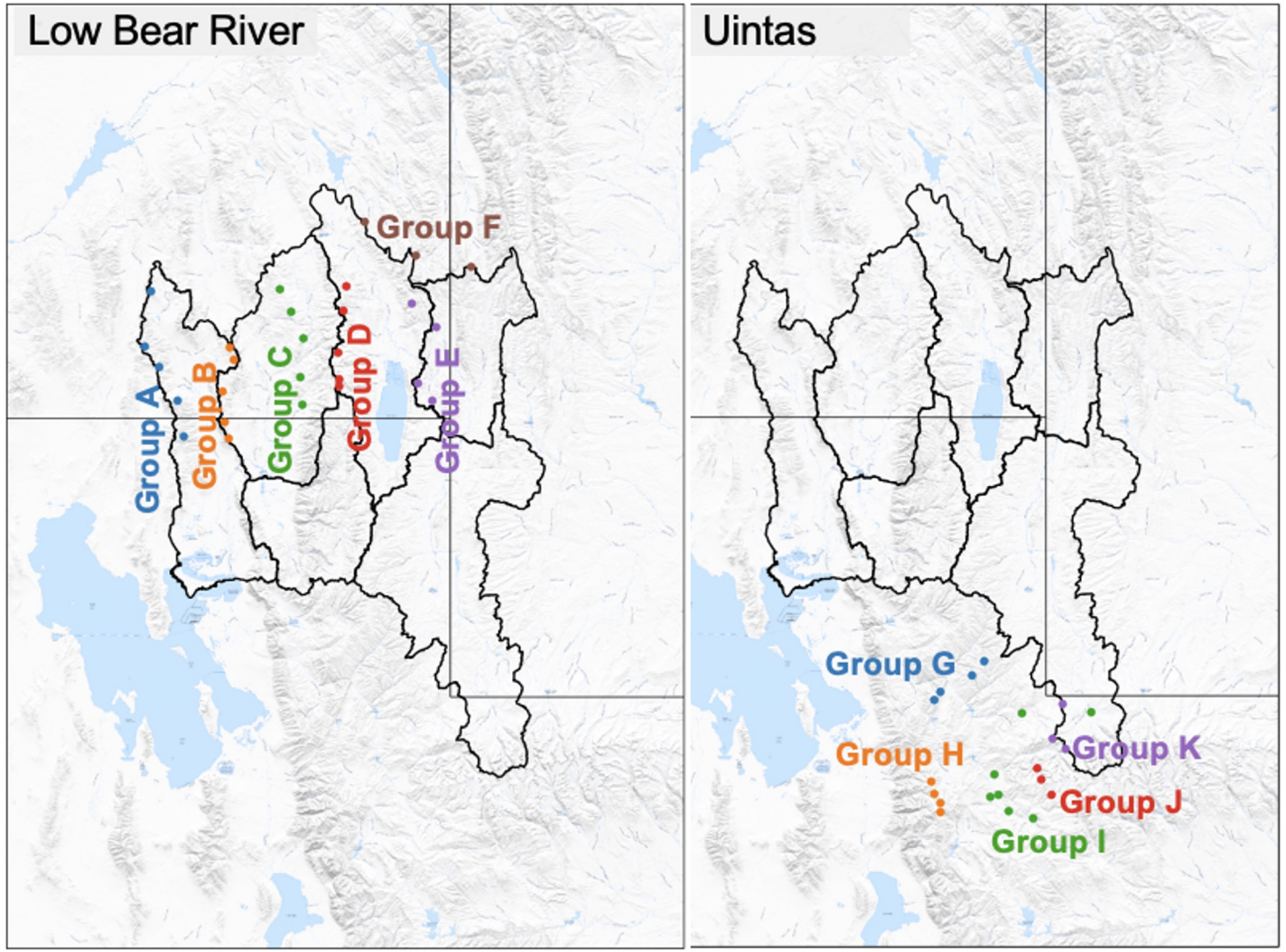
Ground Seeding Simulations Overview

Lower Bear River (LBR):
- 4 Cases/Periods
- 5 Generator groups
- 27 generators

- 10 simulations per case

- 40 in total

Mixed groups:
- 20 individual generators
- 6 mixed groups
- + 104 simulations



Uintas (UIN):
- 4 Cases/Periods
- 5 Generator groups
- 21 generators

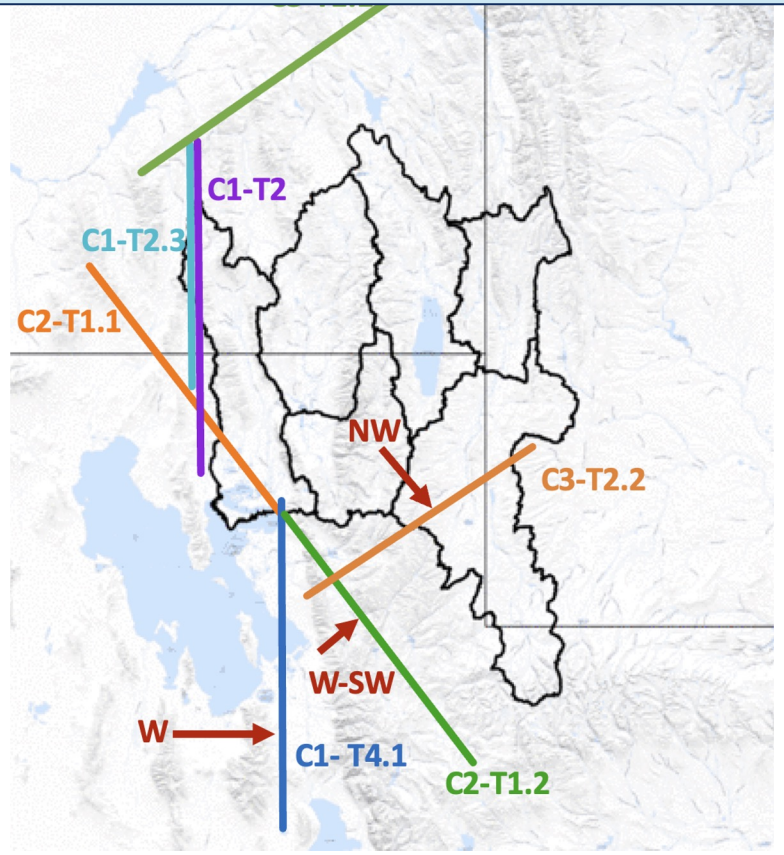
- 10 simulation per case

- 40 in total

Summary of Recommendations

Airborne Seeding

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

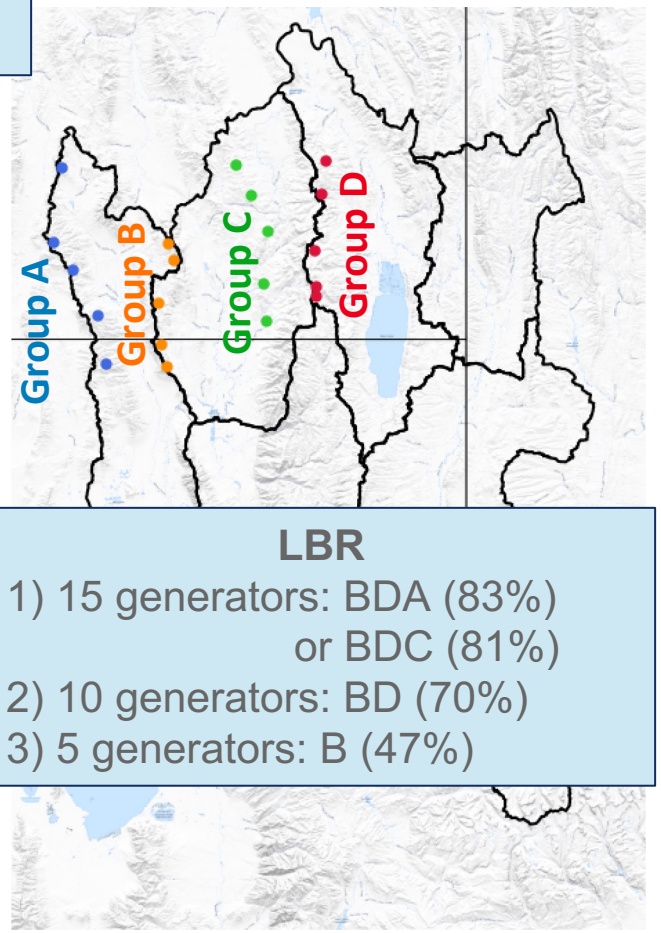


