Web-based Interactive Landform Simulation Model (WILSIM)

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http://www.niu.edu/landform
Outline

• My background
• Purposes of WILSIM
• WILSIM Model (how it works, linear, nonlinear versions)
• Graphical User Interface
• Example results from different scenarios
• Summary
My Background

• Current position
  – Associate Professor, Dept. of Geography, NIU

• Research Interests
  – Geomorphology and Hydrology
    • Martian drainage patterns and paleoclimate implications
    • Quantitative analysis of DEM data
    • Computer simulation of landform evolution
    • Basin morphometry and hydrologic response
  – GIS applications
  – Web-based technology in enhancing teaching and learning

http://www.niu.edu/landform
Introduction

• Landform evolution: an important aspect of earth sciences
  – involves multiple processes over long geologic time
• Ideal topic to train students about systems approach
• Long-term landform evolution cannot be observed directly
• Computer simulation is an ideal tool to teach
• Usually requires special programs or visualization software that is not easily accessible to students

http://www.niu.edu/landform
Purposes of WILSIM

• To provide an easily accessible tool that can improve learning through interactive exploring

• It should
  – simulate first order features resulted from multiple processes
  – be interactive, dynamic, visual, and fun
  – allow for exploration (what-if scenarios)
  – be accessible anywhere anytime, no installation
Visualization and Animation

• Need to see the landform change over time in 3D
• Options:
  – The Virtual Reality Markup Language (VRML)
    • Dynamic changes of complex scene geometry not allowed
  – Java 3D
    • Not available for all computing environments
  – Java Applet
    • Platform independent (write once, run anywhere)
    • 2D
• Choose Java Applet
  – custom renderer to show 3D animation
WILSIM: how it works
(cellular automata algorithm)

- Drop storm event (precipiton) randomly onto a cell of a topographic grid (#1)
- Cause local diffusion at its 4 direct neighboring cells (#3, #5, #7, and #9)
- Erode material from current cell (#1) and move to lowest neighbor (#2)
- Continue to move to the lowest neighboring cell and erode along the way until it reaches the edge of the grid, lands in a pit or its carrying capacity is exceeded
- Start a new precipiton and iterate hundreds of thousands of times

(Figure adapted after Chase, 1992)
WILSIM: linear version

- Amount of erosion is proportional to local slope and erodibility
  \[ P_e = c \times e \times s \]  
  where \( P_e \) is the maximum possible erosion; 
  \( c \) is proportional constant; 
  \( e \) is the erodibility of material in current cell; 
  \( s \) is local slope of current cell;

- Precipitons are independent of each other
WILSIM: non-linear version

• Amount of erosion

\[ P_e = c \times e \times a^{n-1} \times s^m \]  \hspace{1cm} (2)

where \( P_e \) is the maximum possible erosion;
\( c \) is proportional constant;
\( e \) is the erodibility of material in current cell;
\( a \) is contributing area to current cell;
\( s \) is local slope of current cell;
\( m \) and \( n \) are exponent coefficients.

• When \( m=n=1 \), Eq. (2) becomes Eq. (1)
WILSIM: non-linear version (cont’d)

• Contributing Area $a$
  – Run D8 algorithm before each iteration

<table>
<thead>
<tr>
<th>12</th>
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<td>6</td>
<td>8</td>
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- elevation

| ≤ | } | } | } | ≤ |
|   |   |   |   |   |

- flow direction

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<tr>
<td>14</td>
<td>2</td>
<td>1</td>
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<td>11</td>
</tr>
</tbody>
</table>

- contributing area

• Precipitons are now inter-related
  – Previous erosion leads to larger $a$
  – Precipitons tend to follow previous path (ants)

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Graphical User Interface

**Total Iterations:**
**# iterations processed:**

**Initial Conditions**

- **Grid Size:**
  - \( x_{\text{max}} = 60 \)
  - \( y_{\text{max}} = 100 \)

- **End Time:**
  - \# of iterations = 100000

- **Topography:**
  - slope = 0.01

**Advanced Options**

- **Profiles**
- **Hypsometric**
- **Fractal**

**Initial Conditions Parameters**

Select the change you want to make and you will see a horizontal summary joining the radio button and the slider on the right. Use the slider to choose new values:

1. **Grid Size,**
   - This option is used to change the size of the topographic grid
   - a. select \( x_{\text{max}} \) for changing the width of the grid (number of columns).
     - default: 60  minimum: 10  maximum: 100
   - b. select \( y_{\text{max}} \) for changing the length of the grid (number of rows).
     - default: 100  minimum: 100  maximum: 200

2. **End Time,**
   - This option is used to choose number of iterations desired
     - default: 100,000  minimum: 100,000  maximum: 1,000,000
Graphical User Interface (cont’d)

ERODIBILITY PARAMETERS

Select the change you want to make and you will see a horizontal joining the radio button and the slider on the right. Use the slider to choose new values:

1. Uniform,
   This option is used to set a uniform erosion value for the whole topographic grid.
   default: 0.05  minimum: 0.01  maximum: 0.05

2. Break at x,
   This option is used to choose a break point at a certain column
   default: 0  minimum: 0  maximum: max # of columns
   Then, choose the erodibility value for the grid cells on the left and right side of the break point.
   default: 0.05  minimum: 0.01  maximum: 0.05
Graphical User Interface (cont’d)

Select the change you want to make and you will see a horizontal green line joining the radio button and the slider on the right. Use the slider to choose new values:

1. Constant,
   - This option is used to set a constant rainfall rate for the whole duration of the simulation
   - default: 0.10  minimum: 0.05  maximum: 0.15

2. Increasing,
   - This option is used to set the rainfall rate to increase linearly (from minimum to maximum) with time (iterations)
   - A low value should be set:
     - default: 0.05  minimum: 0.05  maximum: 0.14
   - A high value should be set:
     - default: 0.06  minimum: 0.06  maximum: 0.15

***HIGH value should be greater than LOW value***
Graphical User Interface (cont’d)

Select the change you want to make and you will see a horizontal joining the radio button and the slider on the right. Use the slider to choose new values:

1. **Fixed at 0**, This option is used to set uplift rate as 0, i.e., no uplift
2. **Break at x**, This option is used to choose a break point at a certain column
   
   default: 0  minimum: 0  maximum: max # of columns

   Then, choose an uplift rate for grid cells either on the left side or the right side of the break point.
   
   default: 0.0000  minimum: 0.0000  maximum: 0.0003

3. **Break at y**, This option is used to choose a break point at a certain row.
   
   default: 0  minimum: 0  maximum: max # of rows
Graphical User Interface (cont’d)
Graphical User Interface (cont’d)

(Hypsometric curve of the whole simulation grid)
Graphical User Interface (cont’d)
### Constant Erodibility, Constant Climate & No Tectonic Uplift

**Linear Model**

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Snapshots</th>
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<tbody>
<tr>
<td>Image will display after 25% iterations</td>
<td>Image will display after 50% iterations</td>
</tr>
<tr>
<td><img src="image1" alt="Elevation Map" /></td>
<td><img src="image2" alt="Elevation Map" /></td>
</tr>
<tr>
<td><strong>PARAMETERS:</strong></td>
<td><strong>PARAMETERS:</strong></td>
</tr>
<tr>
<td>Grid Size: 100 rows, 60 cols</td>
<td>Grid Size: 100 rows, 60 cols</td>
</tr>
<tr>
<td>Init Slope: 1.0%</td>
<td>Init Slope: 1.0%</td>
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<tr>
<td>Exp. Coeff.: n=1.0, m=1.0</td>
<td>Exp. Coeff.: n=1.0, m=1.0</td>
</tr>
<tr>
<td>Erodibility: uniform: 0.05</td>
<td>Erodibility: uniform: 0.05</td>
</tr>
<tr>
<td>Rainfall: constant: 0.1</td>
<td>Rainfall: constant: 0.1</td>
</tr>
<tr>
<td>Tect. uplift: no uplift</td>
<td>Tect. uplift: no uplift</td>
</tr>
</tbody>
</table>

| Image will display after 75% iterations | Image will display after 100% iterations |
| ![Elevation Map](image3) | ![Elevation Map](image4) |
| **PARAMETERS:** | **PARAMETERS:** |
| Grid Size: 100 rows, 60 cols | Grid Size: 100 rows, 60 cols |
| Init Slope: 1.0% | Init Slope: 1.0% |
| Exp. Coeff.: n=1.0, m=1.0 | Exp. Coeff.: n=1.0, m=1.0 |
| Erodibility: uniform: 0.05 | Erodibility: uniform: 0.05 |
| Rainfall: constant: 0.1 | Rainfall: constant: 0.1 |
| Tect. uplift: no uplift | Tect. uplift: no uplift |
Constant Erodibility, Constant Climate & No Tectonic Uplift

