CETEMPS Hydrological Model

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FIRST 24 HOURS OF SIMULATION

MUSEO MM5 ARCHIVE

RegCM output

NCEP or ECMWF forecast

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MUSEO MM5 ARCHIVE
Why to develop a new Hydrological Model?

• It has been thought for operational purposes

• It is a good “exercise”

Step 1: generating streamflow network from DEM

DEM matrix for the selected domain and resolution is generated

Flow direction matrix is computed

Validation

“Pits” and singularities are corrected
DEM is available with a resolution of 300 m

For each cell the slope is computed as:

\[
\text{Max slope} = \tan \left( \frac{\Delta h}{\Delta x} \right)
\]

Runoff direction

Flow Direction Map – 0 of 54 no-flow points were corrected.
CHyM: Drainage network test

CETEMPS Hydrological Model Preprocessor

Flow Test with "The Rolling Stones" Algorithm

Earth System Physics, The Abdus Salam International Centre for Theoretical Physics
CHyM: Drainage network test
Cellular Automaton CA
Automata generated using Rule 30 appear in nature, on some shells.

Is this a pyramid?
A cellular automaton is a **discrete dynamical system**

- Space, time and states of the system are discrete quantities
- Each point in a regular spatial lattice, called a 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 cells on the lattice are **updated synchronously**
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
One of the infinitive effects that are possible to get using the Langton (1) rule
One of the infinitive effects that are possible to get using the Langton (2) rule
Self reproducing CA – Langton rules (3)
Takeover of the arm caused by the collision of two *evoloops*
CA for CHyM applications

1. CHyM grid is considered an aggregate of cellular automata
2. The status of a cell corresponds to the value of a ChYM matrix (DEM)
3. The state of the cells in the lattice is updated according to following rule:
   \[ h_i \rightarrow h_i + \dot{h} \left( \sum_{j} \hat{a}_j (h_j - h_i) \right) \]
4. All cells on the lattice are updated synchronously
5. Update ends when flow scheme is OK
CHyM: Recipe for DEM pit 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
CHyM: Drainage network test

CETEMPS Hydrological Model Preprocessor

Flow Test with "The Rolling Stones" Algorithm
DEM corrections (m)

DEM Smoothing Algorithm 1 (DSA1)

DEM Smoothing Algorithm 2 (DSA2)
CHyM: DEM pit correction

GETEMPS Hydrological Model Preprocessor

Flow Direction Map – 12 of 12 no-flow points were corrected.
CHyM: DEM pit correction

Flow Direction Map – 19 of 19 no-flow points were corrected.
CHyM: DEM pit correction

GETEMPS Hydrological Model Preprocessor

Flow Direction Map – 19 of 19 no-flow points were corrected.
CHyM: Examples of Drainage Network Extraction

CHyM Graphic Lab

Flow Test with "The Rolling Stones" Algorithm
1. Starting from each cell a stone rolls up to the river's mouth

2. Each time that the stone goes through one cell for this cell a counter is incremented by 1

3. If a quantity $A$ is associated to each stone where $A$ is equivalent to the surface where the stone was at the beginning, for each cell it can be computed the upstream drained surface

$$\sum_{i=1}^{N} A_i$$

4. If a quantity $R$ is associated to each stone where $R$ is equivalent to the precipitation where the stone was at the beginning, for each cell it can be computed the upstream drained precipitation

$$\sum_{i=1}^{N} R_i$$
CHyM: the Rolling Stones Algorithm (RSA)
Step 2: Building Precipitation Fields using different Data Sources

Module 1

- Define subdomain
- Fill cells corresponding to rain gauges
- Fill subdomain matrix – Cr. Formula
- Smooth subdomain matrix using CA algorithm

Module 2

Module 3

Module n
CA for CHyM applications

1. CHyM grid is considered an aggregate of cellular automata.
2. The status of a cell corresponds to the value of a ChYM matrix (DEM).
3. The state of the cells in the lattice is updated according to the following rule:
   \[ h_i \rightarrow h_i + \delta \left( \sum_j \hat{a}_j (h_j - h_i) \right) \]
   But cells corresponding to rain gauges or defined in a previous module are not updated.
4. All cells on the lattice are updated synchronously.
5. Update ends when a stable state is reached.
CHyM Rain field sources: an example
Rainfall data assimilation for 4 August 2005 (11:00 UTC). Panel (a) shows the rain source available at each grid point (green: gauges; grey: model meteorological output used as a source when measurements are not available). In panel (b) only the gauge measurements are used and merged with the Cressman algorithm. The yellow area indicates that for this module there are no available data in these grid points. In panel (c) the same gauge measurements are used but merged using the CA algorithm. In panel (d) the rainfield is shown when the MM5 rainfield is added to the previous one of panel (c) using a Cressman algorithm; and in panel (e) the same field is reported when the CA algorithm is used. Panel (f) is for comparison, to show the rainfield as it is forecast by the MM5 model.
E. Coppola, B. Tomassetti, L. Mariotti, M. Verdecchia and G. Visconti, Cellular automata algorithms for drainage network extraction and rainfall data assimilation, Hydrological Science Journal, 52(3), 2007
For each cell the simulated processes are:

- Runoff
- Evapotraspiration
- Infiltration
- Rainfall
CHyM: Infiltration

Soil moisture storage

Deep percolation

Infiltration

Interflow

Surface Runoff
CHym: Evapotraspiration

Thornthwaite Formula (Thornthwaite and Mather, 1995)

\[ E_{th}(i) = 16 \frac{n(i)}{30} \frac{N(i)}{12} (10 \frac{\bar{T}(i)}{K_1}) K_2 \]

