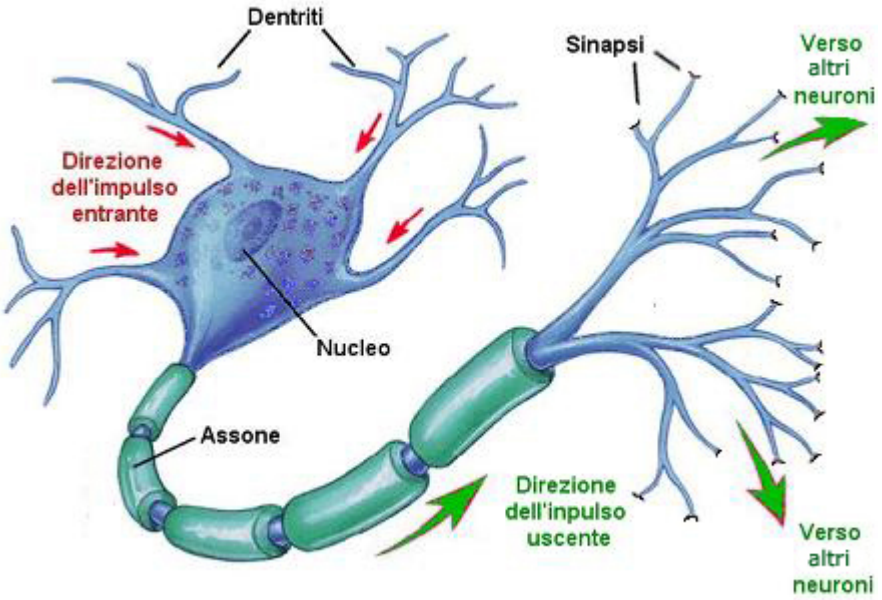
Fundamentals of Cellular Automata Theory and Applications to Hydrological Modeling

M. Verdecchia – ICTP Trieste May, 8 2013

Two observations:

•Nature DOES NOT use complex algorithms to produce complex behavior

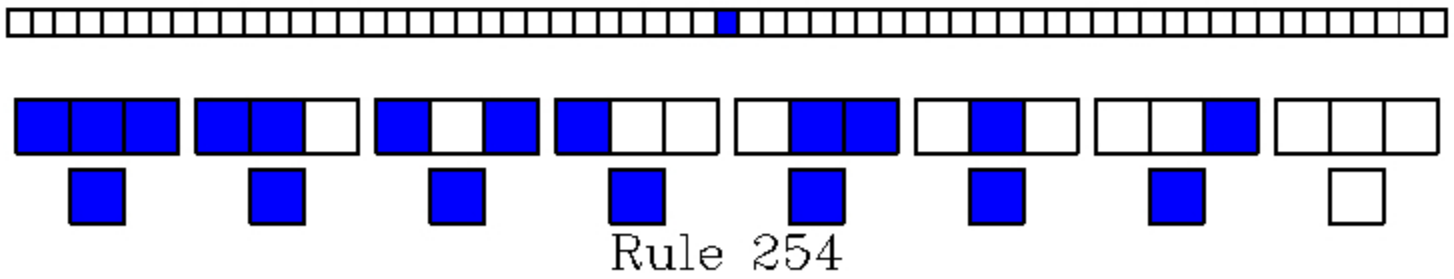
•Many biological systems made with many singular parts seem to have a collective behavior



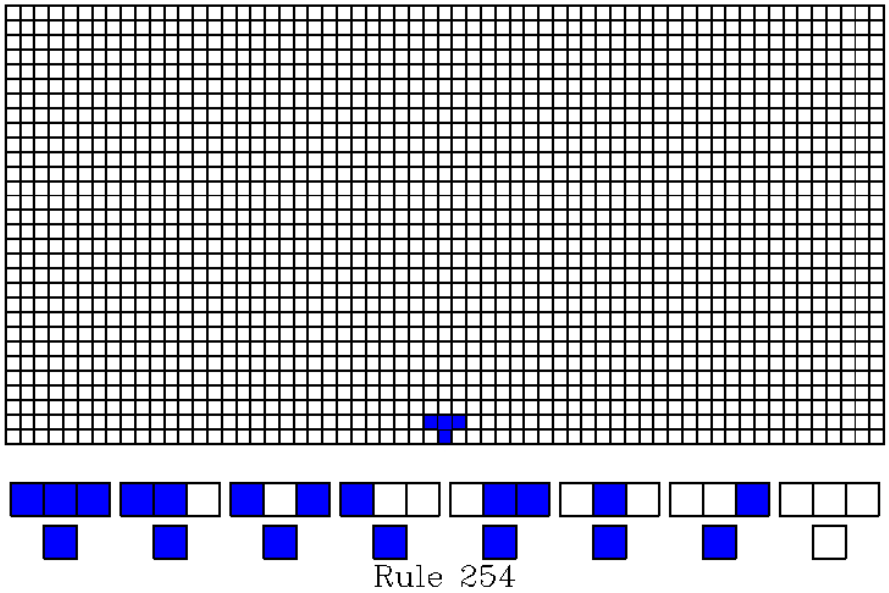
The crucial experiment:

What happen if we create a program without any specific task in mind?

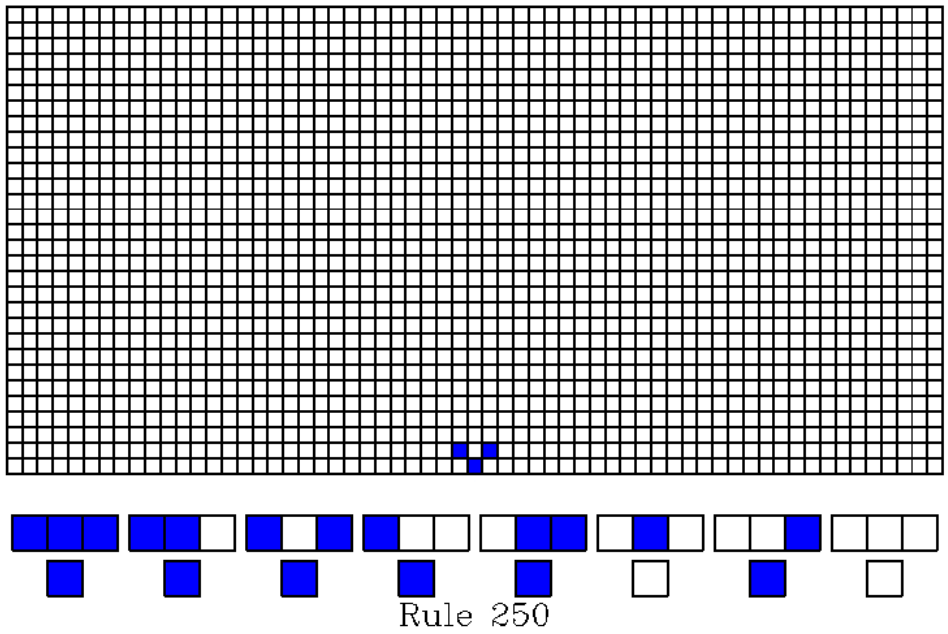
Definition of simple Cellular Automata System



