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Spatial and temporal behavior of annual maximum sub-hourly rainfall intensities from 15-minute to 24-hour durations in central Chile

Comportamiento espacial y temporal de las intensidades máximas anuales subhorarias de precipitación para duraciones desde los 15 minutos a 24 horas en Chile Central

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Articulo por invitación
del Consejo Directivo

Resumen
La intensidad máxima de lluvia es un factor importante de analizar a la hora de determinar si se han producido cambios temporales y espaciales. Se utilizaron los datos recolectados de once pluviógrafos para determinar las intensidades máximas anuales de precipitación para la Región del Maule (centro de Chile), para duraciones desde los 15 minutos hasta las 24 horas, entre los años 1974 y 2009. A cada serie se aplicaron pruebas estadísticas de posición y dispersión junto con la prueba no paramétrica de Mann-Kendall para identificar tendencias. Los resultados mostraron que las intensidades más altas ocurrieron en las estaciones con mayor influencia orográfica y en áreas cercanas a cuerpos de agua. Además, el análisis estadístico reveló que las intensidades máximas de lluvia no muestran tendencias espaciales o temporales en el periodo estudiado. En cambio, los resultados sugieren que las intensidades se han mantenido estables dentro de rangos históricos y no han manifestado cambios importantes en el territorio en estudio.

Palabras clave: Intensidades máximas de lluvia sub-diaria; Intensidades máximas de lluvia sub-horaria; Tendencia de las intensidades de lluvia; Comportamiento espacial de las intensidades de lluvia.

Abstract
Maximum rainfall intensity is an interesting factor to analyze when determining whether temporal and spatial changes have occurred. Data gathered from twelve rain gauges were used to determine annual maximum rainfall intensities for the Maule Region (central Chile), for durations from 15-minute to 24-hour durations, between 1974 and 2009. Statistical tests of position and dispersion were applied to this dataset, along with the non-parametric Mann-Kendall test to identify tendencies. Results showed that the highest intensities occurred at gauging stations with greater orographic influence and in areas near bodies of water. Additionally, the statistical analysis revealed that maximum rainfall intensities did not seem to show spatial or temporal tendencies through time. Instead, results suggest that intensities have remained stable within historic ranges and have not manifested important changes.

Keywords: *Maximum sub-daily rainfall intensities; Maximum sub-hourly rainfall intensities; Trend of rainfall intensities; Spatial behavior of rainfall intensities.*

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1. INTRODUCTION

The Maule region in Chile (34°41' S and 36°33' S) shows a Mediterranean climate and experiences average annual precipitation fluctuating between 600- and 2,300-mm. Annual precipitation increases southward and with terrain elevation. It shows a strong seasonality with a dry summer and 5 months (May to September) concentrating up to 90% of the total annual precipitation (Carrasco *et al.*, 2005; Valdés-Pineda *et al.*, 2013). Winter precipitation occurs due to extratropical fronts arriving to the continent when the Pacific Anticyclone and the midtrack low pressure areas are in their northern position (Garreaud *et al.*, 2009; Valdés-Pineda *et al*, 2013. Rainfall patterns are related to the dynamics atmospheric processes such as El Niño Southern Oscillation (ENSO) (Gonzáles 2016), The warm phase in central Chile (between 30ºS and 35ºS) is associated with an increase in winter rainfall (Ortlieb, 1994; Barrett *et al.*, 2009). Nevertheless, in non-ENSO conditions there are several processes that generate rainfall variability in winter, such as blocking and orographic effects (Montecinos *et al.*, 2011).

Both, the distribution and intensity of precipitation, as well as geomorphology, among other aspects, determine the sensitivity of the territory to meteorological hazards triggered by rainfall, such as flooding of riverbeds, floods, alluvial floods, avalanches, landslides, and swells on coasts (Unesco, 2012). As hydro-climatological events affect social and natural systems, understanding potential changes on frequency, intensity, and duration of extreme events could provide to decision makers with strategies for mitigation and adaptation (Singh *et al.*, 2013; Zubieta & Saavedra, 2009). For instance, the rainfall intensity used for designing waterworks -the maximum value of precipitation expected to occur in a given time frame and associated with a certain return period- is crucial. Rainfall intensity values are obtained from the analysis of records kept by traditional pluviographic stations that register the amount of precipitation over time on a strip of paper, also known as a “pluviographic strip chart”. In Chile, these records are traditionally collected weekly, though there are also daily and monthly records. However, it is unknown whether current gauging networks suffice to capture changes in precipitation patterns, or how current design parameters will be affected by short-term variability and long-term changes.

