Observing and retrieving energy budget components over a vineyard in north-eastern Spain using directional thermal infrared data

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background : TIR data & ET : environmental monitoring

- Thermal data (e.g. MODIS, TRISHNA*, ...) :

[1]

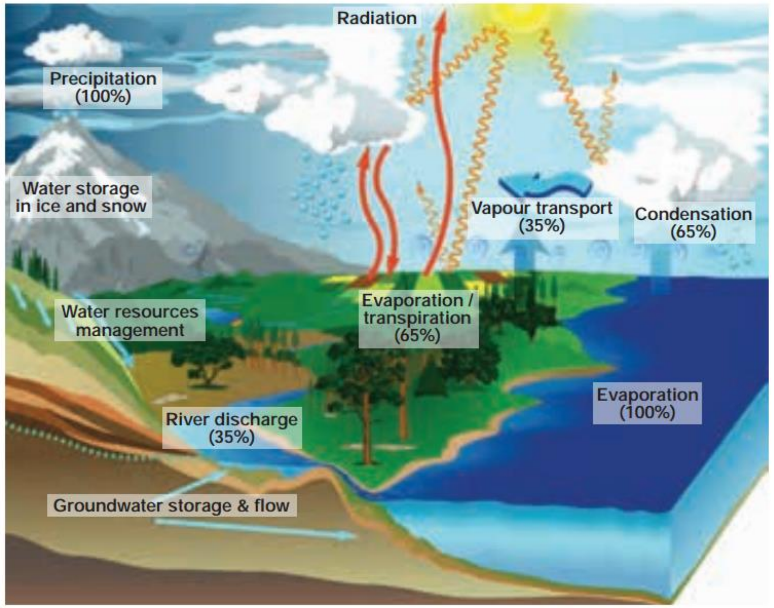
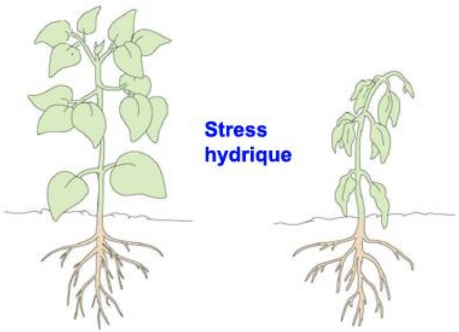


Figure 1.10
Global water and energy cycle of the Earth system and some possible observed values. Courtesy NASA.

  × plant water use and water stress monitoring - important for drought monitoring, irrigation scheduling / optimization, etc.



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  × *towards achievement of "**SDGs 2** (food security), 6, 13, 15, ..."*

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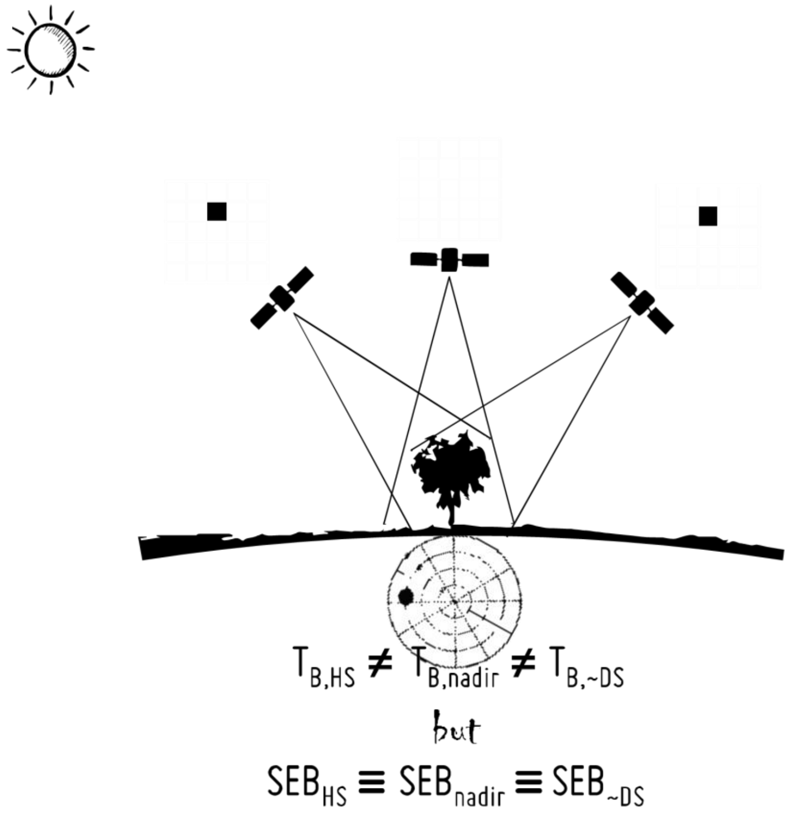
[1]The core of GIScience: a systems-based approach

background : directionality



- Scene simultaneously observed from several directions :
  - acquisition of dissimilar brightness temperatures (TB) likely due to directional anisotropy
  - surface turbulent fluxes are however similar regardless
- Inverting directional TBs using surface energy balance (SEB : point- & contextual-based) models therefore necessitates taking directionality into consideration

