Principle of Geoengineering: Meteorological and Geographical Conditions of the Department of Junín for the Generation of Precipitation in Agriculture

L. F. Mucha, P. A. Jeremias, N. Ambrocio, I. Y. Platero, and J. V. Cornejo

***Abstract*—Geoengineering attempts to remedy the climate crisis through the intervention of dynamic systems to mitigate future scenarios of water drought in agriculture. The provinces of the department of Junín were identified as having the meteorological and geographical conditions where precipitation should be generated for the benefit of agriculture. The meteorological data was obtained from SENAMHI for the period 2000-2020, cloud information derived from the GOES-16 satellite belonging to NOAA was used and the satellite images were resampled using the cubic convolution method to evaluate the cloud parameters under the bands (C05, C08, C10, C11, C13, C15 and C16) in areas with cloud altitude between 6-8 km in the Andes and in the eastern part between 5-7 km within the study area. From this analysis, favorable cloud clusters were identified in relation to the arid zones with extensive croplands where rainfed irrigation is used, using the geodatabase of the Ecological and Economic Zoning (ZEE) of the Regional Government of Junín.**

***Index Terms*—Geoengineering, precipitation generation, GOES-16, cloud seeding.**

I. Introduction

Climate intervention aims to mitigate the impacts of climate change, which represents a global warning. According to the 2018 Intergovernmental Panel on Climate Change (IPCC) report, global mean sea level rise with a global warming of 1.5 ℃ and altered precipitation patterns are projected by 2100 [1]. And recent estimates of the new probabilities of exceeding the above-mentioned value for global warming from the latest IPCC report in 2021 project an intensification of climate change in all regions of the planet [2]. Simulations based on the CMIP6 multi-model of global terrestrial precipitation to 2100, which predicts sudden changes in global and regional precipitation patterns in high latitude and subtropical areas at 5-95% confidence, simulated scenarios of climate change levels (GWL) at global warming of +1. 5, +2 and indicates that climate-smart mitigation measures are required for sustainability in the agriculture sector. Thus, techniques are required that allow for potential mitigation of anomalous changes to the precipitation regime in relation to droughts. Due to the global demand for food that has increased over the last decades, South America is an important supplier due to the increase in agricultural demand [3]. However, the problem is still worsening for the agricultural sector. Reports from the Food and Agriculture Organization of the United Nations (FAO) foresee an increase in the water deficit, which represents a risk for the food security of more than 3.2 billion people worldwide. Peru is one of the most affected countries in South America in terms of hectares of rainfed areas, due to the frequency of high droughts [4] and is globally vulnerable to climate change [5], thus representing an alert to the diversity of climates it possesses, due to its geographical location and the presence of the Andes Mountain system in the longitudinal direction, the Humboldt Current and the South Pacific Anticyclone [6]. The affectation to it, causes the alteration of hydrometeorological variables such as droughts, frosts, snowfalls, summers, hailstorms, heavy rains, floods, among others. For this reason, the agricultu+4 ℃ from 2000-2100 show a 30% decrease in precipitation and extreme increases of up to 30% in the length of days in rainy seasons under 5-95% confidence ranges in South America referring to anthropogenic and natural emissions, according to additional inputs from the US National Oceanic and Atmospheric Administration (NOAA) [7]. These changes are associated with the intensification of floods and droughts globally. Because of this report, the United Nations Framework Convention on Climate Change (UNFCCC) recognizes the susceptibility of global impacts and calls for efforts to mitigate the effects of the climate crisis [8].

Consequently, the Strategic Climate Fund promotes crop adaptation programmes due to the impacts of climate change in developing countries. However, the report of the Inter-American Development Bank (IDB) indicates that temperature changes generate displacement of areas in terms of crop growth and changes in precipitation patterns that alter the water balance of plants, crop loss due to flooding and drought intensification, however, the UNFCCC indral sector is vulnerable and a high priority in Peru [9].

This sector guarantees the provision of food, however it is very sensitive to changes in climate variability, so that the mitigation measures to be considered against drought fit perfectly to counteract the effects of climate change. It will have a direct impact on the quality of life of millions of people as a consequence of drought, which is a climatological

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event with the highest frequency in Peru [10]. As a result, it will affect "more than 2 million hectares of rain-dependent crops, especially potatoes, wheat, barley and maize" [11], 66% of which are rainfed [12]. This affects rainfed campaigns in the Peruvian highlands due to the decrease in the amount of water obtained at the beginning of the year [11]. The department of Jun ń presents persistent climate-related hazards, such as increased temperatures, decreased precipitation, variations in rainfall cycles, floods, frosts and droughts, which aggravate the climatic, economic and social situation. Thus, there is high sensitivity in intensive agriculture [13], which leads to a decrease in crop production.

