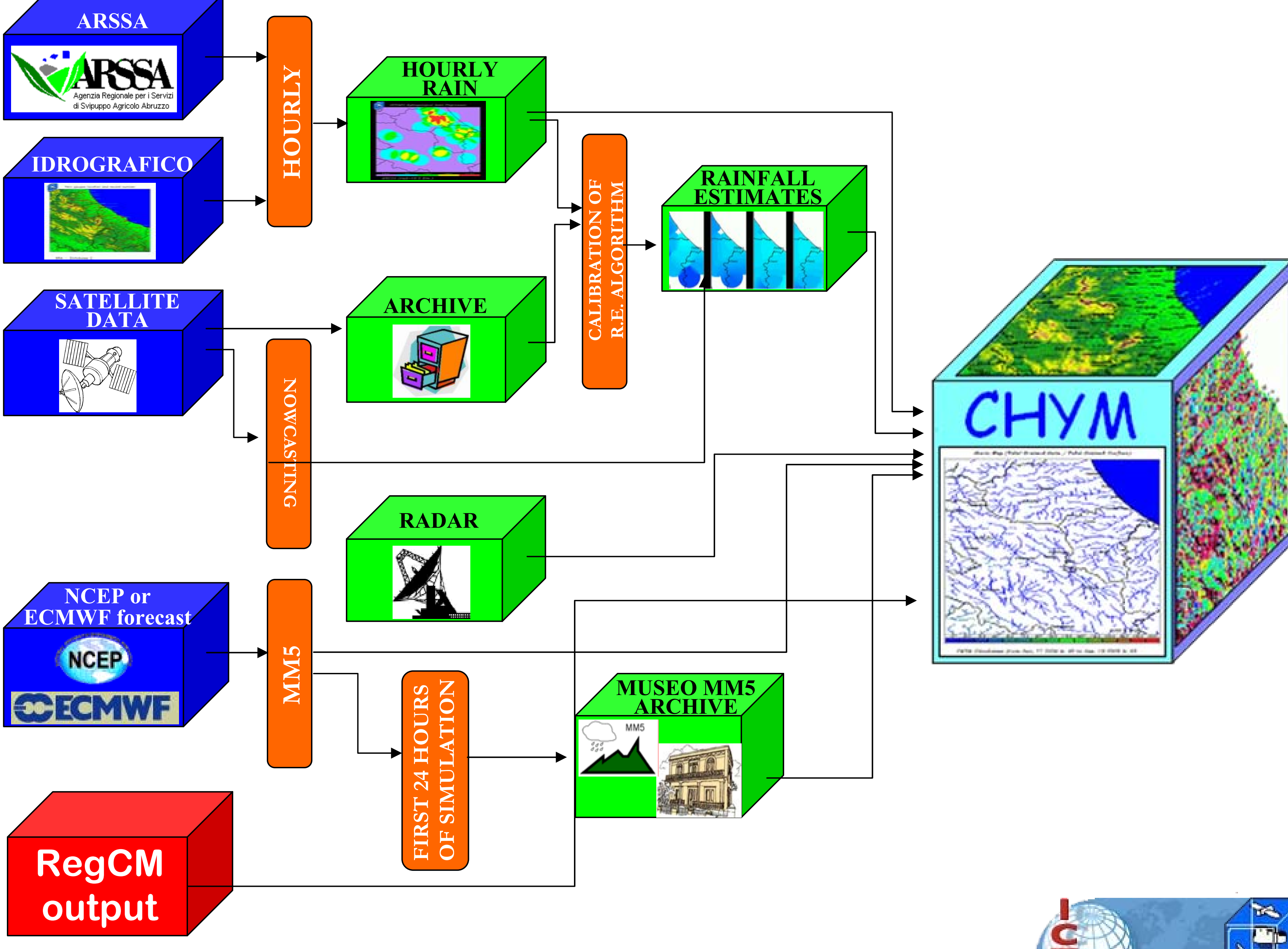
CHyM tutorial

•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

•Hydrological Modelling and the Water Cycle Coupling the Atmospheric and Hydrological Models Series: Water Science and Technology Library , Vol. 63 Sorooshian, S.; Hsu, K.-l.; Coppola, E.; Tomassetti, B.; Verdecchia, M.; Visconti, G. (Eds.) 2008, XI, 291 p. 138 illus., 66 in color., Hardcover ISBN: 978-3-540-77842-4

•Singh, V. P., and D. K. Frevert, Mathematical Models of Small Watershed Hydrology and Application,Water Resource Publications, LLC, Highlands Ranch, Colorado, USA, 2002.

•Singh, V. P., and D. K. Frevert, Mathematical Models of Large Watershed Hydrology, Water Resource Publications, LLC, Highlands Ranch, Colorado, USA, 2002.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CALIBRATION OF
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CHYM

Why to develop a new Hydrological Model?

- It has been thought for operational purposes
- It is a good "exercise"

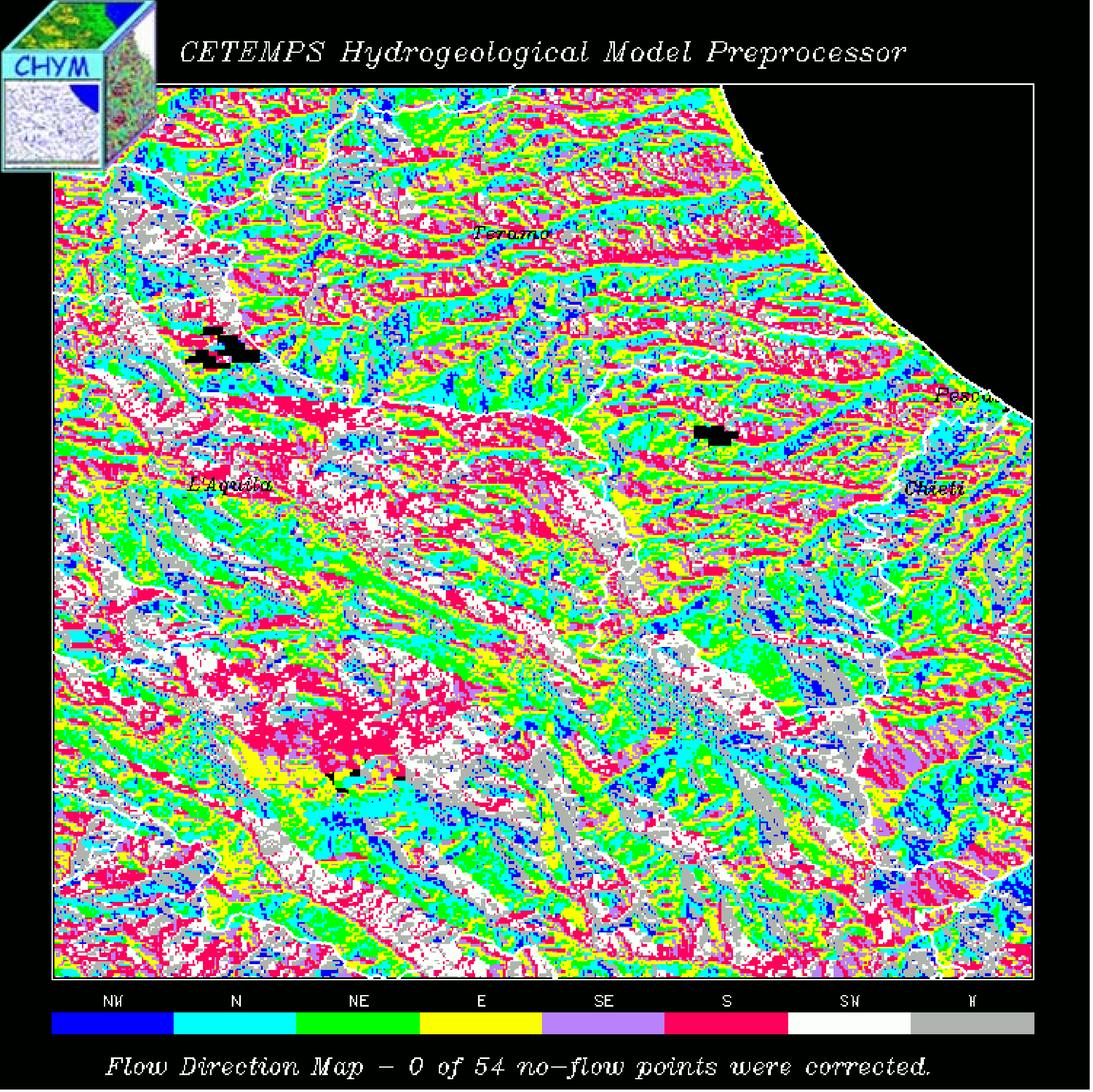
Step 1: generating streamflow network from DEM

DEM matrix for the selected domain and resolution is generated

Flow direction matrix is computed

Validation

"Pits" and singularities are corrected



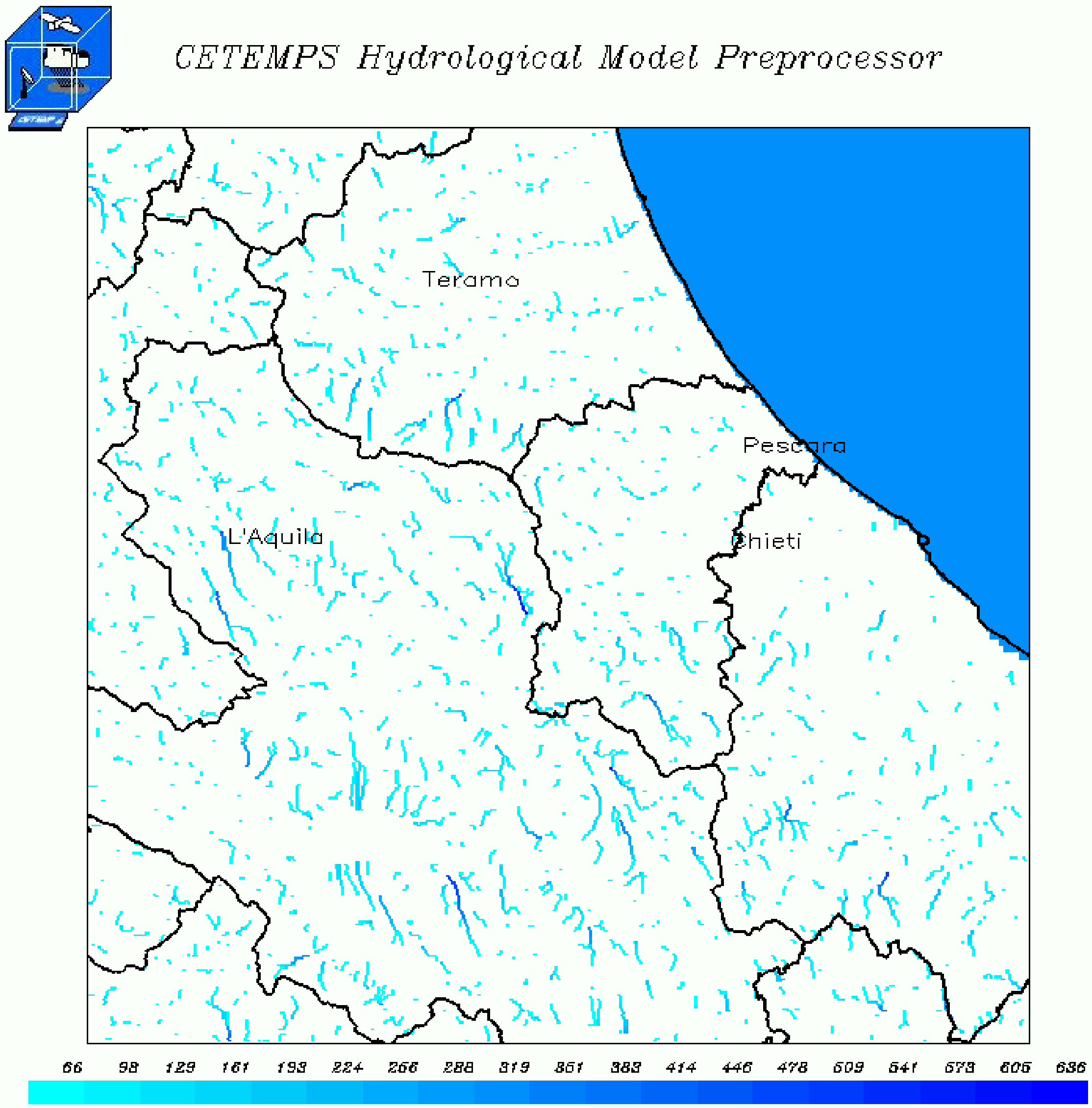
DEM is available with a resolution of 300 m

For each cell the slope is computed as: $\operatorname{atan}\frac{\Delta h}{\Delta x}$

