Predicting Avalanche Incidents in Colorado

By: Joey Huang

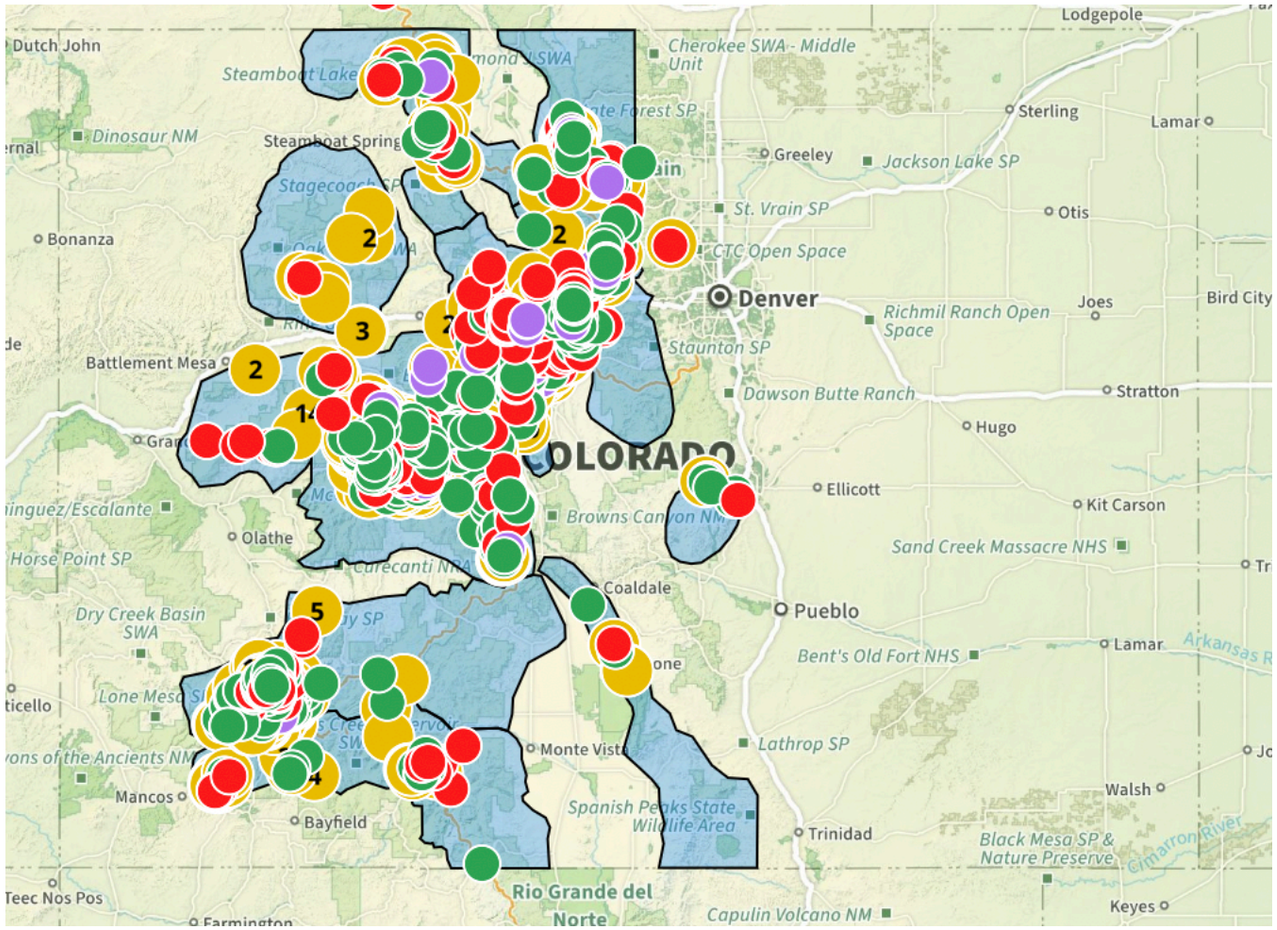
Tracking Colorado Avalanches

- Colorado Avalanche Information Center (CAIC)

A. Human-Reported Incidents

B. Danger Assessments

C. Explosives for Avalanche Control



Colorado has experienced 3680 Avalanche Reports in 2024

Why is this Important?

Incident where a road was shut down for a manually triggered avalanche, preventing any possible traffic incident

- ~27 fatalities across the US; tens of thousands more accidents
- Understanding high-risk areas gives programs like the CAIC information for plans for accident mitigation
- Faster warnings should result in less accidents + deaths

https://www.denver7.com/news/local-news/video-colorados-avalanche-mitigation-effort-on-full-display-along-i-70-wednesday-morning

Overall Goal

- Determine the variable(s) that best predict whether a region is in danger of an avalanche
    - Determine whether these variables change over time
- Build a regression model off of Colorado data
    - Why Colorado?

Avalanche Types

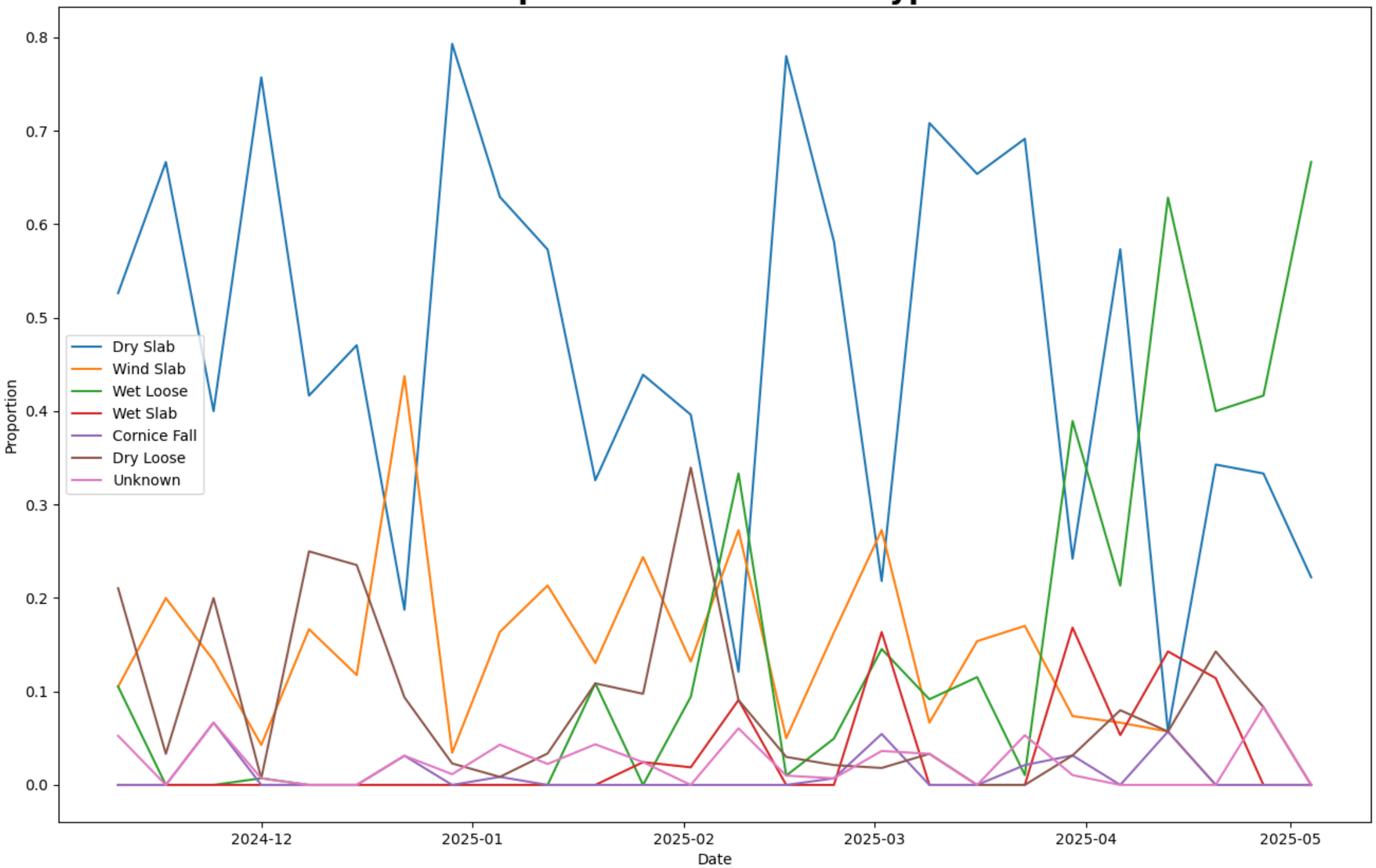
Slab Avalanches

- A cohesive layer of snow is separated from the ground
    - Often triggered by contact, but can be initiated by factors that create pressure on a slab
- Wind/Dry Slab Avalanches
    - Slabs formed by wind deposition, lacks moisture
    - Added stress still main trigger

