The Clic-MD software a tool to analyze thousands of data in seconds: trends of climate and agro climatic indices

El software Clic-MD es una herramienta para analizar miles de datos en segundos: tendencias del clima e índices agroclimáticos

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ABSTRACT. The analysis of climate data is tedious and time-consuming, delaying the analysis of millions of meteorological data worldwide. Local level decision making about climate change requires converting data into information. The aim was to develop software to analyze thousands of meteorological data in seconds. We first designed the database, selected the statistical tests used in time series analyses, and chose agroclimatic indexes, before designing the algorithms. Finally, we developed the software having in mind its easiness of use, and its efficiency for processing data and interpreting results. The software was tested several times by potential users, which allowed improvements in the development and design of the software. Clic-MD includes a set of routines for calculating derived variables most used in land evaluation such as agroclimatic indices, probability of rainfall by month, and others. Clic-MD allows for identifying climate change trends (climate anomalies and extreme events).
Key words: Climate change, climatic anomalies, extreme events, maximum temperature, minimum temperature.

RESUMEN. El análisis de los datos climáticos es tedioso y lento, lo que retrasa el análisis de millones de datos meteorológicos en todo el mundo. La toma de decisiones a nivel local sobre el cambio climático requiere convertir los datos en información. El objetivo fue desarrollar un software para analizar miles de datos meteorológicos en segundos. Diseñamos la base de datos, seleccionamos las pruebas para el análisis de las series de tiempo y los índices agroclimáticos. Desarrollamos el software teniendo en cuenta su facilidad de uso y su eficiencia para procesar datos e interpretar resultados. El software fue probado varias veces por usuarios potenciales. Clic-MD incluye un conjunto de rutinas para calcular las variables derivadas más utilizadas en la evaluación de la tierra, como los índices agroclimáticos, la probabilidad de lluvia por mes y otras. Clic-MD permite identificar las tendencias del cambio climático (anomalías climáticas y eventos extremos).
Palabras clave: Cambio climático, anomalías climáticas, eventos extremos, temperatura máxima, temperatura mínima.

INTRODUCTION

Climate change is a global concern for all areas of life, but especially for cropping (Villers *et al.* 2009, Montiel-González *et al.* 2019, Ortega *et al.* 2019, Montiel-González *et al.* 2021) and livestock farming (Monterroso *et al.* 2011), biodiversity conservation and ecosystems management (Archer and Predick 2008), and human health. A climate change discourse at the global level has been well understood and disseminated, however, there is little understanding about the magnitude and direction of local climate change (Bautista *et al.* 2013). Consequently, this global discourse is applied to explain local effects of climate change, an approach that is not always appropriate. Since mitigation and adaptation actions against the adverse effects of climate change need to be implemented at the local level, knowledge about current local situations derived from local scale data is urgently need for either anticipating potential issues or for taking advantage of the opportunities created by climate change.

While most countries, states and municipalities are designing public policy strategies to cope with climate change (Lioubimtseva and Henebry 2009), local information is needed for appropriate planning and for answering some basic questions (Montiel-González *et al.* 2019, Ortega *et al.* 2019): When analyzing available historical meteorological data, are we observing climate change or only normal variations in climate? Of what kind (pulsed or gradual) and in which direction (warming or cooling) is the climate change we observe? What is the magnitude, period of occurrence, and location of climate change? (Del Río *et al.* 2011, Jain *et al.* 2013, López-Diáz *et al.* 2013).

Analyzing millions of meteorological data is time consuming and carries a high monetary cost. For that reason, software has been created allowing for agile information management, such as CDBm, Moclic (Bautista *et al.* 2013), and others. However, most of the existing software operates by means of obsolete technology that is no longer compatible with newer hardware or has limited applications (Montiel-González *et al.* 2021). The Clic-MD software was created with the aims of: a) identifying trends of climate change and evaluating their magnitude and direction, b) calculating agro climatic indices, c) identifying climatic anomalies or extreme values of climate elements, d) reducing the time needed for data analysis, and e) generating easily interpretable results.

