Statistical assessment of irrigation water over wide areas by the use of ground and Sentinel-2 data

Angeli Luca[a], Battista Piero[b], Chiesi Marta[b], Fibbi Luca[a,b], Gozzini Bernardo[a,b], Pieri Maurizio[b], Maselli Fabio[b]

[a] Consorzio LaMMA, Sesto Fiorentino (FI)
[b] Consiglio Nazionale delle Ricerche, Istituto per la BioEconomia, Sesto Fiorentino (FI)

CONSORZIO LaMMA

Consiglio Nazionale delle Ricerche

Introduction

Water is an essential resource for every-day life and its availability is a fundamental pre-requisite for the sustainable development of earth population.

This is particularly the case for semi-arid regions, which, as a consequence of climate change, are also affected by a reduction of water availability and an increase of air temperature.

In these regions, agricultural activities are the main consumer of water resources, mainly due to irrigation requirements (IW) for extensive summer croplands (corn, tomato, sunflower, etc.).

These requirements are extremely variable both in space and in time therefore estimating crop irrigation over large areas is not trivial and ground based methods can provide only a partial solution.

RESEARCH CONTEXT AND OBJECTIVES:

1. Previous research of our group has developed and tested a methodology which produces **mapped estimates of irrigation water (IW)** in Mediterranean areas through the use of meteorological and satellite data.

2. The current study aims at combining these IW maps with reference IW observations in order to **improve the statistical soundness of the estimates over large areas**.

IW prediction method

- Stems from studies dealing with the actual evapotranspiration (ETa) estimation in Mediterranean areas (also extended to irrigated fields).

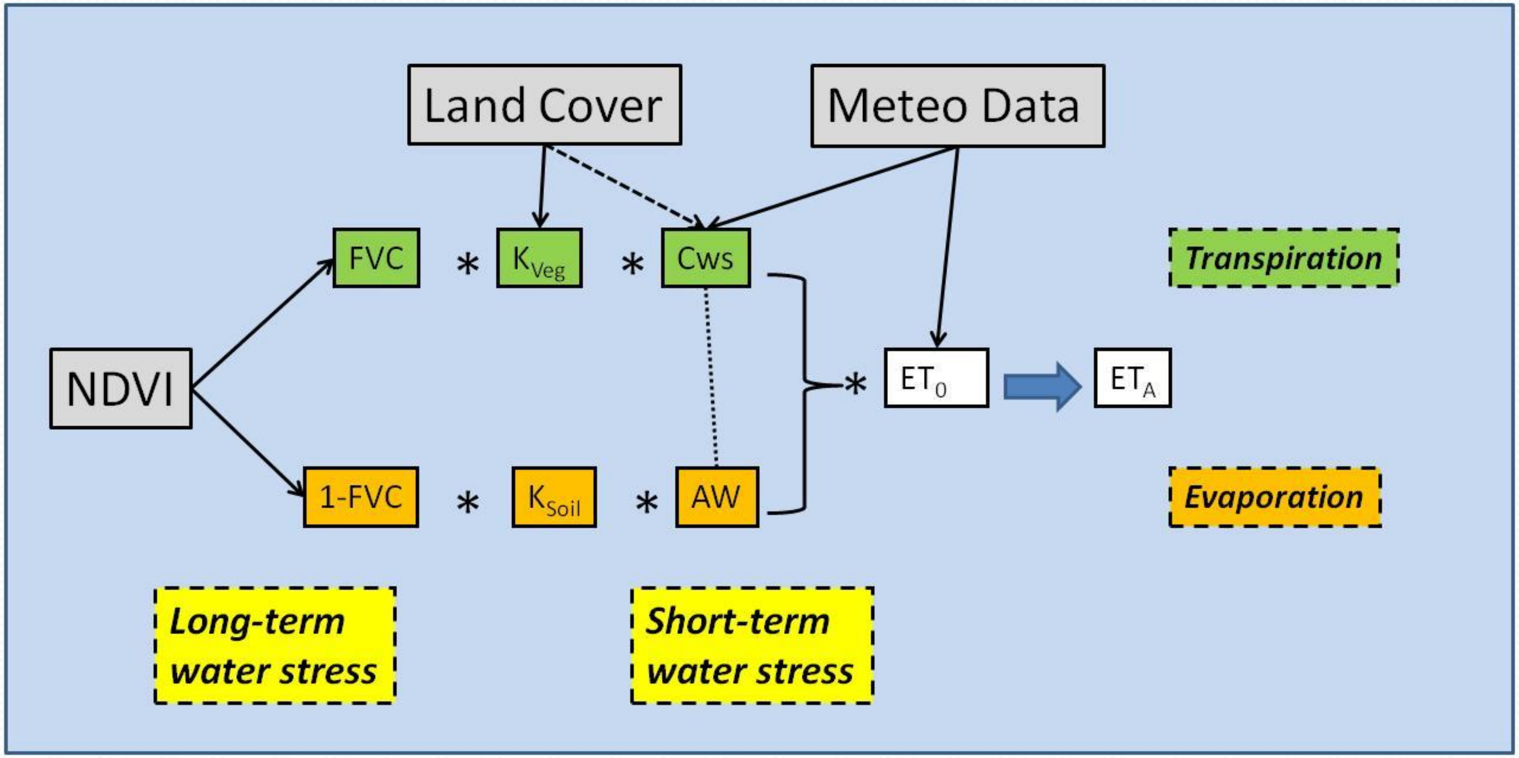
- Implies a **deep knowledge of local agricultural practices** (e.g. the main criteria guiding IW supply, the type of irrigation system, etc.).