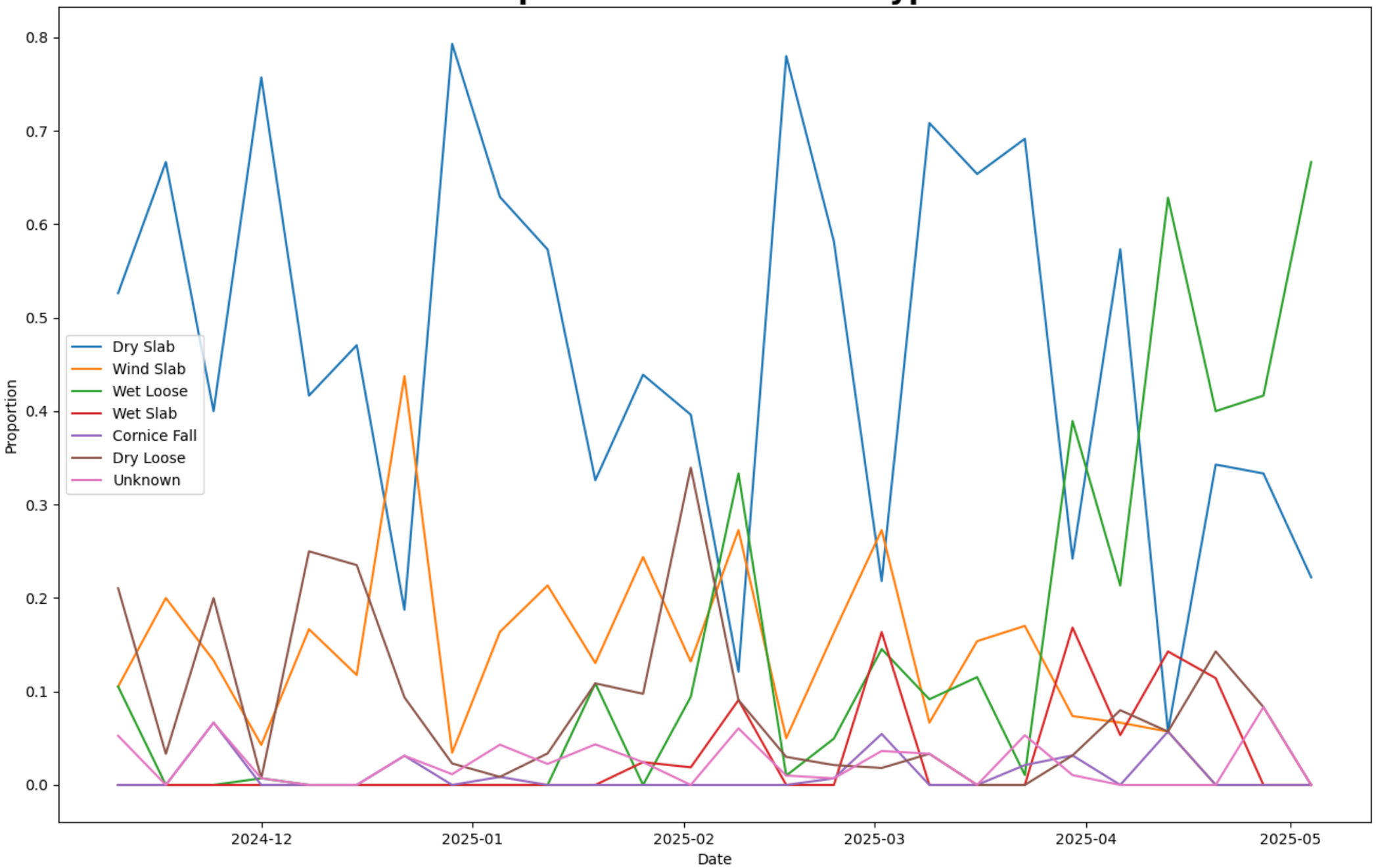
Wet Loose Avalanches

Wet Loose Avalanche triggered by rain on snow

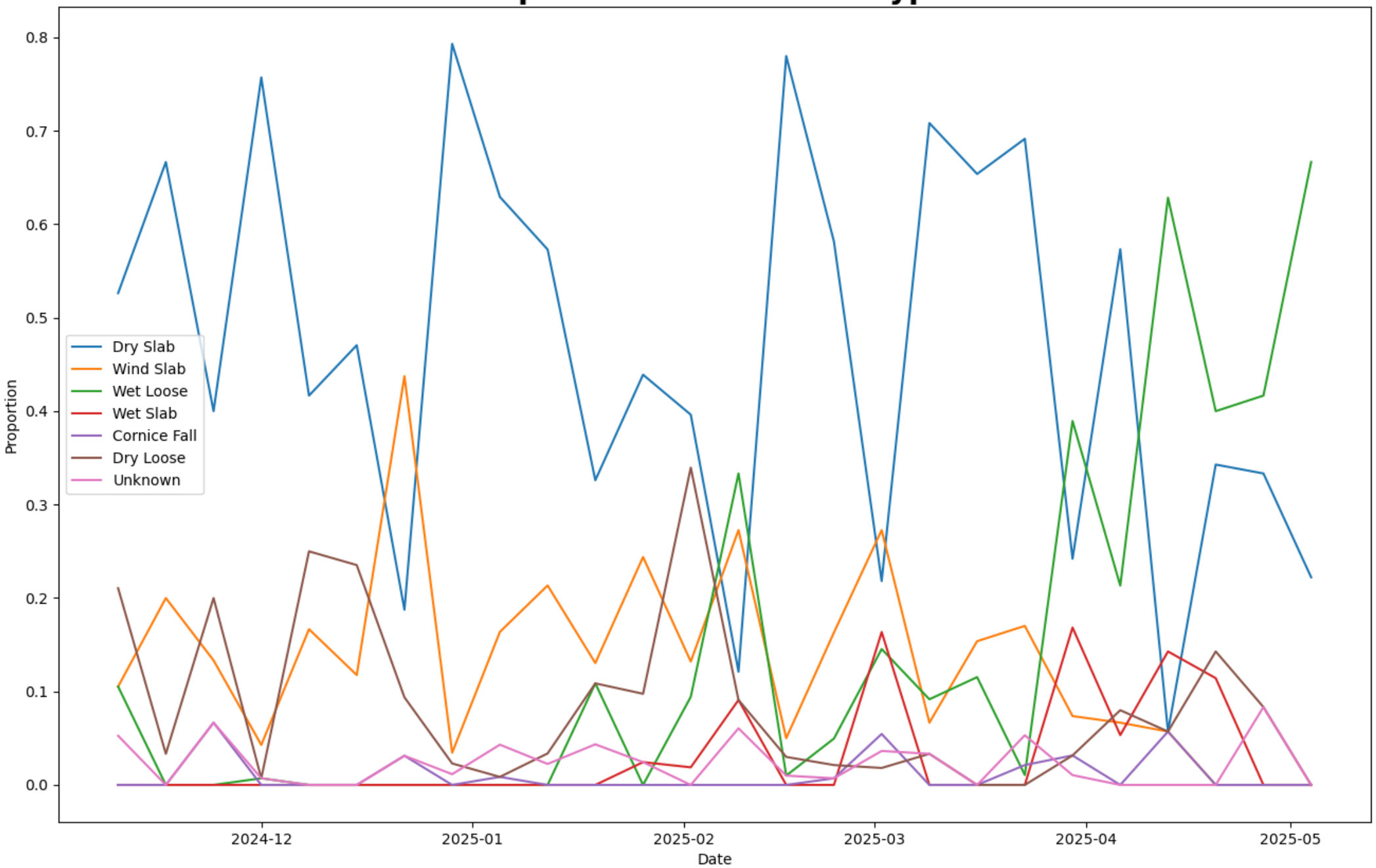
- Occur as a result of a snowy surface losing cohesion and tumbling down a slope
    - Accentuated by higher <u>elevations/slopes</u>
    - Often triggered by <u>precipitation</u> weakening packs of snow, or moisture from melting



Dominated by Dry/Wind Slab Avalanches



Wet Loose Avalanches Introduced



Remaining Avalanche Types

Variables of Interest

- Weather Data (Obtained from European Centre for Medium-Range Weather Forecasts (ECMWF))
    - Precipitation (m)
    - Surface Solar Radiation Downwards (SSRD) (J/m^2)
    - Temperature at 2m (K)
    - Wind Magnitude (m/s)
        - Obtained from north/south and east/west wind components
- Topographical Data (Obtained from OpenTopography Digital Elevation Model (DEM))
    - Elevation (m)

How do we build a Regression Model?

$$Y = \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n + \varepsilon$$

Response Variable (Avalanche Occurrence)

Y intercept

Predictor Coefficients

Predictors (°K, SSRD, etc.)

Error Term

How do we build a Regression Model?

$$Y = \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n + \varepsilon$$

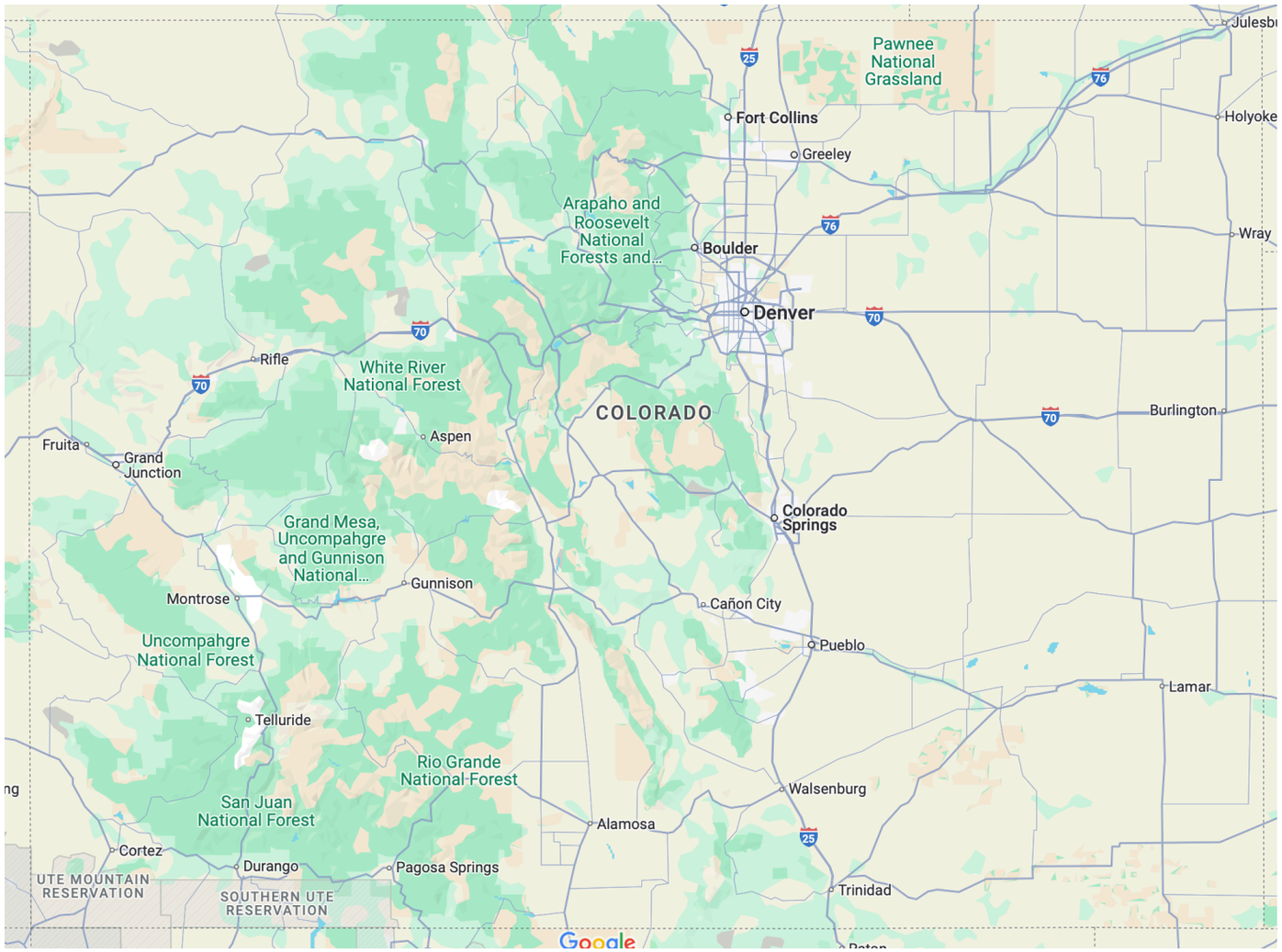
Response Variable (Avalanche Occurrence)