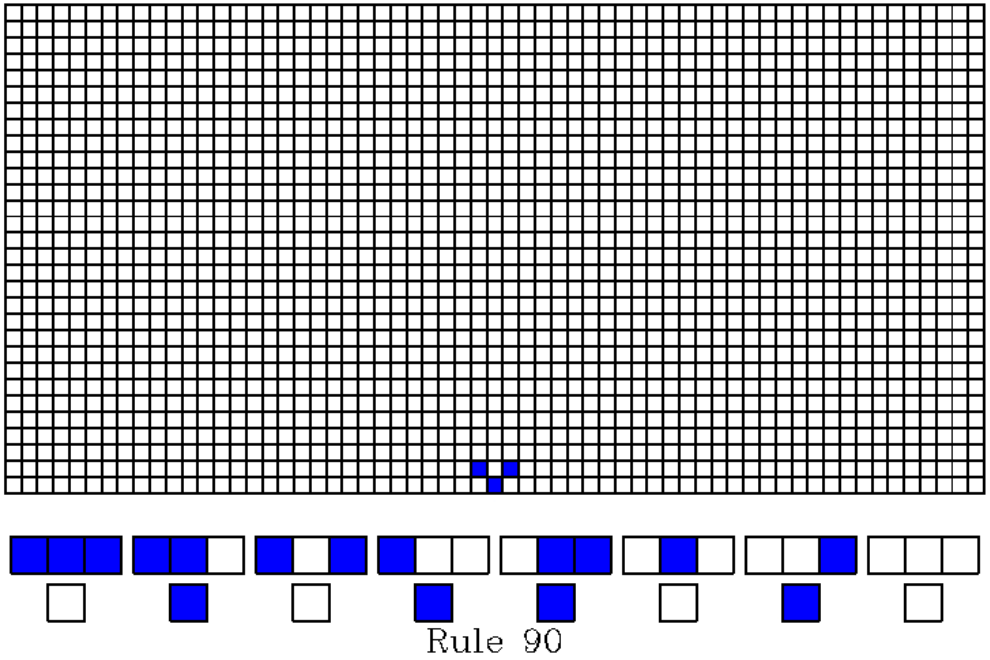
A first experiment with rule 254



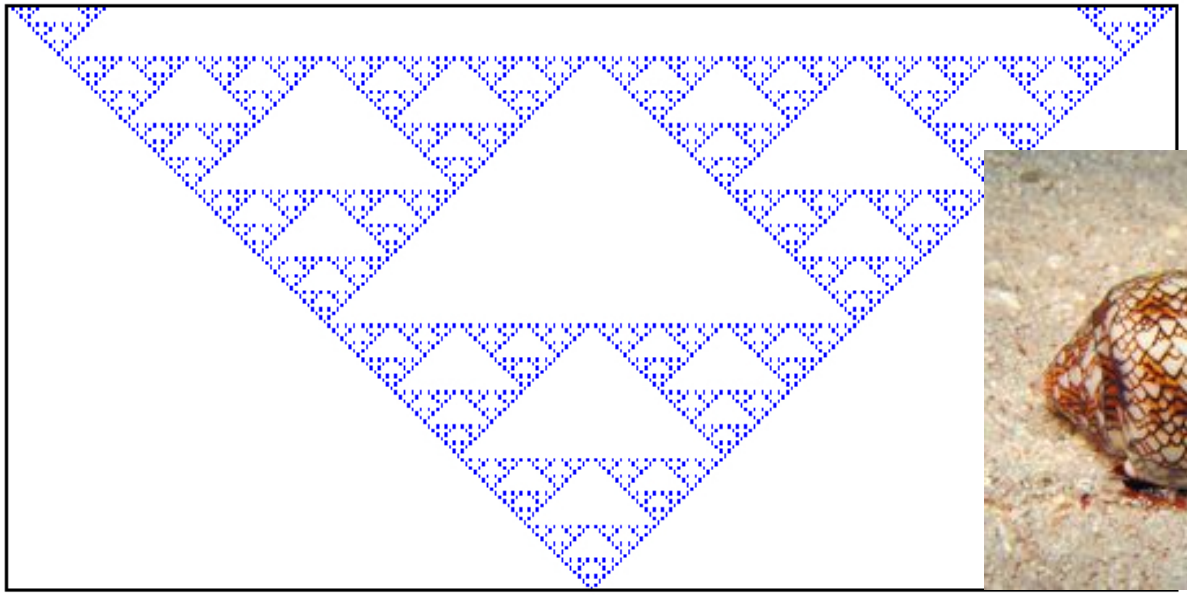
Rule 250

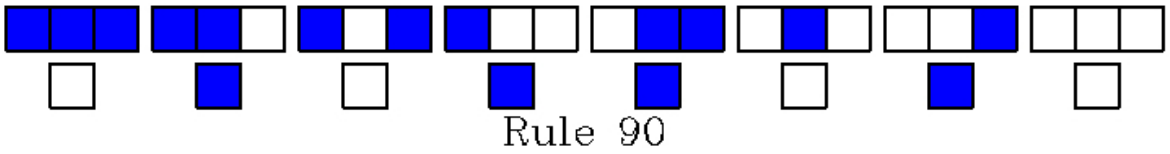


Rule 90

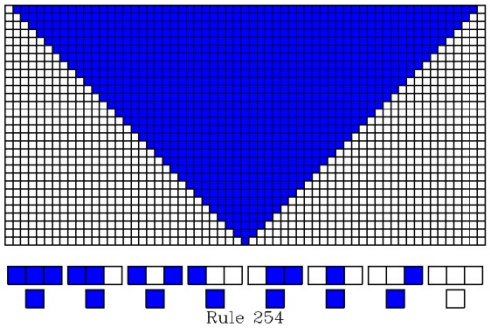


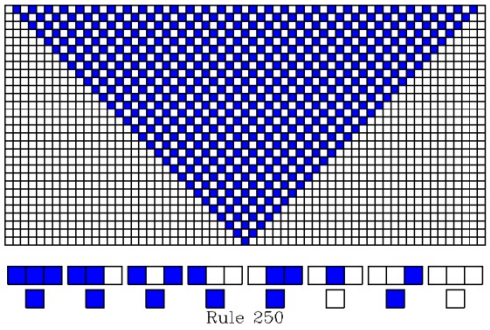
Rule 90

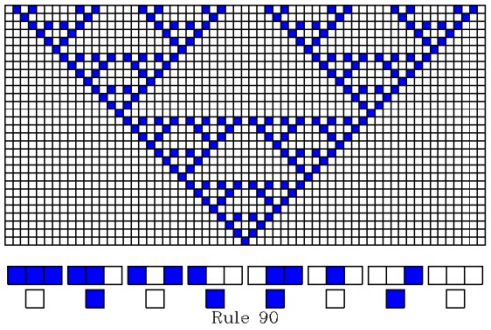




A first conclusion: starting from a very simple configuration, the different rules produce regular o periodic patterns

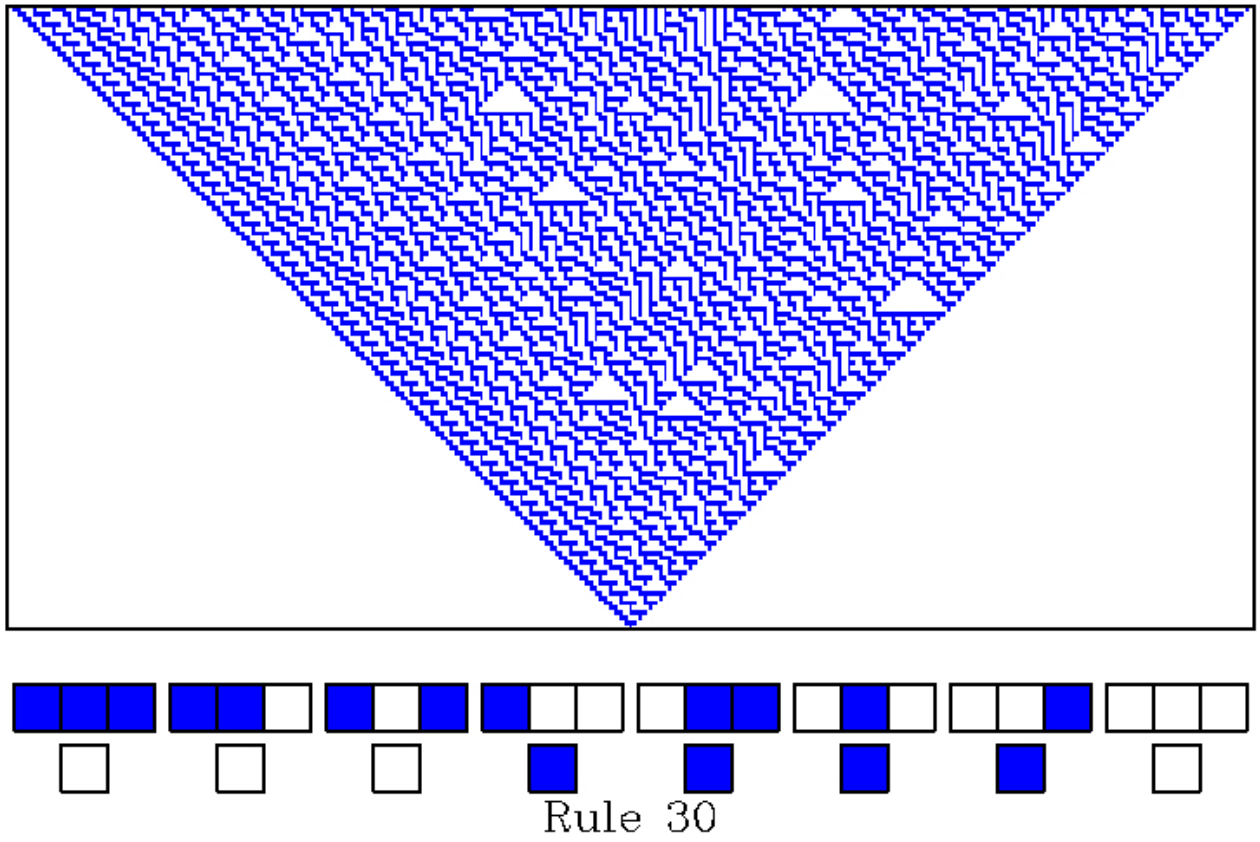




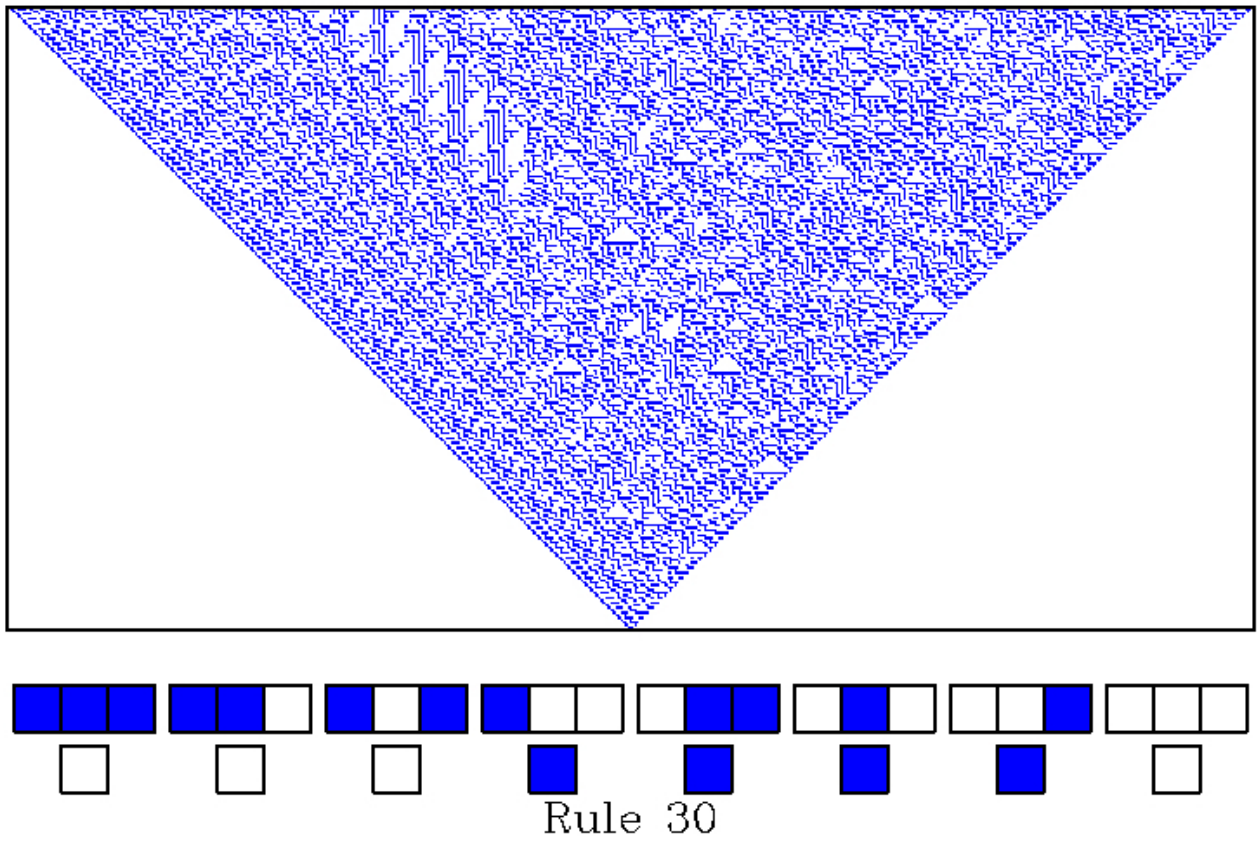


False!