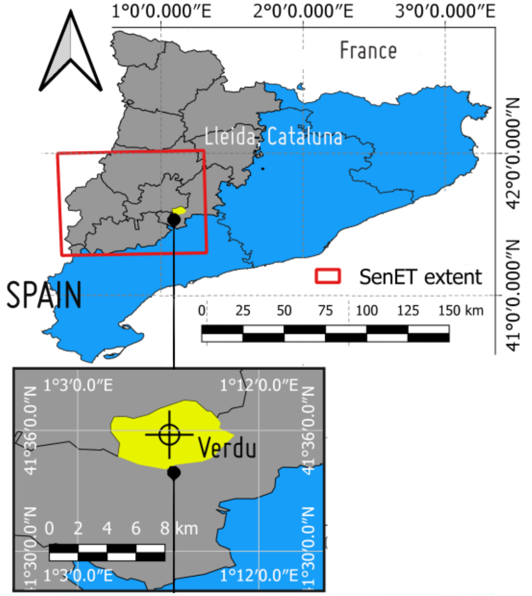
observing and modeling of components: vineyard experimental site

- Surface components data collected over a vineyard is presented
  - Elemental temperatures and reconstruction of directional surface temperatures
  - Observed energy balance corrections
- Modeling of near land surface turbulence
  - Overall fluxes based on a standard direction
  - Consistency in direction-based retrievals

- Observation of surface components and directional temperature reconstruction

- Modeling of surface components

vineyard experimental site: Verdu, SPAIN



Eddy covariance system

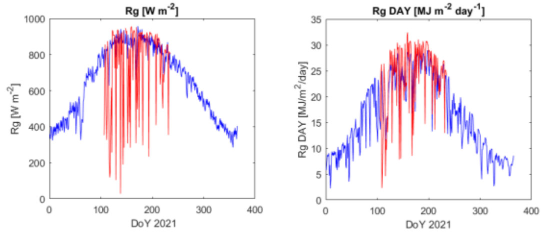
IRT setup [three - 16 by 12 - thermal cameras; ID1,2,3]

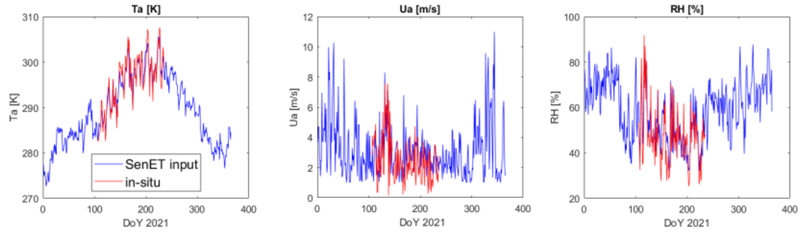
lat / lon : 41.596° N 1.126° E

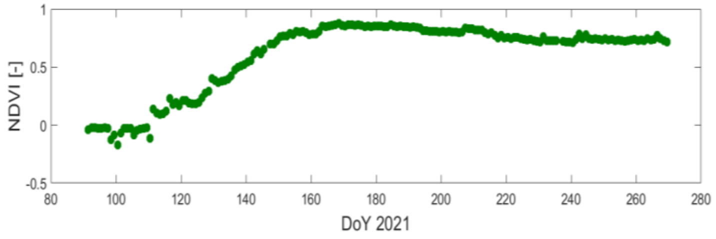
campaign: apr. 2021 – sept. 2021

Instrumentation:

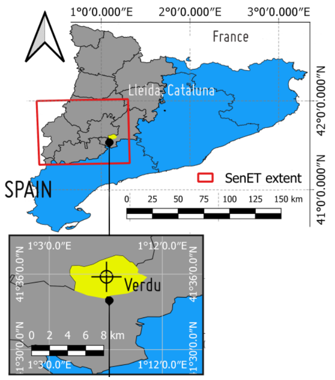
- Flux tower: turbulence, meteorological conditions
- Net radiometers, soil heat plate (SHP, calormtr. corr.)
- Thermal infrared cameras



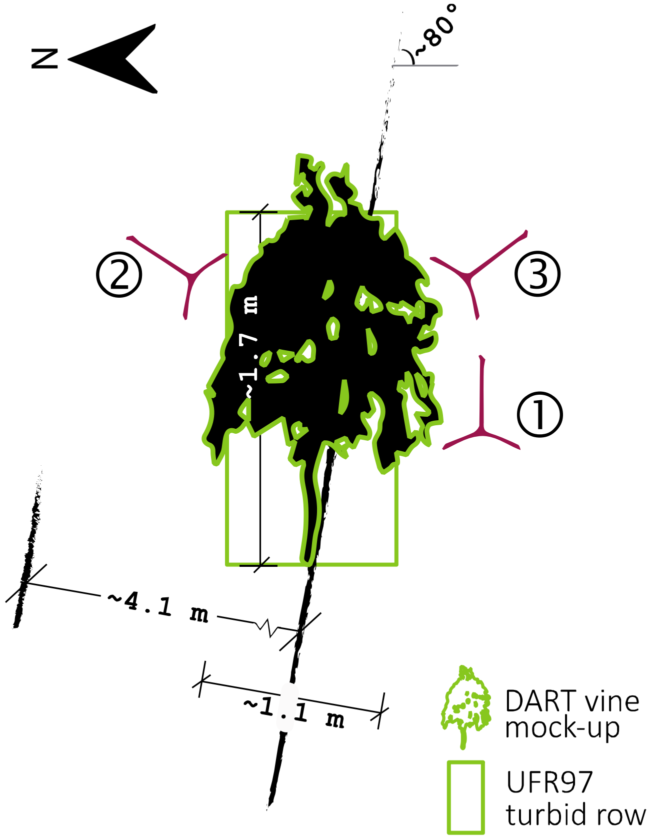




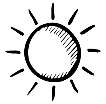
directional surface temperature reconstruction



IRT setup [three - 16 by 12 - thermal cameras; ID1,2,3]



① ID1 observing the 'sunlit' soil
② ID2 viewing the 'shaded' veg.
③ ID3 observing the 'sunlit' veg.