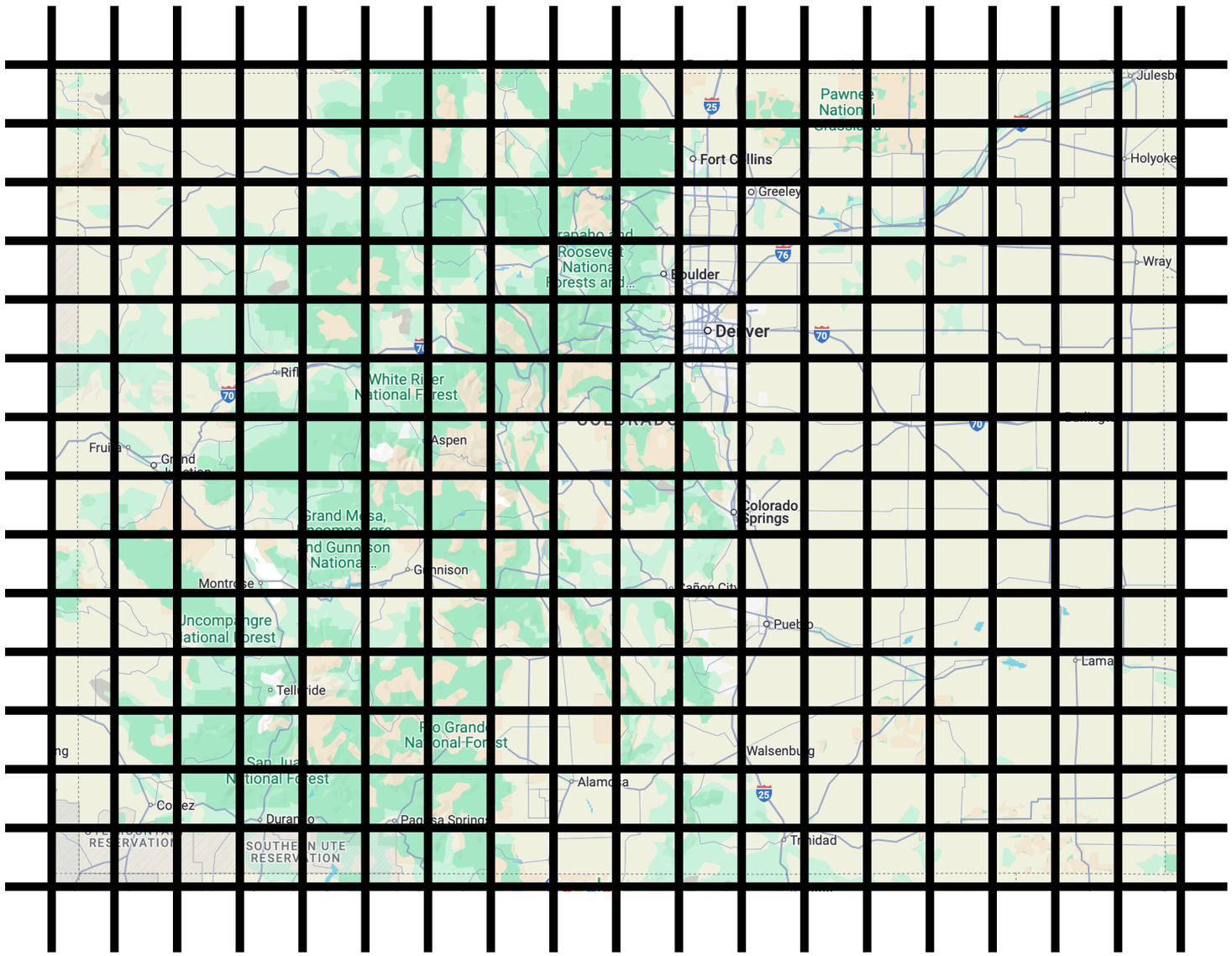
$$log(\frac{P(Y = 1 \mid X = x)}{P(Y = 0 \mid X = x)})$$

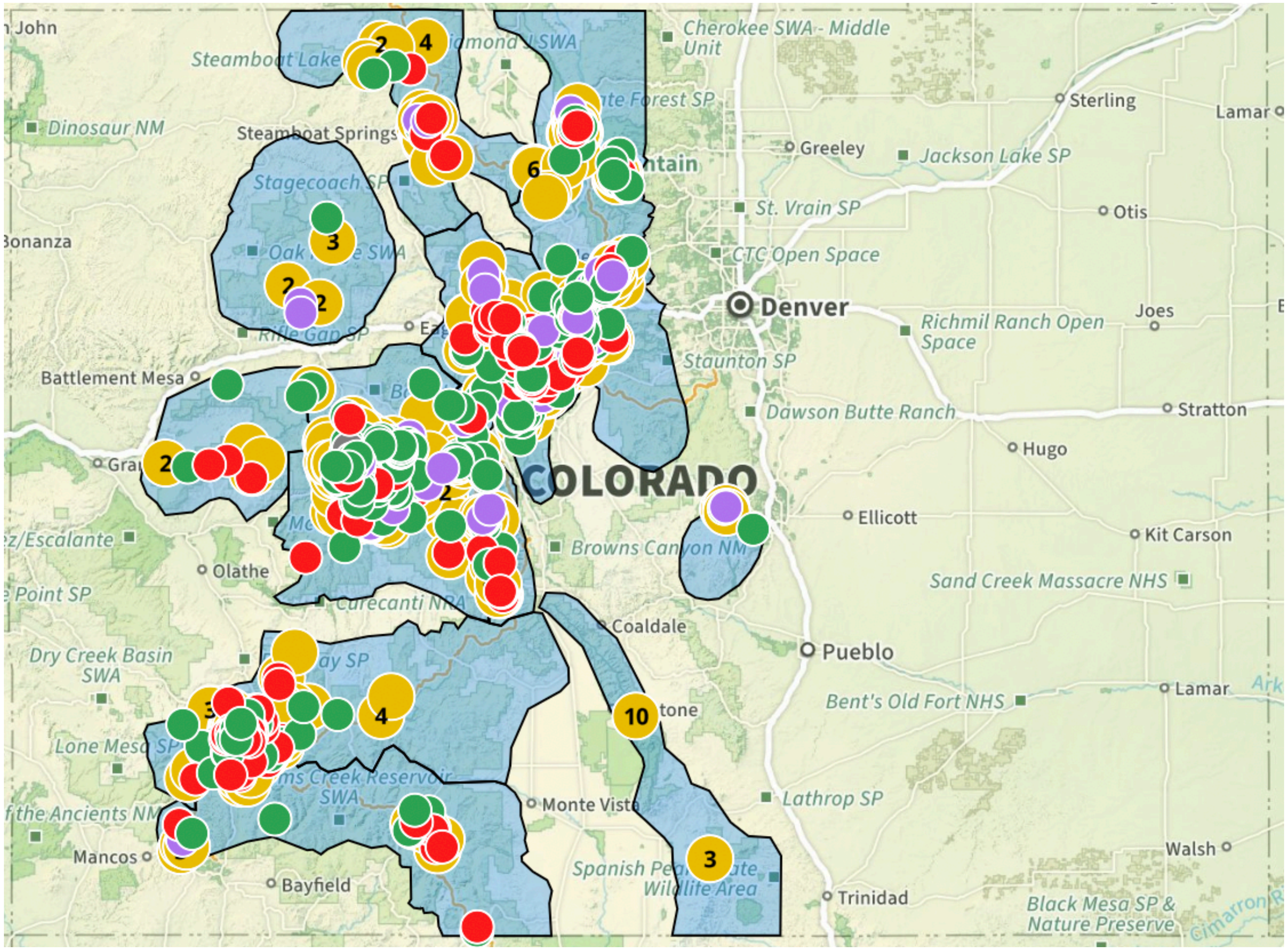
Binary Response (0 or 1)

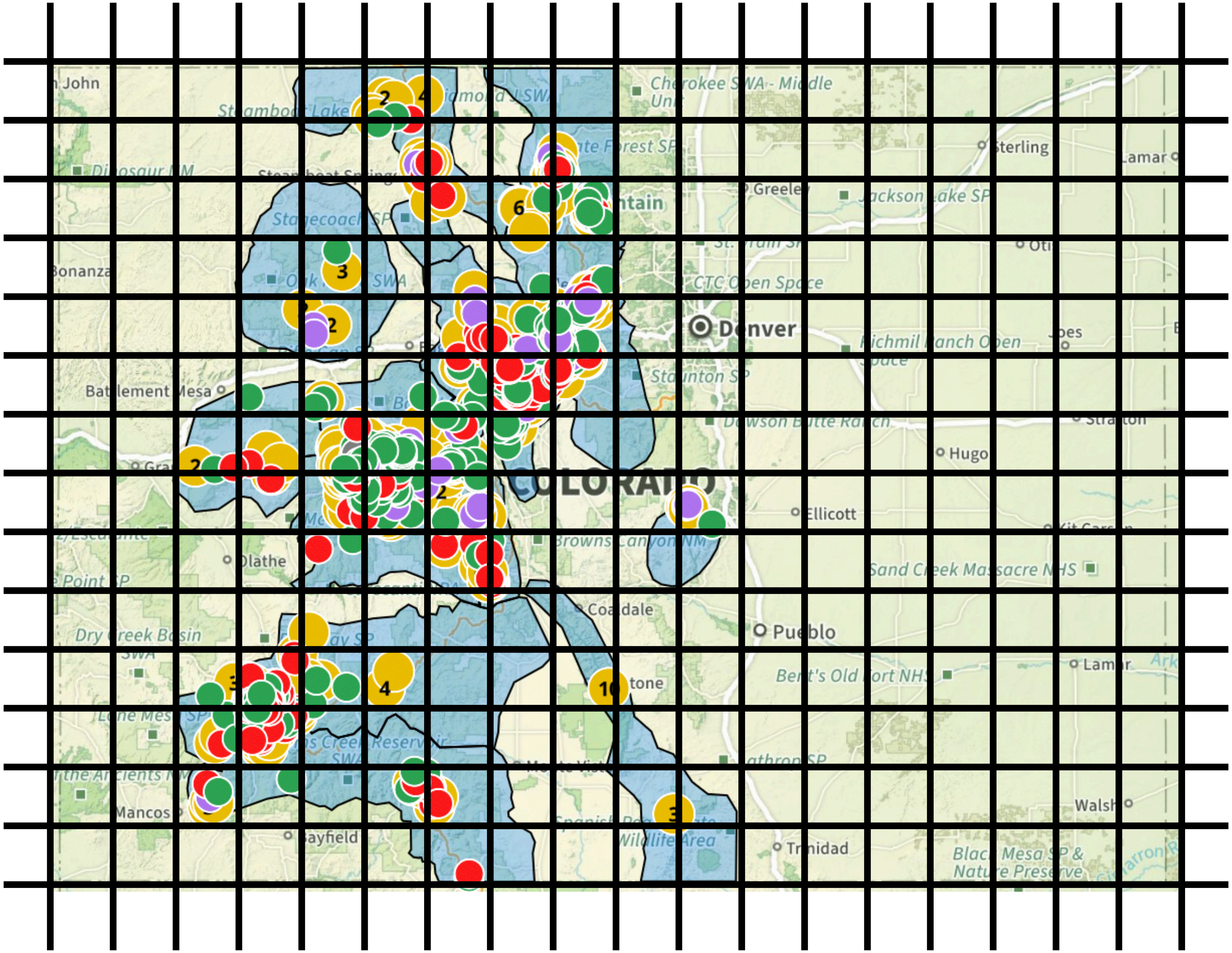
But how do we take a list of all avalanche report over half a year and make it work with this model?