- Based on the joint use of daily meteorological data and NDVI imagery of the investigated area.

The following major steps are identified:

- Development of a method to estimate ETa (named NDVI-Cws) for terrestrial ecosystems;
- Adapting of the NDVI-Cws method to estimate ET_A/Tr_A for irrigated crops;
- Estimation of IW.

NDVI-Cws ET_A estimation method



$$ET_A = ET_0\ (FVC\ Kc_{Veg}\ Cws + (1\text{-}FVC)\ Kc_{Soil}\ AW)$$

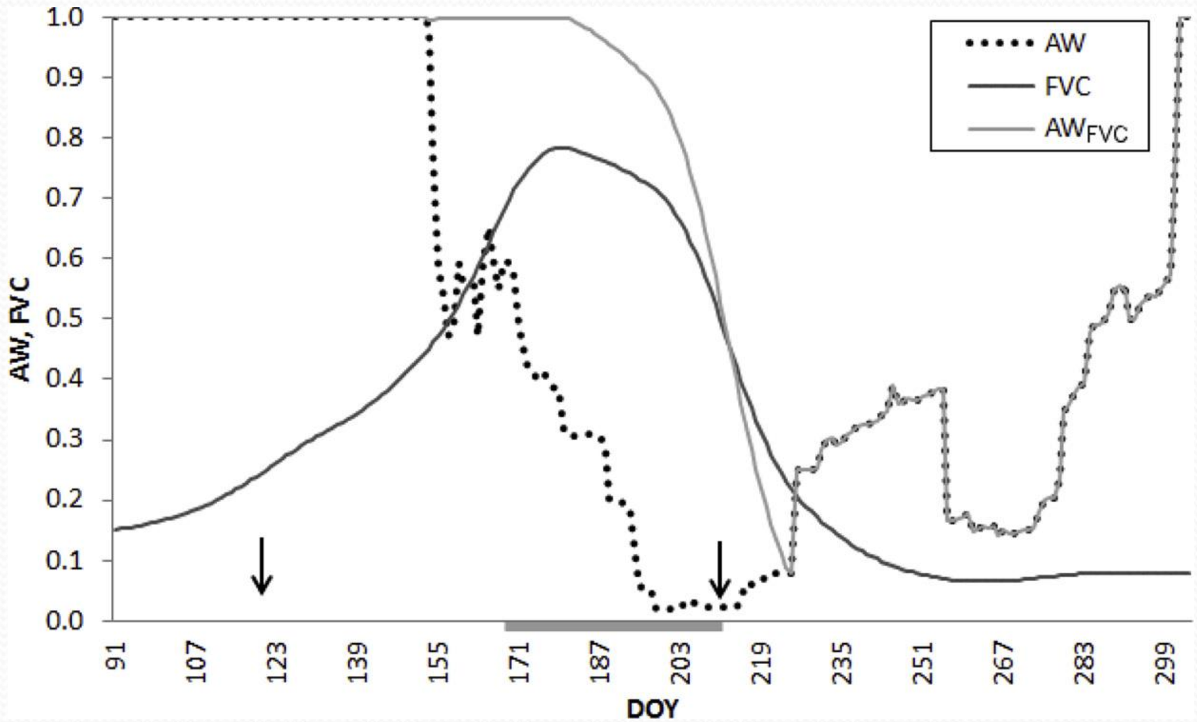
where FVC derives from NDVI, AW = Rain/ET_0 and Cws = (0.5+0.5 AW)

Theoretical foundation of the IW estimation method

In annual crops, increasing or stable FVC during the water stress summer period can be supposed to indicate the occurrence of water supply additional to rainfall.

In contrast, an FVC decrease which progresses during the water stress period indicates no (or limited) additional water supply.

