Statistical Analysis of the Polarimetric Cloud Analysis and Seeding Test (POLCAST) Field Projects

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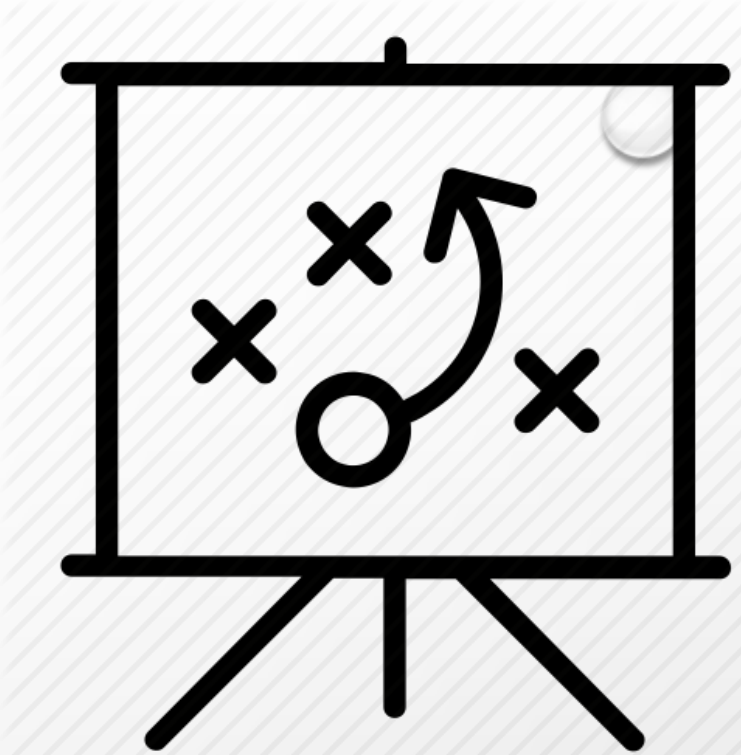
Game Plan



- Motivation for POLCAST
- Randomized Seeding Dataset
- Distribution of Seed Targets
- Summer-time Seasonal Rainfall in Eastern North Dakota
- Radar Analysis of the Randomized Cloud Seeding Dataset
- Conclusions and Future Work

Motivation: State/Country

- Economy of North Dakota
  - Farming/Agriculture is the number one industry of the state brining in more than $4.1 billion annually.
- North Dakota farmers are responsible for >50 % of many crops produced in the United States.

Crop	% of U.S. Production
Flax	96%
Canola	90%
Durum	68%
Pinto Beans	65%
Dry Edible Peas	64%

Motivation:
Economic Impact of Drought or Hail

- Loss of income/jobs for North Dakota.
- Increase in consumer cost when crop loss occurs.
- Cost of the 2002 drought = $223 million in crop damages
- Cost of the 2006 drought = $425 million in crop damages

Motivation: Worldwide

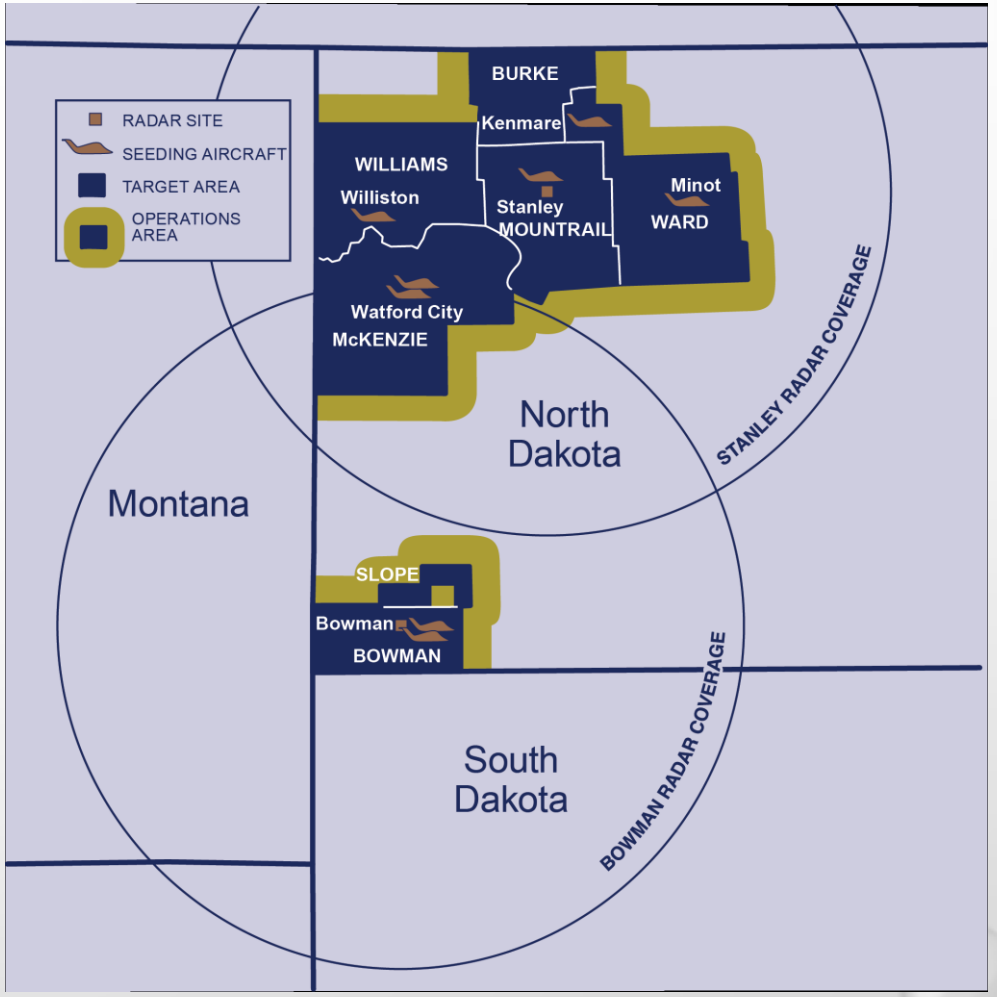
- Expanded from exporting to 63 countries in 1995 to 83 countries as of 2015.

Introduction

- Cloud Seeding Operations in North Dakota
- What is POLCAST?
- Cloud environmental factors in North Dakota
  - Cloud base temperature
  - Cloud base pressure altitude
  - Cloud base cloud condensation nuclei (CCN) concentration
- Rainfall in North Dakota
  - Did North Dakota see typical rainfall during the months of June and July during the years POLCAST field projects took place?

Seeding in North Dakota

- North Dakota Cloud Modification Program (NDCMP)
- AgI Seeding is has been used since 1950's – mainly for hail suppression, but also help increase precipitation efficiency and rain rate.
- Possibility of implement hygroscopic seeding for specifically rainfall efficiency.



Types of Seeding During NDCMP:

Ejectable

AgI Generator

Burn-In-Place

Types of Seeding During NDCMP:

Ejectable

AgI Generator

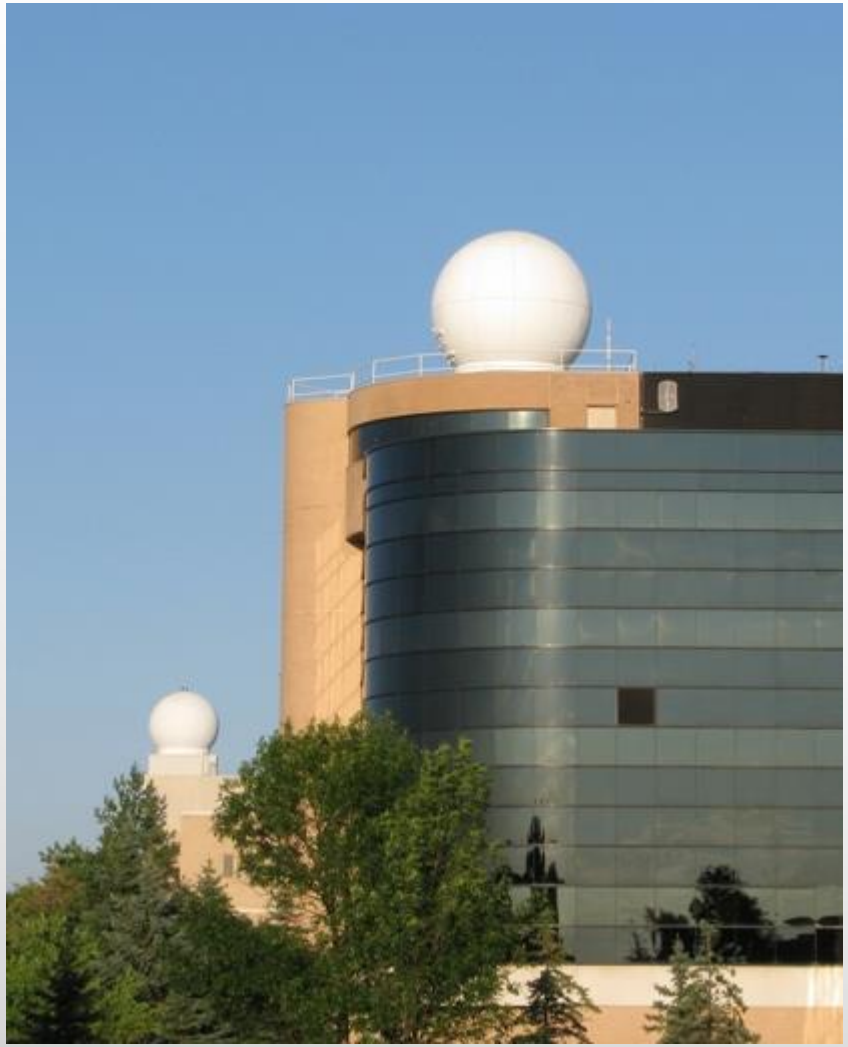
Burn in Place

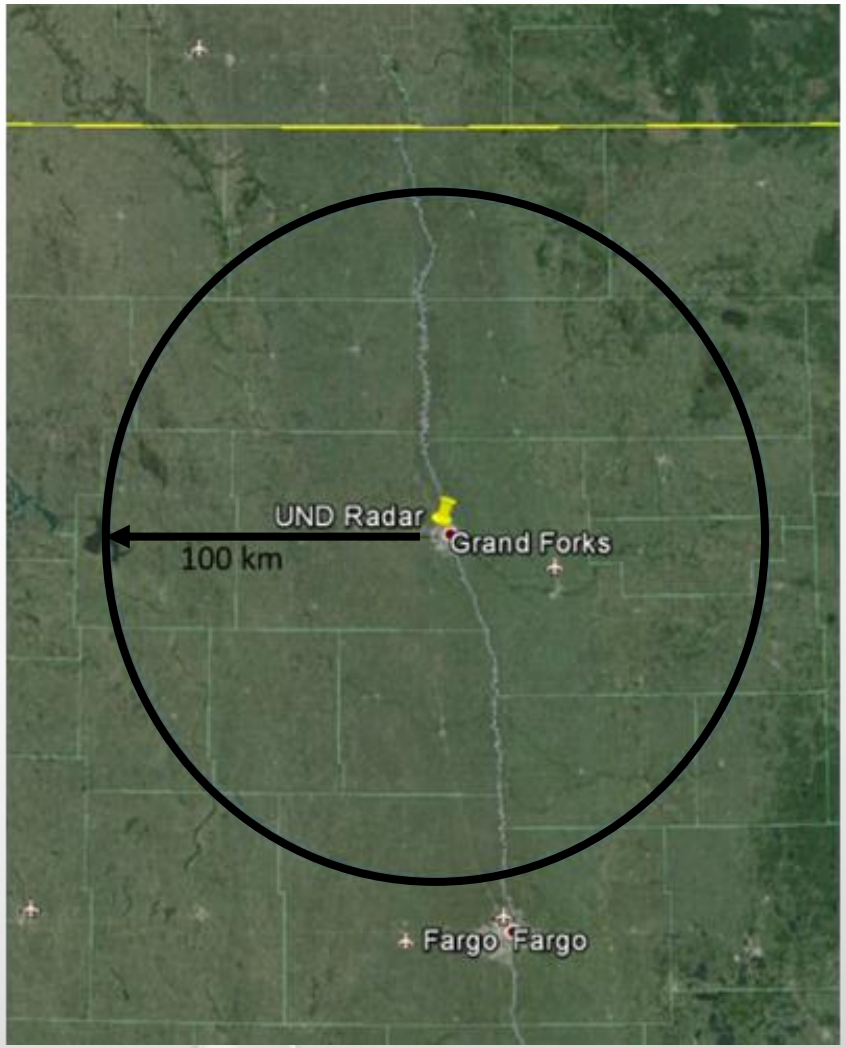
Would hygroscopic flares benefit North Dakota?