MATERIALS AND METHODS

Software Design

Development of the Clic-MD software followed the mexican information technology standards (NMX-I-045-NYCE). The waterfall life cycle model was selected for the software. The tools used for software development were: a) Java programming language, which offers platform independence, high performance, and open source; b) the integrated development environment (IDE) Eclipse, used for writing, testing, and debugging of modular cross-platform applications, containing a list of tasks, and its compilation is real-time (Eclipse 2015); and c) the Java based relational database Apache Derby using 2 MB and having JDBC support allowing for embedding Derby into any Java decision structure. The Derby database is easy to install, deploy and use, and the SQL syntax supports client-server mode (Apache 2014). Figure 1 shows the stages, activities and products we followed for development of the software.

The equations were systematized, and we developed a way to access them from the interface. Calculation algorithms were translated to source code. Results are represented in a graphical interface and tabular format. Request functions are executed via the Java-code and SQL.

System requirements for the operation of Clic-MD are: 1.0 GHz or higher Intel or AMD processor; 256 MB dedicated RAM memory for optimal performance; VGA screen with a recommended resolution of 1200 x 800 and 32 MB of graphics memory for editing or viewing .xls; CD-ROM for installation and a hard drive with 50 Mb of free space for program installation and data; Java Virtual Machine 1.6 or later (JVM); operating systems can be either Microsoft
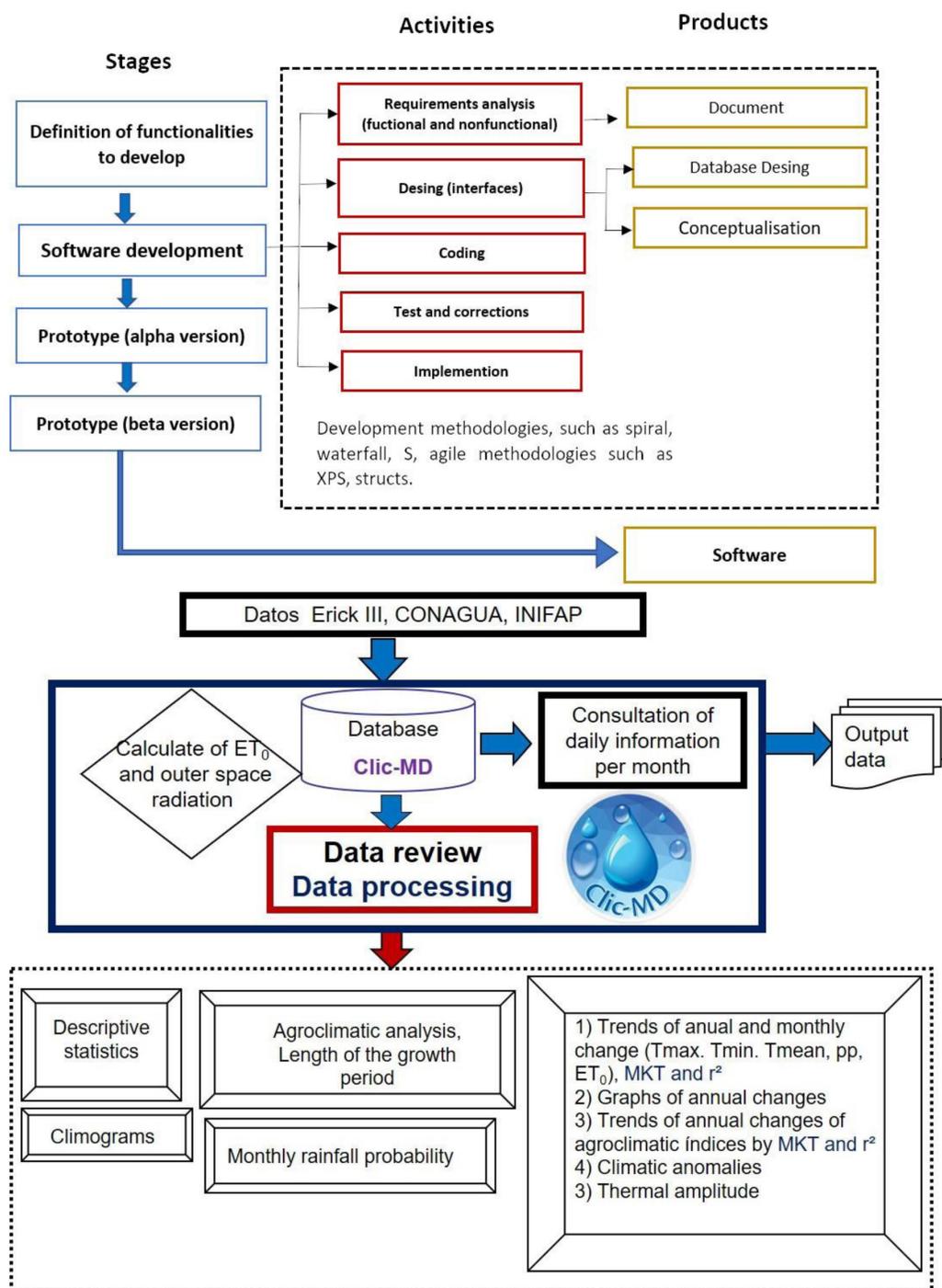
Figure 1. Stages followed for software development and software structure (input data, database, processing, results, and output data).

