living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

Irrigation management through an energy-water balance model driven by remote sensing data

1 POLITECNICO MILANO 1863 2 CESBIO 3 VNIVERSITAT DE VALÈNCIA

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24 May 2022

The SMARTIES project methodology

An operative system to **monitor and forecast crop water need for parsimonious irrigation**

And to set an irrigation strategy: Increasing irrigation efficiency (ton/m³) and water productivity (€/m³)

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Politecnico di Milano (Italy)

Team:
Università degli studi della Tuscia (Italy)
CNR – ISAFOM (Italy)
Meteo operations Italia (Italy)
Aswan university (Egypt)
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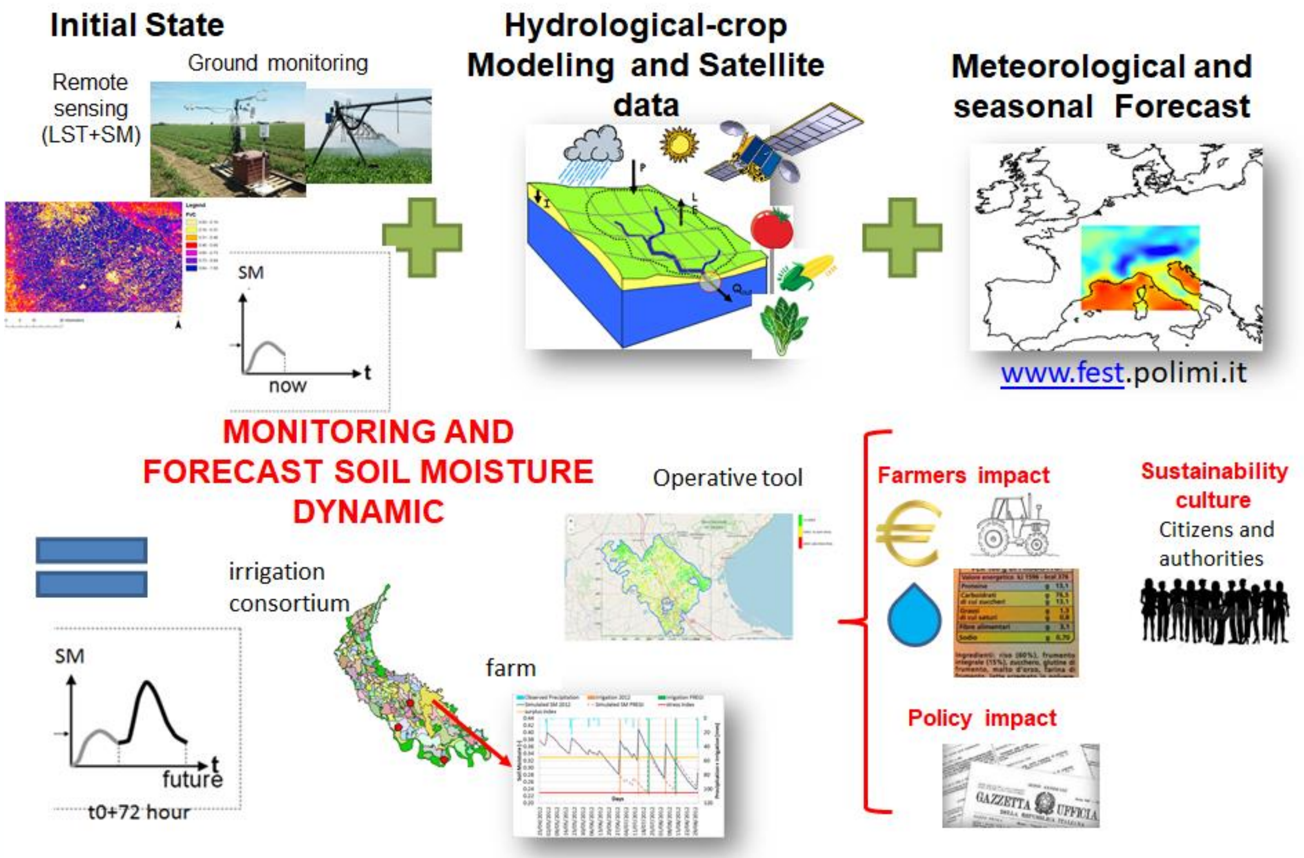
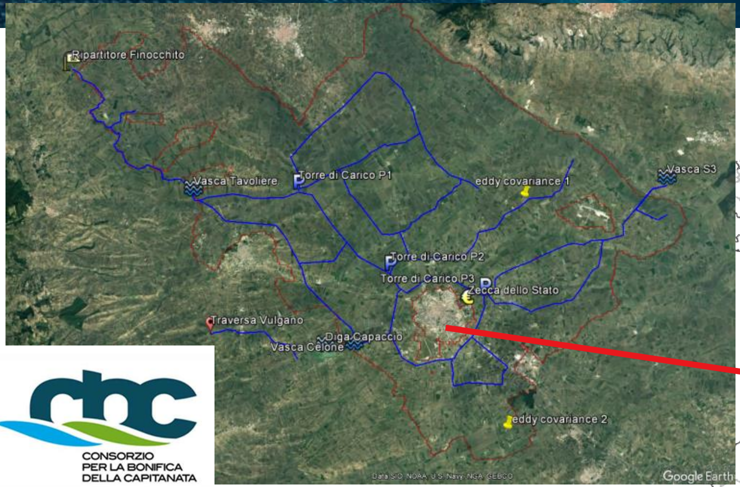
Centre d'Etudes Spatiales de la BIOsphère (France)
Luxembourg Institute of Science and Technology (Luxembourg)
Chouaib Doukkali University (Morocco)
Ecole Supérieure des Ingénieurs de Medjez El Bab (Tunisia)
Institut National de Recherches en Génie Rural, Eaux et Forêts (Tunisia)
Institut Supérieur Agronomique Chott Mériem (Tunisia)

Real time smart irrigation management at multiple stakeholders' levels

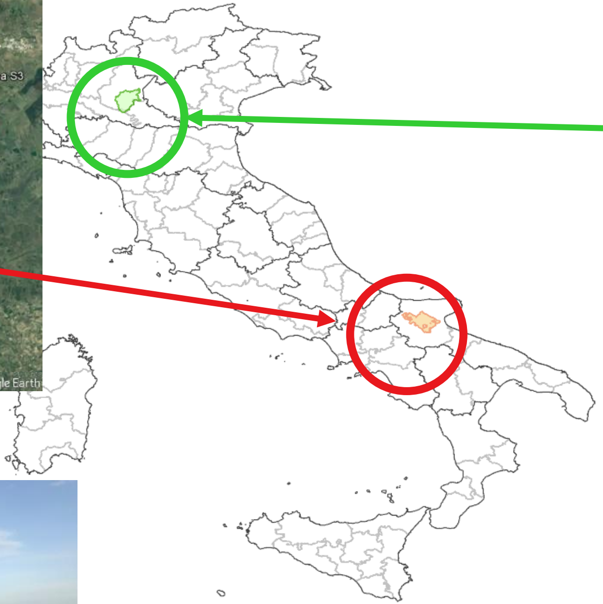


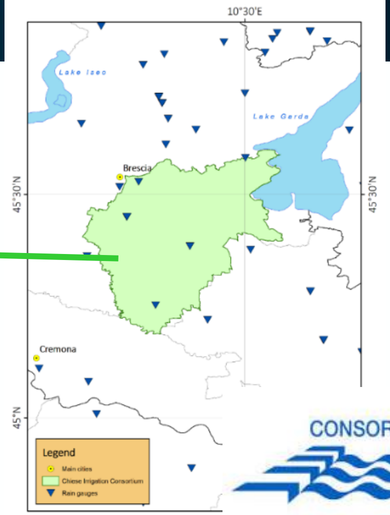
Capitanata and Chiese Irrigation Consortia case studies

esa

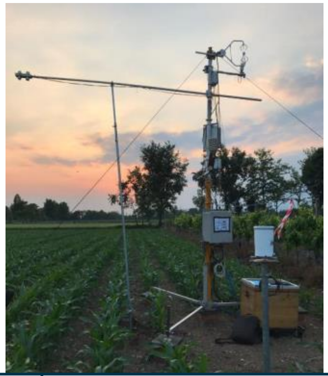


CONSORZIO PER LA BONIFICA DELLA CAPITANATA





CONSORZIO DI BONIFICA CHIESE



Eddy Covariance (EC) stations to measure ET and SM

Irrigation Consortia	Irrigated surface	Irrigation technique	irrigation timing
Chiese	20’000 ha	flooding irrigation	fix scheduled 7,5 days
Capitanata “Sud Fortore” district	50’000 ha	drip (70%) & spring (30%)	on demand

Hydrological model calibration: in-series technique using distributed satellite LST and local discharges

FEST-EWB model

J. Dooge (1986) observing internal state variables of hydrologic model (SM) and LST

Corbari & Mancini, 2014 (JHM)
Corbari et al., 2014, (HSJ)

