Estimation of evapotranspiration and irrigation detection from high-resolution remote sensing: evaluation of different methods over LIAISE campaign

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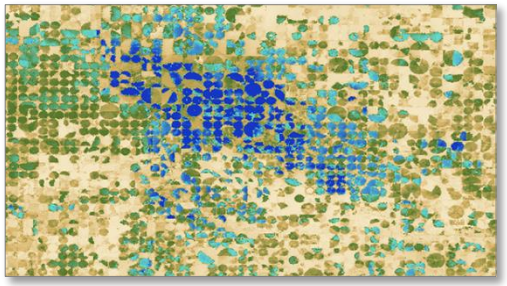
Context

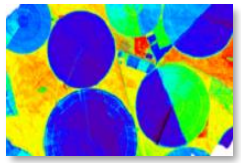
- TRISHNA mission, launches in 2026 (French-Indian)
  - Revisit : 2-3 days
  - 11 spectral bands, with 4 in TIRS, 60m

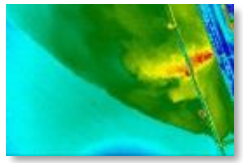
  - 1st goal: plant water stress status, ETR estimation,

    UHI for cities, SST for ocean and lakes

- LIAISE area = Benchmark site for evaluating the ETR of future production chains





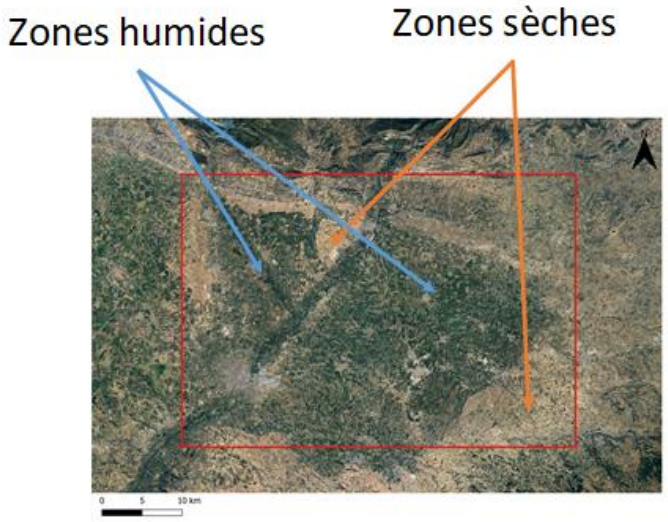


Plan

I. Comparison of daily ETR estimations from 3 methods based on satellite imagery

1)MODSPA **:** **ET_0/Precipitation + NDVI + LCover**
2)SPARSE **: LST + meteo + albedo + LAI + LCover**
3)EVASPA **: LST + Rg + Vegetation index**

II. Exploring approaches for detection and automatic mapping of irrigated areas



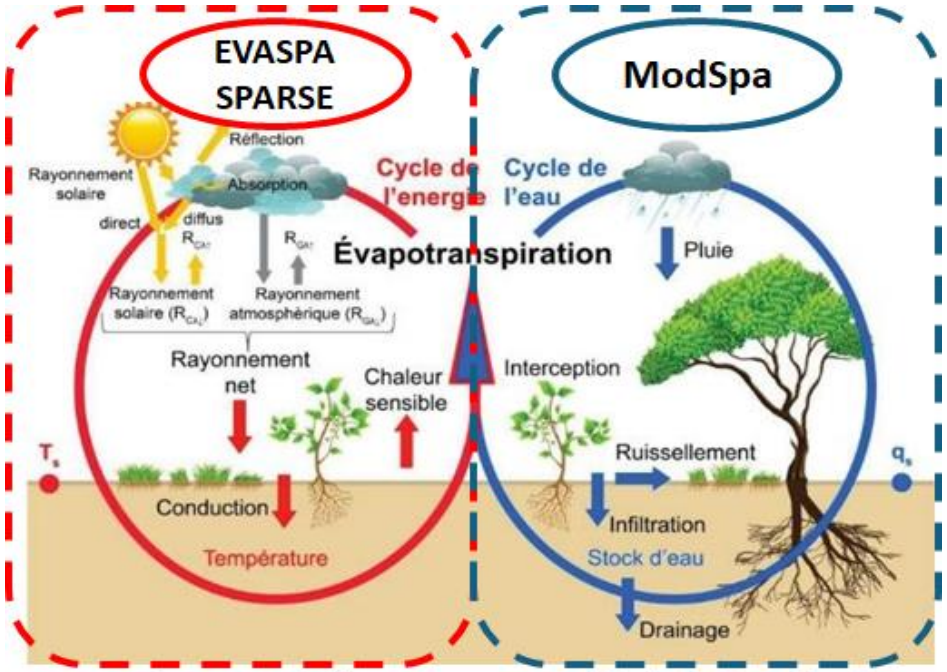


Fig : Détermination de l'évapotranspiration par bilan hydraulique (droite) et bilan énergétique (gauche) [Allier et al. (2013)]

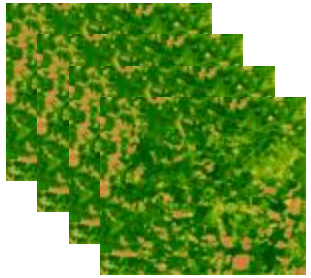
1

ModSpa model : driven by ET0 & NDVI + LC

FAO-56 Method (*Allen et al. 1998*) + simple **W**ater **B**alance model

Input = daily ET_0 & Rain

NDVI time series

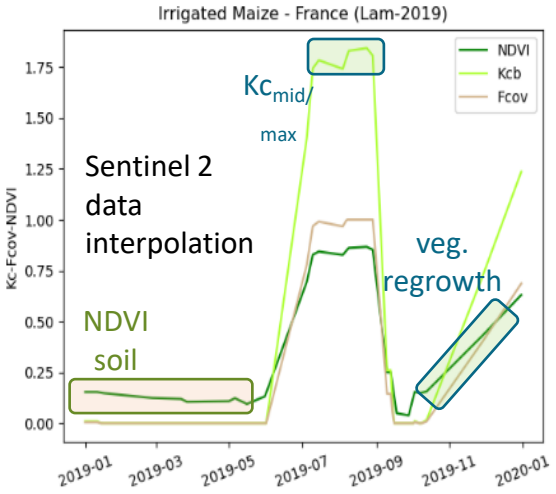


Sentinel 2 SR

Land Cover

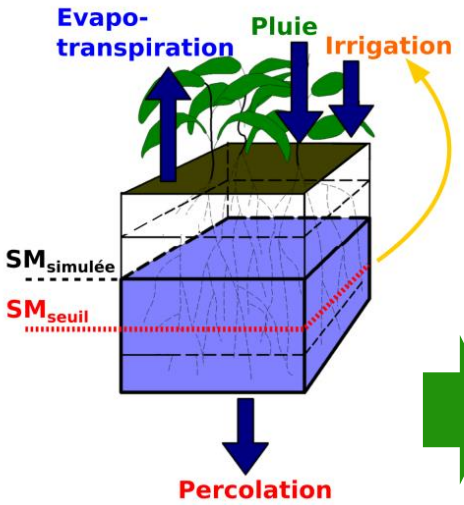
Soil Water Properties

Semi-empirical approach

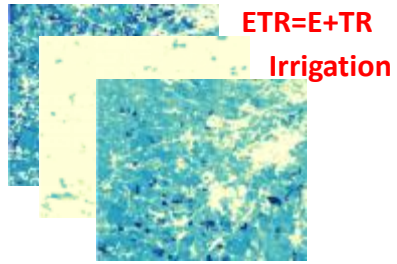


$ETR = Kc \times ET_0$

Irrigation is **simulated**
(optional, based on rules)



time series



output

Daily ETR

$$Kc = \underbrace{Kcb\ Ks}_{\text{plant}} + \underbrace{(Kc_{max} - Kcb)Kr}_{\text{soil}}$$

atmosphere

2

EVASPA approach: driven by LST & VI

Energy Balance model

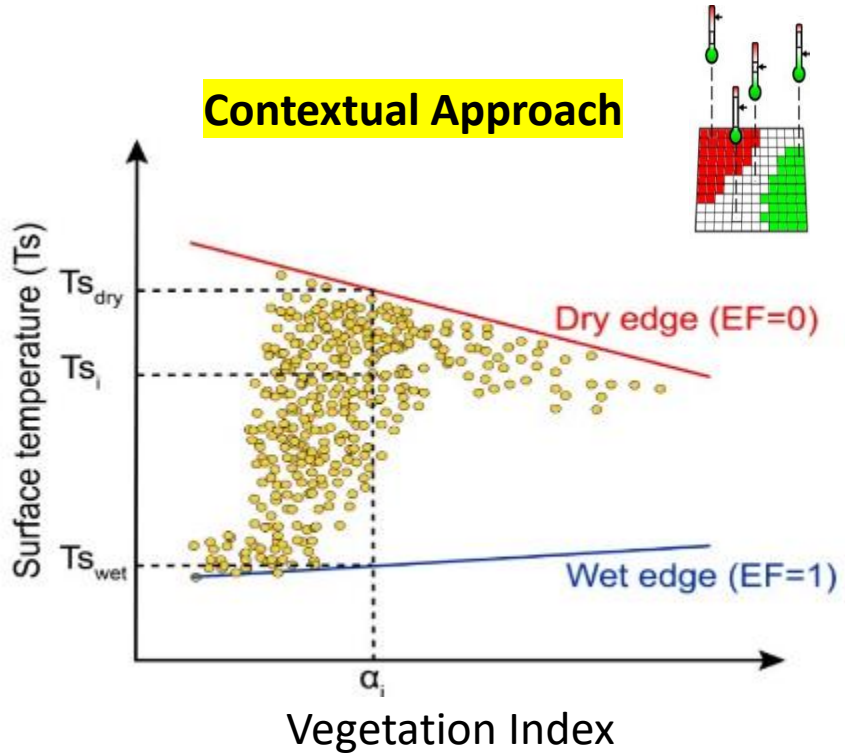
Ensemble of contextual methods (*Gallego-Elvira et al. 2013*)

Input = reduced meteorological forcing

+ LST from remote sensing

+ vegetation index from remote sensing

Temperature image with dry/wet edges identification



output

Instant EF

Instant ETR

daily rescale

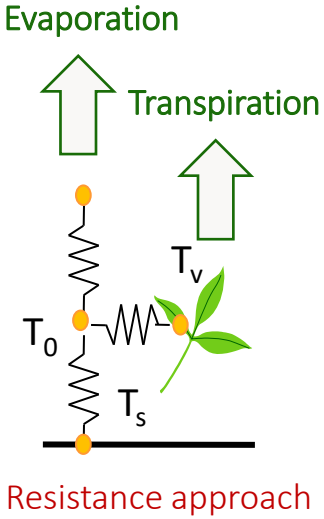
3

SPARSE model: driven by LST, µclimate, LAI + LC

Energy Balance resolution
SPARSE (*Boulet et al. 2015*)

Input = full meteorological forcing
+ LST from remote sensing
+ LAI from remote sensing
+ soil & veg. properties

Physical single pixel model



Resistance approach

Single pixel temperature, Soil & Vegetation characteristics

output

Instant ETR

daily rescale

Methodology for comparison

- RS_NDVI interpolated (Sentinel 2) + meteorological forcing (ET_0/rain)

=> ETR daily with MODSPA

- RS_LST at Landsat overpass (if no clouds)

=> ETR at Landsat date with EVASPA & SPARSE

- Comparison of models

=> with each other

=> with field data from Campaign

All simulations run at a resolution of 90m.