Windows XP SP3, Windows Vista, Windows 7 or releases above XP and Windows Installer 3.1 or later versions, or any version of Linux and Mac supporting JVN (Cános *et al.* 2003).

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Data processing

This software has a set of calculation routines of derived variables which are commonly used in agricultural land evaluation: a) Evapotranspiration (Allen *et al.* 1998; Bautista *et al.* 2009); b) Agroclimatic indices (Delgado *et al.* 2011, Bautista *et al.* 2011); c) length of the growing period (LPC) (Doorenbos and Pruitt 1977, FAO 1996, Smith 2000, García *et al.* 2007); d) Monthly rainfall probability (Bautista *et al.* 2011); e) Plotting of climographs (Orellana *et al.* 2011); f) Trends of climate change using Mann-Kendall test (MK) and correlation index (Carlón and Mendoza 2007, Bautista *et al.* 2013); and g) Identification of climatic anomalies and extreme events (Figure 2).

Input data variables are: maximum, average and minimum monthly temperatures, monthly rainfall, and precise geographic location. The subsequent order of calculation is potential evapotranspiration, agroclimatic indices, and trend analyses.

Evapotranspiration

Estimation of ET0 needs the previous calculation of the extraterrestrial radiation (Ra) and the sunshine hours according the geographical position of the weather station. The empirical calculation of evapotranspiration potential (ET0) using the Hargreaves test is performed as follows (Hargreaves and Samani 1985):

$$ET_0 = C_i(t_{med} - 17.78)(t_{max} - t_{min})^{0.5}Ra$$

where: C_i = 0.0023, a constant; t_{med} = medium or average temperature; t_{max} = maximum temperature; t_{min} = minimum temperature; Ra = extraterrestrial radiation according to latitude, and is calculated by:

$$Ra = \frac{24(60)}{\pi}G_{sc}d_r\left[\omega_s sen(\varphi)sen(\delta) + cos(\varphi)sen(\delta)sen(\omega_s)\right]$$

where: π = Pi; G_{sc} = Solar constant (0.082 MJm^{-2}min^{-1}); d_r = Inverse relative Earth-Sun distance; ω_s = angle at sunset; φ = latitude (rad); δ = Solar declination.

Agroclimatic indices

The agroclimatic indices included are: humidity (HUi), aridity (ARi), concentration of precipitation (PCi), rainfall erosivity or Fournier's modified index (MFi), soil leaching or Arkley's index (Aki), length of growing season (Growing Season, GS) (Delgado *et al.* 2011, Bautista *et al.* 2011) (Table 1).

Length of growing period (LPC). LPC is the period of the year when humidity and temperature are suitable for crop production, for example the yearly lapse of time with continuous rain sufficient for agriculture. The agroecological zone includes and integrates the climate aspect in LPC.

LPC is estimated considering the water balance model according to the ratio of rainfall (P) to potential evapotranspiration (Et$_0$). If LPC is not limited by temperature (> 6.5 ºC), the P/Et$_0$ ratio determines the type of LPC, its beginning, its length, and its termination. LPC ranges from the month when precipitation exceeds half the ET$_0$ until the month when P is less than half the ET$_0$.

