10-12 MAY 2023 ESA-ESRIN

INTERNATIONAL WORKSHOP ON HIGH-RESOLUTION THERMAL EO

“Integration of thermal and optical models for mapping crop evapotranspiration in California”

Oscar R. Belfiore, **Kyle R. Knipper, William P. Kustas, Nicolas Bambach-Ortiz, Andrew J. McElrone, Sebastian Castro, John H Prueger, Nishan Bhattarai, Lawrence E. Hipps, Joseph G. Alfieri, D’Urso G.**

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Dipartimento di Agraria
USDA ARS United States Department of Agriculture Agricultural Research Service
UC DAVIS UNIVERSITY OF CALIFORNIA
Utah State University
OU

grapex
T-REX Tree crop Remote sensing of Evapotranspiration eXperiment
E&J Gallo Winery
california almonds Almond Board of California

Context

What we need?

- Daily ET maps at field scale

How we can do it?

- **Thermal data** is a valuable tool in surface energy balance models for estimating evapotranspiration (ET)

But…we have a problem:

- it is not easy to monitor daily evapotranspiration with passive sensors such as Landsat, the revisit time (8 days) can be insufficient to detect changes in surface moisture or crop phenology, particularly in regions with persistent overcast conditions

The solution (?)

- To address this challenge, the easy implementation of the common gap-filling methods, such as interpolating the ratio of actual to reference ET (ET/ETo) across image acquisition days, offers advantages in an operational context, but might not fully account for the non-linear dynamics of ET, especially over sparse-canopy irrigated crops.

- Integration of the DISALEXI model based on Landsat optical and thermal data and the Shuttleworth-Wallace (SW) ET model based on Sentinel-2 optical data.

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2021-2022

grapex

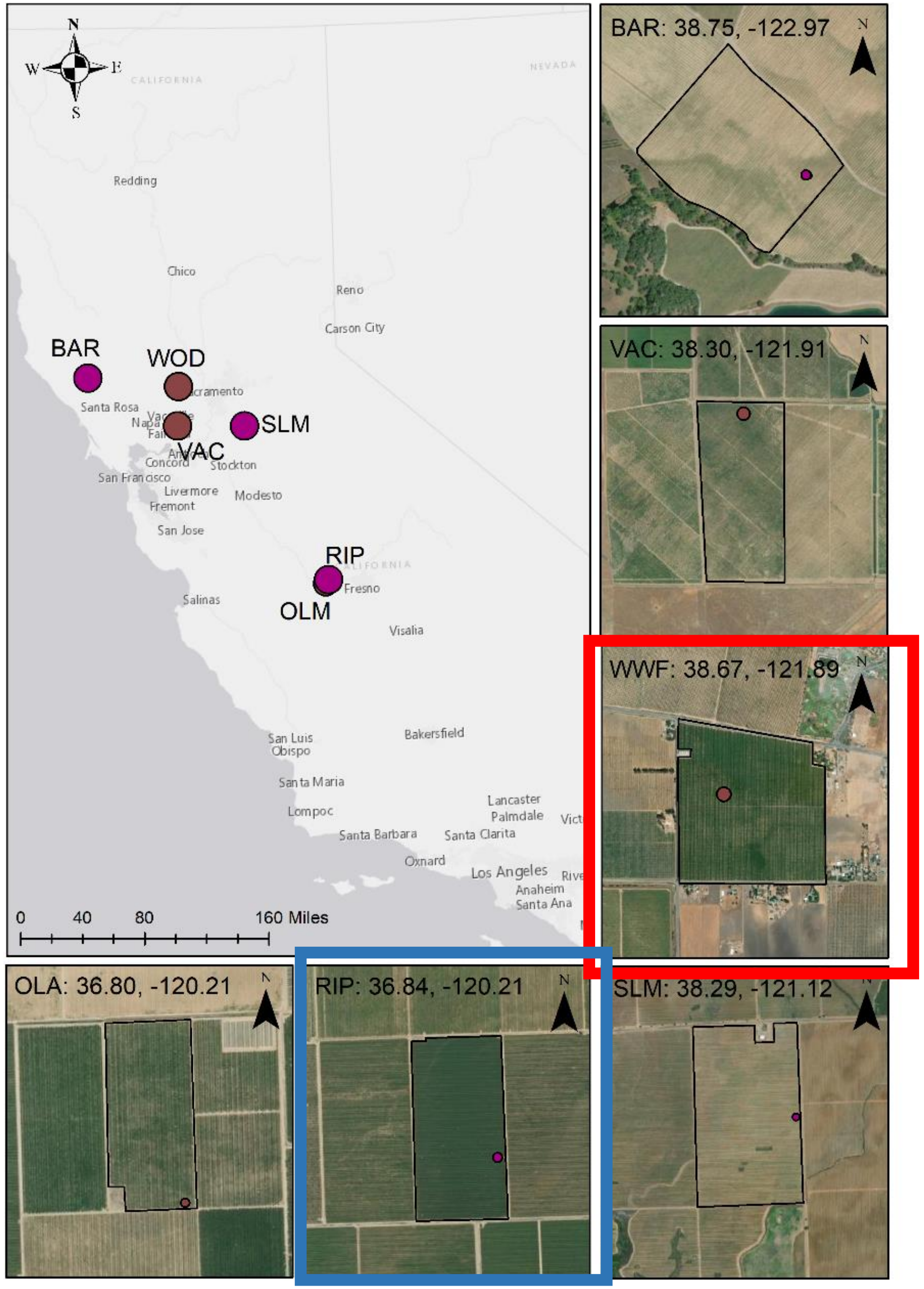
https://youtu.be/_YFmXaroRO8

T-REX

Tree crop **R**emote sensing of **E**vapotranspiration e**X**periment

2021-2022

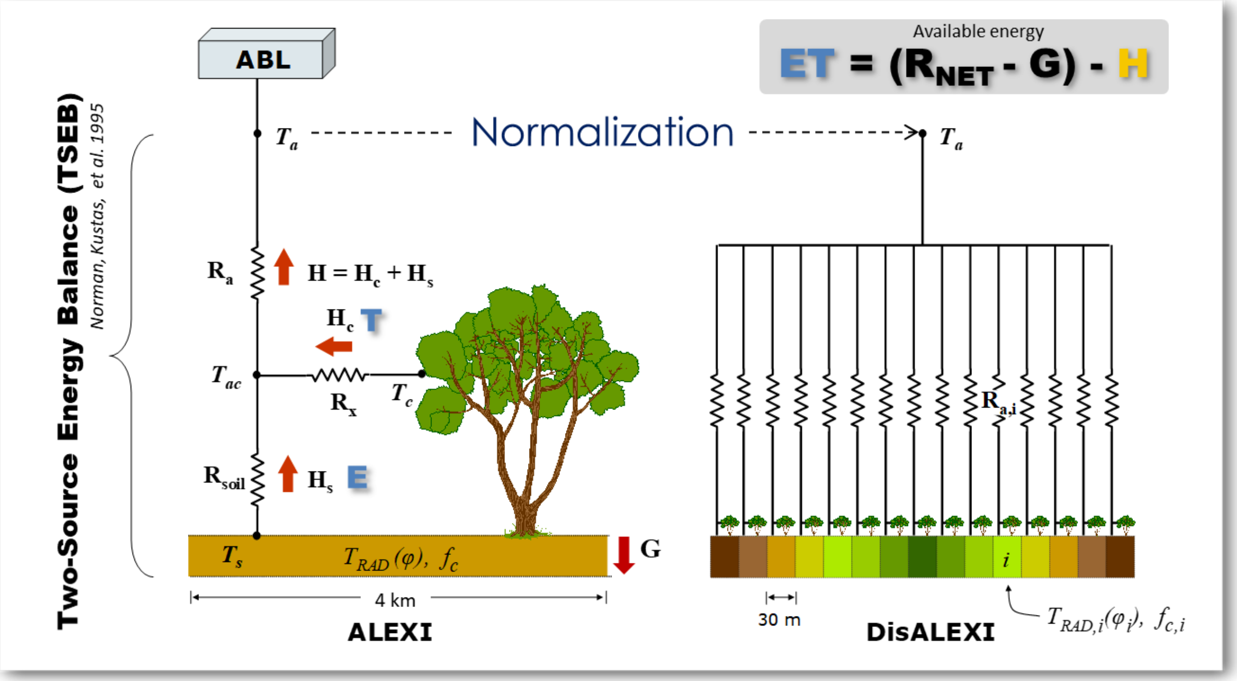
Data Tier	Methods/Models
Flux Tower Data	Eddy covariance method
THERMAL Satellite Data	DisALEXI
OPTICAL Satellite Data	Shuttleworth-Wallace (S-W)



WWF
TREX test site
Almond orchard

RIP760
GRAPEX test site
Vineyard

Thermal based model – ALEXI/DISALEXI

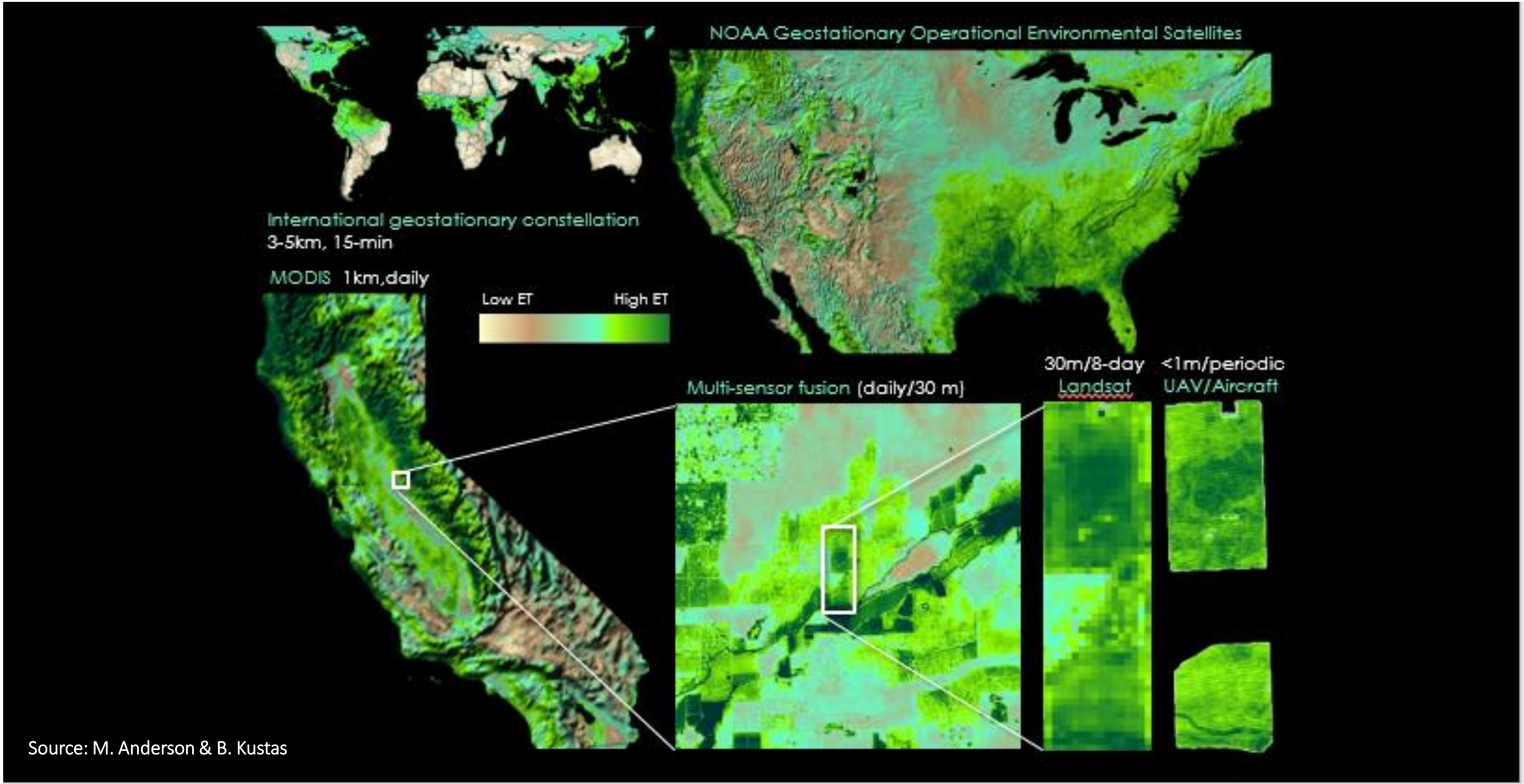


	Regional scale		**Landscape scale**	
Surface temp:	ΔT_{RAD}	- Geostationary	T_{RAD}	- Landsat, ECO, VIIRS
Air temp:	T_a	- ABL model	T_a	- ALEXI
Veg cover:	f_c	- MODIS/VIIRS	f_c	- Landsat, HLS
Albedo:	α	- MODIS/VIIRS	α	- Landsat, HLS