Max slope

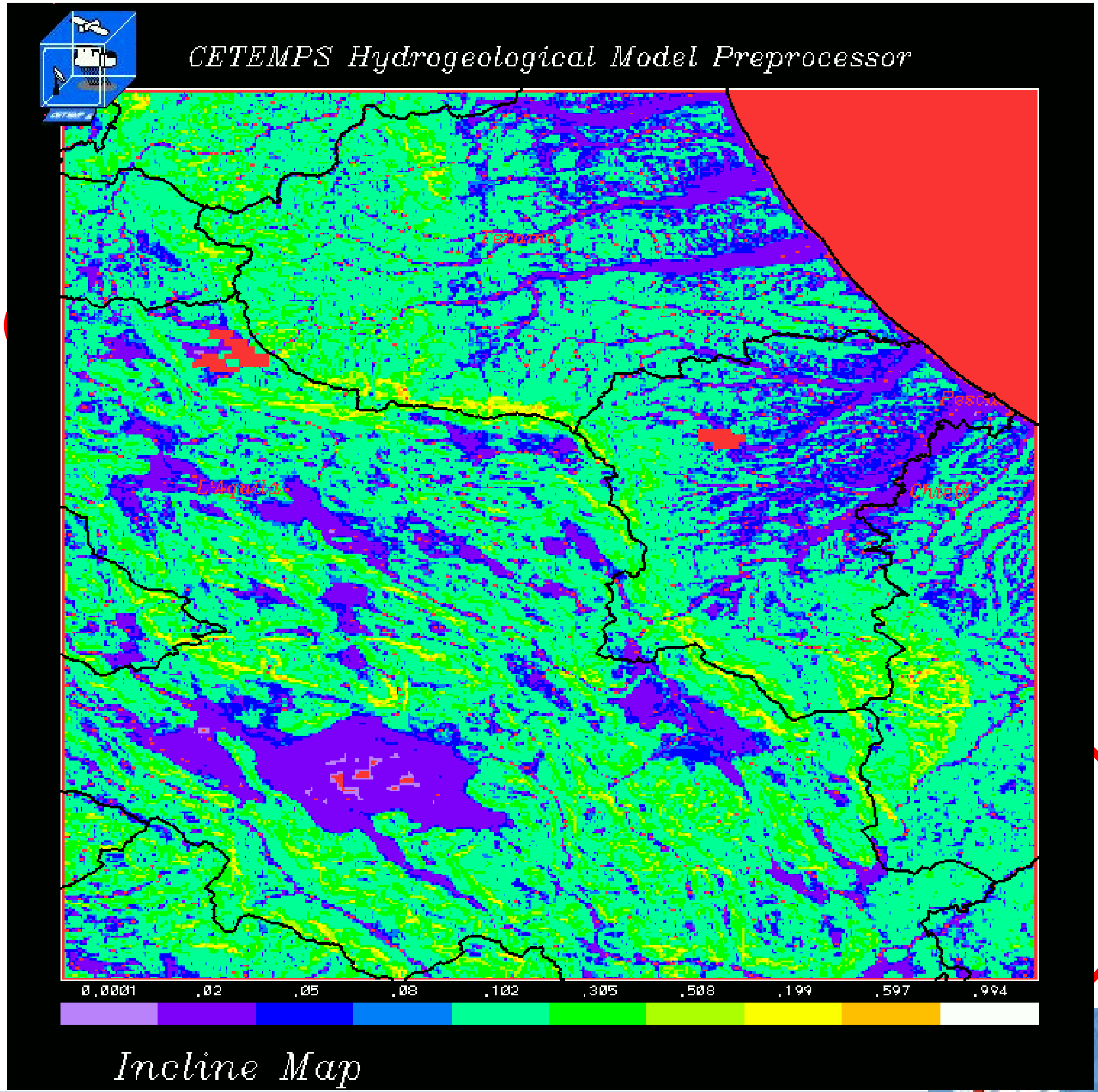
Runoff direction

CHyM: Drainage network test



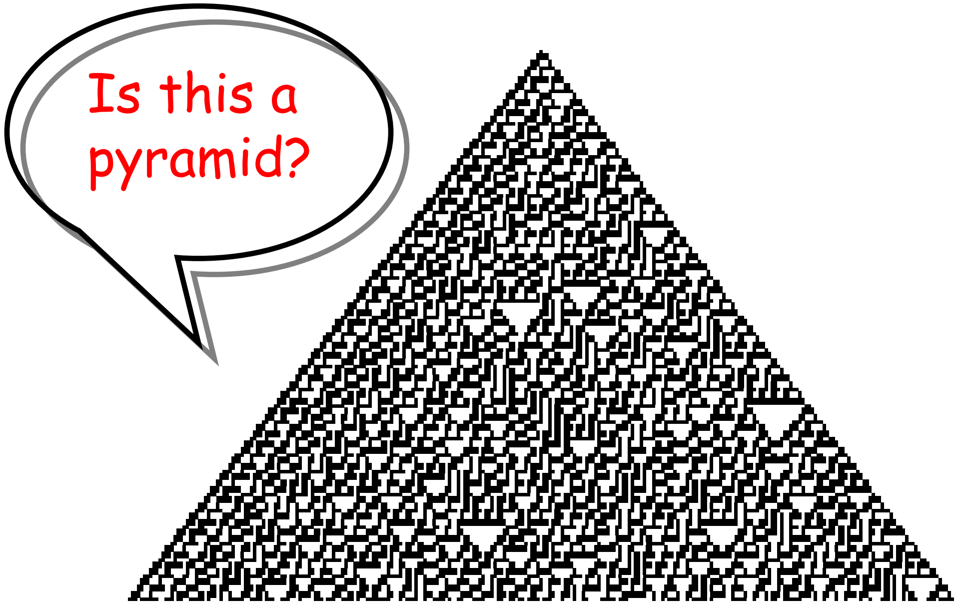
Flow Test with "The Rolling Stones" Algorithm

CHyM: Drainage network test

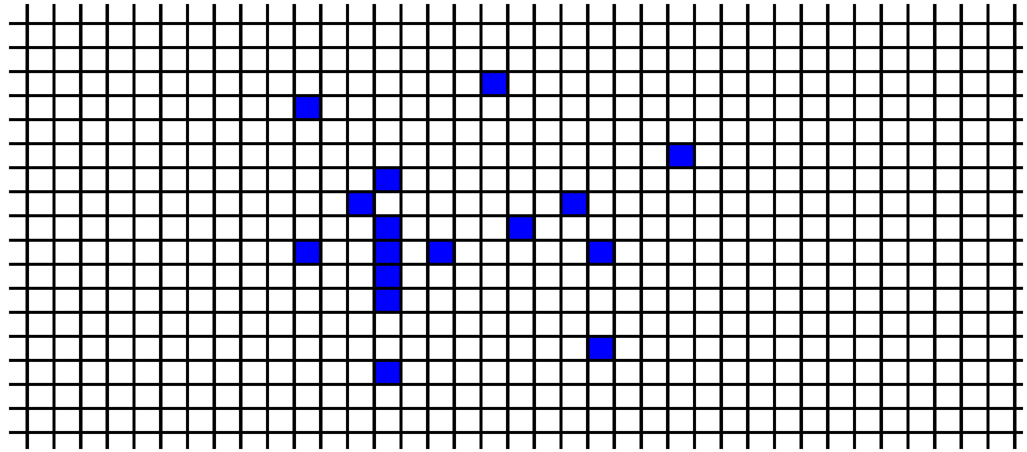


Cellular Automaton CA

Automata generated using Rule 30 appear in nature, on some shells.



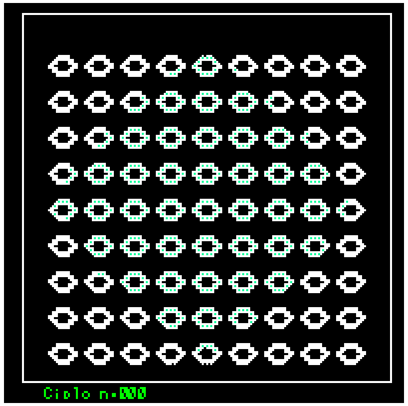
A Cellular Automata definition



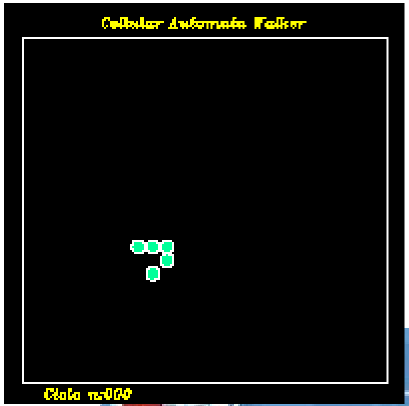
- A cellular automaton is a **discrete dynamical system**
- Space, time and states of the system are discrete quantities
- Each point in a regular spatial lattice, called a cell, can have anyone of a finite number of states
- The state of the cells in the lattice are updated according to a **local rule**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

The game of life

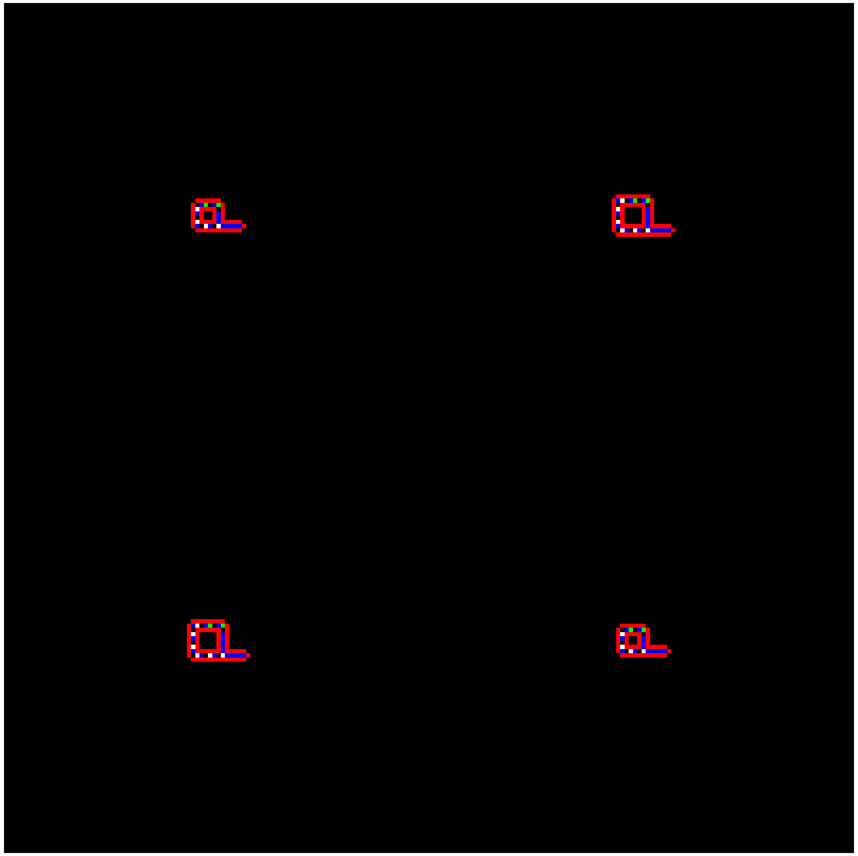
Life rules by Chris G. Langton



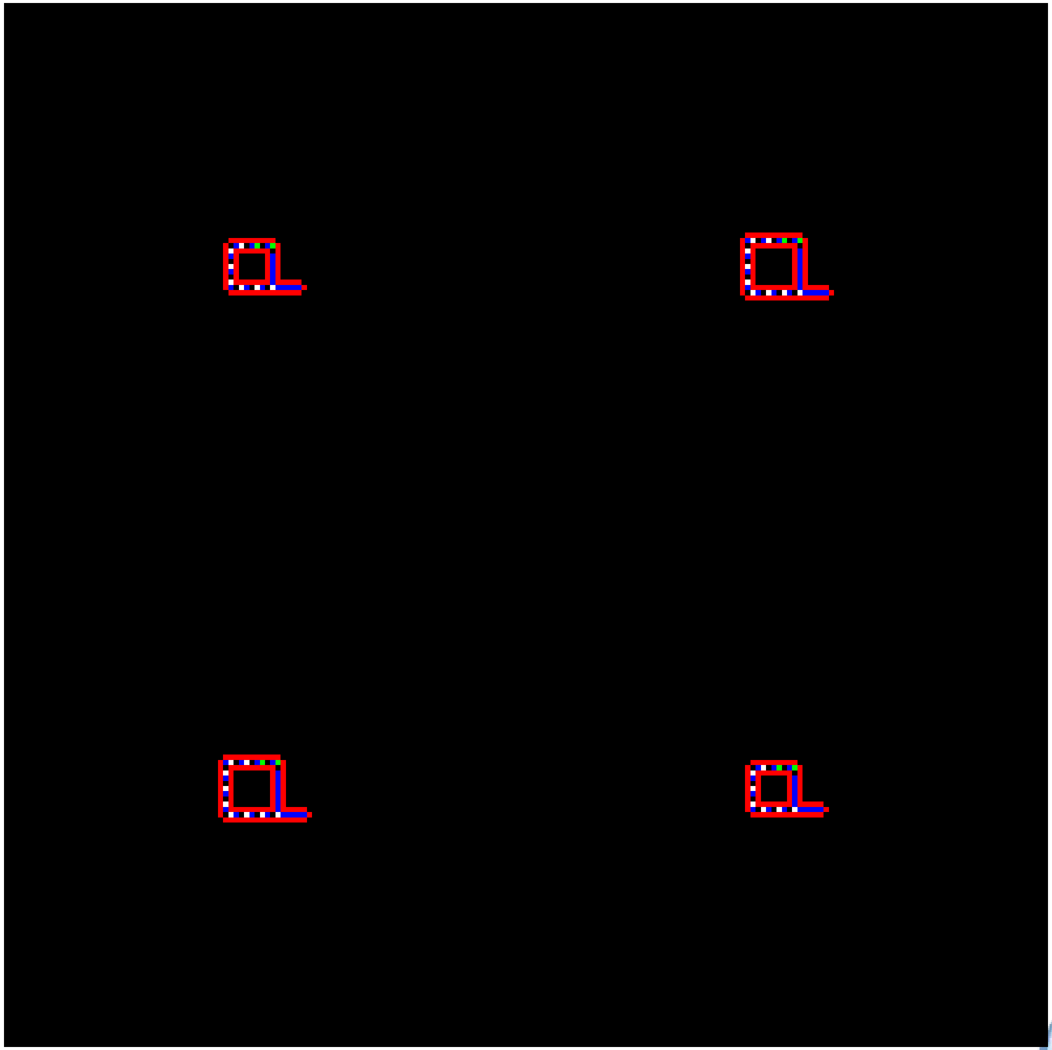
- The status of each CA can be ON or OFF
- If more than 3 CA in the neighborhood are ON CA became OFF
- If less than 2 CA in the neighborhood are ON, CA became OFF
- Otherwise CA became ON



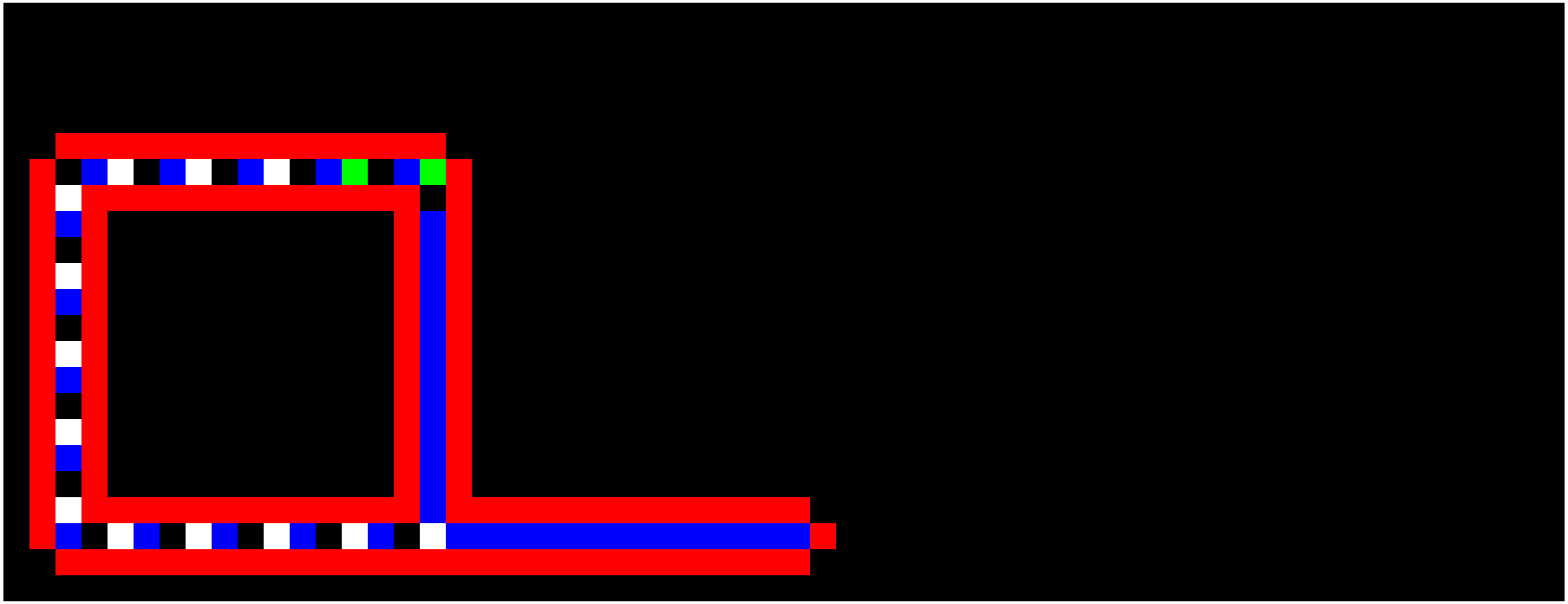
One of the infinitive effects that are possible to get using the Langton (1) rule