It is assumed that precipitation intensities in Chile have changed over the last 35 years, as this variable detects the presence of changes in the behavior of rainfall patterns, both temporally and spatially (Jacques-Coper & Garreaud, 2015). Several authors have suggested that precipitation intensities have increased in recent years in several parts of the world, along with the consequences of such increase, including changes to the temporal distribution of rainfall and changes in the impact on precipitation-runoff processes (Dhakal &Tharu, 2018; Bartolini *et al.*, 2017; Fowler & Hennessy, 1995; Gong & Wang, 2000). Other authors suggest that the increasing trend for intensity of rainfall mostly emerges on shorter time frames (less than an hour), since at such scale rainfall is more sensitive to local atmospheric changes (Westra *et al.*, 2014; IPCC, 2007; Beck *et al.*, 2015). For the specific case of Chile, Jacques-Coper & Garreaud (2015) documented that, beginning in the year 1976, there was a change in rainfall patterns within the country (mainly south of 44°S latitude), suggesting a differential situation that should be detectable by statistical methods and mathematical analyses that evaluate the behavior of climatic data. The Maule Region exhibits Mediterranean features, such as sub-humid Mediterranean, highland temperate rainforest, and warm-temperate (DMC, 2001), defining in time and space rainfall patterns, which, as has been pointed out, show notable differences in mean annual rainfall. Pizarro *et al.* (2008) characterized rainfall behavior using 63 pluviographic stations along Chile (15 of them located in the Maule region), concluding that annual precipitation tends to increase latitudinally, with the highest precipitation values being recorded in the Andean mountain range. On revising rainfall’s temporal trends, a decreasing trend of rainfall was observed during the 1990s with a strong decadal variability (Quintana & Aceituno, 2012). Regarding the temporal concentration of rainfall, this has not been manifested as a change in annual rainfall structure. Pizarro *et al.* (2008) also points out that there are clear spatial patterns and temporal trends for climate aggressiveness, the Fournier Index (FI), the Modified Fournier Index (MFI), and the Precipitation Concentration Index (PCI) derived by Oliver (1980). However, increases in the annual amount of rainfall tend to increment FI and MFI, meaning that as the annual amount of precipitation increases, and so does climate aggressiveness. Similarly, it can be assumed that a higher amount of annual rainfall tends to cause a decrease in rainfall concentration, thus causing a decrease in PCI (Pizarro *et al*., 2008). Also, recently, Sangüesa *et al*. (2018) analyzed daily and monthly records from 89 pluviometric stations in the 1970-2016 period, in a geographical area enclosed by latitudes 29°12'S and 39°30'S. In that study, 18 out of 19 rainfall stations showed increasing trends on daily rainfall concentration as estimated by the GINI index. For monthly data, 16 out of 19 rainfall stations show increasing values for the Precipitation Concentration Index. Thus, differences between daily and monthly concentration trends poses a question regarding changes at sub-daily scales. The analysis of rainfall intensity can often become costly and complex. Data comes mostly from pluviographic strips for a limited number of stations, at different geographical areas. Obtaining rainfall intensity records has normally been considered a tedious process, being limited to durations larger than 1 hour, due to the difficulty of estimating the intensities with human eyes when analyzing paper strips (Deidda *et al*., 2007; Jaklič *et al*., 2016). In fact, most pluviographic stations in the country record rainfall data in strip charts using graph paper on a weekly basis. The dimensions of charts are approximately 44 by 13 cm, where 2 hours of rain are denoted by a 5 mm line drawn horizontally. This explains why it has been possible to obtain measures of precipitation up to a minimum period of 1 hour in visual form. Moreover, Unesco (2007) determined the maximum annual intensities and the rainfall intensity-duration-frequency (IDF) curves for stations located in several regions within the country in this same visual form, which, aside from being a long and tedious process, it does not allow for retrieving values for durations of less than 1 hour. This study analyzes temporal and spatial behaviors of rainfall intensities, for different durations, in order identify changes and trends over the last decades..

2. METHODOLOGY

2.1. Study Area

The study was conducted in the Maule region, located in the south-central zone of Chile. The Maule region is located between latitudes 34°43' S and 36°32' S, enclosing 30,296 km2 (Figure 1). Its climate is largely Mediterranean, but it varies West-East (from the coast to the Andes), becoming more humid closer to the Andes mountain range.

The Maule region has limited rainfall records, with a total of 18 meteorological stations possessing a continuous data through weekly pluviographic strip charts (Figure 1). Beginning in 2010, stations using pluviographic strip charts were replaced by stations with continuous digital recording systems. Newer stations were set to deliver information discreetly every hour, due to the high volume of data that would otherwise be generated if records were taken every 0.2 mm of rainfall. This change has led to a reduction in the temporal resolution of available information, as records are taken hourly in integer values, losing inter-annual data and data recorded in durations of less than 1 hour. For the case of the Maule region, the 18 pluviographic stations have continuous strip charts from 1960 until 2009, although several of these stations have periods with a substantial lack of information (Figure 1). Therefore, pluviographic stations used in this study were located mainly in the central valley and at the foothills of the Andes, at elevations varying from 55 to 668 m.a.s.l. Annual precipitation in the area varies from 599 to 2,172 mm (Figure 1).

2.2 Data Processing

The Technological Center for Environmental Hydrology at the University of Talca developed a pluviographic strip chart processor that allows for the digitization and processing of weekly records (Unesco, 2013). The device interprets the line drawn by the pluviograph and uses the numerical values to obtain the maximum rainfall over time (Figure 2). The maximum resolution that can be obtained is 15 minutes, due to the line width. Even so, this tool allows for the gathering of information not previously counted and provides greater certainty regarding quantitative data estimations. The study used pluviographic strip charts collected from 18 pluviographic stations located in the Maule region. The stations belong to one of the following 3 institutions: General Water Directory (DGA), the Chile's Meteorological Directory (DMC), and the National Electricity Company (ENDESA). The quantity of archived records varied as the station with the largest recording time has 44 years of data, while the station with the smallest records has 15 years (Figure 1). In addition to the above, some of these stations were closed in the 1990s, mostly those located at the foothills of the Andes. For the purpose of this study, only records between 1974 and 2009 were considered, as this period included the largest number of stations with continuous data. Thus, data collected in a 36-year period were obtained from a total of 11 pluviographic stations (Figure 1).

