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Parsimonious modeling of coupled soil moisture-vegetation dynamics

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1. INTRODUCTION

Modeling phenology and photosynthetical activity in water-controlled ecosystems remains a difficult task because of high spatial and temporal variability in the interaction of plant growth and soil moisture. Here we present a nonlinear ecohydrological model that couple the dynamics of vegetation and soil moisture. The study area encompasses 750 km² dominated by broadleaf forest, in central Italy. We prepared 10-year time series (2000–2009) of climatic variables as Fraction of Absorbed Photosynthetically Active Radiation (*FAPAR*) derived from MODIS and of soil moisture derived from an hydrological model, of which 50% were used for model calibration and 50% for model validation.

2. STUDY AREA

The geographical area selected to explore seasonal vegetation dynamics is the Casentino Valley in the Arno river basin (**Fig.1**). A large set of historical data is available, including both fine resolution and daily rainfall records for a considerable number of stations. The basin is representative of a Mediterranean climate, with a total annual precipitation from about 700 to 1700 mm. The study area is mainly made up of water-controlled ecosystems which show sensitive vegetation dynamics to climatic fluctuations.

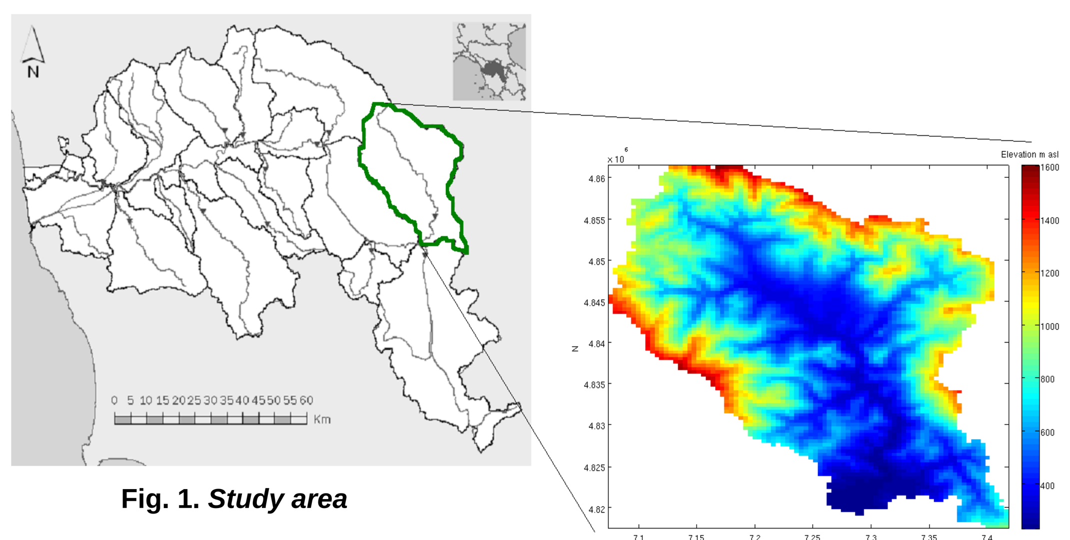

Fig. 1. *Study area*

3. DATASET

(1) *FAPAR* dataset using *JRC-TIP* model **[1]** from MODIS Albedo collection,15-day time step, 400-m spatial resolution; (2) Daily time-series of Precipitation and Solar Radiation from agrometeorological network of Arno river basin, (3) Net Solar Radiation, Soil Moisture and Discharge from *MOBIDIC* hydrological model **[2]** ,(4) CORINE 2000 land cover dataset.

