Sensitivity of the hydrological response in a Mediterranean catchment to different climate model forcing

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SCHOOL OF EARTH & SPACE EXPLORATION
ARIZONA STATE UNIVERSITY

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Surface Hydrology Research Group

Monica Piras(1), Giuseppe Mascaro(1), Roberto Deidda(1) & Enrique Vivoni(2)

(1) Dipartimento di Ingegneria del Territorio, University of Cagliari, Italy, *monicapiras@unica.it*

(2) School of Earth and Space Exploration & School of Sustainable Engineering and the Built Environment, Arizona State University, *vivoni@asu.edu*

Abstract

The Climate Induced Changes on the Hydrology of Mediterranean Basins (CLIMB) Project is a multi-institutional research project, funded by 7th EU Framework Programme, which has the main goal of reducing uncertainties in the quantification of climate change impact in Mediterranean basins. Current studies including IPCC indicate, in fact, that the water budget in these areas will be very likely affected by climate change, with severe impacts on agricultural productivity and drinking water supply. One of the CLIMB study sites is the Rio Mannu at Monastir, a 473 Km^2 catchment located in an agricultural area in southern Sardinia (Italy) with gently rolling topography.

In this study, we show preliminary results on the sensitivity of hydrological response in this basin under climatic changes conditions. For this aim, outputs of several climate models are used to force the TIN-based Real-time Integrated Basin Simulator (tRIBS), a fully distributed, physically based model able to continuously simulate hydrological processes occurring in a basin, by explicitly taking into account variability of meteorological forcing and basin properties. We first present results of the calibration effort, based on a relatively limited dataset consisting of: (i) hydrometeorological data available over 26 years in the period 1922-1996 and including daily rain gage observations, daily streamflow data at the outlet and temperature observations from four stations, (ii) a 10-m Digital Elevation Model, (iii) a digitized soil texture map, (iv) the CORINE land cover map. Once calibrated, we will use tRIBS to simulate the hydrological response in the Rio Mannu basin, under a number of climate change scenarios, generated by several numerical climate models collected by the PRUDENCE project of the FP5, the ENSEMBLES project of the FP6 and the US project PCMDI/CMIP3.

CLIMB Project

Reducing Uncertainty and quantifying risk through an integrated monitoring and modeling system

Motivation

- Climate induced changes on the hydrology of Mediterranean regions are presently occurring and are projected to amplify in the future, with heavy impacts on water availability and occurrence of hydrological extremes.
- Not enough knowledge is available to quantify these changes, due to a lack of suitable and effective hydrological monitoring and modeling systems.
- Projections of future hydrological change, based on climate model results and hydrological modeling schemes, are very uncertain and poorly validated.

Objectives

- Employ and integrate in a new conceptual framework:
  - advanced geophysical field monitoring techniques;
  - remote sensing analyses and retrievals;
  - climate models auditing and downscaling;
  - integrated hydrologic modeling;
  - socio-economic factor assessment to significantly reduce existing uncertainties in climate change impact analysis.
- Improvements will be communicated to stakeholders and decision makers enabling them to utilize the new findings in regional water resource and agricultural management initiatives as well as in the design of mechanisms to reduce potential for conflicts.

Method

We use the tRIBS model to simulate the hydrological response in the Rio Mannu catchment in order to evaluate the effects of climate changes using different climate scenarios generated by several numerical climate models (Fig. 1).