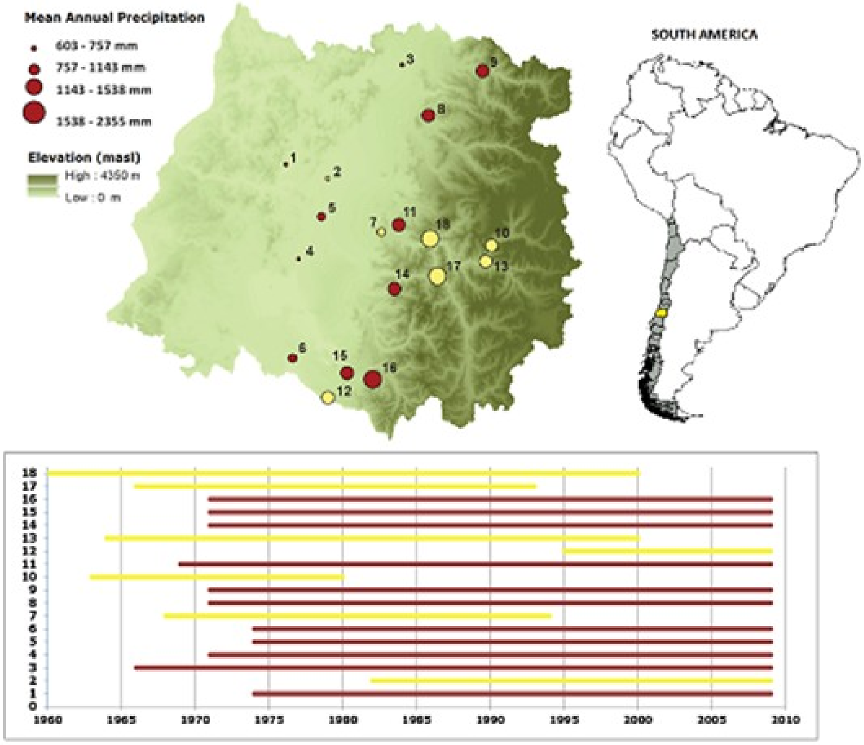

Figure 1. Available pluviographic stations in the Maule region and their time spans. The stations used in the study are shown in red, while those shown in yellow were not included in the study due to a lack of continuous information over time. Stations: 1: Pencahue, 2: Talca, 3: Curicó, 4: Melozal, 5: San Javier, 6: Parral, 7: El Lirio (Colbún), 8: Potrero Grande, 9: Los Queñes, 10: Desagüe Laguna Invernada, 11: Colorado, 12: San Manuel en Perquilauquén, 13: Casa Maquinista, 14: Ancoa Embalse, 15: Digua Embalse, 16: Bullileo Embalse, 17: Melado en la Lancha, and 18: Armerillo

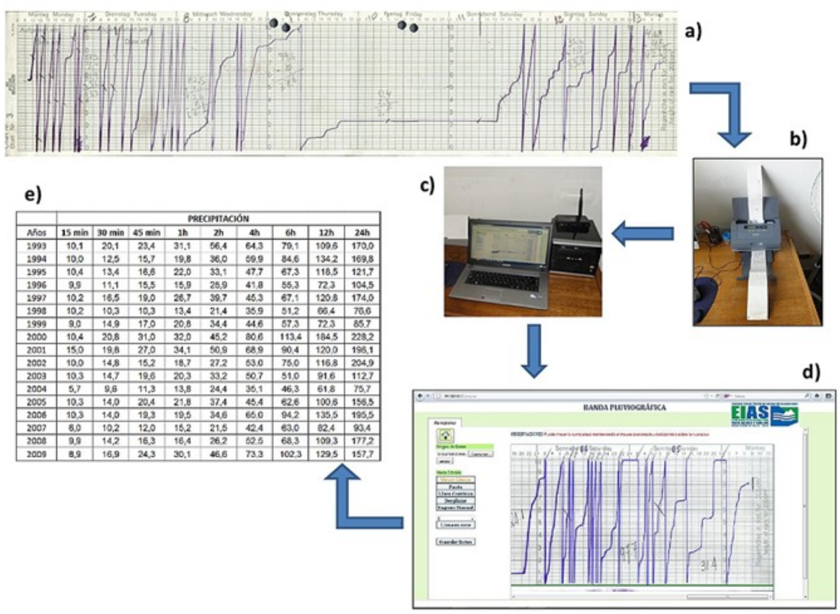

Figure 2. Flowchart of the pluviographic strip chart processor: a) Weekly pluviographic strip chart; b) Automatic feed scanner; c) Software application used to process charts; d) Processed strip chart; e) Data table generated by the processor and sorted on an electronic screen

The pluviographic charts for 10 of the selected stations were weekly strip charts, while those from the remaining stations were monthly strip charts. In order to identify the maximum annual intensity value of a defined duration, continuous sampling was conducted in the selected interval, with a displacement time of 5 minutes, so the cumulated rainfall was recorded in that time interval. Thus, time series were built by picking the highest intensity for each year. With the resulting data, it was possible to analyze the behavior of annual maximum rainfall intensities for durations of 15, 30, and 45 minutes, as well as for 1, 2, 4, 6, 12, and 24 hours, for stations located in the Maule region, with the exception of the Curicó station, where intensities with durations of less than one hour could not be obtained due to the format of its pluviographic strip charts. In order to describe the behavior of the annual maximum intensities, inferential and descriptive statistics were used for each duration: (1) An exploratory data analysis (boxplot) was conducted in order to depict the distribution of the intensity values of each data series, each duration, and for the 11 stations considered. The stations were sorted in terms of their average annual rainfall; (2) The mean, standard deviation, and coefficient of variation were calculated for all stations. The values were placed on a map to analyze the variability with respect to spatial location. Additionally, the Alexandersson's homogeneity test (Alexanderson, 1986) was applied to all time series and all durations; (3) Annual maximum rainfall intensities for different durations were correlated with annual rainfall using the Pearson's correlation coefficient; (4) Afterwards, temporal trends of the maximum annual intensities were analyzed for each duration and station examined, with the purpose of determining whether the variable had shown significant changes in tendencies over the 36-year study period. This analysis was conducted using the non-parametric Mann-Kendall test. This test verifies the existence of tendencies (positive, negative, or none), while also determining the trend's statistical significance to a certain level of confidence; (5) The complete set of records (1974-2009) was further split into two sub-sets (1974-1991 and 1992-2009), and a Gumbel distribution was fitted to obtain return periods of 20 years for each one of the 9 durations previously listed. For the calculation of the Mann-Kendall test, it is required the Kendall's S-statistic and its variance VAR(S). With both values, the standardized Z-value can be obtained when the sample size is greater or equal to 8 (Yue, Pilon, & Cavadias, 2002). The sign and value of the Z-value determines the orientation and meaning of the derived tendency, respectively. For the S-statistic, the following equation was used:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\left(x_j - x_k\right) \tag{1}$$

where the function's $sign\ (x_j\text{-}x_k)$ is defined as:

$$sign\left(x_j - x_k\right) = \begin{cases} 1 & if\, x_j - x_k > 0 \\ 0 & if\, x_j - x_k = 0 \\ -1 & if\, x_j - x_k < 0 \end{cases} \tag{2}$$

wherex_j and x_k are consecutive values of the variable being studied. Then, the variance *VAR(S)* is defined as:

$$VAR\left(S\right) = \frac{1}{18}\left[n\left(n-1\right)\left(2n+5\right) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \tag{3}$$

