WRF-WxMod®: a comprehensive model system for cloud seeding research and applications

Lulin Xue, Roy Rasmussen and Sarah Tessendorf

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NCAR | RESEARCH APPLICATIONS LABORATORY

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- University of Illinois Urbana-Champaign
- University of Colorado Boulder
- Boise State University
- Michigan Technological University
- University of Oklahoma
- Weather Modification International
- Japan Meteorological Research Institute
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NCAR colleagues

- Roy Rasmussen
- Sarah Tessendorf
- Courtney Weeks
- Sisi Chen
- Kyoko Ikeda
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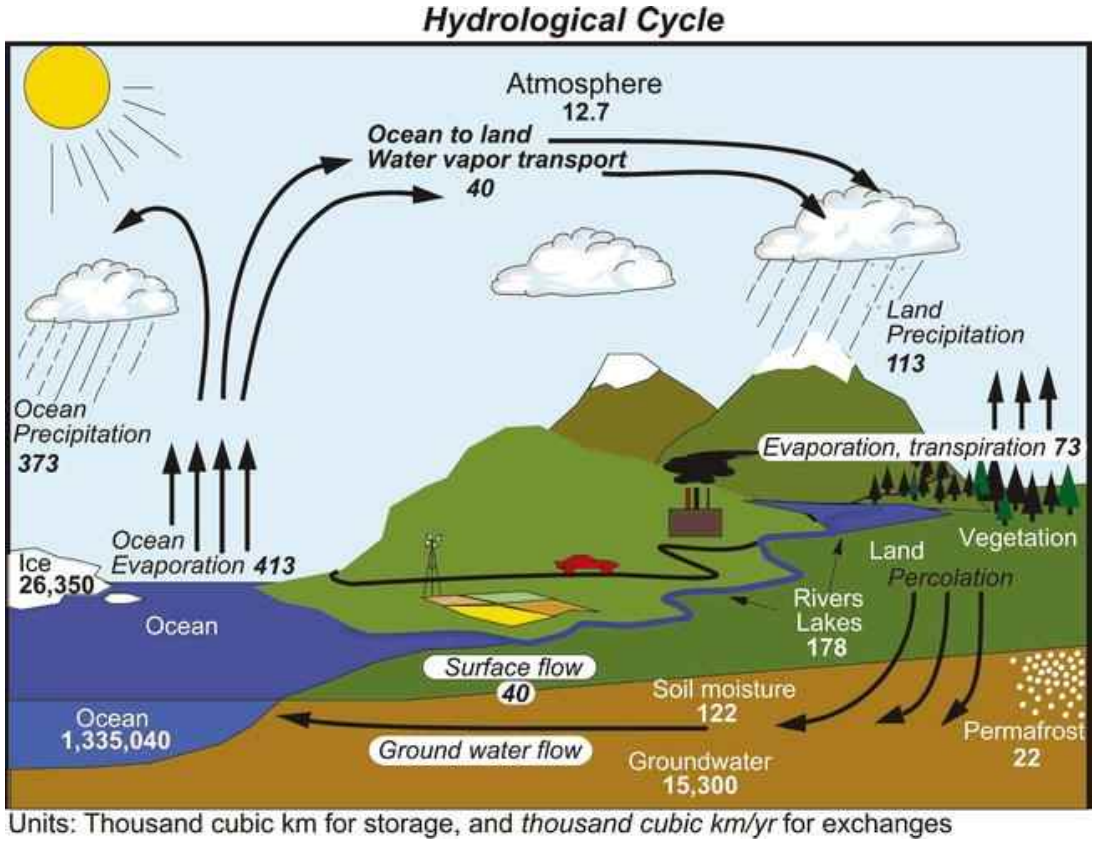
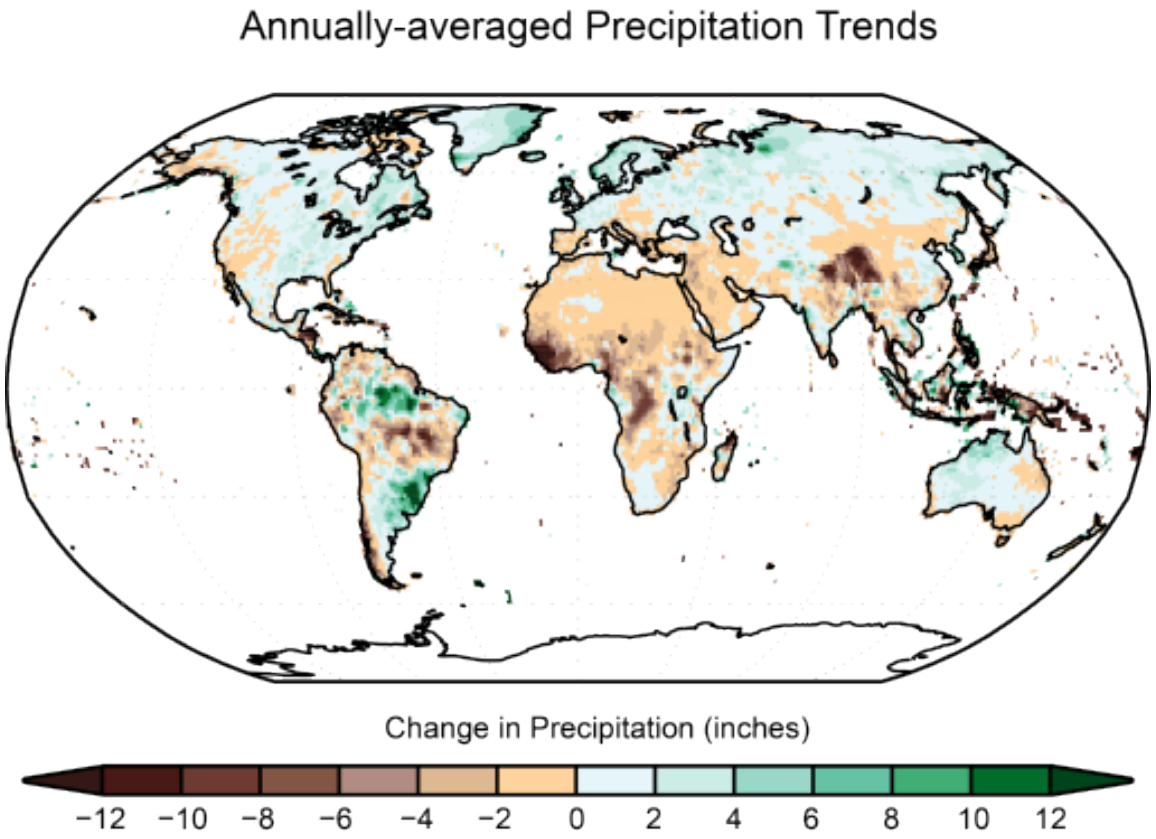
- Hugh Morrison
- Branko Kosovic
- Roelof Bruintjes
- Trude Eidhammer
- Paddy Mccarthy
- Michelle Harrold
- Maria Frediani
- Jamie Wolff
- Andy Gaydos
- Eric Nelson

Global Precipitation Trends



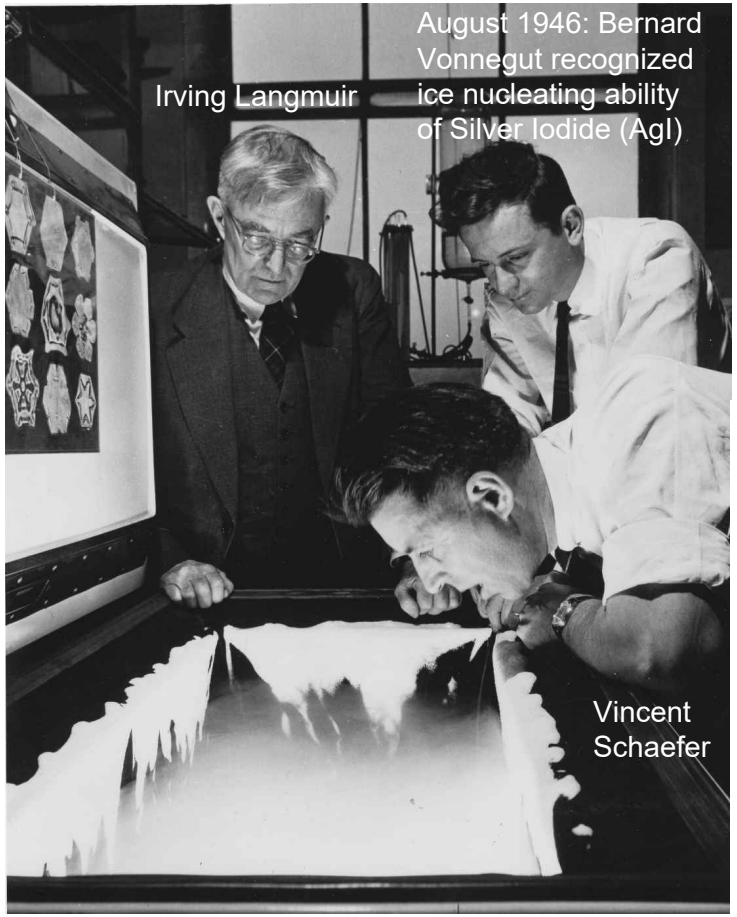
Trenberth et al. 2007

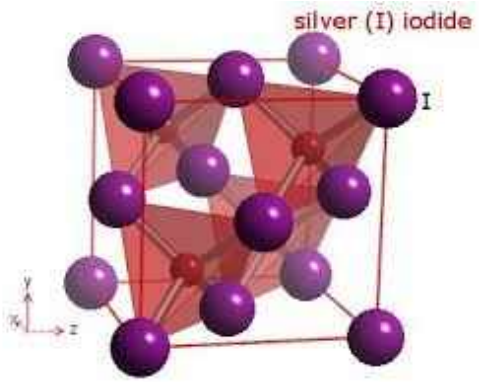


Surface annually averaged precipitation change (in inches) for the period 1986–2015 relative to 1901–1960. (Figure source: NOAA NCEI and CICS-NC).