UIN

C1-T4.1: Limited by airspace availability

- Shift track east/west according to wind speed

Ground-based Seeding



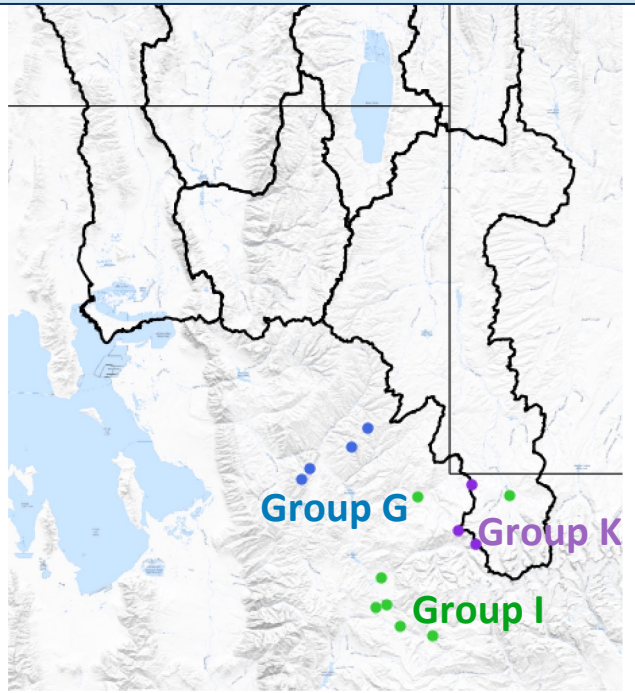
LBR

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

- Shared infrastructure to target all Uintas instead of just headwaters



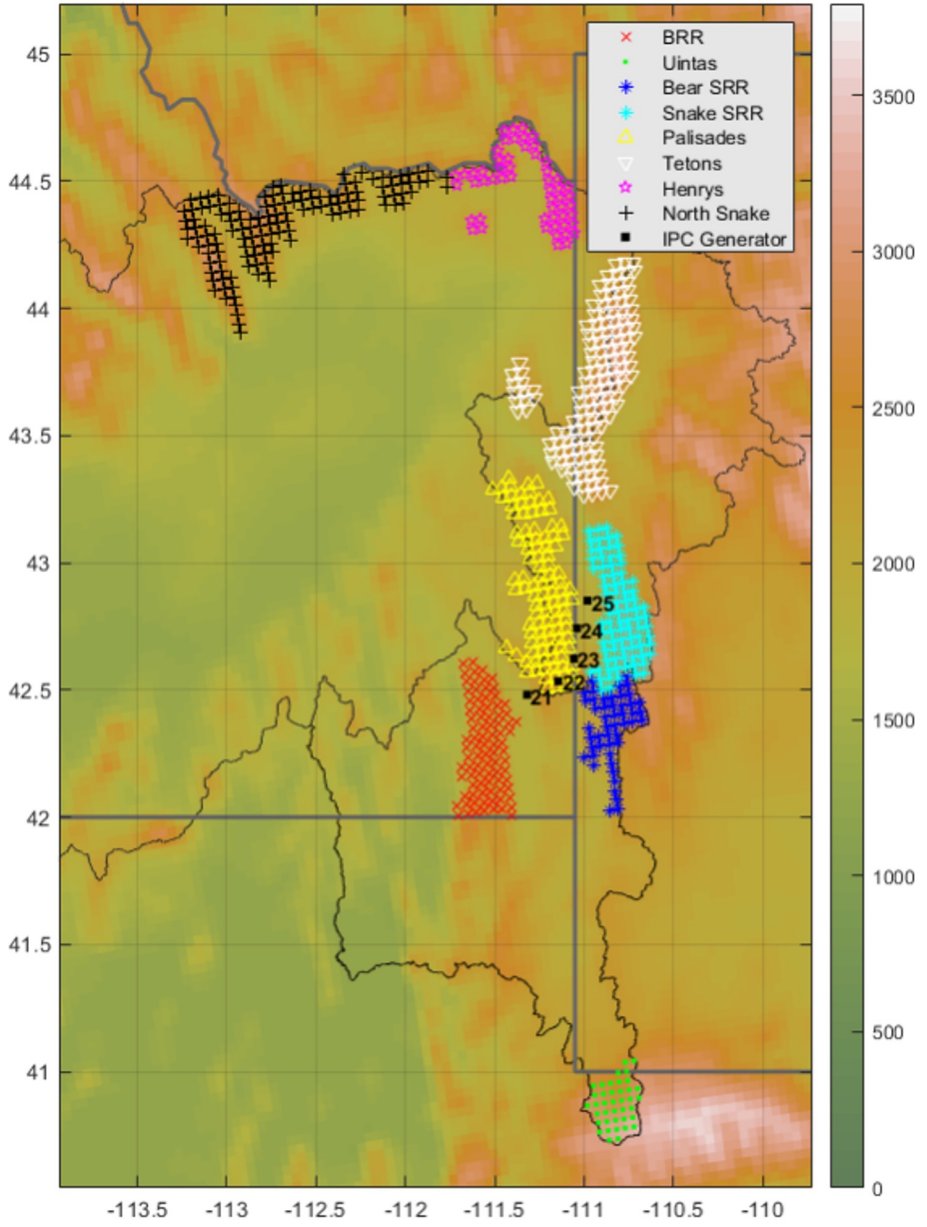
Are there opportunities to partner with Idaho Power's Upper Snake Basin seeding program?

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

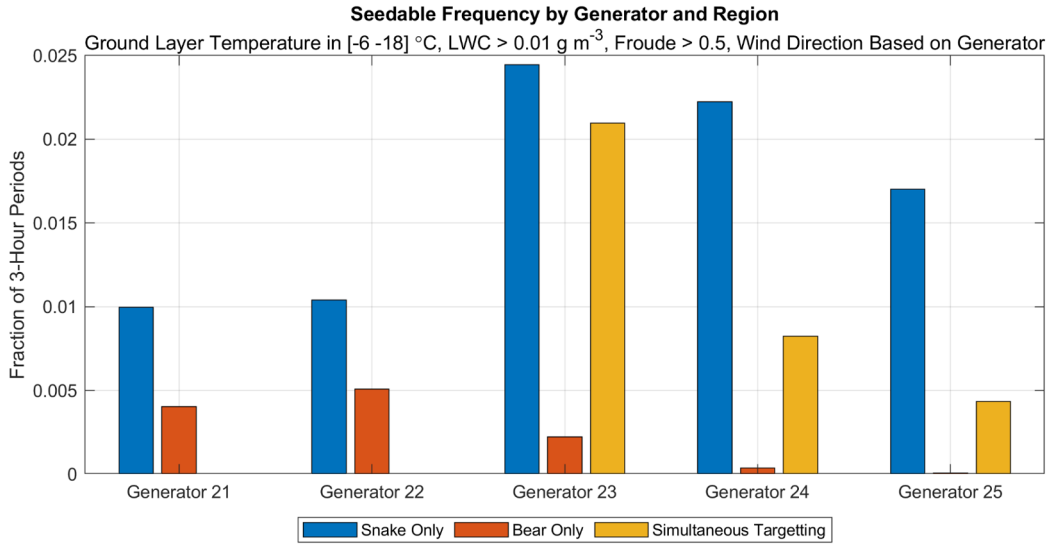
Methods for shared infrastructure analysis

