Third International Symposium
Effects of Climate Change on the World's Oceans
Santos City, Brazil
March 23-27, 2015

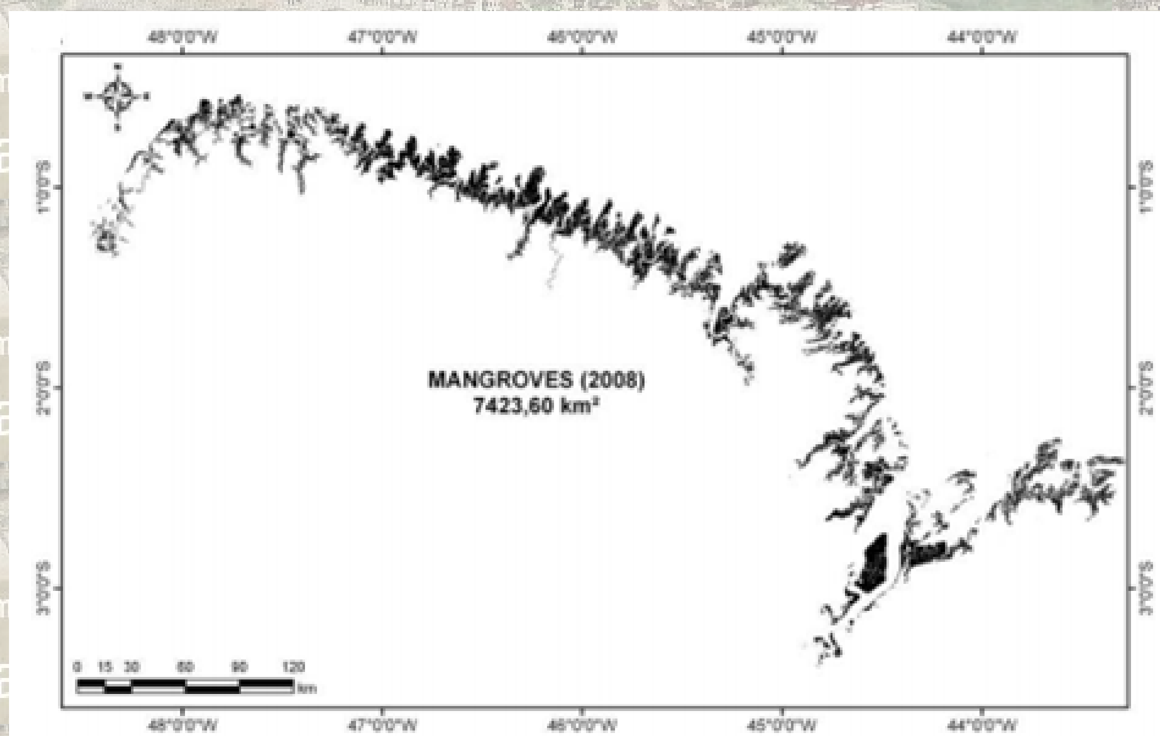
Modeling of the pattern of mangrove resistance to sea-level rise

Denilson da Silva Bezerra
Ceuma University (São Luís-MA/Brazil)

Introduction

- In the context of climate Change, the sea-level rise is a fact;
- And mangrove ecosystem is very sensitive to this process (For example: mangrove can migrate);
- In addition, intense human occupation can influence the mangrove response to climate change;
- Because the mangrove can not colonize human use areas.
- In this project, we propose a methodological approach, using GIS (*Geographic Information System)* and modeling based on cellular automata.

Motivation I: The largest continuous mangrove area of the planet is in the Brazilian Amazon (Wilson et al., 2013)



In terms of total area, the Brazil has the second largest mangrove area in the world (Spalding, Kainumaand and Collins 2010).

Country	Mangrove area (km²)	Proportion of global total
Indonesia	31,894	20.9%
Brazil	13,000	8.5%
Australia	9910	6.5%
Mexico	7701	5.0%
Nigaria	7356	4.8%
Malaysia	7097	4.7%
Myanmar	5029	3.3%
Bangladesh	4951	3.2%
Cuba	4944	3.2%
India	4326	2.8%
Papua New Guinea	4265	2.8%
Colombia	4079	2.7%

Important! Different authors may have different values. But the fact is …

The Brazil has an **extensive mangrove area**.

Motivation II:

The present study is the first Brazilian modeling experiment;

Important: In the context of mangrove response to sea-level rise.

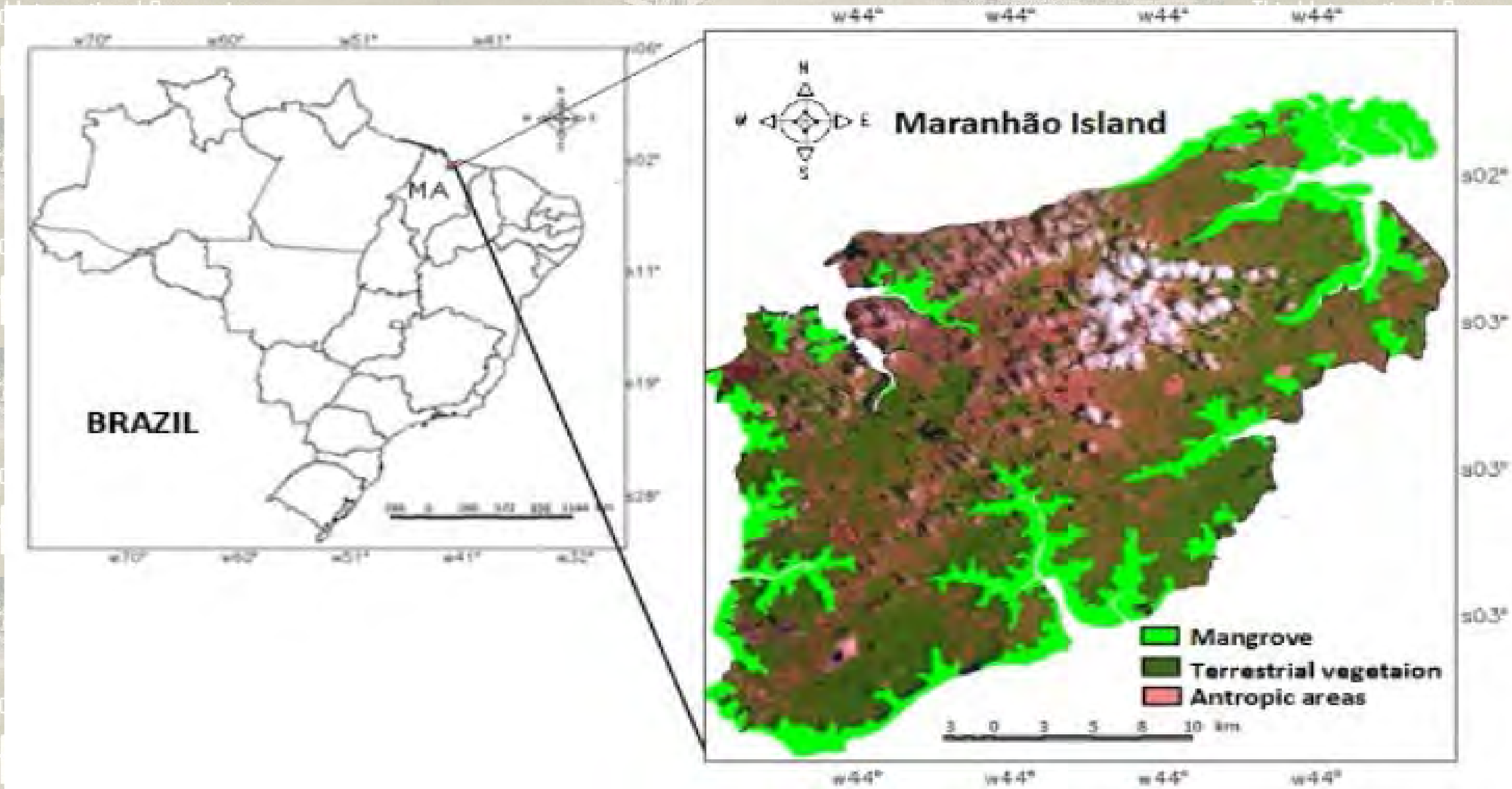
General objective: Simulate the mangrove response pattern to sea-level rise

