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Potential Weather Data Anomolies within the USDA's Pasture Rangeland and Forage Insurance Program

Chad Steven Van Orden

Utah State University

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POTENTIAL WEATHER DATA ANOMOLIES WITHIN THE USDA'S PASTURE, RANGELAND AND FORAGE INSURANCE PROGRAM

by

Chad Steven Van Orden

A research paper submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Applied Economics

Approved:

Brandon Willis, J.D., LL.M. Major Professor	Ryan Bosworth, Ph.D. Committee Member
Ryan Larsen, Ph.D. Committee Member	Tanner McCarty, Ph.D. Committee Member
Man-Keun Kim, Ph.D. Committee Member	

UTAH STATE UNIVERSITY
Logan, Utah
2019

ABSTRACT

Potential Weather Data Anomalies within the USDA's Pasture, Rangeland and Forage Insurance Program

by

Chad Steven Van Orden

Utah State University, 2019

Major Professor: Brandon Willis, J.D., LL.M.
Department: Applied Economics

The purpose of this study is to delve into the functionality of the PRF insurance program. The primary goal is to uncover any underlying anomalies which may inadvertently skew data within the program. Because the USDA uses NOAA's weather stations regardless of location or timing of activation, it is consequential that the collected precipitation data may be inconsistent across both time and space. This phenomenon could have substantial and significant effects on the RMA's PRF insurance program, resulting in producers being compensated inaccurately for their insurance claims.

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INTRODUCTION

The Federal Crop Insurance Corporation (FCIC) was first established by the United States Department of Agriculture (USDA) in 1938 largely as a result of both the Great Depression and the Dust Bowl. After these economic disasters, the USDA sought out to provide a form of risk management for the farm and ranch industries to ensure the security and continual production of agricultural commodities. The FCIC began as an experiment and was limited mostly to a few major crops. Eventually, federal crop insurance became official with the passage of the Federal Crop Insurance Act of 1980. The act allows agricultural production industries to insure against less-than-ideal yields due to weather patterns, pests, or other natural disasters. One may insure the production of crops and livestock alike to mitigate risk. Various distinct insurance plans are available to firms who may be looking to mitigate agricultural risk. Pasture, Rangeland, and Forage (PRF) insurance is merely one of these specified insurance plans.

PRF insurance, informally known by some as “drought insurance” is a program created by the Risk Management Agency (RMA) to protect producers from below-average precipitation. The program operates as a function of precipitation measurements recorded daily by some collection of weather stations overseen by the National Oceanic and Atmospheric Administration Climate Prediction Center (NOAA). The PRF program uses NOAA’s precipitation data to determine payouts on insurance claims based off historical precipitation. Historical information is utilized through the usage of a rainfall index. The rainfall index compares actual amounts of precipitation to historical averages (USDA-RMA).

The PRF insurance program does not incorporate a measurement of production. Rather, the program is designed to protect against a rainfall index comprised of a 70-year average. Various coverage levels may be purchased and assigned to individual time periods. In theory, the program will correctly determine if a particular area of pasture, rangeland or forage ground has received an actual precipitation value above or below the 70-year average. If an area of land has received below-average precipitation during an insured time-period, the system may trigger an indemnity payment to be assigned to the producer as compensation. These payments are then allocated to producers with eligible ground insured by PRF insurance. On the other hand, if an area receives a level of precipitation that is above the 70-year average, the producer may not receive a compensation payment, as there is no given "loss" to reimburse. On a good day, the rainfall index accurately observes and properly portrays what is happening in any given area concerning precipitation levels.

However, if the program were to be functioning incorrectly, a different story may be told about the fate of producers buying into the program. For example, discrepancies in actual recorded precipitation could lead to a misrepresentation of data within the rainfall index. The indemnity payout is a function of the rainfall index, which is a function of actual and available recorded precipitation. For this reason, it becomes crucial to ensure accurate readings at the base level of precipitation measurements in order to prevent deviating from the truth when utilizing an index based on historical averages.

Complaints from PRF producers in the Northern Utah area initially sparked our investigation of the PRF insurance program. Claims of inaccurate weather readings and criticisms of the program itself were made to PRF insurance agents (Willis). One of the first steps taken in this study was a broad analyzation of the gathered precipitation data to skim for noticeable differences or “breaks.” An observable break could represent a systematic change in the data instigated by some external force causing inaccurate results. Since the PRF payout indemnities are linked directly to long-term historical data, inaccurate data archives at this level can have lasting effects for decades to come

LITERATURE REVIEW

Participation in the federal crop insurance program has increased substantially since the passage of the Crop Insurance Reform Act in 1994. After generating under $1 billion in premiums the same year, the program grew to nearly $10 billion in premiums by 2016. In 2007, the RMA introduced rainfall index and vegetation index pilot programs to the FCIP as a means of determining payout indemnities for PRF insurance. The rainfall index functions as a measure of precipitation data. The vegetation index utilizes satellite imagery to regulate levels of greenery or vegetation in specific areas (USDA-RMA).

Eventually the vegetation index was completely replaced by the rainfall index in 2016. More than 52 million acres were enrolled in the PRF program the same year. However, this figure represents only 8% of the nearly 650 million acres of land qualifying for PRF insurance in the United States (USDA-RMA). While the PRF program has grown rapidly since its commencement, insured acreage remains a small percentage of land eligible for enrollment. Current enrollment percentages relative to potential participation suggest that the program may continue to grow in importance over time- particularly in the arid regions of the United States (Carlson et al., 2017).

The USDA takes an average of the recorded historical precipitation and uses that average as the baseline in a historical index. An index of 105 indicates that the precipitation recorded was 5% *above* normal, with an index of 95 indicating a measurement of 5% *below* normal levels. If precipitation for the period purchased is below the normal numbers, the rancher may qualify for a payout. The rancher can purchase coverage levels of 70, 75, 80, 85, and 90%. This level of coverage is then allocated across the year into two-month intervals.

PRF involves only a single peril insurance. In this program, the peril of precipitation is observed on a recurring interval basis. Each interval is comprised of two consecutive monthly periods (Jan-Feb, Feb-Mar, Mar-Apr, Apr-Jun, Jun-Jul, Jul-Aug, Aug-Sep, Sep-Oct, Oct-Nov, and Nov-Dec). Time intervals must be decided on and purchased in the year prior to the insurance period. The insurer may then allocate the purchased coverage level over at least two intervals, without doubling up on months. A minimum coverage level of 10% is required in each chosen interval, with a maximum level of 60%. These allocated levels of coverage must sum together to equal 100% (Westerhold et al., 2018).