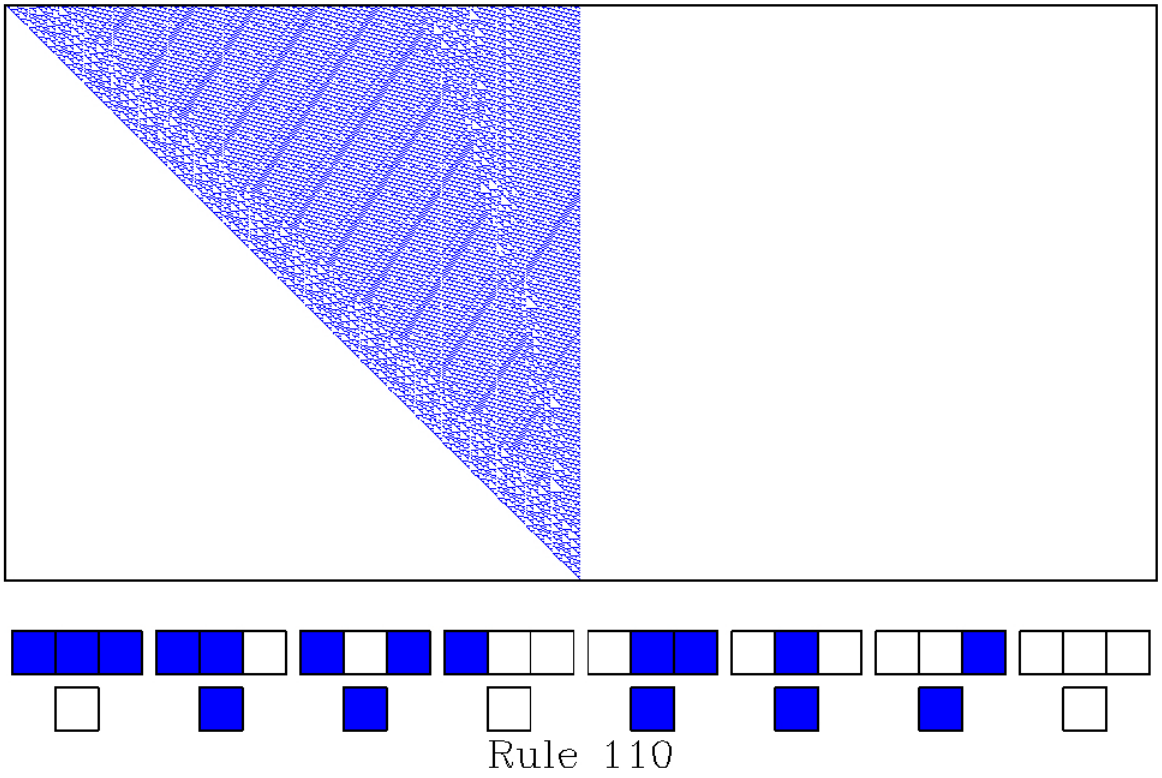
Rule 30



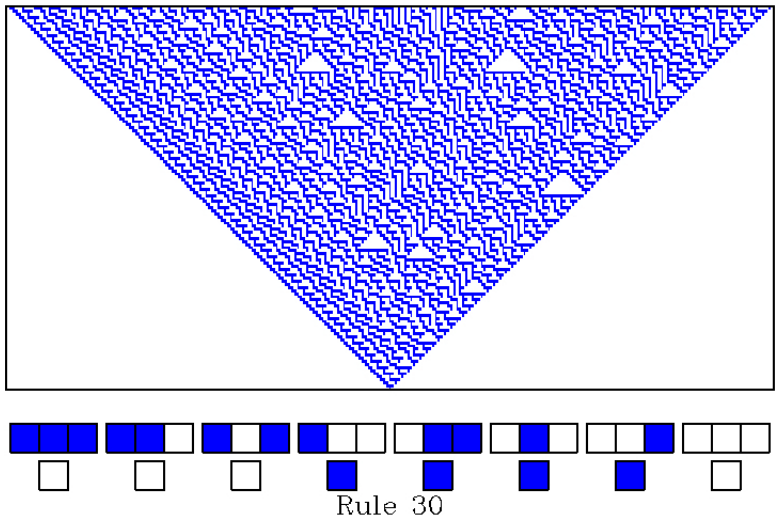
Rule 30

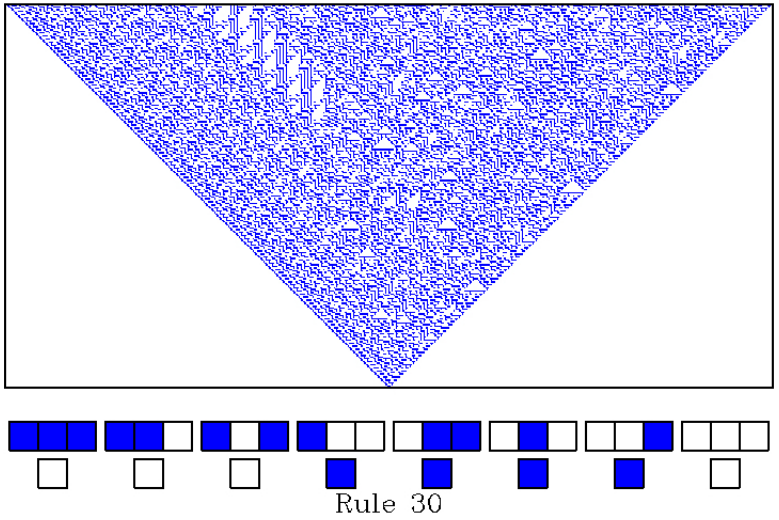


Rule 110



A first conclusion: starting from a very simple configuration and simple rules also complex behavior emerges





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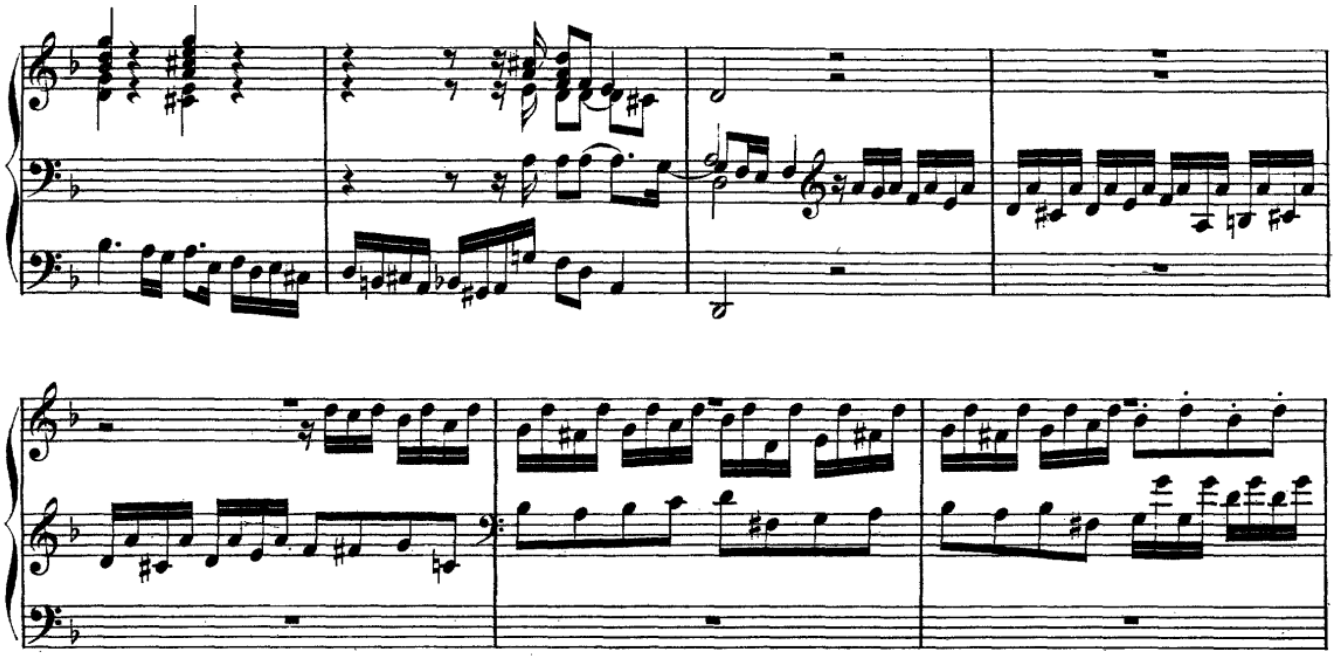


A very ambitious question: when we solve a differential equation in a numerical model , we "simply" discretize an equation written for a continuous system

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_c$$

Can this approach be considered the best one? Or we may investigate to find the "Best Rule" giving the discharge in a cell of the model from the "status" of the closed cells?

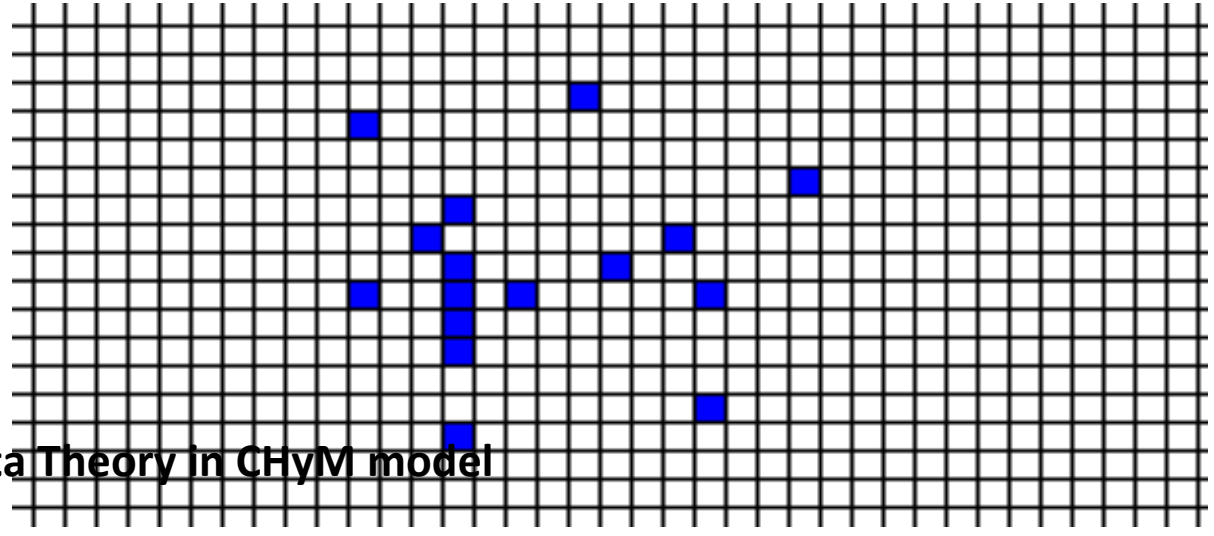
The question is indeed very good… the answer not yet…

Introduction to Cellular Automata Theory
End of Part 1

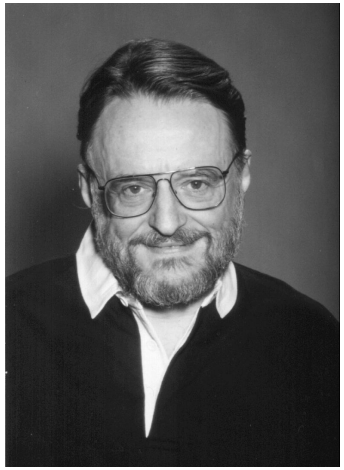
Part 2. Applications of CA theory

Formal definition of 2D Cellular Automata

- ✓ A cellular automaton is a discrete dynamical system
- ✓ Space, Time and States of the System automaton are discrete quantities
- ✓ Each point in a regular lattice, called cell, can have anyone of a finite number of states
- ✓ The state of the cells in the lattice are updated according to a local rule
- ✓ All the cells are updated synchronously

