USGS/WWDC Project - Final Report

PI: Bart Geerts, Dept. of Atmospheric Science

Project Title: Numerical simulations of the impact of cloud seeding in the Wind River Range on precipitation, snowpack, and streamflow

Products

MS thesis: Mazzetti, T, 2019: "Climatology of Favorable Conditions for Ground Based Cloud Seeding In the Wind River Range". Publication 22621623. Available through ProQuest (https://search-proquest-com)
Ph D dissertation: Mazzetti, T, 2022: anticipated for summer '22.

Publications:
Mazzetti, T., B. Geerts. L. Xue, S. Tessendorf, Y. Wang, and C. Weeks, 2021: Potential for Ground-Based Glaciogenic Cloud Seeding over Mountains in the Interior Western United States, and Anticipated Changes in a Warmer Climate. *J. Appl. Meteor. Climat*., https://doi.org/10.1175/JAMC-D-20-0288.1

Mazzetti, T., B. Geerts. L. Xue, and S. Tessendorf, 2021: Towards a better understanding of conditions suitable for glaciogenic seeding of orographic clouds, using simulations of 10 years of operational ground-based seeding. *J. Appl. Meteor. Climat*., in preparation.

Information Transfer Activities

The following presentations have been given at conferences, seminars, and working group meetings:

- Mazzetti, Geerts and Xue, 2019: Climatology of Favorable Conditions for Ground Based Cloud Seeding In the Wind River Range. Oral presentation at the Weather Modification Association (WMA) annual meeting, April '19, Phoenix AZ (presented by Mazzetti)
- Dept of Atmospheric Science seminar, April '19 (Mazzetti)
- How frequently is the Wind River Range a suitable target for ground-based and airborne seeding? Presentation at the Wyoming Weather Modification Technical Advisory Team (TAT) meeting of summer '19, Saratoga (Geerts)
- Xue, Mazzetti, and Geerts 2019: "Glaciogenic cloud seeding potential of cold-season orographic clouds in a warming climate over the mountains in western Wyoming". Oral

presentation at the American Geophysical Union (AGU) Fall meeting: https://agu.confex.com/agu/fm19/meetingapp.cgi/Paper/508901 (presented by Xue)

- Mazzetti, Geerts, and Xue, 2020: "Potential of Glaciogenic Seeding of Cold-Season Orographic Clouds in a Warming Climate". Poster presentation at the American Meteorological Society (AMS) Annual Meeting: https://ams.confex.com/ams/2020Annual/meetingapp.cgi/Paper/364049 (presented by Mazzetti)
- Mazzetti, Geerts, and Xue, 2020: "Potential of Glaciogenic Seeding of Cold-Season Orographic Clouds in a Warming Climate". To be presented at the Weather Modification Association (WMA) annual meeting in 2021 (online or in Corpus Christi TX).
- Mazzetti, et al. 2020: "Potential of Glaciogenic Seeding of Cold-Season Orographic Clouds in a Warming Climate". Virtual oral presentation at the American Meteorological Society (AMS) 19th Mountain Meteorology Conference, July 13-17. Available at https://ams.confex.com/ams/19Mountain/meetingapp.cgi/Paper/376318
- Mazzetti et al. 2022: Towards a better understanding of conditions suitable for glaciogenic seeding of orographic clouds, using simulations of 10 years of operational ground-based seeding. Virtual oral presentation at the 102nd American Meteorological Society (AMS) Annual Meeting. Session on Planned and Inadvertent Weather Modification. 20-24 Jan 2020.
- Mazzetti et al. 2022: Quantifying the impact of 10 years of operational ground-based seeding over the Wind River Range. Presentation at the Wyoming Weather Modification TAT meeting of winter '22, virtual / Cheyenne.

The TAT meetings are attended by representatives from state and federal agencies, and are open to the public. The WMA meetings are attended by weather modification operators and cloud seeding researchers. The AMS and AGU audiences are very diverse.

Public outreach presentations, contributions to popular science magazines, interviews with the media:

- Mazzetti (October 2019): "Potential of Glaciogenic Seeding of Cold-Season Orographic Clouds in a Warming Climate". Public education/outreach, informal "Science on Tap" presentation (October 2019).
- Geerts and others (18 Jan 2020): interview with the Durango Herald, Colorado
- Geerts, Xue (3 Feb 2021): interview for Le Temps (www.letemps.ch), which is one of Switzerland's leading daily newspapers, on cloud seeding efficacy.

