EVALUATION ABOUT THE STIMULATION OF RAINFALL PROGRAM

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ABSTRACT: In a private/ public work was allowed to put in motion the program of cloud seeding, multiregional and multispectral program, created by the common need to face the drought. In this sense and because of the emergency, the regions of Atacama, Coquimbo, Valparaiso and O'Higgins, decided to establish programs to increase the level of rainfalls. The present study has the aim, the evaluation of the program of cloud seeding, to this, an interrelationship analysis was used to compare the performance of rainfalls and the water level (volume of flow) of a control basin, in this case, Maipo River, with the basin where the plan was implemented, then two methods were used, the first defined a rate between the improved and the control basin, the second corresponds to a creation of a model of rainfalls where the dependent variable is the rainfall of basin encouraged as a function to the control basin. Subsequently, was done a test of average hypothesis to the estimate factor (rate) and another to the effects of the model with the effectively precipitated. The data which were observed allow concluding that there is an interrelationship between daily rains of the metropolitan region within the regions of Valparaiso, O'Higgins and Maule. The same is observed in daily middle flow of Copiapó, Elqui, Choapa, Aconcagua, Cachapoal, Tinguiririca and Teno with the flow of Maipo. In relation to the test of the hypothesis of the model, the results show a meaningful difference with respect to a normal year does not exist, for the Regions of Valparaiso and O'Higgins, noticed an increase in rainfalls.

1. INTRODUCTION

According to various rainfall stimulation programs made over the globe for pioneering countries (China and the U.S., among others), no significant differences has been detected between the effectiveness of air and ground system. However, there is a significant difference in the cost of each. Overall, the air system is 3-5 times more expensive than the land (Pook, 2002), whereby the cost / benefit ratio is clearly favorable to the land system. Therefore, many companies in this area have led to the development of land generators (Axisa, 2004).

In Chile the program was implemented in two regions, the first one specifically in Copiapó region in the river with the same name, the studies of the Institute of Agricultural Research (INIA in its Spanish acronym) show that the flow - whose basin has received stimulation from the 90's - have grown by about 40 % compared to the river El Transito, that has a similar behavior where there has not been made similar treatment (Badilla, S. 1982). The second was in O'Higgins, where project implementation was developed in Cachapoal river basin, due to the river flow had a tendency to fall.

The program ran from March 2000 to February 2004. Eight generator sets were installed, covering the entire basin and worked up in the rainy season from March to October each year, without any interruption. In those four years of the program an increase of 15.6% in precipitation was observed, which was reflected in the increased flow in the river Cachapoal and interrupting the downward trend of these, compared with Tinguiririca River the basin immediately adjacent to the south with a similar behavior (Hydromet, 2005).

A public-private work was conducted (or made or done) and it allowed to start cloud seeding initiative, a multiregional and multispectral program, through which the State in conjunction with private sector achieved to give a very clear signal of joint effort generated by the common need to face up drought. In this sense and considering the urgency due to the third consecutive drought year, in Atacama, Coquimbo, Valparaíso and O'Higgins regions, and thanks to the management done by Alex Madariaga, Daniela Norambuena, Francesco Venezian and Mauricio Donoso, respective Ministerial Regional Agricultural Secretaries of the above mentioned regions, it was decided to establish the program in each region with the purpose of increasing the amount of precipitation. This activity was always supported by INIA and especially by Francisco Meza and Fernando Rodríguez, from Coquimbo and Valparaíso regions. Particularly, in the Atacama region the program was started on June 2012 and was ended on September of the same year. During this period a total of 13 flights were conducted (made), nine of them were effective for seeding. From December 2012 to March 2013, during the Altiplanic Summer period, the program also continued.

In Coquimbo region, the Rainfall Stimulation Program (PEP) began to operate on June 2012 and continued until October with 40 flights. In addition, two flights were made in January and February 2013. At present, the funds for a land and air program that includes 50 flight hours and 18 generators to be developed in 2013 year had been approved by the Regional Government and also it is considered making flights during the Bolivian winter if an appropriated opportunity is presented.

In Valparaíso, the PEP was developed from March to October 2012, with 546 hours of land operation in 19 areas and six sowing flights between June and October. Only nine land equipments were operated; the 18 missing equipments were installed in the first quarter of 2013.

In the O'Higgins region, the PEP operated with land equipment between May and October, during 585 land hours. In that period, 22 equipments from a total of 25 were installed and they will be available for this region during 2013.

