CHARACTERIZING BRAZILIAN CLIMATE ZONES FOR UP-SCALING THE SIMULATED CROP YIELD POTENTIAL

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ABSTRACT: Crop models are written as sets of different equations which are solved numerically. They require time series of local environmental drivers like weather conditions and constant parameters that determine sensitivity of processes to both crop state and environment. There is a hamper on the model upscaling from point to region, and the quantification of model output uncertainity at the regional scale. This paper aimed to perform a conceptual analysis of the Brazilian climate zones based on long-term uniform weather data series (air temperature, soil water deficit, rainfall and global solar radiation), were each climatic variable were spatially organized and the maps for each one were generated by a kriging interpolation. The proposed zonation seems coherent with the agroecologycal conditions observed around Brazil, and based on the biomes, there is an agreement with the main Brazilian potential vegetation types and even with the cropping systems spatial distributions. The final map might be used for "bottom-up" upscaling approach in order to extrapolate the location specific data to a broader scale. Further work should focus in the inclusion of soil data to reach a robust zone map to support crop model outputs up-scaling, as well as in the zones validation.

KEYWORDS: modelling, agrometeorology, interpolation

RESUMO: Modelos de crescimento de plantas são constituídos por um conjunto de algoritmos resolvidos numericamente. Necessitam de séries temporais de fatores ambientais locais como dados climáticos e parâmetros que determinam a sensibilidade dos processos referentes ao estado das culturas e ao ambiente. Existe uma dificuldade para a passagem de escala de resultados de simulação dos modelos do ponto para a região, bem como na quantificação da incerteza nos dados de saída em escala regional. Este trabalho teve como objetivo realizar uma análise conceitual das zonas climáticas brasileiras baseadas em uma longa série de dados climáticos uniformes (temperatura do ar, déficit hídrico, chuva e radiação solar global), cuidando para que cada variável climática fosse organizada espacialmente em um mapa gerado por krigagem ordinária. As zonas propostas parecem coerentes com as condições agroecológicas e nos biomas observados no Brasil, demonstrando concordância com os principais tipos de vegetação potenciais brasileiros e até mesmo com a distribuição

espacial dos sistemas de cultivo. O mapa final pode ser utilizado para uma abordagem de escalonamento ponto-região, com a finalidade de extrapolar os dados específicos locais para uma escala mais ampla. Trabalhos futuros devem ser concentrados na inclusão de dados de solos para chegar a um conjunto de zonas mais robusto para apoiar os resultados de extrapolação dos modelos de culturas, bem como na validação das zonas.

PALAVRAS-CHAVE: modelagem, agrometeorologia, interpolação

INTRODUCTION

Dynamic simulation models can increase research efficiency by allowing the analyst to search for strategies and analyze system performance, improve risk management, and interpret field experiments that deal with crop responses to soil, management, genetic or environmental factors (Keating et al. 1999). Crop models tend to be complex and highly nonlinear. They are written as sets of differential equations which are solved numerically. Crop models focus on the representation of crop growth and production and geographically they operate at point-support. The models require two types of input: (1) time series of local environmental drivers like weather conditions, (2) constant parameters that determine sensitivity of processes to both crop state and the environment. The primary outputs of the models are time series of the state variables and process rates (Van Oijen et al., 2009). For crop modelers, upscaling within the soil–plant–atmosphere continuum involves a cascade or transport of knowledge between regimes of increasing spatial scale (Anderson et al., 2003). This is important because an useful application of crop models are the possibility of extrapolation of field experiments for large areas, enhancing the understanding on the cropping systems and crop responses to different management strategies, for instance. To do so, it is always important to represent the model output at other scales which are not always transportable between scales. Computationally, the models tend to be demanding. Statistically, the models tend to be characterized by uncertainty in both inputs and model structure (Van Oijen et al., 2009). These characteristics hamper model upscaling from point to region, and in particular the quantification of model output uncertainty at the regional scale. The objective of this paper is to perform a conceptual analysis of the zonation schemes already published and which would be applicable for upscaling procedures, and propose a zonation climatic for up-scaling location-specific crop model simulated state variables at national levels.

MATERIAL AND METHODS

Key variables used for the climatic zoning

Climatic zones were based on long-term uninform (10-30 years) weather data series from stations of the following sources: Instituto Nacional de Meteorologia–INMET , Sistema de Monitoramento Agrometeorológico–Agritempo, Agência National de Águas–ANA, Empresa Brasileira de Pesquisa Agropecuária–Embrapa, Universidade de São Paulo/ESALQ–USP, and Universidade de Campinas–CEPAGRI/UNICAMP. We finished up with 3458 weather stations distributed throughout the country (Figure 1a). These data were finally organized in a database containing monthly averages of the following variables: solar radiation (MJ m^{-2} d^{-1}), minimum and maximum air temperatures (^{o}C), rainfall (mm $month^{-1}$).