Using both values, the Z-value was calculated using one of the following equations, depending on the S-value:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}}; & if\, S > 0 \\ 0; & if\, S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}}; & if\, S < 0 \end{cases} \tag{4}$$

Once the Mann-Kendall's Z-values were obtained, a qualitative spatial analysis was conducted. In addition to the above, three time periods were determined for each series: 1974-1991, 1992-2009, and the complete period (1974-2009). The Gumbel's probability distribution function was adjusted using the Method of Moments to each time period, determining the value to be reached by the variable "intensity", for a 20-year return period, i.e. P (x≤X) = 0.95, for all durations (Pizarro *et al.*, 2013).

3. RESULTS AND DISCUSSION

The values obtained for the maximum annual rainfall intensities, in mm/h, for the 9 durations previously listed, are shown in Figure 3. Average values were included, along with the maximum and minimum of each series, showing the high variability of the data over the years. As can be observed in Figure 3, among the average annual maximum rainfall intensity values of each duration, Pencahue was the station with the lowest intensity (19 mm/h), whereas Bullileo was the station with the greatest intensity (31.4 mm/h). For maximum values in each series are analyzed instead, other stations, as the Digua Embalse, showed maximum values for the 15- and 30-minute durations of 77.0 and 45.4 mm/h, respectively. Thus, highest intensities were found at the Andes' footfills, while lower values were in the west part of the central valley. Therefore, the spatial patterns of annual maximum rainfall intensities showed a decreasing mountains-to-coastal gradient, most likely due to a strong orographic influence and corroborating the findings by Garreaud (2009).

An exception to the above was the Melozal station, which despite of being located in the central valley and far from any body of water, it registered a maximum value for 15-min duration of 64.5 mm/h, being it the third highest value. This is relevant when considering the design rainfall intensity for hydraulic works.

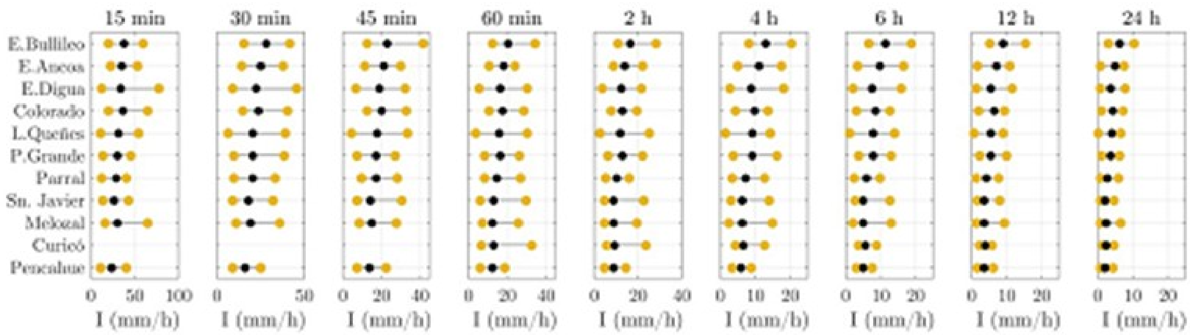

Figure 3. Annual maximum intensity values for durations of 15, 30 and 45 min and 1, 2, 4, 6, 12, and 24 h for the 1974-2009 period

In terms of the standard deviation (Figure 4), the highest values were located in the area with the highest elevations, where annual rainfall and their intensities are greater. Upon analyzing the coefficient of variation linked to the intensities of each duration, a variation between 0.28 (45-minute duration) and 0.41 (24-hour duration) was observed (Figure 5). In general, it was observed that as the duration increases, the coefficient of variation tends to increase slightly, especially for durations greater than 1 hour. When establishing a relationship between annual maximum rainfall intensities and mean annual rainfall for each station, a positive correlation between both variables was observed. Highest correlation (0.4) was found for 24-hour durations, while 15-minute durations showed the lowest correlation value (-0.27, Figure 6). Despite the above, once the correlation coefficient was calculated, the values obtained were low (rarely rising above 0.5). Even for the Colorado station, the coefficient became negative for the 15-min duration and 0 for the 30-min duration. It is also noteworthy that Los Queñes station had a correlation of 0.58 for the 15-min duration, which contradicts the assumption that the sub-hourly intensities would be more connected to an orographic phenomenon than frontal systems. Stations Parral, Bullileo, and Los Queñes showed correlation values above 0.5 for 24-hour durations

(0.58, 0.53 and 0.52, respectively). In relation to the boxplot graphs, as the amount of annual maximum rainfall increased, the intensities tend to increase for the different durations considered in this study (Figure 7). Similarly, the highest intensities were reached in stations experiencing greater orographic influence (i.e. those located in the foothills of the Andes), as well as those near bodies of water, as previously mentioned, corroborating the studies conducted by Pizarro *et al*. (2013). In addition to the above, it was observed that, among the durations greater than 1 hour, 2 groups of stations could be distinguished. The first group is composed by stations located in the Central Valley (Pencahue, Curicó, Melozal, San Javier, and Parral), whereas the second is composed by stations located at the foothills of the Andes (P. Grande, Los Queñes, Colorado, Ancoa E., Digua E. and Bullileo E.). The central valley group of stations showed less rainfall, while simultaneously having lower annual maximum rainfall intensities (stations Pencahue, Curicó, Melozal, San Javier, and Parral). It should be noted that Parral, which had one of the highest annual rainfalls for the central valley (1,000 mm/year), was not among the highest rainfall intensities. The Bullileo station was the station that showed the highest intensities for all durations, emphasizing the small dispersion of its data, as well as the large number of outliers for 15-minute durations. A possible explanation of such behavior is the fact that the station is located very close to a body of water (the Bullileo reservoir), agreeing, once again, with the findings by Pizarro *et al*. (2013).