Thus, mitigation measures on a global scale correspond to climate intervention, also known as geoengineering, which are aimed at counteracting the impacts of climate change. According to the Carnegie Climate Geoengineering Governance Initiative (C2G2), it is a set of techniques that manages large- and small-scale experimental trials [14]. One of the most widely applied techniques is the generation of precipitation or cloud stimulation with silver iodide (Agl) [15] to ensure the sustainability of agriculture and address food security threats. There is a lack of research related to mapping studies for the subsequent application of cloud seeding to areas affected by climate change. In this sense, the research contributes to the scientific community as a model for future studies.

The research therefore analyzed the meteorological and geographical conditions in the department of Jun ń. Determining the provinces suitable for a subsequent application of silver iodide in order to generate precipitation in agriculture, and finally the type of clouds optimal for the generation of precipitation was identified.

II. Materials and Methods

Cloud stimulation was addressed under meteorological and geographical conditions, based on previous in-situ application studies in correlation to the principle of geoengineering to examine the experimental units (convective cloud ensemble) [16]. In the following, the methodology for processing meteorological, spatial and satellite data is presented in order to propose suitable areas for further application.

A. Description of the Study Area

The study area selected for the analysis is the department of Jun ń. It has a surface area of 44 197.23 Km2, located in the central highlands of Peru, comprising two natural regions: the highlands with a surface area of 20 821 Km2 equivalent to 46% and the jungle 23 376 Km2 symbolizing 54%. It is politically divided into 9 provinces, shown in Fig. 1. It has 123 districts with different altitudes ranging from lowland jungle at 250 m above sea level to cold Andean mountains at 5500 m above sea level, giving rise to a great diversity of climates, landscapes and ecosystems [13].

The post-identification of the study area was based on the analysis of SENAMHI on a temporal scale from 1981 to 2018 between the months of January and March of the Standardized Precipitation Index (SPI) characterized meteorological droughts, the department of Jun ń in 2004 and 2005 presented a variation of moderate and severe drought episodes [17]. The study of the Regional Management of Natural Resources and Environmental Management of the Regional Government of Jun ń, allowed to identify the provinces under the level of drought danger in relation to the level of vulnerability of the agricultural activity, being 3 provinces determined; Yauli, Jun ń and Jauja (see Table I) [18].

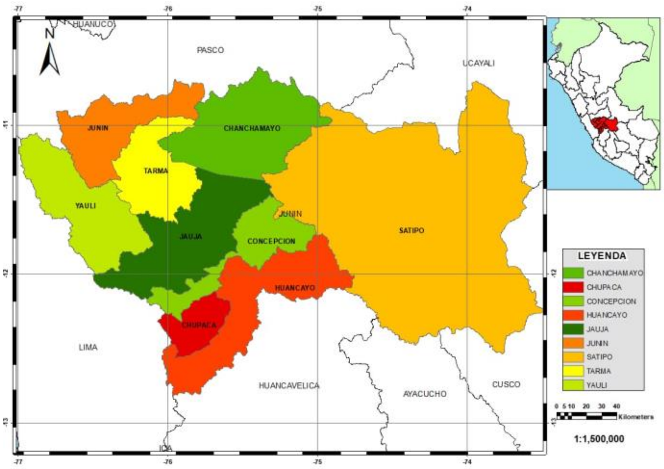

Fig. 1. Provinces of the department of Jun ń.

TABLE I: Relationship between Drought Hazard Level — Agricultural Vulnerability

Province	Drought hazard level (%)		Level of vulnerability of agricultural activity (ha.)	
	High	Very high	High	Very high
Yauli	41.4	53.8	1919.24	1336.19
Jun ń	45.2	26.1	5909.64	6590.92
Jauja	23.6	12.9	13230.75	9726.64

B. Weather Conditions

Daily data on relative humidity (%), total precipitation (mm), maximum and minimum temperatures (◦C) from 20 active meteorological stations were used: 17 Conventional Meteorological stations and 3 Automatic Meteorological stations of SENAMHI in a continuous period of 20 years (2000-2020) (see Table II).

