Precipitation Evaluation of the North Dakota Cloud Modification Project

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Overview

- Motivation and Objective
- Background
- Data Set
- Methodology
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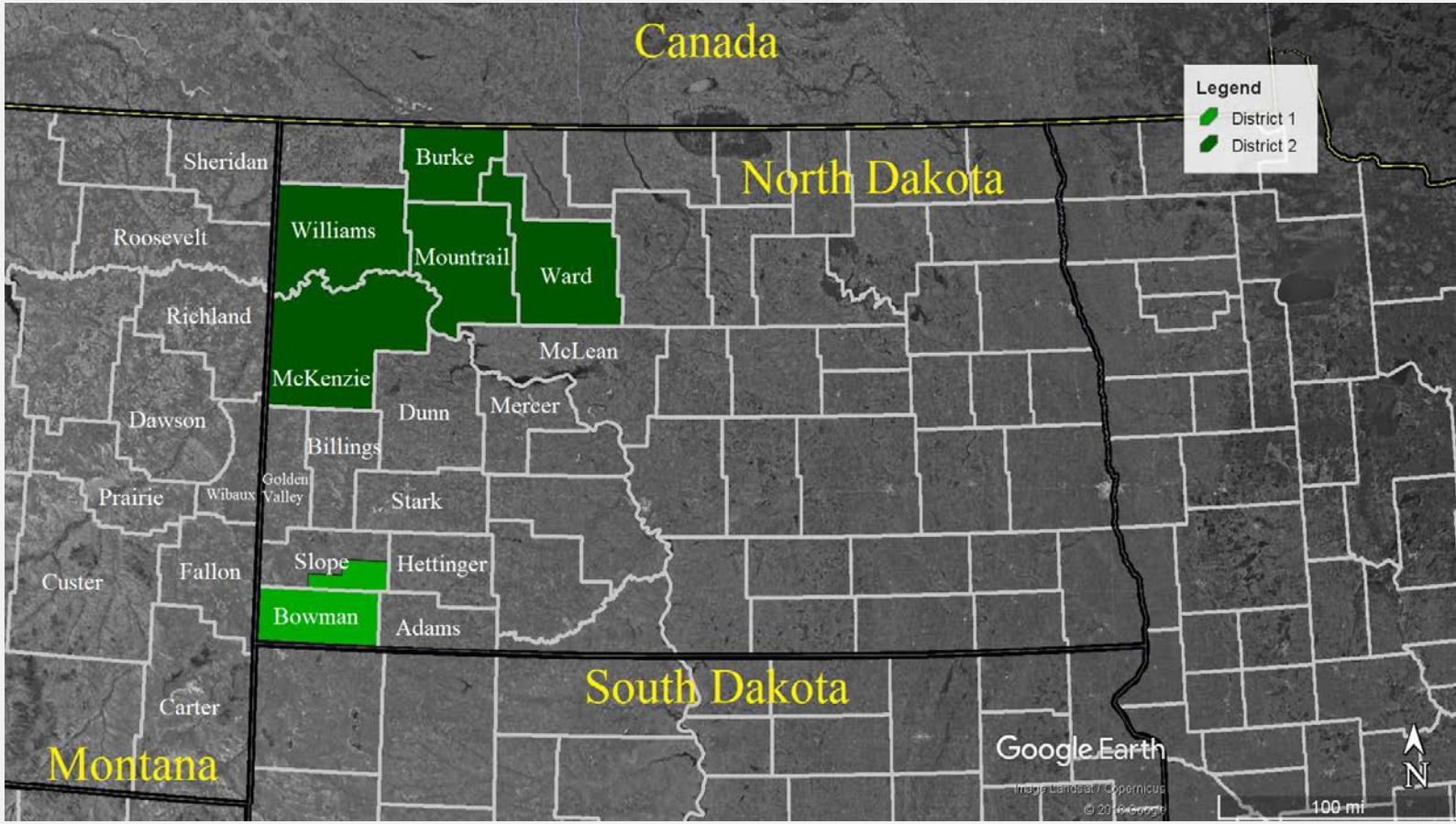
Motivation and Objective

- The North Dakota Cloud Modification Project (NDCMP) costs the state of North Dakota approx. $1.0 million per year or approx. 13 cents per acre (NDCMP 2018).
- The last study performed on the NDCMP was conducted in 2005 (Wise 2005).
- Analyzing the effectiveness of the NDCMP can help future economic cost/benefit ratio studies and are important so sponsors and the public are well informed.
- Determining the effectiveness of the NDCMP at increasing rainfall within the project area.