(θ_s, φ_s)

Inputs :

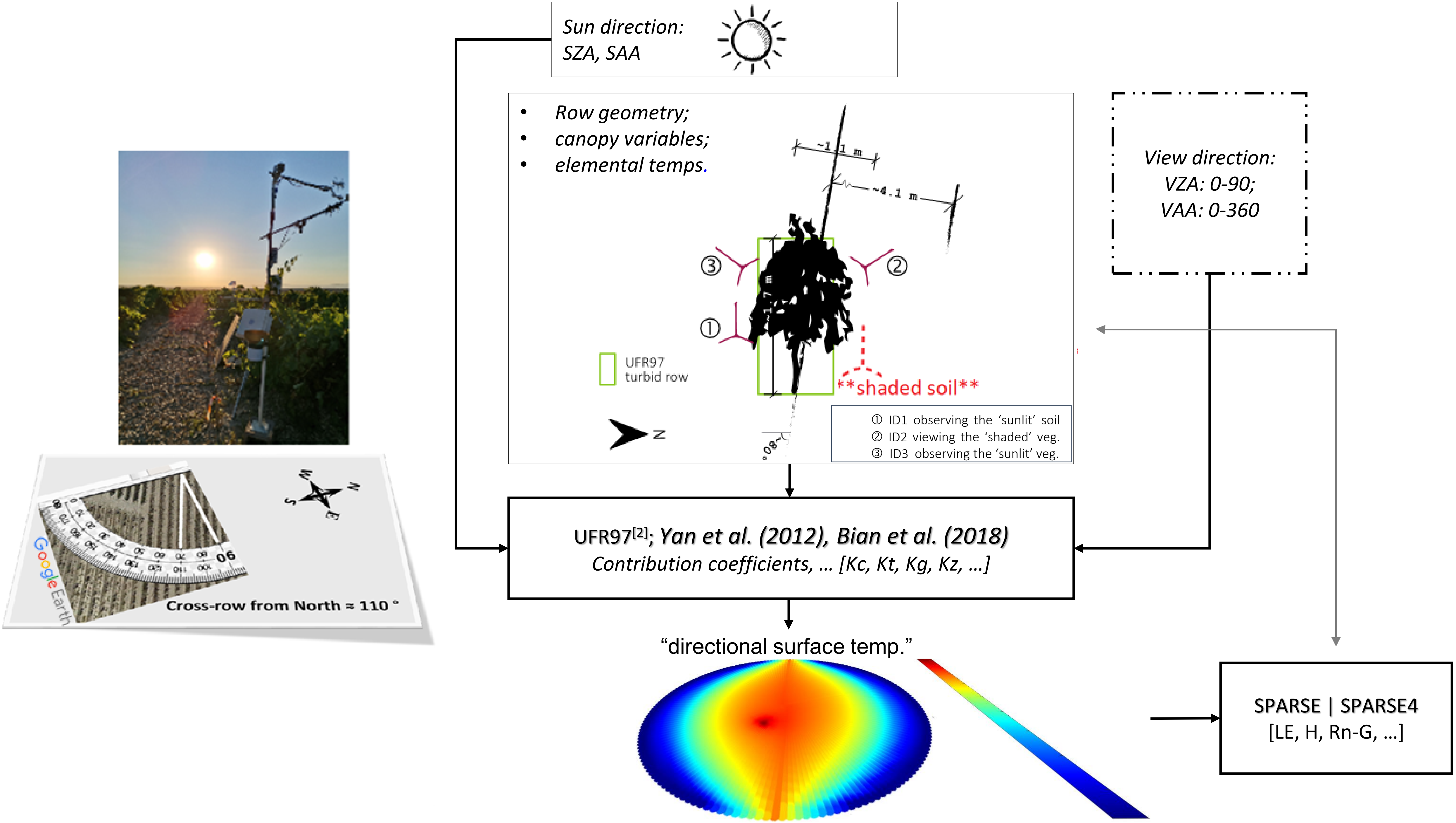
UFR97[2] and 4SAIL[3]

- T_{sun} and T_{shd} ; sun and view directions, row geometry

DART[4]

- $\Delta = (T_{sun} - T_{shd}) \div 2; T_{ave} = (T_{sun} + T_{shd}) \div 2$
- $T_{ill} = T_{ave} + \Delta; T_{shd} = T_{ave} - \Delta$
- T_{ill}, T_{shd} assigned to respective illuminated and shaded elements simulated by 3D DART radiative transfer (mockup, sun and view dir., row geom.)