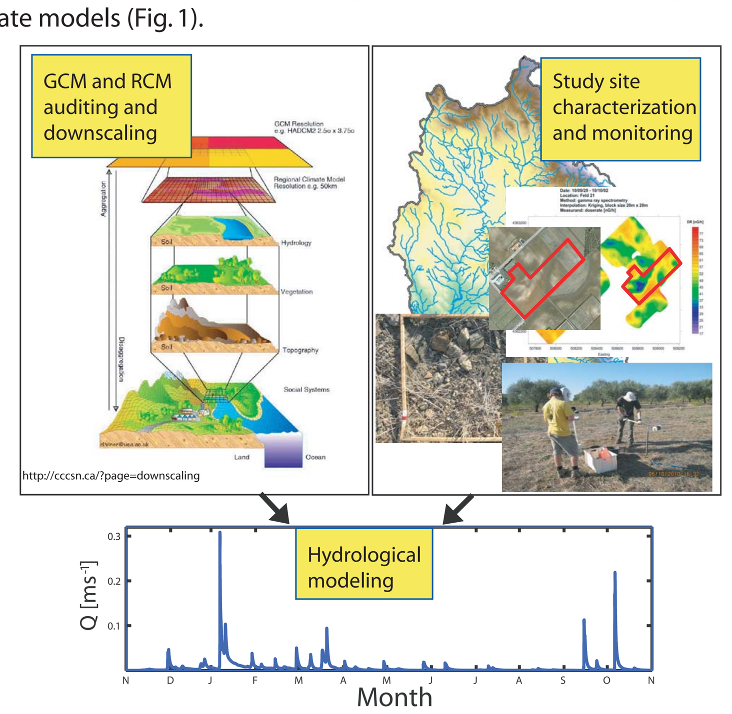


Fig. 1 - Schematisation of the methodology.

Hydrological Model Characteristics

TIN based real time integrated basin simulator (tRIBS) is a fully-distributed model of coupled hydrologic processes (Fig. 2).

- Interception and evaporation.
- Coupled vadose and saturated zones with dynamic water table.
- Moisture infiltration waves.
- Soil moisture redistribution.
- Topography-driven lateral fluxes in vadose and groundwater.
- Four runoff generation mechanisms.
- Radiation and energy balance.
- Hydrologic and hydraulic routing.
- Model outputs include time series at distributed locations and spatial outputs of several hydrological variables (e.g. streamflow, evapotranspiration, soil moisture).

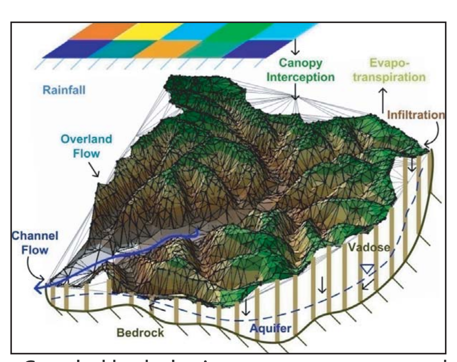


Fig. 2 - Coupled hydrologic processes represented in the tRIBS model over a complex triangulated terrain (Ivanov et al. 2004).

Study case and dataset

Our study site is located in the southern Sardinia (Italy) and is characterized by a nested configuration (Fig.3):

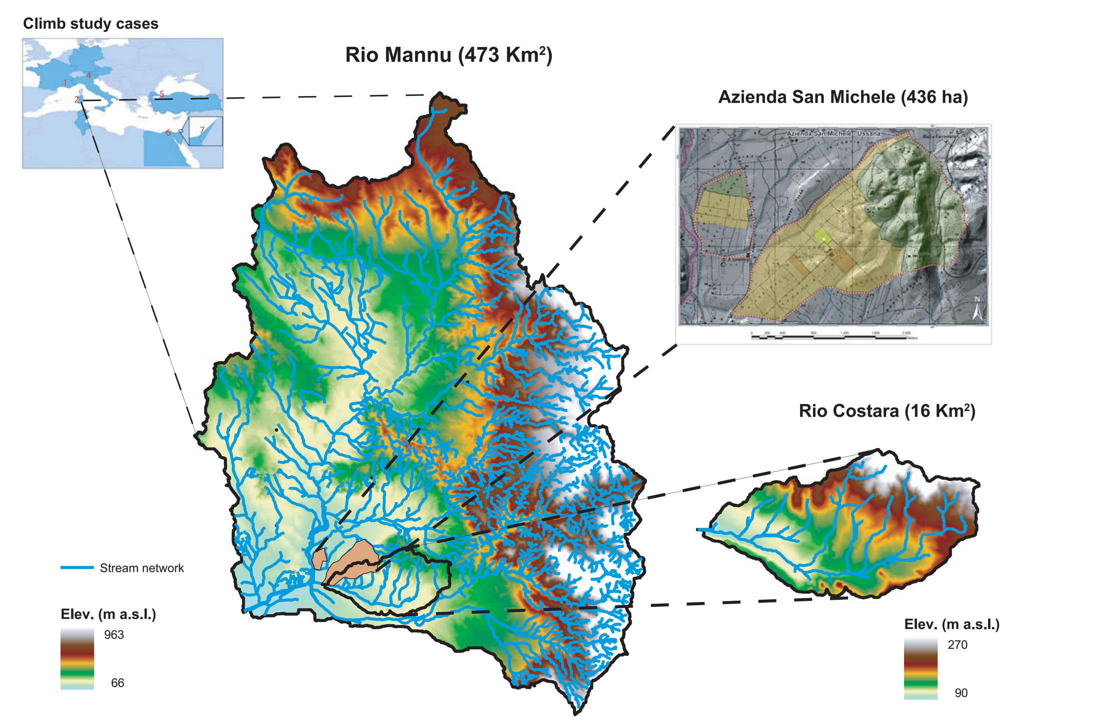
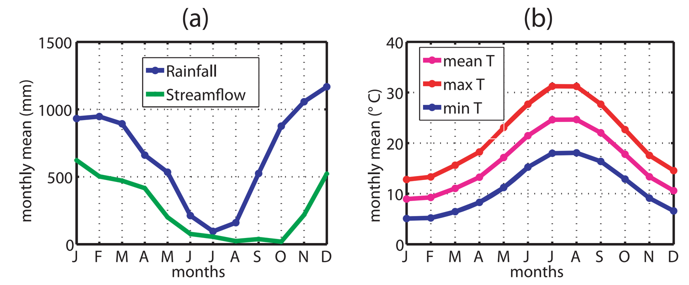


