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Geostatistical anisotropic modeling of carbon dioxide emissions in the Brazilian Negro basin, Mato Grosso do Sul

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Abstract. This paper presents a methodology for spatial modeling of carbon dioxide - CO2 - emitted from soils of the Negro River basin located in the Pantanal region in the state of Mato Grosso do Sul, Brazil. Geostatistical procedures of analysis and prediction were applied to a sample point set of CO2 emission rates observed in this region. A previous analysis of samples, throughout semivariogram surfaces, detected an anisotropic behavior of the CO2 emissions in the region. The spatial modeling of CO2 was conducted through the geostatistical estimation procedure known as kriging, considering the anisotropic behavior of the samples. The resulting model is presented as a map of CO2 emissions, clipped by the boundaries of the Negro basin, which can be used individually or for future spatial modeling and decision-making activities related to this phenomenon in the Pantanal region.

Key-words: modeling CO_2 emissions, geostatistics, semivariograms, anisotropy, kriging.

Resumo. Este artigo apresenta uma metodologia para modelagem espacial de dióxido de carbono - CO2 - emitido pelos solos da região da bacia do rio Negro situada na região Pantanal do estado do Mato Grosso do Sul, Brasil. Procedimentos geoestatísticos de análise e predição foram aplicados a um conjunto amostral pontual das taxas de emissão de CO2 observados nessa região. Uma análise prévia das amostras, através de semivariogramas de superfície, detectou um comportamento anisotrópico desse atributo. Realizou-se a modelagem espacial do CO2 através do procedimento de estimação geoestatístico, conhecido como krigeagem, considerando-se o comportamento anisotrópico revelado pelas amostras. Como resultado da modelagem é apresentado um mapa de CO2, recortado pelos limites da bacia do Negro, que pode ser utilizado individualmente ou para futuras modelagens espaciais no sentido de tomadas de decisão em relação a esse fenômeno na região do Pantanal.

Palavras-chave: modelagem de emissões de CO_2, geoestatística, semivariogramas, anisotropia, kriging.

1. Introduction

The cycle of carbon dioxide, CO_2, has been thoroughly studied, mainly because CO_2 is one of the gases in the atmosphere that has been considered responsible for what is now called the greenhouse effect. The other gases are methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6).

The greenhouse gases absorb part of the infrared radiation reflected by the earth's surface, preventing it from escaping into space. Thus the surface of earth is being heated because of the greenhouse effect, causing global warming and having a direct effect on climate change on our planet (Shah, A., 2014).

The CO_2 is sequestered from the atmosphere only by the absorption of the other two reservoirs: oceans and terrestrial biomass. The main sources of net CO_2 emissions to the atmosphere are deforestation and industrial activities that burn fossil fuels. Also, soils around the globe have increased their emissions of carbon dioxide in recent years. The increasing temperatures are likely to cause a net release of carbon dioxide from soils by triggering microbes to speed up their respiration of plant debris and other organic matter (Bond-Lamberty, 2010).

Studies of the global balance of CO_2 show that the emission is increasing while the sequestration of CO_2 is decreasing in recent years. So, it is important have methodologies that allow spatial modeling the CO_2 reservoirs, including sequestration and emission rates influenced both by anthropogenic and natural phenomena. The results of these studies allow taking decisions on mitigating the damaging effects of this phenomenon on our planet.

Geostatistical analysis and methods has been applied successfully to model the spatial behavior of natural phenomena over specific regions of the earth surface (Deutsch and Journel, 1998; Goovaerts, 1997; Isaaks and Srivastava, 1989). The great advantage of using geostatistical approaches is that one can determine and consider the spatial autocorrelation of the attribute by semivariogram analysis taken directly from the sample set. Also anisotropic behaviors of the attribute can be detected showing directions of more or less continuity of the phenomenon in the studied region (Camargo et al., 2001).

This article presents a geostatistical methodology for spatial modeling of CO_2 emissions from a set of samples gathered in the Pantanal wetland region of Mato Grosso do Sul - MS, in Brazil, within the Negro River basin. Previous inspection of the samples, by surface semivariogram analysis, showed that the behavior of CO_2 emissions in the region of interest is anisotropic. The detected anisotropy is considered by the applied geostatistical prediction, known as kriging, in order to obtain more reliable representation of this attribute in the considered region.

