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Evaluating topographic and hydrologic attribute sensitivity to upscaled resolution DTMs from LIDAR data

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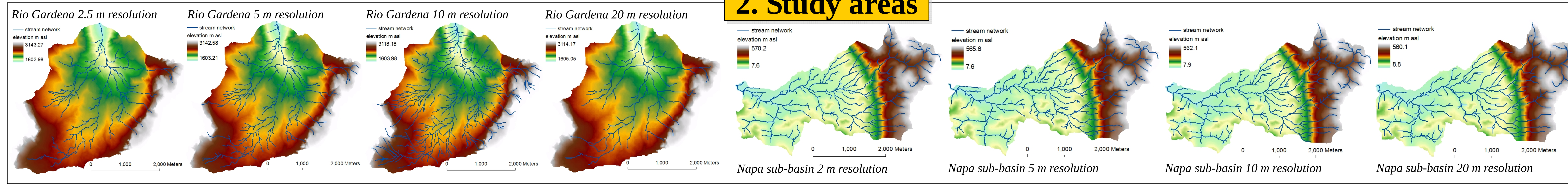
1. Introduction

Raster-based Digital Elevation Models (DTMs) have been extensively used for determining topographic attributes playing a key role in hydrological models. Several studies reported that the hillslope hydrologic response is strongly affected by the local topography. Despite the increasing availability of fine resolution topographic data captured by LIght Detection And Ranging (LIDAR) technique, some drawbacks arise, both from the computational point of view and because their high spatial detail does not match with the one of other spatialized attributes (e.g. land use, vegetation cover, climate etc.). A compromise is then needed to satisfy the computational effort and at the same time make the spatial input homogeneous, by either downscaling the coarsest ones or by upscaling the finest ones. Usually, during resampling of original DTM, topographic details could be lost because of smoothing effects. For this reason it is necessary to investigate *whether* and *how* a coarser resolution DTM can preserve hydrologic information, crucial for modeling performances and reliability, as uncertainties in the inputs propagated into the output prediction, producing biases.

In this work two case studies are presented starting from LIDAR DTMs, the former in Italy (Rio Gardena river basin, at 2.5 m of resolution) and the latter in California (subwatersed of Napa river, at 2 m of resolution). A series of DTMs having 5, 10 up to 20 m grid size are derived from the finest resolution DTMs, applying the aggregation method consisting in averaging the values of the input cells that the coarser output cell encompasses. Each DTM was corrected from hydrologically spurious features (pits and flat areas) by PEM4PIT model (Grimaldi et al., 2007), then stream networks were automatically extracted by *curvature/drop analysis* approach (Tarboton & Ames, 2001; Nardi et al., 2008) (2). Several topographic and hydrologic characteristics are derived for the different grid cell sizes, e.g. the cumulative elevation distribution (hypsometry), the stream network metrics and geometry (Horton parameters and sinuosity index), the TOPMODEL topographic index, the potential soil saturation spatial patterns, the flow path length etc. Above attributes are all useful for different hydrologic modelling approaches (from lumped to distributed) to evaluate the catchment runoff response to rainfall. Analyses of the impact in changing DTM cell spacing are reported here focusing on differences among methods solely based on topography (3), on stream network (4), on basin averaged and distributed topographic attributes (5) or on distinguish between stream network and hillslope behaviour (6).