4. MODELING APPROACH

We pursue the objective of identifying a parsimonious and robust ecohydrological model that can retain basic response behavior of the system and that can be forced by a limited number of climate variables. A scheme of the ecohydrological model is reported in **Fig. 2**.

$$\begin{cases} \dfrac{dx}{d\tau} = u_1(1-r\cdot x)(1-x) - B\cdot x - EF\cdot u_2\cdot y\cdot\left(1-e^{-A\cdot x}\right) \\[2ex] \dfrac{dy}{d\tau} = \beta\cdot EF\cdot u_2\cdot y\cdot\left(1-e^{-A\cdot x}\right)(1-y) - \alpha(y-y_0) \end{cases}$$

x = relative soil saturation (soil moisture in the range 0-1)
y = fraction of photosynthetically active radiation absorbed by the vegetation (*FAPAR* in the range 0-1) — STATE VARIABLES
P (t)= precipitation [m/s]
Rn (t)= net radiation [W/m²=J/s m²] — INPUT
u_1 = dimensionless precipitation term [-]
u_2 =dimensionless net radiation term [-]
τ= yearly time scale [-]
c = time factor = 1/(8760*3600) s^{-1}
w = active soil thickness [m]
L =latent heat of vaporization [J/kg]
ρ = water density [kg/m³]
r = potential runoff coefficient
B = baseflow coefficient
EF = potential evaporative fraction
A = soil moisture exploitation curve coefficient
β = carbon/water equivalence parameter
α = plant death parameter
y_0 = minimum *FAPAR* value

dimensionless time and state variables

$$u_1(\tau) = \frac{P(t)}{w\cdot c}$$

$$u_2(\tau) = \frac{Rn(t)}{w\cdot\rho\cdot L\cdot c}$$

$$\tau = \frac{t}{c}$$

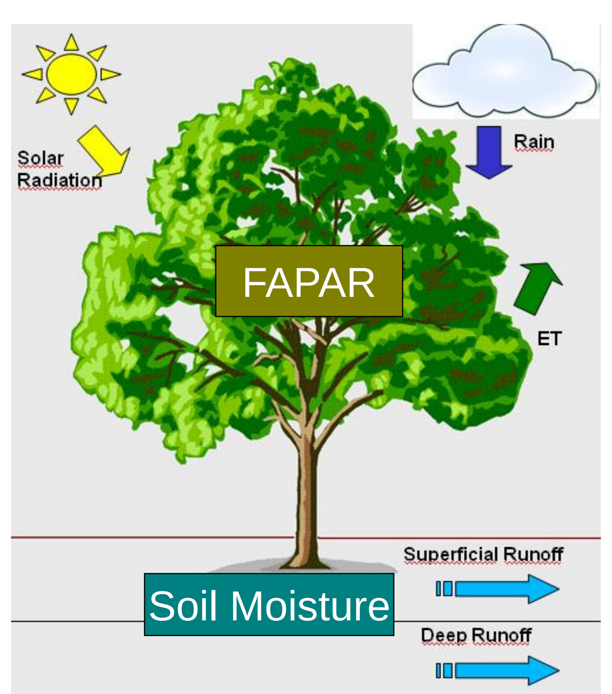

Fig. 2. *Model scheme, where soil moisture and FAPAR are the state variables*

5. MODEL CALIBRATION

The model was calibrated using observed MODIS *FAPAR* values, Soil Moisture and Discharge data from *MOBIDIC* hydrological model **[2]** for years 2000-2005. Parameters (**Fig.3**) were optimized using the Nelder-Mead optimization algorithm.