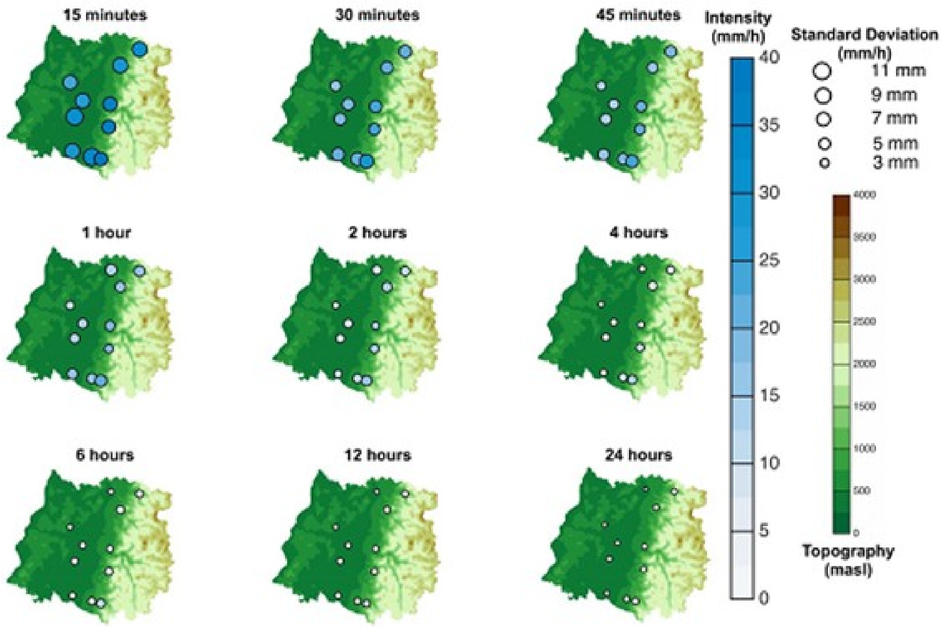

Figure 4. Maximum annual rainfall intensities for different durations, as mean values and their respective standard deviation, between the 1974-2009 period

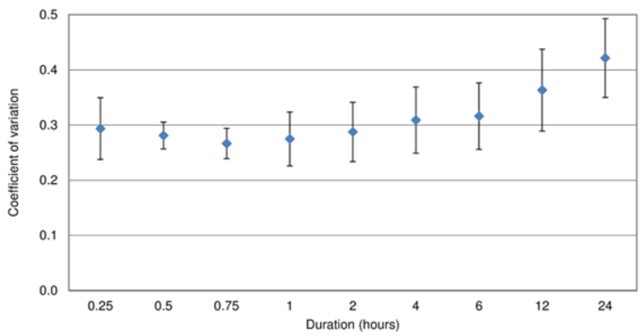

Figure 5. Coefficients of variation for annual maximum intensities, for each duration, calculated with mean values from all stations, for the 1974-2009 period

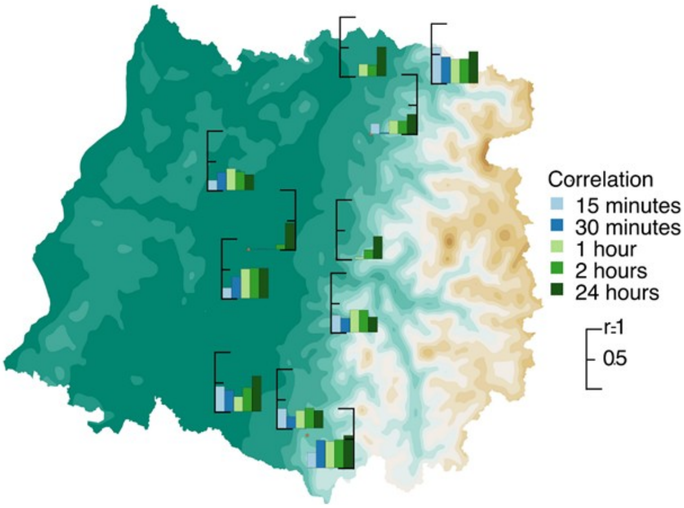

Figure 6. Correlation coefficients between the annual maximum intensity and annual precipitation for durations of 15 minutes and 1, 12, and 24 hours, between 1974 and 2009

In relation to the boxplot graphs, as the amount of annual maximum rainfall increased, the intensities tend to increase for the different durations considered in this study (Figure 7). Similarly, the highest intensities were reached in stations experiencing greater orographic influence (i.e. those located in the foothills of the Andes), as well as those near bodies of water, as previously mentioned, corroborating the studies conducted by Pizarro *et al.* (2013).

In addition to the above, it was observed that, among the durations greater than 1 hour, 2 groups of stations could be distinguished. The first group is composed by stations located in the Central Valley (Pencahue, Curicó, Melozal, San Javier, and Parral), whereas the second is composed by stations located at the foothills of the Andes (P. Grande, Los Queñes, Colorado, Ancoa E., Digua E. and Bullileo E.). The central valley group of stations showed less rainfall, while simultaneously having lower annual maximum rainfall intensities (stations Pencahue, Curicó, Melozal, San Javier, and Parral). It should be noted that Parral, which had one of the highest annual rainfalls for the central valley (1,000 mm/year), was not among the highest rainfall intensities.

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For 15-minute, 30-minute, 1-hour, and 2-hour rainfall durations, annual maximum rainfall intensities occur more frequently during winter months (May, June, and July), although it is noteworthy that summer months showed a negligible frequency of intensities (Figure 8). This fact is relevant for planning in the face of extreme events, such as floods and landslides.

Based on the Mann-Kendall analysis (Figure 9), the Digua Embalse station stood out as it showed a positive and significant trend ($p<0.05$), for durations ranging from 15 minutes to 2 hours. However, the behavior of this location obeys to local-scale characteristics, not suggesting a spatial pattern (Pizarro *et al.*, 2013).