Also gridded insolation, wind, vapor pressure, landcover

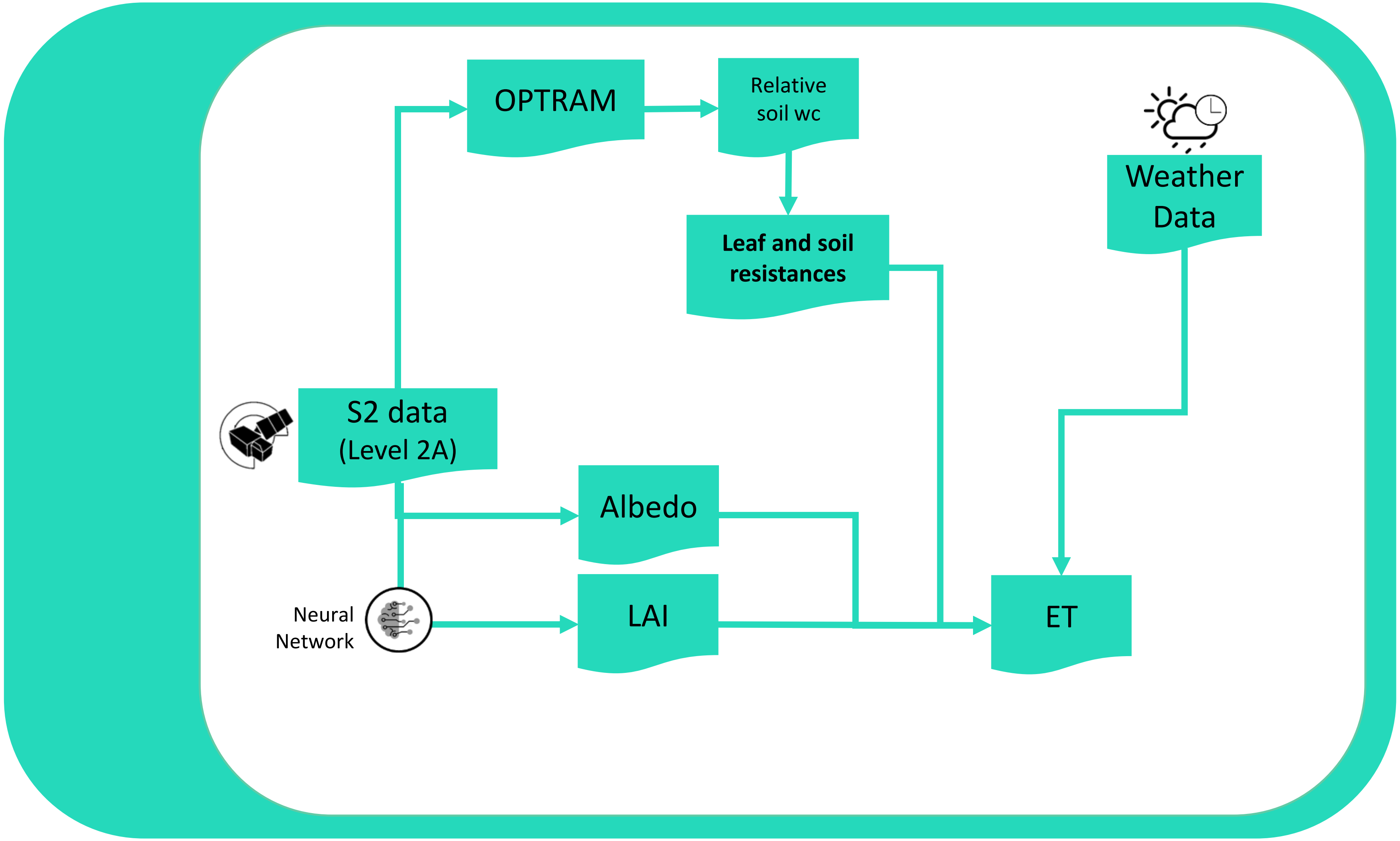
Source: M. Anderson & B. Kustas

MULTI-SENSOR/MULTI-SCALE ET MAPPING



Source: M. Anderson & B. Kustas

Spectral based model –Shuttleworth-Wallace (SW) model


OPTRAM

Relative soil wc

Leaf and soil resistances

Weather Data

S2 data (Level 2A)

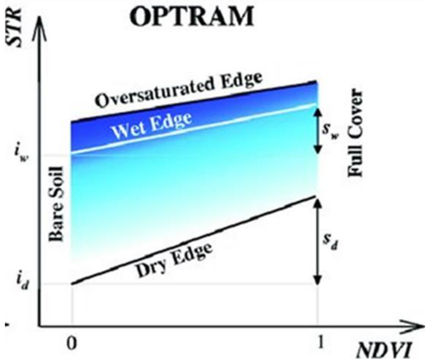
Albedo

Neural Network

LAI

ET

Sadeghi et al (2017)
proposed a physical “OPtical TRApezoid Model”
https://doi.org/10.1016/j.rse.2017.05.041



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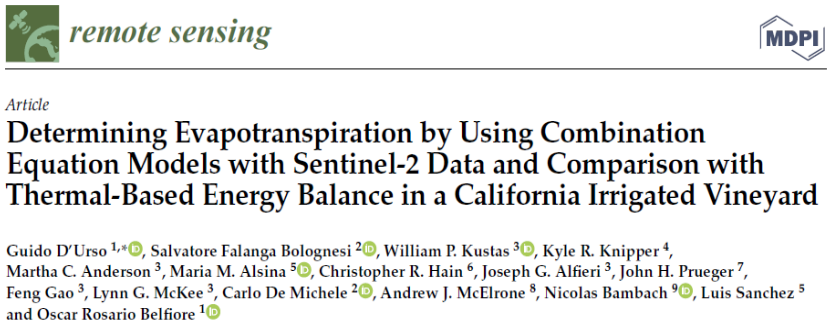
GRAPEX Campaign 2018



remote sensing

MDPI

Article

Determining Evapotranspiration by Using Combination Equation Models with Sentinel-2 Data and Comparison with Thermal-Based Energy Balance in a California Irrigated Vineyard

Guido D'Urso [1,*], Salvatore Falanga Bolognesi [2], William P. Kustas [3], Kyle R. Knipper [4], Martha C. Anderson [3], Maria M. Alsina [5], Christopher R. Hain [6], Joseph G. Alfieri [3], John H. Prueger [7], Feng Gao [3], Lynn G. McKee [3], Carlo De Michele [2], Andrew J. McElrone [8], Nicolas Bambach [9], Luis Sanchez [5] and Oscar Rosario Belfiore [1]

Data Tier	Methods/Models
Flux Tower Data	Eddy covariance method
THERMAL Satellite Data	DisALEXI ALEXI/DisALEXI (DataFusion)
OPTICAL Satellite Data	Penman-Monteith (P-M) Shuttleworth-Wallace (S-W)

Irrigated vineyard - Ripperdan, California, U.S

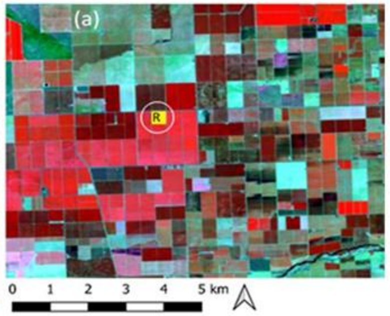
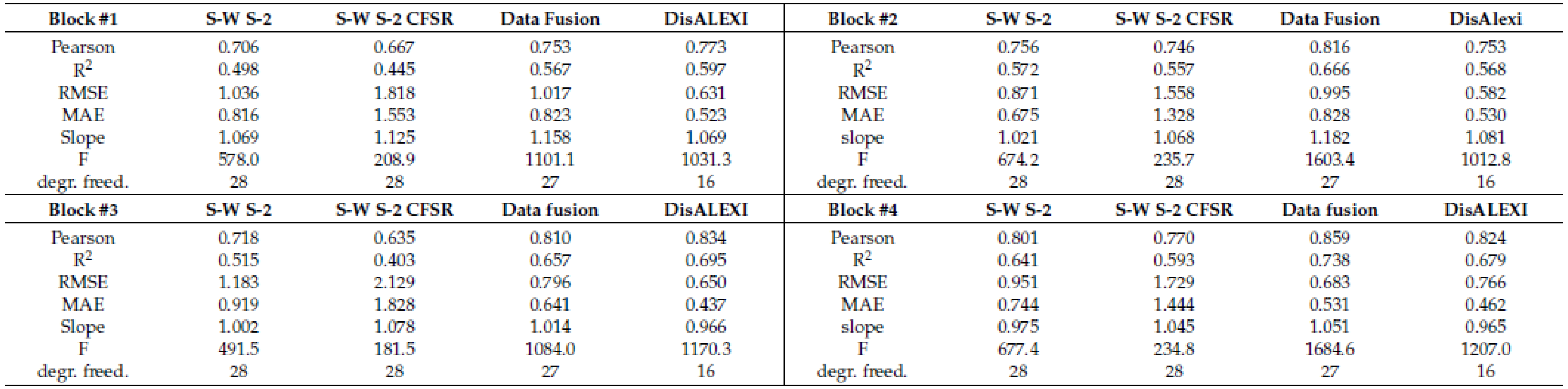
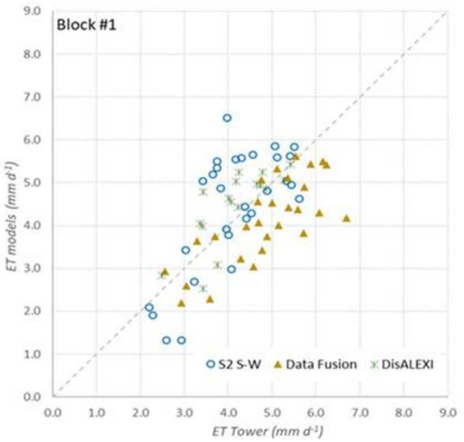


Table 4. Statistical evaluation of daily E (mm d^{-1}) from the three approaches: S-W S-2, S-W S-2 with CFSR meteorological input, DisALEXI and Data Fusion vs. flux tower data.



