

Remote Sensing and Citizen science supporting irrigation monitoring in the Capitanata Irrigation Consortium (Italy)

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 **GROW OBSERVATORY**

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Citizen science: GROW h2020 project



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Growing

Whatever your scale, location or experience, your food production can benefit, and you can make a difference.



Science

Help us address science challenges and data gaps, from creating soil maps to enhancing climate prediction models and Earth observation from satellites.



Policy

Together we will build evidence to support policy change towards climate action, zero hunger and life on land.

a sustainable citizen platform and community to generate, share and utilise information on land, soil and water resource

Sensors by Location



 **GROW OBSERVATORY**

The Italian GROW observatory

- **456** multi-purpose low-cost sensors (*Parrot Flower Power*) have been scattered in the Capitanata Irrigation Consortium (Apulia, Italy)

They measure: **Soil moisture**

surface air temperature

illuminance



<https://knowledge.growobservatory.org/index.html@p=1196.html>

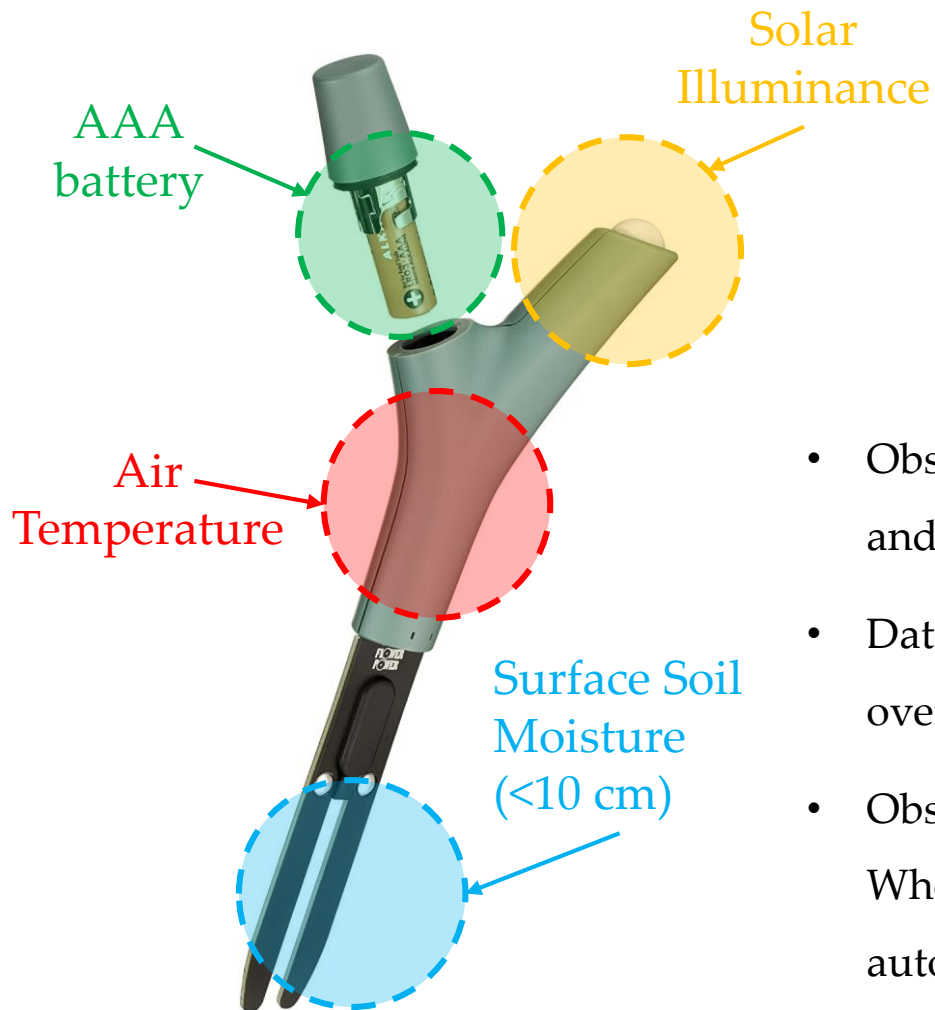


1 Data gathered by the on-ground sensor network have been compared to those of a **professional station** those obtained by **remote sensing data**

2 Data from the sensors has been used to formulate two irrigation-driving indicators, called **Irrigation Water Needs** (IWNs) based on SM thresholds (**SM-IWN**) Evapotranspirational demand (**ET-IWN**)



Parrot Flower Power specifics



Variable	Unit	Range	Accuracy
Air Temperature	°C	-5 to +50 °C	1.5 °C
Solar Illuminance	Lux	0.1 to 200 lux	15 %
Surface Soil Moisture	Vol %	0 to 50%	3 %

- Observations are automatically taken every **15 mins** and stored on the device
- Data can be saved for up to 80 days before being overwritten
- Observations can be accessed via app. When positioned in close vicinity of the sensor, it automatically connects via the Bluetooth Low Energy (LE) protocol, collecting the data and uploading it to a cloud database

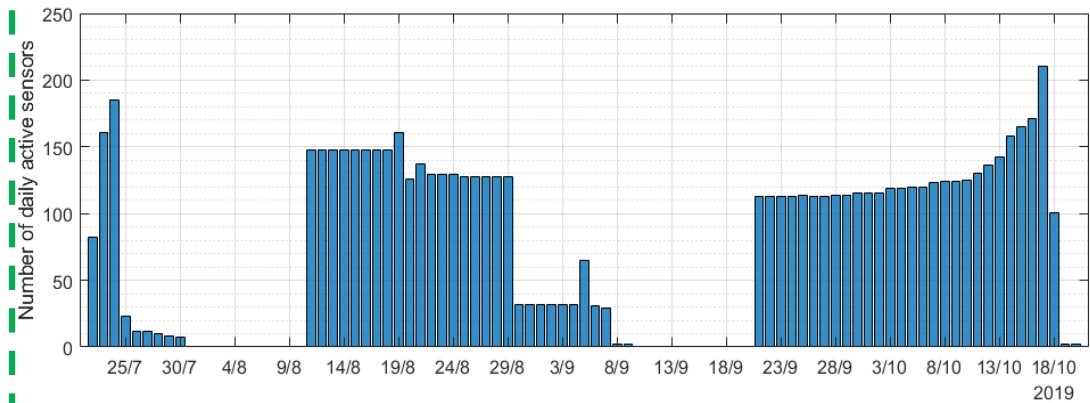


Parrot Monitoring statistics

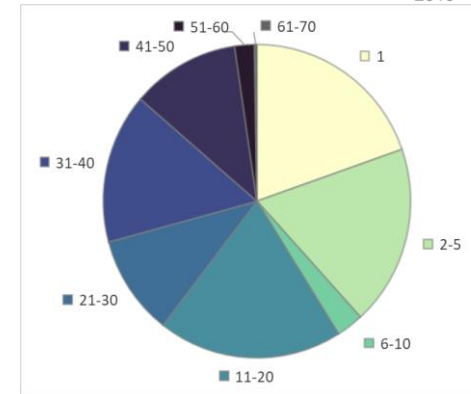
Monitoring period, 91 days

22nd July - 20th October 2019

Two **no-data periods**: early August and first half of September. In the other days, there were **102 active** sensors.