Soil water balance

$$P_{tot} = R + ET_{eff} + D + (SM_{t+1} - SM_t) \cdot Z$$

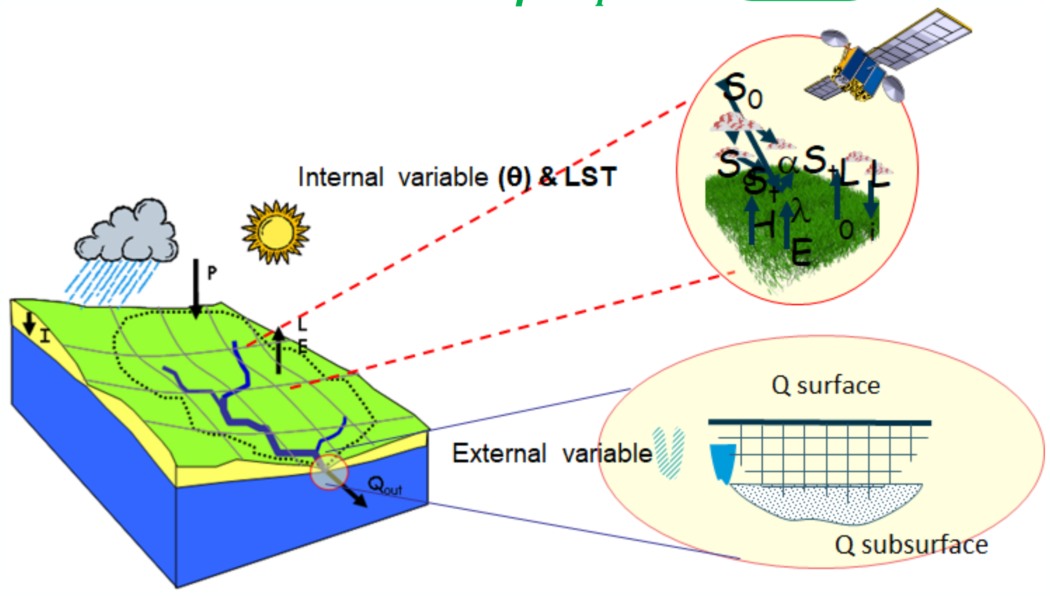
Energy balance

$$Rn - G - H - LE = \frac{dS}{dt}$$

$$ET_{eff} = \frac{LE}{\rho \cdot c_P}$$

FEST-EWB

$$[Rsd(1-\alpha) + Rld - \varepsilon_S B RET^4] - \frac{g}{dz}(RET - T_{zero}) =$$
$$= f_V \cdot \rho c \frac{RET - Ta}{r_A} + (1 - f_V) \cdot \rho c \frac{RET - Ta}{r_{ABS}} + f_V \cdot \frac{\rho c}{\gamma} \frac{e_S(RET) - e_A}{r_A + r_C} + (1 - f_V) \cdot \frac{\rho c}{\gamma} \frac{e_S(RET) - e_A}{r_{ABS} + r_S}$$



RET is the Representative Equilibrium Temperature, which is the **temperature that closes the energy balance equation**. The model generates the surface temperature (RET) as an output and allows a direct comparison with satellite LST (Land Surface Temperature) data. This supports model parameter calibration and instrument local ground monitoring extrapolation over large areas.

It is reasonable to use evaporation flux "measurements" similarly to discharge measurements

LST for soil surface parameters Calibration

Q for Calibration surface and subsurface routing parameters

Dooge, J.C.I. (1986). Looking for hydrologic laws, Water Resour. Res., 22 (9) 46S-58S.

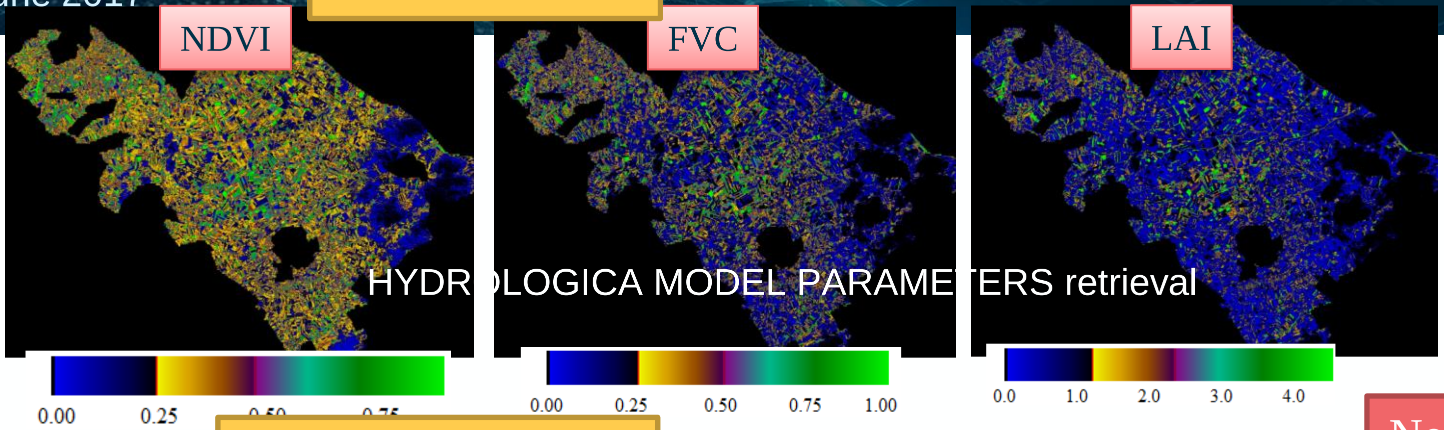
Operative satellite data and hydrological parameters and variables

