COPING WITH PRECIPITATION VARIABILITY

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Abstract. The precipitation high variability and its intermittency suggest the use of percentiles to obtain a more detailed description of this variable. In general, the percentiles produce classes which allow a better comparison between correlated points. In our case the comparison is done using rain gage data from Midland and San Angelo, Texas. Apparent changes in precipitation associated with cloud seeding operations over the San Angelo area are estimated by regression analysis, but conditional probabilities are used to support potential positive increases in some years. This technique seems adequate to be used also in insurance claims. Spectral analysis is also used to detect weather modification signals.

1. Introduction

The natural variability of precipitation has been reported as the main problem against an accurate description of this variable. In addition, for the evaluation of Weather Modification programs this characteristic behaves like a noise, which may mask the effects of the seeding operations even in the cases where such effects are great. Three main difficulties can be quoted:

- The accuracy of the measurements (network density, data quality…)
- The seeding effect may be small in relation to the natural variability
- The natural complexity of the phenomena and operations

Together with high variability (Horinouchi, 2002), precipitation shows **intermittency** (the random alternation of wet and dry spells: **spatio-temporal clustered structured precipitation fields**). Both properties, high variability and intermittency, in combination with the aforementioned difficulties, lead to study the precipitation variables through aggregated values over time and space in an attempt to find regular patterns in accumulative values (usually monthly and annual values). The procedure allows simple descriptions of precipitation in terms of central and dispersion measures, but these descriptions have problems when they are used in weather modification evaluations: the noise due to the precipitation characteristics is not avoided. These problems suggest the need of a more detailed description of precipitation. Two Australian scientists proposed (Gibbs and Maher, 1967) one alternative which consists in arranging precipitation values in percentiles. The technique allows classifying the values into categories and avoids also some of the weakness of the mean description. As a matter of facts, it seems to export the high variability problem to only one of the categories, the upper one that does not have upper bounds. This paper presents briefly the application of this technique to detect possible impacts of cloud seeding operations at one point in West Texas Weather Modification target area (target point: San Angelo) by comparison with a point outside and upwind the target area (control point: Midland) (Bomar et al, 1999; Ruiz Columbié et al, 2003a) using rain gage data for the period 1948-2004 (NOAA National Data Centers, Information Service online).

Here is opportune to indicate that the technique has a potential use to characterize the behavior of precipitation for crop insurance purposes. Crop yield insurance by area consists in insurance taken out to recover financial losses due to poorly yielding crops. The estimation of losses clearly depends on the standard climatological measures used. The use of the mean as a standard for precipitation might hurt the insurance company during the very dry and dry years (averages are strongly affected by extreme values), whereas the aforementioned more complex characterization of precipitation might attenuate the claims to pay.

Back to evaluation, calculated potential increases of precipitation due to cloud seeding operations appeared to inherit the property of intermittency. This new situation led the authors to a spectral analysis of the data in an additional attempt to detect possible signals of modification. Fast Fourier Transforms of annual and monthly precipitation values were calculated for the target and control points.

2. Percentile Description

Monthly, seasonal and annual precipitation values can be classified according to table 1:

Table 1: Classes for precipitation values

Very Dry Class:	Precipitation < percentile 20th
Dry Class:	percentile 20th < Precipitation < percentile 40th
Normal Class:	percentile 40th < Precipitation < percentile 60th
Wet Class:	percentile 60th < Precipitation < percentile 80th
Very Wet Class:	percentile 80th < Precipitation