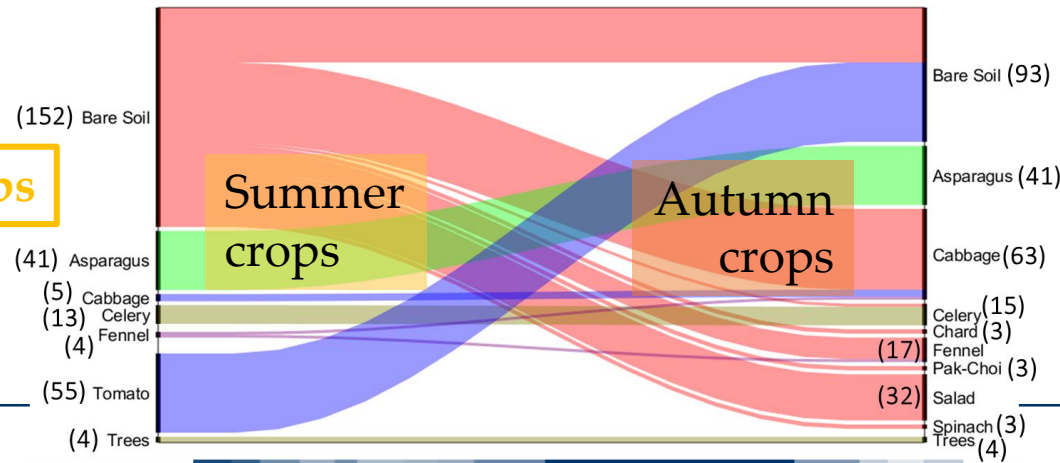
The average number of days with data for a given sensor was **18.76** sensors (20%) provided data for only **1** day, 158 (41%) provided at most 20 data-days.



In **Summer** most sensors are placed in **bare-soil** fields. The only active crops are **Asparagus** and **Tomato**

In **Autumn** all the **Tomato** has been harvested (going back to **Bare Soil**) and some winter vegetables have started their growth. The most represented is **Cabbage** (56 sensors)

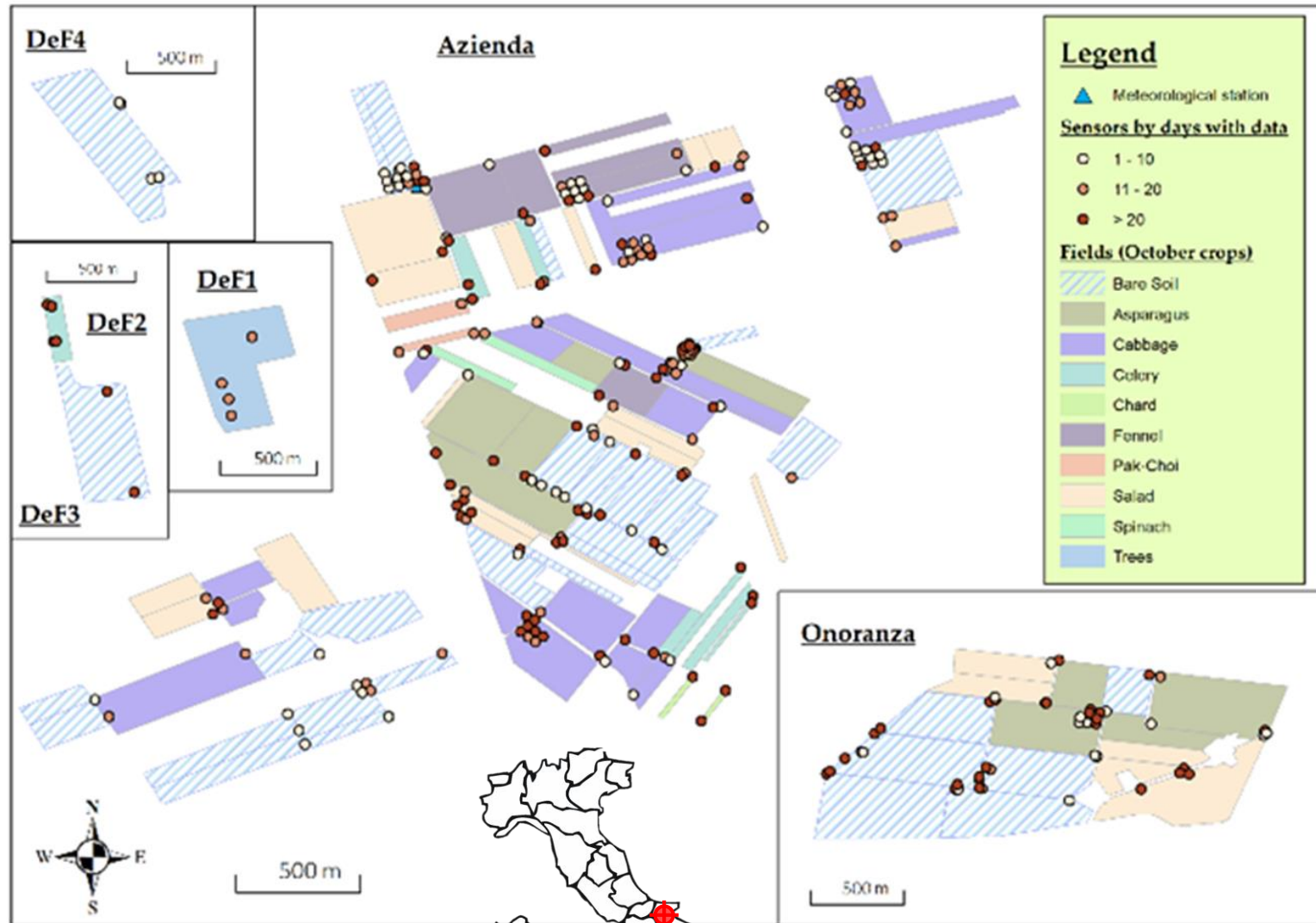
Crops







Sensor distribution (Autumn crops)