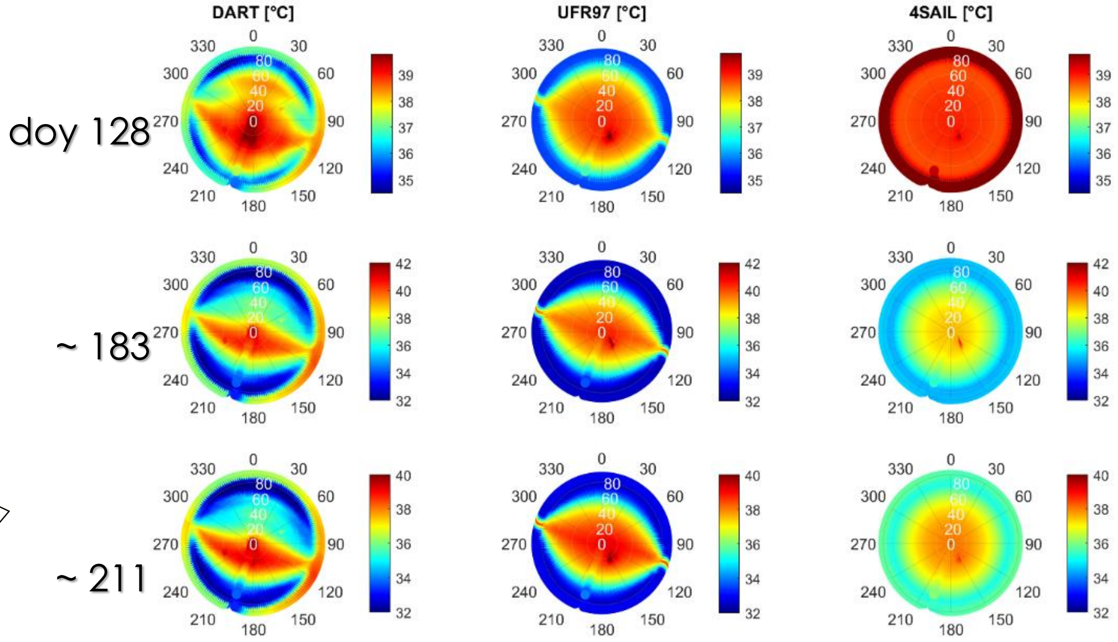
[2]Bian et al. (2018), Yan et al. (2012); [3]Verhoef et al. (2007); [4]Gastellu et al. (1996)

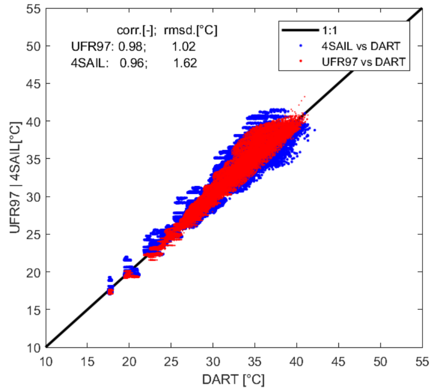


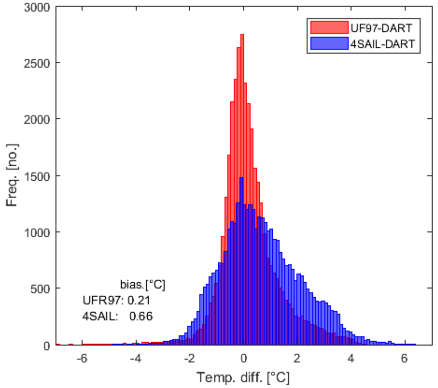
Sun direction:
SZA, SAA
Row geometry;
canopy variables;
elemental temps.
~1.1 m
~4.1 m
③
②
①
UFR97
turbid row
shaded soil
① ID1 observing the 'sunlit' soil
② ID2 viewing the 'shaded' veg.
③ ID3 observing the 'sunlit' veg.
N
~80°
View direction:
VZA: 0-90;
VAA: 0-360
UFR97[2]; Yan et al. (2012), Bian et al. (2018)
Contribution coefficients, … [Kc, Kt, Kg, Kz, …]
"directional surface temp."
SPARSE | SPARSE4
[LE, H, Rn-G, …]
Google Earth
Cross-row from North ≈ 110 °

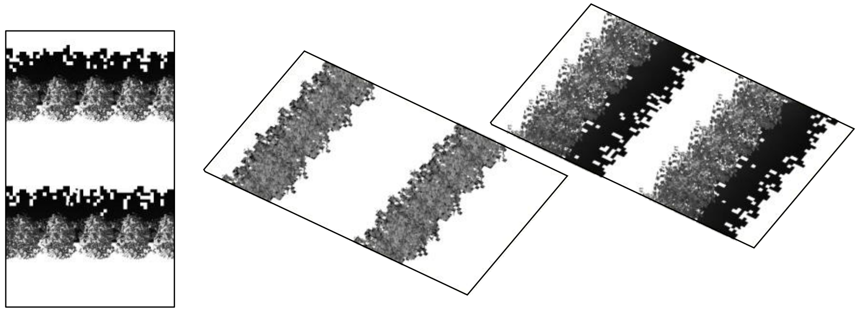
directional surface temperature ¦ UFR97, 4SAIL vs DART

- overall shape/distribution of simulated directional temperatures simulated by UFR97 similar to DART
- Some phenomenon not reproduced however