5 june 2017

DATA integration **IMPROVES** revisit time

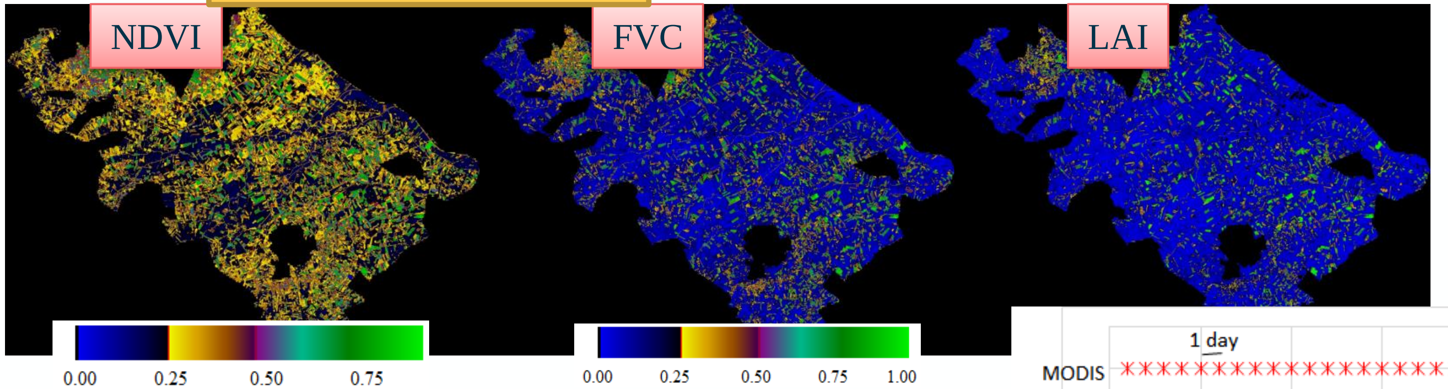
Sobrino et al., 2017

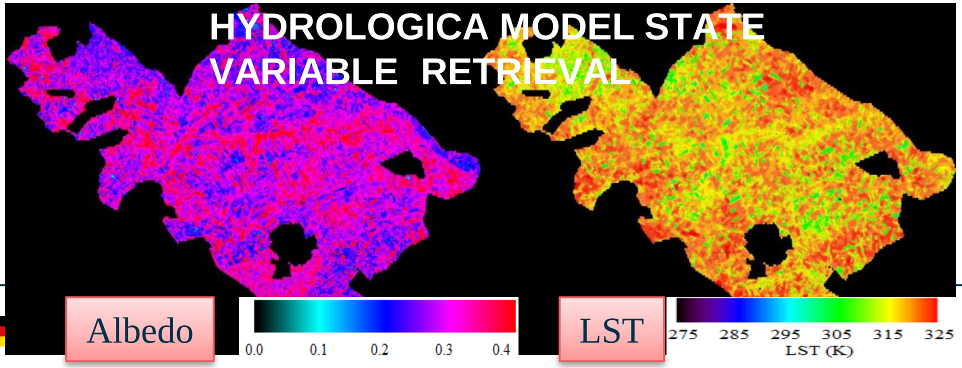
SENTINEL-2 MSI

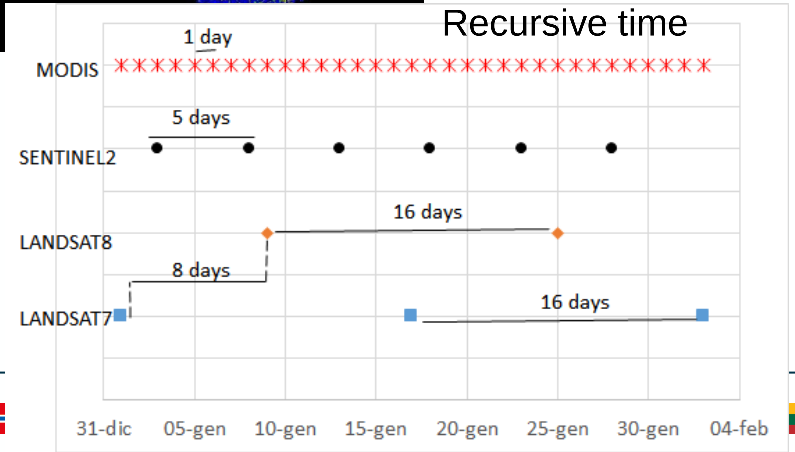


Near real time images

LANDSAT-8 OLI/TIRS

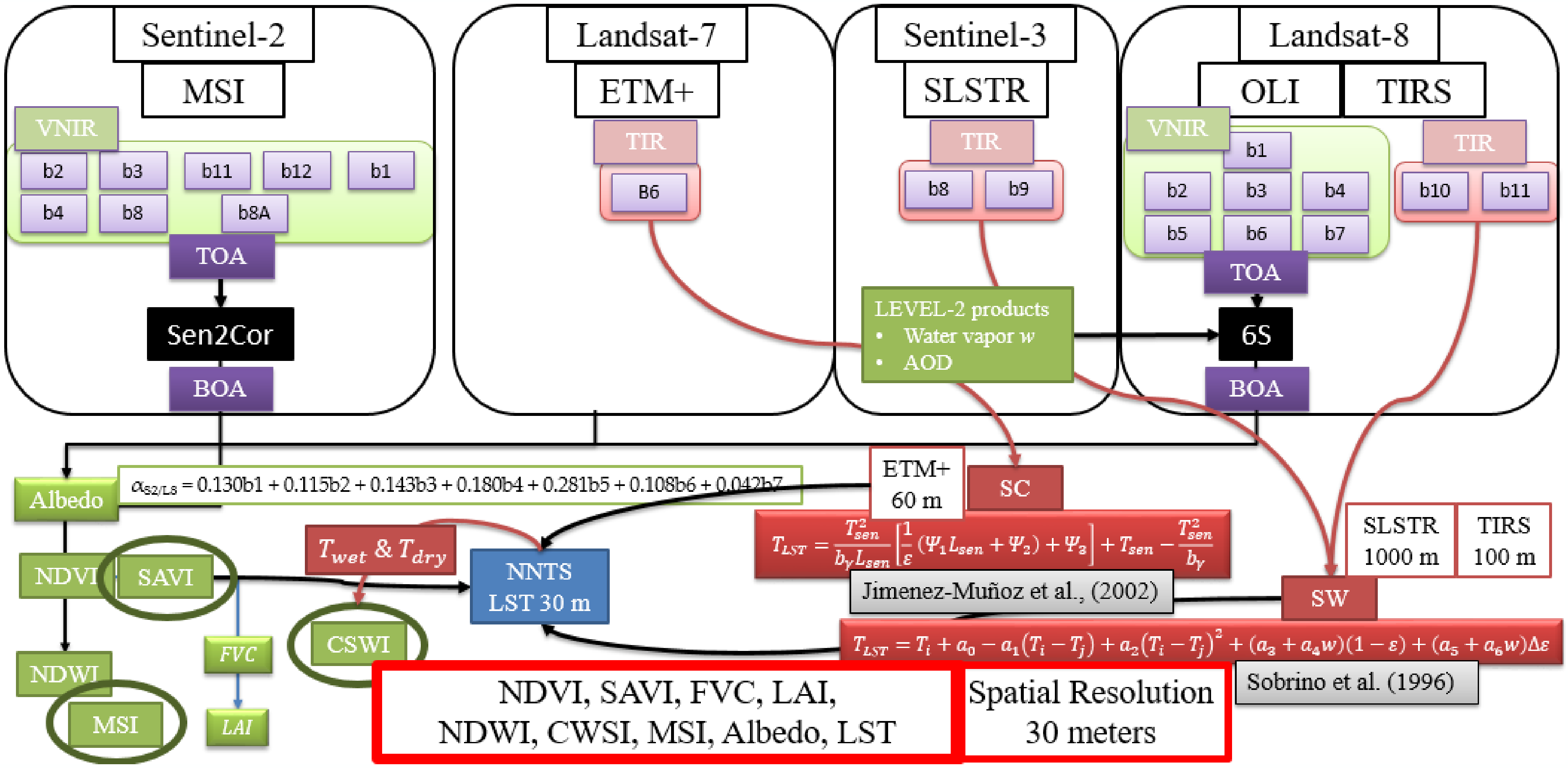






Satellite data retrieval: the real time chain

Processing chain and algorithms for near-real time satellite data



Satellite data retrieval: Land Surface Temperature

Sentinel-3 & Landsat-8 (1000 & 100 meters)

Split Window algorithm for LST retrieval

$$T_{LST} = T_i + a_0 + a_1(T_i - T_j) + a_2(T_i - T_j)^2$$

$$+(a_3 + a_4 w)(1 - \varepsilon) + (a_5 + a_6 w)\Delta\varepsilon$$

$$\varepsilon = f(NDVI - THM)$$

Landsat-7 (60 meters)

Single Channel (SC) algorithm for LST retrieval

$$T_{LST} = \frac{T_{sen}^2}{b_\gamma L_{sen}}\left[\frac{1}{\varepsilon}(\Psi_1 L_{sen} + \Psi_2) + \Psi_3\right] + T_{sen} - \frac{T_{sen}^2}{b_\gamma}$$

Nearest Neighbor Temperature Sharpening (NNTS) method (Skokovic, 2017).

Statistical relation at coarse satellite resolution

$NDVI + NDWI$

LST

→

NDVI-NDWI layer (30 m)

$LST = f(NDVI, NDWI)$

→

FINAL LST at 30 m

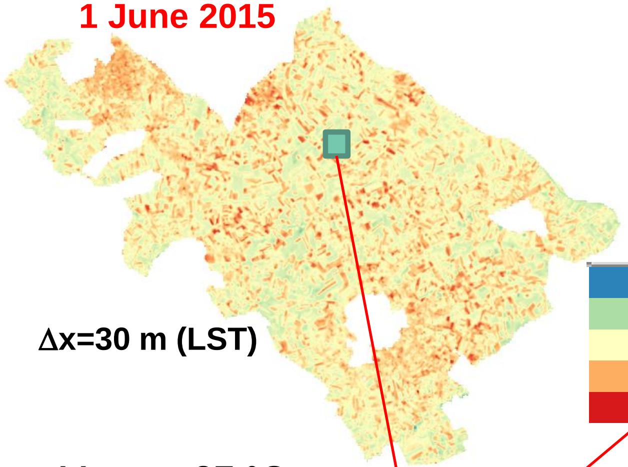
Satellite data and pixel-wise hydrological model
field and district scale Soil moisture monitoring

SATELLITE ⟷ **HYDROLOGICAL MASS ENERGY MODEL FEST-EWB**

LANDSAT 8 Surface Temperature

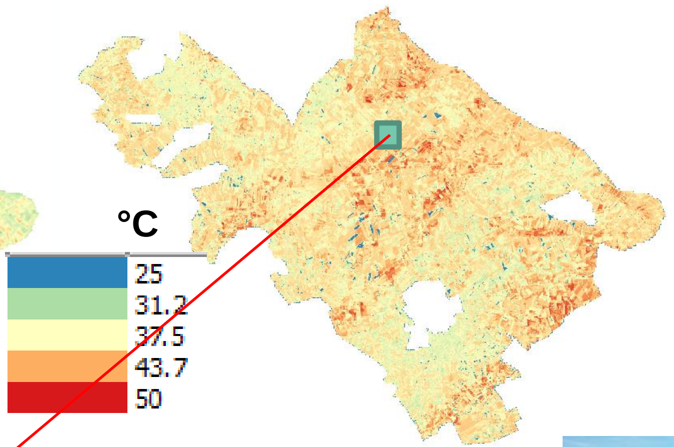
RET | **Soil moisture**

1 June 2015

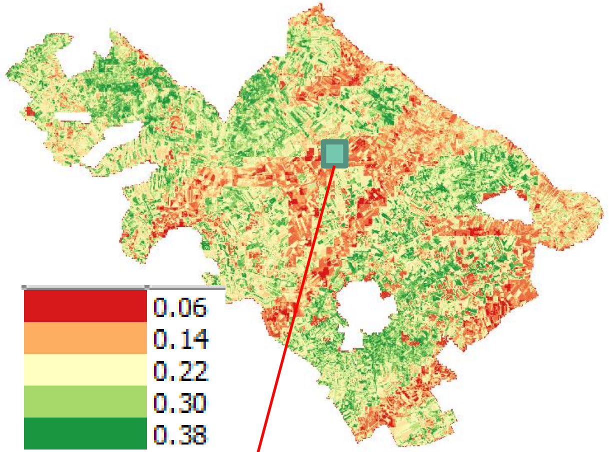


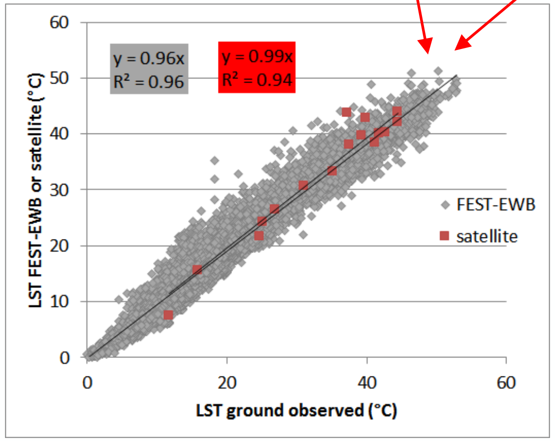
Δx=30 m (LST)

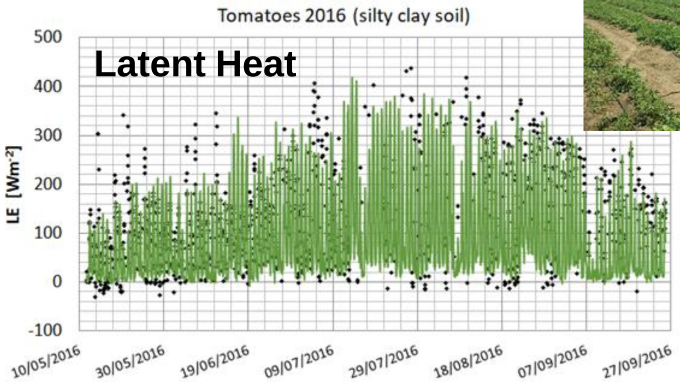
Mean = 37 °C

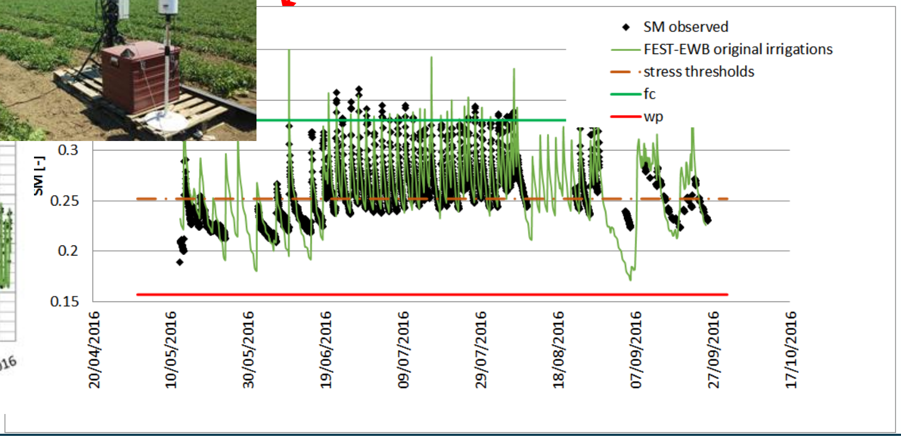


Mean = 36.5 °C







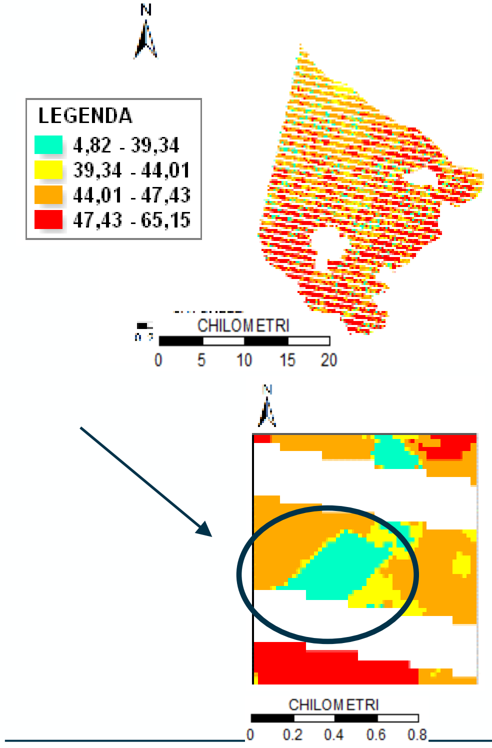


The effect of irrigation distribution on modeled fluxes

When irrigation is applied only in vegetated areas with **NDVI>0.3** (as per satellite data)**, LST from FEST-EWB correclty reproduces the satellite-observed LST**

