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Use of global reanalysis data in the study of the aridity index in the Magdalena-Cauca macro-basin, Colombia

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Abstract

The Magdalena-Cauca macro-basin (MCMB) in Colombia, by its tropical location, annually experiences the effects of movement of the Intertropical Convergence Zone, and it is highly affected by interannual macro-climatic phenomena, such as El Niño–Southern Oscillation (ENSO). With the aim of increasing the use of global reanalysis and remote sensing data for supporting water management decisions at the watershed scale and within the framework of the eartH2Observe research project, the aridity index (AI) was calculated with three different data sources. Precipitation products and AI results were compared with their corresponding in-situ national official data. The comparison shows high correlations between the AI derived from observed data and AI obtained from the reanalysis, with Pearson correlation coefficients above 0.8 for two of the products investigated. This shows the importance of using global reanalysis data in water availability studies on a regional scale for the MCMB and the potential of this information in others macrobasins in Colombia including the Orinoquia and Amazon regions, where in-situ data is scarce.

1 Introduction

Aridity is a feature of the region's climate, defined as a climatic phenomenon of long-term shortage of moisture (Maliva & Missimer, 2012). It is generally estimated using the annual mean evapotranspiration and runoff. When the potential evaporation rate is fairly low, then, for a given amount of precipitation, runoff is likely to exceed evapotranspiration (Arora, 2002), the opposite case results in the definition of aridity. Mapping aridity using indicators can guide intervening decisions in water management, as it is shown in several studies, such as the one on waterholes in Southern African areas by Dzinotizeia et al. (2017) or establishing economic value in irrigation, depending on soil moisture, by Rey et al. (2016).

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AI is used to support studies contributing to sustainable development, biodiversity and environmental conservation, and adaptation to climate change specially in developing countries. In Colombia, aridity is estimated as the water deficit in a period, or on the other hand, the exceedance (generally greater than 30 years), based on in-situ observations of precipitation, temperature, and radiation. Having a limited hydroclimatic monitoring network in some regions of the country, AI estimations that can support decision making processes are uncertain. In this sense, remote sensing and reanalysis data are regarded as one of the most appropriate approaches to evaluate aridity in sparsely instrumented areas.

Within the framework of the eartH2Observe research project (www.earth2observe.eu), AI estimations were obtained using three different global reanalysis datasets. To evaluate them, the region in Colombia with the best monitoring network was taken as a case of study, to have a strong base of comparison. This is the Magdalena-Cauca macro-basin (MCMB) with an area of about 257,000 km^2 (MADS, 2014) and about 1.4 climatological stations per 1000 km2, compared to other regions in the country (Amazon and Orinoquia), where there are less than 0.5 stations in the same area (MAVDT & IDEAM, 2011).

All this with the main purpose of increasing the use of global reanalysis and remote sensing data in regions poorly instrumented, as a potential input for hydrometeorological studies, planning and forecasting (Li et al., 2016).

2 Materials and methods

The MCMB is the most important basin in Colombia, drains about 25% of the total territory of Colombia, being the primary fluvial system in the country where almost 80% of Colombian population lives. Figure 1 depicts the general location of the MCMB, and its main channels, the Cauca River on the west and the Magdalena River on the east, both draining northwards to the Caribbean Sea.

