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A GIS for Regional Assessment of the Climate Change Impacts on Crop Irrigation Requirements.

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ABSTRACT

To perform climate change impacts studies on the crop irrigation requirements is necessary to use climate change scenarios data produced by regional climate models, which are distributed in space and have long data series (e.g. 30 years) relative to several climatic variables. It is also necessary to take into account observed meteorological data recorded in weather stations networks, to characterize the baseline scenario and to correct the bias of the climate models data. Thus, to handle large amounts of spatial distributed data it is necessary to create a geospatial database to properly manage such volumes of data. For this purpose, georeferenced data relative to soils, crops and climate (observed climate data from weather stations and climate change scenarios) must be integrated into a GIS database.

On this study a GIS application, namely GISClimReg, was developed in order to: i) perform spatial analysis on climate change scenarios data; ii) produce automatically digital maps of the most relevant climatic variables; iii) integrate the irrigation simulation models with the GIS database allowing the quantification of crop water requirements at a regional scale. The regional climate models considered on this study were: the HadRM3P (scenarios A2 and B2) with a spatial resolution of 50 km, the HIRHAMh (scenario A2) with a resolution of 25 km and the HIRHAMhh (scenario A2) with a spatial resolution of 12 km. The climate models data correspond to the 2071-2100 period and were obtained from the PRUDENCE project. These data sets were complemented with observed meteorological information from SAGRA weather stations network, located in the Alentejo region (south of Portugal).

GISClimReg is able to operate over several files containing meteorological data (including the RCM models output and the weather stations data) and to automate spatial interpolation of meteorological variables. Interpolated grids resulting from that interpolation can be converted into a regularly spaced grid of 10 km resolution, creating a kind of virtual meteorological network, were the soil water balance model can run to

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calculate the crop water requirements for the several climate change scenarios considered. As a result, the crop water requirements maps produced for the study region enable the assessment of the climate change impacts over the crop irrigation requirements at a regional level.

Keywords: GIS, Irrigation requirements, Simulation models, Climate change, Spatial analysis, Portugal.

1. INTRODUCTION

Assessment studies relative to the impacts of climate change on irrigated agriculture usually require long time series (e.g. 30 years) of several meteorological variables. These data series are relative to data from climate models, to assess future climate change conditions, and data from weather stations, to characterize the current situation. The climatic data produced by the regional climatic models (RCM) is spatially distributed, presenting grids with a typical spatial resolution of 50 km. RCM data generally have considerable deviations in relation to the meteorological data observed in weather stations for the same time periods. Thus, it is generally advisable to perform the bias correction of the climate change scenarios data through the calculation of the correction factors between the RCM simulated data for the control period and the observed data. There are several methods available for the correction of the RCM data series bias which can be highlighted the delta change method used in this work (Graham et al., 2007; Lenderink, 2007). Due to large volume of meteorological data it is necessary to have georeferenced databases and a GIS application to manage all these meteorological data series quickly and efficiently, performing automatically the correction of the RCM climatic data deviations.

In the scope of irrigation studies have been developed several GIS applications with the aim of assessing crop irrigation requirements at the regional level or to allow the management of water resources (Carreira, 1997; Döll, 2002; Fortes et al., 2005; Todorovic and Steduto, 2003). In these studies it is usually used a soil water balance model, which runs in a GIS environment, using a vector approach(Carreira, 1997; Fortes et al., 2005), where were defined a set of homogeneous polygons in which the simulations were performed, or using grids of data relative to climate, soil and crops (Döll, 2002; Todorovic and Steduto, 2003). Recently Todorovic et al. (2013) calculated reference evapotranspiration (ET_o) to the Mediterranean basin, through the use of the weather stations of the CLIMWAT 2.0 database (FAO, 2013), producing raster maps of the crop water requirements.
The goals of this study were:

i. To create a geospatial database to properly manage the large amounts of spatial distributed data necessary to perform a climate change impacts assessment over the irrigated agriculture. For this purpose, georeferenced data relative to soils and climate (observed climate data from weather stations and climate change scenarios) were integrated into a GIS database;

ii. To develop a GIS application, with a user friendly interface, to: i) manage climate change scenarios data series automatically; ii) perform spatial analysis of the data stored in the GIS database; iii) to produce final maps of the main agrometeorological variables relevant for the irrigation purposes.

iii. To develop a platform to integrate the irrigation simulation models with the GIS database in order to quantify the crop water requirements on a regional scale.