2. Objective

The objective of this work is to model the spatial distribution of CO_2 emitted from soil in the Negro River basin, MS, in Brazil. The CO_2 input dataset is represented as sample points and is modeled using the kriging geostatistical approach considering the attribute anisotropy. The methodology and the results are presented and analyzed with graphics, reports and maps.

3. Material and Methods

This work uses the software SPRING - Sistema de Processamento de Informações Georeferenciadas - for the geostatistical analysis performed in the sample set of CO_2 considered. SPRING is a Geographic Information System - GIS - used to input, store, manipulate, analyze and output spatial information in a single integrated computational platform (Camara et al., 1996).

The study area is the Negro River basin in the Pantanal biome, whose coordinates of geographical location and projection information are illustrated in **Figure 1**. The Pantanal Biome occupies 7% of the southern part of the state of Mato Grosso (MT) and 25% of the northwestern part of the state of Mato Grosso do Sul, in Brazil, covering a total area of 150,355 km². Beyond the border, it extends through northern Paraguay and eastern Bolivia. The region is an alluvial plain influenced by rivers that drain the basin of the Upper Paraguay, where it develops a fauna and flora of rare beauty and abundance.

The data used in this work were provided by FUNCATE - Fundação de Ciência e Tecnologia Espaciais - the Foundation for Space Science and Technology, under the document named "Segunda Comunicação Nacional do Brasil à Convenção-Quadro das Nações Unidas sobre Mudança do Clima" ("Second Brazilian National Communication to the Framework United Nations Convention on Climate Change"), available at the web site: www.mct.gov.br/index.php/content/view/326988/Texto_Completo_Publicado.html.

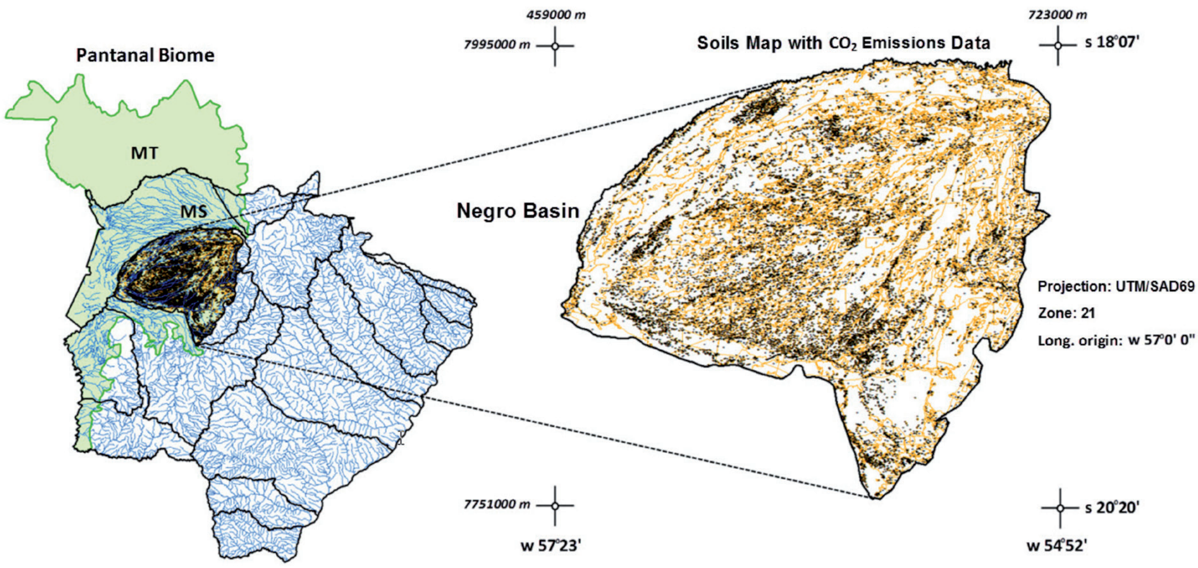

Figure 1. Pantanal biome (green shading) highlighting the Negro basin.

