



Marco Verdecchia
University of L'Aquila, Italy

**CHyM** model for flood alert mapping





Integration of remote sensing techniques and numerical modeling for the forecast of severe weather

Work Package 2 - Hydrological Modeling



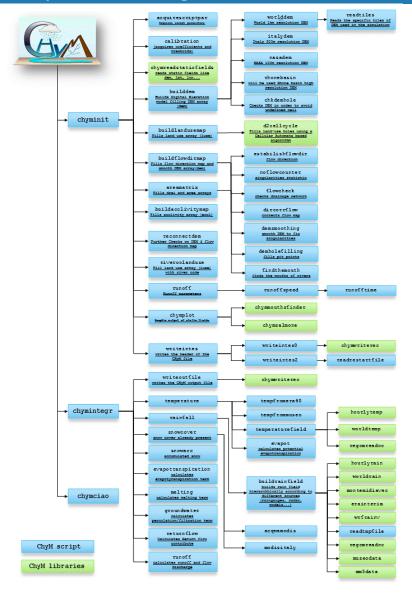


#### **CHyM - Architectural characteristics**

☐ 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 Unix 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:



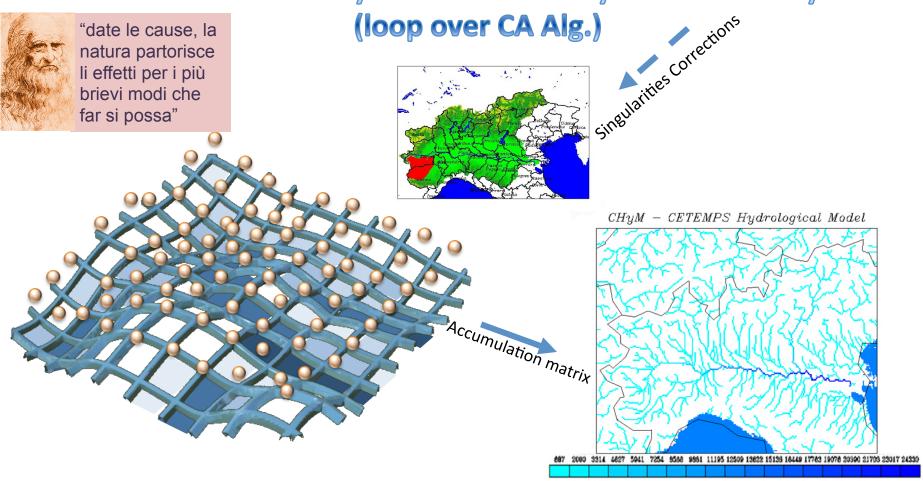








#### **DEM and LU arrays - Flow Dir. Array - Accum. Array**

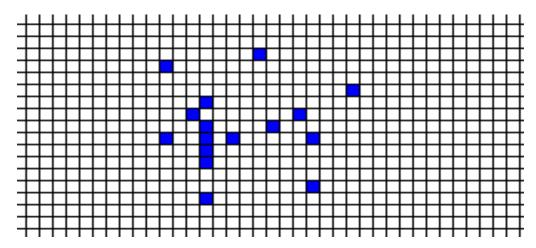






In order to solve numerical singularities and merge different data set of observational/predicted data, CHyM model uses an original Cellular Automata based algorithms

#### A Cellular automata definition

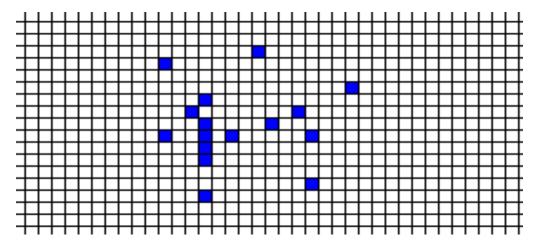


- A cellular automata is a discrete dynamical system (Space, time and states of the system are discrete quantities)
- Each point in a regular spatial lattice, called a cell, can have anyone of a finite number of states
- The state of the cells in the lattice are updated according to a local rule
- All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