- **Specific objectives**:
- Develop a conceptual model;
- Translate the conceptual model in computer language to allow the simulation exercise;
- Simulate mangrove response patterns to sea-level rise.

Case Study: Maranhão Island

- Maranhão Island (see figure below) is located on the Brazilian Amazon;
- The Maranhão Island has low relief with altitudes of up to 60 meters;
- Maranhão Island has 146.49 km2 mangrove area;
- Tidal rise in the Maranhão Island is 6 m.

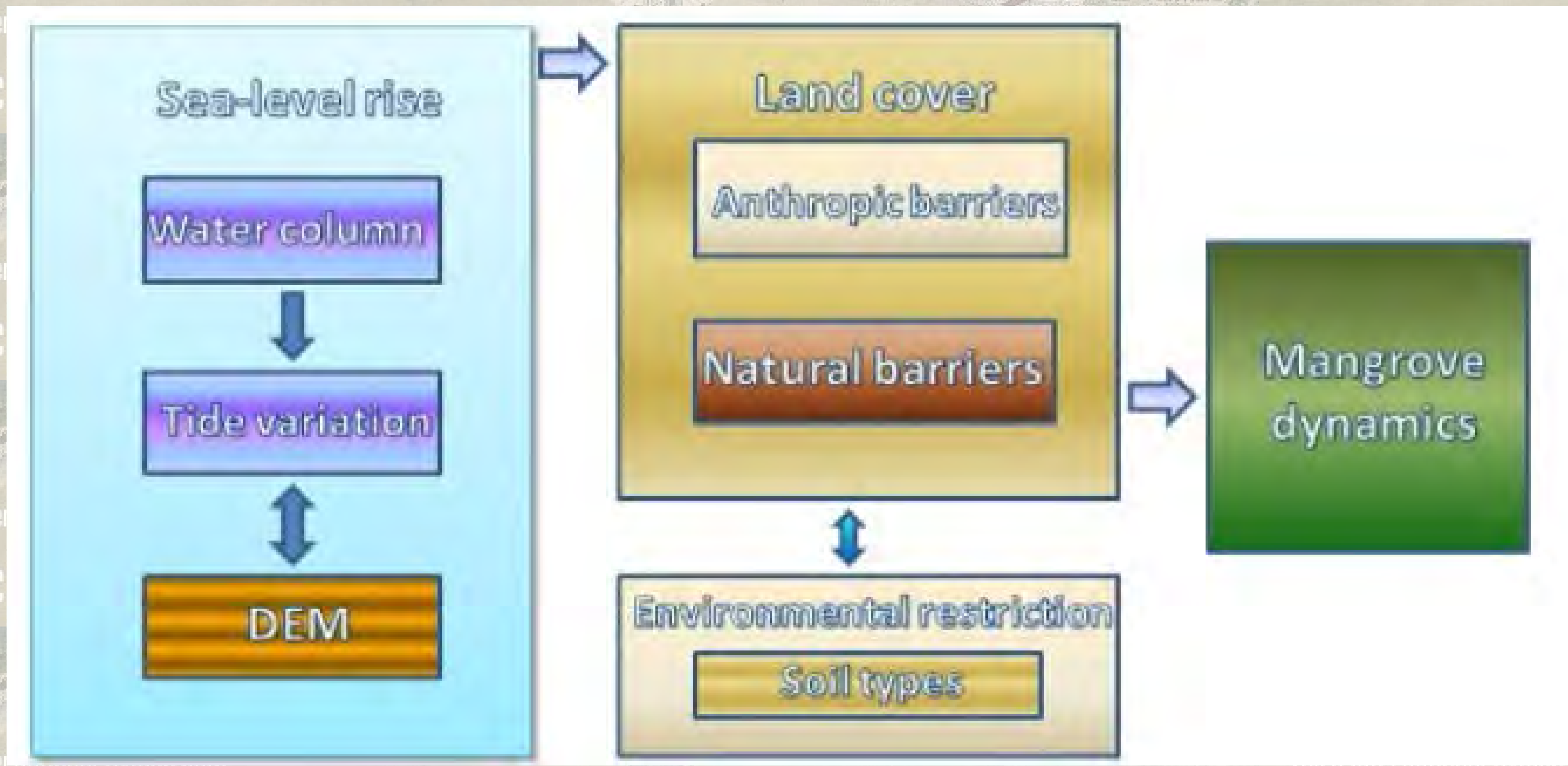
Case Study: Maranhão Island



Conceptual Model

- The mangrove responses to sea-level rise depend on factors such as topography (Digital Elevation Model – DEM), tidal range, land cover in adjacent areas, coastal dynamics and mean rate of sea-level rise (Mcleod & Salm 2006, Lovelock & Ellison 2007).
- Our conceptual model have four components: sea-level rise, land cover, environmental restrictions for the mangrove migration (only soil types) and mangrove dynamics (For example, mangrove migration, loss of mangrove area, mangrove resistance to sea-level rise).

