Cetemps HYdrological Model

Marco Verdecchia - University of L'Aquila, Italy

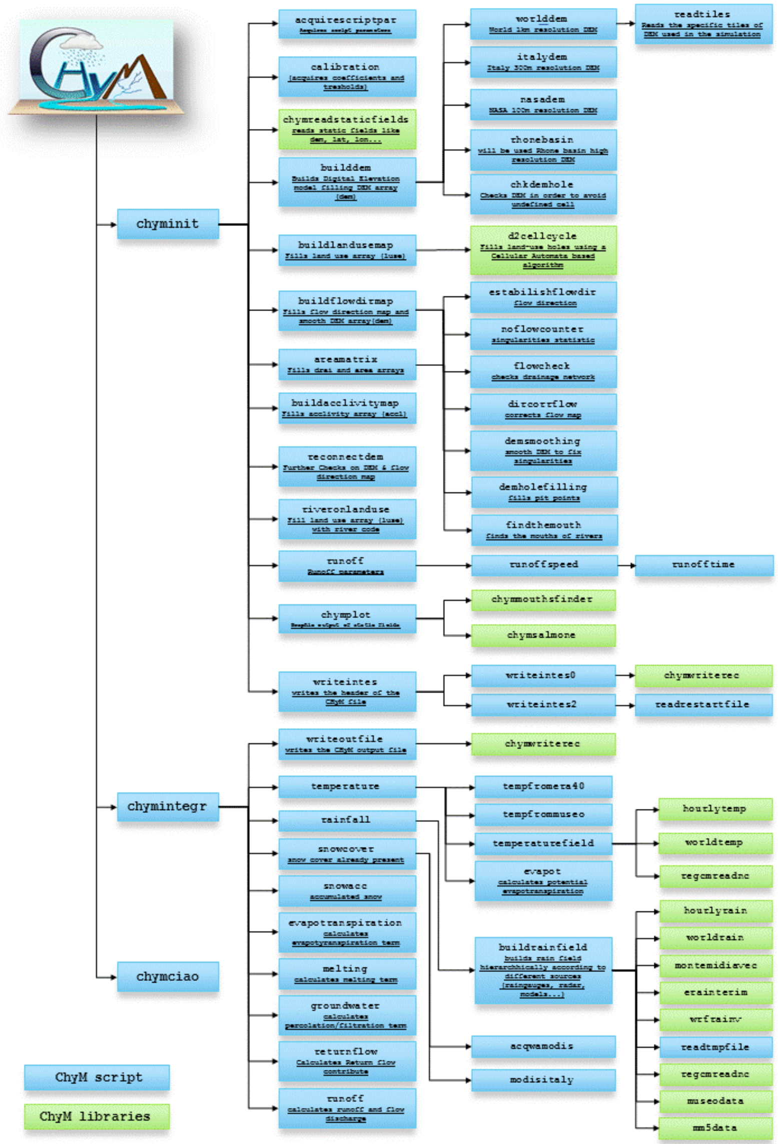
CHyM hydrological model
Numerical and Physical theory
and
Applications for flood alert mapping

Developed by M. Verdecchia, E. Coppola, B. Tomassetti and L. Mariotti

CHyM - Architectural characteristics

- Distributed grid-based hydrological model;
- Different sets of precipitation data can be assimilated and merged in a hierarchical way at each hourly time step;
- It includes an explicit parameterization of different physical processes contributing to hydrological cycle;
- It runs in any geographical domain with any resolution up to DEM resolution, drainage network is extracted by a native algorithm implemented in CHyM code;
- It runs in any Linux platforms;
- It doesn't use licensed software (GIS etc.), but graphic application are based on the GKS (low level library) developed by NCAR
- It reads, in the current implementation, precipitation and temperature fields from:
    - RegCM, MM5, WRF, Era-40, trimm, Persiann, rain gauge (any sparse data), radar, satellite estimation

Water Resources in Developing Countries: Hydroclimate modelling and Analysis tool



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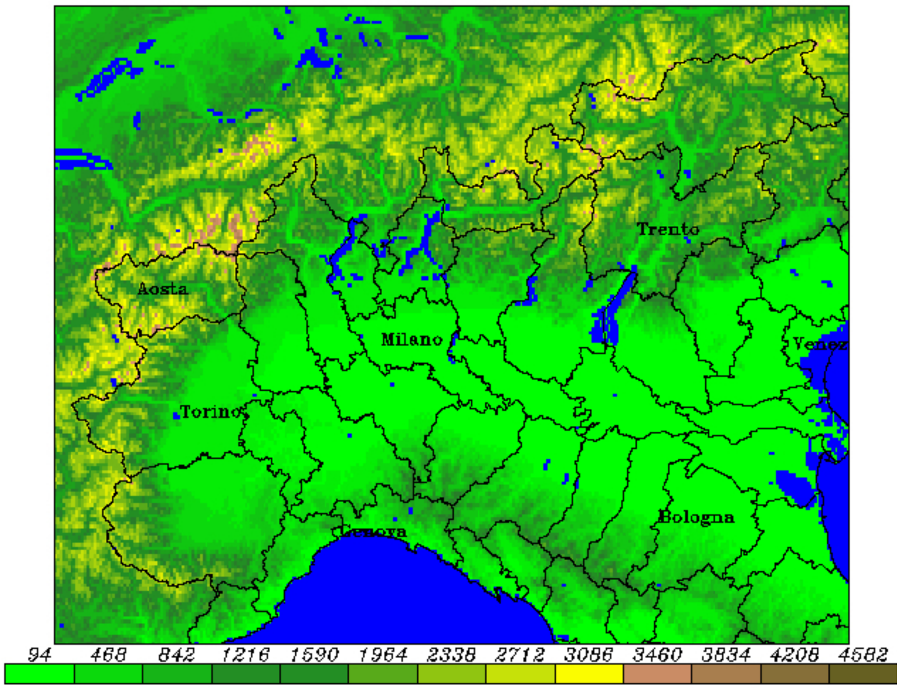
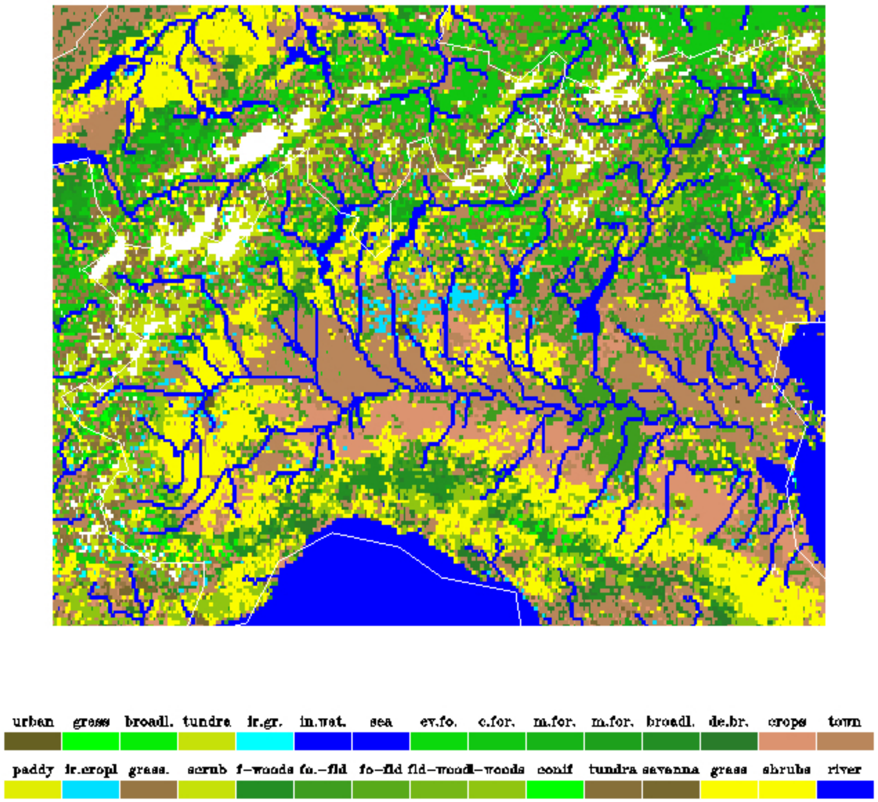
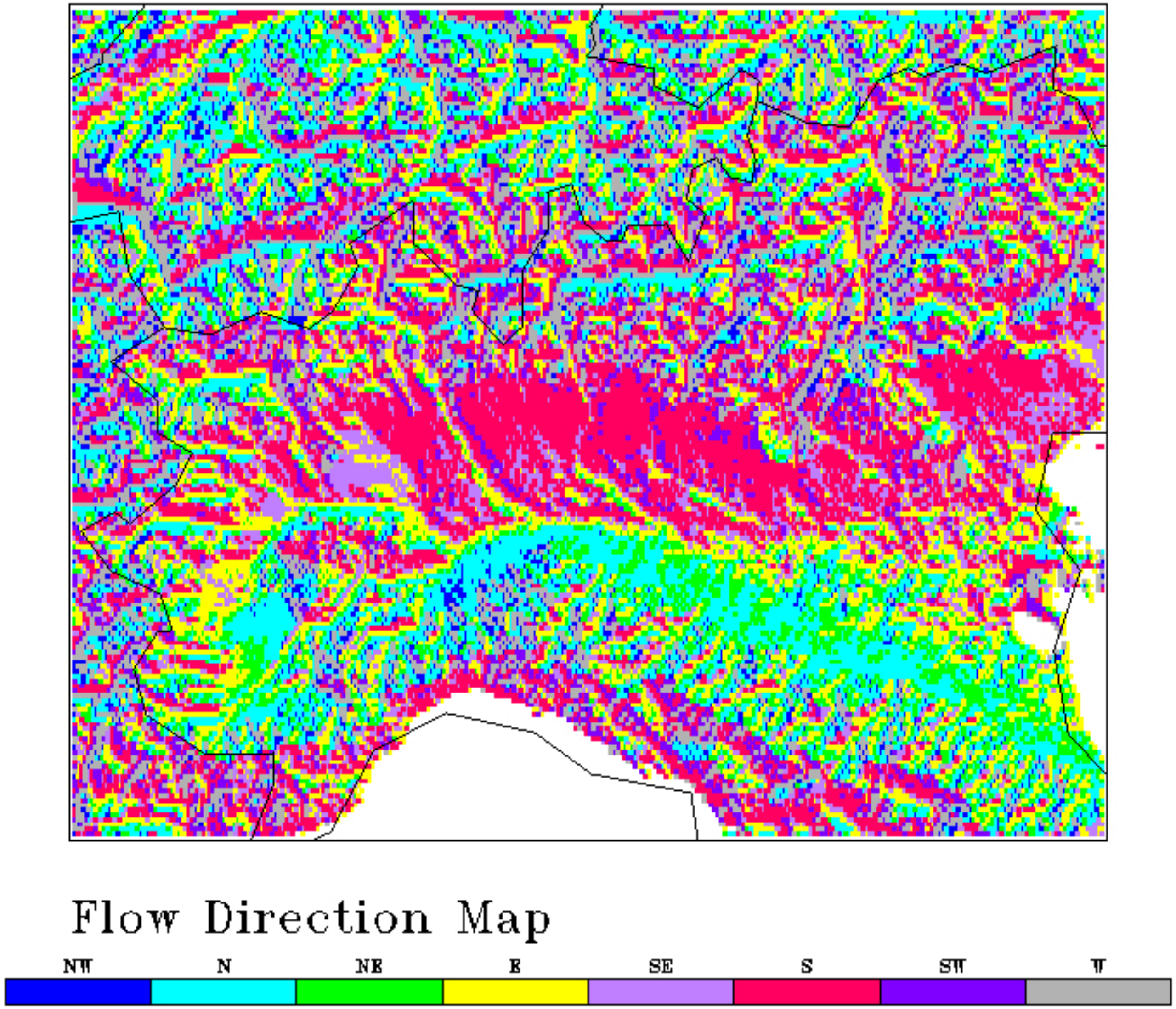
CETEMPS Hydrological Model



Digital Elevation Model – Approx. Res: 2216.6 meters.

CETEMPS Hydrological Model (Land Use)





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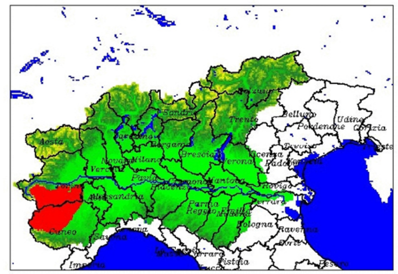
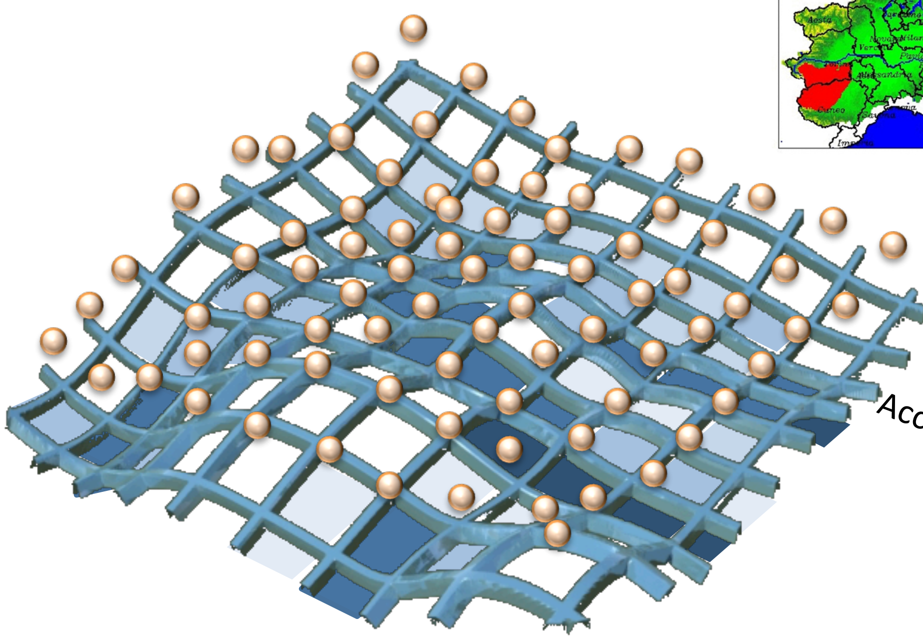
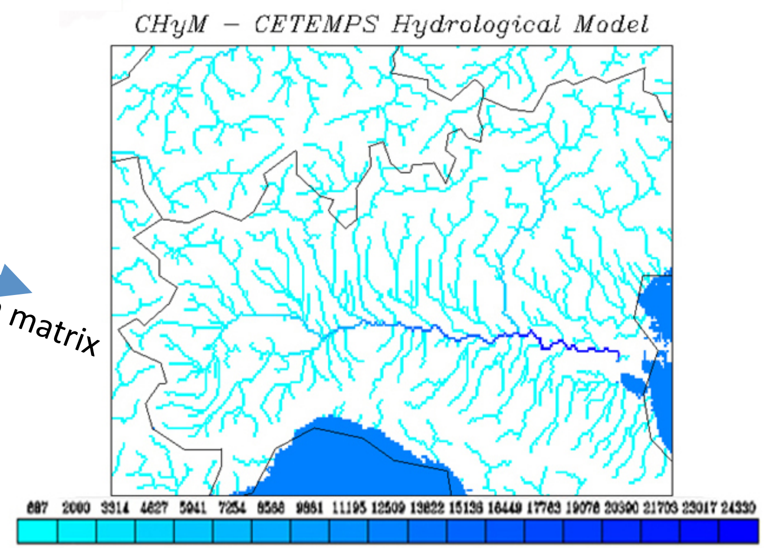
DEM and LU arrays - Flow Dir. Array – Accum. Array (loop over CA Alg.)