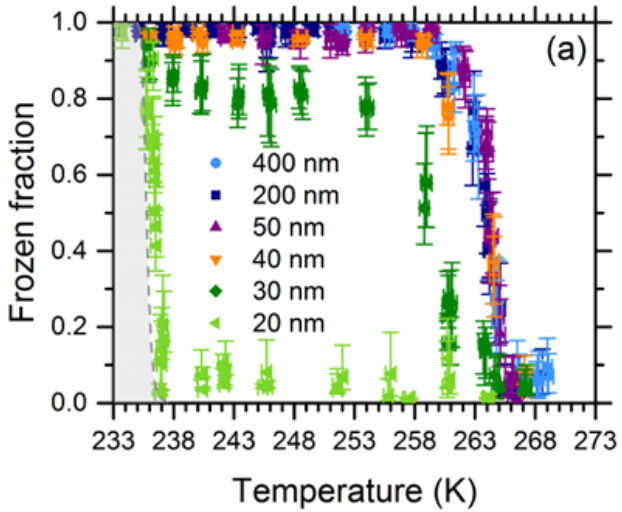
Weather Modifications

The beginning of weather modifications (1940s)

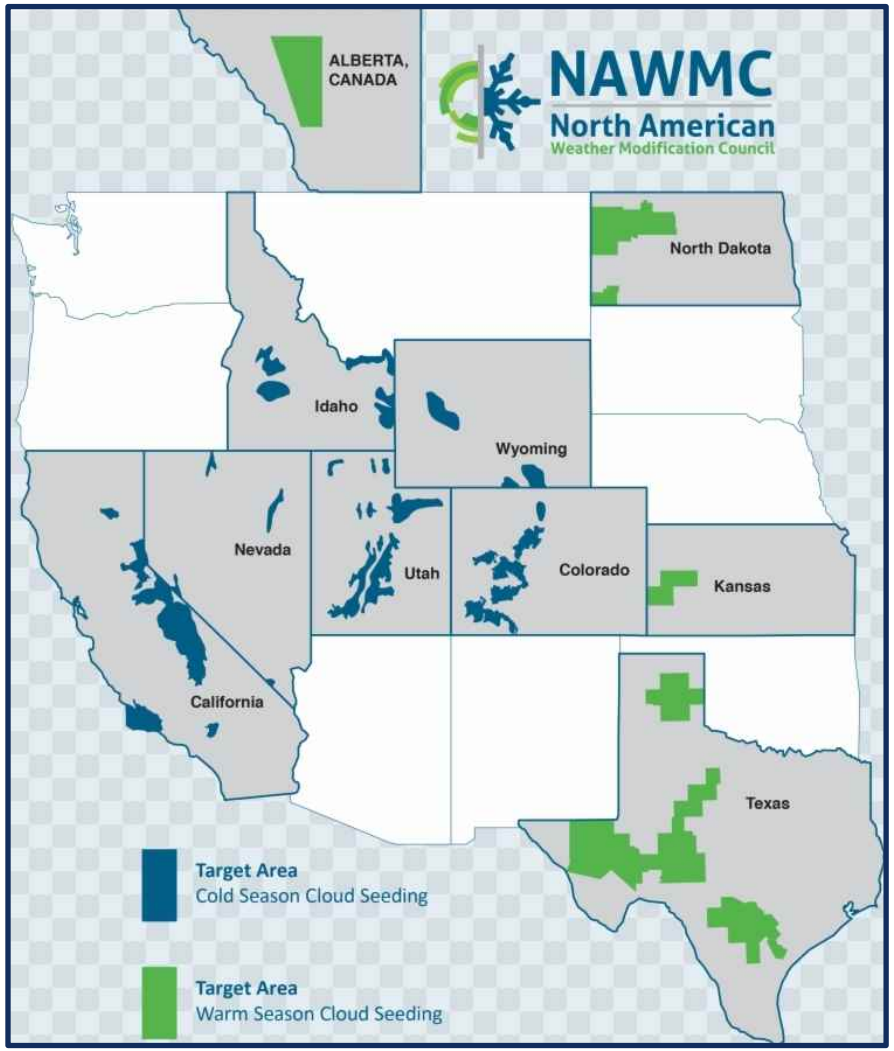




Marcolli et al., ACP, 2016



Weather Modification in the US



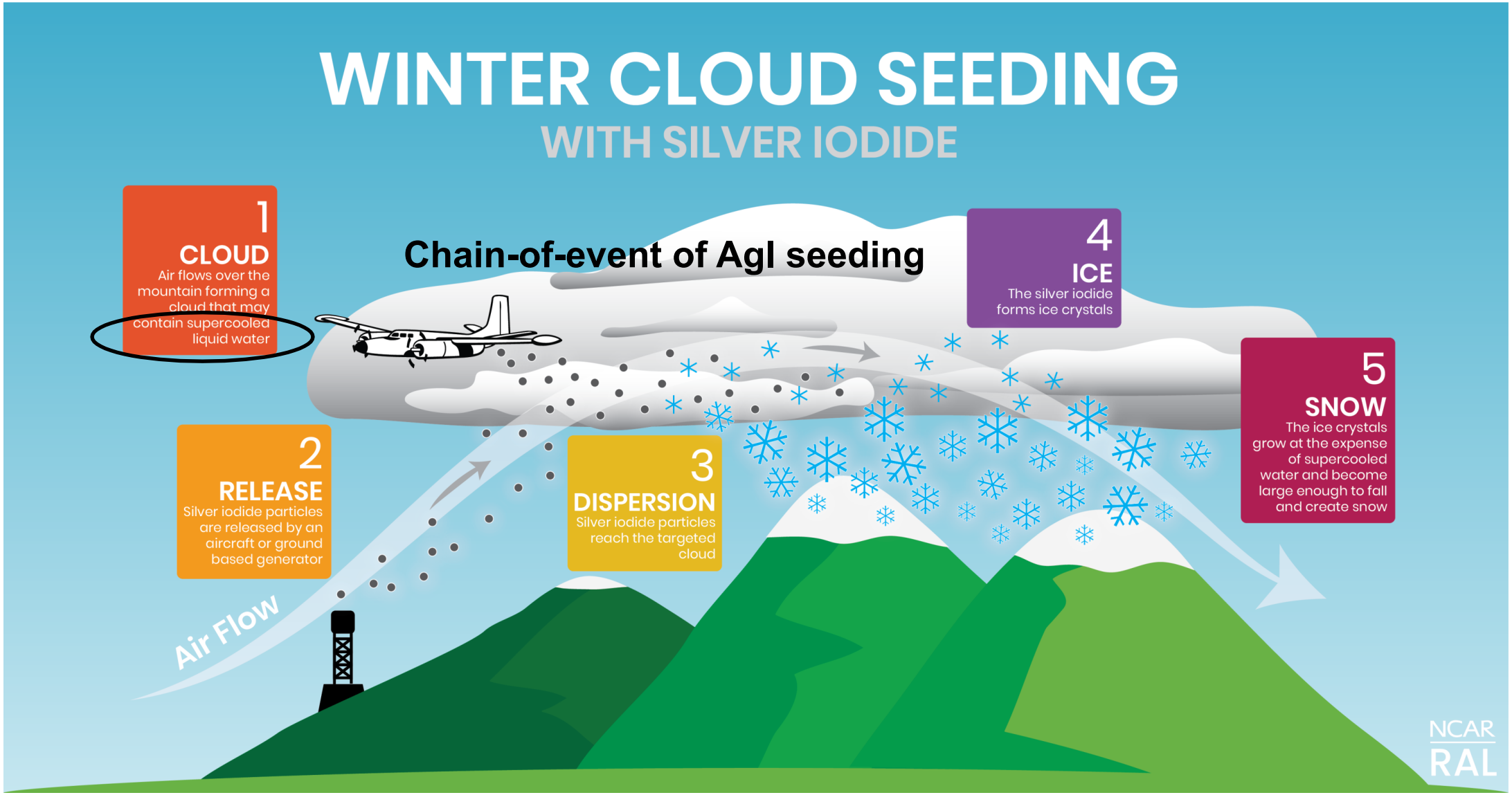
39 active weather modification programs in the US

