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Monthly Precipitation Indexes' tendency analysis in the state of Ceará, Brasil

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Abstract — The state of Ceará is a semiarid region in the north-eastern part of Brazil, with high spatial and temporal variability of precipitation embarrassing water resources management. The objective of this study is to describe and analyze the trend of monthly precipitation indices developed by the CLIVAR Expert Team on Climate Change Detection. Data from 55 weather stations in the state of Ceará from 1974 to 2009 was analysed. In general a decreasing trend in monthly precipitation was observed over almost all the state of Ceará, with a noticeable exception in January. The results point to a tendency for the dry months to become dryer and a decrease in intensity. Monthly maximum daily precipitation is generally increasing in all months and over the all area under study. The spatially varied behaviour should be taken into account when managing water resources for urban and rural supply, as well as dry and irrigated crop production.

Keywords — Ceará, Climate Change, CLIVAR, Precipitation indexes

1 INTRODUCTION

Water resources may suffer impacts from changes in mean and extreme precipitation values: increasing soil erosion, surface and groundwater contamination, which may increase the risk of diseases and may include loss of property, possible failure in agriculture and livestock development, from either an increase or decrease in precipitation distribution patterns. Changes in extreme rather than mean values show greater impact on climate change, and its analysis becomes very important [1].

In a study conducted by Alexander *et al.* [2], 37% of the stations studied globally – mostly from the Northern Hemisphere and parts of Australia - showed a significant annual tendency towards wetter conditions, suggesting that global wetting is likely to be part of a longer term trend.

The state of Ceará is within a semiarid region in the north-eastern part of Brazil, with high spatial and temporal variability of precipitation, not being uncommon, in some regions, to occur 70% of annual precipitation in only one month [3]. The beginning of the rainfall season also has temporal and spatial variability, making water resources management in the region a difficult task.

Inappropriate use of natural resources may have a negative significant impact in this semi-arid region, where fragile ecosystems are present. Farming, in this region, is mostly rain-fed, and knowledge of its variability is of extreme importance [4].

The water resources plan of the state of Ceará - Plano de Recursos Hídricos do Estado do Ceará – divides the territory into four zones (Fig. 1): Litorânea (Ocean), Serrana (Sierra), Cariri and Semi-arid [3].

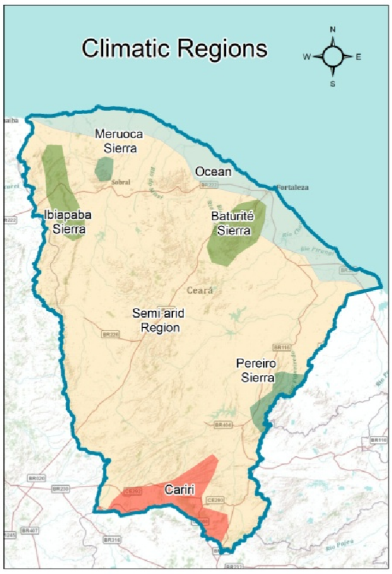

Fig. 1 - Climatic Regions in the State of Ceará, Brazil

The overall water deficit in the state runs for approximately 10-11 months, except for the Ocean area and mild hill area and Cariri, where the deficit runs for 6 to 8 months, starting in June-July and ending in January-February [3].

Considering the spatial and temporal variability of precipitation regimes in Ceará it's worth the effort in trying to identify long term patterns and

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tendencies in precipitation itself and associated indices.

Local climate change may be assessed by analysis of time series of meteorological indices calculated from temperature and precipitation records [4].

The CLIVAR (Climate Variability and Predictability) expert team on climate change developed a series of extreme climate indices from daily temperature and precipitation data to study climate changes [2].

In the studies conducted by Santos and Brito [5] and Santos *et al.* [4] in a semi-arid region in Brazil (Rio Grande do Norte, Paraíba, and Ceará states), climate changes detected by CLIVAR's indices seem to be a response not only from local scale, but also large scale phenomena. Variations in CLIVAR's indices were linked to changes in Sea Surface Temperature (SST) in El Niño regions 1+2 and 3, and Tropical North Atlantic (TNA) and Tropical South Atlantic (TSA). Results show a tendency towards more humid conditions at a yearly scale, especially in continuous wet days, total annual precipitation, and extreme precipitation values.

According to Magrin *et al.* [6], a substitution of semi-arid vegetation by arid vegetation is expected to occur in some areas of the north-eastern Brazil owed to the combined effects of land-use and climate change [7].