Project Background

- The NDCMP has ran a non-randomized cloud seeding operation in ND since 1976.
  - (Schneider and Langerud 2011)
- Primary goal of the program is hail suppression to reduce crop loss, but precipitation enhancement was quickly added.
- Operations are conducted in two districts during June, July, August and occasionally early September.
  - (NDARB 2018)



Previous Evaluations of the NDCMP

- By using National Weather Service (NWS) Cooperative Observer Program (COOP) rain gauges, Smith et al. (2004) studied whether a cloud seeding effect was present.
- A target/control methodology consisting of 11 stations in the NDCMP target area and 25 stations in eastern Montana as the control was used.
- Results showed little to no increase in rainfall in this analysis and a p-value of 0.32.

Previous Evaluations of the NDCMP

- Wise (2005) analyzed the effects of the NDCMP using a target, downwind and control approach.
- The control/downwind region was determined by daily storm motion from 1999 to 2002.
- North Dakota Atmospheric Resource Board Cooperative Observer Network (NDARBCON) rain gauges were used for 1977 to 2003.
- Results found an increase in rainfall of at least 5 % in four out of seven cases.
  - Of those four, only two were determined statistically significant

    (p-value < 0.05)

Combining Data

- Langerud and Gilstad (2003) compared NDARBCON and NWS COOP gauges over a 23-year period from 1977-1999.
- Rain gauges were compared multi-annually and annually.
- Results showed rainfall totals within approx. a half an inch per year and a correlation of 0.998.