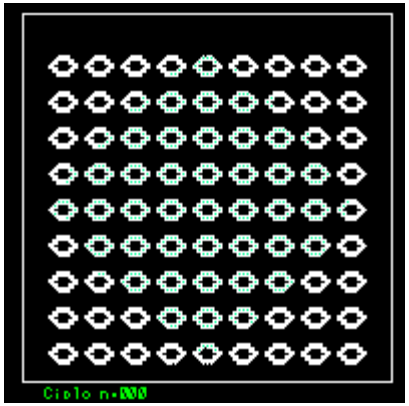


Applications of Cellular Automata Theory in CHyM model

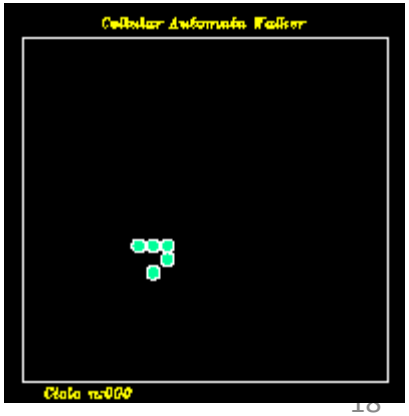


The game of life

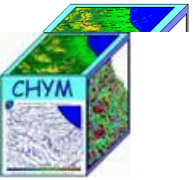
Life rules by Chris G. Langton



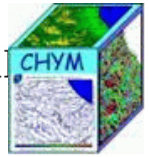
- The status of each CA can be ON or OFF
- If more than 3 CA in the neighborhood are ON CA became OFF
- If less than 2 CA in the neighborhood are ON, CA became OFF
- Otherwise CA became ON

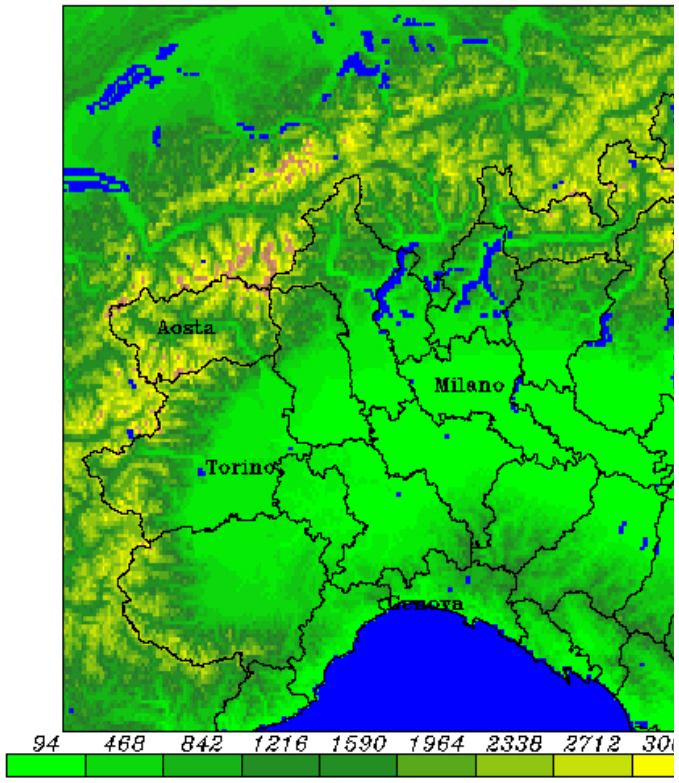


What happen when you run CHyM script?



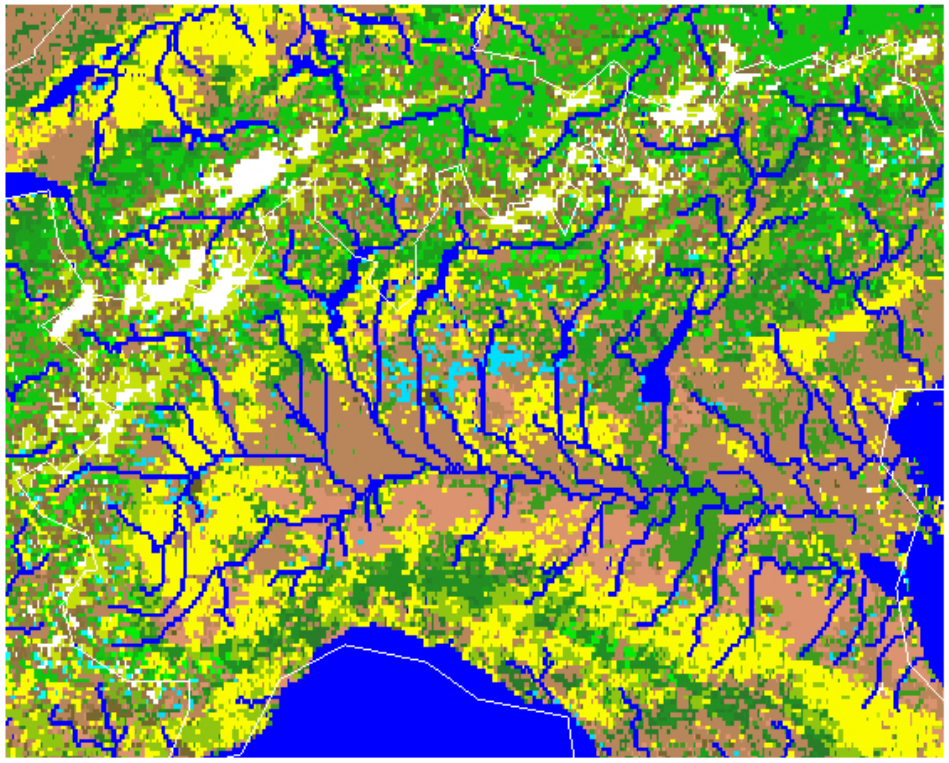
CETEMPS Hydrologica

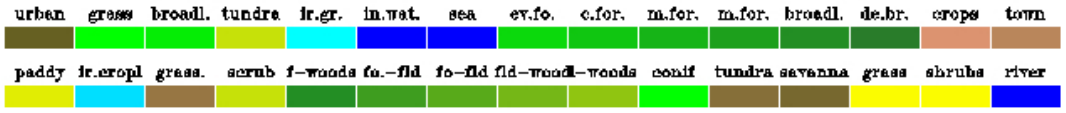




Digital Elevation Model – Approx. Res:

CETEMPS Hydrological Model (Land Use)





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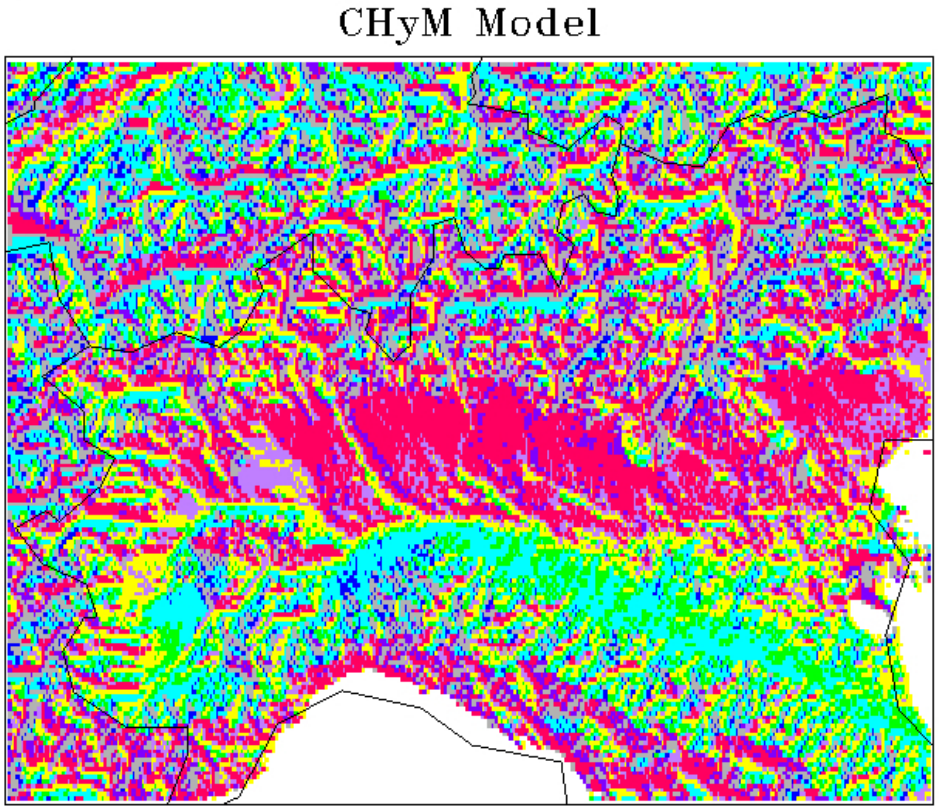
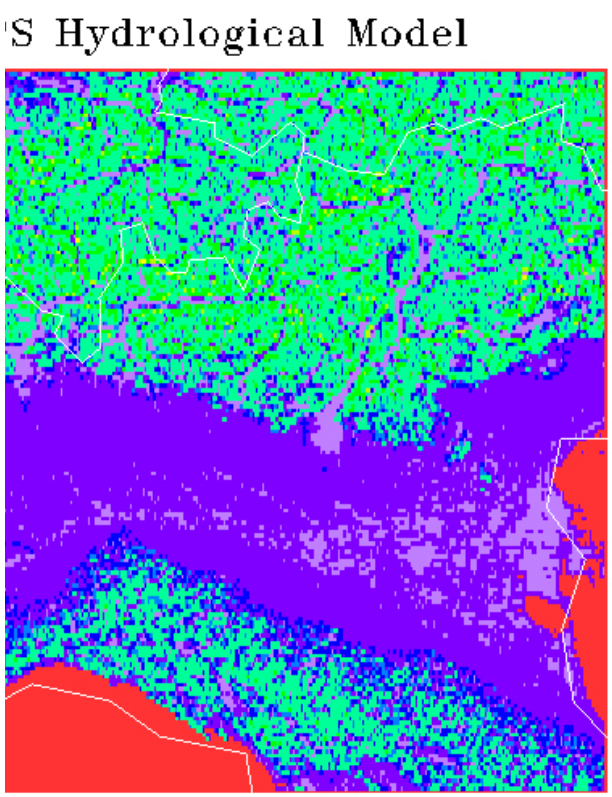
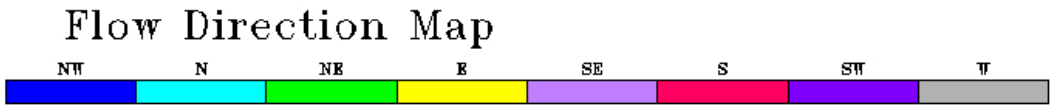
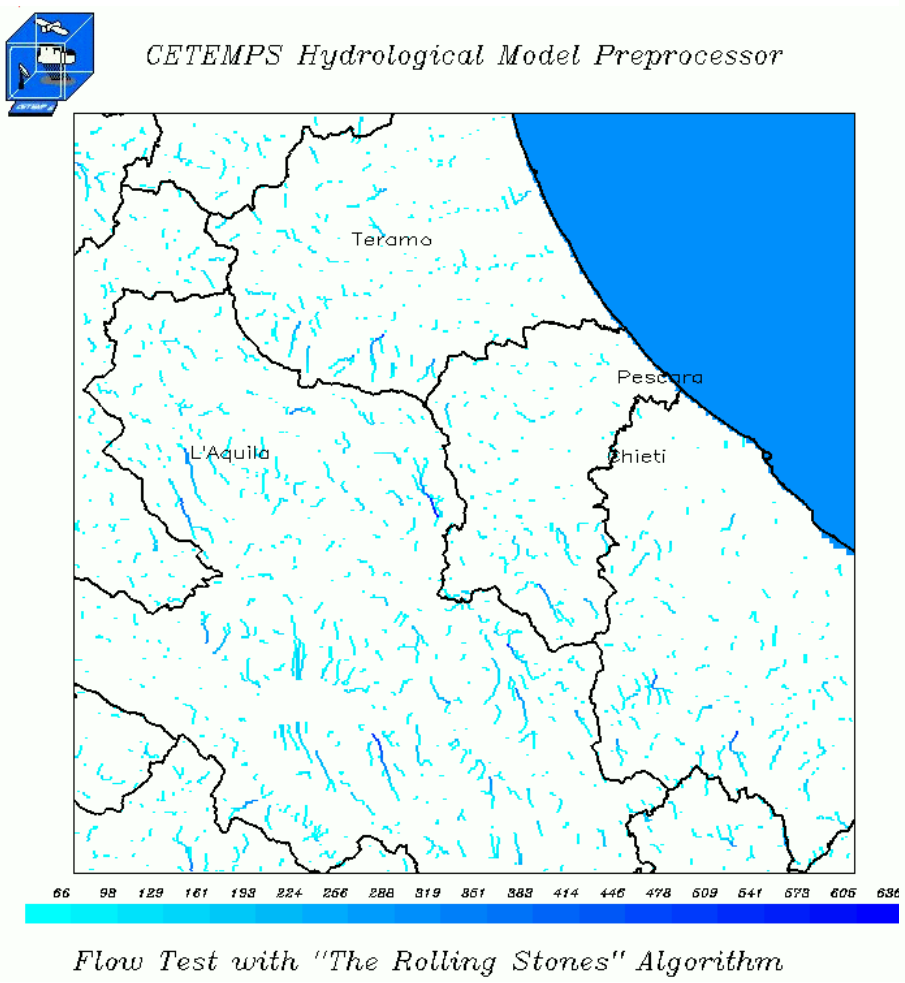
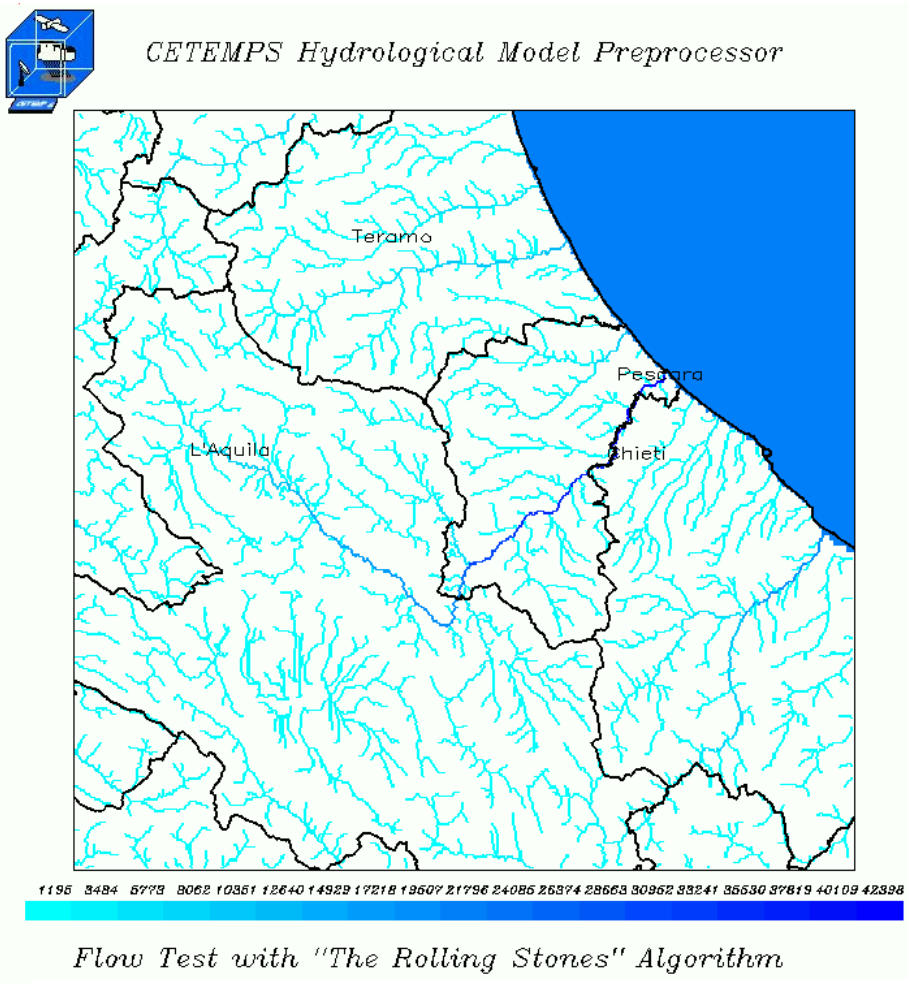