Act i: Building an Observation

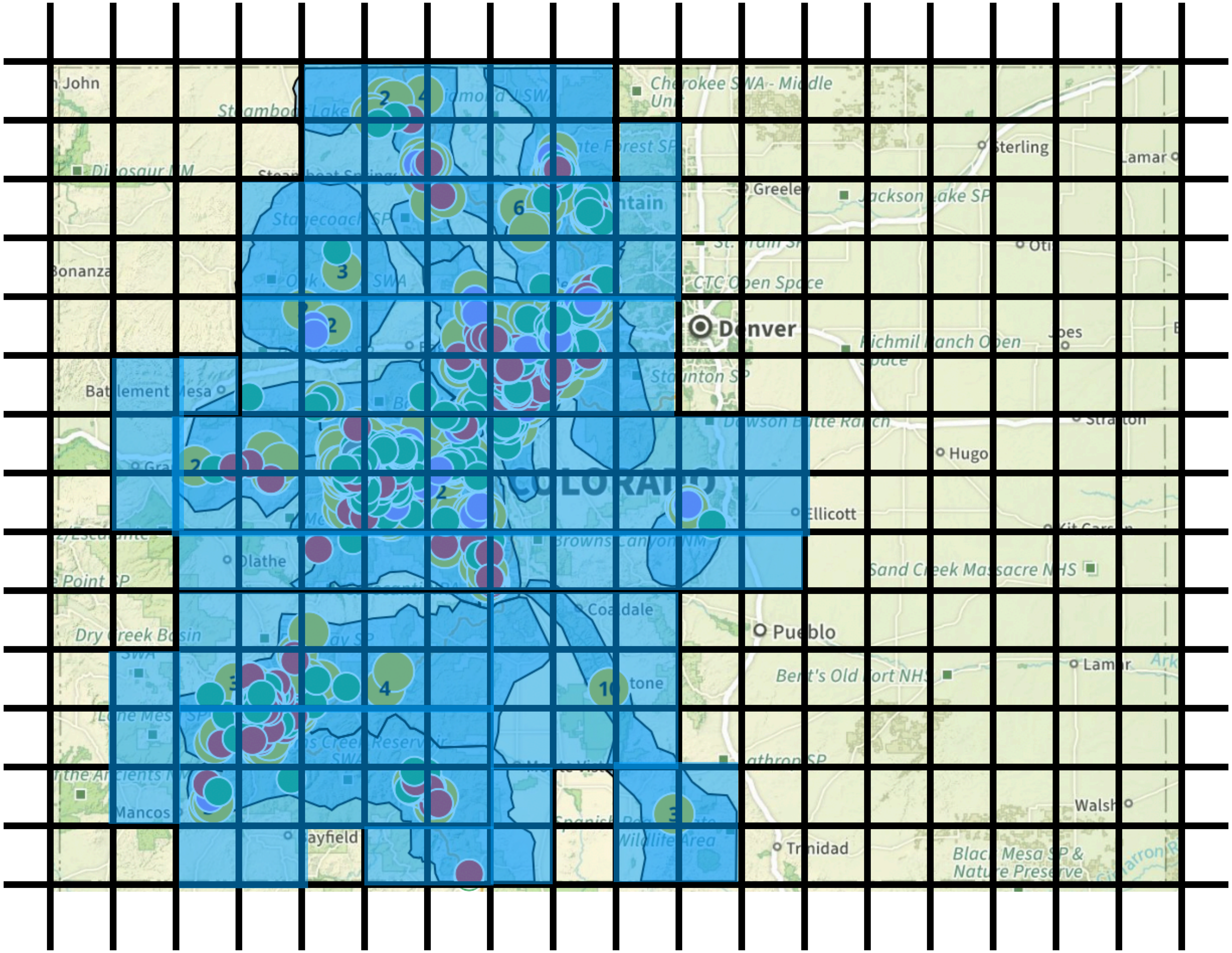



Fort Collins
Greeley
Boulder
Denver
Colorado Springs
Pueblo
Aspen
Montrose
Gunnison
Telluride
Durango
Walsenburg
Trinidad
Alamosa
Wray
Holyoke
Julesburg
Rifle
Fruita
Grand Junction
Cortez
Lamar
COLORADO
SOUTHERN UTE RESERVATION
SOUTHERN UTE RESERVATION
White River National Forest
Uncompahgre National Forest
Rio Grande National Forest
San Juan National Forest
Pawnee National Grassland
Grand Mesa, Uncompahgre and Gunnison National ...
Roosevelt National Forests and ...
Canon City
25
70
76

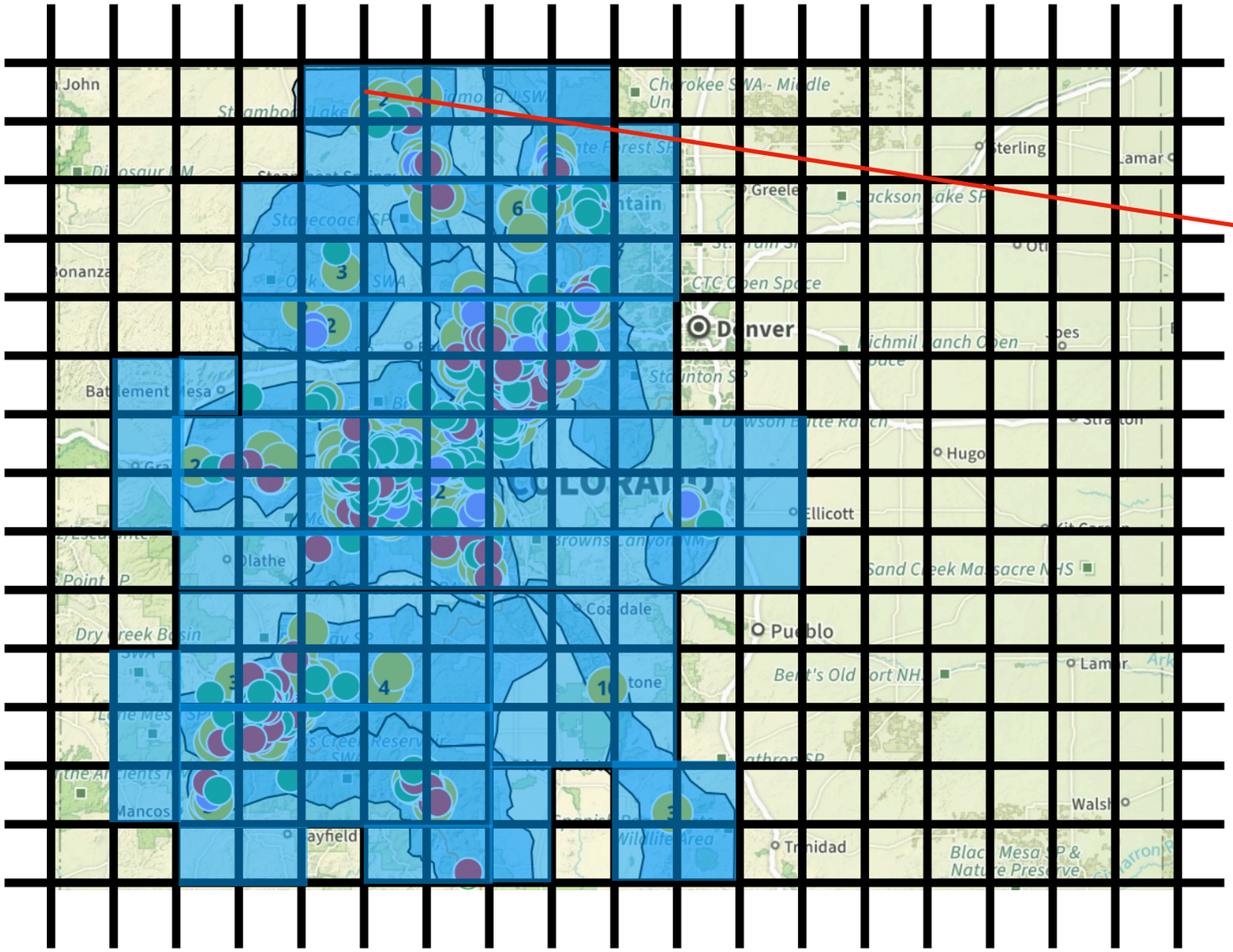

Steamboat Springs
Dinosaur NM
Stagecoach SP
Battlement Mesa
Olathe
Dry Creek Basin SWA
Lone Mesa SP
Mancos
Bayfield
Monte Vista
Coaldale
COLORADO
Denver
Greeley
Sterling
Lamar
Jackson Lake SP
St. Vrain SP
CTC Open Space
Otis
Richmil Ranch Open Space
Joes
Staunton SP
Dawson Butte Ranch
Stratton
Hugo
Ellicott
Kit Carson
Browns Canyon NM
Sand Creek Massacre NHS
Pueblo
Bent's Old Fort NHS
Lathrop SP
Trinidad
Walsh
Black Mesa SP & Nature Preserve
Bonanza



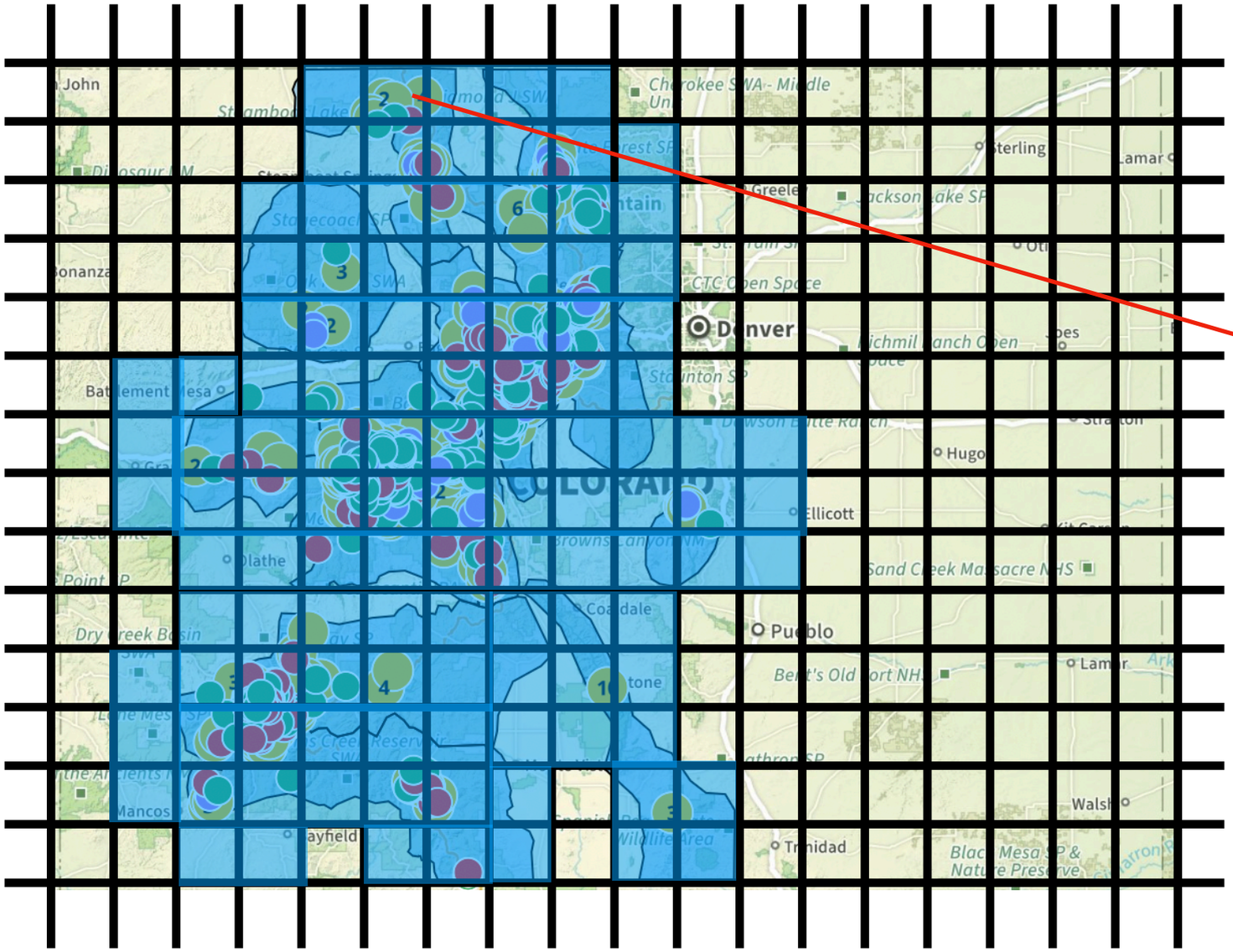
Denver
Greeley
Sterling
Hugo
Ellicott
Pueblo
Walsh
Coaldale
Mancos
COLORADO



Sterling
Hugo
Ellicott
Olathe
Coaldale
Pueblo
Trinidad
Walsh
Mancos
Bonanza
Battlement Mesa
Denver
Greeley



Cell #	Number of Avalanches	Precipitation	Other Weather Data
1	0	.3 inches	…
2	2	0 inches	…
…	…	…	…
n	1	.5 inches	…