Conceptual Model (Figure)



Modeling experiment: BR-Mangrove

- The programming language use: LUA (http://www.lua.org/portugues.html);
- Lua is a powerful programming language, fast and light, designed to extend applications;
- It is a language used in various computer games;
- The modeling platform that was used is the TerraME (http://www.terrame.org/doku.php).

the TerraME website

www.terrame.org/doku.php

Login

article | discussion | show pagesource | old revisions

TerraME

navigation
- Software
  - TerraME
  - LuccME
  - Documentation
  - People
  - FAQ
- Courses

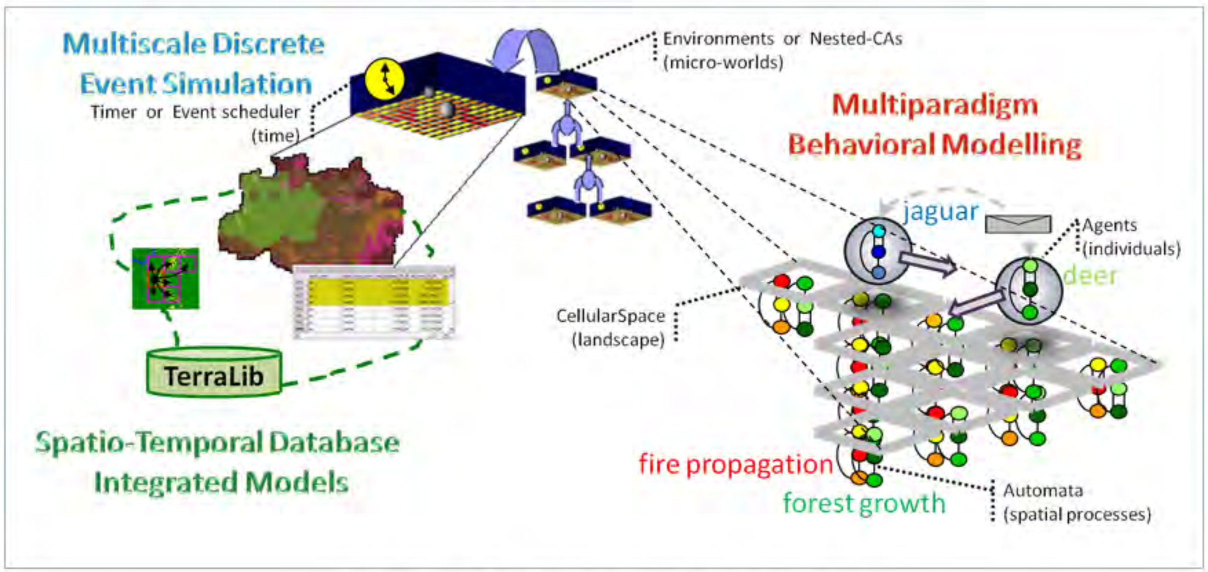
search

Go | Search

toolbox
- What links here
- Recent changes
- Media Manager
- Site index
- Printable version
- Permanent link
- Cite this article

qr code

TerraME: Simulation and Modelling of Terrestrial Systems



TerraME overview: Modeling Nature-Society Interactions

TerraME is a programming environment for spatial dynamical modelling. It supports cellular automata, agent-based models, and network models running in 2D cell spaces. TerraME provides an interface to TerraLib geographical database, allowing models direct access to geospatial data. Its modelling language has in-built functions that makes it easier to develop multi-scale and multi-paradigm models for environmental applications.

TerraMe Programming Language: Extension of LUA

LUA is the language of choice for computer games

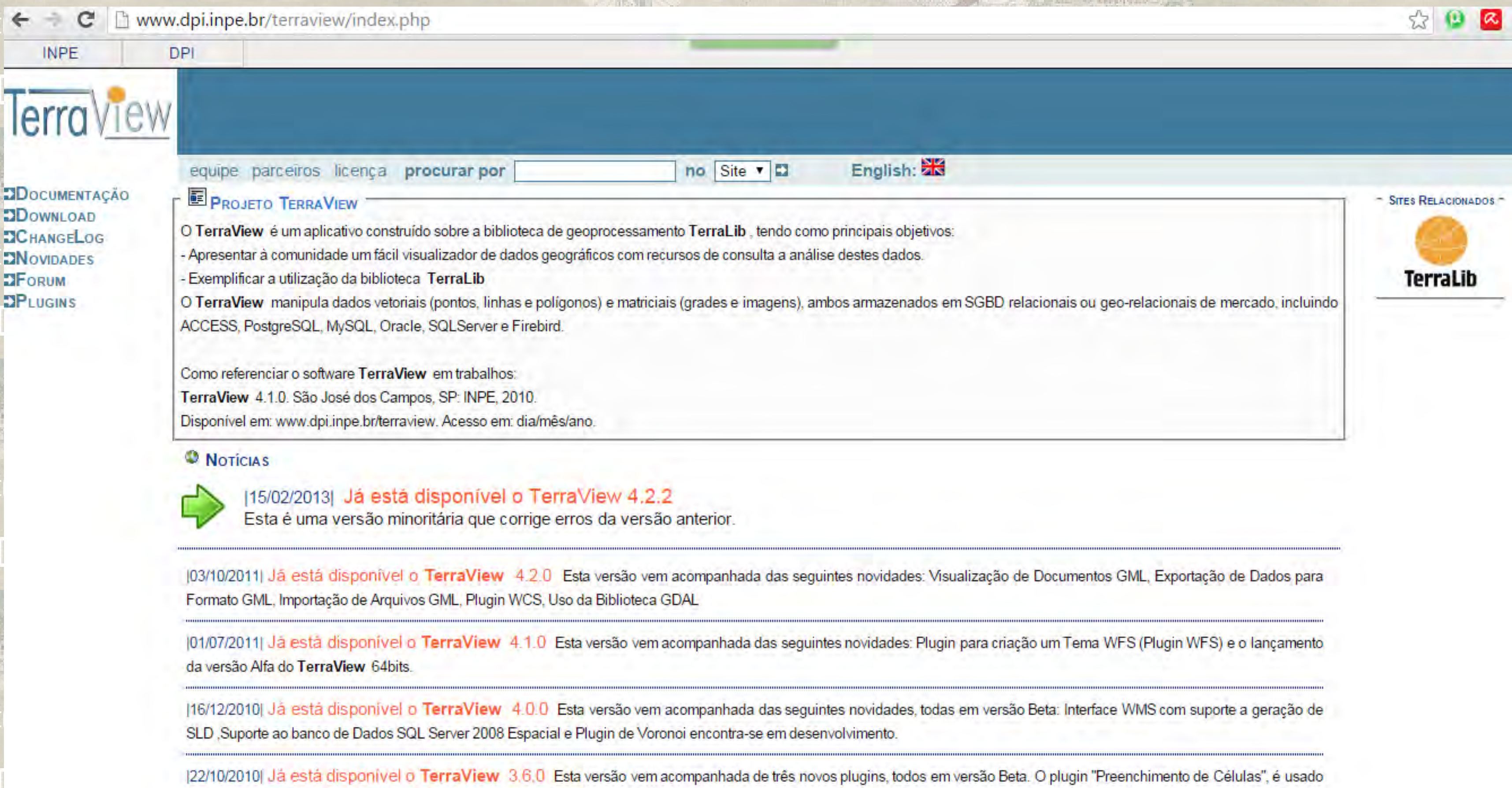
source: the LUA team

[Ierusalimschy et al, 1996]

Geographical Database and Cellular Space

- Our implementation is based on the cellular automata computational model, a logical system which has the concept of cell as the basic unit: each cell has a state and attributes (Wolfram 1983).
- The geographical database and cellular space were organized in the software TerraView (http://www.dpi.inpe.br/terraview/index.php).

the TerraView website



www.dpi.inpe.br/terraview/index.php

INPE | DPI

TerraView

equipe parceiros licença **procurar por** no Site English:

- Documentação
- Download
- ChangeLog
- Novidades
- Forum
- Plugins

Projeto TerraView

O **TerraView** é um aplicativo construído sobre a biblioteca de geoprocessamento **TerraLib**, tendo como principais objetivos:
- Apresentar à comunidade um fácil visualizador de dados geográficos com recursos de consulta a análise destes dados.
- Exemplificar a utilização da biblioteca **TerraLib**

O **TerraView** manipula dados vetoriais (pontos, linhas e polígonos) e matriciais (grades e imagens), ambos armazenados em SGBD relacionais ou geo-relacionais de mercado, incluindo ACCESS, PostgreSQL, MySQL, Oracle, SQLServer e Firebird.