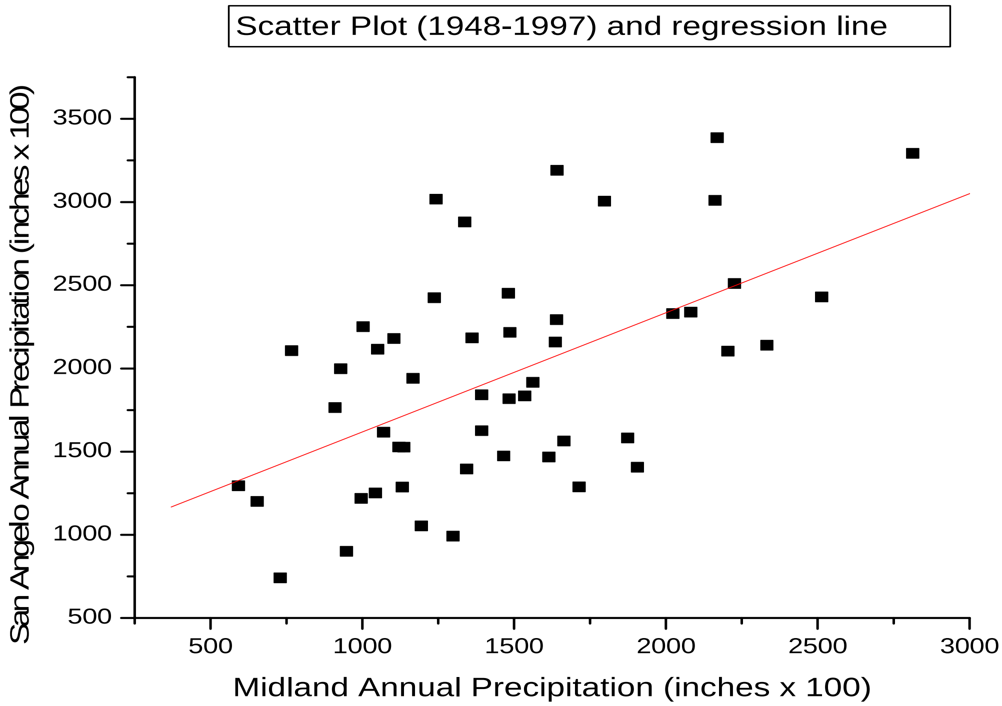
With these classes, months, seasons, and years can be classified and drought can be monitored. Drought is a complex phenomenon, but is mainly associated with relatively long periods when precipitation is below median values (very dry or dry periods). It is very important to determine when wetter periods can stop a drought. The answer should consider whether or not the embedded wet periods supplied enough precipitation to counteract the damages, and also determine the statistical distribution of the return period of very dry and dry precipitation values.

Table 2 shows the applications of this methodology for the annual values of precipitation at the control and target points during the period 1948-1997 (years with available data and previous to the West Texas Weather Modification Program redesigned to implement massive and dynamic cloud seeding operations all year along, but only on seedable convective conditions) (Ruiz Columbié et al, 2003b).

Table 2: Classes for annual precipitation at Midland and San Angelo

	Midland Annual Precipitation (1948-1997)	San Angelo Annual Precipitation (1948-1997)
20th percentile:	**10.49 in**	**13.46 in**
40th percentile:	**12.77 in**	**16.25 in**
60th percentile:	**15.06 in**	**21.15 in**
80th percentile:	**18.80 in**	**24.25 in**
Median:	13.93 in	19.16 in
Mean :	15.07 in	19.38 in
Standard deviation:	5.51 in	6.49 in

Values of annual precipitation at Midland and San Angelo show a significant linear correlation as the following Scatter Plot (Graphic 1 below) shows:



The correlation-regression analysis showed a correlation coefficient of **r = 0.54** (significant at $\alpha = 0.05$) and a regression equation:

$$\mathbf{Y} \text{ (San Angelo)} = 0.70\ \mathbf{X} \text{ (Midland)} + 9.32$$

The standard deviation of the regression is **S = 5.50 inches**, whereas its corresponding Working-Hotelling amplitude is **δ = 1.54 inches**. The equation allows calculating the predicted values of annual precipitation at San Angelo and later comparing them with the actual values to determine potential increases associated to the seeding operations. Table 3 shows these results together with the classification of operational years at both places:

Table 3: Annual Precipitation Actual Values, Predicted values for San Angelo and Differences (1998-2004)