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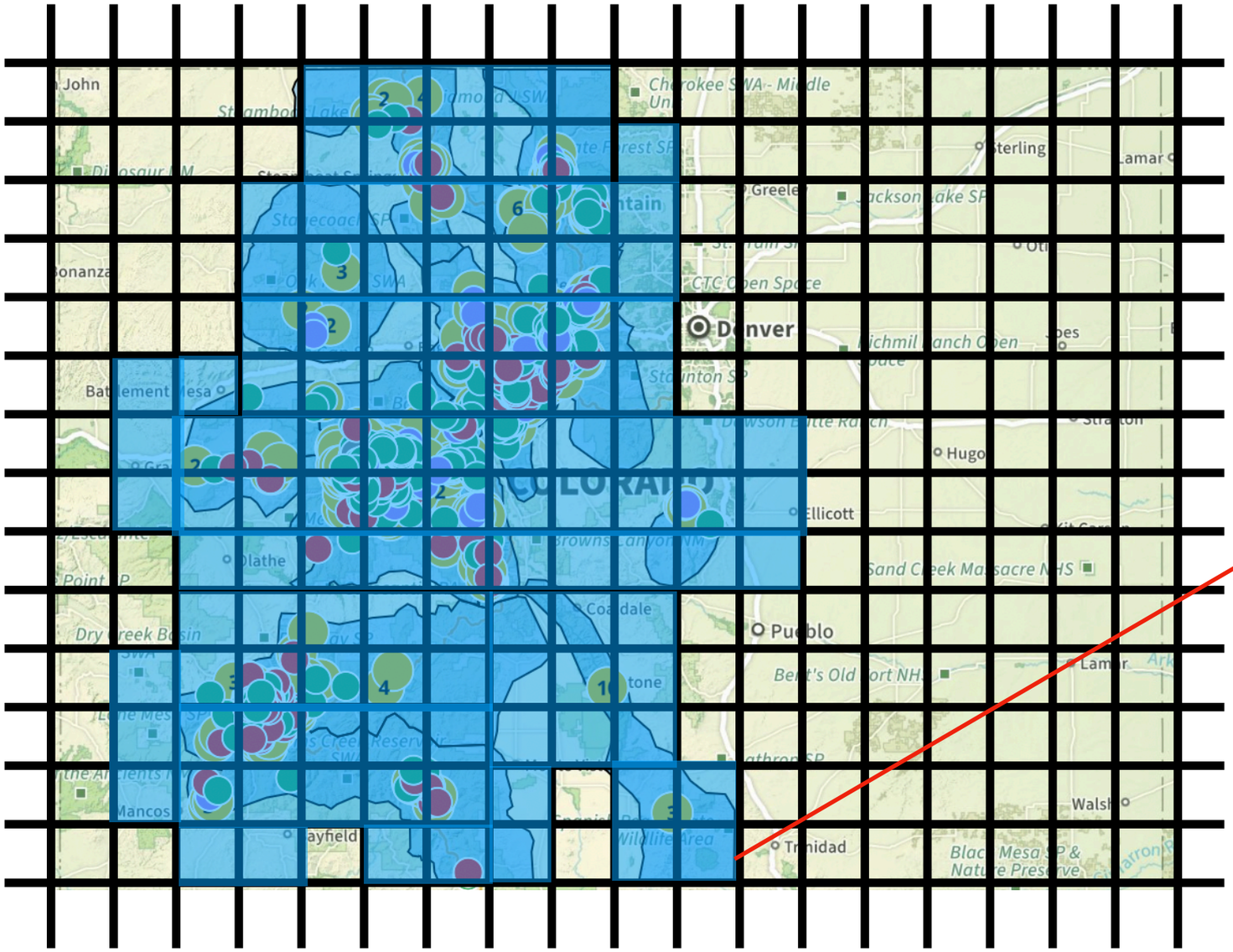
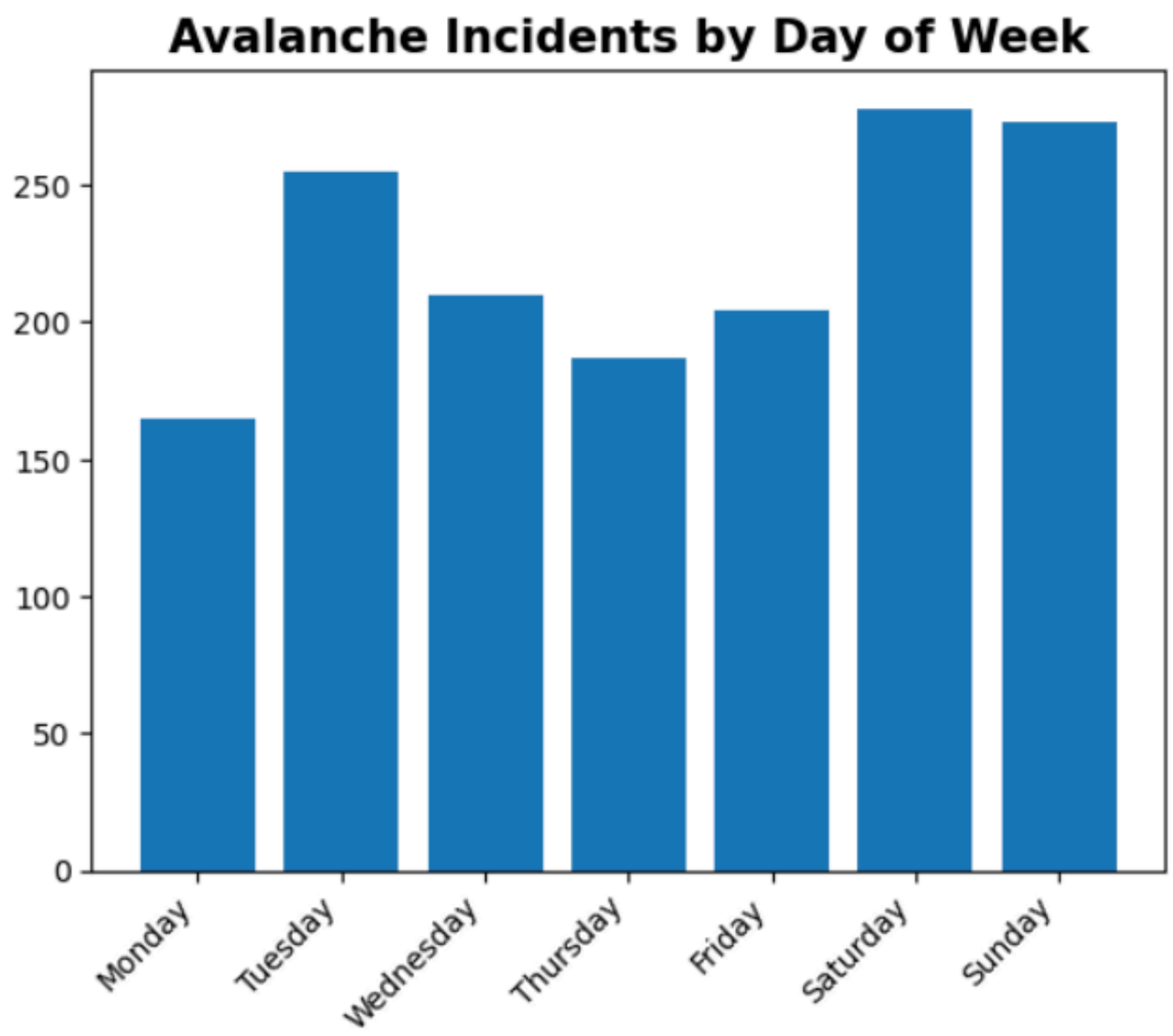


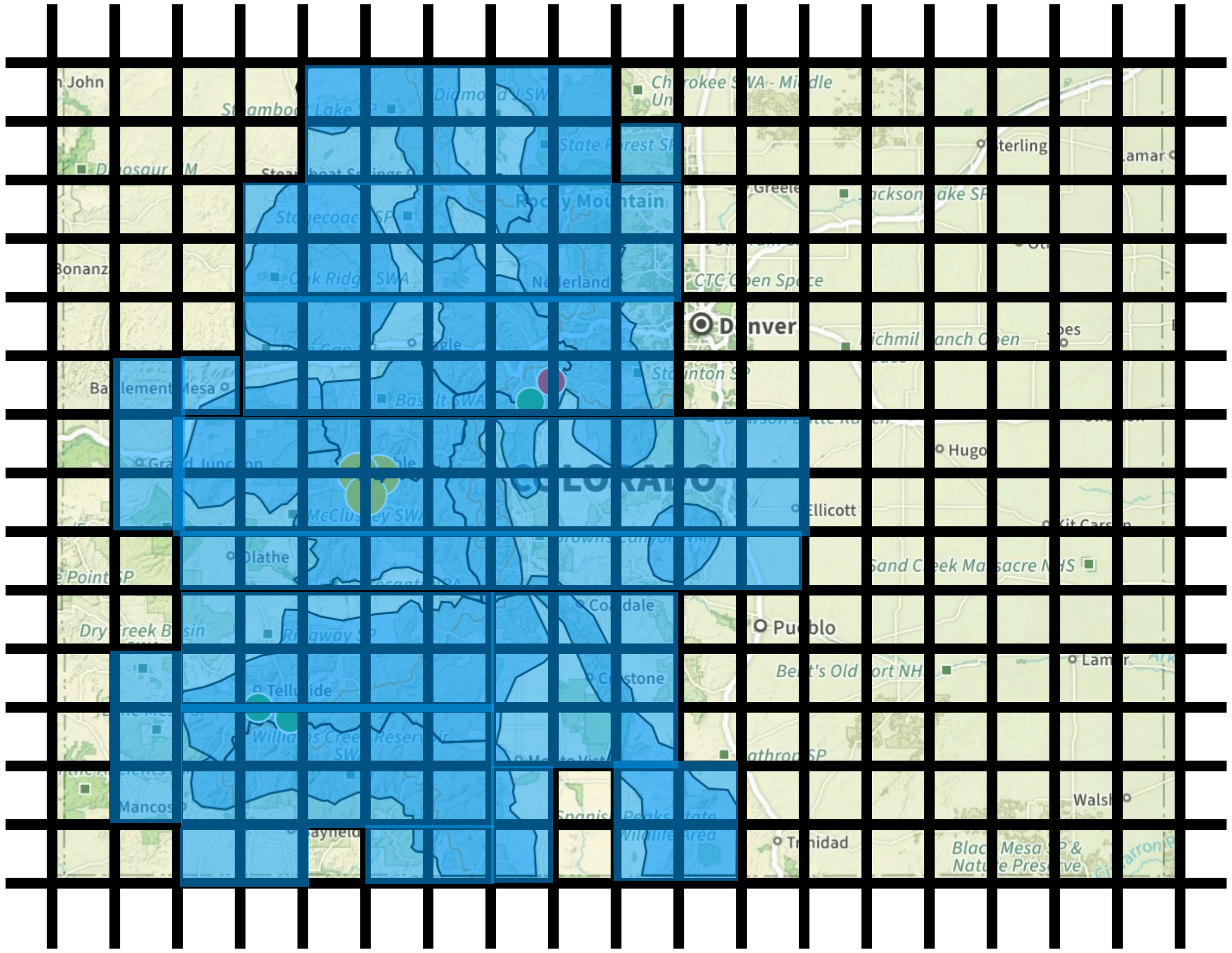
Cell #	Number of Avalanches	Precipitation	Other Weather Data
1	0	.3 inches	…
2	2	0 inches	…
…	…	…	…
n	1	.5 inches	…