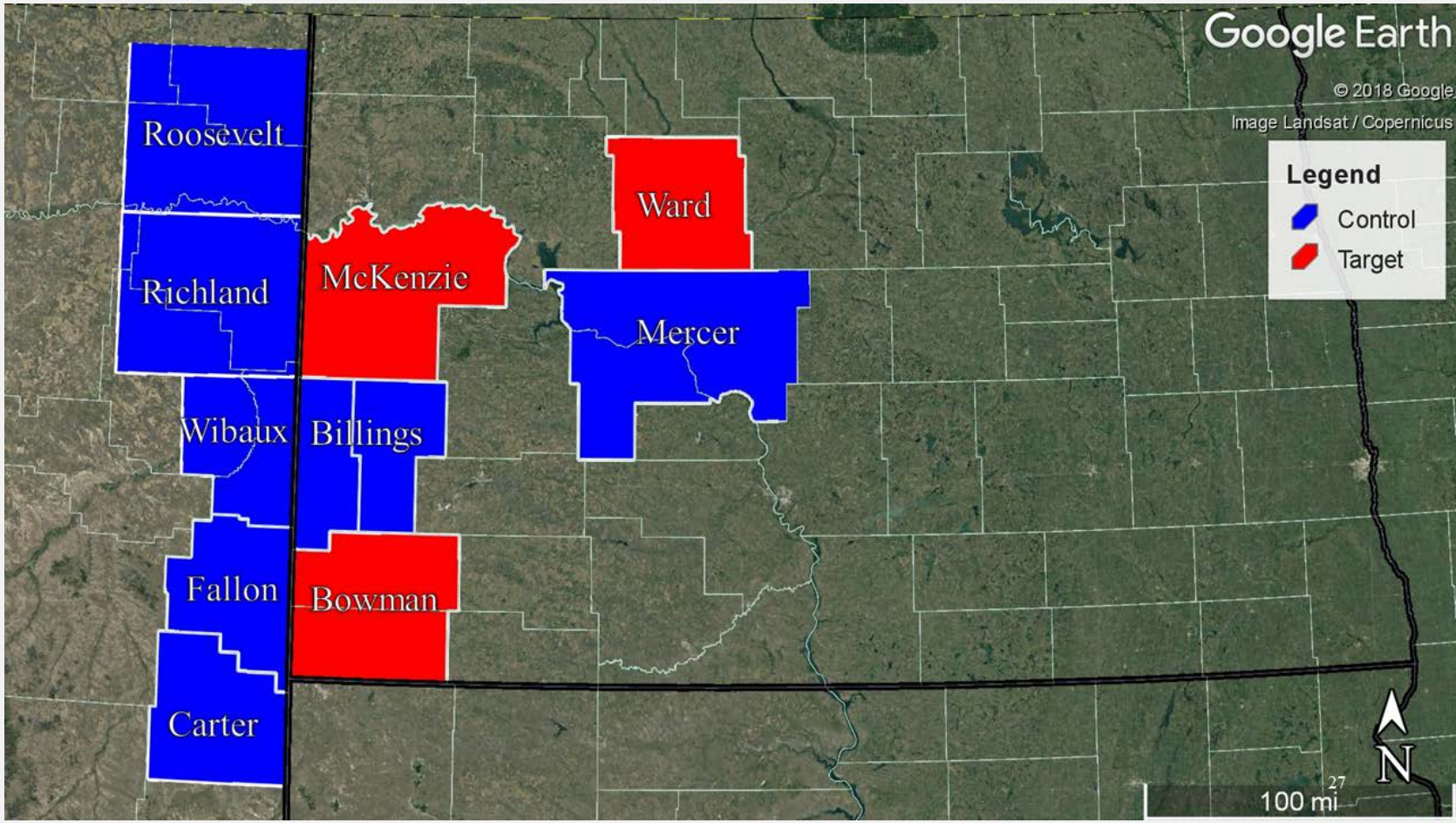
Methodology: Target/Control

- The target regions are determined by the years active in the NDCMP.
- Bowman, Slope, McKenzie, and Ward Counties were selected.
- Controls were designated as counties that have not participated in the NDCMP or only participated in a relatively short period.
- Downwind effects proved challenging for selecting controls
- DeFelice et al. (2014) found that downwind effects from cloud seeding increases rainfall by 5 – 15 %, and Wise (2005) found a 13% increase in downwind rainfall within the NDCMP.

Counties	District	Years Participated	Total Years
Adams	1	1977-1980	4
Bowman	1	1977-2018	42
Hettinger	1	1977-1988	12
Slope	1	1977-2018	42
Burke	2	2015-2018	4
McKenzie	2	1977-2018	42
McLean	2	1977-1984	8
Mountrail	2	1977-2018	42
Ward	2	1977-2018	42
Williams	2	1997-2018	22

Methodology: Target/Control

- Storms in western ND move W to E
- Control areas were created to mitigate downwind effects
- Bowman
  - Bowman and Slope Counties
- “Billings”
  - Billings and Golden Valley County
- Wibaux
  - Wibaux and part of Dawson County
- Mercer
  - Mercer and Mclean County
- Richland and Roosevelt
  - Parts of several MT counties
- Fallon, Ward, Carter and McKenzie
  - Political boundaries



Methodology: Monthly Rainfall for a Single Station

$$M_s = \sum_{d=1}^{N} Rain_d$$

- M_s = the calculated monthly rainfall for a given station
- $Rain$= the rainfall amount recorded on a given day
- N = the number of days in the given month

Methodology: Area Averaged Monthly Rainfall

$$\bar{T}_{area} = \frac{\sum_{s=1}^{n} M_s}{n}$$

- $\bar{T}_{area}$ = area averaged rainfall
- M_s = the calculated monthly rainfall for a given station
- n = number of valid stations within the area

Methodology: Statistical Methods

- To analyze the target and control rainfall differences, the following statistical methods were used:
  - Single ratio
  - Double Ratio
  - Bootstrapping

Methodology: Single Ratio

- Once the rainfall for a given evaluation was completed, a single ratio between target and control were calculated for the pre-NDCMP and NDCMP periods.
- Each target was assigned to different control areas based on the proximity of their location.
- McKenzie was paired with:
  - Richland, Roosevelt, Wibaux, and Billings
- Bowman was paired with:
  - Carter, Fallon, Wibaux and Billings

Methodology: Single Ratio

$$SR = \frac{\sum_{n=1}^{years} \bar{T}_{target}^{June,July,August,or\ Seasonal}}{\sum_{n=1}^{years} \bar{T}_{control}^{June,July,August,or\ Seasonal}}$$