Air temperature parrot data and satellite LST

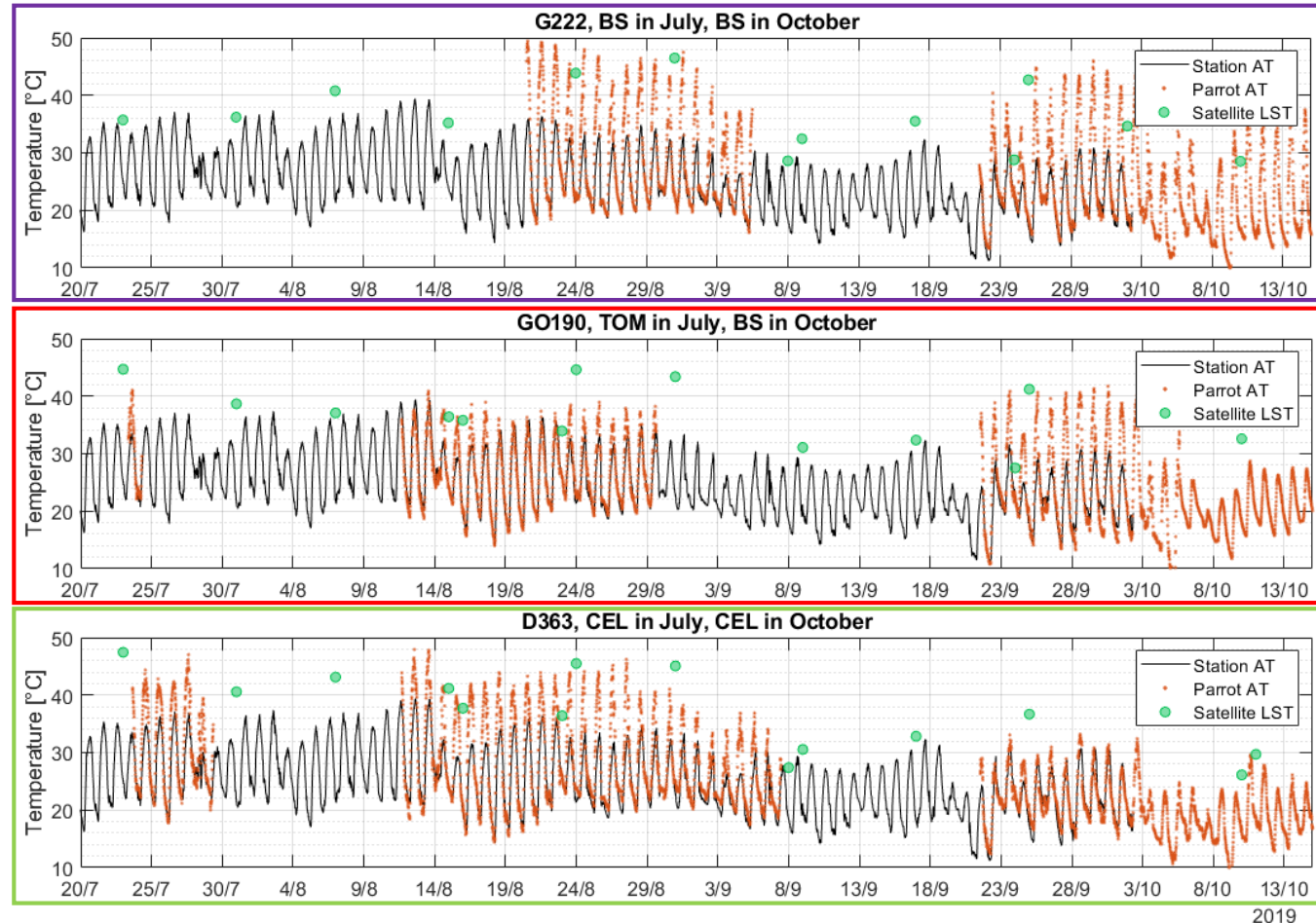


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The Air Temperature (AT) sensors measurements have been compared with those from the Davis stations and the Land Surface Temperatures (LSTs) from Landsat 7 and 8 (with resolution 30m).

Bare-field sensors provide data close to the stations' in the night-time, with higher values during the day (+10°C). This may be due to the height difference: 10 cm (sensors) against 2 m (station).

Tomato-field data show the plants shadow, with lower temperatures before the harvest.



A **Celery**-field sensor shows a progressive temperature decrease along with the plant growth.

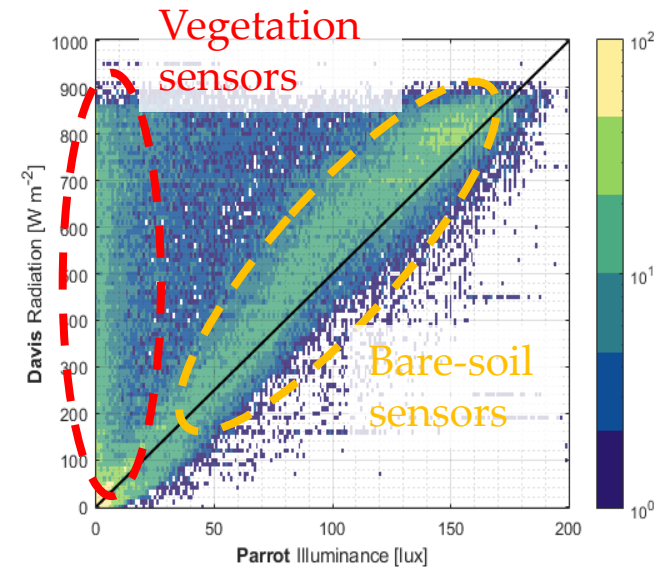


Solar Illuminance and satellite LAI data

Solar Illuminance data from the sensors has been employed as a proxy to evaluate solar radiation attenuation caused by leaf shadow over the Parrots.

