Statistical Evaluation of Weather Modification Programs

Compare Seeded Cloud to Unseeded Clouds

- Skeptics questioned whether the two classes of clouds were the same.
- Were the seeded clouds “better” than unseeded clouds?
- Randomization
  - Randomly seed and not seed clouds; afterwards, compare the two populations.
- Blind Experiments
  - The people carrying out the experiments could not tell whether they were seeding or not seeding.

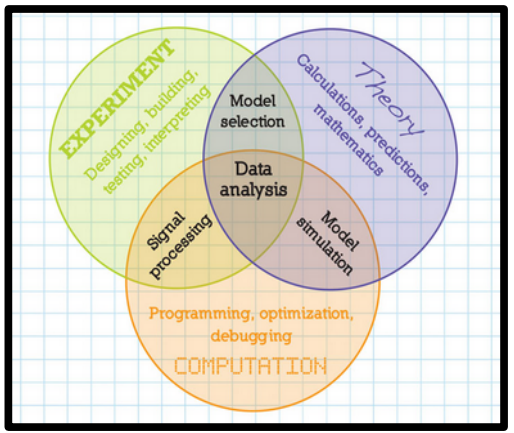
Initial Results – Statistical Studies

- The results were not nearly so spectacular as people were hoping.
- Many experiments showed no effects on precipitation.
  - There are a lot of ways to go about seeding a cloud.
  - Many of these seeding techniques may not be effective.
  - How can we tell how to optimize the seeding techniques?