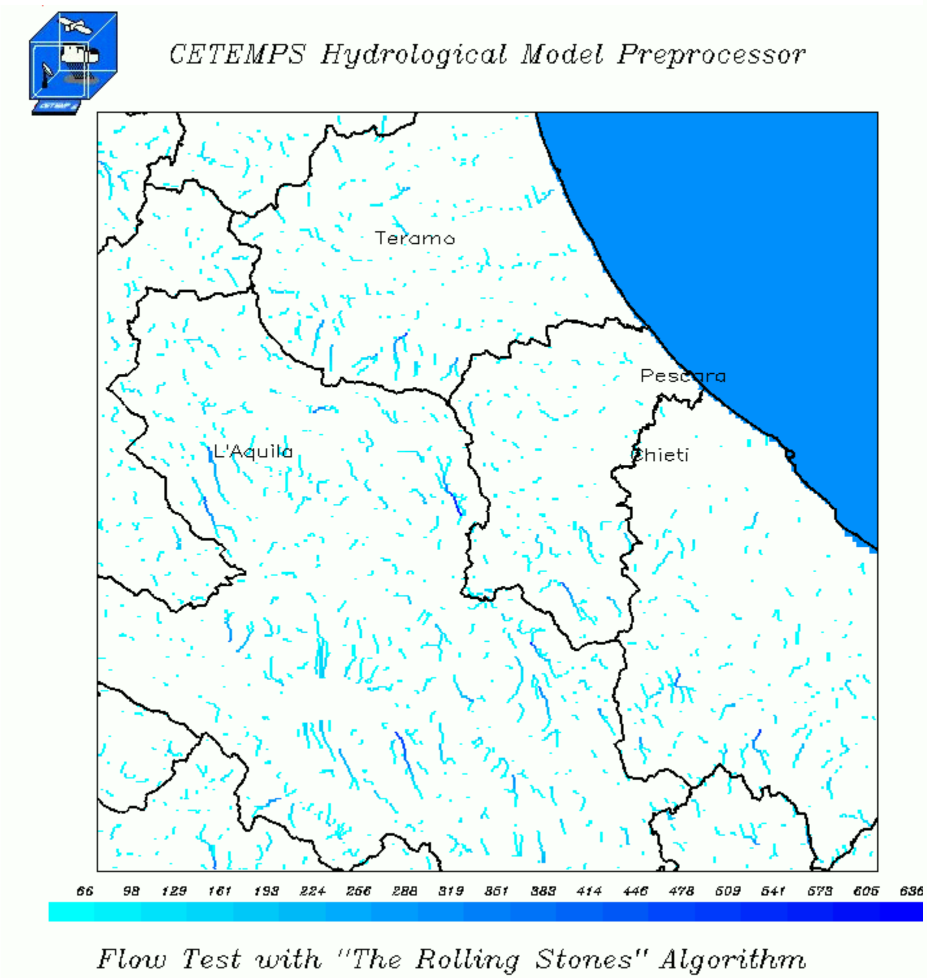


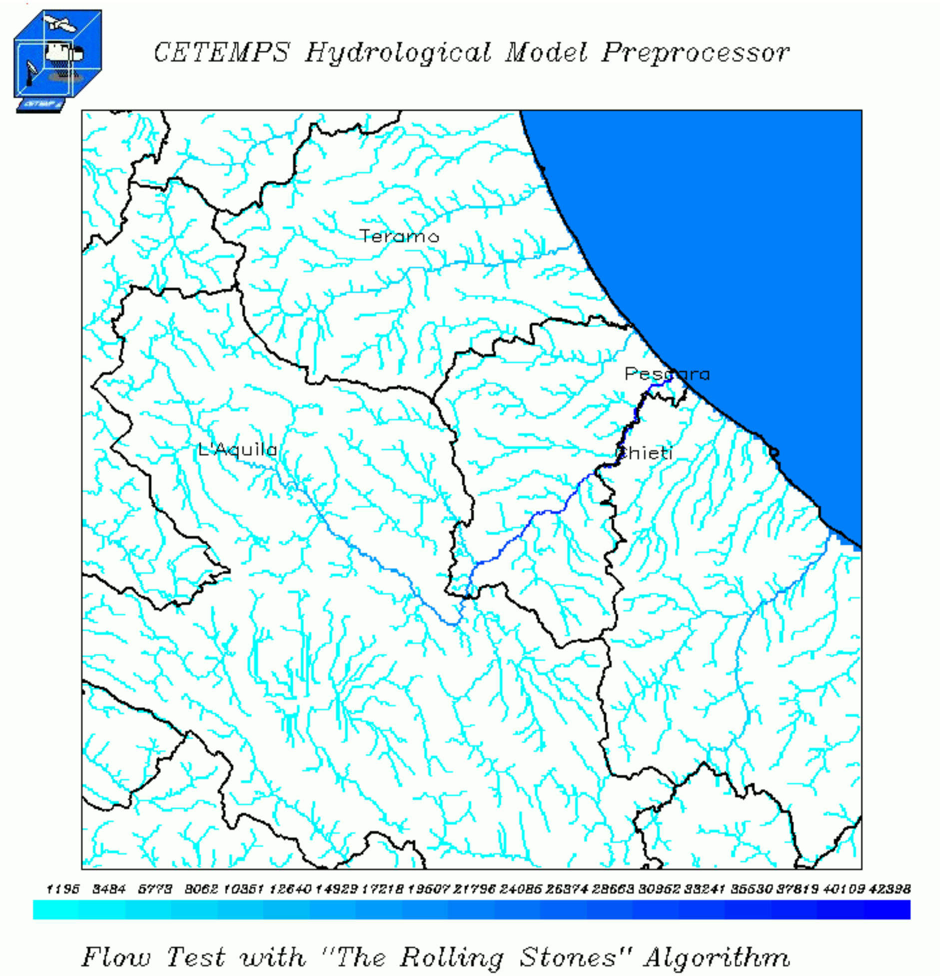
Singularities Corrections



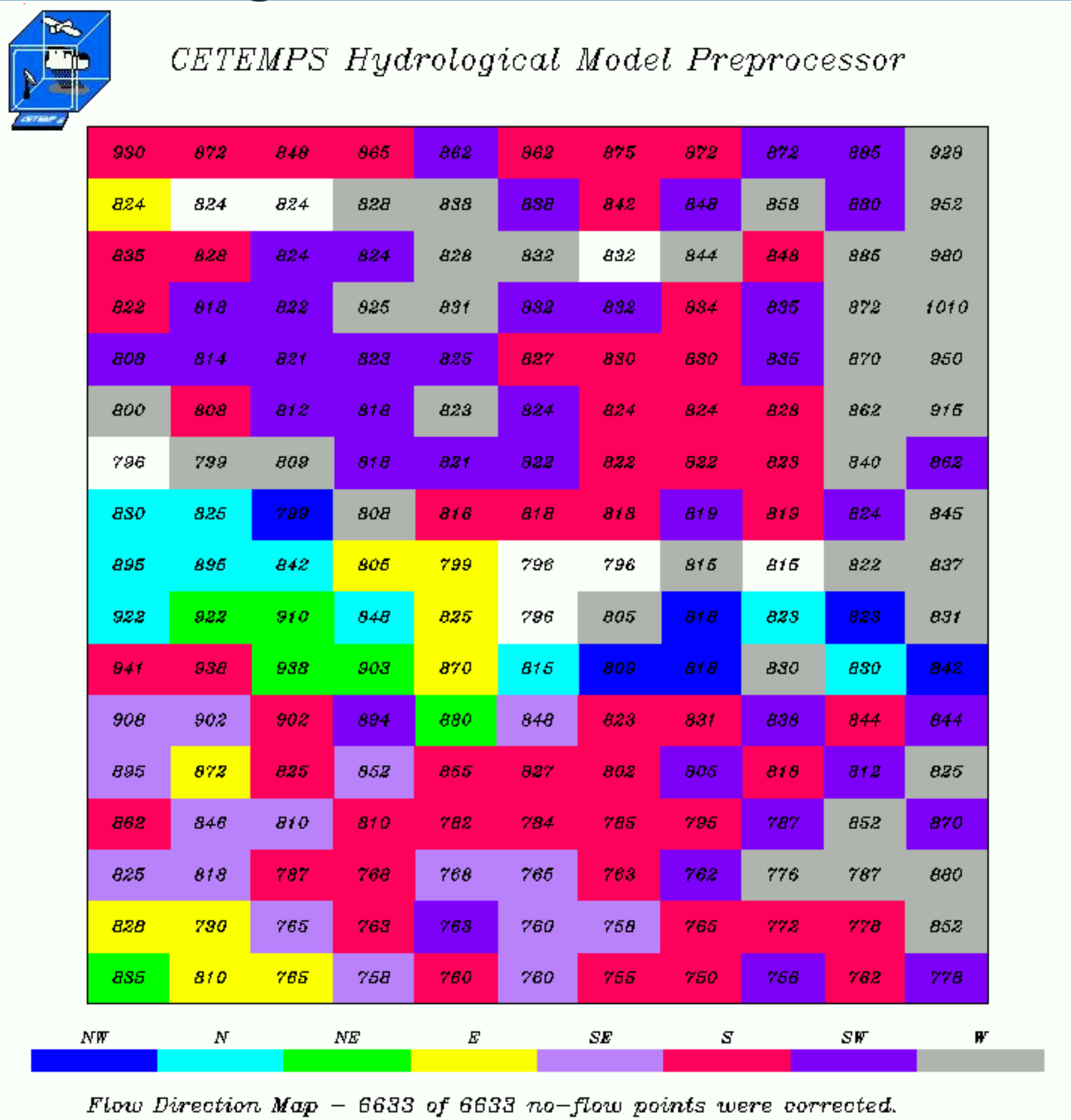
Accumulation matrix







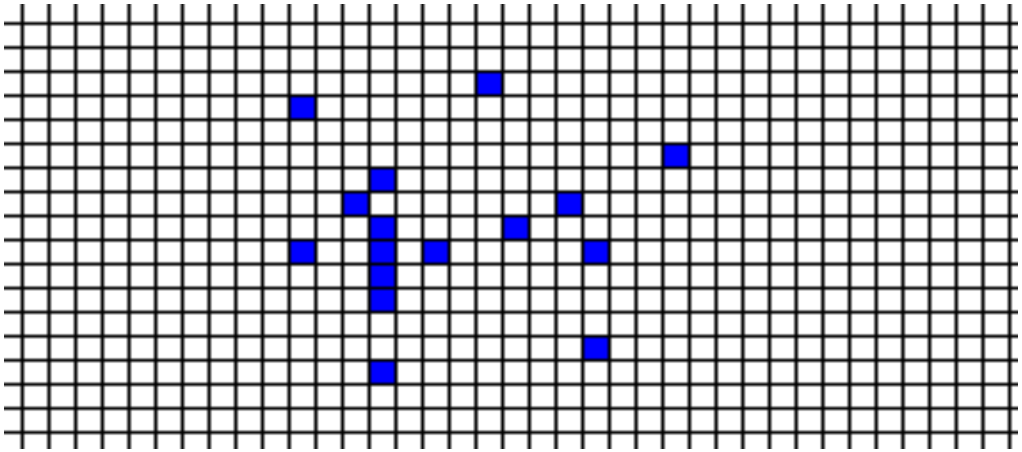
Applications of Cellular Automata Theory in CHyM model



Applications of Cellular Automata Theory in CHyM model

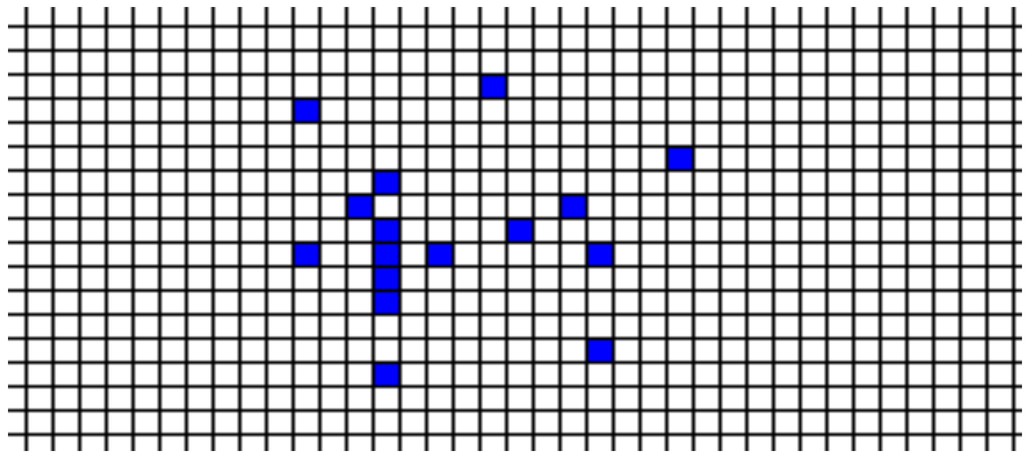
In order to solve numerical singularities and merge different data set of observational/predicted data, CHyM model uses an original Cellular Automata based algorithms

A Cellular automata definition



- A cellular automata 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

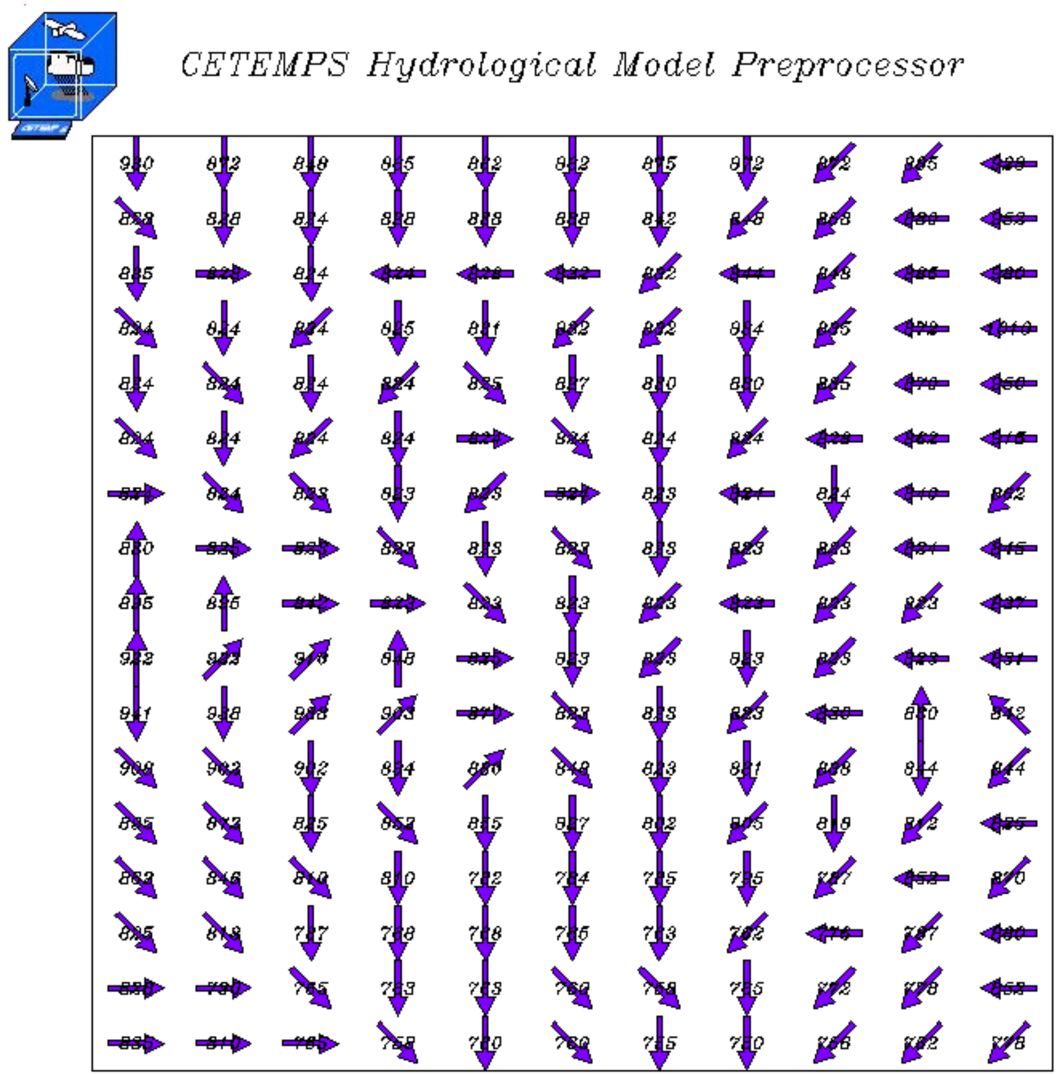
How Cellular Automata theory is applied to solve DEM singularities



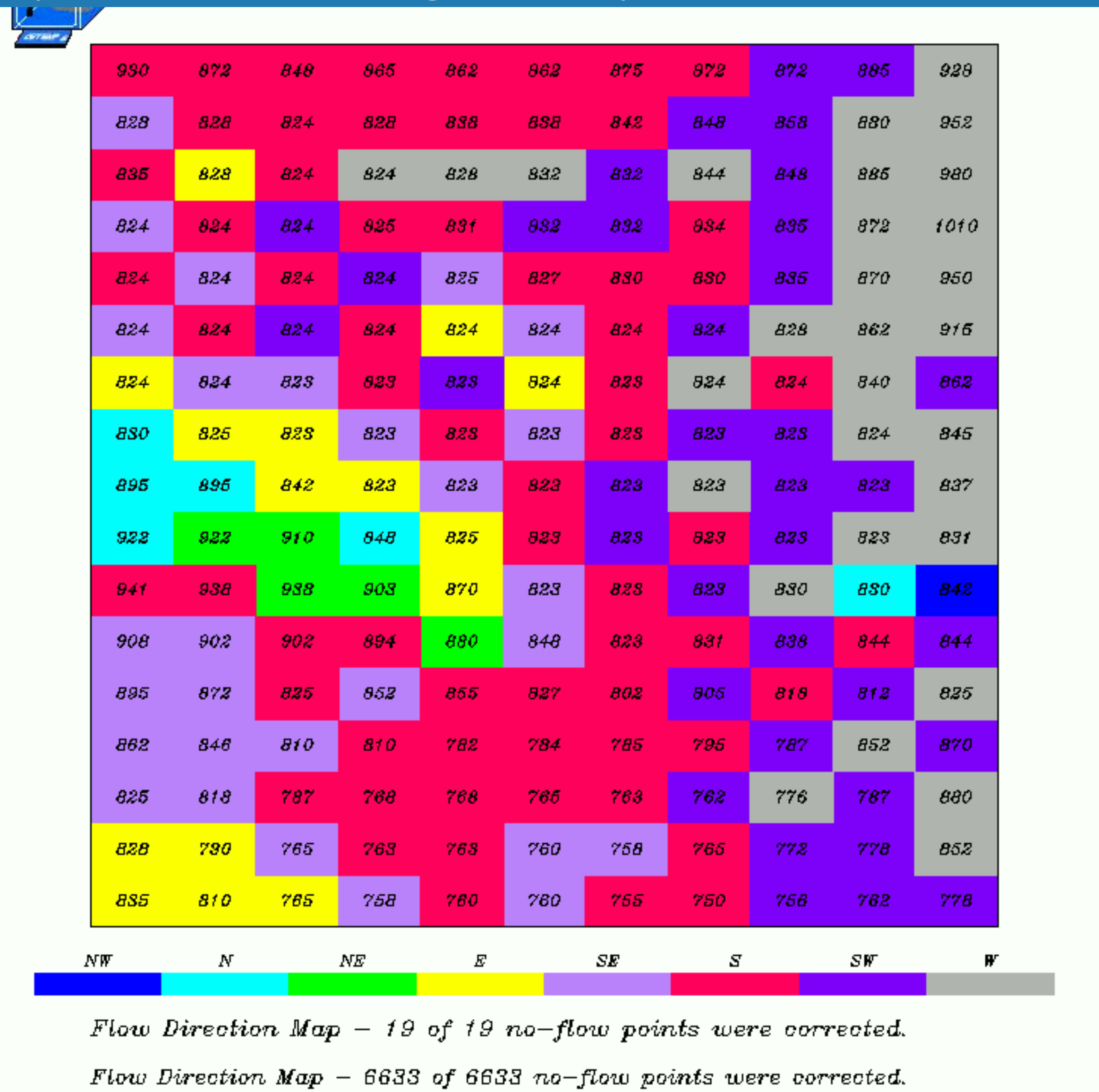
- CHyM grid is considered an aggregate of cellular automata
- The status of a cell corresponds to the value of a CHyM matrix (DEM)
- The state of the cells in the lattice is updated according to following rule

