Development of a plugin for spatial downscaling satellite precipitation data for groundwater models and its application on semi-arid zones

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RESUMO

O uso de dados de precipitação estimados por sensoriamento remoto são uma poderosa ferramenta na gestão de recursos hídricos. O satélite TRMM (Tropical Rainfall Measumement Mission) por exemplo permite estimar a precipitação diária desde 1997 em escala global. Contudo, a baixa resolução espacial destes produtos (~27km) os tornam pouco utilizados em estudos de detalhe como em minas e áreas industriais. Diversos estudos apresentam soluções para realizar o downscaling (redução de escala) destes produtos para torná-los compatíveis com tais estudos. Contudo são tipicamente soluções customizadas, que não são disponibilizadas como uma ferramenta de fácil manuseio para outros usuários. O NETCDF Toolbox é um novo *plug-in* com uma interface amigável para fazer os processos de redução de escala (*downscaling*) de dados de precipitação dentro da suíte ArcGIS. A ferramenta foi desenvolvida em *Python* e é compatível com modelos de regressão linear e não linear. É também apresentado um procedimento para ser usado em conjunto com o *plug-in* para extração, análise, e correlação dos dados de precipitação TRMM com estações pluviométricas. O *plug-in* foi testado em duas regiões semi-áridas, localizadas no México e no Peru. Em ambas as áreas haviam poucos pontos de medição e também falhas nas séries temporais. O NETCDF Toolbox foi capaz de executar o procedimento de redução de escala de precipitação de forma satisfatória. As variáveis utilizadas com dados de alta resolução para o modelo de regressão foram o Modelo Digital de Elevação e o Índice de Vegetação Normalizada (NDVI). A validação cruzada com os dados reais apresentou valores de r^2 superiores a 0.86, mostrando boa relação entre as variáveis. Ambos os tipos de modelo de correlação foram executados, alcançando resoluções de 30m em uma das áreas e de 1km para a outra.

PALAVRAS-CHAVE: PRECIPITATION DOWNSCALING, TRMM, NUMERICAL MODELS

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ABSTRACT

A plug-in for ArcMap® was developed to generate precipitation raster data with higher grid resolution. Based on correlation between precipitation data from Tropical Rainfall Measuring Mission (TRMM) satellite and Digital Elevation Model (DEM) data. The procedure and the resulting tool proved to be capable to execute the downscaling and generate outputs to assess the uncertainty of the methodology. The tool was tested in two semi-arid zones in Mexico and Peru, both regions with scarce precipitation data. The Regression function shows a r^2: 0.86 for the DEM variable and r^2: 0.56 for NDVI. The cross-validation with the land gauges shows r^2 from 0.86 to 0.91.

1- INTRODUCTION

The Tropical Rainfall Measuring Mission (TRMM) satellite mission has been providing daily precipitation measures since 1997. For some groundwater modelling projects its spatial resolution (27km x 27km) may not be enough, especially in small areas of interest such as mining or industrial sites. Different studies around the world have mentioned that precipitation is closely related to other geographic factors like vegetation and local terrain (Badas et al., 2005, Immerzeel et al. (2009), Shi and Song (2015), Ulloa et al. (2017)). As the resolution of these factors is relatively higher, the spatial resolution of precipitation can be greatly improved by establishing a statistical relationship between precipitation and these factors by performing a spatial downscaling methodology.

2- OBJECTIVES

The main objective of this work is the development of a practical and user-friendly tool and procedure for downscaling remote sensing precipitation data and to generate synthetic gauges for hydrogeological studies (i.e. Numerical modelling, water balances).

3- METHODS

For the software programming, the environment used was Python Integrated Development Program (IDLE). The main principle of the statistical spatial downscaling method is based on the relationships between precipitation and various land surface environmental variables (Badas et al., 2005; The Onema & Taigbenu 2009). The corresponding statistical model, which is established at a coarse resolution, is applied to high-resolution variables of the land surface environment to downscale the precipitation data. At the present, the main environmental variables selected for downscaling models is the normalized difference vegetation index (NDVI) or a digital elevation model (DEM). This relationship have been tested by many linear and nonlinear regression models (Jing et al., 2016).