Non-Linear Model

**PARAMETERS:**
- Grid Size:
  - rows: 100
  - cols: 60
- Init Slope: 1.0%
- Exp. Coeff.:
  - n: 1.2
  - m: 1.2
- Erodibility: uniform 0.05
- Rainfall: constant 0.1
- Tect. uplift: no uplift

**PARAMETERS:**
- Grid Size:
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  - cols: 60
- Init Slope: 1.0%
- Exp. Coeff.:
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  - m: 1.2
- Erodibility: uniform 0.05
- Rainfall: constant 0.1
- Tect. uplift: no uplift
Constant Erodibility, Constant Climate & Tectonic Uplift

Linear Model

Image will display after 25% iterations

Image will display after 50% iterations

Image will display after 75% iterations

Image will display after 100% iterations
Different Erodibility, Constant Climate & Tectonic Uplift
Linear Model

Image will display after 25% iterations

Image will display after 50% iterations

Grid Size:
rows: 100
cols: 50
Init Slope:
1.0%
Exp. Coeff.:
n: 1.0
m: 1.0
Erodibility:
break at x:
L: 0.01
R: 0.05
Rainfall:
constant: 0.1
Tect. uplift:
T: 1.0E-4

Image will display after 75% iterations

Image will display after 100% iterations

Grid Size:
rows: 100
cols: 50
Init Slope:
1.0%
Exp. Coeff.:
n: 1.0
m: 1.0
Erodibility:
break at x:
L: 0.01
R: 0.05
Rainfall:
constant: 0.1
Tect. uplift:
T: 1.0E-4
Different Erodibility, Constant Climate & Tectonic Uplift
Non-Linear Model

Image will display after 25% iterations

Image will display after 50% iterations

Image will display after 75% iterations

Image will display after 100% iterations

Grid Size:
rows: 100
cols: 50
Init Slope:
1.0%
Exp. Coeff.:
n: 1.2
m: 1.2
Erodibility:
break at x:
L: 0.01
R: 0.05
Rainfall:
constant: 0.1
Tect. uplift:
T: 1.0E-4
Constant Erodibility, Increasingly Drier Climate & Tectonic Uplift

Linear Model
## Constant Erodibility, Increasingly Drier Climate & Tectonic Uplift
### Non-Linear Model

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<td>Erodibility: uniform: 0.05</td>
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</tr>
<tr>
<td>Rainfall: decreasing: lo: 0.05, hi: 0.15</td>
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<tr>
<td>Tect. uplift: T: 1.0E-4</td>
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| ![Image](http://www.niu.edu/landform) | ![Image](http://www.niu.edu/landform) |
| Grid Size: rows: 100, cols: 50 | Grid Size: rows: 100, cols: 50 |
| Init Slope: 1.0% | Init Slope: 1.0% |
| Exp. Coeff.: n: 1.2, m: 1.2 | Exp. Coeff.: n: 1.2, m: 1.2 |
| Erodibility: uniform: 0.05 | Erodibility: uniform: 0.05 |
| Rainfall: decreasing: lo: 0.05, hi: 0.15 | Rainfall: decreasing: lo: 0.05, hi: 0.15 |
| Tect. uplift: T: 1.0E-4 | Tect. uplift: T: 1.0E-4 |
Summary

• Comparing with the linear version, the nonlinear version of WILSIM more faithfully simulates natural erosion processes
  – Results look more realistic:
  – More integrated drainage networks and extending further upstream
  – More incision in valleys in the uplifting block and more escarpment retreat
  – Rougher surface (higher fractal dimension)
• WILSIM can help enhance the learning of landform evolution processes and concepts through its visualization and exploration capability
• Accessible anywhere, easy to use, no installation
• Limitations
  – Simplified model of real world
  – Scale (spatial, temporal) needs to be calibrated


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