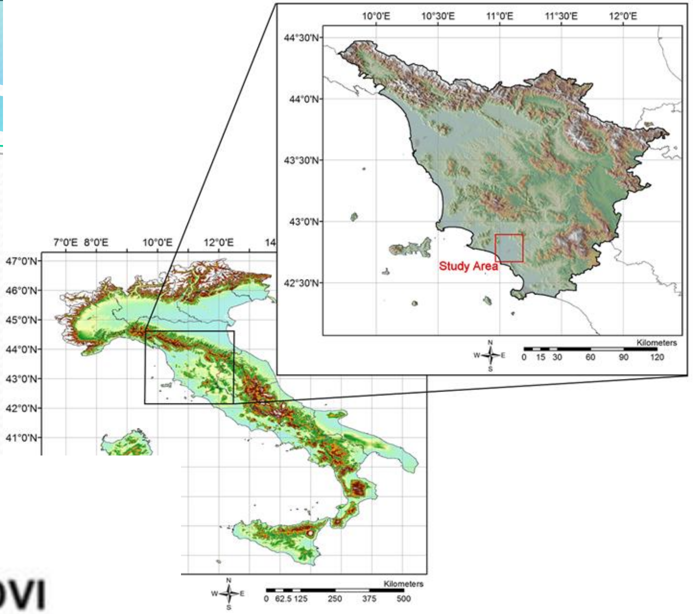
Based on this principle, AW is modified if FVC (NDVI) increases during the water stress period.

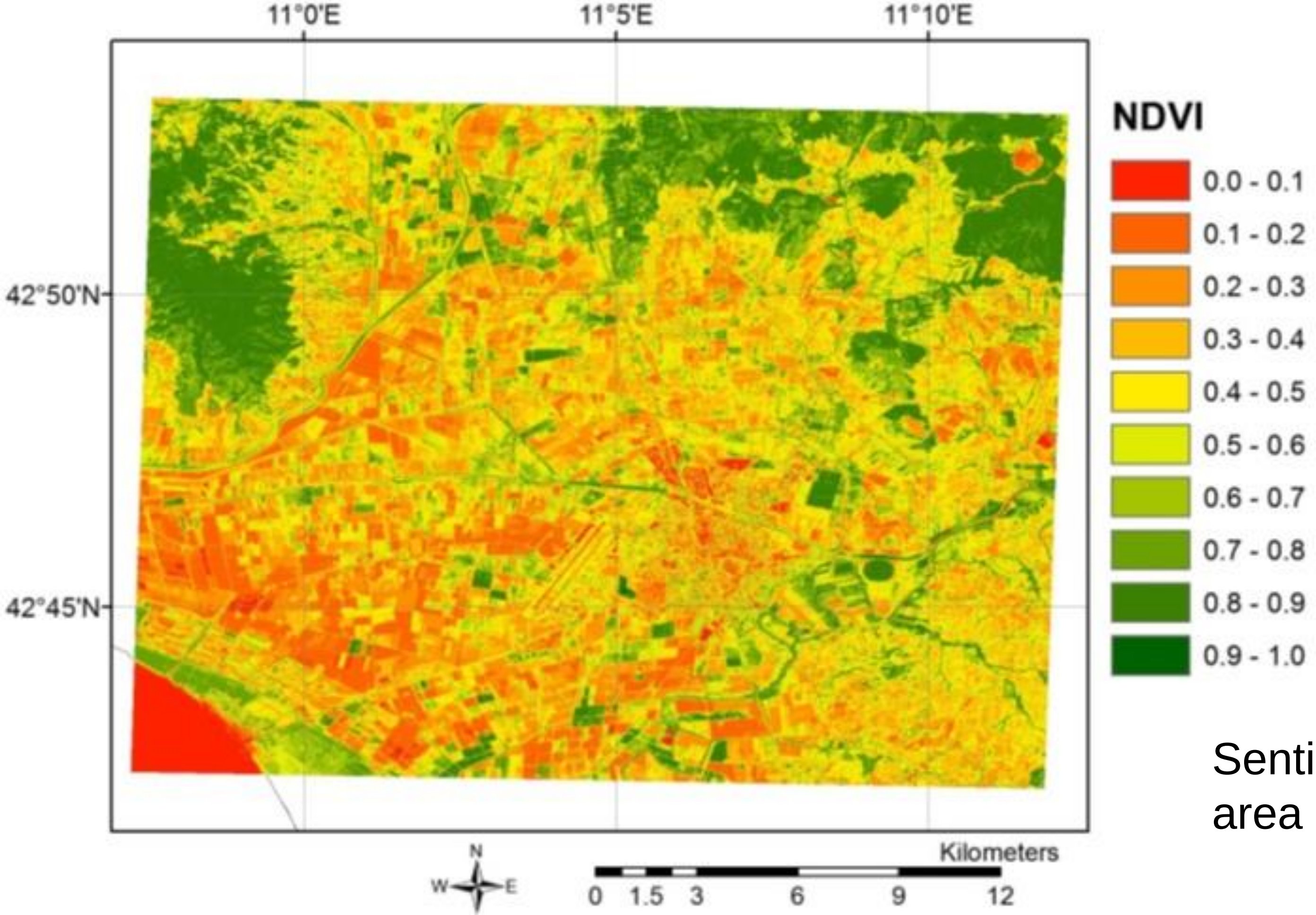


Seasonal evolution of the water stress scalars and of the corresponding FVC for an irrigated tomato field.