$1,000 per acre foot of water in western Kern, California in 2021*

Winter orographic cloud seeding has a strong scientific basis

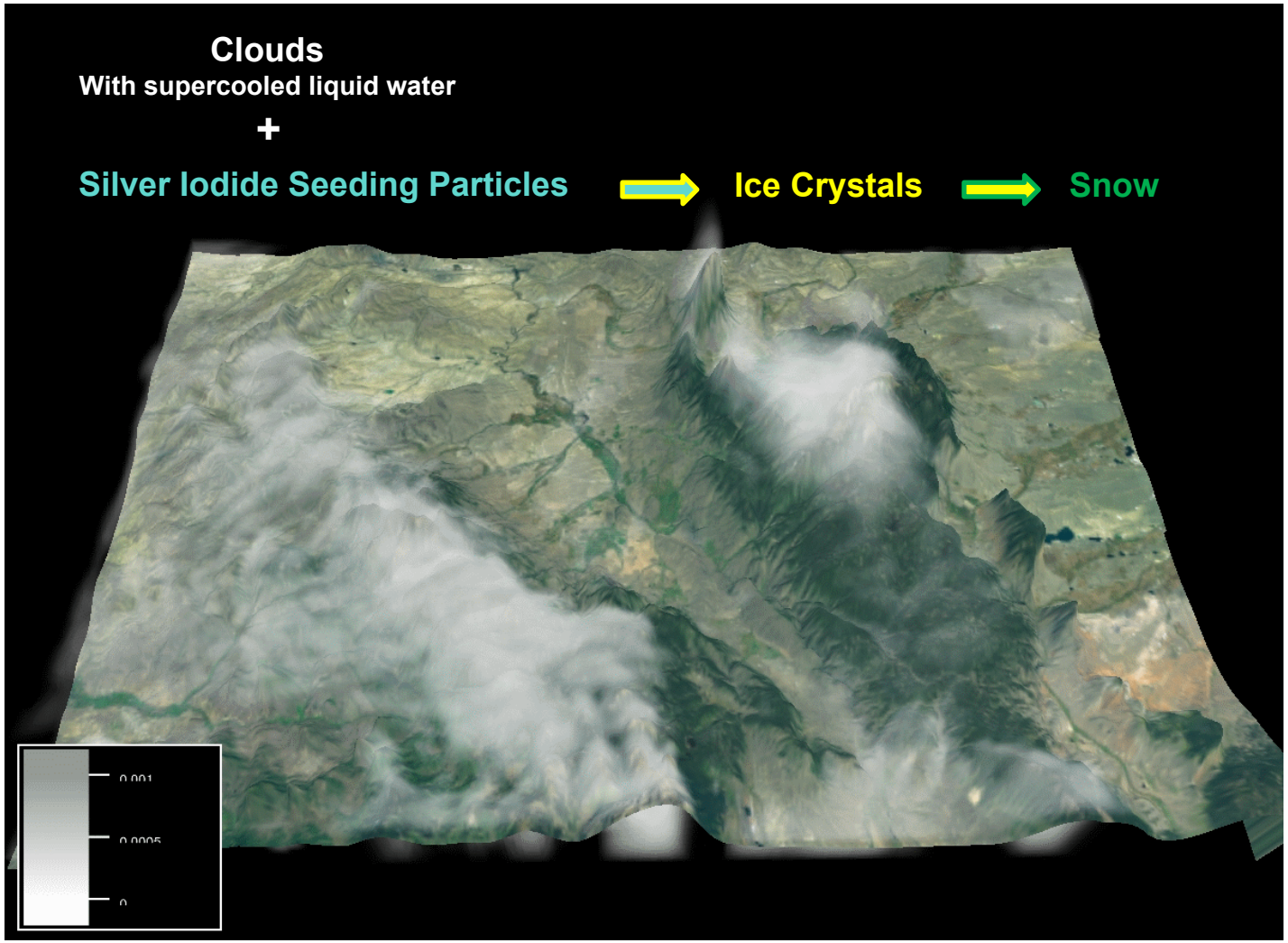
* https://gvwire.com/2021/06/03/westlands-wants-to-buy-120000-acre-feet-of-water/

Glaciogenic Seeding of Orographic Clouds with AgI*

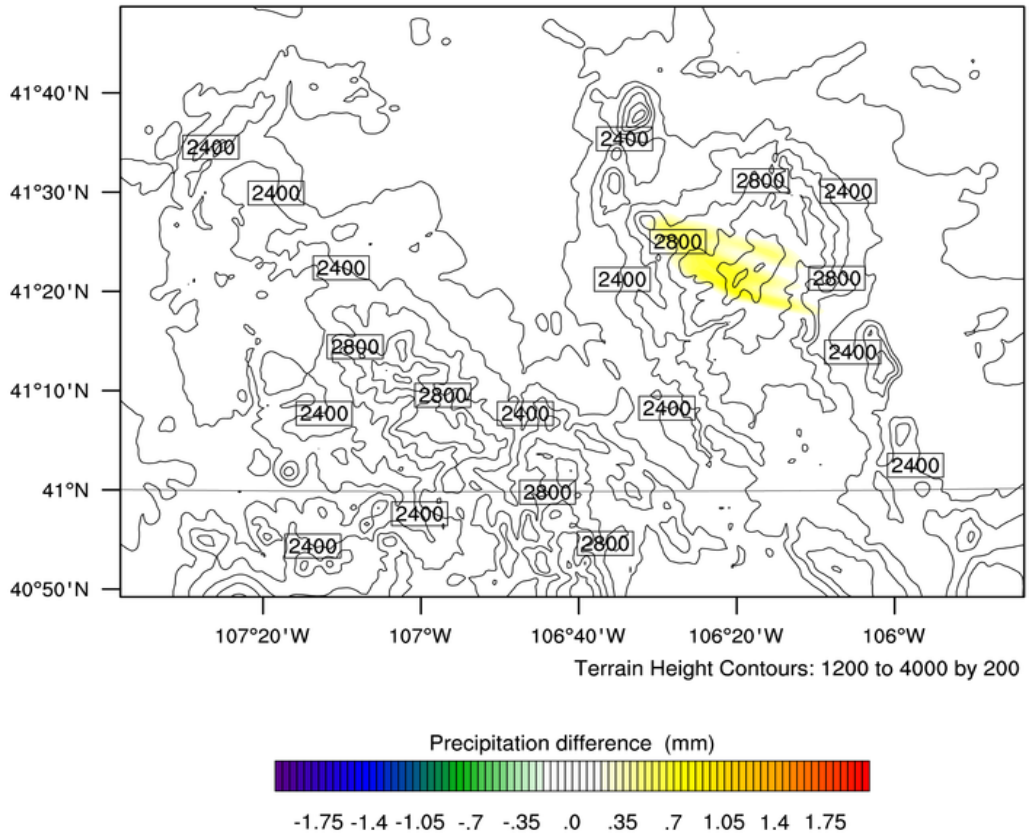


* A natural laboratory for aerosol-cloud-precipitation interactions research!