For this study two types of data have been used: The first is a polygon representing the outline of the Negro Basin, that was used as a clipping mask for the resulting maps and the second is a set of 5601 points (centroids) having values associated with the estimated CO_2 emission from the soil map as shown in **Figure 2**. The CO_2 emissions vary according to the soil types of the Negro region.

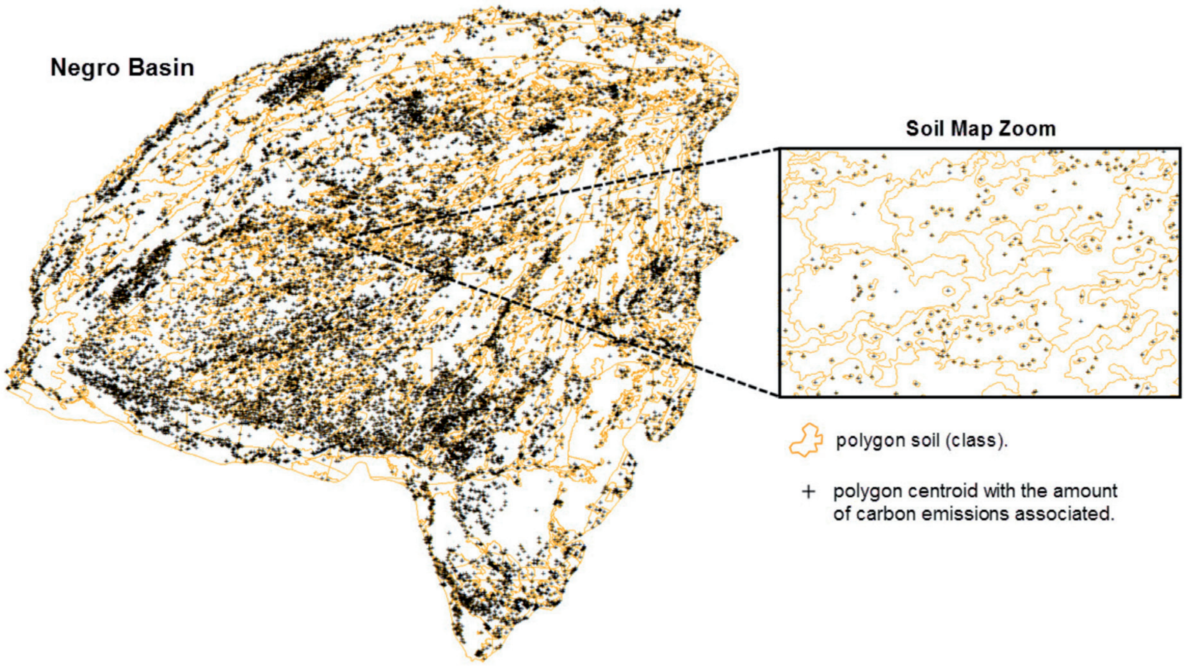

Figure 2. Distribution of the sample data set of CO_2 in the Negro Basin.

The methodology used in the development of this work follows these steps:

1. Database storage of the CO_2 sample data set and of the polygon surrounding the region of interest. These data layers were loaded in the SPRING GIS.

2. Exploratory analysis of the CO_2 sample set in order to understand the statistical properties of the data such as the normality of the distribution, for example.

3. Removal of trends in the CO_2 data to get a residual information having a constant stationary mean all over the region. These residuals are used to set the semivariograms.

4. Verification of anisotropy in the data by analysis of surface semivariograms.

5. Generation of empirical semivariograms for the two anisotropic directions detected in the surface semivariogram analysis.

6. Fitting of the empirical semivariograms, in both directions, by theoretical models.

7. Defining manually one final theoretical semivariogram model that considers the two directions of the anisotropy detected in the sample set.

8. Modeling CO_2 emissions applying the geostatistical kriging estimator, considering the final theoretical semivariogram.