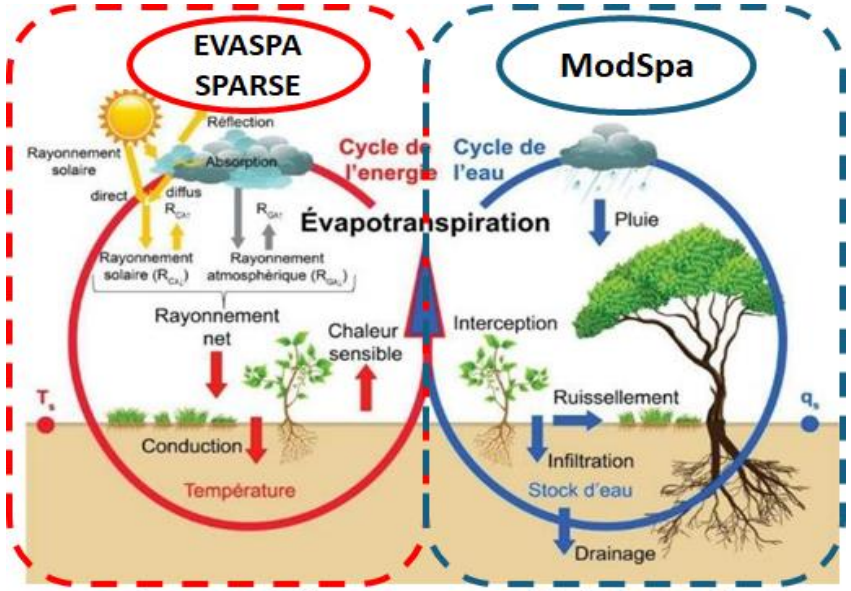


Fig : Détermination de l'évapotranspiration par bilan hydraulique (droite) et bilan énergétique (gauche) [Allier et al. (2013)]

LIAISE 2021 timeline

winter ~~crop~~ 06-17 ELS PLANS 09-29

nuts ~~tree~~ 04-01 PREIXANA 10-12

irrigated alfalfa 04-19 LA CENDROSA 10-10

irrigated vineyard 04-01 VERDU 09-27

irrigated ~~corn~~ 06-29 IRTA CORN 09-04

01-01 ERA5-Land - IDEWA stations (Albesa, Alguerri, Vallfogna) - MSG 12-31

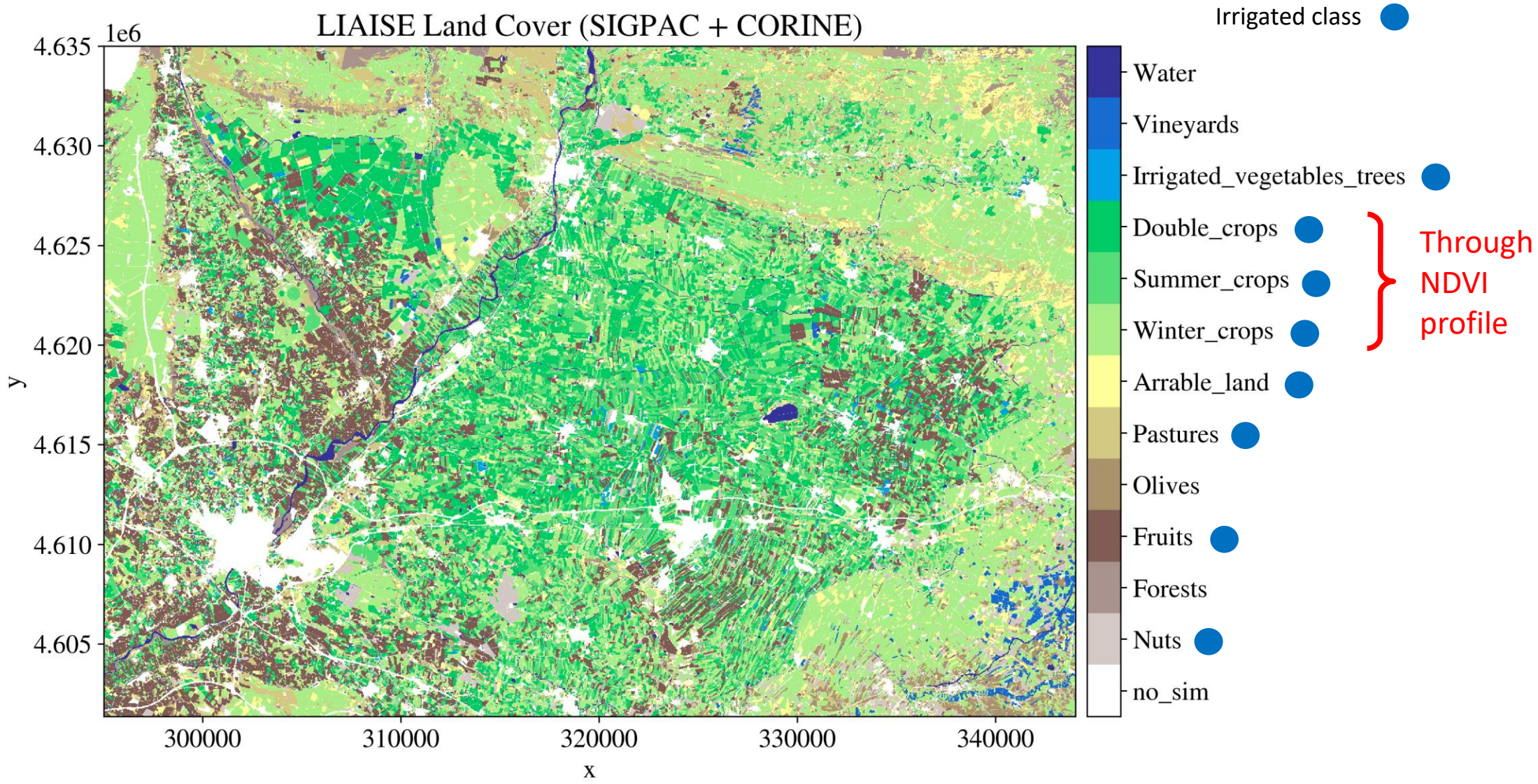
01-01 ModSpa 12-31

2021 LandSat 8 clear images

2021-03-28, 2021-04-13, 2021-07-02, 2021-07-18, 2021-09-20, 2021-10-22, 2021-11-07

6 LandSat 7 clear images during the period, not exploited in current work

MODSPA & SPARSE require a land cover map



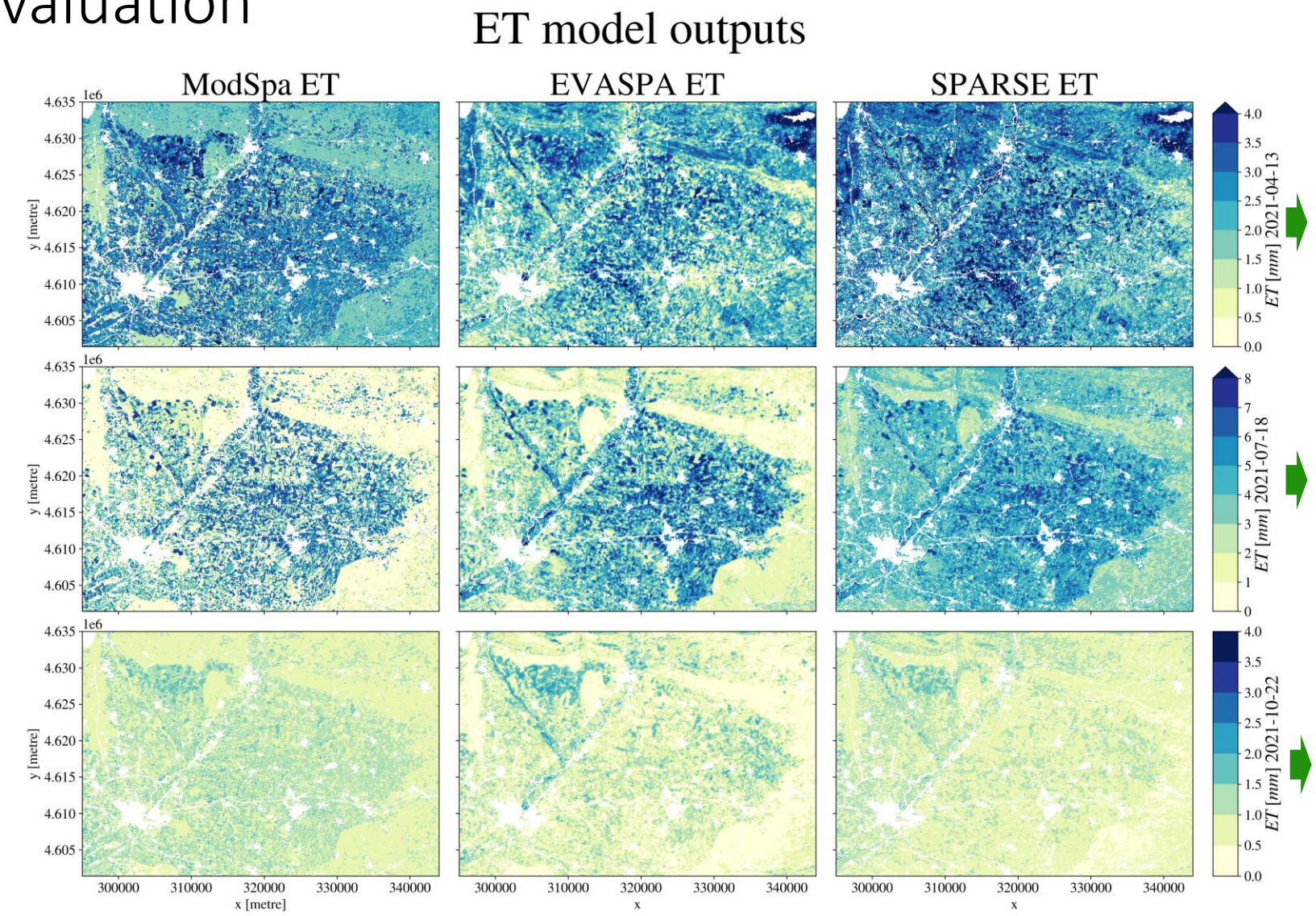
Spatial evaluation

Landsat 8 dates :