Block #1	S-W S-2	S-W S-2 CFSR	Data Fusion	DisALEXI	Block #2	S-W S-2	S-W S-2 CFSR	Data Fusion	DisAlexi
Pearson	0.706	0.667	0.753	0.773	Pearson	0.756	0.746	0.816	0.753
R^2	0.498	0.445	0.567	0.597	R^2	0.572	0.557	0.666	0.568
RMSE	1.036	1.818	1.017	0.631	RMSE	0.871	1.558	0.995	0.582
MAE	0.816	1.553	0.823	0.523	MAE	0.675	1.328	0.828	0.530
Slope	1.069	1.125	1.158	1.069	slope	1.021	1.068	1.182	1.081
F	578.0	208.9	1101.1	1031.3	F	674.2	235.7	1603.4	1012.8
degr. freed.	28	28	27	16	degr. freed.	28	28	27	16
Block #3	**S-W S-2**	**S-W S-2 CFSR**	**Data fusion**	**DisALEXI**	**Block #4**	**S-W S-2**	**S-W S-2 CFSR**	**Data fusion**	**DisALEXI**
Pearson	0.718	0.635	0.810	0.834	Pearson	0.801	0.770	0.859	0.824
R^2	0.515	0.403	0.657	0.695	R^2	0.641	0.593	0.738	0.679
RMSE	1.183	2.129	0.796	0.650	RMSE	0.951	1.729	0.683	0.766
MAE	0.919	1.828	0.641	0.437	MAE	0.744	1.444	0.531	0.462
Slope	1.002	1.078	1.014	0.966	slope	0.975	1.045	1.051	0.965
F	491.5	181.5	1084.0	1170.3	F	677.4	234.8	1684.6	1207.0
degr. freed.	28	28	27	16	degr. freed.	28	28	27	16

Daily ET - Validation



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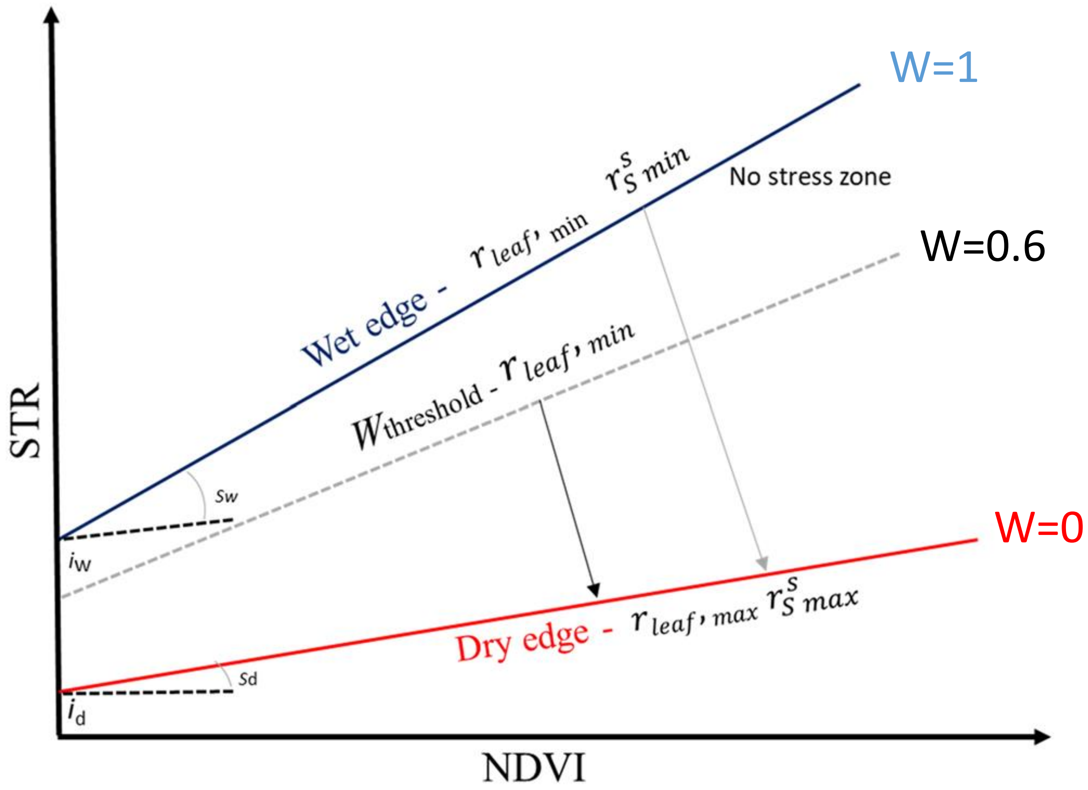
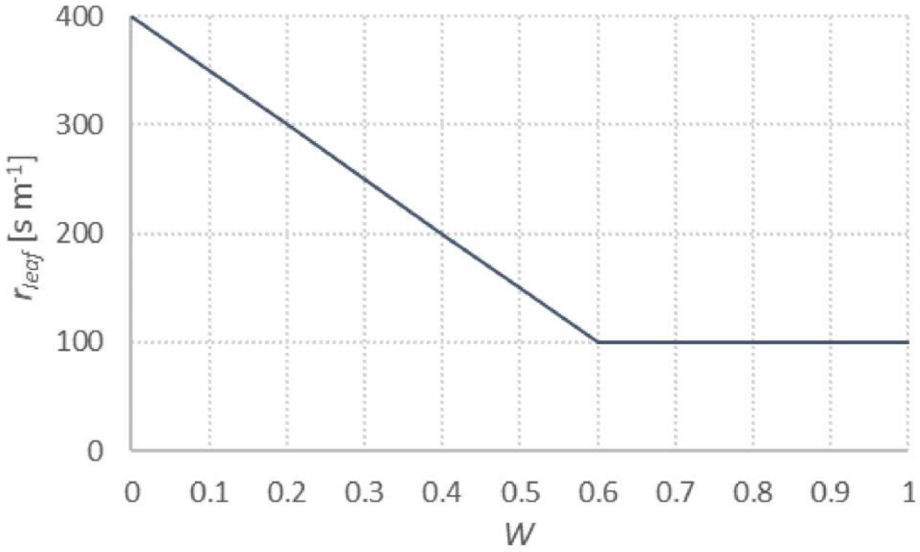
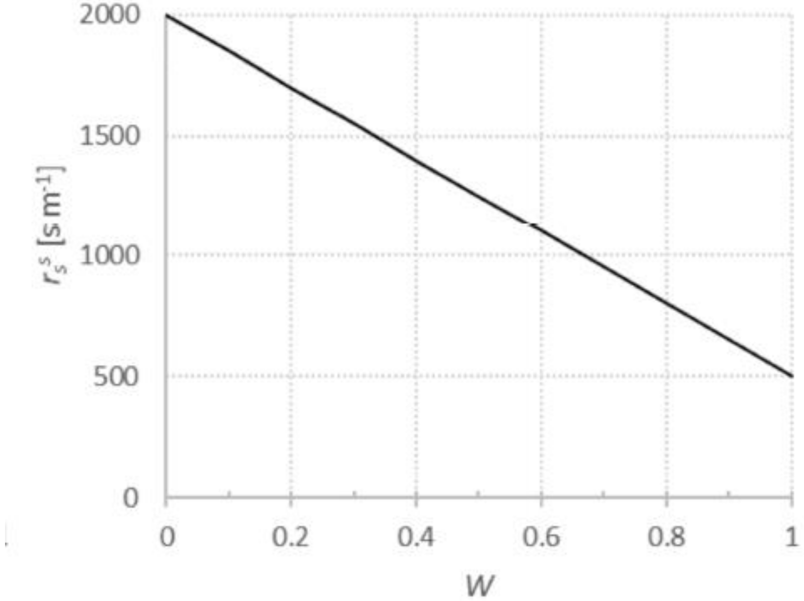
Shuttleworth-Wallace (SW) model and OPTRAM approach

- Linking Substrate and Canopy Resistance with SWIR Observations







$$STR = \frac{(1-\rho_{SWIR})^2}{2\,\rho_{SWIR}}$$

$$STR_d = i_d + s_d NDVI$$

$$STR_w = i_w + s_w NDVI$$

$$W = \frac{STR - STR_d}{STR_w - STR_d}$$

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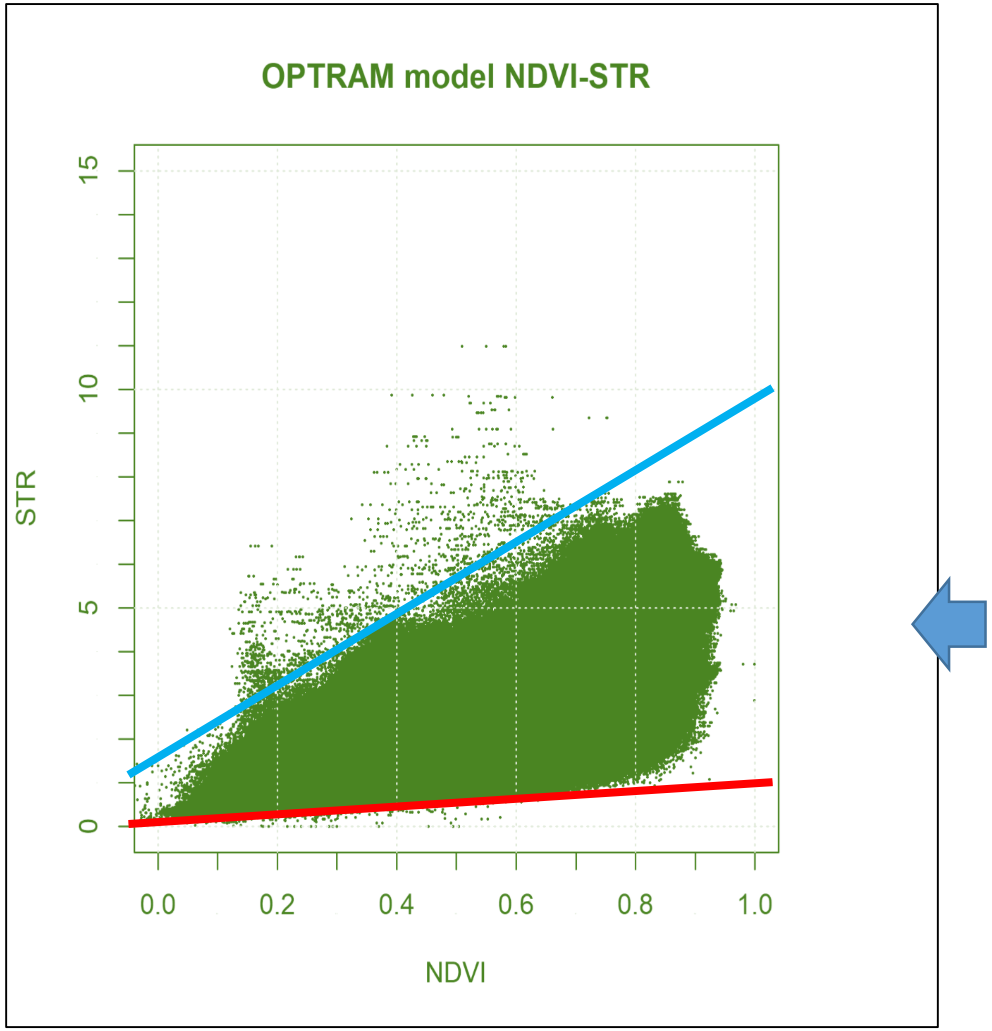
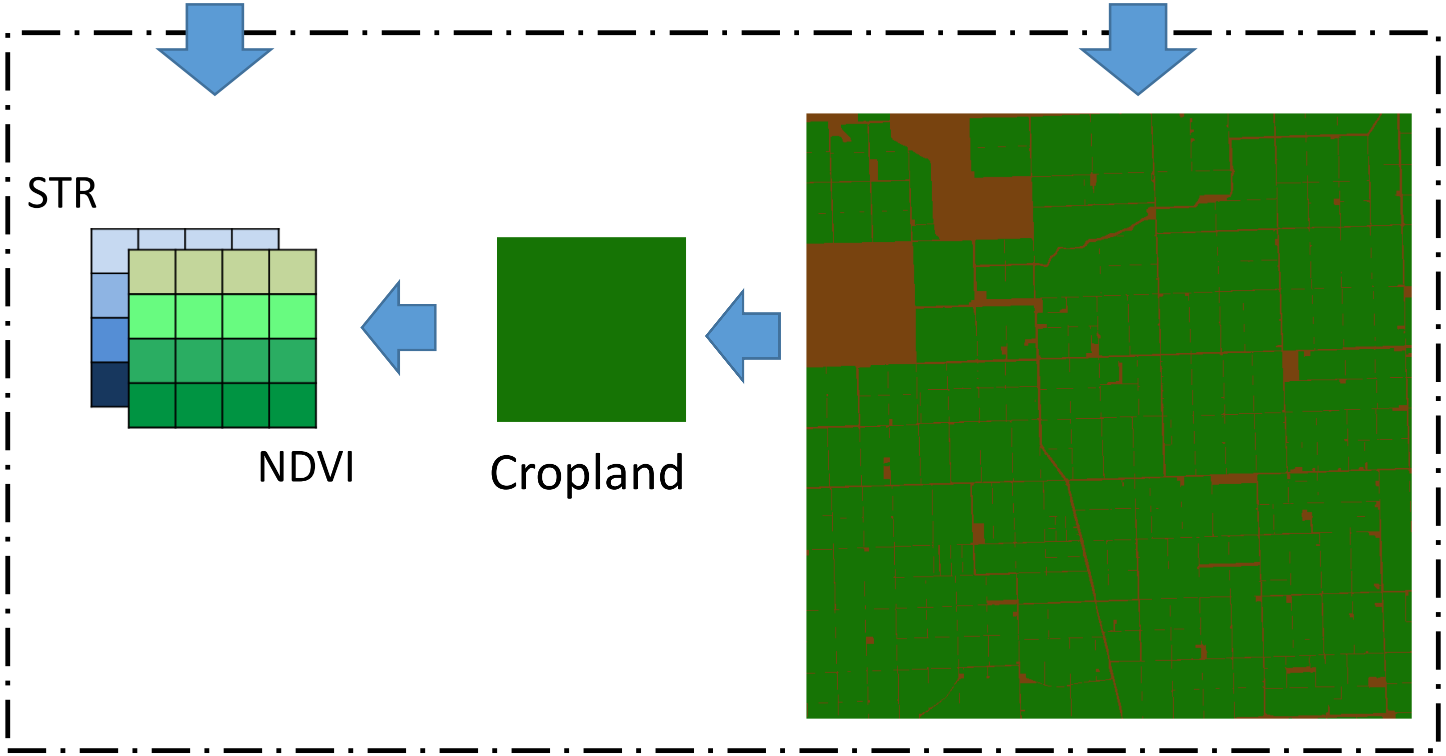
Spatial and Temporal domains - OPTRAM parametrization