	Midland	San Angelo	Predicted	**D** (= Actual – Predicted)
1998	5.40 in (**vd**)	12.98 in (**vd**)	13.10 in	**- 0.12 in**
1999	7.60 in (**vd**)	13.52 in (**d**)	14.64 in	**- 1.12 in**
2000	9.65 in (**vd**)	15.14 in (**d**)	16.08 in	**- 0.94 in**
2001	9.85 in (**vd**)	18.53 in (**n**)	16.22 in	**2.31 in**
2002	9.35 in (**vd**)	14.41 in (**d**)	15.87 in	**- 1.46 in**
2003	11.18 in (**d**)	19.76 in (**n**)	17.15 in	**2.61 in**
2004	21.46 in (**vw**)	30.48 in (**vw**)	24.34 in	**6.14 in**

(**vd** means very dry year, **d** means dry year, **n** means normal year, **vw** means very wet year)

The results indicate apparent decreases (negative values of D) during 1998, 1999, 2000, and 2002, but all these decreases are smaller than the Working-Hotelling amplitude (**δ = 1.54 inches)** and therefore are within the natural noise. However, the apparent increases during 2001, 2003, and 2004 appear to be significantly above the noise. **There is an intermittency pattern in D but its positive values seem to be significant.**

It is important to notice that between 1999 and 2002 the values of annual precipitation at Midland were always very dry (four years in a row), whereas the corresponding values of annual precipitation at San Angelo never fell into the very dry class. The matrix of conditional probability between Midland and San Angelo for the period 1948-1997 is showed below (table 4):

Table 4: Matrix of conditional probabilities for the classes (San Angelo/ Midland)

	San Angelo				
Midland	vd	d	n	w	vw
vd	0.6	0.0	0.3	0.1	0.0
d	0.2	0.3	0.2	0.2	0.1
n	0.1	0.3	0.2	0.2	0.2
w	0.1	0.3	0.2	0.2	0.2
vw	0.0	0.1	0.1	0.3	0.5

Under the assumption that annual precipitation values are independent, the probability of the event "San Angelo non-very dry years four times in a row when Midland was very dry four times in a row" is equal to 0.4 x 0.4 x 0.4x 0.4 = **0.03**; a rare event that happened maybe due to the seeding operations.

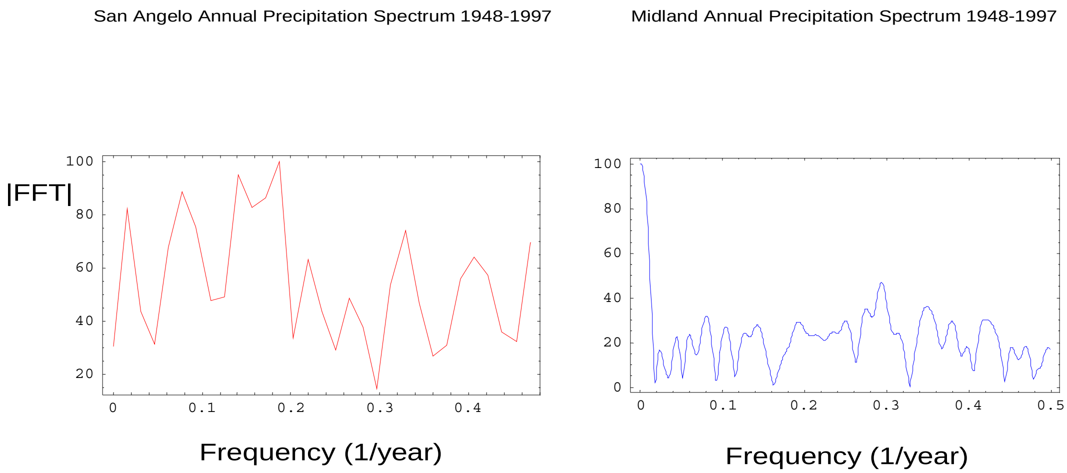
3. Spectral Analysis

The **F**ast **F**ourier **T**ransform (**FFT**) was used to detect cycles (quasi-oscillatory components) in the precipitation time series for Midland and San Angelo. Usually, cycles in a time series generates relative maximums in the spectrum. The mathematical expression for the absolute value of FFT is:

$$|(FFT)n| = \Sigma k \; fk \exp(-2\pi ink/N)$$

where the summation is in k = 0,1,2…N and fk are the corresponding time series values. A program written in Mathematica allowed to do fast calculations and graphics. The first application was done over annual precipitation values for the period 1948-1997 and the following graphic shows the results:

Graphic 2: Spectra of Annual Precipitation for San Angelo (red) and Midland (blue) (1948-1997)

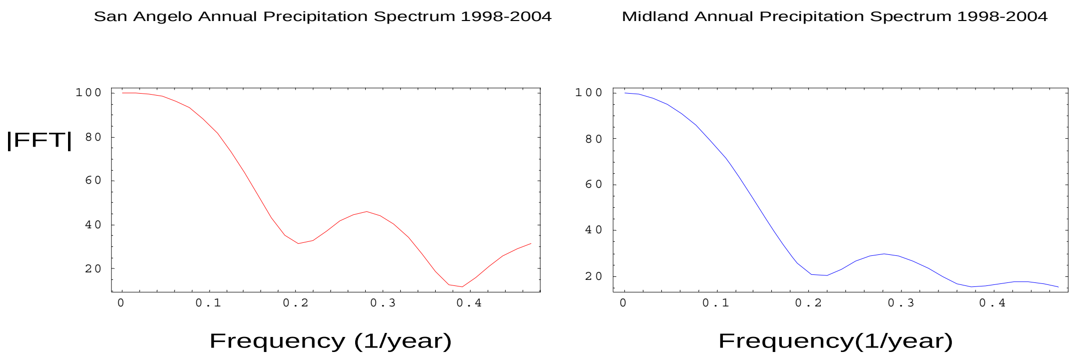


San Angelo Annual Precipitation Spectrum shows notable peaks at frequencies 0.016, 0.075, 0.14, 0.19, and 0.325 with respective approximate periods (the inverse of frequency) of 63 years, 13 years, 7 years, 5 years and 3 years. Midland Annual Precipitation Spectrum shows its peaks at frequencies 0.075, 0.16, 0.23, 0.36, and 0.43 with respective approximate periods of 13 years, 6 years, 4 years, 3 years, and 2 years.

Notice also that the differences in amplitude between both spectra.

Similar calculations were done for the period 1998-2004, when the operational program took place over the West Texas Weather Modification target area. The results are illustrated in Graphic 3 below:

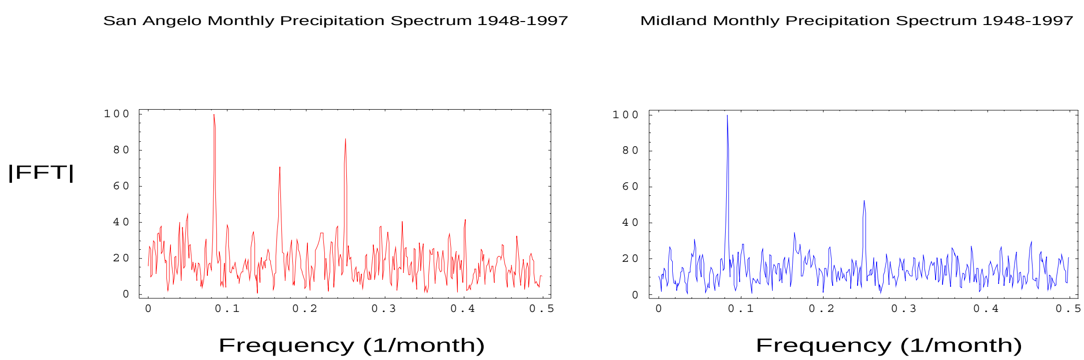
Graphic 3: Spectra of Annual Precipitation for San Angelo (red) and Midland (blue) (1998-2004)



Both spectra are very similar with peaks about the same frequency 0.28 (period 3.5 years). The annual precipitation spectra seem not to show any modification.