AgI Cloud Seeding Parameterization*

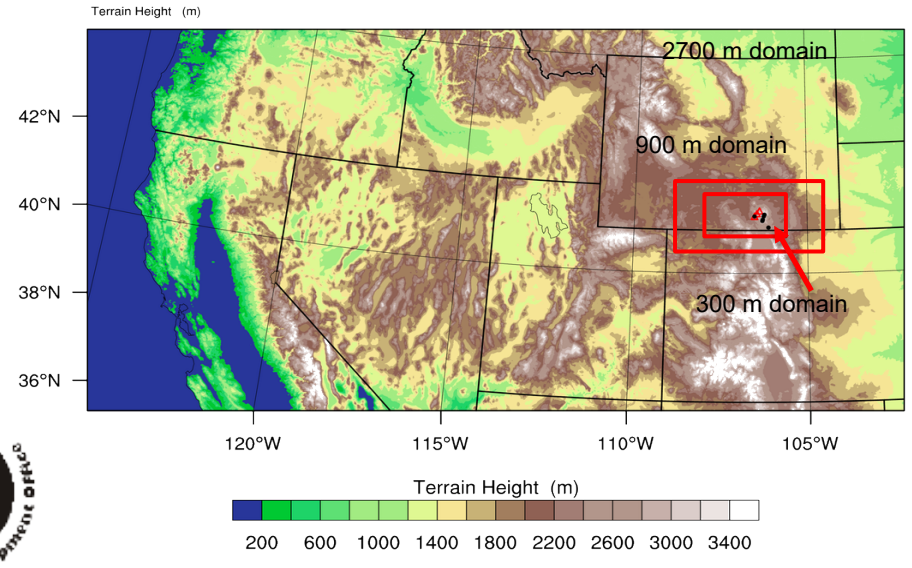


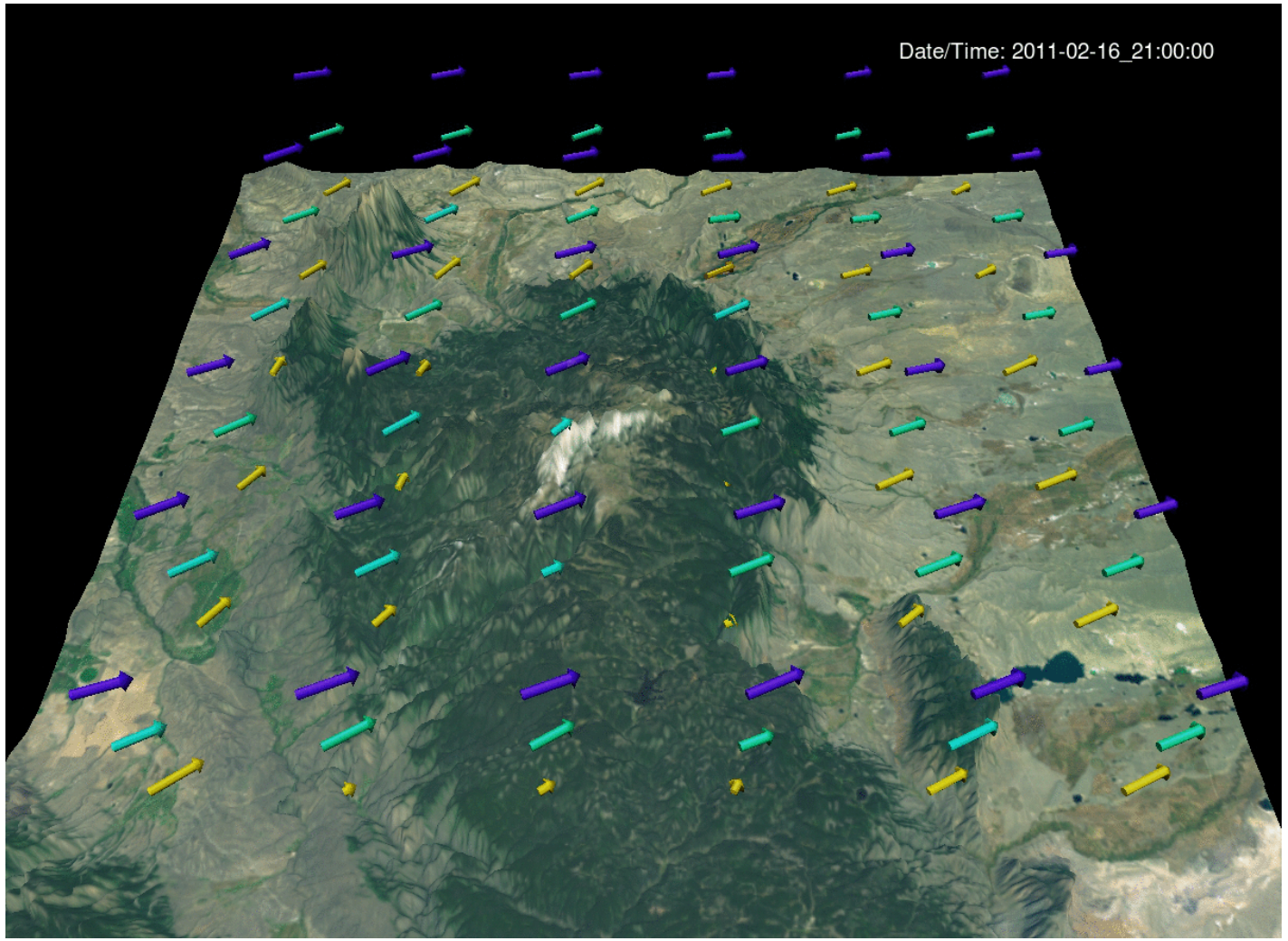
Simulated precipitation change due to cloud seeding

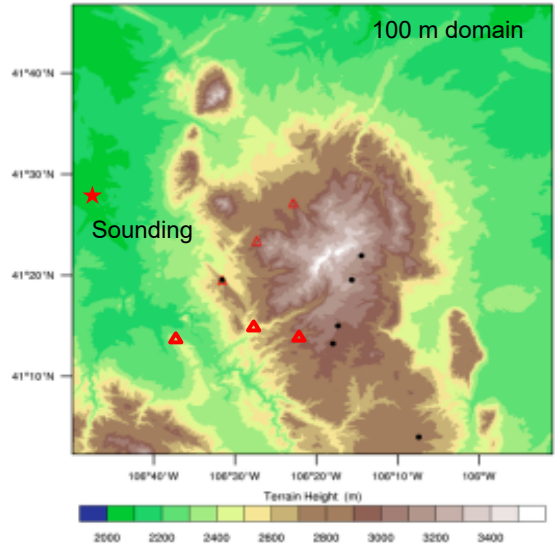


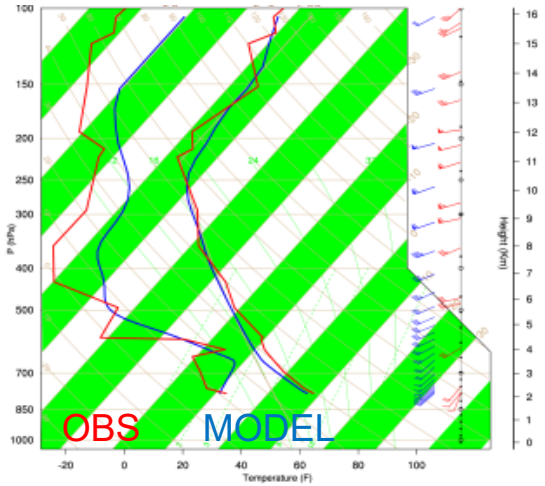
Xue et al. 2013a, b and Geresdi 2017, 2021

