Hydrological modelling for flood forecasting and water management

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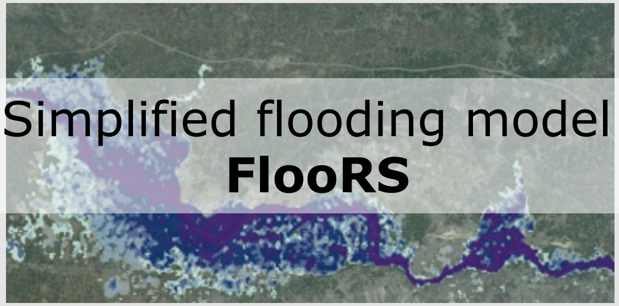
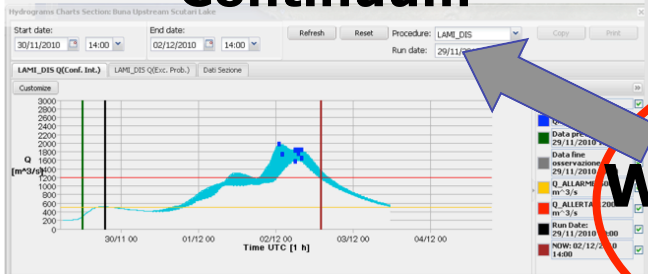
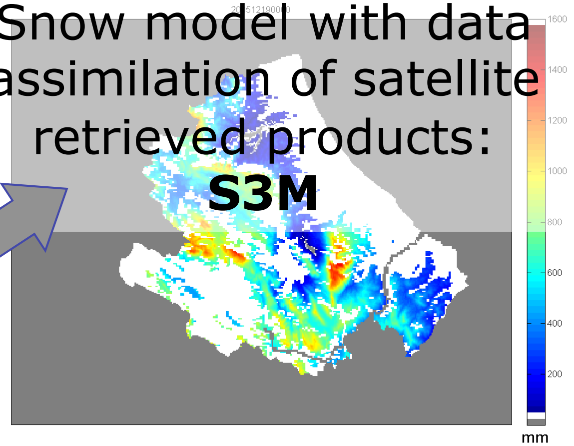


Simplified flooding model:
FlooRS

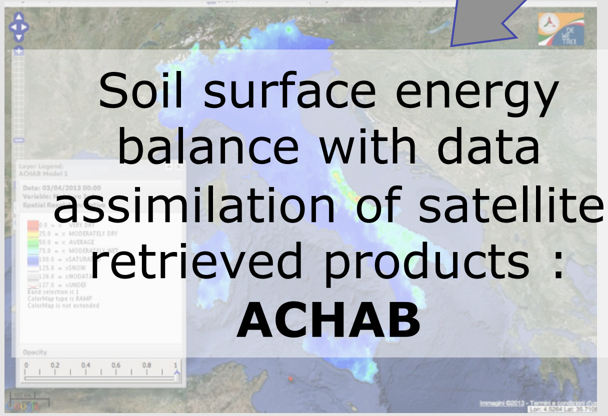


Continuous hydrological model:
Continuum

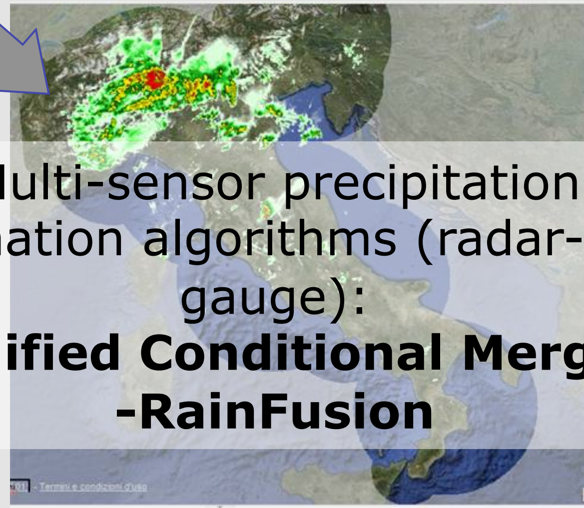


Snow model with data assimilation of satellite retrieved products:
S3M

Water Related Risks
Models-Tools



Soil surface energy balance with data assimilation of satellite retrieved products :
ACHAB



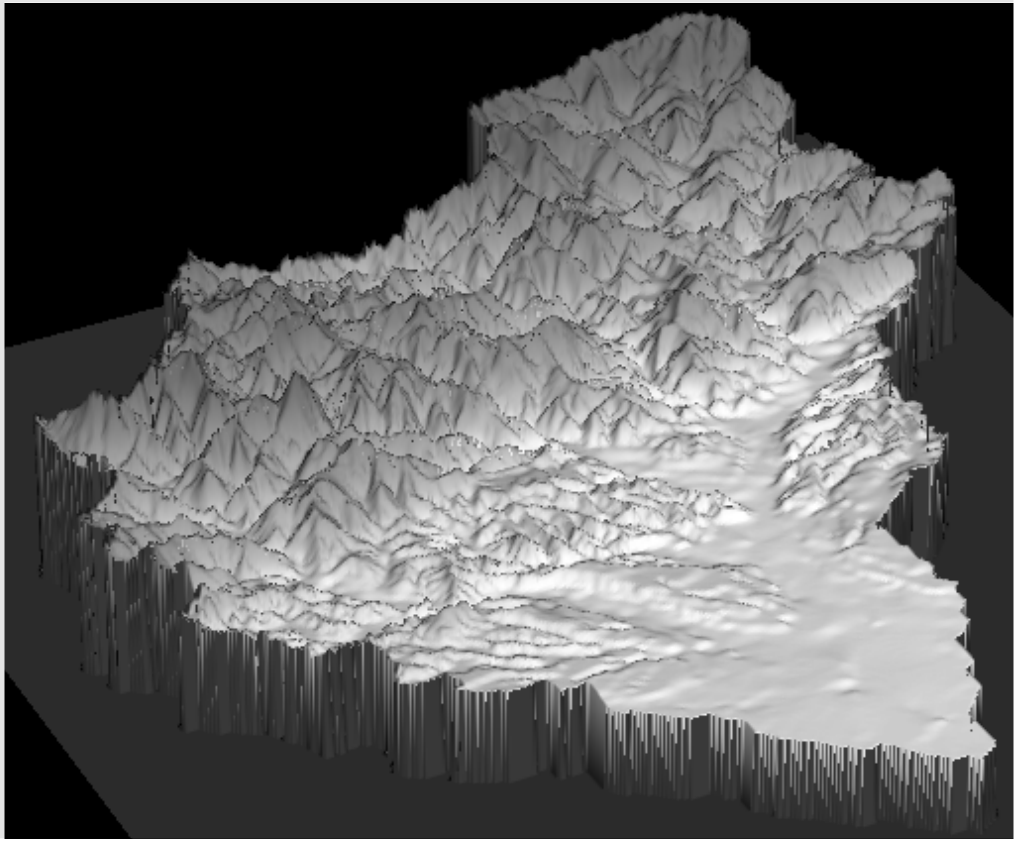
Multi-sensor precipitation estimation algorithms (radar-rain gauge):
-Modified Conditional Merging
-RainFusion

Continuous hydrological model for discharge simulation and forecast : CONTINUUM

Team: F. Silvestro, S. Gabellani, F. Delogu, R. Rudari, G. Boni, P. Laiolo

Main characteristics:

- Simple but complete description of main processes of Hydrological Cycle
- Fully Distributed
- Complete Mass Balance
- Energy Balance
- Based on simple terrain data
- Possibility of using remote sensing data
- Ability of data assimilation
- Reduced number of calibration parameters



Overview

Model description

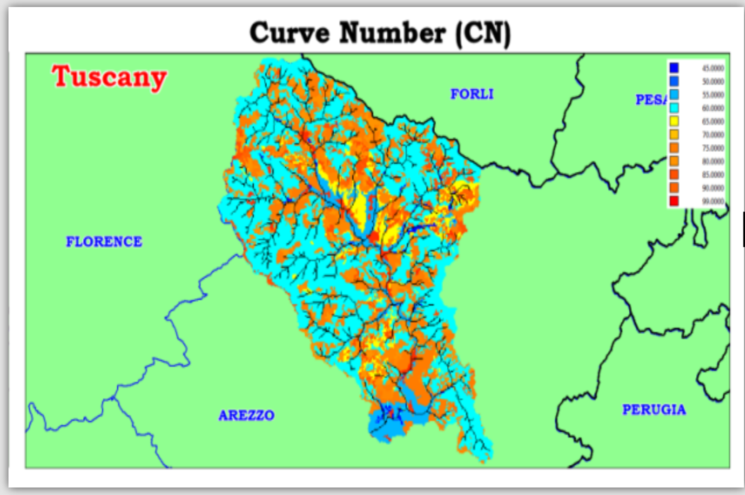
- Drainage network individuation
- Mass Balance 1: Sub-surface flow
- Mass Balance 2: Water table
- Mass Balance 3: Surface flow
- Energy balance
- Input data
- Outputs

Application on Orba basin

Modifications for Alpine environment and hydraulic structures

Application on Buna+Drin basin, introduction of lakes

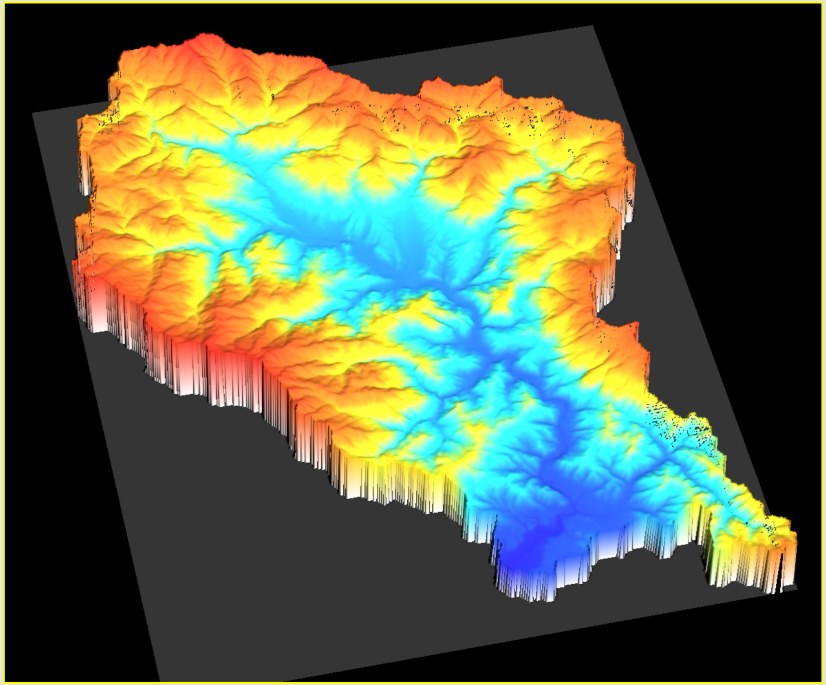
Terrain input data



Curve Number (SCS) maps for vegetation, soil use and soil type description

Soil parameters estimation

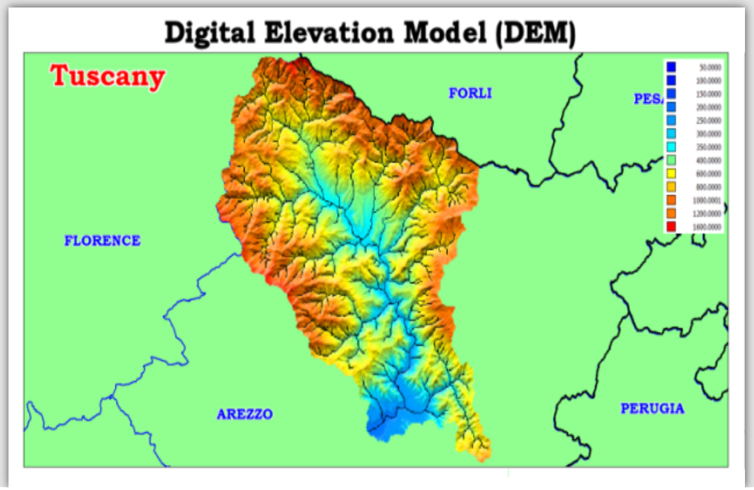
Digital Elevation Model



Flow Directions

Morfologic Filter

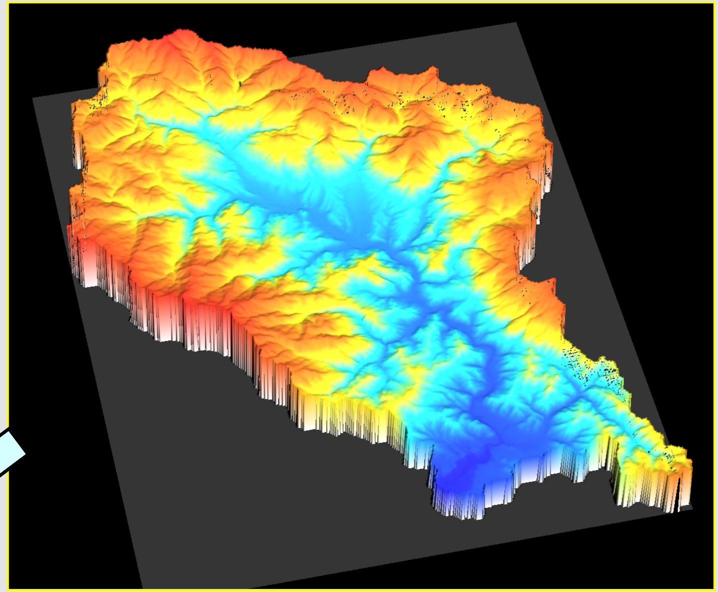
Drainage network



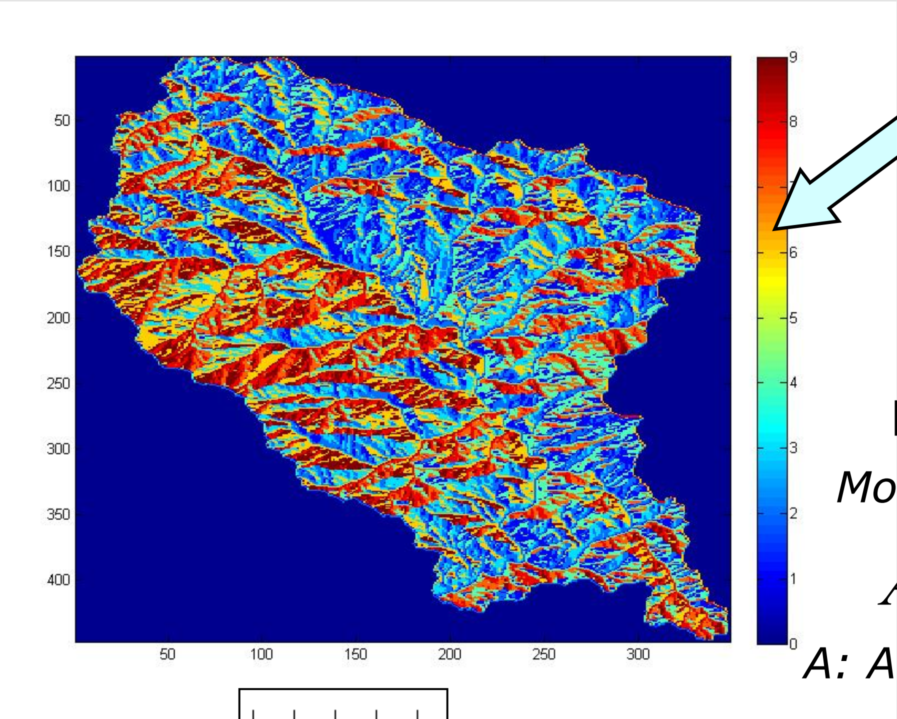
Drainage network

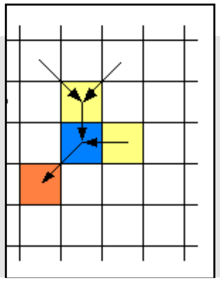
Digital Elevation Model

Giannoni et al. (2000, 2005)