grey bar = irrigation period
two arrows = transplanting and harvesting dates

Study area: Maremma





Sentinel-2 MSI image of the area in June 2018.

Main features of some **rainfed and irrigated cropped fields** characterizing the study area in the 2018 growing season.

Crop type	Sowing	Transplanting	Harvesting	Irrigation
Set-aside	-	-	-	No
Winter wheat	November (2017)		Mid-June	No
Chickpea	February		Early July	No
Late tomato		Late May	Early September	Yes
Early corn	Mid-April		Late August	Yes
Late corn	Mid-June		Mid-October	Yes

Study data

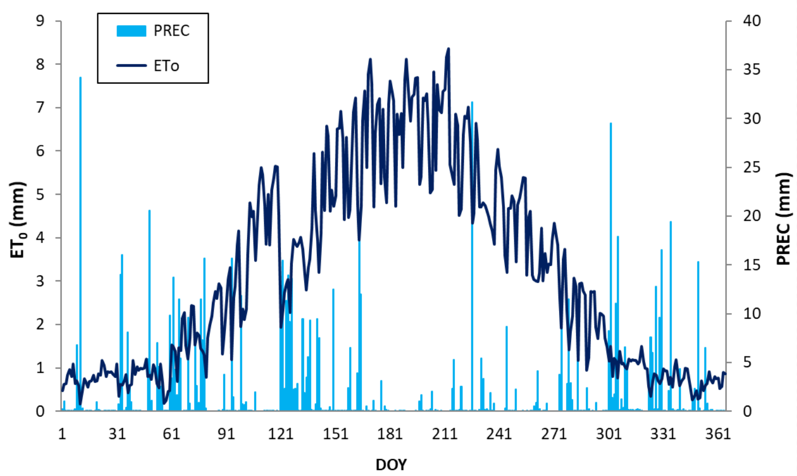
Ground data

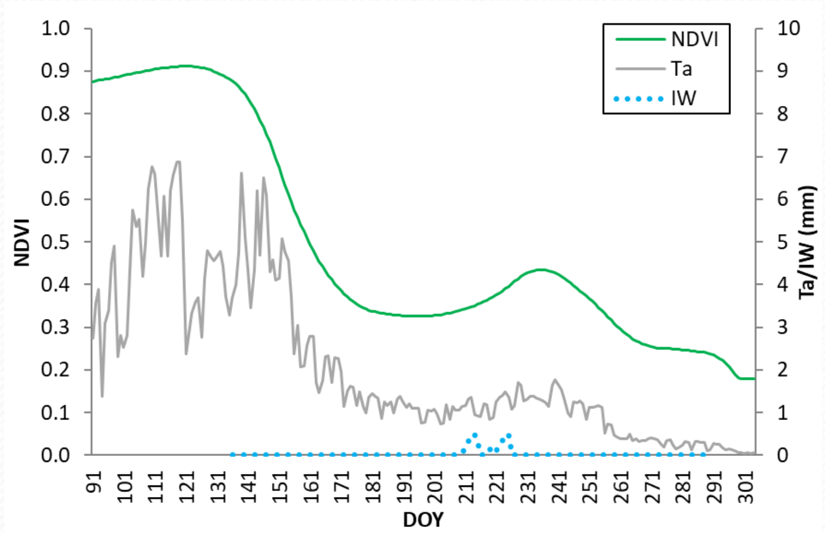
- Daily meteorological data collected at the monitored tomato field.
- Interpolated meteorological data at 250-m spatial resolution.
- A 1:10000 scale map of the annual crops.
- A water meter to quantify the IW in the field.