For convenience, the USDA has incorporated NOAA’s grid system into their payout process. The 48 contiguous states are divided into 0.25-degree latitude by 0.25-degree longitude, or approximately 17x17 mile grids at the equator. Any pasture, rangeland, or forage ground within each individual grid qualifies for coverage policies determined by the local weather stations closest to the respective grid. Typically, the closest four to ten weather stations are integrated into the payout calculation (usually within a 30 km radius). Indexes cannot be traced back to the reported activity of any one individual station (USDA-RMA). Each weather station’s recorded data is then weighted according to its proximity from the center of the specified grid, giving more weight to those stations closest to the centroid of a particular grid, and less weight to those further away (Willis).

Producers are allowed to specify which time frames (two-month intervals) he or she would like to purchase coverage for. PRF insurance is unique in this sense, since coverage is allocated to insure the time periods chosen by the producer. Furthermore, the indexes for individual grids are determined by an interpolated value based on the grid as a whole, as opposed to exact measurements of precipitation in specific locations, or even from specific weather stations. Therefore, gridded precipitation data cannot be traced back to a single reporting station (USDA-RMA). Data may be collected from a changeable group of weather stations at various locations throughout the grid.

In a study regarding the rainfall index for insurance purposes, Maples, Brorsen and Biermacher examine the implications of such a program for cool-season foraging-specifically for ryegrass production. The study discusses the high correlations in the rainfall index with actual precipitation measurements. However, the issue encountered here becomes the limited risk protection available for forage risk in the cooler seasons. This refers particularly to the December-January interval which in reality is not an available time period for coverage options. The study shows this time interval to be statistically significant and positively correlated with production yields. Furthermore, the authors suggest that producers enrolling in the PRF insurance program allocate the greatest weight of coverage to this unfortunately unavailable interval. Ultimately, the lack of correlation between precipitation and production yields suggests that modifications could be made to improve the viability of the program in such a way that would more greatly benefit producers while reducing the cost of subsidized insurance programs (Maples, Brorsen, & Biermacher, 2016).

As mentioned before, each grid has a handful of weather stations assigned to determine the weighted precipitation levels for that specific area. If between four and ten active weather stations are available within a 30 km radius, those respective stations are used. If there are not between four and ten stations available, the radius is increased

(Willis). Oftentimes there are stations capturing precipitation levels in the mountains as well as in the valleys. This allows averages across elevations to be determined to give the most accurate representation of the moisture in any particular grid.

DATA

Prior to this study, complaints had been made from PRF producers in the Northern Utah area about the functionality of the PRF insurance program. Producers made claims of inaccurate weather readings and criticized the program of withholding merited indemnities, even during years with below-average precipitation. Producers in Northern Utah also claimed that the program began withholding indemnities only after a new weather station was activated in the Raft River Mountains of grid 26167. These claims provoked a closer examination of the grid.

Upon further inspection, it was discovered that a new NOAA weather station had become active in grid 26167 in the year 2010. This new station (named George Creek, UT station) is located near the centroid, implying this station is heavily weighted in grid 26167. Furthermore, the new weather station is located at 9,005 feet in the Raft River Mountains. The Rosette weather station is also located near the centroid and sits at 5,685 feet. This introduces a high-elevation (suggesting higher precipitation) station near the centroid of a grid located in a traditionally arid area. An additional grid was then utilized to compare to the observations of grid 26167.

Grids 26167 and 33663 in Park Valley, UT and Kalispell, MT, respectively are the two grids initially and primarily analyzed. At first glance, there appears to be a break of some sort within the historical indexes of both grids around the year 2008. The indexes in Park Valley and Kalispell each appear to be increasingly larger and more positive (above 100) after this point in time. Similarly to Park Valley, an additional station was introduced in grid 33663 at the end of the year in 2010. The newly introduced weather station in Montana is located in the Blacktail Mountains at 5,650 feet. This introduces a high-elevation station in another relatively arid grid. The new station sits over 40% higher in elevation than the town of Kalispell. With this newfound knowledge, a more rigorous analysis of the data ensued.

The first area of data collection began with a grid in northern Utah where PRF insurance appeared to be an infeasible option for producers. Rainfall index data was accessed and observed on the USDA’s website using the RMA’s PRF “Support Tool.” The support tool allows one to locate specific grids and observe historical indexes for the respective grid. Index data is available in Excel-compatible .CSV format. After converting the data into Excel format, the data is ready to be analyzed with preliminary experiments. The data is set up in a time-series format with a row for each year of rainfall indexes and a corresponding column for each two-month interval of the respective year.

Summary Statistics

Summary statistics were immediately calculated to identify apparent changes in trends across time. By computing summary statistics, it can be shown how the rainfall index mean has fluctuated over time. Fluctuations in the mean should be sure signs of change in precipitation trends, ranging from dry, drought-like indexes to wet, flood-like indexes. Mean rainfall indexes for the Park Valley area (Figure 1) and the Kalispell area (Figure 2) are computed for annual trends as well as seasonal trends in the rainfall index.

Table 1. Park Valley Rainfall Indexes, 1996-2018

Grid 26167 (Park Valley, UT) Rainfall Index from 1996-2010												
	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	**Overall Average**
Mean	103.23	97.69	99.43	89.91	83.49	78.93	74.39	84.99	93.67	90.18	112.84	**91.70**
Max	222.70	193.10	241.40	178.80	203.10	276.10	227.90	217.70	157.90	217.70	339.80	**225.11**
Min	40.60	13.70	32.20	33.40	14.90	9.60	23.90	34.90	12.90	14.80	16.50	**22.49**
Std. Dev	55.24	54.84	54.78	46.04	60.36	70.22	55.44	52.12	40.72	50.05	86.51	**56.94**
Grid 26167 (Park Valley, UT) Rainfall Index from 2011-2018												
	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	**Overall Average**
Mean	183.05	178.94	181.45	161.76	102.09	54.04	86.91	144.45	181.55	144.99	162.21	**143.77**
Max	374.30	347.90	236.10	247.30	210.50	101.50	170.30	265.20	323.90	259.10	286.20	**256.57**
Min	59.00	84.30	73.10	118.40	55.00	20.70	3.00	22.40	80.00	65.10	23.50	**54.95**
Std. Dev	99.33	78.78	53.08	43.50	56.37	27.20	59.72	84.01	86.50	58.52	89.24	**66.93**

Note: A cell highlighted in yellow indicates an absolute change of >25% in the mean rainfall index. A cell highlighted in red indicates an absolute change in the mean of >50%.