Drainage directions

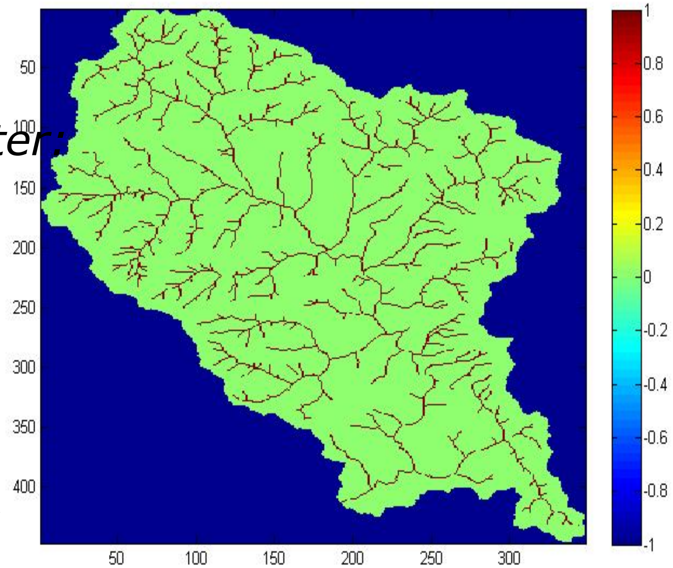




Morphologic Filter:

$$A \cdot s^{k} = C$$

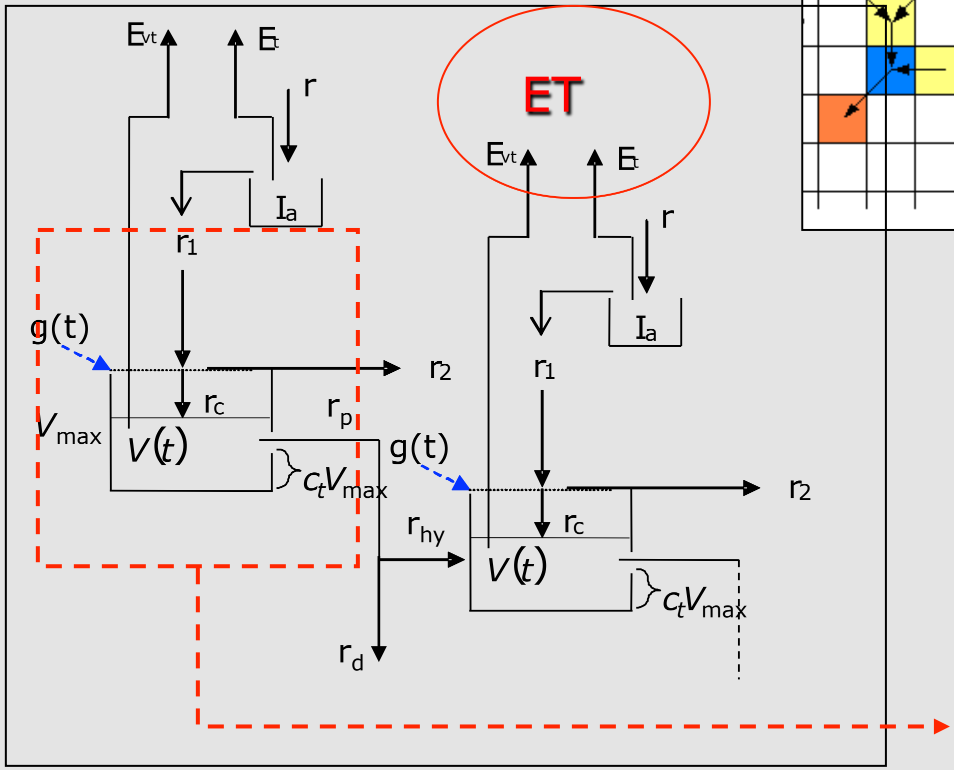
A: Area; s: slope

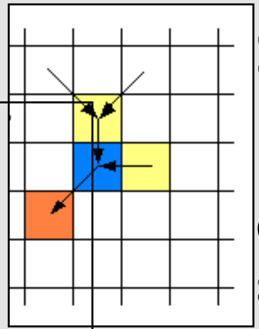


Drainage network

Interception, Subsurface flow and Infiltration

Mass balance at cell scale.
Tank schematization:





Ia : vegetation interception

g(t) : filter depending on soil saturation

ET: Total evapotranspiration

Deep Flow (% percolation) : flow in deep soil layer and water-table recharge, depending on terrain slope.

Modified Horton Scheme

(*Diskin and Nazimov*, 1994; *Gabellani et al.*, 2008)

r = rainfall

r_1= effective rainfall

r_2= runoff

r_c= infiltration

r_p= percolation

r_{hy}= subsurface flow

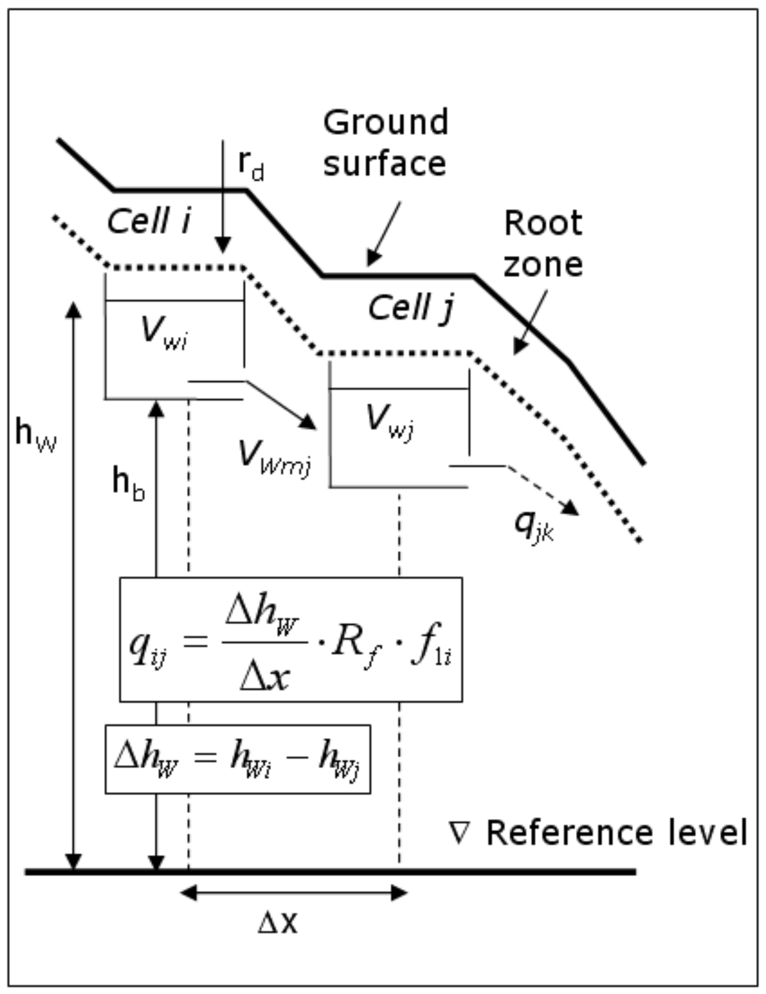
r_d= deep flow

The spatial resolution depends on DTM resolution (~ 100 – 1000 m)
The max vegetation interception Ia can be evaluated using literature values, vegetation cover maps, LAI (leaf area index) retrieved by satellite data

<u>Two calibration parameters: c_t and c_f</u>

Deep Flow and Water-Table

Mass balance at cell scale. The **Deep Flow** deriving from upper soil layer recharge the water-table.
The flow in the water-table is regulated by the Darcy low and depends on the difference of the heights between two neighbor cells



$$V_{Wm} = V_{W\max} \cdot \left(1 - \frac{tg(\beta) - tg(\beta_{\min})}{tg(\beta_{\max}) - tg(\beta_{\min})}\right)$$

(*Saulnier et al.*, 1997)

β: downslope index (*Hjerdt et al., 2004*)

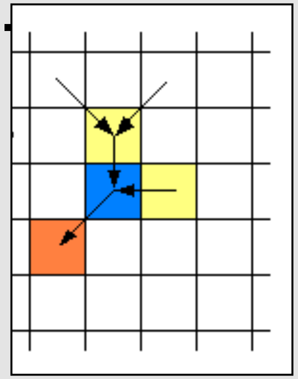
V_{Wm}=max water-table storage for the cell
h_b=height of the bedrock

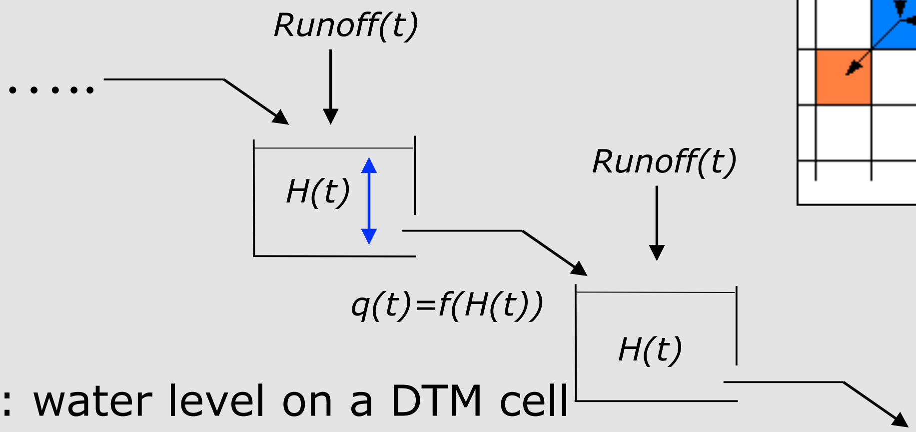
When $h_w(t)$ reaches the level $V_{Wm}+h_b$, the deep flow (r_d) nullify and all the percolation becomes susurface flow

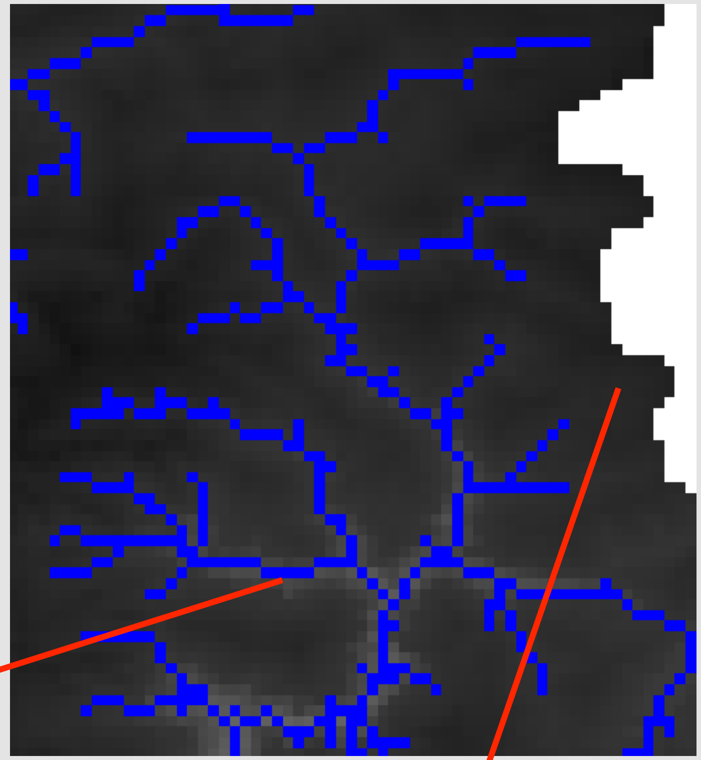
<u>Two calibration parameters: V_{Wmax} and R_f</u>

Surface Flow

Mass balance at cell scale.
Linear and Non-Linear
Tank schematization:







H(t) : water level on a DTM cell

q(t):Flow per unit of surface

i_f : stream branch slope

Channel: $q_c(t) = u_c \cdot \sqrt{i_f} \cdot h^{1.5}$

Hill-slope: $q_h(t) = \Delta x \cdot u_h \cdot h$

(*Wooding*, 1965; *Todini and Ciarapica*, 2001)

$$\frac{dh_i}{dt} = I_i - \frac{1}{\Delta x} \cdot q(t)$$

Fully distributed simple schematization that allows to describe the discharge evolution in every location of the basin.