The database developed in this work concerns the Alentejo region, South of Portugal, allowing the assessment of the impacts of climate change on crop water requirements, for a region highly threatened by climate change (Miranda et al., 2006; Mourato, 2009).

2 GIS Database and the GISClimReg application

2.1 Climate GIS Database

This work started with the construction of a GIS database, concerning the georeferenced climate data. For this purpose we used the ArcGIS tools from ESRI®. Climate data comprise both observed climate data from weather stations and climate change scenarios produced by the RCM models. The RCM considered in this work were: HadRM3P (scenarios A2 and B2) with a spatial resolution of 50 km, HIRHAMh (scenario A2) with a resolution of 25 km and HIRHAMhh (scenario A2) with a spatial resolution of 12 km. The A2 and B2 scenario refers to the SRES emissions scenarios defined by Nakicenovic et al. (2000). The climate models data are relative to the 2071-2100 period, with a monthly time step, and were obtained from the PRUDENCE project (Christensen, 2005). The observed meteorological data was obtained through the SAGRA weather stations network, located in the Alentejo region in Portugal (COTR, 2013). The climate variables considered were all the necessary to compute reference evapotranpiration (ET_o) using the FAO Penman-Monteith method (Allen et al., 1998) which are: solar radiation (R_s) [$MJm^{-2}day^{-1}$], maximum air temperature (T_{max}) [ºC], minimum air temperature (T_{min}) [ºC], maximum relative humidity (HR_{max}) [%], minimum relative humidity (RH_{min}) [%], average wind speed at 2m height (U_2) [ms^{-1}]. Precipitation was also considered [$mm.day^{-1}$] to perform the soil water balance.

The first step consisted on the rearrangement of the files provided by the RCM models, which had different spatial resolutions. The information provided by those models was adequately organized in a simple ascii text files. To create this new database automatically, a VBA application was developed in order to read the RCM output files and to create new files in the GIS database with a common structure for all the RCM models. Figure 1 shows the structure of the database created in a tree representation and as can be seen the original grids of the RCM models are maintained:

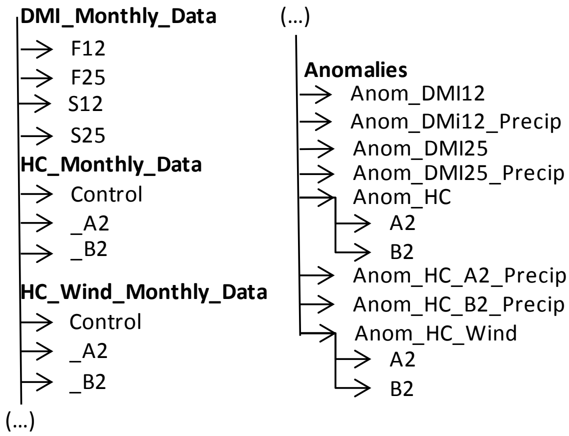

Figure 1. Representation of the GIS database tree structure.

2.2 GISClimReg Application

The GISClimREg application was developed through VBA programming language on ArcGIS. This application is able to perform spatial analysis of the RCM data and to produce automatically raster maps, generated by the spatial interpolation of the RCM grid data. GISClimREg retrieves information from the GIS database, relative to the different models grids allowing data analysis according to the parameters selected by the user (e.g. climate variable, temporal period, months, interpolation method, statistical operation, correction factor, etc.). Based on these parameters it is produced an intermediate file which is later spatial interpolated by kriging or inverse distance weighting (IDW) methods (Fig. 2). Using GISClimREg, the user can also clip the resultant interpolated surfaces using the desirable geographic limits (e.g. the administrative boundaries) (Fig. 3).