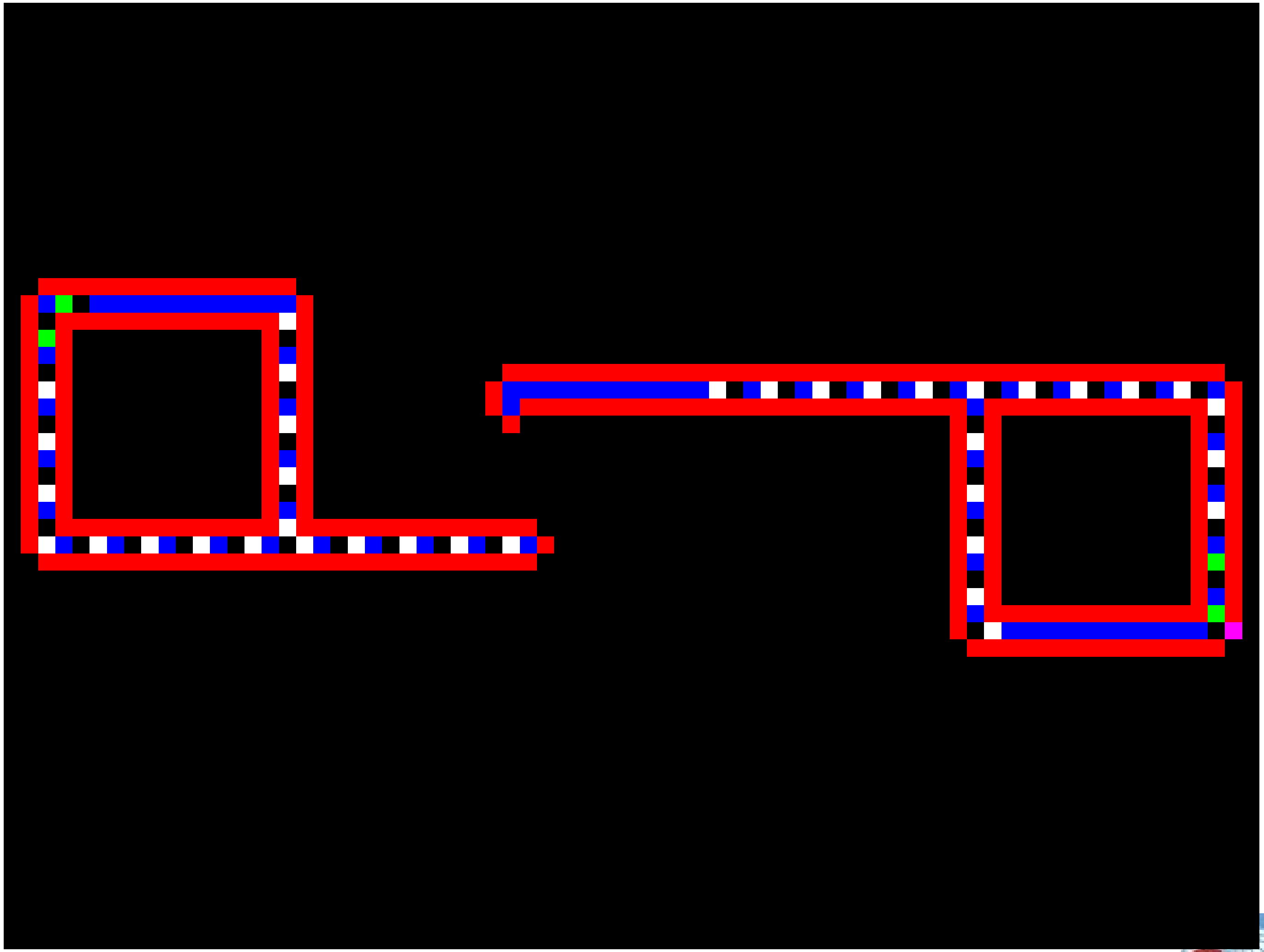
One of the infinitive effects that are possible to get using the Langton (2) rule



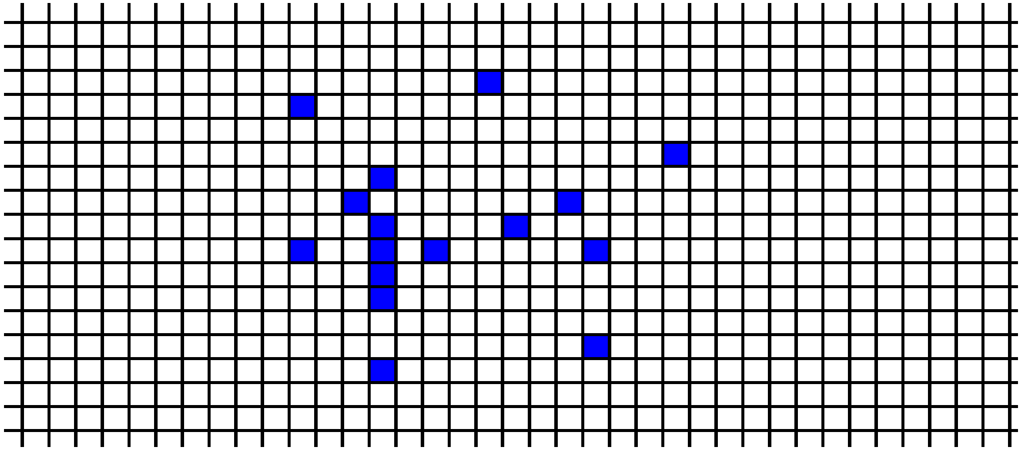
Self reproducing CA – Langton rules (3)



Takeover of the arm caused by the collision of two *evoloops*



CA for CHyM applications



- ✓ 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**

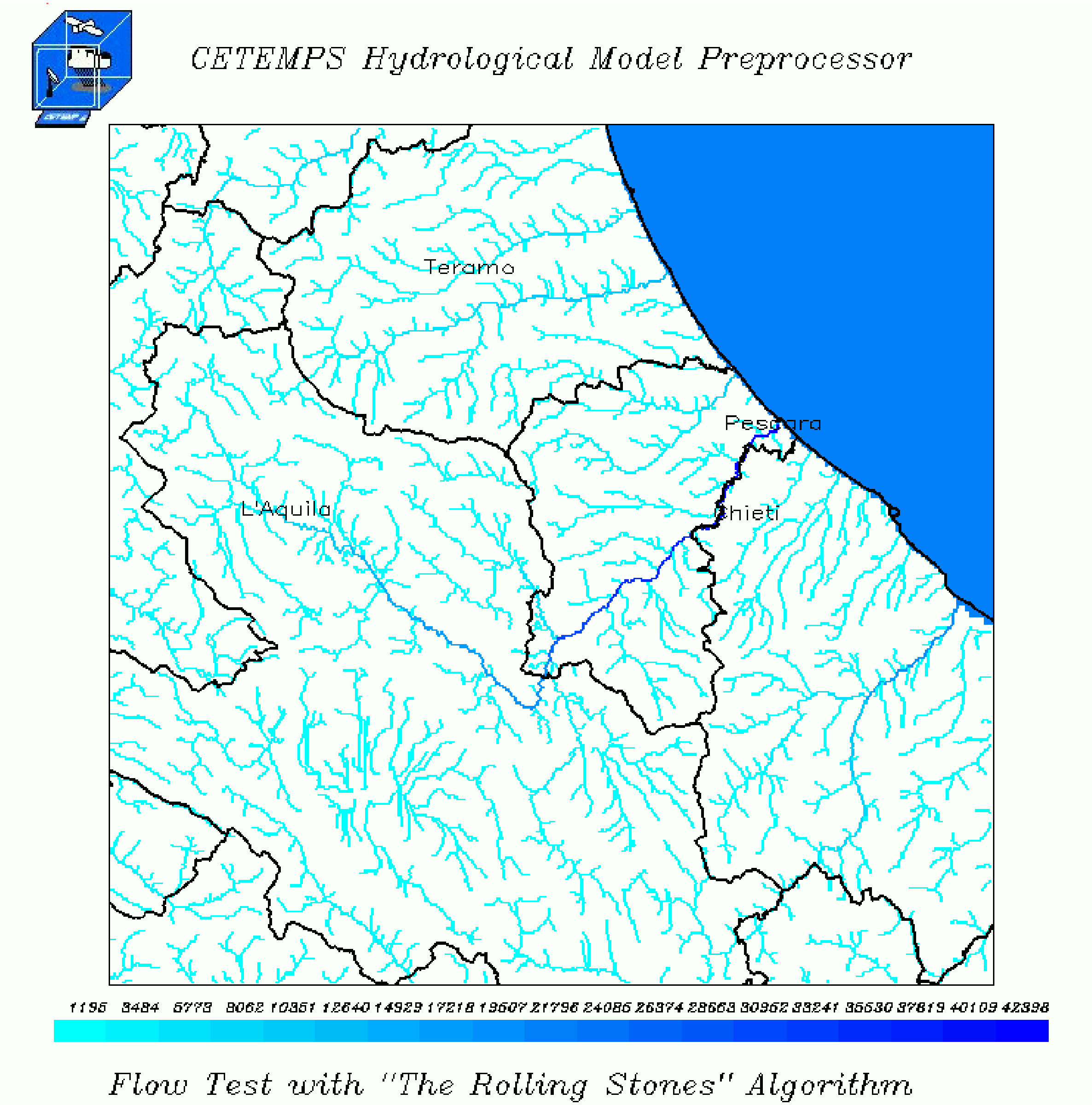
$$h_i \rightarrow h_i + \alpha\left(\sum_j^8 \beta_j (h_j - h_i)\right)$$

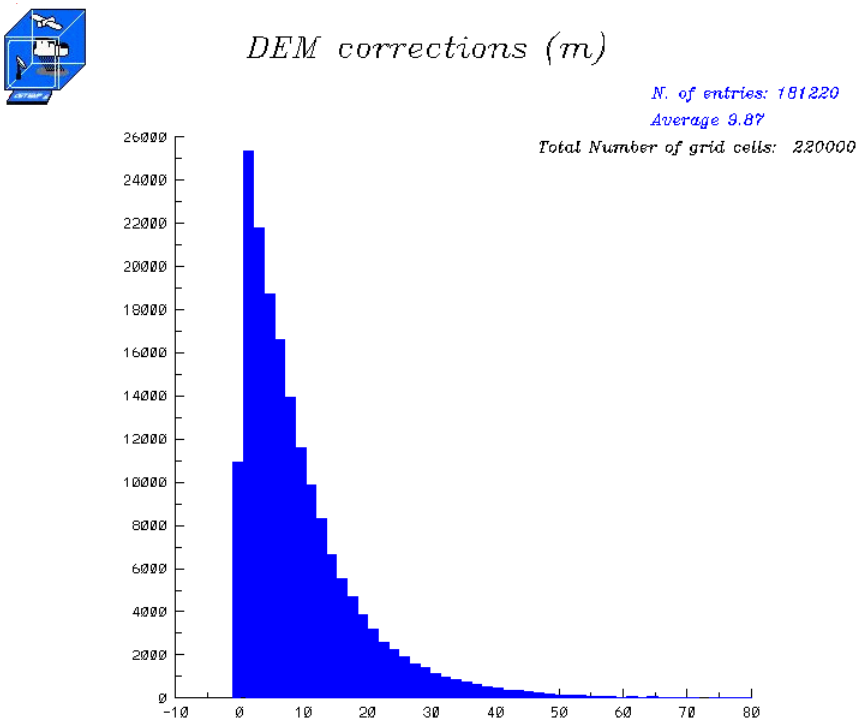
- ✓ All cells on the lattice are updated synchronously
- ✓ Update ends when flow scheme is OK

CHyM: Recipe for DEM pit correction

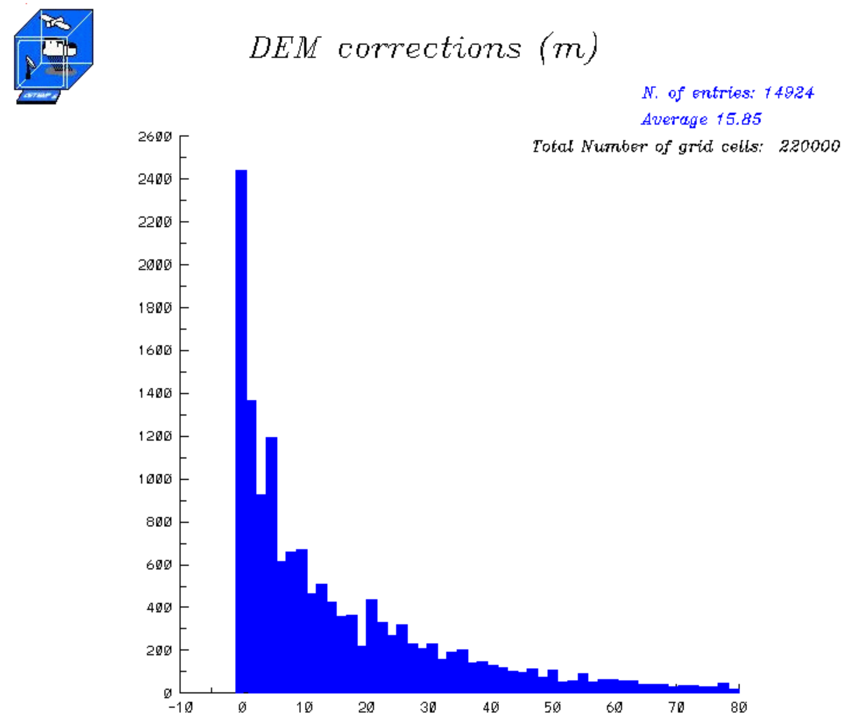
- Smooth DEM using CA rules until FD can be obtained for all the cells
- Generate streamflow network using smoothed DEM
- Use "true" DEM and modify ONLY the cells draining toward an higher cell

CHyM: Drainage network test



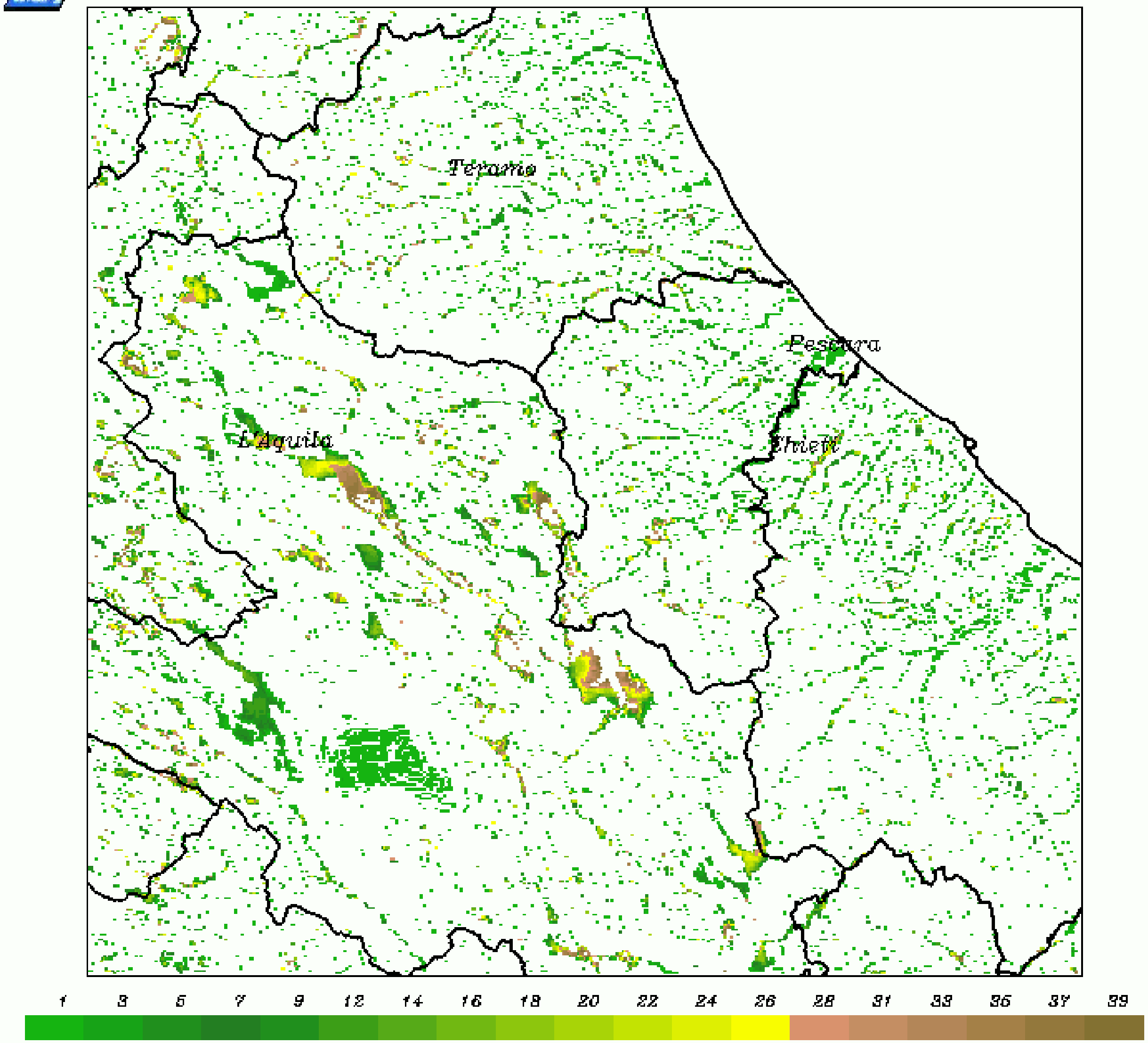


DEM Smoothing Algorithm 1 (DSA1)