This study aims to evaluate the Stimulation of Precipitation Program in regions and basins considering precipitations and flows for the agricultural season 2012-2013, that is to say, since April 2012 to February 2013. Specifically for precipitations analysis the period from May to October 2012 was covered. For flows the period April 2012-February 2013 was examined.

2. CONTENTS AND METHODS

For precipitations the analysis was made considering the major cities and for the flows the major rivers from the regions mentioned above were examined.

2.1 <u>Data Base Precipitations</u>

For precipitation, the data bases from 1990 to 2012 available in Chile's Meteorological Directorate were analyzed. The months examined were chosen according to the characterization of climate for each region. In order to cover at least the 70% of precipitation in every region, the unit of analysis was defined as the daily, monthly and annual accumulated precipitation considering the period from May to October.

Once the data base was established, a consistency analysis was carried out in the measurements of precipitations, through Box Cox graphics. In that way, it was possible to identify if the data base was having anomalous data and for eliminating them the Tukey's methodology (1977) was used (Peña, D. 2002).

Flows

For flows, the data base from 2006 to 2013 available in the Directory General of Water (DGA in its Spanish acronym) was analyzed. The agricultural period was defined between April and March, because this sector of the economy is the largest consumer of water (78% of consumptive rights), in consequence flow of rivers vary depending on its requests. It was established as data analysis the daily flow between April and March of every year. Having established the basis of data, we repeated the analysis of consistency in measurements of flow through graphs Box Cox, to eliminate any anomalous data, the methodology used is that proposed by Tukey (1977).

This method is simple to apply and is based on the statistical properties of the normal distribution. One limitation of this method is that no single hypothesis tests performed to evaluate if the observation is atypical.

2.2 Analysis

The analysis methodology is used by Zhanyu Yao (2009) for rainfall and flow, which is composed of two parts. The first was performed as a correlation analysis in order to establish the link between rainfall and flow regions of Atacama, Coquimbo, Valparaíso and O'Higgins with a control watershed. In this case, control basins were those of the Metropolitan and Maule, which was not part of the program, using graphs to represent the behavior of the data by region and the corresponding statistic.

Later, identified the difference in magnitude of the rainfall and flow between these regions, to define a parameter that compensates for this "natural" difference (because the regions under study have different annual rainfalls and flows).

The parameter is defined as follows:

$$\frac{\textit{Rainfalls region i}}{\textit{Rainfalls region Metropolitana}} = \boldsymbol{\gamma}\text{i}$$

$$\frac{\textit{Flow of the river i}}{\textit{Flow of the river Maipo}} = \delta\text{i}$$

Where the parameters γ and **δ** represent respectively the relation of the rainfalls between the region *i*-esima and the Metropolitan, and the relation of the flow of the river *i*-esima and the Maipo River.

Once the relation is identified, the parameters γ and **δ** are estimated between the regions that have been stimulated and the region of control. Calculated β and α for each region, the following tests of hypothesis were realized, since it allows to prove an affirmation about the parameter that, for our case is the reason of rainfalls or flows between the stimulated region and the Metropolitan region. For which a void hypothesis was defined, for the rainfalls consistent in:

Null hypothesis for rainfall:
"The average of the parameter β in the period 1990 to 2011 is equal to the average of the parameter β for the period 2012."

Null hypothesis for flow:
"The average of the parameter α in the period April 2006 to March 2012 is equal to the average of the parameter α for the period April 2012 until March 2013."

Once established the correlation that exist between the rainfalls of the regions stimulated with the control basin, it was proceeded to define a model of linear regression, for that, daily major rainfalls more than five mm and less than 100 mm were used, because according to the protocol of the program it operates when the rainfalls are in this range. The dependent variable is the rainfalls of the stimulated basin and the independent variable is the basin of control, in that way the model is expressed like

$$Y = \beta + \beta_1 X_1 + \varepsilon$$

where:
Y, is the dependent variable, each basin rainfall stimulated.
X_1 are the explanatory variables, control basin.
β, β_1, are the parameters to be estimated
ε, are random errors and must fulfill the following assumptions as Weisberg (2005):

- Are normal 0 averages and constant variance.
- No autoreciprocity

Once defined the linear regression model that best fits rainfall and the assumptions above, the estimated daily, monthly and yearly rainfalls of the year 2012 by region stimulated were done.