2. Study areas

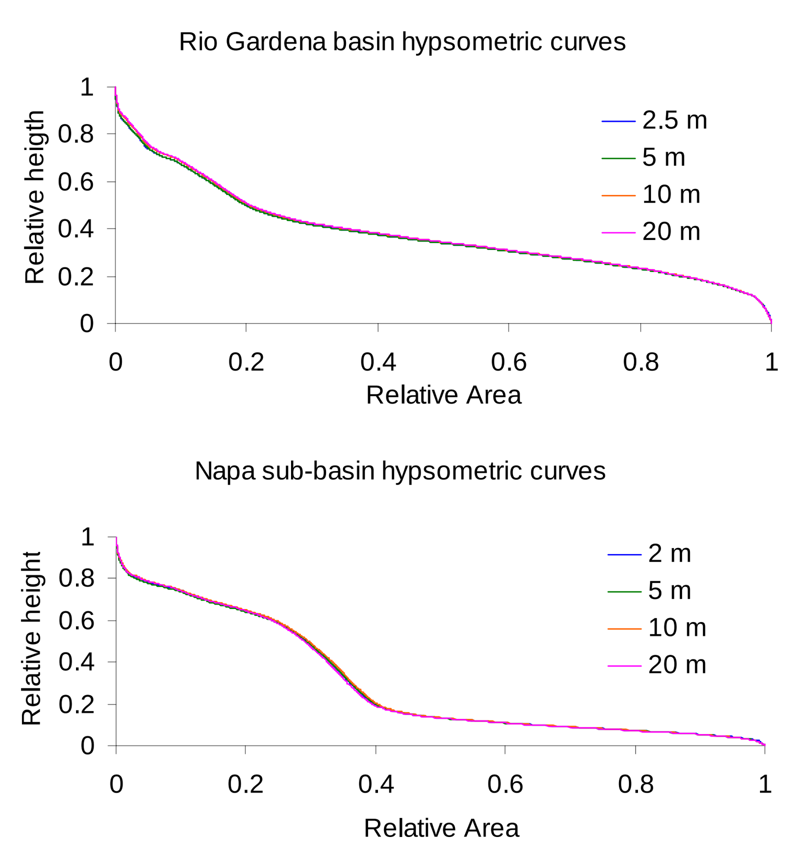


3. Hypsometry

To estimate the effect of geomorphic information on basin hydrologic response, a simple approach (Luo and Harlin, 2003) is here considered to determine the theoretical travel time of a water drop moving down an impermeable and frictionless surface represented by the hypsometric curve. This travel time is calculated as:

$$t = \int_0^1 \frac{dx}{\sqrt{2\int_0^x a_x\,dx}}$$

where a_x is the horizontal component of the gravity acceleration scaled by total relief and dx is the drop traveled (interval of relative area).



Rio Gardena basin				
Resolution	2.5 m	5 m	10 m	20 m
hypsometric integral	0.375	0.375	0.381	0.382
theoretical travel time (s)	37.6	36.5	34.6	33.7

Napa sub-basin				
Resolution	2 m	5 m	10 m	20 m
hypsometric integral	0.297	0.295	0.299	0.294
theoretical travel time (s)	21.9	22.1	21.3	20.5

4. Stream network

Basin	Resolution	R_b	R_l	R_a	R_s	maxord	L_{maxord}	L_{max}	L_{tot}	D_d
Napa	2 m	3.83	2.19	4.24	1.85	5	3813.9	8420.8	69699.9	6.67
	5 m	3.56	2.07	3.95	1.56	5	3684.2	8032.5	60080.7	5.78
	10 m	3.72	2.13	4.14	1.85	5	3571.2	7876.9	65311.4	6.25
	20 m	3.51	2.02	3.92	1.71	5	3721.1	7841.5	59999.1	5.73
Rio Gardena	2.5 m	4.23	1.85	4.66	1.18	4	1732.3	6688.8	45379.0	3.30
	5 m	3.29	1.64	3.40	1.19	5	1715.1	6505.0	61035.3	4.44
	10 m	4.01	1.75	4.43	1.22	5	1665.2	6793.0	100064.9	7.28
	20 m	3.82	1.67	4.13	1.28	4	1672.3	6222.2	39140.9	2.84

R_b = *Bifurcation ratio*
R_l = *Length ratio*
R_a = *Area ratio*
R_s = *Slope ratio*
maxord = maximum Strahler's order
L_{maxord} = *length of the maximum order channel link*
L_{tot} = *total length of stream network*
D_d = *drainage density*

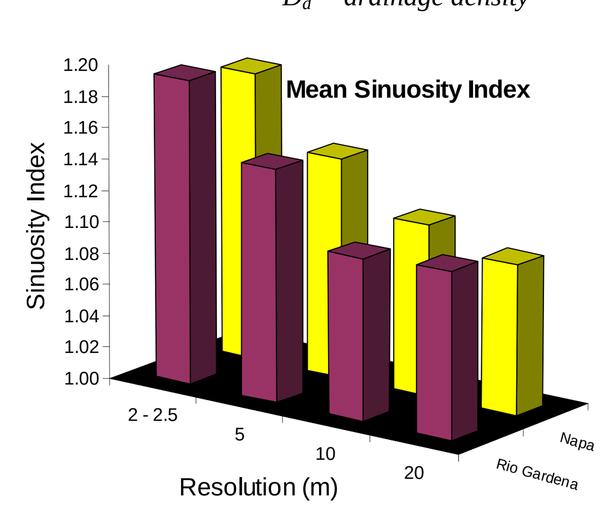
Basin	Resolution	t_p (hrs)	Q_p (hr^{-1})	IR=t_p*Q_p	IR_simplified
Napa	2 m	0.589	0.96	0.567	0.548
	5 m	0.581	0.97	0.565	0.548
	10 m	0.556	1.02	0.564	0.547
	20 m	0.590	0.95	0.562	0.546
Rio Gardena	2.5 m	0.286	1.97	0.564	0.550
	5 m	0.307	1.89	0.580	0.570
	10 m	0.280	2.00	0.561	0.549
	20 m	0.290	1.95	0.567	0.556