SATELLITE LST

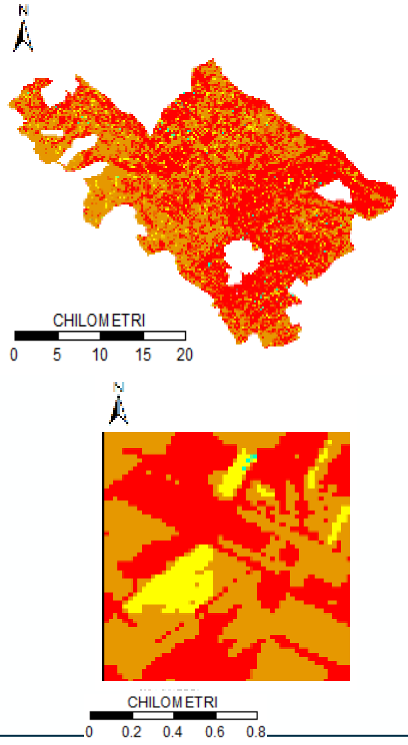
for 53 images 2017-2018



FEST-EWB LST

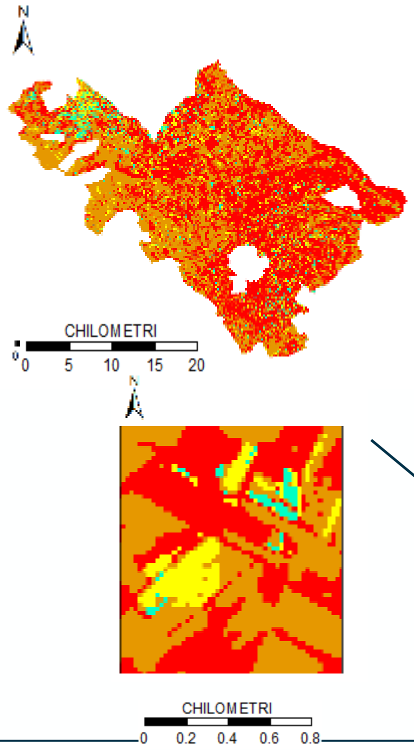
(a) Uniform distribution of irrigation

Mean error 4.7 °C



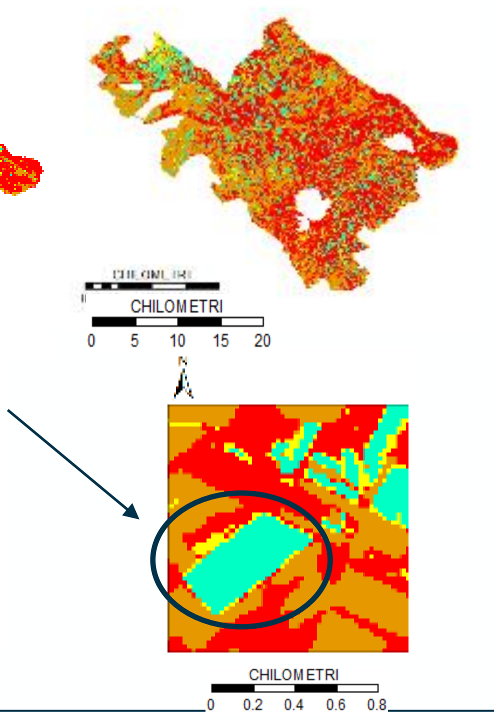
(b) irrigation in all vegetated area

Mean error 4.0 °C

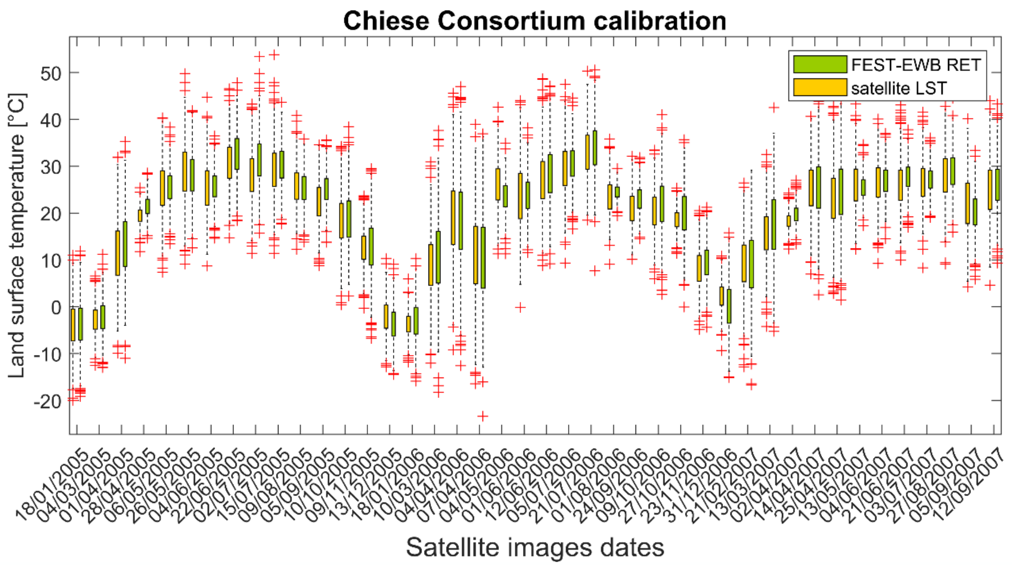


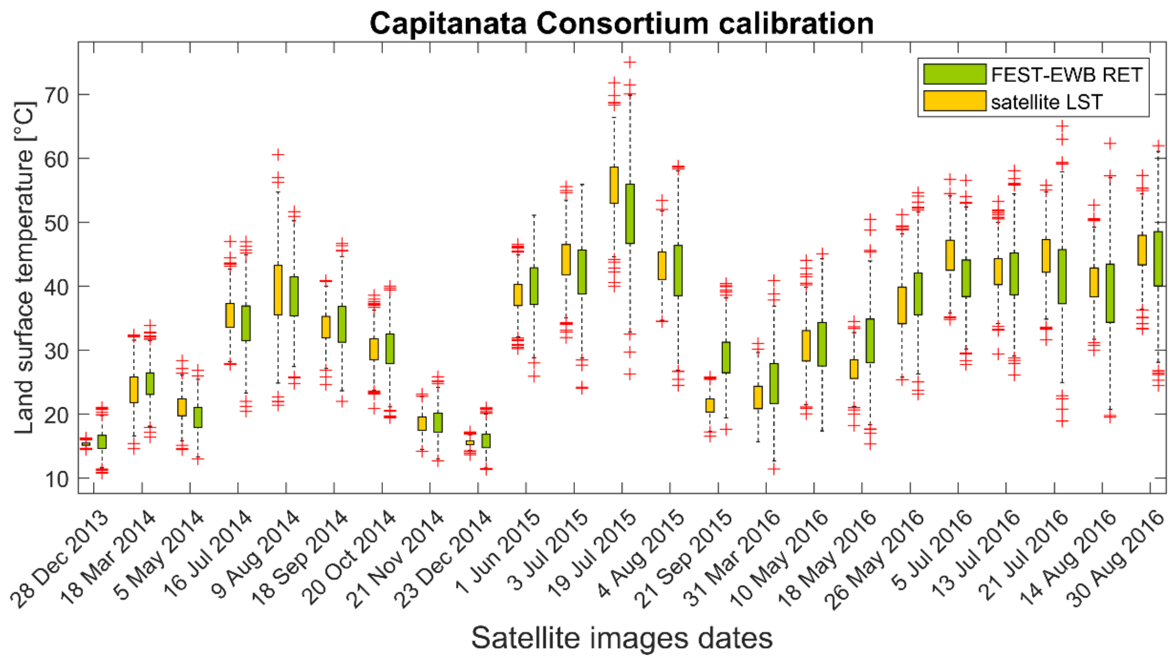
(c) Irrigation in all vegetated areas with NDVI>0.3