Spatial resolution depends on DTM resolution (~ 100-1000 m)

<u>Two calibration parameters: u_c and u_h</u>

Energy Balance and Evapotranspiration

Energy balance: Force restore equation approximation (solution of the heat diffusion equation, with purely sinusoidal forcing)

(Lin, 1965; *Caparrini et al.*, 2004)

$$R_n = H + LE - G$$

$$\frac{d(LST)}{dt} = 2\sqrt{\pi\omega}\left(\frac{R_n - H - LE}{P_{soil}}\right) - 2\pi\omega\left(LST - T_D\right)$$

- **LST : Land Surface Temperature**
- **R_n : net radiation**
- **H : sensible heat flux**
- **LE: latent heat flux**
- **P_{soil}: thermal inertia (f(s))**
- **ϖ: Dominant Frequency (1/24 hours)**

Heat fluxes and evapotranspiration determination:

$$H = \rho_a c_p C_h W\left(LST - T_a\right) \qquad LE = \rho_a \lambda C_h W \beta\left(q_s^* - q_a\right)$$

$$q_s^* = 0.611 \cdot \exp\left(17.3 \cdot \frac{\left(LST - T_{rif}\right)}{\left(237.3 + LST - T_{rif}\right)}\right)$$

Heat diffusion coefficient

$$ET = \frac{LE}{\rho_w \cdot \lambda} = \frac{\rho_a}{\rho_w} \cdot C_h W \beta\left(q_s^* - q_a\right)$$

Beta Model:

$$s = \frac{V(t)}{V_{max}}$$

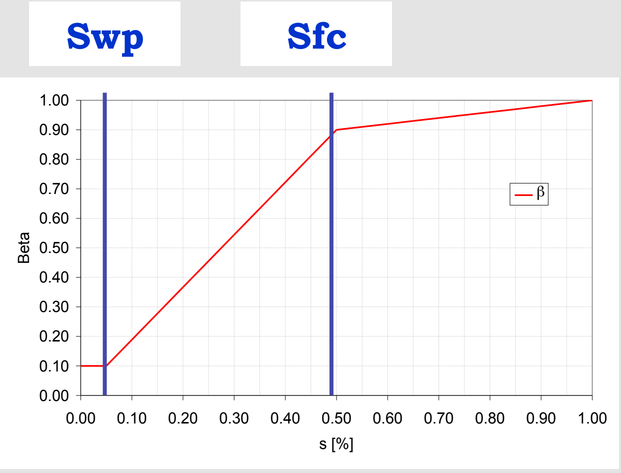
$$\beta = \beta\left(s\left(t\right)\right)$$

$$\beta = a \qquad 0 < s < s_{wp}$$

$$\beta = \frac{(b-a)}{\left(s_{fc} - s_{wp}\right)}\left(s_{fc} - s_{wp}\right) \qquad s_{wp} < s < s_{fc}$$

$$\beta = \frac{(1-b)}{\left(1 - s_{fc}\right)} s + 1 - \frac{(1-b)}{\left(1 - s_{fc}\right)} \qquad s > s_{fc}$$

$$where: \quad a = 0.1 \quad b = 0.9$$



Ground surface input data

Hydrologic and Meterologic data input, derived from network gauges, are: Short Wave Radiation (1), Wind Speed (2), Rain (3), Temperature (4) and Relative Humidity (5).

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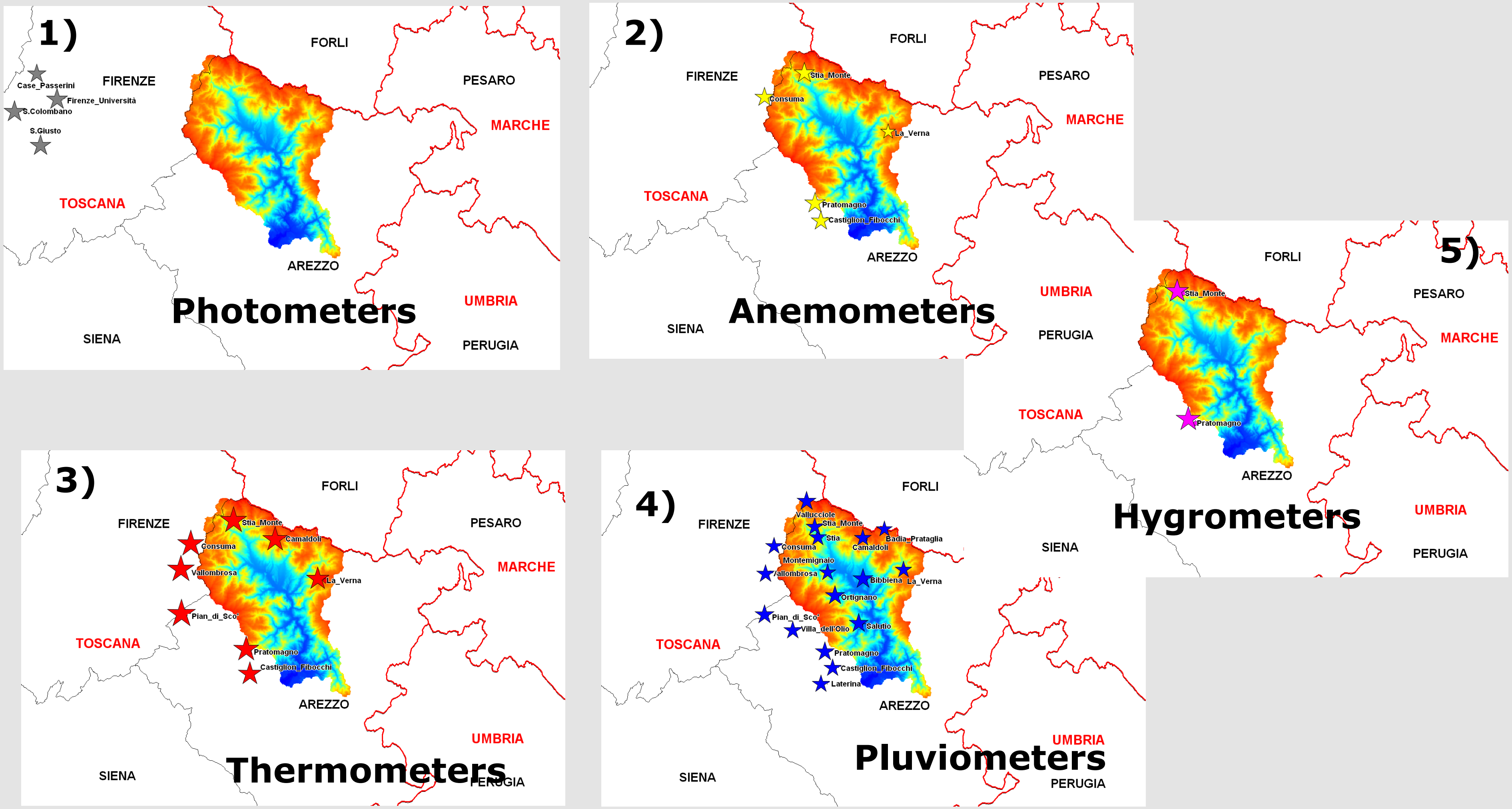
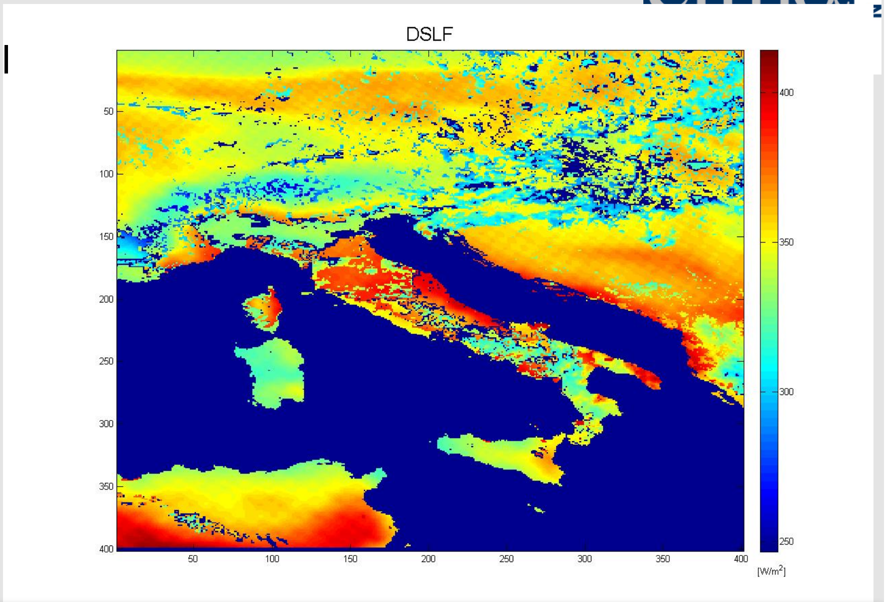


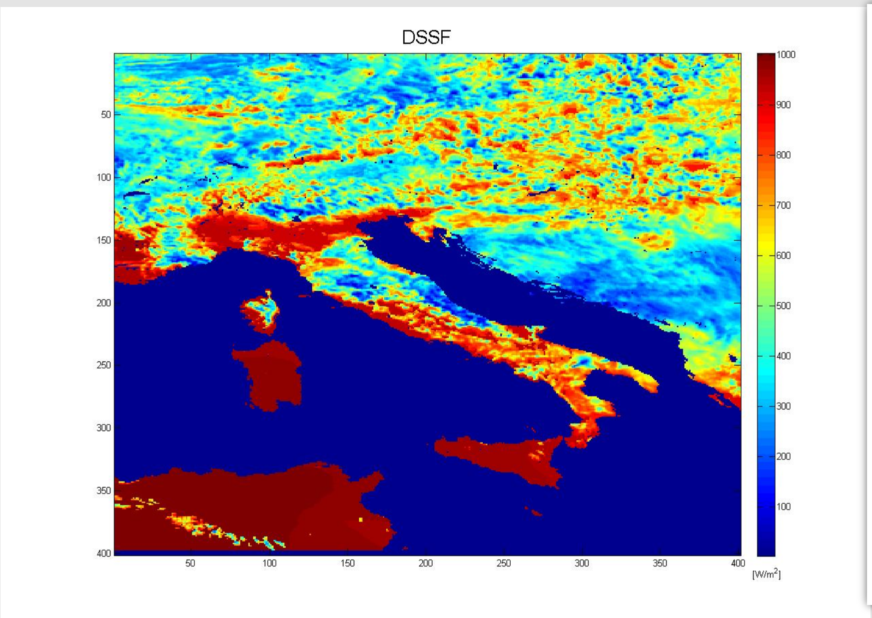
Satellite input data (optional)

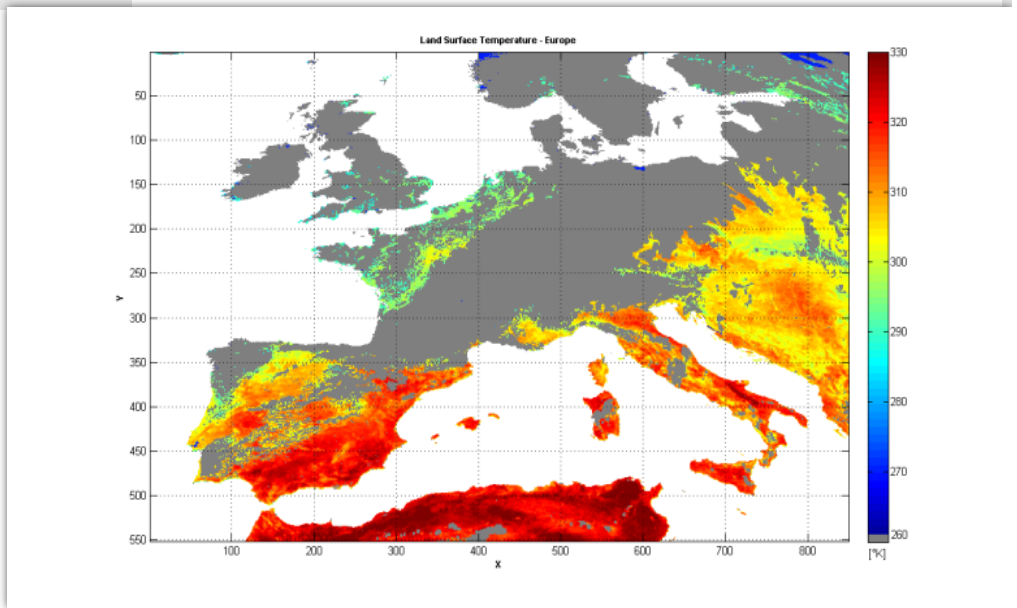
Possibility of using satellite data as input of the model and in data assimilation processes.