Table 2. Kalispell Rainfall Indexes, 1996-2018

Grid 33663 (Kalispell, MT) Rainfall Index from 1996-2010

	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	**Overall Average**
Mean	105.89	100.01	105.47	110.91	110.87	104.17	86.27	100.75	111.05	104.47	109.57	**104.50**
Max	218.10	206.90	188.20	238.60	251.90	228.70	157.40	198.40	227.40	276.60	288.20	**225.49**
Min	43.50	51.70	63.00	49.70	55.40	32.40	13.10	32.30	41.10	25.20	36.30	**40.34**
Std. Dev	50.06	41.06	39.69	53.86	56.54	51.89	47.70	50.23	45.80	63.16	75.43	**52.31**

Grid 33663 (Kalispell, MT) Rainfall Index from 2011-2018

	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	**Overall Average**
Mean	194.64	231.69	211.50	148.84	131.24	113.78	66.14	84.35	150.03	184.00	185.31	**154.68**
Max	253.50	319.40	289.50	251.60	208.10	205.10	126.10	188.90	260.30	250.20	246.50	**236.29**
Min	144.80	161.30	140.70	53.70	37.40	52.30	17.10	20.50	68.50	116.10	124.90	**85.21**
Std. Dev	35.88	54.90	57.53	55.81	62.69	64.82	34.18	60.54	57.52	55.63	42.60	**52.92**

Note: A cell highlighted in yellow indicates an absolute change of >25% in the mean rainfall index. A cell highlighted in red indicates an absolute change in the mean of >50%.

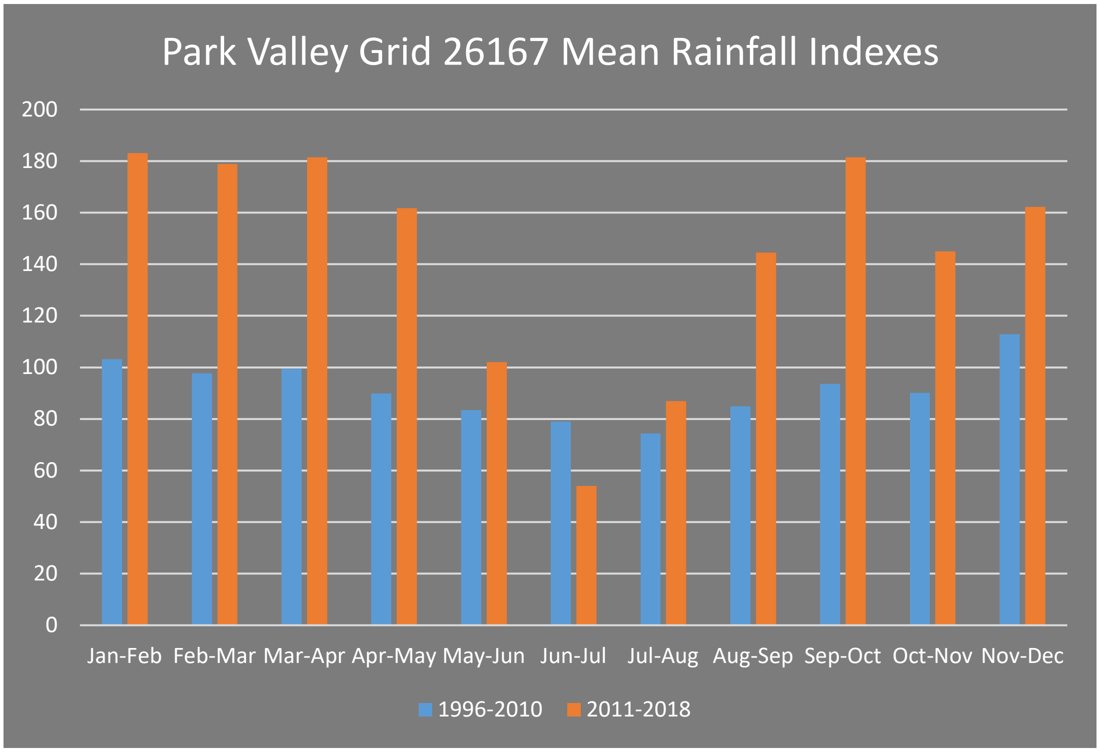

Figure 1. Grid 26167 rainfall index averages, 1996-2018

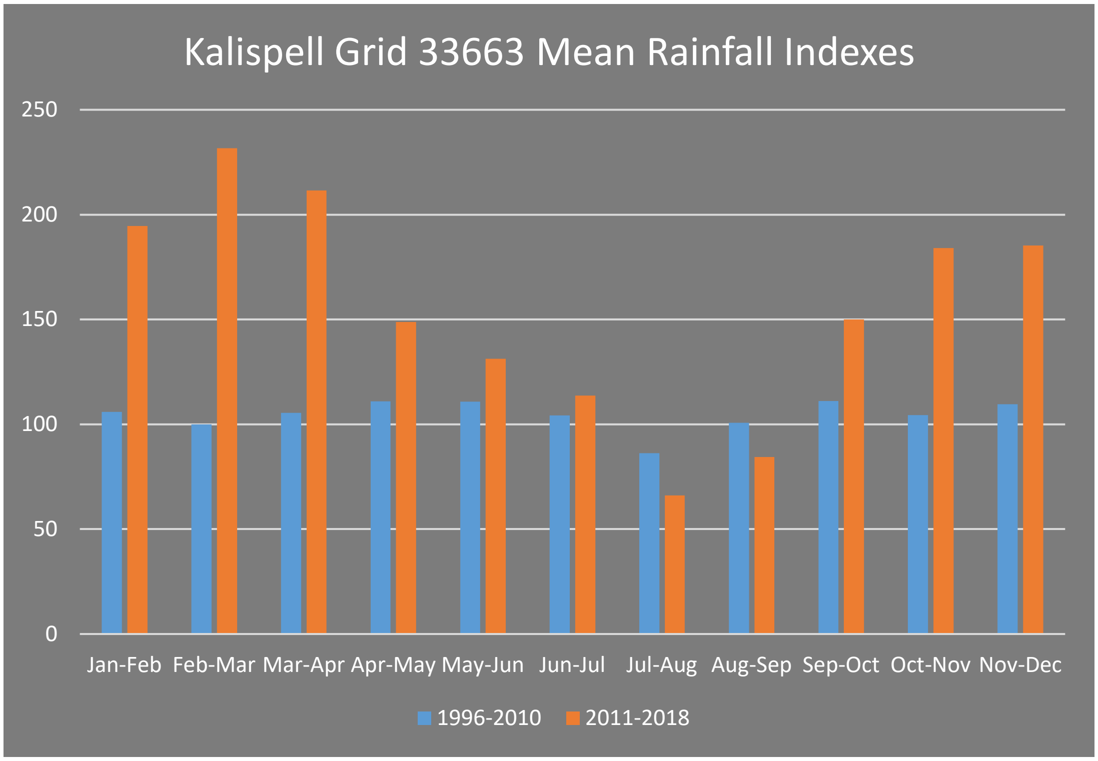

Figure 2. Grid 33663 rainfall index averages, 1996-2018

Figure 1 displays how the rainfall index for grid 26167 has performed on average for each available insurance interval for the last twenty-three years. The mean rainfall indexes over the last eight years are compared to the previous fifteen years. It can be observed that the rainfall index has increased by at least 25% on average for nine of the eleven two-month intervals, with seven of those increasing by more than 50%. Furthermore, the overall average of the rainfall indexes increased by more than 50% from the first time period to the second. Figure 2 exhibits similar results, with seven of the eleven two-month intervals increasing by at least 25%. Moreover, five intervals, including the overall average increased by more than 50%. The intervals where these radical increases take place are primarily during the cold-weather months for both observed areas.