POLarimetric Cloud Analysis and Seeding Test

- The first POLCAST project in 2006 had the main objective to determine if a signature could be seen in clouds seeded with hygroscopic flares.
- Randomly seed/sample convective target clouds within 100 km of the UND radar.
- Hygroscopic flares are burned at cloud base when a case is called as seed.
- Cloud base measurements (cloud condensation nuclei (CCN) concentration, temperature and pressure altitude) taken from instruments on the aircraft in seed and non-seed cases.

NorthPol C-Band Radar:





How a POLCAST Case is Called

Is the environment promising for convection in the defined area?

No

No flights occur.

Yes

The seeding aircraft take off from Fargo toward the location of a possible target.

Do any clouds in the area have the following characteristics?

- An updraft of 500 ft/min (determined by the pilot)
- A rain free base
- Cloud base temperature between 0 ºC and 20 ºC
- Evidence of growth in the early stage of development.

No

Look around for another possible target.

No, another cloud is not found.

End the day.

Yes, another cloud is found.

Yes

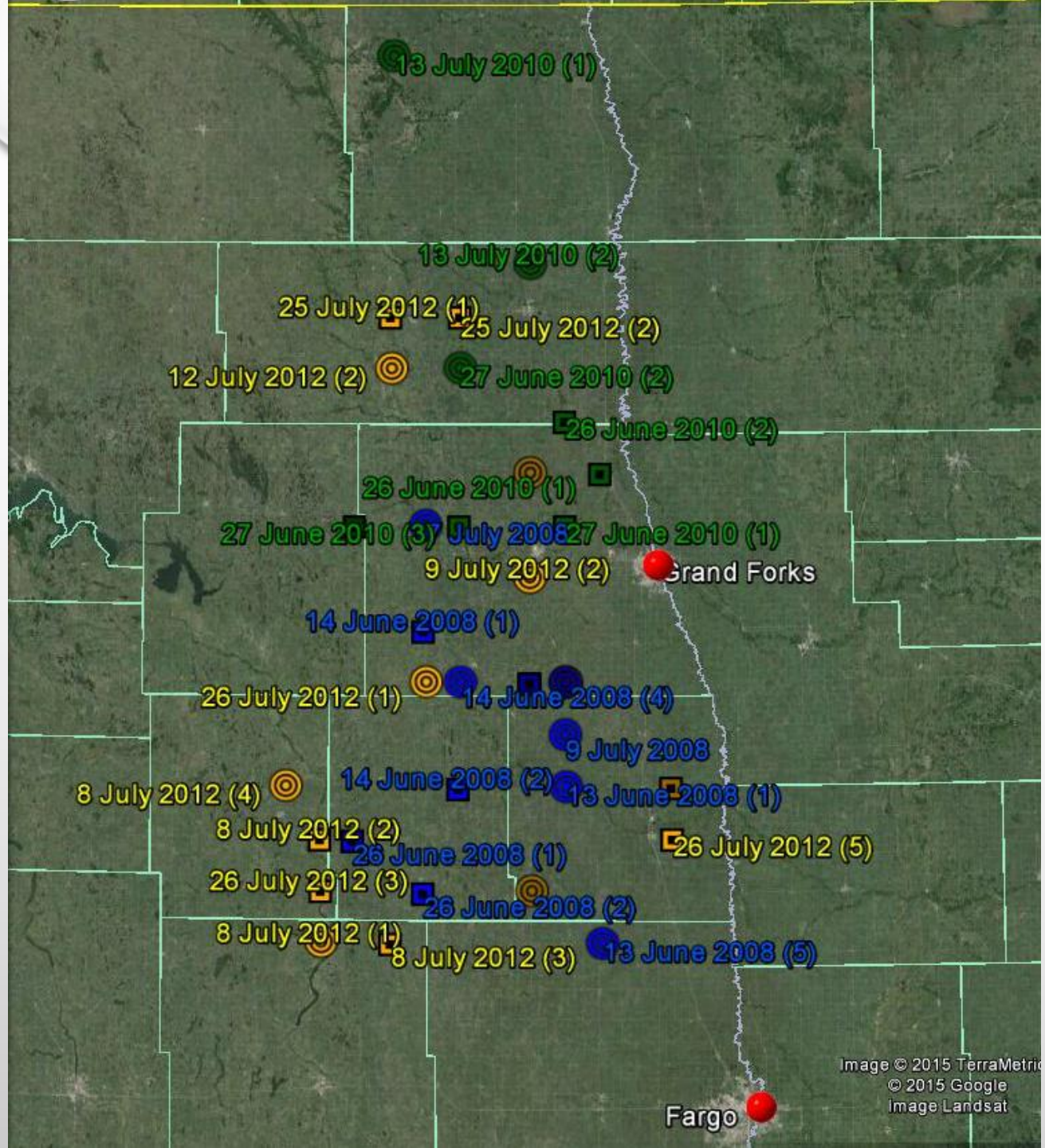
Decide if the target will be called as a case and open an envelope to determine if the case is seed or non-seed.

Seed

Circle in the updraft to define an area of influence and light flares to seed the cloud for ≈12 minutes. Sample the cloud.

Non-Seed

Circle in the updraft to define an area of influence and sample the cloud for ≈12 minutes.



North Dakota Cloud Targets

2008 ● Seed ■ Non-Seed

2010 ● Seed ■ Non-Seed

2012 ● Seed ■ Non-Seed

Total Cases:

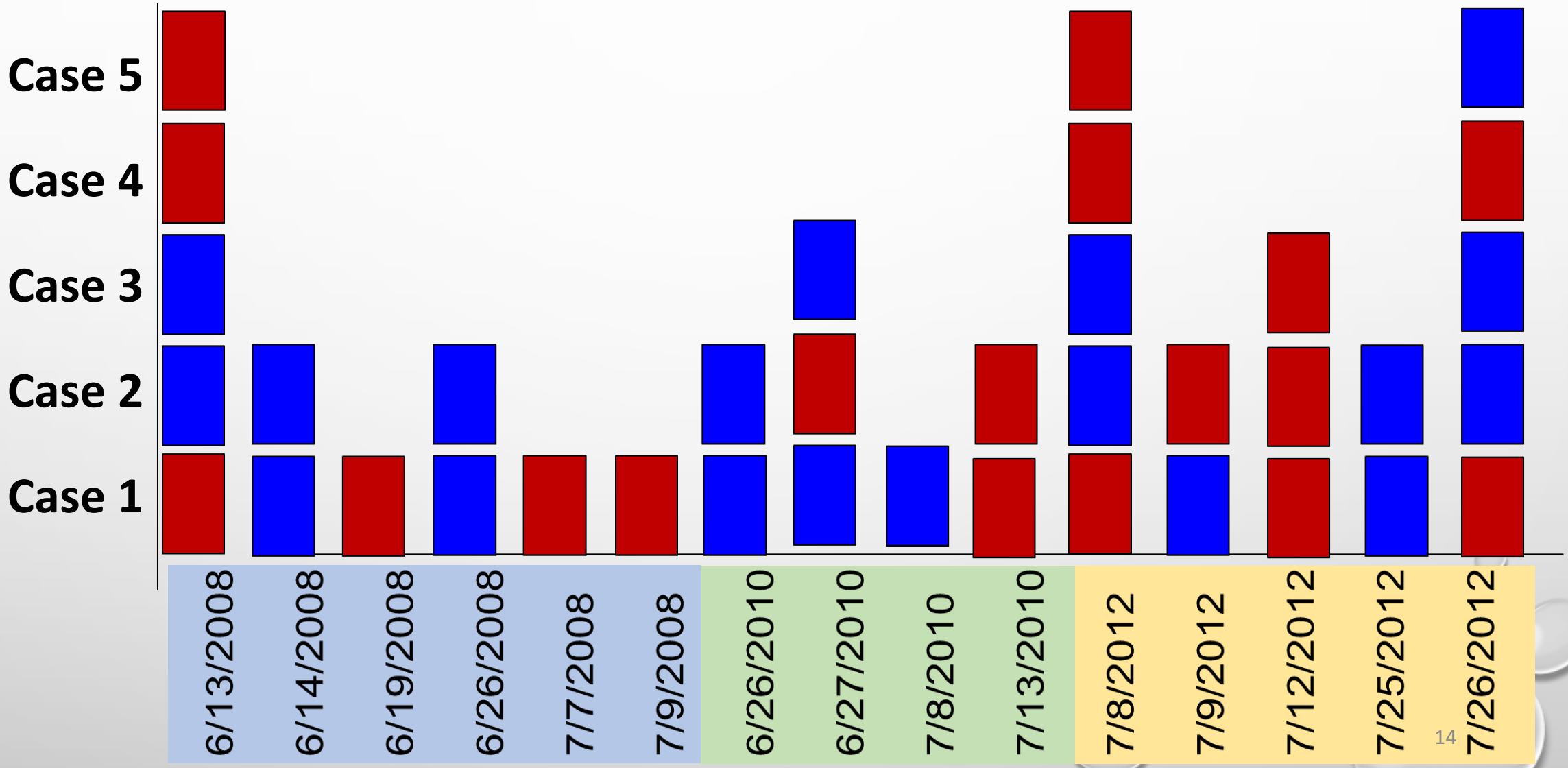
19 Non-Seed Cases

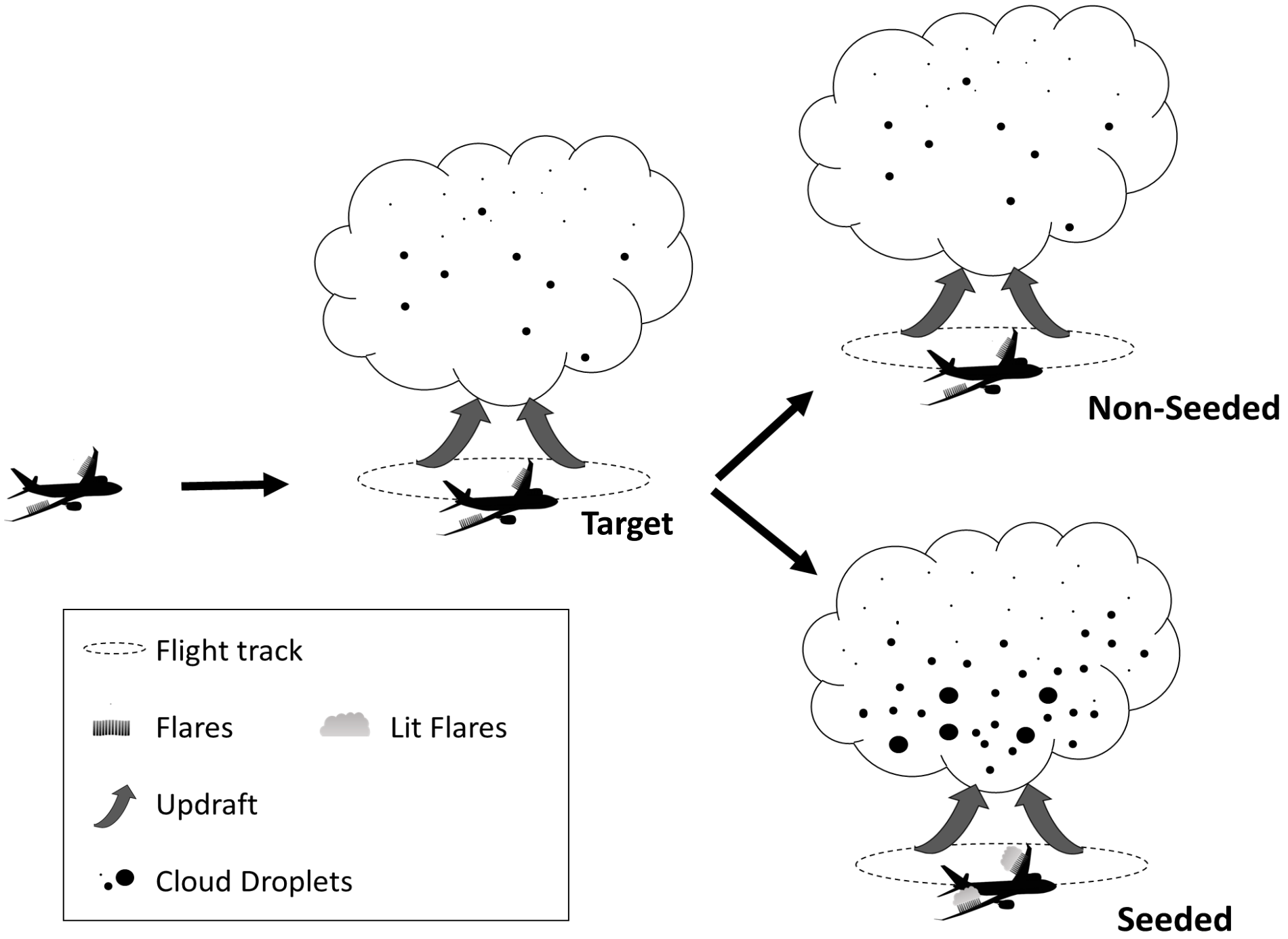
18 Seed Cases

Data

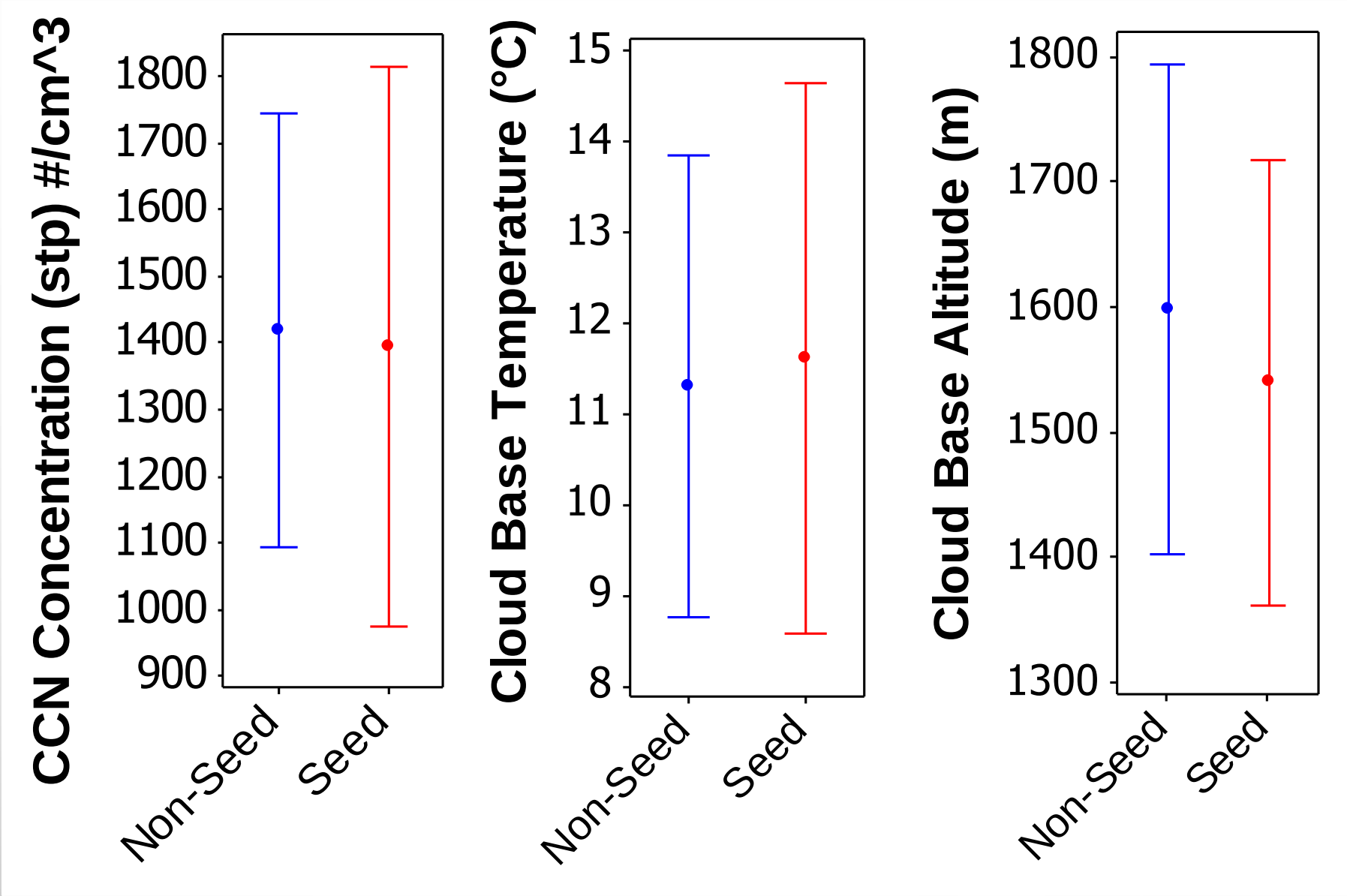
Seeded Case

Non-Seeded Case




Target
Non-Seeded
Seeded
Flight track
Flares
Lit Flares
Updraft
Cloud Droplets

POLCAST Target Distribution



Mann-Whitney Statistical Test Results

Ranks: Cloud Base Cloud Condensation Nuclei Concentration for 2008, 2010, and 2012 combined		
	Non-Seed Cases	Seed Cases
Number of Cases	19	18
Mean Rank	19.87	18.08
Sum of Ranks	377.50	325.50
Mann-Whitney Test Statistic	**154.5**	
Significance	0.621	

Ranks: Cloud Base Temperature for 2008, 2010, and 2012 combined		
	Non-Seed Cases	Seed Cases
Number of Cases	19	18
Mean Rank	18.08	19.97
Sum of Ranks	343.50	359.50
Mann-Whitney Test Statistic	**153.5**	
Significance	0.599	

Ranks: Cloud Base Cloud Pressure Altitude for 2008, 2010, and 2012 combined		
	Non-Seed Cases	Seed Cases
Number of Cases	19	18
Mean Rank	19.66	18.31
Sum of Ranks	373.5	329.5
Mann-Whitney Test Statistic	**158.5**	
Significance	.707	

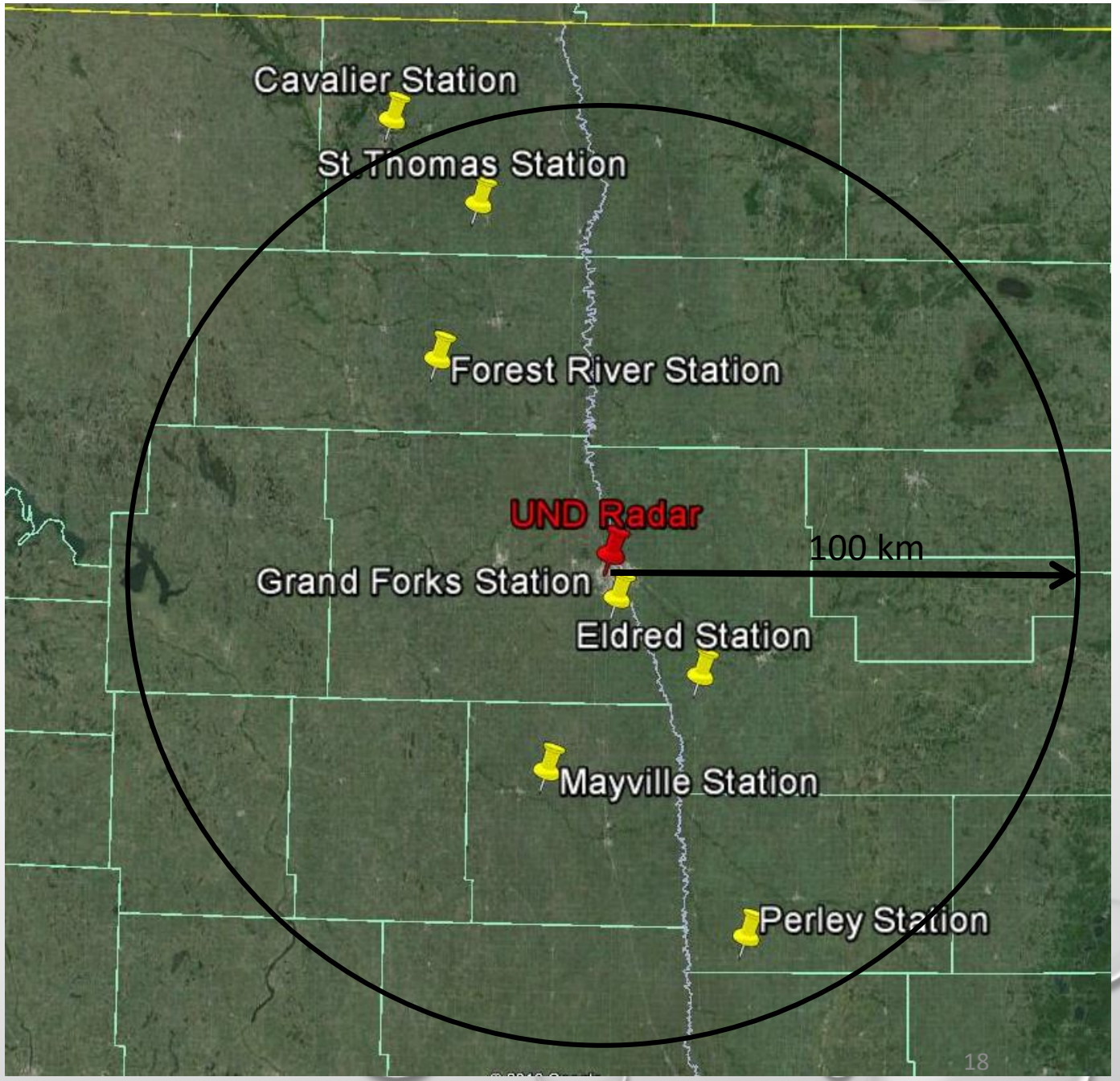
NDAWN Stations

Minnesota:

- Eldred
- Perley

North Dakota:

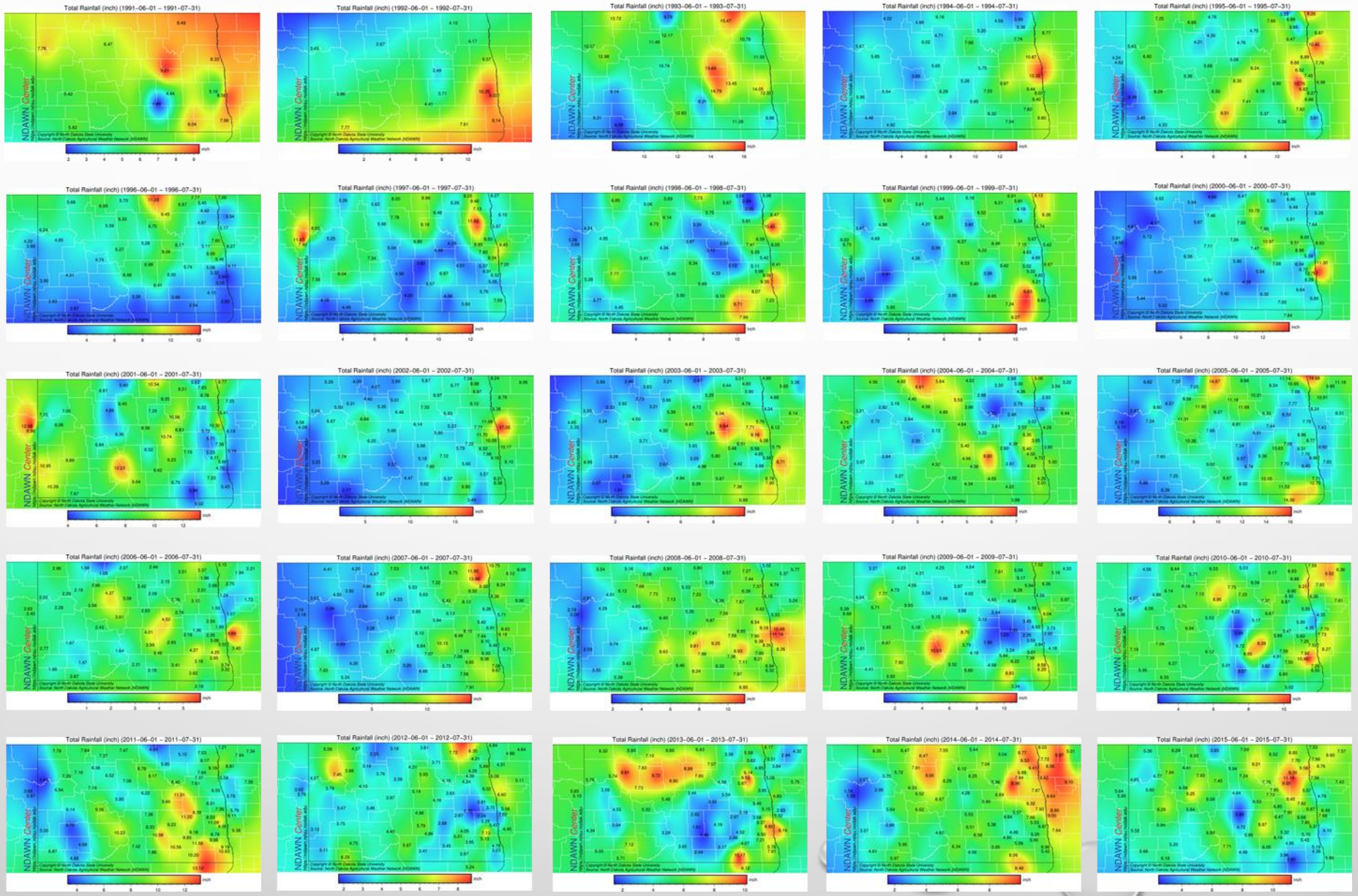
- Cavalier
- Forest River
- Grand Forks
- Mayville
- St. Thomas