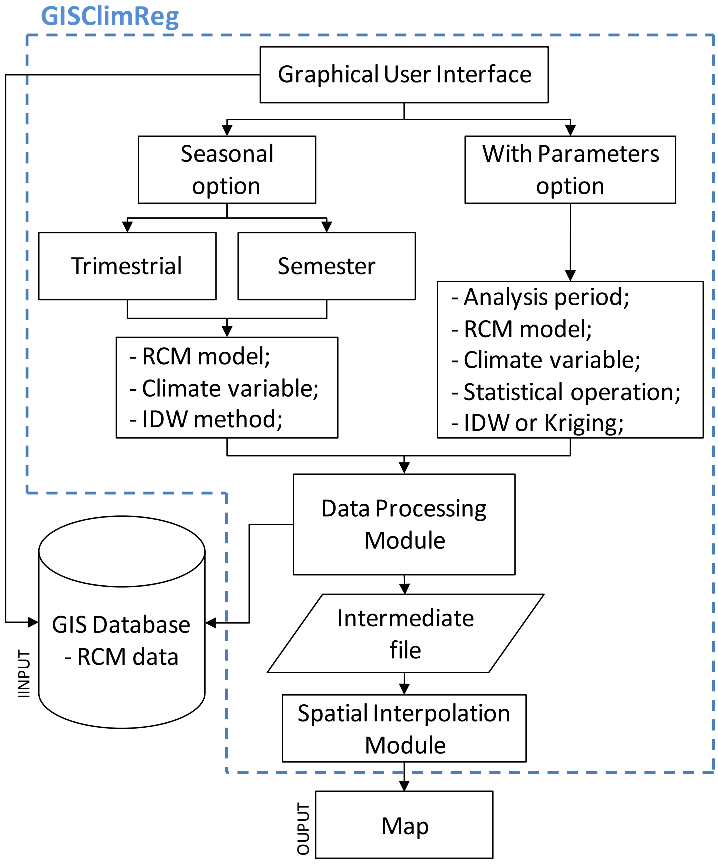

Figure 2. Flowchart of the GISClimReg application.

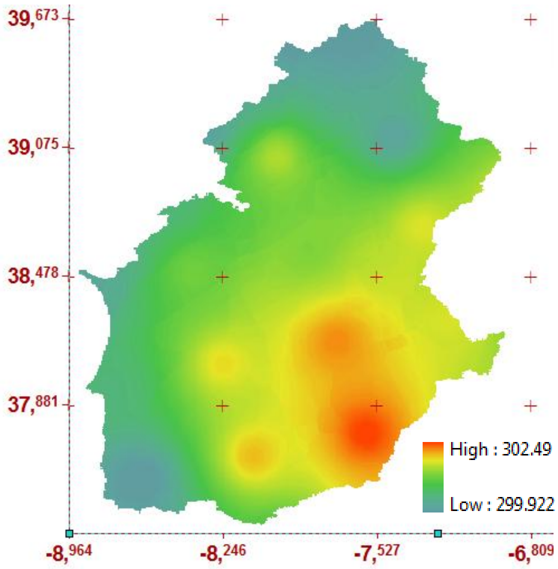

Figure 3. Maximum Temperature (K) map for the Alentejo region produced by the GISClimReg application.

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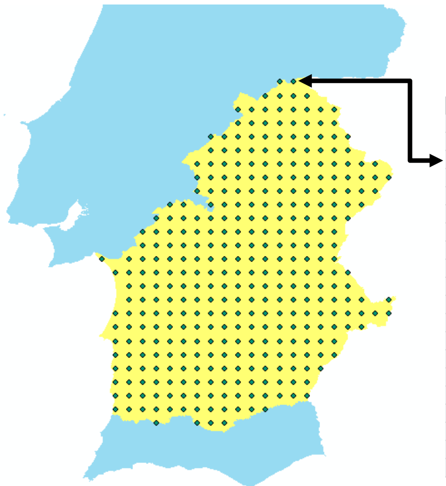
2.3 Models Plataform

In order to run the soil water balance simulation model, a new 10km resolution grid was created to produce a regular grid points simulating a virtual weather station network. This grid stores the information concerning to soils and to climate information. The meteorological data files, including the climate change scenarios and the observed data from the SAGRA network (COTR, 2013) were interpolated to this new grid using the Interpolator software (Rolim et al., 2011). To associate soil data to each point of the new grid (Fig. 4) was extracted the soil type from the soils map produced by the *Instituto De Desenvolvimento Rural e Hidráulica do Ministério da Agricultura, Desenvolvimento Rural e Pescas* (IDRHa, 1999).