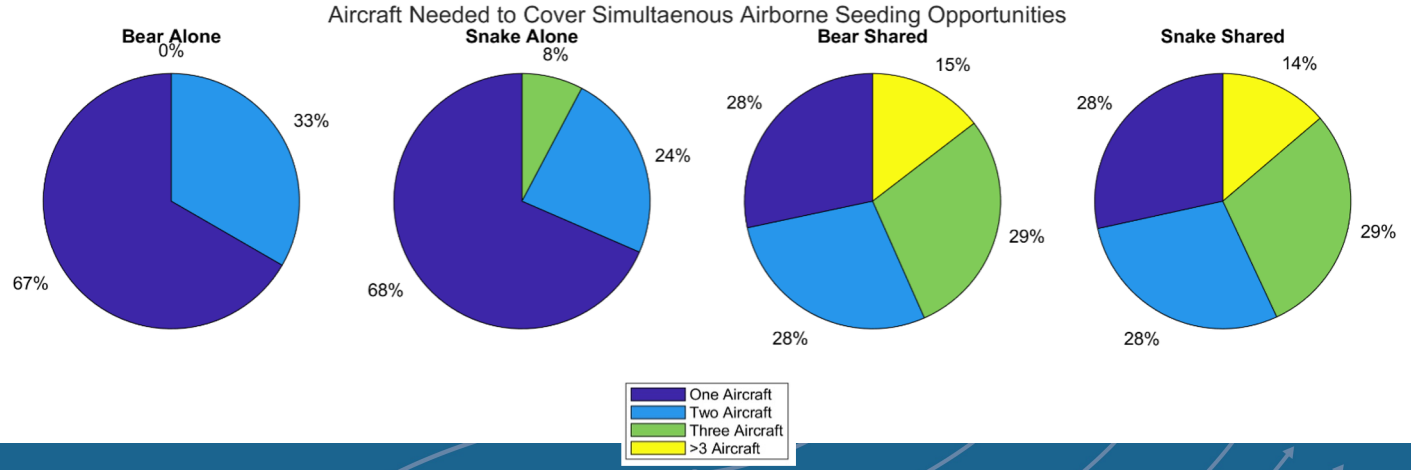
- Climatology analysis uses CONUS model simulation to assess:
  - Frequency of time that a shared aircraft could be used to target one basin or the other, as well as the possibility to target both simultaneously
  - Frequency of time and conditions under which existing generators targeting the Upper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



Shared Infrastructure Climatology Results

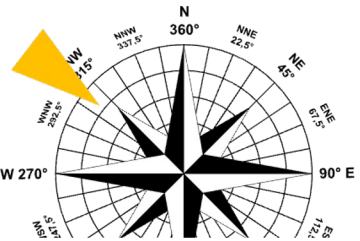
- Generators 21 and 22 can target the Bear portion of the SRR when winds are not favorable to target the Snake, **increasing the generator usage by nearly 150%**
- Generators 23–25 can simultaneously **target both regions 25–45% of the time they'd be operating anyway**
- A shared 3rd aircraft **reduces missed opportunities from >30% to ~15%** compared to both programs operating one aircraft each
  - 3rd shared aircraft could also be used when seedable conditions persist for longer than a single crew could operate