9. Cutting the rectangular grids using the surrounding polygon of the region of interest.

4. Results and Discussion

Figure 3 illustrates the database created in SPRING showing the distribution of the CO_2 samples in the Negro basin. Also the functions of the geostatistical module available in SPRING are presented in this figure.

Figure 4 presents the univariate statistics, along with the histogram, of the CO_2 samples, and the residuals are presented in **Figure 5**. These residuals were obtained after running the remove trends function of the SPRING software.

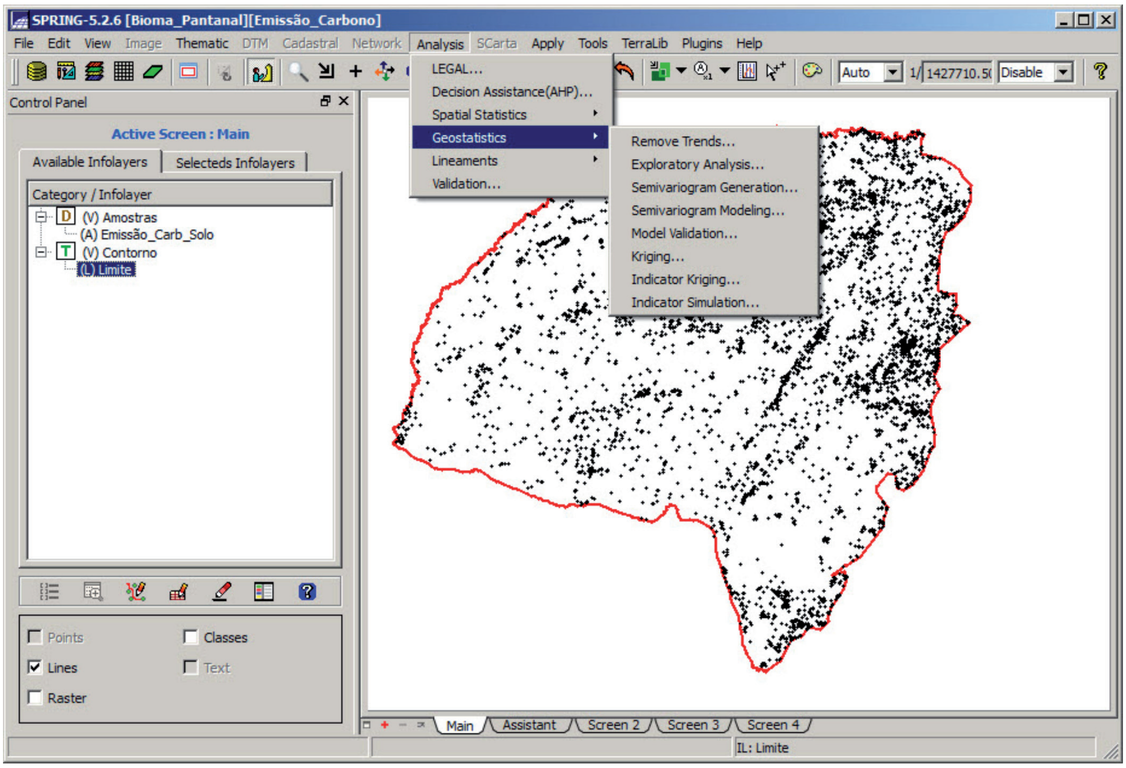

Figure 3. Spatial Distribution of the sample set of CO_2 emissions in the Negro basin and the functions available in SPRING to perform geostatistical analysis.