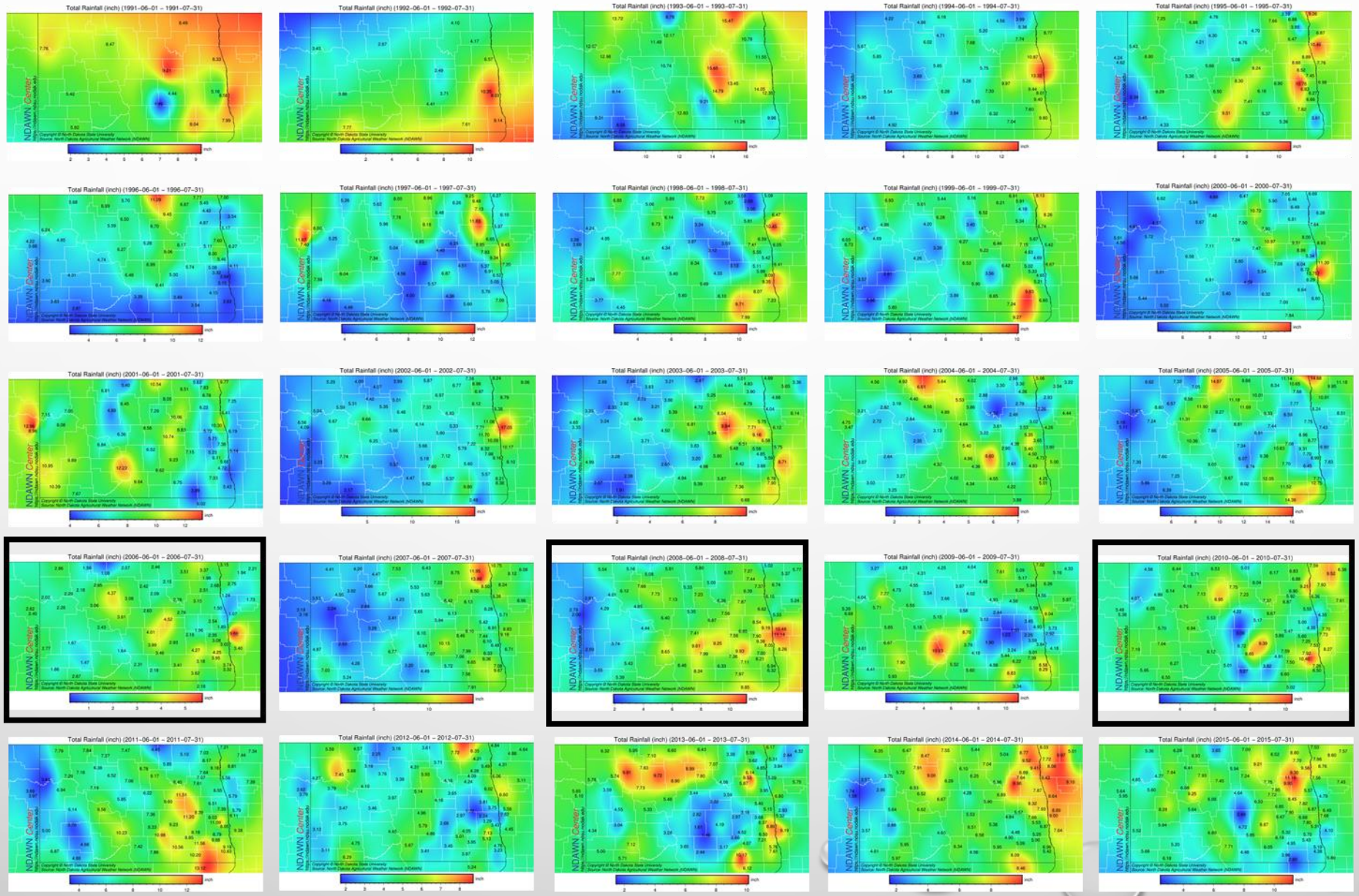
Average Percentage of Rainfall (April – October)

Station and Years of Data	June	July	June and July
Cavalier, ND (1993-2015)	20 %	19 %	39 %
Mayville, ND (1995-2015)	18 %	18 %	36 %
Grand Forks, ND (1990-2015)	21 %	18 %	39 %
St. Thomas, ND (1994-2015)	20 %	19 %	39 %
Forest River, ND (1991-2015)	20 %	19 %	39 %
Perley, MN (1995-2015)	20 %	18 %	38 %
Eldred, MN (1995-2015)	20 %	18 %	38 %

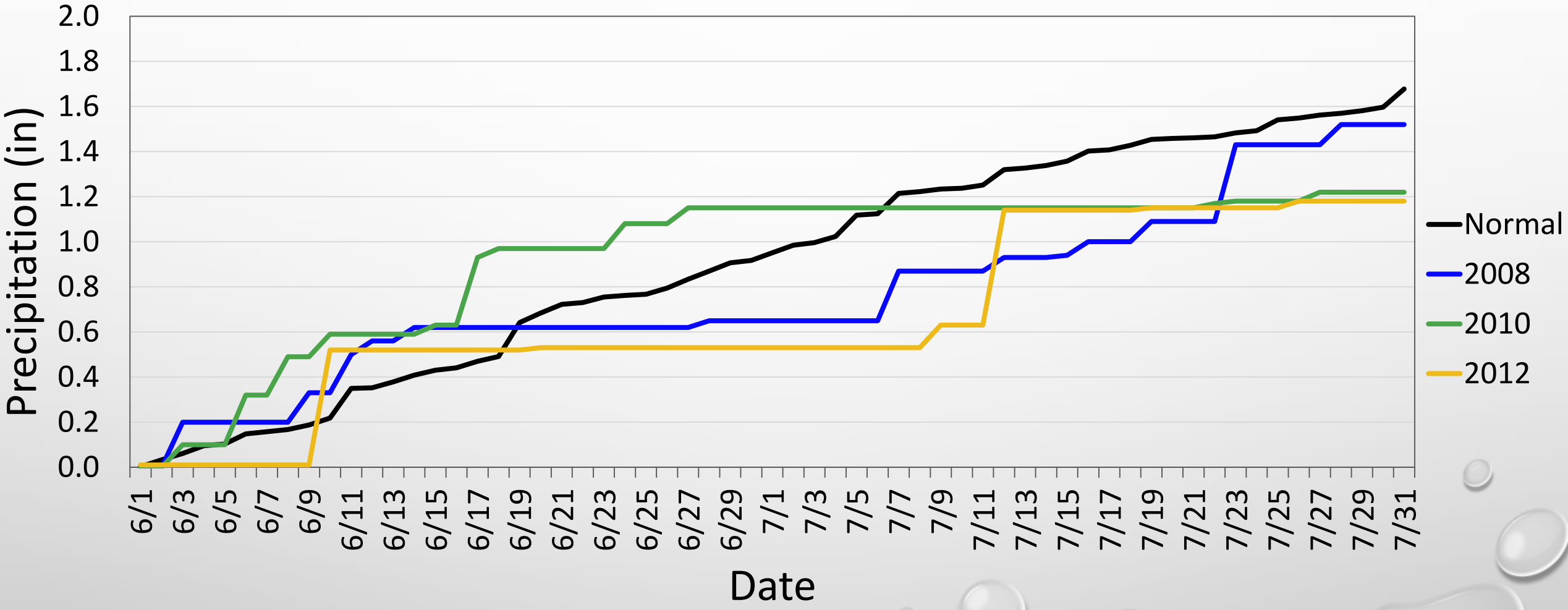
Total Rainfall : 1991 - 2015



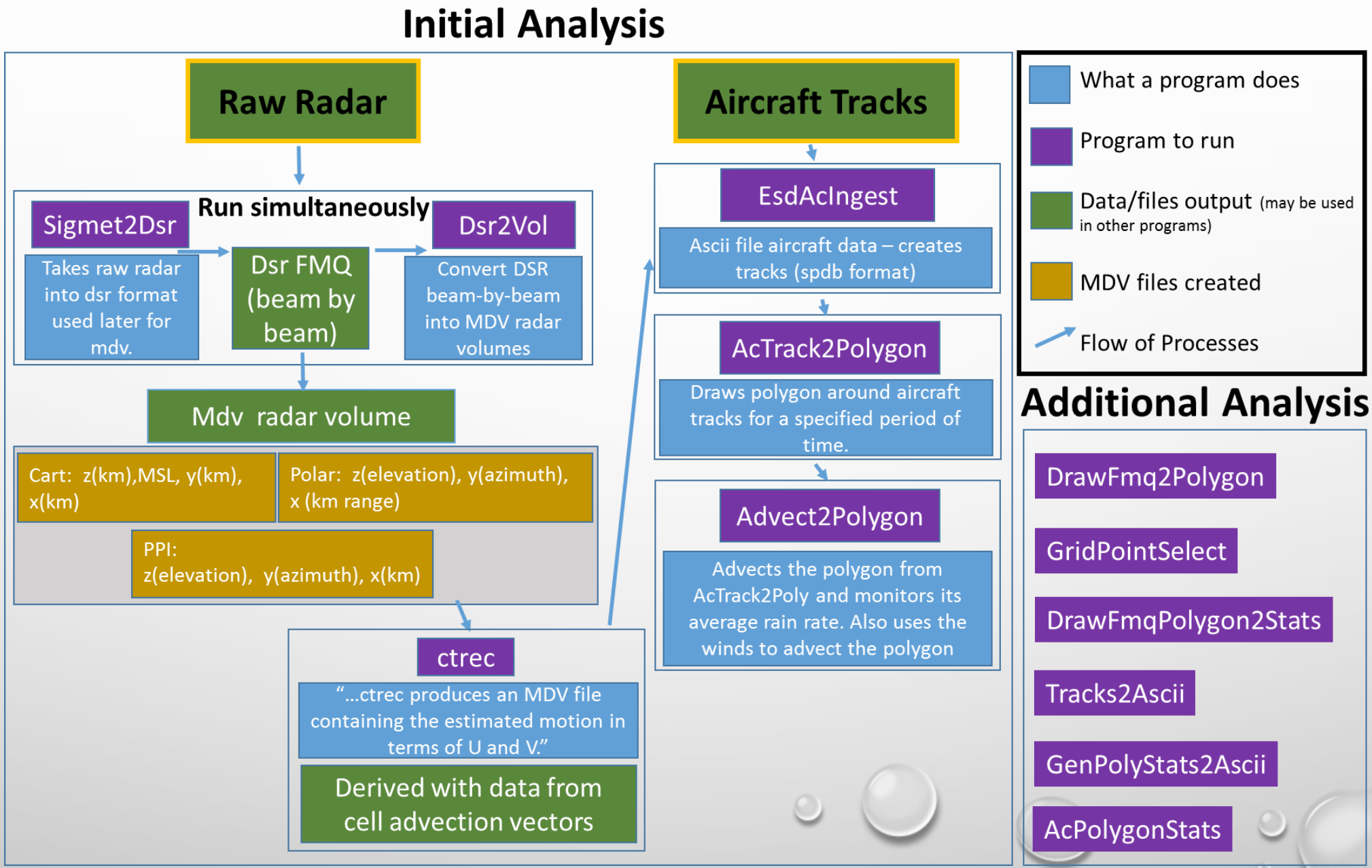
Total Rainfall : 1991 - 2015



Grand Forks: 1990-2015



TITAN Scripts for Analysis of the POLCAST Field Projects



Analysis of POLCAST with TITAN:

Reflectivity (Z): The amount of echo intensity returned to the radar after hitting precipitation in units of dBZ.
Differential reflectivity (ZDR): The difference between horizontal and vertical reflectivity in units of dBZ.