Fig. 3 - Study site representation and location.

In this study we present the calibration effort of the hydrological model for the **Rio Mannu** watershed (Fig. 3, Fig. 4, Fig. 5, Fig. 6, Fig. 7).



(c)

Rio Mannu terrain characteristics (from a 10-m DEM)			
H_{min}	H_{max}	H_{mean}	s
[m]	[m]	[m]	[%]
66	963	296	17.3

Fig. 4 - (a) Monthly mean rainfall and streamflow; (b) monthly mean temperatures; (c) terrain characteristics for the Rio Mannu area.

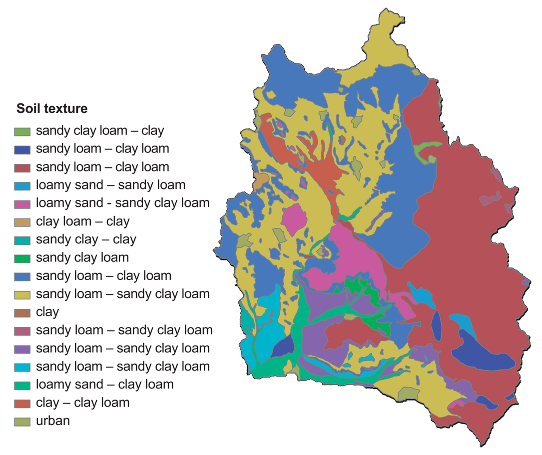


Fig. 5 - Soil texture map derived from a digitized map 1:250,000. Classes defined using pedotransfer functions and soil profiles.