Mean error 3.5 °C



Soil water – energy model calibration against LST satellite at Consortium scale

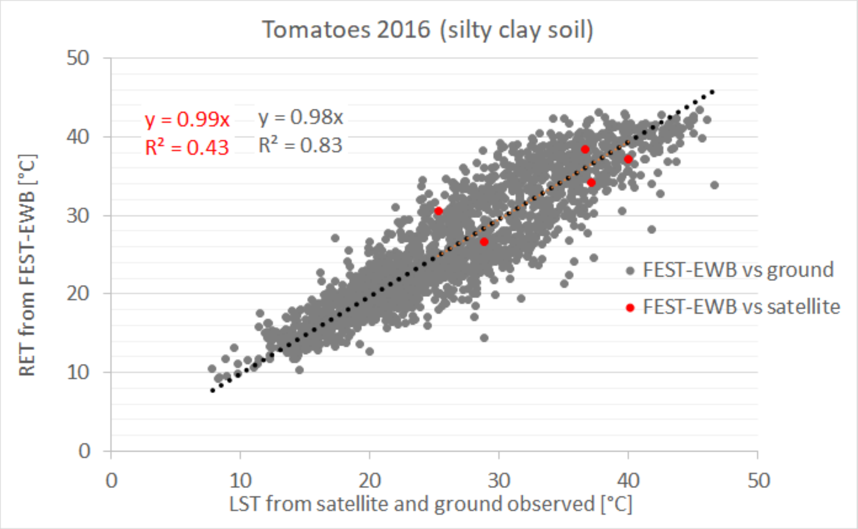


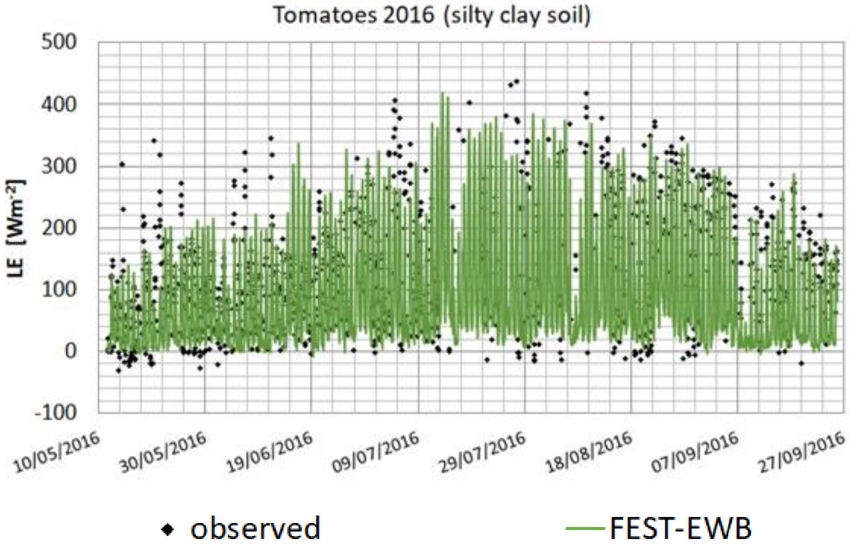


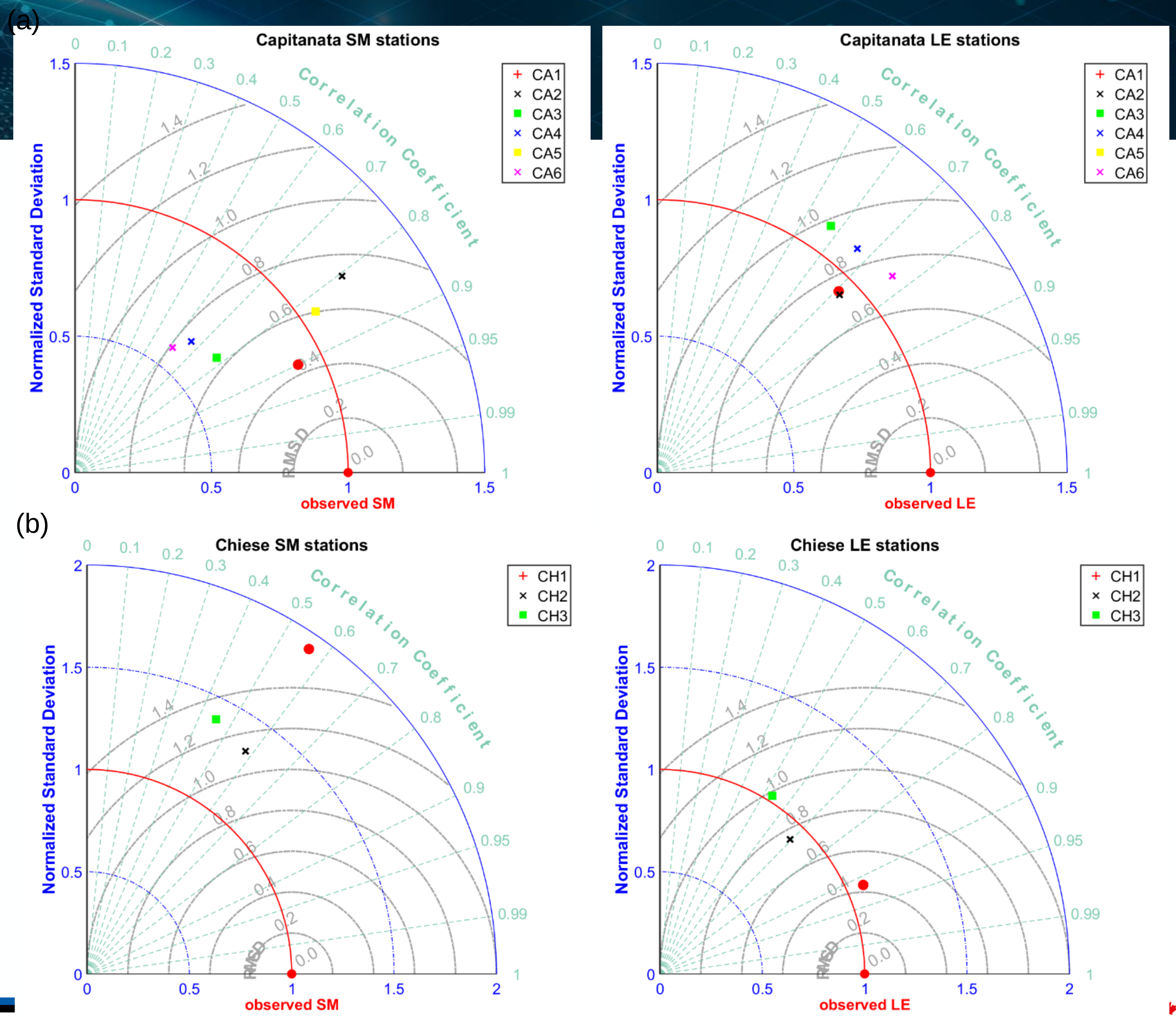
FEST-EWB model validation at field scale
Tomatoes field with sandy soil (2016)

After calibration

RMSE		(Rn-G) = m (H+LE)		R^2	
SM	0.07				
LST	2.2	LST	1.00	LST	0.80
LE	139.90	LE	0.84	LE	0.81
G	46.88	G	0.94	G	0.61
Rn	54.42	Rn	0.95	Rn	0.94
H	50.12	H	1.10	H	0.62






(a)
Capitanata SM stations
Normalized Standard Deviation
Correlation Coefficient
RMSD
observed SM
CA1
CA2
CA3
CA4
CA5
CA6
Capitanata LE stations
Normalized Standard Deviation
Correlation Coefficient
RMSD
observed LE
CA1
CA2
CA3
CA4
CA5
CA6
(b)
Chiese SM stations
Normalized Standard Deviation
Correlation Coefficient
RMSD
observed SM
CH1
CH2
CH3
Chiese LE stations
Normalized Standard Deviation
Correlation Coefficient
RMSD
observed LE
CH1
CH2
CH3

“SIM” IRRIGATION STRATEGY for water saving

The SIM strategy allows to decrease the passages over the FC threshold, reducing the percolation flux with a saving of irrigation volume

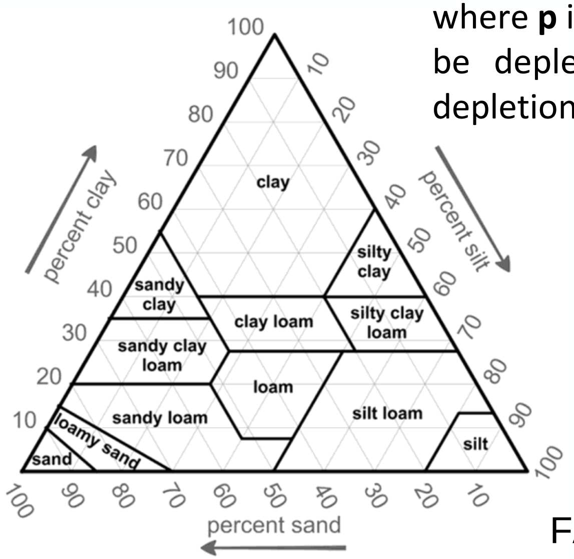
Irrigation intensity for irrigation system:

Drip
Sprinkler
Furrow

The SIM strategy is based on irrigating only when the soil moisture reaches FAO

Stress threshold = FC – p * (FC – WP)

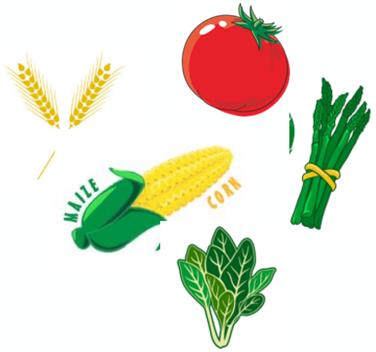
where **p** is the average fraction of Total Available Soil Water (TAW) that can be depleted from the root zone before moisture stress (Soil water depletion fraction), FC = field capacity, WP = wilting point.



SOIL Hydraulic Parametrization

FAO (Allen et al., 1996)