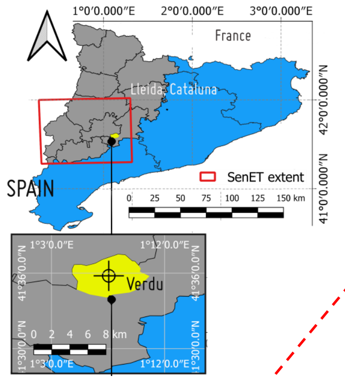


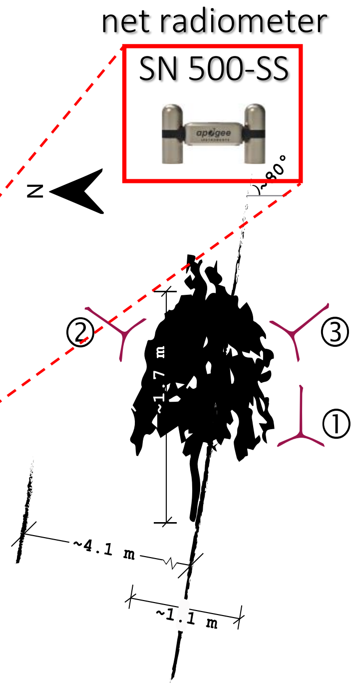




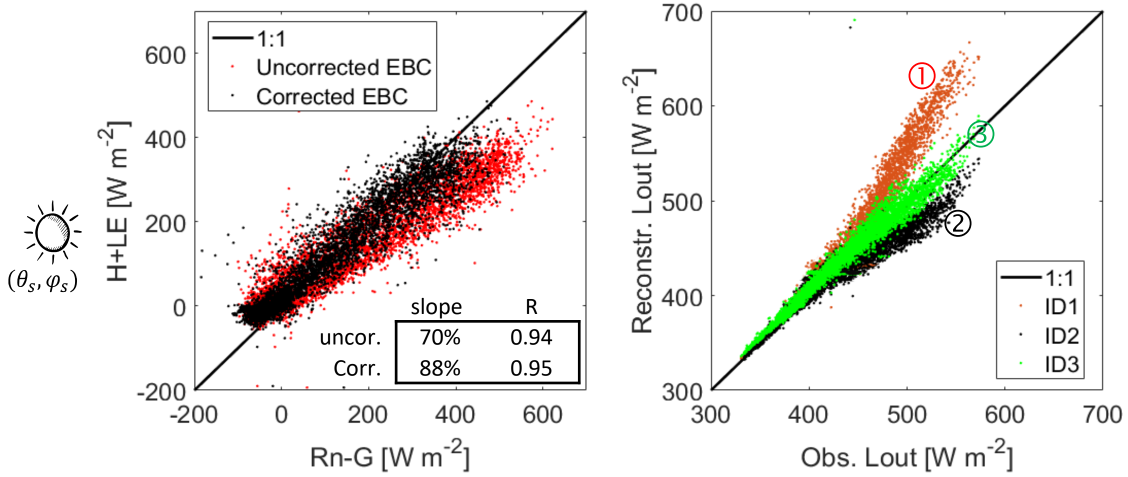
Nadir **Hot spot** **Anti hot spot**

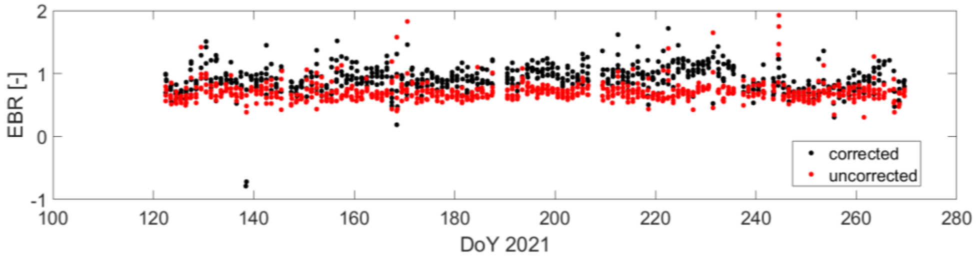
energy balance closure





Eddy covariance system





Observed energy imbalance indirectly ascribed to scale issues

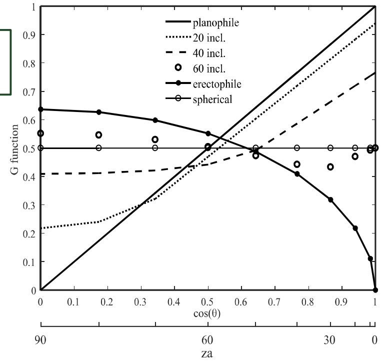
$$\boxed{\mathbf{R_n} - \mathbf{G}^*} = \lambda\mathrm{E} + \mathrm{H}$$

- Observation of surface components and directional temperature reconstruction

- Modeling of surface components

directionality, SEB - UFR97 & SPARSE

leaf incl. functions - G

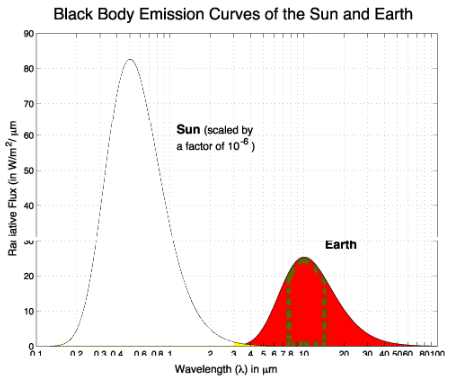


- Out-of-canopy TIR radiation [2][5][6] :-
  - Dual source (soil [g] and vegetation [v]) :