The analysis of the meteorological data was carried out using MATLAB software, by interpolating the data collected from each station in the study area. Standard deviations were obtained for the estimation of monthly and annual averages of temperature and relative humidity. Likewise, the accumulated averages correspond to the precipitation variables.

The temperature study was carried out on the basis of the average daily maximum and minimum temperatures, averaged for each month and year. On the other hand, the analysis of total annual average precipitation was obtained from the arithmetic average acquired from the historical series from 1970 to 2010, which was extracted from the geodatabase from the Ecological and Economic Zoning - Land Use Planning of the Regional Government of Jun ń [13]. For the effectiveness of promoting precipitation in optimal clouds with silver iodide (Agl), the following parameters of maximum temperature (℃), minimum temperature (℃), relative humidity (%) and precipitation (mm) were established.

TABLE II: LOCATION OF WEATHER STATIONS

Province	Station name	Altitude (m.s.n.m)	Latitude	Length
Huancayo	Acopalca	3839	11°55'38.82"	75°06'58.5"
	Santa Ana	3295	12°00'15"	75°13'15"
	Viques	3186	12°09'47"	75°14'07"
Concepción	Comas	3640	11°44'55"	75°07'45"
	Ingenio	3390	11°52'51"	76°17'16"
	Runatullo	3690	11°35'01"	75°03'01"
Tarma	Huasawasi	2750	11°15'42"	75°37'15"
	Tarma	3000	11°23'49	75°41'25"
Chupaca	Huayao	3360	12°02'18"	75°20'17"
	Laive	3860	12°15'08"	75°21'19"
	San Juan de Jarpa	3660	12°07'28.3"	75°25'54.4"
Junín	Junín	4120	11°08'35.8"	75°59'19.6"
Yauli	La Oroya	3910	11°34'07"	75°57'34"
	Marcapomacocha	4447	11°24'15.83"	76°19'29.51"
	Yantac	4617	11°20'44.97"	76°24'16.31"
	Yauli	4094	11°40'0.1"	76°04'59.9"
Chanchamayo	Pichanaki	546	10°57'56"	74°49'57"
Satipo	Puerto Ocopa	690	11°08'01"	74°15'01"
	Satipo	660	11°13'41"	74°37'03"
Juja	Ricrán	3820	11°32'22"	75°31'26"

C. Geographical Conditions

The vertical distances of the 20 weather stations from the land surface point are shown below (see Fig. 2).

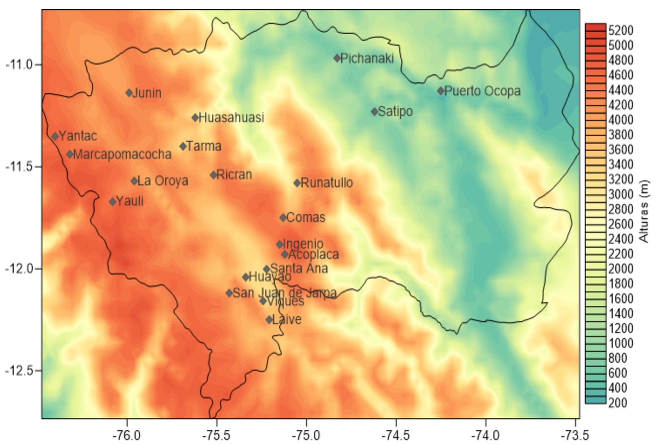

Fig. 2. Heights of weather stations.

1) Data collection

Meteorological images from the GOES-16 Geostationary Operational Environmental Operational Satellite were used. The GOES series collaborates between NOAA and NASA to predict weather phenomena. The Geostationary Operational Environmental Satellite (GOES)-R is the Advanced Baseline Imager (ABI), its spectral bands measure energy at different wavelengths [19] and provide radiometric information of the Earth's surface, atmosphere and cloud cover [20]. Spatial and spectral information from the 16 satellite bands (see Table III) was collected for cloud mass detection.