GIUH analysis: Time to peak (t_p), *peak flow rate* (Q_p), *v* is the channel flow velocity assumed here as 2 m/s. IR *is a dimensionless ratio based only on basin morphology*, IR_simplified *is evaluated as* $0.58(R_b/R_a)^{0.55}$. (Rodriguez Iturbe and Valdés, 1979)

$$t_p = \frac{0.44 \cdot L_{max\,ord} R_b^{0.55} R_a^{-0.55} R_l^{-0.38}}{v}$$

$$Q_p = \frac{1.31 \cdot 10^{-3}}{L_{maxord}} \cdot R_L^{0.43}$$

Sinuosity Index (Arya, 2001) is defined as: SI = TL/FL where TL (m) the length of the stream link and FL (m) the length of the straight line connecting start and end node of the link.

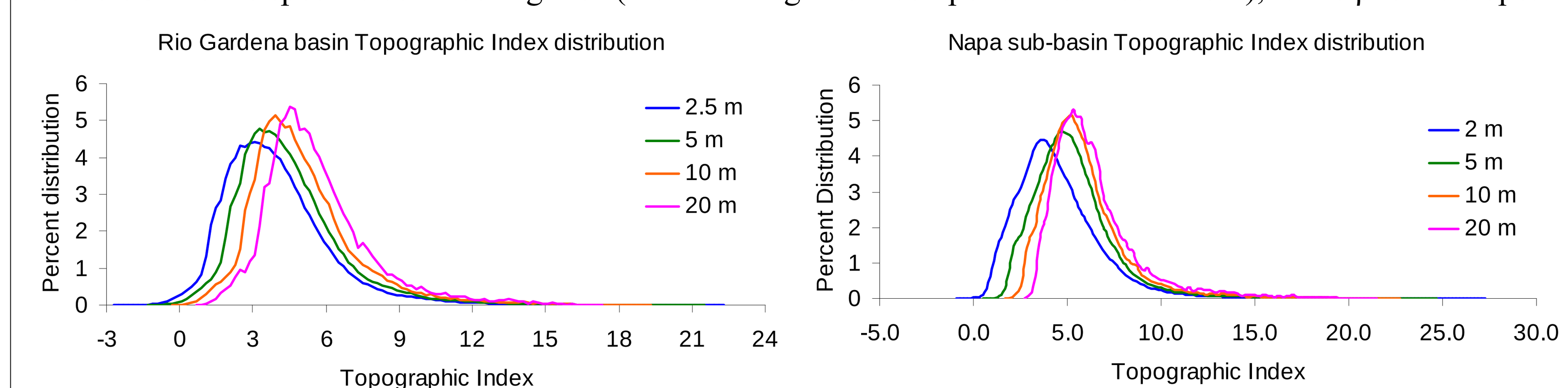


5. Basin scale

5.1 Topographic Index

For each DTM and resolution the Topographic Index (*TI*) was calculated as: $TI = \ln\left(\frac{SCA}{\tan\beta}\right)$

where SCA is the specific contributing area (area draining into a cell per unit contour width), while β is the slope.