Monthly rainfall probability. The probability model used for the analysis of historical monthly precipitation data is the Gamma function. Adjusting the Gamma function to monthly precipitation records is based on the calculation of the parameters that shape the function (Thom 1958, Bautista *et al.* 2016).

First an auxiliary variable A needs to be calculated: $A = In\bar{X} - \left(\frac{1}{N}\right)\left(\sum InX\right)$,
Where: ln $\bar{X}$ = natural logarithm of the average of the data, N = amount of data and $\sum InX$ = sum of the natural logarithms of the data.

After A is calculated, it is possible to calculate α = alpha and β = beta, the two variables that will shape the probability function adjusted to each month's value:

$$\alpha = \frac{1 + \sqrt{1 + \frac{3}{4}A}}{4A}, \beta = \frac{\bar{X}}{\alpha}$$

Once α and β are calculated, the gamma probability function f (X) can be calculated:

$$f(X)\frac{x^{a-1}exp(-\frac{x}{\beta})}{\beta^a\tau(a)}$$

The area under the curve of this function calculated with its corresponding integral represents the probability to find a lesser or equal value, i.e. the limit value to the right used as reference. For precipitation
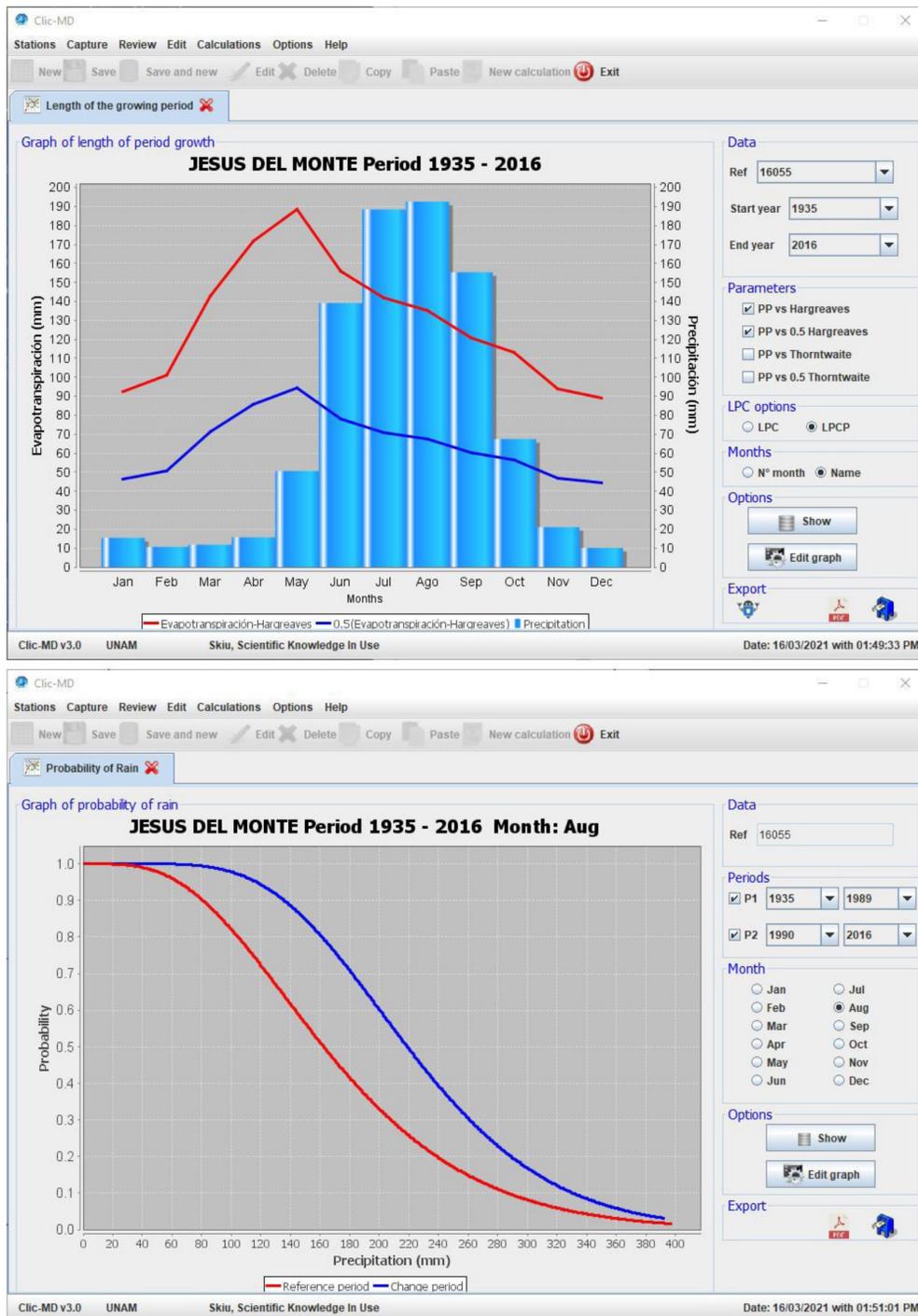
Figure 2. Length of growing period and probability of rain per month for two selected periods.