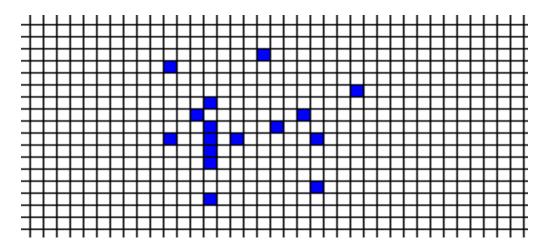
$$h_i \rightarrow h_i + \alpha \left( \sum_{j=1}^{8} \beta_j (h_j - h_i) \right)$$

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





#### How Cellular Automata theory is applied to solve DEM singularities



#### The simple recipe:

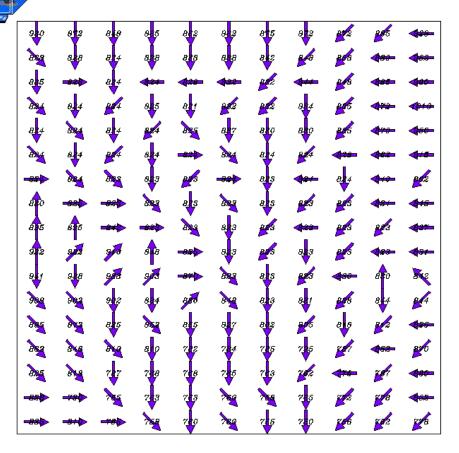
- Smooth DEM using CA rules until FD can be obtained for all the cells
  - Generate streamflow network using smoothed DEM
- Use "true" DEM and modify ONLY the cells draining toward an higher cell





#### How Cellular Automata theory is applied to solve DEM singularities

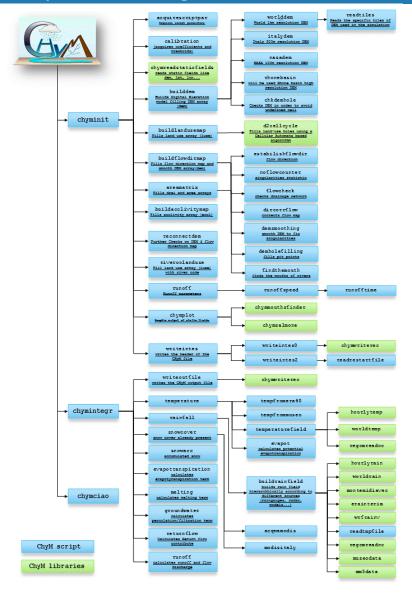
CETEMPS Hydrological Model Preprocessor





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









#### Parametrization of physical processes contributing to hydrological cycle Surface runoff

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:

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

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

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





#### Parametrization of physical processes contributing to hydrological cycle Melting

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

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

$$A_{tr} = \left[0.6 + 0.2\sin(\Psi)\right](1.0 - 0.4\sigma_{H})(1.0 - 0.7\sigma_{M})(1.0 - 0.4\sigma_{L})$$

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



A complete description can be find starting from: http://cetemps.aquila.infn.it/mvlib/11.html



#### Parametrization of physical processes contributing to hydrological cycle

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#### CHyM model Version 5.00 documentation

<u>Source code</u> available for local users only The basic equations of CHyM model are available <u>here</u>.

This page is organized with four different tables. In the <u>first table</u> the general purpose routines available in the chym library are listed and documented. In the <u>second table</u> a complete description of CHyM internal flags written in the header of the output file is reported. In the <u>third table</u> the CHyM script parameters are listed and described. The <u>table 4</u> lists the arrays used inside CHyM fortran code and related meaning. The <u>documentation of CHyMLab utility</u> is now also available.

#### Invoking CHyM from unix shells:

#### chym [Outfile] [Inpfile] [Startdate] [IntTime] [Pfile] [Tfile]

The six arguments corresponds to different parameters of CHyM script descripted in the third table, if these arguments are explicitely specified when invoking CHyM script, the values set inside the script are ignored. The meaning of each argument are listed:

- [Outfile] specifies the value of the script parameter OFILE, namely the file where CHyM model will store the results of simulation.
- [Inpfile] specifies the value of the script parameter RFILE, namely the file to be used for restart, this parameter is actually used only if the parameter RESTART>0.
- [Startdate] specifies the value of the script parameter DATE, namely the start date in the integer format YYMMDDHH.
- [IntTime] specifies the value of the script parameter NSLI, namely the number of hourly steps of integration.
- [Pfile] specifies the value of the script parameter PFILE, namely the file where the precipitation fields are saved or read.
- [Tfile] specifies the value of the script parameter TFILE, namely the file where the temperature fields are saved or read.