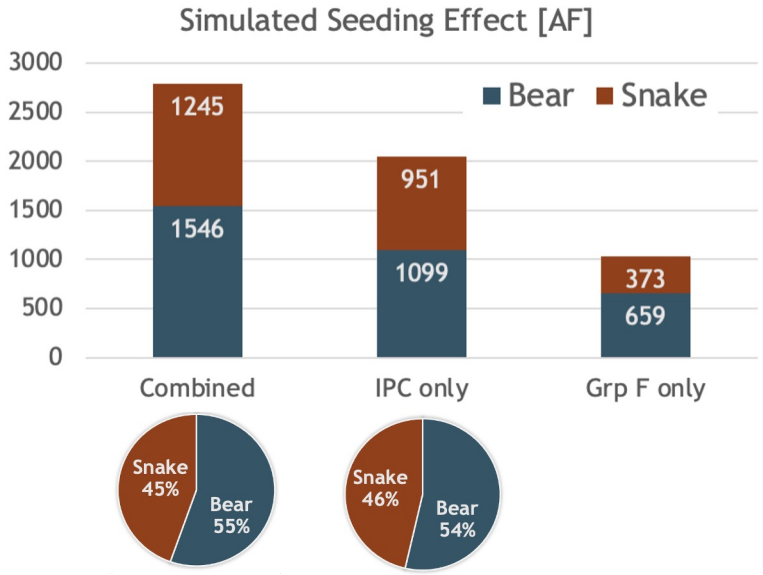


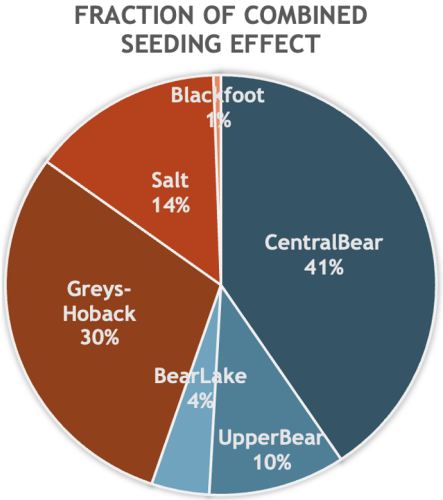


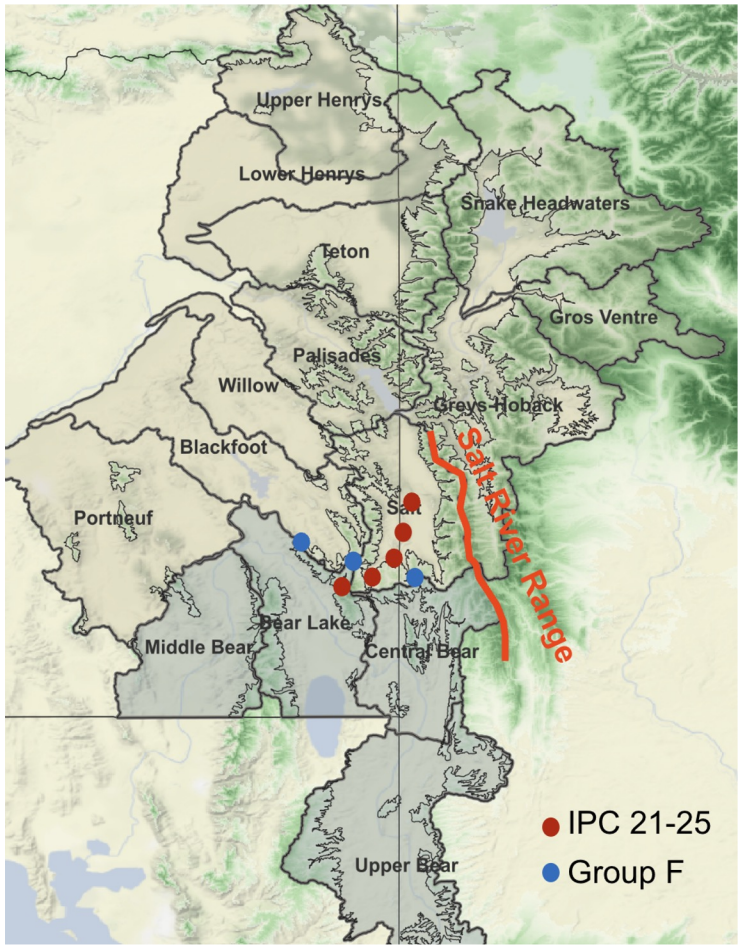
Impact from Cases Selected for Shared Infrastructure