- SR = single ratio
- $\bar{T}$ = area averaged rainfall

Methodology: Double Ratio

$$DR = \frac{SR_{1977-2018}}{SR_{1950-1975}}$$

- SR = single ratio for the given time period
- DR = Double ratio given ins decimal form

Methodology: Bootstrapping and One-Tailed Statistical Test

- Bootstrapping is used to randomly resample the data set multiple times to enable calculation of uncertainty, confidence intervals, and significance (Hesterberg et al. 2005).
- Bootstrapping does not assume a Gaussian, or any specific distribution type, for the data set population
- One-tailed statistical test is used to determine whether the double ratio for a particular target/control pair is statistically significant.
- A one-tailed statistical test checks if the critical area of a distribution is greater than or less than a specified value (Lane et al. 2003).

Results: Single Ratio

Target/Control	June		July		August		Seasonal	
	1950-1975	1977-2018	1950-1975	1977-2018	1950-1975	1977-2018	1950-1975	1977-2018
McKenzie/Billings	0.84	1.00	0.95	1.03	0.92	0.89	0.89	0.98
McKenzie/Richland	1.13	1.17	1.06	1.12	1.04	1.17	1.09	1.15
McKenzie/Wibaux	0.88	1.05	0.98	1.09	0.96	0.94	0.92	1.03
McKenzie/Roosevelt	1.21	1.12	1.09	1.06	1.02	1.20	1.12	1.12
Bowman/Billings	0.89	1.01	0.96	0.89	0.84	0.88	0.90	0.94
Bowman/Wibaux	0.93	1.06	0.99	0.94	0.88	0.93	0.94	0.99
Bowman/Carter	0.94	0.91	0.95	0.96	1.01	0.88	0.96	0.92
Bowman/Fallon	1.20	1.19	1.20	1.28	1.25	1.23	1.21	1.23
Ward/Mercer	0.99	1.01	0.96	0.93	1.04	0.93	0.99	0.96