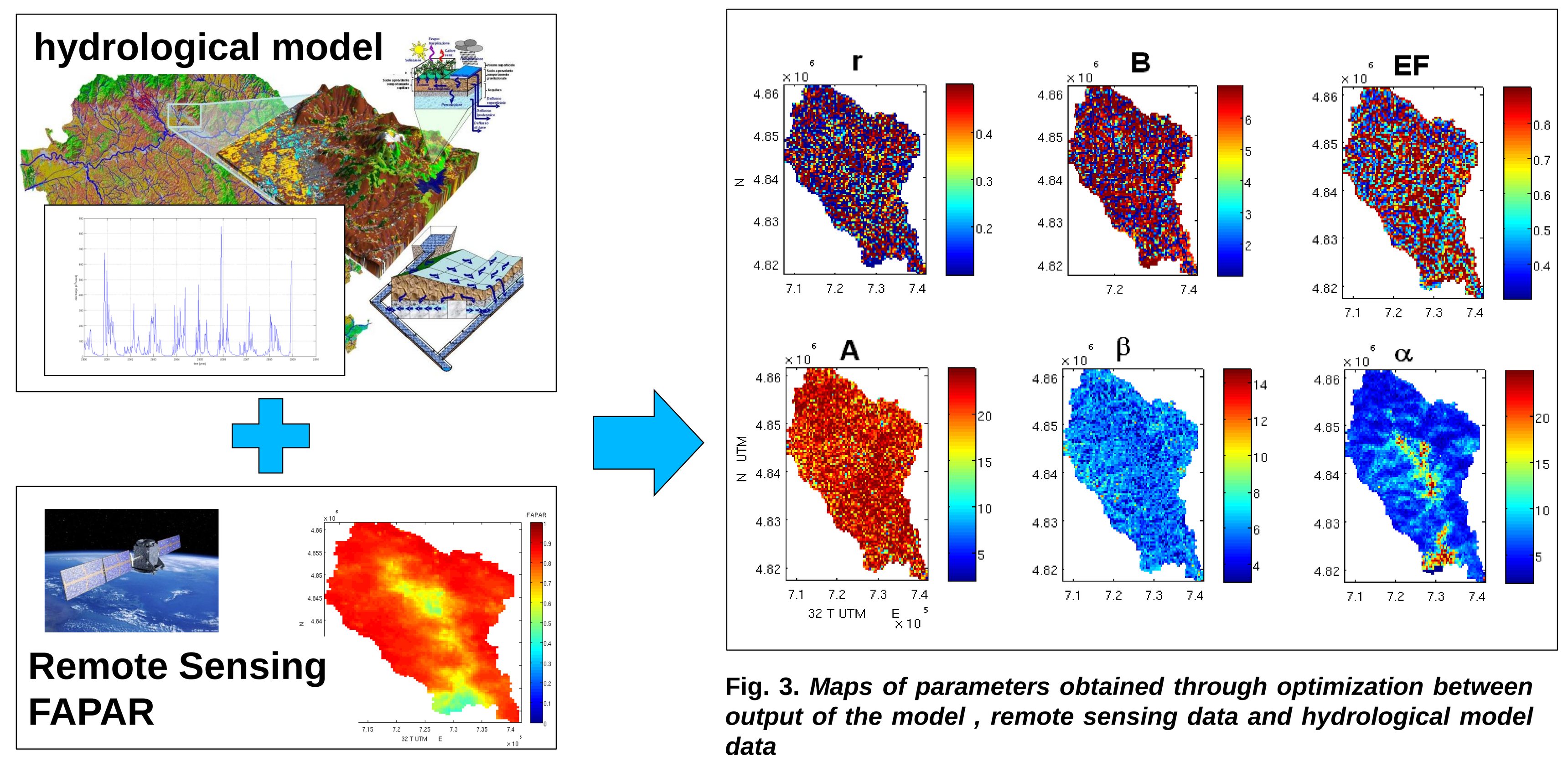

Fig. 3. *Maps of parameters obtained through optimization between output of the model , remote sensing data and hydrological model data*

6. RESULTS

The model mimics quite well the behavior of soil moisture and *FAPAR* for the Casentino basin. Simulations show how the coupled model can follow the *FAPAR* seasonal patterns, driven by net radiation and soil moisture forcings. Also the length for leaf onset and leaf offset were fairly correctly predicted (**Fig. 4**).