Satellite data

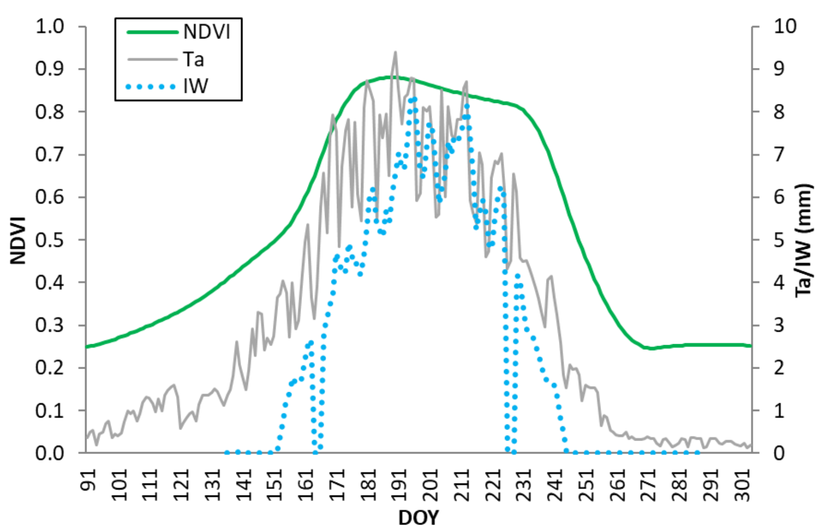
- NDVI MVC imagery of Sentinel-2 MSI, at 10-m spatial resolution and 15-day temporal step. Data are available for 2018 and 2019.