Data preparation

For the data from ANA, air temperature and solar radiation were not available. For these, monthly air temperature was estimated from equation based on geographical coordinates and altitude developed for Brazil by (Marin et al., 2003) and SRTM (Farr et al., 2007) elevation data (90m resolution) (Fig 1b). Following (Marin et al., 2012), estimated monthly air temperature were them used for solar radiation estimating using the (Bristow and Campbell, 1984) method previously calibrated using A=0.7812, B=0.00515, and C=2.2 as model parameters.

These data were used to calculate the water balance (Thorthwaite and Mather, 1955) and the total annual soil moisture deficit was used as input variable for identifying the climatic zones. To do so, we assumed soil available water capacity of 1 mm cm^{-1} and a soil water depth of 1 m. Reference evapotranspiration (ETo) were estimated following (Camargo et al., 1999) which agreed with standardized Penman-Monteith method (Allen et al., 1998) for Brazilian weather conditions.

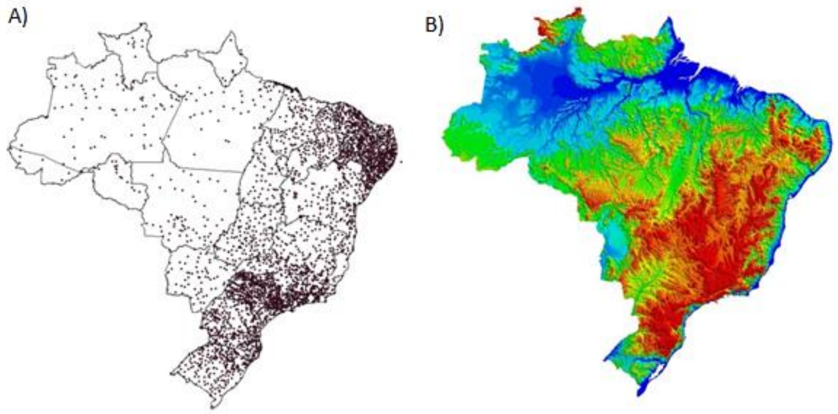

Figure 1. Weather station spatial distribution (A) around the country and the SRTM elevation data used for mean air temperature up-scaling.

Mapping procedures

The data of each climatic variable were spatially organized and the maps for each one were generated by kriging interpolation. For each variable, the class limits definitions were made according Table 1 in order to identify the different climate zones occurring around the country, rather than to identify the climate constraints for the crop as a common practice in agroclimatic zoning). Maps of each variable were created and crossed with the others producing a final map with hundreds of classes and thousands of polygons. Simplification of the information, following (Schuster et al., 2009), was an iterative process with the goal of producing 1:1000.000-scale data that is easy to read everywhere on the map. In three iterations the number of map units was decreased to 31. The original labels for units that were to be lumped were changed to the new label, and then a dissolve was performed on the polygons to create one polygon. Some remaining areas were too complex and not clearly legible, so additional small polygons were deleted unless they were important for defining the extent of a map unit. Small polygons in close proximity to each other were manually combined into larger polygons, which involved snapping arcs together to make the outline of the new polygon, building the coverage, running a label error check, and deleting any extra labels.

Table 1: Climatic variables and respective ranges defined after kriging interpolation

Mean air temperature (ºC)	Annual soil water deficit (mm)	Annual rainfall (mm)	Annual mean global solar radiation (MJ m^{-2} d^{-1})
<13	0 - 150	400 - 800	21.6 - 23.2
13 - 15	150 - 300	800 - 1200	23.2 - 24.8
15 - 17	300 - 450	1200 - 1600	24.8 - 26.4
17 - 19	450 - 600	1600 - 2000	26.4 - 28
19 - 21	600 - 750	2000 - 2400	28 - 29.6
21 - 23	750 - 900	2400 - 2800	
23 - 25	900 - 1050	2800 - 3200	
25 - 27	1050 - 1275	3200 - 3600	
> 27			

RESULTS AND DISCUSSION

Van Oijen et al. (2009) reviewed the scale changes procedures available in the literature and summarized it in seven main methods. One of the most important strategy pointed out by them is the stratification into homogeneous subregions and extrapolation the point simulations. This is the approach on which zonation schemes should be include. Zonation schemes, however, vary widely in defining the size and boundaries with similar climate. (van Wart et al., 2013) founded five main schemes around world for mapping scales equal or smaller than 1:5.000.000. They analyzed each one and ended up concluding the question of choosing the best one is a question of balance the need for comprehensive description of the spatial variation of climates over diverse regions and the need to avoid excessive complexity with large number of difficult to measure input variables. The proposed climatic zonation here proposed is an attempt to keep compromised with this balance by using simple climatic data and reach a final map covering all Brazil in a reasonable spatial scale, and delimitating the most important climatic difference throughout the country.