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

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



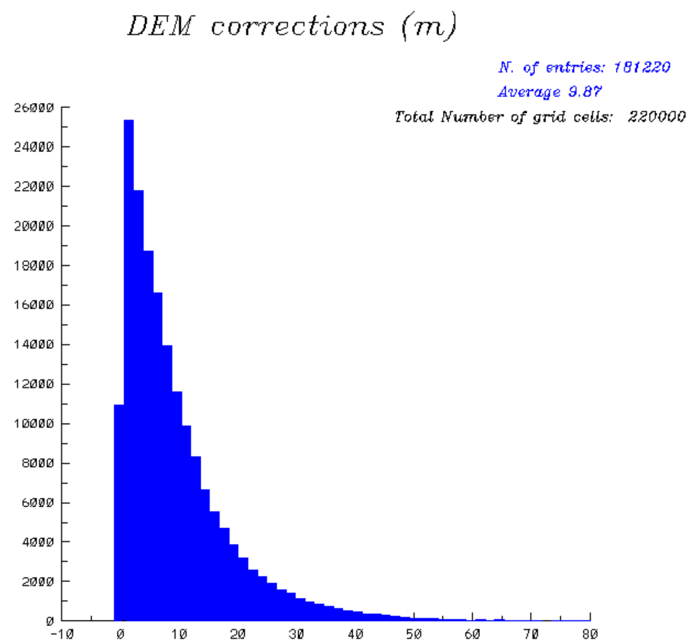
Applications of Cellular Automata Theory in CHyM model



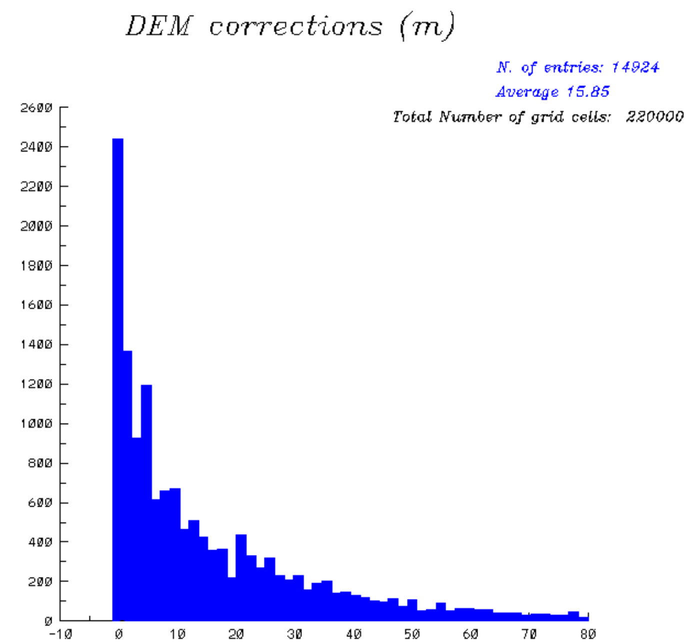
Applications of Cellular Automata Theory in CHyM model

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

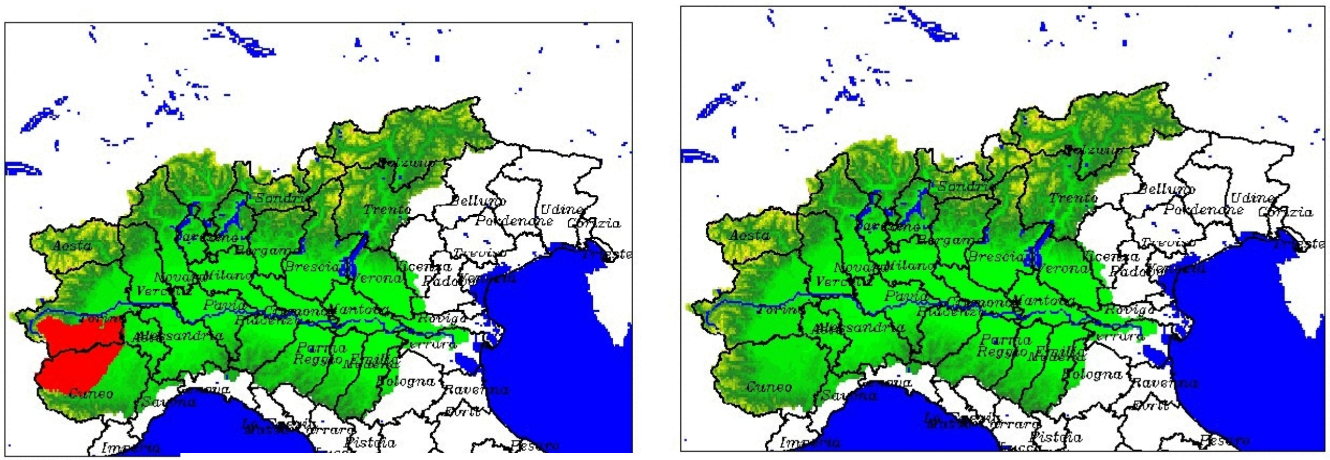


DEM Smooting Algorithm 1 (DSA1)

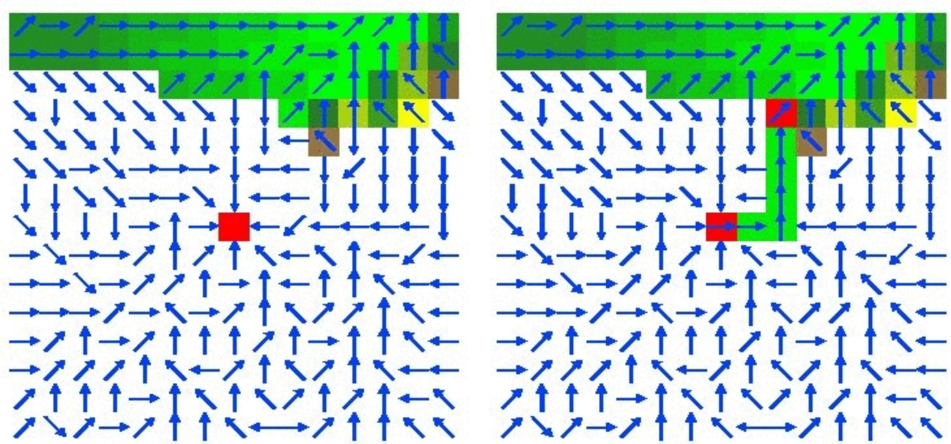


M Smooting Algorithm 2 (DSA2)

Further improvements for flow direction extraction: anastomosis

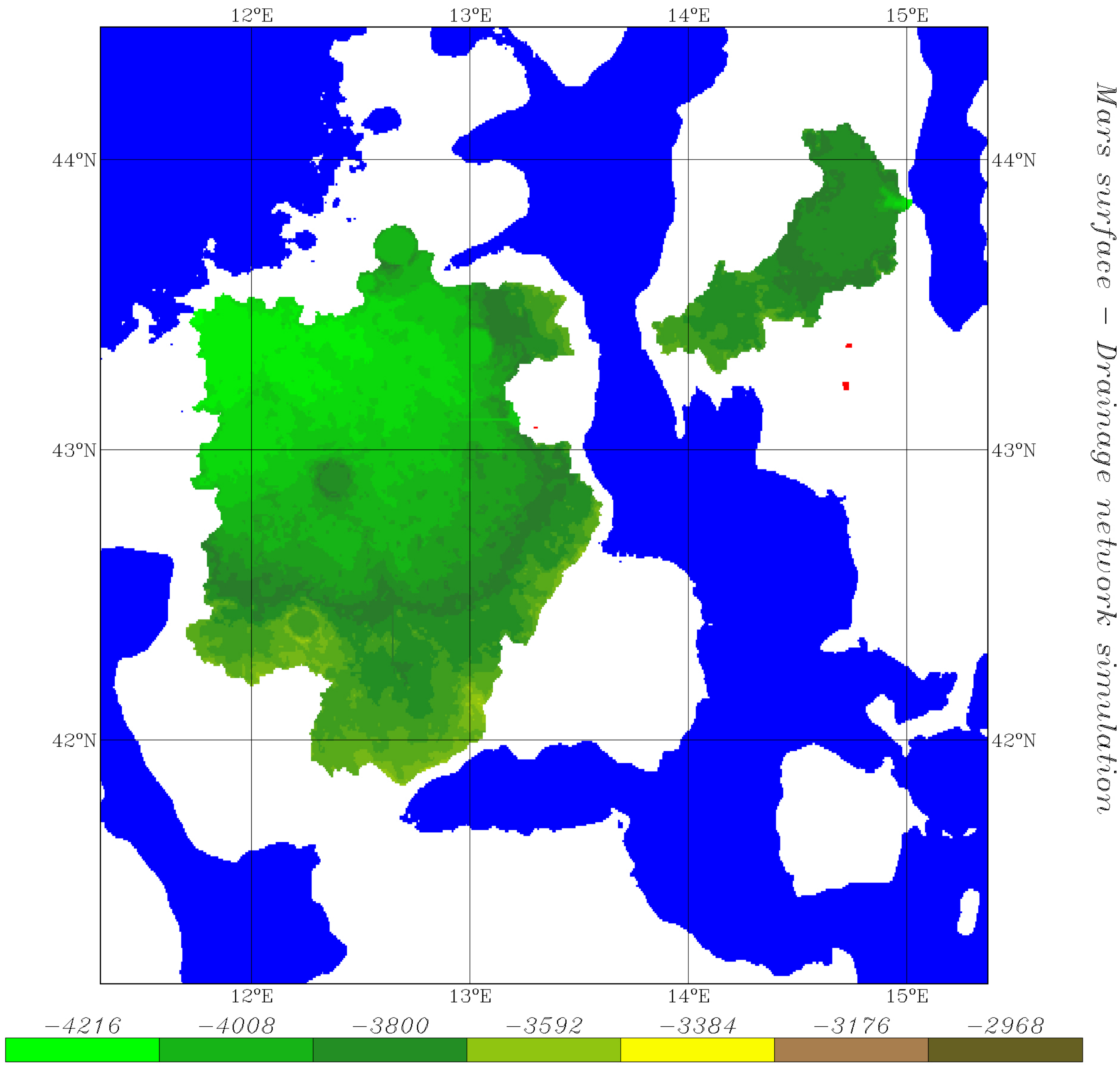


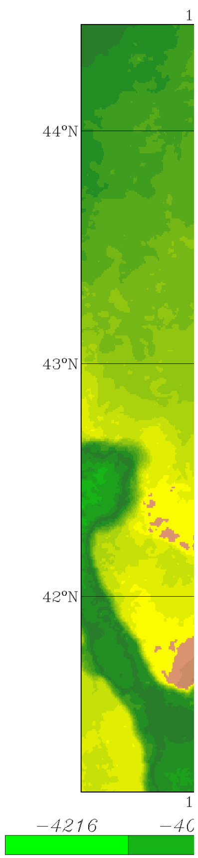
The red cells locate the circulatory anastomosis

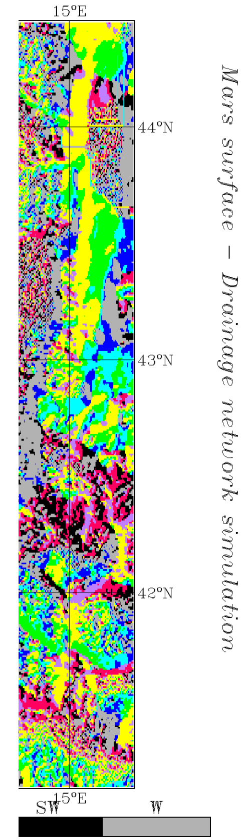


Before surgical procedure *After surgical procedure*

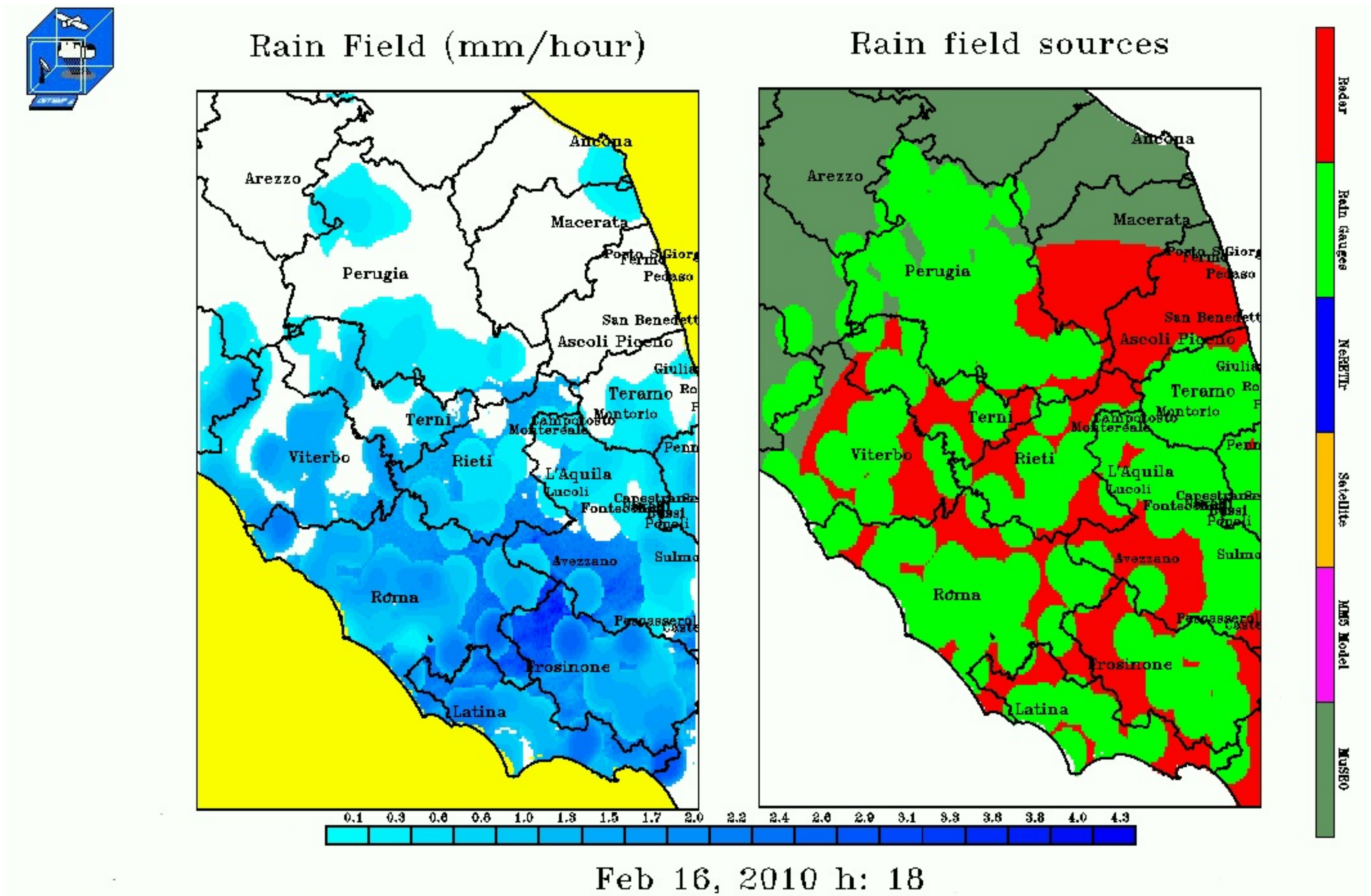
River basins: #033 – #017







Water Resources in Developing Countries: Hydroclimate modelling and Analysis tool