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



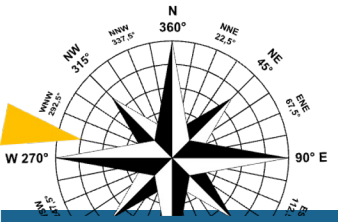


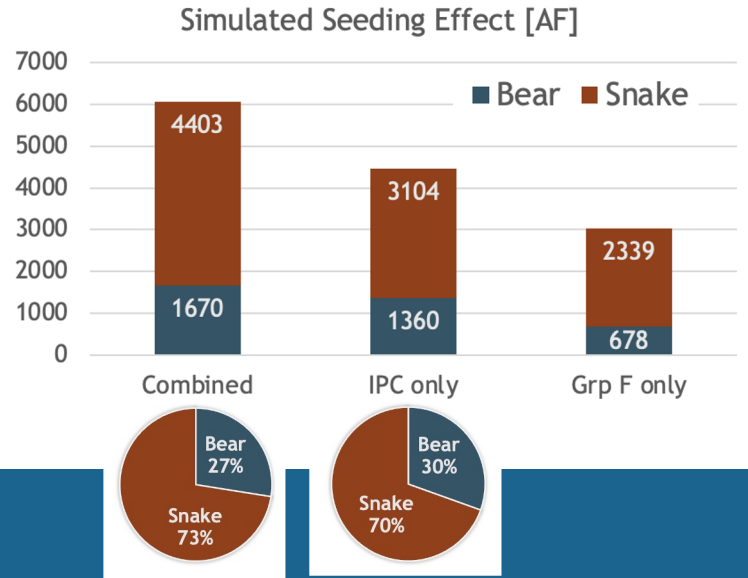


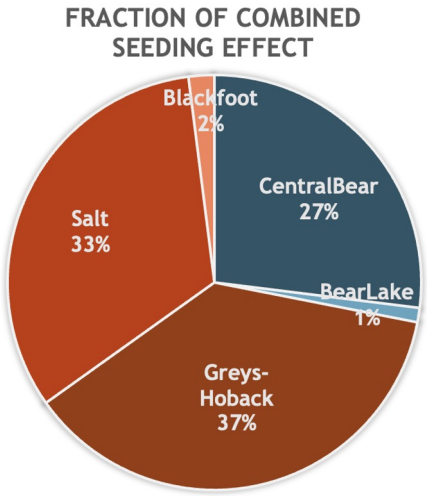


Impact from Cases Selected for Bear River Basin