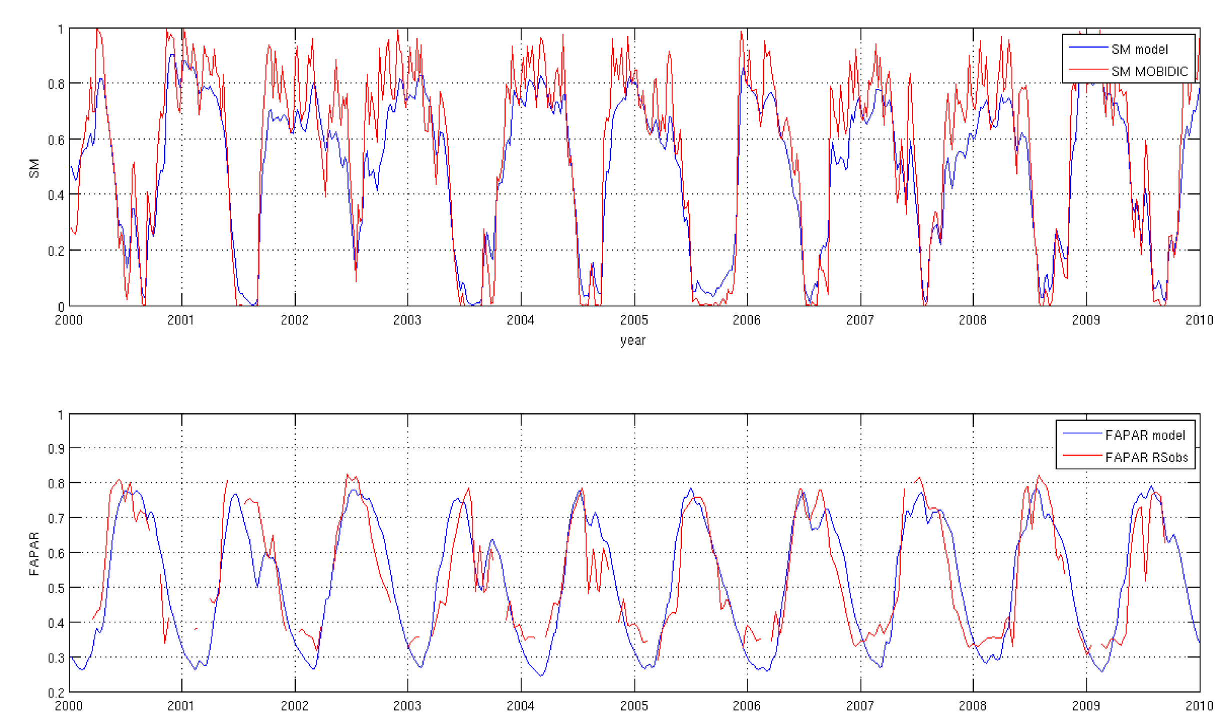

Fig. 4. *Difference between modeled (blue) and observed (red) soil moisture and FAPAR for Casentino basin*

It's well known that the phenological cycle is mainly forced by the following factors (1) photoperiod (i.e. daylength), (2) temperature enhancements of photosynthetic biochemistry and (3) soil moisture availability **[3]**. Dependence of *FAPAR* on soil moisture is captured during heat wave of summer 2003: the decrease in soil moisture during summer triggers a vegetation collapse (**Fig. 5**).