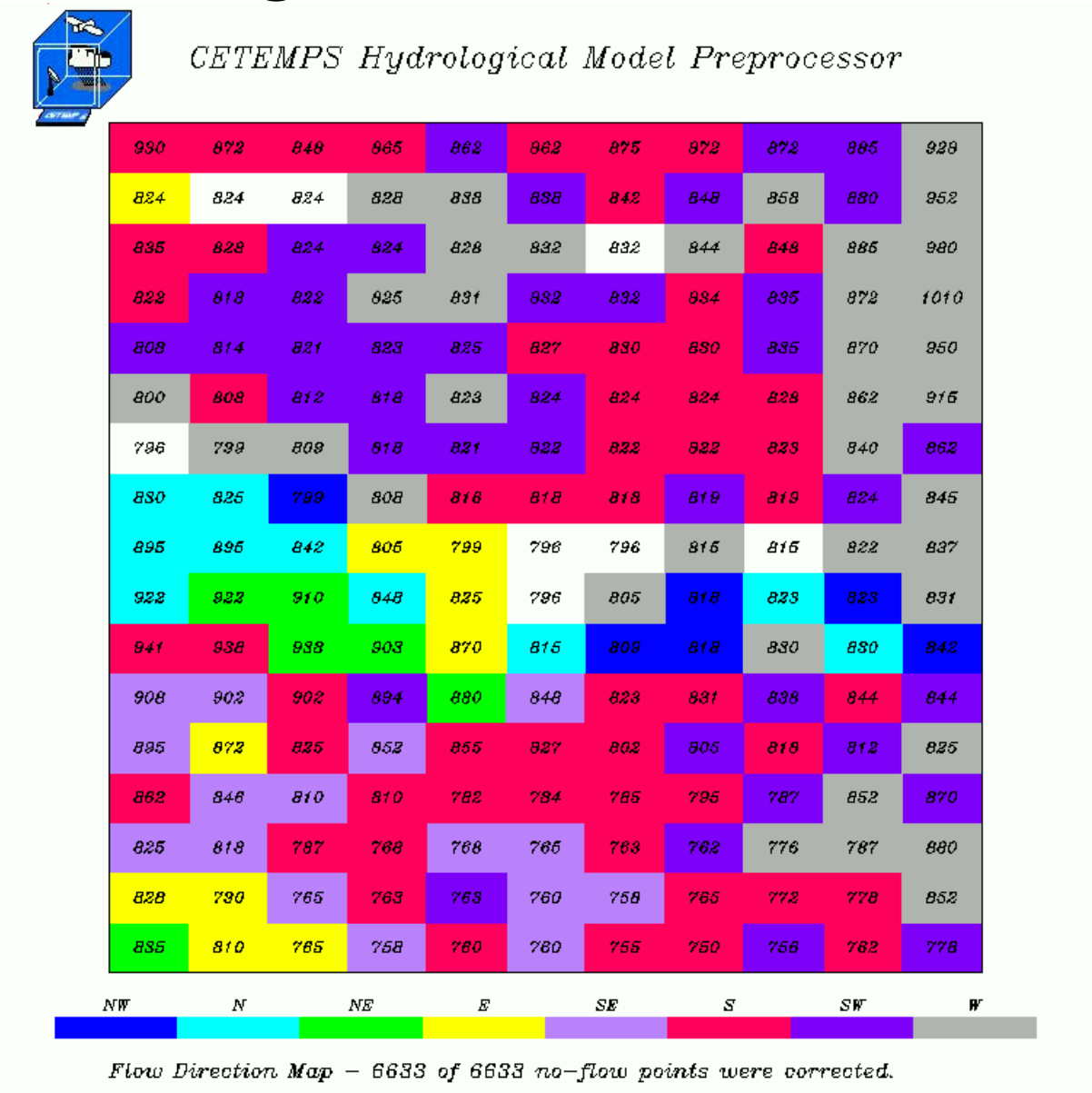
A first set of drainage network





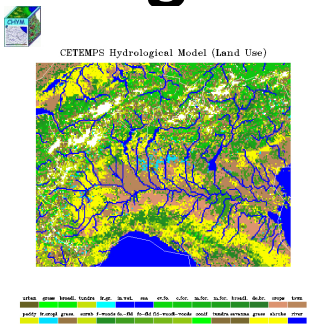
Applications of Cellular Automata Theory in CHyM model