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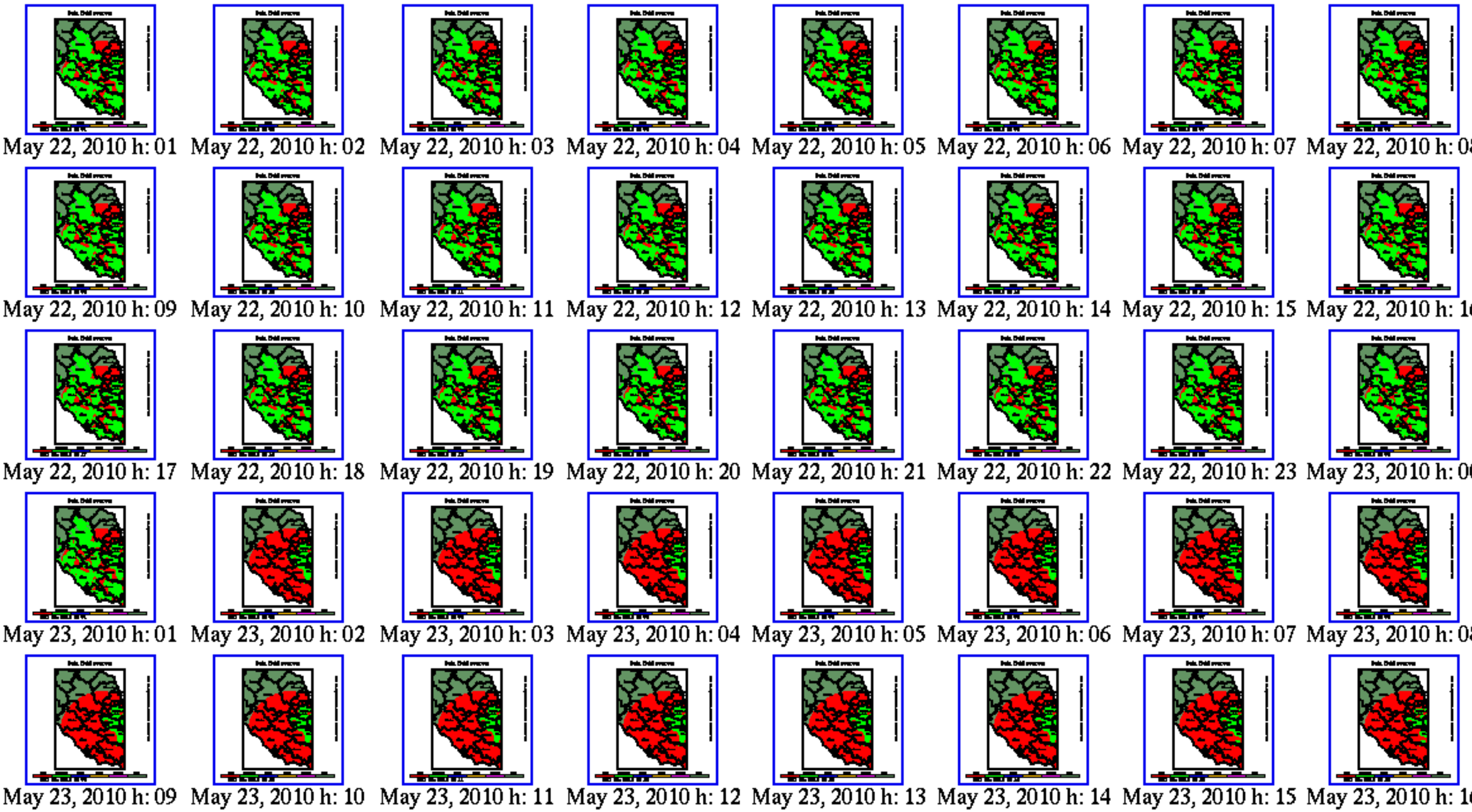
May 22, 2010 h: 01
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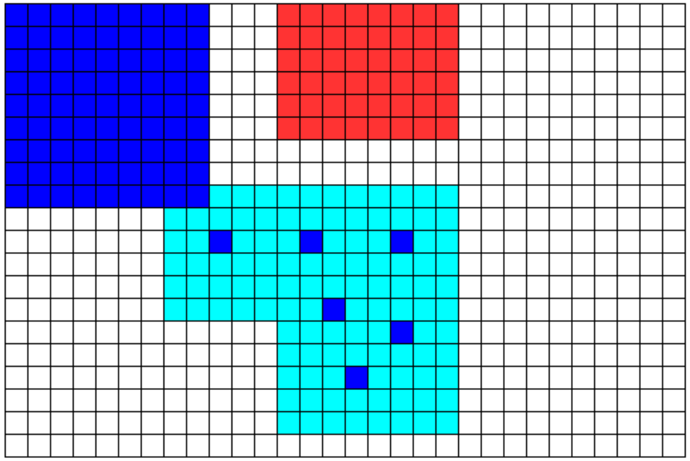
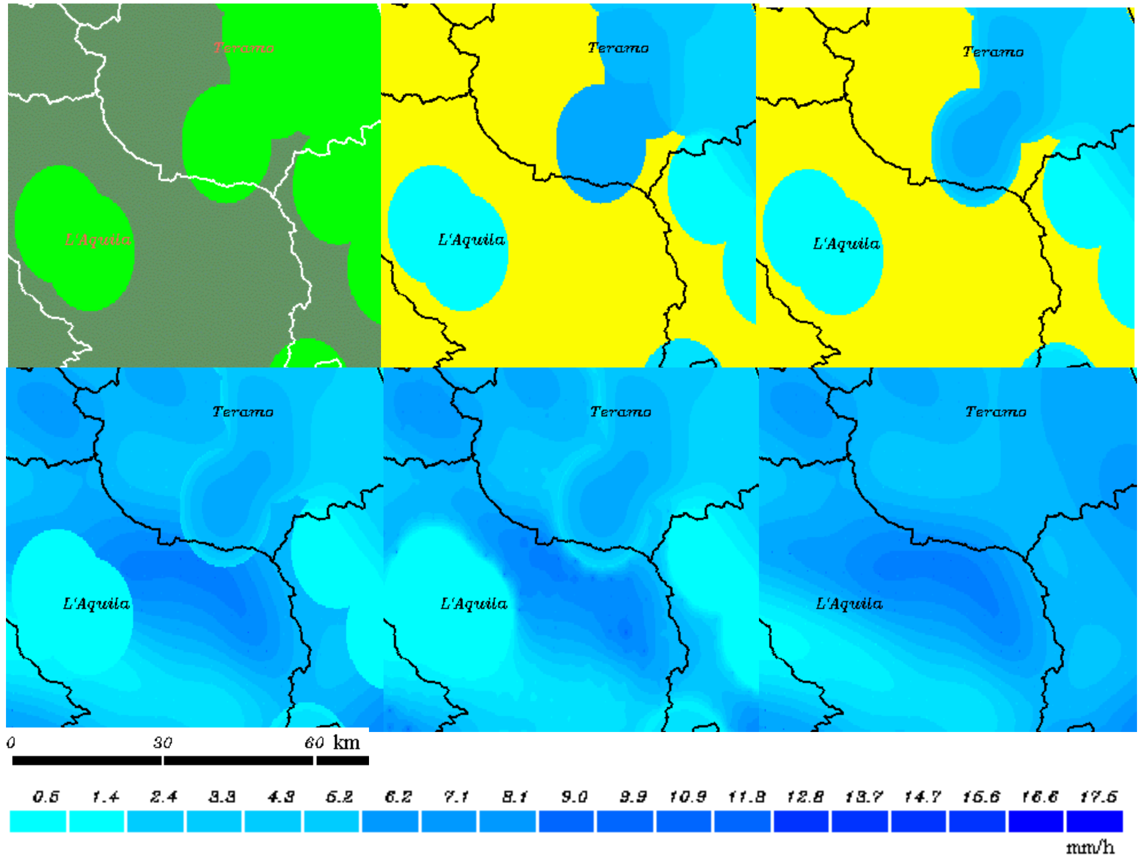


- CHyM grid is considered an aggregate of cellular automata
- The status of a cell corresponds to the value of precipitation
- The state of the cells in the lattice is updated according to following rule

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

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



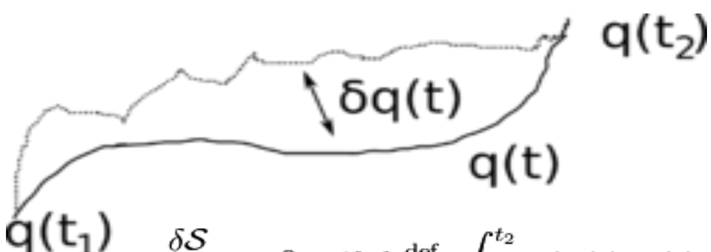
E. Coppola, B. Tomassetti, L. Mariotti, M. Verdecchia and G. Visconti, Cellular automata algorithms for drainage network extraction and rainfall data assimilation, Hydrological Science Journal, 52(3), 2007.

According to the Hamilton (Leonardo) principle, CHyM model assumes that surface flow occur with a strong preferential direction.

Leonardo da Vinci (1452-1519)

«...Ogni azione fatta dalla natura non si pò fare con più brieve modo co' medesimi mezzi... Date le cause la natura partorisce li effetti per i più brievi modi che far si possa...»

Hamilton's principle or principle of stationary action



$$\frac{\delta \mathcal{S}}{\delta \mathbf{q}(t)} = 0 \quad \mathcal{S}[\mathbf{q}] \stackrel{\text{def}}{=} \int_{t_1}^{t_2} L(\mathbf{q}(t), \dot{\mathbf{q}}(t), t)\, dt$$

William Rowan Hamilton (1805 –1865)

Parametrization of physical processes contributing to hydrological cycle
Channel flow

Based on the kinematic wave approximation (*Lighthill and Whitam, 1955*) of the shallow water wave, the equations used by CHYM model to simulate the surface routing overland and for channel flow, are the continuity and momentum conservation equations:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_c \qquad Q = \alpha A^m$$

$$\alpha = \frac{S^{1/2} R^{2/3}}{n} \qquad R = \beta + \gamma D A^{\delta}$$

S is longitudinal bed slope of the flow element , ***n*** the Manning's roughness coefficient while ***R*** is the hydraulic radius that can be written as a linear function of the drained area

Parametrization of physical processes contributing to hydrological cycle

Surface runoff

:

$$\frac{\partial \varphi}{\partial x} + \frac{\partial y}{\partial t} = \xi$$

$$\alpha = \frac{S^{1/2} R^{2/3}}{n}$$

$$\partial \varphi / \partial x + \partial y / \partial t = \xi$$

φ is flow rate over the longitudinal dimension (m^2/sec) of the grid point and ξ is the rate of water inflow per unit of area (m/sec).

The momentum equation is, also in this case, a linear relationship between the flow rate and the water depth, but the Manning's roughness coefficient is increased by a factor M_n to take into account that flow occur with lower speed.

The value of M_n is typically around 4.5 and the optimal value is established, for the specific geographical domain, during the calibration phase.

Melting

$$M = T_F T + S_{RF}(1-\alpha)G_{\downarrow}$$

$$G_{\downarrow} = C_s A_{tr} \sin(\Psi)$$

$$A_{tr} = \left[0.6 + 0.2\sin(\Psi)\right](1.0 - 0.4\sigma_H)(1.0 - 0.7\sigma_M)(1.0 - 0.4\sigma_L)$$

$$\sin(\Psi) = \sin(\varphi)\sin(\delta_s) - \cos(\varphi)\cos(\delta_s)\cos\left(\frac{2\pi t_{utc}}{t_d} - \lambda\right)$$

T_f is set 0.005 mm $hour^{-1}$ $^{o}C^{-1}$ and it is specified by cpar(4)
S_{RF} is set to 0.0094 mm $hour^{-1}$ $m^2/(watt\ ^0C)$ and is specified by cpar(5)

Parametrization of physical processes contributing to hydrological cycle
Return flow

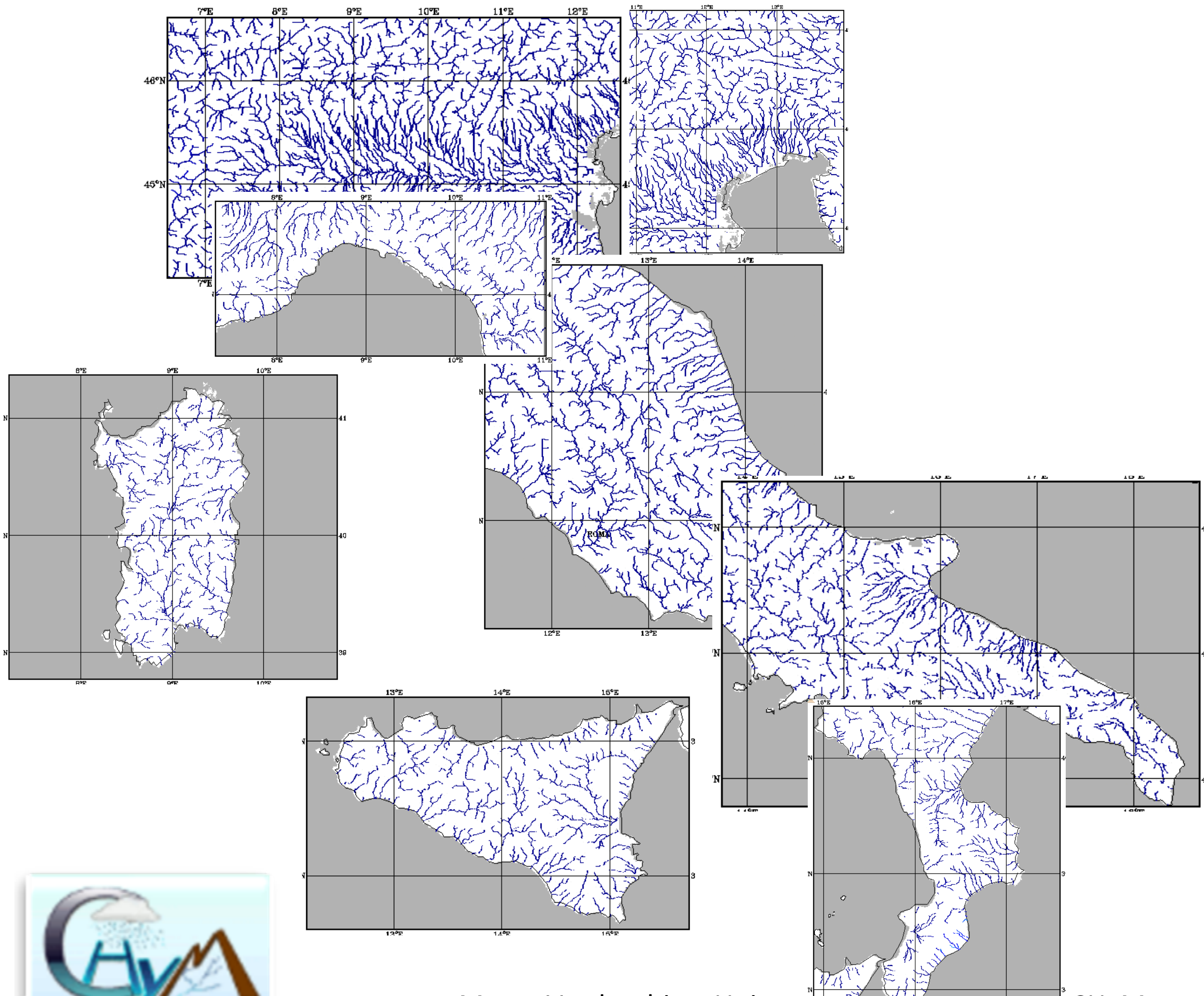
:

CHyM model parametrizes the return flow assuming that its contribution to surface flow is proportional to the total infiltration in the upstream basin during the last N days.

$$R_f = \theta \iint_{Up} I(t,s)\,dt\,ds$$

The space integral is calculated over the whole upstream basin of each cell, while the time integral is carried out over the last N days, being N a value to be optimized during the calibration process. Typical value for small and medium basins are
N = 90 days, $\theta = 5 \times 10-7$ mm hour^{-1} km^{-2}

Water Resources in Developing Countries: Hydroclimate modelling and Analysis tool



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Flood alert mapping
Validation of flood alarm index

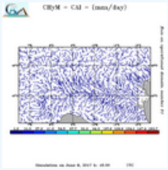
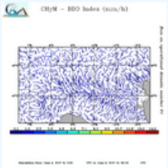
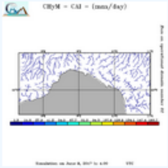
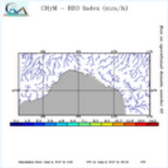
cetemps.aquila.infn.it/chymop/

CHyM – CETEMPS Hydrological Model

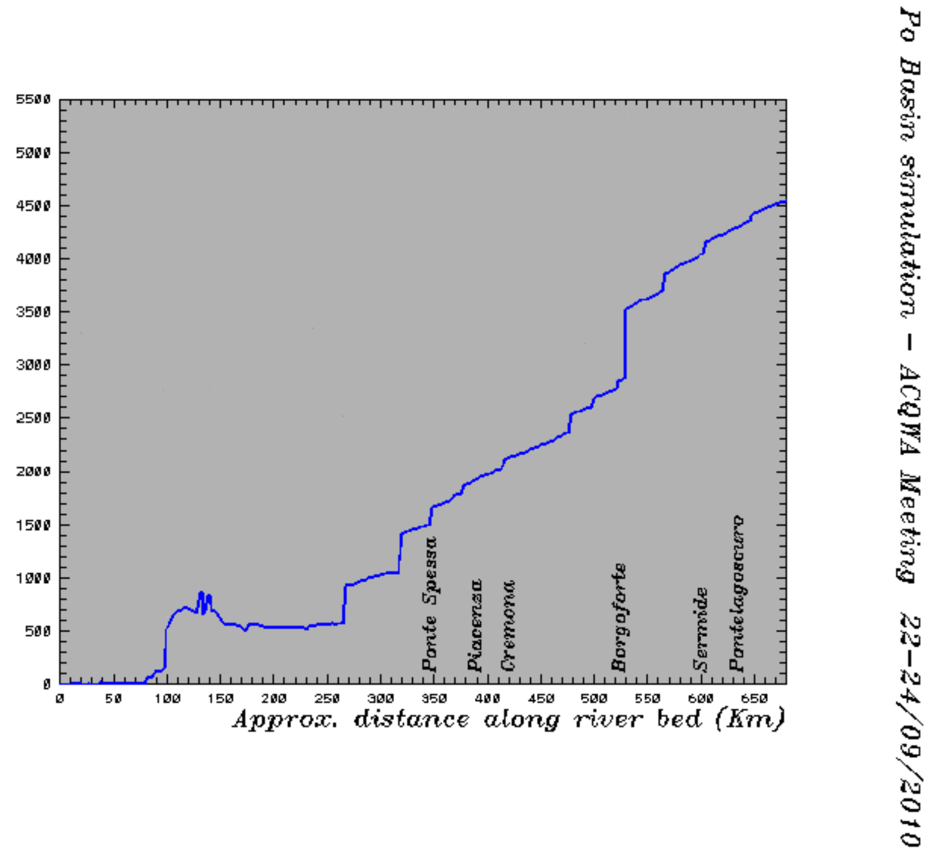
Operational Simulation

How these Indices are calculated

Worst Expected Event

Domain 01 - Po Basin **NO HIGH RESOLUTION WRF FORECAST AVAILABLE FOR THIS RUN** **Last Simulation** Fri Jun 9 04:02:51 CEST 2017	 Stress Index	 Stress Index
Domain 02 - Liguria **NO HIGH RESOLUTION WRF FORECAST AVAILABLE FOR THIS RUN** **Last Simulation** Fri Jun 9 06:07:08 CEST 2017	 Stress Index	 Stress Index