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







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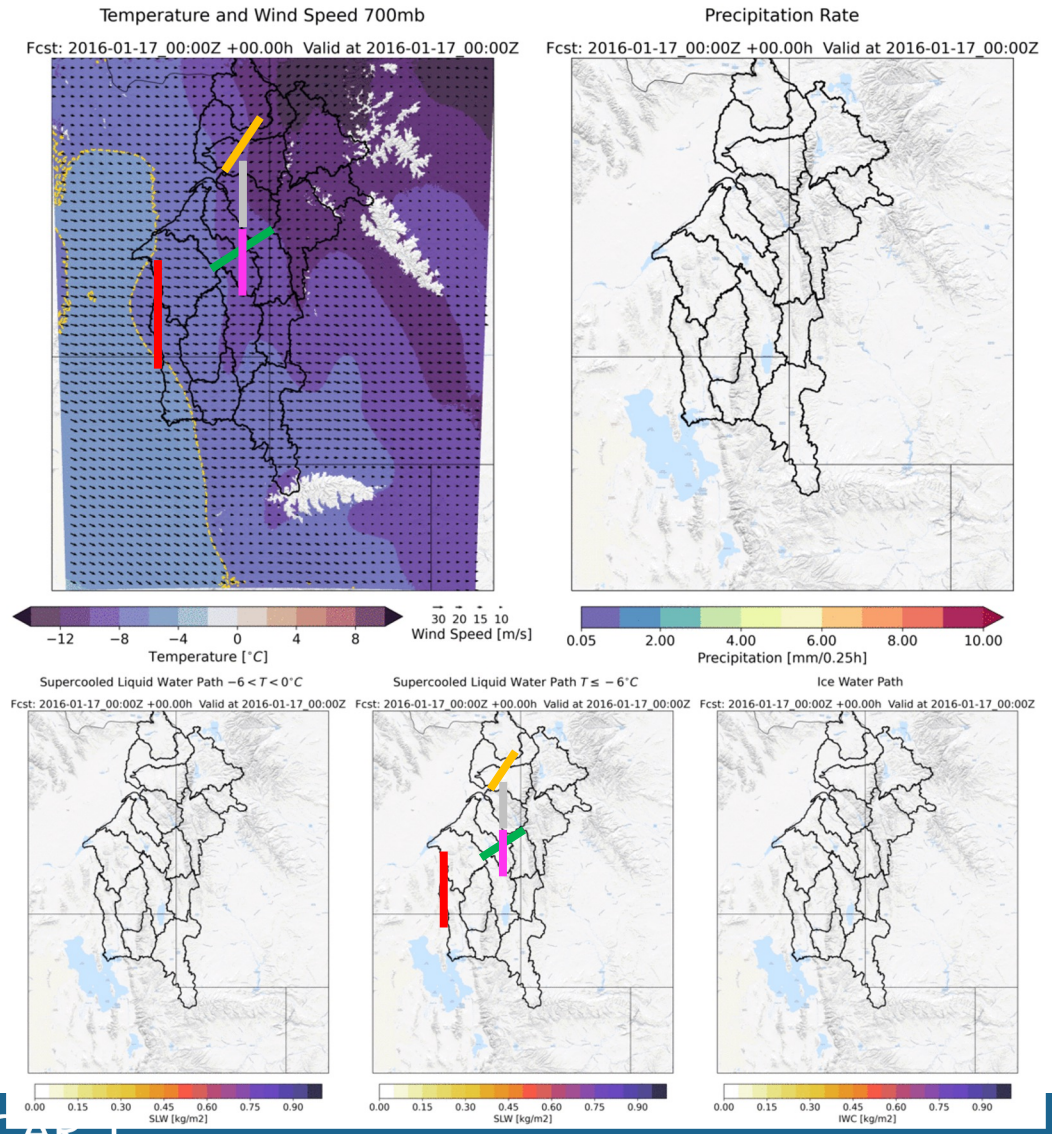
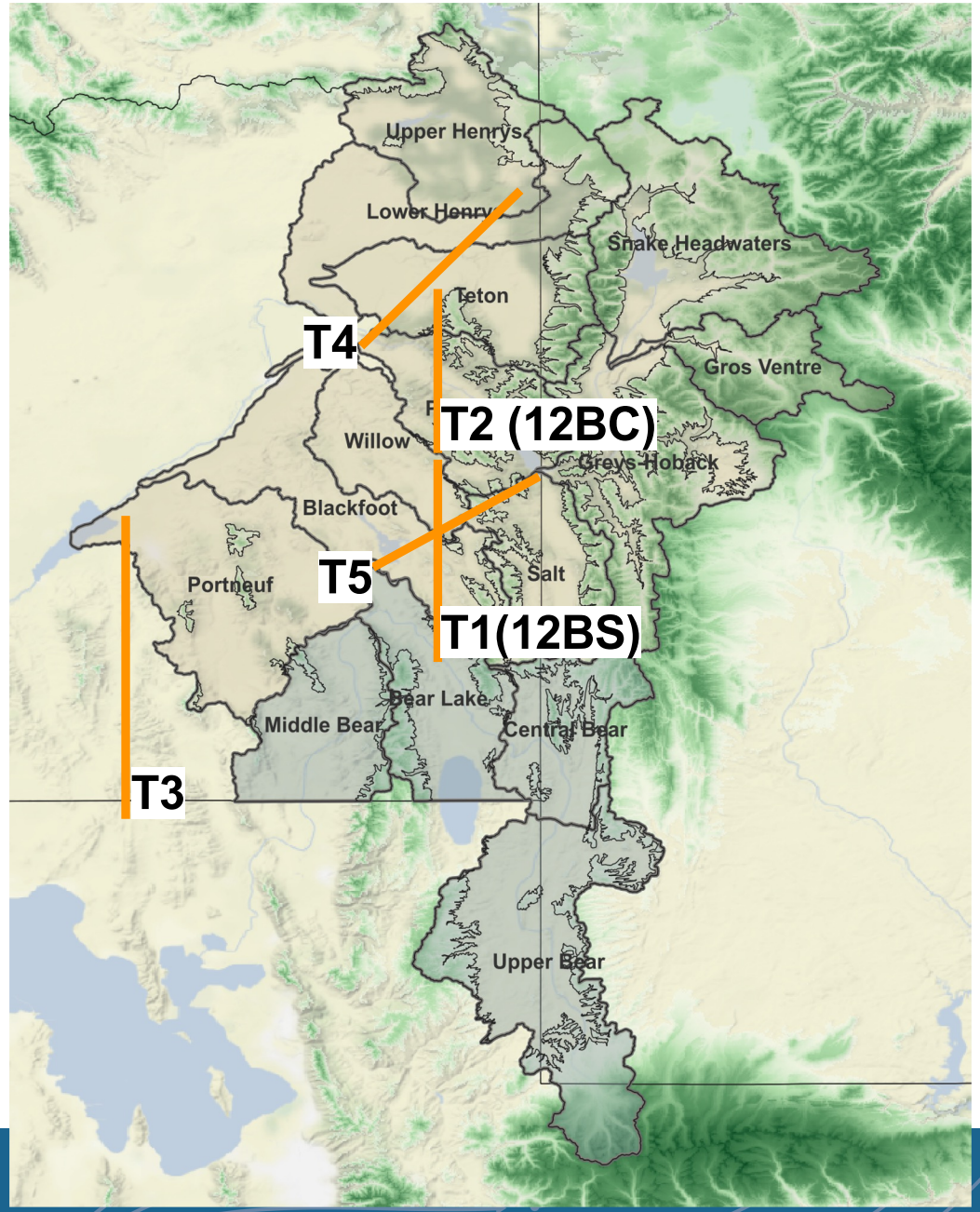
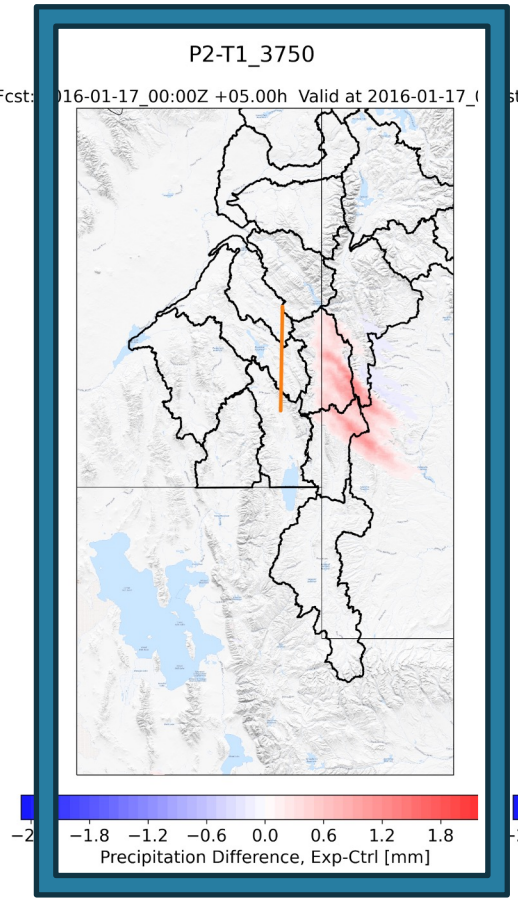
Airborne Seeding Experiment