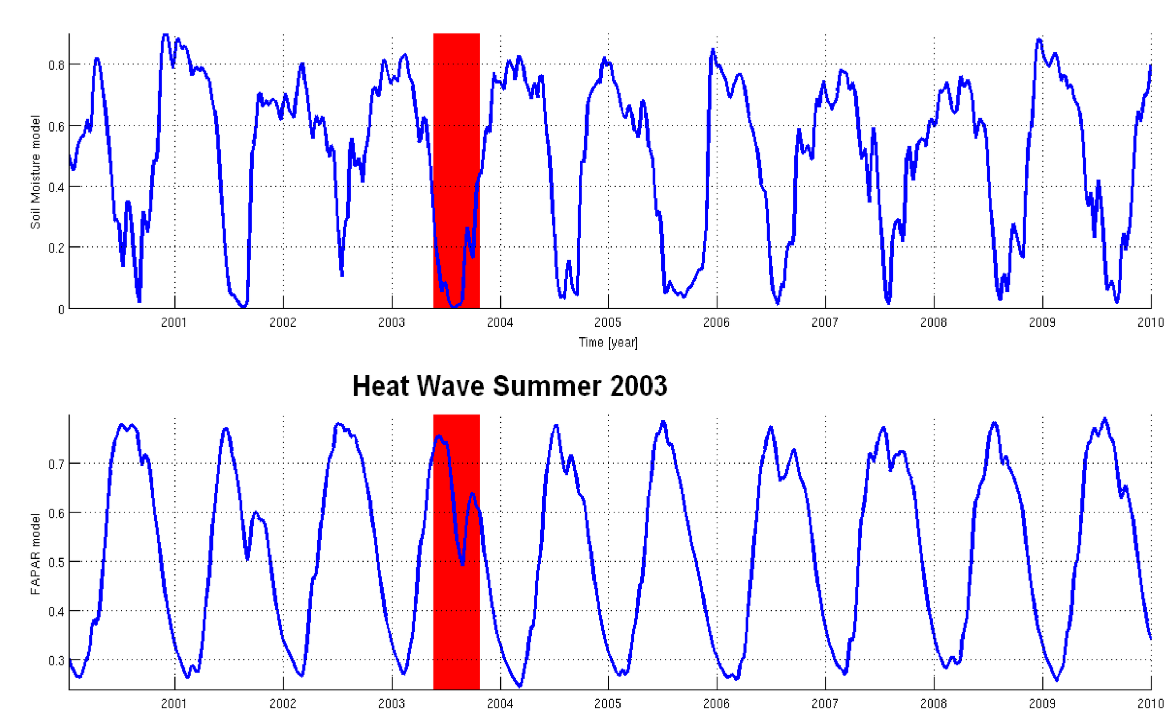

Fig. 5. *Modeled average values of soil moisture (top) and FAPAR (bottom) for Casentino Valley*