Examples of satellite data used to supply lacking of ground measurements are:

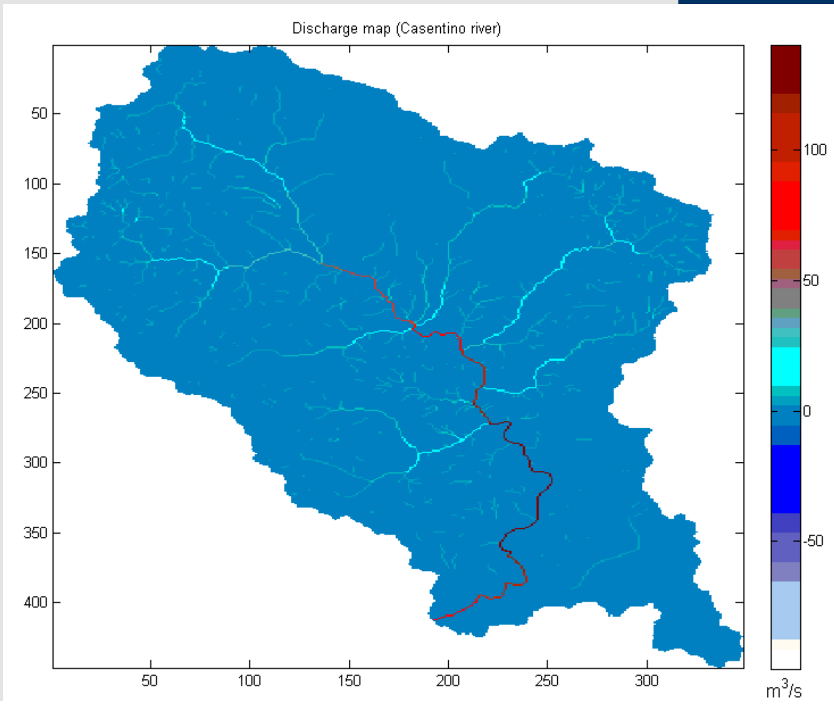
DSSF (Down-welling Surface Short-wave Flux)
DSLF (Down-welling Surface Long-wave Flux)
ALBEDO



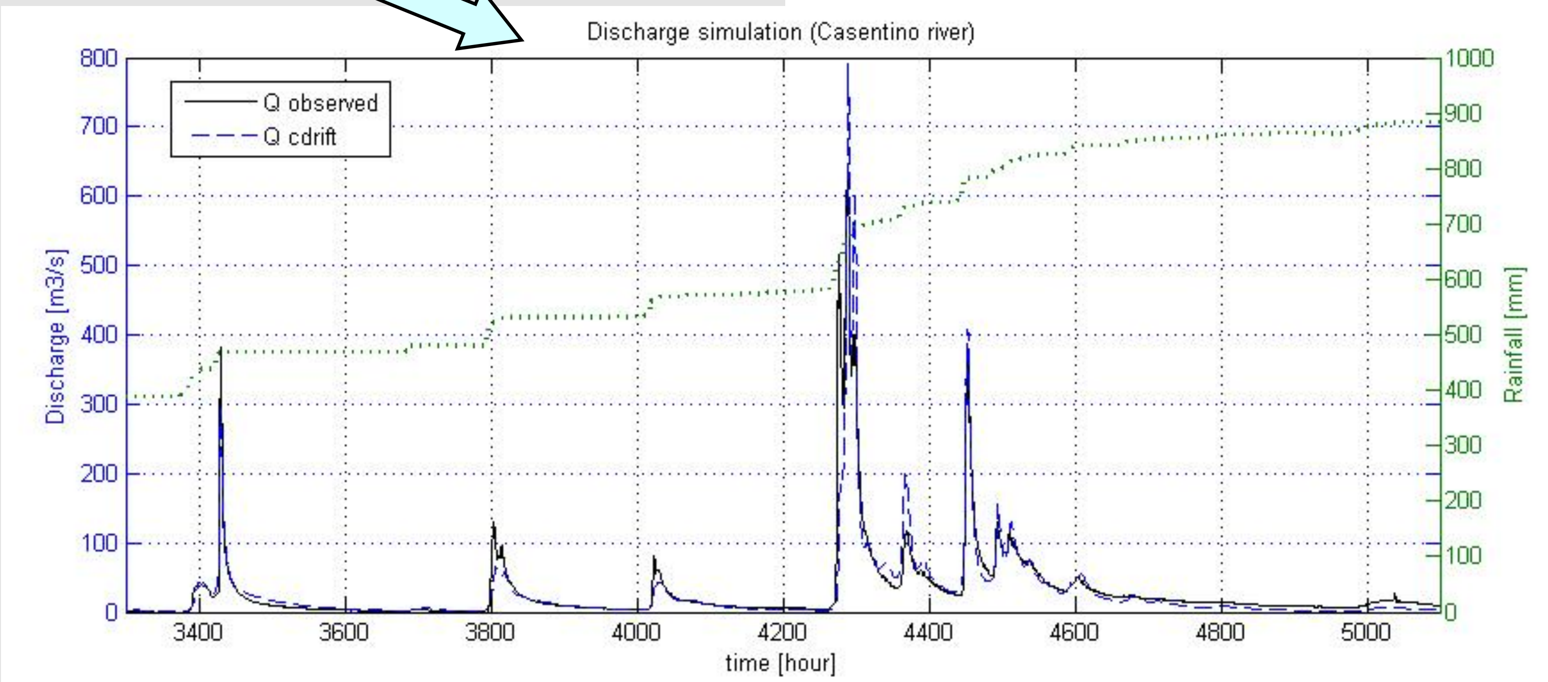


Output : Discharge

Discharge in every basin location:
Discharge map at a certain time
Instant (time resolution 10,…60, min)



Hydrograph on a set of
predefined control sections

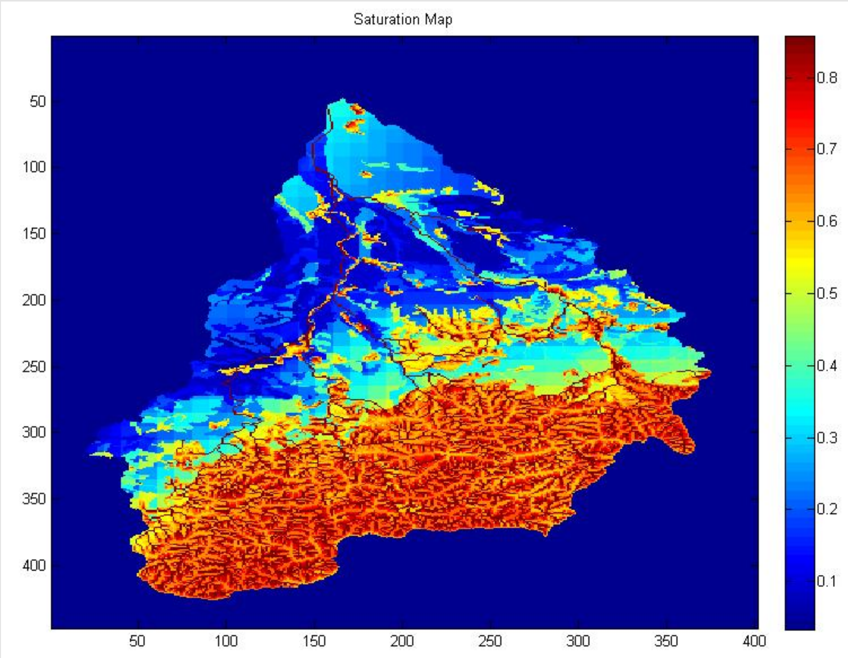


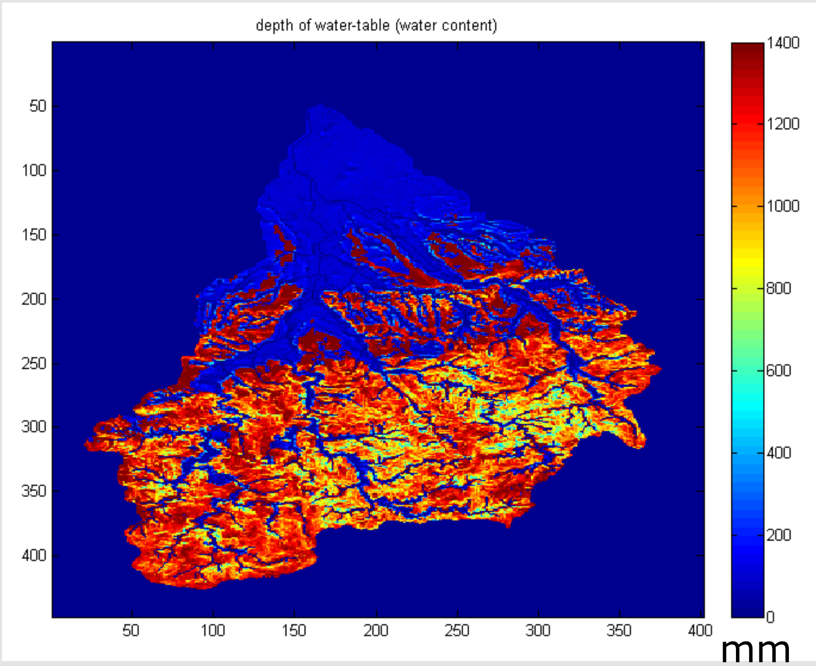
Other Outputs

- Evapotranspiration estimation
- **LST estimation**

All the state variables:
- Soil humidity
- Watertable distance from root-zone
- Ground surface water level
- Vegetation retention

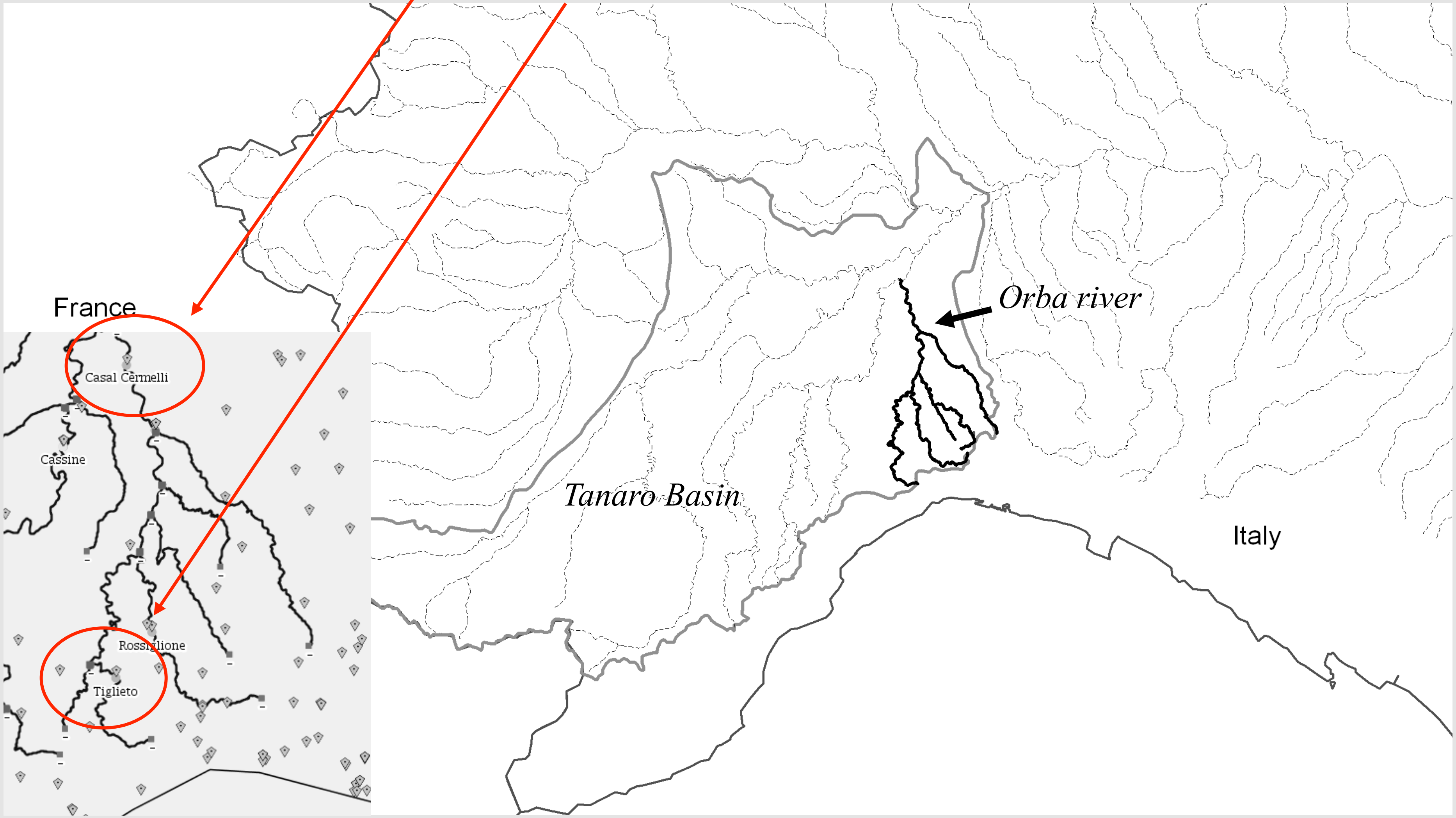
Time variant maps on predefined time steps (ex. 1 hour, 1 day...)