The stations Parral, Melozal, Pencahue, and Colorado, on the other hand, showed negative trends for all durations, but very few of them were significant. Results from the analysis indicate that other stations had mostly negative, non-significant, trends except for Pencahue and Potrero Grande, which tended to show positive, non-significant trends. Given the above, it can be said that, from an annual perspective, there are no clear rainfall behavior patterns within the study area.

A total of 96 time series were tested for data derived from 11 stations (10 with 9 durations, and 1 station with 6). Among them, 62 (64.6%) were negative trends and 34 (35.4%) were positive trends.

However, it is worth noting that, over a 36-year period, only 13 (13.5%) of the trends were significant, 6 of which (6.3%) were positive and the remaining 7 (7.3%) were negative (Figure 10). In other words, it is not possible to say that annual maximum rainfall intensities have changed; in fact, most series (77%) showed that rainfall intensities for durations between 4 and 24 hours have decreased. In terms of rainfall durations shorter than 60 minutes, the number of positive and negative tendencies were similar (46% and 54%, respectively), even though other studies suggest that short-term rainfall intensities are increasing (Westra *et al.*, 2014; Vasiljevic, McBean, &Gharabaghi, 2012; Valdés-Pineda *et al.*, 2013). Differences on trends and spatial distribution must be closely analysed in order to unravel potential changes on the direction, trajectories and precipitable water. Also, preliminary results suggest that maximum intensities within the year also occur during summer time, having a potential effect on the design of waterworks and irrigations system, but also affecting the preparedness of productive systems.

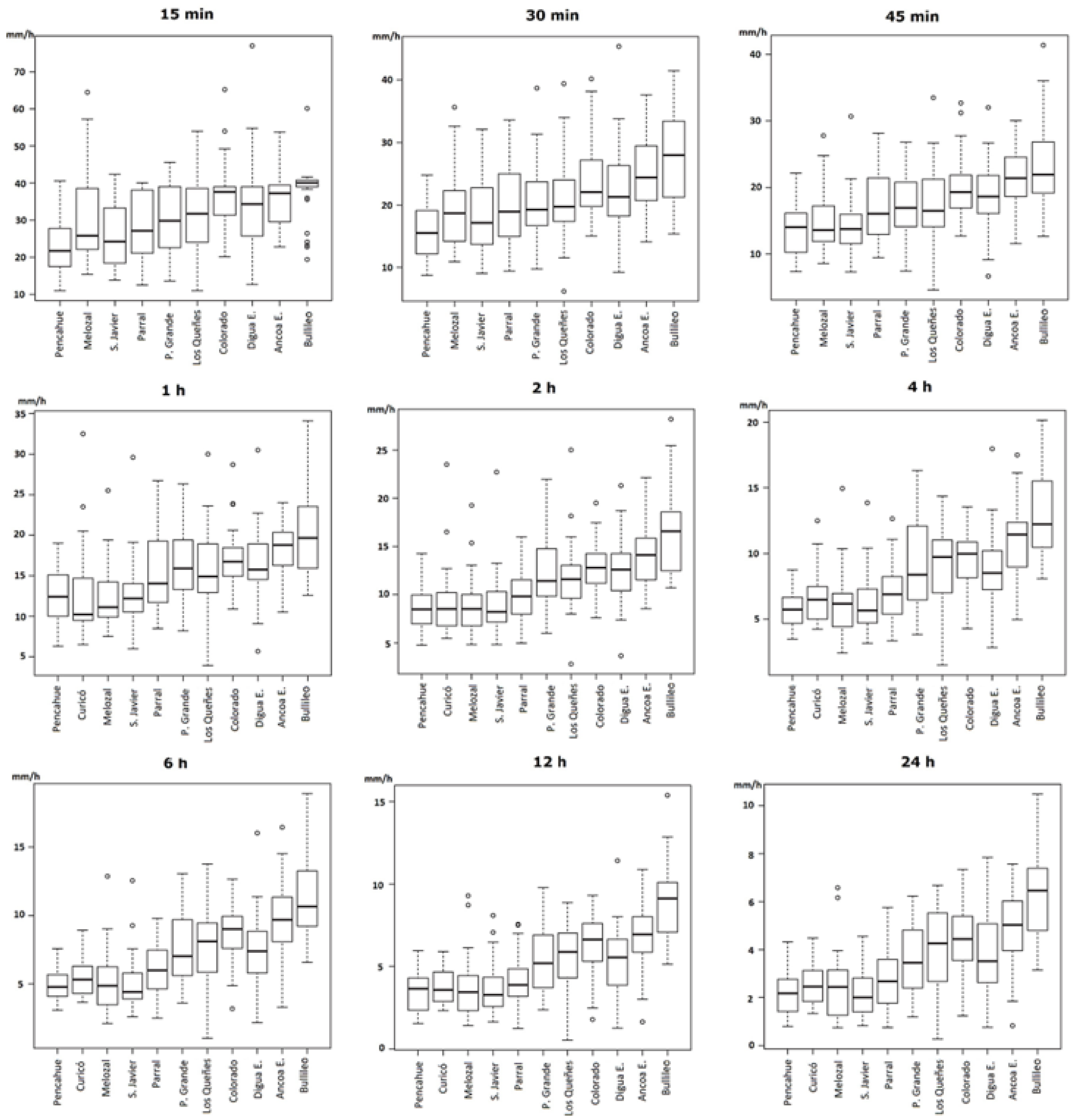

Figure 7. Boxplot graphs for the average annual maximum intensity
for durations of 15, 30, and 45 minutes, and for 1, 2, 4, 6, 12, and 24 hours, between 1974 and 2009
for pluviographic stations sorted by annual precipitation from smallest to greatest