2021-04-13

2021-07-18

2021-10-22



spring = a starting signal

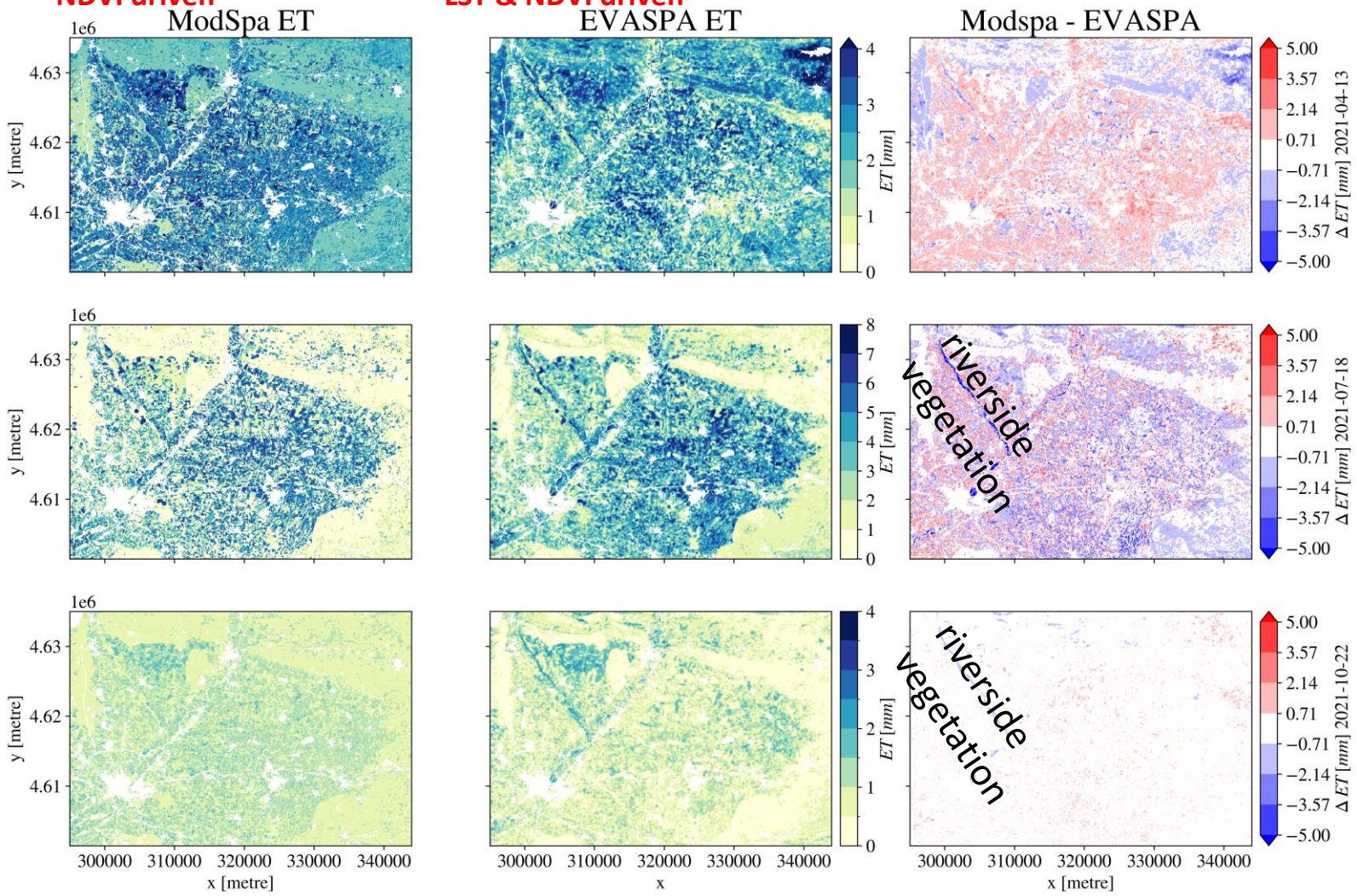
Irrigated vs. dry pattern appears more clearly in summer

winter = ET driven by climatic demand > quite similar for all models

NDVI driven | **LST & VI driven** | **LST & LAI driven**

MODSPA vs. EVASPA

NDVI driven **LST & NDVI driven**



spring = a starting signal

- **dry area evapotranspirates more with EVASPA**
- **wet area evapotranspirates more with MODSPA**

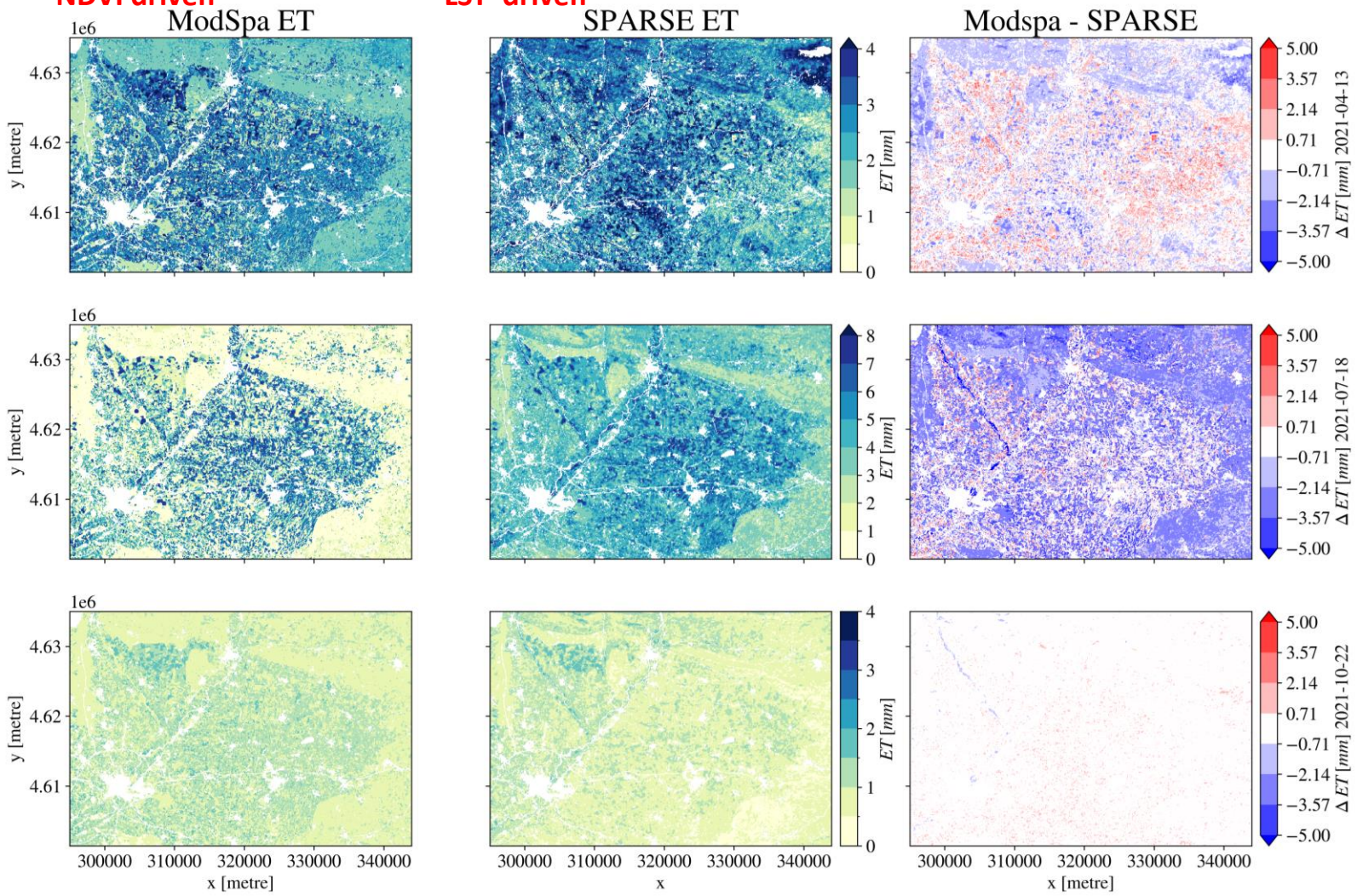
summer

- **vegetation & cold LST : detected great to thermal**
- **stress & unstressed crops can differ between EVASPA & MODSPA => EVASPA observes a reality**
  => MODSPA simulates the water balance

winter = low signal due to low fluxes

MODSPA vs. SPARSE

NDVI driven **LST driven**



spring = a starting signal

- **dry area evapotranspirates more with SPARSE**
- **wet area evapotranspirates more with MODSPA**