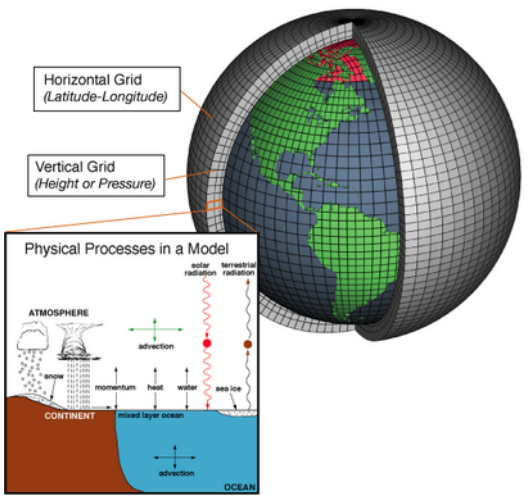
Types of Statistical Evaluations

- Black Box

- Physical Experiments



- Computer Model

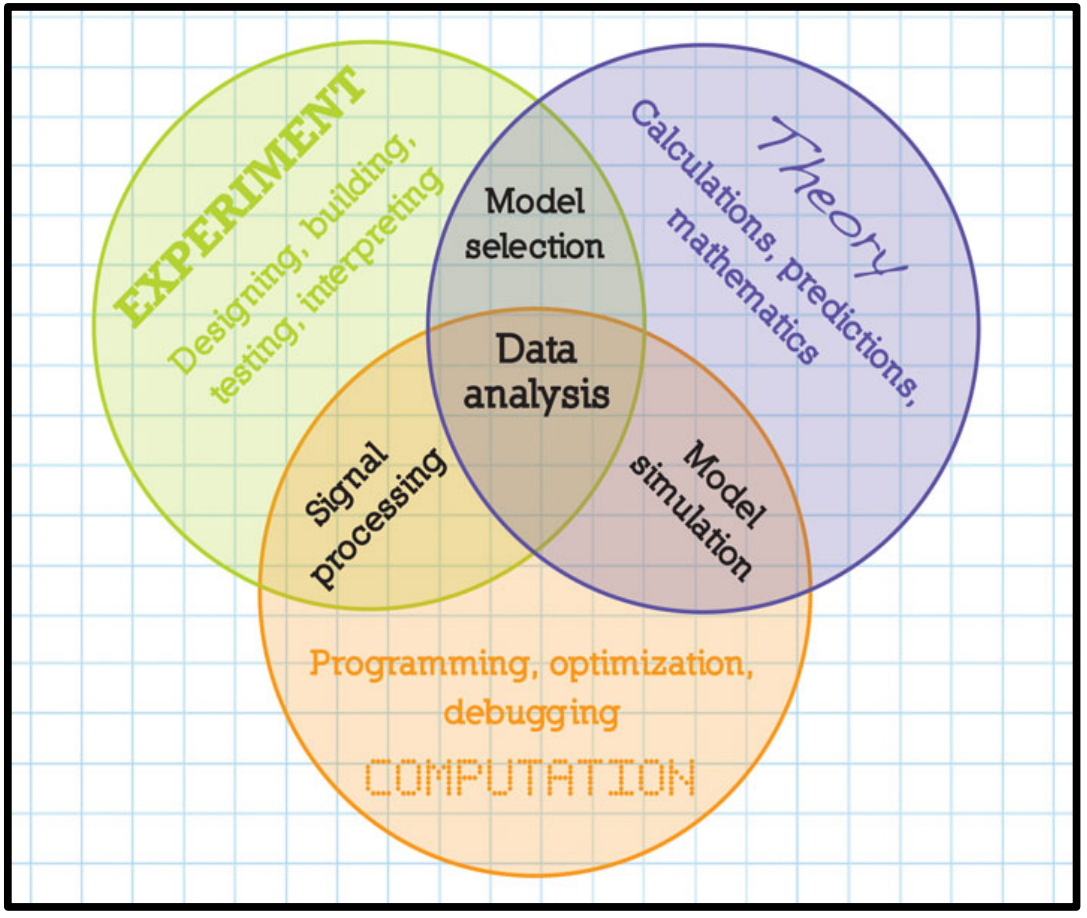


Black Box Experiments

- Most of the early seeding experiments were of the “Black Box” type.
- There was an input (seeding) and an output (precipitation).
- There was no knowledge of what went on in-between.

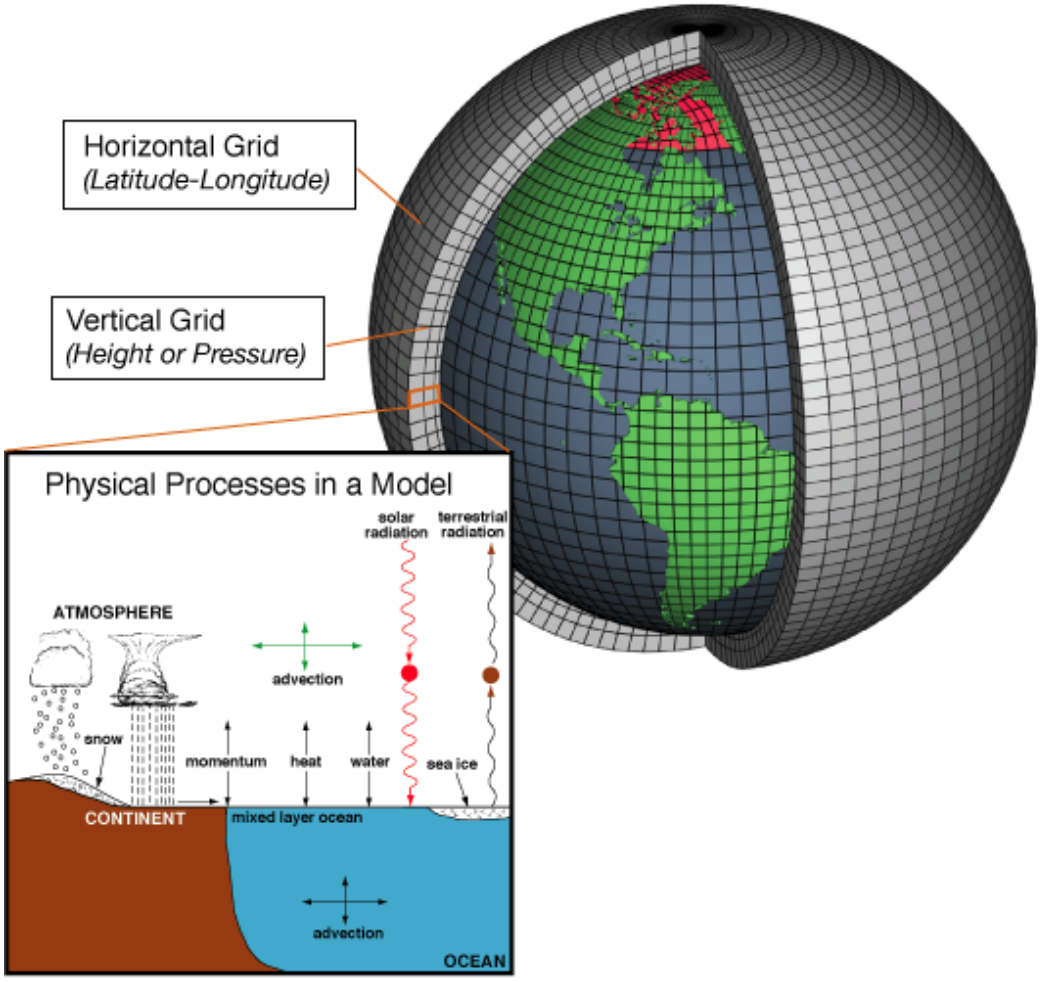
Physical Experiments

- Rather than just looking at the input and output, the intermediate steps were examined.
- If there was a step that was missing, the reason(s) could then be investigated.