The analysis was extended to monthly data searching for a better resolution. Graphic 4 shows the spectra for these time series for the period 1948-1997:

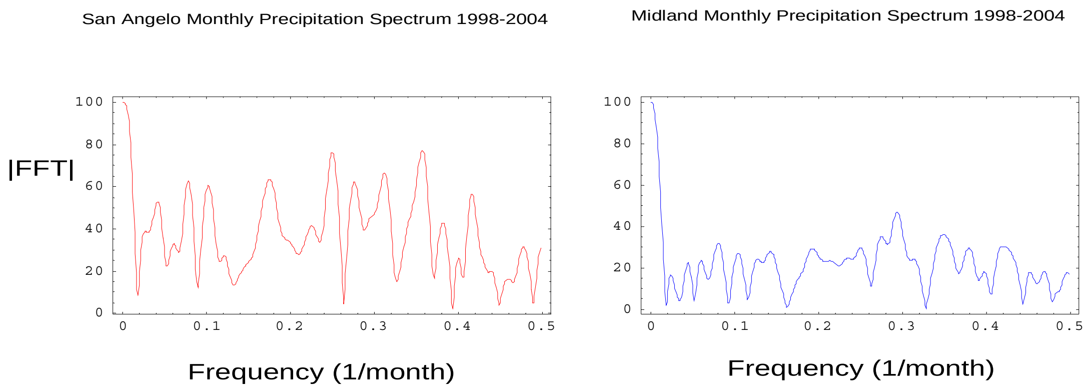
Graphic 4: Spectra of Monthly Precipitation for San Angelo (red) and Midland (blue) (1948-1997)



San Angelo Monthly Precipitation Spectrum 1948-1997 shows peaks at frequencies 0.08, 0.16, and 0.25 with respective approximate periods of 12 months, 6 months, and 4 months. The peaks for Midland Monthly Precipitation Spectrum 1948-1997 are at frequencies 0.08 and 0.25.

There is a slight peak at frequency 0.16 but it barely overcomes the noise. The corresponding analysis for the period 1998-2004 is showed in graphic 5 below:

Graphic 5: Spectra of Monthly Precipitation for San Angelo (red) and Midland (blue) (1998-2004)



The last graphic shows a notable difference about frequency 0.3 (approximate period 3 months) between San Angelo and Midland. The San Angelo Spectrum has four relative peaks near this frequency, whereas the Midland Spectrum has one peak at about 0.29 and another peak that barely overcomes the noise at about 0.35. A possible interpretation of the multiple peaks on the San Angelo Spectrum might be that **the seeding operations in place generated cycles that enhanced the spectral structure (a multi-frequency pattern, like a chord in music) while the Midland Spectrum kept a simpler structure (like a single note in music).** This interpretation should be considered heuristically as a hypothesis which should be confirmed (or refuted) analyzing other cases.

4. Conclusions

The obtained results seem to point out that cloud seeding operations may generate signals that are detectable with the proper mathematical tools. Some statements might be enounced:

1) **The use of percentiles** appears to cope well with the high variability of precipitation since values and all the classes but one obtained lower and upper bounds. For the case analyzed in this paper, the class of very wet years is the only one without upper bounds;
2) **Increases in precipitation** calculated by regression seem to inherit the natural precipitation intermittency, although in our case only the positive increases appear to be significant;
3) **The Spectral Analysis** for annual data did not show any signal of modification, but its extension to monthly values seems to indicate that cloud seeding operations are capable to generate quasi-oscillatory components in precipitation.

These conclusions should be considered as preliminary since the analysis was done only for a particular project and comparing only two fixed points. The search for similar patterns in other examples will empower or not these conclusions.

5. References

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