Act ii: Repetition + Aggregation over Time



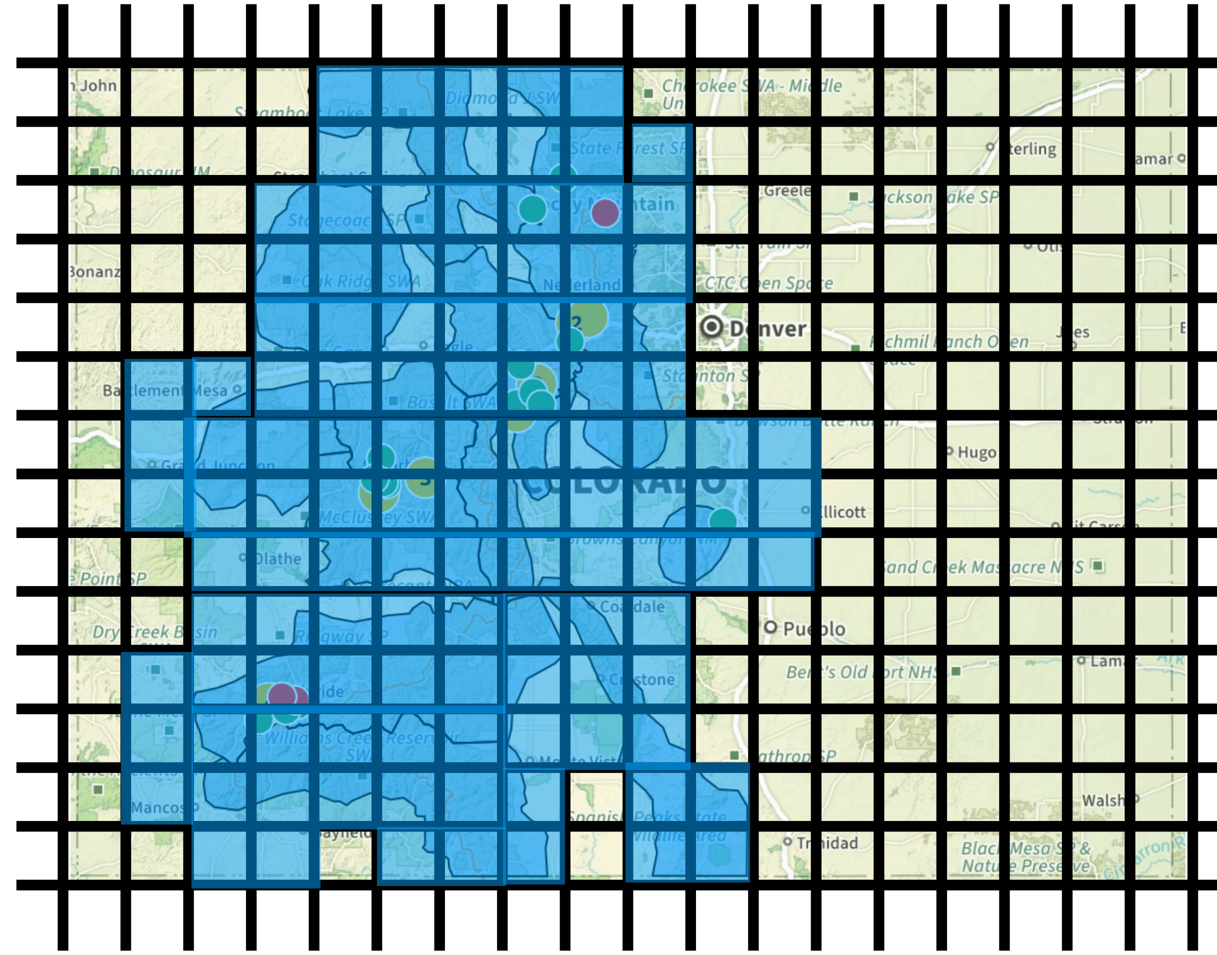
Why do we see more incidents on the weekends?

Week 1



Cell #	Number of Avalanches	Precipitation	Other Weather Data
1	0	.1 inches	…
2	0	.05 inches	…
…	…	…	…
n	1	.5 inches	…

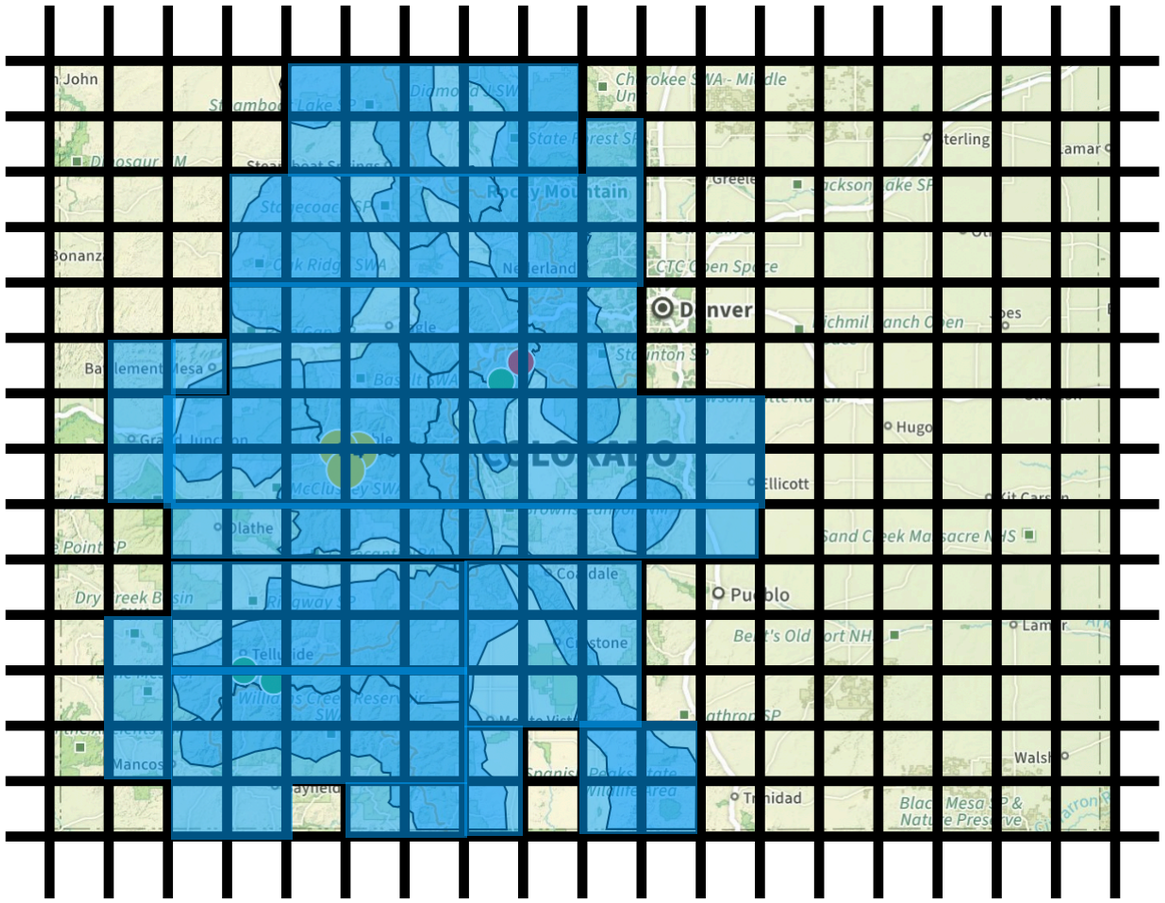
Week 2



Cell #	Number of Avalanches	Precipitation	Other Weather Data
1	0	.01 inches	…
2	1	0 inches	…
…	…	…	…
n	0	.03 inches	…

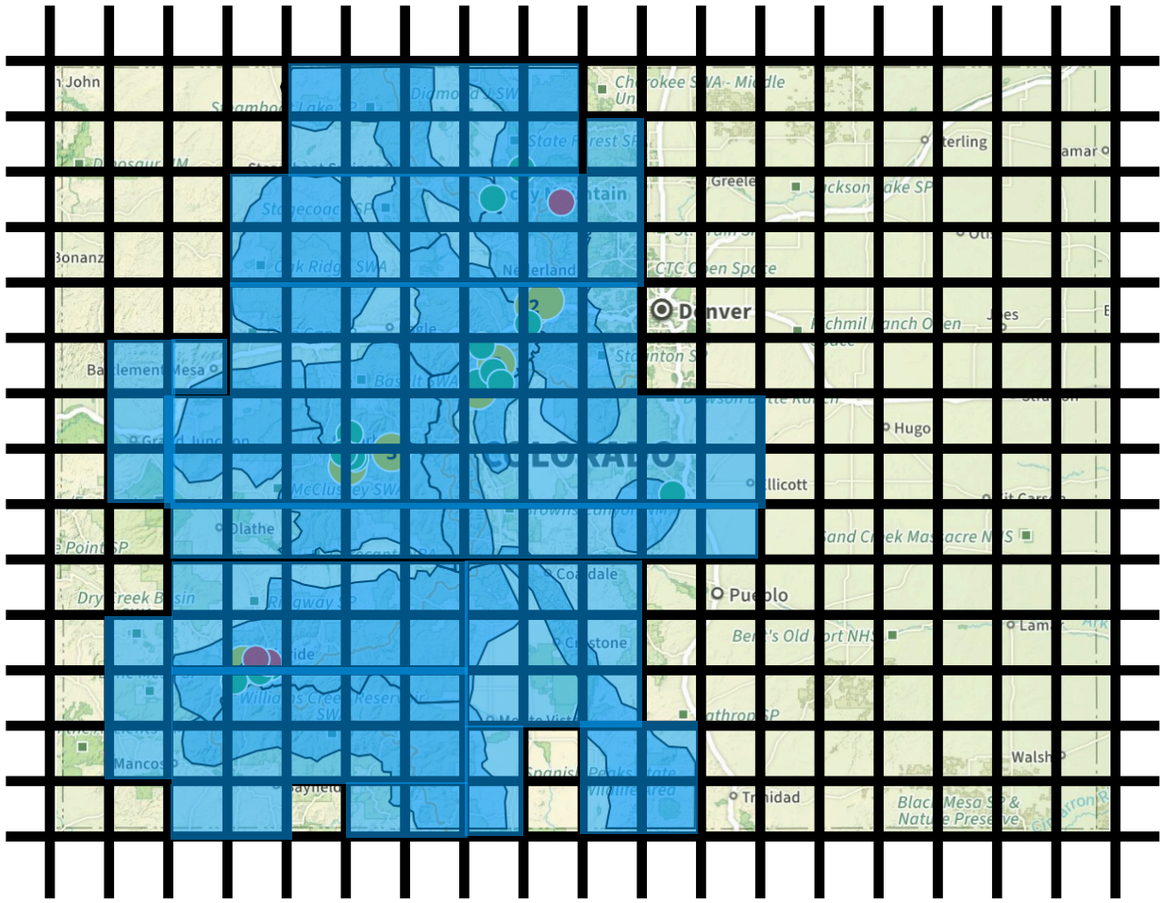
Act iii: Fitting Multiple Regression Models

Week 1



Cell #	Number of Avalanches	Precipitation	Other Weather Data
1	0	.1 inches	…
2	0	.05 inches	…
…	…	…	…
n	1	.5 inches	…

Week 2



Cell #	Number of Avalanches	Precipitation	Other Weather Data
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…	…	…	…
n	0	.03 inches	…

Cell #	Number of Avalanches	Precipitation	Other Weather Data
1	0	.1 inches	…
2	0	.05 inches	…
…	…	…	…
n	1	.5 inches	…

$$Y = \beta_0 + \beta_1 X_1 + \dots$$

Cell #	Number of Avalanches	Precipitation	Other Weather Data
1	0	.01 inches	…
2	1	0 inches	…
…	…	…	…
n	0	.03 inches	…

$$Y = \beta_0 + \beta_1 X_1 + \dots$$

*Where $Y = log(\frac{P(Y = 1 \mid X = x)}{P(Y = 0 \mid X = x)})$

Week 1:

*Where $Y = log(\frac{P(Y=1 \mid X=x)}{P(Y=0 \mid X=x)})$

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Week 2:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Week 3:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Week n:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