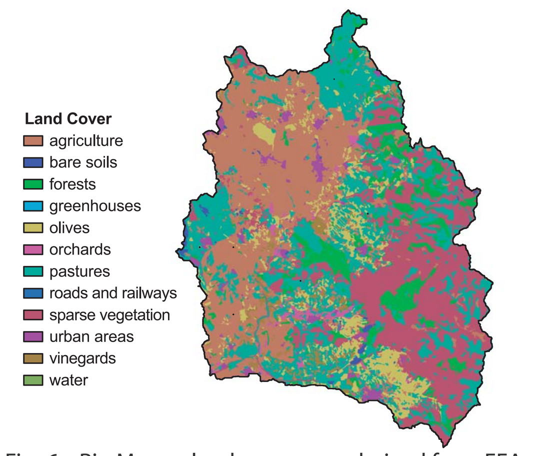


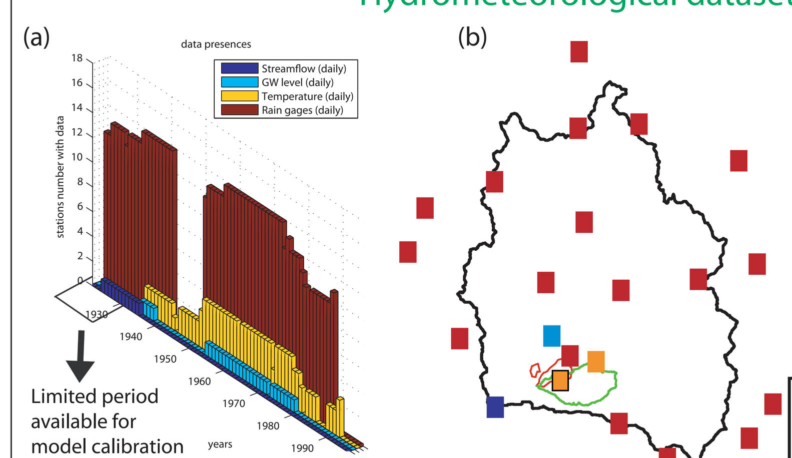
Fig. 6 - Rio Mannu land cover map derived from EEA CORINE project 2008.

Fig. 7 - Different typical land covers in the Rio Mannu watershed (wheat, grapes, olives and pastures).

The Rio Mannu basin was selected for the following reasons:

- It contains the Azienda San Michele, an experimental farm managed by AGRIS (Regional Agency for Research in Agriculture of Sardinian Region, partner of CLIMB) representing a small-scale study case for CLIMB. Here continuous monitoring is conducted of hydrometeorological variables and productivity of several crops that are fundamental in the Sardinian economy.
- Several field campaigns have been conducted together with CLIMB partners, including:
  - Geophysical campaigns such as Ground-Penetrating Radar, Electrical Resistance Tomography, and Gamma Ray Spectrometry to investigate the shallow subsurface.
  - Collection of soil samples and vegetation measurements in October 2010.

Hydrometeorological dataset



- About 8 rain gages working at the same time.
- Streamflow measurements covering **only eleven years** (1925-1935).
- Four stations with minimum and maximum temperatures.
- One station of groundwater levels.

- Limited data availability for model calibration.
- Limited period for model calibration, constrained by the presence of streamflow data.
- Low resolution (i.e., daily).

Fig. 8 - (a) Data presence from 1922 to1996, archived in technical reports of the Italian Hydrologic Survey (the 'Annali Idrologici'); (b) Stations' locations.

Hydrological model calibration

Topographic representation via Triangulated Irregular Networks (TINs)

- Significant reduction of computational nodes as compared to grid-based models.
- Multiple resolution domains.
- Preservation of linear features such as stream networks and terrain breaklines.

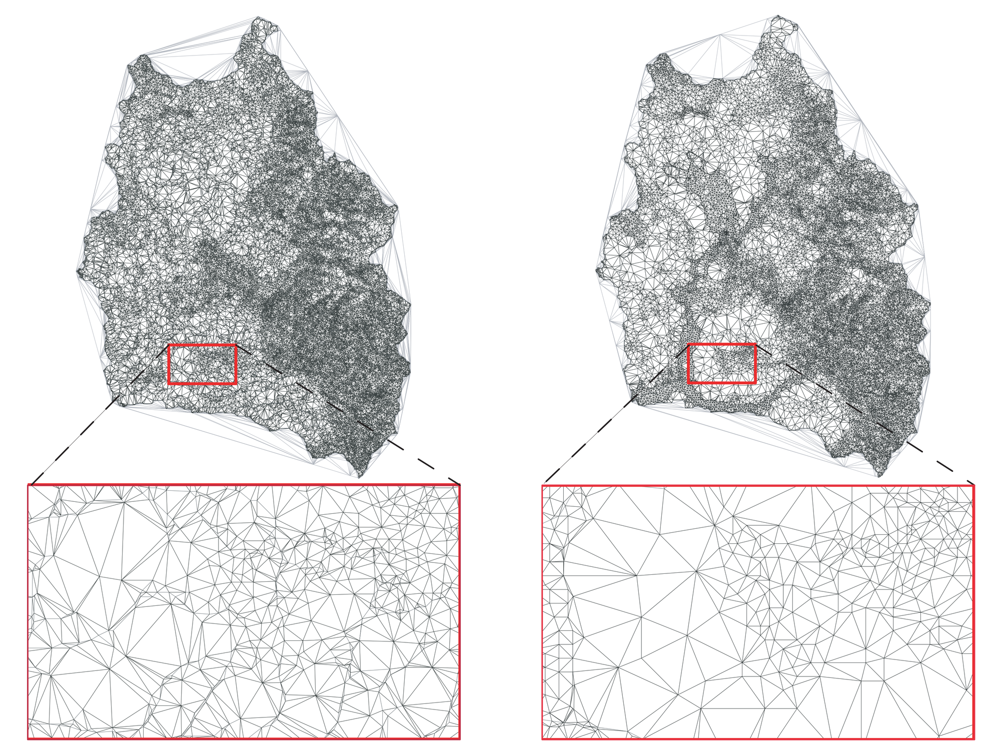
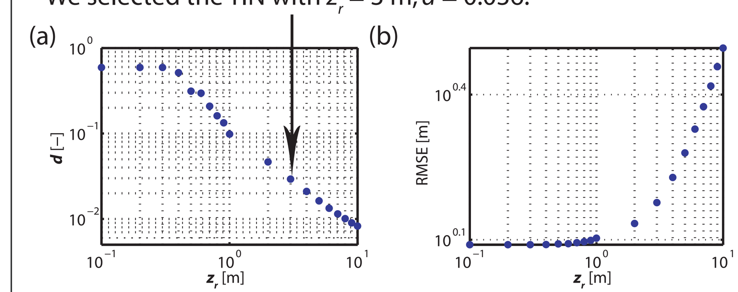