TABLE III: THE APPROXIMATE CENTRE WAVELENGTH (UM), BAND NUMBER, BAND TYPE, BAND NICKNAME AND THE HIGHEST SPECTRAL RESOLUTION (KM) [19]

Central Wavelength	Band	Type	Nickname	Best Sapatial Resolution
0.47	1	Visible	Blue	1
0.64	2	Visible	Red	0.5
0.86	3	Near- Infrared	Veggie	1
1.37	4	Near- Infrared	Cirrus	2
1.6	5	Near- Infrared	Snow/Ice	1
2.2	6	Near- Infrared	Cloud Particle Size	2
3.9	7	Infrared	Shortwave Window	2
6.2	8	Infrared	Upper-level Water Vapor	2
6.9	9	Infrared	Midlevel Water Vapor	2
7.3	10	Infrared	Lower-level Water Vapor	2
8.4	11	Infrared	Cloud- Top Phase	2
9.6	12	Infrared	Ozone	2
10.3	13	Infrared	"Clean" Longwave Window	2
11.2	14	Infrared	Longwave Window	2
12.3	15	Infrared	"Dirty" Longwave Window	2
13.3	16	Infrared	CO2, Longwave	2

The first 6 bands show the reflectance factor and bands 7 to 16 are analyzed according to the brightness temperature. The images were obtained from January to March, starting at 15:00 UTC-5 Time Zone.

2) Spectral parameters

It relies on the radiative properties of clouds, expressed in brightness temperature difference (DBT), brightness temperature (BT) and reflectance. Also, physical parameters such as cap height, optical thickness and cloud phase are used to identify favourable ones. Radiative parameters were used as surrogates for the physical parameters of the clouds:

TABLE IV: RADIATIVE PARAMETERS RESPECT TO % INFLUENCE

Radiative parameters	% Influence
DBT band 13 (10.3um)	30
DBT band 8 (6.2um) - band 13 (10.3um)	30
DBT band 16 (13.3um) - band 13 (10.3um)	10
DBT band 11 (8.4um) - band 13 (10.3um)	15
BDT band 11(8.4um) - band 15 (12.3um)	10
Reflectance of Band 5 (1.6um)	5

3) *Data pre-processing*

ARCGIS 10.3 software was applied for the pre-processing and processing of ABI GOES 16 satellite images [21]. The geographic coordinate system GCS_WGS_1984 was used and the ABI GOES 16 bands were downloaded in netCDF format. In addition, the image was resampled with the cubic convolution method using the Resample Grids tool of raster tools.

For the georeferencing of the image, the extreme points of the ABI image were determined, these have E/W and N/S scan angles. The processing of the ABI images calculated the brightness temperature of the bands C13, C08, C11, C16 using the raster calculator tool, the reflectance of the C02 band using the Planck equation ($T = [fk2 / (Ln((fk1 / L\lambda) + 1)) - bc1] / bc2$), ($\rho fv = \rho v * \cos(\Theta)$) and with raster calculator tool, the reflectance of the C02 band using the Planck equation ($T = [fk2 / (Ln((fk1 / L\lambda) + 1)) - bc1] / bc2$), ($\rho fv = \rho v * \cos(\Theta)$) and with raster calculator suggested by NOAA. Where ρv is the reflectance and ϴ is the solar zenith angle of the satellite, considering 83 º for the investigation.

4) *Development of techniques or methodologies*

The favourable clouds were identified with the Arctoolbox reclassify and Weighted overlay tool (DBT11 - band 15, BDT11 - band 13, BDT8 - band 13, BT - band 13, BDT16 - band 13 and Reflectance 5). Finally, a map was generated according to the sum of favourable conditions expressed as spectral parameters which is classified into 5 categories; very low, low, medium, high and very high probability of favourable clouds.

III. RESULTS

A. *Weather Conditions*

1) *Maximum and minimum temperature*

The results of the annual maximum and minimum accumulated temperatures of the 3 meteorological stations corresponding to La Oroya, Marcapomacocha and Yantac processed from 2000 to 2020. The La Oroya station in 2016 reaches a maximum temperature higher than 16.5 ℃ (see Fig. 3) and in the year 2000 has a minimum temperature lower than 1 ℃ (see Fig. 4) compared to the other years processed. Similarly, the Marcapomacocha station in 2016 has a maximum temperature of 12.5 ℃ (see Fig. 5) and in 2005 a minimum temperature below 2 ℃ (see Fig. 6). On the other hand, the Yantac station in 2004 and 2016 the maximum temperature exceeds 10.5 ℃ (see Fig. 7) and regarding the minimum temperature in 2004, 2005 and 2008 it reaches a lower value below 0.5 ℃ (see Fig. 8). It can be inferred that in the province of Yauli it does not affect the subsequent application of silver iodide, as the clouds have a different temperature, which is optimal for the application.