*Where $Y = log(\frac{P(Y=1 \mid X=x)}{P(Y=0 \mid X=x)})$

Week 1:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Week 2:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Week 3:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Week n:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Precipitation Coefficient

Week #	Regression Coefficient for Precipiation
1	0.04
2	0.10
3	-0.08
...	...
n	0.01

*Where $Y = log(\frac{P(Y=1 \mid X=x)}{P(Y=0 \mid X=x)})$

Week 1:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Week 2:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Week 3:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots$$

Week n:

$$Y = \beta_0 + \beta_1 X_1 + \underline{\beta_2} X_2 + \dots$$

SSRD Coefficient

Week #	Regression Coefficient for Precipiation	Regression Coefficient for SSRD
1	0.04	0.24
2	0.10	0.03
3	-0.08	0.001
...	...	...
n	0.01	-0.20

Repeat for each Predictor

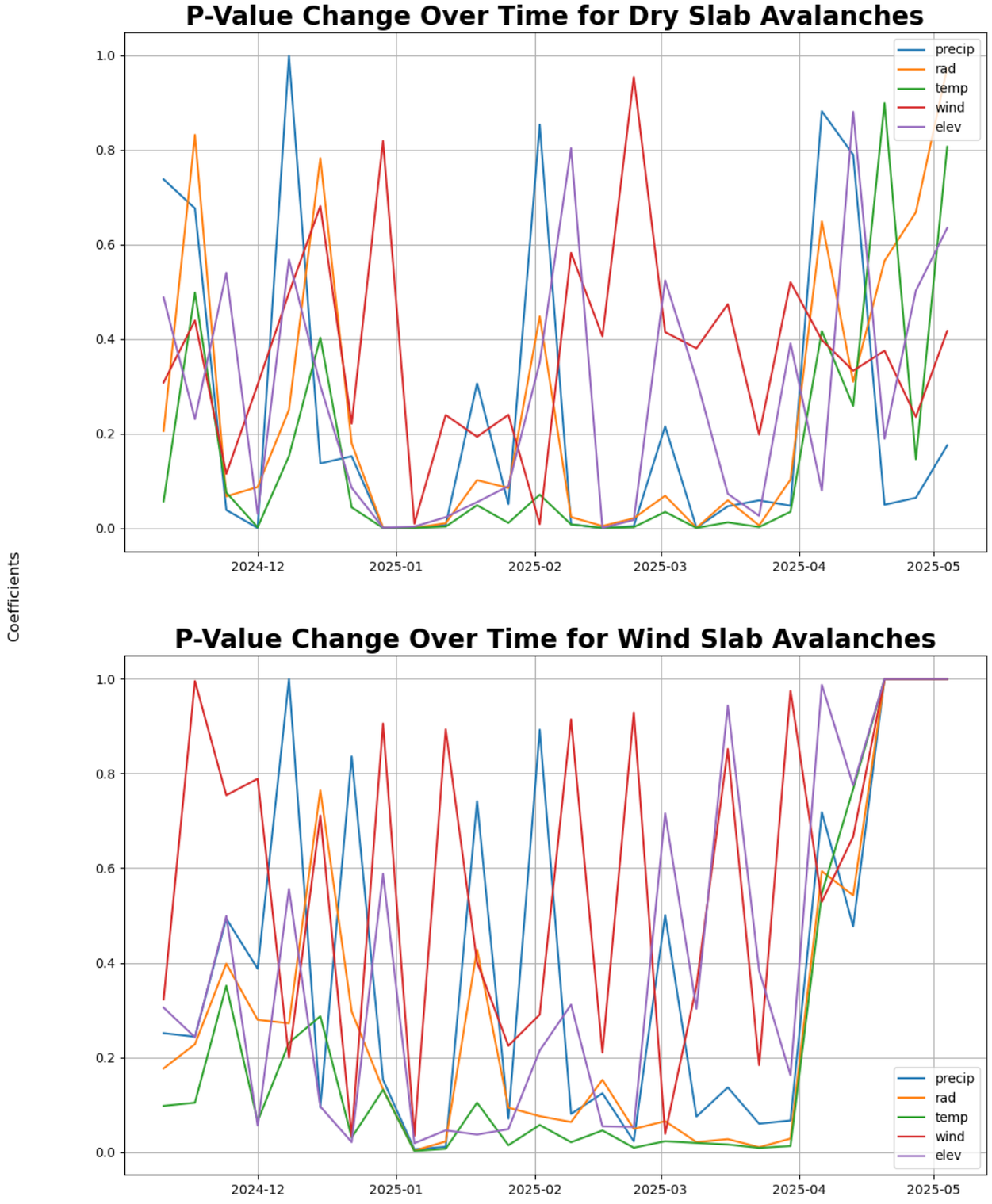
Week #	Regression Coefficient for Precipiation	Regression Coefficient for SSRD	Regression Coefficient for Temperature	Regression Coefficient for Wind Magnitude	Regression Coefficient for Elevation
1	0.04	0.24	0.002	-0.03	0.10
2	0.10	0.03	-0.08	0.12	0.004
3	-0.08	0.001	0.13	-0.12	0.03
...	...	...	...	...	...
n	0.01	-0.20	0.007	0.43	0.004

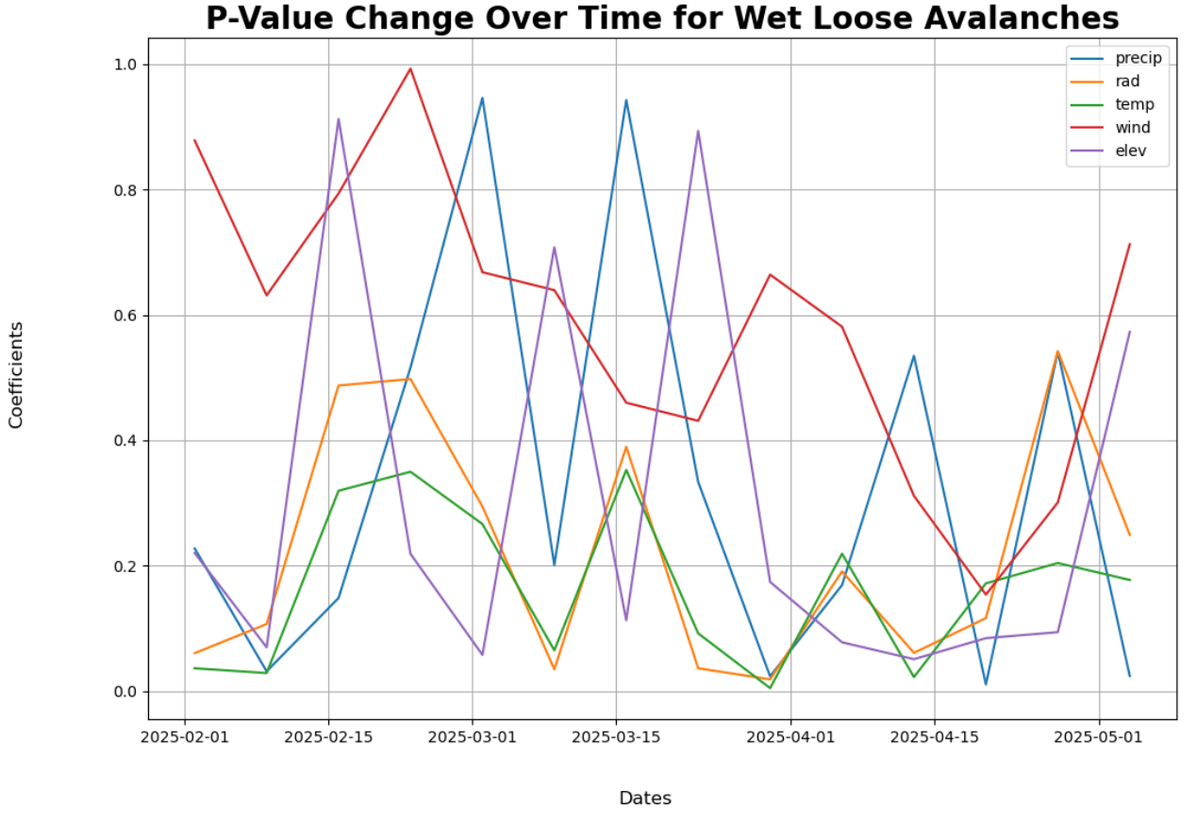
Week #	Regression Coefficient for Precipiation
1	0.04
2	0.10
3	-0.08
...	...
n	0.01