Fig. 9 - Multiple resolution TINs for watershed terrain representation.

- Different TINs have been created and compared. We selected the TIN with $z_r = 3$ m, $d = 0.036$.



Parameters used to quantify spatial aggregation from DEM to TIN:

$d = \frac{n_t}{n_g}$ horizontal point density

$r_e = \frac{r}{\sqrt{d}}$ equivalent cell size

z_r vertical tolerance

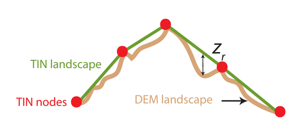


Fig. 10 - TIN aggregation characteristics for the watershed. (a) d vs z_r; (b) Root Mean Square Error (RMSE) between TIN and original DEM as a function of z_r.

Comparison of terrain attributes of the original DEM, selected TIN and aggregated DEM with the same resolution as TIN.

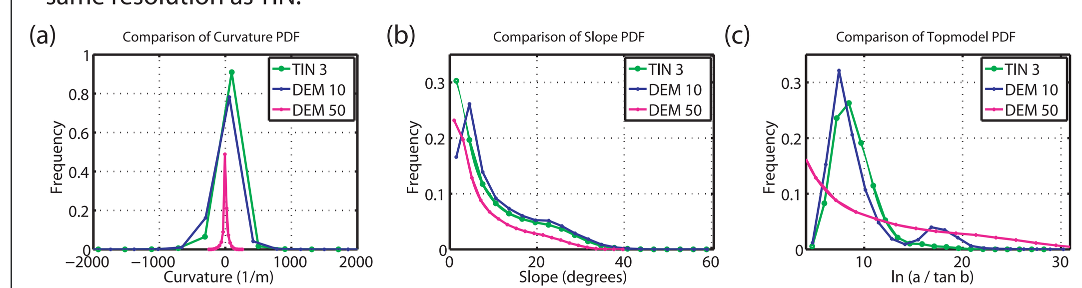
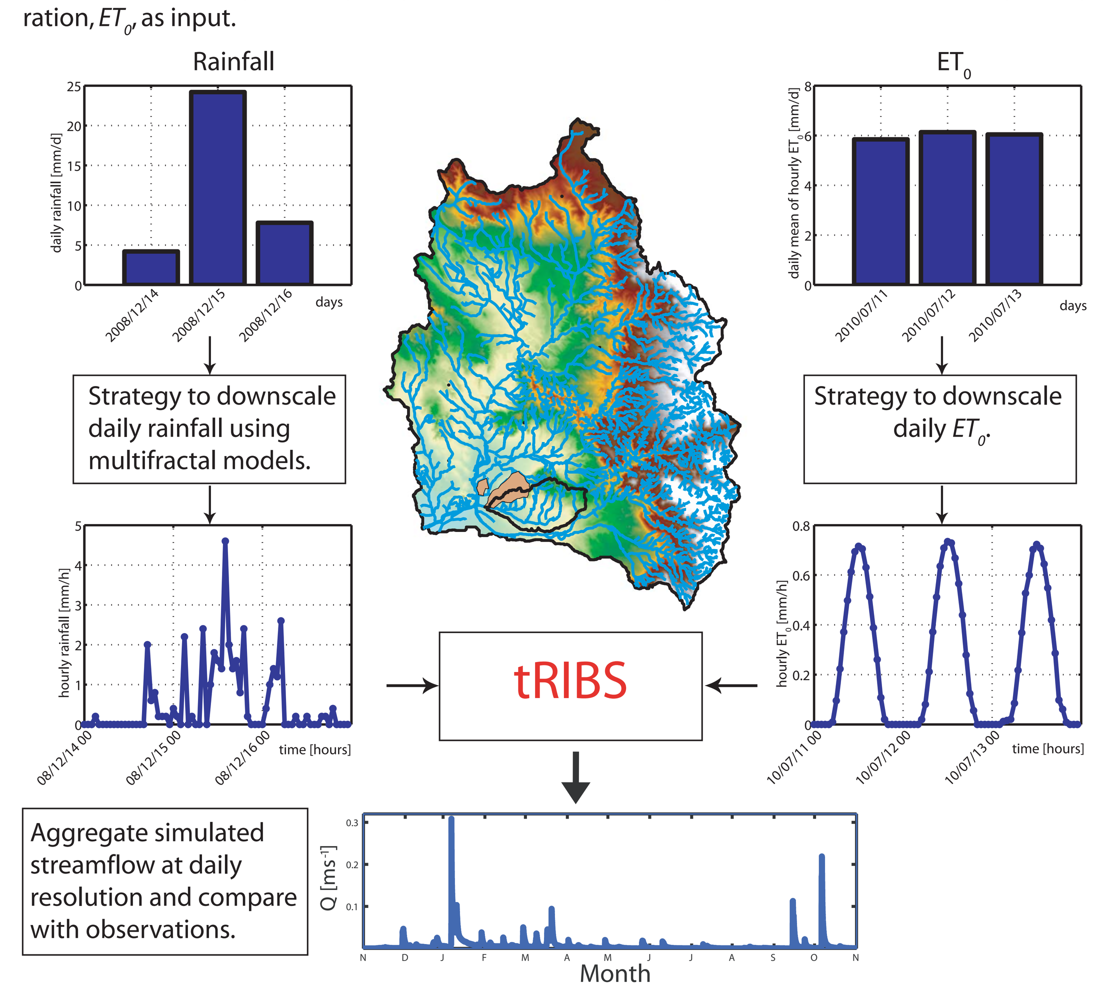


Fig. 11 - Comparison of frequency distributions of curvature (a), slope (b) and topographic index (c) of the DEM and the TIN. Included are the original DEM (10-m res.), the aggregated DEM at 50-m res. and the selected TIN model. Both the aggregated DEM and the TIN have an equivalent number of nodes ($d = 0.036$).