The proposed zonation seems coherent with the agroecologycal conditions observed around Brazil. We concluded this based on the biomes since there is an agreement with the main Brazilian potential vegetation types and even with the cropping systems spatial distributions. For instance, it is possible to identify the Cerrado biome looking to the zones 13 to 14 and 34-36. We were also able to identify the Coastal Tablelands in zones 15 to 16 and 1-2. Pantanal biome can be identified in zones 3 to 5.

However, some zone classes showed up repeated in different regions of the country were found and this seems to be a result of the iterative process to reduce the number of polygons after the first map crossing. Despite the incoherence of this repetition in terms of climate conditions, we recommend the use of the map in the current version inside each political region of the country, in order to avoid any spatial confusion in the up-scaling process.

The final map (Figure 2) might be used for “bottom-up” upscaling approach in order to extrapolate the location specific data to a broader scale. A refinement of the map would be the inclusion of soil variables which could better highlight the environmental different among zones and aggregate the similar ones inside homogeneous classes. Other beneficial future work would be validate and compare the zones using the weather data from different weather stations within a zone or by performing and comparing crop model simulated output variables. The same approach would be applicable among neighbor’s zones to check how they differ from each other.

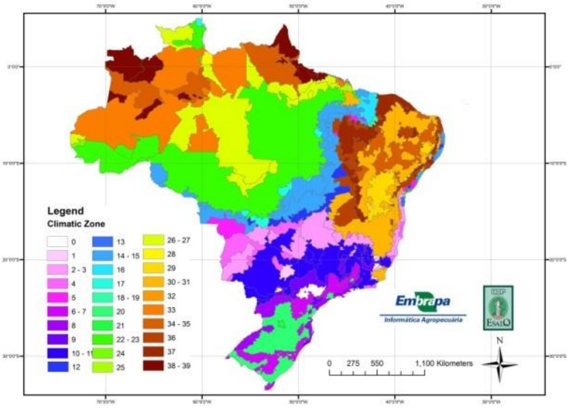

Figure 2. Zonation of Brazil based on homogenous climatic zones approach.

CONCLUSIONS

All zonation schemes are limited by choice and quality of the underpinning data used to derive them, the data availability and the final spatial scale design for the final product. The climatic zone proposed balanced simple input data reasonably spread throughout the country and data preparation and mapping procedures to assure the homogeneity of the found zones. Further work should focus in the inclusion of soil data to reach a robust zone map to support crop model outputs up-scaling, as well as in the validation of the zones using weather data series or crop model output variables.

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome 300.

Anderson, M.C., Kustas, W.P., Norman, J.M., 2003. Upscaling and downscaling—A regional view of the soil–plant–atmosphere continuum. Agronomy Journal 95, 1408–1423.

Bristow, K.L., Campbell, G.S., 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agricultural and Forest Meteorology 31, 159–166.

Camargo, A.P., Marin, F.R., Sentelhas, P.C., Picini, A.G., 1999. Ajuste da equação de Thornthwaite para estimar a evapotranspiração potencial em climas áridos e superúmidos, com base na amplitude térmica. Revista Brasileira de Agrometeorologia 7, 251–257.

Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D., Alsdorf, D., 2007. The Shuttle Radar Topography Mission. Reviews of Geophysics 45, n/a–n/a.

Marin, F.R., Jones, J.W., Singels, A., Royce, F., Assad, E.D., Pellegrino, G.Q., Justino, F., 2012. Climate change impacts on sugarcane attainable yield in southern Brazil. Climatic Change 1–13.

Marin, F.R., Pandorfi, H., Ferreira, A.S., 2003. Estimativas das temperaturas máximas, médias e mínimas mensais para o Brasil., in: Anais... Presented at the Congresso Brasileiro de Agrometeorologia, CBA, Santa Maria, pp. 761–762.

Schuster, J.E., Caruthers, C.G., Heinitz, A.C., Meyers, K.D., 2009. Compilation and Production of the 1:500,000-scale Geologic Map of Washington State, and Some Aspects of 1:24,000-scale Map Production at the Washington Division of Geology and Earth Resources, in: Digital Mapping Techniques ’07 - Workshop Proceedings. Presented at the Digital Mapping Techniques ’07 - Workshop, Association of American State Geologists, Columbia.

Thorthwaite, C.W., Mather, J.R., 1955. The water balance. Drexel Institute of Technology – Laboratory of Climatology,, Centerton.

Van Oijen, M., Thomson, A., Ewert, F., 2009. Spatial upscaling of process-based vegetation models: An overview of common methods and a case-study for the UK. Methods 1, 3.

Van Wart, J., van Bussel, L.G., Wolf, J., Licker, R., Grassini, P., Nelson, A., Boogaard, H., Gerber, J., Mueller, N.D., Claessens, L., 2013. Use of agro-climatic zones to upscale simulated crop yield potential. Field Crops Research.