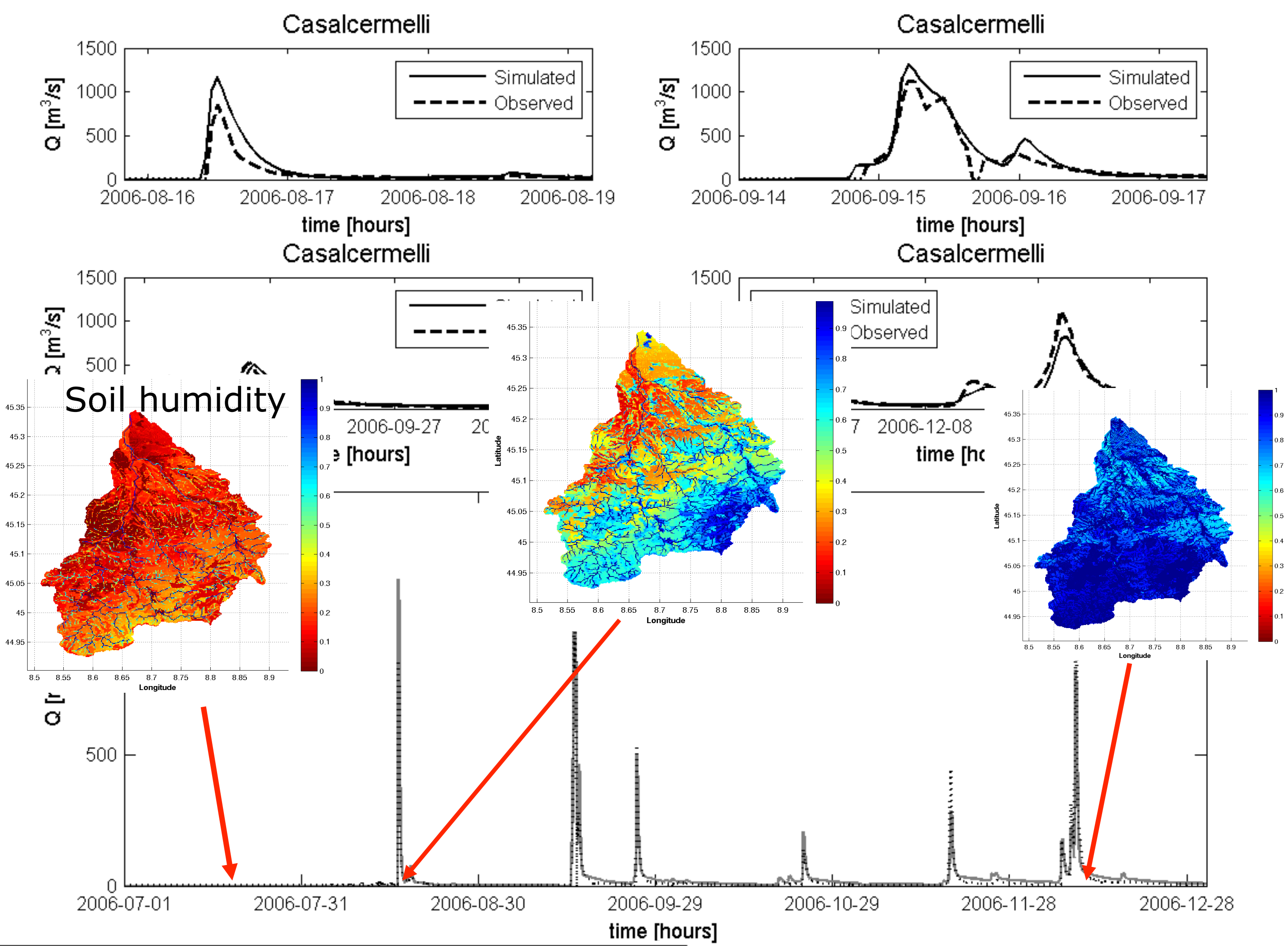


Research application: Orba basin

Two gauged stream level sections have been considered:
Casalcermelli, Area=800 km^2
Tiglieto, Area=75 km^2



Comparison between simulated and observed (Section: Casalcermelli Area=800 km^2)



Outlet section	RMSE [$m^3 s^{-1}$]	Nash and Sutcliffe [−]	Chiew and McMahon [−]	CORR [−]
Casalcermelli	1.84	0.89	0.85	0.95
Tiglieto	1.62	0.70	0.76	0.90

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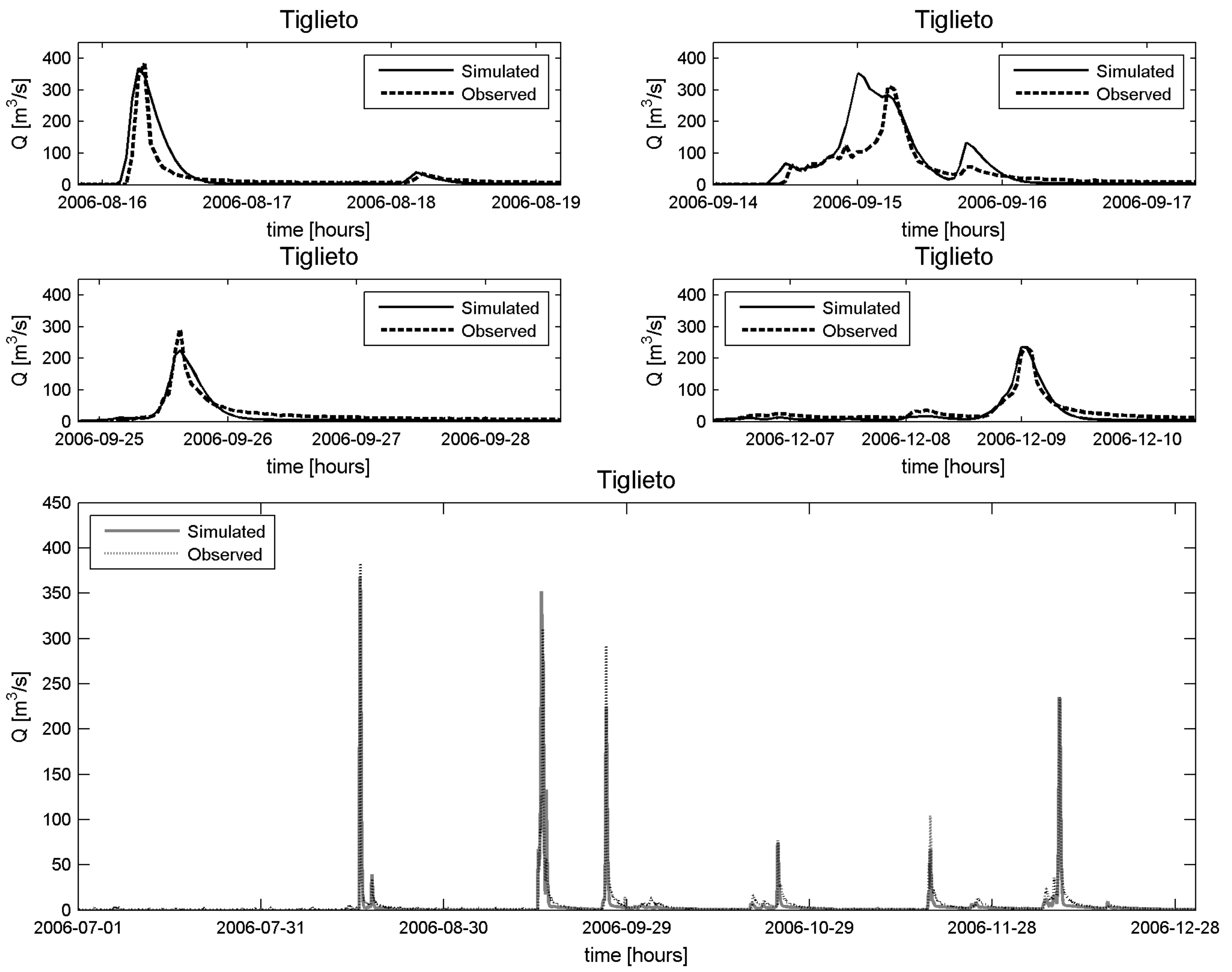
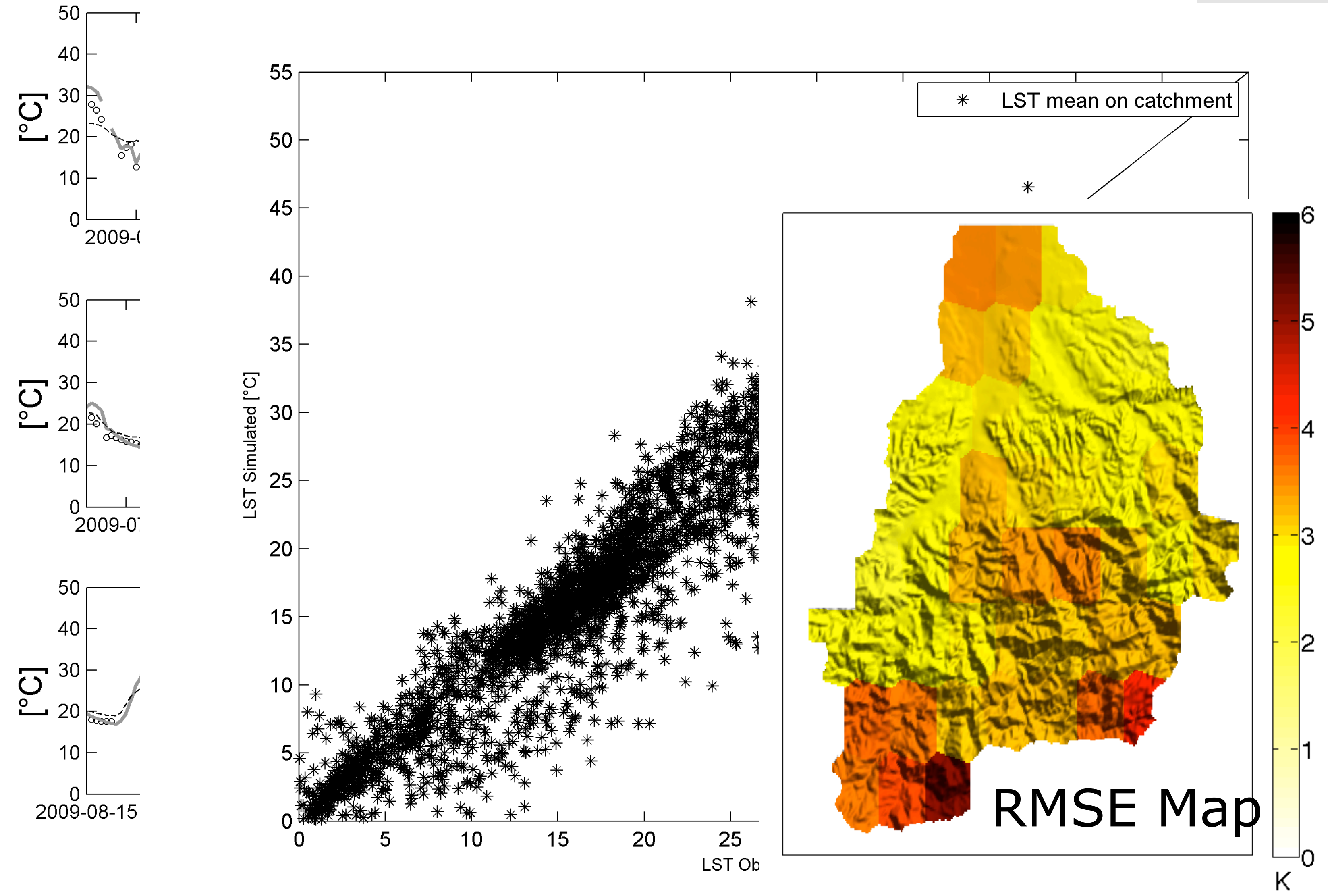
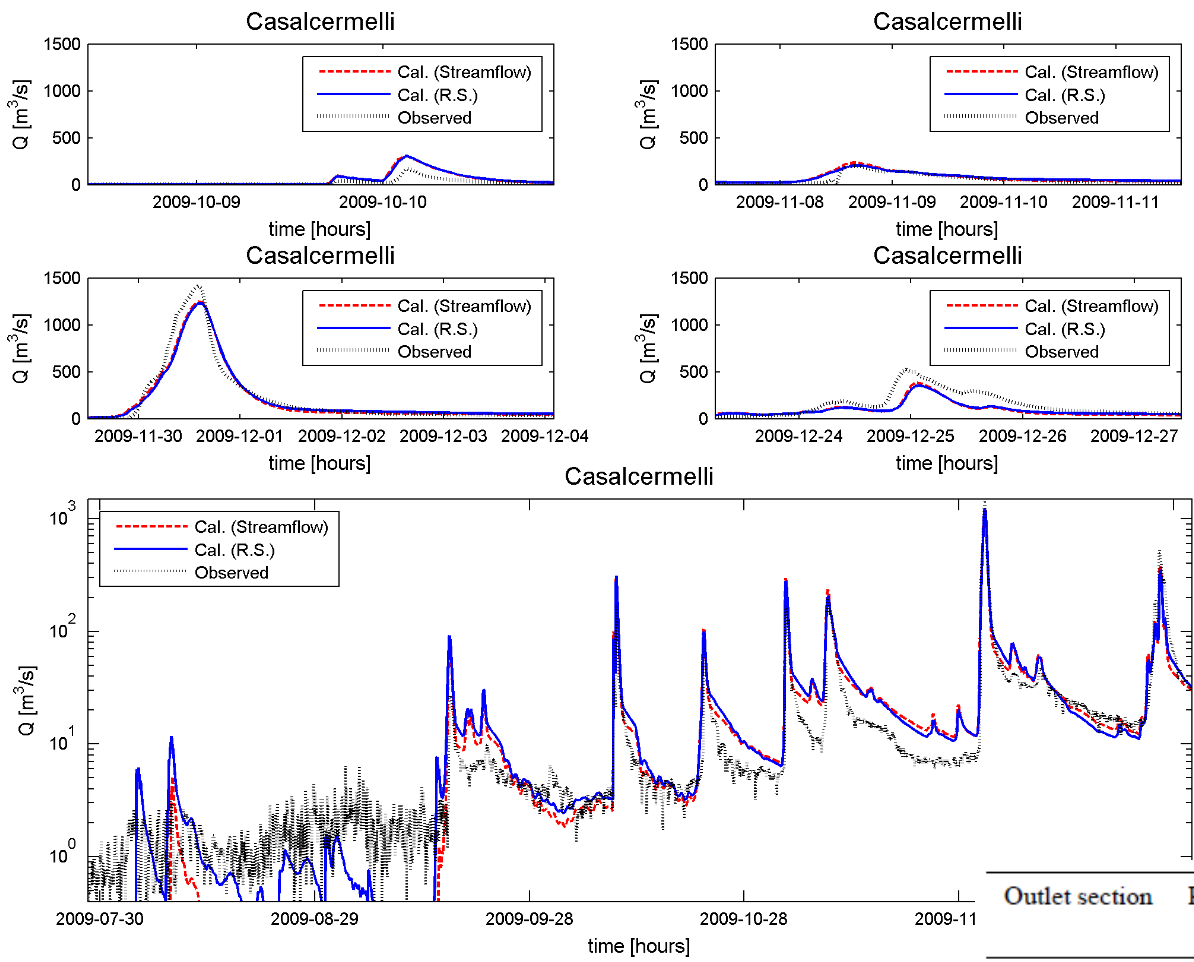
Comparison between simulated and observed discharge (Section: Tiglieto, Area=75 km²)



Comparison between simulated and observed (LandSAT, res. About 4.5 km) Land Surface Temperature (time-LST plot) . Mean value on catchment.