Vegetation types



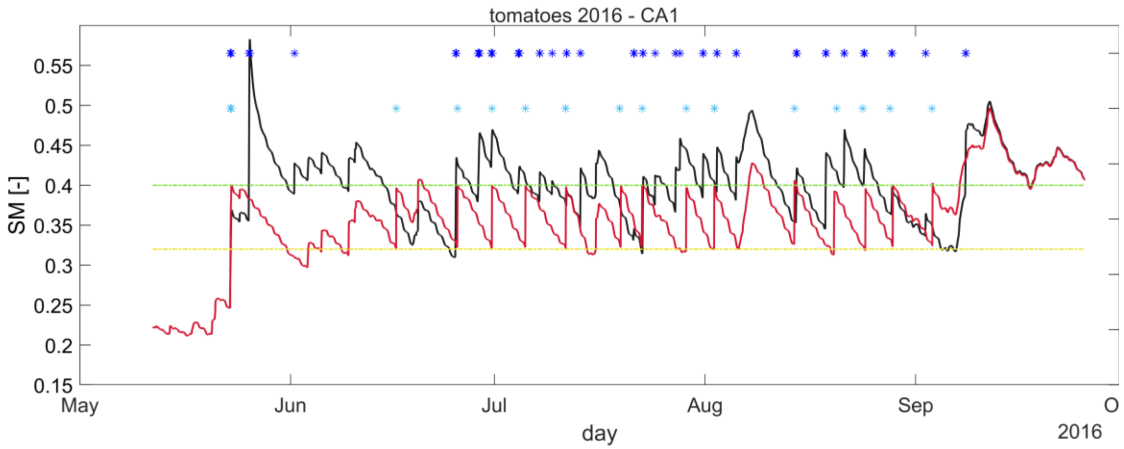
P is function of crop type

Crop	Threshold
Wheat	0.182
Corn	0.19
Sunflower	0.198
Barley	0.182
Poppy	0.166

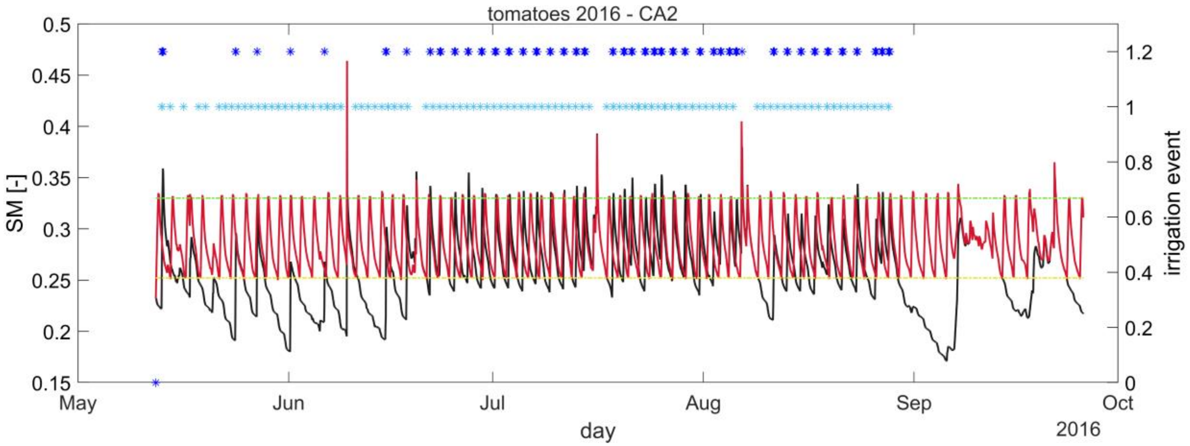
“SIM” IRRIGATION STRATEGY: effect on soil moisture

Capitanata Consortium fields: tomatoes

Silty clay soil



Sandy soil



		Irrigation (mm)	Number of irrigations	Rainfall cum (mm)
Farm 1 (2016)	**Observed**	**547.9**	**27**	**145**
	SIM	**322.3**	**15**	
Farm 2 (2016)	**Observed**	**646.6**	**43**	**150**
	SIM	**590**	**90**	
Farm 3 (2017)	**Observed**	**1000**	**43**	**28**
	SIM	**850**	**25**	

Tthe SIM strategy allows to reduce the passage over the FC threshold reducing the percolation flux with a saving of irrigation volume

FEST-EWB & SAFY model: crop yield

FEST-EWB: Flash – flood Event – based Spatially – distributed rainfall – runoff Transformation – including Energy - Water Balance
SAFY : (Simple Algorithm For Yield Estimate)

Soil water balance

$$P_{tot}=R+ET_{eff}+D+(\theta_{t+1}-\theta_t)*Z$$

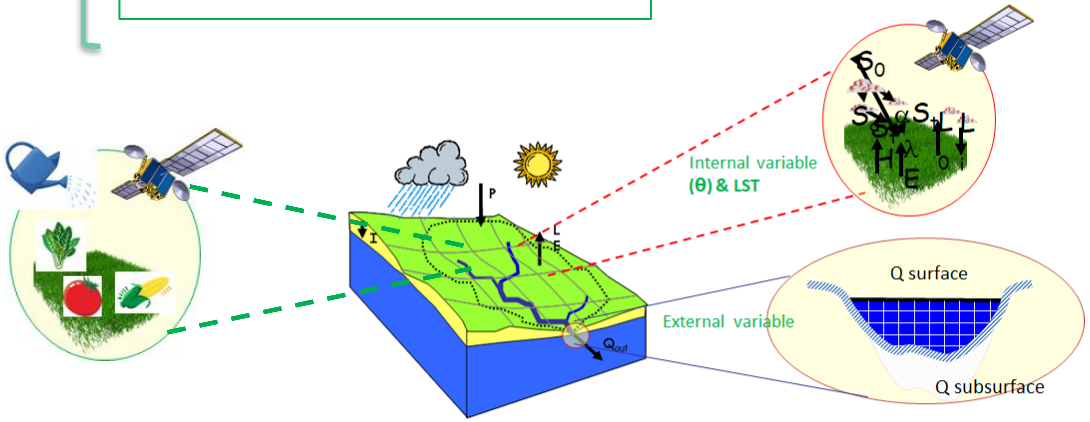
Energy balance

$$Rn - G - H - LE = \frac{dS}{dt} \qquad ETeff = \frac{LE}{rCp}$$

Crop grow

$$\Delta DAM = APAR \cdot Pgro\_Lue \cdot F_T(Ta)K_s$$

Corbari & Mancini, 2014 (JHM)
Corbari et al., 2014, (HSJ)
Battude et al., 2018,
Duchemin et al .2008



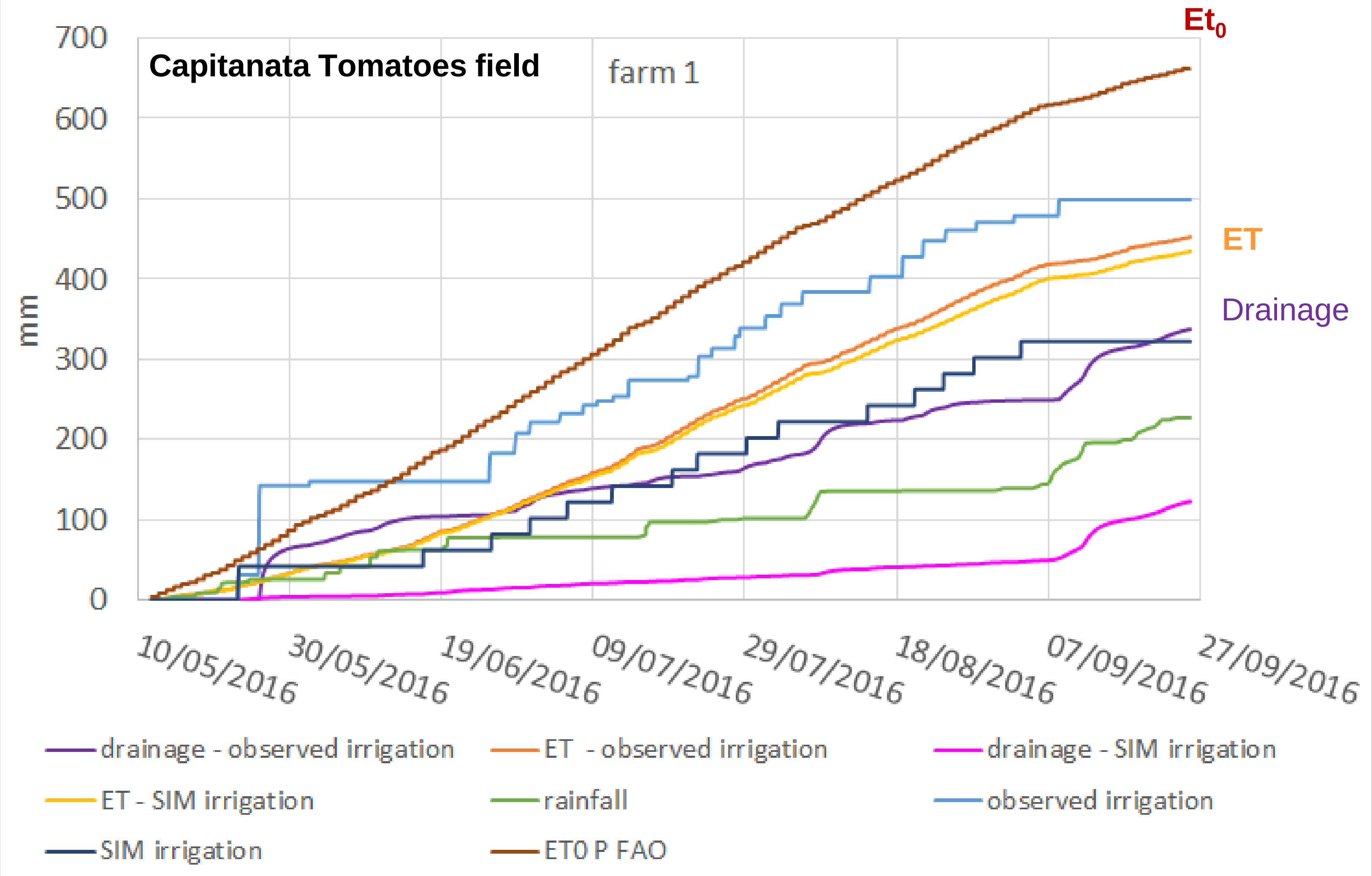
LST (SM,ET) for soil surface parameters Calibration pixel by pixel

LAI for crop parameters Calibration

Q for Calibration surface and subsurface routing parameters

“SIM” IRRIGATION STRATEGY: saving water and improve water efficiency?