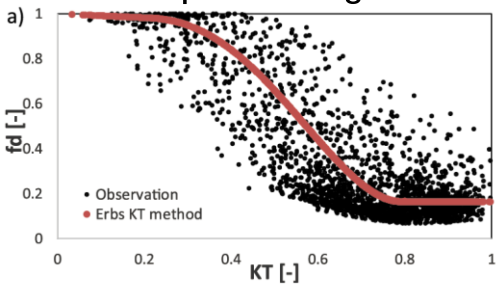
$$L_\lambda \uparrow (\theta_v) = f\big(T_g, T_v\big) \text{ - } \textit{gap fraction}\, b(\theta_v) \ \& \ \textit{vegetation cover}\, 1 - b(\theta_v)$$

  - With directionality consideration – sunlit [s] / shaded [h] soil/vegetation elements :

$$L_\lambda \uparrow (\theta_v, \Phi_v) = f\big(T_{gs}, T_{gh}, T_{vs} T_{vh}\big) \text{ - UFR97**}^{[2]}$$



Erbs et al. (1982) - S ↓ partitioning



- Radiative budget (net radiation):

$$R_n = (S \downarrow - S \uparrow) - (L \uparrow - L \downarrow) = \sum_{xx} R_{n,xx}$$

- Surface energy budget (SEB):-
  - SPARSE [7] extended and coupled [8] with **UFR97[2]
    ∴ 4 EB Eqs – SPARSE4

$$R_{n,xx} - G^* = \lambda E_{xx} + H_{xx}\ ;$$
$$xx = \text{snlit/shd(s/h),soil/veg. (g/v)}$$

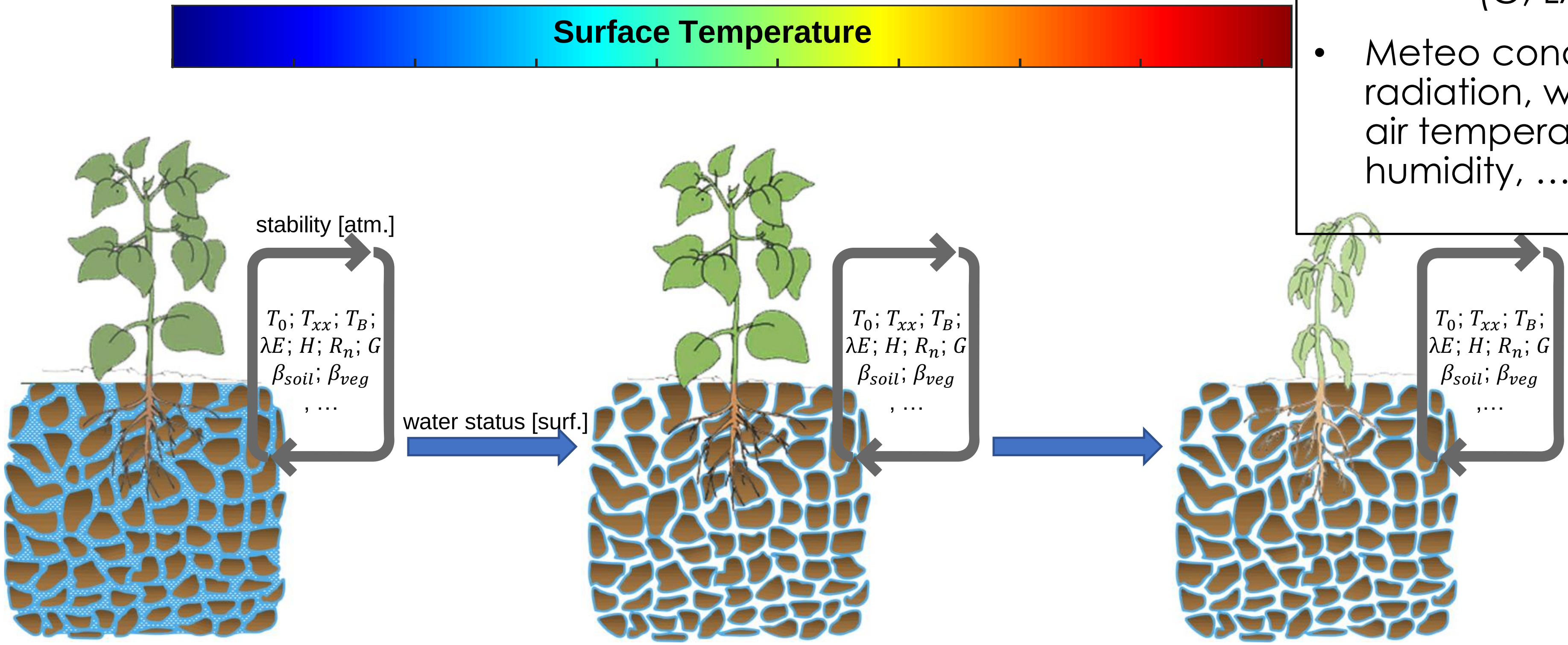
[7]Boulet et al. (2015); [8]Mwangi, Boulet, Olioso (2022)

directionality, SEB - UFR97 & SPARSE

- How ?