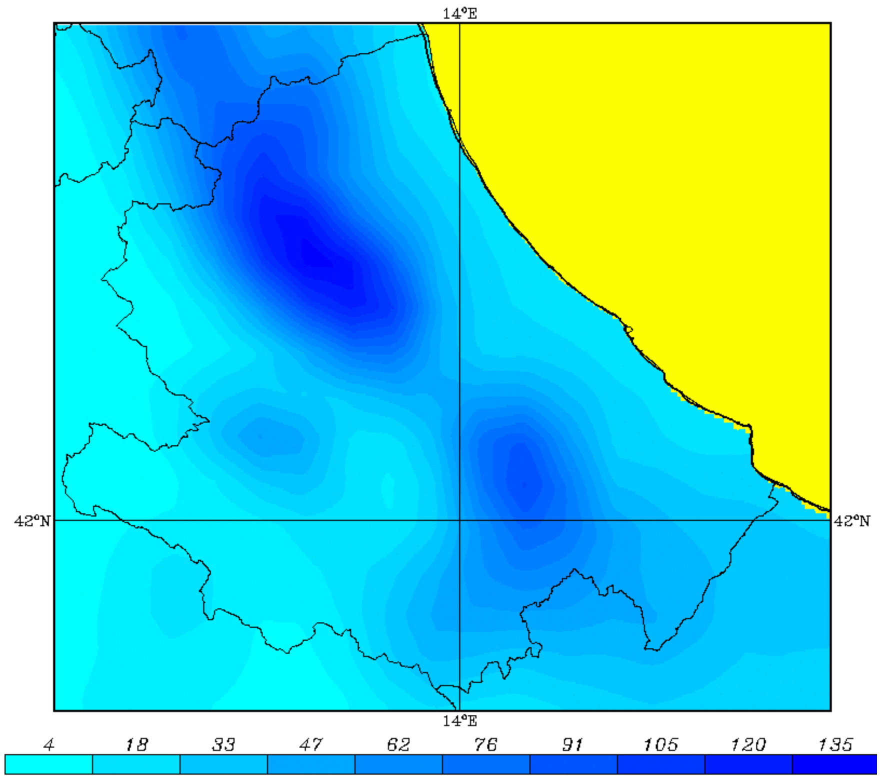
April 12, 2005 h: 12



Po river – Flow discharge (m3/sec)

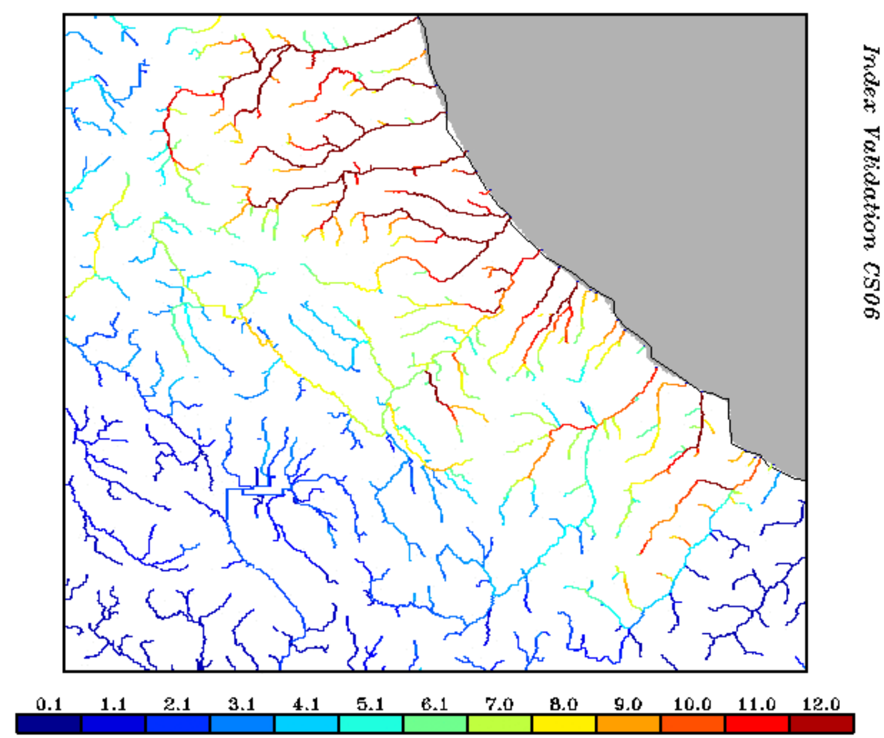
A first (very) important step:
The map of accumulated precipitation CANNOT be considered a flood alert map

Accumulated rain (mm)



Simulation from November 15, 2017 h: 0.00 to November 15, 2017 h: 12.00

CHyM – BDD Index (mm/h)



Simulation from November 15, 2017 h: 0.00 UTC to November 16, 2017 h: 0.00 UTC

Predicting possible severe hydrological events
Flood alert mapping

- A deterministic prediction of discharge is often difficult because reliable time series of flow discharge are not always available, especially for small basins
- Floods are often observed for small basin where model calibration is difficult
- Flood occurrence depends also on the morphologic characteristics of the river
- It is not straightforward to establish a discharge value above which flood is expected to occur.


Si mobilitò per gli alluvionati

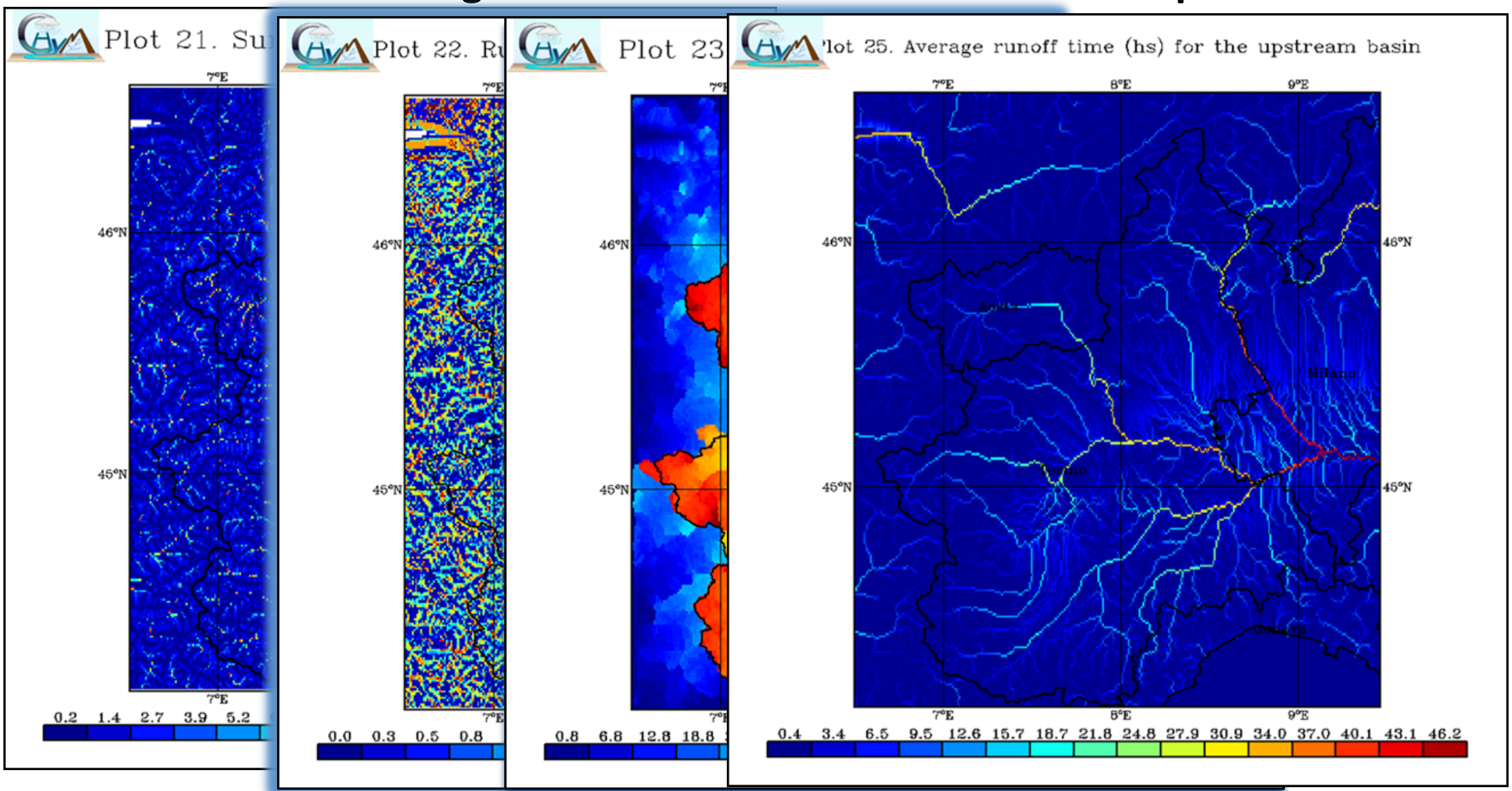
E' il 2 novembre 2004. Quello che vedete pagaiare è Daniele Molmenti. Non è un allenamento, non è un fiume: è una strada. E' il campione che va ad aiutare gli alluvionati. Grande anche allora!

Flood alert mapping

Definition of alarm index – CAI (CHyM Alarm index)

$$CAI(t,j) = \frac{\int_{t-\Delta T_i}^{t} \int_{Up_j} P(t,s)\,dt\,ds}{\int_{Up_j} ds}$$

Flood alert mapping
Average runoff time is calculated in four steps



Flood alert mapping

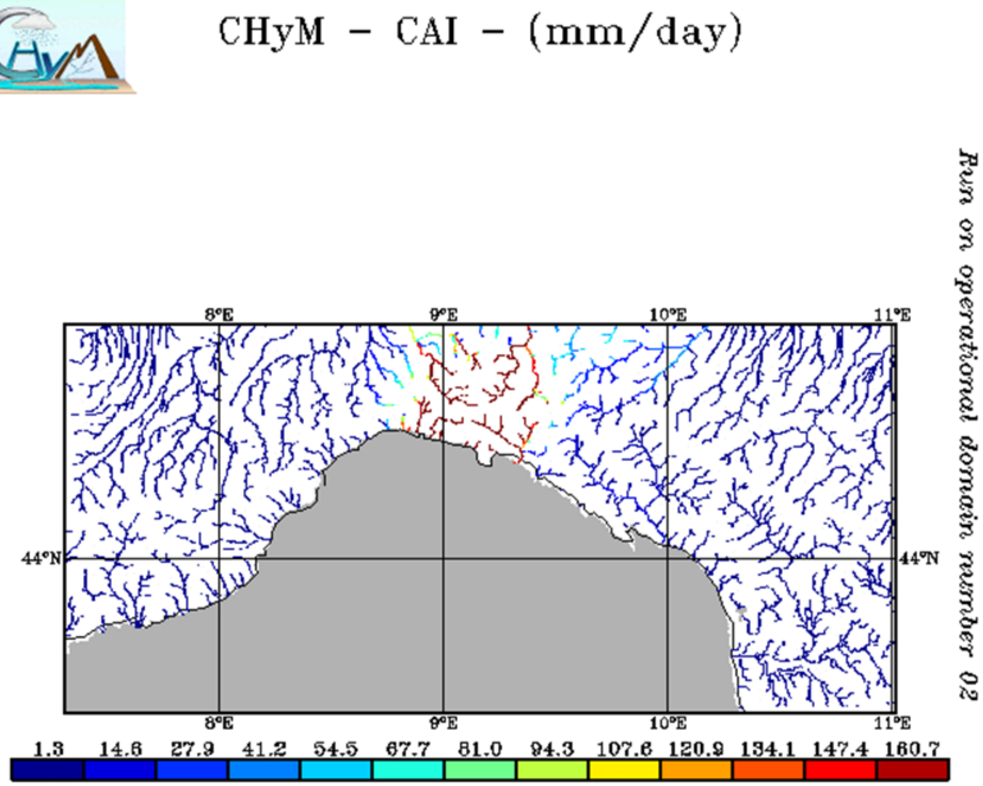
Definition of alarm index – BDD (Best Discharge-based Drainage alarm index)

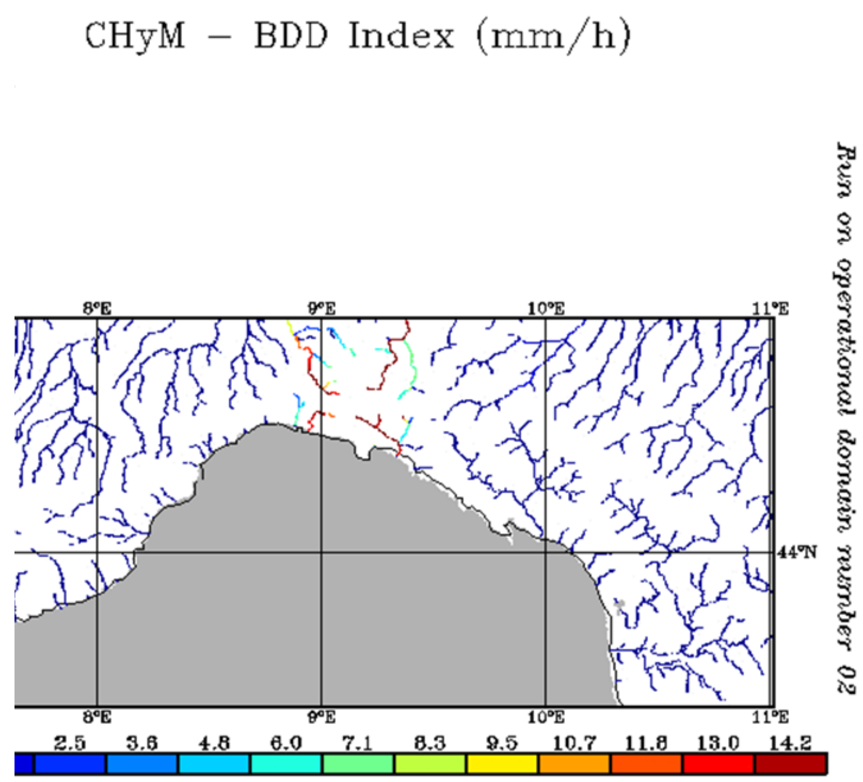
$$BDD_i(t_1 - t_2) = \frac{\max_{t_1 \to t_2}(Q_i(t))}{R_i^2}$$

$$R = \beta + \gamma D A^{\delta}$$

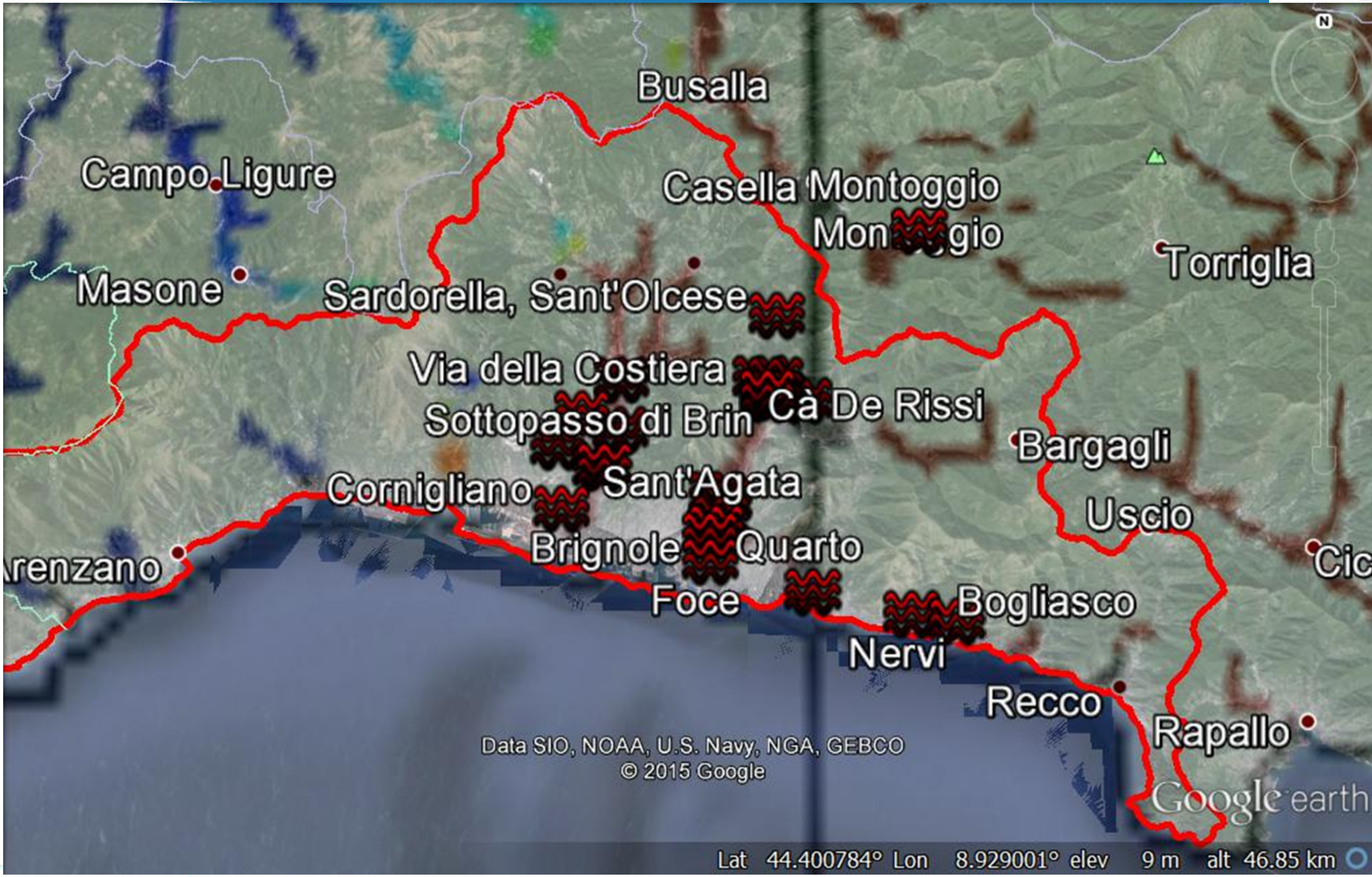
$$\alpha = \frac{S^{1/2} R^{2/3}}{n} \qquad Q = \alpha A^{m}$$

Flood alert mapping
Application to different case studies – Genova – October 2014