Calculate rain rate

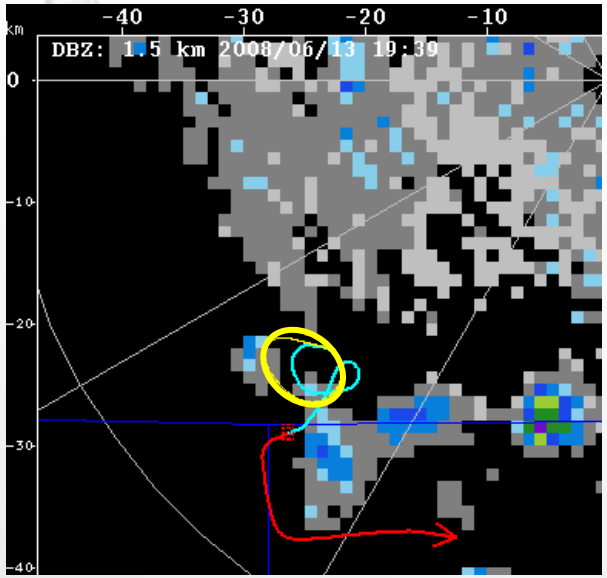
Z-R Relationship Equation used for Summer Deep Convection

$$Z = 300 * R^{1.4}$$

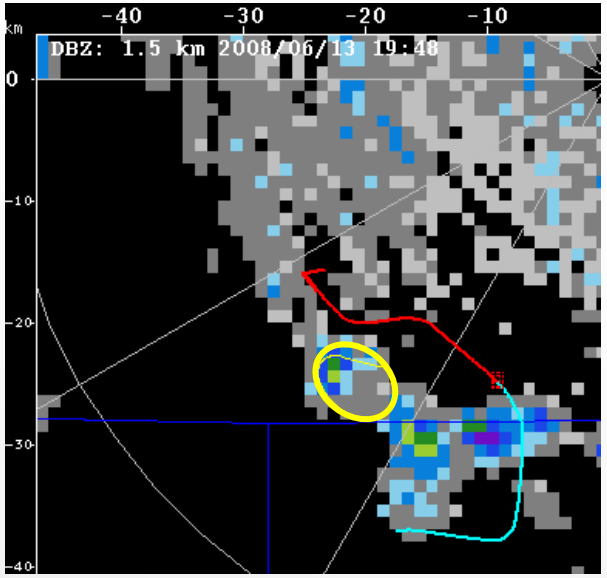
Z = reflectivity (mm^6/m^3)
R = Rain rate in mm/hr

Seeding Area Track

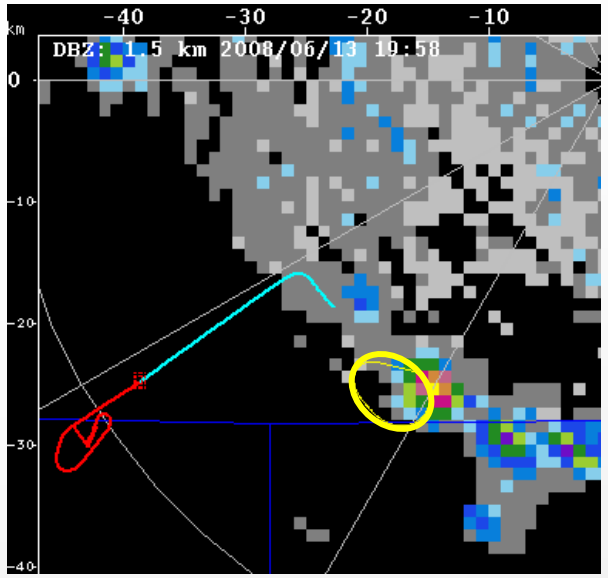
June 13, 2008 **19:39**



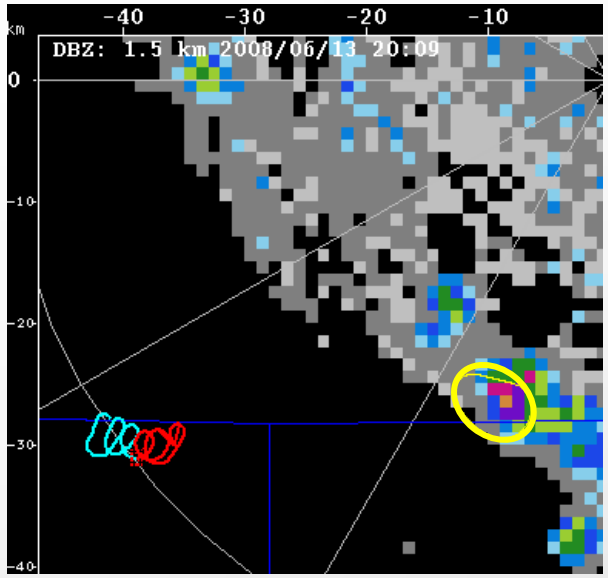
June 13, 2008 **19:48**



June 13, 2008 **19:58**



June 13, 2008 **20:09**



Analysis of the Seeding Track:

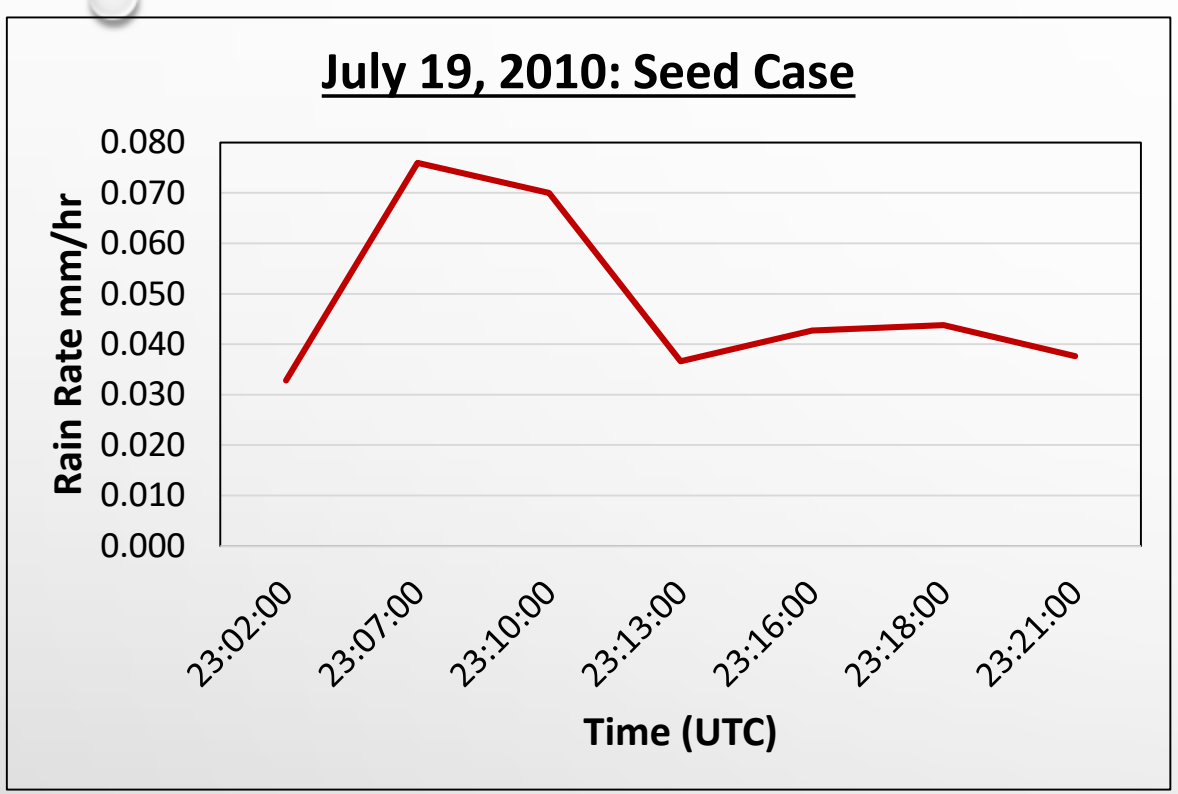
Use AcTrackPolygon to draw a polygon around the seeding area

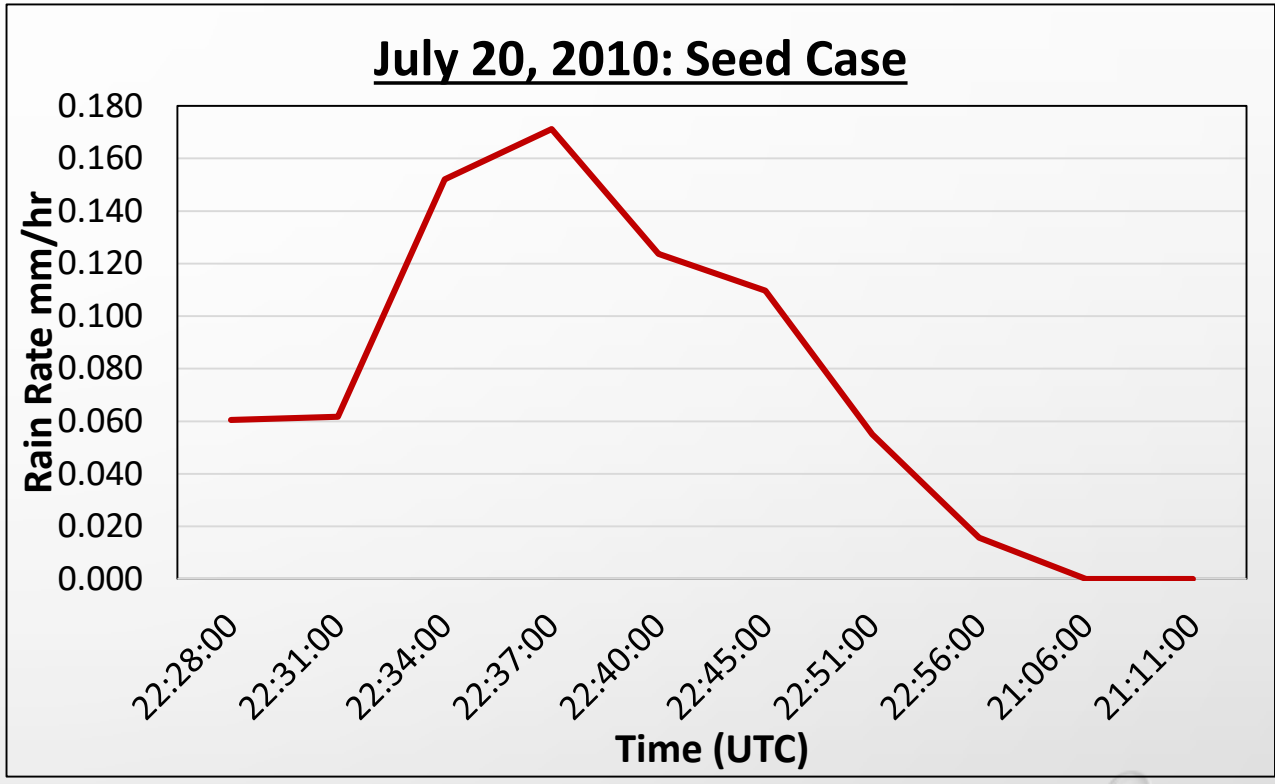
Use AdvectPolygon to advect a polygon around time of the seeding and track over a defined time period.

Look at the reflectivity in the polygon – see how it changes over time.

Analyze differences in seeded vs. non-seeded cases

Preliminary Results





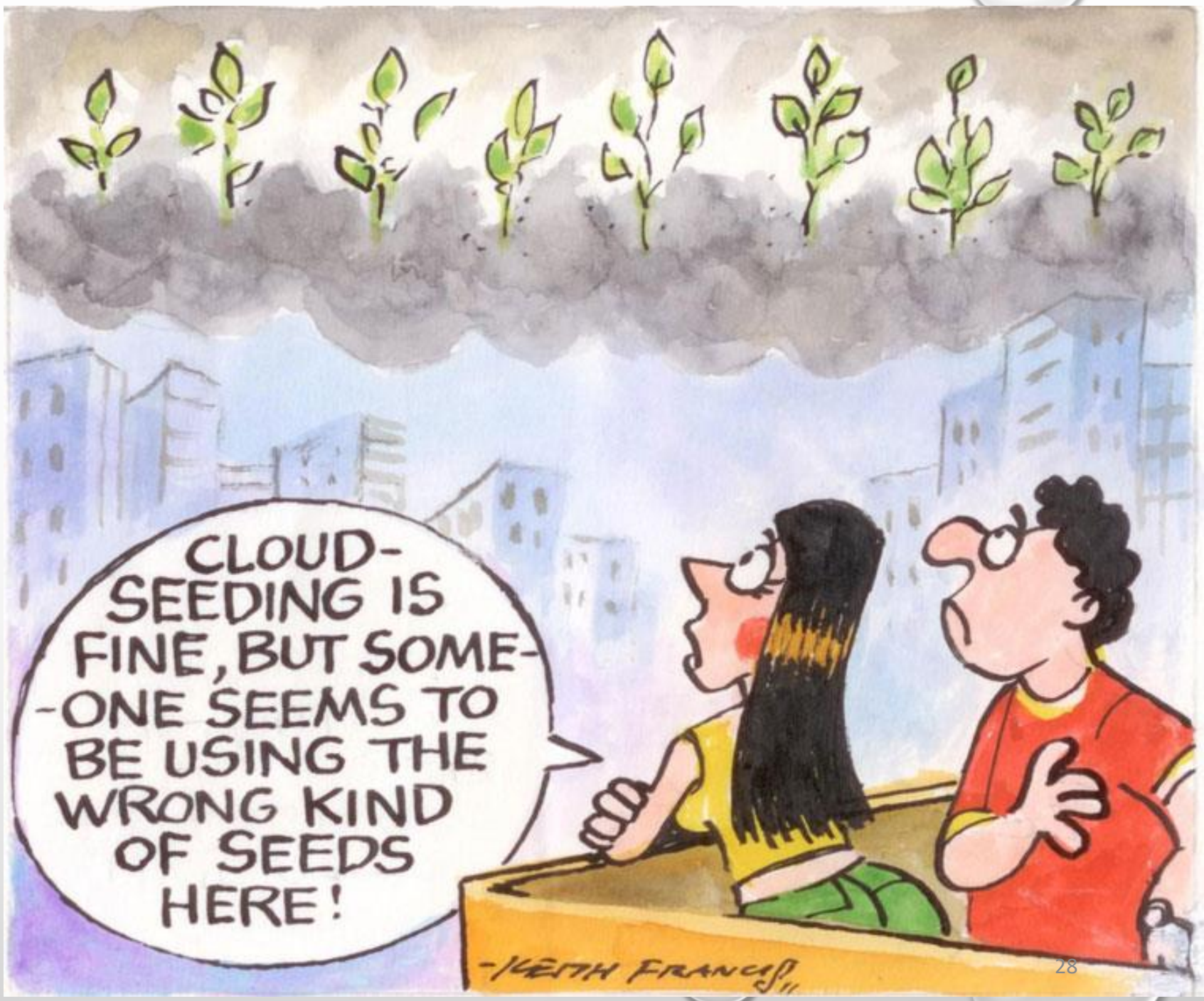
Conclusions

- Environmental factors are distributed in seed and non-seed cases.
- Grand Forks, North Dakota receives 20 percent in June and 18 percent in July of the total rainfall between April and October (calculated from NDAWN station data).
- Rainfall in eastern North Dakota was typical during June and July of 2008, 2010, and 2012.