DEM singularities



Applications of Cellular Automata Theory in CHyM model

CA concepts to correct DEM singularities

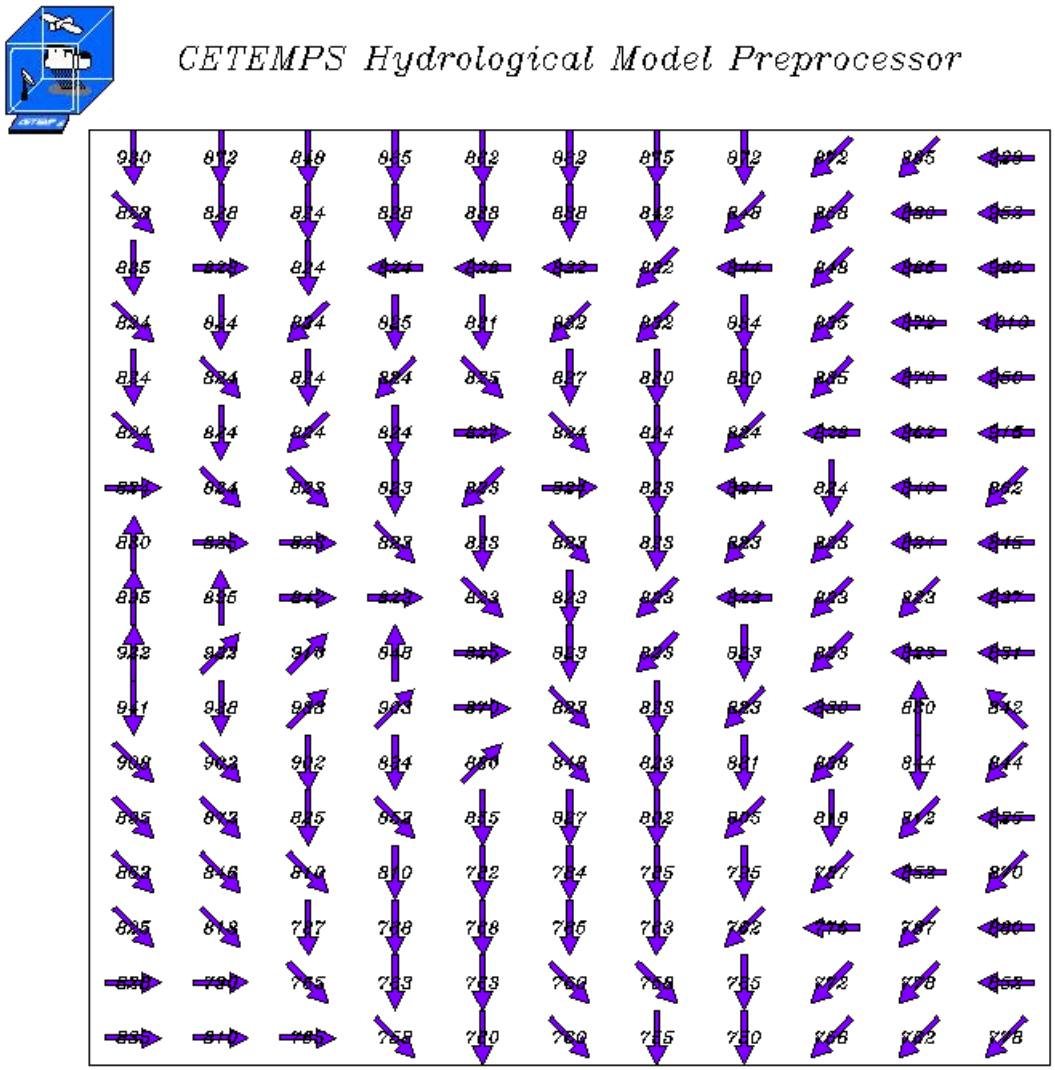


- ✓ CHyM grid is considered an aggregate of cellular automata
- ✓ The status of a cell corresponds to the value of a CHyM matrix (DEM)
- ✓ The state of the cells in the lattice is updated according to following rule

$$h_i \rightarrow h_i + \alpha\left(\sum_j^8 \beta_j (h_j - h_i)\right)$$

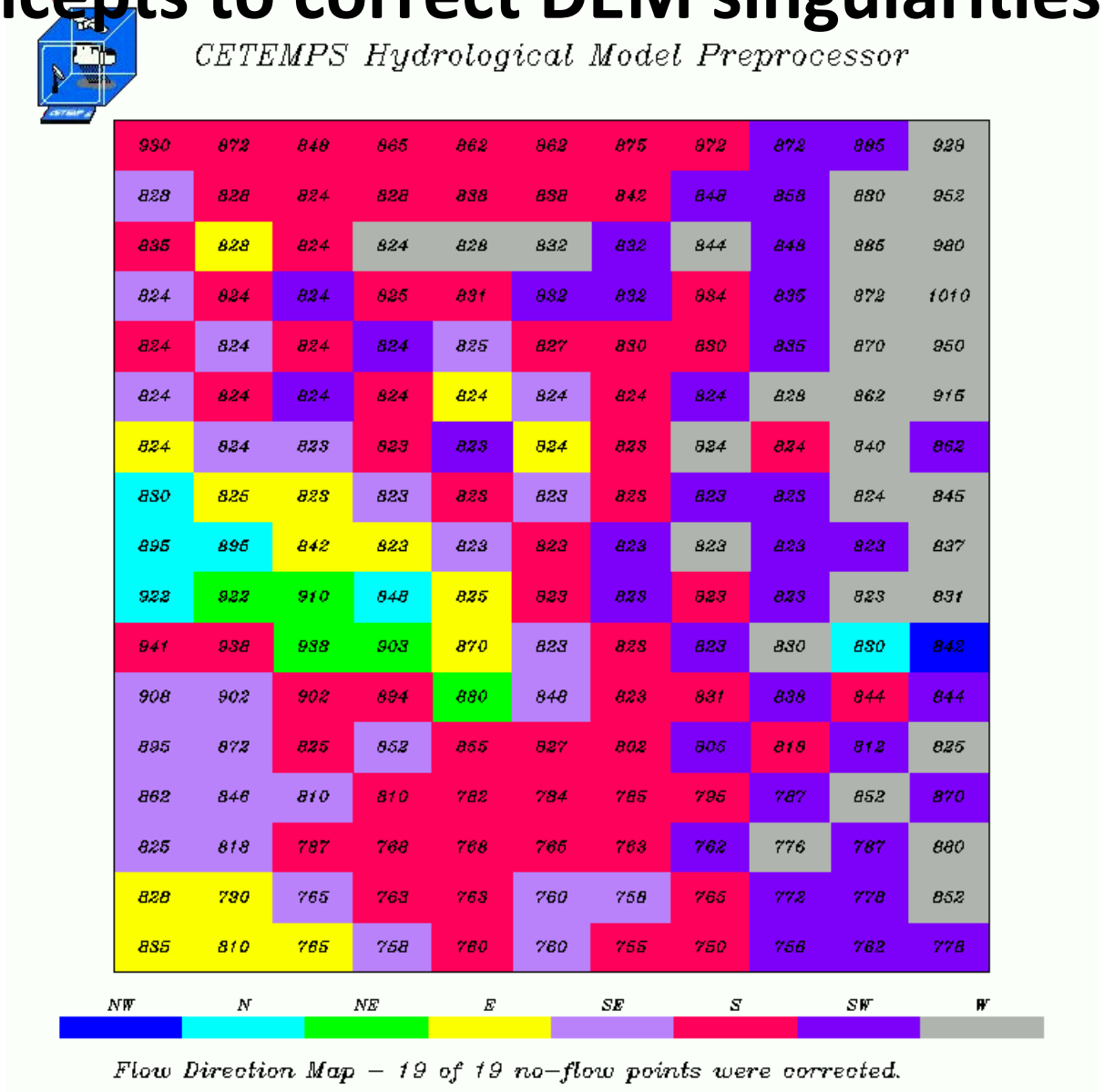
- ✓ All cells on the lattice are updated synchronously
- ✓ Update ends when flow scheme is OK

CA concepts to correct DEM singularities



Applications of Cellular Automata Theory in CHyM model

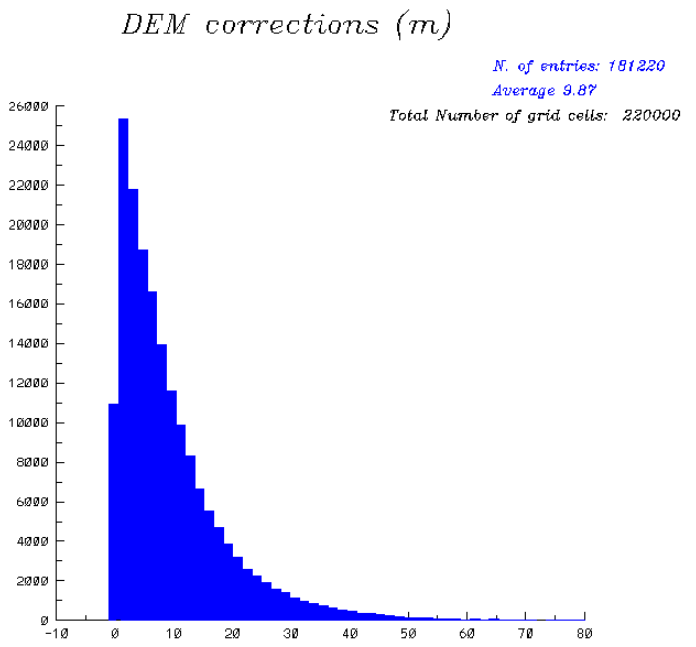
CA concepts to correct DEM singularities



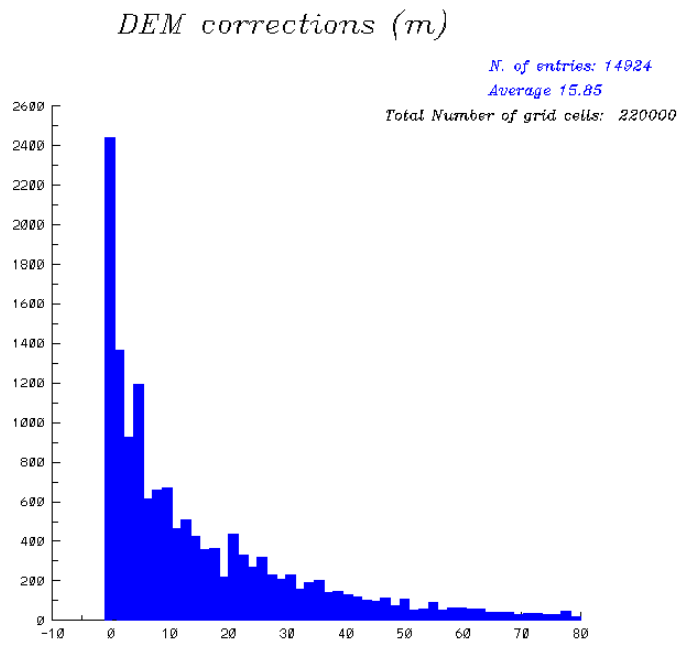
Applications of Cellular Automata Theory in CHyM model

Recipe for DEM pits and flat areas correction

- ❑Smooth DEM using CA rules until FD can be obtained for all the cells
- ❑Generate streamflow network using smoothed DEM
- ❑Use "true" DEM and modify ONLY the cells draining toward an higher cell

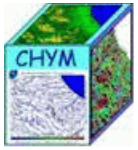


DEM Smooting Algorithm 1 (DSA1)

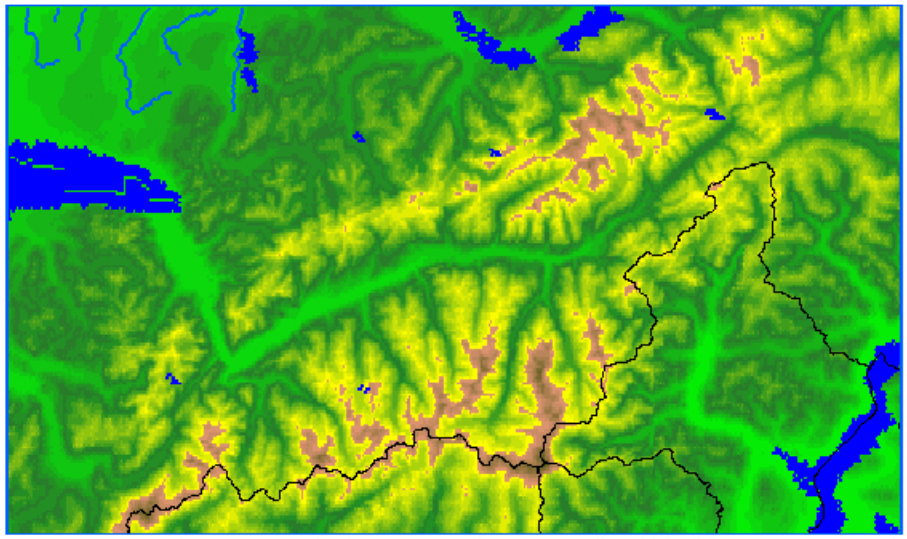


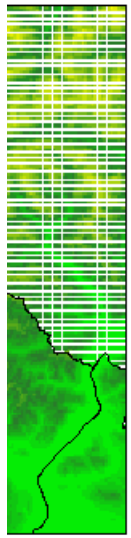
M Smooting Algorithm 2 (DSA2)