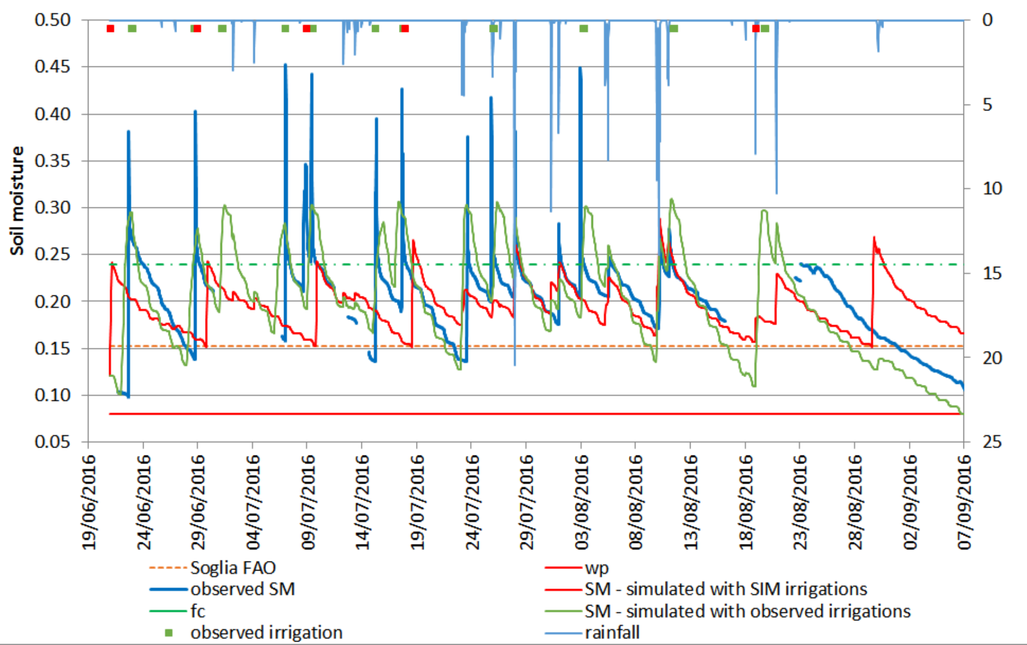
Rainfall	+ Irrigation	=	ET	+ Drainage	+ DW		
145	+ 547	=	450	+ 320	- 70	(mm)	
145.	+ 322	=	440	+ 110	- 80	(mm)	SIM IRRIGATION

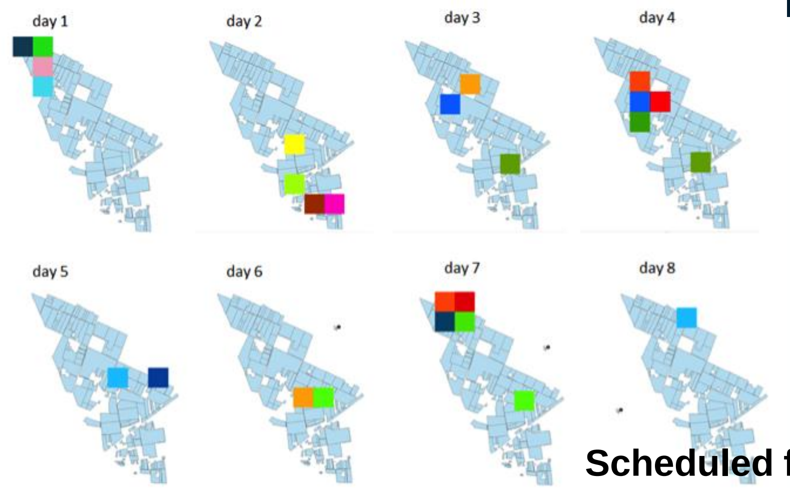


Tomatoes Crop yield:
-with observed irrigation **120** ton/ha
-with SIM strategies **116,3** ton/ha

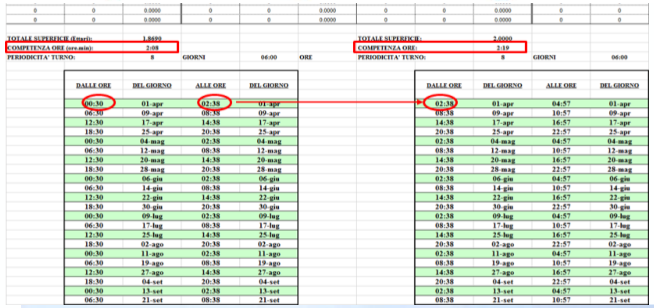
"SIM" IRRIGATION STRATEGY: REANALYSIS RESULTS on soil moisture

Chiese irrigation consortium Fields, Maize





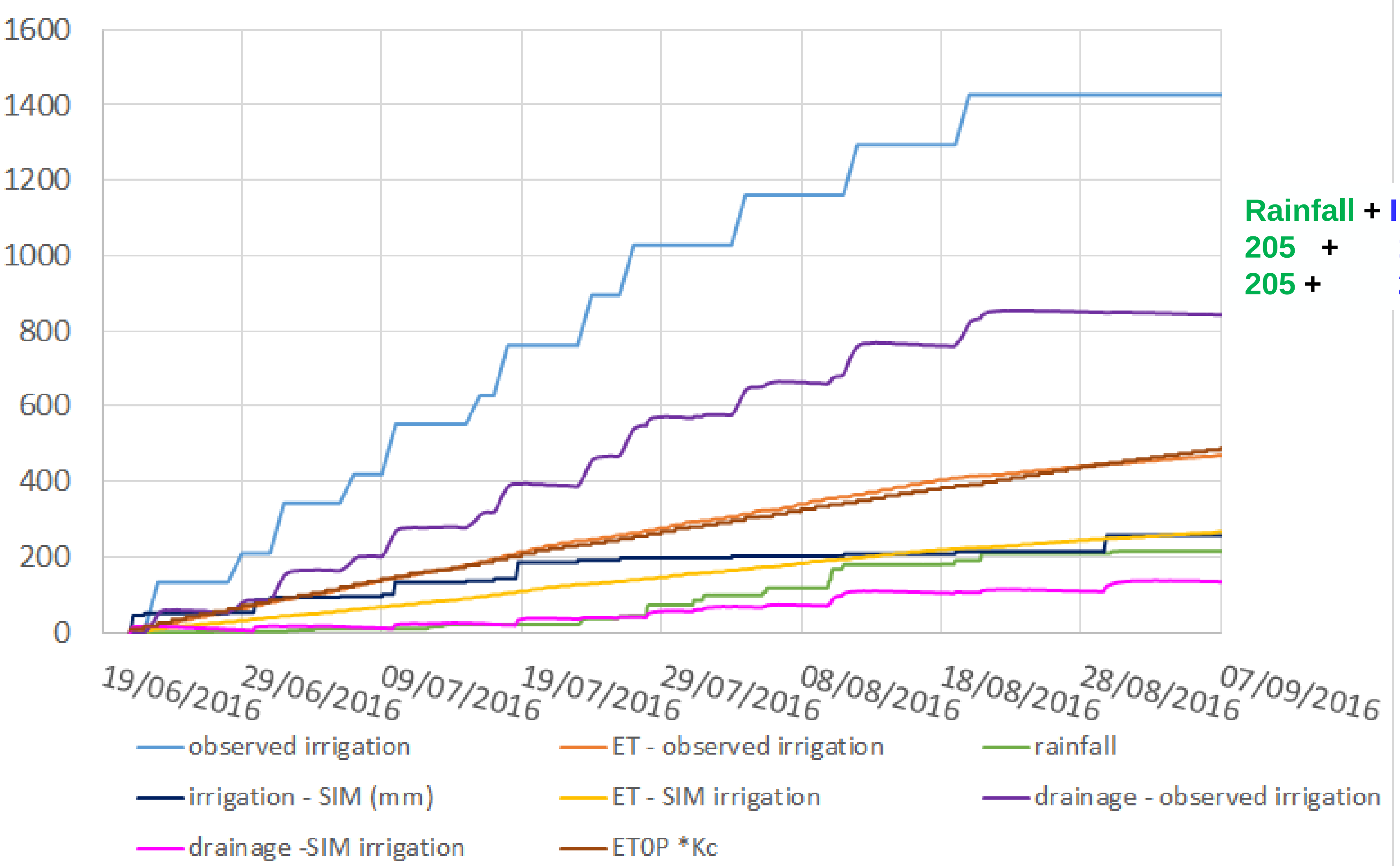
Scheduled flooding irrigation



		Irrigation (mm)	Number of irrigations	Rainfall cum (mm)
2016	**Observed**	**1426**	**11**	**269**
	SIM	**301**	**5**	
2017	**Observed**	**1480**	**17**	**223**
	SIM	**488**	**10**	
2018	**Observed**	**1750**	**13**	**515**
	SIM	**200**	**5**	

"SIM" IRRIGATION STRATEGY: where are we saving water?

Chiese irrigation consortium **Maize fields – Northern Italy**



Rainfall + Irrigation = ET + Drainage + DW

205 + 1450 = 500 + 870 –285 (mm)

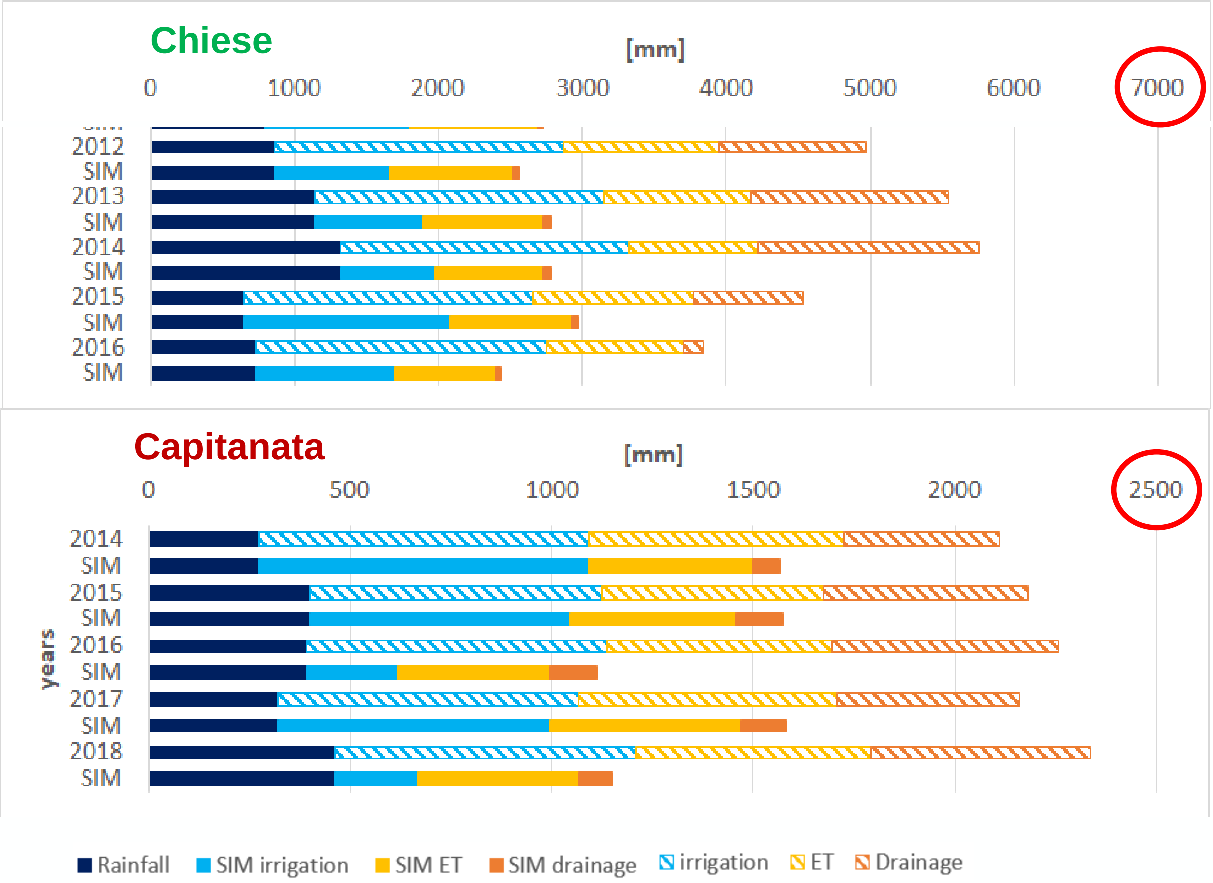
205 + 290 = 295 + 170 – 30 (mm) SIM

Crop yield:

-with observed irrigation **9,1** ton/ha

-with SIM strategies **8,9** ton/ha

SIM IRRIGATION OPTIMIZATION STRATEGY:
Comparing consortium scale: water fluxes



The coupled FEST-EWB – SAFY model – SIM irrigation strategy

Comparing consortium scale: economic indices

Irrigation water use efficiency

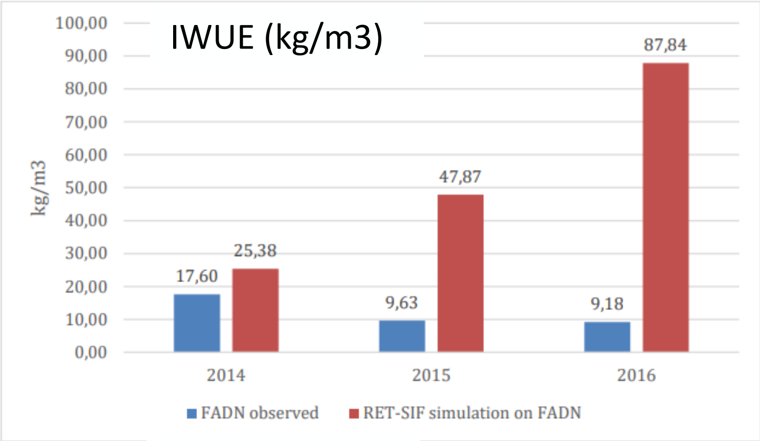
$$IWUE = \frac{Yield}{Irr\ vol} = \frac{kg/ha}{m^3/ha}$$

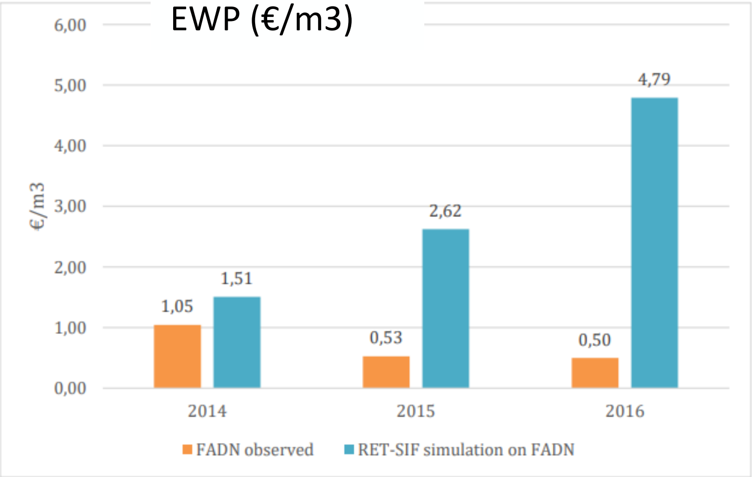
economic water productivity

$$EWP = \frac{Gross\ margin}{Irr\ vol} = \frac{€/ha}{m^3/ha}$$

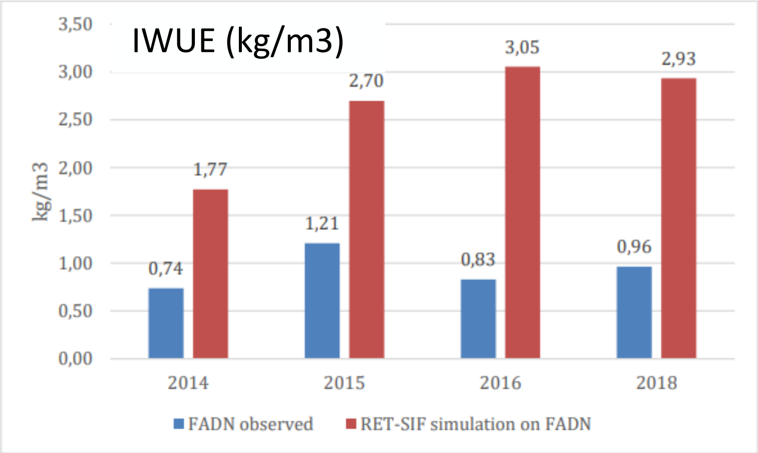
Observed: EU Farm Accountancy Data Network (FADN)
SIM: simulated with FEST-EWB-SAFY model

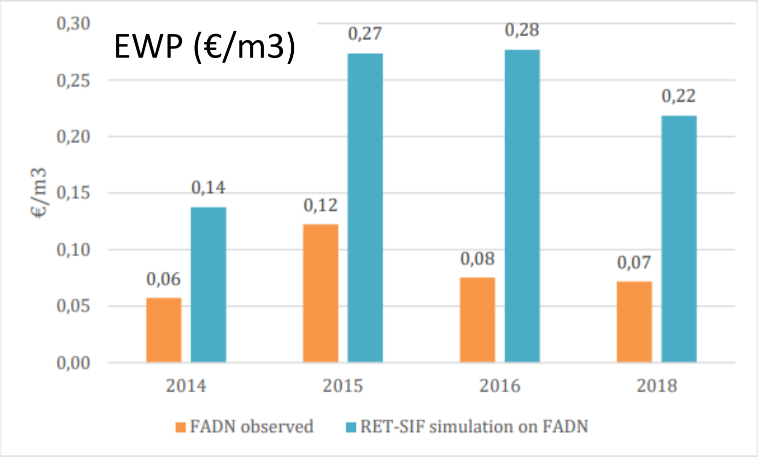
Tomatoes Capitanata consortium





Maize Chiese consortium





The SIM dashboard WATER INFORMATION SYSTEM

Real-time monitoring:
www. sim.polimi.it

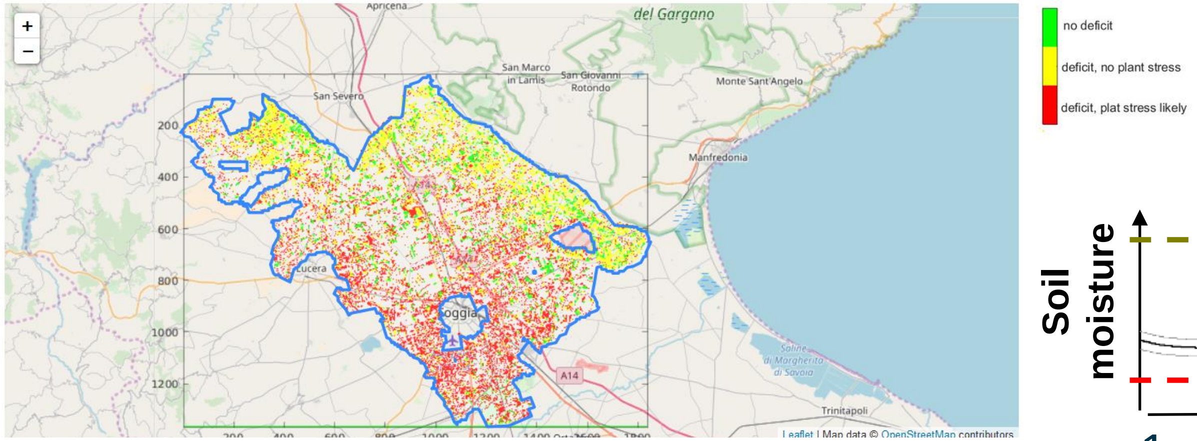
Capitanata sud Fortore agricultural basin: Water deficit

The following map displays the daily mean water deficit obtained coupling a hydrological model (FEST-EWB or ETMonitor) with several meteorological models outputs (WRF, ECMWF, BOLAM, MOLOCH). In green the areas where soil moisture is higher than the field capacity, in yellow the areas where soil moisture is in between the field capacity and the crop stress threshold, in red the areas where soil moisture is below the crop stress threshold.

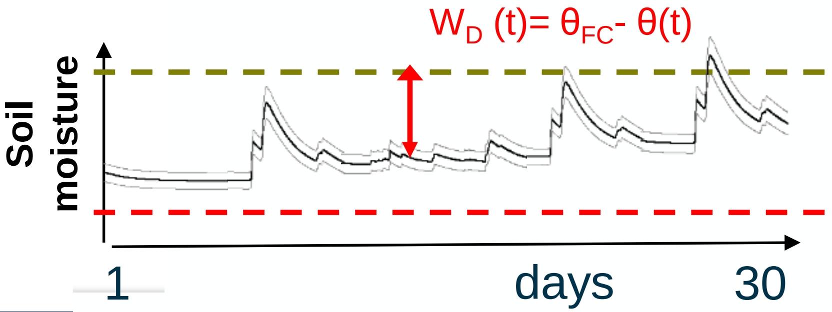
Idrological Model: FEST EWB | Emission Date: 2017-10-16 | Forecast time: Present | Apply

Reset Map | Histogram

Basin scale



Area
50'000 ha



Daily spatial mean for the agricultural basin

spatial mean for present and forecasted hydro-meteorological outlooks. The "Present" column is computed with observed meteorological data. The highlighted sector refers to interval of hydro-meteorological model outlooks.

Concluding remarks

- Satellite data may provide a significant help in distributed hydrology, in particular for field and basin surface hydrology. This is especially assessed if hydrological models equations explicit those variables retrievable directly from Satellite remote sensing (e.g., LST).

- The synergy with remote sensing data helps to achieve these results: a) in surface model calibration; b) in state variable retrieval

- Distributed hydrology, for its intrinsic nature, can support water engineering