Dispersion of AgI Particles over Complex Terrain



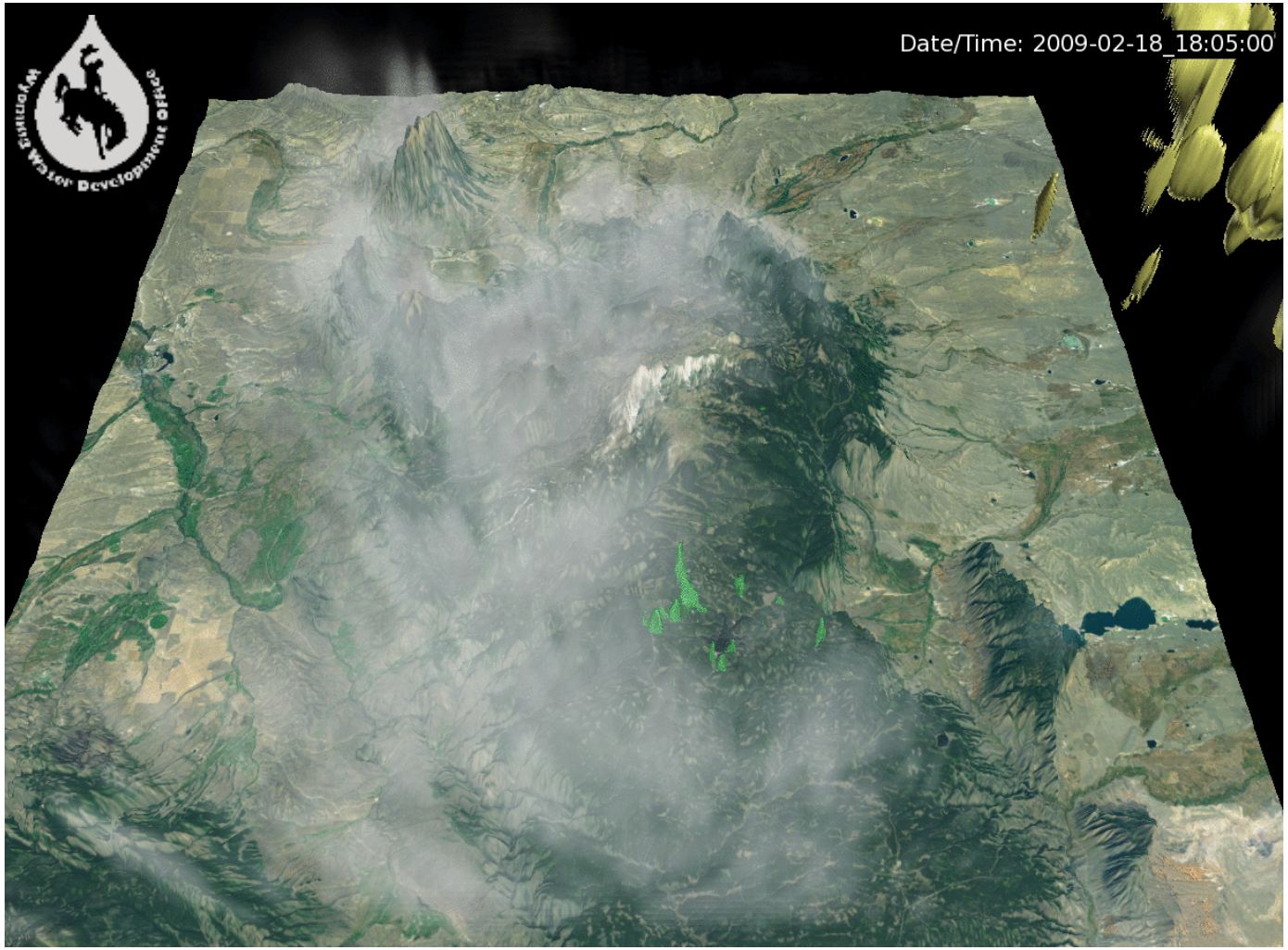




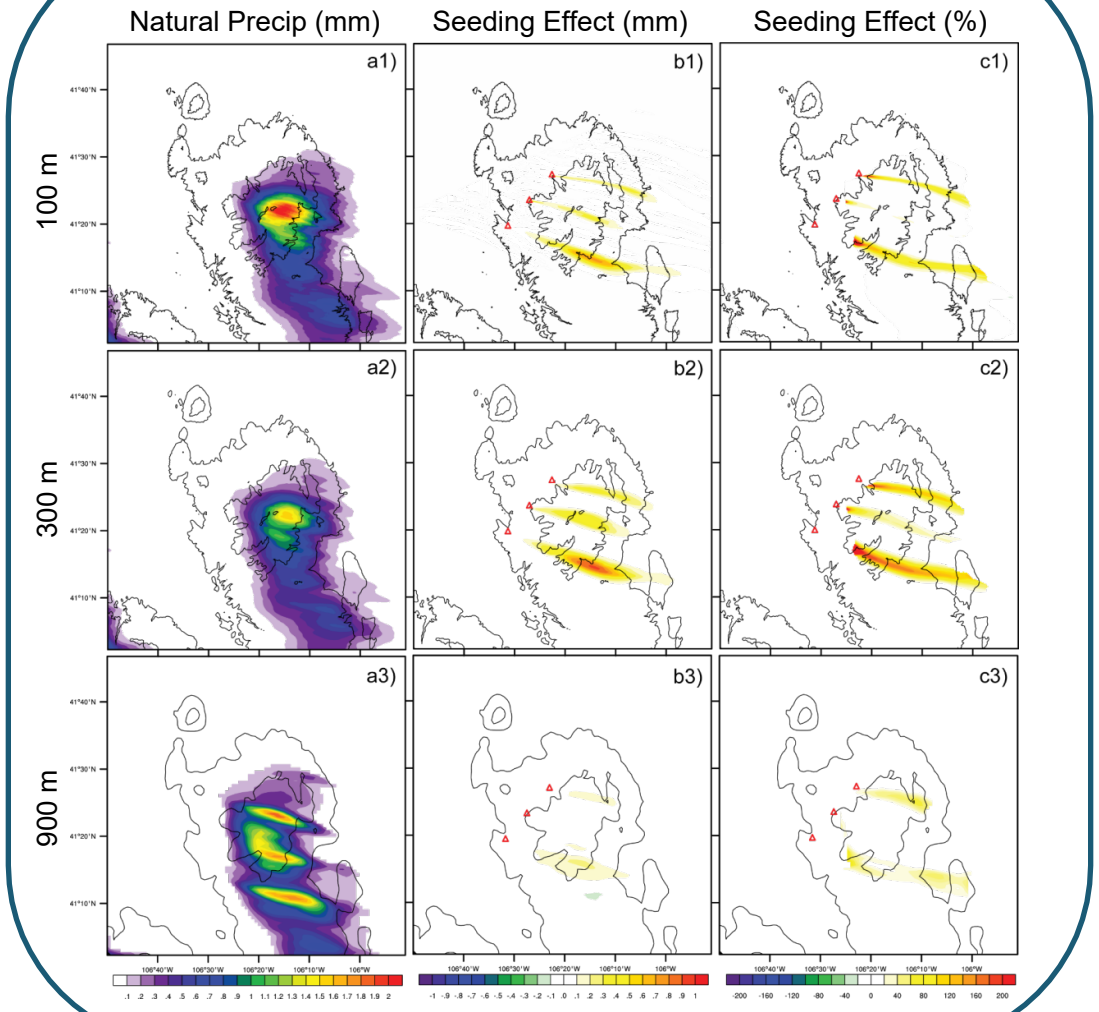


Boe et al. 2014 and Xue et al. 2014

AgI Seeding Effect on Orographic Clouds and Precipitation



Seeding effects depend on grid spacing and are localized (36 to 97 af)



Chu et al. 2014, 2017a,b and Xue et al. 2016, 2017, 2022

Seeding Program Effect Evaluation

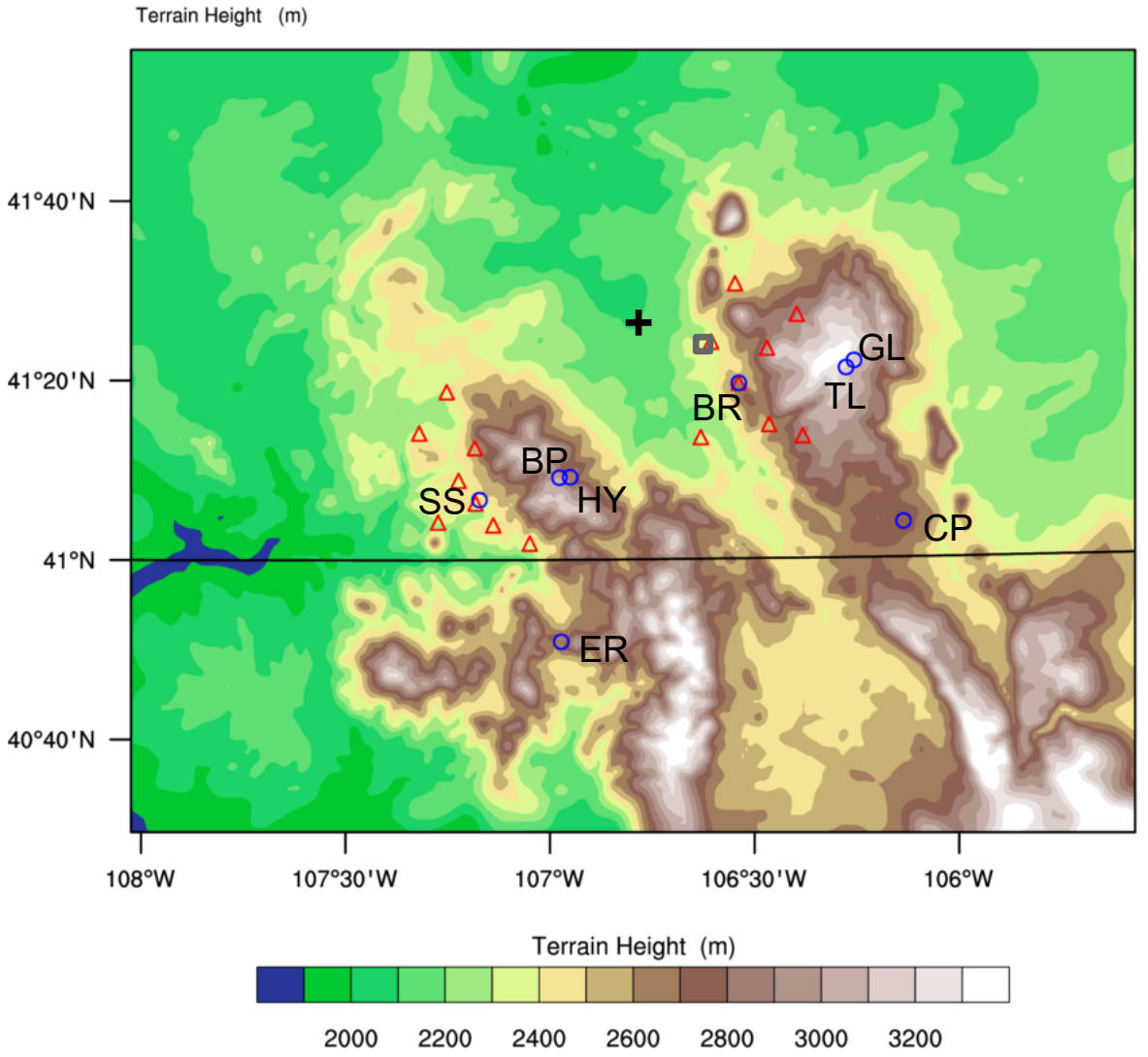
Wyoming Weather Modification Pilot Program