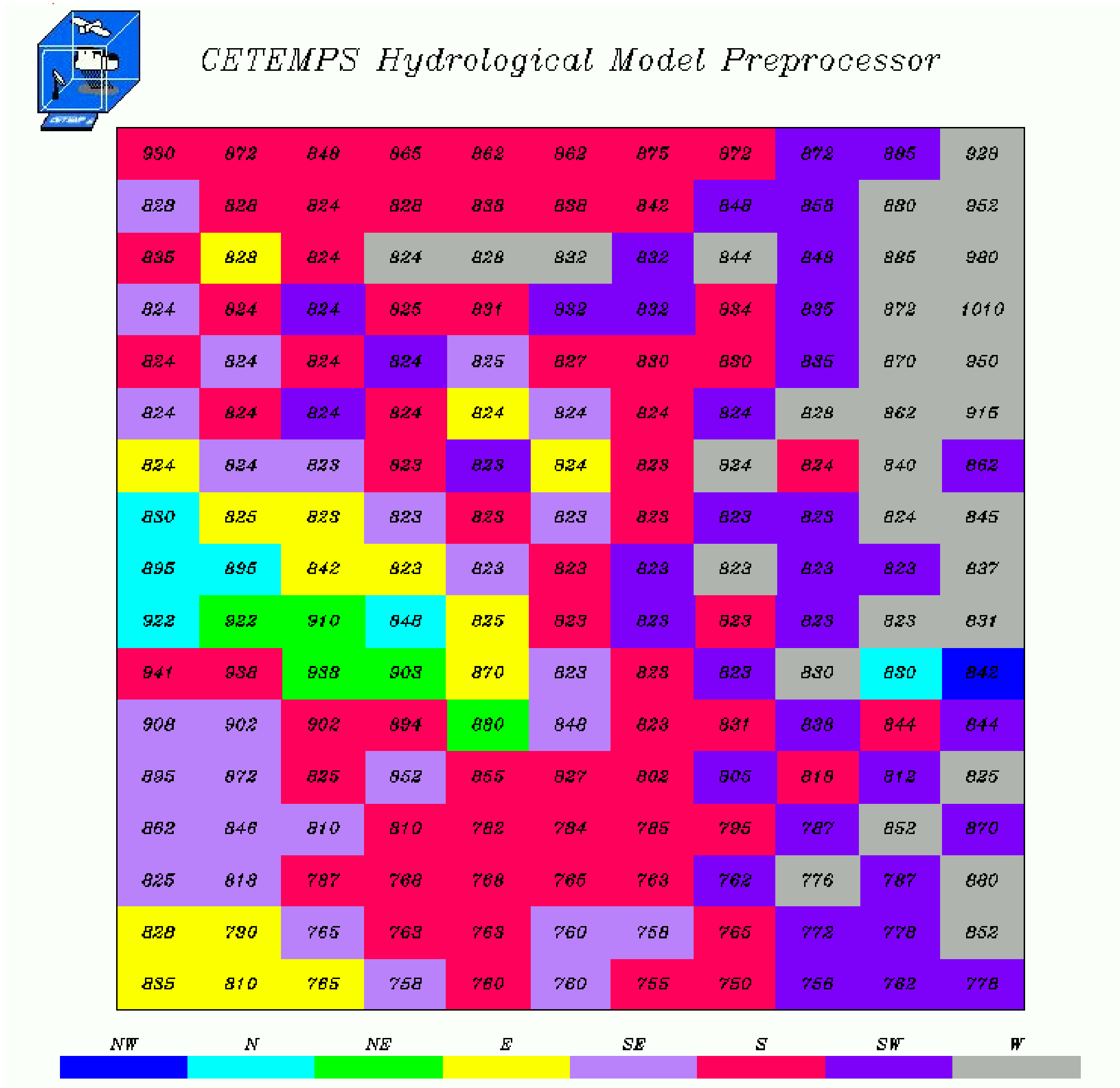


DEM Smoothing Algorithm 2 (DSA2)

Dem differences

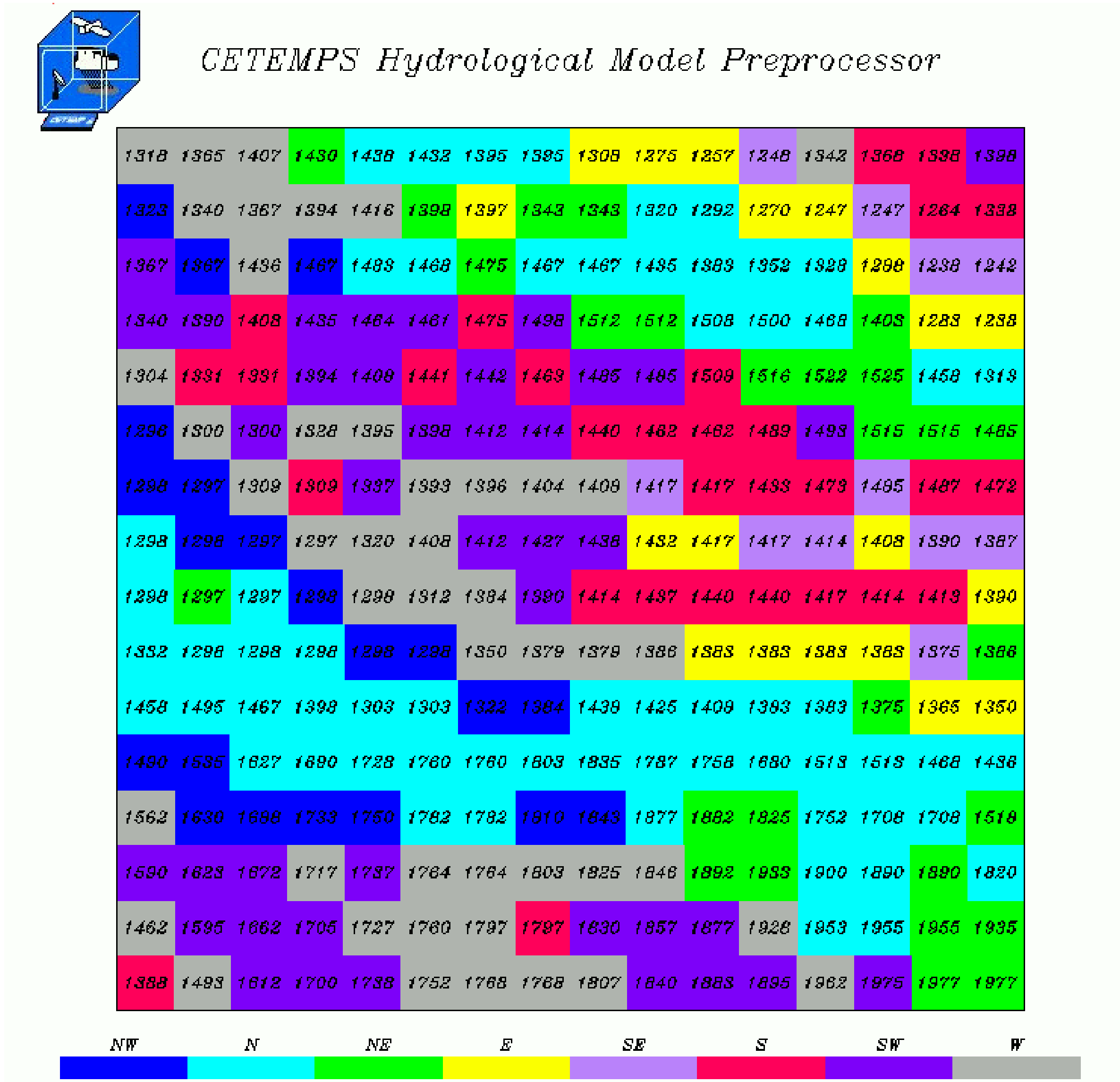


CHyM: DEM pit correction



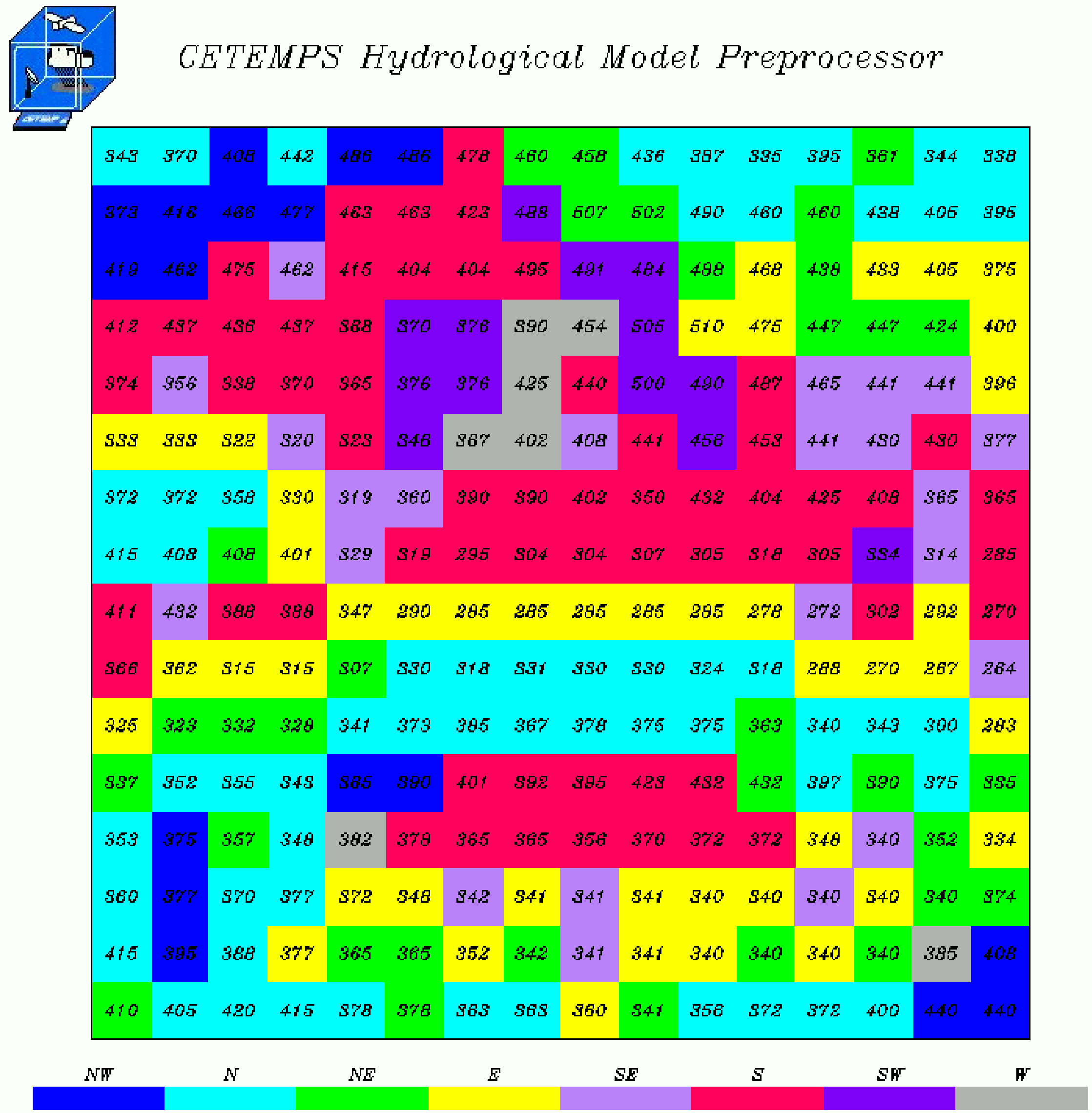
Flow Direction Map – 19 of 19 no-flow points were corrected.

CHyM: DEM pit correction



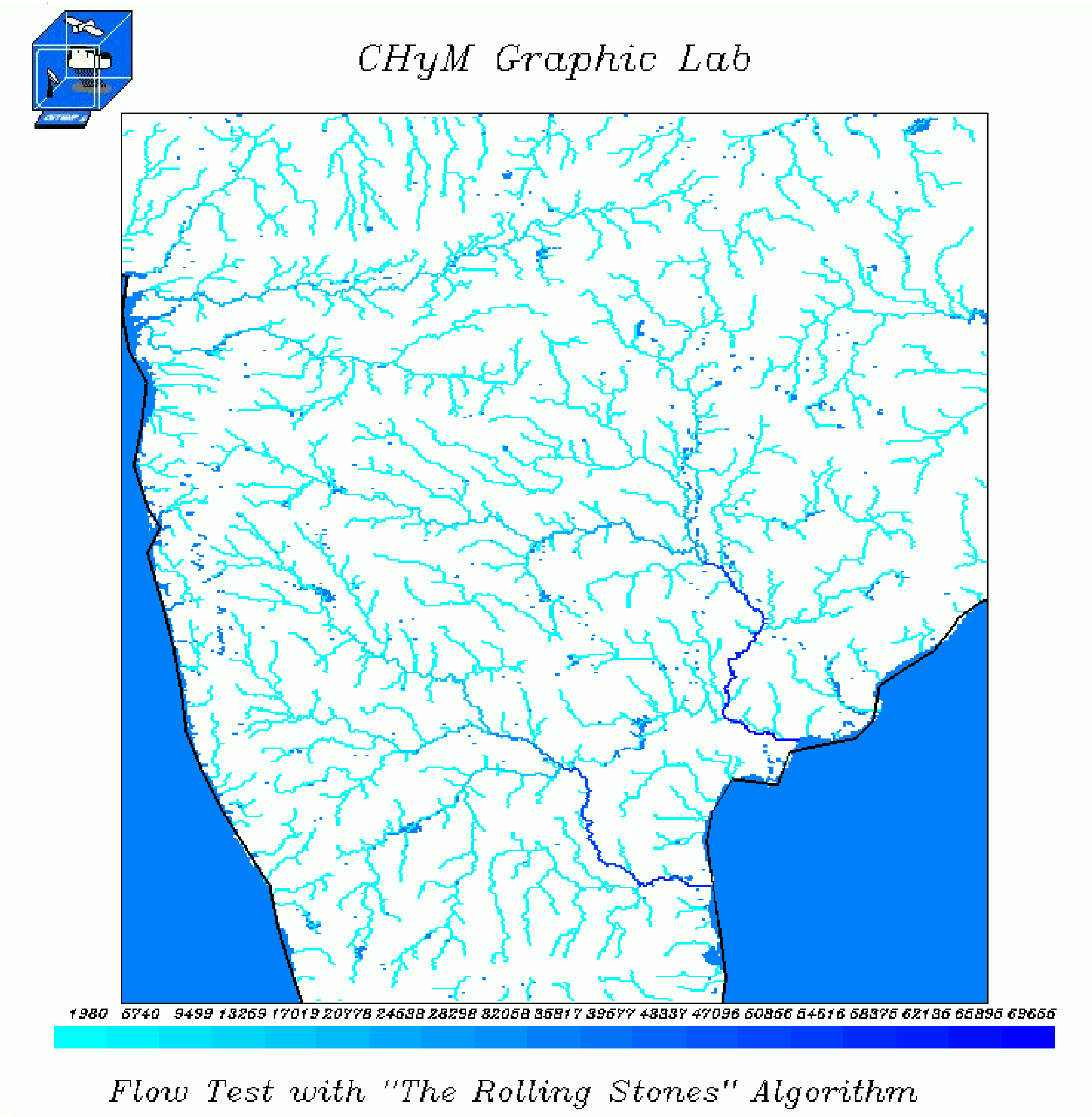
Flow Direction Map – 19 of 19 no-flow points were corrected.