Examples for 2018

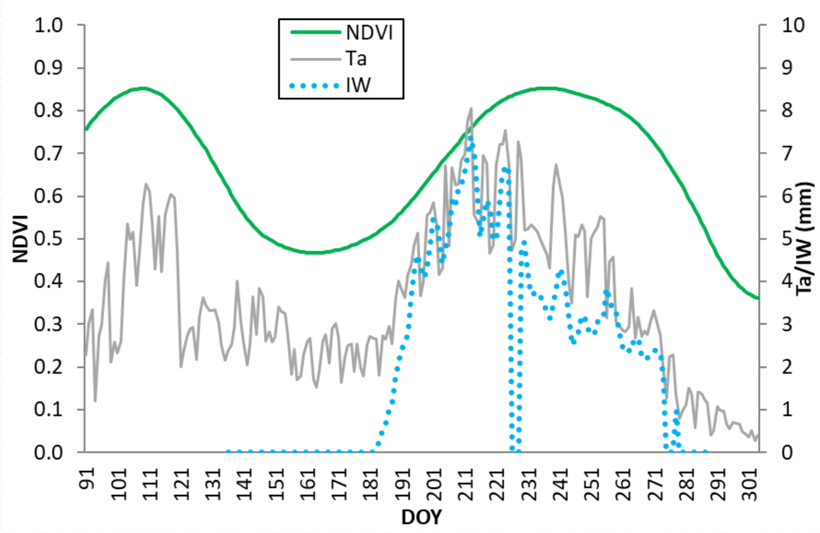




Winter wheat



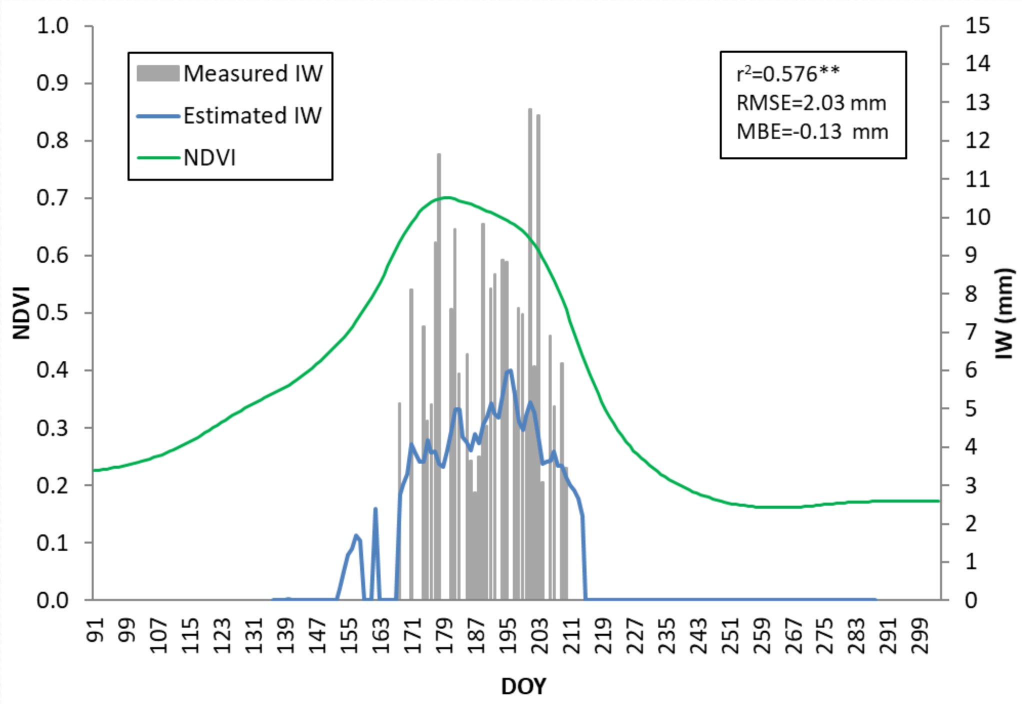
Corn sown in late spring



Corn sown in summer

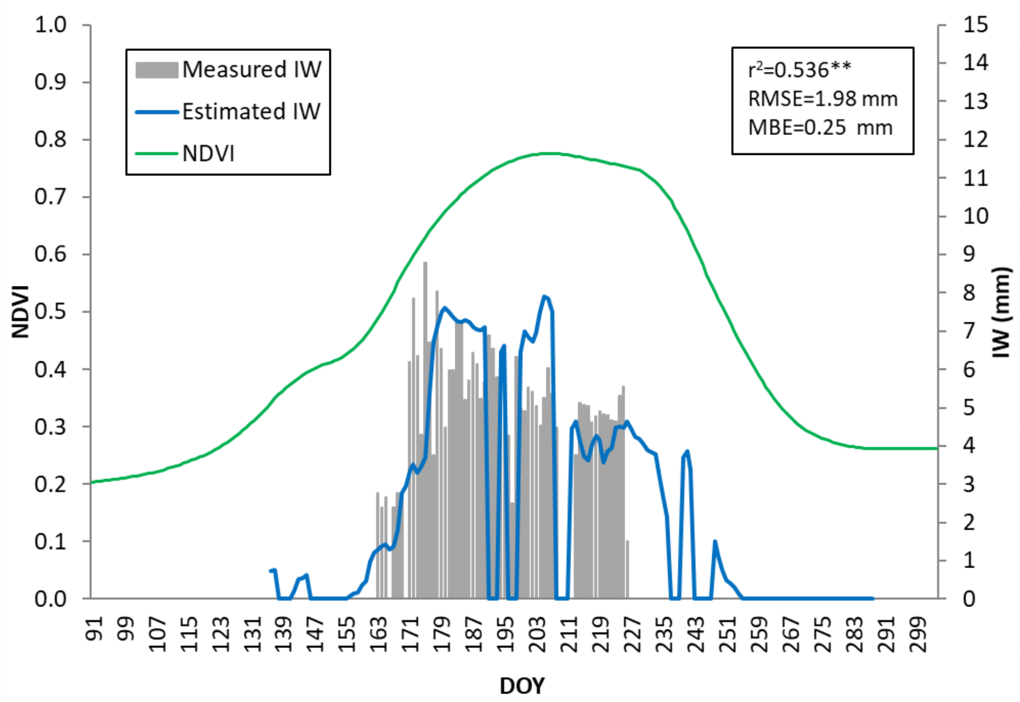
Validation of the IW estimates (1)

Crop type	Transplanting	Harvesting	Measured IW (mm)	Estimated IW (mm)
Early tomato	28/04/2018	31/07/2018	221	202