$10M Confirmatory randomized cloud seeding research program funded by the state of Wyoming

118 quality-controlled randomized seeding experiment (RSE) units from 2008 to 2014 winters

~3% Traditional statistical evaluation method reached a small positive value without statistical significance

11K+ Try to evaluate the seeding effect of all RSE cases in WWMPP using the AgI seeding capable model



Breed et al. 2014 and Rasmussen et al. 2018

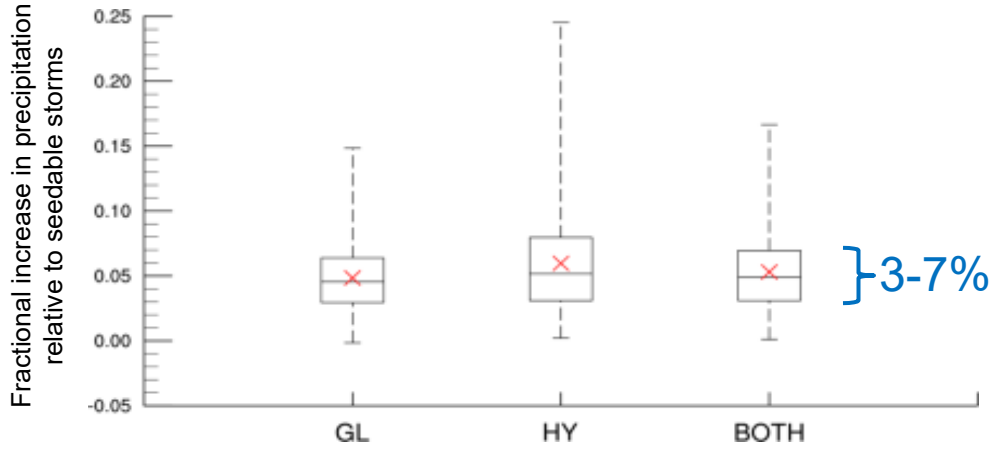
Seeding Program Effect Evaluation

Ensemble design

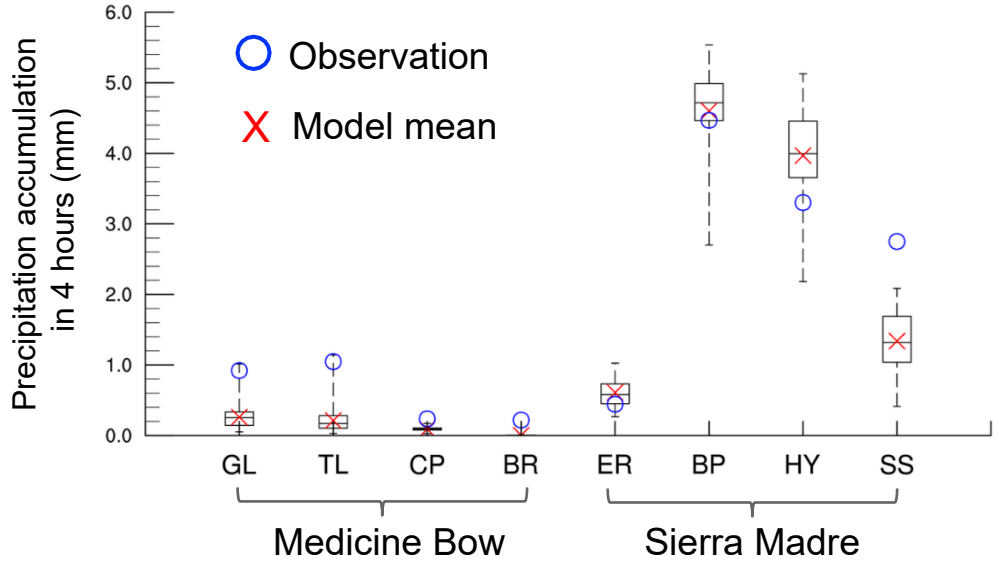
- 3 large-scale forcing data: ERA-Interim, CFSR (CFS2), and NARR
- 1 control and 3 seeding simulations (different seeding physics)
- 8 combinations of PBL, CCN, IN, and boundary conditions
- 118 RSE cases
- Total number of 12h-long 900m simulations : 3*4*8*118=11,328

Ensemble seeding effect

Spread of simulated seeding effects from ensemble for WWMPP



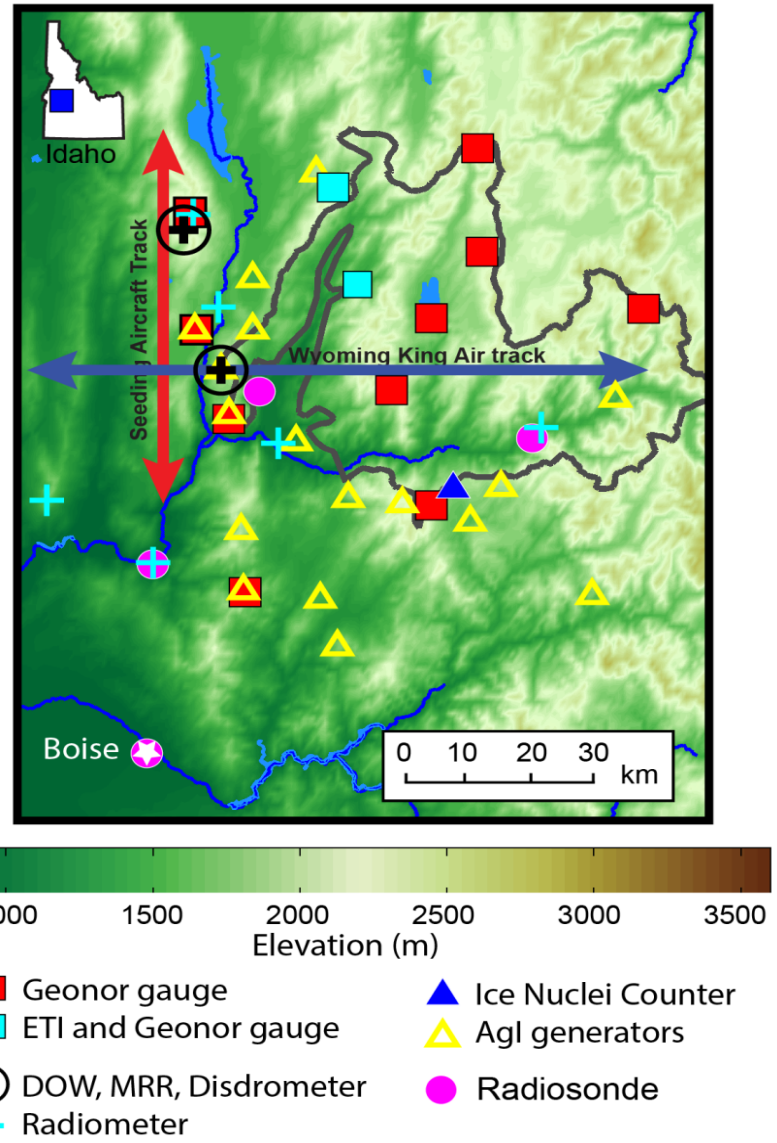
Precipitation validation



Total water gained

Total absolute extra water gained:
4500 +/- 1800 acre feet
~$3 to 7M @Kern water price

Seeded and Natural Orographic Wintertime clouds: the Idaho Experiment



24 IOPs from Jan. to Mar. 2017. Funded by NSF and IPC (Public Private Partnership)

Investigate cloud seeding impacts utilizing observations combined with models

Provide the observations to help evaluate and improve the cloud seeding parameterizations