#### <u>CHyM model – User information</u>

#### A complete description can be find starting from: http://cetemps.aquila.infn.it/mvlib/11.html

#### **Table 1**. General purpose fortran subroutine included in the CHyM library

#### Reading CHyM output file

Read from the source specified by the first argument the CHyM static fields. This data will be stored in the arrays defined within the chymdata module. This subroutine also read the header of the file containing the vectors mchym, rchym and schym.

chymreadstaticfields is actually an interface (means that the name of the subroutine is the same, but you may invoke it using a different combination of arguments) and you may invoke it in four different ways namely specifying the file name or logic unit (first argument) and specifying (or not) a two digit integer option as second argument; if the second argument is not specifyed the value 00 for it is assumed.

- If an integer is passed as first argument the fields are read form this logic unit; if a string is passed as first argument, the subroutine assumes that this argument specifyes the filename to be opened in a free logic unit, in this case the file is closed after reading the fields.
- Valid options for the integer flag are 00, 01, 10 and 11. More specifically: If the second digit is = 1, this subroutines check whether or not the parameters defining the grid written in the file corresponds to the grid defined by the parameters that are currently stored in the mchym/rchym vectors (this option is usually used by CHyM model in order to restart from a previous run); if the first digit is 1 a short list of info is given on standard output, specifying the grid and other informations about the CHyM output you are reading.

The subroutine chymreadstaticfields provides a very siple way to retrieve the basic fields of a CHyM simulation. As an example to plot the DEM of the selected domain only a three-line program is needed:

use chymdata , only : chymreadstaticfields call chymreadstaticfields('tmp/Po.chym') call chymplot(1, 'dLl')



chymreadstaticfields([lun/file],[flag])



#### <u>CHyM model – User information</u>

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c and dynamical





#### <u>CHyM model – User information</u>

#### A complete description can be find starting from: http://cetemps.aquila.infn.it/mvlib/11.html

#### General purpose flags This script parameter allows to select the compiler used to compile the CHyM fortran code. If this parameter is not set by the user the CHyM script will try to compile with gfortran, ifort and COMP pgf90 compiler (in this other) on the linux platforms. For other operating systems CHyM script will try to use the vendor specific compiler, namely f90 for HP-alpha platforms, f90 for SunOS and Sylicon Graphics platforms, xif for IBM-Irix platforms. **VERB** A logical script variable. If it is set to "true" many verbose information are provided on standard output during the compilation and execution phase. The following flags determines how the CHyM output file will be built and used to restart a simulation. RESTART csh parameter is an integer coded value determining the manner used by CHyM model to build the static fields and inizialize the dynamical fields. • RESTART=0 means that a new run is started and a new output file must be created, the name of the output file is established by the OFILE csh parameter described below. The static fields are calculated from the CHyM database and dynamical fields, as an example the flow discharge are initialized with a null value. Not that in this case an adequate phase of spin-up is needed before resonable values of dynamical fields are reached. • RESTART=1 means that a new run is started, but the simulated geographical domain is the same as a previous one. In this case the static fields (DEM, Land use, etc.) are read from the file specified by the RFILE csh parameter described below. If the user does not specify a value for RFILE csh parameter, CHyM assume that the input and output file are the same, namely RFILE=OFILE, Warning: in this case the existing input file will be overwritten. Also with RESTART=1 the dynamical fields are initialized with a null value and an adequate phase of spin-up is needed before resonable values of dynamical fields are reached. • RESTART=2 means that CHyM have to continue a previous run. In this case static fields are read from the file specifield by RFILE csh parameter described below and also the dynamical fields are inituialized reading form RFILE files the time slice corresponding to the date of start of the current run. A new output file si created (the name is specified by OFILE script parameter) RESTART Please, also carefully consider what follow: If you want to restart the model in a proper way, you have to save at least: Flow discharge field (code "por") 2. Ground Water Content (code "gwt") Accumulated snow (code "sno") 4. Deep ground water content (code "dgw") as a consequence the csh parameter SAVEFLD must, at least, contains these four fields, namely: set SAVEFLD = "por,gwt,sno,dgw" If you do not save these fields, one or more of the above listed fields are re-initialized to zero at the restart of the run. . If RESTART>0 the the CHyM csh parameters DEMF, NLON, NLAT, SLON, SLAT, DIJ are ignored