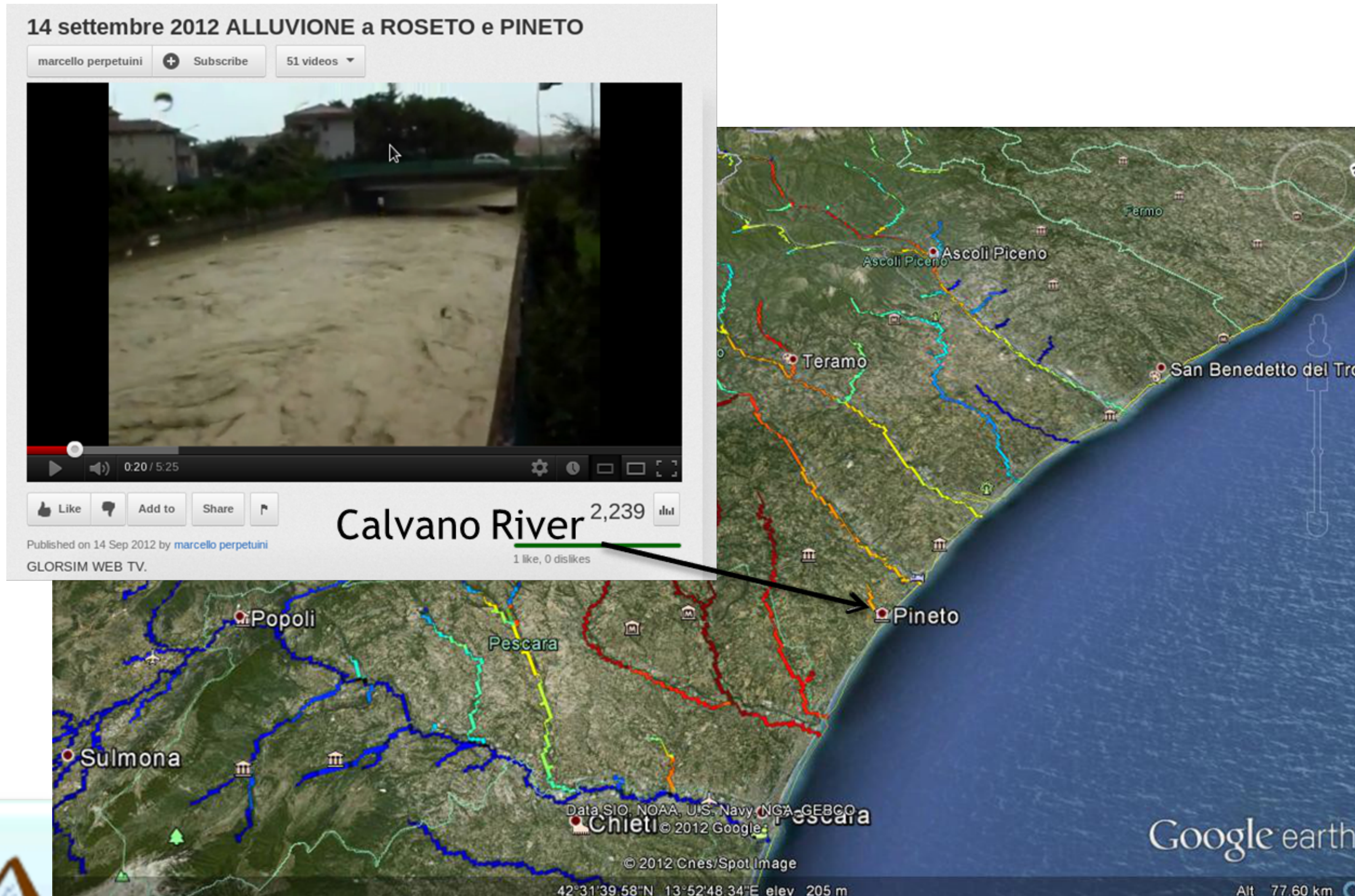


Flood alert mapping operationally available at URL
http://cetemps.aquila.infn.it/chymop


Busalla
Campo Ligure
Casella Montoggio
Montoggio
Torriglia
Masone
Sardorella, Sant'Olcese
Via della Costiera
Cà De Rissi
Sottopasso di Brin
Bargagli
Cornigliano
Sant'Agata
Uscio
Brignole
Quarto
Arenzano
Cica
Foce
Bogliasco
Nervi
Recco
Rapallo
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2015 Google
Google earth
Lat 44.400784° Lon 8.929001° elev 9 m alt 46.85 km

Flood alert mapping

Application to different case studies – Abruzzo region – Sep 2012



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Flood alert mapping

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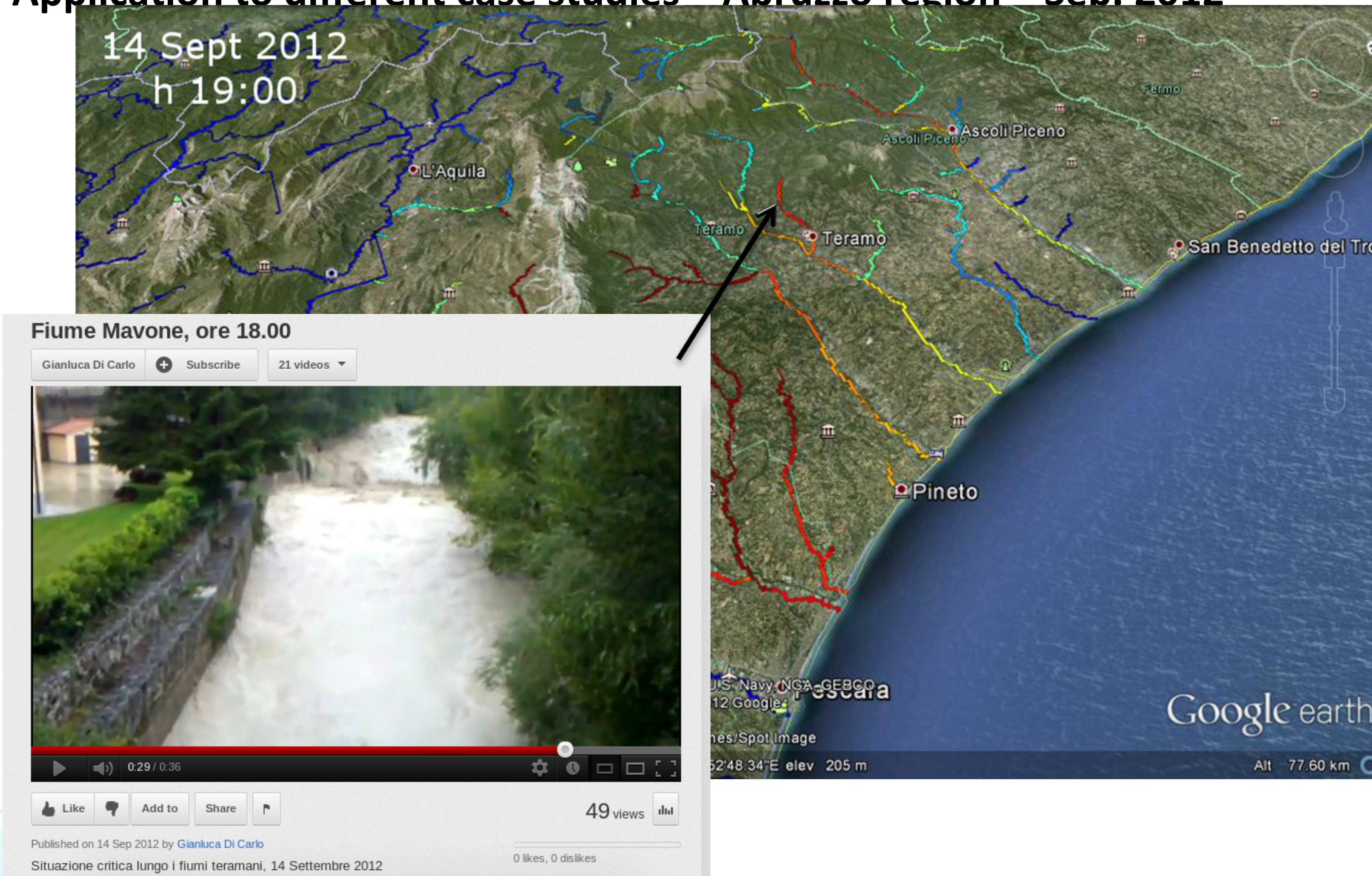

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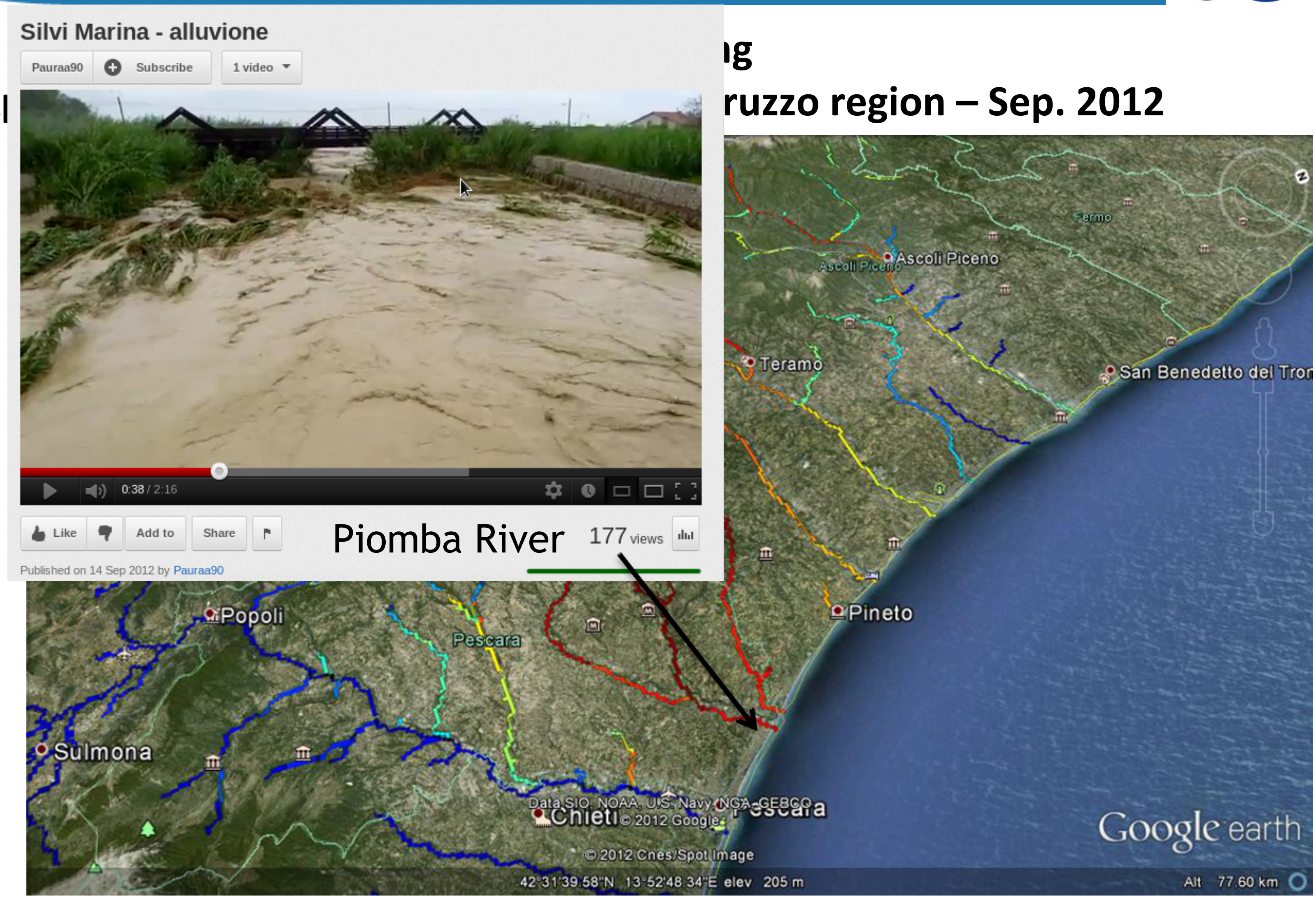
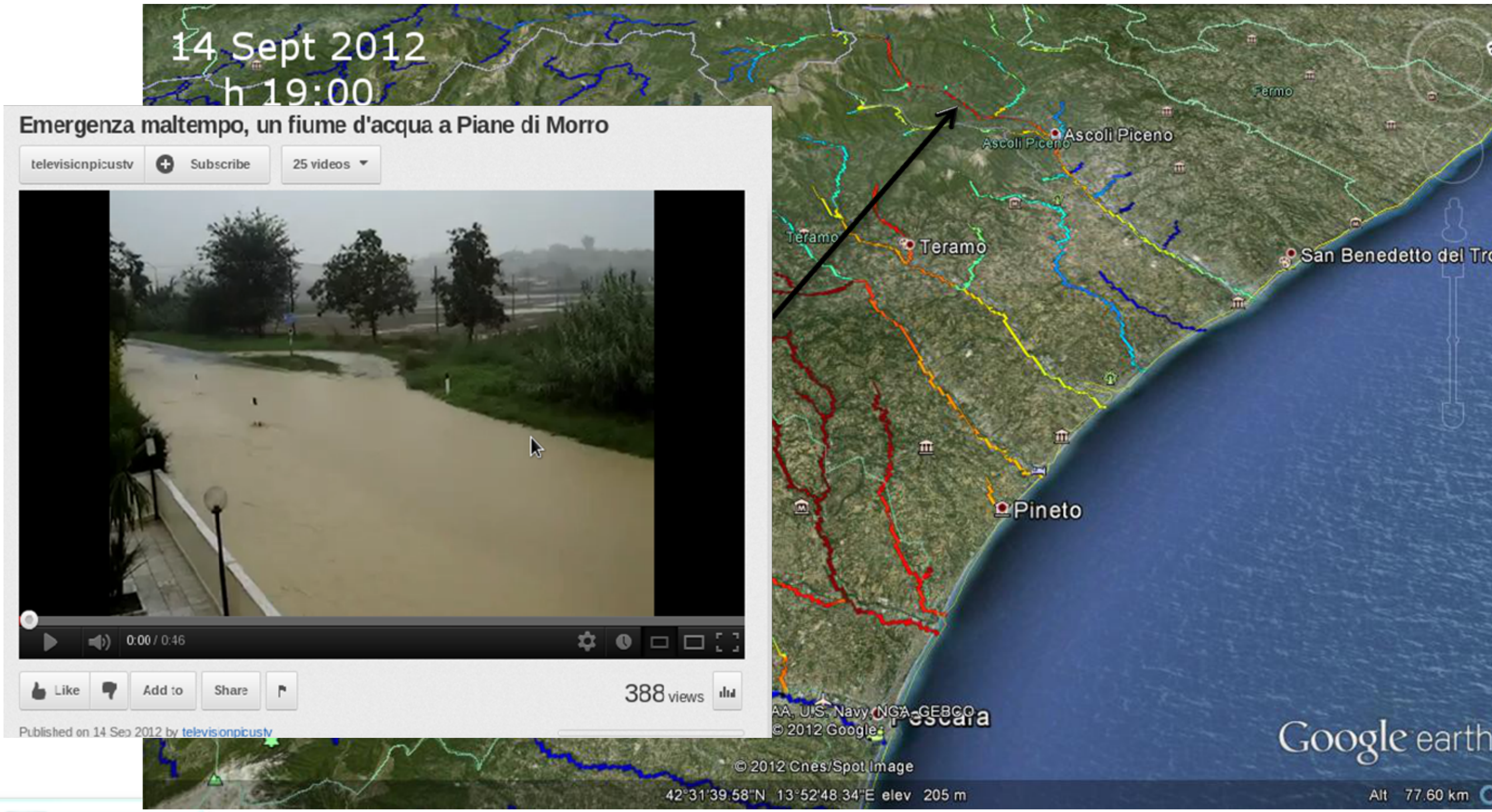
A… …ruzzo region – Sep. 2012



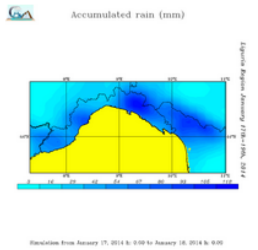
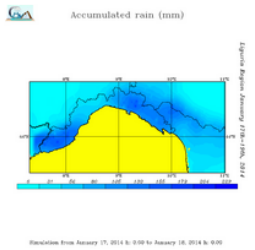
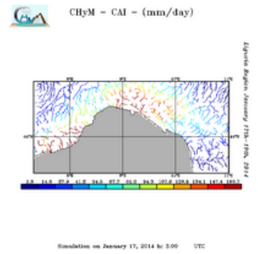
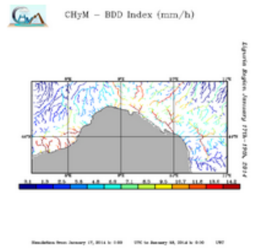
Flood alert mapping

Application to different case studies – Abruzzo region – Sep. 2012



CS22 - Liguria Region - 17th-19th January, 2014

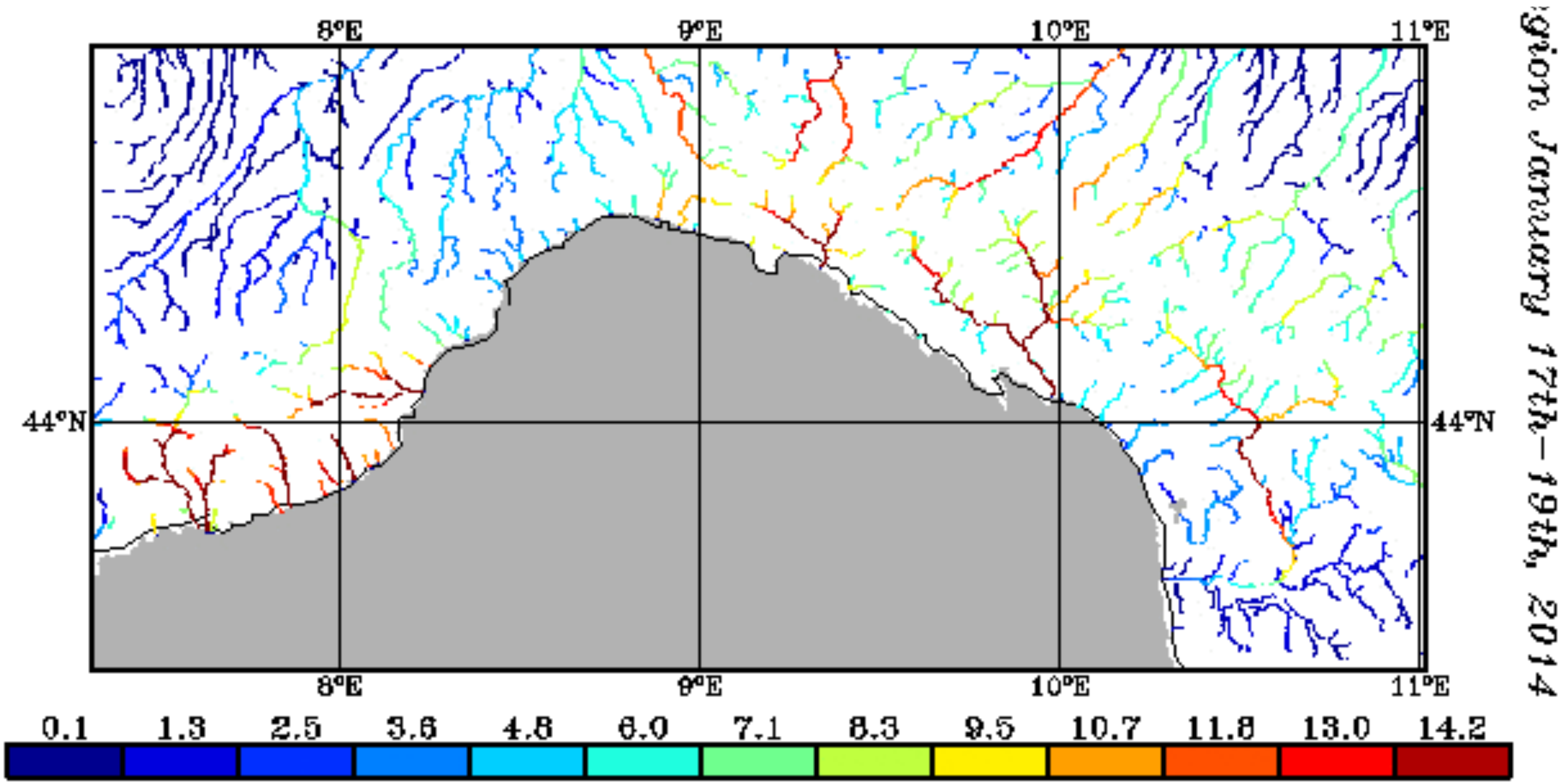
Heavy rainfall caused severe floods and landslides in the whole territory of the Liguria region. Quickly the event involved also the Emilia Romagna Region causing an extended flooded area.