The objective of this study is to describe and analyze the trend of monthly precipitation indices - total precipitation, precipitation intensity and frequency, duration of wet and dry spells - in the state of Ceará, Brazil. Spatial interpolation of indices' slopes were evaluated to provide an overall view for trends in the state of Ceará. Raingauges with significant trends were highlighted.

2 Data and Methods

2.1 Data

The analysis was performed using daily precipitation data from 55 weather stations from 1974 to 2009 (36 years), period with low or no missing data, scattered throughout the state of Ceará (Fig. 2).

No stations were excluded based on proximity to urban areas and normally implicit urban heat island effect, because they do not seem to have an effect on long term trends [8].

A homogeneity test was performed on the annual data using the Shapiro-Wilk parametric hypothesis test of composite normality with a significance level of 5%.

Fig. 2- Precipitation gauges location

2.2 CLIVAR Indices

The precipitation indices developed by the CLIVAR Expert Team on Climate Change Detection were evaluated on a monthly basis. These indices are based on percentiles, absolute values, threshold values and duration [2] and their computation is:

PWD - monthly precipitation on wet days precipitation ≥ 1 mm

$$PWD_j = \sum_{w=1}^{W} RR_{wj} \quad (1)$$

CDD - Monthly maximum length of dry spell, maximum number of consecutive days with rainfall < 1mm

$$CDD_j = \max\left(\text{days}\left(RR_{ij}\right) < 1mm\right) \quad (2)$$

CWD - Monthly maximum length of wet spell, maximum number of consecutive days with RR ≥ 1mm

$$CWD_j = \max\left(\text{days}\left(RR_{ij}\right) \geq 1\text{mm}\right) \quad (3)$$

NWD - Monthly count of days with precipitation ≥ 1 mm

$$NWD_j = \text{days}(RR_{ij} \geq 1\text{mm}) \quad (4)$$

NP75/NP90/NP95 – monthly number of days with precipitation above the 75/90/95 percentile

$$NP_{pj} = \text{days}(RR_{ij} \geq P_p) \quad (5)$$

Rx1day - monthly maximum 1-day precipitation

$$\mathrm{Rx1day_j} = \max\left(\mathrm{RR_{ij}}\right) \qquad (6)$$

Rx5day -monthly maximum consecutive 5-day precipitation

$$\mathrm{Rx5day_j} = \max\left(\mathrm{RR_{kj}}\right) \qquad (7)$$

SDII - Simple daily intensity index

$$\mathrm{SDDII_j} = \frac{\sum_{w=1}^{W} \mathrm{RR_{wj}}}{W} \qquad (8)$$

Where:

- j – month in analysis
- RRij - daily precipitation amount on day i in month j
- RRkj - precipitation amount for the 5-day interval ending day k, in month j
- RRwj - daily precipitation amount on wet days, w (RR $\geq$ 1mm) in month j.
- W - number of wet days
- p - user defined threshold (75, 90, and 95th percentiles)
- Pp- precipitation at 75, 90, 95 percentiles

Extreme frequency indexes were calculated at a monthly scale at different cut-offs - 75th, 90th and 95th percentiles rather than a fixed threshold ([9],[10], [11]), due to the spatial variation of rainfall intensity. Percentiles were evaluated using all data set, and seasonality was accounted for by examining the indexes on a monthly basis [12].

2.3 Data Analysis methods

A linear trend was evaluated using regression analysis on indexes. The slopes were estimated, tested for being equal to zero and identified whenever statistically different at the 5% significance level.

A spatial interpolation on the slope of calculated indexes was performed using the inverse distance weighted (IDW) interpolation algorithm, assuming that data from stations that are closer together tend to have more similar characteristics than stations that are farther apart.

Trends (even if not statistically significant) are identified, in the following figures, in blue if positive, and in red if negative. The stations that showed significant positive or negative trends (5% significance level) are identified in blue and red dots, respectively, whereas the stations that did not show a significant trend are identified in small black dots.

3 Results and Discussion

The monthly precipitation analysis carried out for the state of Ceará shows a season pattern with a dry period beginning in July and ending in November, and a wet period extending between the months of December and June. March and April are the wettest months (Fig. 3), as a result of the Southerly movement of the Intertropical Convergence Zone [13].