CHyM: DEM pit correction



Flow Direction Map — 19 of 19 no-flow points were corrected.

CHyM: Examples of Drainage Network Extraction



CHyM: the Rolling Stones Algorithm (RSA)

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

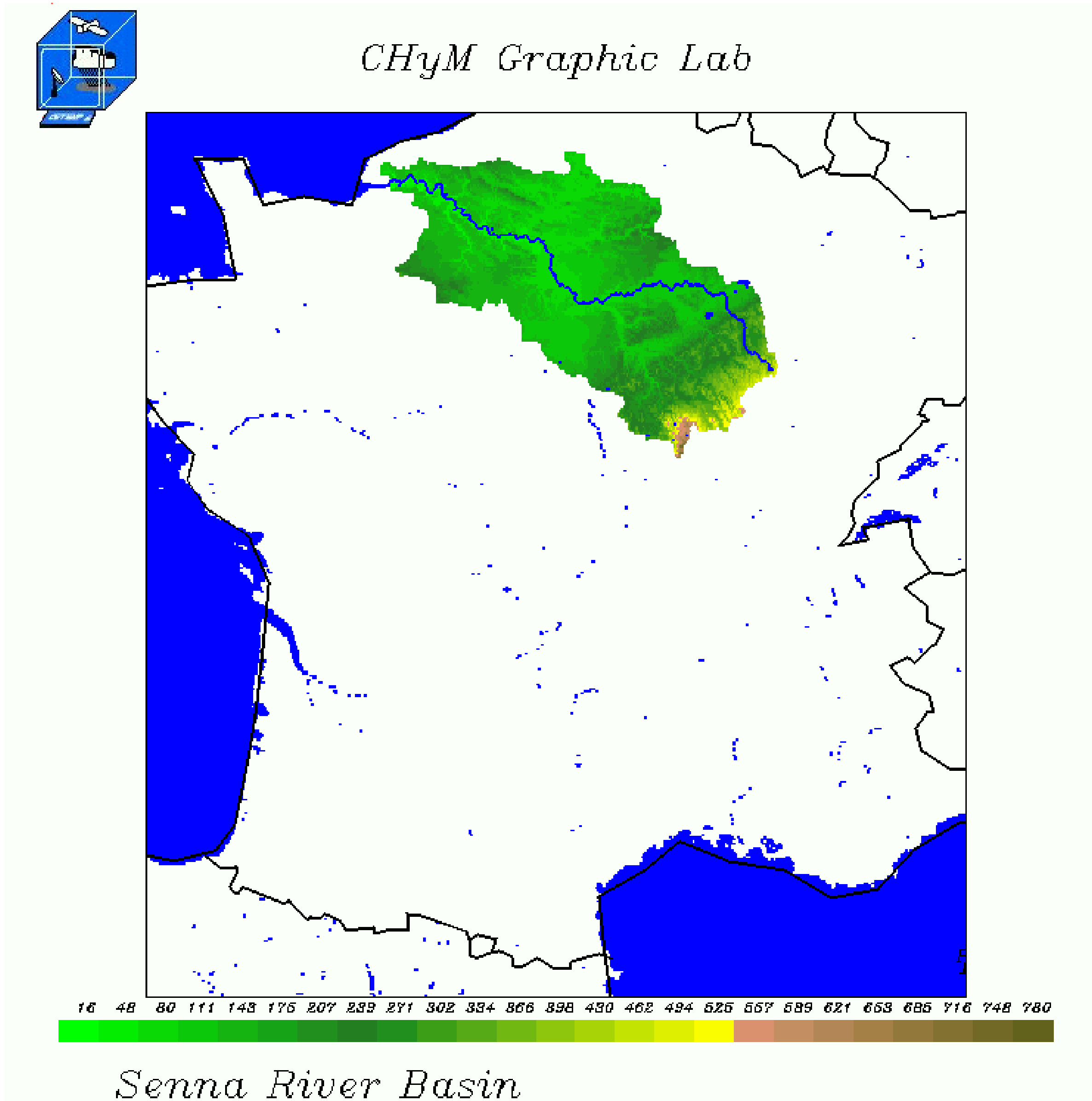
3. If a quantity *A* is associated to each stone where *A* is equivalent to the surface where the stone was at the beginning, for each cell it can be computed the upstream drained surface

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

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

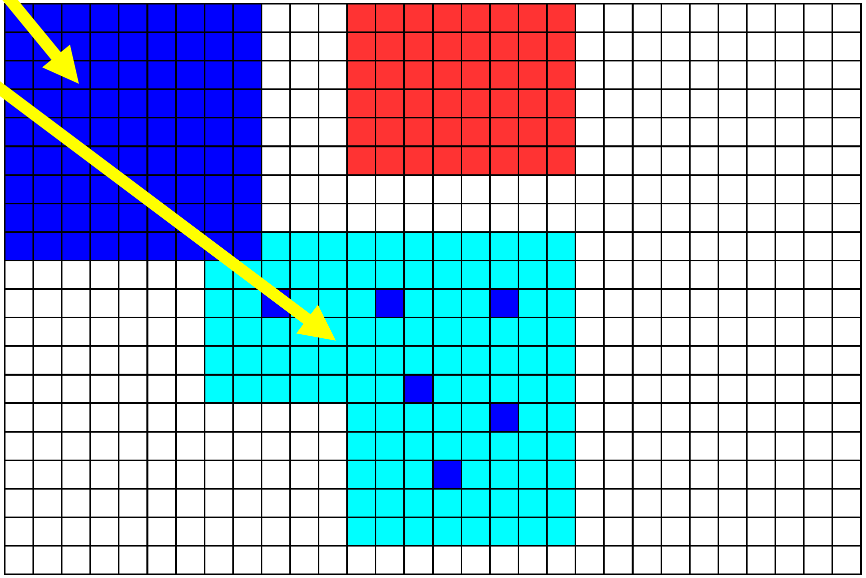
Module 1

Module 2

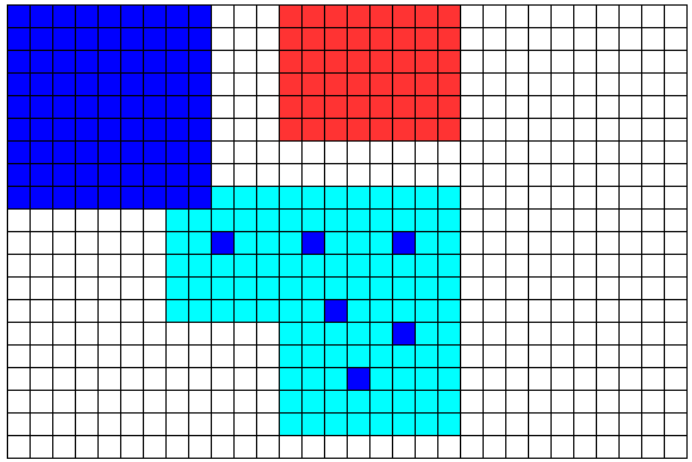
- Define subdomain
- Fill cells corresponding to rain gauges
- Fill subdomain matrix – Cr. Formula
- Smooth subdomain matrix using CA algorithn

Module 3

Module n



CA for CHyM applications



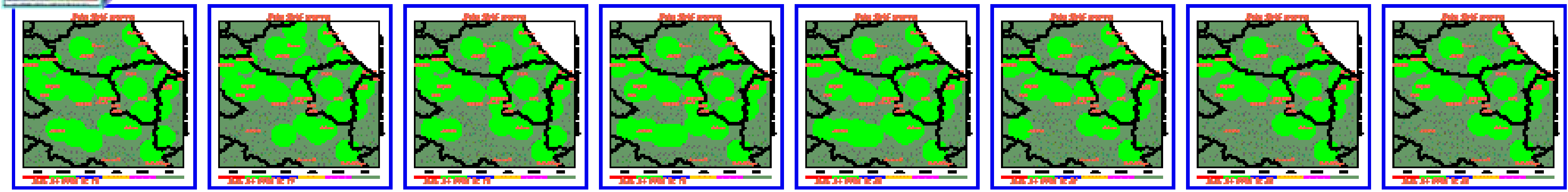
- ✓ CHyM grid is considered an aggregate of cellular automata
- ✓ The status of a cell corresponds to the value of a ChYM matrix (DEM) (RAIN)
- ✓ The state of the cells in the lattice is updated according to following **rule**

$$h_i \rightarrow h_i + \alpha\left(\sum_{j}^{8} \beta_j (h_j - h_i)\right)$$

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 (Update ends when flow scheme is OK)

CHyM Rain field sources: an example



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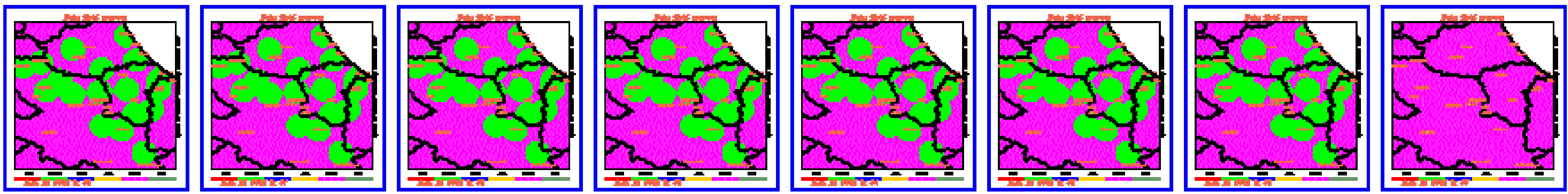
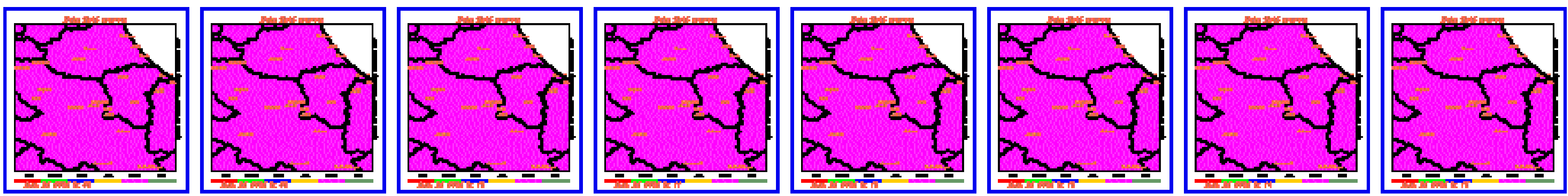
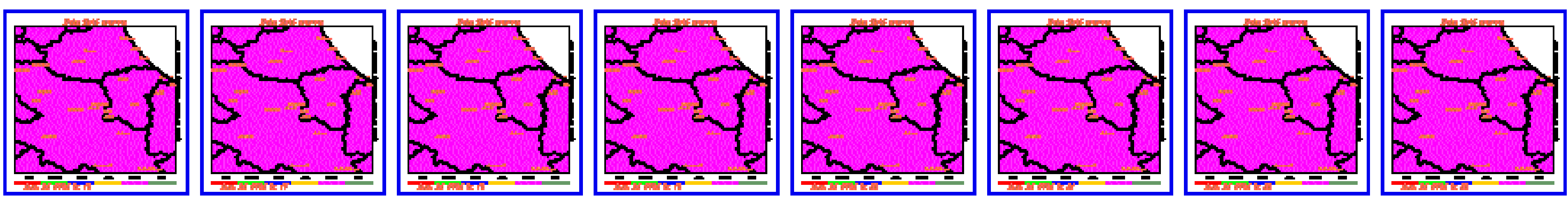


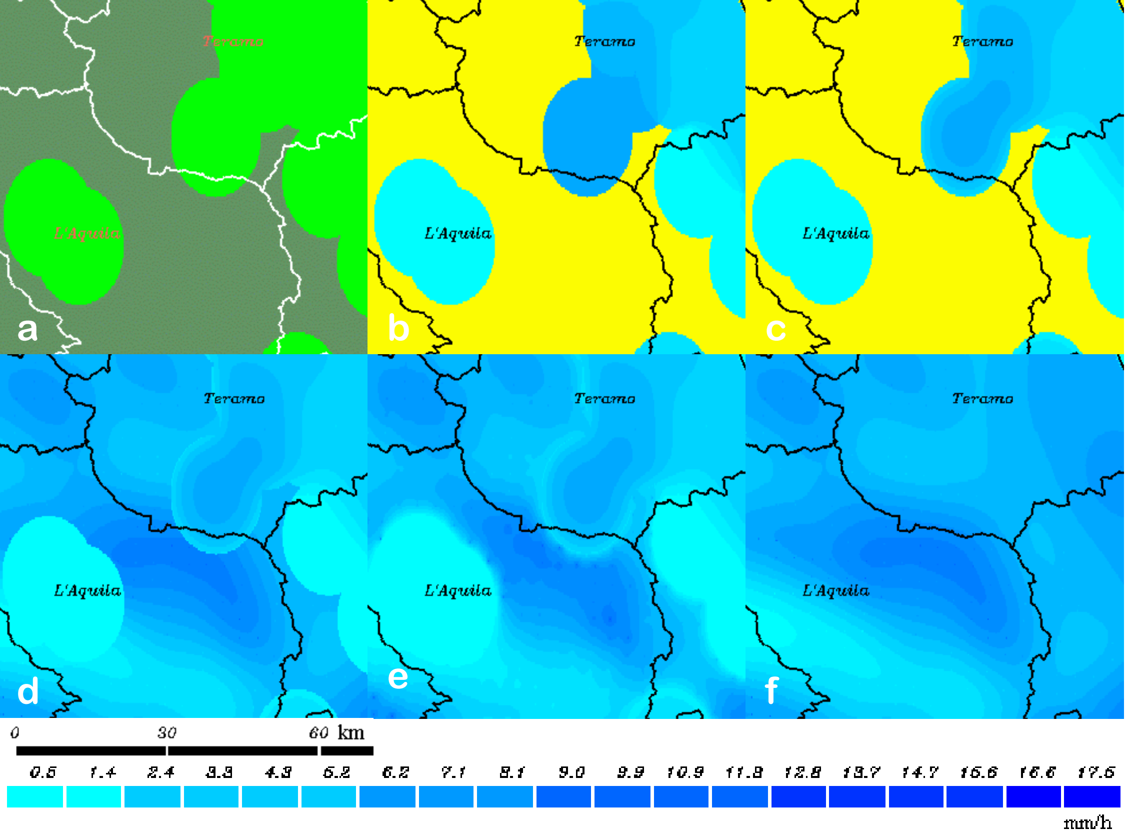
Aug, 25 2005 h: 00 | Aug, 25 2005 h: 01 | Aug, 25 2005 h: 02 | Aug, 25 2005 h: 03 | Aug, 25 2005 h: 04 | Aug, 25 2005 h: 05 | Aug, 25 2005 h: 06 | Aug, 25 2005 h: 07