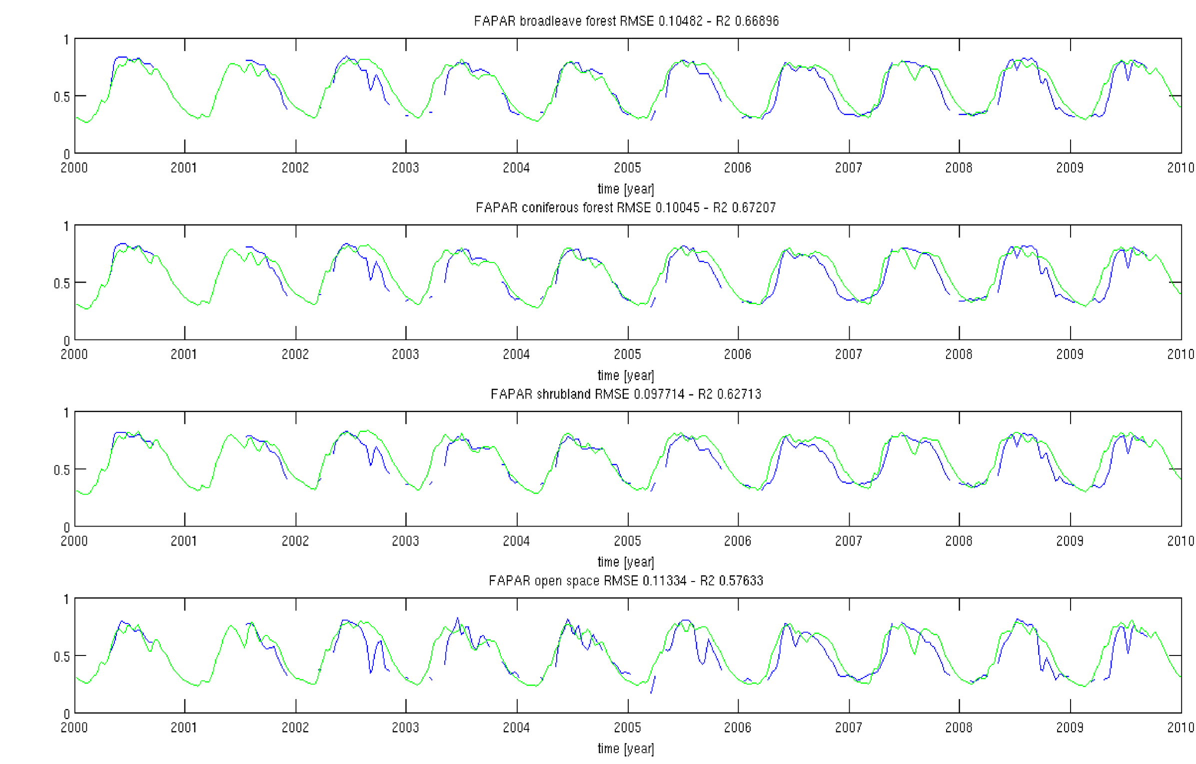

Fig. 6. *Difference between modeled (green) and observed (blue) FAPAR for the 4 different Land Uses of Casentino basin. Coniferous and decidous forest show higher coefficients of determination R^2*

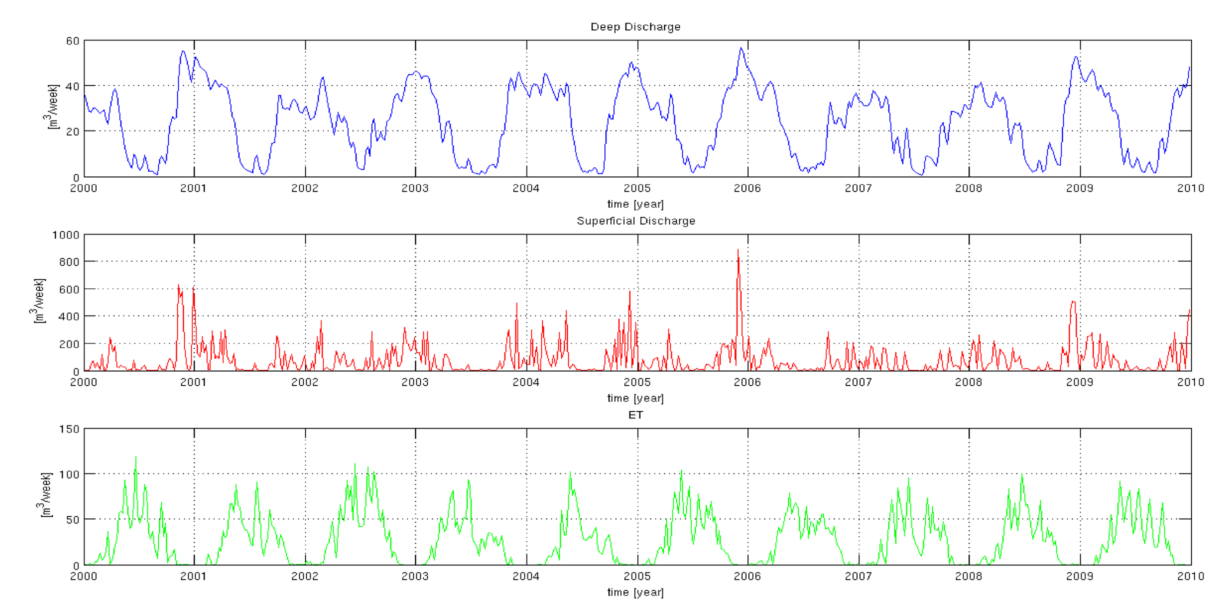

Fig. 7. *Components of hydrological balance of eco-hydrological model: ET(green), deep discharge (blue) and superficial discharge(red).*