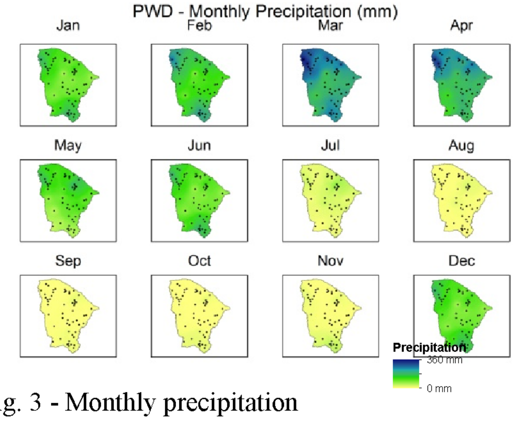

Fig. 3 - Monthly precipitation

During the wet period, the rainfall is mainly distributed in the Ocean, Sierras and Cariri regions as characterized in Fig. 1.

PWD - Monthly Precipitation Trend

An overall increase in monthly precipitation (positive trend) was observed in January, and from June to August, being more accentuated in January (bigger slope), which is wetter than the June-July-August trimester (Fig. 4). This trend is inverted (a declining trend in precipitation) from September to November, during the dry season.

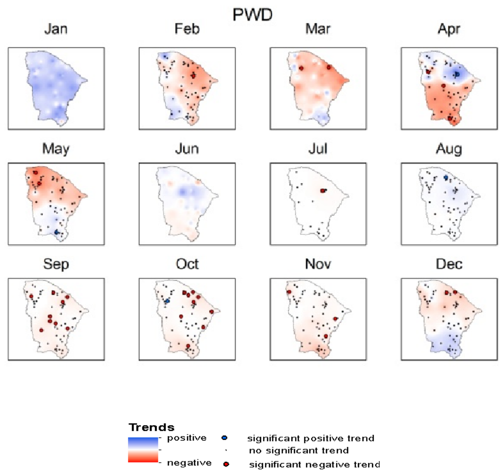

Fig. 4- Monthly precipitation trend

Drier conditions (negative slopes) were also observed in the wetter months of February to May.

Actually, a decreasing trend in monthly precipitation was observed in the southern part of the state of Ceará in April, followed by a reverse decreasing in the northern part in the month of May, with increasing trends in the complementary areas of the state.

Contrary to what was stated by Santos *et al.* [4], who observed an increase in the humidity conditions in Ceará based on annual precipitation indices, this study shows a general tendency towards a decrease in monthly precipitation values (except for the wet month of January and dry months of June to August). These results are in accordance with the results obtained by Moncunill [13] who based the study in the 1961 – 2003 period, and verified that, apart from the month of January, a decreasing trend is expected in annual precipitation over almost all the state.

The results suggest that the dry season starts with a tendency towards a slight increase in monthly total precipitation and ends with a decrease in total precipitation, implying that the drier months are becoming drier.

The wettest months show evidence of also becoming drier at the end of the season except for the Ocean and Cariri regions.

CDD – continuous dry days - maximum length of dry spell

The monthly maximum length of dry spells shows an increasing and significant trend almost over the entire state of Ceará from September to November, which are also the drier months, implying that dry spells are intensifying in the dryer months. As for the other months, an increasing trend is also verified, sparsely distributed throughout the region. Except for the Ocean region, a significant decrease in length of dry spells was observed for August and December and for March and June in the north-western Sierra area.

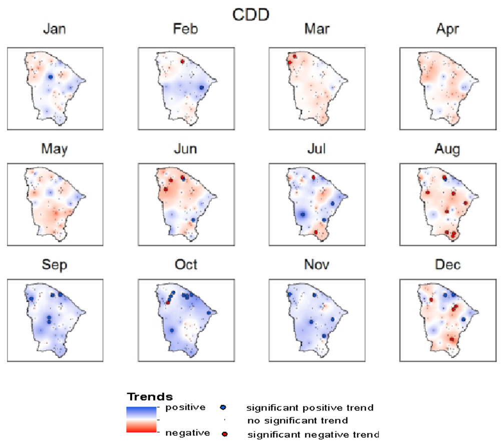

Fig. 5 - Montlhy number of continuous dry days' trend

CWD – continuous wet days - (monthly maximum length of wet spell)

Analysing the tendencies for the number of continuous wet days, it's noticed a propensity for this index values to increase in January and August through all Ceará state. For the other months, an increasing trend also occurs in some restricted areas over the region. However, analysing both the area of decreasing trends and the number of months in which they occur, a global decreasing trend in monthly maximum length of wet spell was verified.