#### <u>CHyM model – User information</u>

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		Table 4. Arrays defined and used inside CHyM fortran code - Please note the lis	t 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	runoff
area	*	Area of each cell (Km²)	areamatrix	cvmm2m3, cvm32mm, runoff
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	СНуМ
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	runoff
evap	evp	Actual evapotranspiration term (mm)	potevapotransp	evapotranspiration





#### <u>CHyM model – User information</u>

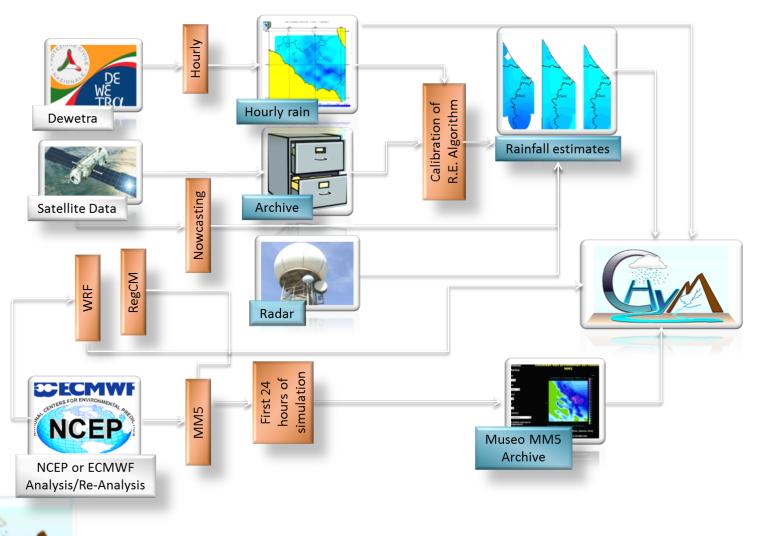
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	Contains the calibration parameters, the list of different components follows:	
cpar(52)	<ol> <li>Return flow factor, the return flow contribute is proportional to the this factor, to the drained area and the average precipitation in the upstream 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</li> <li>Alpha coefficient for the calculus of hydraulic radius. Used inside runoffspeed subroutine. Default=0.0015</li> <li>Beta coefficient for the calculus of hydraulic radius. Used inside runoffspeed subroutine. Default=0.050</li> <li>Melting temperature factor. Used inside melting subroutine. Default=0.050</li> <li>Melting shortwave radiation factor. Used inside melting subroutine. Default=0.0094</li> <li>River/land threshold (Km²). Used inside runoffspeed and riveronlanduse subroutines. Default=100.0</li> <li>Number of days to consider for return flow. Used inside returnflow subroutine. Default=90</li> <li>Reduction of manning coefficient for channel flow. Used inside runoffspeed subroutine. Default=4.5</li> <li>River/land threshold (Km²). Above this threshold returnflow factor is computed. Used inside returnflow subroutine. Default=200.0</li> </ol>	(see description)