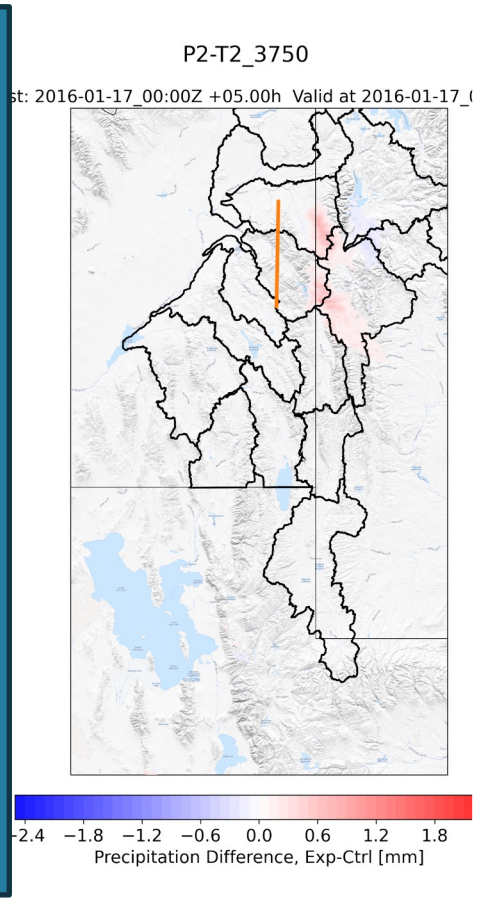
Airborne Case: 2016-01-17 seeding period from 00:30 to 1:45Z