Then we proceeded to do an average hypothesis test for two dependent populations wondering if both are equal or not, to this we define the following null hypothesis:

"The difference of the average for the actual daily rainfall with rainfall estimated by the model is 0, that is to say, the observed rainfalls in the basin evaluated, are equal to those projected by the model"

3. RESULTS AND DISCUSSION

The following graph (Figure 1) shows that rainfall in the cities of Valparaiso, Rancagua and Curico are highly correlated with those of Santiago, (0.84, 0.93 and 0.80 respectively) indicating that there is a positive, that is to say, when one increases the other does so in constant proportion. The correlation between Santiago and La Serena is 0.3 lower (0.48), but still significant. In case of Caldera, there is no correlation with the other stations.

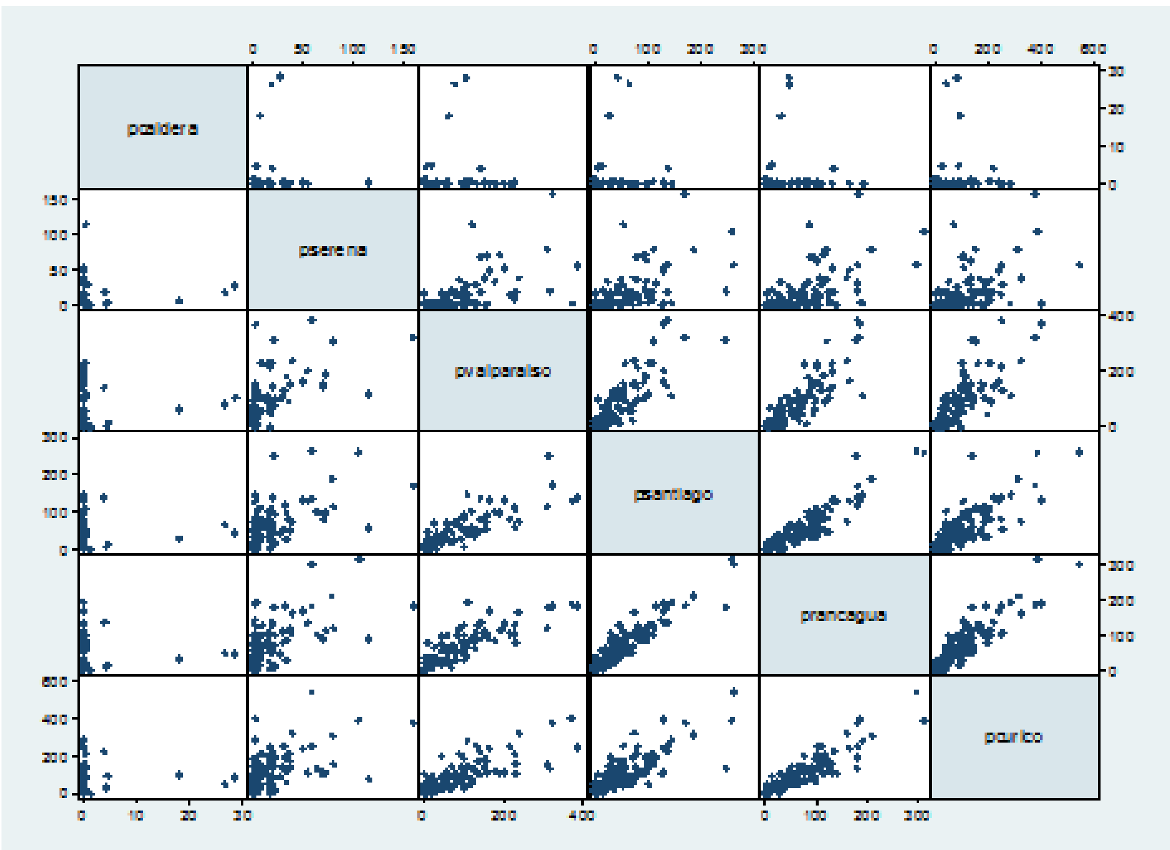