Sentinel-2 images

Land cover map

CALIFORNIA NATURAL RESOURCES AGENCY



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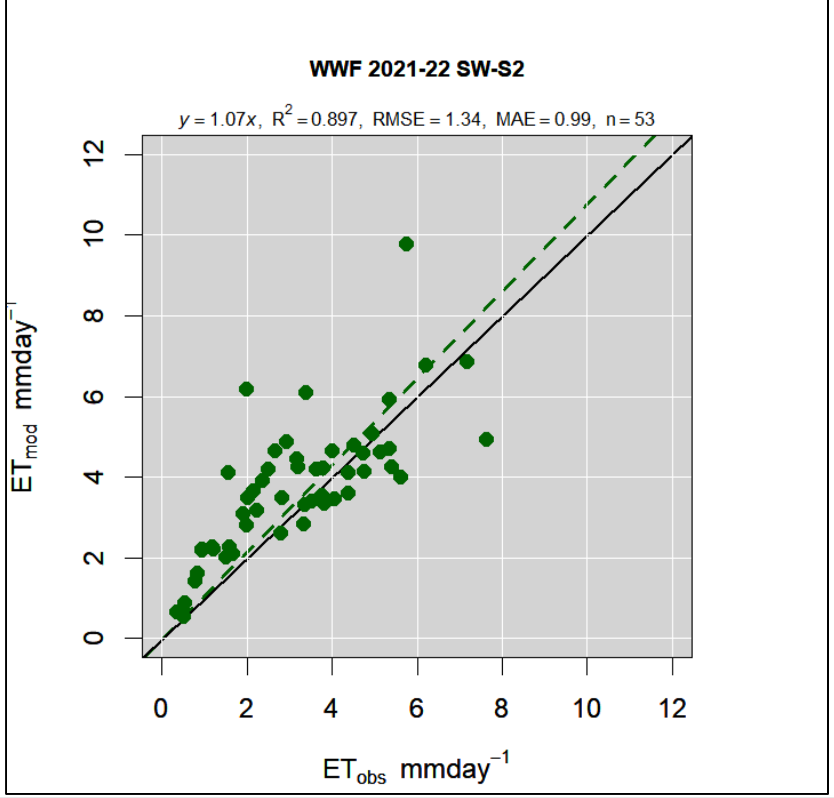
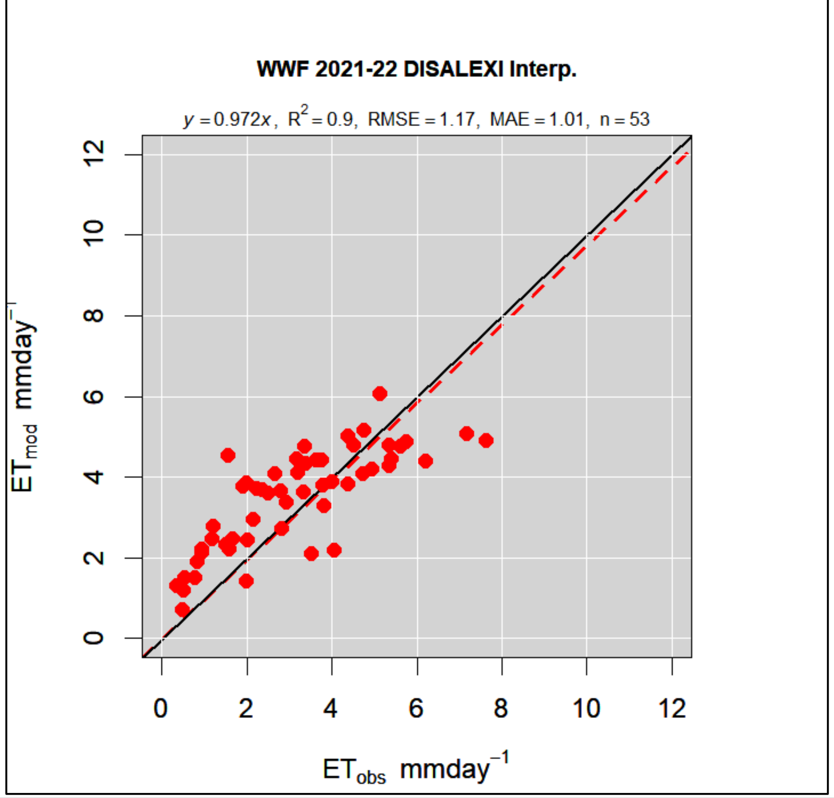
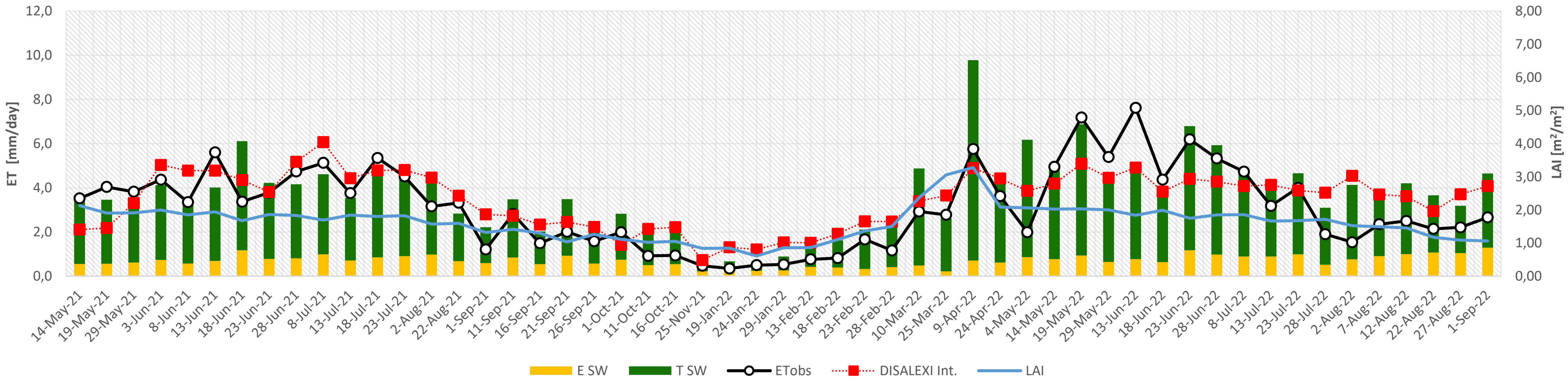
WWF


WWF 2021-22 SW-S2

$y = 1.07x$, $R^2 = 0.897$, RMSE = 1.34, MAE = 0.99, n = 53


WWF 2021-22 DISALEXI Interp.