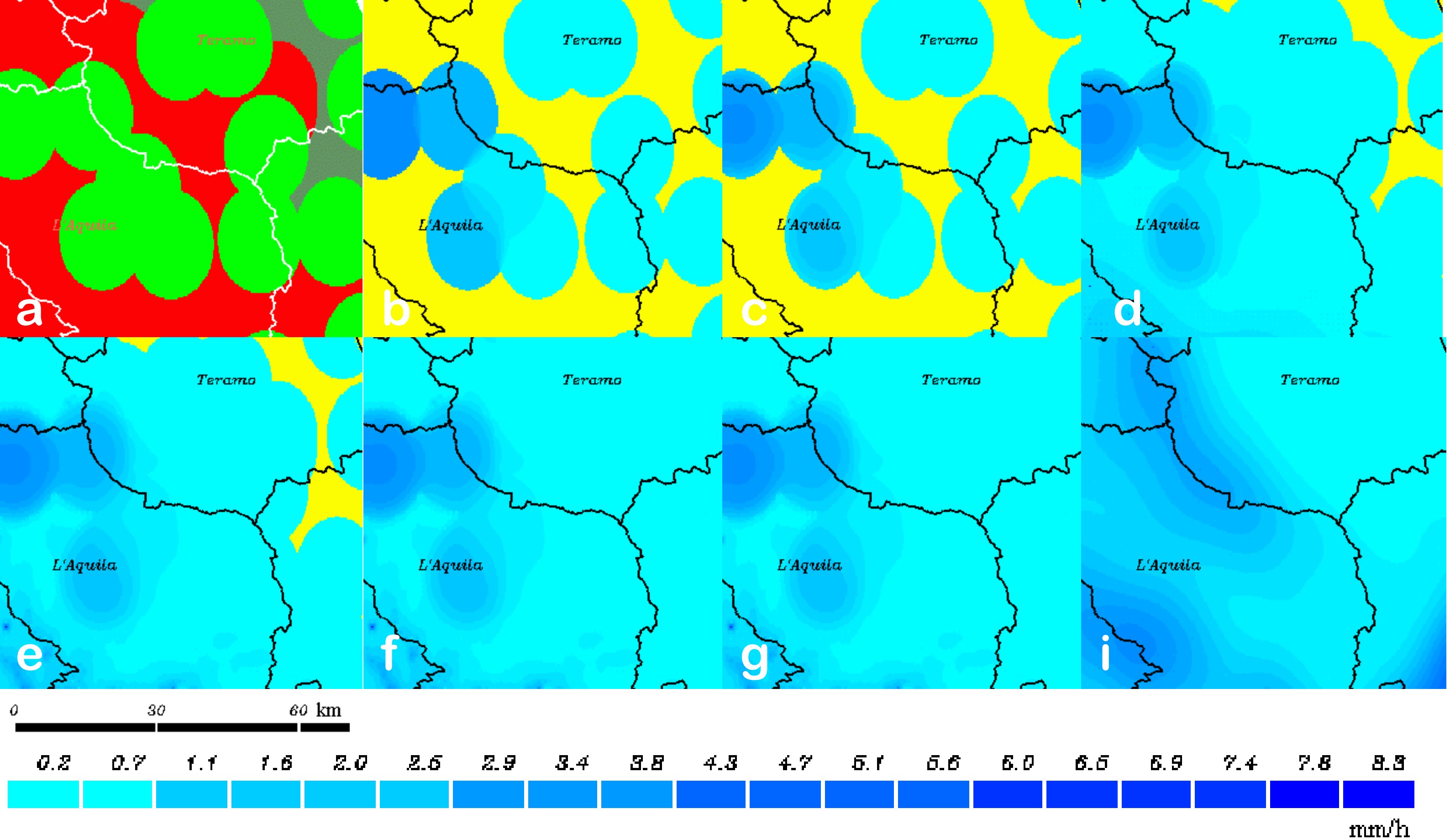
Aug, 25 2005 h: 08 | Aug, 25 2005 h: 09 | Aug, 25 2005 h: 10 | Aug, 25 2005 h: 11 | Aug, 25 2005 h: 12 | Aug, 25 2005 h: 13 | Aug, 25 2005 h: 14 | Aug, 25 2005 h: 15



Aug, 25 2005 h: 16 | Aug, 25 2005 h: 17 | Aug, 25 2005 h: 18 | Aug, 25 2005 h: 19 | Aug, 25 2005 h: 20 | Aug, 25 2005 h: 21 | Aug, 25 2005 h: 22 | Aug, 25 2005 h: 23

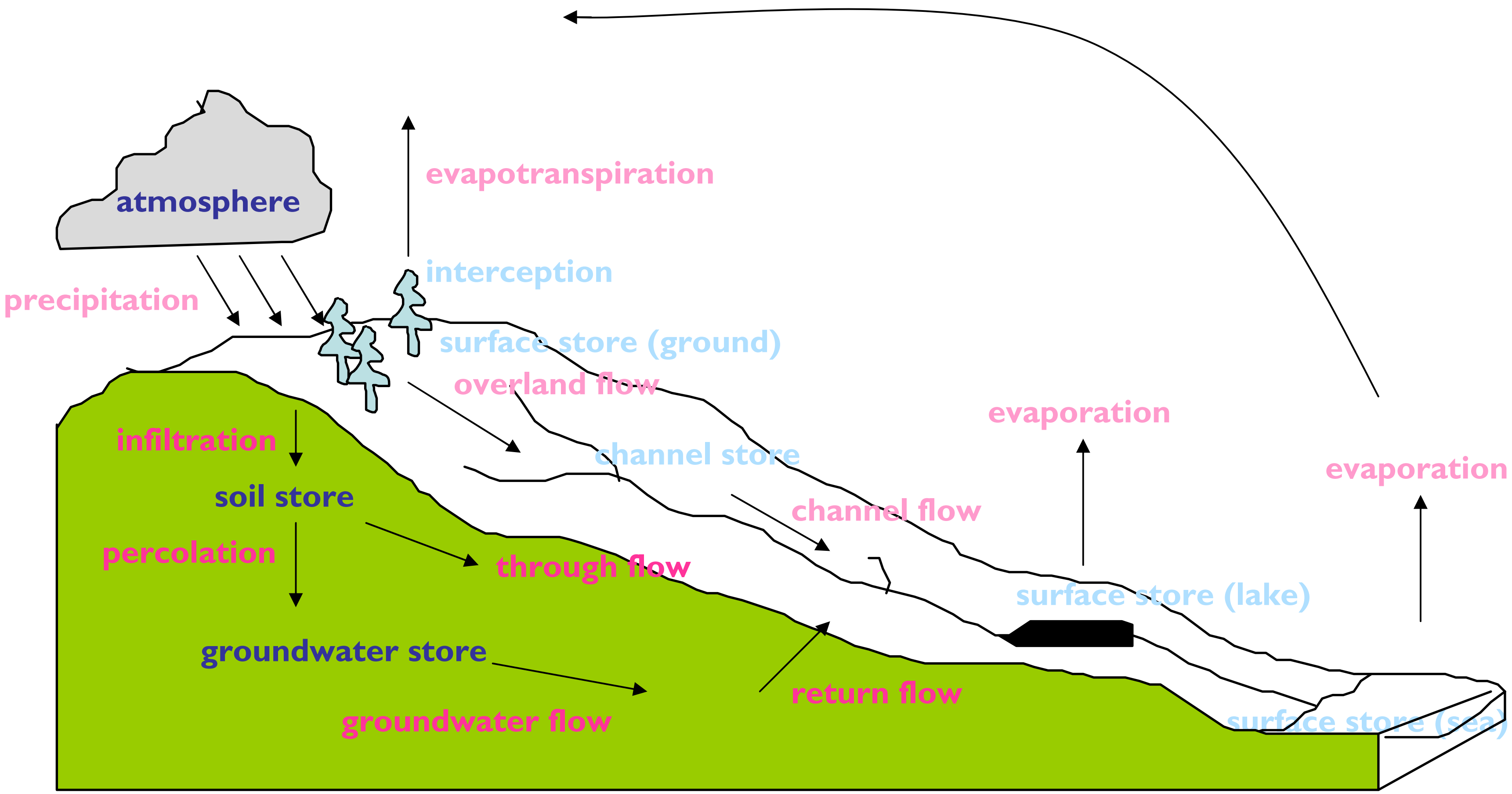


Rainfall data assimilation for 4 August 2005 (11:00 UTC). Panel (a) shows the rain source available at each grid point (green: gauges; grey: model meteorological output used as a source when measurements are not available). In panel (b) only the gauge measurements are used and merged with the Cressman 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

The hydrological cycle



From School of Geography, University of Leeds Course material

For each cell the simulated processes are:

Rainfall
Runoff
Evapotraspiration
Infiltration

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

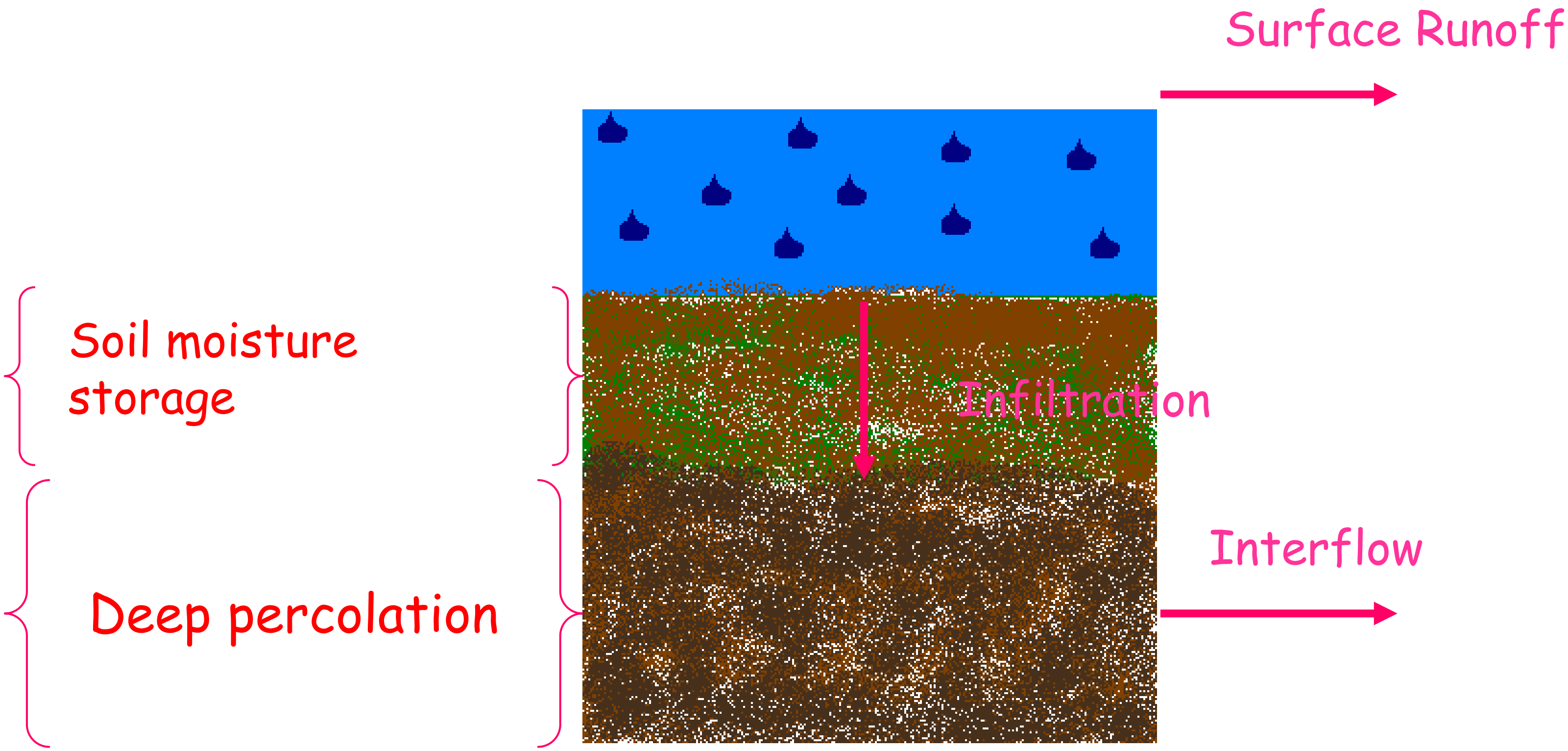
1/R= wetter perimeter

n= Manning's roughness coefficient

$R = \beta + \gamma D\delta$ R is the hydraulic radius that can be written as a linear function of the drained area D as:
$R = \beta + \gamma D^{\delta}$

B, γ and δ are empirical constants to be calibrated

CHyM: Infiltration



CHym: Infiltration

The infiltration term is given by:

$$I(t) = I_s(t) - P_s(lu)$$

where **Is(*t*)** and **Ps(*lu*)** are respectively the **infiltration** and the **percolation** rate at the ground surface.

Ps(lu) is only dependent from the kind of **landuse (lu)** of the considered cell and its value is established during the calibration of the model.

$$\mathbf{I(t) = I_{lu} - \kappa r(t)}$$

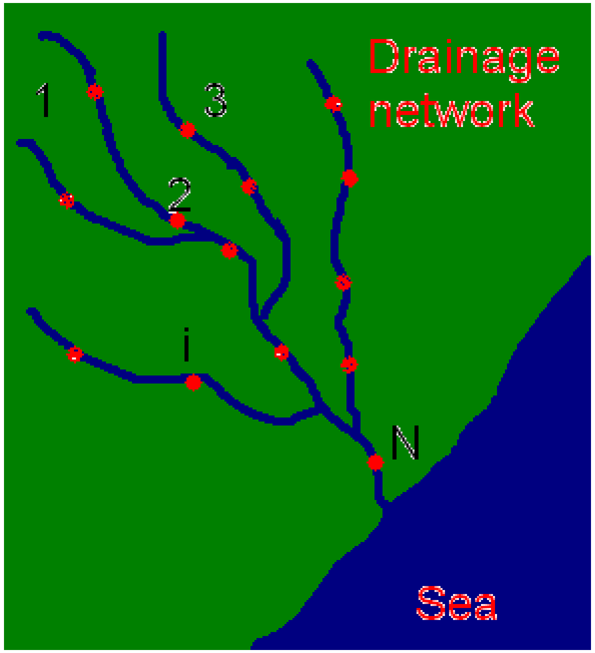
CHym: Evapotraspiration

Thornthwaite Formula (Thornthwaite and Mather, 1957)

$$ET_p = k_c \cdot ET_0$$

where k_c is the crop factor that is a function of land use. For details about the computation of the reference evapotranspiration refer to Todini (1996) and Thornthwaite and Mather (1957)