Downscaling daily hydrometeorological data

tRIBS requires hourly data of precipitation and meteorological variables or reference evapotranpiration, ET_0, as input.



Downscaling strategy for ET_0.

1) We computed hourly ET_0 with the FAO Penman-Monteith (PM) equation, ET_{0PM}^h from meteorological data (global solar radiation, temperature, relative humidity, wind speed) provided by ARPAS (Sardinian Regional Agency for Environmental Protection).

1a) We calibrated for each month a dimensionless function $f^d(m)$ (Fig. 12) simulating the diurnal cycle of ET_0, defined as:

$$f^d(m) = \frac{1}{n}\sum_{i=0}^{n} \frac{ET_{0PM,i}^h}{\sum_{i=0}^{n} ET_{0PM,i}^h} \qquad n = [1,24] \quad m = [1,12]$$

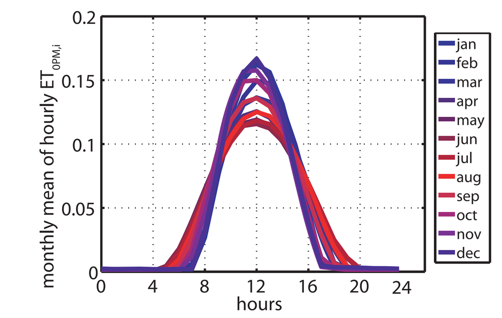


Fig. 12 - Downscaling ET process: modulation function $f^d(m)$.