Model forcings:

- biophysical parameters (G, LAI, ...),
- Meteo conditions, radiation, wind speed, air temperature and humidity, ...



$E_{pot} \geq E > E_{min}$; $T = T_{pot}$

$1 \geq \beta_{sol} > \beta_{sol\_min}$; $\beta_{veg} = 1$

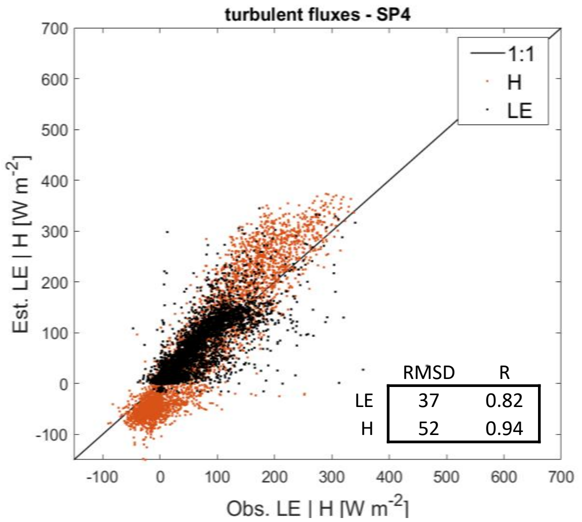
$E = E_{min}$; $T_{pot} \geq T > T_{min}$

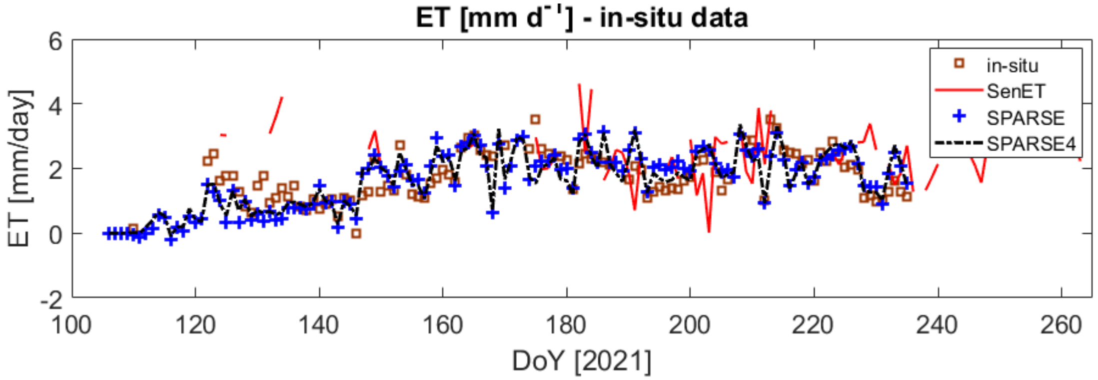
$\beta_{sol} = \beta_{sol\_min}$; $1 \geq \beta_{veg} > \beta_{veg\_min}$

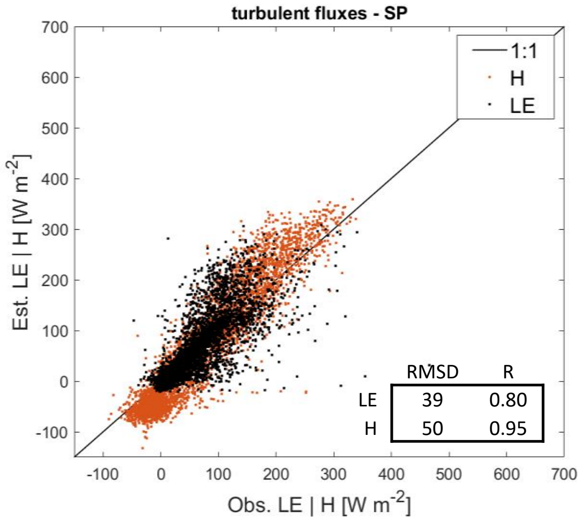
$E = E_{min}$; $T = T_{min}$

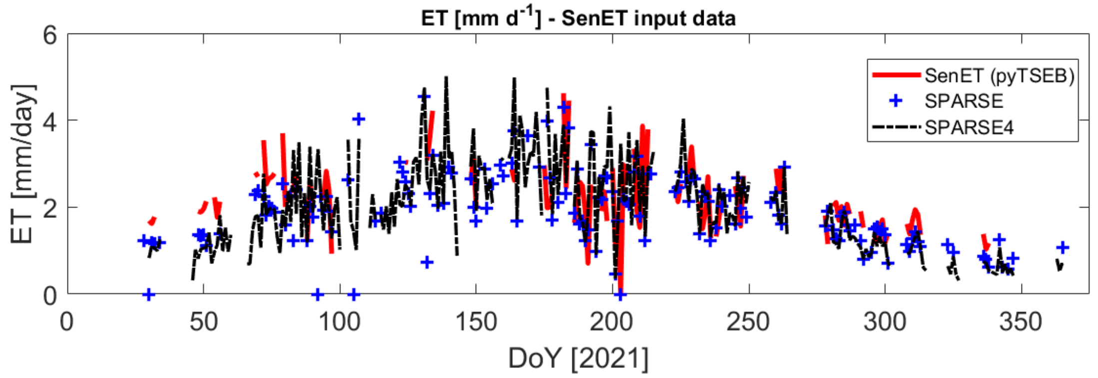
$\beta_{sol} = \beta_{sol\_min}$; $\beta_{veg} = \beta_{veg\_min}$