La Oroya Station

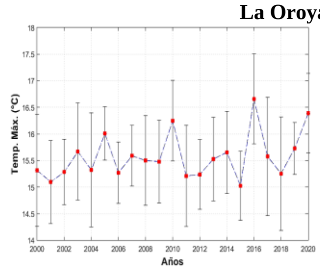

Fig. 3. Whisker box (T °max) -Station La Oroya.

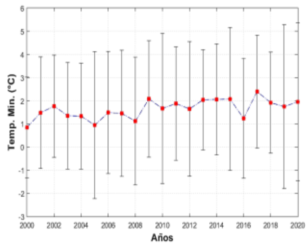

Fig. 4. Whisker box (T °Min)-Station La Oroya.

Marcapomacocha Station

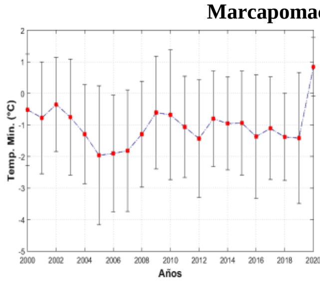

Fig. 5. Whisker box (T ° Máx)-Station Marcapomacocha.

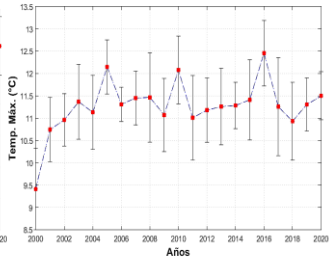

Fig. 6. Whisker box (T ° Min)-Station Marcapomacocha.

Yantac Station

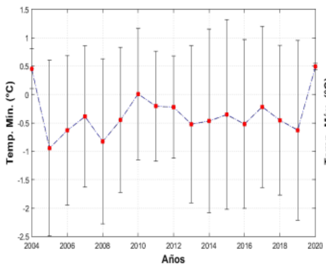

Fig. 7. Whisker box (T ° Máx)-Station Yantac.

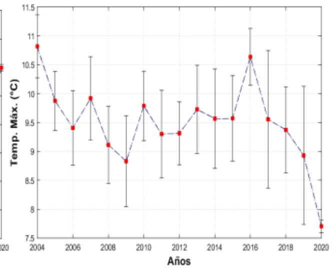

Fig. 8. Whisker box (T ° Min)-Station Yantac.

2) *Precipitation*

Yauli Province

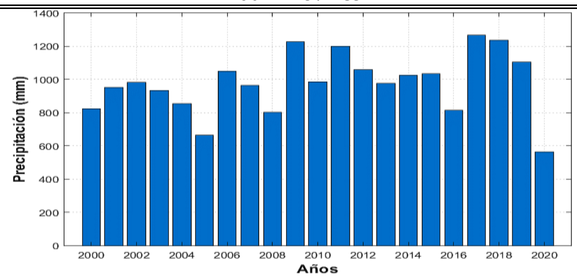

Fig. 9. Whisker box (P mm)-Station La Oroya.

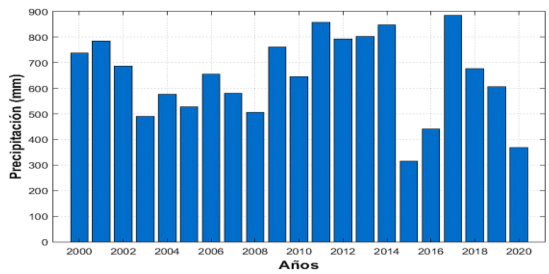

Fig. 10. Whisker box (P mm)-Station Marcapomacocha.

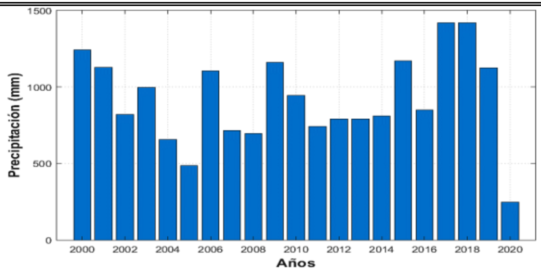

Fig. 11. Whisker box (P mm)-Station Yantac.