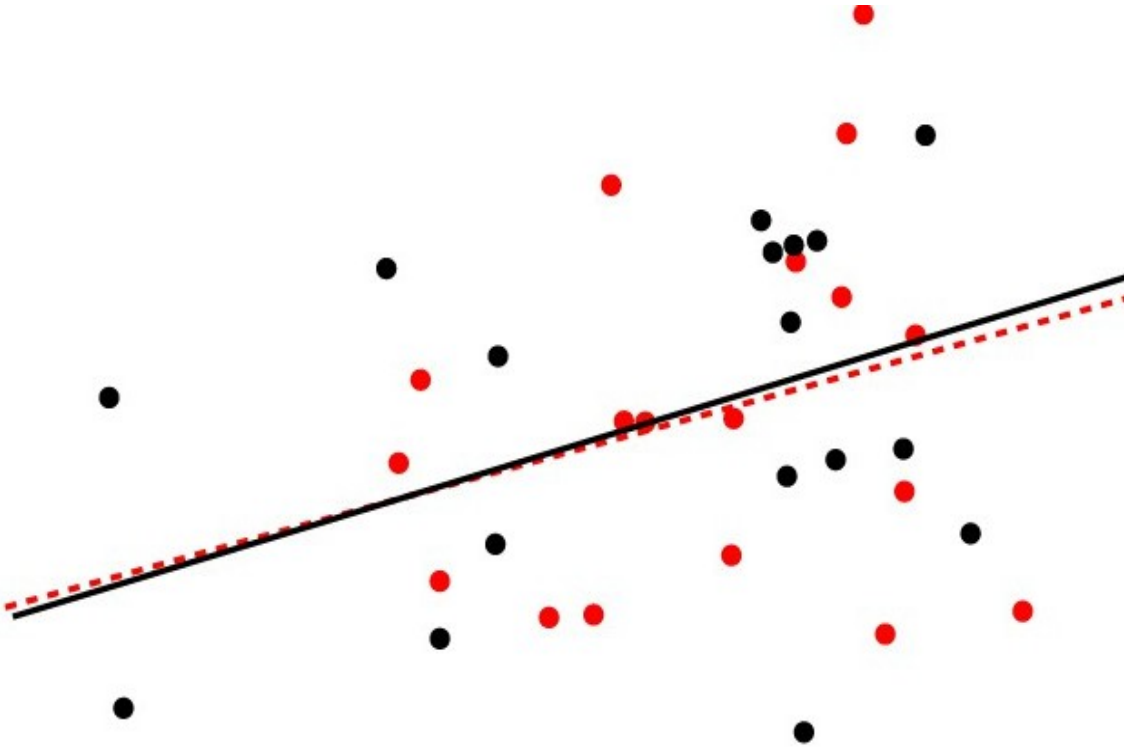
Computer Model

- Limited by computer resources and physical understanding of cloud processes.
- Very new. Research is being conducted on winter-time orgraphic storms