Figure 1: Corrulation of rainfall

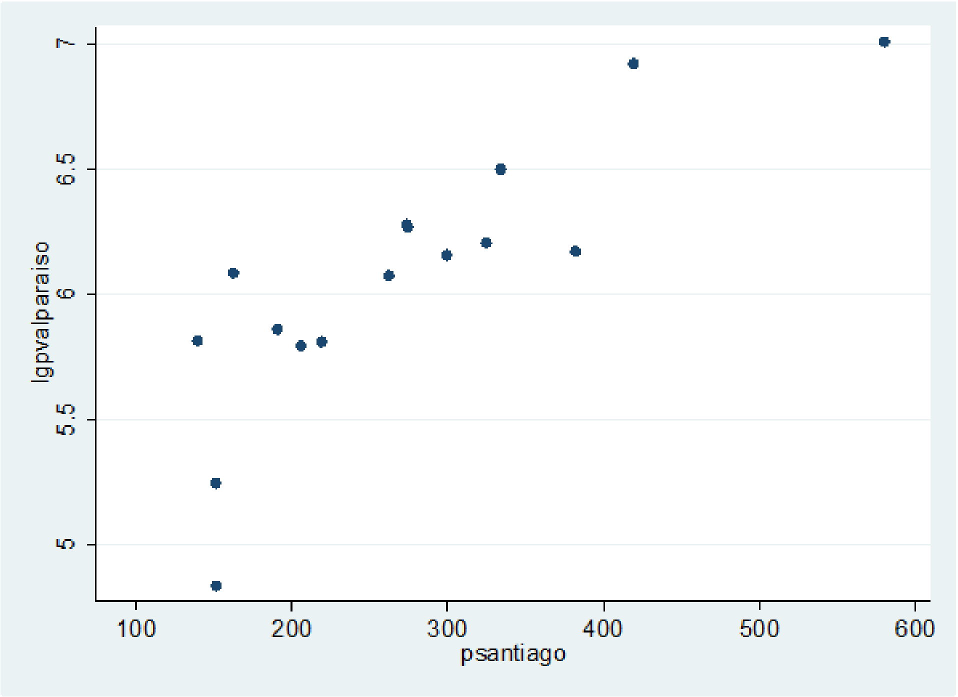

Figure 2: Correlation of rainfall the Natural logarithm rainfall Valparaiso with rainfall Metropolitana

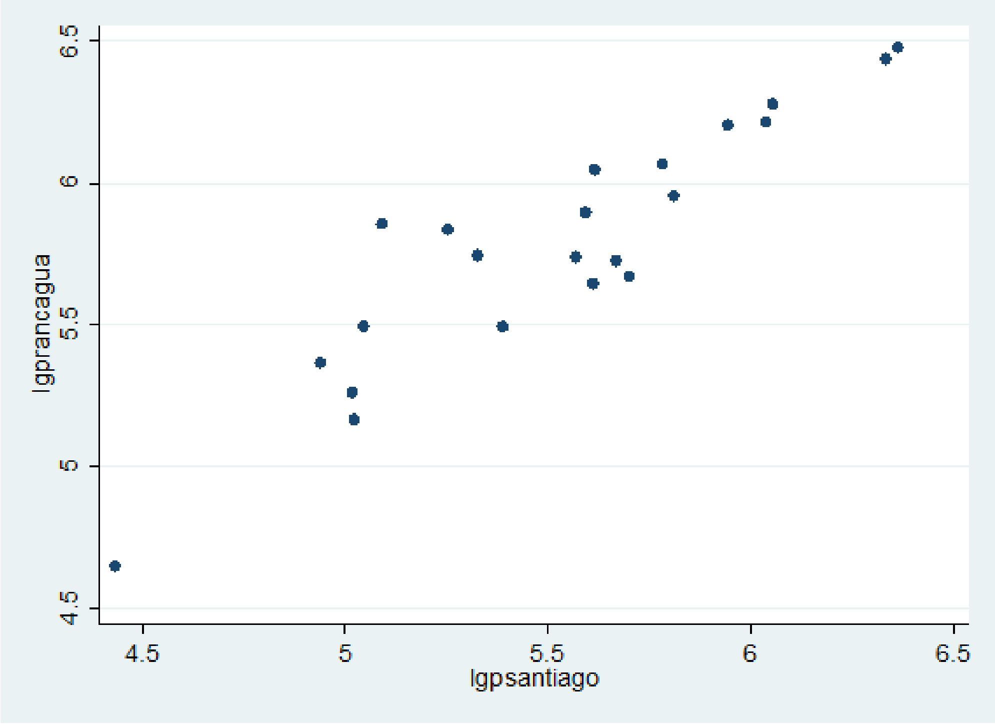

Figure 3 Correlation of rainfall the Natural logarithm rainfall O´Higgins with Metropolitana

To those cases where statistical correlation was found, we proceeded to perform the hypothesis test for each parameter. The results indicate that, for the region of Coquimbo no significant difference between the mean of the parameter for the period 1990 to 2011 and the average of the parameter for the period 2012. That is, there is no difference in the change of rainfall with historical and what happened this year compared to the control region. In other words, rainfall of 2012 had the same behavior as the historic respect to the metropolitan region.