Future Work

- Complete the TITAN analysis.
- Bootstrap rain rate data to create new sets of data – varying in statistical significance.
- Determine feasibility of hygroscopic seeding in North Dakota.

Questions?


CLOUD-SEEDING IS FINE, BUT SOME-ONE SEEMS TO BE USING THE WRONG KIND OF SEEDS HERE!
-KEITH FRANCIS

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DeBartolo, Don, and About Don DeBartoloDon C. DeBartolo Is a Series 3 Licensed Broker Registered with the National Futures Association (NFA). As a Former Arbitrage Clerk in the S&P 500 Futures Pit at the Chicago Mercantile Exchange (CME), Don Has Floor Trading Experience. Ta. "Market Spotlight: Canola." *Daniels Trading*. N.p., 27 Apr. 2016. Web. 16 Apr. 2017 . <https://www.danielstrading.com/market-analysis/2014/02/26/market-spotlight-canola>.

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Acknowledgement:

North Dakota Atmospheric Research Board for sponsoring the POLCAST field projects and data analysis.
Weather Modification International for sponsoring my attendance to the 2017 WMA Meeting.

Total POLCAST Cases - Seed: 21 Non-Seed: 23

Seed: 7 Non-Seed: 6

POLCAST2

Date	Type	Echo
13 Jun 2008	Seed	Yes
13 Jun 2008	Non-Seed	Yes
13 Jun 2008	Non-Seed	Yes
13 Jun 2008	Seed	No
13 Jun 2008	Seed	Yes
14 Jun 2008	Non-Seed	Yes
14 Jun 2008	Non-Seed	No
19 Jun 2008	Seed	No
21 Jun 2008	Seed	Yes
26 Jun 2008	Non-Seed	Yes
26 Jun 2008	Non-Seed	No
07 Jun 2008	Seed	Yes
09 Jun 2008	Seed	Yes

6 Cases Analyzed

Seed: 5 Non-Seed: 9

POLCAST3

Date	Type	Radar Echo
24 Jun 2010	No Seed	Yes
26 Jun 2010	No Seed	Yes
26 Jun 2010	No Seed	No
27 Jun 2010	No Seed	Yes
27 Jun 2010	Seed	Yes
27 Jun 2010	No Seed	Yes
8 July 2010	No Seed	Yes
13 July 2010	Seed	Yes
13 July 2010	Seed	Yes
19 July 2010	No Seed	Yes
19 July 2010	Seed	Yes
20 July 2010	No Seed	Yes
20 July 2010	Seed	Yes
20 July 2010	No Seed	No

Seed: 9 Non-Seed: 8

POLCAST4

Date	Type	Radar Echo
8 July 2012	Seed	Yes
8 July 2012	No Seed	Yes
8 July 2012	No Seed	Yes
8 July 2012	Seed	Yes
8 July 2012	Seed	Yes
9 July 2012	No Seed	Yes
9 July 2012	Seed	Yes
12 July 2012	Seed	Yes
12 July 2012	Seed	Yes
12 July 2012	Seed	Yes
25 July 2012	No Seed	Yes
25 July 2012	No Seed	Yes
26 July 2012	Seed	Yes
26 July 2012	No Seed	Yes
26 July 2012	No Seed	Yes
26 July 2012	Seed	Yes
26 July 2012	No Seed	Yes

Single Ratio

$$SR = \sum \frac{Seeded\ Measurements}{Number\ of\ Seeded\ Cases} / \sum \frac{Nonseeded\ Measurements}{Number\ of\ Nonseed\ Cases}$$

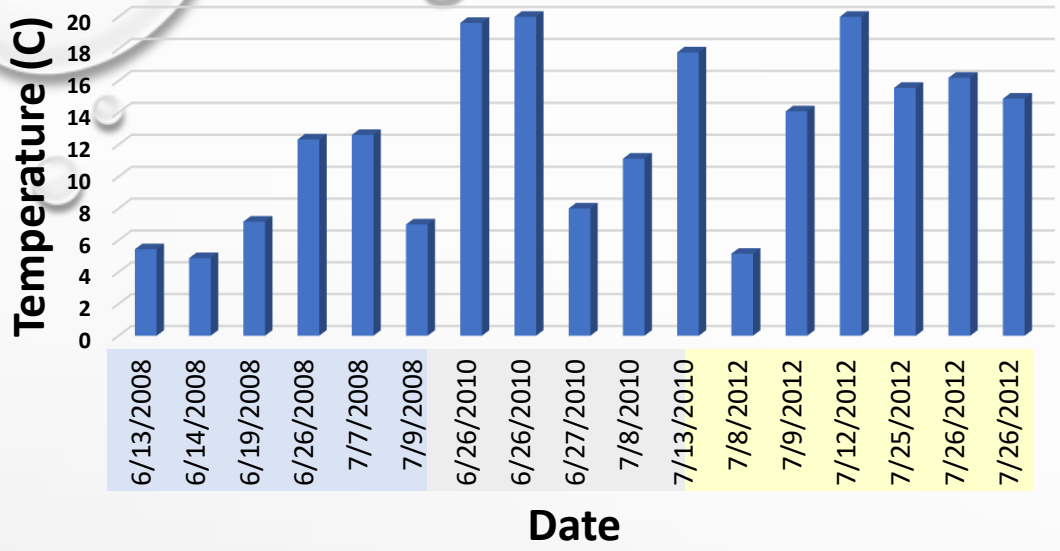
Environmental Factor	Number of Non Seed Cases	Sum of measurements of environmental factors.	Number of Seed Cases	Sum of measurements of environmental factors.	Single Ratio
Cloud Base Temperature	19	208.8	18	214.8	1.03
Cloud Base Pressure Altitude	19	27,697.8	18	30,344.8	0.96
Cloud Base Cloud Condensation Nuclei Concentration	19	25,085.9	18	26,974.2	0.98

$Temp$: $\frac{Seed}{NonSeed} = \frac{214.8}{208.8} = 1.03 = \Delta\ 3\%$

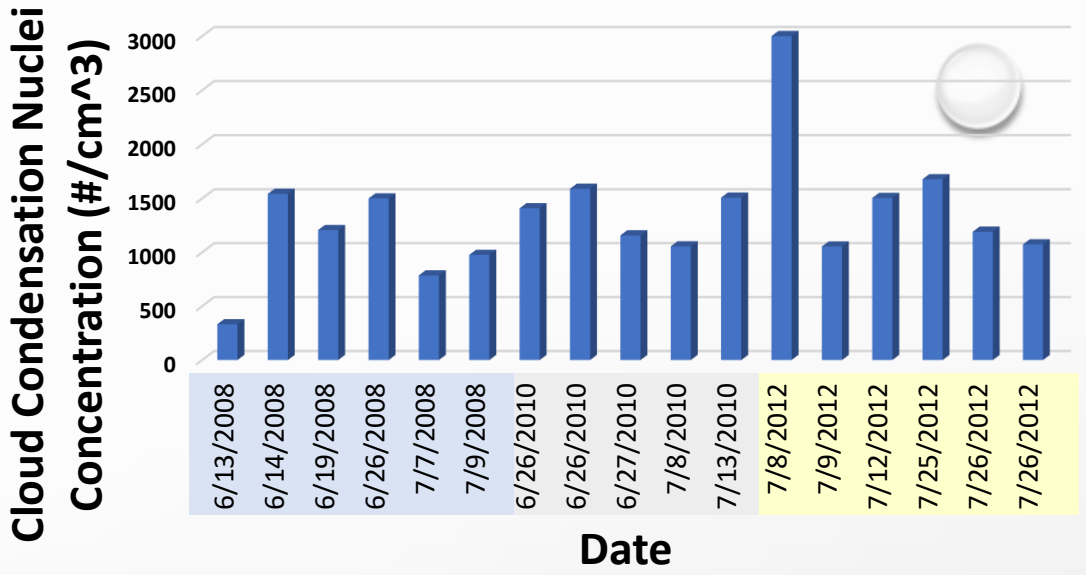
$Pres.Alt$: $\frac{Seed}{NonSeed} = \frac{25085.2}{25085.9} = 1.08 = \Delta\ 8\%$