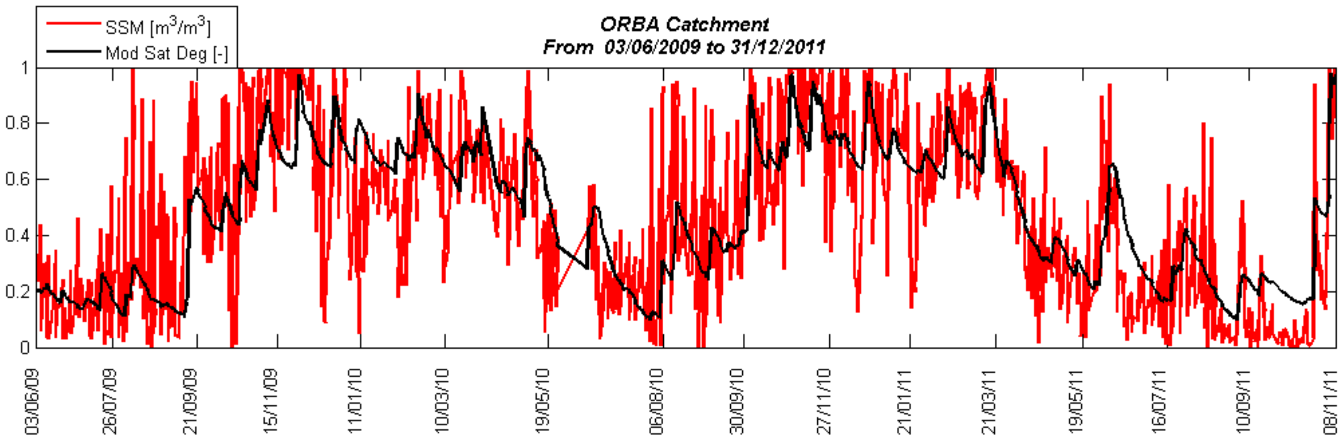
LST is an explicit state variable. It can be used in **data assimilation** framework or as a constraint in the **calibration proce**



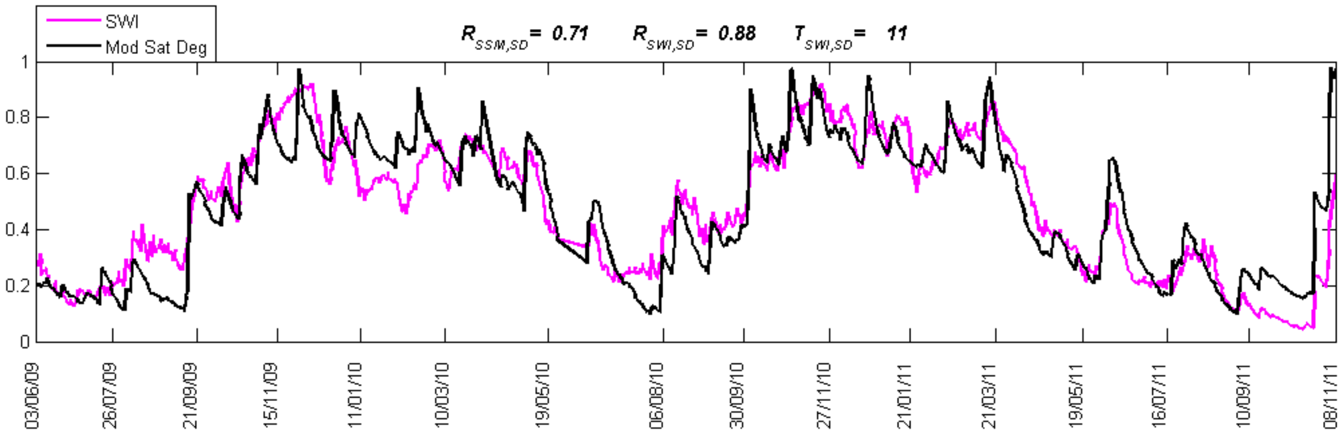
Calibration of most sensitive parameters based on basin <u>characteristics derived by DEM and by comparison of modelled and satellite LST (Land SAT, res.)</u>. Streamflow data are **not** used

Outlet section	Period	RMSE $[m^3\,s^{-1}]$	Nash and Sutcliffe [−]	Chiew and McMahon [−]	CORR [−]
Casalcermelli	2006	1.9	0.86	0.84	0.94
	2009	1.28	0.90	0.89	0.95
Tiglieto	2006	1.58	0.69	0.78	0.89
	2009	0.89	0.81	0.85	0.92

Comparison with Soil Humidity retrieved by satellite. HSAF products (H-07 res. About 25 km)



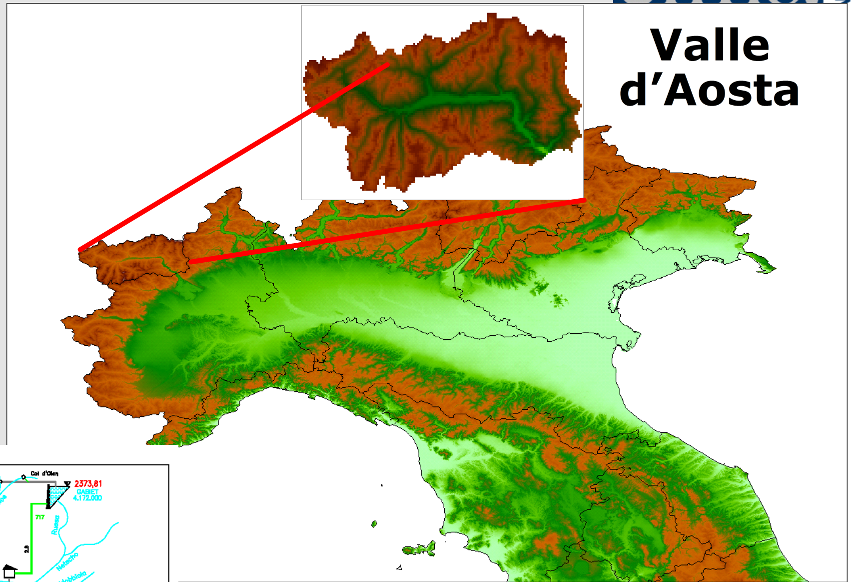
Soil saturation degree of the model at basin scale compared with raw satellite data (Surface Soil Moisture)

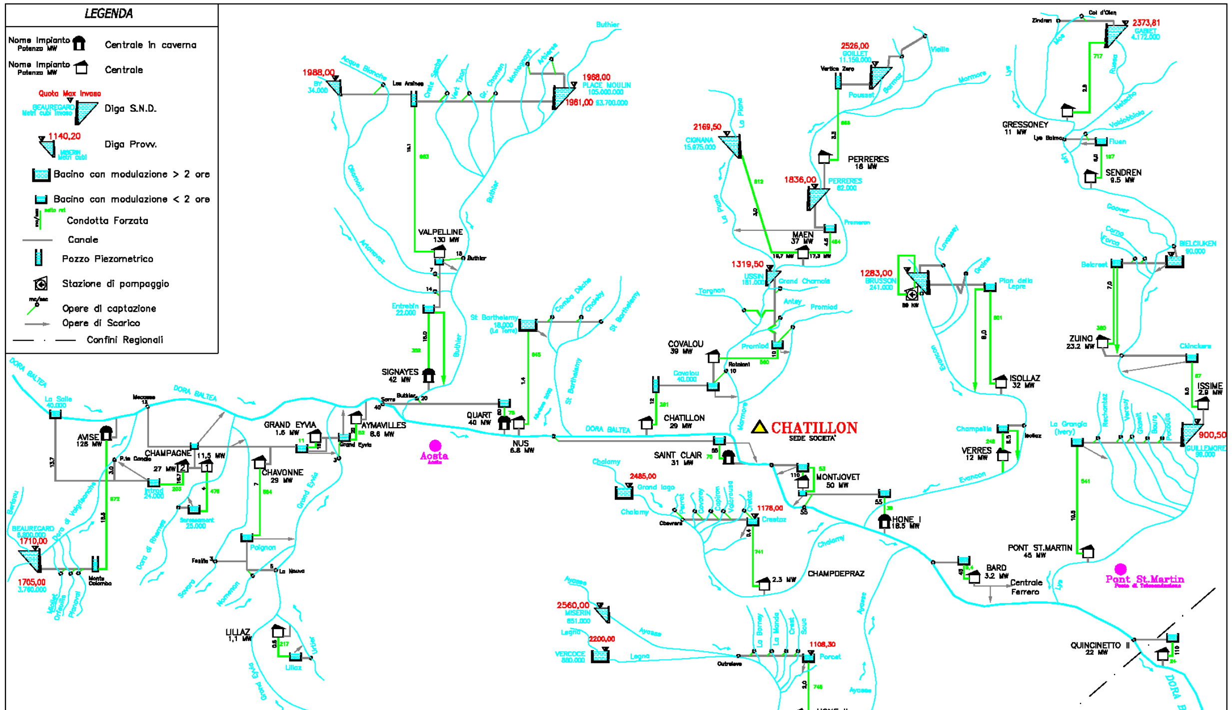


Soil saturation degree of the model at basin scale compared with Soil Water Index derived by satellite data with standard methodologies (*Brocca et al., 2011*)

Application: Vda region (Dora Basin)
Operational running in real-time

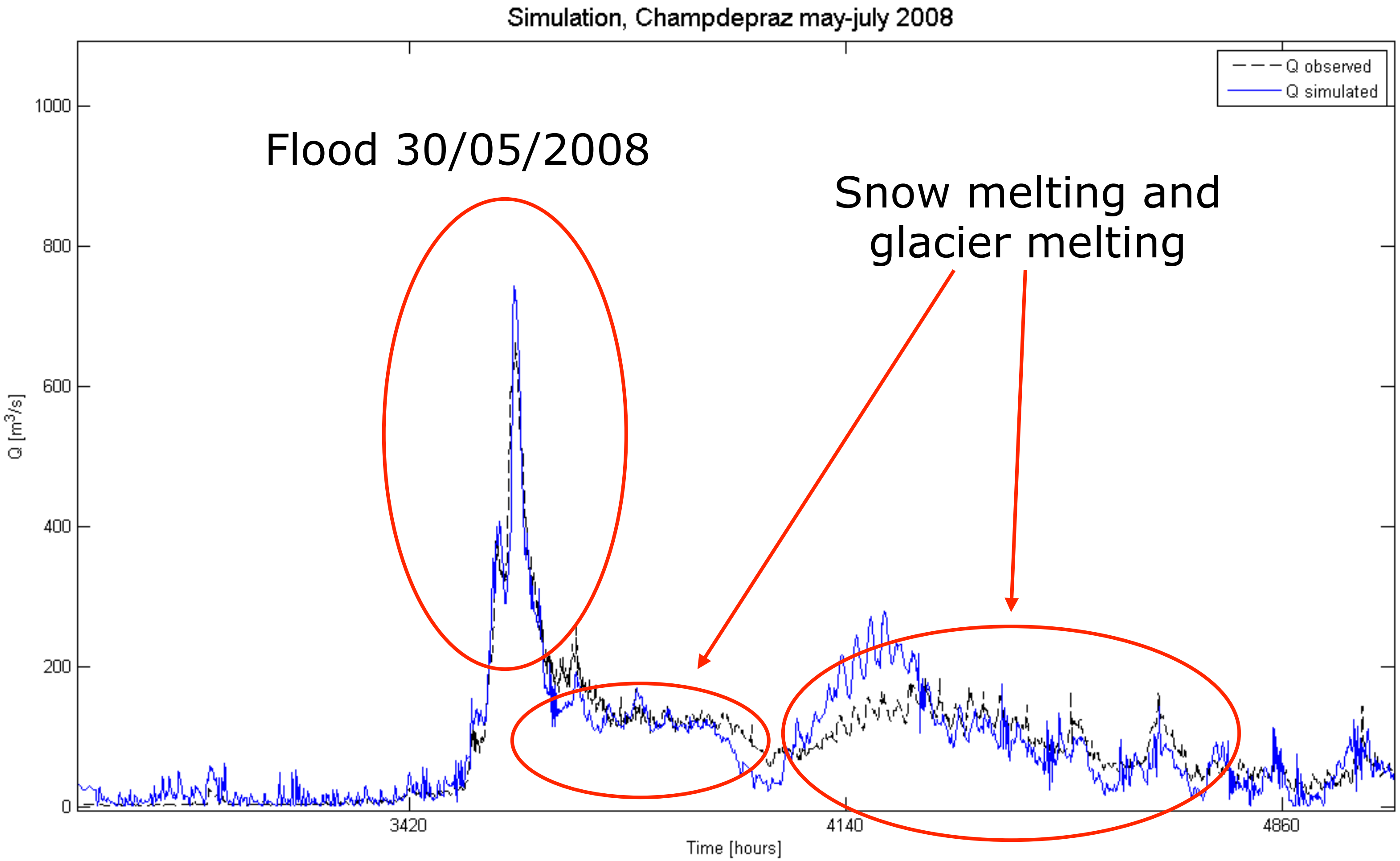
Taking into account:
- Presence of dams
- Hydraulic structures management
- Snow fall and snow melting processes
- Glacier





Courtesy of CVA

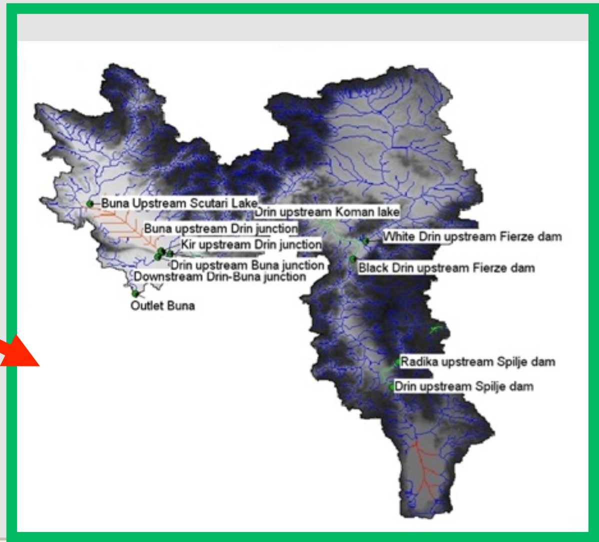
Discharge simulation on the Champdepraz outlet section.
Period from may to july 2008