The accumulated annual rainfall of the Meteorological Stations corresponding to La Oroya, Marcapomacocha and Yantac (see Fig. 9, 10 and 11) exceeded the average of 500 mm of precipitation in periods 2000-2019 and values below 300 mm correspond to the years 2020 Drastic variability occurs in 2020. Additionally, it is inferred that there is a direct relationship between the intensity of the rain and the type of orographic cloud to promote rain in the province of Yauli, due to the descent of the humid air that originates the high temperatures.

In the year 2003 and 2020 in the 3 stations of the province of Yauli, it can be seen in the graphs that there is less precipitation compared to the other years.

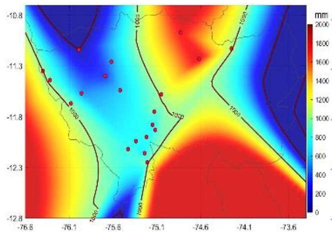
Fig. 12. Minimum precipitation map - Station Yauli, 2003.

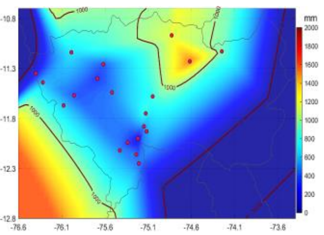
Fig. 13. Minimum precipitation map - Station Yauli, 2020.

3) *Relative humidity*

Yauli Province

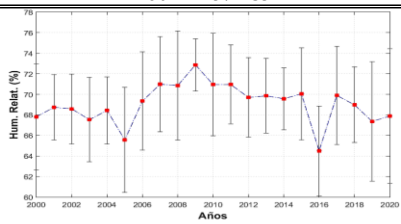

Fig. 14. Whisker box (HR%)-Station La Oroya.

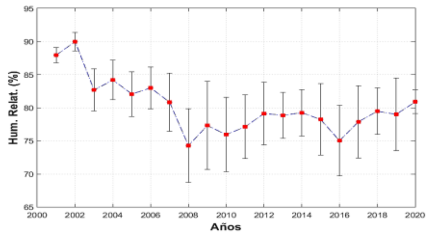

Fig. 15. Whisker box (HR%)-Station Marcapomacocha.

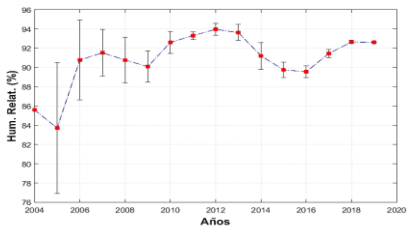

Fig. 16. Whisker box (HR%)-Station Yantac.

The area covered by the image subscenes corresponds to the central part of the Peruvian territory, the department of Jun ń. According to the Ecological and Economic Zoning (ZEE) of the department of Jun ń (2015), the department presents a strong temperature gradient (ratio between vertical and horizontal change) due to its topographic characteristics, varying from a warm humid climate over the high Andean zone and the jungle to a frigid and slightly humid climate in the Andes.

Yauli Province

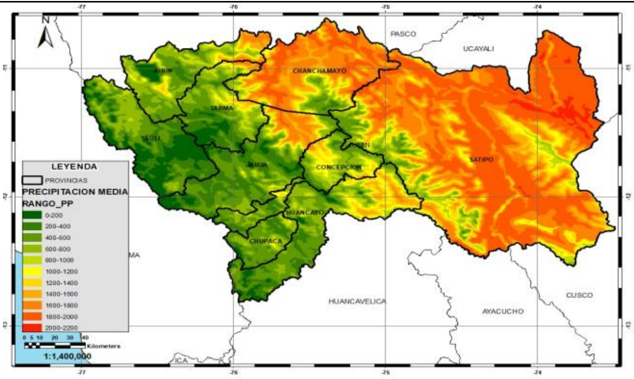

Fig. 17. Temperature map (1970-2010) – Jun ń.

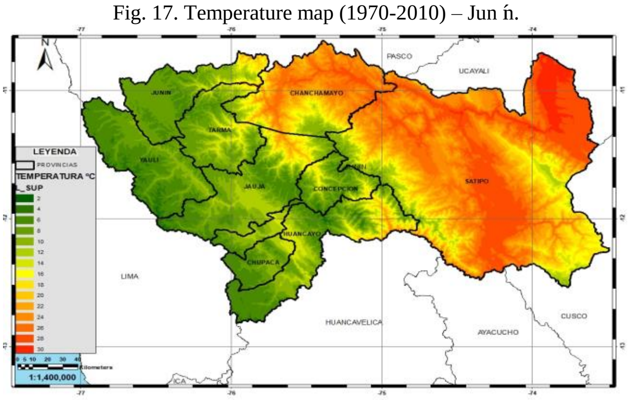

Fig. 18. Average precipitation map (1970-2010) – Jun ń.