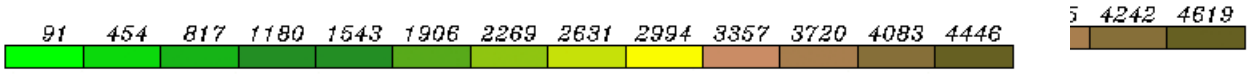
CA concepts to correct DEM singularities



CHyM river tracking



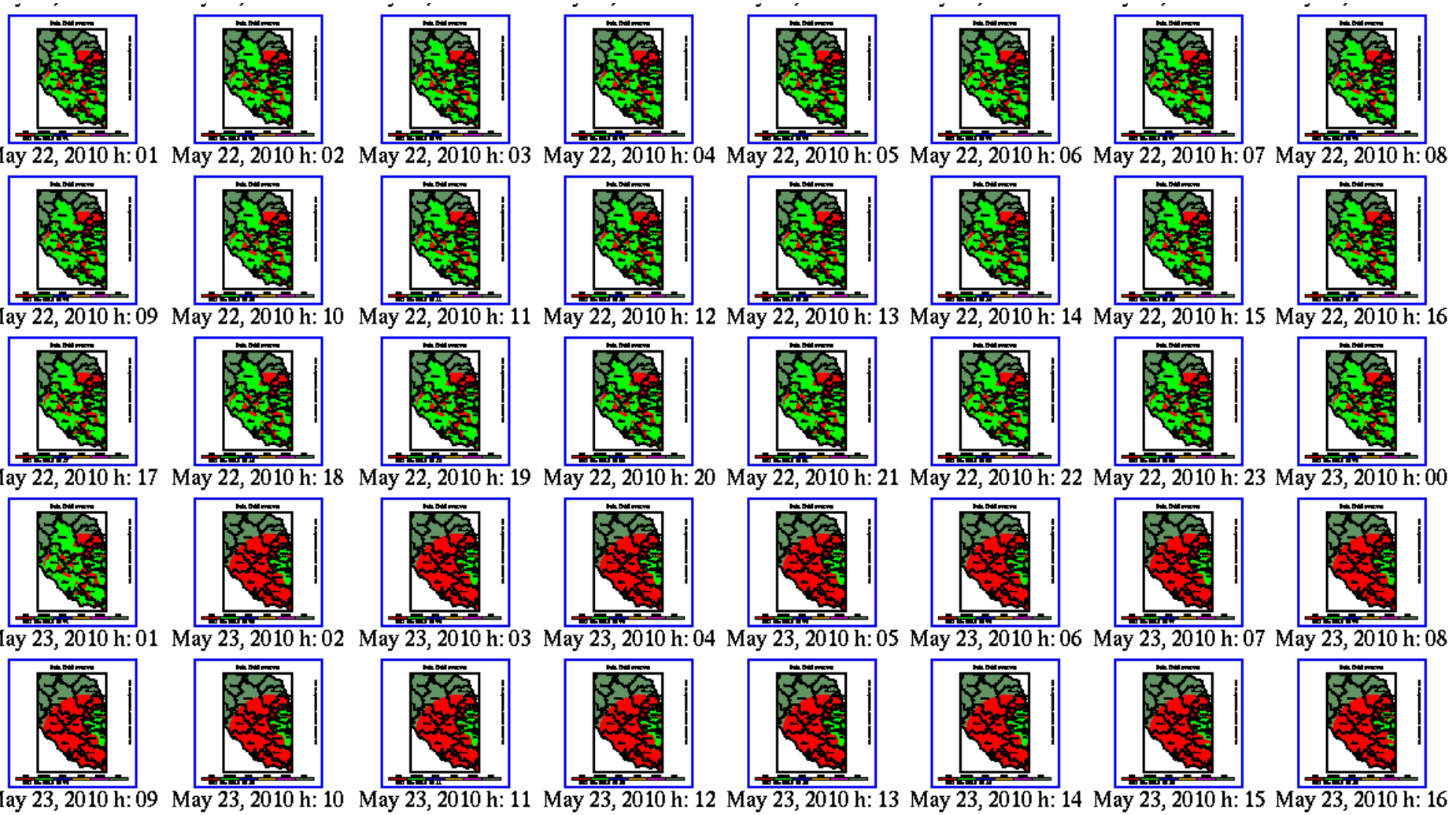




tmp001.gif

Applications of Cellular Automata Theory in CHyM model

CA concepts to merge different precipitation data



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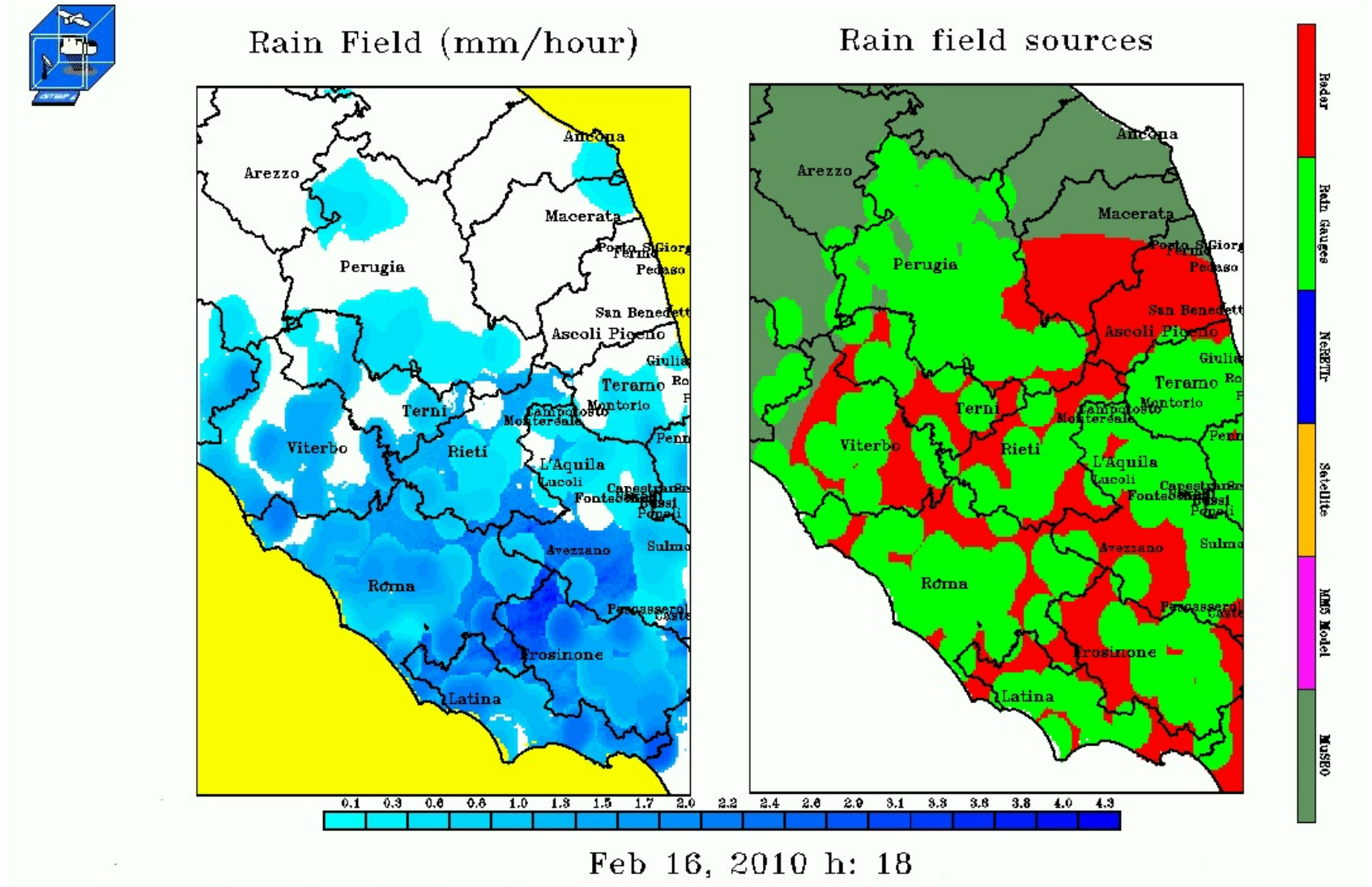

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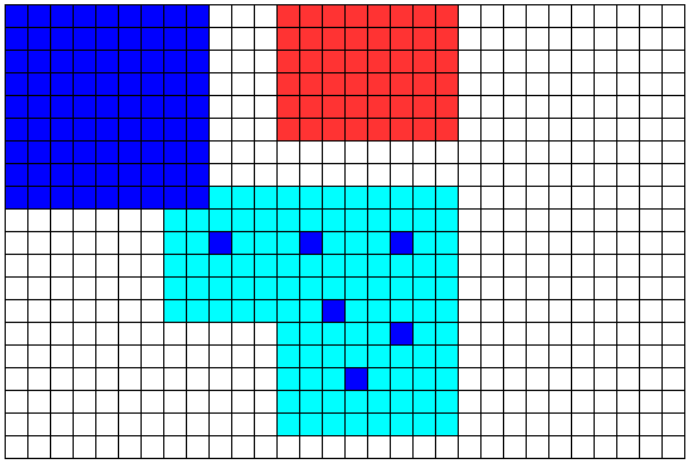