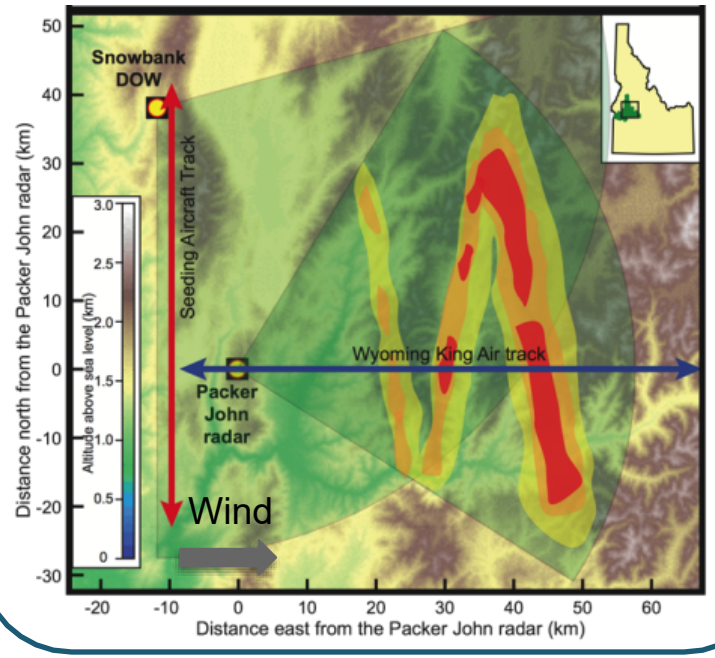
NCAR ILLINOIS University of Colorado Boulder UW NSF IDAHO POWER An IDACORP Company BOISE STATE UNIVERSITY WEATHER MODIFICATION INTERNATIONAL

Tessendorf et al. 2019, Rauber et al. 2019 and Flossmann et al. 2019

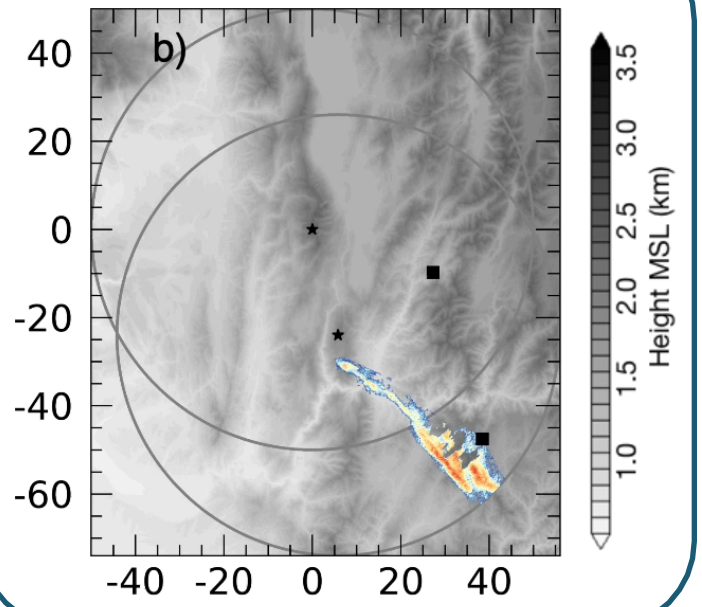
Seeded and Natural Orographic Wintertime clouds: the Idaho Experiment

Strategy was to fly the research aircraft directly in silver iodide seeding plumes to detect and measure the impacts of seeding and provide data to improve and constrain WRF-WxMod®

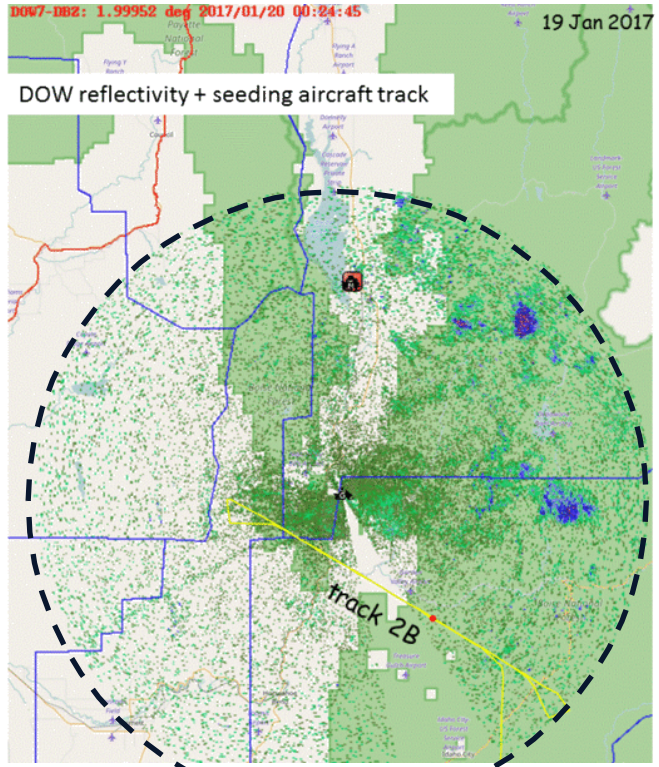
Hypothetical seeding signals



IOP5 DOW reflectivity



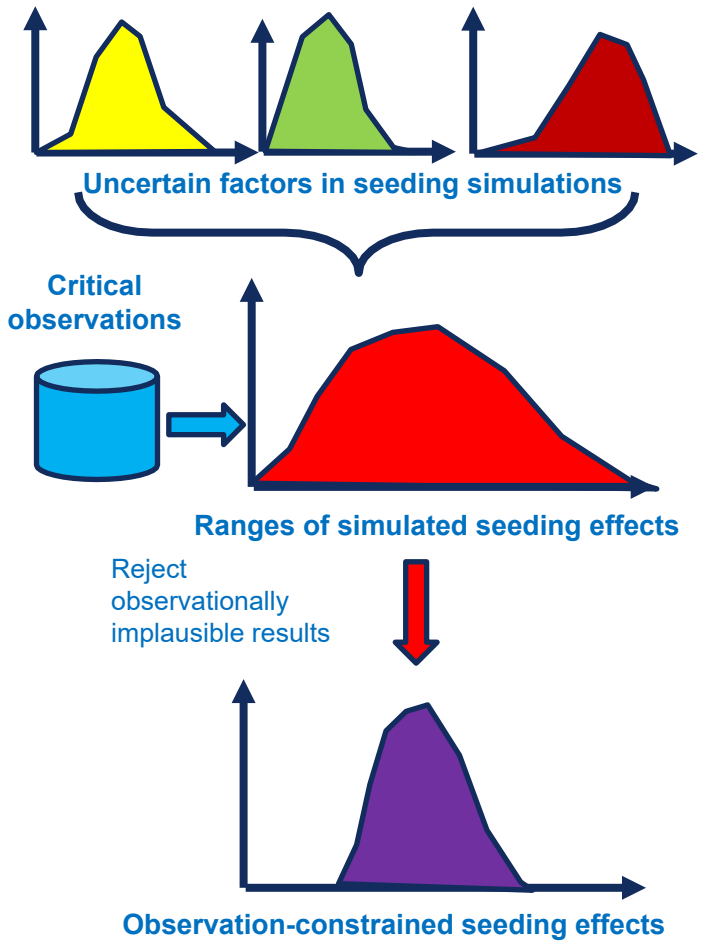
IOP6 DOW reflectivity and seeding aircraft track



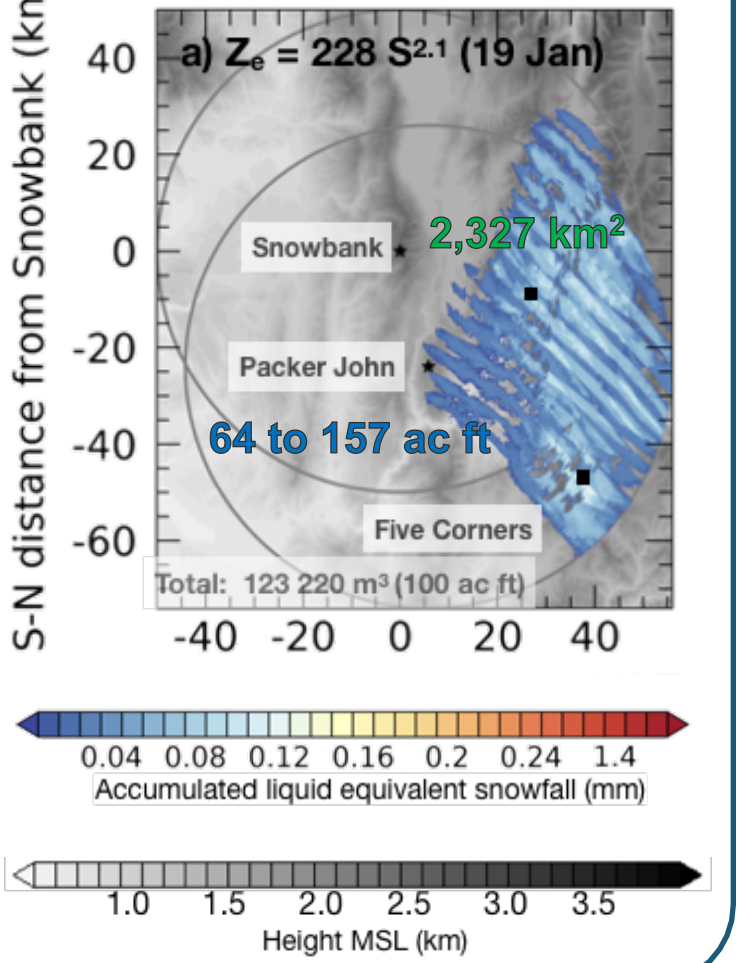
French et al. 2018, Tessendorf et al. 2019, Friedrich et al. 2020 and 2021