The support tool provided by the RMA also demonstrated that the area within grid 26167 had received "above-average precipitation" for ten out of the last eleven annual averages (years 2008-2018). "Above-average precipitation" indicates that there is more than enough moisture available for PRF producers in an area, resulting in indemnity payments being withheld. Upon further observation, it was noticed that ten out of the *prior* eleven years (1997-2007) had received "*below*-average precipitation" for their respective annual averages. An inference drawn here is that there was consistency in the functionality of the program for one decade, and then a transformation took place to cause an opposite but equally consistent trend in functionality. Here, the question at hand becomes: What has caused this sudden change in the rainfall index, and is it an organic or man-made change? After the discovery of these time-series "breaks" in the data, it became apparent that further data collection and analysis would be required.

Monthly precipitation measurements were then collected the Rosette weather station in Park Valley for the purpose of comparing the index trends to the precipitation trends. Actual precipitation measurements and weather station location data was accessed from NOAA's website by using the "Find a Station" tool. This tool was utilized by locating specific weather stations near or within specific grids and manually imputing the data into an excel file for analyzation. Comparing the rainfall index data with actual precipitation data allows hypotheses to be drawn about the accuracy of the rainfall index with respect to actual precipitation. If actual precipitation trends fluctuate proportionately with rainfall indexes, it can be inferred that an increase or decrease in rainfall indexes in grid 26167 is an accurate representation of weather trends in the Park Valley area. However, if there are disproportionate changes between the recorded precipitation and the rainfall index, this could be interpreted as the presence of anomalies within the PRF insurance program.

Mean Absolute Deviation

Mean Absolute Deviation (MAD) calculates the residuals (deviations from the mean) and averages them across each two-month interval. Historical indexes are split into three (3) seven-year time-series categories: the first group consists of precipitation index data for years 1997-2003; the second for 2004-2010; the third for 2011-2017. The three groups are then compared against one another and checked for significant variations. The same process is also done for the actual precipitation measurements recorded by the Rosette weather station during the same three periods. This is done for every two-month interval within each group, as well as an average of each seven-year period, giving a mean or average of the absolute deviations for each of the three groups. Ultimately, calculating the MAD gives an indication of variability levels.

Table 3. Mean absolute deviations of rainfall index in grid 26167, 1997-2017

MAD of Park Valley, UT Rainfall Index												
	Jan/Feb	Feb/Mar	Mar/Apr	Apr/May	May/Jun	Jun/Jul	Jul/Aug	Aug/Sep	Sep/Oct	Oct/Nov	Nov/Dec	**Average**
1997-2003	35.93	52.71	32.09	47.96	57.61	59.33	49.06	37.17	48.87	36.60	57.99	**46.85**
2004-2010	49.04	42.69	51.87	37.94	53.63	66.41	42.21	41.97	19.76	44.14	66.00	**46.88**
2011-2017	105.67	86.14	90.84	65.87	46.59	42.13	43.06	62.63	95.50	58.84	93.36	**71.88**

Table 4. Mean absolute deviations of precipitation recorded by Rosette, UT station, 1997-2017

MAD of Recorded Precipitation from Rosette, UT Station												
	Jan/Feb	Feb/Mar	Mar/Apr	Apr/May	May/Jun	Jun/Jul	Jul/Aug	Aug/Sep	Sep/Oct	Oct/Nov	Nov/Dec	**Average**
1997-2003	1.30	0.99	1.12	1.67	1.73	1.25	0.77	1.04	1.08	0.60	0.91	**1.13**
2004-2010	1.28	0.64	1.08	1.36	1.65	1.17	0.41	0.33	0.60	0.91	1.23	**0.97**
2011-2017	1.07	0.73	0.94	1.99	1.52	0.50	1.23	1.81	1.69	0.71	0.78	**1.18**

Table III contains the MADs for the rainfall index of grid 26167. In Table III, the residuals average out virtually identically across the two earlier periods. However, after 2010 the mean absolute deviation increases over 50% for the latest seven-year period. Every two-month interval's MAD is substantially higher in the latest period (bottom row) except for three intervals. May/Jun, Jun/Jul, and Jul/Aug either decrease or remain constant in variability.

Table IV captures the MAD of the recorded precipitation from the Rosette, UT weather station. The results of the recorded precipitation data are comparable, without the blatancy seen in the MAD of Table III. There is a jump in variation during the last period (2011-2017) compared to the first two periods, similar to the rainfall index MADs. This confirms that there has been more variation in the precipitation patterns in the more recent years compared to the previous decade. However, the jump in variation is not as severe in the actual recorded precipitation as it appears to be in the index data. The index data shows an increase in variation of over 50% in the latest seven-year average, while the actual recorded precipitation shows an increase of only 21.65%. This difference in the levels of change in variability suggests that while precipitation patterns may be trending towards a more inconstant pattern, the rainfall index has experienced a much more definite and drastic shift in variation than actual recorded precipitation.

After preliminary analyses of the data in grid 26167, additional grids with their respective rainfall indexes were collected. Furthermore, additional recorded precipitation data was collected from the following weather stations: George Creek, UT; Grouse Creek, UT; Blacktail Mountains, MT; Glacier Airport, MT. This led to the further collection of weather station data, including station location, elevation, and actual recorded precipitation for the purpose of running statistical analyses. While searching for supplementary grids, the PRF support tool was again utilized to find grids with apparent breaks in their reported data. Additional grids were also sought out which contain uninterrupted or “unbroken” consistencies in rainfall indexes across time. The characteristics of these grids may be compared to those of grids with inconsistencies in the rainfall index. This comparison is done in order to identify potential clues which might explain a sudden change in recorded precipitation, i.e. introduction of new weather stations, weather station location, elevation of stations, etc. Additional grids included in this study are grids 28875, 33663, 27077, 27381, 25308, and 25823. The relative locations of these grids are Ashton, ID; Kalispell, MT; Afton, WY; Pinedale, WY; Cheyenne, NE; and Wichita, KS, respectively.