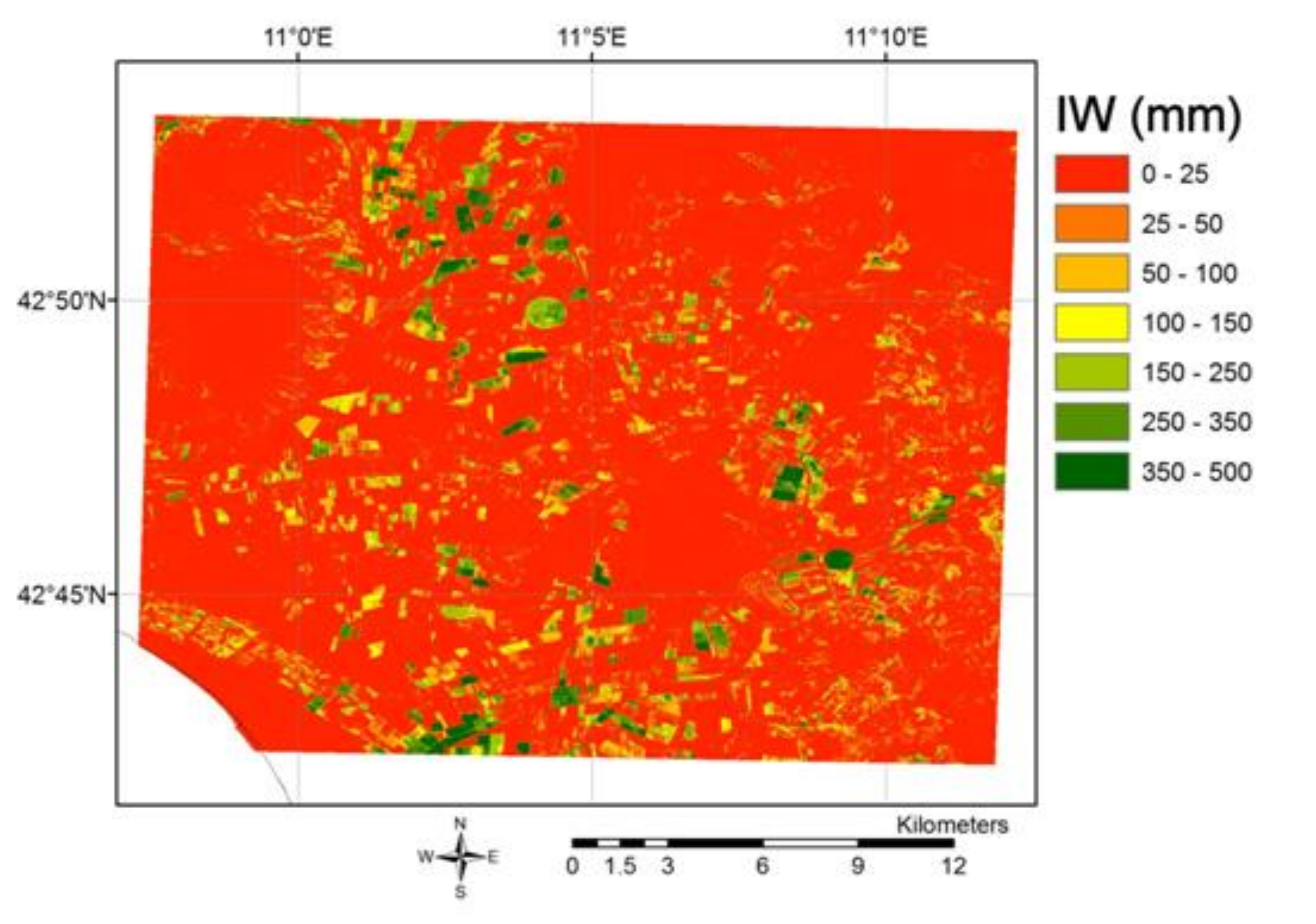


Validation of the IW estimates (2)

Crop type	Sowing	Harvesting	Measured IW (mm)	Estimated IW (mm)
Early corn	18/04/2019	19/08/2019	299	338



IW map of Maremma area



Statistical approach

- Applied to infer IW measured at some fields to the whole investigated area.

- It would imply the availability of a large number of field measurements

- To overcome these issues and increase the precision of the ground sampling, the **regression estimator** is applied to independent datasets informative on IW.

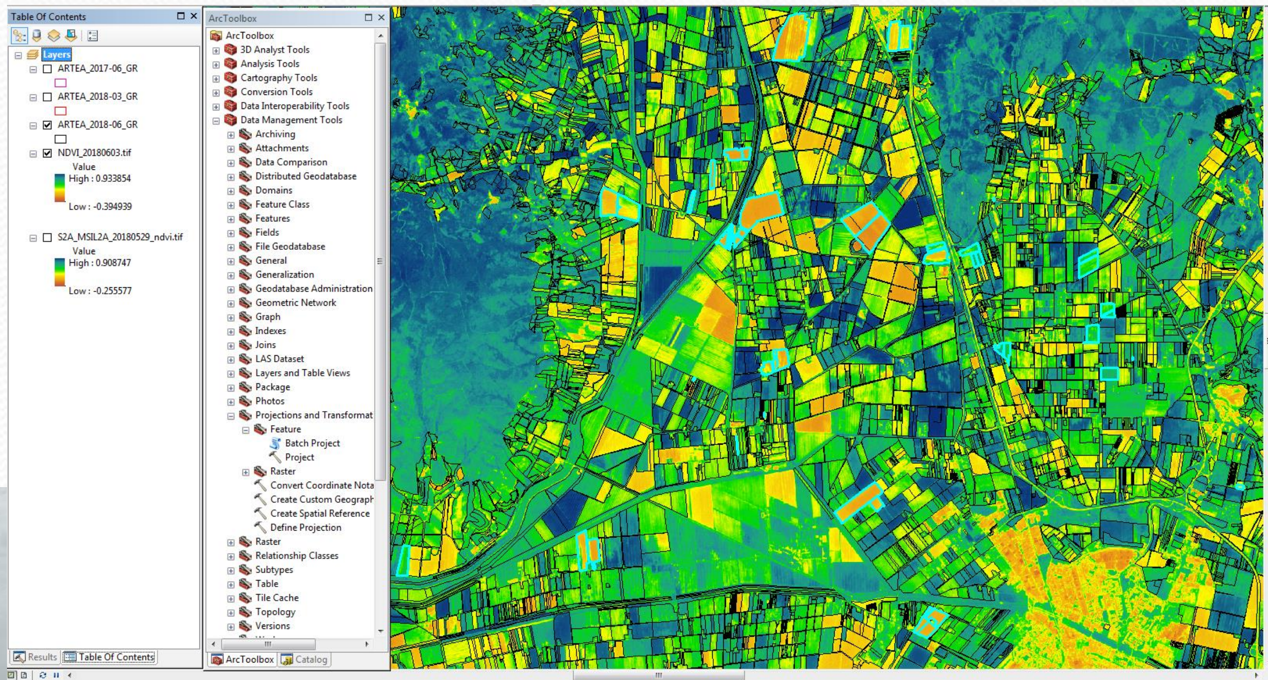
The regression estimator improves the statistical properties of a small ground sample by the use of an auxiliary variable extended over the entire study area.