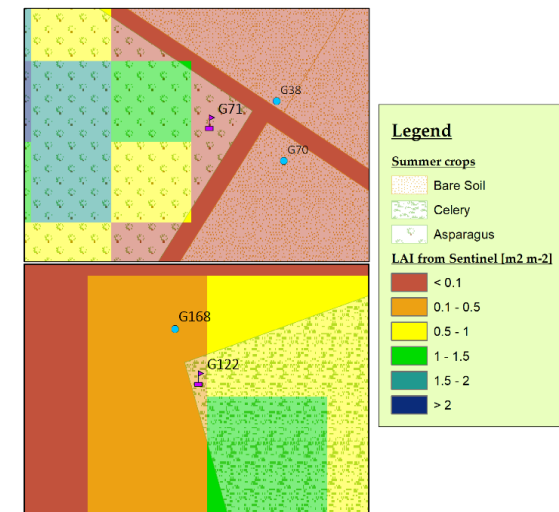
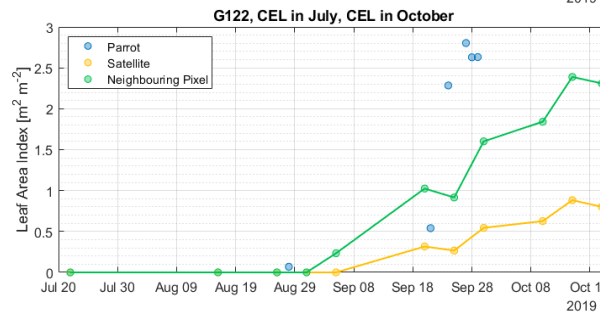
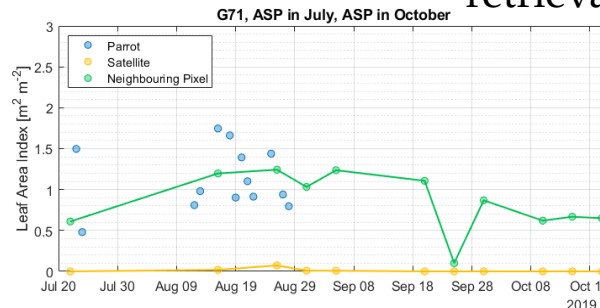
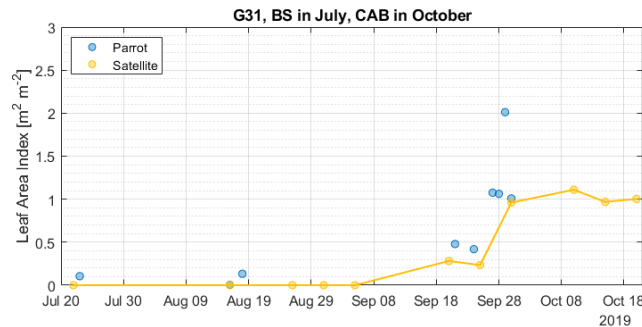
$$LAI = -\frac{\ln\left(\frac{I_{veg}}{I_{bare}}\right)}{K(\varphi)} \quad K(\varphi) \stackrel{\text{def}}{=} \frac{\sqrt{x^2 + \tan^2(\varphi)^2}}{x + 1.774(x + 1.182)^{-0.733}}$$

With the formulas above, the Leaf Area Index (LAI) can be obtained, to be compared with satellite retrievals from Sentinel-2 (30m).



Field-corner sensors can be **misinterpreted** by the satellite retrieval (Landsat and Sentinel 2 data)

Some **positive**-correspondence cases occur

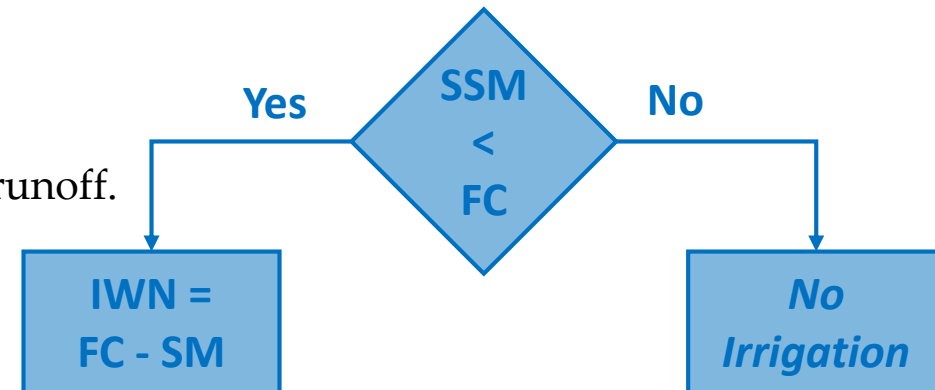




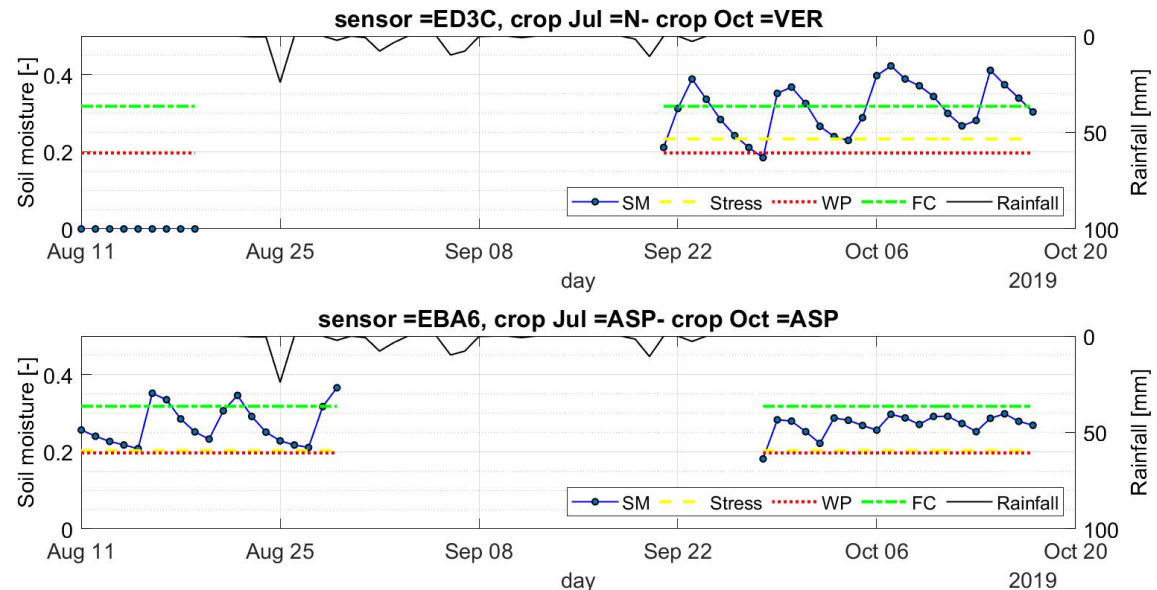
Surface Soil Moisture (SM) data could be employed to formulate an operative tool for irrigation water computation: the SM-based Irrigation Water Need (**SM-IWN**).