CHyM: Stress index



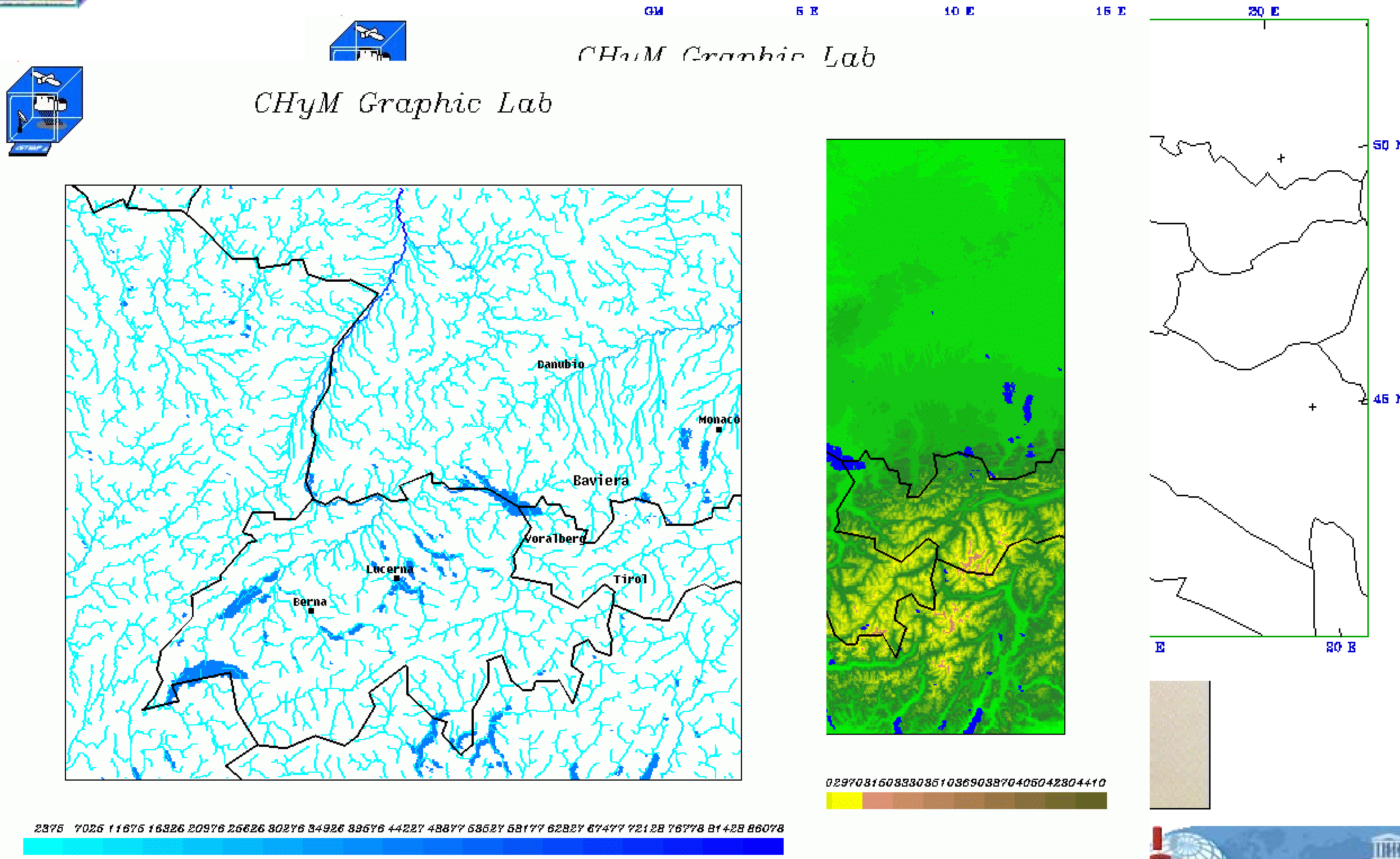
$$\frac{\sum_{i=1}^{N} R_i}{\sum_{i=1}^{N} A_i} = AI$$

R_i = rain

A_i = drained surface

AI= Alarm Index

CHyM: simulation of Aug 22-23 2005 event



Flow Test with "The Rolling Stones" Algorithm

...f Aug 22-23 2005 event

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ALLUVIONI IN AUSTRIA, SALE A TRE IL NUMERO DEI MORTI

E'salito a tre il bilancio delle vittime del maltempo in Austria nelle ultime ventiquattr'ore. A Ruethe, nella provincia di Vorarlberg, nella parte ovest del Paese, le squadre di soccorso hanno recuperato oggi da un seminterrato allagato il cadavere di un uomo di 52 anni. Ieri una persona era stata travolta e uccisa da una frana a Langenfeld, nel Tirolo; nella Stiria una cinquantenne era stata trascita via dall'acqua che aveva invaso la sua abitazione. All'appello manca ancora una persona; altre diciassette sono rimaste ferite. Le piogge hanno interessato in particolare le province del Vorarlberg e del Tirolo, dove sono stati registrati i danni maggiori. I meteorologi annunciano un miglioramento delle situazione gia' da oggi. "Il peggio e' passato", ha affermato Siegfried Jaches, portavoce del ministro dell'Interno. Nei prossimi giorni si potra' fare una stima dei danni.

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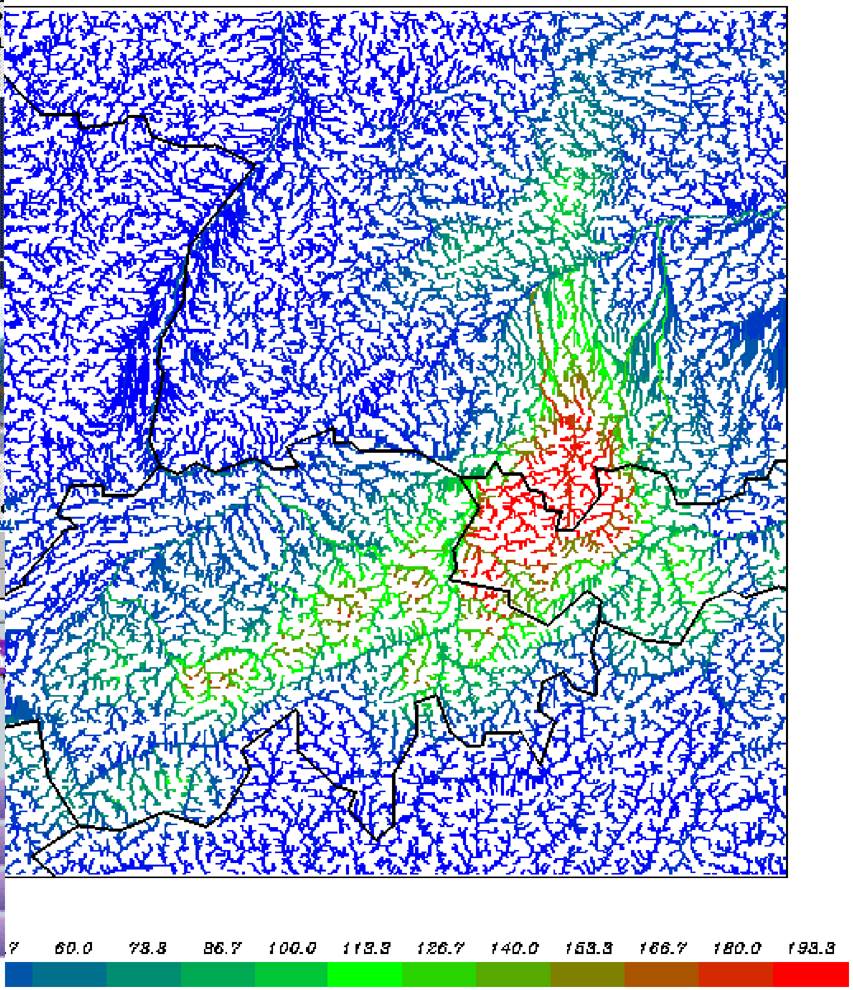
Inondations: les pays alpins en état d'alerte

agrandir la photo

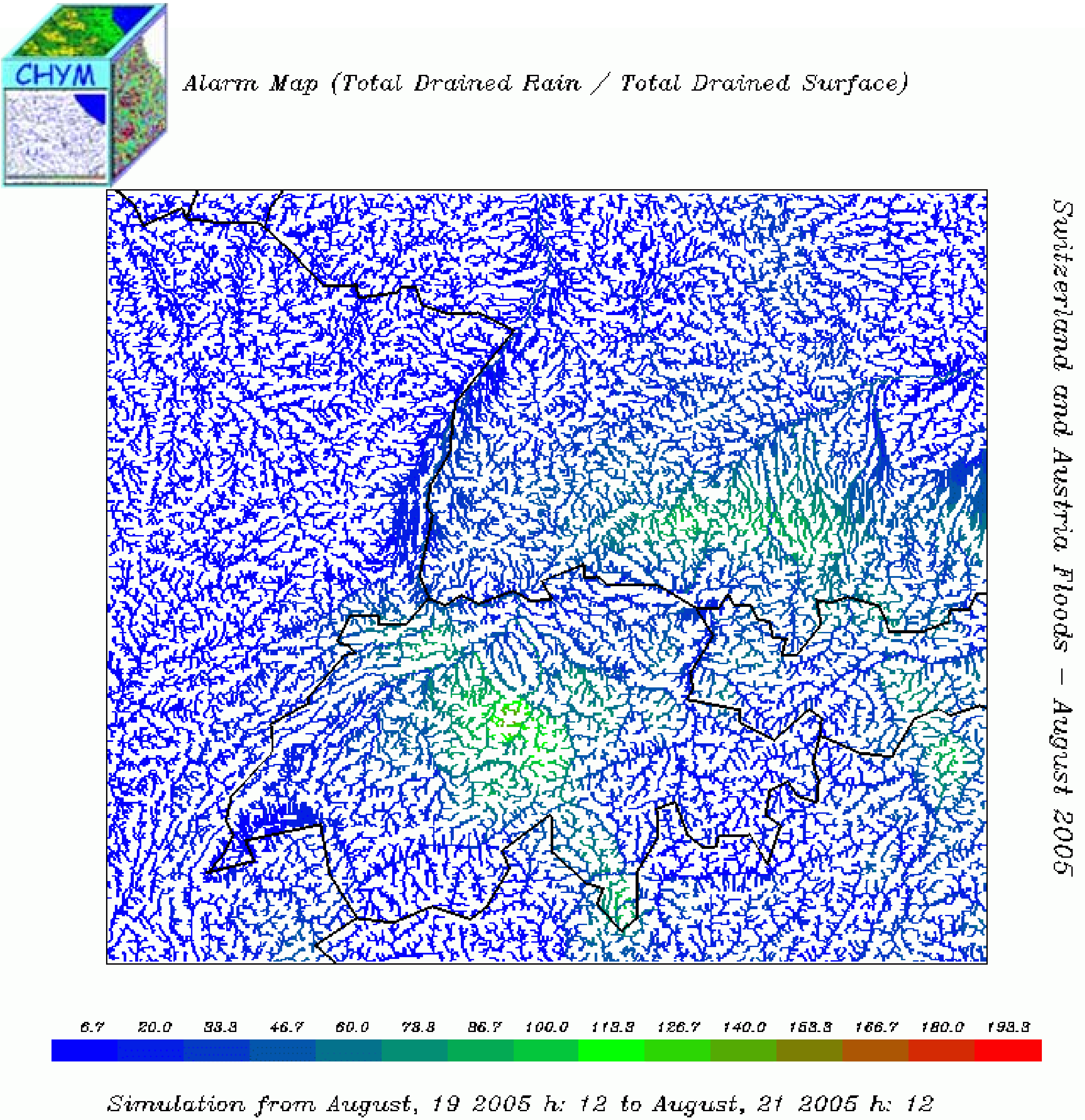
VIENNE (AFP) - La Suisse, l'Autriche et le Sud de l'Allemagne et des pays d'Europe de l'Est sont en état d'alerte depuis plusieurs jours après des inondations meurtrières, les plus graves depuis 1999 dans l'arc alpin, qui ont déjà provoqué des millions d'euros de dégâts.

...ap (Total Drained Rain / Total Drained Surface)



...m August, 21 2005 h: 12 to August, 23 2005 h: 12

CHyM: simulation of Aug 22-23 2005 event



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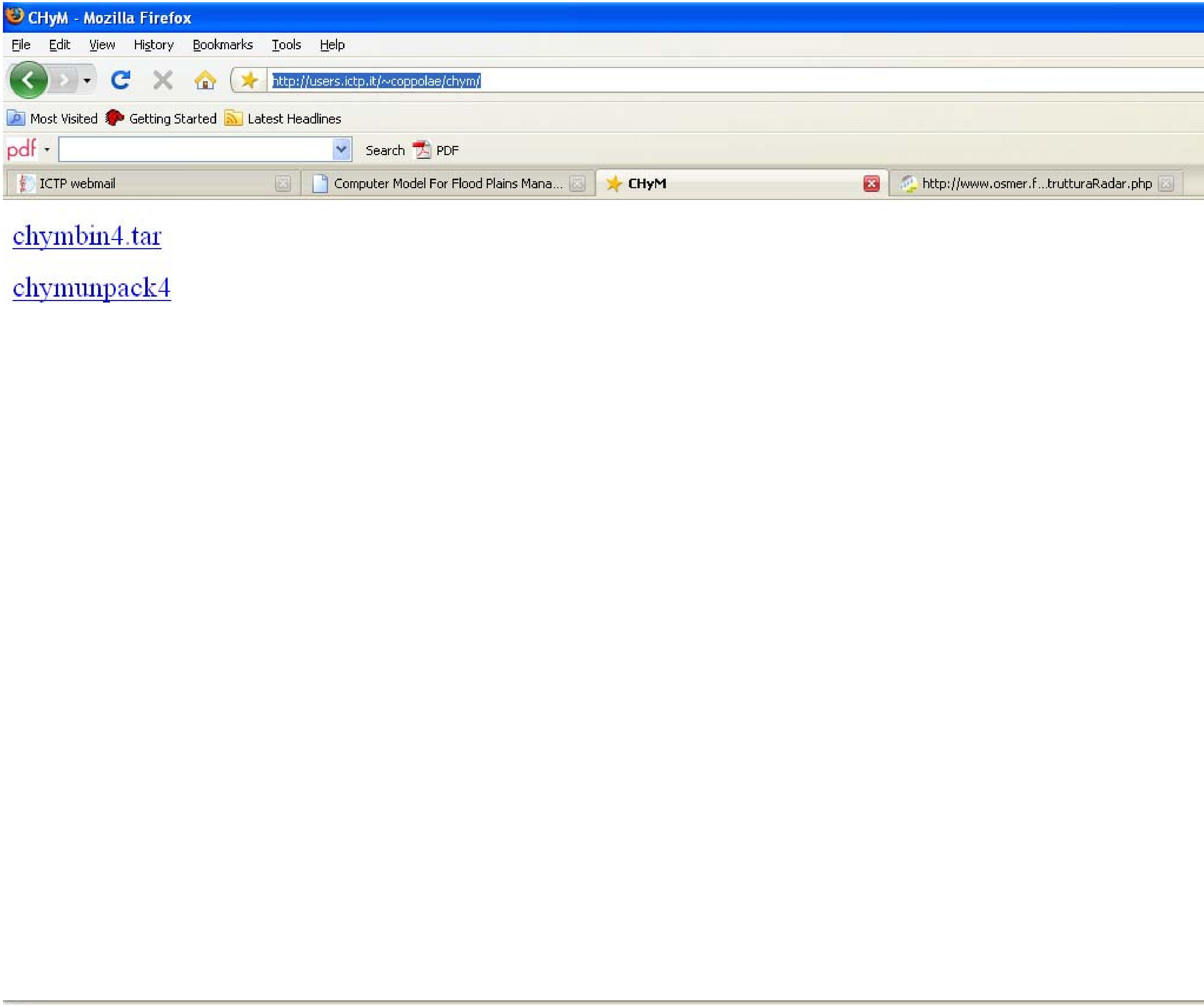
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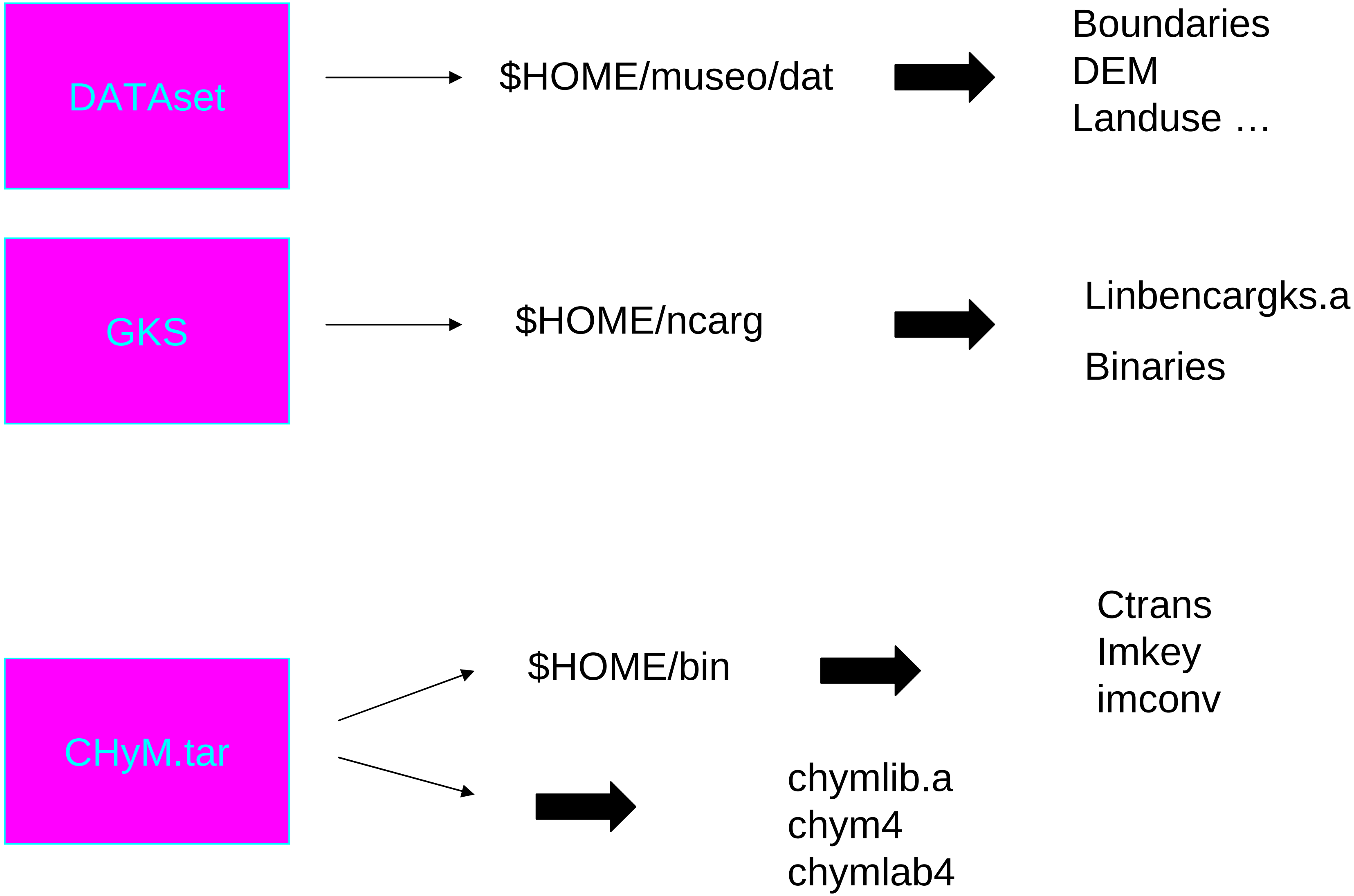
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Linbencargks.a
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CHyM.tar
$HOME/bin
Ctrans
Imkey
imconv
chymlib.a
chym4
chymlab4