In order to detect significant changes in the historical index, annual averages were computed for the rainfall indexes of each individual grid and compared to the averages in various time frames within the last 70 years. This comparison allows an observation of the rainfall index across time in order to identify large jumps or breaks in the data. While observing weather station data from NOAA, it became apparent that numerous new weather stations were constructed and activated around similar time periods: in the early 1980’s and around 2008-2010. For this reason, particular time frames were chosen to encapsulate these dates in order to determine if new weather station placement or location might be correlated with changes in mean annual precipitation. The results are as follows:

Table 5. Changes in average index values for multiple grids, 1948-2018

Park Valley, UT Grid 26167			
	1948-1979	1980-2009	2010-2018
Mean Index Values	94.54	92.76	143.53
% Change in Mean		-1.9%	+54.7%
Kalispell, MT Grid 33663			
	1948-1979	1980-2009	2010-2018
Mean Index Values	78.40	105.49	159.90
% Change in Mean		+34.55%	+51.58%
Ashton, ID Grid 28875			
	1948-1979	1980-2009	2010-2018
Mean Index Values	97.33	95.04	129.69
% Change in Mean		-2.35%	+36.46%
Afton, WY Grid 27077			
	1948-1979	1980-2009	2010-2018
Mean Index Values	86.61	109.11	117.77
% Change in Mean		+25.98%	+7.94%
Pinedale, WY Grid 27381			
	1948-1979	1980-2009	2010-2018
Mean Index Values	79.35	116.07	121.79
% Change in Mean		+46.27%	+4.93%
Cheyenne, NE Grid 25308			
	1948-1979	1980-2009	2010-2018
Mean Index Values	96.59	106.19	91.15
% Change in Mean		+9.94%	-14.17%
Wichita, KS Grid 23823			
	1948-1979	1980-2009	2010-2018
Mean Index Values	92.71	108.66	97.06
% Change in Mean		+17.19%	-10.67%

Note: A cell highlighted in yellow indicates an absolute change of >25% in the mean rainfall index. A cell highlighted in red indicates an absolute change in the mean of >50%.

The Park Valley grid's rainfall index experiences an increase of over 50% in the mean of the annual average from 2010-2018. This suggests that the precipitation in this area should have increased correspondingly by approximately 50% in the last decade or so. The Kalispell grid's rainfall index experiences a similar increase of 51% in the mean of the annual average from 2010-2018. This is consistent with the Park Valley grid, and again suggests that precipitation in the Kalispell area should have increased dramatically since 2009.

Ashton, ID saw a less dramatic increase in the rainfall index during the same time period, but the area should still be able to expect recorded precipitation to increase proportionately by at least 30%. Afton and Pinedale WY grids see slight increases in the latest time frame. However, an apparent and observable increase in the historical index occurred between 1980 and 2009 in both grids when compared to the average between 1948 and 1979. Moving to the Midwest, the data illustrates a relatively stable rainfall index in both Cheyenne and Wichita, experiencing absolute changes on average of no more than 20% in the past forty years. It is also noted that there are relatively insignificant changes in elevation in the areas surrounding the respective centroids of these two grids.

After observing the changes in the mean of annual averages, NOAA's website was utilized further to locate any relatively new weather stations near or within each respective grid. Stations which were activated during the general timeframe that major breaks in the index take place were then flagged and recorded. The results are as follows:

Table 6. Newly introduced weather stations in suspect grids during time periods with changing variation (early 1980s and late 2000's)

<table>
<tr><td colspan="4">**Park Valley, UT** - Elevation: 5685'</td></tr>
<tr><td>**Year**</td><td>**Station Name**</td><td>**Elevation (feet)**</td><td>**% Change in Elevation**</td></tr>
<tr><td>2010</td><td>George Creek, UT</td><td>9004</td><td>+58%</td></tr>
<tr><td colspan="4">**Kalispell, MT** - Elevation 2939'</td></tr>
<tr><td>**Year**</td><td>**Station Name**</td><td>**Elevation (feet)**</td><td>**% Change in Elevation**</td></tr>
<tr><td>1979</td><td>Hand Creek, MT</td><td>5032</td><td>+71%</td></tr>
<tr><td>1979</td><td>Noisy Basin, MT</td><td>6040</td><td>+105%</td></tr>
<tr><td>1980</td><td>Badger Pass, MT</td><td>6899</td><td>+135%</td></tr>
<tr><td>1981</td><td>Pike Creek, MT</td><td>5928</td><td>+102%</td></tr>
<tr><td>1981</td><td>Emery Creek, MT</td><td>4350</td><td>+48%</td></tr>
<tr><td>2011</td><td>Blacktail Mountains, MT</td><td>5649</td><td>+92%</td></tr>
<tr><td colspan="4">**Ashton, ID** - Elevation: 1588'</td></tr>
<tr><td>**Year**</td><td>**Station Name**</td><td>**Elevation (feet)**</td><td>**% Change in Elevation**</td></tr>
<tr><td>2007</td><td>Grand Targhee, WY</td><td>9258</td><td>+78%</td></tr>
<tr><td>2009</td><td>West Yellowstone, MT</td><td>6676</td><td>+28%</td></tr>
<tr><td colspan="4">**Afton, WY** - Elevation: 6246'</td></tr>
<tr><td>**Year**</td><td>**Station Name**</td><td>**Elevation (feet)**</td><td>**% Change in Elevation**</td></tr>
<tr><td>1981</td><td>Snider Basin, WY</td><td>8061</td><td>+29%</td></tr>
<tr><td>1981</td><td>Blind Bull Summit, WY</td><td>8648</td><td>+38%</td></tr>
<tr><td>1982</td><td>Salt River Summit, WY</td><td>7760</td><td>+24%</td></tr>
<tr><td>1983</td><td>Spring Creek Divide, WY</td><td>8999</td><td>+44%</td></tr>
<tr><td>1983</td><td>Cottonwodd Creek, WY</td><td>7670</td><td>+23%</td></tr>
<tr><td colspan="4">**Pinedale, WY** - Elevation: 7211'</td></tr>
<tr><td>**Year**</td><td>**Station Name**</td><td>**Elevation (feet)**</td><td>**% Change in Elevation**</td></tr>
<tr><td>1979</td><td>Hobbs Park, WY</td><td>10,098</td><td>+40%</td></tr>
<tr><td>1981</td><td>Elkhart Park G.S., WY</td><td>8648</td><td>+38%</td></tr>
<tr><td>1981</td><td>Townsend Creek, WY</td><td>8701</td><td>+21%</td></tr>
</table>

Kalispell saw the introduction of five new stations in the surrounding area from 1979-1981. On average, all of these new stations are 92% higher in elevation than the town of Kalispell. An additional station was activated in the grid in the year 2011. This station also sits over 90% higher in elevation than Kalispell. Ashton saw the introduction of two new stations in the surrounding area: one in 2007 sitting 78% higher in elevation than the town of Ashton; the other in 2009, at 28% greater elevation.