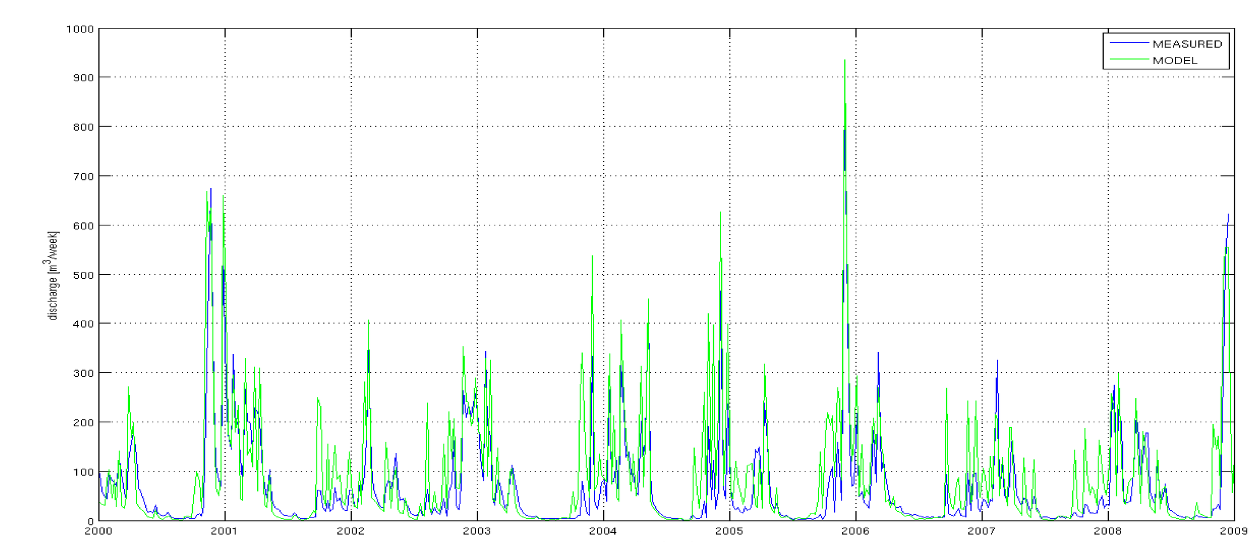

Fig. 8. *Difference between modeled (green) and observed (blue) weekly discharge of Casentino basin*

7. CONCLUSIONS

Results shows that eco-hydrological model including feedbacks between soil moisture and plant growth adequately predicts leaf dynamics (**Fig.9**). The eco-hydrological model was successfully operationalized for the Casentino catchment based on current landcover characteristics, historic climate and runoff data, along with several parameters necessary in defining the basin.