CCN: $\frac{Seed}{NonSeed}$ =30344.8/27697.8=1.10= Δ 10%

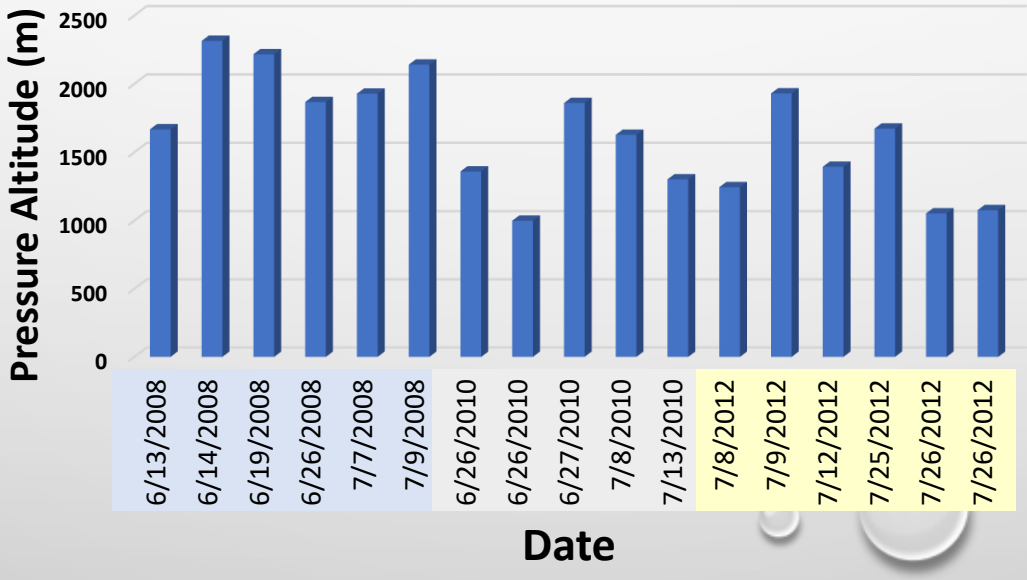
Mean Cloud Base Temperature



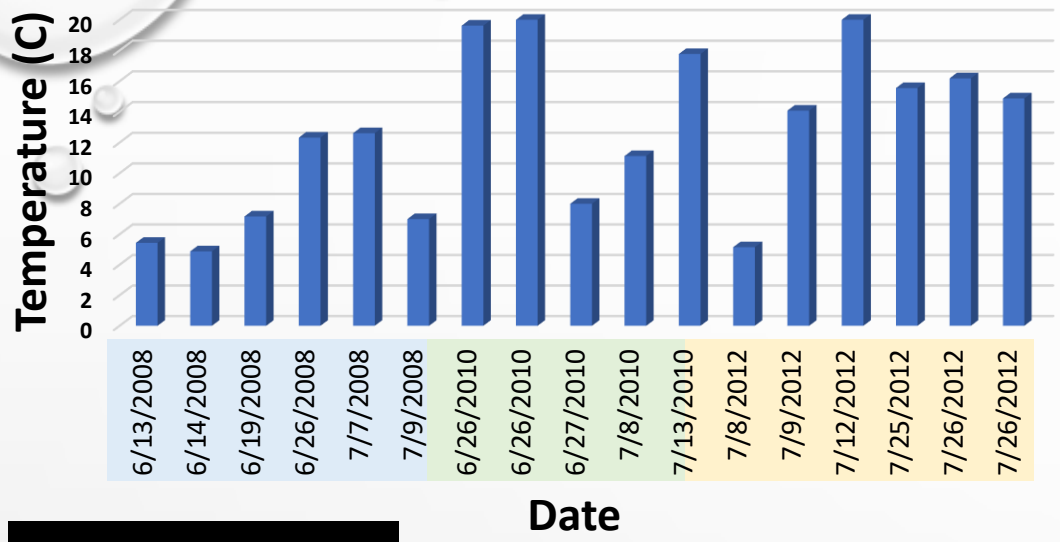
Mean Cloud Base CCN



Mean Cloud Base Pressure Altitude

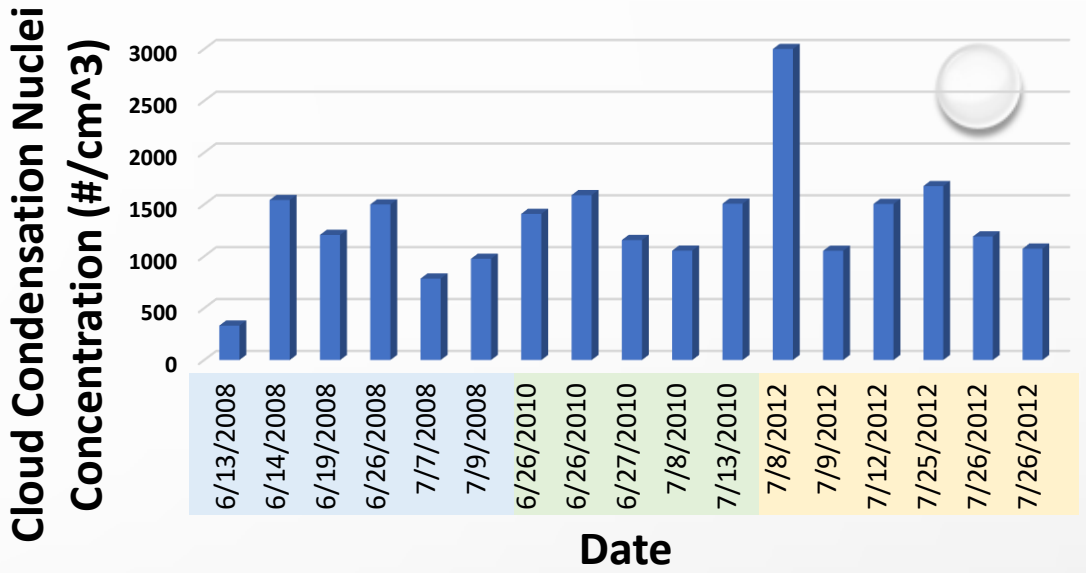


Mean Cloud Base Temperature



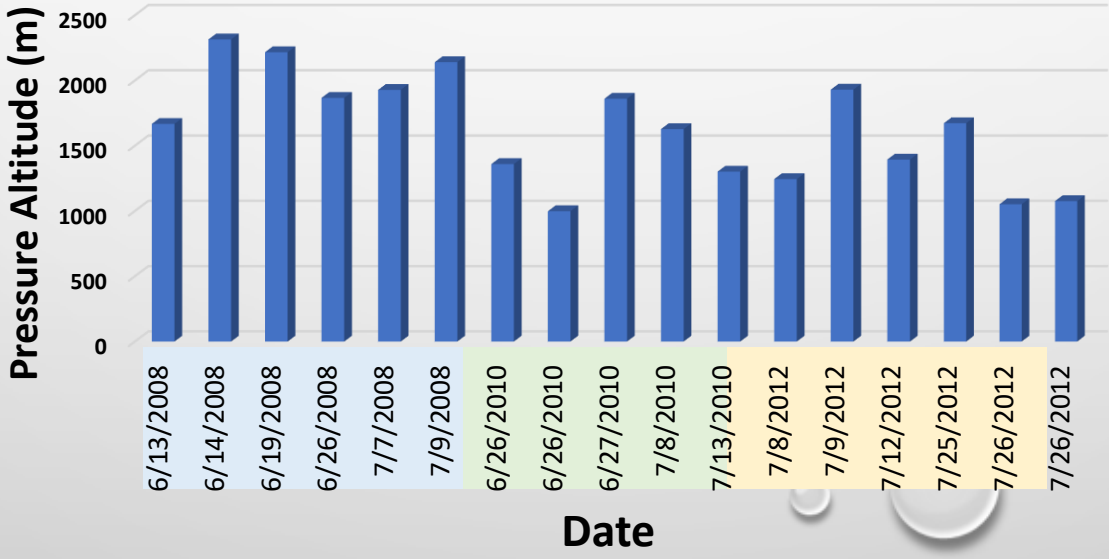
Average = 13 C

Mean Cloud Base CCN



Average = 1330 #/cm^3

Mean Cloud Base Pressure Altitude



Average = 1630 m

Measurement	Average Value: Seed Days	Average Value: Non-Seed Days	Percent Difference
Cloud Base Temperature	11 ºC	12 ºC	7.8 %
Cloud Base Pressure Altitude	1673 m	1556 m	7.3 %
Cloud Base Cloud Condensation Nuclei Concentration	1271 #/cm^3	1381 #/cm^3	8.3 %

1 measurement from each day a flight took place

Mann-Whitney Statistical Test

$$U = n_1 n_2 + \frac{n_2(n_2+1)}{2} - \sum_{i=n_1+1}^{n_2} R_i$$

U=Mann-Whitney U test

n_1 = Sample size one

n_2= Sample size two

R_i = Rank of the sample size

Mann-Whitney Statistical Test

$$U = n_1 n_2 + \frac{n_2(n_2+1)}{2} - \sum_{i=n_1+1}^{n_2} R_i$$

U=Mann-Whitney U test

n_1 = Sample size one **(SEED)**

n_2= Sample size two **(NON-SEED)**

R_i = Rank of the sample size

Null hypothesis = distributions of both the seed and non-seed cases are identical.

Statistical Tests : Mann-Whitney U Test

Alpha = 0.05 (two-tailed)

n1\n2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2							0	0	0	0	1	1	1	1	1	2	2	2	2
3				0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8
4			0	1	2	3	4	4	5	6	7	8	9	10	11	11	12	13	14
5		0	1	2	3	5	6	7	8	9	11	12	13	14	15	17	18	19	20
6		1	2	3	5	6	7	10	11	13	14	16	17	19	21	22	24	25	27
7		1	3	5	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
8	0	2	4	6	7	10	13	15	17	19	22	24	26	29	31	34	36	38	41
9	0	2	4	7	10	12	15	17	20	23	26	28	31	34	37	39	42	45	48
10	0	3	5	8	11	14	17	20	23	26	29	33	36	39	42	45	48	52	55
11	0	3	6	9	13	16	19	23	26	30	33	37	40	44	47	51	55	58	62
12	1	4	7	11	14	18	22	26	29	33	37	41	45	49	53	57	61	65	69
13	1	4	8	12	16	20	24	28	33	37	41	45	50	54	59	63	67	72	76
14	1	5	9	13	17	22	26	31	36	40	45	50	55	59	64	67	74	78	83
15	1	5	10	14	19	24	29	34	39	44	49	54	59	64	70	75	80	85	90
16	1	6	11	15	21	26	31	37	42	47	53	59	64	70	75	81	86	92	98
17	2	6	11	17	22	28	34	39	45	51	57	63	67	75	81	87	93	99	105
18	2	7	12	18	24	30	36	42	48	55	61	67	74	80	86	93	99	106	112
19	2	7	13	19	25	32	38	45	52	58	65	72	78	85	92	99	106	113	119
20	2	8	13	20	27	34	41	48	55	62	69	76	83	90	98	105	112	119	127

Statistical Tests : Mann-Whitney U Test

Alpha = 0.05 (two-tailed)

63	67	72	76
67	74	78	83
75	80	85	90
81	86	92	98
87	93	99	105
93	99	106	112
99	106	113	119
105	112	119	127

Property	Test Statistic (U)
Mean Cloud Base CCN Concentration	154.5
Mean Cloud Base Temperature	153.5
Mean Cloud Base Altitude	158.5

If U > 106 accept the null hypothesis that properties are randomly distributed.

Statistical Tests : Mann-Whitney U Test

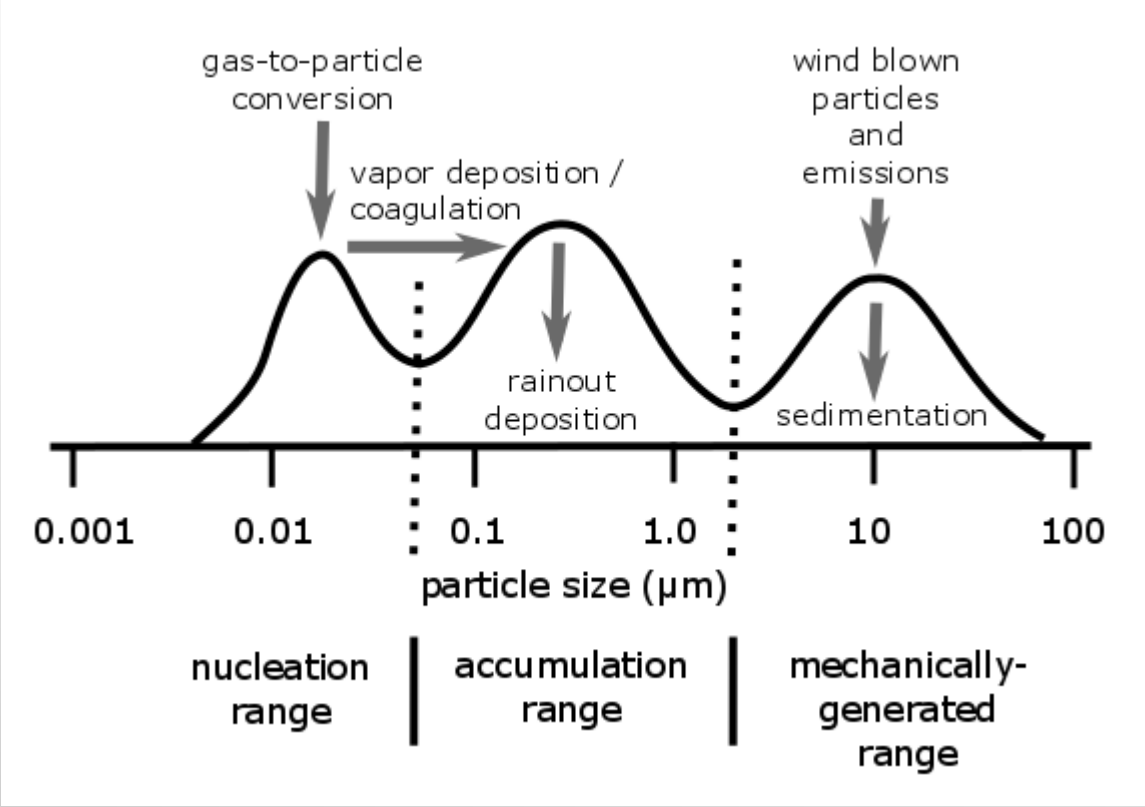
Alpha = 0.05 (two-tailed)

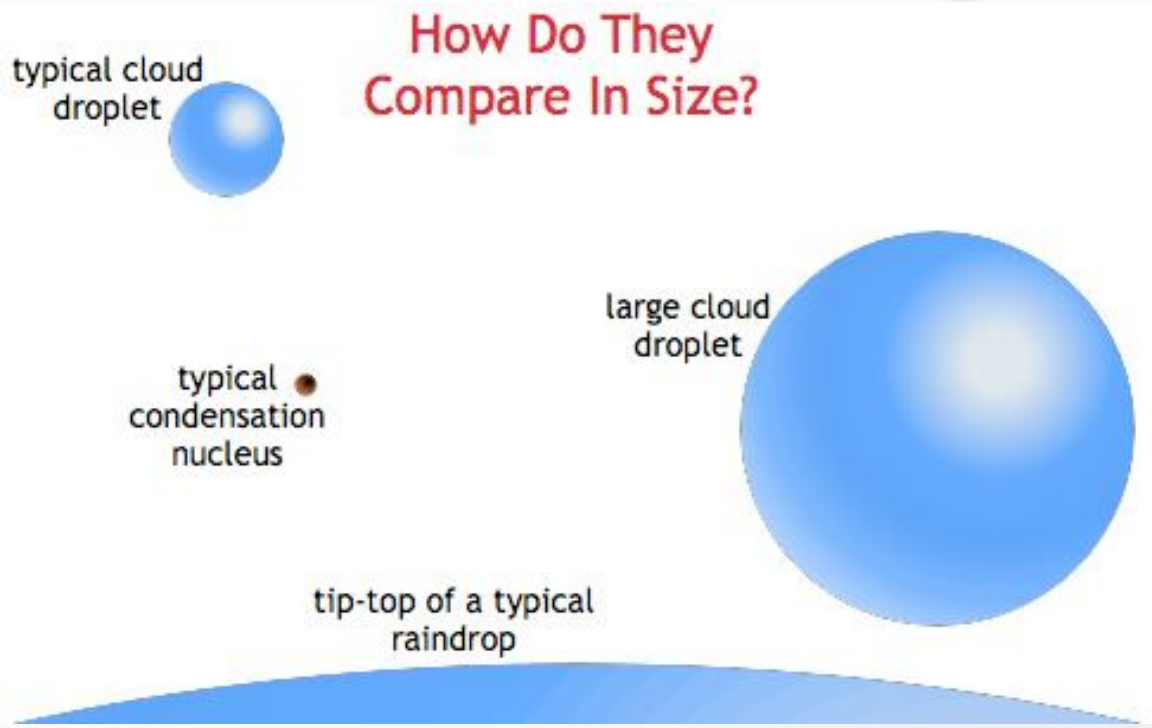
63	67	72	76
67	74	78	83
75	80	85	90
81	86	92	98
87	93	99	105
93	99	106	112
99	106	113	119
105	112	119	127