analysis we need the probability of finding a higher or equal precipitation to each value, so it is necessary to calculate the complement simply obtained by subtracting 1 to each value.

Table 1. Agroclimatic indices.

$HUi = \dfrac{P}{ET_0}$	ARi is the number of months when potential evapotranspiration exceeds precipitation.	GS is the number of months of the year when the average temperature exceeds 5 °C
Where: P = precipitation ET_0 = potential evapotranspiration		
$PCi = 100 \times \sum \dfrac{p^2}{P^2}$ $MFi = \sum \left(\dfrac{p^2}{P} \right)$		AKi is the sum of the monthly precipitations minus the potential evapotranspiration value of those months where precipitation exceeds evapotranspiration
Where: p = monthly precipitation P = annual precipitation Where: p = monthly precipitation P = annual precipitation		

Climographs

Climographs are graphical representations of average monthly rainfall in mm (y-axis) and average monthly temperature in degrees Celsius (y'-axis) (Orellana *et al*. 2011). According to the Gaussen aridity index (Precipitations in mm = Temperatures in °C x 2), the axis of precipitation is twice the average monthly temperature, therefore showing dry and wet months. In dry months the value of average precipitation is lower than two times the value of average temperature, and higher in wet months.

Trends of temperature and precipitation

The procedure for the MK test begins by simply comparing the most recent data of the time series with previous values. A score of 1 is given if the latest concentration is larger, or a score of -1 if it is smaller. The total score for the data series is the MK statistic, which is compared against a critical value to verify if data show a trend of change, and if so, if it is an increasing or a decreasing trend (Carlón and Mendoza 2007). The process for the analysis is as follows:

The n data pairs (x_1,y_1), $(x_2,y_2),\ldots(x_n,y_n)$ are indexed according to the magnitude of the value of x, such that $x_1 \leq x_2 \leq \ldots \leq x_n$ and y_i is the value of the dependent variable corresponding to xi. All n (n-1)/2 ordered pairs of yi values are examined. Let P be the number of cases where $y_i > y_j (i > j)$, and let M be the number of cases where $y_i < y_j (i > j)$. The test statistics is defined by S = P-M. For n > 10, the test is conducted using a normal approximation. The standardized test statistic Z is calculated:

$$z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases}$$

$$Var(S) = n(n-1)\dfrac{2n+5}{18}$$

The null hypothesis is rejected at significance level α if $|Z| > Z_{(1-\alpha)/2}$, where $Z_{(1-\alpha)/2}$ is the value of the standard normal distribution with a probability of exceedance of α/2. For example, at α = 0.05 the null hypothesis would be rejected for |Z| > 1.96. In case some x and/or y values are tied, the formula for Var(S) is modified. If the sample size is less than 10, then it is necessary to use tables for the S statistic.