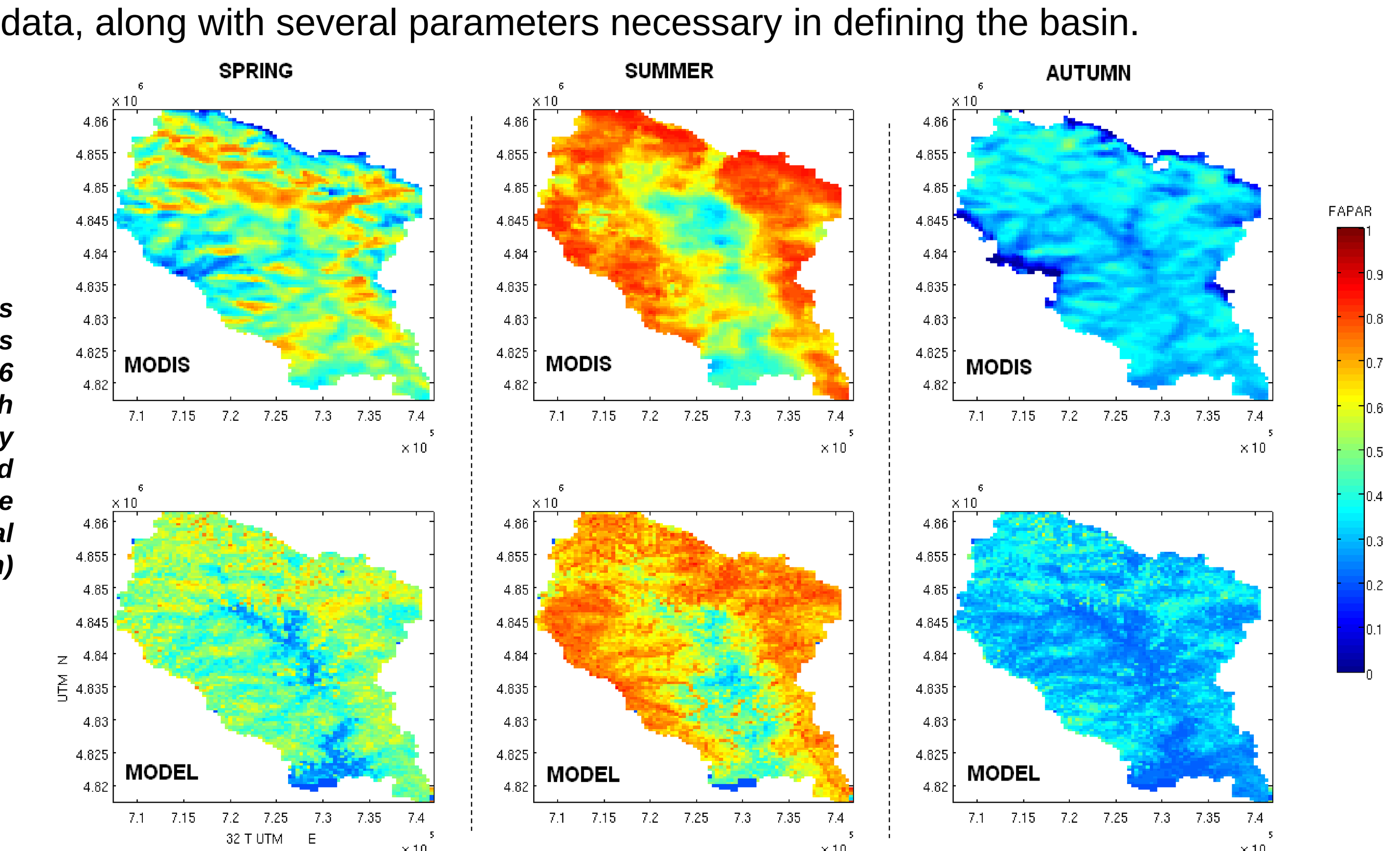

Fig. 9. *FAPAR maps for 3 differents seasons of year 2006 obtained through MODIS repository (top) and generated using the ecohydrological model (bottom)*

REFERENCES

[1] Pinty, B., Lavergne, T., Dickinson, R. E., Widlowski, J.- L., Gobron, N., and Verstraete, M. M. (2006). Simplifying the interaction of land surfaces with radiation for relating remote sensing products to climate models. *Journal of Geophysical Research*.111 **[2]** Castelli F., G. Menduni and B. Mazzanti, (2009). A distributed package for sustainable water management: a case study in the Arno basin. In *Role of Hydrology in Water Resources Management*, H.J. Liebscher et al. Eds., IAHS Publ. 327, pp. 52-61. **[3]** Eagleson P.S. (2002) Ecohydrology: Darwinian Expression of Vegetation Form and Function. *Cambridge University Press.*