Case Study	WRF FORECAST Acc. Rain Map	OBS Acc. Rain Map	CAI Map	BDD Map
				

Nr	22
Area	Liguria Region
Date	January 17th-19th, 2014

Summary Analisys	
WRFvsOBS	Average
C-SAL	Good
C-SAT	Very Good
B-SAL	Very Good
B-SAT	Good

Documentation	ARPAL Report CFL Report ARPAL-CFL Report Official Site Idro-Meteo-Clima ARPAE COPERNICUS Emergency Management Service
Analysis	Appunti Liguria_Event.kmz CAI animation BDD animation



Marco Verdecchia – University of L'Aquila, Italy - CHyM model for flood alert mapping

emergency.copernicus.eu/mapping/list-of-components/EMSR067

COPERNICUS
Emergency Management Service

European Commission

Home » »

Home | What is Copernicus | EMS - Mapping | EMS - Early Warning System | News

LATEST NEWS · 2017-05-01 | [EMSN034] Coastal flood risk analysis for population and assets, Caparica, Setúbal, Portugal

EMS - MAPPING

- Service Overview
- Who can use the service
- How to use the service
- Products: Rapid Mapping
- Products: Risk and Recovery
- Quality control / Feedback
- User Guide

RAPID MAPPING

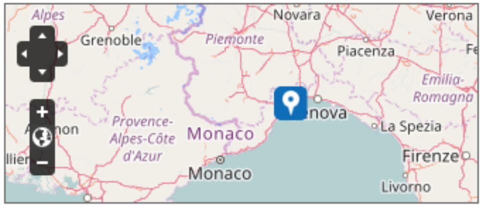
- List of Activations
- Map of Activations
- GeoRSS Feed

RISK AND RECOVERY

- List of Activations
- Map of Activations
- GeoRSS Feed

EMSR067: Floods in Emilia Romagna and Liguria, Italy

Event Time (UTC): 2014-01-18 21:00
Event Time (LOC): 2014-01-18 22:00
Event Type: Flood
Activation Time (UTC): 2014-01-22 13:40
Reference maps produced: 2
Delineation maps produced: 2
Grading maps produced: 2
Activation Status: Closed
Affected Countries/Territories:
Italian Republic
Area Descriptor: Liguria, Provinces of Genova, La Spezia, Imperia. Emilia Romagna, Province of Modena
Authorized User:
Italy|Presidenza del Consiglio dei Ministri - Dipartimento della Protezione Civile - Centro Situazioni
Activation Reason:
Heavy rainfall caused severe floods and landslides in the whole territory of the Liguria region. Quickly the event involved also the Emilia Romagna Region causing an extended flooded area.
Requested Product: Flood area extent and damage extent



Tweet Coverage map: GeoRSS:

Filter by map type: · ALL · GRADING · DELINEATION · REFERENCE

Water Resources in Developing Countries: Hydroclimate modelling and Analysis tool

GLIDE number: N/A
Activation ID: EMSR138
Product N.: 03BETTOLA, v2, English

Bettola - ITALY
Flood - 14/09/2015
Grading Map

Cartographic Information

1:10000 — Full color ISO A1, high resolution (300 dpi)

0 — 0.25 — 0.5 — 1 km

N

Grid: WGS 84 UTM zone 32N UTM 32N map coordinate system
Tick marks: WGS 84 geographical coordinate system

Legend

Crisis Information
- Landslide
- Mudflow

General Information
- Area of Interest

Settlements
- Populated Place

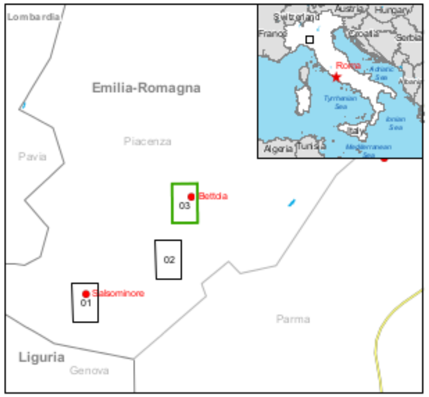
Hydrology
- River
- Lake

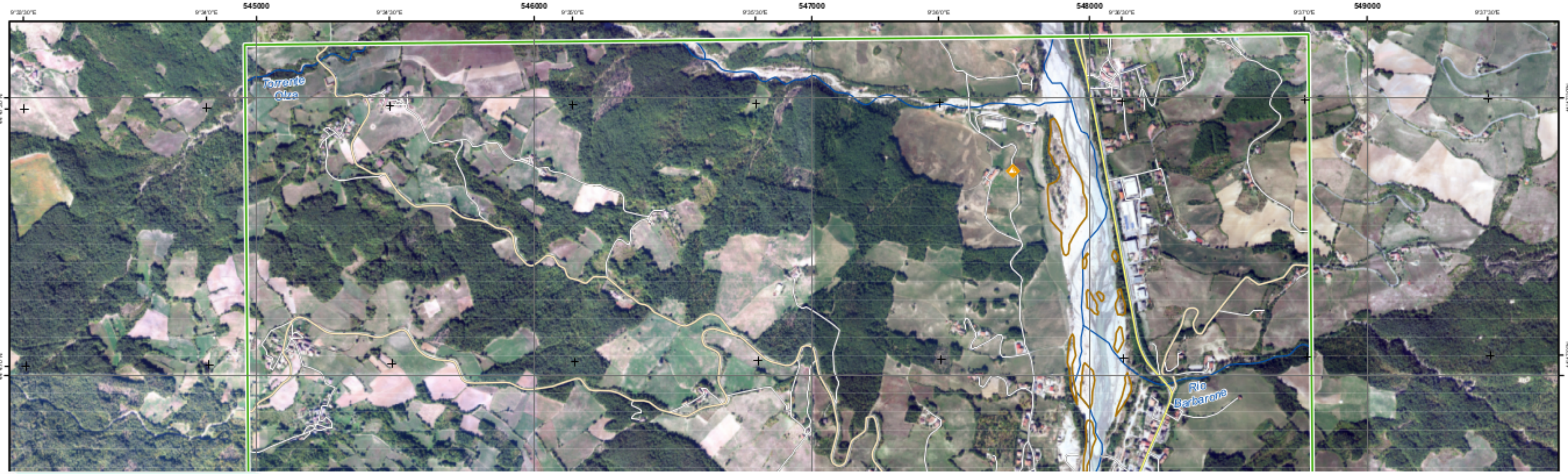
Transportation
- Primary Road
- Secondary Road
- Local Road

Land use - Land Cover
Features available in vector data

Consequences within the AOI

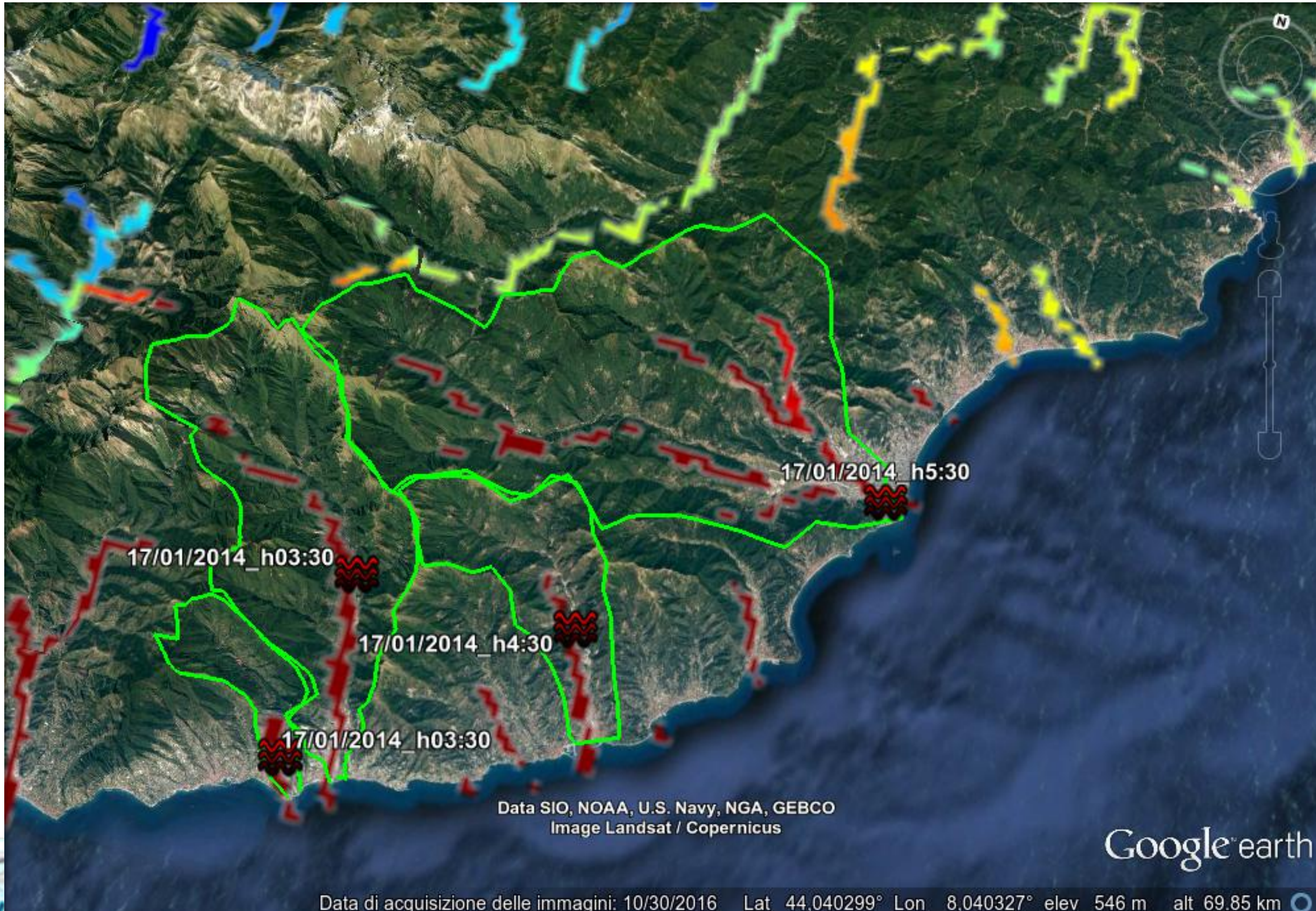
			Destroyed	Highly damaged	Moderately damaged	Negligible to slight damage	Total affected	Total in AOI
Landslide		No.	-	3	-	-	3	
Mudflow		ha	-	28.3	-	-	28.3	
Estimated population	Inhabitants in related areas		0	0	0	0	0	3256
Transportation	Primary roads	km	0	0	0	0	0	7.5
	Secondary roads	km	0	0	0	0	0	17
	Local roads	km	0	0	0	0	0	58
Land use	Bare ground	ha	0	25.3	0	0	0	247.3
	Cropland	ha	0	3.2	0	0	0	1272.8
	Woodland	ha	0	0.1	0	0	0.1	860.2

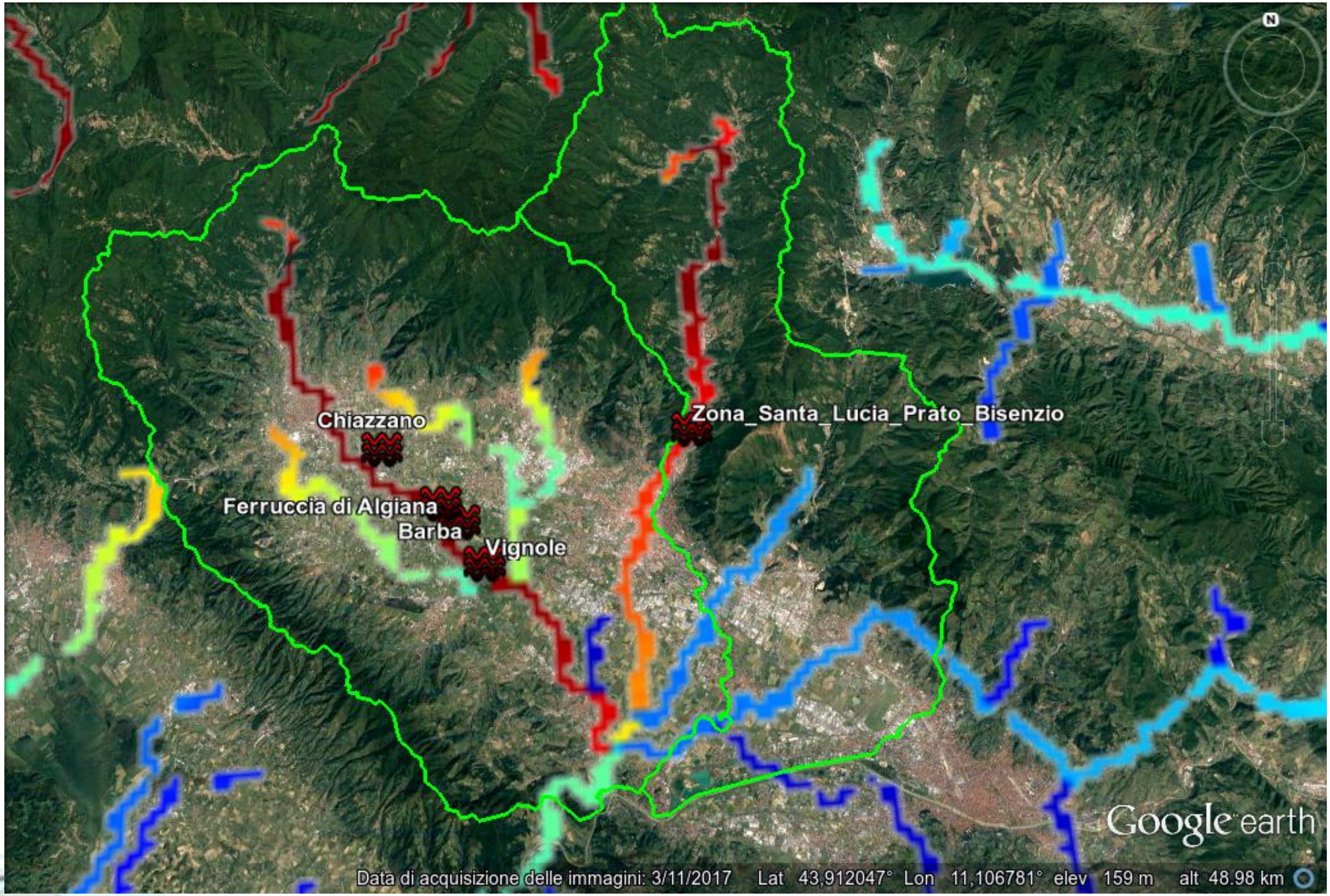




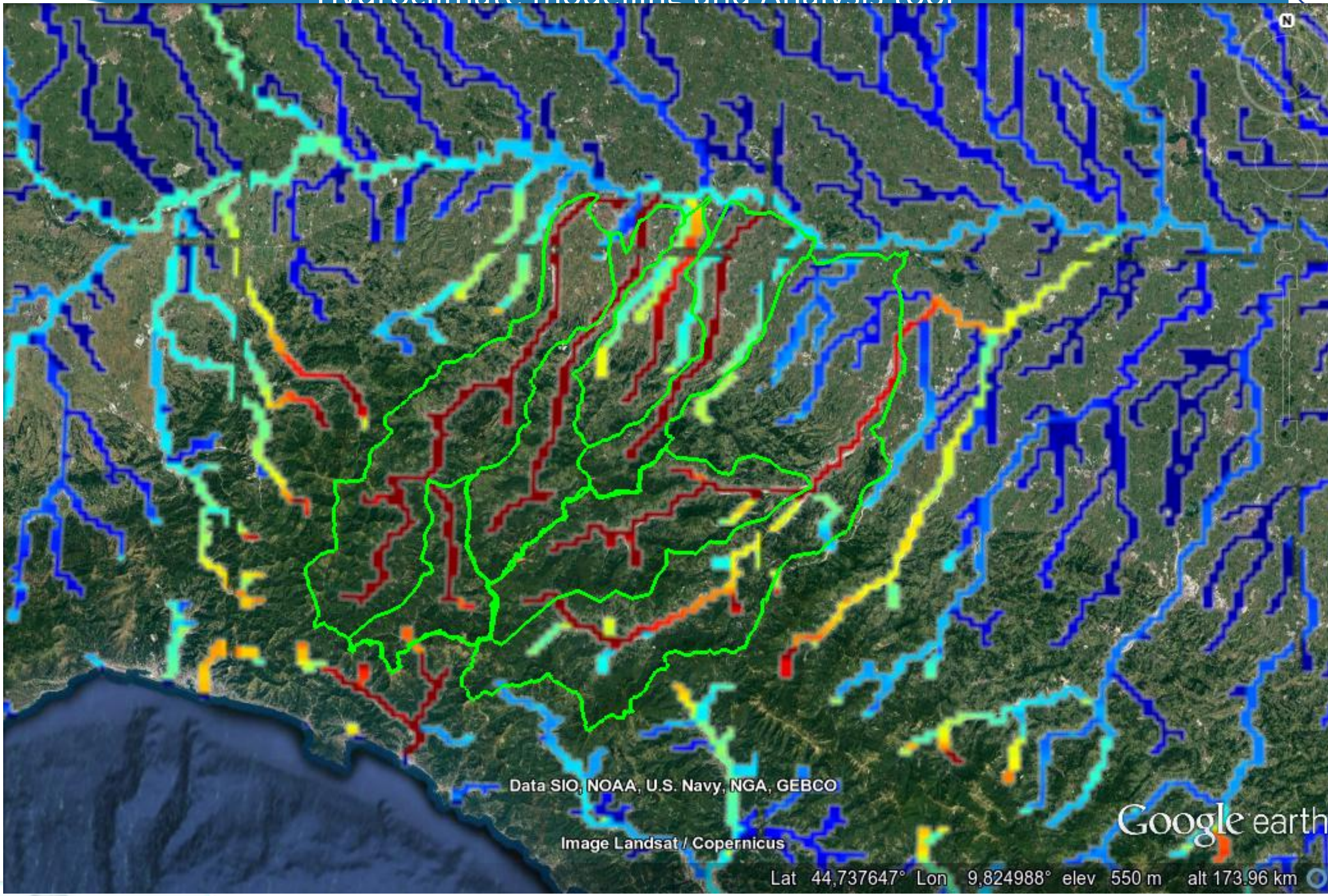
Marco Verdecchia – University of L’Aquila, Italy - CHyM model for flood alert mapping