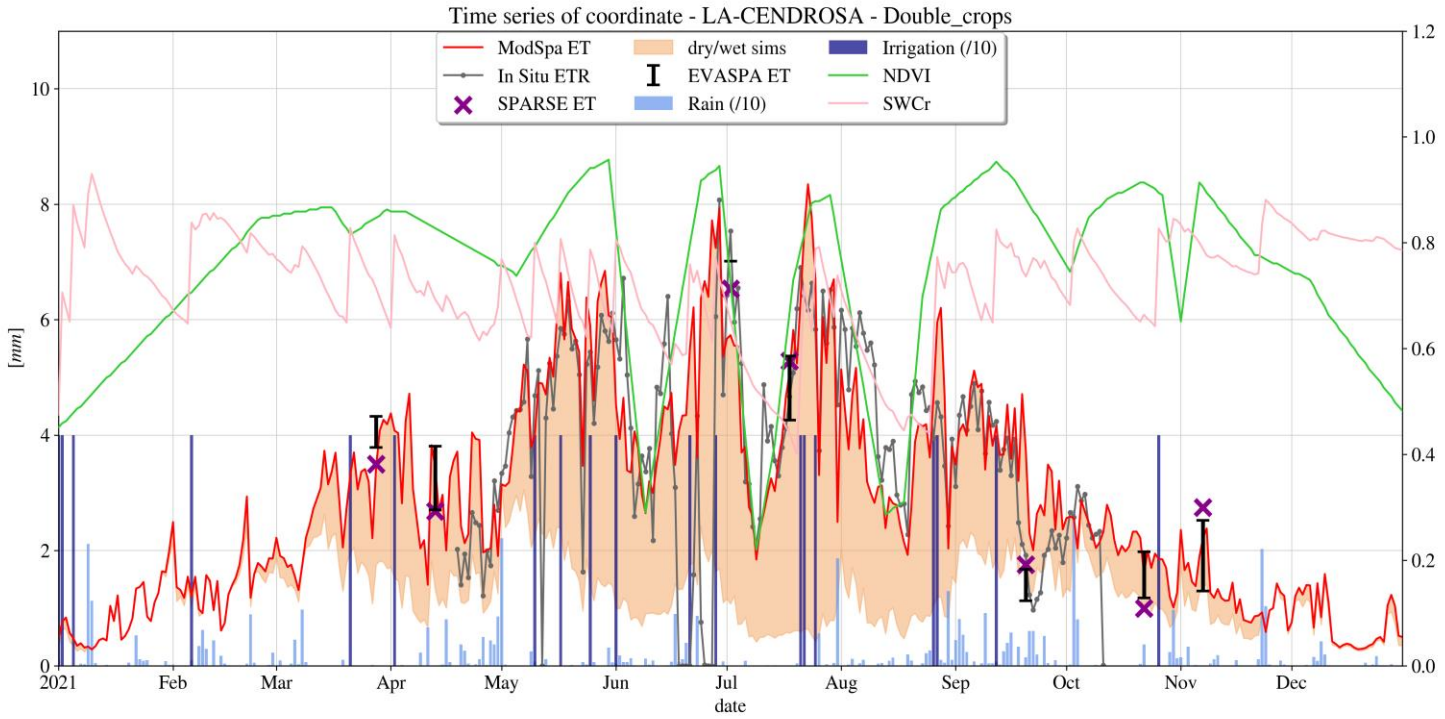
- **vegetation & cold LST : detected with thermal**
- **stress & unstressed crops can differ between SPARSE & MODSPA => SPARSE observes a reality**
  => MODSPA simulates the water balance