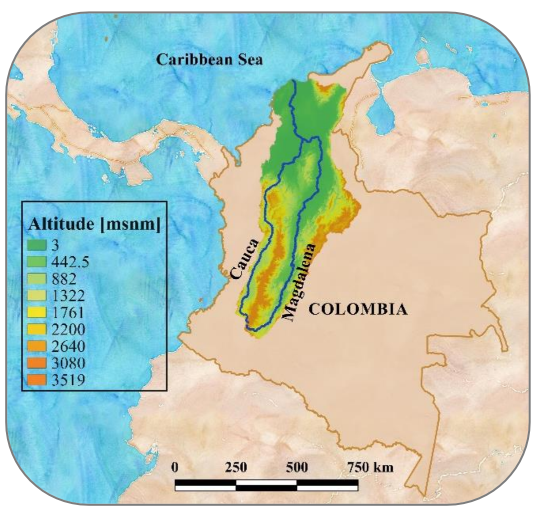

Figure 1 Location of the Magdalena-Cauca macro-basin

In the MCMB, the AI was initially calculated using the in-situ data provided by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM, for its acronym in Spanish), which currently operates around 2,670 meteorological stations in the watershed, of which 2,256 stations with precipitation data and 467 with maximum, minimum and average temperature data were used for the analysis. Daily time series for precipitation and temperature at the different sites were pre-processed; data gaps were not filled, and spatial interpolations were conducted using Kriging with External Drift (KED) for precipitation and Cokriging for air temperature.

Three reanalyses datasets, globally and freely available in the eartH2Observe project repository (https://wci.earth2observe.eu/) were used to derived AI:

1. Multisource Weighted-Ensemble Precipitation – MSWEP (Beck et al., 2017): It is a new fully global precipitation dataset with a high 3-hourly temporal and 0.25° spatial resolution. It was specifically designed for hydrological modelling, as a mixture of rainfall datasets, based on rain gauge, streamflow gauge, earth observations and reanalysis data
2. Watch Forcing Data Methodology applied to ERA Interim – WFDEI (Weedon et al., 2014): It is a meteorological forcing dataset for the 1979 – 2012 period, including eight meteorological variables at 3-hourly time steps, and daily averages. It was built on a 0.5° grid with the methodology of the WATCH project, which included simulating the global cycle of terrestrial water in the twentieth century through a series of hydrological models and corrected by comparison with other global models.
3. ERA Interim (v1) (Dee et al., 2011): This data set comes from the ERA-Interim, rescaled to a resolution of 0.25°.

A large number of aridity indices have been proposed in the literature; nevertheless, in Colombia the components of the aridity index equation are mainly potential evapotranspiration (PET) and actual evapotranspiration (AET), as expressed in equation [1] (IDEAM, 2010):

$$AI = \frac{PET - AET}{PET} \qquad [1]$$

In this study, daily values of potential and actual evapotranspiration were calculated based on the Hargreaves and Budyko formulations presented in equations [2] (Hargreaves, 1994) and [3] (Budyko, 1974), respectively:

$$PET = 0.0023\ RA\ (T°C + 17.8)\ \ (T_{max} - T_{min})^{0.5} \qquad [2]$$

In which RA: Extraterrestrial radiation in the same units of equivalent water evaporation (a function of latitude and month), T°C: average temperature in degrees Celsius, Tmax - Tmin: maximum and minimum temperature.

$$AET = \sqrt{PET\ P\ tan\,h\frac{P}{PET}\left[1 - cos\,h\frac{PET}{P} + sin\,h\frac{PET}{P}\right]} \qquad [3]$$

3 Results and discussion

As the goal of this study was to validate the use of global reanalysis data in aridity studies on a regional scale, the AI was calculated with the three evaluated datasets, resulting in the maps shown in Figure 2, where the AI, according to IDEAM (2014) is classified in seven categories: AI<0.15, High Water Surplus; 0.15<AI<0.19, Water Surplus; 0.20<AI<0.29, Moderate to Water Surplus; 0.30<AI<0.39, Moderate; 0.40<AI<0.49, Moderate to Water Deficit; 0.50<AI<0.59, Water Deficit and AI>0.60, High Water Deficit.