The provinces with high rainfall and temperatures are Satipo and Chanchamayo, however provinces such as Yauli, Jauja and Jun ń have average annual rainfall (1970-2010) in the range of <0-800 PP>, the most critical being Yauli due to variations in the rainfall regime. Therefore, there is a rainfall deficit in the 30 years studied. Additionally, the provinces of Yauli, Jun ń, Jauja, Chupaca, Huancayo and Tarma have low to medium temperatures <6 ℃-16 ℃>, which allows a scarce formation of orographic clouds based on the ascension of convective clouds (see Fig. 17, 18).

B. *Geographical Conditions*

Map of Department of Jun ń

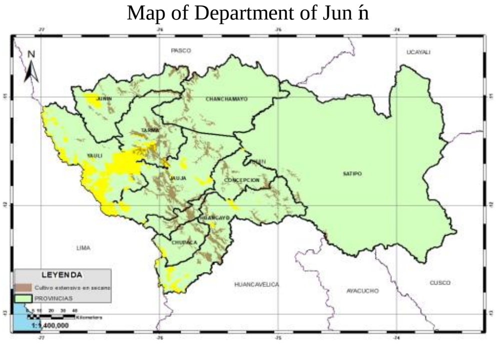

Fig. 19. Rainfed crops.

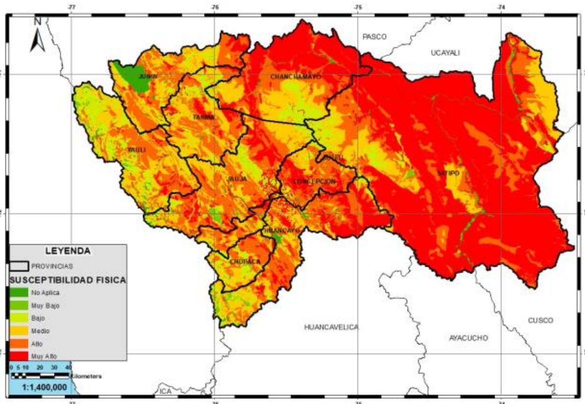

Fig.20. Physical susceptibility.

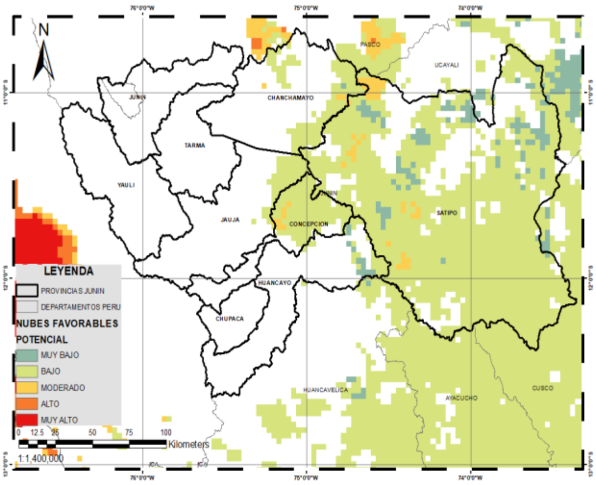

Fig. 21. Favourable cloud cover from 15:00 UTC time zone.

The results of the processing based on the extensive cultivation areas in dry land have a large amount in the northeast area specifically in the province of Yauli (see Fig. 19) being a province with greater extension in agricultural production that is carried out by means of dry farming Compared to the jungle that does not have the problem due to lack of water, due to the permanent period of rain that occurs throughout the year. The physically very high susceptible areas are located in the lowland jungle of Peru; Chanchamayo and Satipo. And provinces such as Yauli, Jauja, Tarma and Jun ń are within the very low to high range, being these areas in overlapping areas with drought the most preponderant for the stimulation of precipitation, so Yauli persists as a province graphically conditioned (see Fig. 20).