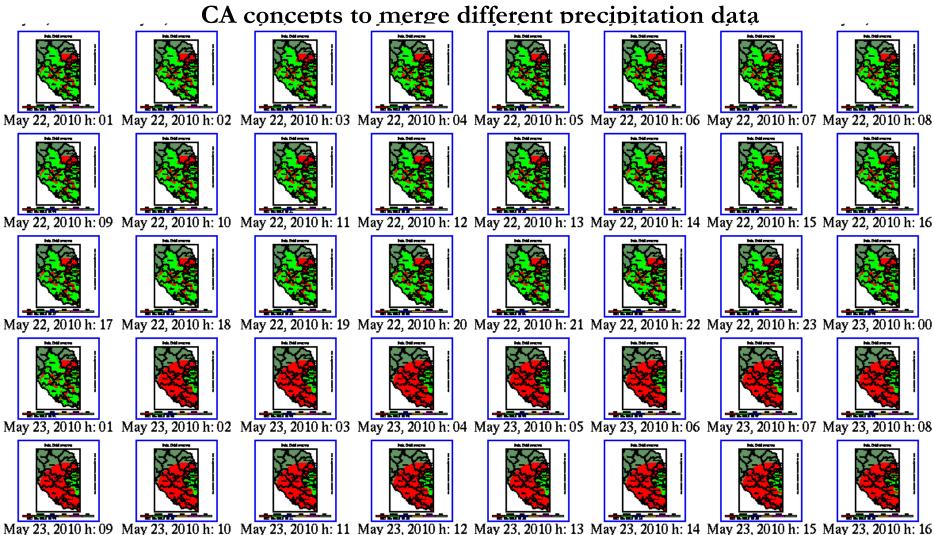




#### Merging different precipitation data set





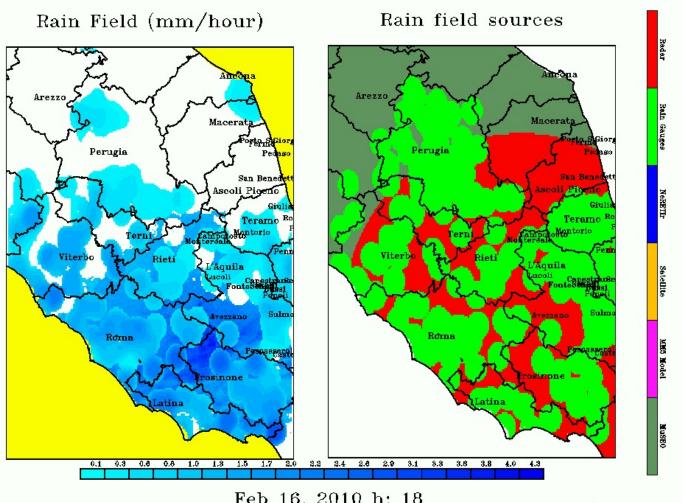






#### CA concepts to merge different precipitation data









# 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.









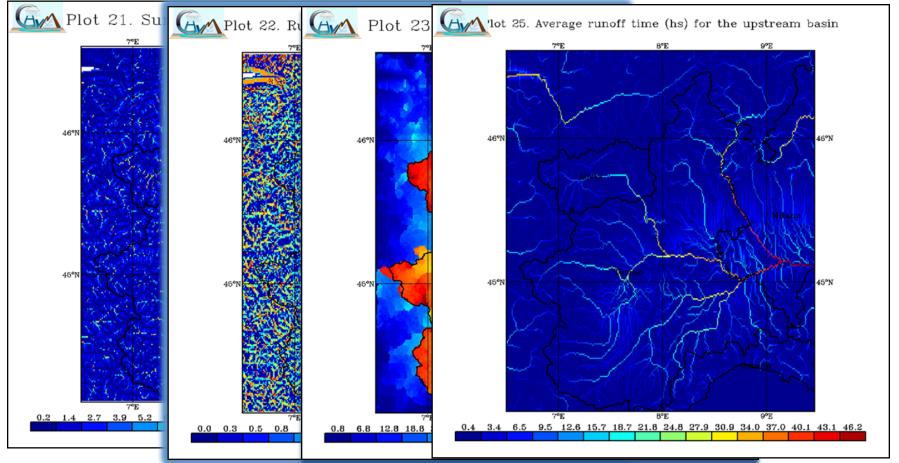
# Flood alert mapping Definition of alarm index – CAI (CHyM Alarm index)

$$CAI2 = \frac{\int_{t-\Delta t_i}^{t} \int_{Up_i} P(t,s) dt ds}{\int_{Up_i} ds}$$