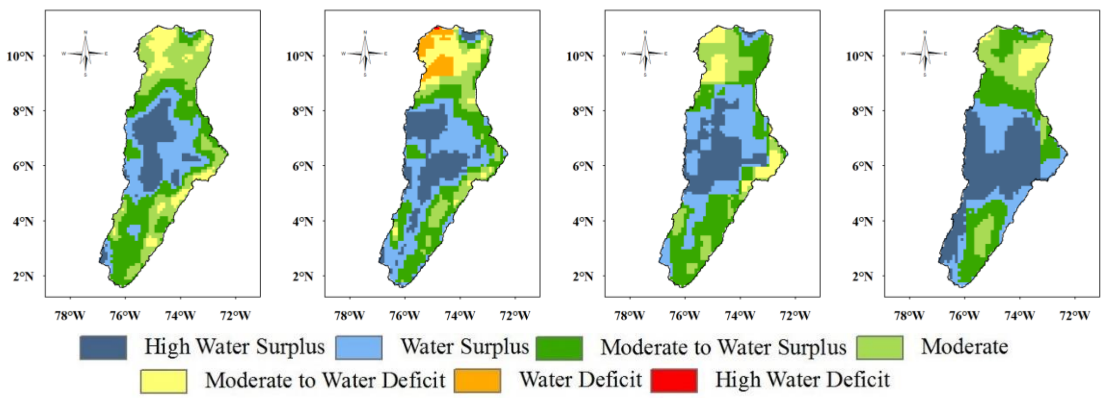

Figure 2 Aridity Index (AI) calculated using from left to right: a) In-situ [IDEAM] data b) MSWEP c) WFDEI d) ERA Interim V1

From the results derived using the in-situ information (Figure 2a), it is evident that there are no significant water deficits in the MCMB. 60% of the basin is between large, moderate and water surplus, corresponding to the central area of the MCMB, where the largest precipitation (around 3495 mm/yr) occurs. In the northern flat area of the MCMB, there are water deficits near the discharge of the Magdalena River, into the Caribbean Ocean. In this low area evapotranspiration is the largest and precipitation is below the average of the MCMB (around 2150 mm/yr).

The AI estimations made using the three-reanalysis evaluated, in general show a good identification of the different AI areas. To objectively contrast the results, the BIAS metric was evaluated, measuring in percentage, the differences between the in-situ AI results and the reanalysis. The Pearson correlation coefficient was also computed, as a measure of the linear correlation between the results, as shown in Figure 3.

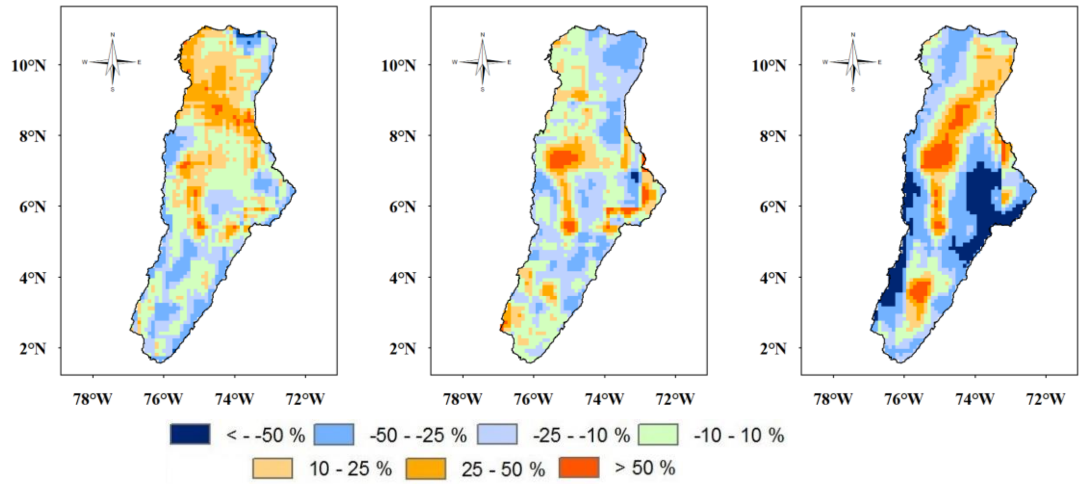

Figure 3 BIAS of AI from: a) MSWEP [ρ=0.86] b) WFDEI [ρ=0.83] c) ERA Interim V1 [ρ=0.63] (light colours show small variations - ρ is the Pearson correlation coefficient)