The Kendall correlation coefficient τ is defined as: $\tau = \dfrac{S}{\frac{n(n-1)}{2}}$

As with other types of correlation coefficients, τ can only take values between -1 and 1, its sign indicating the sign of the slope of the relationship, and the absolute value indicating the strength of the relationship. Because the test only considers the rows of data, it can be used even in cases where some of the data are disapproved. This is an important feature of this test for its application in climatology, because when there are missing values in a data set, a correction to the formula for the variance of S is introduced so that all missing values will be added:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i i(i-1)(2i+)}{18}$$

where t_i is the number of links of extent i.

Clic-MD allows for selecting the climate elements and agro climatic indices to which the MK trend test is applied and the results of the test are displayed on the screen showing the parameters trend statistics (S), variance (Var), number of cases (N), and standardized Z value (Zstd). If Z > 1.96, the data series are statistically significant, in other words, a trend exists. A positive value of Z indicates an upward trend and a negative value indicates a downward trend in the data series.

Climatic anomalies and extreme events

A special graph was made for showing deviations from the average values of weather elements in a selected period with the following characteristics: a) years are plotted along the x-axis; b) on the y-axis a horizontal line is placed corresponding to the average temperature or rainfall for the period; c) on the Y axis, the bars correspond to values deviating from the average both up and down. Click-MD allows for selection of meteorological variables (for example, *Tmax*, *Tmed*, *Tmin*, and precipitation) and months. Generally, it is observed that the period of change is in the most recent years, but each weather station has its own period of change. A graph of probability of occurrence or Gauss distribution is afterwards made. Stable and change periods are shown in the same figure. The tails on the x-axis of the curves indicate the magnitude of extreme events with a probability of occurrence of 0.01 to 0.05 (Beniston 2008).

RESULTS AND DISCUSSION

The calculation of the annual agro climatic indices is displayed in tables together with the analysis of change trends. When there is an increasing trend, the checkbox will be red and when there is a decreasing trend, the checkbox is blue, allowing for an easy interpretation of numerical results. The length of the growth period can be plotted per year or for time periods and it is possible to select the more convenient type of evapotranspiration for cases (Figure 2). Monthly rainfall bars that lie between the two evapotranspiration lines indicate the months when rain is sufficient for crops, but if the bars are below half of the evapotranspiration value indicate months of insufficient rainfall. Finally, when the line is above potential evapotranspiration there is excess of water and the period is wet. The length of the growth period or months of continuous rain is information of paramount importance in agronomy. In the example shown in Figure 2, the length of the growing period is five months with three months of wet period and seven months of water deficit. With supplemental irrigation water applied during May and November, the growing period could reach up to seven months.

Clic-MD allows for quick automatic calculation of the curve of accumulated precipitation by month in two periods, which allows for inferring changes in rainfall between a reference period and another lapse of time. It is recommended that the period to be compared must be of at least 20 years. Notice that the shape of the curve can be concave in a wet month or convex in a dry. Figure 2 shows an example of increasing rainfall in August during the second period. Data are displayed by clicking on the "show" button. The graphs can be edited, exported as PDF or sent by e-mail.

We recommended starting with summary data to know if there is a changing trend. Once the months in which to evaluate the identified change are selected, it is recommended to use the graphs of increases and decreases for identifying the reference period and the period of change, and afterwards continue with the analysis of anomalies using both the baseline and the change periods (Figure 3).