- \( N \) = daylength
- \( K_1 \) = thermal index
- \( K_2 = f(K_1) \)
**CHym: Runoff**

**Continuity equation**

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

- \(A\) = cross sectional area of the river
- \(Q\) = flow rate of water discharge
- \(q_c\) = rain for length unit

**Momentum equation**

\[
Q = \frac{S^{1/2}R^{2/3}}{n} A
\]

- \(S\) = slope
- \(1/R\) = wetter perimeter
- \(n\) = Manning’s roughness coefficient
\[ \frac{\sum_{i=1}^{n} R_i}{\sum_{i=1}^{n} A_i} = AI \]

- \( R_i \) = rain
- \( A_i \) = drained surface

CHyM: Stress index
Soverato Flood simulation

Alarm Map (Total Drained Rain / Total Drained Surface)

Simulation from September, 09 2000 h: 12 to September, 11 2000 h: 12
CHyM: simulation of Aug 22-23 2005 event

Flow Test with "The Rolling Stones" Algorithm

Earth System Physics, The Abdus Salam International Centre for Theoretical Physics
Inondations: les pays alpins en état d'alerte

VIENNE (AFP) - La Suisse, l'Autriche et le Sud de l'Allemagne et des pays d'Europe de l'Est sont en état d'alerte depuis plusieurs jours après des inondations meurtrières, les plus graves depuis 1999 dans l'arc alpin, qui ont déjà provoqué des millions d'euros de dégâts.
CHyM: simulation of Aug 22-23 2005 event
First ICTP workshop on RegCM-CHYm coupling June 2006

Chym is flying all over the world ....
Impact of Climate Change in the Po valley: downscaling high resolution RegCM output by coupling with ChYM hydrological model

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Dowscaling from large scale to hydrological scale
CMIP3 models

TAS BIAS (SON): CECILIA = -0.794544

T2m BIAS (SON): CECILIA = -0.245699

TAS change A2 (SON): CECILIA = 3.72512

T2m change A2 (SON): CECILIA = 4.04903

TAS change A1B (SON): CECILIA = 3.48008

T2m change B2 (SON): CECILIA = 3.45196
CMIP3 models

PREC BIAS % (SON): CECILIA = 16.8362%

precip BIAS % (SON): CECILIA = 12.5489%

PREC change A2 (SON): CECILIA = -9.20164%

precip change A2 (SON): CECILIA = -4.21851%

PREC change A1B (SON): CECILIA = -6.55319%

precip change B2 (SON): CECILIA = 0.555306%
ECO summary

TAS change A1B (DJF)

TAS change A1B (JJA)

PREC change A1B (DJF)

PREC change A1B (JJA)
Zonal average of ECO signal
Zonal average of ECO signal in the observations
High resolution experiment over the Mediterranean basin

- **Model configuration**
  - 20-km grid point spacing
  - Full Mediterranean domain
- **Experiment design**
  - Forcing fields from PRUDENCE RegCM simulations at 50 km.
  - Reference simulation
    - (1961-1990)
  - A2, B2 scenario simulations
    - (2071-2100)
CHyM hydrological model set-up

• 1 km resolution; 110945.0 km² drained area
• control run 1961-90 driven by RegCM control run
• scenario run 2071-2100 driven by RegCM A2 scenario run
Po river discharge change

Earth System Physics, The Abdus Salam International Centre for Theoretical Physics
Po mean discharge 1961-79

CHyM model

Observations

m^3/s

Po 1918-1979
Observations

- m$^3$/s

Graphs showing seasonal variations in flow rates.
Observations

![Graph showing river flow observations over time](image)

**m^3/s**

![Map of river drainage network](image)
Climate change effects on the Po basin: conclusions

Increase in precipitation in winter-spring lead to and increase in discharge for winter and early spring for all the whole PO basin as previously found for the Danube and Rhine catchment (Hageman and Jacob, 2007, Climate Change; Graham et al., 2007)

Peak spring flows occurs about one month earlier in the basin as it was also found for the Lule River Basin (Graham et al., 2007, Climate Change)

Reduction up to 70% of the basin discharge is found from May to November mainly in the upper part of the basin. An increase in the river discharge is observed in winter months.
Aerosol effects on hydrological cycle

Erika Coppola, Laura Mariotti et al.
CETEMPS Hydrological Model Preprocessor

Flow Test with "The Rolling Stones" Algorithm
1969–2002
RegCM3 SFC AIR TEMP (deg C)

1969–2002
RegCM Precipitation (mm/day)

CRU SFC AIR TEMP (deg C)

CRU Precipitation (mm/day)

RegCM–CRU SFC AIR TEMP (deg C)

RegCM–CRU Precipitation (mm/day)

Courtesy of F. Solmon
Precipitation differences 1969-2006

DUST - NODUST

Dry _ Wet Years

Based on WMO standardized mean Sahel rainfall

Courtesy of F. Solmon

Earth System Physics, The Abdus Salam International Centre for Theoretical Physics
Precipitation differences % (1982-2006)
Discharge differences
Very preliminary conclusion on dust effects on the Niger basin runoff

The Niger discharge shows a decrease of runoff up to 15% although only a 5% of decrease is observed in Precipitation

This reduction is found as well if we compute the difference between dry-wet events runoff, although this difference is bigger.

The drying of the basin strength the hypothesis of positive feedback related to dust radiative forcing in the maintenance of dry period over the west African basins as suggested by Konare et al. (2008)

(A regional climate modeling study of the effect of desert dust on the West African monsoon, JJR, accepted)
Thanks