The base-principle is to keep the soil SM as close as possible to the Field Capacity threshold, in order to minimize water losses by superficial runoff.

- If $SSM > FC$, no irrigation is provided
- If $SSM < FC$, the irrigation amount is defined as the water input required to increase the SSM up to the FC threshold



two examples of **SM dynamics**.
The ups and downs caused by the irrigation events are clearly visible. Apart from the **Field Capacity (FC)** and **Wilting Point (WP)** threshold, a Stress Threshold is also considered, following FAO-56 prescriptions

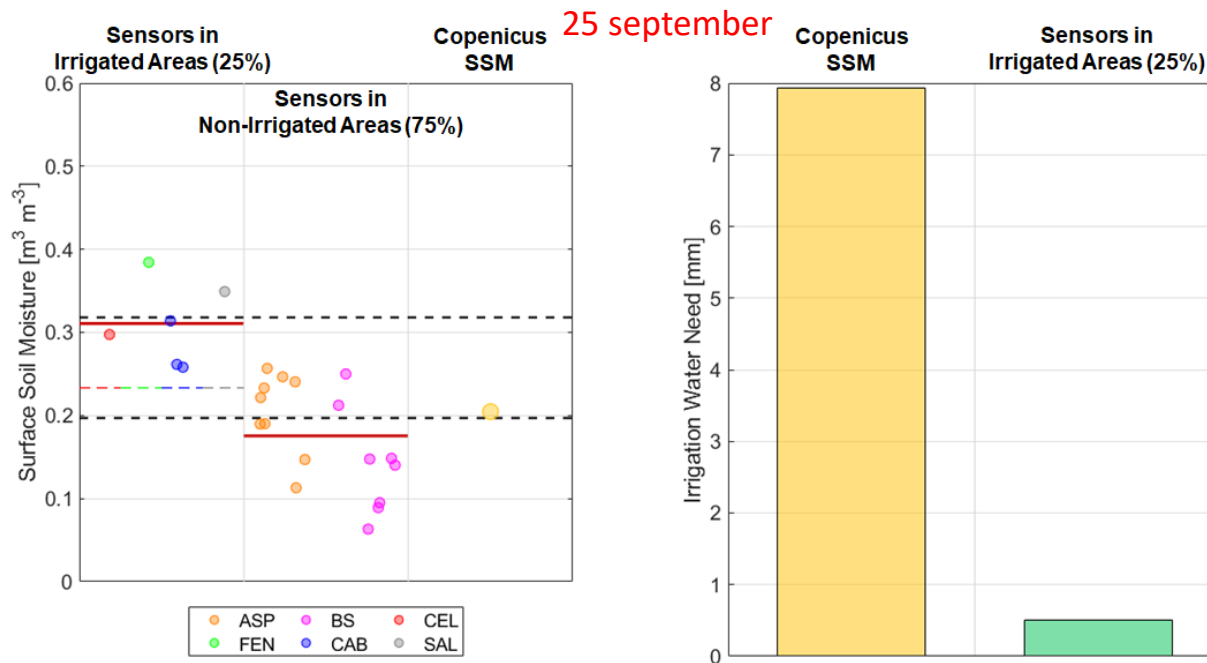
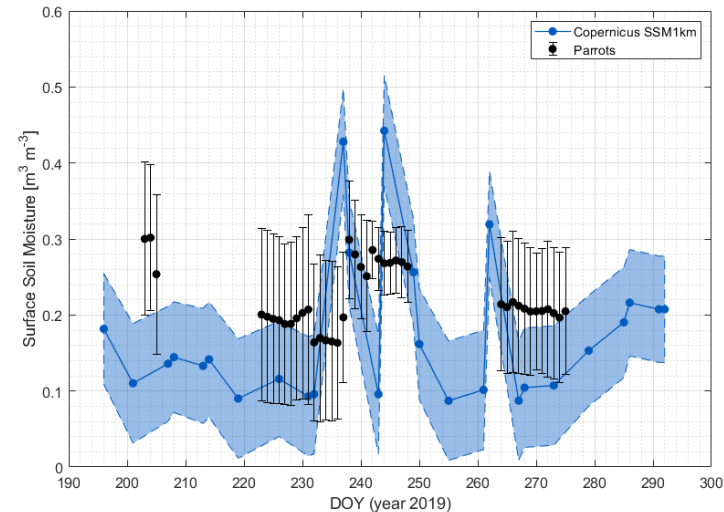


$$\text{stress} = FC - p \cdot (FC - WP) \quad p = p_{FAO} + 0.04 \cdot (5 - ET)$$



SM-IWN: comparison between Sentinel 1 Copernicus SSM1km and Parrot sensors

The **scale difference** between the two datasets accounts for the difference in SSM values, with the RS data underestimation caused by the influence of **bare-soil areas** in the same pixel as the sensors.



The Copernicus SSM1km value for the pixel is similar to the Parrots SM in bare soil, being the pixel area $\frac{3}{4}$ non-vegetated.