Como referenciar o software **TerraView** em trabalhos:
TerraView 4.1.0. São José dos Campos, SP: INPE, 2010.
Disponível em: www.dpi.inpe.br/terraview. Acesso em: dia/mês/ano.

Sites Relacionados
TerraLib

Notícias

|15/02/2013| Já está disponível o TerraView 4.2.2
Esta é uma versão minoritária que corrige erros da versão anterior.

|03/10/2011| Já está disponível o **TerraView** 4.2.0 Esta versão vem acompanhada das seguintes novidades: Visualização de Documentos GML, Exportação de Dados para Formato GML, Importação de Arquivos GML, Plugin WCS, Uso da Biblioteca GDAL

|01/07/2011| Já está disponível o **TerraView** 4.1.0 Esta versão vem acompanhada das seguintes novidades: Plugin para criação um Tema WFS (Plugin WFS) e o lançamento da versão Alfa do **TerraView** 64bits.

|16/12/2010| Já está disponível o **TerraView** 4.0.0 Esta versão vem acompanhada das seguintes novidades, todas em versão Beta: Interface WMS com suporte a geração de SLD ,Suporte ao banco de Dados SQL Server 2008 Espacial e Plugin de Voronoi encontra-se em desenvolvimento.

|22/10/2010| Já está disponível o **TerraView** 3.6.0 Esta versão vem acompanhada de três novos plugins, todos em versão Beta. O plugin "Preenchimento de Células", é usado

Cells States and Cells Attributes

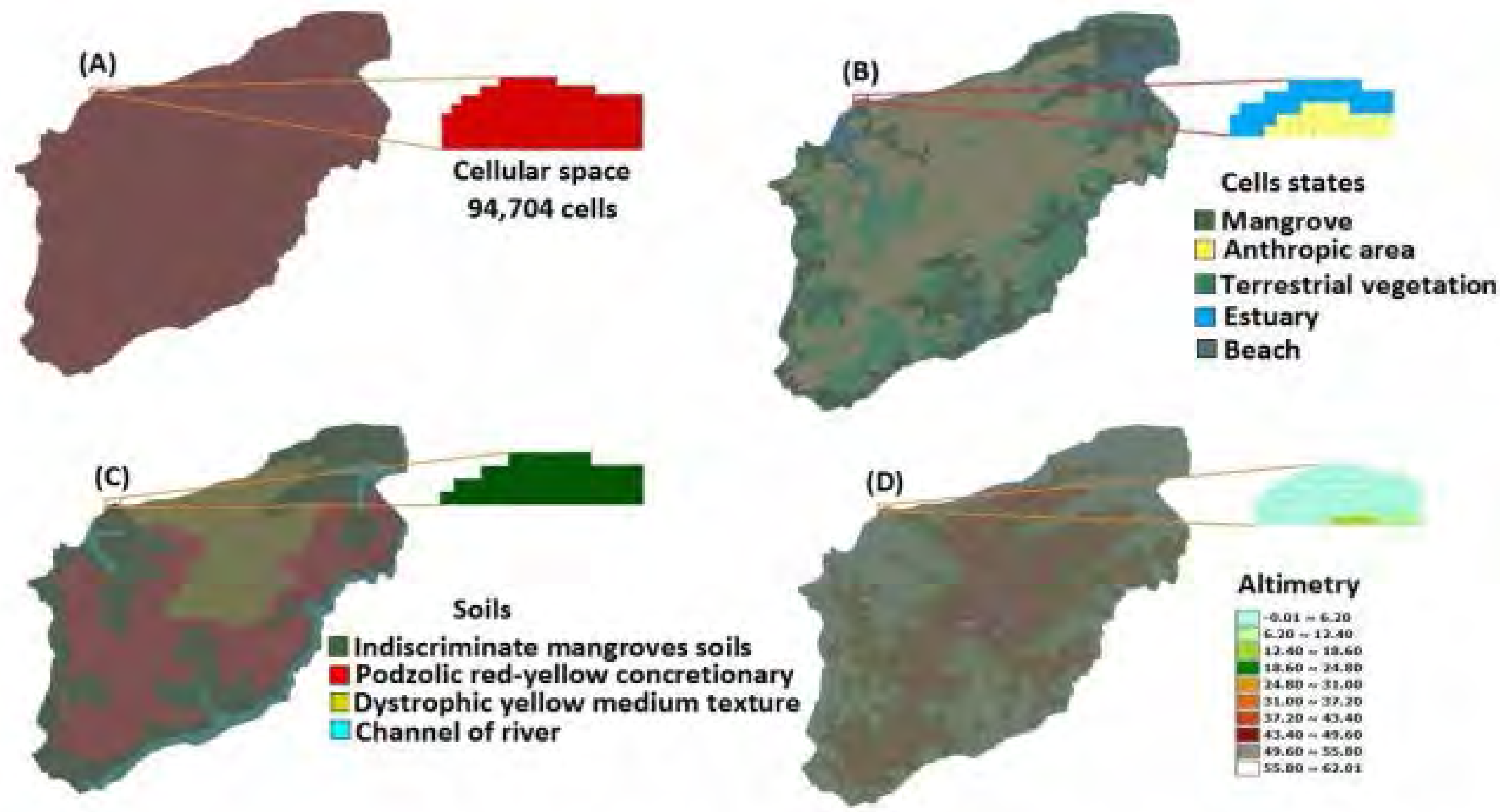
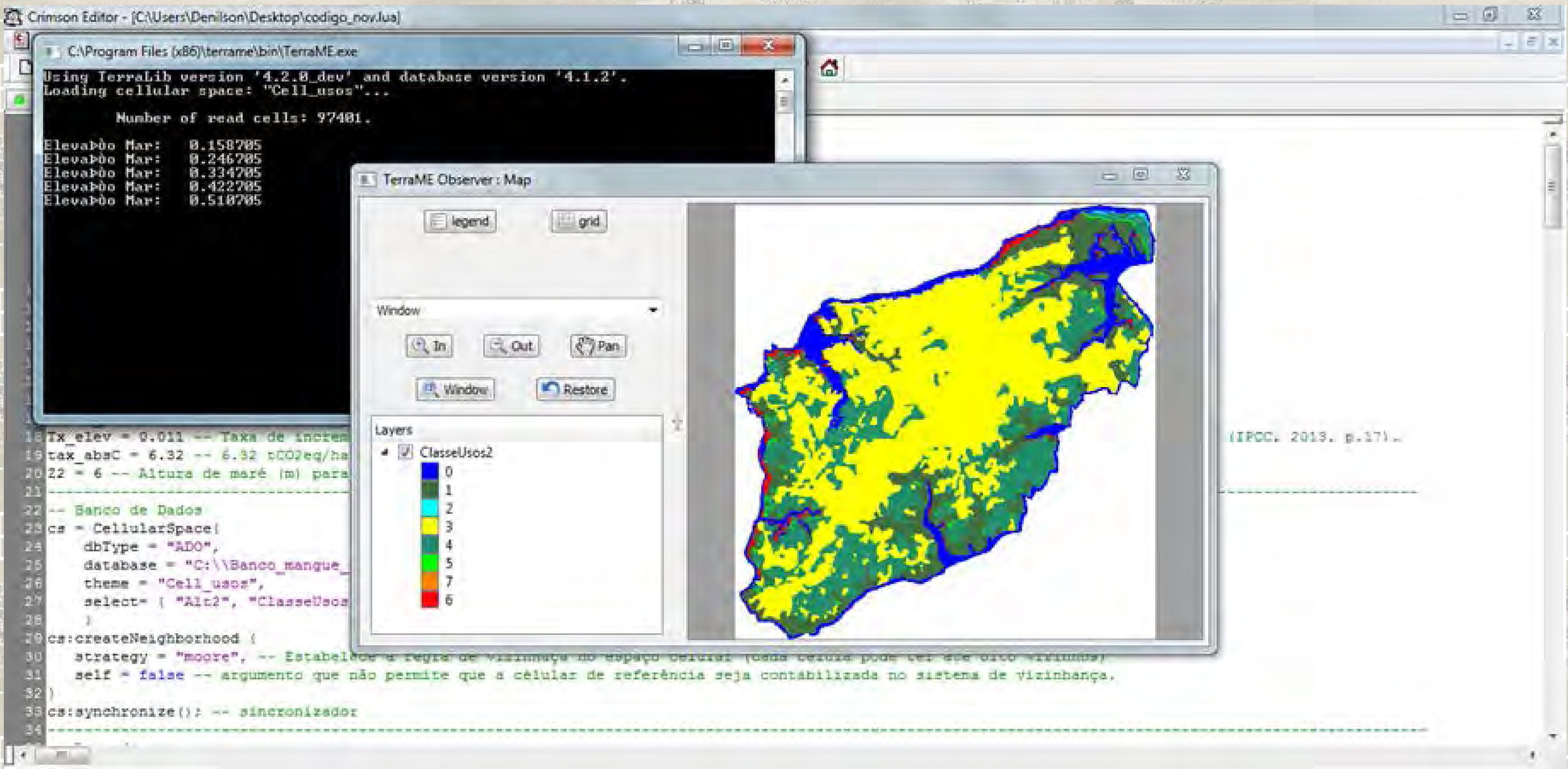