Clic-MD makes possible to identify trends in climate change in sequential increases by correlation analysis or in pulses using the Mann-Kendall test. For example, in the Progreso Yucatán, Mexico, weather station we have identified increases in maximum temperature during May having negative impact on the population. Clic-MD calculates normal distribution graphs for two periods in order to identify in them climate anomalies (in peaks) and extreme events
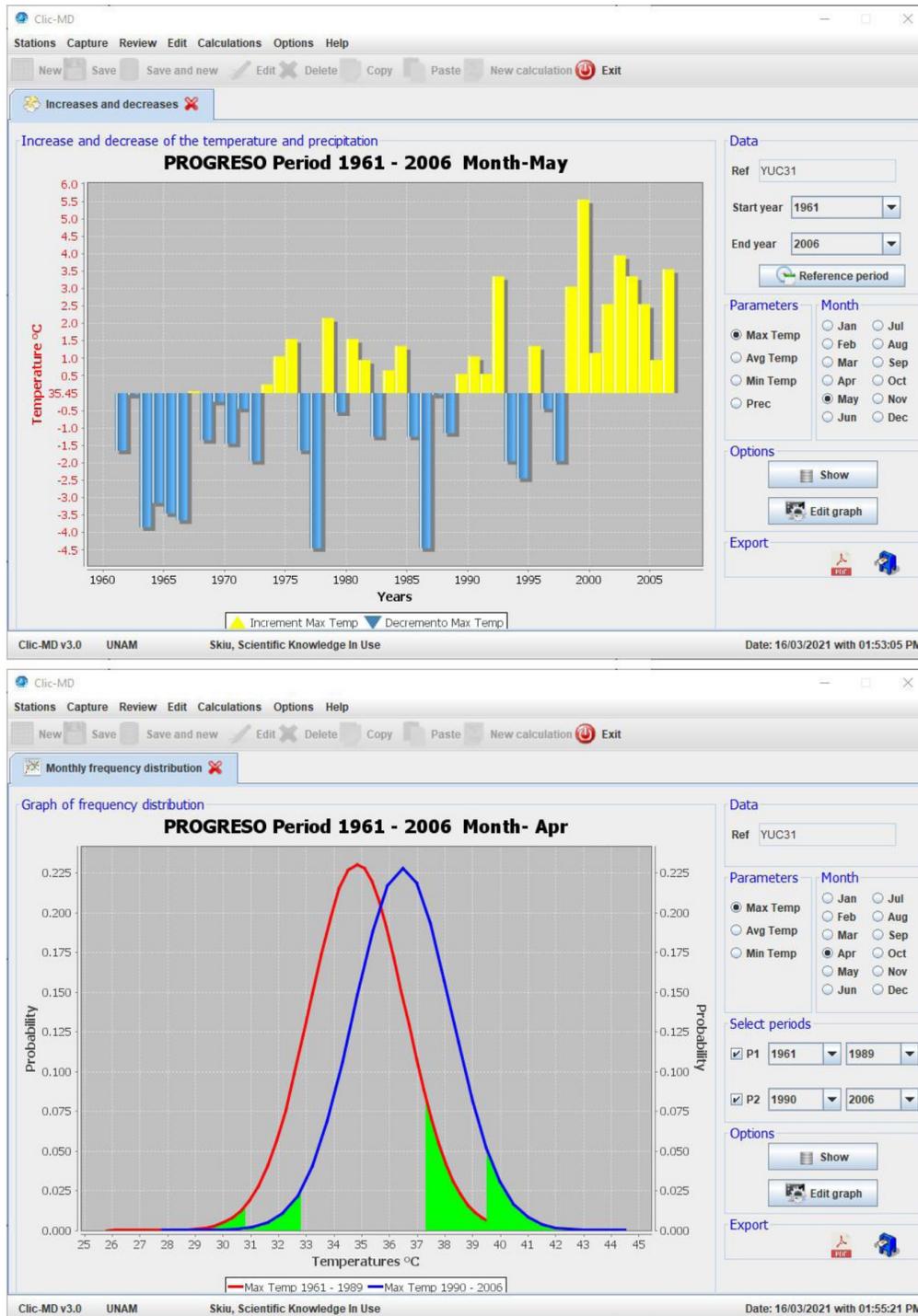
Figure 3. Increase and decrease around mean values and values of extreme temperatures by month.

(in tails), thus making possible to appreciate climate changes. In this example, you can see the displace-

ment of extreme values: the red line is the Gauss bell of the reference period and the comparison pe-

riod is traced in blue (Figure 3). We can see that both the minimum and the maximum values of maximum temperature have shifted towards the right, meaning that the minimum extreme values disappeared, and the maximum extreme values increased. The extreme events in this example increased from 40 to 42° C, namely a weather anomaly of 2° C in higher maximum temperature is displayed.

Clic-MD allows for storing, managing and visualizing thousands of meteorological data in seconds, providing a clear representation of climate trends and extreme events in local and regional settings.

The use of Clic-MD lowers the cost of decision-making processes by obtaining accurate data with minimal expenses. For example, a statistics-trained professional would need seven months for analyzing meteorological data from a single weather station using Excel, but the same task can be made in 20 minutes in Clic-MD, displaying 436 graphs from one meteorological station (Figure 4).