- Geerts (28 Feb 2021): interview for Science et Vie (https://www.science-et-vie.com/), a French magazine

Student Support

Mazzetti, Thomas, M.Sc., spring 2019. Fully funded through this project
Mazzetti, Thomas, PhD student, since summer '19. Fully funded through this project through the grant's expiration in 2021.

Notable Achievements and Awards

Thomas Mazzetti was a recipient of the 2018 North American Weather Modification Council student award, which supported his presentation at the 2019 WMA meeting.

Thomas Mazzetti passed the preliminary examination in January 2021, admitting him to PhD candidacy.

Project Impact

Thomas Mazzetti has been working extensively with our NCAR collaborators (Lulin Xue, Sarah Tessendorf, and Roy Rasmussen) in the past year to become familiar with Xue et al. (2013) seeding module, the WRF modelling framework, and WRF Hydro. This project relies on a 6.0M core hour allocation on the Cheyenne supercomputer at the NCAR Wyoming Supercomputer Center. Thomas has prepared the procedures for two separate high-resolution WRF simulations for all seeding operations that were conducted over the WRR during the past 10 cold seasons, one sequence with seeding and one without (control). This allows us to quantify the impact of seeding on snowfall and snowpack evolution. This work was completed for 1 winter, but issues have been identified, and we are rerunning this using a different framework (single high-resolution domain). Our key preliminary (unpublished) finding is that *the seeding impact is positive, and that 90% of the snowfall enhancement resulted from just over 10% of the cases, i.e. the AgI-induced yield is much higher in some winter storms than in others*.

We also have used our 30-year regional climate simulation (called the IWUS (Interior Western US), Wang et al. 2018), funded through a previous WRP grant, to characterize the natural snowfall over the Wind River Range, and to identify conditions that are suitable for cloud seeding. We find that about 50% of the natural precipitation can be seeded over the Winds (Mazzetti 2019). Of that, 80% falls in unblocked conditions, and is seedable from the ground; the other 20% requires a seeding aircraft, since the AgI nuclei from the ground generators remain at

low levels, unable to be lofted over the mountain because the low-level flow is blocked. The inclusion of airborne seeding expands the seeding window by 65% over the Winds.

Mazzetti et al. (2021) broaden this study by quantifying the feasibility of glaciogenic seeding to enhance precipitation for all mountain ranges in the interior western United States mountains, using 10 years of environmental and cloud data from the 4 km IWUS regional climate simulation. This paper's focus is on ground-based seeding of clouds. Frequency of occurrence of established criteria for seeding efficacy, related to temperature, cloud liquid water, static stability and flow patterns, are examined. The presence of supercooled liquid water in clouds is validated using passive microwave radiometer data. The Froude number is computed locally (rather than for a pre-defined mountain range) to determine the likelihood of the flow being blocked by downstream terrain, in which case ground-based seeding is not effective.

Mazzetti et al. (2021) also evaluate the changes in the feasibility of cold-season glaciogenic seeding in a warming climate, by means of 10 years of data from the IWUS simulation, but for the climate circa 2060. This future climate uses the Pseudo-Global Warming technique with perturbations from the retrospectives climate given by the IPCC RCP8.5 scenario. The main finding is a *significant reduction in seedability in the interior Pacific Northwest, but little reduction over the mountains in Colorado and Wyoming*. Thus, cloud seeding techniques may need to be adapted in a changing climate.

In the last three months, Thomas resumed configuring the reworked model and ensemble configuration for simulation the impact of the first 10 years of ground-based seeding in the WRR. The full 10-year set of ensemble simulations should be completed by mid-spring 2021. Following this, we will evaluate the output, run WRF Hydro simulations to quantify the impact on streamflow, and submit a publication by the end of 2021.

Statement of COVID-19 impact on research:

The COVID-19 pandemic resulted in a ~9 month delay in the submission of the paper Mazzetti et al. (2021), on account of a number of issues, including access to large data files from home, disruptions in the computer based daily work flow, adaptation to a drastically different lifestyle, altogether resulting in reduced productivity. Also, planned visits to NCAR facilities for training and collaboration with coauthors/collaborators were canceled, and conducted remotely, which was less valuable and less efficient a learning experience. Finally, we intended to present at conferences that ended up being canceled or were held online, namely the 2020 WMA meeting (postponed), 2020 ICCP meeting in Pune, India (postponed), and 2020 AMS Mountain Met Conference (online presentation).