If SM-IWN are computed using Copernicus SM, too high values are obtained in contrast to the one needed by crop fields

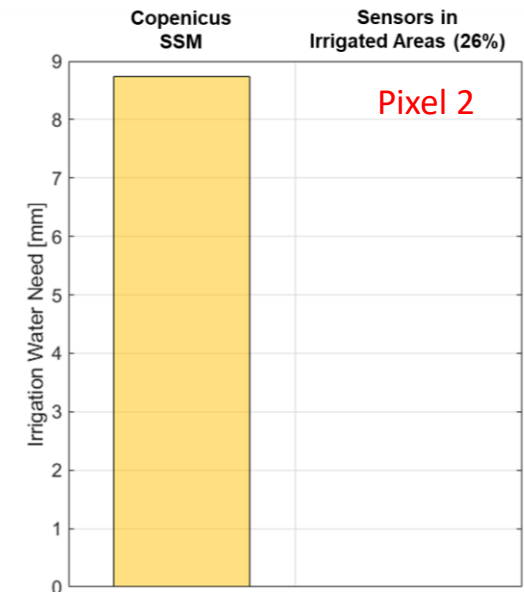
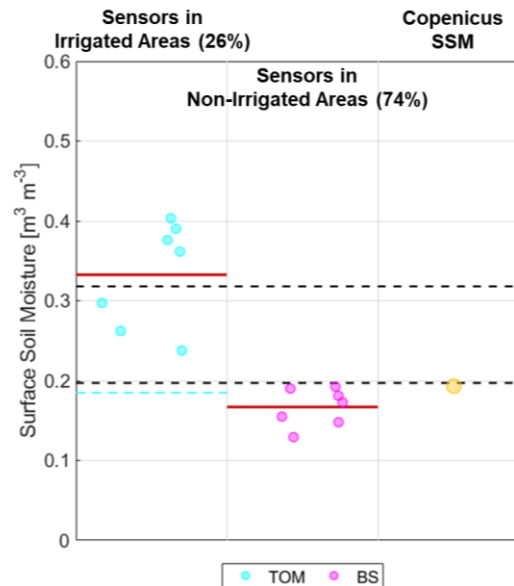
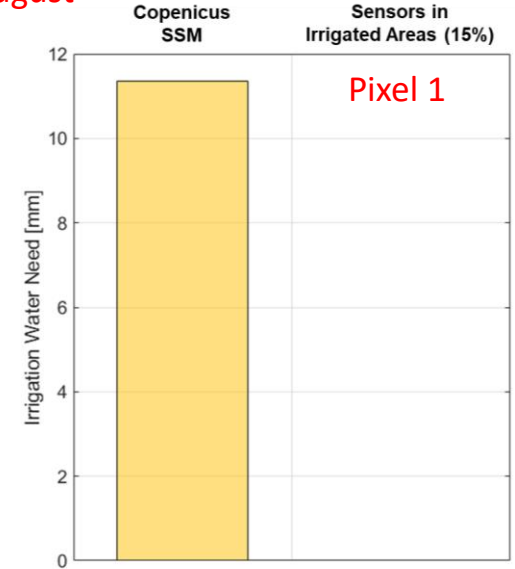
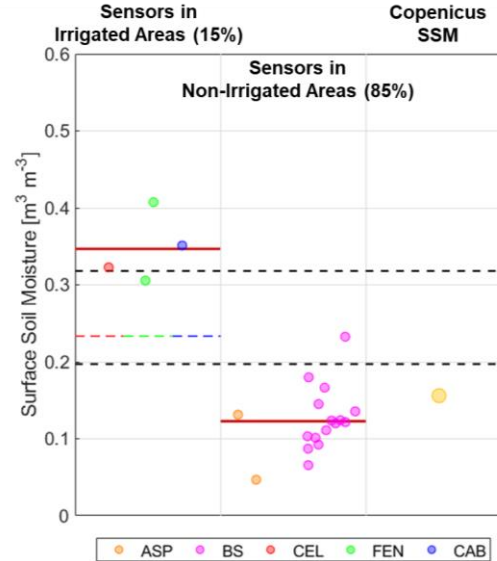


SM-IWN: comparison between Sentinel 1 Copernicus SSM1km and Parrot sensors

In these other examples, cases in which the average “Irrigated-Areas” sensor SSM values are above the Field Capacity threshold are shown. In these cases, **no irrigation is suggested** (IWN=0) by the sensors, while the satellite data would counsel important irrigation amounts (around 10 mm).

From these plots it appears clearly how irrigating following the low resolution Copernicus SSM 1km satellite implies a **much higher water consumption** than following the on-ground sensor data.

20 august





$$ETP = 1.3 \frac{\Delta}{(\Delta + \gamma)} R_s$$

Priestley-Taylor
formulation

Based on Parrot
SM data,
meteorological
data

Potential to actual evapotranspiration

$$\beta(SM) = \begin{cases} 0 & \text{for } SM \leq WP \\ \frac{SM - WP}{FC - WP} & \text{for } WP < SM < FC \\ 1 & \text{for } SM \geq FC \end{cases}$$

Vegetated area

$$ET = \beta \cdot ETP$$

$$\alpha = 0.082 \cdot SM + 9.173 \cdot SM^2 - 9.815 \cdot SM^3$$

Bare soil area

$$ET = \alpha \cdot ETP$$

Residual energy balance model

Latent heat flux at the time
passage of satellite LST

$$LEi = Rni - Gi - Hi$$

LEi = latent heat
Rni = net radiation
Gi = ground heat flux
Hi = sensible heat flux

Daily ET

$$LE_{day} = LEi \cdot R_{sday} / R_{si}$$

(Cammalleri 2014)