# 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)

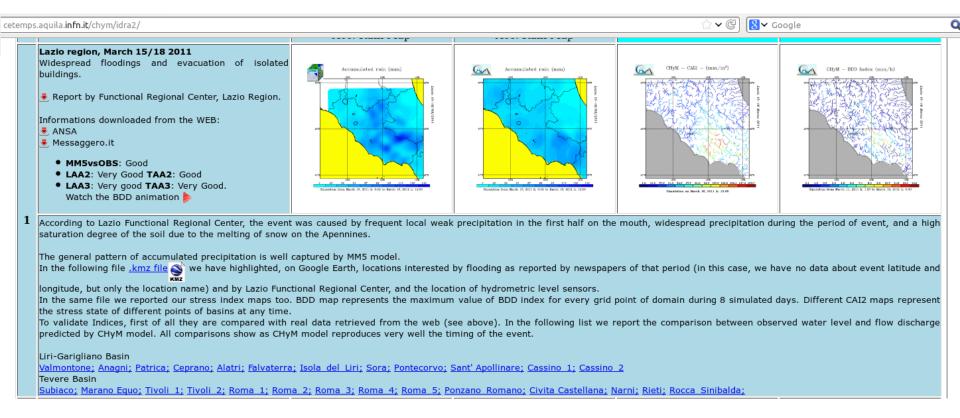
$$BDD_i(t_1 - t_2) = \frac{\max_{t_1 \to t_2}(Q_i(t))}{R_i^2}$$

$$R = \beta + \gamma DA^{\delta}$$





### Flood alert mapping Validation of flood alarm index







## Flood alert mapping Validation of flood alarm index

	ALG1			ALG2			ALG3		
	Mapping	Timing	False Alarm?	Mapping	Timing	False Alarm?	Mapping	Timing	False Alarm
Case Study 1	***	***		***	***		****	****	
Case Study 2	***	***		***	***		****	***	
Case Study 3	***	***		安全安全	***		***	***	
Case Study 4			Yes			Yes			No
Case Study 5	****	***		****	***		****	***	
Case Study 6				<b>k</b>					
Case Study 7	***	***		***	***	1	****	****	
Case Study 8	***	***		***	***	1	****	****	
Case Study 9									
Case Study 10	***	***		***	***		****	****	
Case Study 11	***	***		***	***	1	****	***	
Case Study 12	***	***		***	***	i i	**	**	
Case Study 13	***	***		***	***	i i	***	***	
Case Study 14	***	***		***	***		****	****	
genda:									
Very bad	🍌 Bad	Aver	age	***	🛖 Good	<b>→</b>	<b>★★★★</b> Very Good		



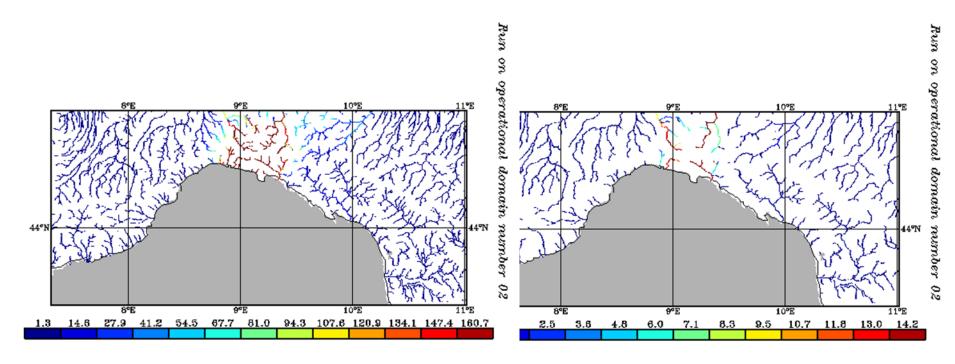


# Flood alert mapping Application to different case studies – Genova – October 2014



CHyM - CAI - (mm/day)