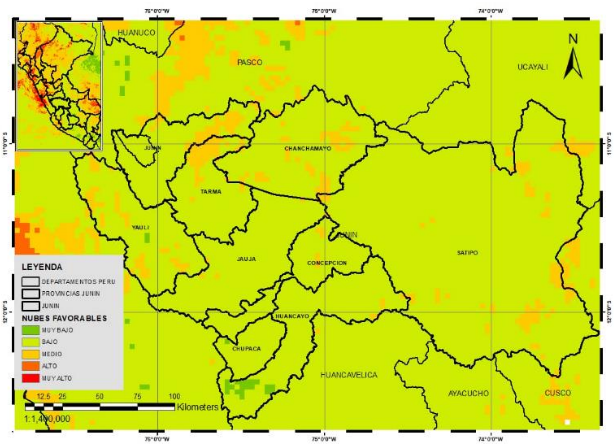

Fig. 22. Favourable cloud cover from 18:00 UTC time zone.

The results for the identification of favourable clouds with respect to the temporal location in the provinces of the department of Jun ń, from 15:00 UTC Time Zone. Based on the time analyzed, the range of the degree of cloud potentiality is detailed in the range from very low to very high, to determine the potential points of application (see Fig. 21). Therefore, convective clouds from 18:00 UTC Time Zone and increases the values of clouds with favorable potential from low to medium in the provinces of Tarma, Chanchamayo, Yauli and Satipo (see Fig. 22).

IV. Discussion of Results

In comparison with other investigations, they are also supported by the study of climatic factors and anomalies that circulate in the atmosphere to affect the frequency and intensity of precipitation, leading to the existence of the disturbance of the water balance and the occurrence of drought in the department of Jun ń. Thus, studies such as that of convective storms over the central Andes of Peru in the analysis of spatial and temporal variability of precipitation in the Andes, found that cloud systems occur in the Amazon-Andes transition due to the mechanism of orographic forcing for hydrometeors, thus being one of the studies that resembles this research in identifying areas of rainfall variability using PR-TRMM and KuPR-GPM radars, but still being insufficient to propose systems or methods that take advantage of potential areas of precipitation flow, wind currents, climates that favor the growth of any type of crop [22].

And in global areas, the application of this technique on a small scale of geoengineering represents achievements in countries such as the United States, Russia, China, Israel, South Africa in strengthening areas with critical indexes of low precipitation and climate variability in application of silver iodide in a model of cumulonimbus cloud [23], having studies on the comparison of the effects based on the application of compounds in regions of the above-mentioned countries. This indicates that there are still no studies that compile the information based on data processed in cabinet at national or country level in proposed potential areas for the application of this technique. Thus, the study in Peru has potential as a model methodology and application proposal.

The results obtained in the research regarding the processing of satellite images resulted in favorable clouds from 18:00 hours for the Junin department, compared to the research [24] conducted in Colombia also presents a difference in temperature brightness with trends at two hours, the first at 16:30 Time Zone then at 18:30 Time Zone, which estimates the increase of cloudiness in the south of its region and greater extension in the Andean region, thus seeing the presence of frequent storms. Likewise, it can be seen in the department of Junin is in the range of the Time Zone.

Finally, the study [25] mentions that for the estimation and forecast of precipitation, a variable of great importance is the wind speed at the altitude of the top of the cloud, as well as the wind direction. Therefore, it is also arguable that the processing of these variables is not necessarily obtained by the meteorological and hydrological institutions of the country. Geostationary satellites are also used to track clouds, wind direction and wind speed. In this way, the ideal study area for cloud stimulation can be better identified for the benefit of the agricultural sector.

V. Conclusions

The department of Junín presents favorable meteorological and geographical conditions for the application of cloud seeding as an alternative to mitigate climate change against the consequences it generates to agriculture in the department of Junín, finally the research presents satisfactory results in terms of the objectives set, regarding the identification of the ideal study area (province) for a future application of precipitating cumulus clouds with silver iodide from 18:00 UTC Time Zone, being Yauli the province that meets the conditions required for the application, based on a larger agricultural extension area in the entire department of Junín.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Nilson Ambrocio, Paola Jeremias and Lilian Mucha carried out the research from start to finish. The contribution is the search of information, data collection, data analysis and writing of the article.

Iralmy Platero is the main advisor of research study and Jose Cornejo participated in the redaction instruction. Finally all authors approved the final publication.

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