4- RESULTS

There were 3 scripts developed to perform the Downscaling Methodology: **1) Extract Values from NetCDF:** This tool can extract the centroid value from the precipitation original, non-downscaled, resolution dataset (.CDF file) and merge them into one time-series table; **2) Raster Zonal Upscale:** This tool resample the high resolution data (DEM, NDVI) using different statistical indexes (mean, mode, median, max, min, geometric mean) using an specific zone feature; **3) Raster Point Extraction**: This tool is capable to convert a set of multi-temporal raster into a simple time-series in .csv format, with the descriptive statistics for a zonal or point location.

4.2 Performing the Downscaling procedure

This process uses the correlation function between the NetCDF file (TRMM data) and other raster data (NDVI, DEM, Wetness) to generate a better precipitation data based on this correlation. 1) First, the tool Extract values from NetCDF and generates the time series of all the pixels of the precipitation raster. This step is crucial for the statistical analysis and the filtering processes of the precipitation raw data; 2) Use the tool Raster Zonal Upscale to match the high-resolution raster (DEM, NDVI) to the same resolution of the coarse precipitation data; 3) From the tool called Upscaling Raster Centroid and Upscaling Raster Zonal, it is generated the excel table with the pixel value for the same spatial location of the TRMM pixels. This step will normalize the variability of the high-resolution raster and will give the descriptive statistics that will allow the correlation. It is necessary to build a excel table with the NDVI/DEM pixel values (resulted from the upscaled Tool) and precipitation value (resulted from the toll Extract values from NetCDF). The correlation can be accessed in a simply excel sheet, or in a more robust data analysis software to find the best regression function. After the regression function between NDVI and precipitation data is found, the next step is to apply this function using the Raster Calculator tool inside ArcGIS.

4.3-Validation

To evaluate the reliability of the tool two areas were selected to validate the method. Area 1 is in Province of Arequipa, Southern Peru (Figure 1). The region is characterized by desertic vegetation with altitudes varying from sea-level to 4,400m. The area is a suitable scenario to analyze the influence of topography on precipitation as the average rainfall varies from 150mm to 450mm at the highest portions. It was used the DEM to correlate the precipitation, with r^2: 0.86. The correlation with the land gauges reaches Pearson's r^2: 0.82 - 0.98 for monthly averages. The original dataset was downscaled to a 1kmx1km raster.

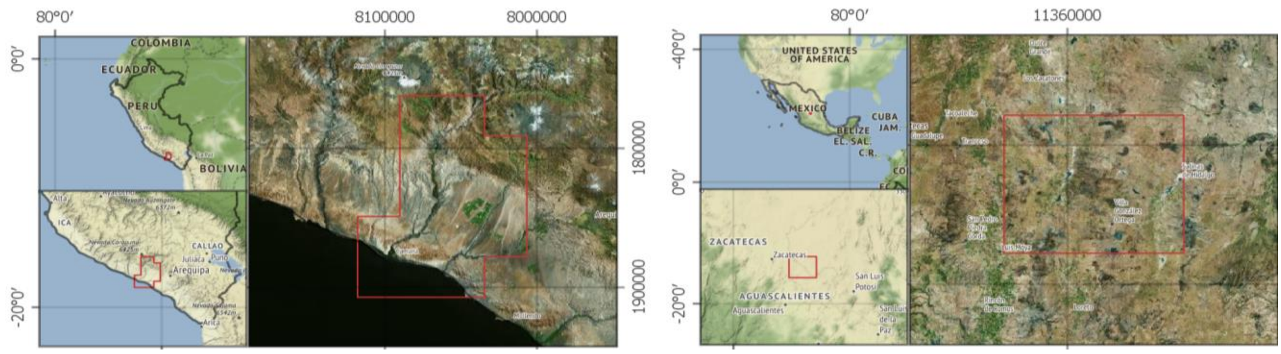

Figure 1 Location of the areas used to test the Downscaling tool; A- Area 1 is located at Southern Peru; B- Area 2 is located at Southeast of Zacatecas, Mexico