Figure Cellular space: (A) Empty cellular space (B); Cell states; (C) Attribute-soils; (D) Attribute-Altimetry.

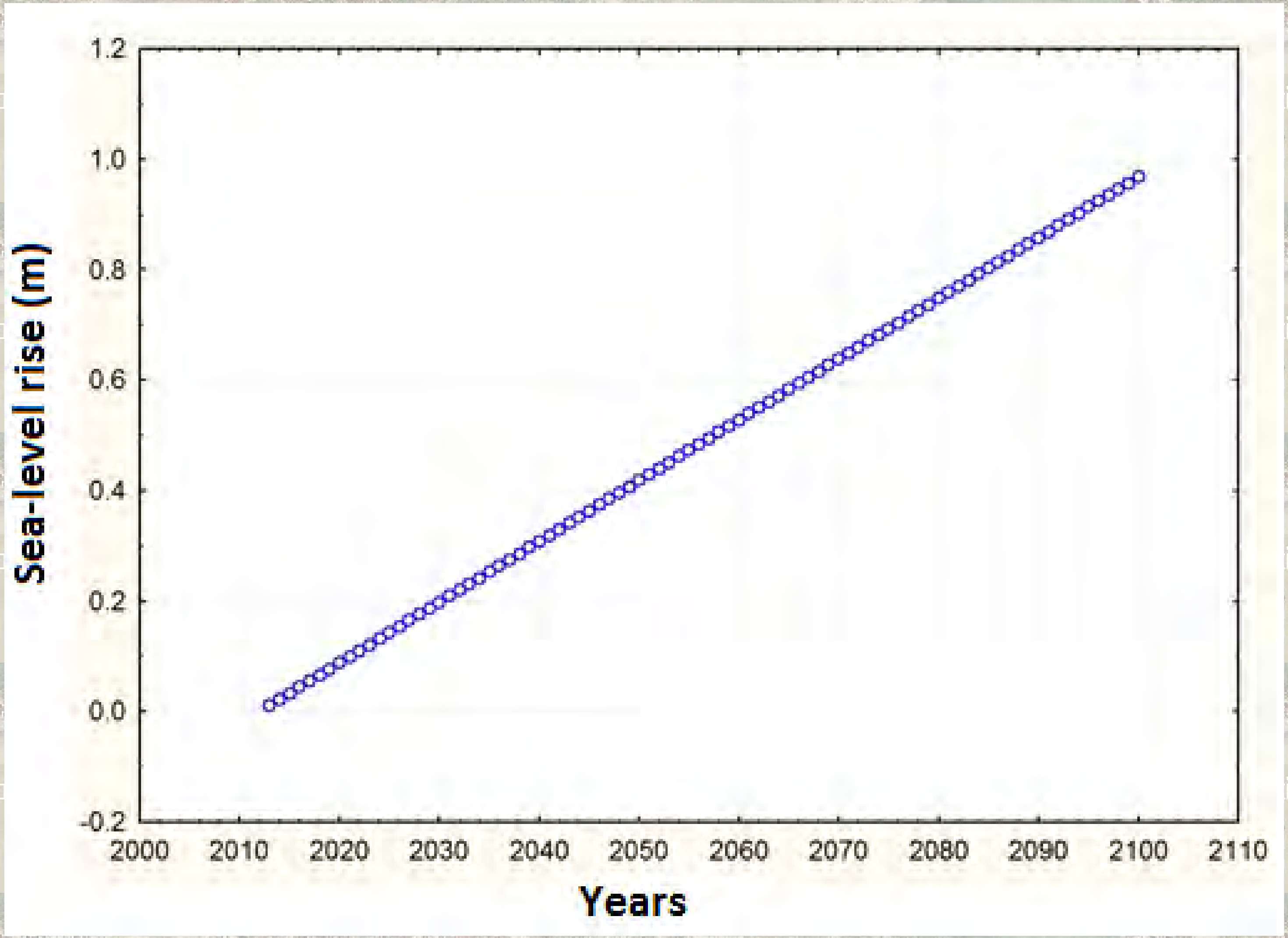
Results

- The simulation considers 88 events of elevation from 0.011 to 0.97 m (period 2012 to 2100);
- The results are presented in terms of total area (ha), mangrove migration (ha) and mangrove inundation (ha).