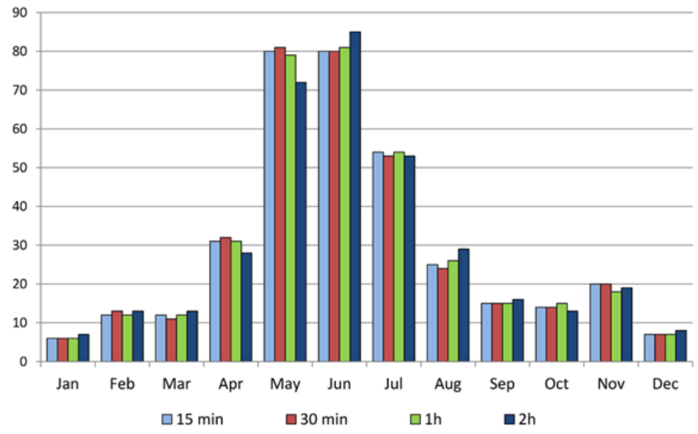

Figure 8. Frequency of occurrence for maximum annual intensities at all stations, under different durations

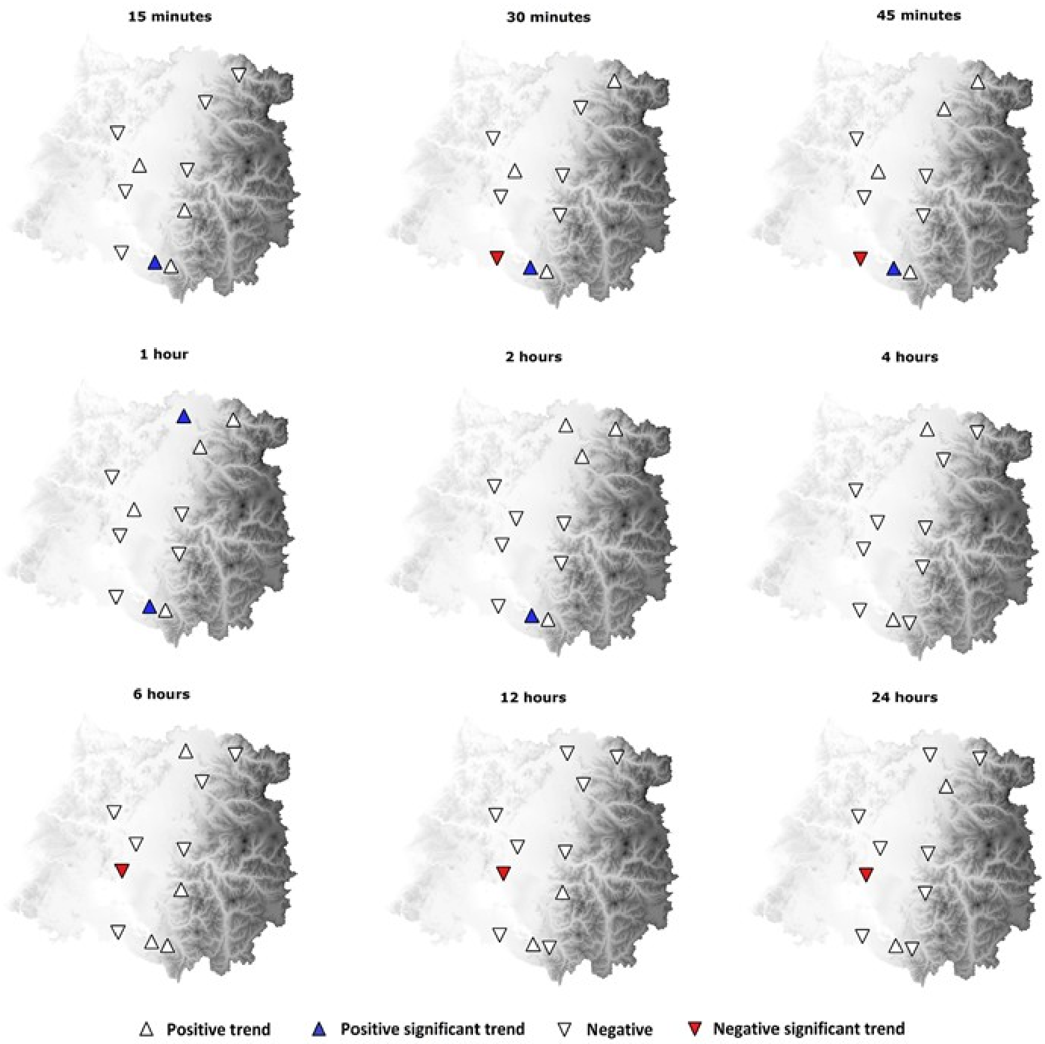

Figure 9. Trend map (Mann-Kendall) of maximum rainfall intensities
for 15-, 30-, and 45-minute, and 1-, 2-, 4-, 6-, 12-, and 24-hour durations