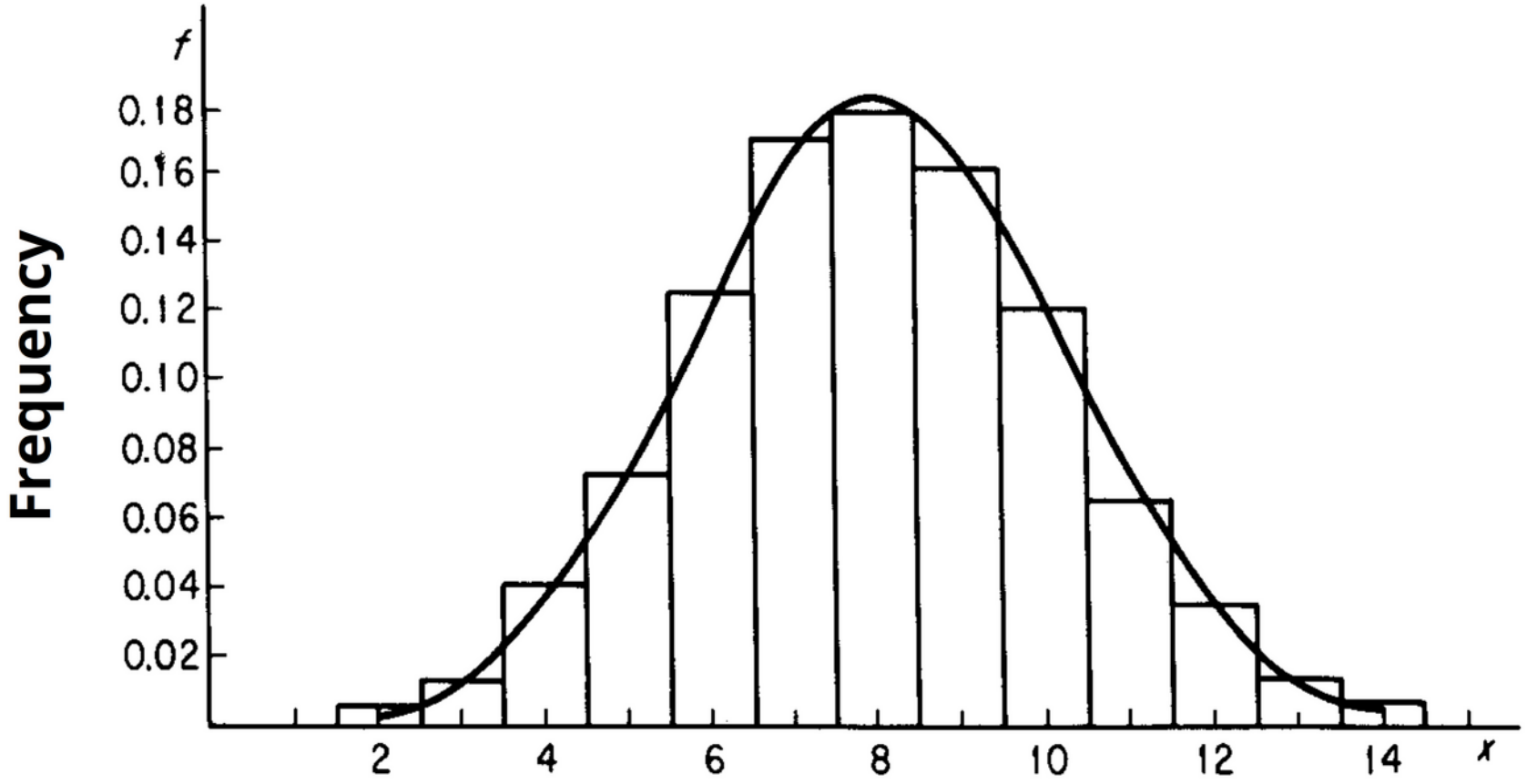


Issues with Statistical Evaluations

- Distribution Types
- Similar Distributions
  - Hypothesis Testing
- Sample Size