$$\widehat{\mu}_y = \overline{y} + b(\mu_x - \overline{x})$$

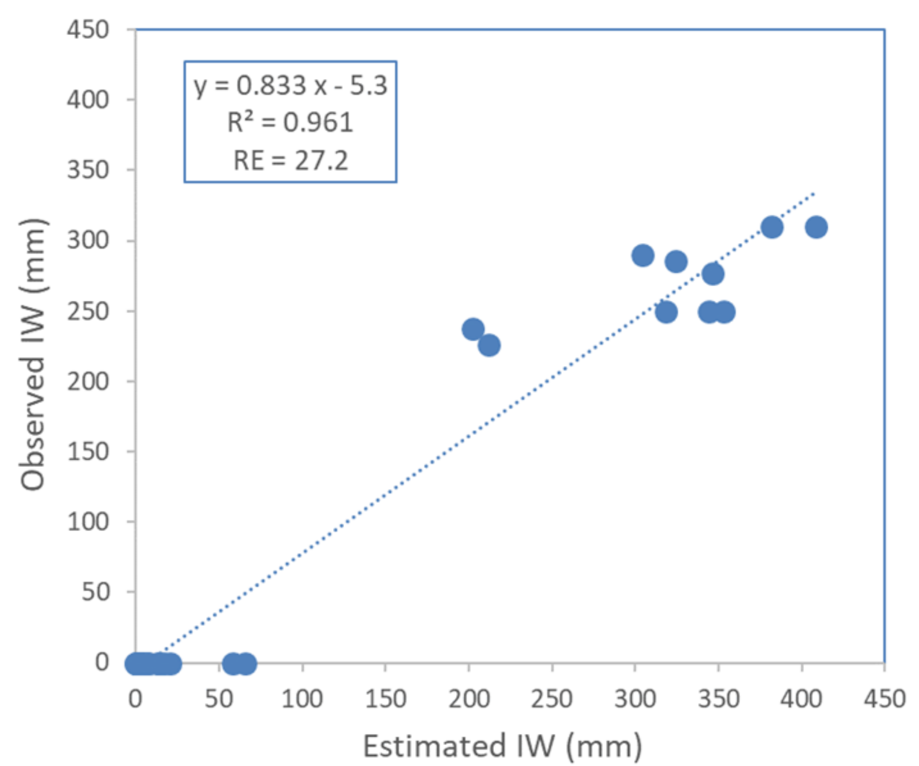
where $\widehat{\mu}_y$ is the estimated population average of the variable of interest, $\overline{y}$ is the sample average of the same variable, μ_x and $\overline{x}$ are the population and the sample averages of the auxiliary variable, and *b* is the slope of the regression between the two variables.

Ground truth available for 2018

- 5 selected tomato fields, both early and late varieties
- 5 selected corn fields, both early and late varieties
- 20 selected non-irrigated fields (wheat and barley)



Regression estimator



The application of the regression estimator improves the precision of the IW estimates, i.e. corrects the population average and reduces its uncertainty depending on the correlation between IW observed and estimated.

IW (mm)	Average	Standard deviation
Ground sample	93	131
Regression estimator	43	25

Relative Efficiency = 27.2

Conclusions

The previously proposed method can provide daily IW estimates in areas characterized by high land cover fragmentation, i.e. is capable of **identifying both not irrigated and irrigated cropped fields**, as well as of predicting the intensity and timing of irrigation events.

The statistical soundness of the IW estimates can be improved through the combination with few ground samples; in particular, the regression estimator can be proficiently applied to obtain enhanced IW predictions over wide areas.

This information can be utilized by public or private environmental stakeholders for planning and regulating the correct uses of water resources, whose demand is notably increasing due to both the ongoing climate change and the rising consume for human activities.

THANKS FOR YOUR ATTENTION!

Some references:

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