$$H_0 : \beta_1 = 0$$

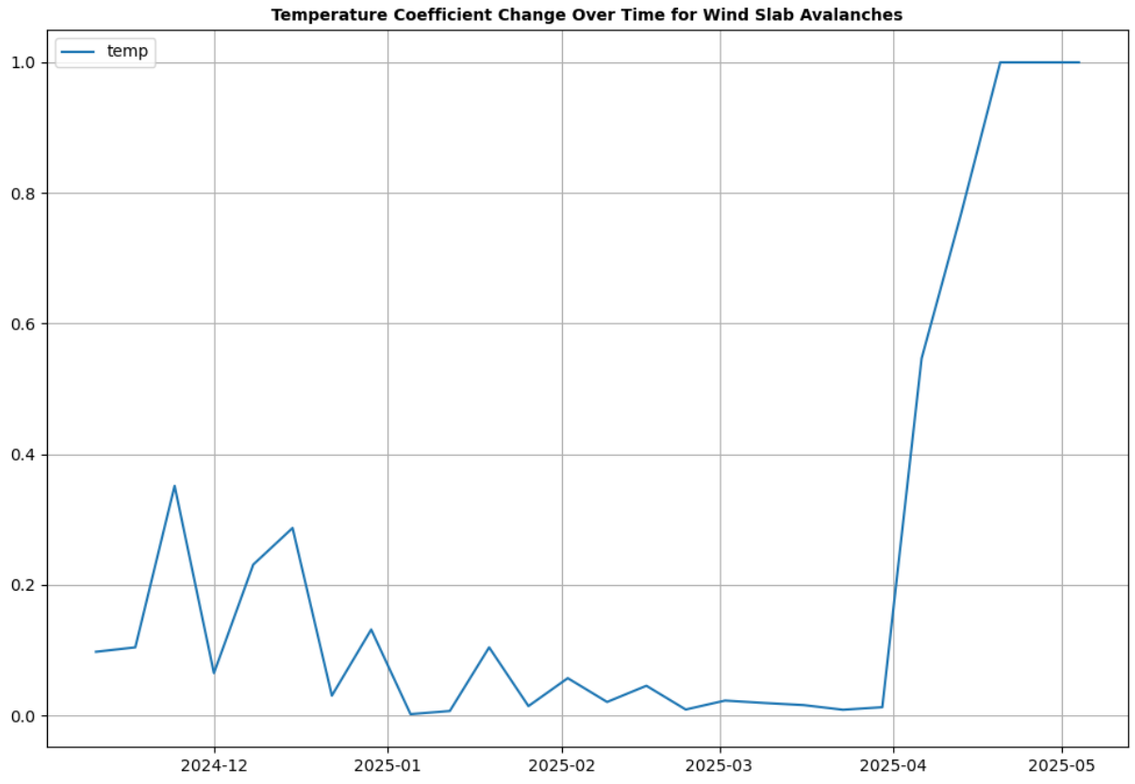
$$H_A : \beta_1 \neq 0$$

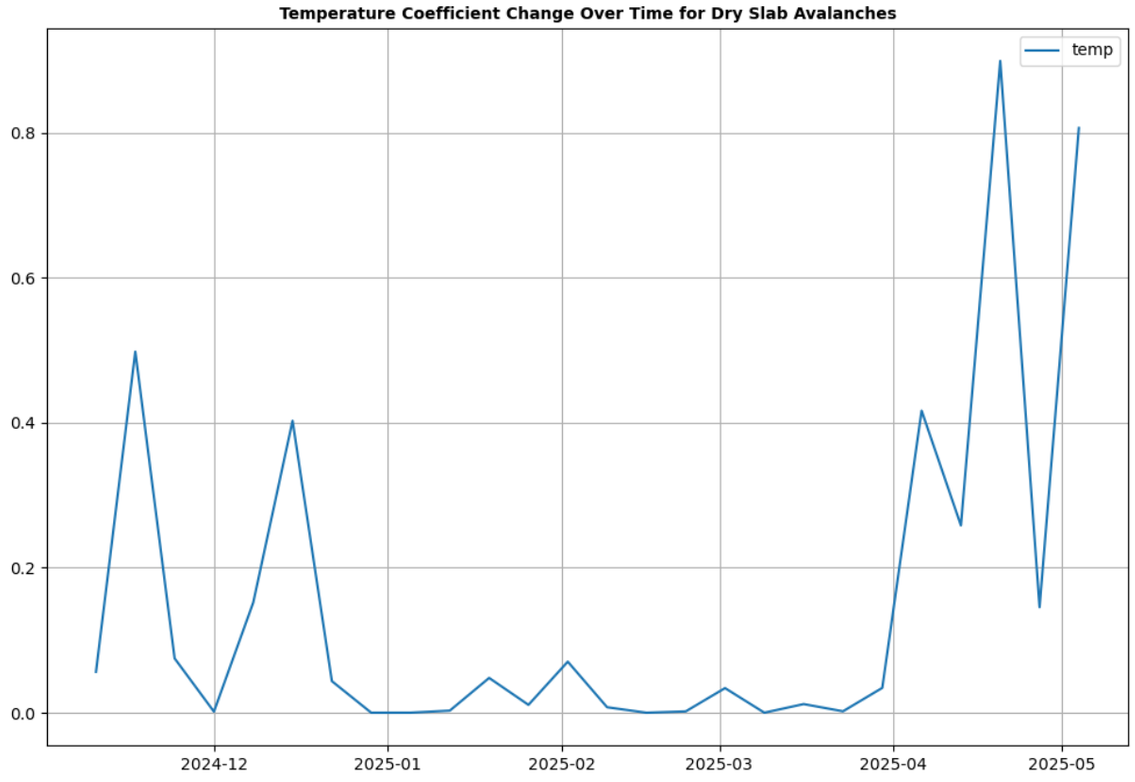
Week #	P-values of Coefficients for Precipitation
1	0.5
2	0.23
3	0.002
...	...
n	0.01

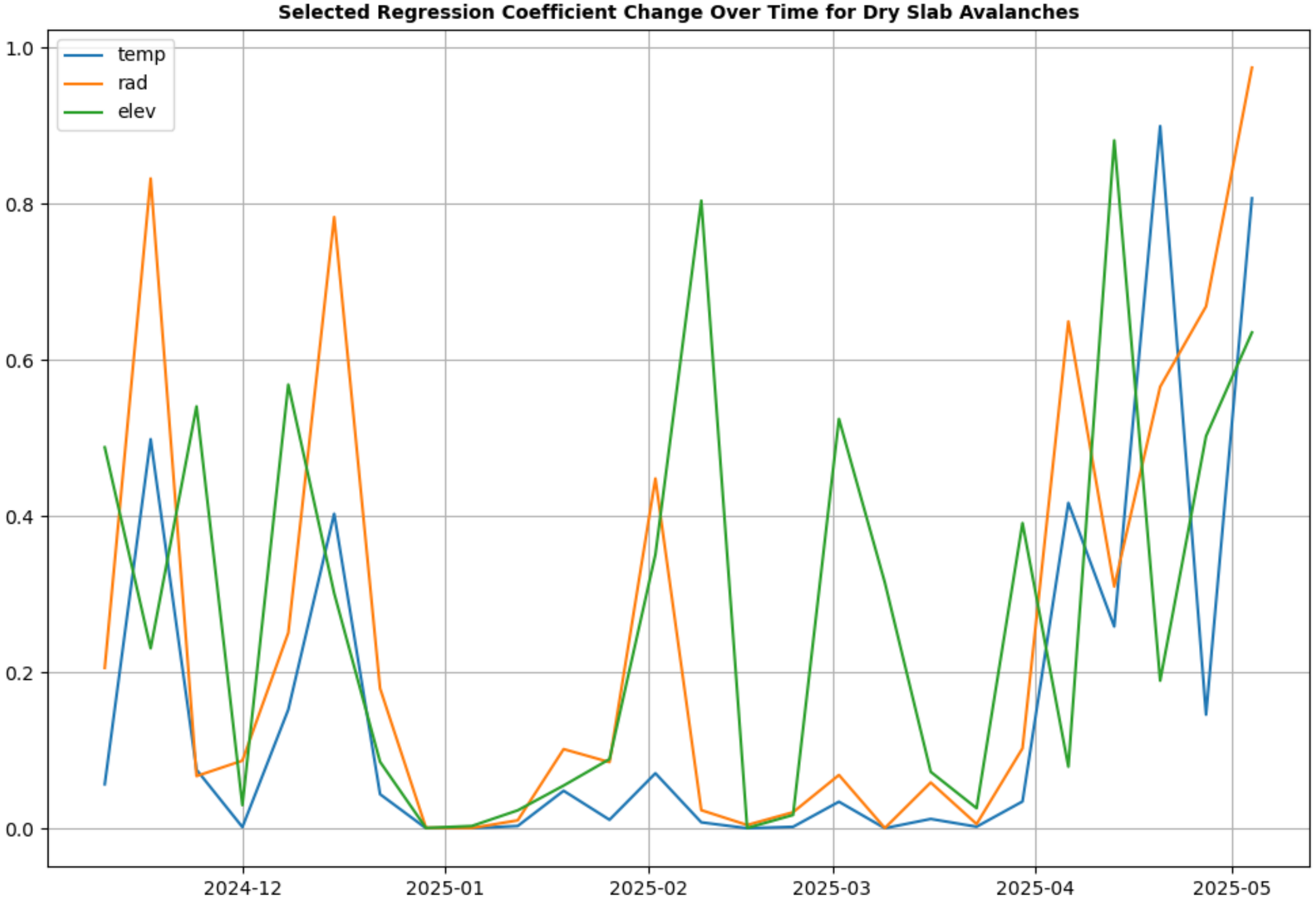

P-Value Change Over Time for Dry Slab Avalanches
precip
rad
temp
wind
elev
1.0
0.8
0.6
0.4
0.2
0.0
2024-12
2025-01
2025-02
2025-03
2025-04
2025-05
Coefficients
P-Value Change Over Time for Wind Slab Avalanches
Dates


P-Value Change Over Time for Wet Loose Avalanches
precip
rad
temp
wind
elev
1.0
0.8
0.6
0.4
0.2
0.0
2025-02-01
2025-02-15
2025-03-01
2025-03-15
2025-04-01
2025-04-15
2025-05-01
Coefficients
Dates

Assessing the Results

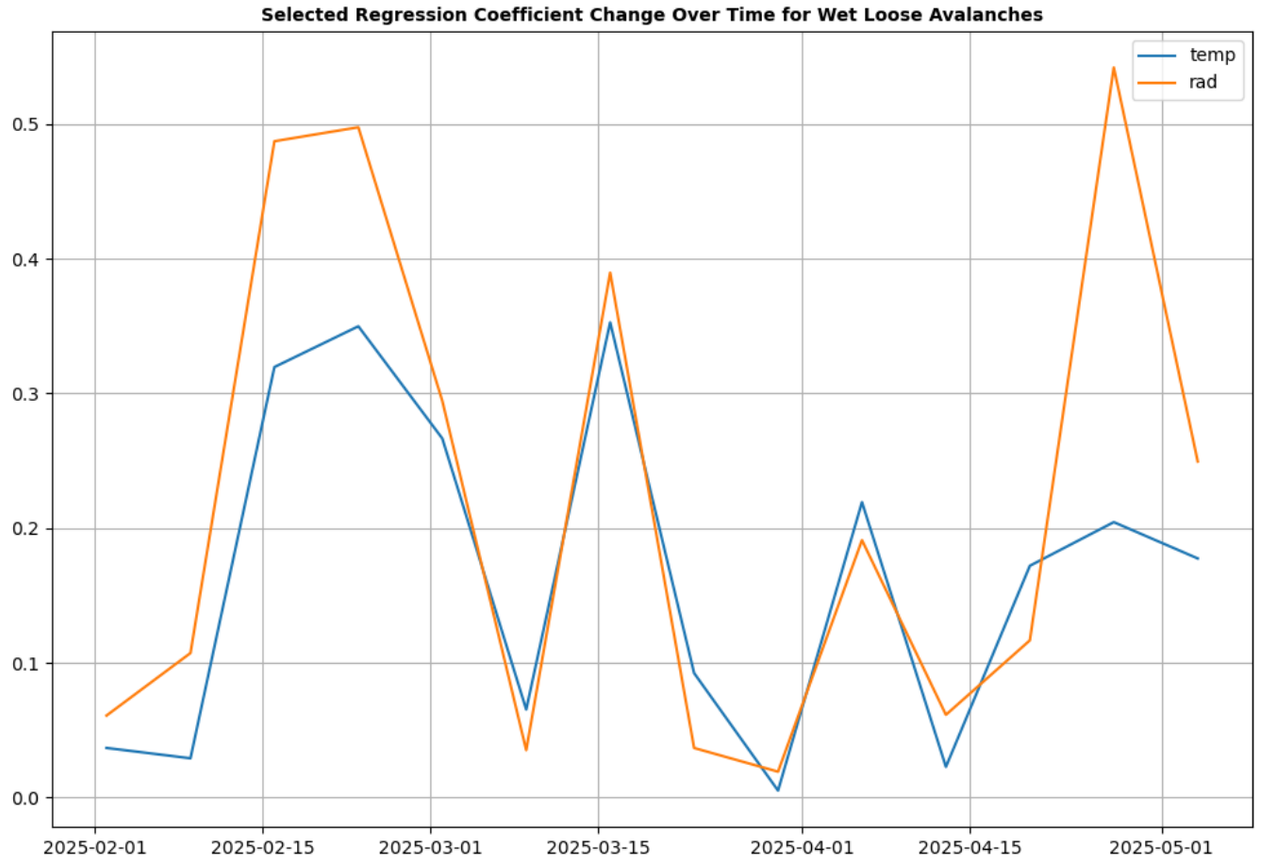

Temperature Coefficient Change Over Time for Wind Slab Avalanches
temp
1.0
0.8
0.6
0.4
0.2
0.0
2024-12
2025-01
2025-02
2025-03
2025-04
2025-05


Temperature Coefficient Change Over Time for Dry Slab Avalanches
temp
0.8
0.6
0.4
0.2
0.0
2024-12
2025-01
2025-02
2025-03
2025-04
2025-05


Selected Regression Coefficient Change Over Time for Dry Slab Avalanches
temp
rad
elev
1.0
0.8
0.6
0.4
0.2
0.0
2024-12
2025-01
2025-02
2025-03
2025-04
2025-05

What could’ve been improved/potential errors

- Lack of wider range for some variables
  - What range of temperatures did I record in my observations?
- Multicollinearity
  - What are we really measuring when tracking both temperature + solar radiation?



What could’ve been improved/potential errors

- Assuming Independence
  - Each cell lacks spatial dependence
  - Overconfidence in predicting meaningful relationships
- Type I errors in hypothesis testing
  - Conducted over 1500 hypothesis tests across this whole project
  - Likely a large number of false positives