$y = 0.972x$, $R^2 = 0.9$, RMSE = 1.17, MAE = 1.01, n = 53



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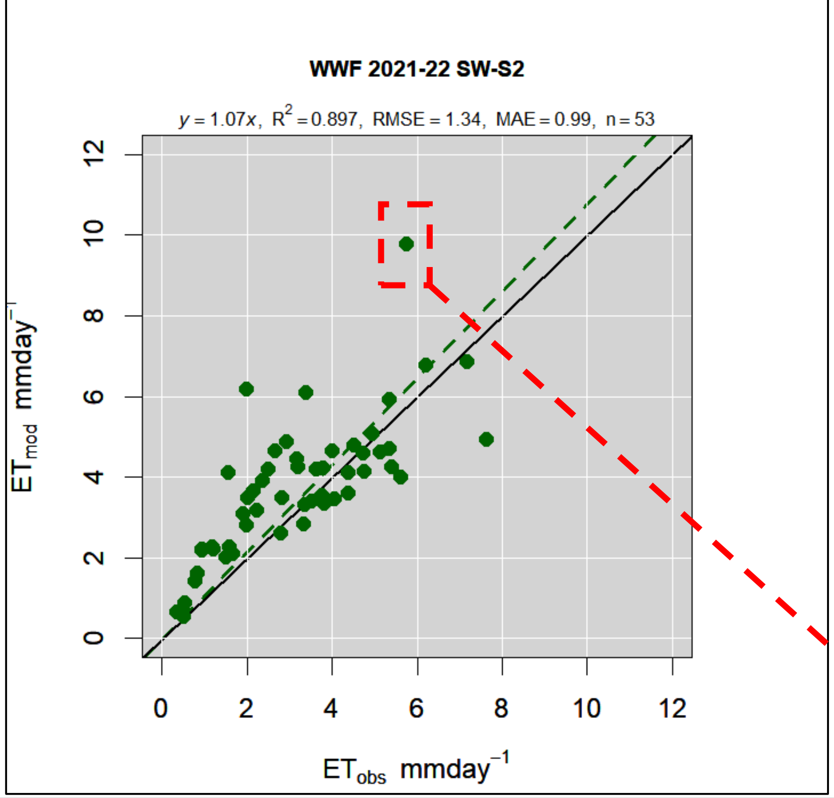
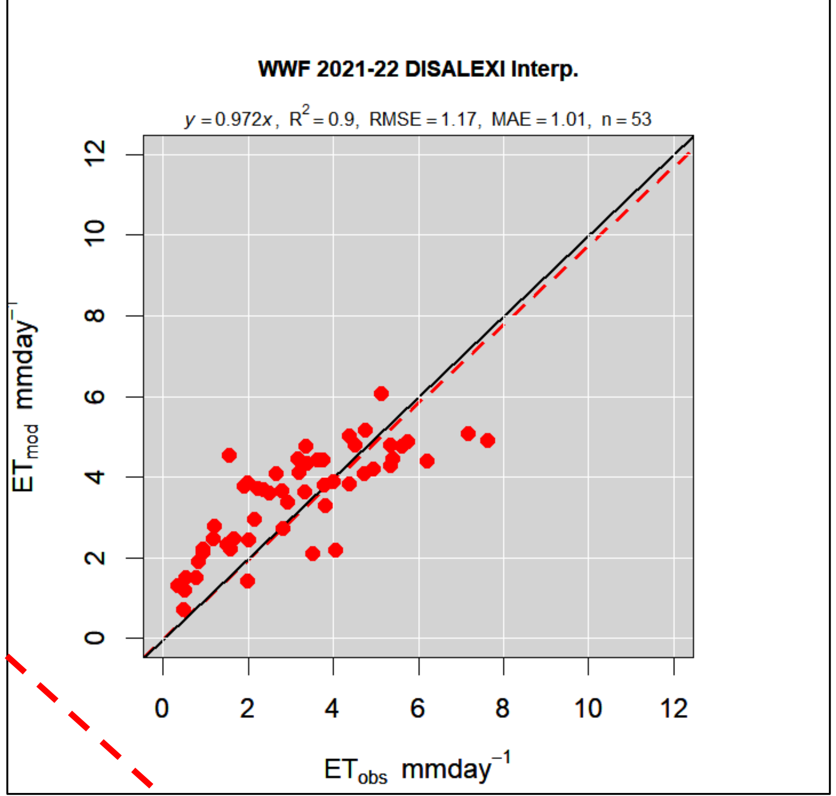
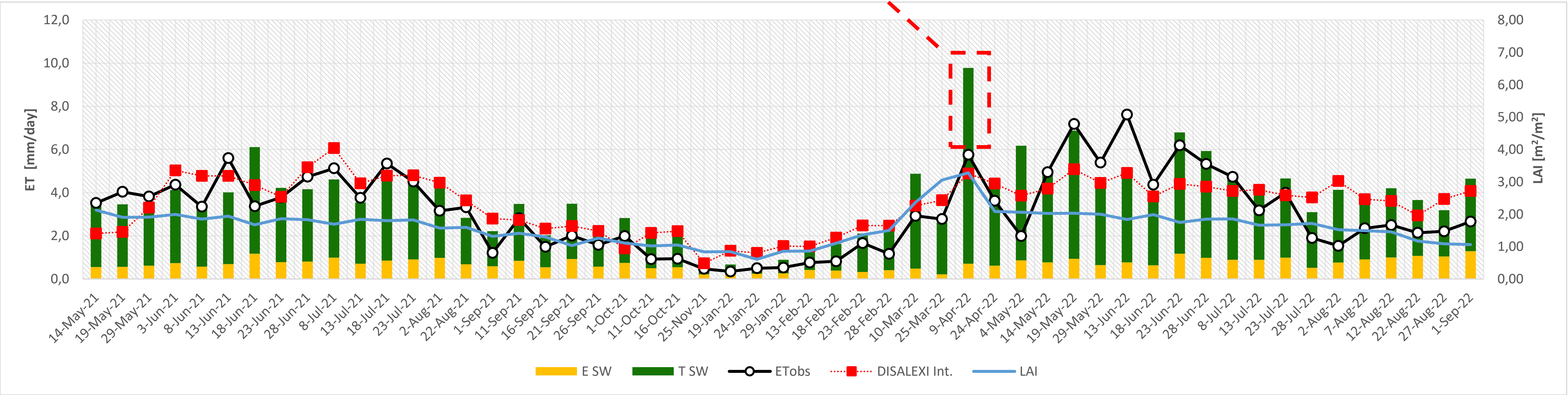
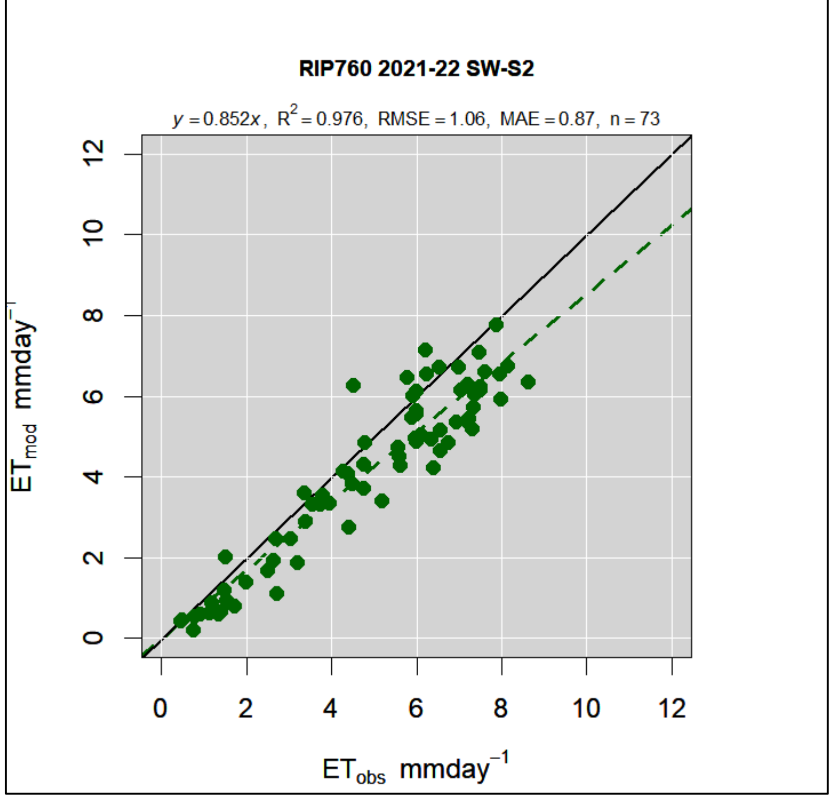
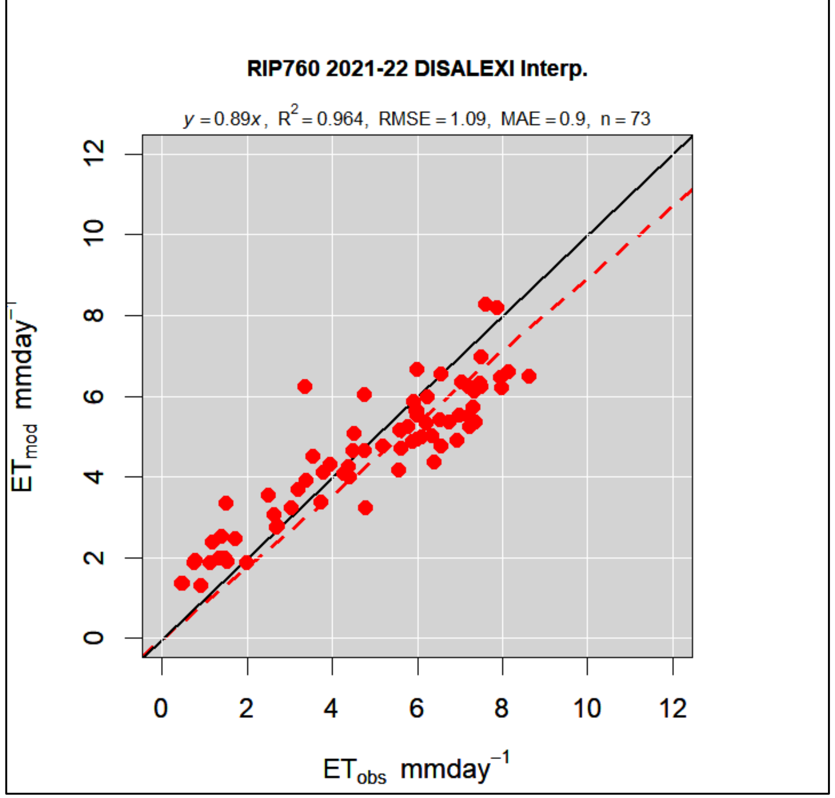


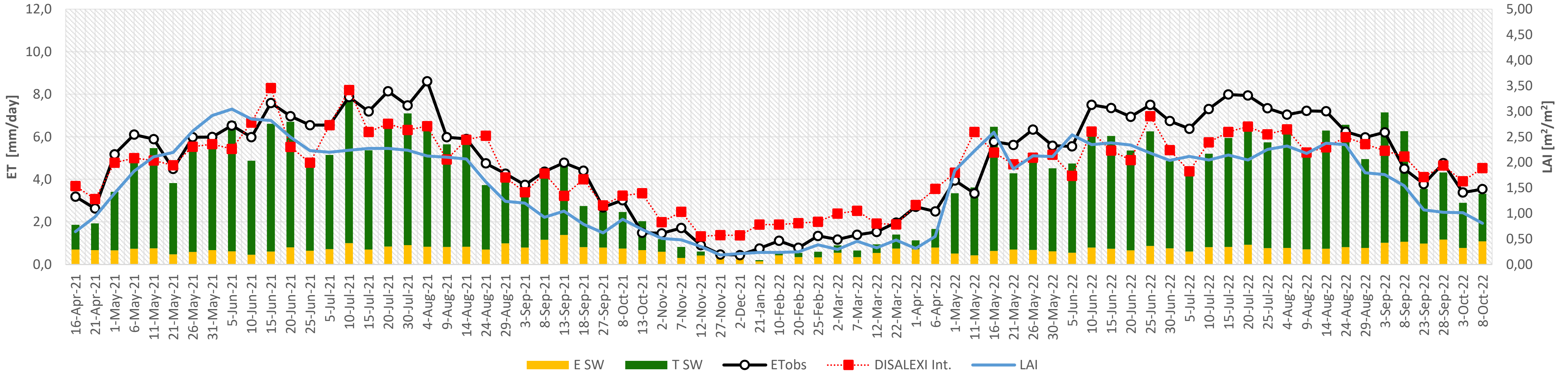




RIP760


RIP760 2021-22 SW-S2
$y = 0.852x$, $R^2 = 0.976$, RMSE = 1.06, MAE = 0.87, n = 73
ET_{mod} mmday^{-1}
ET_{obs} mmday^{-1}
0
2
4
6
8
10
12


RIP760 2021-22 DISALEXI Interp.
$y = 0.89x$, $R^2 = 0.964$, RMSE = 1.09, MAE = 0.9, n = 73
ET_{mod} mmday^{-1}
ET_{obs} mmday^{-1}
0
2
4
6
8
10
12