N.B. In the histograms TI values are resampled at 0.2 interval

5.2 Spatial Pattern of Saturated areas

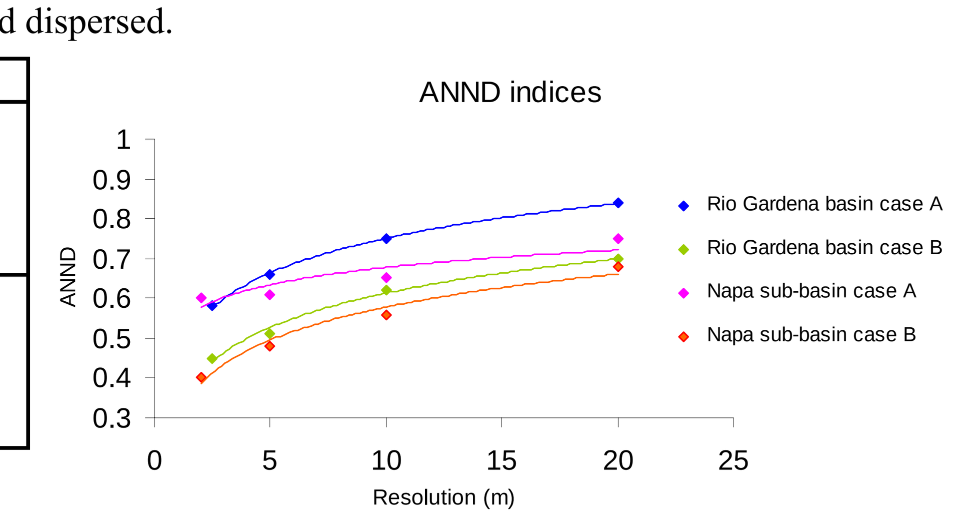
Saturated areas are assumed where the Wetness Index $WI = \left(\frac{R \cdot SCA}{T \cdot \tan\beta}\right) \geq 1$ and then $TI \geq \ln\left(\frac{T}{R}\right)$

where *T* is the lateral soil transmissivity (m^2/hr) while *R* (m/hr) is the steady state spatially homogeneous recharge rate. Two cases are considered to extract saturated areas: A) where $TI \geq \ln(2'000)$ and B) where $TI \geq \ln(10'000)$

Then the degree of spatial clustering among saturated map cells is evaluated by the Average Nearest Neighbor Distance (ANND) index for both cases. It measures and averages the distance between each cell center and its nearest neighbor cell center location. If the average distance is less than the average for a hypothetical random distribution (ANND<1), analyzed points are considered clustered. If the average distance is greater than a hypothetical random distribution (ANND>1), the features are considered dispersed.

Basin	Resolution	case A	case B
Rio Gardena basin	2.5 m	5.79	2.73
	5 m	7.81	3.64
	10 m	10.71	4.75
	20 m	14.56	6.55
Napa sub-basin	2 m	8.13	3.48
	5 m	11.27	4.82
	10 m	14.99	6.62
	20 m	20.60	9.89

Percent of saturated areas in the two cases A and B



N.B. Trendlines are logarithmic with R^2 > 0.80

5.3 TOPMODEL analysis

Assuming for both study areas constant basin parameters required in TOPMODEL (Beven and Kirkby, 1979) framework:
T = 0.0005 (is the lateral soil transmissivity, m^2/s)
m = 0.04 (is the transmissivity decrease parameter, m)
the mean and the local soil moisture deficit (D_{mean} and D, respectively, in m) of the basin are calculated as:

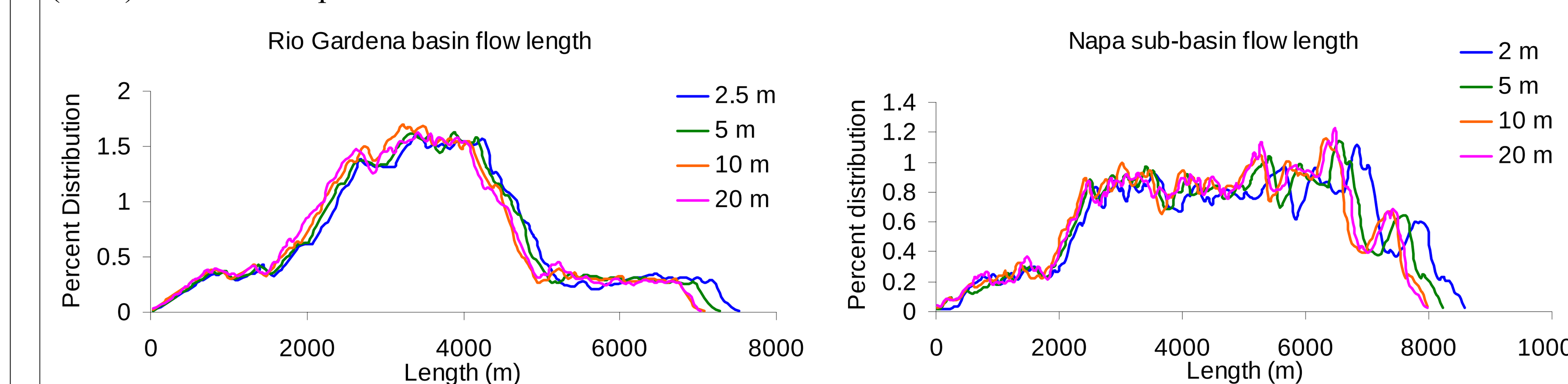
$$D_{mean} = -m\ln(R) + m\ln(T) - m(TI_{mean}) \qquad D = D_{mean} - m(TI) - m(TI_{mean})$$