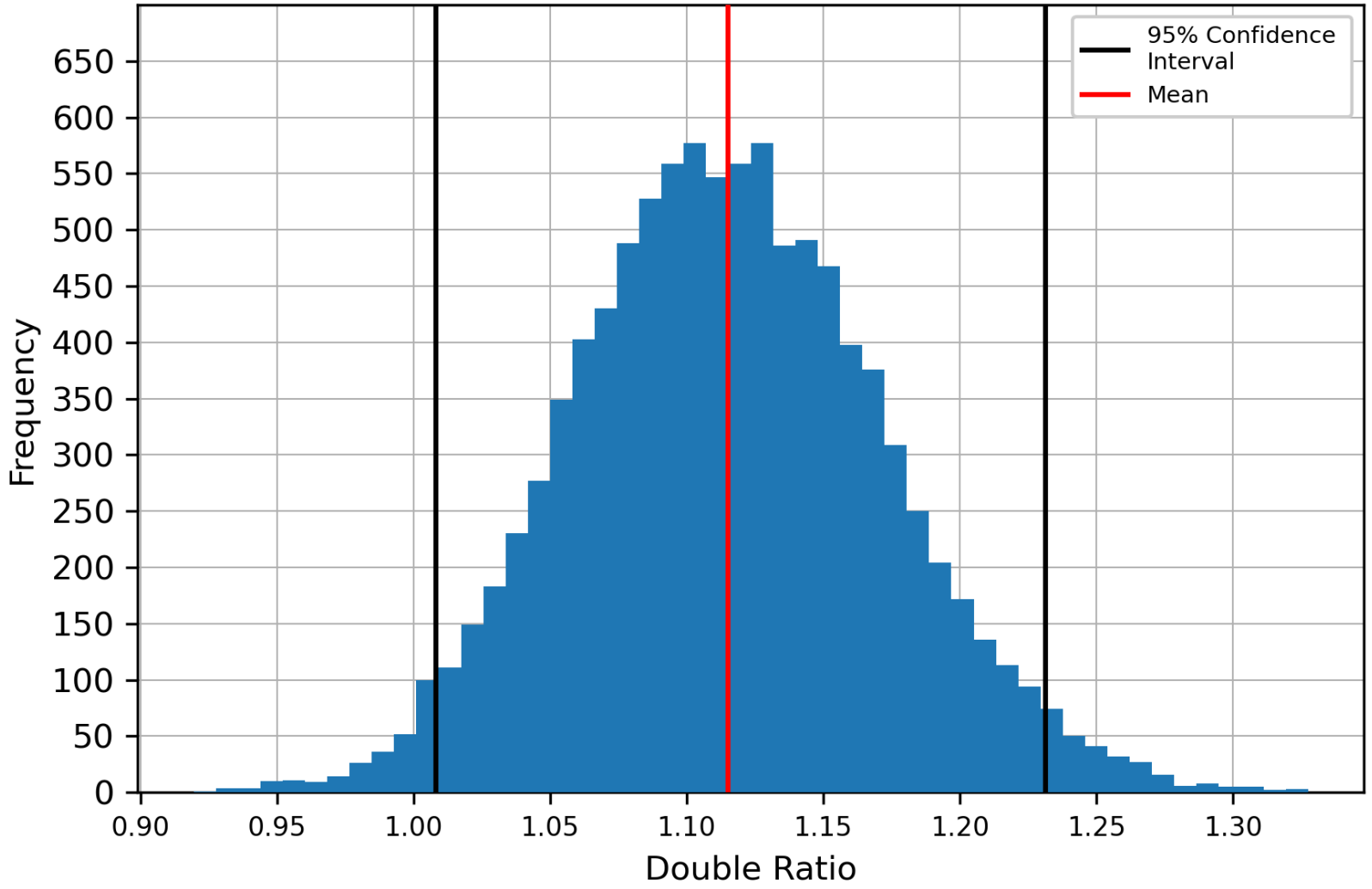
Results: Double Ratios

Target/Control Pair	June	July	August	Seasonal
McKenzie/Billings	1.19	1.08	0.97	1.10
McKenzie/Richland	1.04	1.06	1.13	1.06
McKenzie/Wibaux	1.19	1.24	0.96	1.12
McKenzie/Roosevelt	0.93	0.97	1.18	1.00
Bowman/Billings	1.13	0.93	1.05	1.04
Bowman/Wibaux	1.14	0.95	1.06	1.05
Bowman/Carter	0.97	1.01	0.87	0.95
Bowman/Fallon	0.99	1.07	0.98	1.01
Ward/Mercer	1.02	0.97	0.89	0.97

Results: Bootstrapping

Target/Control Pair	Double Ratio	95% Confidence	Significance > 1.0
McKenzie/Billings	1.10	0.99 - 1.22	96.5%
McKenzie/Wibaux	1.12	1.01 - 1.23	98.5%
McKenzie/Richland	1.06	0.98 - 1.15	94.0%
McKenzie/Roosevelt	1.00	0.90 - 1.10	46.5%
Bowman/Billings	1.04	0.93 - 1.16	75.0%
Bowman/Wibaux	1.05	0.94 - 1.17	85.0%
Bowman/Fallon	1.01	0.91 - 1.12	60.0%
Bowman/Carter	0.95	0.86 - 1.05	19.0%
Ward/Mercer	0.96	0.87 - 1.07	27.5%

Results: Bootstrapping McKenzie/Wibaux



Conclusions

- Six out of nine Target/Control pairs have targets receiving at least 2% or more seasonal rainfall than expected based on corresponding controls
- Out of six double ratios, two are statistically signification at 95% confidence level
  - Three are statistically significant at the 90% confidence level
- Average increase in seasonal rainfall for all target areas was 1.03
  - Results regarded as lower limits due to contamination of the pre-project period data
- Result offers support for a claim of modest, compared to yearly variability, precipitation increases in western North Dakota

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Questions?

EXTRA SLIDES

Missing Data

- Despite having vast amounts of rain gauges available throughout the history of the NDCMP, time consistency (e.g. year-to-year reporting) of rain gauge observations were an issue.
- To handle missing data for the NDARBCON gauges, gauges were checked to see if a complete record for June, July, or August were available.
- If a gauge had a complete record for at least one of the months, it was used towards the calculation of monthly total rainfall for the year.

McKenzie County Rain Gauges 1950-2018