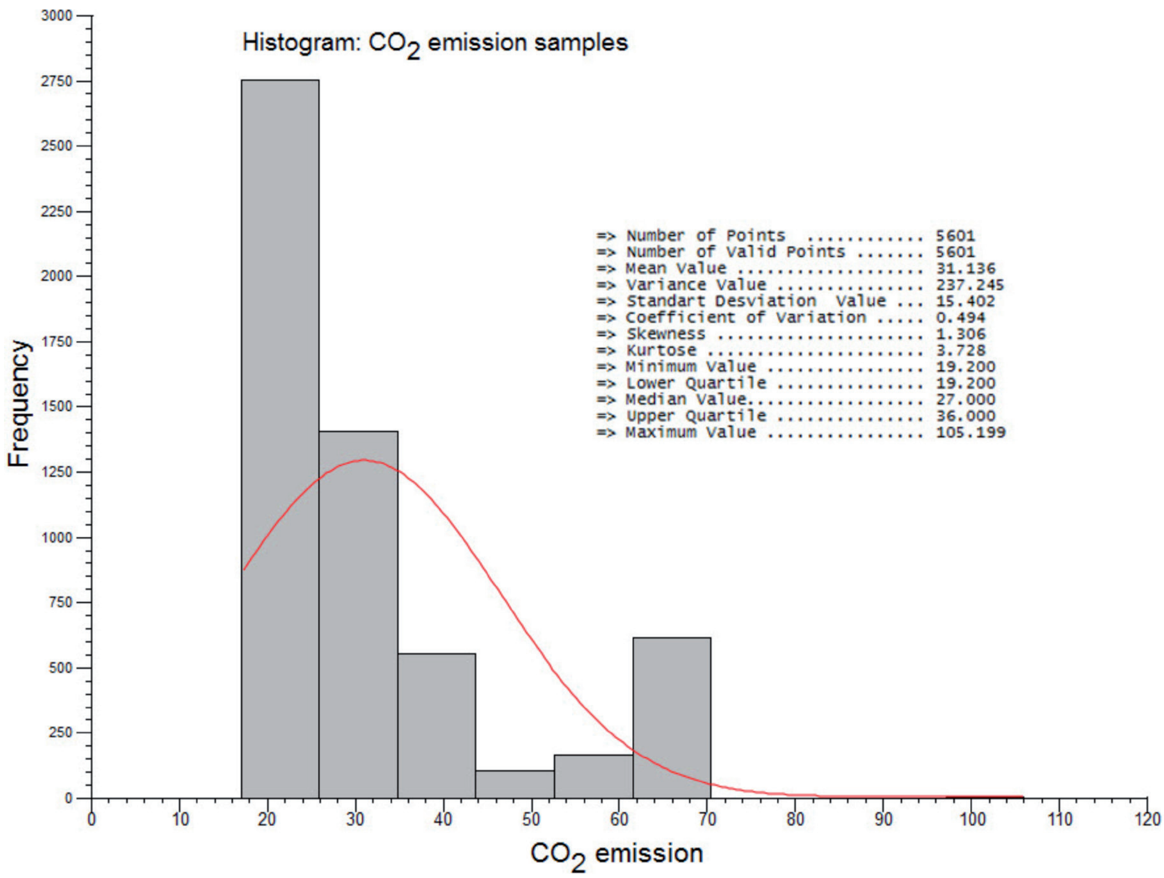

Figure 4. Univariate statistics and histogram of the CO_2 emission samples

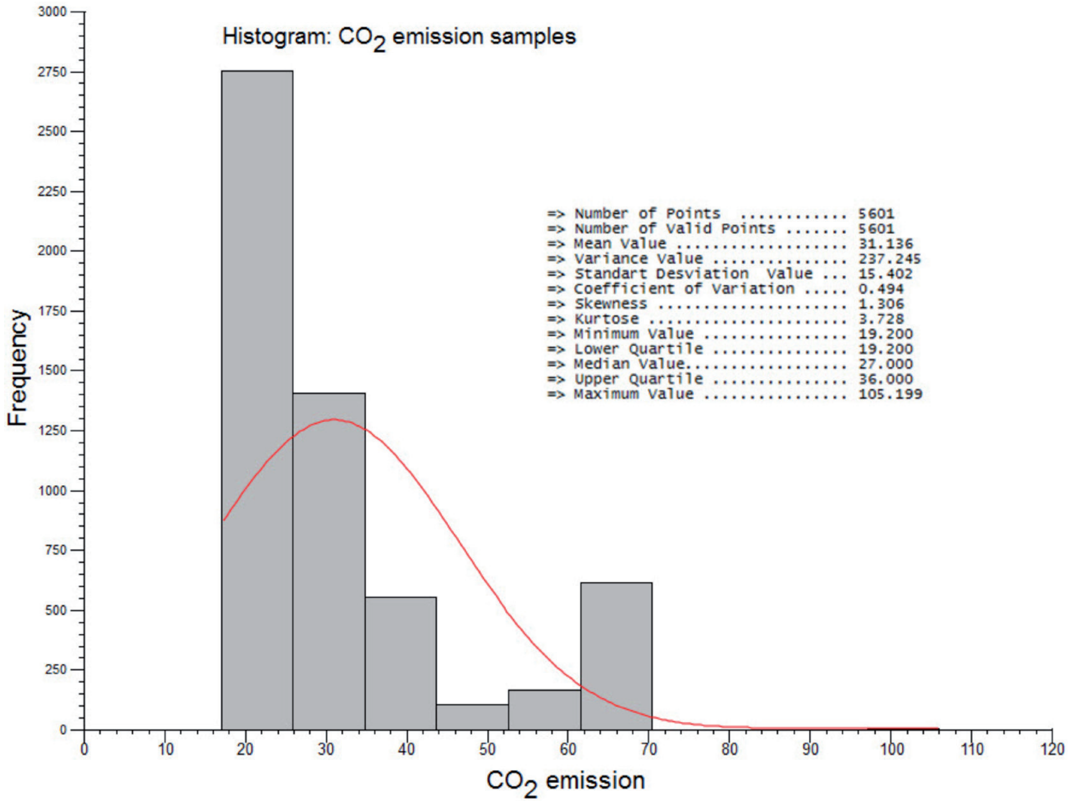