	A	B	C	D	E	F	G	H
1	OID_1	NAME	LONG	LAT	COD1	COD2	COD3	CONCELHO
2	0	Ponto_001	-7,70213	39,6318	Ex	Arx		NISA
3	1	Ponto_002	-7,61223	39,6318	Ex	Arx		NISA
4	2	Ponto_003	-7,79203	39,5419	null	null	null	N/D
5	3	Ponto_004	-7,70213	39,5419	Ex			NISA
6	4	Ponto_005	-7,61223	39,5419	Ex	Arx		NISA
7	5	Ponto_006	-7,52233	39,5419	Px	Ca		NISA
8	6	Ponto_007	-7,97183	39,452	null	null	null	N/D
9	7	Ponto_008	-7,88193	39,452	Px	Pxr	Px(d)	GAVIAO
10	8	Ponto_009	-7,79203	39,452	Ppt(p)	Ppr(p)	Par(p)	NISA
11	9	Ponto_010	-7,70213	39,452	Pg			NISA
12	10	Ponto_011	-7,61223	39,452	Pg(d)	Arg		NISA
13	11	Ponto_012	-7,52233	39,452	Pg(d)	Arg		CASTELO DE VIDE
14	12	Ponto_013	-7,43243	39,452	Arg			CASTELO DE VIDE
15	13	Ponto_014	-7,34253	39,452	Arg			MARVAO
16	14	Ponto_015	-7,97183	39,3621	null	null	null	N/D
17	15	Ponto_016	-7,88193	39,3621	Ppt(p)	Ppr(p)		GAVIAO
18	16	Ponto_017	-7,79203	39,3621	Pg(d)	Pdg(p)		CRATO
19	17	Ponto_018	-7,70213	39,3621	Pg(d)	Pg		CRATO
20	18	Ponto_019	-7,61223	39,3621	Pg(d)	Arg		CRATO

Figure 4. Soil data associated to each point of the 10 km grid.

Currently is being made the integration of a simplified soil water balance model in the GISClimReg application to calculate crop water requirements based on the 10km grid data. This model reads the climate and soil data files associated to each grid point and compute the crop water requirements, saving the results in an output file associated to that point.

3 CONCLUSIONS

On this study was developed a GIS database to store and manage the large amounts of climatic data concerning the climate change scenarios.
It was created the application GISClimReg in VBA, using ArcGIS, composed by a calculation module to perform the spatial analysis of meteorological variables stored in the GIS database, and a graphical user interface that allows the selection of the meteorological variable and of several parameters. The GISClimReg produces as final result a map of the meteorological variable under study.

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The GIS platform to run the soil water balance simulation model is under development, having been built a grid with a 10 km spatial resolution covering the entire region of the Alentejo. At each point of this grid is assigned a fictitious weather station, which contains the future meteorological data series interpolated for that point. Each grid point is also associated with the predominant soil and its main characteristics.
The simplified soil water balance model will operate on this grid, and is currently being integrated in the GISClimReg application. In the future this simplified soil water balance will be replaced by the IrrigRotation model (Rolim and Teixeira, 2008), that allows to compute the irrigation requirements of one given crops rotation. As further developments can be pointed the development of a WEBGIS interface that will make available the maps concerning the main results obtained with the assessment of the crops irrigation requirements for the climate change scenarios.
It is also possible to predict that the conceptual framework of this GIS is likely to be adopted in other agronomic or environmental studies that need to process a large volume of spatially distributed time series.

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