Application: Buna + Drin basins (Albania)

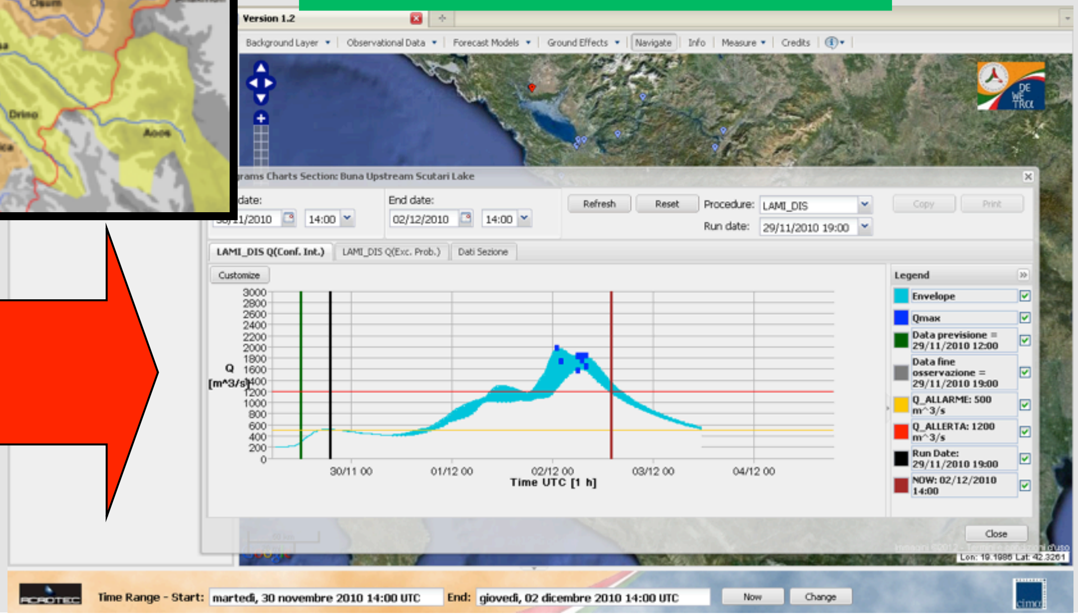
Operational running in real-time

Total area about 18000 km²



Objective: individuating the portion of drainage network that normally is not interested by river flow propagation but behave like a lake. Effects on the Floods

Probabilistic Forecast Framework

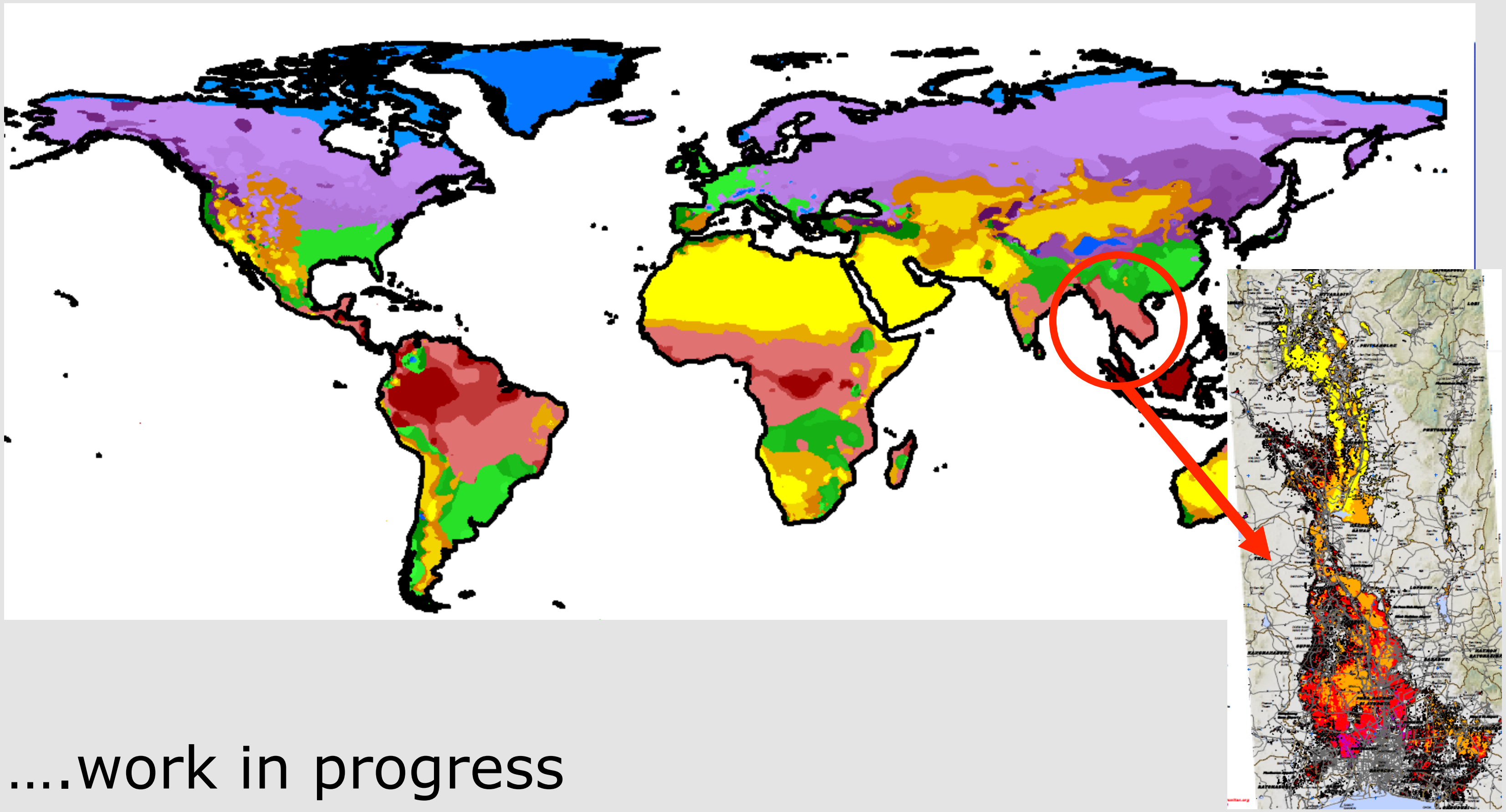


The model **cannot** simulate the real extension of the water bodies, but only the water volume.

UNISDR Project, Global Assessment Report

Application of Continuum at **Global Scale** with a coarse resolution (about 10000 m)

Simulation of past with reanalysis + Simulation of future scenarios based on Climatic Models



....work in progress

Thank You

<u>Main reference:</u>

Silvestro, F., Gabellani, S., Delogu, F., Rudari, R., Boni, G., (2013), Exploiting remote sensing land surface temperature in distributed hydrological modelling: the example of the Continuum model. Hydrol. Earth Syst. Sci., 17, 39-62, doi: 10.5194/hess-17-39-2013.

Hydrol. Earth Syst. Sci., 17, 39–62, 2013
www.hydrol-earth-syst-sci.net/17/39/2013/
doi:10.5194/hess-17-39-2013

Hydrology and Earth System Sciences

Exploiting remote sensing land surface temperature in distributed hydrological modelling: the example of the Continuum model

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Subsurface and Deep Flow: Modified Horton Equations

Soil filter

$$g(t) = f_0 + (f_1 - f_o)\cdot \frac{V(t)}{V_{\max}} \Rightarrow f_1 = c_f f_0 \qquad V_{fc} = c_t V_{\max}$$

Functions of soil type and use (CN)

Basin scale parameters

Percolation

$$r_p(t) = -f_1 \frac{V(t) - c_t V_{\max}}{V_{\max}(1-c_t)} \Rightarrow b = \sin\beta \Rightarrow \begin{cases} r_{Hy} = b \cdot r_p(t) \\ DeepFlow = (1-b)\cdot r_p(t) \end{cases}$$

If $r_1(t) > g(t)$:

$$\begin{cases} V(t) \le c_t V_{\max} \\ \dfrac{dV}{dt} = f_0 + (f_1 - f_o)\cdot \dfrac{V(t)}{V_{\max}} \end{cases}$$

$$\begin{cases} V(t) > c_t V_{\max} \\ \dfrac{dV}{dt} = f_0 + (f_1 - f_o)\cdot \dfrac{V(t)}{V_{\max}} - f_1 \dfrac{V(t) - c_t V_{\max}}{V_{\max}(1-c_t)} \end{cases}$$

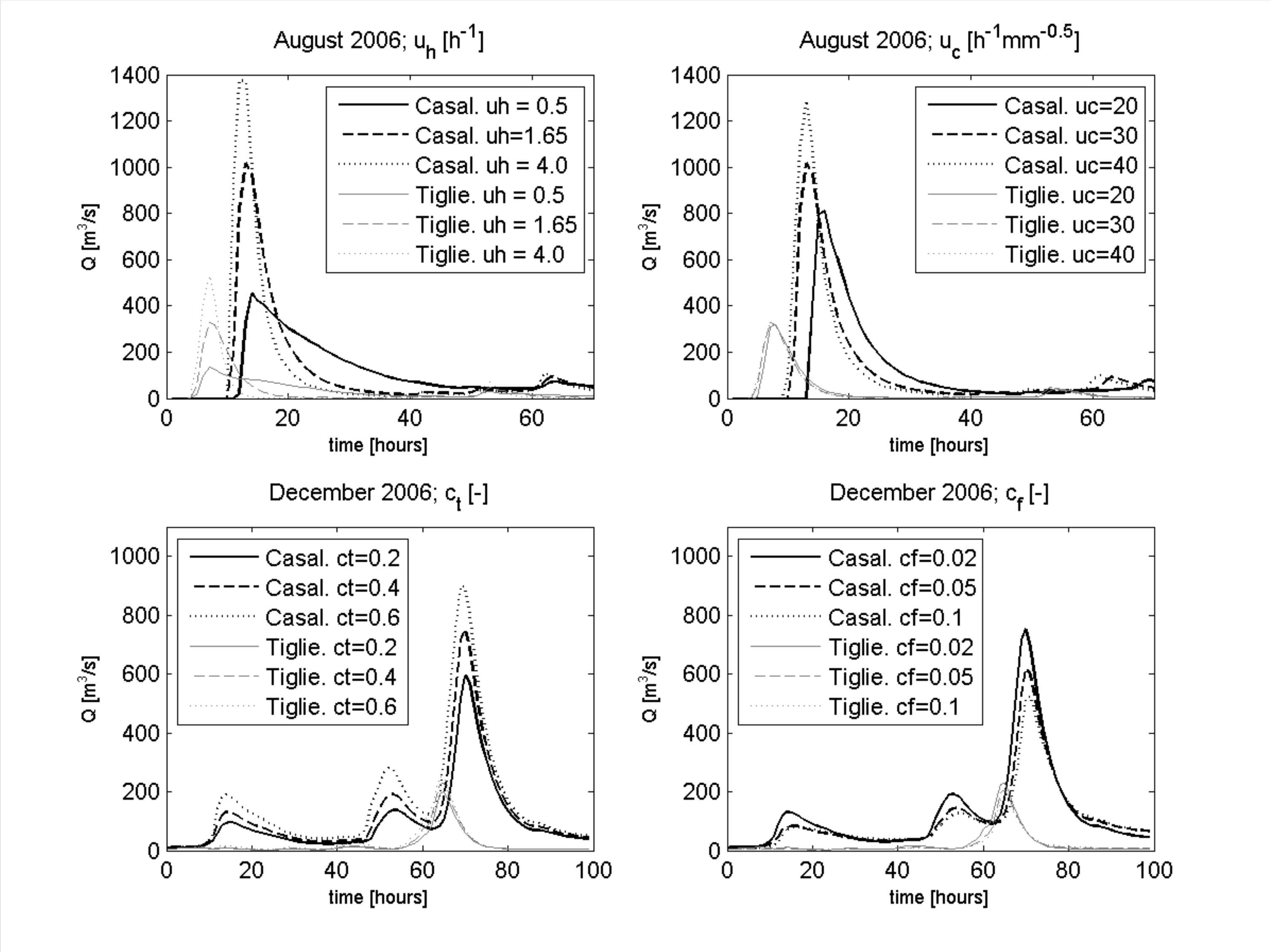
If $r_1(t) \le g(t)$:

$$\begin{cases} V(t) \le c_t V_{\max} \\ \dfrac{dV}{dt} = r_1(t) \end{cases}$$

$$\begin{cases} V(t) > c_t V_{\max} \\ \dfrac{dV}{dt} = r_1(t) - f_1 \dfrac{V(t) - c_t V_{\max}}{V_{\max}(1-c_t)} \end{cases}$$