Advantages of the use of Clic-MD include:

Clic-MD will allow decision-makers working on affairs related to the anticipation and adaptation to climate change with a more professional, efficient and timely practice. Clic-MD will enable farmers to make accurate diagnosis of adaptation measures dealing with climate change. Clic-MD will allow researches and students to achieve a better working quality and an improved climate data analysis. Clic-MD will provide governmental agencies a better understanding of the problem linked with climate change at the local level, where policy decisions are made.

A large part of Mexico's agricultural land is used for rainfed agriculture, in both, for climates with many dry months (Delgado *et al*. 2011, Delgado *et al*. 2017, Montiel-González *et al*. 2019), and for the scarcity of good quality water aquifers (Delgado *et al*. 2010). It is for this reason that in recent years, a large number of meteorological stations have been installed throughout the country, which have allowed the analysis of millions of data (Lobit *et al*. 2018a,b) and also tools have been created for the analysis of these data with agroclimatological objec-

tives (Bautista *et al*. 2019, Montiel *et al*. 2019, Ortega *et al*. 2019). This is how this new Clic-MD tool can be used to analyze thousands of data on seconds for agroclimatic purposes.

A rainfed agriculture requires specific climate indicators for the crops, which could be designed with a good knowledge of the physiology of the crops and with a detailed knowledge of the elements of the climate (Ortega *et al*. 2019), in this sense the Clic-MD software plays an important role. On the other hand, climate change is the most serious global environmental problem, and requires the interaction of inter and trans-disciplinary efforts, where the development of software (Villora *et al*. 2016), such as Clic-MD, is key for decision-making. Remote and proximal sensors are used to obtain meteorological data (Mendelsohn *et al*. 2007, Lobit *et al*. 2018a), so new indexes and software for rapid and precise analysis are being developed (Bautista *et al*. 2013, Ault *et al*. 2015, Ortega *et al*. 2019). The Clic-MD software is yet another tool that allows both agroclimatic analysis and climate change (direction and magnitude).

Clic-MD is a new tool allowing users to organize, store, and process millions of monthly records of temperature and rainfall in seconds. Clic-MD improves estimation of ET_0 by using the empirical equations of Hargreaves and Thornwite. The capability of Clic-MD for calculation of agroclimatic indices, length of growth period, and probability of precipitation by month can be used for improving agricultural practices and for reducing human impact on the environmental. The main function of Clic-MD is the agile, quick, and precise identification of monthly and annual climate change trends (direction, magnitude, and period of change). In addition, colored display provides the user of Clic-MD a graphical and numeric representation that is easy to interpret in terms of the significance of the climate change observed in the processed data.

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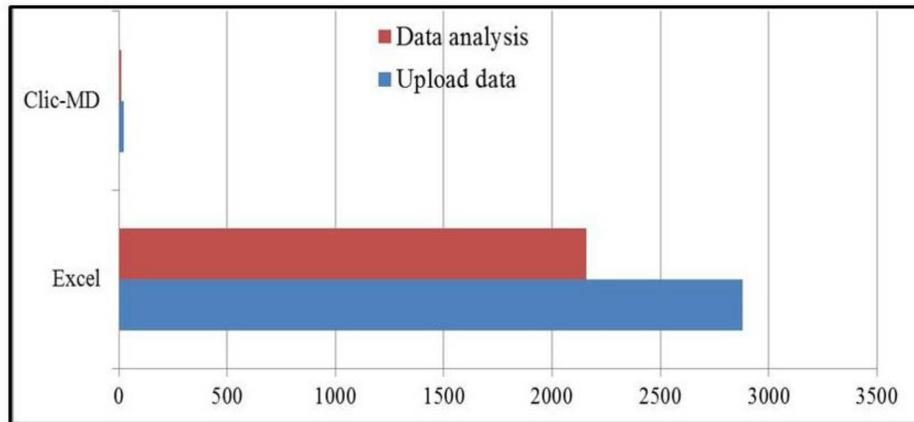
Figure 4. Time in hours needed for analyzing data from one weather station and generating 436 graphics.

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