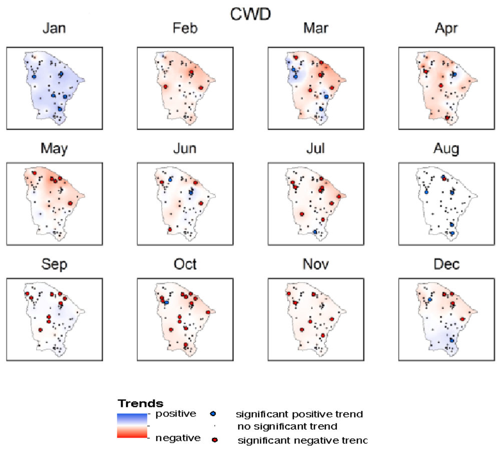

Fig. 6 - Monthly number of continuous wet days trend

NWD – number of wet days

A generalized decreasing tendency for the entire Ceará region is observed for NWD. Exceptions were verified in the wet months of January, March, April and June and the dry month of August.

The results obtained for the CDD, CWD and NWD indices indicate a tendency for the dry months to become dryer and wet months to become wetter.

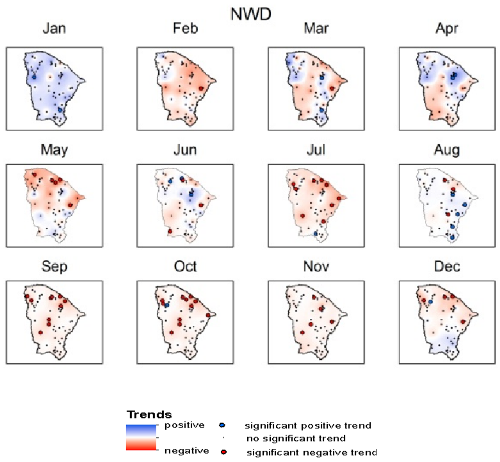

Fig. 7 - Monthly number of wet days trend

N_P75/90/95 - number of days with precipitation above the 75/90/95 percentile

January reveals an increasing trend for the number of days with precipitation above all the analysed percentiles (75/90/95). From February till May there is a decreasing tendency starting on the Ocean and east and north-east Sierra region of Ceará and rotating clockwise for Cariri, in April, and again to Ocean and western Sierra, in May. From June to December it was not noticed a clearly trend for NP75, NP90 and NP95.

The results indicate a general decreasing trend in precipitation intensity for the wetter months

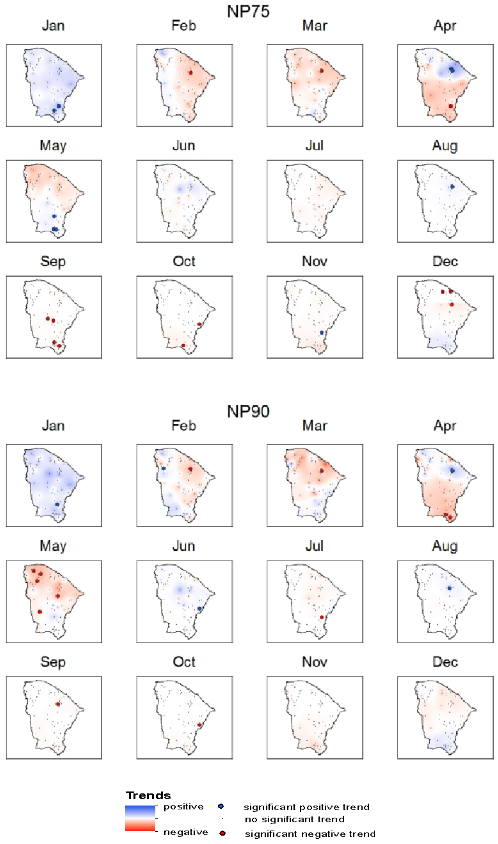

Fig. 8 - Monthly number of wet days trend for 75th/90th and 95th percentiles

Rx1day-monthly maximum 1-day precipitation

In general, an increase in the monthly maximum daily precipitation (Rx1day) trend was verified for the whole state of Ceará. This increasing trend is significant in the western Semi-arid and Cariri regions in February, by the Ocean and northern Sierra regions in April, June and August and in Cariri in May (Fig. 9).