Figure 5. Univariate statistics and histogram of the residuals of CO_2 emission samples

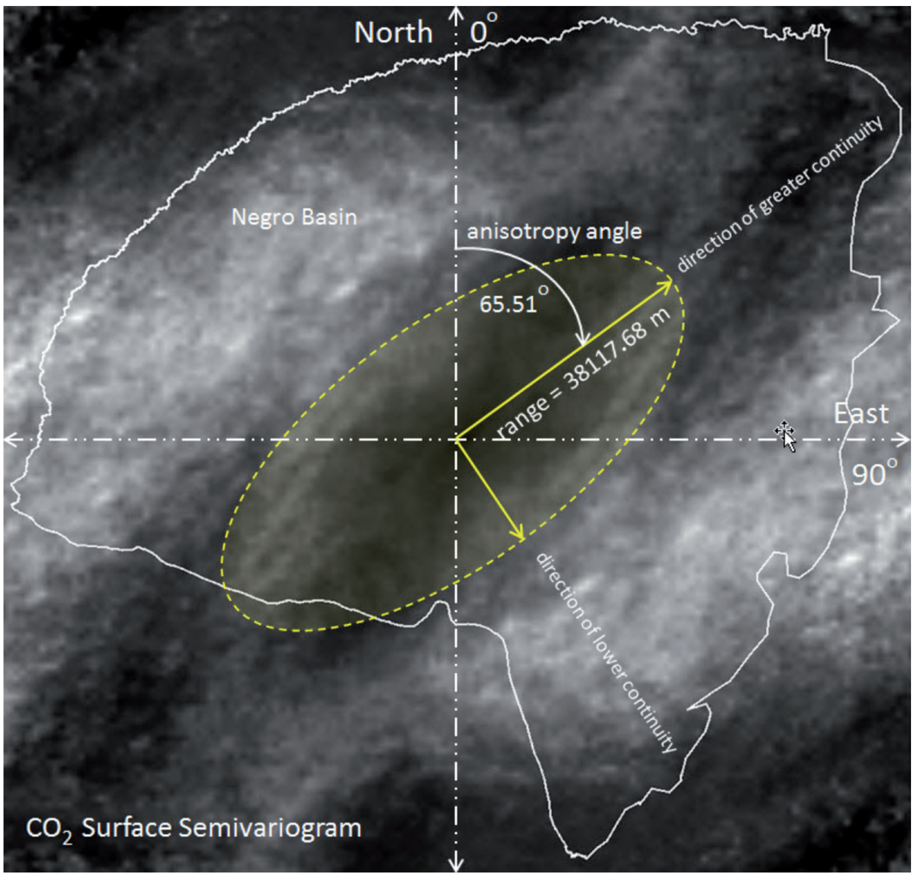

Figure 6. CO_2 surface semivariogram showing the two anisotropic directions.