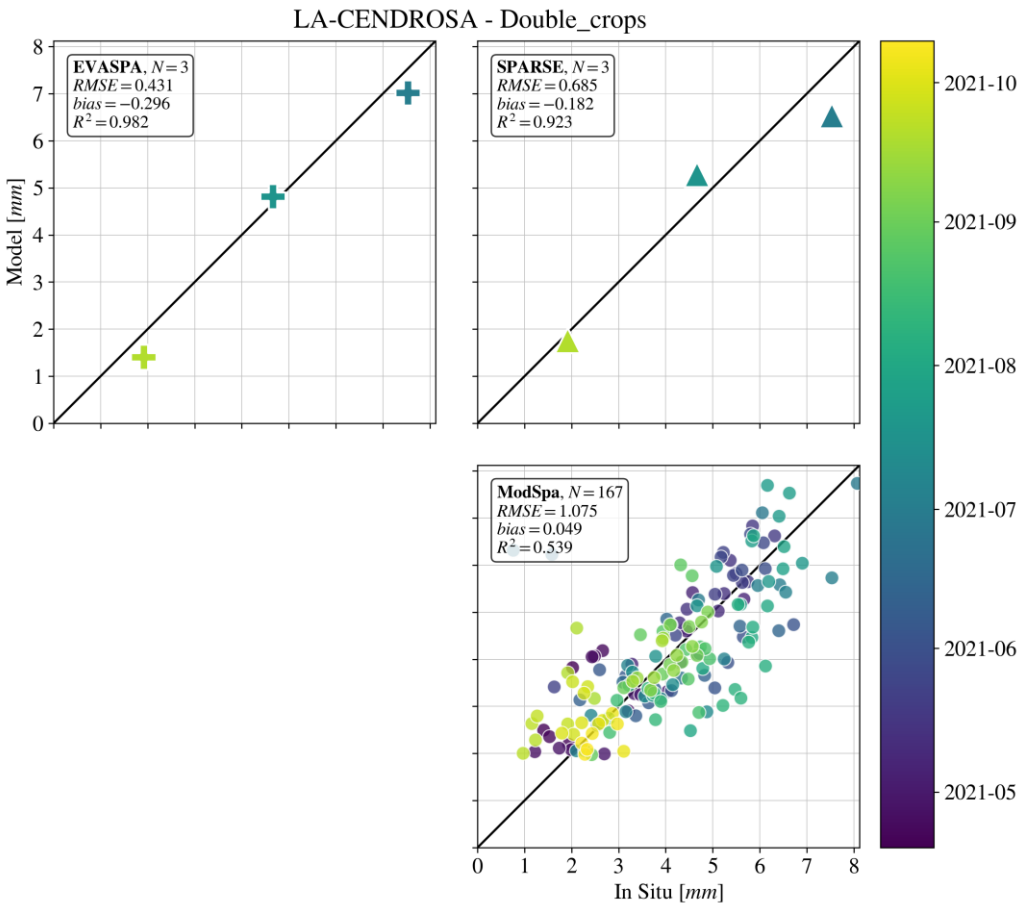
summer

ETRsparse >> ETRmodspa

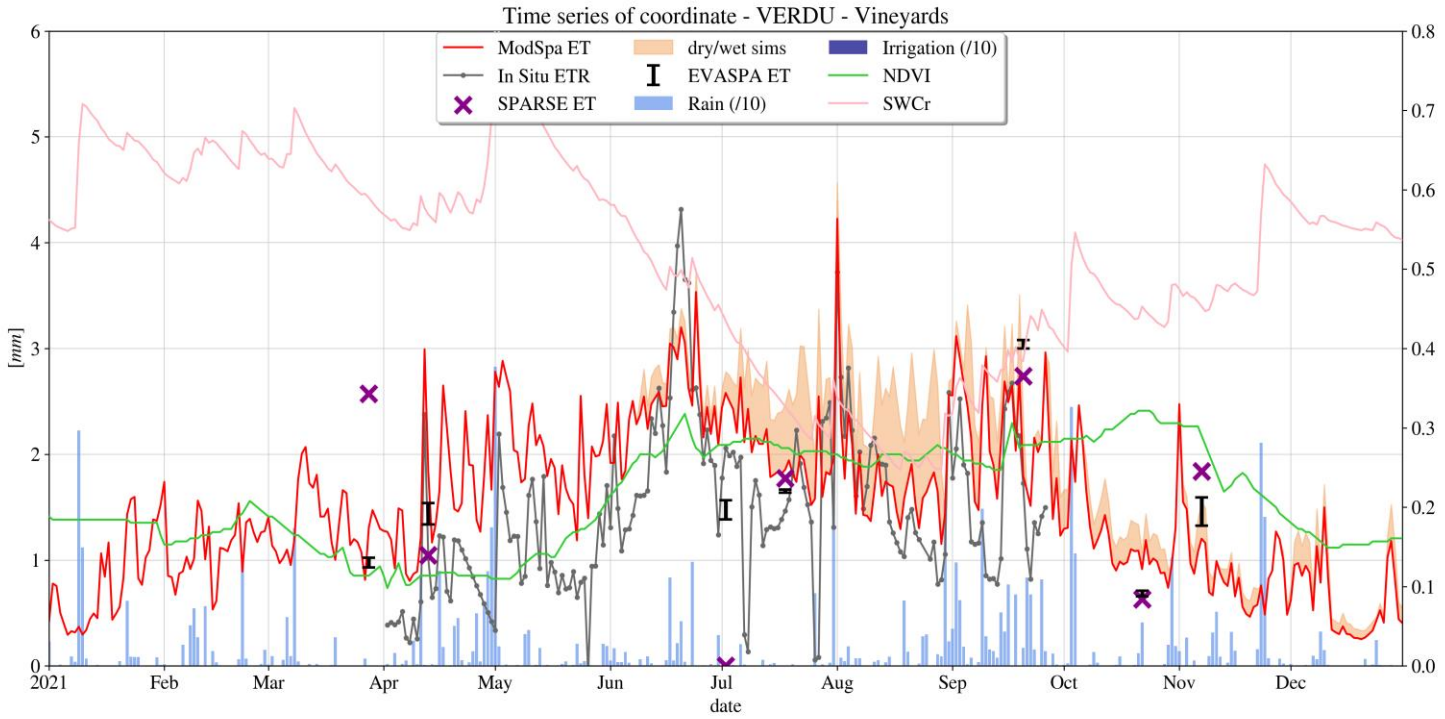
winter = low signal due to low fluxes

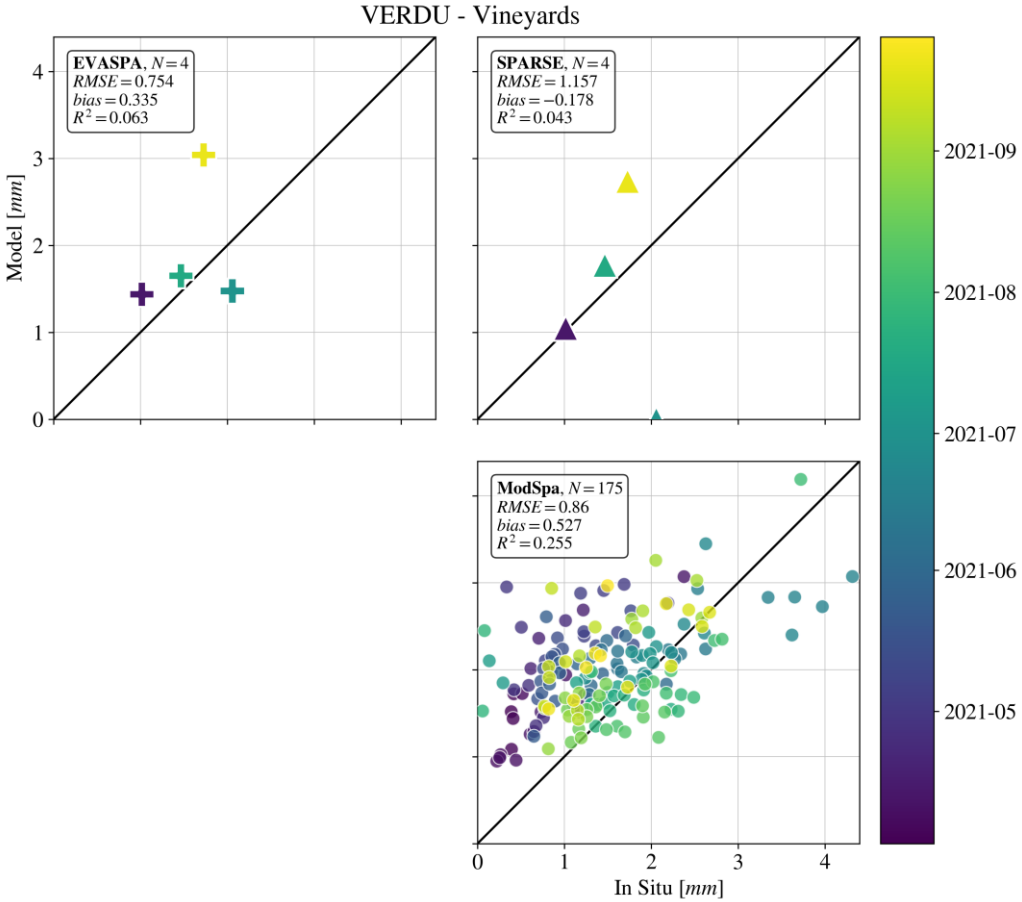
Field comparison : Irrigated alfalfa
La-Cendrosa





Field comparison : Irrigated vineyard VERDU





II. Irrigation detection

Each model has a water stress equivalent :

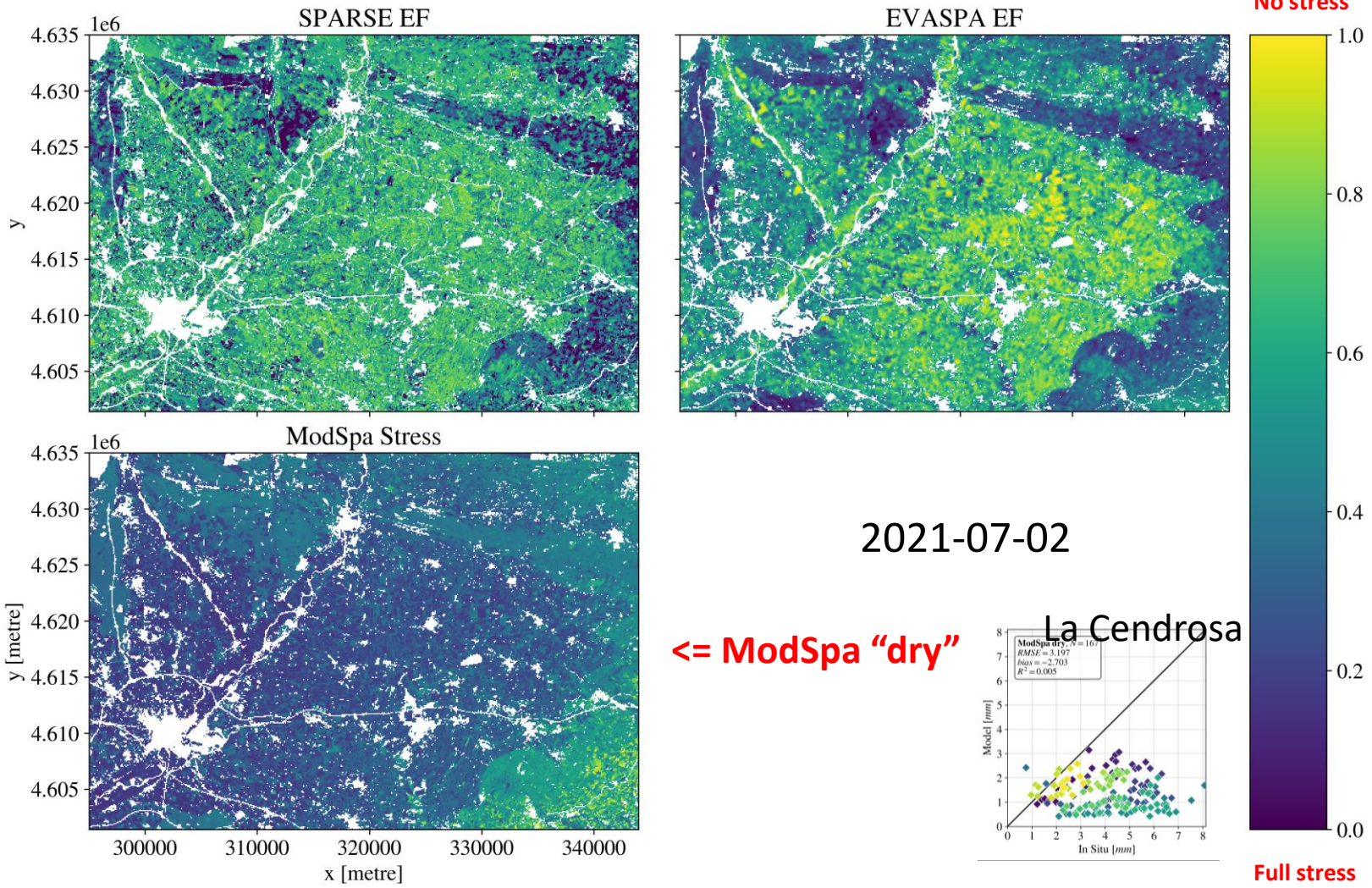
- SPARSE : $\mathrm{EF} = \frac{\mathrm{LE}}{\mathrm{Rn} - \mathrm{G}}$
- EVASPA : $\mathrm{EF} = \frac{\mathrm{Ts_{dry}}(\alpha) - \mathrm{Ts}(\alpha)}{\mathrm{Ts_{dry}}(\alpha) - \mathrm{Ts_{wet}}(\alpha)}$
- ModSpa :

$$\text{stress} = \mathrm{K_s F_{Cov}} + \mathrm{K_r}(1 - \mathrm{F_{Cov}})$$

plant

soil

These stresses can be compared to highlight differences



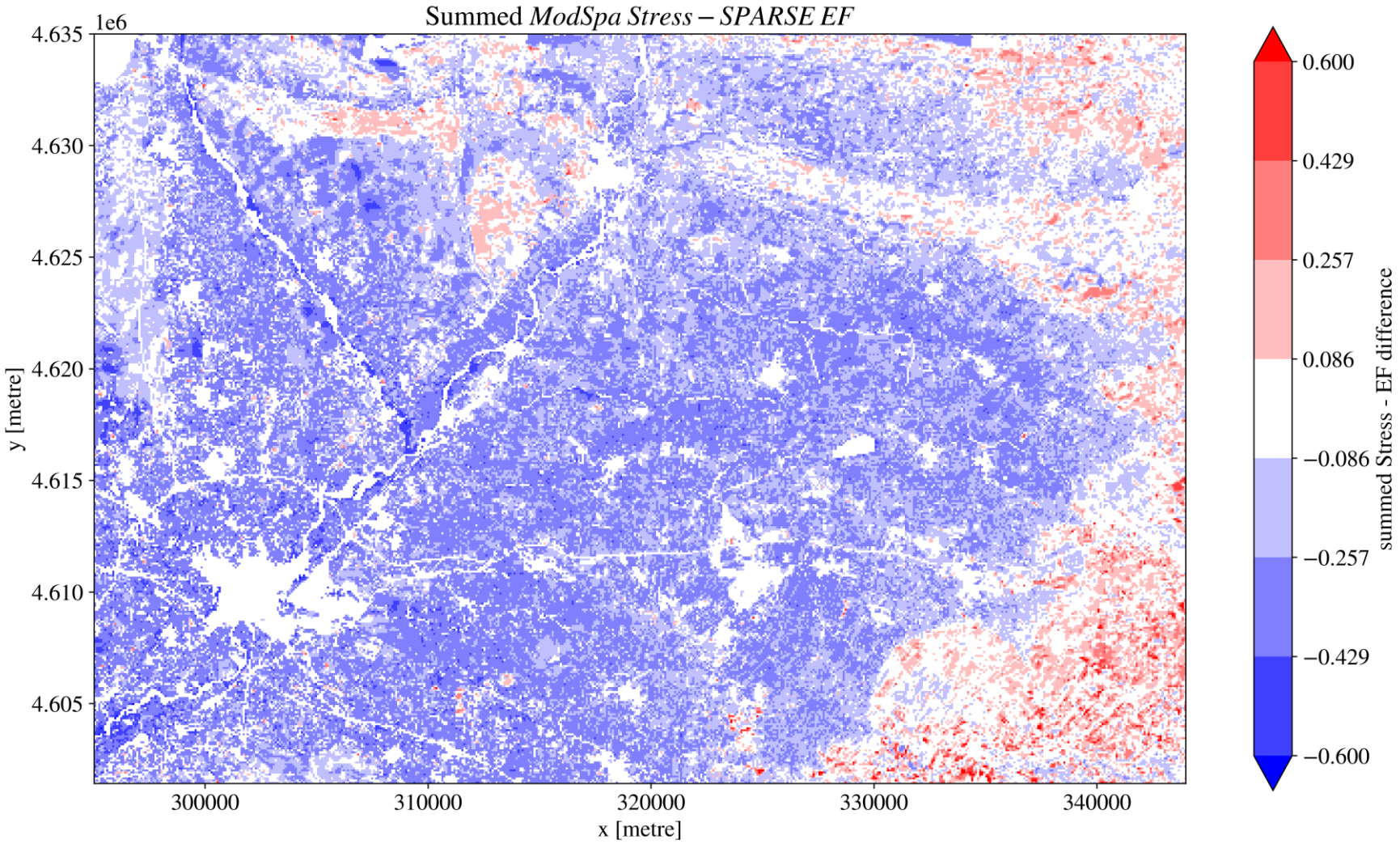
2021-07-02

<= ModSpa "dry"