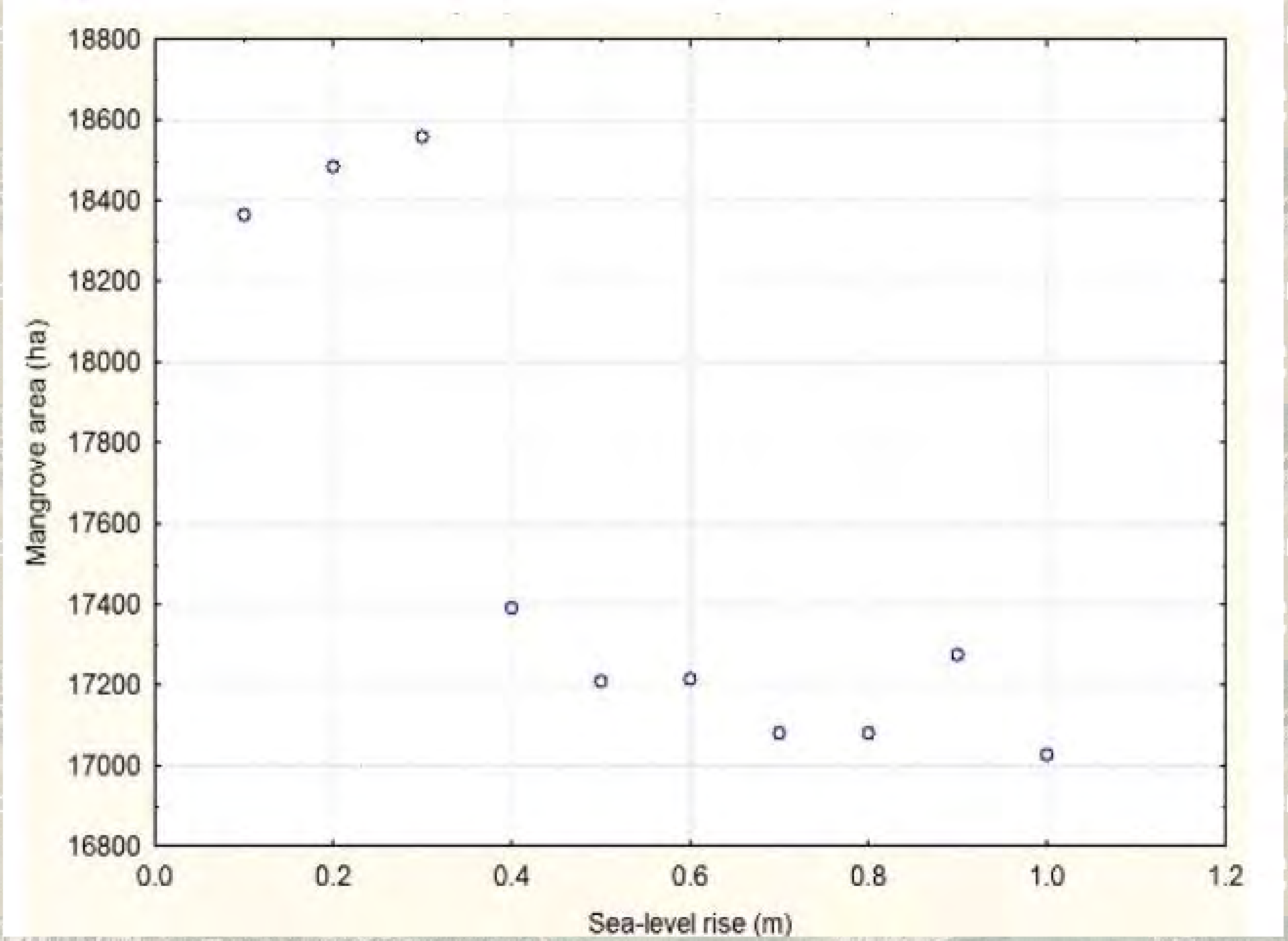
Results: Br-mangrove in action!