Considering a rainfall of 25 mm, the changes in baseflow rate (Q_b) prior to rainfall and in runoff (RO) due to rainfall are examined for the different cell resolutions, either for case A and for case B above.

Basin	Resolution	TI_{mean}	case A D_{mean} (m)	case A R (m/s)	case A Q_b (m^3/s)	case A RO (m^3)	case B D_{mean} (m)	case B R (m/s)	case B Q_b (m^3/s)	case B RO (m^3)
Rio Gardena	2.5 m	3.95	0.15	2.50E-07	3.215	51595.31	0.21	5.00E-08	0.664	41079.84
	5 m	4.48	0.12		3.162	69113.13	0.19		0.661	54765.63
	10 m	5.03	0.10		3.070	93992.50	0.17		0.655	73495.00
	20 m	5.63	0.08		2.943	129610.00	0.14		0.644	102020.00
Napa	2 m	4.50	0.12	2.50E-07	2.401	56524.70	0.19	5.00E-08	0.505	44377.90
	5 m	5.33	0.09		2.305	79460.00	0.16		0.494	62705.00
	10 m	5.86	0.07		2.221	104320.00	0.13		0.488	82467.50
	20 m	6.43	0.05		2.080	139320.00	0.11		0.472	111260.00

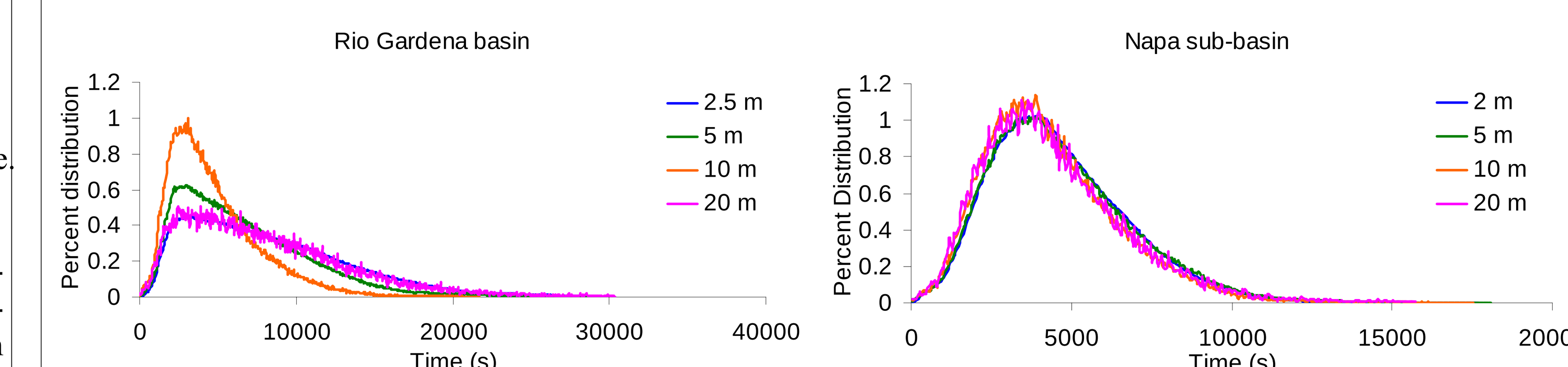
6. Hillslope *vs.* channel

The flow length (the distance each cell has to the outlet along the flow path) is computed assuming a single direction of flow for the channel network (LTD method, Orlandini et al., 2003) and the multiple flow approach of Quinn et al. (1991) for the hillslopes.