The Afton and Pinedale areas experienced the activation of several new stations in the early 1980s. Seven new stations were activated near Afton from 1981-1983, all averaging a 30% higher elevation than the town of Afton. Similarly, Pinedale saw six new stations introduced in the surrounding area from 1979-1983. These new stations averaged 25% higher elevation than the town of Pinedale.

METHODOLOGY

In order to determine the significance and magnitude of changes in recorded precipitation levels, two key methodologies were utilized: Probability Density Functions (PDFs) and Analyses of Variance (ANOVA).

Probability Density Functions

The @Risk Software package is used to fit the data into probability density functions (PDFs). PDFs from both the Park Valley and Kalispell grids are used for two different parts: Part One compares distributions of rainfall indexes[1] in grids 26167 and 33663, individually, between two specific time periods. Part Two distributes precipitation patterns recorded by local weather stations[2] within the two grids at hand during the same respective time frames as Part One. The PDFs will compare before and after the time that a specific, single, new high-elevation weather station was introduced to each respective grid.

In Part One, Figures 3 and 4 represent the actual rainfall indexes in Park Valley and Kalispell, respectively. Figure 3 distributes the historical rainfall indexes before and after the George Creek station was activated in grid 26167. Figure 4 represents the Kalispell historical rainfall indexes for grid 33663 before and after the Blacktail Mountain station was activated.

Part Two compares Figures 5 and 6, which contain distributions of actual precipitation measurements. Figure 5 distributes the actual precipitation amounts recorded by the Rosette weather station in grid 26167 before and after the George Creek station was introduced. Figure 6 displays recorded precipitation from the Kalispell Glacier Airport weather station during the

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[1] Rainfall index data gathered from USDA-RMA website https://prodwebnlb.rma.usda.gov/apps/prf

[2] Precipitation data collected from NOAA website https://www.ncdc.noaa.gov/cdo-web/datatools/findstation

same respective time periods. The Glacier Airport weather station has been actively recording data for the Kalispell area for over a century, and is located in grid 33963, adjacent to grid 33663.

A null hypothesis here is that precipitation trends are consistent with trends in the rainfall index. Ultimately, Part Two will be compared to Part One to test the null hypothesis.

ANOVA

Rainfall indexes are split into two individual time-series datasets for each of the two grids. The two time periods are analyzed for changes in average and variance, and the statistical significance of any revealed changes. Grids 26167 and 33663 alike will compare historical indexes for time periods 1996-2010 and 2011-2018.

EMPIRICAL RESULTS

Probability Density Functions Results

This section allows a comparison of simulated density functions of actual rainfall indexes and recorded precipitation data. Figures 3 and 4 illustrate simulations of rainfall indexes in grids 26167 and 33663, respectively. Figures 5 and 6 distribute simulations of recorded precipitation data from local weather stations in both respective grids. The results are as follows:

PDF for Index

Figure 3 reports a mean rainfall index of 89.47 for grid 26167 before 2011. After 2011, the mean index increases by over 60%. Figure 4 displays comparable results for grid 33663. Mean rainfall index increases by over 50%, and a major shift can be seen in the distributions. Increases in standard deviation and the maximum recorded index values can also be observed. This indicates that average precipitation levels have increased approximately by 60% in the Park Valley area over the last eight years, compared to the mean of the previous fifteen-year average. Kalispell should have experienced a similar increase in precipitation levels, as the respective rainfall index likewise shows a vast swing in summary statistics during the distributed time periods.

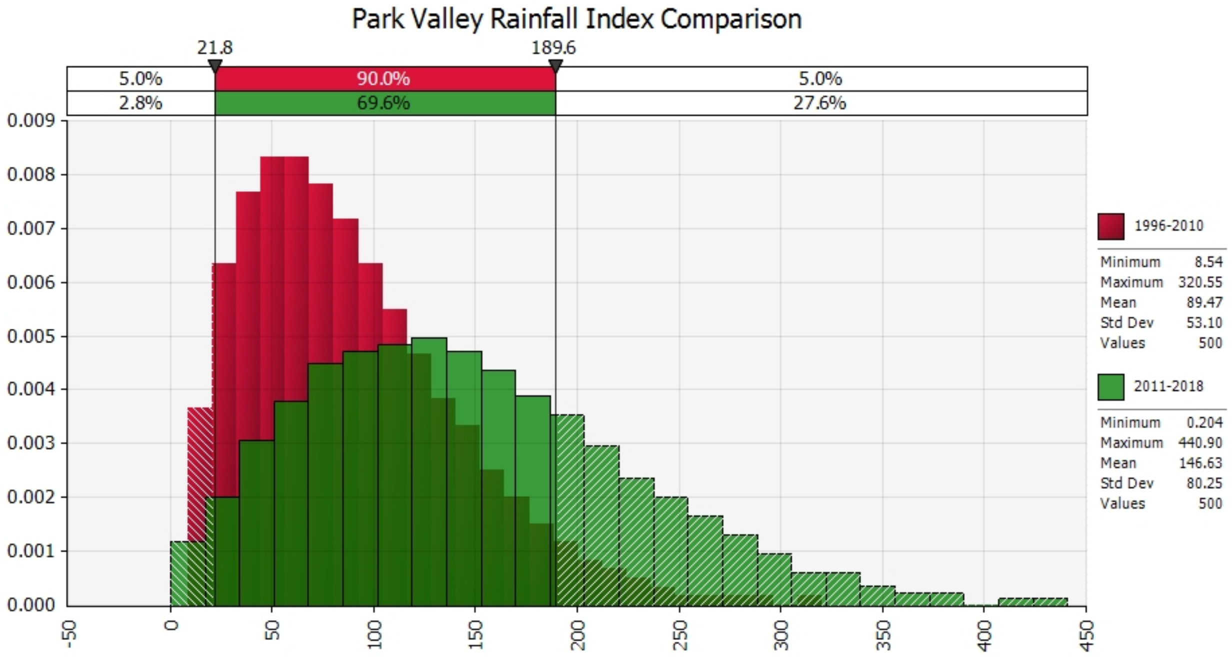

Figure 4 Simulated probability density functions of actual rainfall indexes in grid 26167 during time period 1996-2010 compared to time period 2011-2018