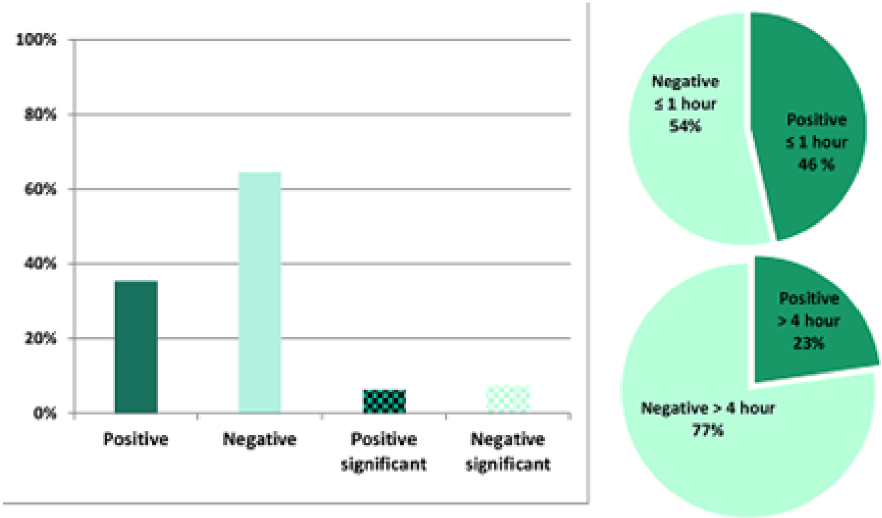

Figure 10. Trend values for the entire data set analyzed, as percentages

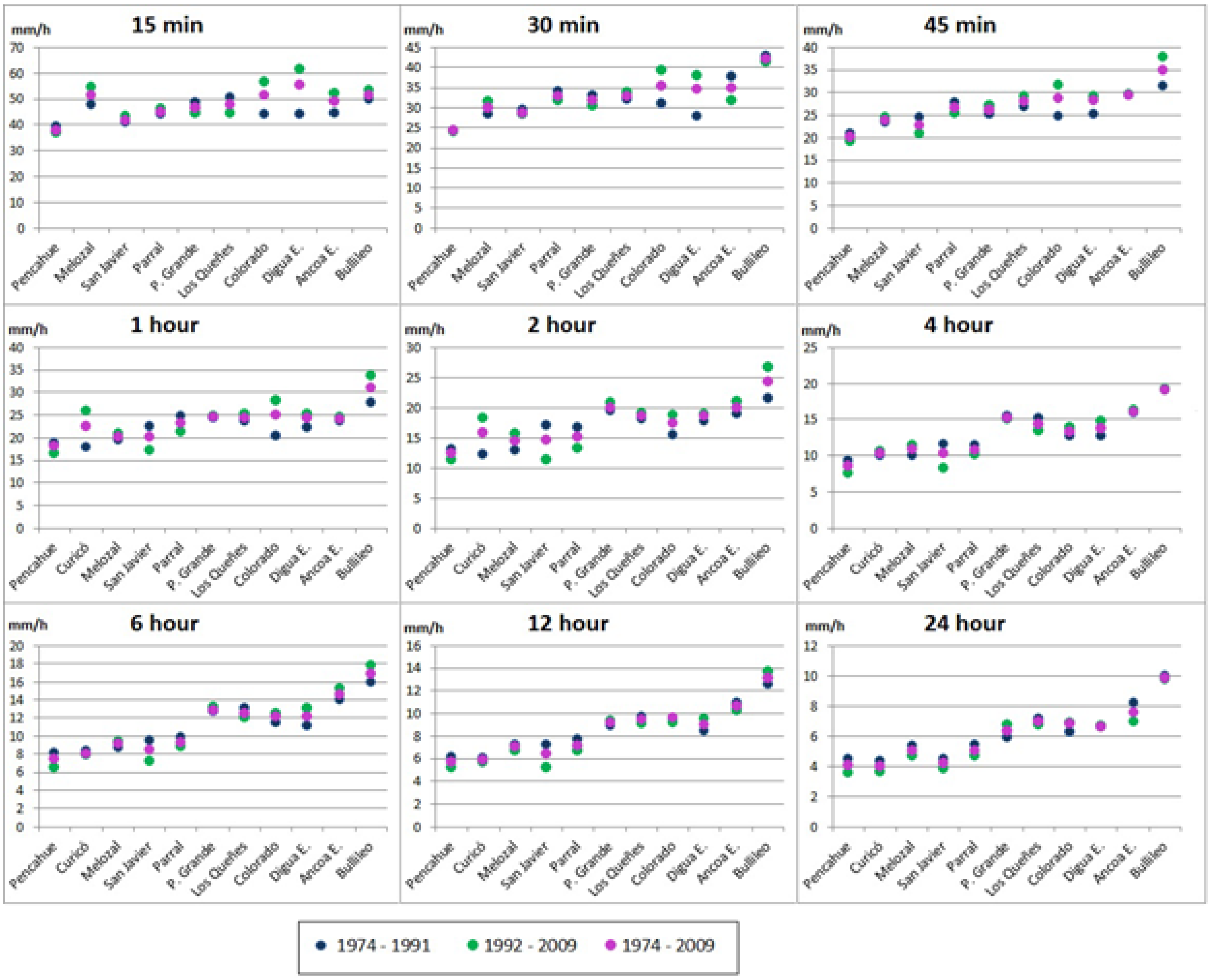

Figure 11. Comparison of annual maximum rainfall intensities for a 20-year return period, applied to the three timeframes (1974-1991, 1992-2009, and 1974-2009), considering each duration and station.

The above results suggest that annual maximum rainfall intensities from the 11 analyzed stations have not changed significantly (positive or negative trends). Similarly, the analysis under different time periods (obtained from the fitted Gumbel function) showed no differences among the three groups (1974-1991, 1992-2009, and 1974-2009), with the exception of a few stations (Colorado and Digua Embalse) (Figure 11).

It is not possible to unravel the reasons why there is a high differential on annual maximum rainfall intensities between both time periods, based on our current database. However, one explanation could be the geographical location of the stations (near bodies of water), as suggested by Pizarro *et al*. (2013).

Such differential is only expressed in durations equal or shorter than one hour, an indication of the need for further analysis, with more information, to be able to find more results. It is suggested to explore synoptic patterns for rainfall and other relevant climatological fields.

4. CONCLUSIONS

A relevant number of annual maximum rainfall intensities in the Maule region showed largely non-significant, negative trends. For intensities of less than one hour, there was no clear tendency through time or space; however, for intensities longer than four hours, most stations showed a tendency to decrease over time, though such tendencies weren't statistically significant. This means that, considering the period analyzed, it is not possible to infer changes in temporal behavior patterns for annual maximum rainfall intensities.

Finally, the trend analysis showed that, for the 11 stations and different durations studied, the intensities between 1974 and 2009 did not display patterns of spatial or temporal behavior. The results instead show that the intensities have stayed within known ranges and have not shown any significant changes. However, it is advisable to expand the work performed in this study to other latitudinal areas of the country, in order to add more information to the data used in this study, which could then be used to either confirm or rule out the existence of significant changes to behavioral patterns of annual maximum rainfall intensities.

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