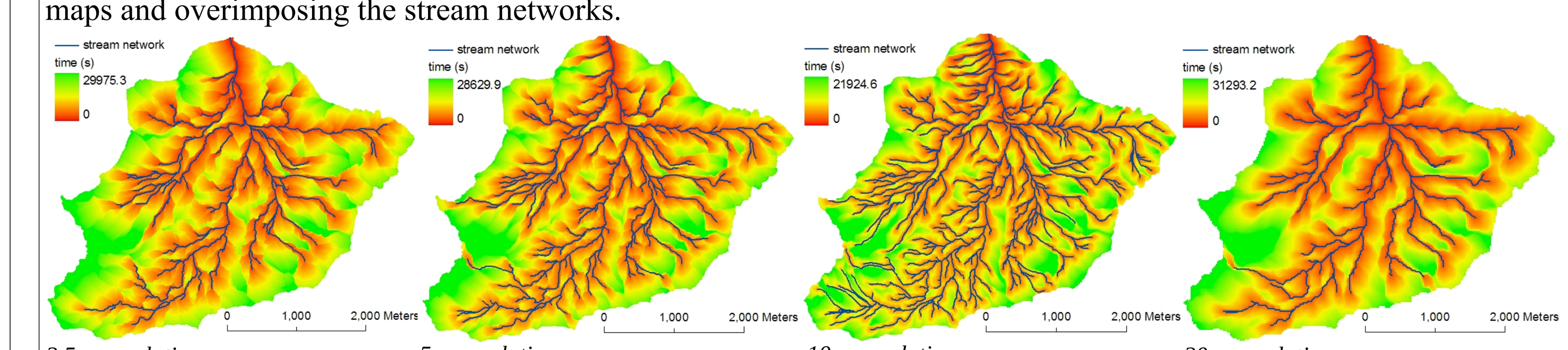
N.B. In the histograms flow length values are resampled at 50 m interval

Considering two different flow velocities on channels (2 m/s) and on hillslopes (0.05 m/s) the time of flow (flow time) from each cell to the outlet is computed.



N.B. In the histograms flow time values are resampled at 50 s interval

The singular behaviour of Rio Gardena response in the case of flow time is here analyzed comparing the flow time maps and overimposing the stream networks.



7.Conclusions

Results show that when considering "lumped" approaches the basin hydrologic responses don't reveal strong differences: i) the theoretical travel time based on hypsometry slightly decreases in increasing resolution; ii) GIUH parameters t_p and Q_p present very similar values showing no significant trend in changing DTM spacing.

When focusing on spatially variable attributed assumed as influencing runoff (e.g. Topographic Index and saturation spatial patterns), the analysis reveals a stronger dependence on DTM resolution: when this increases, the mean of TI distribution shifts toward higher values and percent of basin saturated areas increases, also showing a larger clustering index.

Runoff computation by TOPMODEL semi-distributed scheme shows, with increasing resolution, a decrease of the mean moisture deficit of the basin and consequently a runoff increase somewhat evident.

Finally, distinguishing the behaviour of hillsope and channels, the highest differences are for the steepest basin (Rio Gardena), whose response seems influenced by resolution in terms of channel network branching, affecting the distribution of flow velocities in the basin.

Arya, 2001 - *Sinuosity of Streams*, Webplished, (http://arcscripts.esri.com)
Beven K., Kirkby M., 1979 - *A physically-based variable contributing area model of basin hydrology*, Hydrological Sciences Bulletin, 24.
Grimaldi S., Nardi F., Di Benedetto F., Instanbulluoglu E., Bras R.L., 2007 - *A physically-based method for removing pits in digital elevation model*, Adv. Wat. Resour., 30(10).
Luo W., Harlin J.M., 2003 - *A theoretical travel time based on watershed hypsometry*, Journal of the American Water Resources Association, August 2003, 785-792.
Nardi F., Grimaldi S., Santini M., Petroselli A., Ubertini L., 2008 - *Hydrogeomorphic properties of simulated drainage paterns using digital elevation model: the flat area issue*, Hydrological Science Journal, 53(6).
Orlandini S., Moretti G., Franchini M., Aldighieri B., Testa B., 2003 – *Path-based methods for the determination of non dispersive drainage directions in digital elevation models*, Water Resour. Res., 39(6).
Rodriguez-Iturbe I, Valdés J.B., 1979 - *The geomorphlogic structure of hydrologic response*, Water Resour. Res., 15(6).
Quinn P., Beven K, Chevallier P., Planchon O., 1991 - *The prediction of hillslope flow paths for distributed hydrological modeling using digital terrain models*, Hydrological Processes, 5.
Tarboton D.G., Ames D.B., 2001 - *Advances in the mapping of flow networks from digital elevation data*, World Water and Environmental Resources Congress, Orlando, Florida, May 20-24, ASCE.
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