1b) We computed daily aggregated ET_0 from hourly estimates, $ET_{0PM}^{d\_agg}$ and compared them with daily estimates, ET_{0PM}^d (Fig. 13a).

2) We computed daily ET_0 based on daily T_{max} and T_{min} with the 1985 Hargreaves equation, ET_{0H}^d.

3) We fitted a line to represent the relation between ET_{0H}^d and $ET_{0PM}^{d\_agg}$ (Fig. 13b). It can be inferred from this figure that ET_{0H}^d estimations are as good as daily aggregated $ET_{0PM}^{d\_agg}$.

4) Thus, we can downscale starting from the Hargreaves daily estimates, ET_{0H}^d, in the period of model calibration (items 1a and 2).

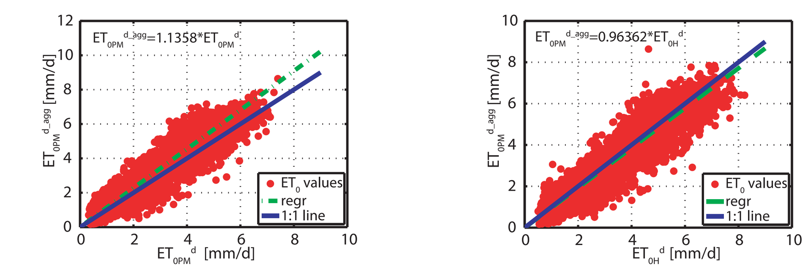


Fig. 13 - Downscaling ET process: (a) $ET_{0PM}^{d\_agg}$ versus ET_{0PM}^d, (b) $ET_{0PM}^{d\_agg}$ versus ET_{0H}^d.

Future work

- Apply an algorithm to downscale daily rainfall using a multifractal model (Deidda et al., 1999), calibrated with high-resolution (5-min) data collected by automatic rain gages in the period (1988-1996).
- Install two new streamflow gage stations in the Rio Costara watershed (Fig. 3) to investigate, in controlled conditions, the hydrological response of a basin containing the Azienda San Michele (Fig. 14).

Fig. 14 - Sections where streamflow gages will be installed: (a) Rio Costara, (b) Azienda S. Michele channel, (c) type of weir (V-notch) that will be installed.

- Use historical and downscaled data to calibrate the hydrological model.
- Select future climate scenarios, extract outputs of hydrometeorological variables from GCM and RCM, and eventually apply statistical downscaling techniques.
- Run the hydrological model with inputs derived from climate models to evaluate impacts of climate change on the water budget in the Rio Mannu basin.

References

Allen, R.G., Pruitt, W. O., Wright, J. L., Howell, T. A., Ventura, F., et al. (2007). A recommendation on standardized surface resistance for hourly calculation of reference ETo by the FAO56 Penman-Monteith method. Agricultural Water Management, 1--300.

Deidda, R., Benzi R., & Siccardi F. (1999), Multifractal modeling of anomalous scaling laws in rainfall, Water Resources Research, 35(6), 1853--1867, doi:10.1029/1999WR900036.

Ivanov, V. Y., Vivoni, E. R., Bras, R. L. & Entekhabi. D. (2004), Chatchment hydrologic response with a fully distributed triangulated irregular network model, Water Resources Research, 40, 1--23.

Ivanov, V. Y., Vivoni, E. R., Bras, R. L. & Entekhabi. D. (2004), Preserving high-resolution surface and rainfall data in operational-scale basin hydrology: a fully distributed physically-based approach, Journal of Hydrology, 80--111.

Vivoni, E. R., Ivanov, V. Y., Bras, R. L. & Entekhabi. D. (2004), Generation of Triangulated Irregular Networks based on Hydrological Similarity, Journal of Hydrologic Engineering ASCE/ July/August2004, 288--302.

Vivoni, E. R., Ivanov, V. Y., Bras, R. L. & Entekhabi. D. (2005), On the effects of triangulated terrain resolution on distributed hydrologic model response, Hydrological Processes, 19, 2101--2122.