Results in Figure 3 show, for the WFDEI and ERA Interim V1 datasets, a general overestimation of the surplus on the Cauca River basin (west) and downstream the confluence with the Magdalena River. For these two products, in high mountain areas underestimations of the water availability are put on display, which increase specially towards the east and west boundaries of the basin (ranges of the Colombian Andes), and are maximum for the ERA Interim V1 dataset. The MSWEP product stands out in the comparison, since its mean BIAS is close to zero and it has the best correlation with the results from the in-situ data. Due to the problems highlighted above, BIAS and correlation coefficient are inferior for the WFDEI and ERA Interim V1 datasets.

The differences in the AI results are fully dependent on the inputs used, that is, precipitation (P) and potential evapotranspiration (PET). In order to better understand the AI results, a comparison of the P fields was conducted using in-situ interpolated data. No comparison for PET was developed, since the same in-situ database and formulations (Hargreaves and Budyko) were used throughout the analysis.

Precipitation from each of the three reanalyses investigated was compared with the interpolated baseline gridded field (Rodríguez, Werner, et al., 2017) and evaluated with the root-mean-square error (RMSE) and BIAS. Figure 4 shows the results of the RMSE (Rodríguez, Sánchez, et al., 2017), with average values similar for WFDEI and ERA Interim V1 datasets close to 90 mm per month, and on average around 50 mm per month for MSWEP. In the highlands and down the confluence between the Cauca and Magdalena Rivers, the WFDEI and ERA Interim V1 show the largest errors.

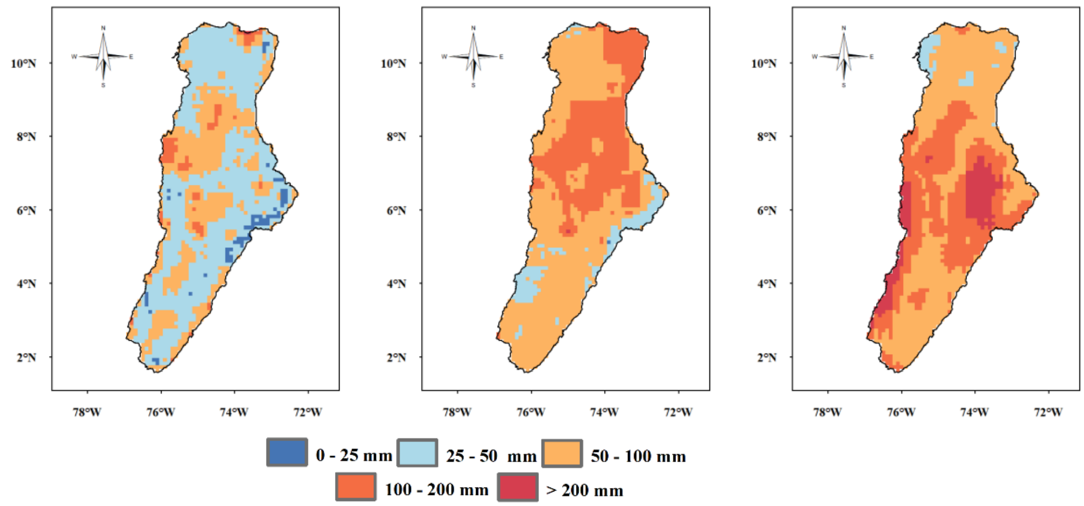

Figure 4 Monthly RMSE from precipitation products: a) MSWEP b) WFDEI c) ERA Interim V1 (blue colours show low RMSE, while orange and red colours show high RMSE values)