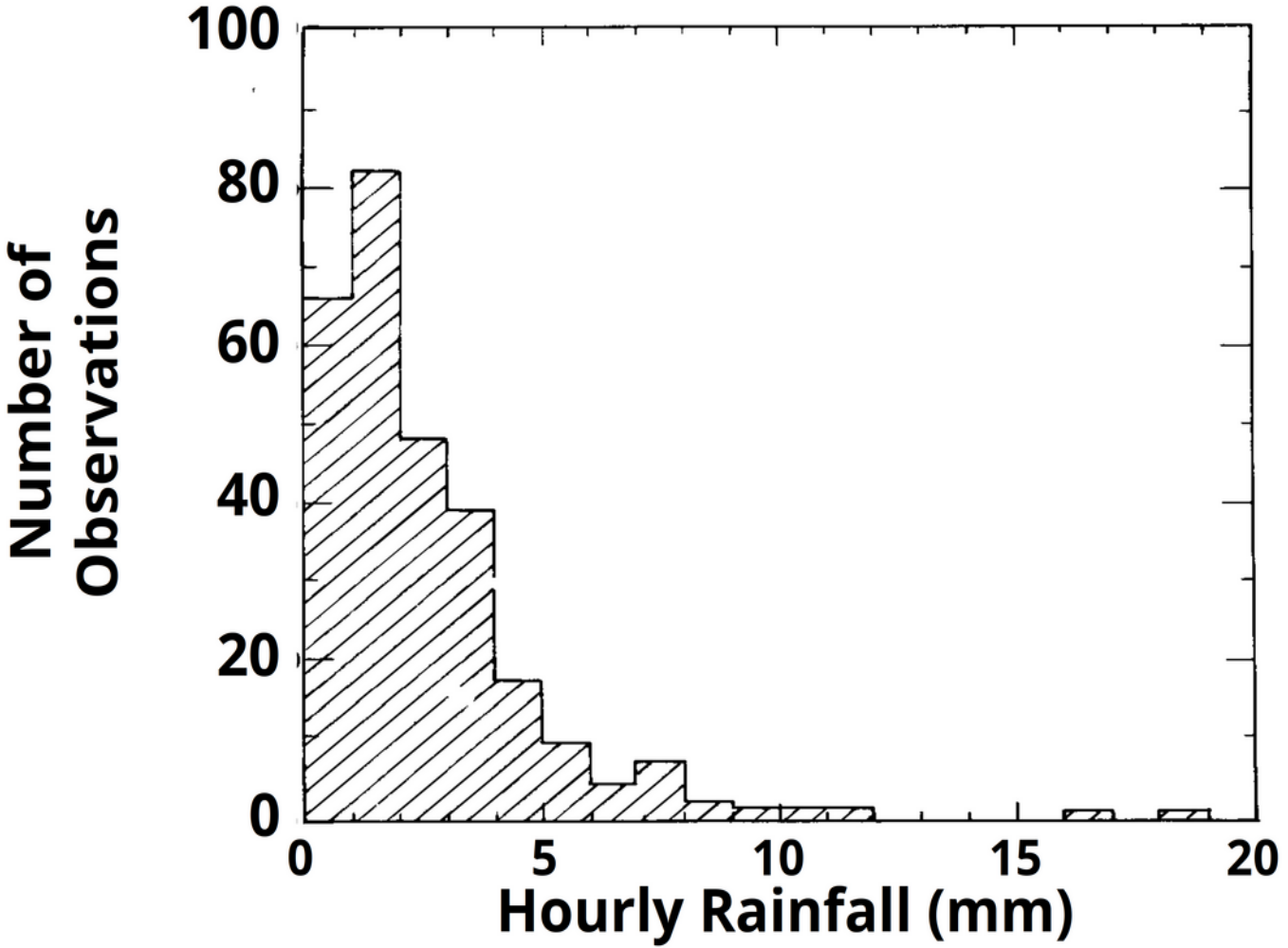


Normal Distribution



Normal Curve Approximation to the Binomial

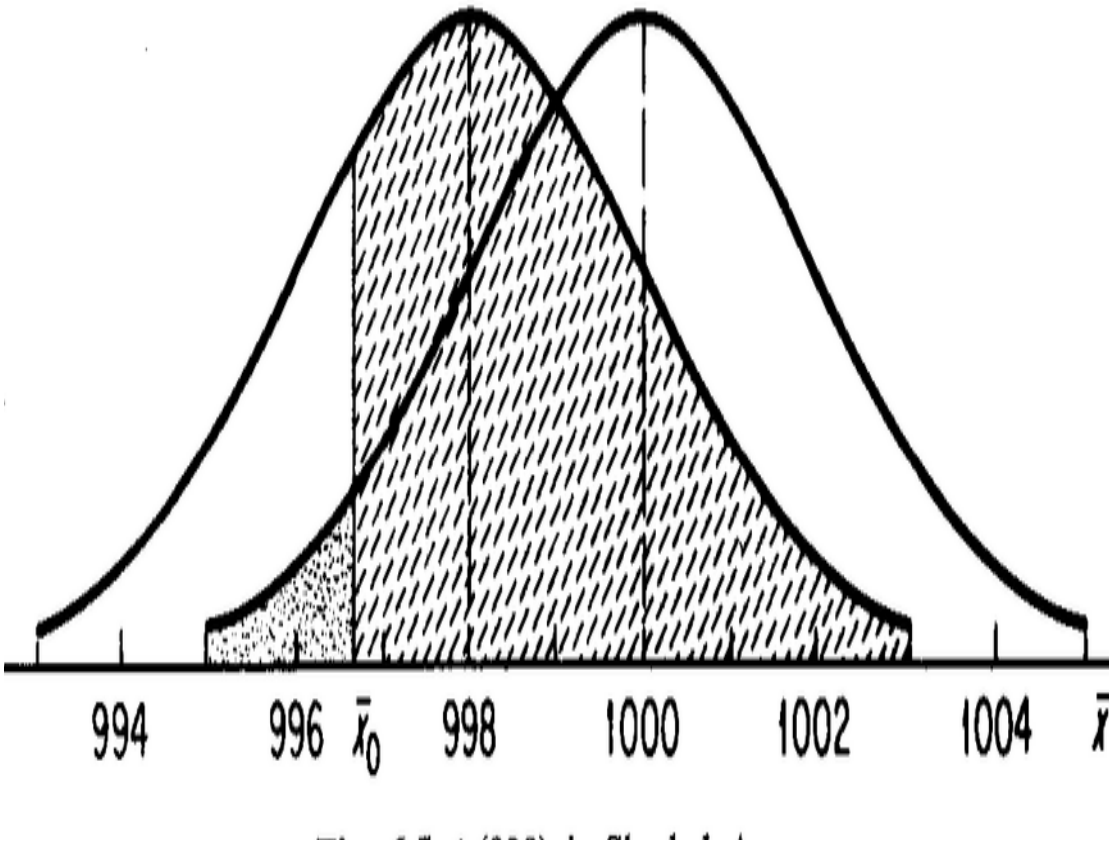
Rain-fall Distribution



Is this a normal distribution?

Hypothesis Testing

- Generally, we have two sets of measurements:
  - The unseeded set
  - The seeded set
- Are there any differences between these two sets of measurements that are not the result of random chance?