Constrain Simulated Seeding Effect with Observations

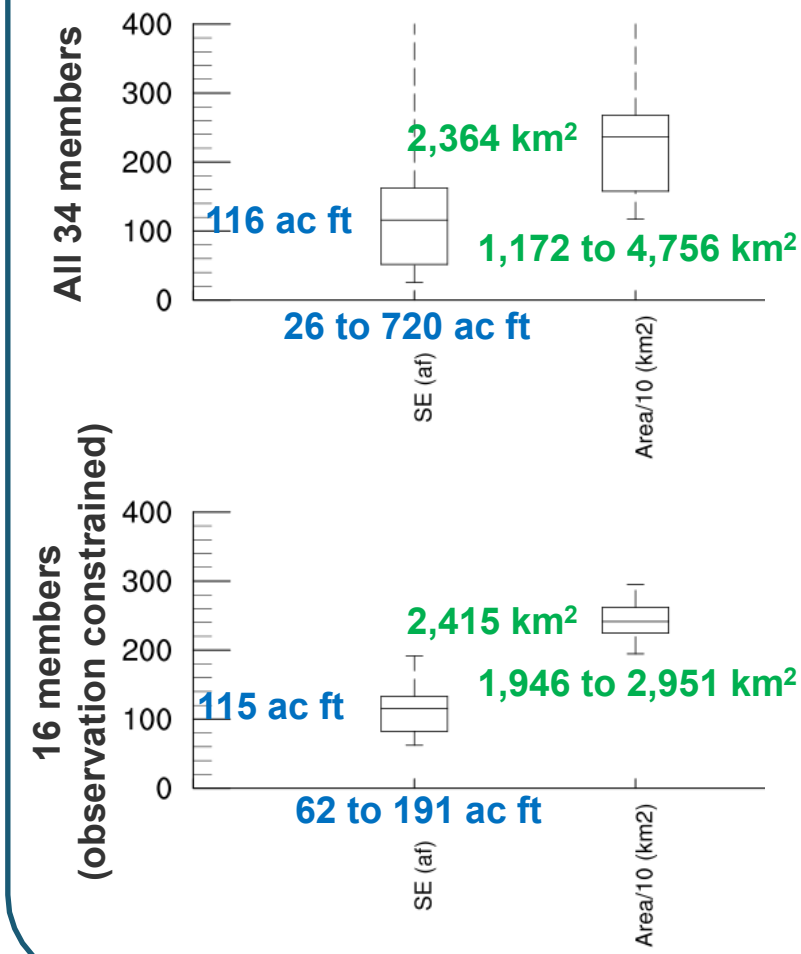
Observation-constrained ensemble simulation framework



Radar-derived seeding effects on precipitation and area

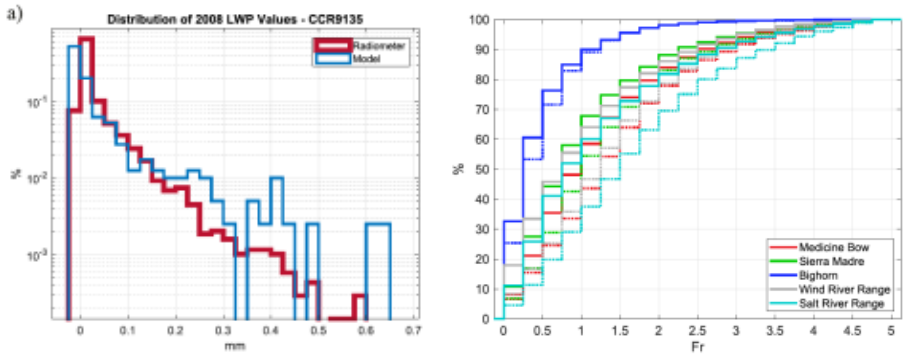


Simulated seeding effects on precipitation and area

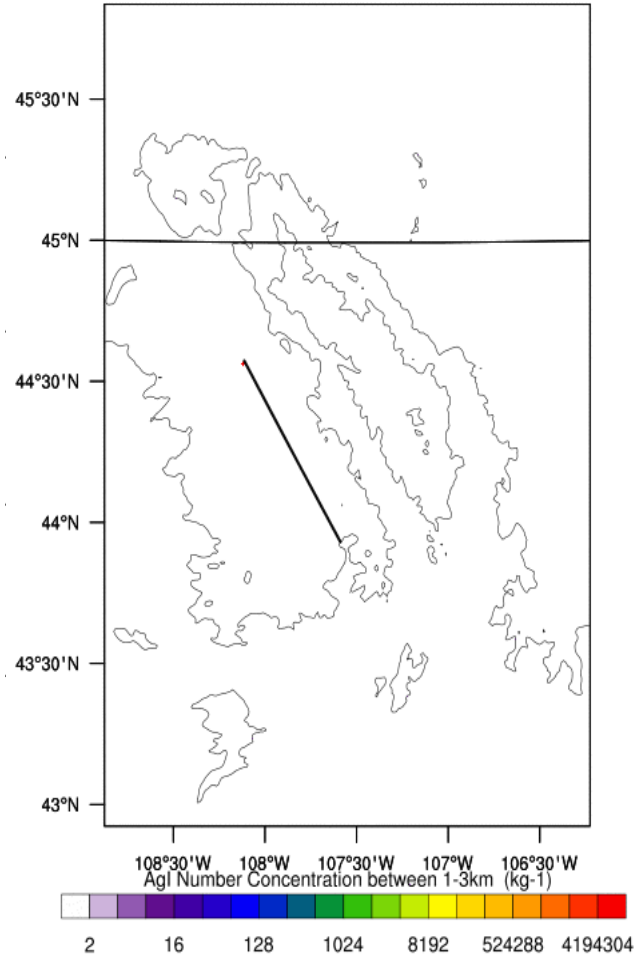


Applications of WRF-WxMod

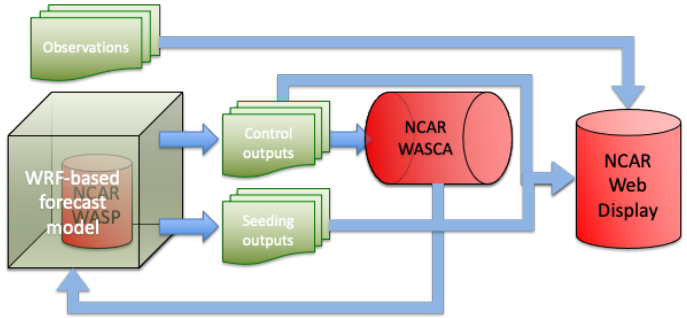
Climatology of seeding conditions

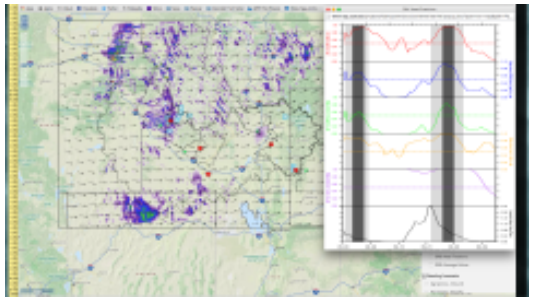


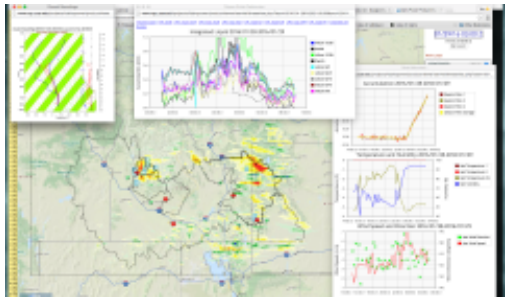
Program design



Seeding forecast







Tessendorf et al. 2020 and Xue et al. 2022

Summary

Quantify Cloud Seeding Precipitation Impacts

- Water security under climate change and population increase
- Cloud seeding as a technology to increase water supplies has been applied widely
- Quantification of cloud seeding effects was nearly impossible in the past

Progress in Addressing This Actionable Science Question

- Physical models to simulate glaciogenic and hygroscopic cloud seeding effects were developed
- Fundamental understanding of the chain-of-event associated with cloud seeding was improved
- Observations and ensemble seeding simulations were combined to quantify the seeding effect

Applications to Address Climate Resilience

- The WRF-WxMod system provides capabilities of assessing climatology of cloud seeding conditions in current and future climate scenarios, seeding program design, and real-time seeding forecast.
- When used at the scale where seeding physics are reasonably resolved, WRF-WxMod can provide guidance and assessment of seeding impacts over large areas and long time period.