Figure 7 shows the empirical, experimental, and the fitted, conceptual, unidirectional semivariograms for the detected anisotropic directions. Both directions were modeled with Gaussian functions and the individual parameters of each fitted curve are reported in **Table 1**.

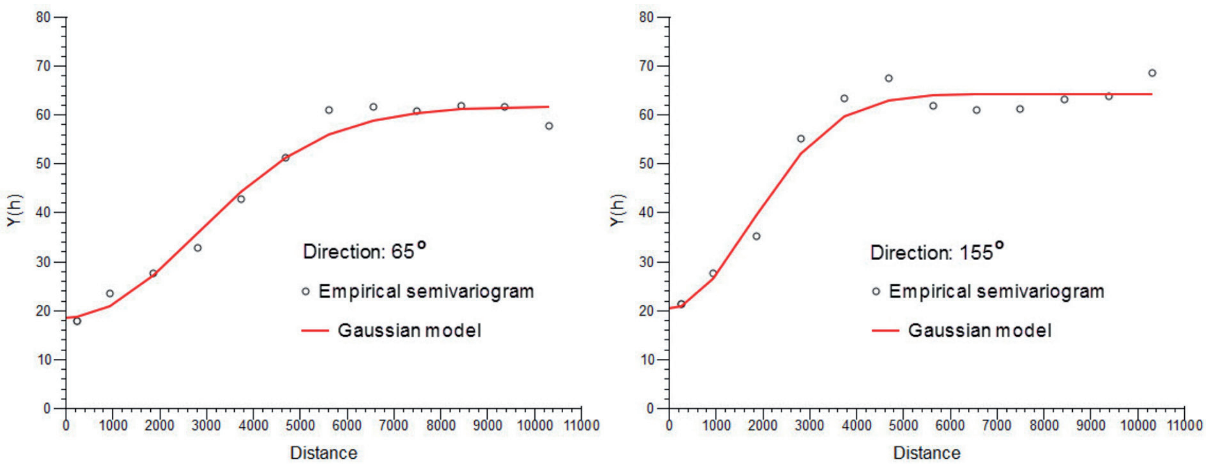

Figure 7. Empirical, along with the fitted conceptual, semivariograms for the directions 65º (left) and 155º (right) degrees.

Table 1. Semivariogram parameters for the two anisotropic directions.

Direction (degrees)	Model	Nugget Effect C_o	Sill C	Range a (meters)
65º	Gaussian	18.25	43.15	6847.01
155º	Gaussian	20.35	45.66	4317.67

The final semivariogram model, built from the combination of the two models reported in **Table 1**, is according to **Equation 1**:

$$G(\mathbf{h}) = 18.25 + 2.1*Gauss\,(\mathbf{h}_{65}/a_{65},\, \mathbf{h}_{155}/.000001)\ + \\ 41.05*Gauss(\mathbf{h}_{65}/a_{65},\, \mathbf{h}_{155}/a_{155}) + 2.61*Gauss(\mathbf{h}_{65}/100000,\, \mathbf{h}_{155}/a_{155}) \qquad \mathbf{(1)}$$

where: a_{65} = 6847.01, a_{155}=4317.67; $\mathbf{h}_{65}$ and $\mathbf{h}_{155}$ are the modules of the vector projections in the directions 65 and 155 degrees respectively.

Figure 8 presents the spatial distribution of CO_2 evaluated by the proposed methodology in this work. The spatial modeling of CO_2 was held through the ordinary kriging estimation procedure, considering the anisotropic behavior shown by the considered samples. The resulting model is presented in a map of emission rates of CO_2, clipped by the boundaries of the Negro basin, which can be used individually or for future spatial modeling in decision-making activities related to this phenomenon in the Pantanal region.