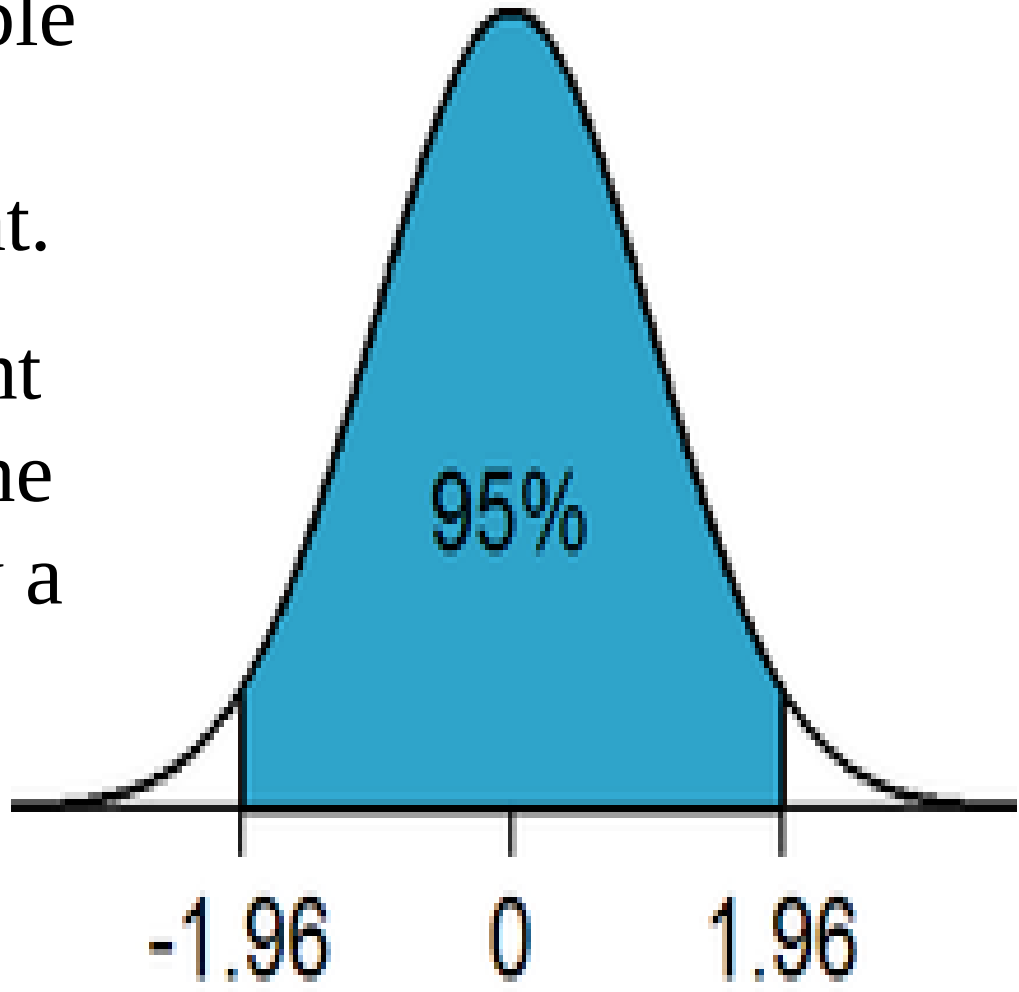


Formulation of the “Null Hypothesis”

- The null hypothesis is generally stated in a way that it will be rejected if there is a likely difference between the two samples.
- An example of the null hypothesis is “The two distributions are the same.”
- Assumption is made that the distribution is sampled randomly.