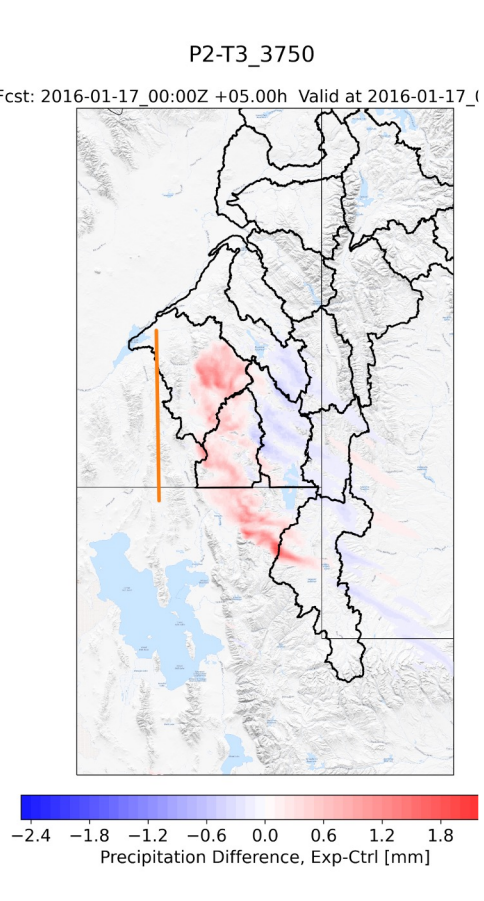


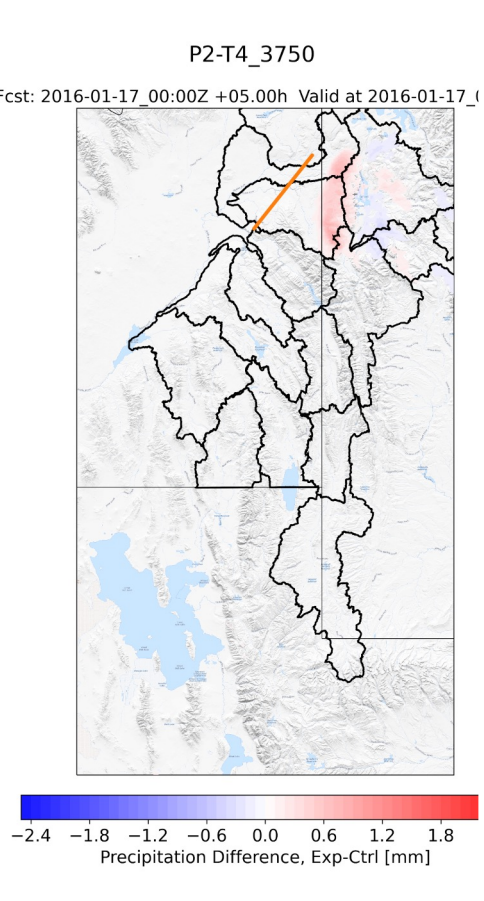


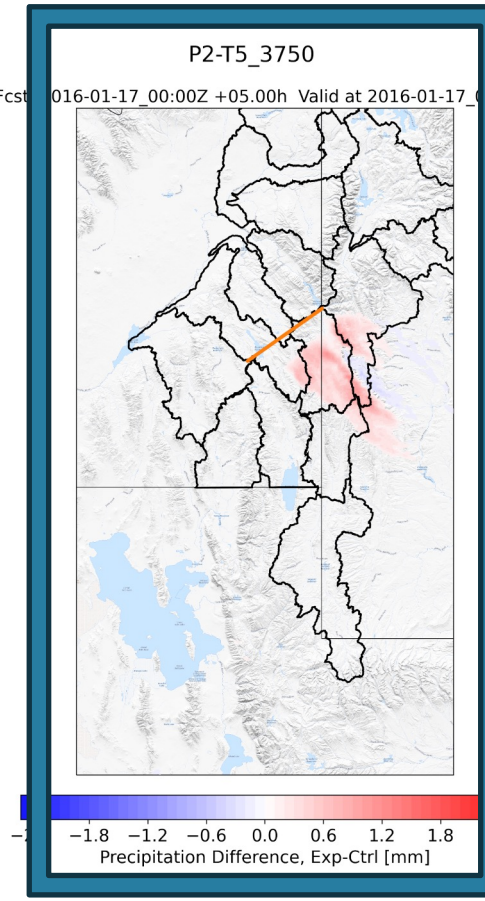
Airborne Seeding Experiment











Simulated Seeding Effect = $P_{Exp} - P_{Ctrl}$

Decrease Simulated Precipitation — Increase Simulated Precipitation

	3750m				
	T1	T2	T3	T4	T5
Total	866	281	524	369	893
Bear	248	3	174	8	43
Snake	617	278	350	361	850

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Simulated Seeding Effect of Shared infrastructure between the Upper Snake and Bear River Basins

Ground-based simulation results:

- A combined infrastructure of generators benefit both basins: for the configurations and cases studied in this analysis, the combined effect from the addition of the proposed Group F Bear River Basin generators was able to produce more precipitation than the existing IPC generators (21-25) alone in all simulated experiments
- Cases with a primary NW wind component (315 deg) produced roughly even fractions between Bear and Snake
- Cases with a primary W-NW wind component (280 deg) produced a higher fraction (~70%) of the simulated seeding effect over Snake

Airborne simulation results:

- Under W, NW winds, the existing IPC track 12BS (T1) can yield precipitation that benefit the Snake and the Bear
- The T3 track proposed for BRB can also be used to seed both basins, despite the accelerated growth process that shifted precipitation towards west in this simulation

Key Points

A methodological 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