La Cendrosa

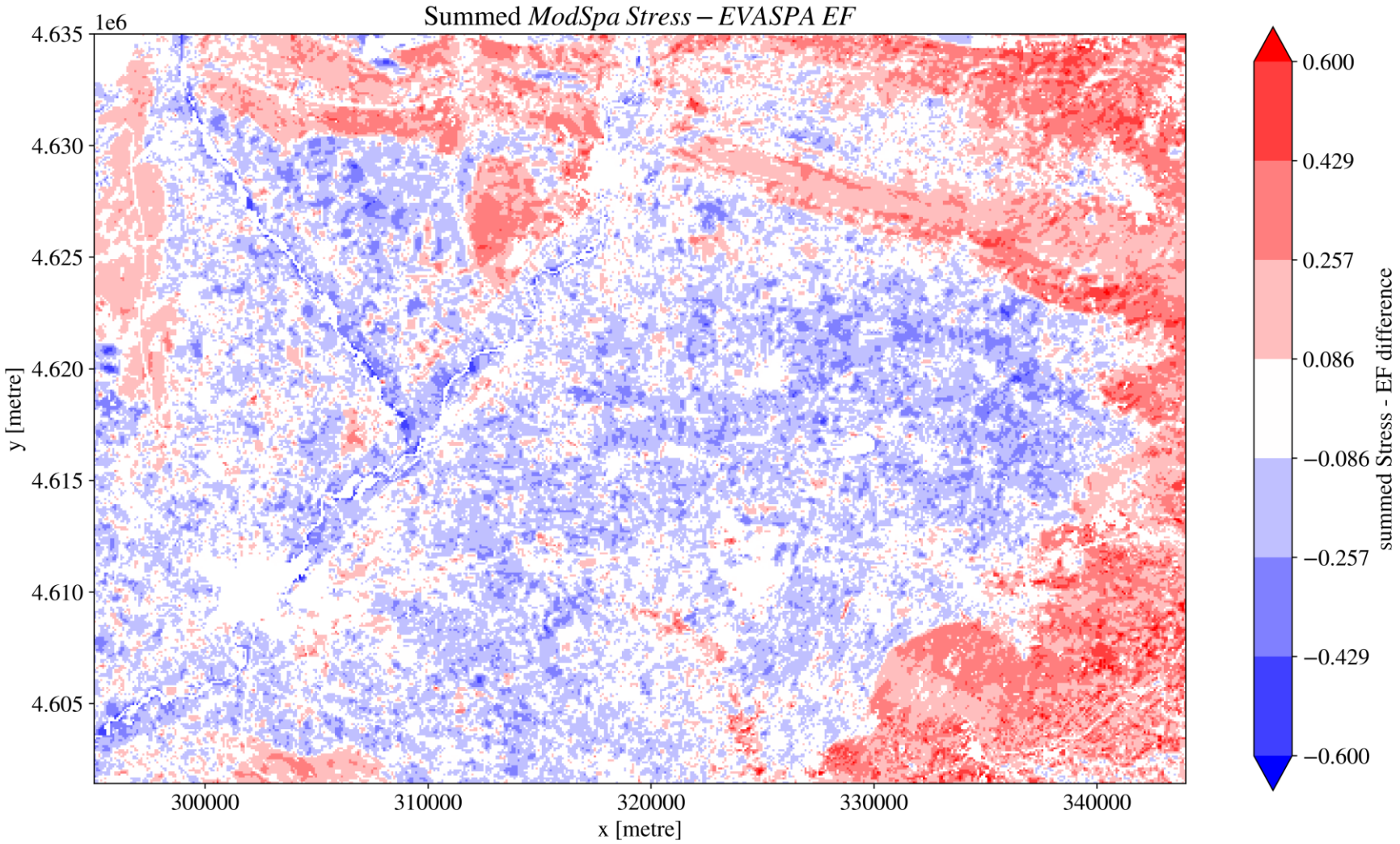
Stress difference with dry ModSpa

- Blue : ModSpa dry has a higher stress than SPARSE
- Red : SPARSE has a higher stress than ModSpa



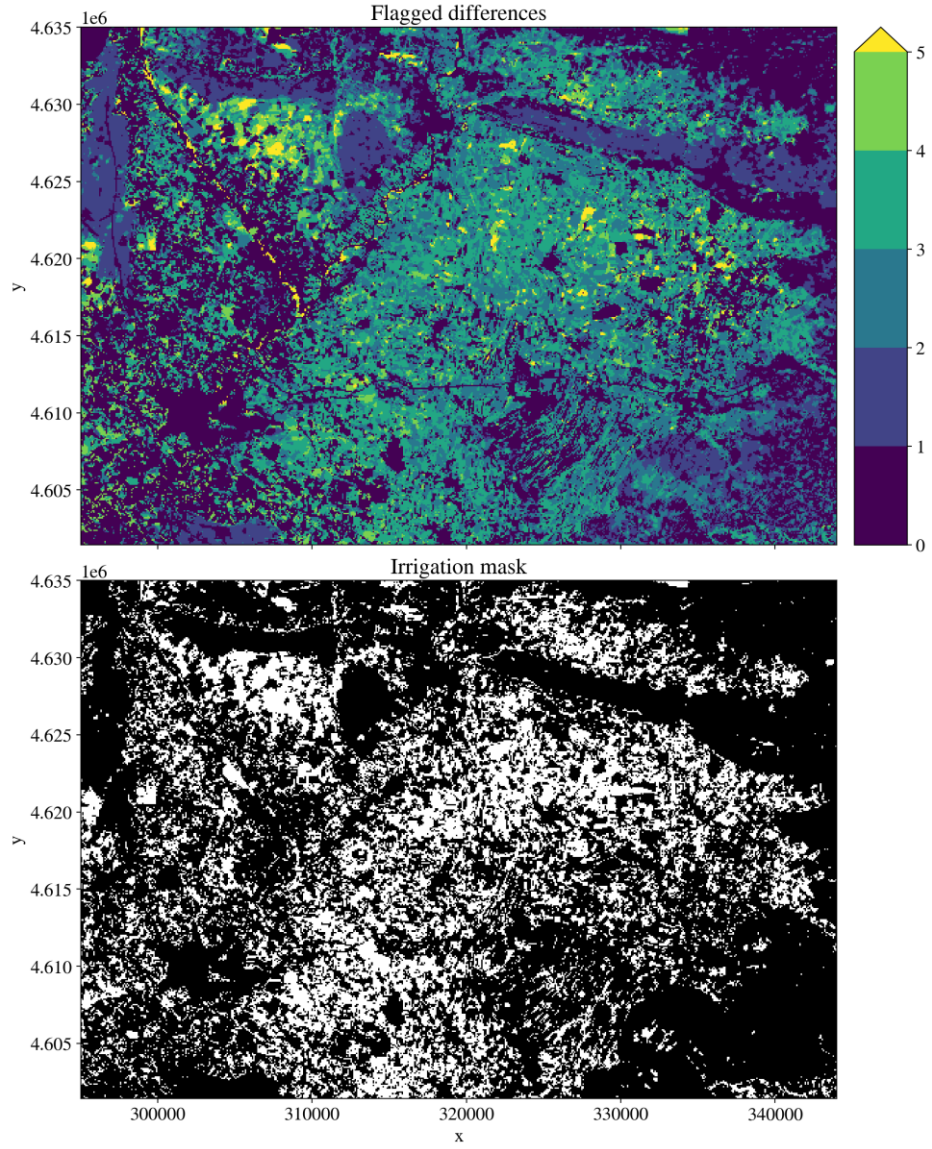
Stress difference with dry ModSpa

- Blue : ModSpa dry has a higher stress than EVASPA
- Red : EVASPA has a higher stress than ModSpa



Detection through flags per date

- The difference of stress between dry ModSpa and the Thermal model is evaluated for every pixel at every date sufficiently far from a rain event (5 days).
- For each date, a pixel is flagged if the difference between dry ModSpa and the Thermal model stress is bigger than a certain threshold.



CONCLUSION & PROSPECTS

I - ETR estimation & model comparison:

- General agreement of the models fairly good on LIAISE dataset
- Sutdy area is interesting for model inter-comparison

II - Irrigation detection & mapping

- Challenges :
  - Having enough valid dates during the irrigation period
  - Finding optimal thresholds for detection
  - Understanding each model bias and how to take it in account
  - Getting adapted validation data