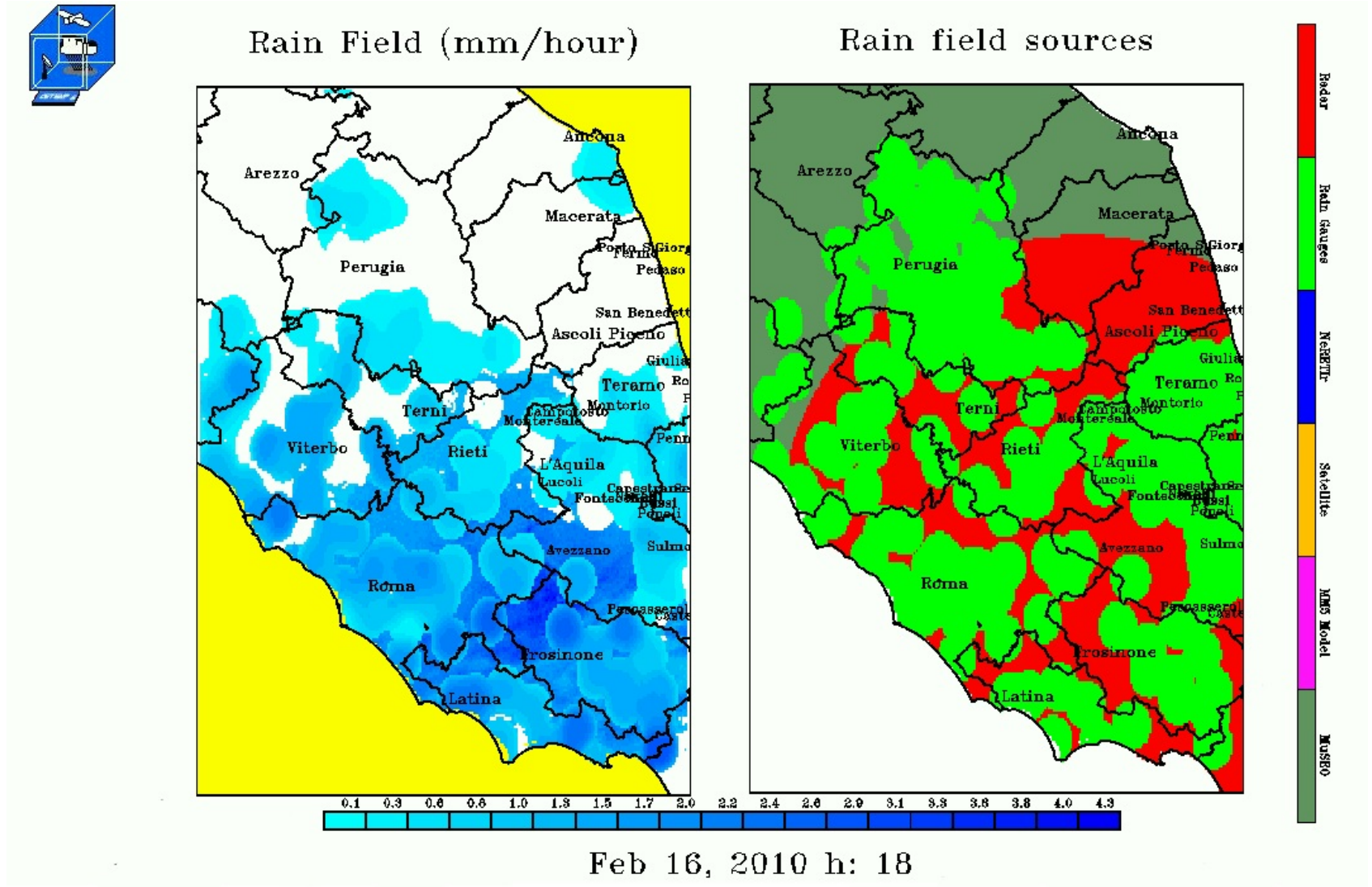
- ✓ CHyM grid is considered an aggregate of cellular automata
- ✓ The status of a cell corresponds to the value of precipitation
- ✓ The state of the cells in the lattice is updated according to following rule

$$h_i \rightarrow h_i + \alpha\left(\sum_j^8 \beta_j (h_j - h_i)\right)$$

But cells corresponding to rain gauges or defined in a previous Module are not updated

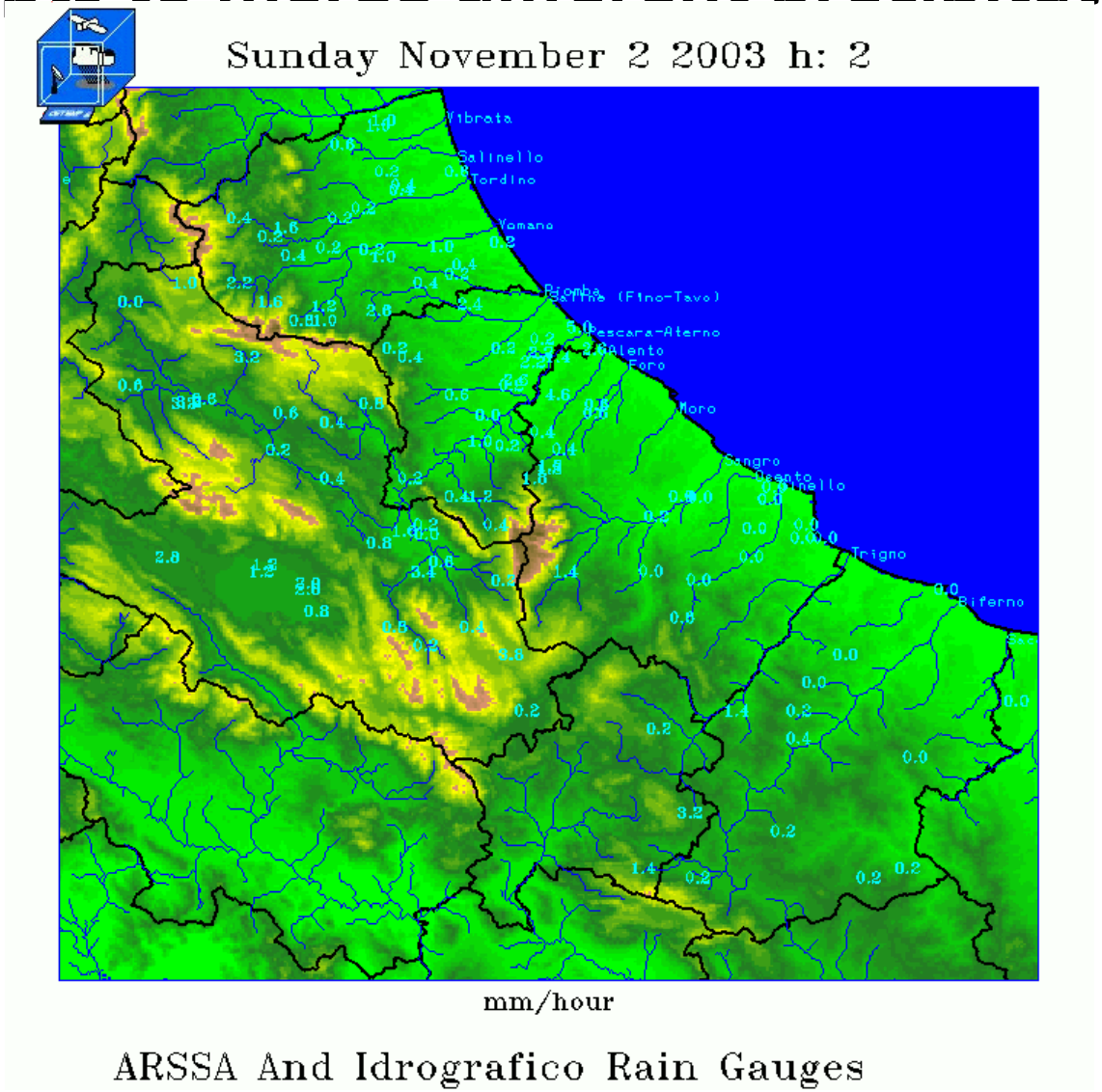
- ✓ All cells on the lattice are updated synchronously
- ✓ Update ends when a stable state is reached

CA concepts to merge different precipitation data



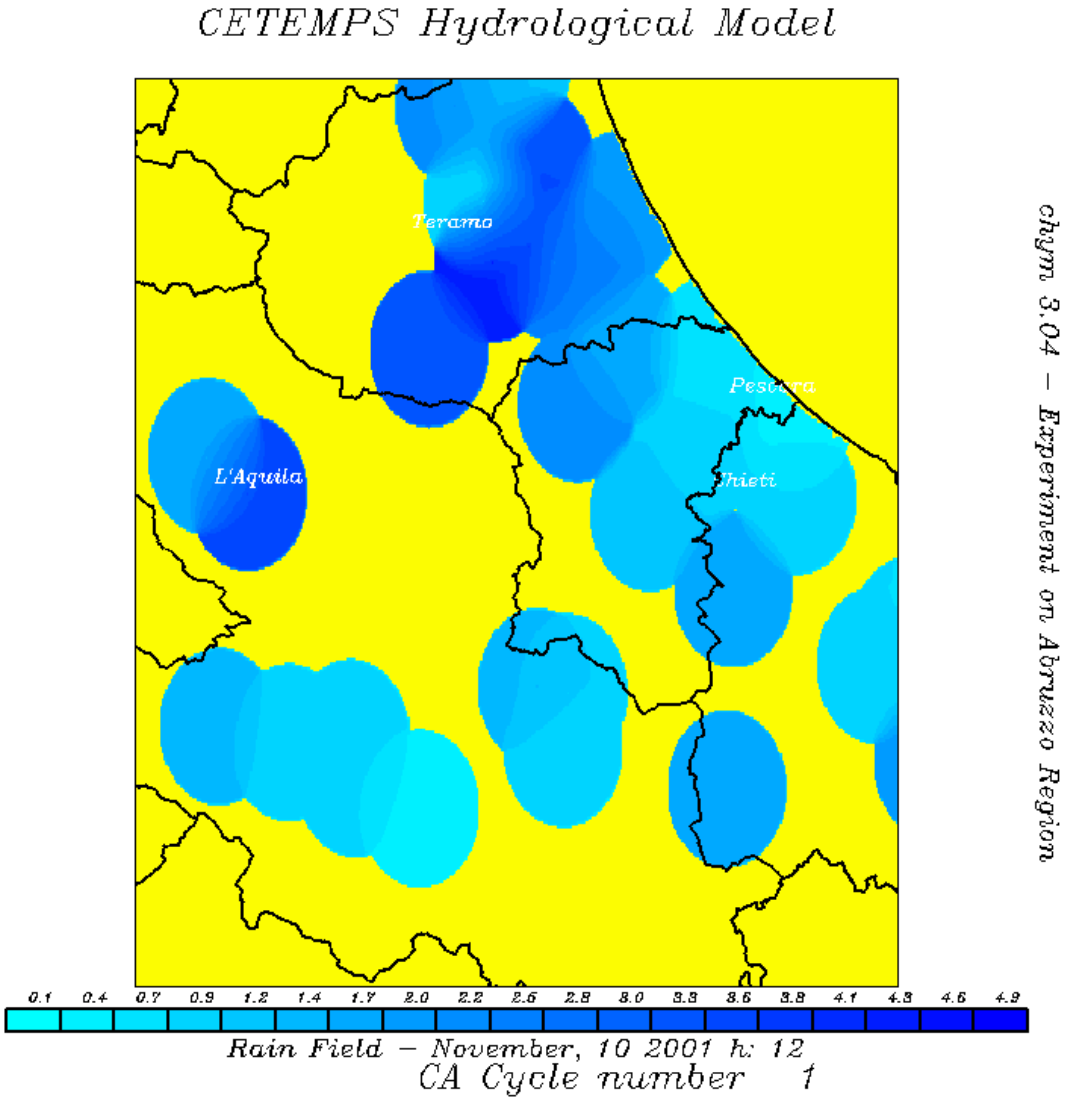
Applications of Cellular Automata Theory in CHyM model

CA concepts to merge different precipitation data



Applications of Cellular Automata Theory in CHyM model

CA concepts to merge different precipitation data



Applications of Cellular Automata Theory in CHyM model

CA concepts to merge temperature data

Temperature field from MM5

Temperature field after CA algorithm