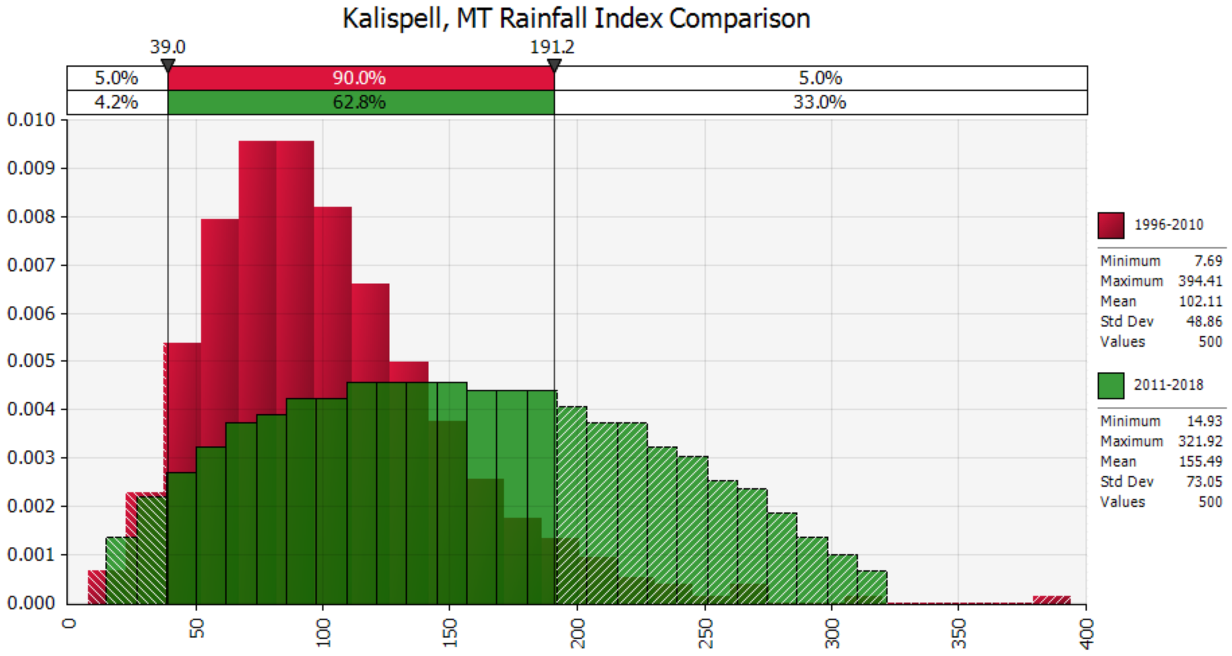

Figure 3. Simulated probability density functions of actual rainfall indexes in grid 33663 during time period 1996-2010 compared to time period 2011-2018.

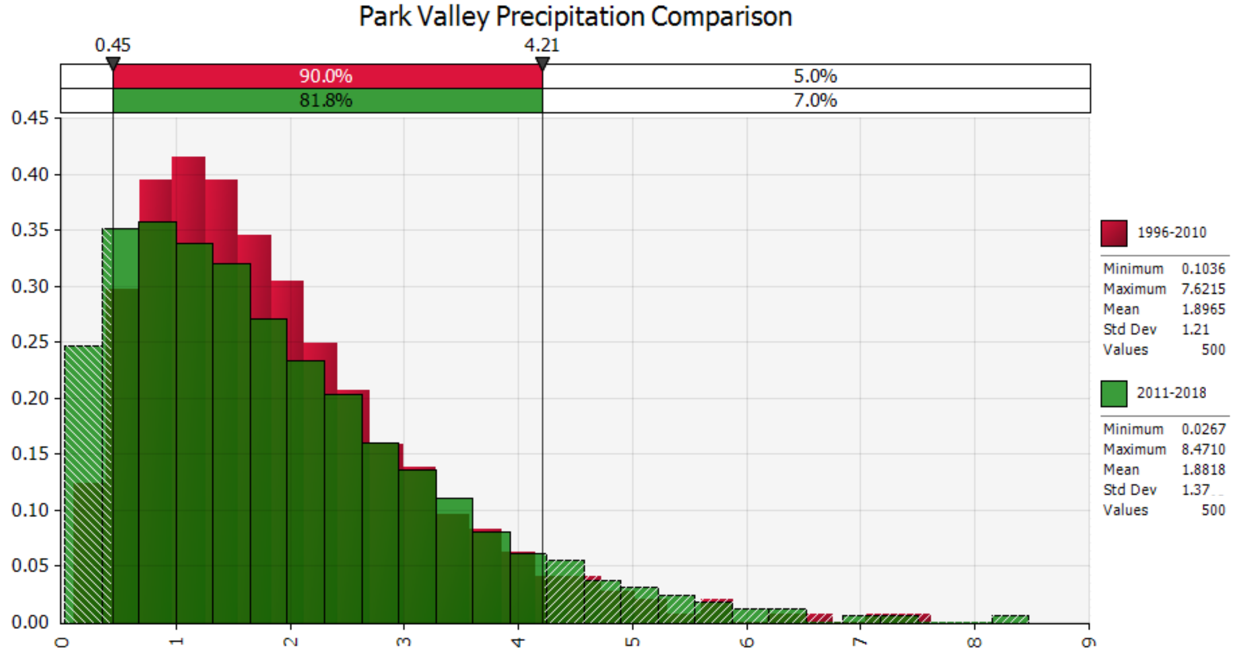

Figure 5. Simulated distributions of actual monthly precipitation values recorded by Rosette, UT weather station. Comparison of time periods 1996-2010 and 2011-2018