Property	Test Statistic (U)	Accept hypothesis?
Mean Cloud Base CCN Concentration	154.5	✓
Mean Cloud Base Temperature	153.5	✓
Mean Cloud Base Altitude	158.5	✓

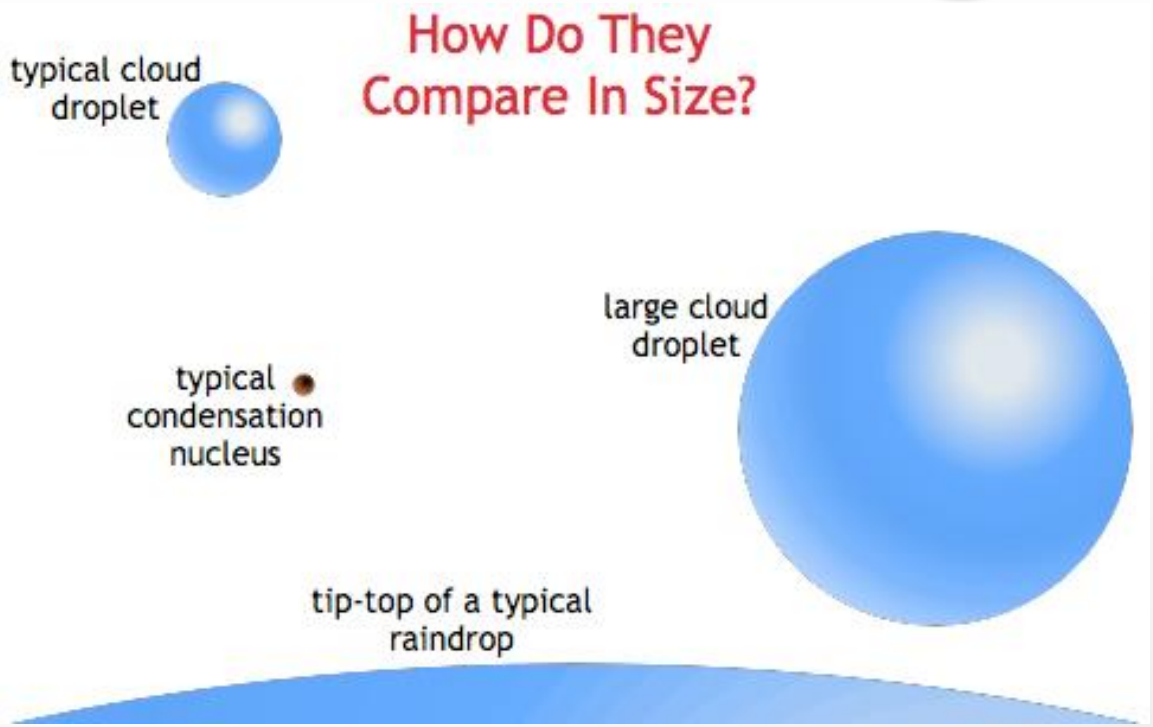
If U > 106 accept the null hypothesis that properties are randomly distributed.

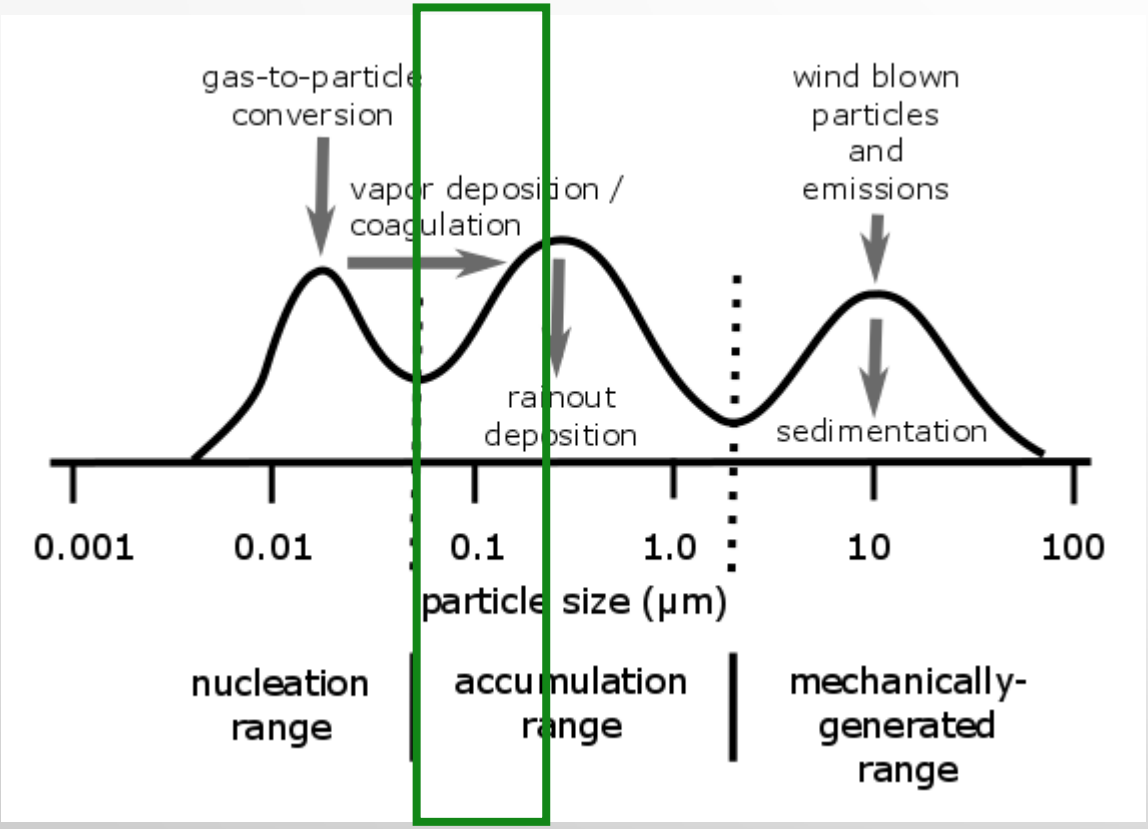
Importance of CCN Diameter For Raindrop Formation





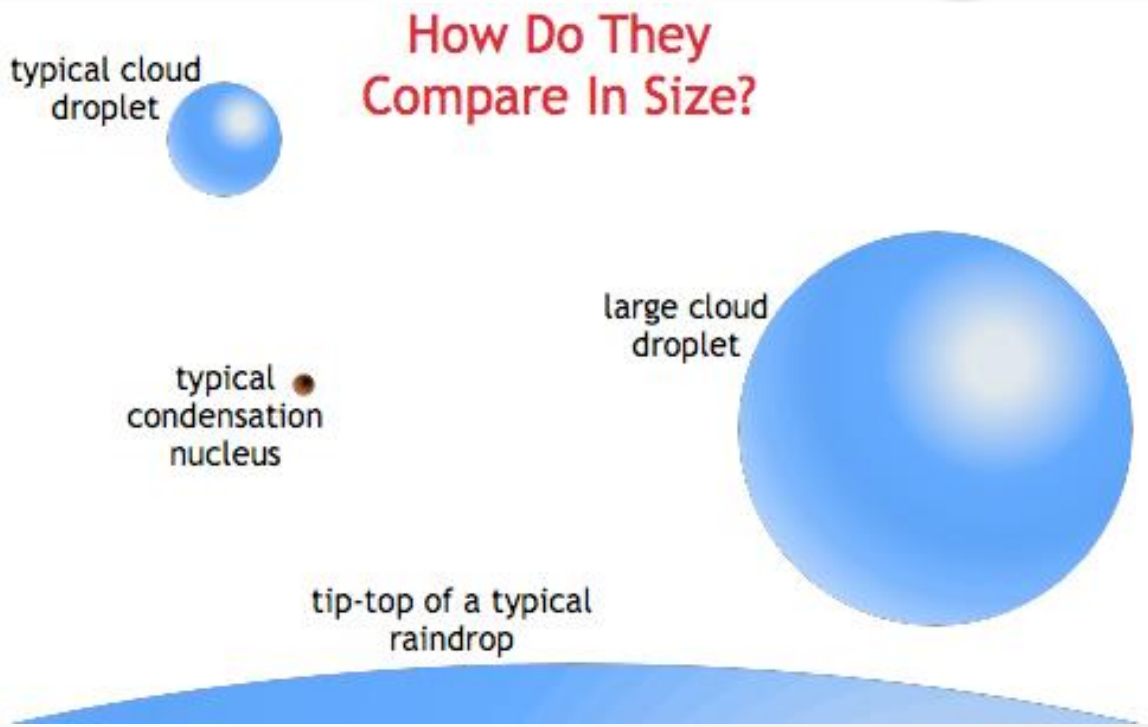
Importance of CCN Diameter For Raindrop Formation

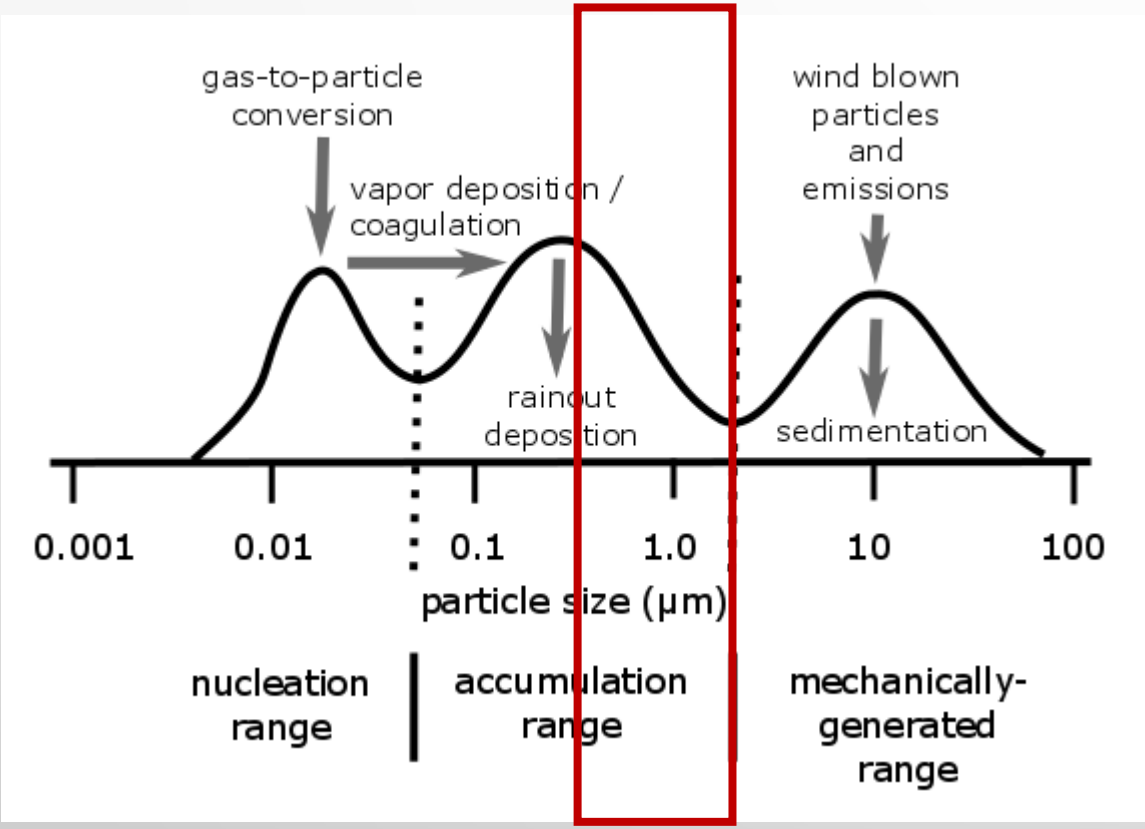




North Dakota clouds contain mainly nucleation size particles.

Importance of CCN Diameter For Raindrop Formation





Introduce more accumulation size particles to increase efficiency of precipitation formation.

Warm Cloud Rain Drop Formation: Collision and Coalescence