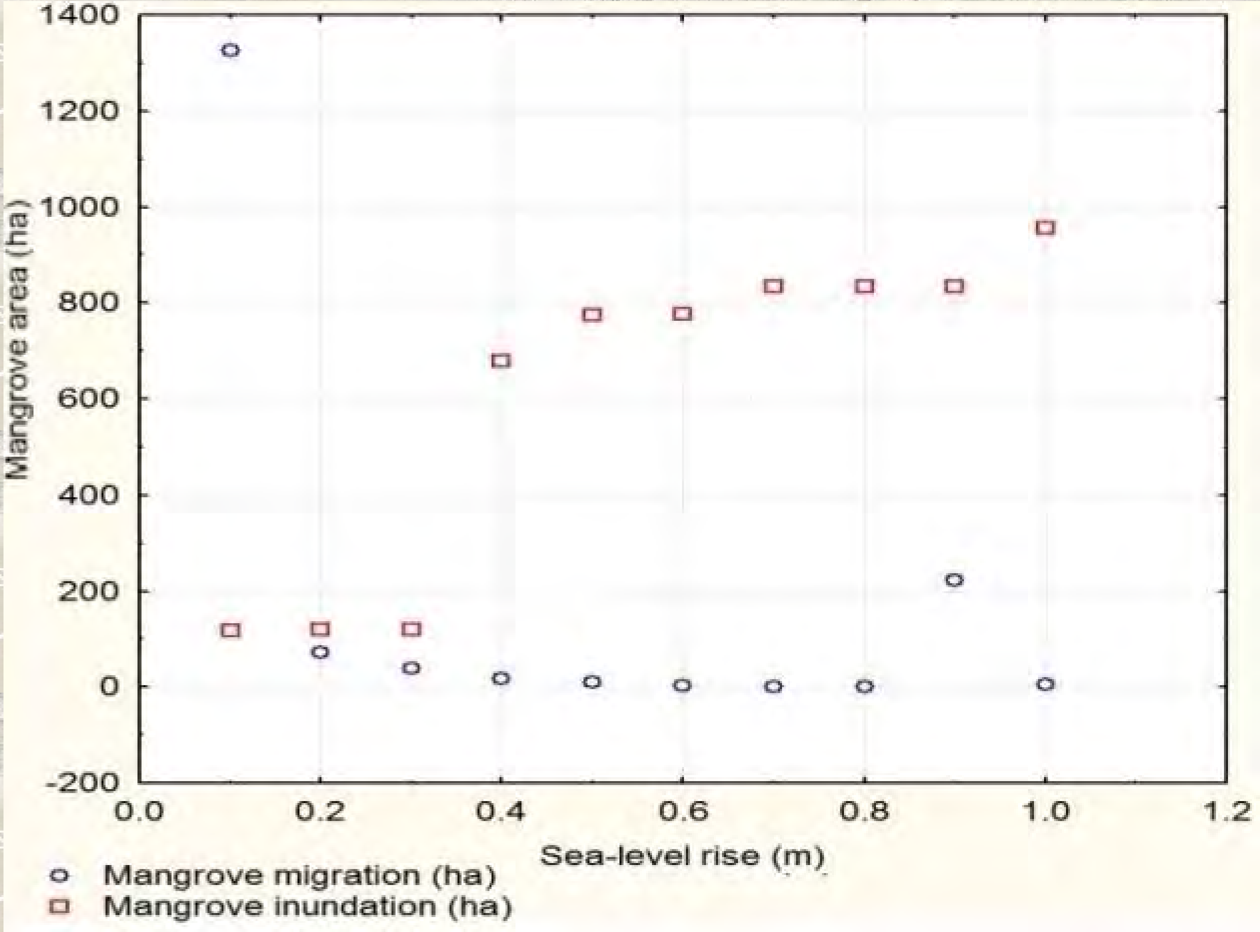
Results: Simulation of sea-level rise



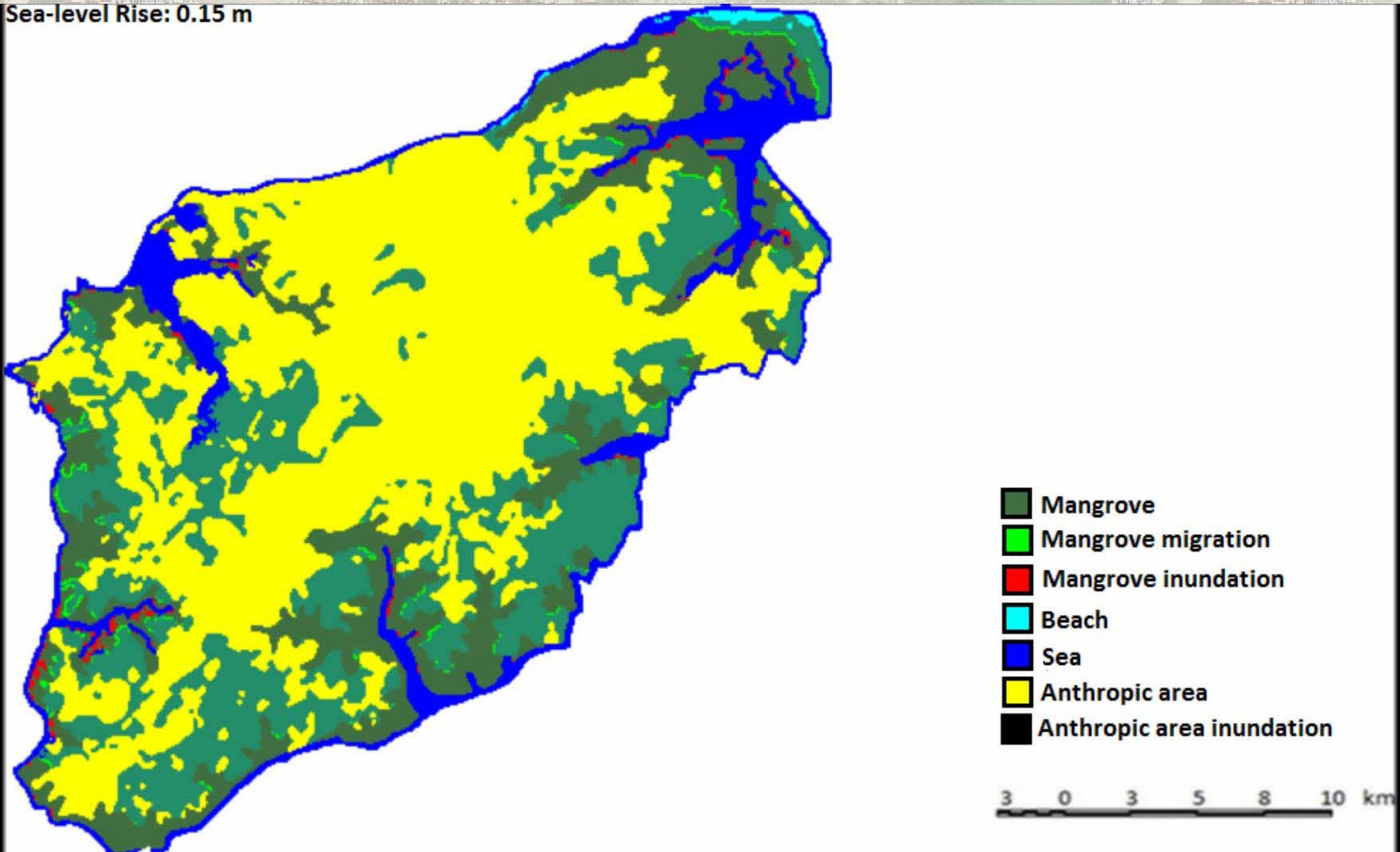
Results: Simulation of mangrove area



Results: mangrove migration and mangrove inundation.



Results: A little movie of the simulation



Final considerations

- The modelling experiment can be use to promote a better understanding of the mangrove responses to potencial events of sea-level rise;
- But one must take into consideration environmental and human factors;
- In this context, the human forms of use and occupation in adjacent areas to mangrove must be considered.

And last: the code

```
-- Sea-Level Rise Impacts on Mangrove Ecosystem
-- Case Study: Maranhão Island
-- Authors: Denilson da Silva Bezerra, Silvana Amaral, Milton Kampel, Pedro Ribeiro de Andrade
-- Project funded by CAPES
--
-- Cell States and Cell attributtes
SEE = 0
MANGROVE = 1
ANTHROPIC_AREA = 3
ANTHROPIC_AREA2 = 8
TERRESTRIAL_VEGETATION = 4
MANGROVE_SOIL = 4
MANGROVE_SOIL2 = 7
BEACH = 2
CHANNEL_RIVER = 2
MANGROVE_MIGRATION = 5
MANGROVE_INUNDATION = 6
--
-- Model Parameters
Area_cell = 1   -- Cell area in ha
Initial_time = 1 -- correspondent to 2013
Final_time = 88 --  correspondent to 2100
Tx_elev = 0.011 -- Rate of sea-level rise (m) in a scenario of increase of approximately 0.81 m by 2100 (IPCC, 2013, p.17).
Z = 6 -- Tide height on the Maranhão Island (Ferreira, 1988).
Year_initial = 2012
-----------------------------------------------------------------------------------------------------------------------------------------------
-- Database
cs = CellularSpace{
    dbType = "ADO",
    database = "D:\\Banco_mangue_4.2.0\\mangue.mdb",
    theme = "Cell_usos",
    select= { "Alt2", "ClasseUsos2", "ClasseSolos" }
    }
cs:createNeighborhood {
   strategy = "moore",
   self = false
}
cs:synchronize();
-----------------------------------------------------------------------------------------------------------------------------------------------
-- Legend
ClasseUsos2Leg = Legend{
    grouping = "uniquevalue",
    colorBar = {
        {value = SEE, color = "blue"},
        {value = MANGROVE, color = {66,111,66}},
        {value = BEACH, color = "cyan"},
        {value = ANTHROPIC_AREA, color = "yellow"},
        {value = ANTHROPIC_AREA2, color = {0,0,0}},
        {value = TERRESTRIAL_VEGETATION, color = {35,142,104}},
        {value = MANGROVE_MIGRATION, color = {0,255,0}},
        {value = MANGROVE_INUNDATION, color = "red"}
    }
}
```