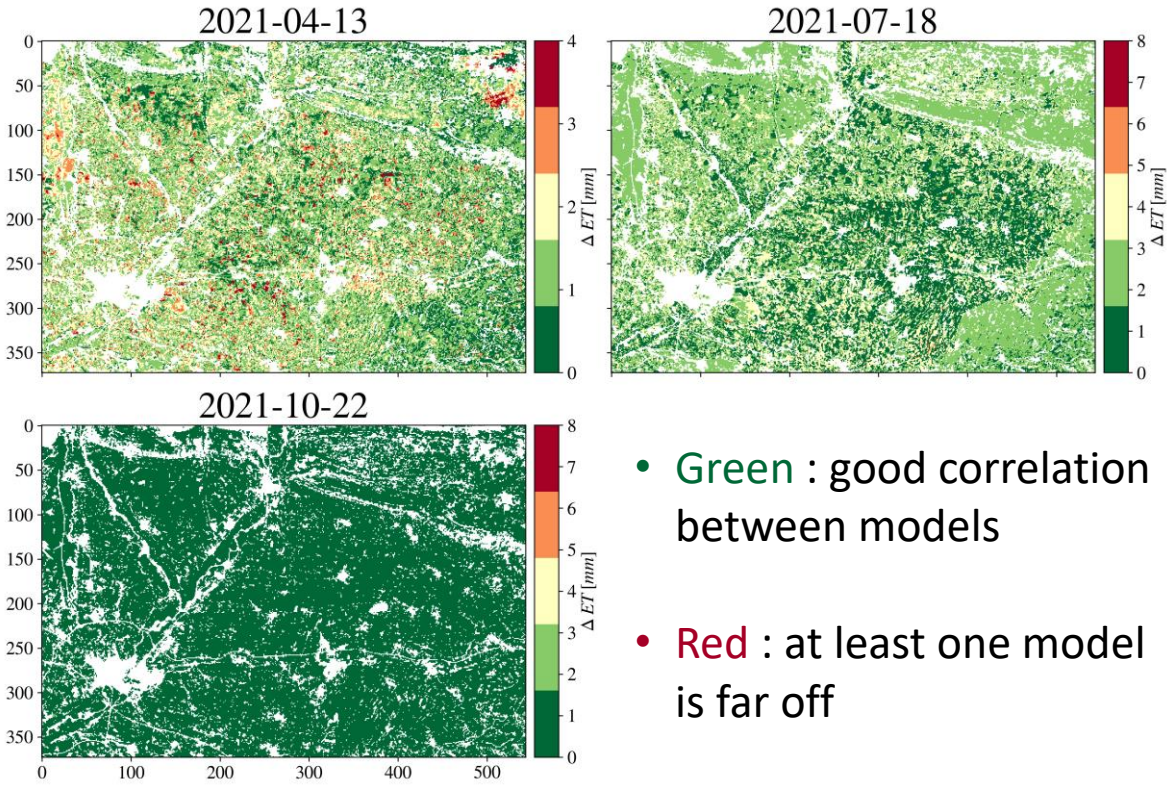
Prospects:

- Add Landsat 7 images to increase temporal resolution (even with LSC-off)
- Add Landsat 9 for periods after September 2021

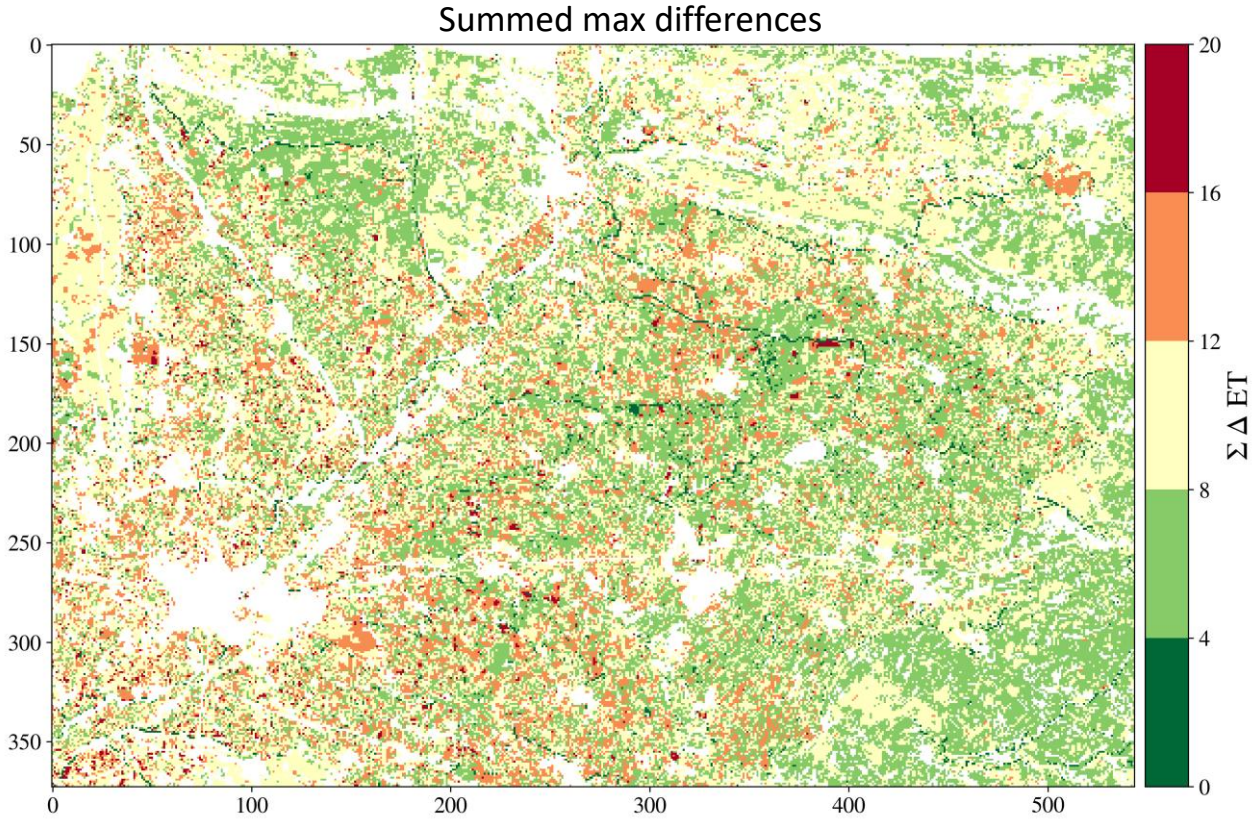
Additional slides

Max model difference per pixel

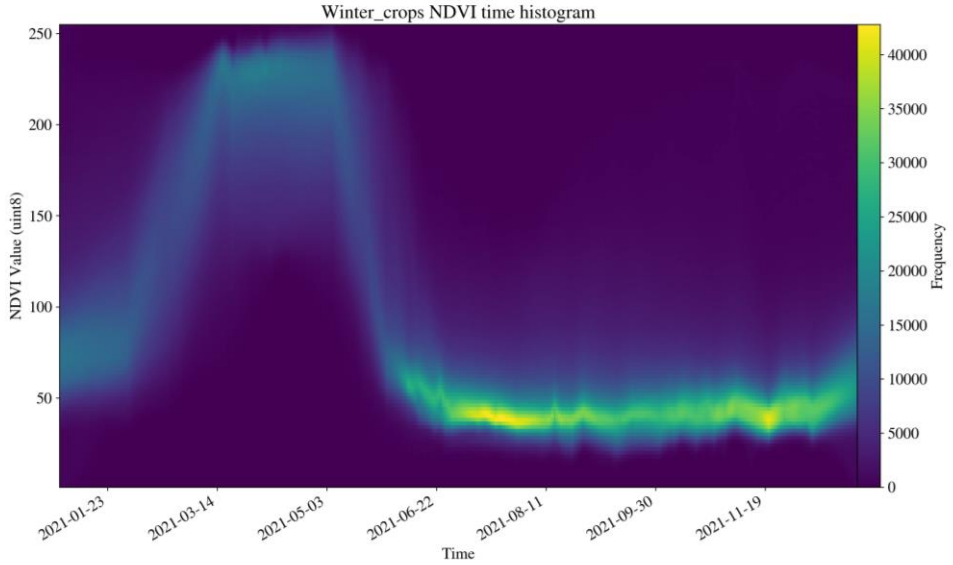
Possibility to highlight issues with land cover, irrigation choices or some other model error.