ET [mm/day]
LAI [m²/m²]
0,0
2,0
4,0
6,0
8,0
10,0
12,0
0,00
0,50
1,00
1,50
2,00
2,50
3,00
3,50
4,00
4,50
5,00
16-Apr-21
21-Apr-21
1-May-21
6-May-21
11-May-21
21-May-21
26-May-21
31-May-21
5-Jun-21
10-Jun-21
15-Jun-21
20-Jun-21
25-Jun-21
5-Jul-21
10-Jul-21
15-Jul-21
20-Jul-21
30-Jul-21
4-Aug-21
9-Aug-21
14-Aug-21
24-Aug-21
29-Aug-21
3-Sep-21
8-Sep-21
13-Sep-21
18-Sep-21
27-Sep-21
8-Oct-21
13-Oct-21
2-Nov-21
7-Nov-21
12-Nov-21
27-Nov-21
2-Dec-21
21-Jan-22
10-Feb-22
20-Feb-22
25-Feb-22
2-Mar-22
7-Mar-22
12-Mar-22
22-Mar-22
1-Apr-22
6-Apr-22
1-May-22
11-May-22
16-May-22
21-May-22
26-May-22
30-May-22
5-Jun-22
10-Jun-22
15-Jun-22
20-Jun-22
25-Jun-22
30-Jun-22
5-Jul-22
10-Jul-22
15-Jul-22
20-Jul-22
25-Jul-22
4-Aug-22
9-Aug-22
14-Aug-22
24-Aug-22
29-Aug-22
3-Sep-22
8-Sep-22
23-Sep-22
28-Sep-22
3-Oct-22
8-Oct-22
E SW
T SW
ETobs
DISALEXI Int.
LAI

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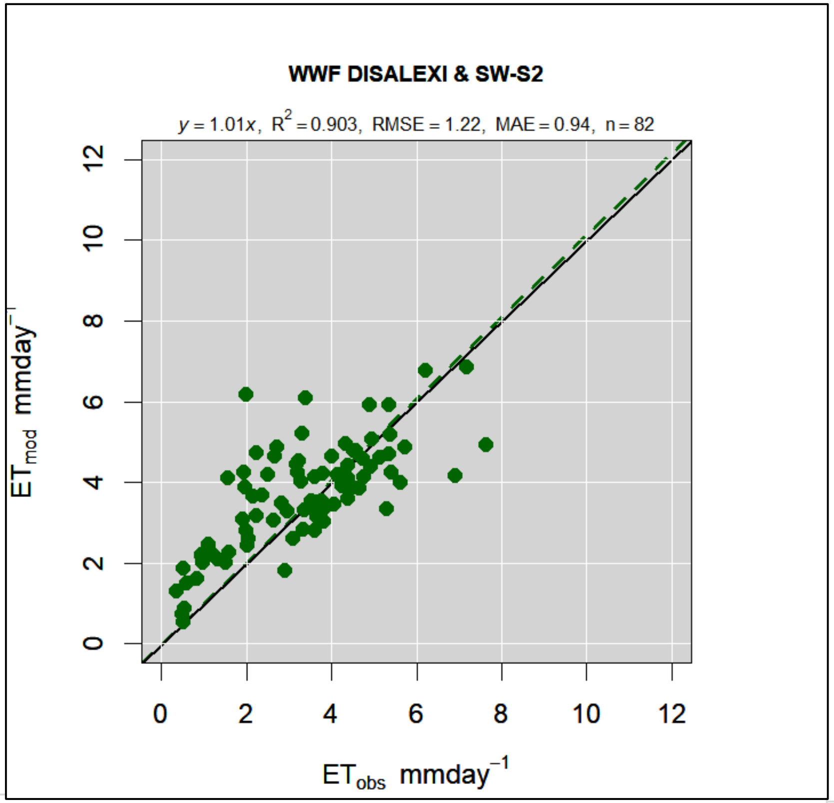
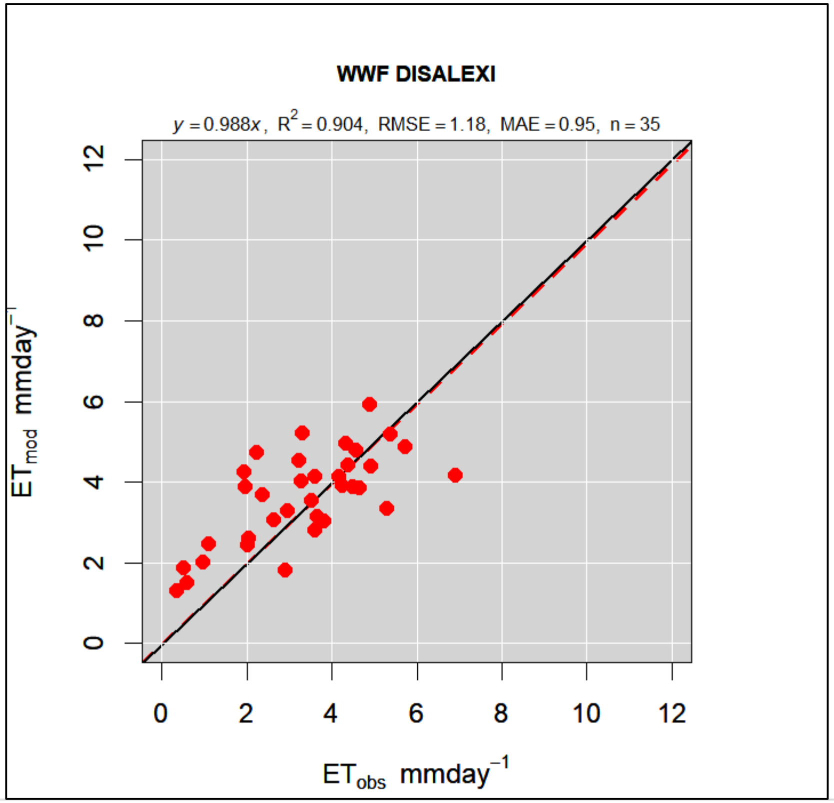
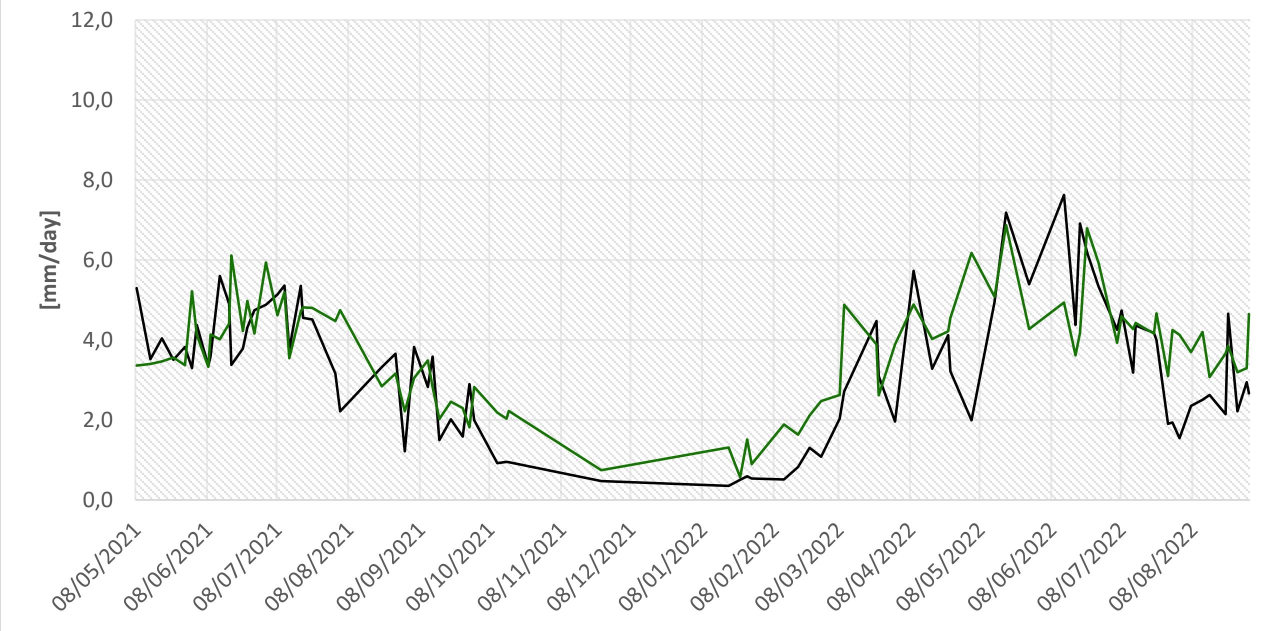
WWF