The opposite occurs in the regions of Valparaiso and O'Higgins, where there is significant difference between the average of β calculated over the period 1990 and 2011 and the average β for 2012. It is rejected the null hypothesis statistical test average as the average of the calculated parameter for 2012 is higher for both the historic regions, as shown in Table 1.

Given the results described above, were performed correlation models for the regions of Valparaiso and O'Higgins. The procedure of the functional form of the model was defined, that is to say determine the linear transformation of data that best suits them and fulfill the assumptions that the estimators are unbiased.

To stay Valparaiso model follows

$$\ln(pp_v) = \beta_1\, pp_{cc} + \beta_0$$

pp_v = Precipitation Valparaiso
pp_{cc} = Precipitation Santiago

To stay O´Higgins model follows

$$\ln(pp_O) = \beta_1 \ln(pp_{cc}) + \beta_0$$

pp_O = Precipitation O´Higgins
pp_{cc} = Precipitation Santiago

In Tables 2 and 3 the parameter estimates, which determines the precipitation for the basins stimulated.

Once the model proceeded to perform hypothesis testing, as noted in the chapter on the methodology to test the hypothesis is: "The difference in average real annual rainfall with rainfall estimated by the model is 0, is mean observed rainfall in the basin evaluated are equal to those projected by the model."

The hypothesis test indicates that there is no statistically significant difference between the observed and projected in the model, that is to say, the observed rainfall behave according to what is considered a normal year.

Table 1: Hypothesis Testing

Region	Historical Average	Average 2012	Significance	Difference
Coquimbo	0,18	0,06		-67%
Valparaíso	1,24	1,91	**	54%
O´Higgins	1,44	1,86	**	29%
Maule	2,39	2,09		-13%

* Significant parameter with a level of 1% ($p<0,01$)
** Significant parameter with a level of 5% ($p<0,05$)

Table 2: Testing the model Valparaíso

variable	Parameter	Coefficien
rainfall Metropolitana	β_1	0.0038*
Constant	β_0	5,026*
Variance of the error term u	σ^2_u	1,36
Adjusted coefficient of determination	R^2	0,66
Number of Observations		16

* Significant parameter with a level of 1% (p<0,01)
** Significant parameter with a level of 5% (p<0,05)

Table 3: Testing the model O´Higgins

variable	Parameter	Coefficien
Natural Logarithm rainfall Metropolitana	β_1	0.834*
Constante	β_0	1,17**
Varianza del termino de error u	σ^2_u	0,63
Coeficiente de determinación ajustado	R^2	0,83
Numero de Observaciones		22

* Significant parameter with a level of 1% (p<0,01)
** Significant parameter with a level of 5% (p<0,05)

4. CONCLUSION

Data analysis indicates that there is correlation between rainfall in the Metropolitan area and that of the Coquimbo, Valparaiso, O'Higgins and Maule regions. There is also a correlation between the flow volume of Copiapó, Elqui, Choapa, Aconcagua, Cachapoal, Tinguirririca and Teno rivers, with that of the Maipo River. This allowed defining a parameter for rainfalls and another one for flow volume, in order to compare them with the control region, that is, the Metropolitan area.

An increase in rainfall by rainfall index for the regions of Valparaiso and O'Higgins is observed. However, for the region of Coquimbo there is no difference in rainfall, due to the shortage of fronts in the region.

As for the coincidences that would explain this difference or equality in average, although it is evident that these generate promising initial results, it is not possible to attribute them to any phenomenon, because of the insufficient data available since the outset of the program. Therefore, a new model of regression methodology is recommended to measure causality. This requires further collection of data regarding the application of the program, which means that researchers must wait for at least another application period. New analyses require the bringing new variables into the study such as the number of fronts a year, weather conditions (relative humidity, temperature, isotherm, etc.).

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