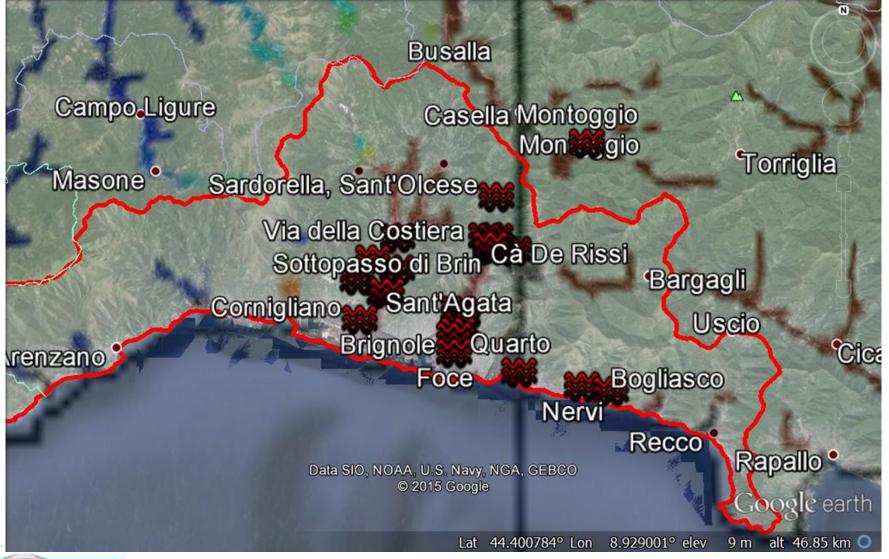
CHyM - BDD Index (mm/h)





Flood alert mapping operationally available at URL <a href="http://cetemps.aquila.infn.it/chymop">http://cetemps.aquila.infn.it/chymop</a>