Area 2 is in the Southeast region of Zacatecas state, Mexico (Figure 1). The climate is arid to semi-arid. Average annual precipitation is approximately 500 mm, of which 80% occurs from June through September. The climate is semi-arid at the site and arid to desert at northeast. Precipitation data from TRMM were first validated against the two gauge data available from CONAGUA. The validation used the period of 2001 to 2014.

The regression function with the NDVI shows a low relationship (r^2: 0.56) with an inverse correlation. Although the cross-validation shows a r^2: 0.90 and 0.91 for the monthly averages with the gauges within the site. The original dataset was downscaled to a 30mx30m raster. In both correlations, outlier data (less than 5% of the sample population) were removed.

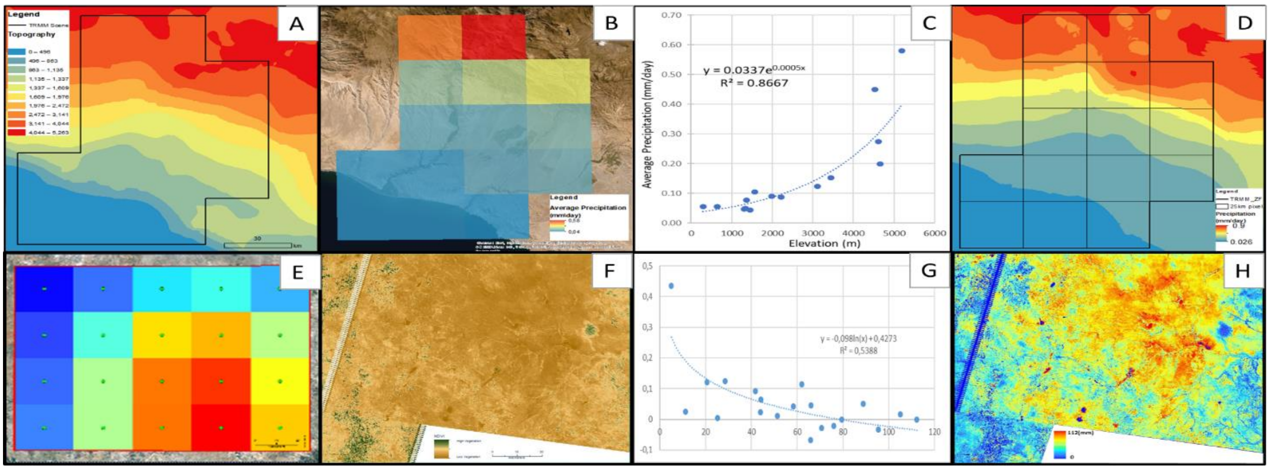

Figure 2 Downscaling steps for Area 1 (A-D) and Area 2 (E-H); A- High Resolution DEM; B- TRMM Precipitation Dataset (27.8km); C- Regression model DEM-Precipitation; D- 1km Downscaled Precipitation; E- TRMM Dataset; F- NDVI; G- Regression Model NDVI-Precipitation; F-Final 30m Downscaled Precipitation.

5- CONCLUSION

NETCDF Toolbox is a new plugin with a user-friendly interface to make the downscaling processes of remote sensing precipitation data. This software consists of a new GIS-based semi-automated procedure, which was mostly developed in Python and is flexible to any linear and nonlinear regression model of downscaling. The plugin was tested in two arid and semi-arid lands with scarce direct measurements and was shown to be capable of performing the downscaling procedure with satisfactory results.

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