YouTube Movie

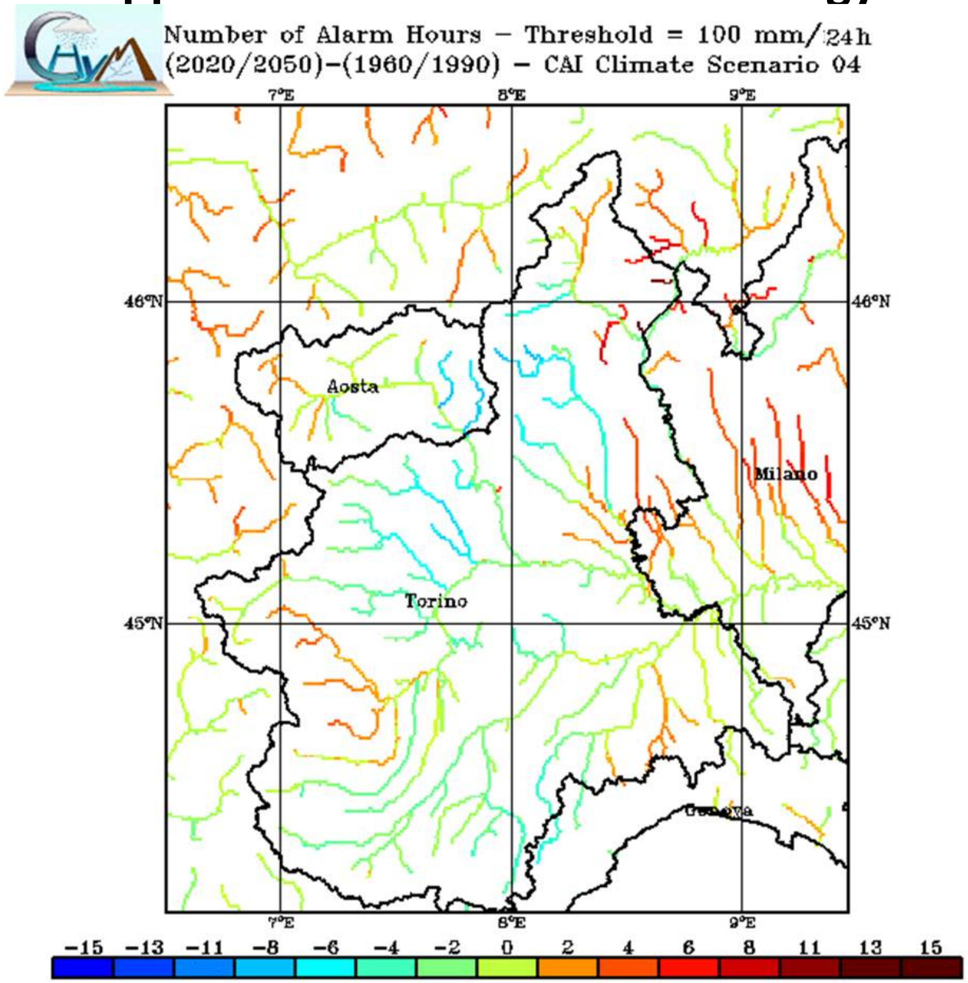

17/01/2014_h5:30
17/01/2014_h03:30
17/01/2014_h4:30
17/01/2014_h03:30
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Google earth
Data di acquisizione delle immagini: 10/30/2016 Lat 44.040299° Lon 8.040327° elev 546 m alt 69.85 km



Marco Verdecchia – University of L'Aquila, Italy - CHyM model for flood alert mapping


Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Google earth
Lat 44.737647° Lon 9.824988° elev 550 m alt 173.96 km

Flood alert mapping
Application to different climatology




"That's all Folks!"

Lab session
Few suggestions about model calibration and CHyM (any) model application

*** A model cannot be considered as "*black box*"**
The model "*does not work properly*" is the "*normal condition*"

*** Model is just an approximation of the actual world**

*** A "*Physical*" solution is always better than a "*numerical*" solution**

A first suggestion:
Select the process(es) whose numerical implementation must be refined and a period where such process is more important

A second suggestion:
Change only one parameter to evaluate the effect of the single parameter

CHyM Libraries - Mozilla Firefox

cetemps.aquila.infn.it/mvlib/11.html

Table 4. Arrays defined and used inside CHyM fortran code - The list is not yet complete

Array name	Save code	Meaning	Modified or Updated by	Used by
accl	*	Acclivity field. It is expressed as the sinus of the terrein slope in the direction of surface flow.	buildacclivitymap	runoffspeed
alfa		Surface runoff speed (m/sec), it also corresponds to the proportionality factor between flow discharge Q and wet section area A in the momentum equation.	runoffspeed (also automatically calculated after reading static field)	runoff
	ara	Surfce water available for runoff. This field is not stored in a specific array, but it is saved after the water balance has been calculated for each cell. The routine chymreaddynamicfields stores the data in work array *wkm1*	rainfall, evapotranspiration, melting, groundwater	CHyM
area	*	Area of each cell (Km²)	areamatrix	cvmm2m3, cvm32mm, runoff
bdd		BDD alarm index calculate as a function of flow-discharge	bddfield	
bwet	wet	Wet area (m²)	runoff	
deepw	dgw	mm of water infiltrated in the deep layer in the last N days (see component 7 of cpar vector described below)	groundwater	returnflow
dem	*	Digital Elevartion Model (m)	buiddem,angioplasty, demsmoothing,demholefilling	CHyM
ddeepw		Drained infiltrated water in the deep layer in the last N days (see component 7 of cpar vector described below)	groundwater	returnflow
drai	*	Total drained area of each cell (Km²)	areamatrix	riveronlanduse, calibration, returnflow, runoffspeed
dx		Channel lenght (m) for each cell.	runoffspeed (also automatically calculated after reading static field)	runoff
evap	evp	Actual evapotranspiration term (mm)	potevapotransp	evapotranspiration
fmap	*	Coded value for surface flow direction, **1** means North-West, **2** means North, **3** means North-East, **3** means North-East, **4** means East, **5** means South-East, **6** means South, **7** means South-West, **8** means West. estabilishfowdir, angioplasty, dircorrflow	buildacclivitymap, demsmoothing	runoff, runoffspeed
gh2o	gwt	Total content of water for each cell (m³)	groundwater, evapotranspiration (is it right?)	
lon	*	Longitude of each grid point	acquirescriptpar	CHyM
lat	*	Latitude of each grid point	acquirescriptpar	CHyM
luse	*	Land Use (coded value)	buildlandusemap,calibration, riveronlanduse	CHyM
modis		A real array containing a coded value, 1 means that the cell is covered by snow, 0 means that the cell is not covered by snow.	snowcover	snowcv
port	por	Flow discharge (m³/sec)	runoff	
			rainfall, datisparsi,	

Other vectors defined and used inside CHyM fortran code - The list is not yet complete

Vector name	Meaning	Calculated, set or updated by	Used by
iriv(nlon+nlat)	Contains the sequence of longitude indexes from the mouth up to the spring of the selected river. The sequence of indexes is rebuilt by the library routine *chymsalmone*; the vector is dimensioned *nlon+nlat* but the number of point actually belonging to the sequence is saved in the integer variable *nselrp*. The river can be selected by the csh parameter RIVER and the river mouths of the selected geographical domain can be visualized setting the value 8 for the PLOT option or using the the command *"show river* from CHyMLab utility.	plotting	writeoutfile
jriv(nlon+nlat)	Same as iriv vector but for latitude indexes	plotting	writeoutfile
cpar(52)	Contains the calibration parameters, the list of different components follows: 1. Return flow factor, the return flow contribute is proportional to the this factor, to the drained area and the average precipitation in the upstream basin in the past N days; the number N is established by the parameter cpar(7) descript below. Used inside *returnflow* subroutine. Default=4.8e-07 2. Alpha coefficient for the calculus of hydraulic radius. Used inside *runoffspeed* subroutine. Default=0.0015 3. Beta coefficient for the calculus of hydraulic radius. Used inside *runoffspeed* subroutine. Default=0.050 4. Melting temperature factor. Used inside *melting* subroutine. Default=0.050 5. Melting shortwave radiation factor. Used inside *melting* subroutine. Default=0.0094 6. River/land threshold (Km²). Used inside *runoffspeed* and *riveronlanduse* subroutines. Default=100.0 7. Number of days to consider for return flow. Used inside *returnflow* subroutine. Default=90 8. Reduction of manning coefficient for channel flow. Used inside *runoffspeed* subroutine. Default=4.5 9. River/land threshold (Km²). Above this threshold *returnflow*factor is computed. Used inside *returnflow* subroutine. Default=200.0 10. Precipitation threshold (mm) above which flow occur over channel instead of land (see cpar(6) discussed above) 11. Beta coefficient used to calculate BDD index (def=0.55). In principal this parameter should be the same of cpar(3), but it is set in a separate way in order to avoid confusions between different version.	calibration	(see description)
evc(110,12)	Monthly average potential evaporation (mm) depending on land use type (first index) and month (second index).	chymdata module	potevapotransp
infi(110)	Infiltration and interception capacity (mm) for each land use type	chymbd, calibration	groundwater
logun(10)	Logic units used by different routines for I/O operations, specific use of each component follow: 1. Logic unit used to write CHyM output 2. Logic unit used to write CHyM log 3. Logic unit used to write CHyM output in grads format 4. Logic unit used to read MM5 output file 5. Logic unit used to read or write temperature file 6. Logic unit used to read or write precipitation file	1. writeintes0 2. MAIN 3. gradsheader 4. definerainsources 5. potevapotransp 6. rainfall	1. writeoutfile 2. CHyM 3. writeoutfile 4. mm5data 5. potevapotransp 6. rainfall
manning(110)	Manning coefficient for each landuse type (m/sec)	chymbd, calibration	runoffspeed
perc(110)	Percolation from surface to deep ground (mm/hour) for each land use type	chymbd, calibration	groundwater

```
subroutine calibration
use chymdata , only : cpar,infi,perc,lago,fiume
implicit none

cpar( 1)=4.8e-07! Return flow factor (4.8e-07)
cpar( 2)=0.0015 ! Alpha coefficients for hydraulic radius (0.0015)
cpar( 3)=0.050  ! Beta coefficients for hydraulic radius
cpar( 4)=0.050  ! Melting temperature factor (0.050)
cpar( 5)=0.0094 ! Melting shortwave rad. factor (0.0094)
cpar( 6)=100.0  ! River/land threshold (Km2) (500.0)
cpar( 7)=90.0   ! Number of days to consider for return flow (90)
cpar( 8)=4.5    ! Reduction of land/channel manning coefficient
cpar( 9)=200.0  ! River/land threshold (Km2) for returnflow
cpar(10)=100.0  ! Rain Thresh above which channel flow occur
cpar(11)=0.55   ! Parameter beta used to calculate BDD
cpar(12:20)=0.0 ! Not yet used

infi= 40.0
infi(lago)=0.0
infi(fiume)=0.0
infi(12)=0.0    ! Ice

perc=infi*0.01
call basincalibration
return
end
```

Based on the kinematic wave approximation (*Lighthill and Whitam, 1955*) of the shallow water wave, the equations used by CHYM model to simulate the surface routing overland and for channel flow, are the continuity and momentum conservation equations:

Channel flow

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

$$Q = \alpha A^m$$

$$\alpha = \frac{S^{1/2} R^{2/3}}{n}$$

$$R = \beta + \gamma D A^{\delta}$$

S is longitudinal bed slope of the flow element , ***n*** the Manning's roughness coefficient while ***R*** is the hydraulic radius that can be written as a linear function of the drained area

Channel flow

$$\partial\varphi/\partial x + \partial y/\partial t = \xi$$

cpar(6) is drained area threshold (tipycally 100 Km^2)
cpar(8) is the increasing coefficient of Manning equation
cpar(2) and cpar(3) are β and γ coefficients to calculate the hydraulic radius

Melting

$$M = T_F T + S_{RF}(1-\alpha)G_{\downarrow}$$

$$G_{\downarrow} = C_s A_{tr} \sin(\Psi)$$

$$A_{tr} = \left[0.6 + 0.2\sin(\Psi)\right](1.0 - 0.4\sigma_H)(1.0 - 0.7\sigma_M)(1.0 - 0.4\sigma_L)$$

$$\sin(\Psi) = \sin(\varphi)\sin(\delta_s) - \cos(\varphi)\cos(\delta_s)\cos\left(\frac{2\pi t_{utc}}{t_d} - \lambda\right)$$

T_f is set 0.005 mm hour^{-1} $^oC^{-1}$ and it is specified by cpar(4)
S_{RF} is set to 0.0094 mm hour^{-1} m^2/(watt ^{0}C) and is specified by cpar(5)

Return flow

CHyM model parametrizes the return flow assuming that its contribution to surface flow is proportional to the total infiltration in the upstream basin during the last N days.

$$R_f = \theta \int_{UpStream} \int_{N-Days} I(t,s)\,dt\,ds$$

The space integral is calculated over the whole upstream basin of each cell, while the time integral is carried out over the last N days, being N a value to be optimized during the calibration process. Typical value for small and medium basins are
N = 90 days (cpar(7)), θ= 5 × 10−7 mm hour^{-1} km^{-2} (cpar(1))

Evapotranspiration

The reference evapotranspiration ET_0 is approximated as a linear function of temperature and is calculated according to:

$$ET_0 = \alpha + \beta N W_{ta}(h,T) T$$

According to Thornthwaite and Mather (1957), CHyM model calculates the potential evapotranspiration ET_P, for each elementary cell, as a function of the evapotranspiration in saturated soil conditions ET_0

$$ET_P = K_c \, ET_0$$

being K_c the so-called crop factor that is a function of crop type.

Evapotranspiration

The potential evapotranspiration is computed as a function of the evapotranspiration in saturated soil conditions (Thornthwaite and Mather, 1957), according to the formula:

$$ET_p = k_c ET_0$$

Kc is set in the array evc(LU,MON) of CHyM code

where k_c is the crop factor that is a function of crop type. The reference evapotranspiration ET_0 is approximated as a linear function of temperature and is calculated according to:

$$ET_0 = \alpha + \beta N W_{ta}(h, T) T$$

```
real evc(lntypes,12)
data (evc( 1,i),i=1,12)
2       /0.20,0.20,0.20,0.20,0.20,0.20,0.20,0.20,0.20,0.20,0.20,0.20/
data (evc( 2,i),i=1,12)
2       /0.60,0.65,0.70,0.75,0.80,0.80,0.85,0.85,0.85,0.80,0.80,0.60/
data (evc( 3,i),i=1,12)
2       /0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90/
data (evc( 4,i),i=1,12)
2       /0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90,0.90/
data (evc( 5,i),i=1,12)
2       /0.60,0.70,0.95,1.05,1.05,0.80,0.80,0.80,0.80,1.20,1.10,0.60/
```

```
subroutine calibration
use chymdata , only : cpar,infi,perc,lago,fiume
implicit none

cpar( 1)=4.8e-07! Return flow factor (4.8e-07)
cpar( 2)=0.0015 ! Alpha coefficients for hydraulic radius (0.0015)
cpar( 3)=0.050  ! Beta coefficients for hydraulic radius
cpar( 4)=0.050  ! Melting temperature factor (0.050)
cpar( 5)=0.0094 ! Melting shortwave rad. factor (0.0094)
cpar( 6)=100.0  ! River/land threshold (Km2) (500.0)
cpar( 7)=90.0   ! Number of days to consider for return flow (90)
cpar( 8)=4.5    ! Reduction of land/channel manning coefficient
cpar( 9)=200.0  ! River/land threshold (Km2) for returnflow
cpar(10)=100.0  ! Rain Thresh above which channel flow occur
cpar(11)=0.55   ! Parameter beta used to calculate BDD
cpar(12:20)=0.0 ! Not yet used

infi= 40.0
infi(lago)=0.0
infi(fiume)=0.0
infi(12)=0.0    ! Ice

perc=infi*0.01
call basincalibration
return
end
```

Infiltration

Percolation