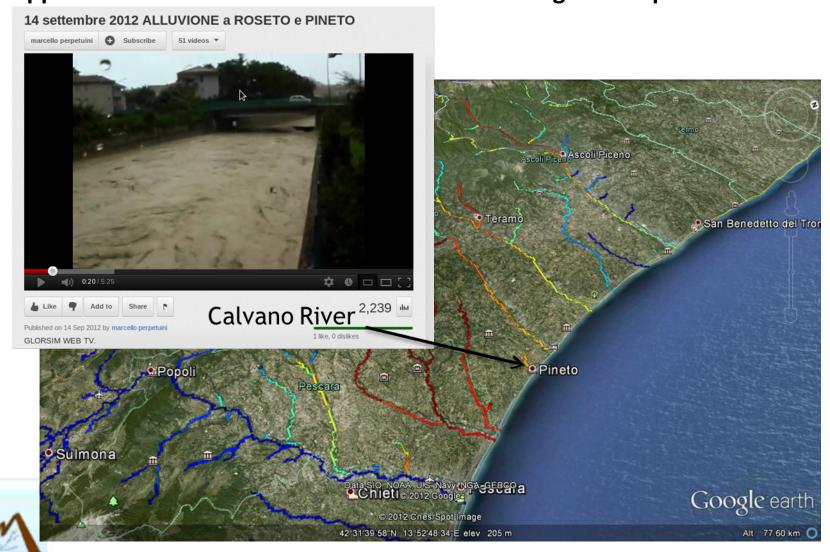






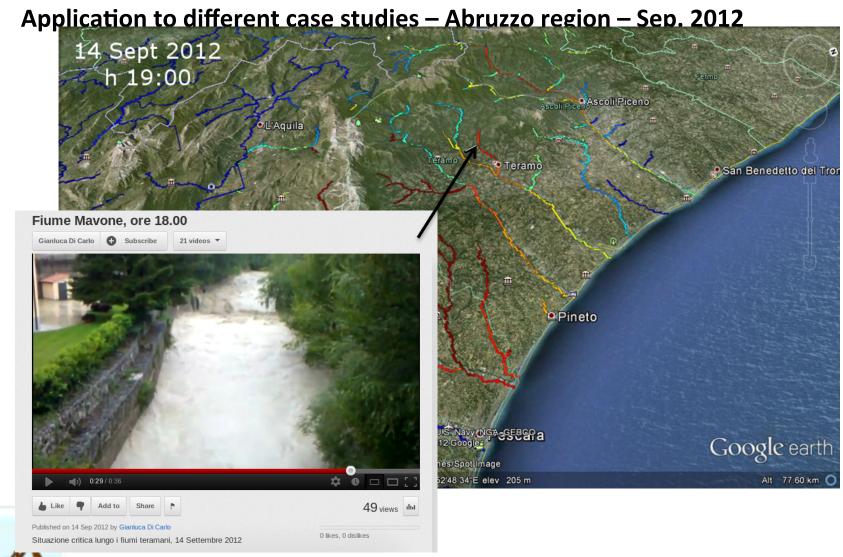


# Flood alert mapping Application to different case studies – Abruzzo region – Sep 2012

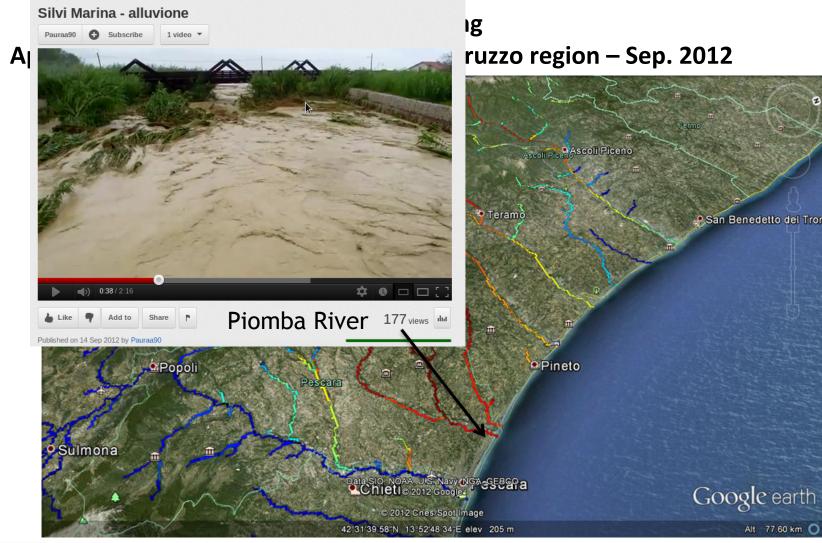




Flood alert mapping



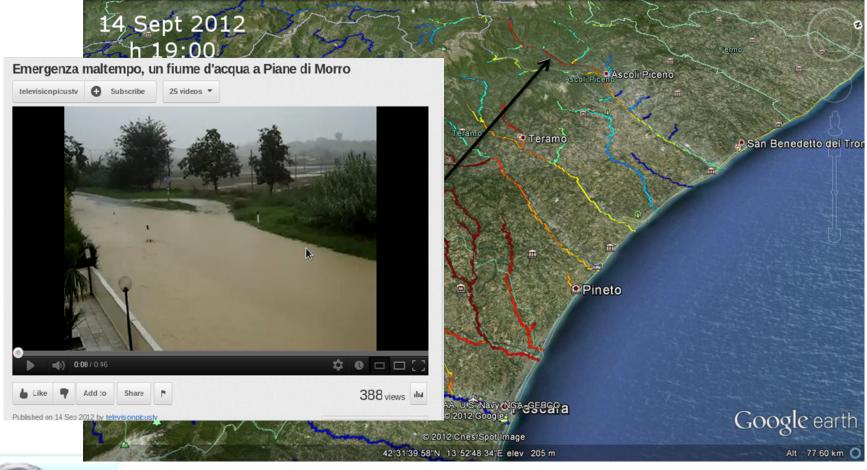






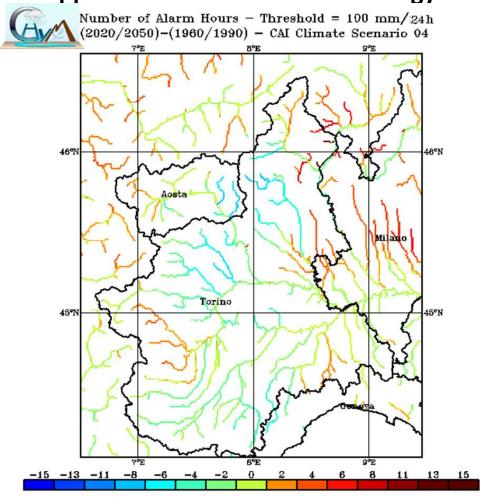


# Flood alert mapping Application to different case studies – Abruzzo region – Sep. 2012





# Flood alert mapping Application to different climatology













# Flood alert mapping Application to different case studies