In spite of this generalized increasing tendency, the study also reveals the occurrence of significant and local decreasing trends for Rx1day, namely for the northern Sierra region in February, September and October, for the Semi-arid region in April, September and October and for the eastern Sierra region in November.

These results suggest that extreme precipitation events revealed through Rx1day are increasing.

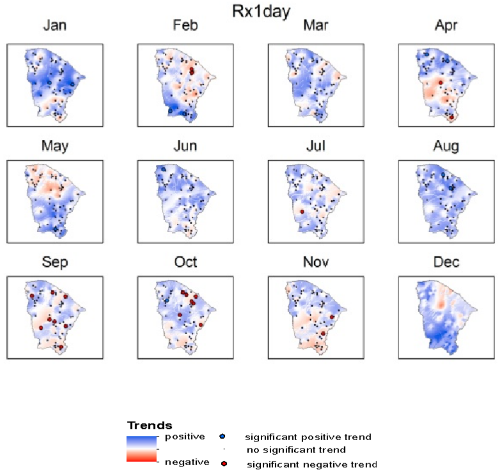

Fig. 9 - Monthly maximum daily precipitation trend

Rx5day - monthly maximum consecutive 5-day precipitation

The behaviour of this index is quite similar to that observed for the monthly maximum 1-day precipitation. This alikeness trend was somehow expected since the 5 consecutive days with maximum precipitation (Rx5day) probably contain the unique day with maximum precipitation (Rx1day).

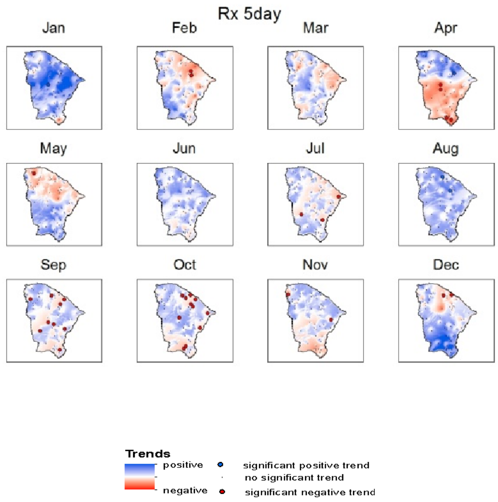

Fig. 10 - Monthly maximum 5 day precipitation trend

SDII (Simple daily intensity index)

In general it can be stated from the analysis that there is an increasing trend for the simple daily intensity index in the beginning of the wet period (December-January) and in the wet-dry transition period (May-August), while in the remaining months the opposite trend occurs (Fig. 11).

Nevertheless, exceptions appear, with local decreasing trends for stations located in the northern Sierra region, Cariri and western Semi-arid in May, June and July, respectively, and local increasing trends arising in stations located at south western Semi-arid, Semi-arid and northern Sierra and Ocean regions, respectively from February to April.

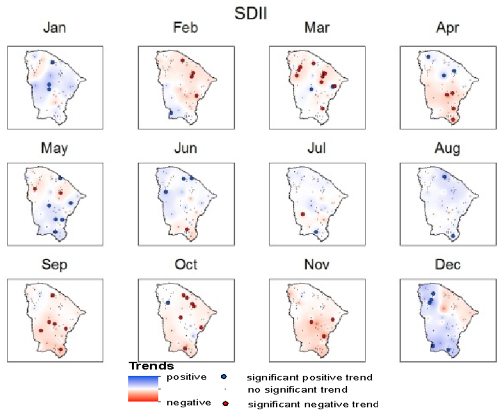

Fig. 11 - Monthly Simple Daily Intensity Index trend

4 CONCLUSIONS

This study reveals a change in the precipitation regime in the state of Ceará.

The results obtained for the dry and wet spells, and number of wet days indices, point to a tendency for the dry months to become dryer.

In general a decreasing trend in monthly precipitation was observed over almost all the state of Ceará, with a noticeable exception in January.

The driest months (September-November) show a decreasing trend in total precipitation followed by an increasing trend in dry spells and dry days with a consequent decrease in intensity. This may affect germination of some crops that are very important for economic development.

Extreme precipitation events revealed through Rx1day and Rx5day are generally increasing over the state of Ceará.

The spatially varied behaviour should be taken into account when managing water resources for urban and rural water supply, as well as dry and irrigated agriculture.

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