CHyM: script

```
set cont=0
 set var=1
 set REST = "false"                    # if true output file grid is used
 set INPUTFILE = 01010100_eraint.dat

 set FILES = `ls /scratch/smr2029/chym/$INPUTFILE`

  foreach FILE ($FILES)
     echo "$FILE"
     set DATA = `basename $FILE _eraint.dat`
     echo "$DATA"
     @ cont = $cont + $var
     echo "$cont"

     set OUTFILE = `echo "./tmp/chymout.$DATA"`
     echo "$OUTFILE"

set IOSTESSO = `basename $0`
set VERSION =  "4.0"
set RELEASE = "Date of Release: May 5, 2009"
```

```
#------------------------------------------------------- Variables Setting -----
#
#            Grid parameters (ignored if REST = "true")
#
set NLON = 650                              # number of longitudes
set NLAT = 300                              # number of latitudes
set SLON = 7.20                             # 1st longitude  (Rif. 13.20)
set SLAT = 44.06                            # 1st latitude   (Rif. 41.76)
set DIJ  =  0.0090                          # lat-lon resolution (min. 0.0027)
set DEMF = "3"                              # 1 Italy DEM, 2 world DEM, 3 both
#set REST = "false"                         # if true output file grid is used
#set REST = "true"                          # if true output file grid is used
set ITEMPmon="true"                         # if true archived ERA40 temperatures are used
set ITEMPhour="false"                       # if true RegCM's temperatures are used

#                  Rain source specification
set RSRC  = "regcmfile"                     # museo, mm5file, satellite
                                            # intdb, neretir, radar, regcmfile
set IFILE1 = "$FILE"
set IFILE2 = "mm5/23JAN_CET_D4"             # set newmm51 in the main program
set MUSDM = 3                               # domain to be used for museo
                                            # if = 0 is automatically tested
set WHEN = 1                                # time resolution of the output
```

```
set NSLI  = 1                         # num. of time slices to be produced

set DATE  = "$DATA"                            # start date in the format yymmddhh
                                     #  or automatic (since 3 days before)
set STEP  = 060                            # num. of time step per hour

set RFILE = "tmp/chymrest.out"             # Output file
set RFILEsave = "tmp/chymrest.out.save"            # Output file save
set OFILE = "$OUTFILE"                         # Output file

set NOW   = `date "+%A, %B %d %Y"`
set TITLE = "$IOSTESSO $VERSION - Exp in Po valley - 19$DATE"

#                    Graphic parameters
set PLOT =   005               # 0 produce all maps
                           # 1 produce DEM map
                           # 2 produce landuse map
                           # 3 produce flow direction plot
                           # 4 produce incline plot
                           # 5 produce Flow Check plot
                           # 6 produce ARSSA stations location plot
```

```
# 7 produce rebuilt points map after each module
                    #   river mouths i-j coordinates, note: you MUST
                    #   correctely specify RIVER index
                    # 9 produce the whole drainage network
                    # 10 produce the rain sources map
                    # 11 Histogram for DEM corrections
                    # 12 DEM corrections map
                    # 13 Temperature Field
                    # 14 Potential Evapotranspiration
                    # 101- prod. rain plot at (PLOT-100)th time step
                    # Other values = no plot produced
set RIVER = 06          # Select a river for plot 8, 0 means all rivers
set ZOOM  = -1          # if > 0 plot is a zoom as following parameters
set LON1  = 280         #    first x (lon) grid point to be plotted
set LON2  = 310         #    last x (lon) grid point to be plotted
set LAT1  = 110         #    first y (lat) grid point to be plotted
set LAT2  = 120         #    last y (lat) grid point to be plotted
#-------------------------------------------------------------------------------
#------------------------------------------ Do not modify beyond this line --
#-------------------------------------------------------------------------------
```

Chym variables

```
c       lat(nlon,nlat)  ---> Latitudes
c       lon(nlon,nlat)  ---> Longitudes
c       dem(nlon,nlat)  ---> DEM height (meters)
c       accl(nlon,nlat) ---> slope (tangent of angle in the flow direction)
c       fmap(nlon,nlat) ---> integer showing flow dir (1-8 from NW to W)
c       luse(nlon,nlat) ---> integer for Land use code (see landuse.code file)
c       area(nlon,nlat) ---> area (Km2) of each cell
c       drai(nlon,nlat) ---> Total Drained Area of each cell (Km2)
c       rsrm(nlon,nlat) ---> RainSouRce Map with following codes
c                              6 --> radar
c                              7 --> RegCM output file
c                              8 --> micra
c                              9 --> rain gauges
c                             10 --> neretir
c                             11 --> arssa
c                             12 --> MM5 output file
c                             13 --> museo
c       alfa(nlon,nlat) ---> runoff speed (m/sec)
c       dx(nlon,nlat)   ---> distance between each cell and the drained one
c       port(nlon,nlat) ---> Cell-Channell discharge (portata m3/sec)
c       bwet(nlon,nlat) ---> Wetted area x cell-channel lenght (m3)
c       h2o(nlon,nlat)  ---> total water content per each cell (m3)
c       dh2o(nlon,nlat) ---> change in water content in the current time step
c       infi(nlon,nlat) ---> Infiltration
```

Chym physical processes

Subroutine runoff(i,j)
Subroutine evapot(i,j)
Subroutine graundwater(i,j)

percolation (x mm/h)

Infiltration (x mm)

groudwater flow -> return flow

```
if (iplot.eq.10) call plotsrcsmap(adesso)
     if (itemphour) call evaptparamTP(ih)        ! Laura
     call evapotranspiration   ! evapotranspiration
     call groundwater          ! percolation - infiltration - interception
     work2=work2+rain
     if (mod(ih,itout).eq.0) then
       mchym(50)=3                       ! Internal use in the subrotine writerec
       work2=work2/itout
       call writerec(11,'ara','rv',work2,nlon*nlat,idate,actsource)
       work2=0.
     end if
     if (ih.eq.nsli) then
       mchym(50)=3                       ! Internal use in the subrotine writerec
       call writerec(111,'ara','rv',rain,nlon*nlat,idate,actsource)
     end if
     write (6,'(16x,a)') '> Calculating Runoff and Flow Discharge'
     do imin=1,stepxhour
       dh2o=0.0
       call runoff (imin,ih)   ! runoff  Laura aggiunti i parametri di input
       call flowdischarge     ! flow discharge
```

```
subroutine flowdischarge
     include '${IOSTESSO}_common.f'
     include '${IOSTESSO}_fields.f'
     do i=2,nlon-1
       do j=2,nlat-1
         idir=fmap(i,j)
         if (luse(i,j).ne.mare.and.idir.ge.1.and.idir.le.8) then
           rainload=area(i,j)*1.0e+03*(rain(i,j)+dgh2o(i,j))/stepxhour
           h2o(i,j) =h2o(i,j)+dh2o(i,j)+rainload
           bwet(i,j)=h2o(i,j)/dx(i,j)   !bwet= Wetted area x cell-channel lenght (m3)
           port(i,j)=alfa(i,j)*bwet(i,j)   !alfa= runoff speed (m/sec)
         endif
       enddo
     enddo
     return
     end
```

```
subroutine runoff (imin,ih)
      include '${IOSTESSO}_common.f'
      include '${IOSTESSO}_fields.f'
      integer imin,ih,tao
      do i=2,nlon-1
        do j=2,nlat-1
          idir=fmap(i,j)
          if (luse(i,j).ne.mare.and.idir.ge.1.and.idir.le.8) then
            dm=port(i,j)*deltat
            if (dm.gt.h2o(i,j)) dm=h2o(i,j)
            dh2o(i,j)=dh2o(i,j)-dm
            dh2o(i+ir(idir),j+jr(idir))=dh2o(i+ir(idir),j+jr(idir))+dm
           tao=20*(8E06)
           dgh2o(i+ir(idir),j+jr(idir))=dgh2o(i+ir(idir),j+jr(idir))
                                  +0.0005*gh2o(i,j)*(1-exp(-deltat*imin*ih/tao))
          endif
        enddo
      enddo
      return
      end
```

```
subroutine fillalpha
      include '${IOSTESSO}_common.f'
      include '${IOSTESSO}_fields.f'
      real mann
      alfa=0.0
      alpha=0.0015    ! Coefficients for hydraulic radius
      beta=0.05
      gamma=0.33
     delta=3.5       ! Param. for land/channel flow  ! Best 3.5 - test only
     tresh=100.0
      do i=2,nlon-1
        do j=2,nlat-1
          idir=fmap(i,j)
          land=luse(i,j)
          mann=0.043                              ! Best 0.043 - test only
          mann=manning(luse(i,j))
          if (idir.ge.1.and.idir.le.8.and.land.ne.mare.and.land.gt.0) then
            if (land.gt.100.or.land.le.0) then
              write(6,'(10x,a,i5)') 'Wrong value for landuse code: ',land
              stop 'flux error inside fillalpha'
            endif
            dx(i,j)=distance(lat(i,j),lon(i,j),
      2           lat(i+ir(idir),j+jr(idir)),lon(i+ir(idir),j+jr(idir)))
            if (drai(i,j).gt.tresh) then
               enne=mann/delta
            else
               enne=mann
            endif
            hrad=alpha+beta*((drai(i,j)*1.e00)**gamma)
            alfa(i,j)=((hrad**0.6666*accl(i,j)**0.5)/(enne))
          endif
        end do
```

Cellular Automata smoothing

```
…
      ncyc=400
       write (6,'(15x,a,i5,a)')'DEM Smoothing with CA alg:',ncyc,' cycles'
       do ii=1,ncyc
          call d2cellcycle(dem,noflow,plot,nlon,nlat,0.005)
       enddo
      ncyc=1000
      write (6,'(15x,a,i5,a)')'DEM Smoothing with filling alg:',ncyc,' cycles'
       do ii=1,ncyc
          call demholefilling
       enddo
…
```

Chymlab

To plot static fields

plot [plottype]

The following are plottype:

- atlante to plot a geographic representaion of CHyM domain
- dem to plot Digital Elevation Model
- drainnet to plot the whole drainage network
- drainriver to plot the drainage network of a river
- flowcheck to plot the Flow Check Test
- flowdir to plot the flor direction map
- landuse to plot the Land Use map
- riverbasin to plot a river basin
- riverondem to plot a river on DEM

To plot dynamical fields at fixed time slice

plot [plottype] [timeslice]

if timeslice is missing, current value of tslice is assumed

The following are plottype:

- rain to plot the rain field at the current time slice
- drain to plot the drained rain field at the current time slice
- rsource to plot the rain field sources at the current time slice
- portata to plot the flow discharge at the current time slice
- wetarea to plot the wetted area at the current time slice

To plot dynamical fields between 2 time slices

plot [plottype] [islic1] [islic2]

if [islic1-2] are missing, current value of islic1 and islic2 are assumed

The following are plottype:

- alarm to plot the alarm map in the current time interval
- arain to plot the accumulated rain in the current time interval

To plot fields along the river path
plot [plottype] [riverindex]
if riverindex is missing, current value of "Selected river" is assumed
The following are plottype:
rivalarm to plot alarm map along the river path
rivslope to plot slope along the river path
rivdem to plot DEM along the river path
rivdrai to plot Drained area along the river path
rivport to plot Drained area along the river path

To show parameters
show [option]
possible show option are:
file to show the parameters of the current simulation
river to show the list of the rivers
param to show the current settings of parameters
selpoint to show the current selected point values

To set parameters
set [option] [value]
possible option are:
river to set the river
tslice to set the time slice
islic1 to set the first interval time slice
islic2 to set the last interval time slice
plotsize to set the size (in pixel) of the plots
plotform to set plots format (0=bmp,1=gif,2=tiff)
xmaxv to set Maximum value of plots calculated if < 0)

To get help
help
to display the full help

To exit form CHyMLab
exit (or quit)
to exit from CHyMLab

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- Operational
- ERA-15
- ERA-40
- ERA Interim

On-line

- A good place to begin
- How to find data
- Main steps
- General information
- Top 5 questions

ECMWF Interim Re-analysis Data Archive

The Interim re-analysis project **ERA Interim** will cover the period from 1989 to 2013, overlapping the earlier ECMWF 40 year re-analysis.

The period from 1989 to 1998 is now available.

This Level III-B archive is subdivided into three classes of data sets and further details of the contents will be added later:

- Full Resolution atmospheric
- Wave
- Atmospheric Monthly Means

The data sets are based on quantities analysed or computed within the ERA Interim data assimilation scheme or from forecasts based on these analyses.

Data Server

- Much ERA Interim data is available from the ECMWF Data Server at no charge for research usage.
- the first 10 years of the ERA Interim data from the Data Server can be supplied by ECMWF Data Services.

http://www.ecmwf.int/research/