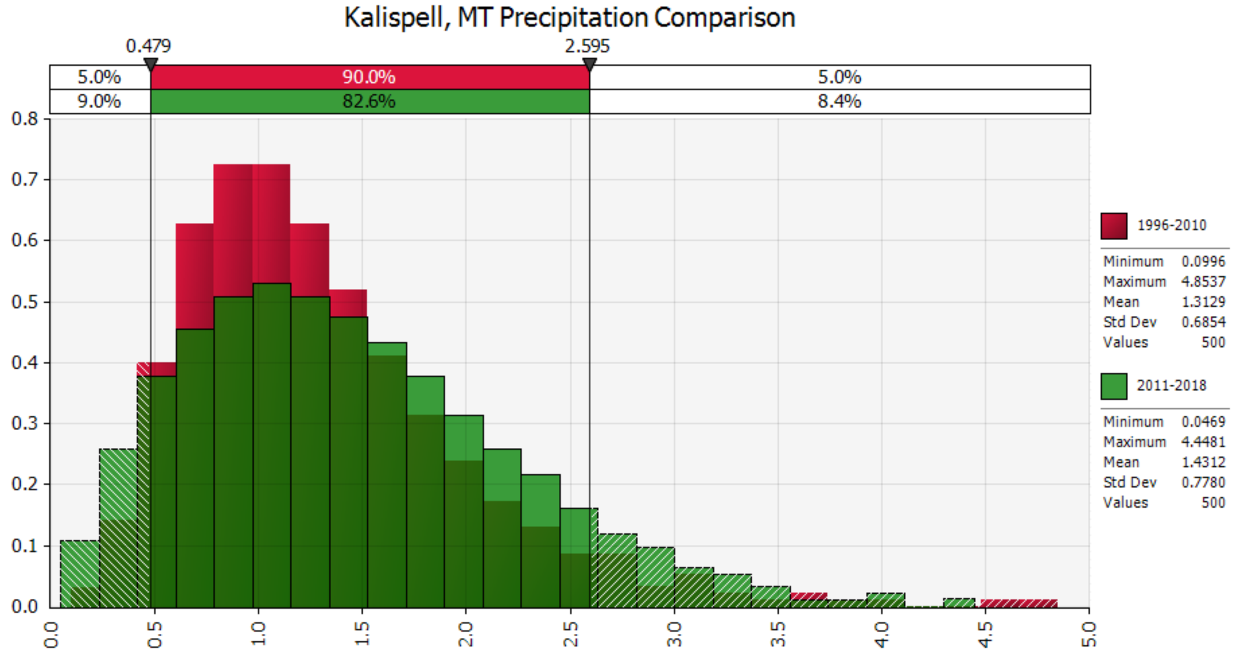

Figure 6. Simulation of actual monthly precipitation values recorded by Kalispell Glacier Airport, MT station. Comparison of time periods 1996-2010 and 2011-2018

PDF for Precipitation

Figure 5 reports a mean precipitation of 1.89 inches per month at the Rosette weather station from 1996-2010. From 2011-2018, average precipitation had only a slight and negative change. Figure 6 shows a similar distribution for the Kalispell Glacier Airport station. The mean increases by approximately 9% between the two time periods and has an increase in standard deviation, suggesting that local precipitation has experienced an increase in mean and variance since 2011. This result is significantly less than the 50+% increase in the average rainfall index during the same respective timeframes in grids 26167 and 33663 alike.

Analysis of Variance Results

This section demonstrates the ANOVA of rainfall indexes from grids 26167 and 33663. Indexes are compared between two time periods which reflect index behavior before and after a single, high-elevation station is introduced to each respective grid. Significance is tested at the .01 level.

Grid 26167

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
1996-2010	163	14577.2	89.43067	2849.07
2011-2018	90	13209	146.7667	6482.66

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	190618.2	1	190618.2	**46.07113	**8.18E-11	**6.736922
Within Groups	1038506	251	4137.475			
Total	1229124	252				

Grid 33663

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
1996-2010	163	16676.9	102.3123	2342.775
2011-2018	90	14046.25	156.0694	5264.608

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	167564.7	1	167564.7	**49.5929	**1.81E-11	**6.736922
Within Groups	848079.7	251	3378.803			
Total	1015644	252				

**Note: (****) indicates statistical significance at the .01 level

Similar to the PDF results, both grids experience increases of more than 50% in the mean rainfall index from the first time period to the second. Variances for both grids also double in both grids between the two periods. ANOVA confirms that changes in rainfall indexes are statistically significant in grids 26167 and 33663.

CONCLUSION

From the results of multiple empirical analyses, evidence points towards the presence of anomalies within the functionality of the PRF insurance program. It can be inferred that the placement of individual weather stations may in certain circumstances inadvertently skew rainfall indexes for the PRF insurance program- at least in the Intermountain West region. As the results demonstrate, it is apparent that some external force has instigated a major change in the rainfall index trends for grids 26167 and 33663. This shift in the index appears to have occurred without a proportionate shift in actual precipitation levels.

Grids which encompass areas with large changes in elevation appear to be more susceptible to erratic basis risk (risk revealed by the index). If further study and analyses take place, it is hypothesized that similar results would occur among grids with large changes in elevation. It is also hypothesized that the introduction of new, high-elevation stations can skew data toward an increasingly more positive rainfall index, while local weather stations fail to observe similar results in actual precipitation patterns.

The new George Creek station sits near the highest elevation point of grid 26167. Naturally, this station will record the highest amounts of precipitation. Moreover, George Creek station is likely the most heavily-weighted station in its grid, as it sits near the centroid of the grid. This combination of characteristics appears to over-explain the precipitation measurements for the Park Valley area. Likewise, in grid 33663 the new Blacktail Mountain station sits at a significantly higher elevation than the local townships. As a result, farmers and ranchers enrolled in PRF insurance in the lower elevation areas of grids 26167 and 33663 are beginning to notice a diminishing return on their investments in PRF insurance. The rainfall indexes for grids

26167 and 33663 no longer appear to reflect the true nature of the environments in which these grids are located.

The anomalies discovered in this study could in turn lead to a lack of indemnity payments made to producers who may, in reality, qualify for insurance compensations. Likewise, said anomalies might also lead to an overpayment of indemnities if the distribution is skewed in favor of the producers. Any deviance from the correct and true amount of precipitation may consequentially lead to an unfair payment and misallocation of government resources.

Further studies on the logistics of the PRF insurance program could prove beneficial. The rainfall index functions as a continually updating average of historical precipitation, with respect to the historical average, beginning in 1948. Studies may be performed to determine the most effective method of updating the historical mean over time. In addition, studies on the current calculating and weighting methods of precipitation data for could provide insight to the "black box" process of calculating the rainfall index.

While generating the PDFs and ANOVAs for both the Kalispell and Park Valley grids, it became apparent that there were holes in the available data. Recall, not all weather stations are consistently reporting precipitation data on a daily basis. Stations may sporadically go offline for an indefinite amount of time. When this is the case, running effective statistical analyses becomes extremely difficult. In the areas where complete datasets were available, Ordinary Least Squares (OLS) Regressions were attempted during this study. The regressions were limited to specific datasets of reporting stations during particular time periods where necessary precipitation data was recorded and accessible. Attempted regressions illustrated possible signs of high-elevation stations robbing low-elevation stations of statistical significance. However, regressions were eventually ruled out of the study due to indications to collinearity issues.

Potential solutions to the identified anomalies include reintroduction of the vegetation index; communication between NOAA and USDA concerning weather station placement and activation; a new insurance policy for pasture, rangeland, and forage ground, or other amendments to the current program. If the importance of the PRF insurance program continues to grow, so will the importance of maintaining a high standard of quality within the program. With an insurance program designed to mitigate risk for all agricultural producers, participation in the program should not inherently bring added risk. This gives reason enough for agricultural economists and PRF policyholders alike to actively pursue accurate and constructive improvements the PRF insurance program.

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