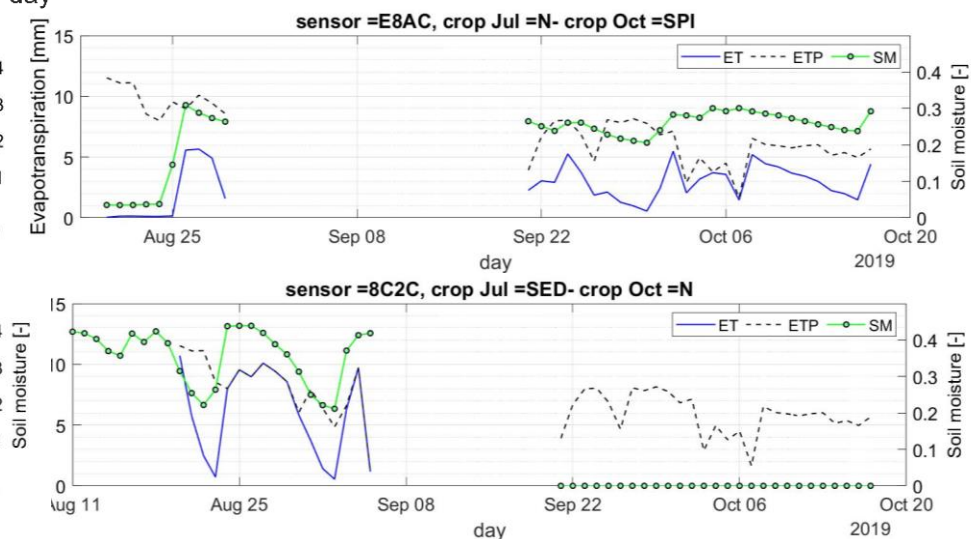
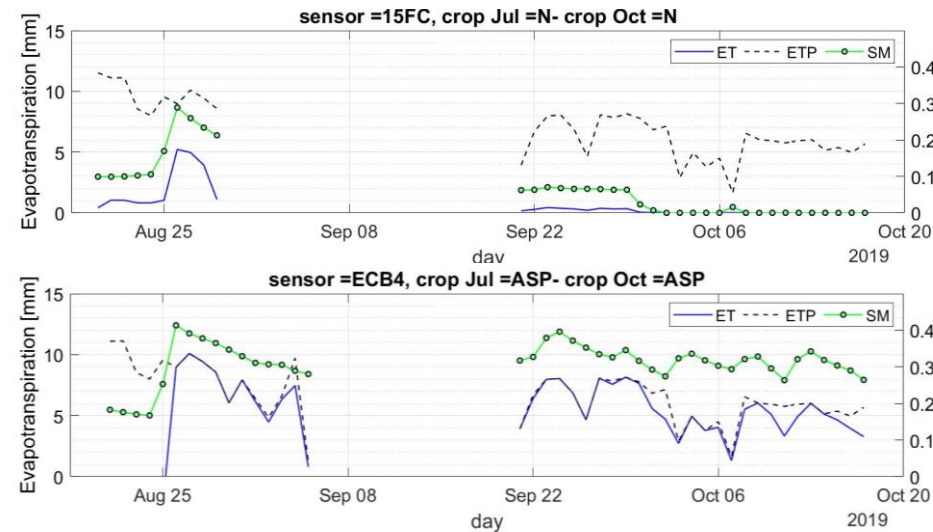
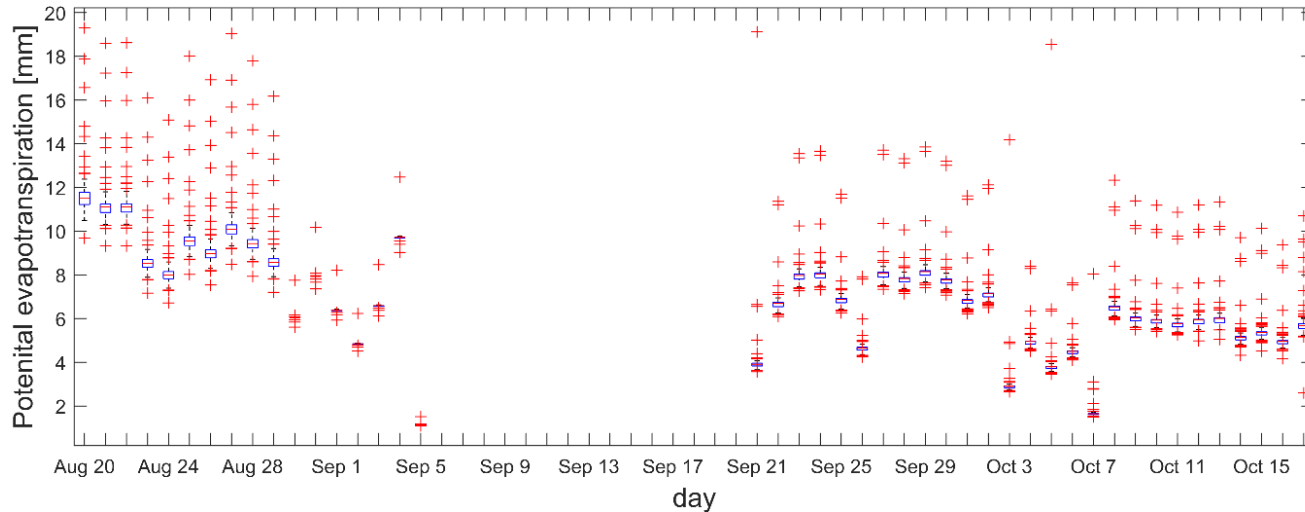
$$ET_{day} = LE_{day} / (p \cdot \lambda)$$

Based on
satellite LST
and vegetation
information,
meteorological
data

Corbari et al., 2015



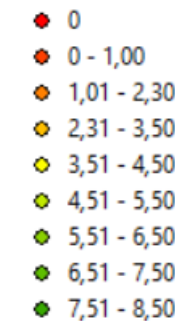
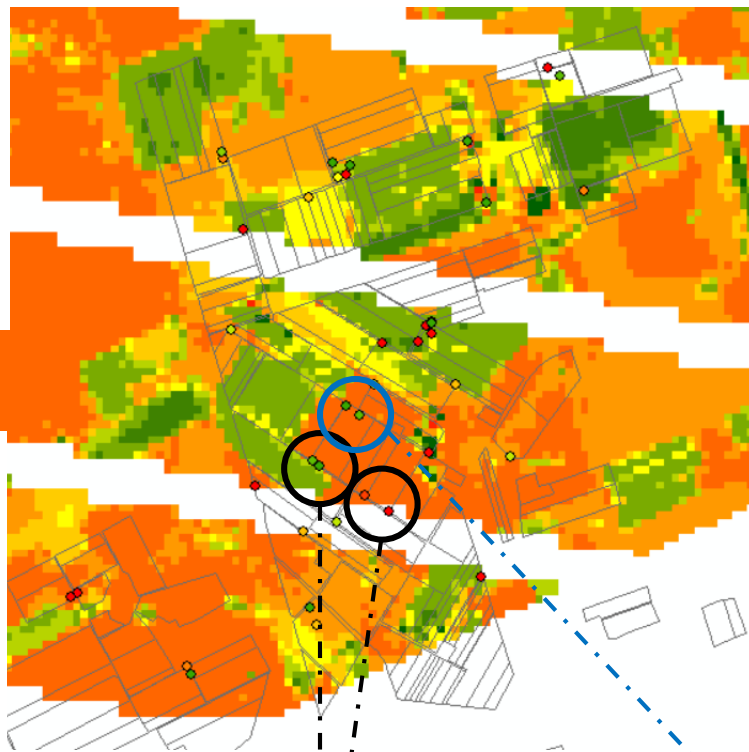
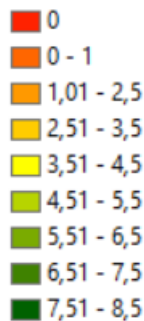
Potential to actual evapotranspiration