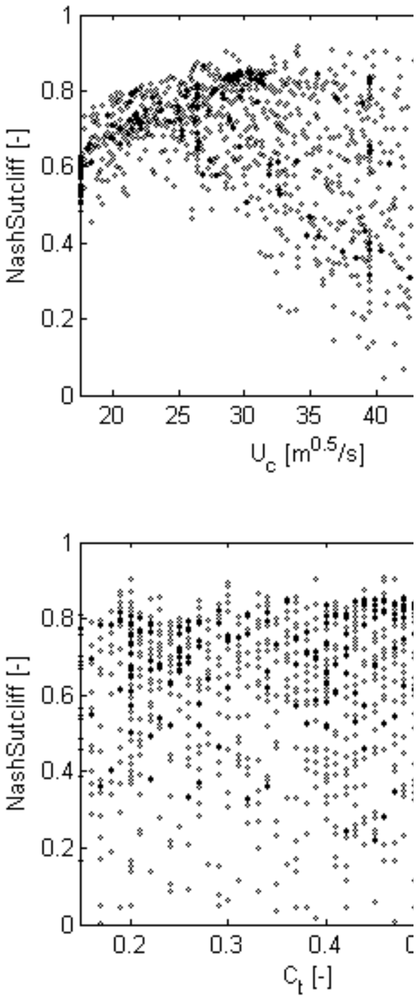
Application: Orba basin

Overland Flow and Sub-Surface Flow parameters sensitivity

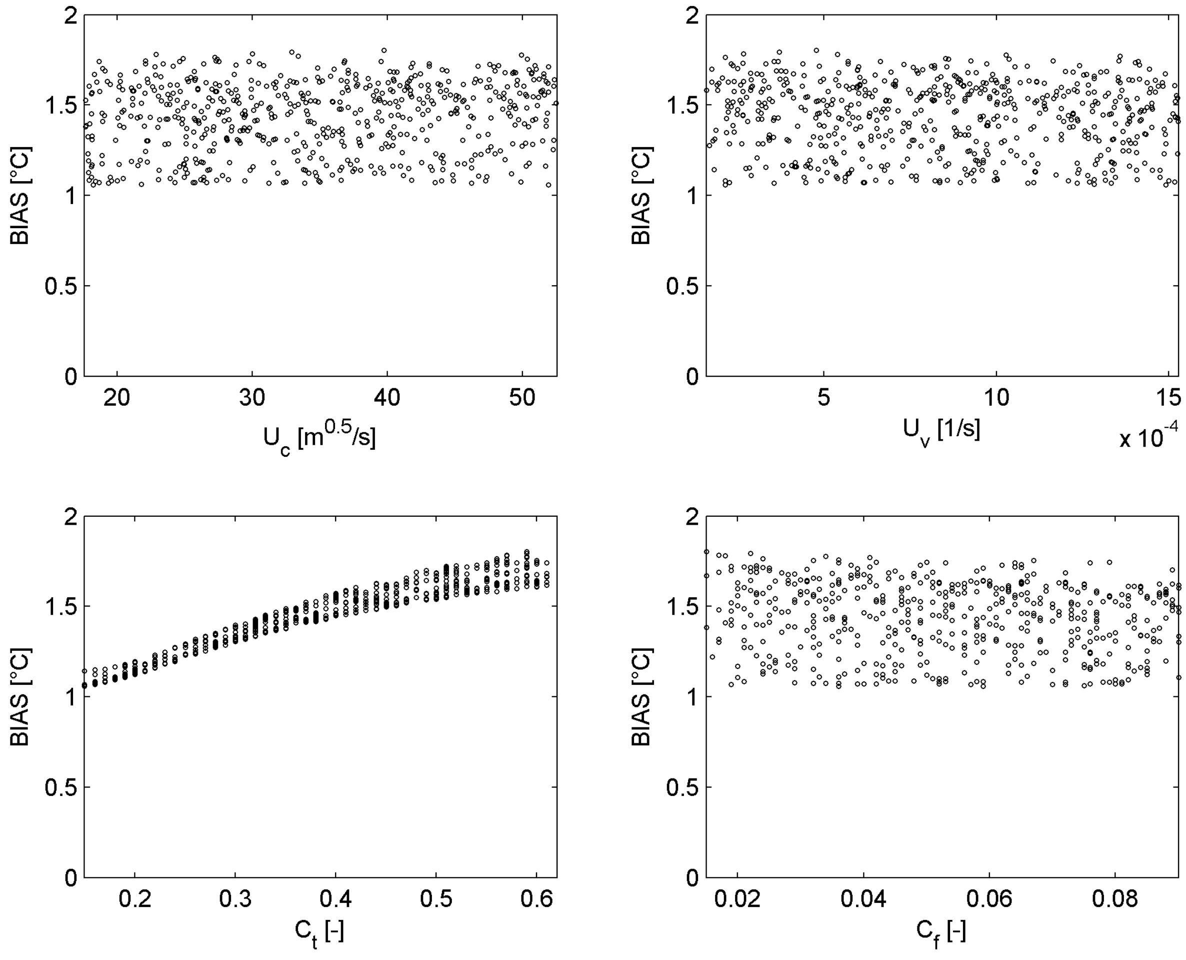


Uncertainty Analyses of most sensitive Calibration Parameters

Streamflow



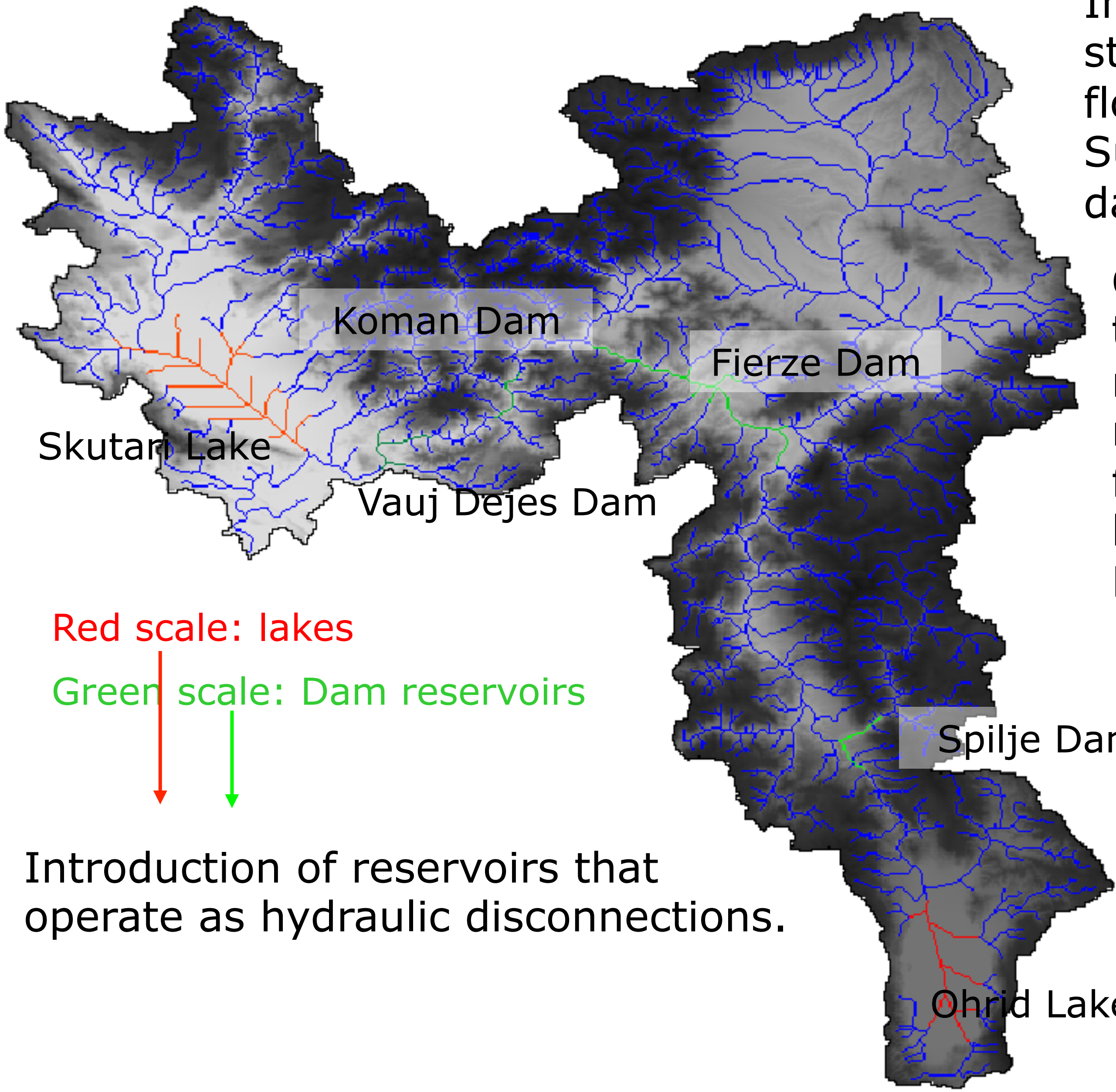
LST



In the green and red stretches the overland flow is suppressed. Surface routing feeds the dam reservoir or the lake.

Objective: individuating the portion of drainage network that normally is not interested by river flow propagation but behave like a lake. Effects on the Floods

The model **cannot** simulate the real extension of the water bodies, but only the water volume.

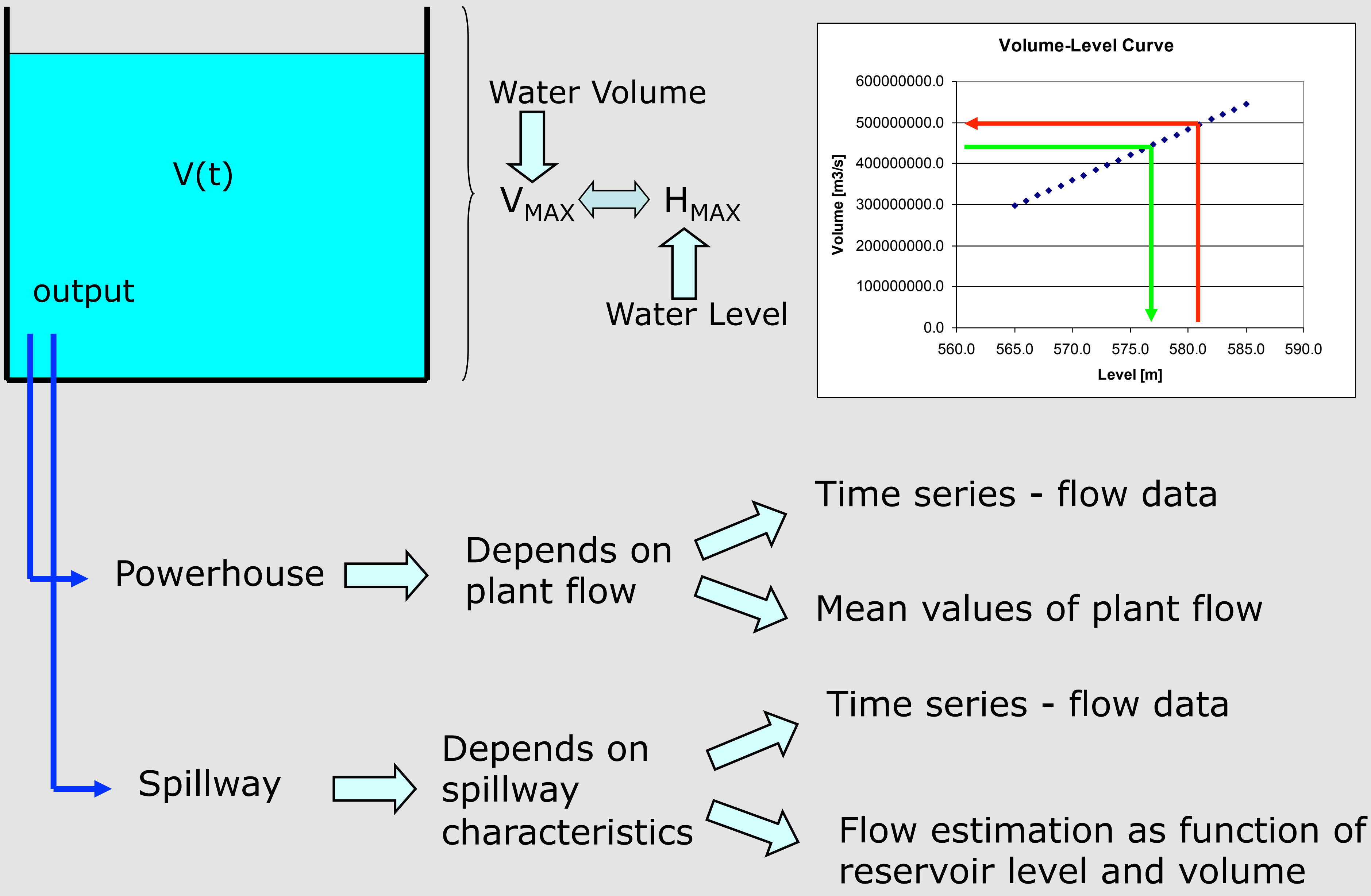


Red scale: lakes

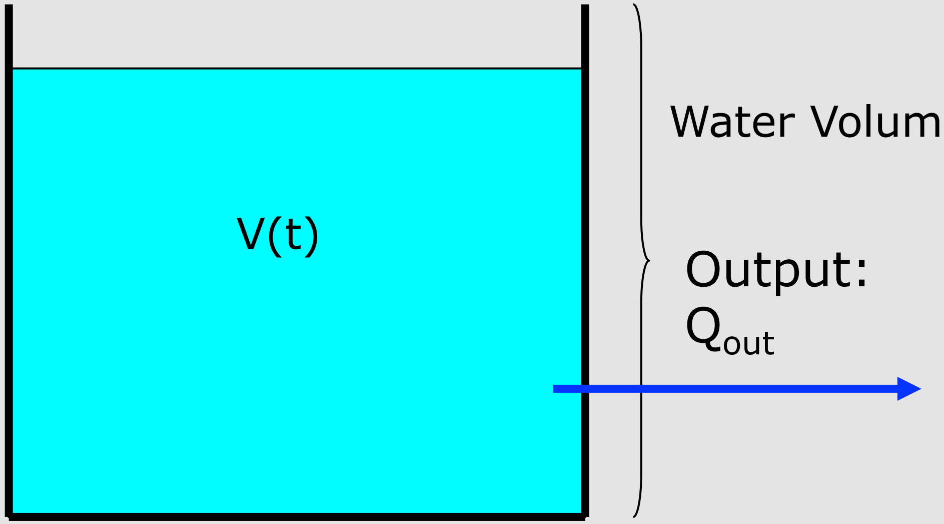
Green scale: Dam reservoirs

Introduction of reservoirs that operate as hydraulic disconnections.

DAM reservoir



Lake reservoir



$$Q_{out}=f(V(t))$$

Flow estimation as a function of water volume in the lake