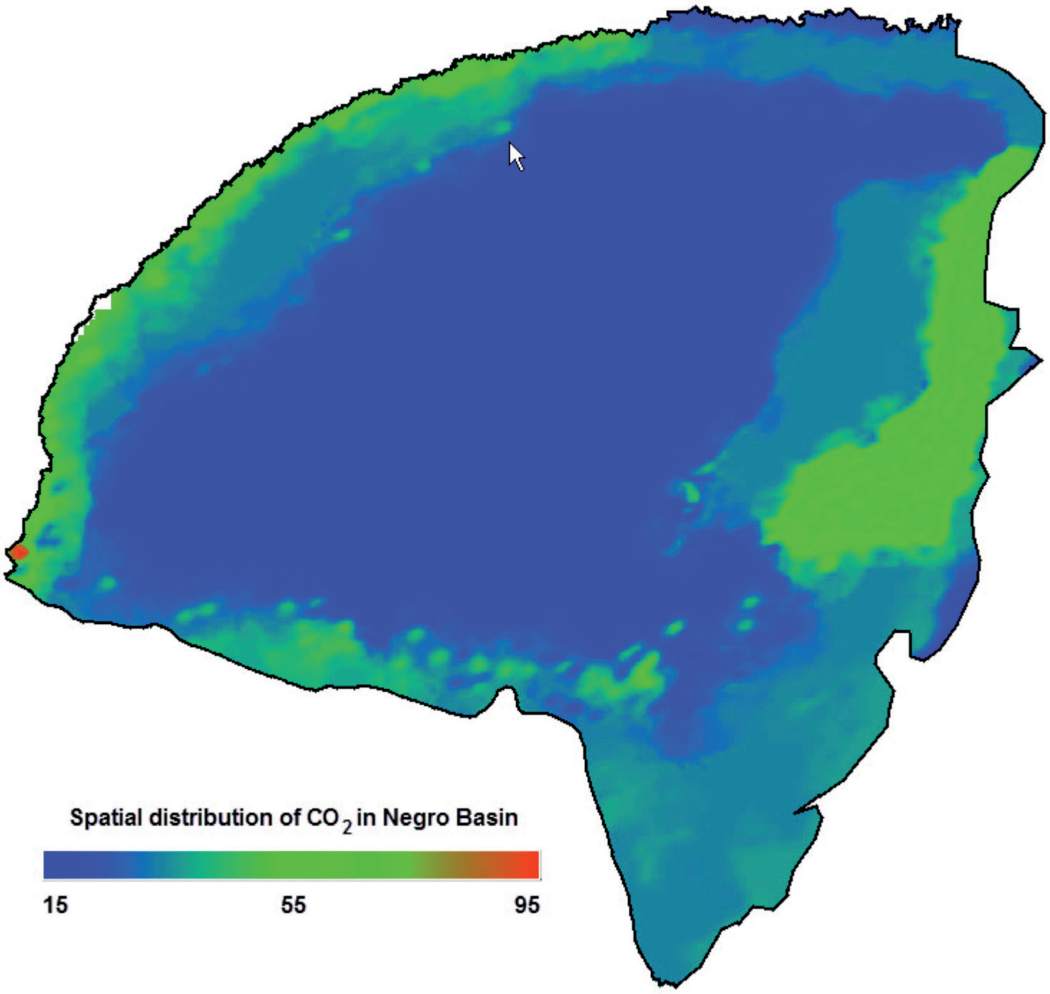

Figure 8. Map of CO_2 emission estimated by the kriging approach considering the its anisotropic behavior.

5. Conclusions and Suggestions

The geostatistical module of the SPRING software was used successfully to model the distribution of CO_2 emissions in the Negro basin, considering their anisotropic behavior. The great advantage of using geostatistical approaches, compared with deterministic methods, is that one can determine and consider the spatial autocorrelation of the attributes that are modeled by variograms taken directly from the sample set. This study used anisotropic modeling because this type of behavior had previously been detected, by the surface variogram, in the CO_2 sample analysis.

The results presented in this paper suggest that this methodology can be applied to model other attributes of the Pantanal region, such as temperature, soil nutrients, etc. In the future we intend to apply variations of geostatistical approaches, as indicator and regression kriging, to compare the results with those obtained in this work.

6. References

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