Statistical Significance Level

- As a general rule, the acceptable confidence level should be defined prior to the experiment.
- A confidence level of 5 percent or lower, means rejection of the null hypothesis if there is only a 5 percent chance that the two data sets came for the same population.



Sample Size Required

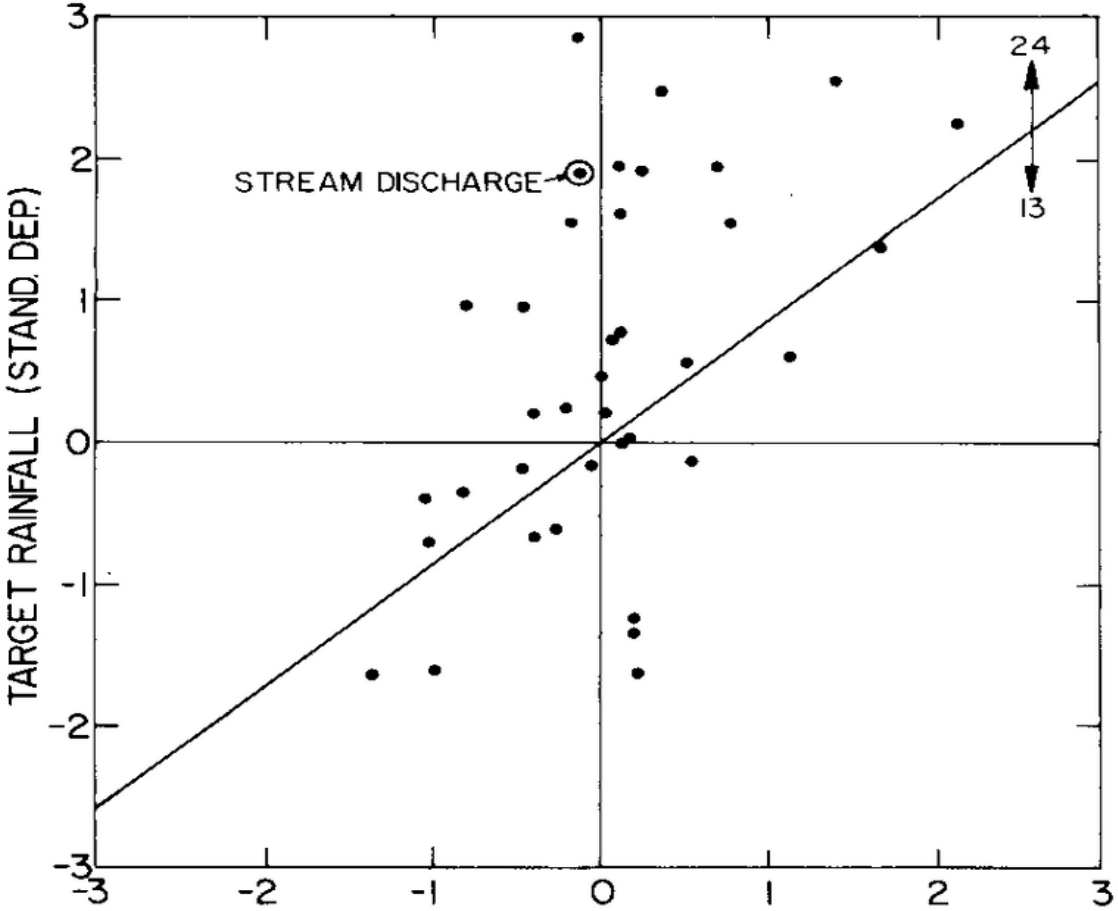
- For large effects as compared to natural variability, number would be small
- For small effects relative to natural variability, number needed is large!
- Also depends on how “good” the samples are.
- Operational program seed everything; hence, n unseeded cases available for analysis.

Historical Regression Analysis

- Uses historical data as the unseeded data set.
- Uses some sort of co-variate as a predictor of the precipitation.
  - Co-variate can be anything that has a reasonably good correlation with the actual precipitation.
  - The co-variate has often been a “control area” where there is no seeding taking place.

Historical Regression Example

- Scatter diagram showing normalized monthly target and control rainfall amounts for operational cloud seeding projects in western U.S.
- There are 24 entries above the historical regession line and 13 below it.
  - Indicating a increase in precipitation.