Residual energy balance model

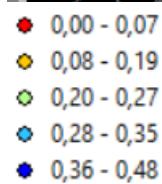
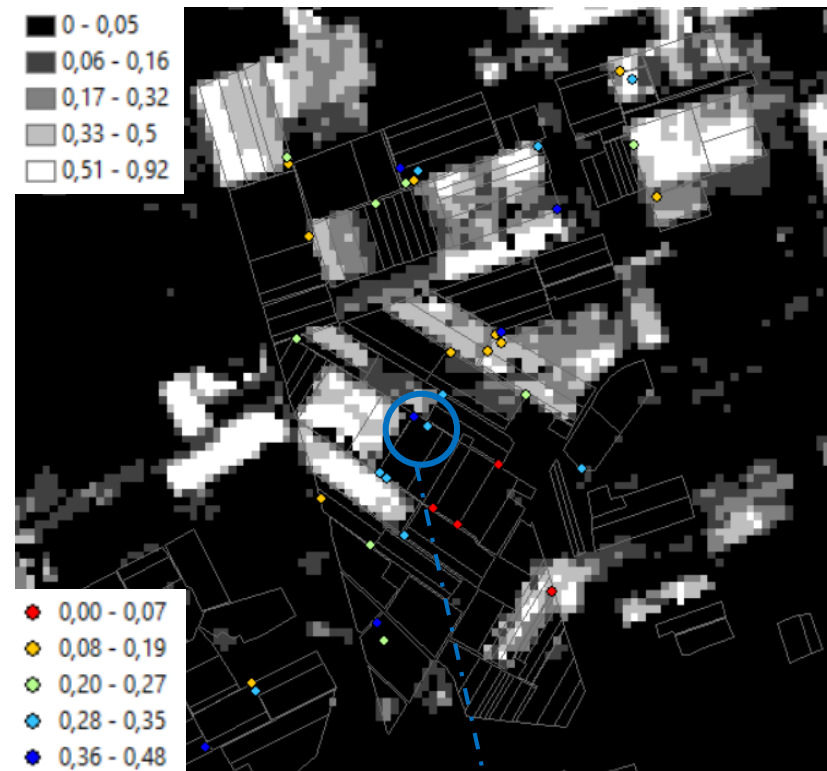
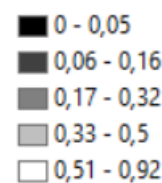
ET residual [mm/day] (24 sept)



ET Parrot [mm/day] (24 sept)

Good agreement between
ET Parrot and ET residual
both for bare soil and
vegetated fields

Sentinel 2 A - vegetation fraction (25 sept)



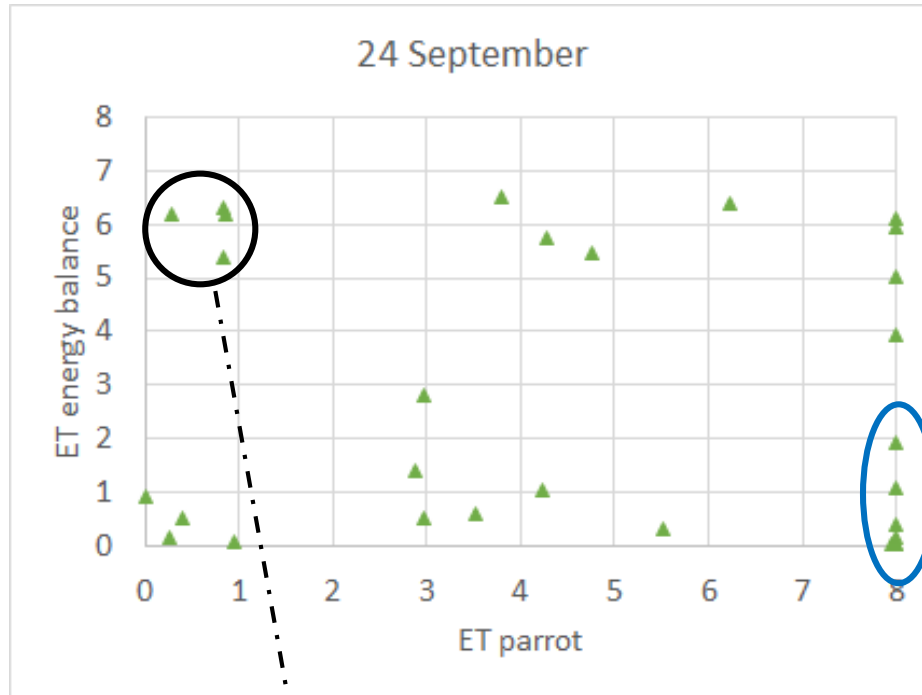
SM Parrot (24 sept)

Disagreement: high ET
Parrot while very low ET
residual

High soil moisture values
from Parrot over a satellite
bare soil field → in reality
the field was just sown and
drip irrigated



Irrigation Water Need ET-IWN from evapotranspiration



Disagreement: high ET
Parrot while very low ET
residual

High soil moisture values
from Parrot over a satellite
bare soil field → in reality
the field was just sown and
drip irrigated

Disagreement: low ET
parrot values with high ET
from satellite residual

Low soil moisture values measured from Parrot (Asparagus
field with subterranean drip irrigation) → in reality the field is
fully vegetated with 0,95 of vegetation fraction and low LST
values



Parrot sensors

- Out of the 456 sensors, only 107 (23%) provided meaningful data (covering more than a couple of days)
- Huge effort required to distribute and provide maintenance for 456 sensors
- Many sensors have been lost during tractor harvest operations

Remote sensing data

- information is already provided in an areal pixel-wise form and are easy-to-retrieve and with much less data gaps
- Low spatial resolution of SSM 1km satellite data are not suitable for irrigation management
- High resolution LST data can help to obtain ET but with some discrepancies with ground observed data

Corbari et al., Citizen science supporting agricultural monitoring with hundreds of low-cost sensors, *submitted to Computers and Electronics in Agriculture, 2021*

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