And last: the code

```
-- Observers
 obsMap = Observer{ subject = cs, type = "map", attributes = {"ClasseUsos2"},legends = {ClasseUsos2Leg} }
-- obsMap = Observer{ subject = cs, type = "image", DB_HOME = TME_PATH .. "C:\\Program Files (x86)\\terrame", attributes = {"ClasseUsos2"},legends = {Cla
------------------------------------------------------------------------------------------------------------------------------------------------------------
-- Model Loop for sea-level rise
for time = Initial_time, Final_time, 1 do

    coord = Coord{x = 68, y = 132}
    cellreference = cs:getCell(coord)
    cellreference.Alt2 = 0,147705
    --
    Mangrove_area = MANGROVE or MANGROVE_MIGRATION -- Total area of mangrove in ha
    Mangrove_area_remaining = MANGROVE -- Area of remaining mangrove in ha
    Mangrove_area_inundation = MANGROVE_INUNDATION -- Mangrove inundation in ha
    Mangrove_area_migration = MANGROVE_MIGRATION -- Mangrove migration in ha
    SOIL2_AREA_progradation = MANGROVE_SOIL2 -- areas of progradation of mud (ha)
    ANTHROPIC_inundation = ANTHROPIC_AREA2
    --
    --
    forEachCell(cs, function(cell)
        -- Simulation of the rising sea level
        if cell.ClasseUsos2 == SEE and cell.Alt2 >=0 then
            Increased_see = cell.Alt2 + (time * Tx_elev)
            -- Sea-level rise in the cell reference
            Elev_cellreference = cellreference.Alt2 + (time * Tx_elev)
            -- rate of vertical accretion of mud - Txa (in mm)
            Elev_mm = Elev_cellreference * 1000 -- Sea-level rise in mm
            Txa = 1.693 + (0.939 * Elev_mm) -- Equation proposed by Alongi (2008) with R2 = 0,704 and p < 0,001
            Txa_m = Txa / 1000 -- Txa in metrs
            -- Increment of the area of tidal influence
            Z_m = Z + Elev_cellreference
            -- Find the lowest neighbor
            countNeigh = 0
            forEachNeighbor(cell,   function(cell, neigh)
                if (cell.Alt2 >= neigh.Alt2) then
                    countNeigh = countNeigh + 1
                end
            end)
            --
            -- Simulating the advancement of mud banks
        if (cell.ClasseSolos == MANGROVE_SOIL or cell.ClasseSolos == CHANNEL_RIVER) and (neigh.ClasseSolos ~= MANGROVE_SOIL) then
            forEachNeighbor(cell, function(cell, neigh)
               if (neigh.Alt2 <= Z_m) and
               (neigh.ClasseUsos2 ~= SEE)then
                    neigh.ClasseSolos = MANGROVE_SOIL2
                    SOIL2_AREA_progradation = SOIL2_AREA_progradation + Area_cell
                end
            end)
        end
        --
```

And last: the code

```
        -- rate of vertical accretion of mud in each cell
        if (cell.past.ClasseSolos ~= MANGROVE_SOIL2 and cell.ClasseSolos == MANGROVE_SOIL2) or (cell.ClassesSolos == MANGROVE_SOIL) and
           (cell.ClasseUsos2 ~= SEE) then
            cell.Alt2 = cell.Alt2 + Txa_m
        end
        --
        -- Simulating the flow of water to the neighbors
        if (countNeigh > 0) then
        flux = Increased_see / countNeigh
        end
            --
        --
        -- Simulation of the inundation from neighboring
        if cell.ClasseUsos2 == SEE and neigh.ClasseUsos2 ~= SEE then
            forEachNeighbor(cell, function(cell, neigh)
                if  Increased_see >= (neigh.Alt2 + flux) then
                    neigh.ClasseUsos2 = SEE
                end
            end)
        end
        --
        --
      end
    end)
    --
    --End: Simulation of the sea-level rise
    ----------------------------------------------------------------------------------------------------------------------------------------------
    -- Simulation of mangrove migration
    forEachCell(cs, function(cell)
        if(cell.ClasseUsos2 == MANGROVE) then
            forEachNeighbor(cell, function(cell, neigh)
                 if (neigh.ClasseUsos2 ~= MANGROVE) then
                    if (Z_m >= neigh.Alt2) and
                       (neigh.ClasseUsos2 == TERRESTRIAL_VEGETATION) and
                       (neigh.ClasseSolos == MANGROVE_SOIL or MANGROVE_SOIL2) then
                             neigh.ClasseUsos2 = MANGROVE_MIGRATION
                    end
                end
            end)
        end
    end)
    --
    -- Simulation of mangrove inundation
    forEachCell(cs,function(cell)
        if (cell.past.ClasseUsos2 == MANGROVE or cell.past.ClasseUsos2 == MANGROVE_MIGRATION) and cell.ClasseUsos2 == SEE then
        cell.ClasseUsos2 = MANGROVE_INUNDATION
        Mangrove_area_inundation = Mangrove_area_inundation + Area_cell
        end
    end)
    --
```

And last: the code

```
    -- Simulation of mangrove migration
    forEachCell(cs,function(cell)
        if cell.past.ClasseUsos2 == TERRESTRIAL_VEGETATION and cell.ClasseUsos2 == MANGROVE_MIGRATION then
        Mangrove_area_migration = Mangrove_area_migration + Area_cell
        end
    end)
    --
    -- Simulation of remaining mangrove
    forEachCell(cs,function(cell)
        if cell.past.ClasseUsos2 == MANGROVE and cell.ClasseUsos2 == MANGROVE then
        Mangrove_area_remaining = Mangrove_area_remaining + Area_cell
        end
    end)
    --
    -- Simulation of total area (mangrove)
    forEachCell(cs,function(cell)
        if (cell.ClasseUsos2 == MANGROVE or
        cell.ClasseUsos2 == MANGROVE_MIGRATION) then
        Mangrove_area = Mangrove_area + Area_cell
        end
    end)
    --
    -- Simulation of anthropic area inundation
    forEachCell(cs,function(cell)
        if cell.past.ClasseUsos2 == ANTHROPIC_AREA and cell.ClasseUsos2 == SEE then
        cell.ClasseUsos2 = ANTHROPIC_AREA2
        ANTHROPIC_inundation = ANTHROPIC_inundation + Area_cell
        end
    end)
    Year = Year_initial + time
    --
    print("Year:", Year)
    print("Total area:", Mangrove_area)
    print("Remaining area:", Mangrove_area_remaining)
    print("Progration:",SOIL2_AREA_progradation)
    print("Vertical accretion:",Txa_m)
    print("Sea-level rise:",Elev_cellreference)
    print("Tide height:",Z_m)
    print("Mangrove migration:",Mangrove_area_migration)
    print("Mangrove inundation:",Mangrove_area_inundation)
    print("Anthropic area inundation:", ANTHROPIC_inundation)
    -- --
    --
--  if i == 88 then
--      cs:save(i,"result","ClasseUsos")
--  end
    cs:notify()
end
print("Simulation performed with successfully")
```

Thank you very much!

denilson_ca@yahoo.com.br