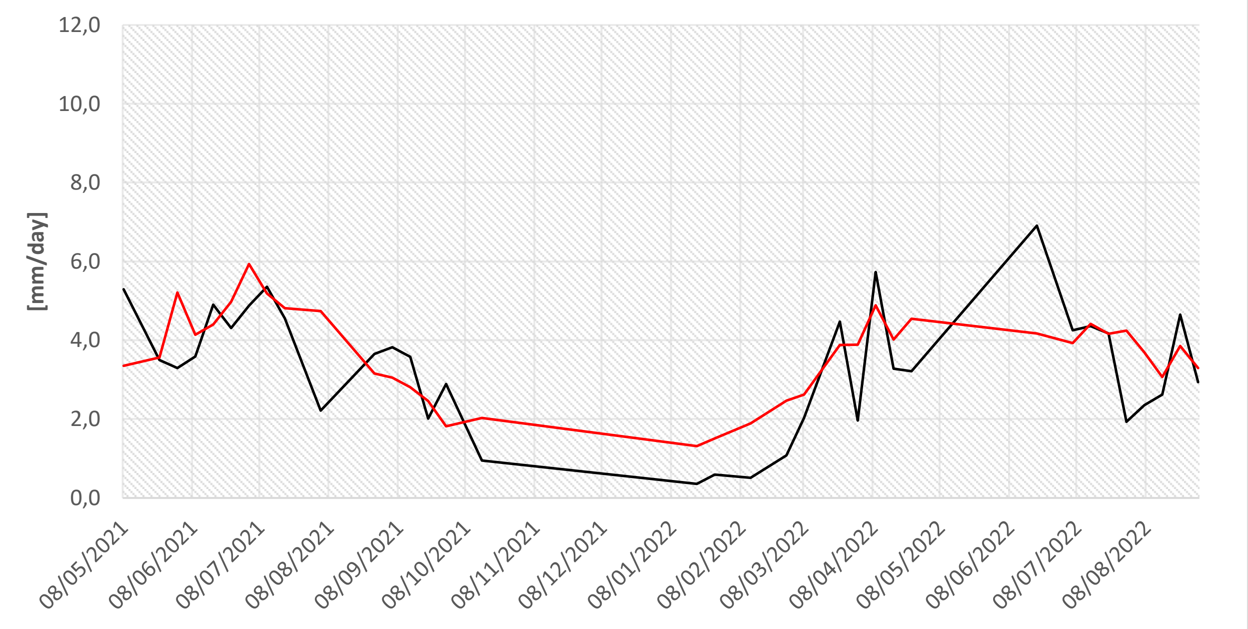

WWF DISALEXI & SW-S2

$y = 1.01x$, $R^2 = 0.903$, RMSE = 1.22, MAE = 0.94, n = 82


WWF DISALEXI

$y = 0.988x$, $R^2 = 0.904$, RMSE = 1.18, MAE = 0.95, n = 35





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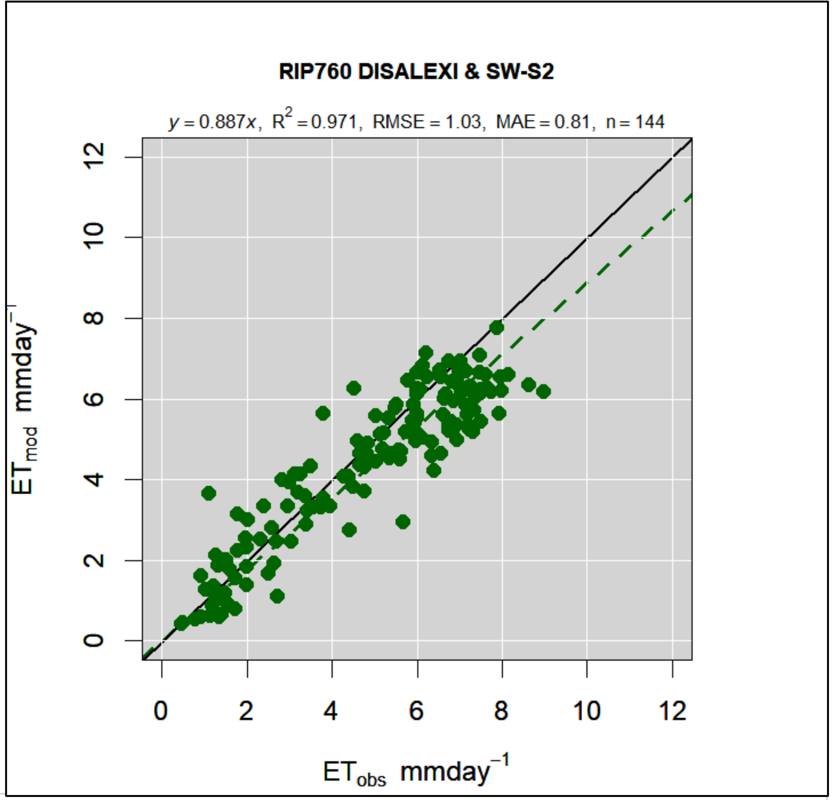
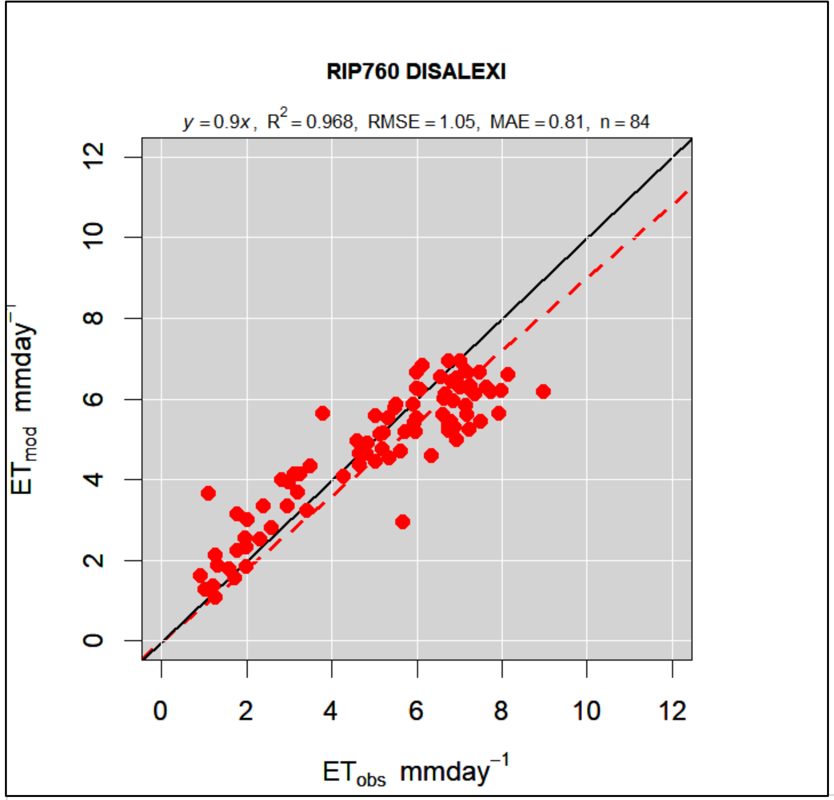
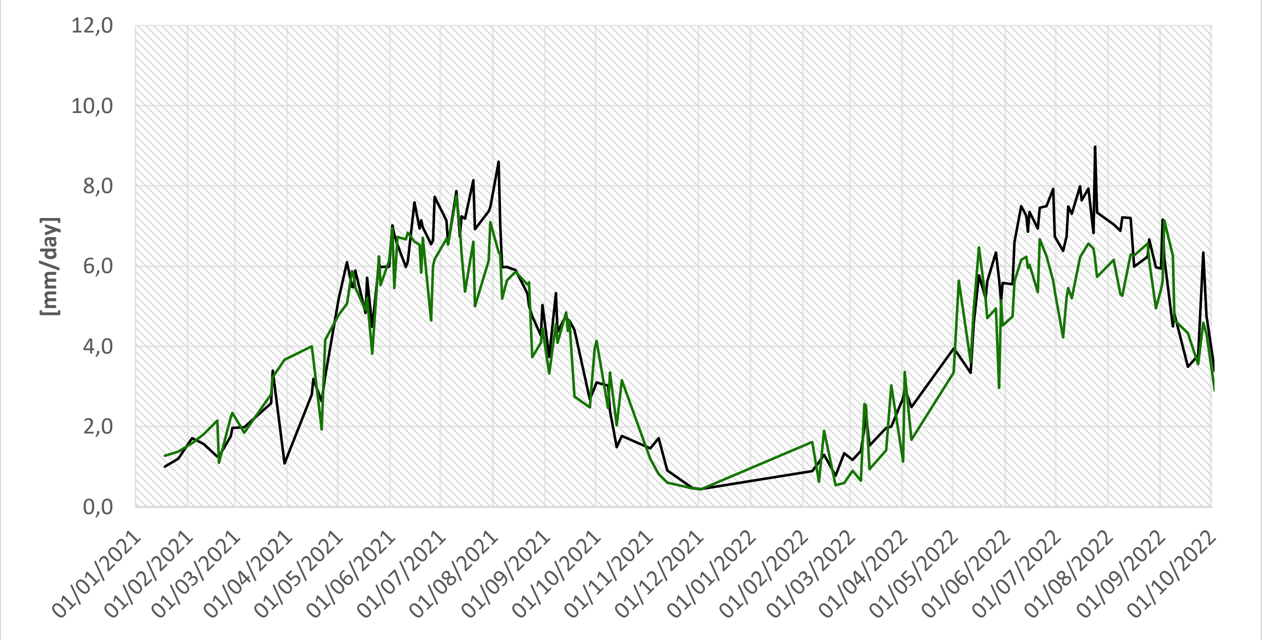
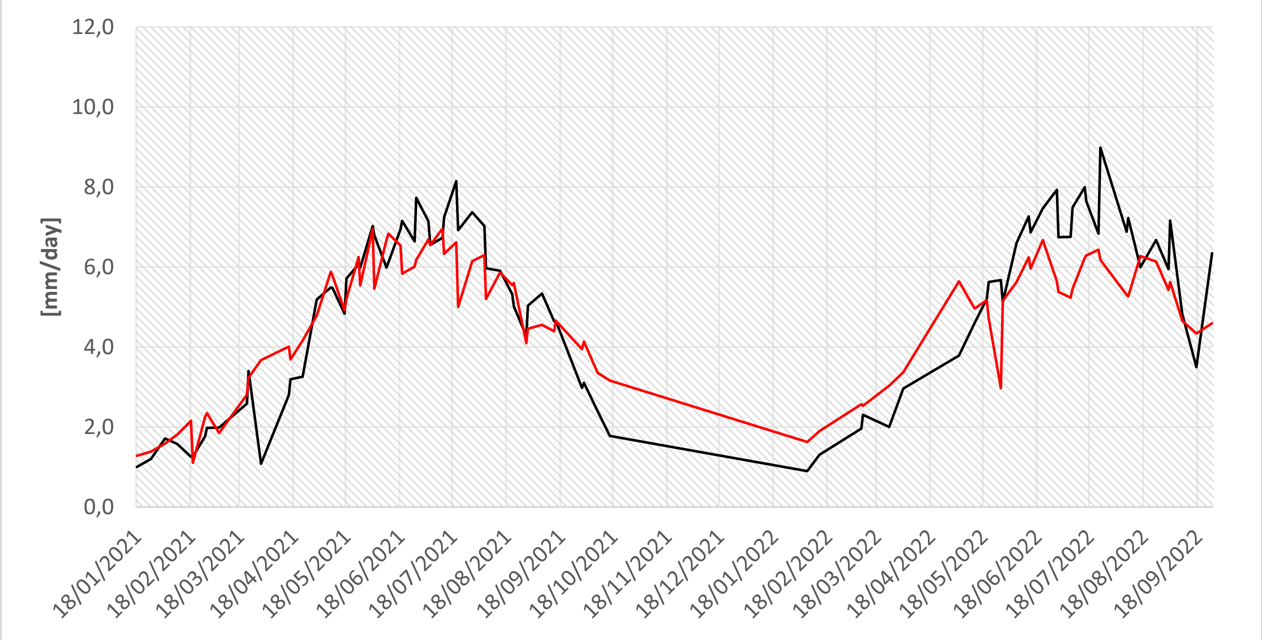
RIP760









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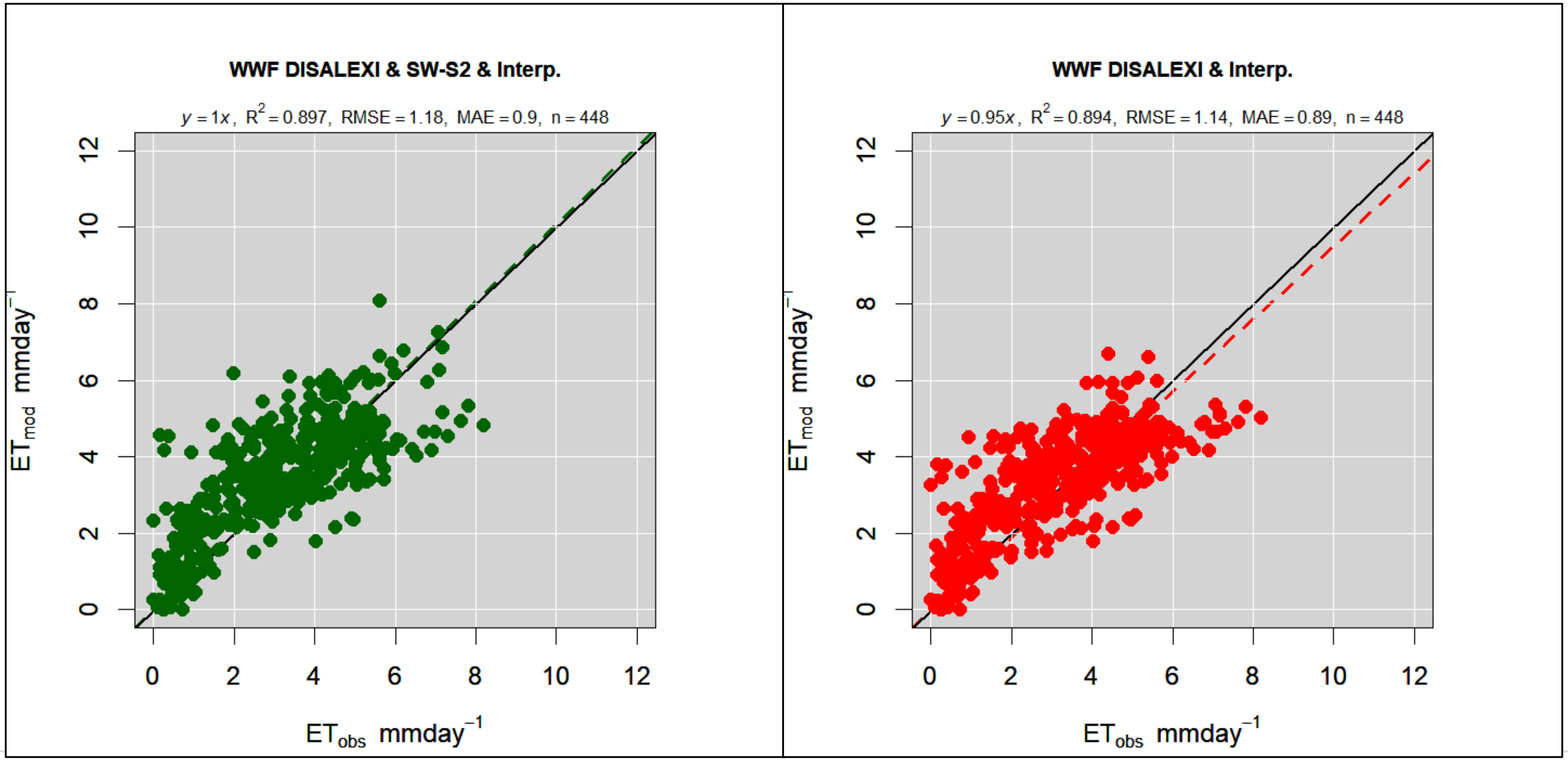
WWF