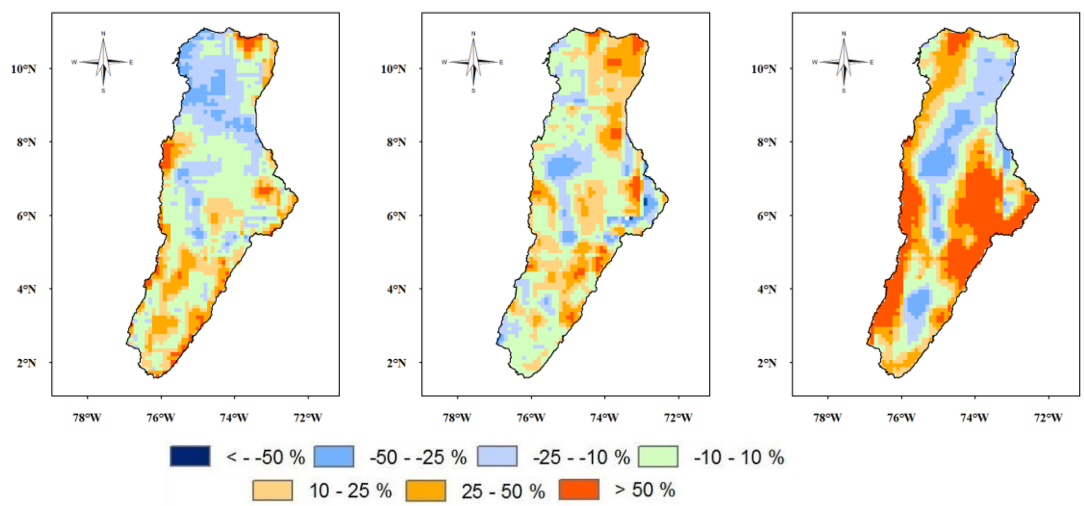

Figure 5 BIAS from precipitation products: a) MSWEP b) WFDEI c) ERA Interim V1 (light colours show small differences; dark colours show largest differences)

As expected, results of the BIAS of the precipitation products shown in Figure 5 unveil harmony and correspondence with the AI BIAS (Figure 3); i.e. where there is overestimation in the metric, there is a deficit of rain. It is important to note that the differences correspond mostly to underestimations of available water. This indicates that the reanalyses maintain in general the same trend as the observed precipitation field and have a great value for those cases in which local data are scarce or unavailable. It is also clear that to make more usable data from reanalysis, correction in BIAS for precipitation is needed using in-situ benchmarking fields.

4 Conclusions

Several aridity index (AI) estimations were made from three global reanalyses datasets, and comparisons between them were performed, using the in-situ official information and those obtained from the reanalysis. Finding that global datasets, such as the ones here investigated, are suitable for the study of water availability in the MCMB and its results are in general consistent with the in-situ derived index, proving to be useful for AI assessments.

Results of this study show that the reanalysis that considers the Multisource Weighted-Ensemble Precipitation – MSWEP is the one which better represents aridity conditions in the MCMB, although downstream, near the basin outlet, is the WFDEI dataset the one with the lowest BIAS. It is in the high-altitude areas of the MCMB where precipitation from the reanalysis has, the lowest predictive capacity, probably because these are the areas with the more complex terrain and the lowest number of gauge stations.

On the other hand, use different global reanalysis involves variability of the input data, so an analysis of it must be done. In this study we evaluate the error of the precipitation data, showing that the errors found in the AI calculations are congruent and proportional to the meteorological differences. To minimize them an ensemble of the reanalysis or a specific downscaling process could provide better results.

The AI is a measure of water availability, for supporting long-term water resources decisions in the MCMB in Colombia, and contributions of the reanalysis are not only on reproducing reasonably well the AI derived from in-situ data, but also on producing a consistent gridded map of the AI for the whole MCMB and are promising for deriving other water availability indices in other macro-basins in Colombia (as Amazon and Orinoquia), where data is limited.

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