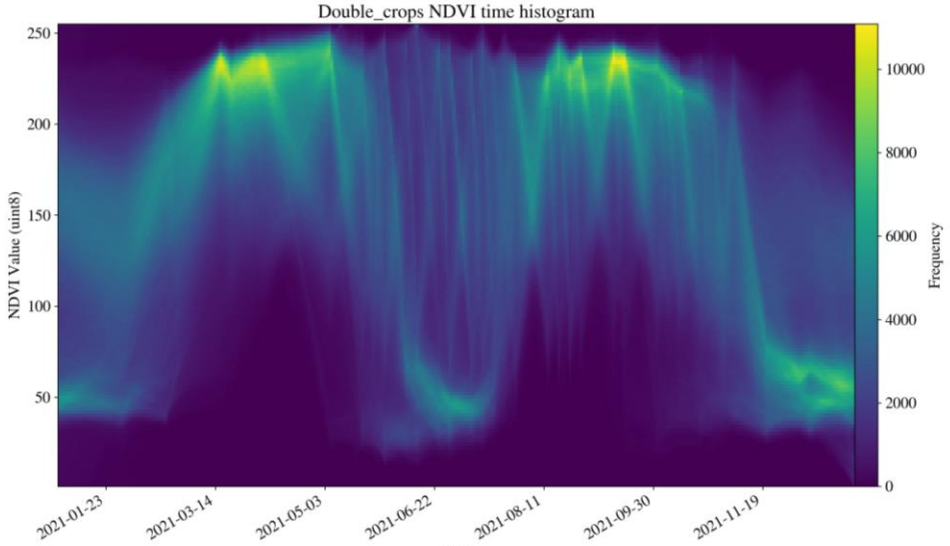


- Green : good correlation between models
- Red : at least one model is far off

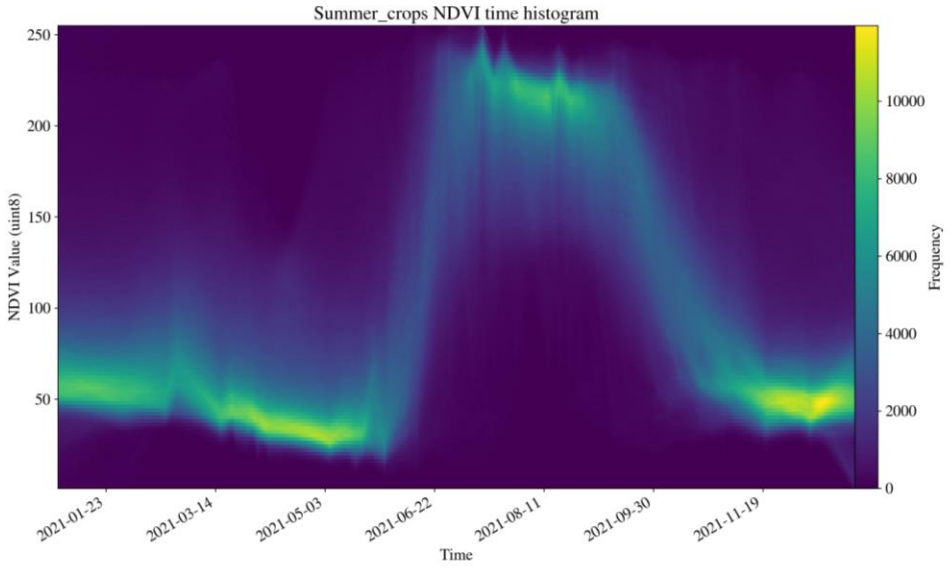


Class attribution through NDVI time series

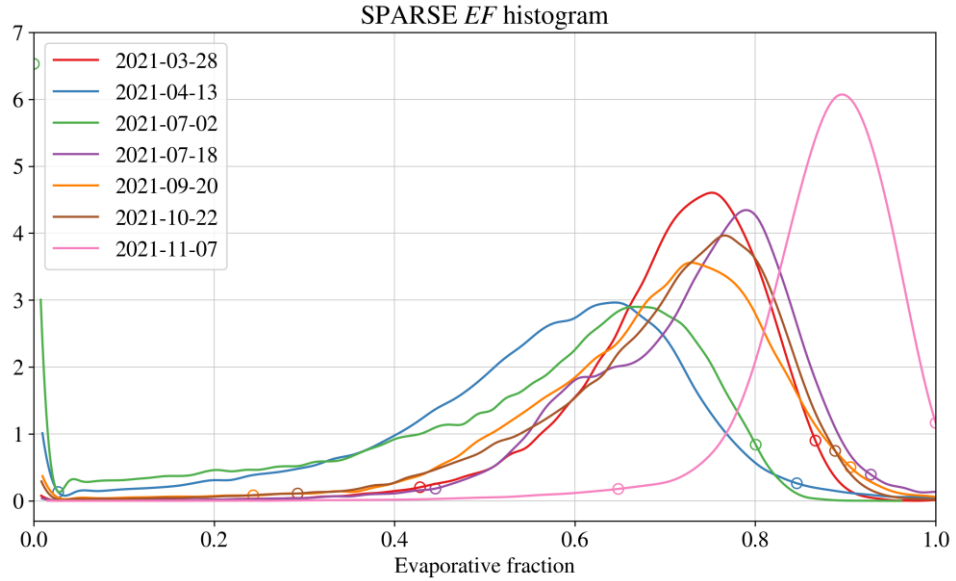


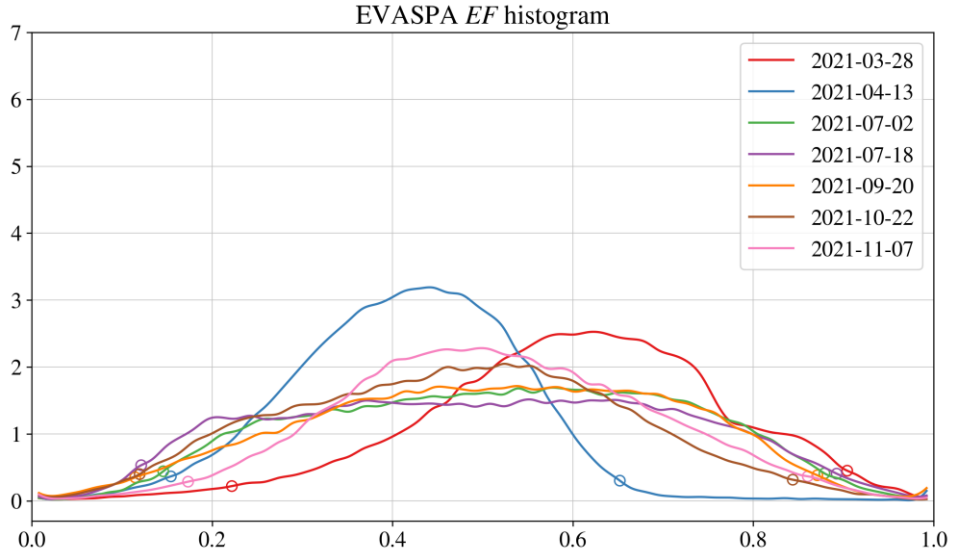


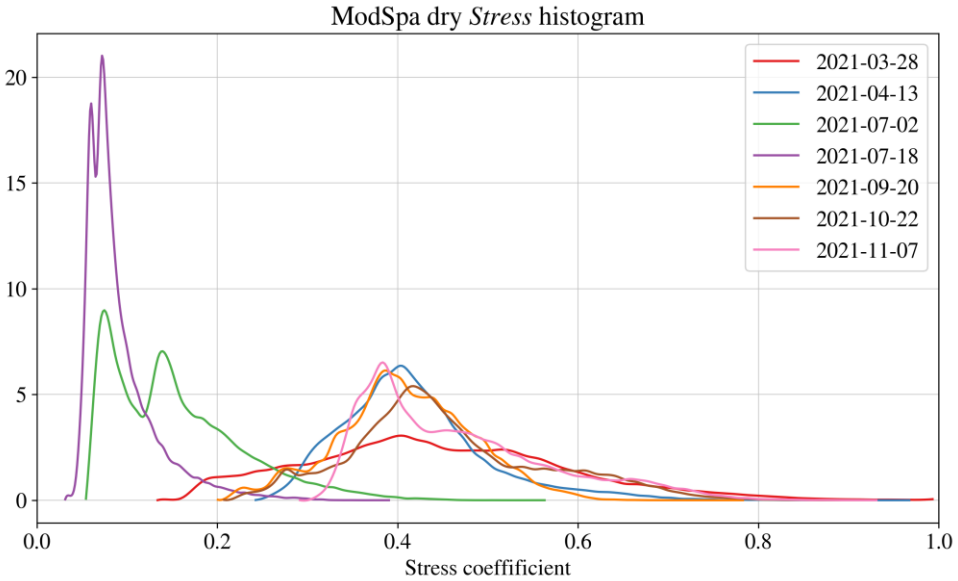
The arable land class was separated in winter, summer and double crops based on the NDVI dynamic over the year (pixel wise).



Stress histograms of different models

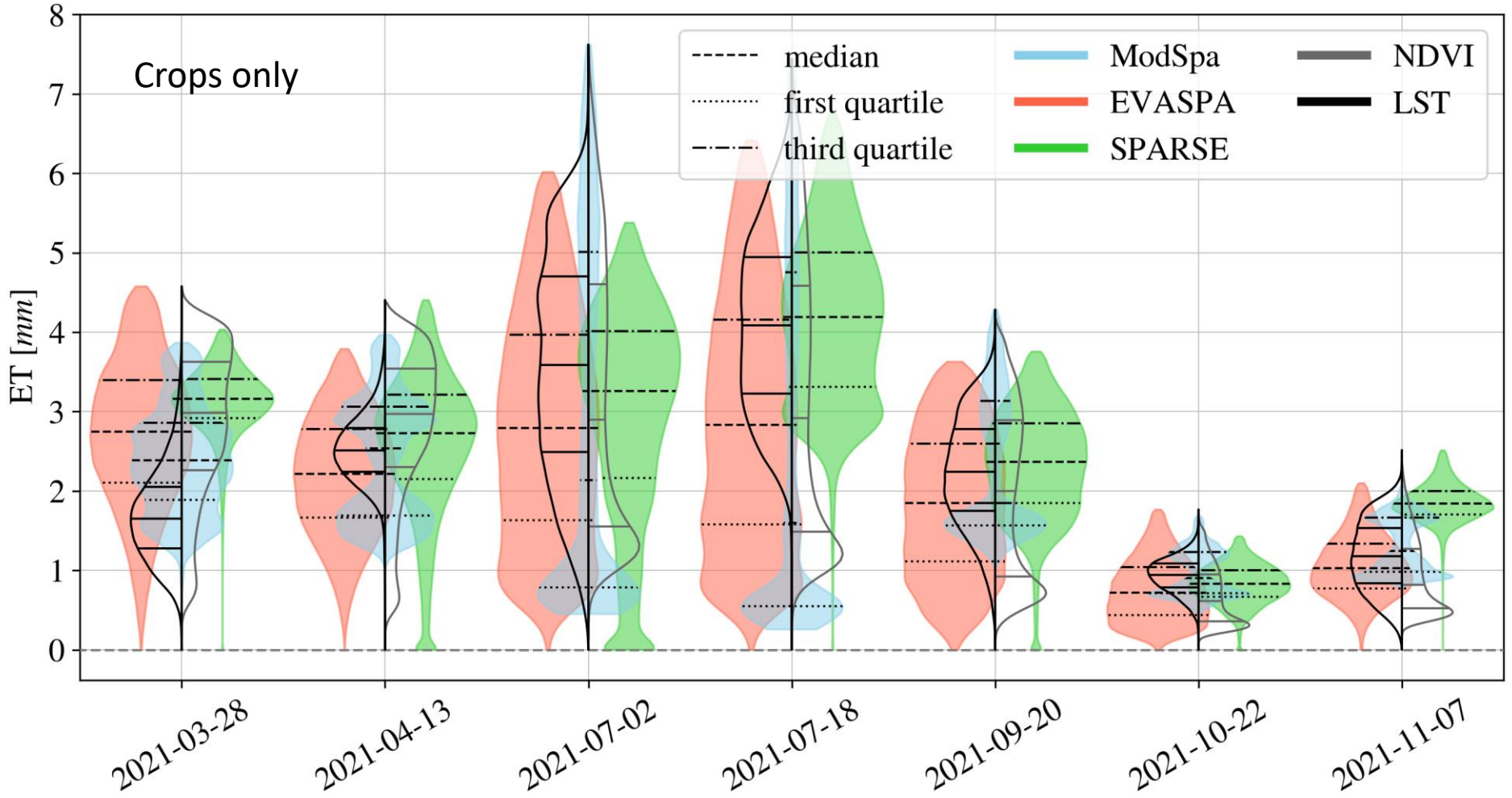






Here we can clearly see that two dates (in july) have a drastically different behavior : when the water demand is the highest, dry ModSpa has an important stress, which clearly indicates that irrigation is missing.

Distribution evaluation



Irrigation is decided through Land Cover (for now)

Irrigated	Non Irrigated
Nuts	No sim
Fruits	Forests
Pastures	Olives
Arable land	Winter crops
Summer crops	Vineyards
Double crops	
Irrigated vegetables and trees	