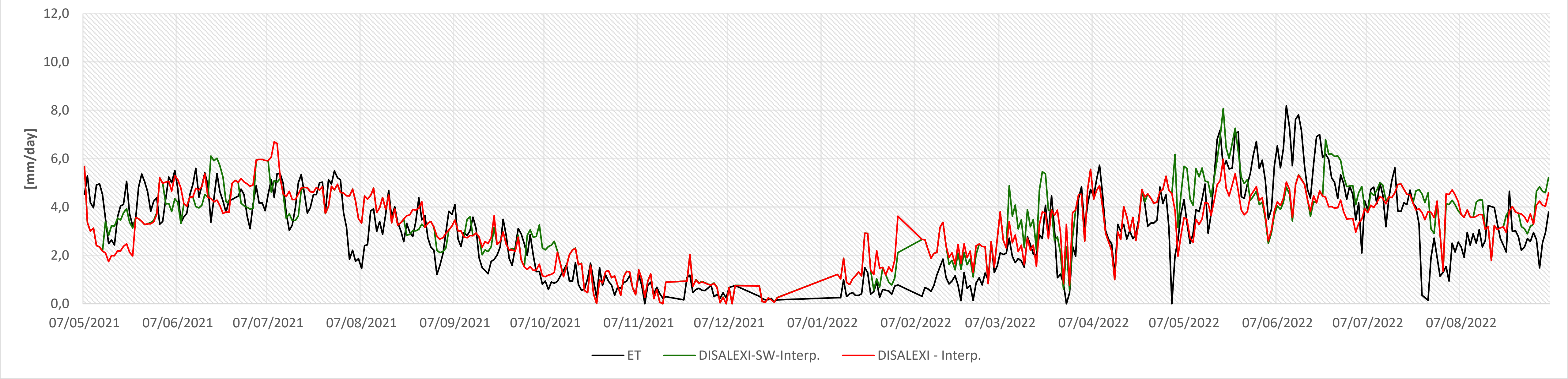


WWF DISALEXI & SW-S2 & Interp.

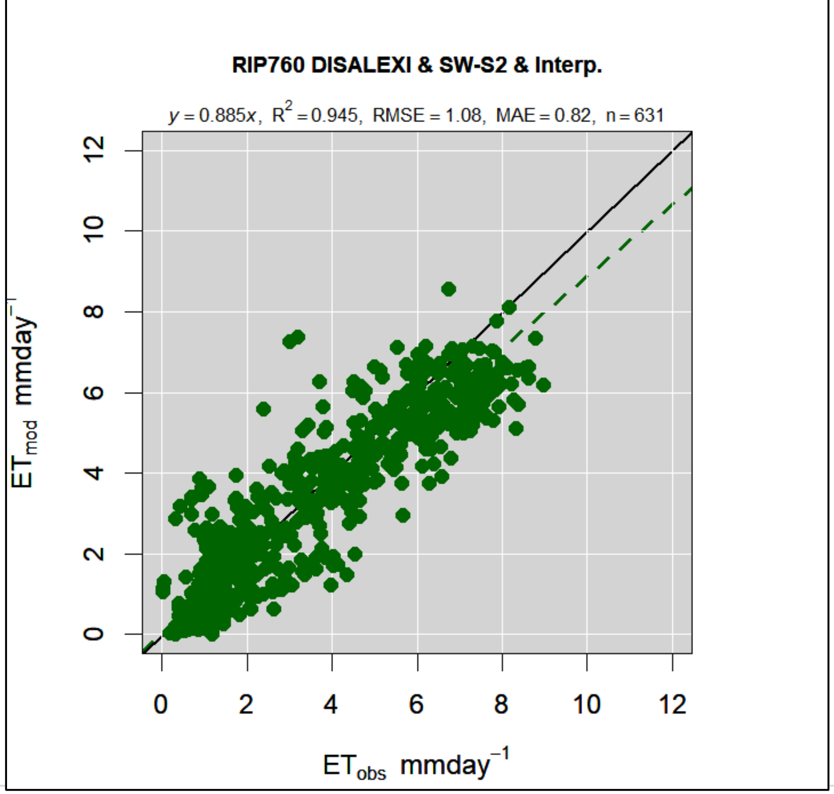
$y = 1x$, $R^2 = 0.897$, RMSE = 1.18, MAE = 0.9, n = 448

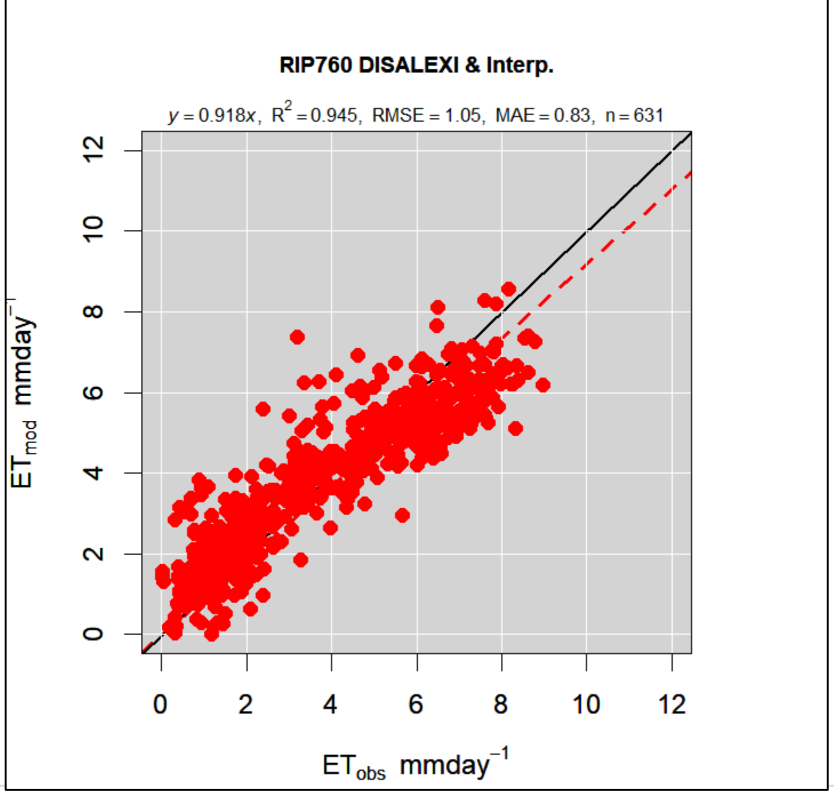
WWF DISALEXI & Interp.

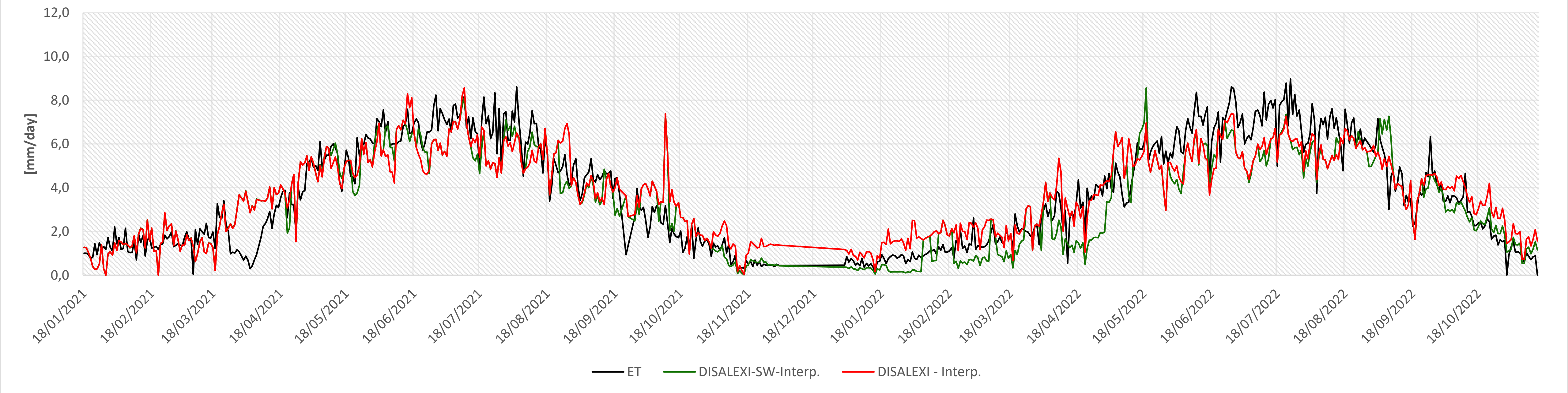
$y = 0.95x$, $R^2 = 0.894$, RMSE = 1.14, MAE = 0.89, n = 448



RIP760


RIP760 DISALEXI & SW-S2 & Interp.
$y = 0.885x$, $R^2 = 0.945$, RMSE = 1.08, MAE = 0.82, n = 631
ET_{mod} mmday^{-1}
ET_{obs} mmday^{-1}
0
2
4
6
8
10
12


RIP760 DISALEXI & Interp.
$y = 0.918x$, $R^2 = 0.945$, RMSE = 1.05, MAE = 0.83, n = 631
ET_{mod} mmday^{-1}
ET_{obs} mmday^{-1}
0
2
4
6
8
10
12


12,0
10,0
8,0
6,0
4,0
2,0
0,0
[mm/day]
18/01/2021
18/02/2021
18/03/2021
18/04/2021
18/05/2021
18/06/2021
18/07/2021
18/08/2021
18/09/2021
18/10/2021
18/11/2021
18/12/2021
18/01/2022
18/02/2022
18/03/2022
18/04/2022
18/05/2022
18/06/2022
18/07/2022
18/08/2022
18/09/2022
18/10/2022
ET
DISALEXI-SW-Interp.
DISALEXI - Interp.

Conclusions

- The DISALEXI and SW models confirm their reliability for the estimation of ET for irrigated tree crops.

- For the production of real-time ET maps on a daily scale, the delay in the availability of atmospherically corrected thermal data can represent a limit, therefore the integration of thermal and spectral models is a promising approach.

- **ET/ETo** interpolation method still offers advantages in an operational context.

Further developments

- Homogenize the input data:
  - EO data → HLS
  - Weather data → CFSR, ERA5…

- Test additional gap-filling method/approach:
  - i.e. smoothing, gap-filling, and interpolation of the input EO data instead of output data

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Thanks for your attention

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