H. C. S. Thom (1957b)

Historical Regression Analysis Issues

- The samples have not been taken randomly.
- Time may be changing the relationship between the co-variate and the actual response variable.
  - May not be accepted, if not randomized.
    - Therefore, very difficult to evaluate operational programs.

Single Area Statistical Analysis

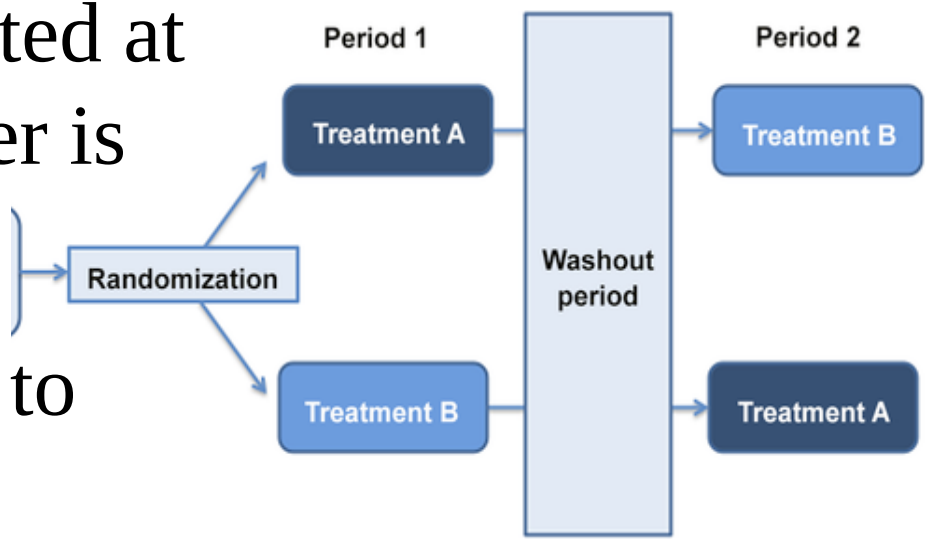
- The single area type of experiment uses randomized seeding in one target area.
  - Storm units (perhaps days) are selected on a random basis and either seeded or not seeded.
  - At the end of the program, the response variable from the seeded cases is compared to the that from the unseeded cases.
  - This tends to be a rather inefficient means of conducting an experiment.

Target-Control Statistical Analysis

- The single area type of experiment uses randomized seeding in one target area.
  - Storm units (perhaps days) are selected on a random basis and either seeded or not seeded.
  - At the end of the program, the response variable from the seeded cases is compared to the that from the unseeded cases.
  - This tends to be a rather inefficient means of conducting an experiment.

Randomized Cross-over Statistical Analysis

- Two areas are selected and for each "storm", one of the areas is selected at random to be seeded and the other is left as a control.
  - The seeded areas are compared to the unseeded areas.
  - This is the most efficient means of conducting a randomized experiment.



Use of Ratios for Cloud Seeding Evaluation

Ratio = Rain(S)/Rain(NS)

What about using the ratio of rainfall from seeded (S) an unseeded (NS) events?

Seeded Cases	Non-seeded Cases	Ratio (S/N)
0.01”	0.10”	0.1
0.10”	0.01”	10
Total .11”	**Total** .11”	**Mean Ratio** 5.05

5.05 = (0.1+10.0)/2 = Mean Ratio

- It is important how to do the ratio. Should sum the precipitation first and then do ratios, not an mean of ratios.

What is the ratio of the precipitation totals?

Cloud Seeding Statistical Analyses Issues

- One of the problem areas is uncertainty about the exact shape of the probability density distribution function.
- Even if the normal precipitation is well defined (big if), there may well be changes in the seeded distribution, other than just the mean.
- It takes a lot of data to define the distribution function well.

Other Types of Statistical Analyses

- Non-parametric statistical tests make no assumptions about the about the distribution function.
- The most common of these are the “rank” tests.
  - Rather than looking at the amount of precipitation from each storm, the events are ranked from the smallest to the largest.
  - The question that is addressed is, “Do the ranks of the seeded storms differ significantly from the ranks of the unseeded storms?”

Stratification of Data

- Perhaps seeding will be more effective under some conditions than others; in fact, there may actually be some decreases expected under some conditions.
- It might be advantageous to look at those cases separately.
  - One possible conceptual model is when the cloud top temperatures are warmer than -20 °C and decreases in the precipitation at colder temperatures.
  - Use only those cases that fell into the “warm” category and analyze that subset of the total data set.