modeling: surface components - fluxes



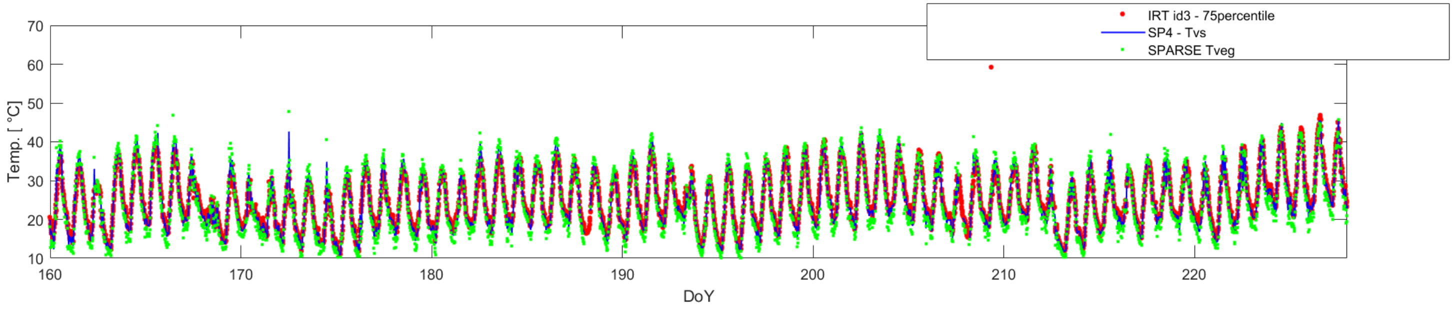




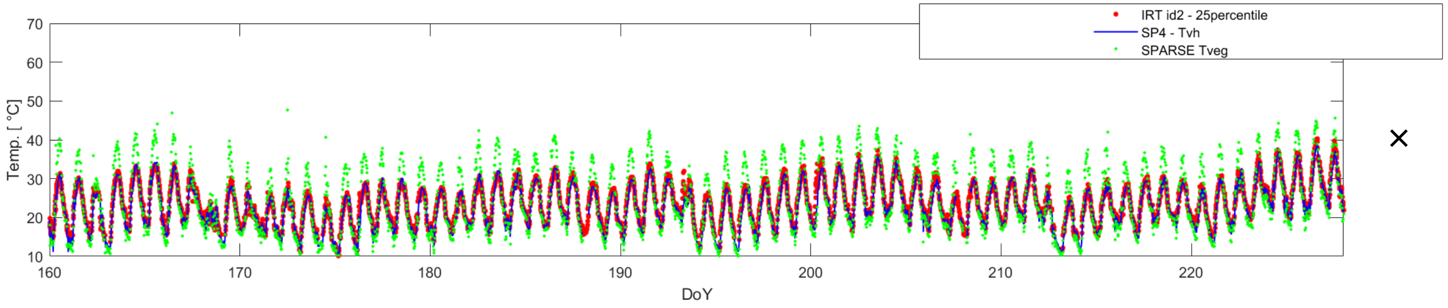


modeling: surface components – temp.

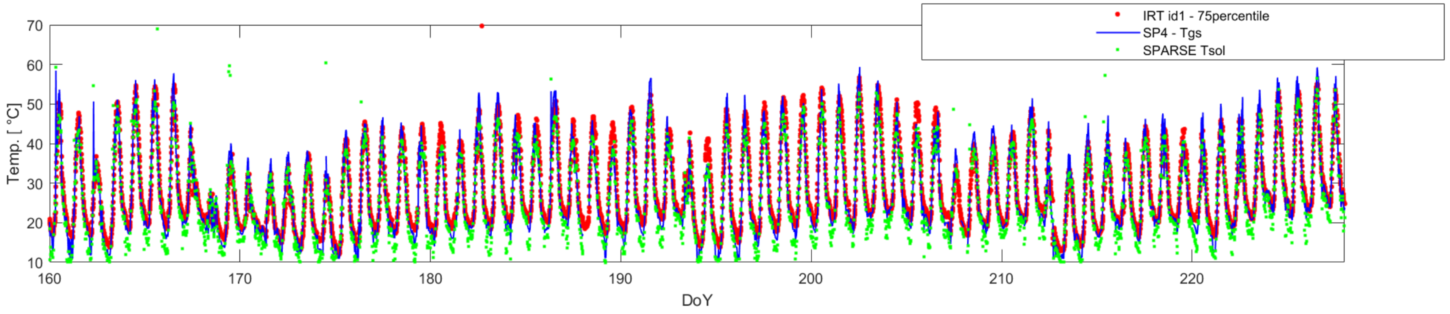
Illuminated veg.



shaded veg.

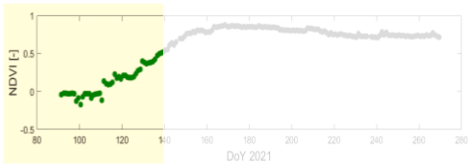


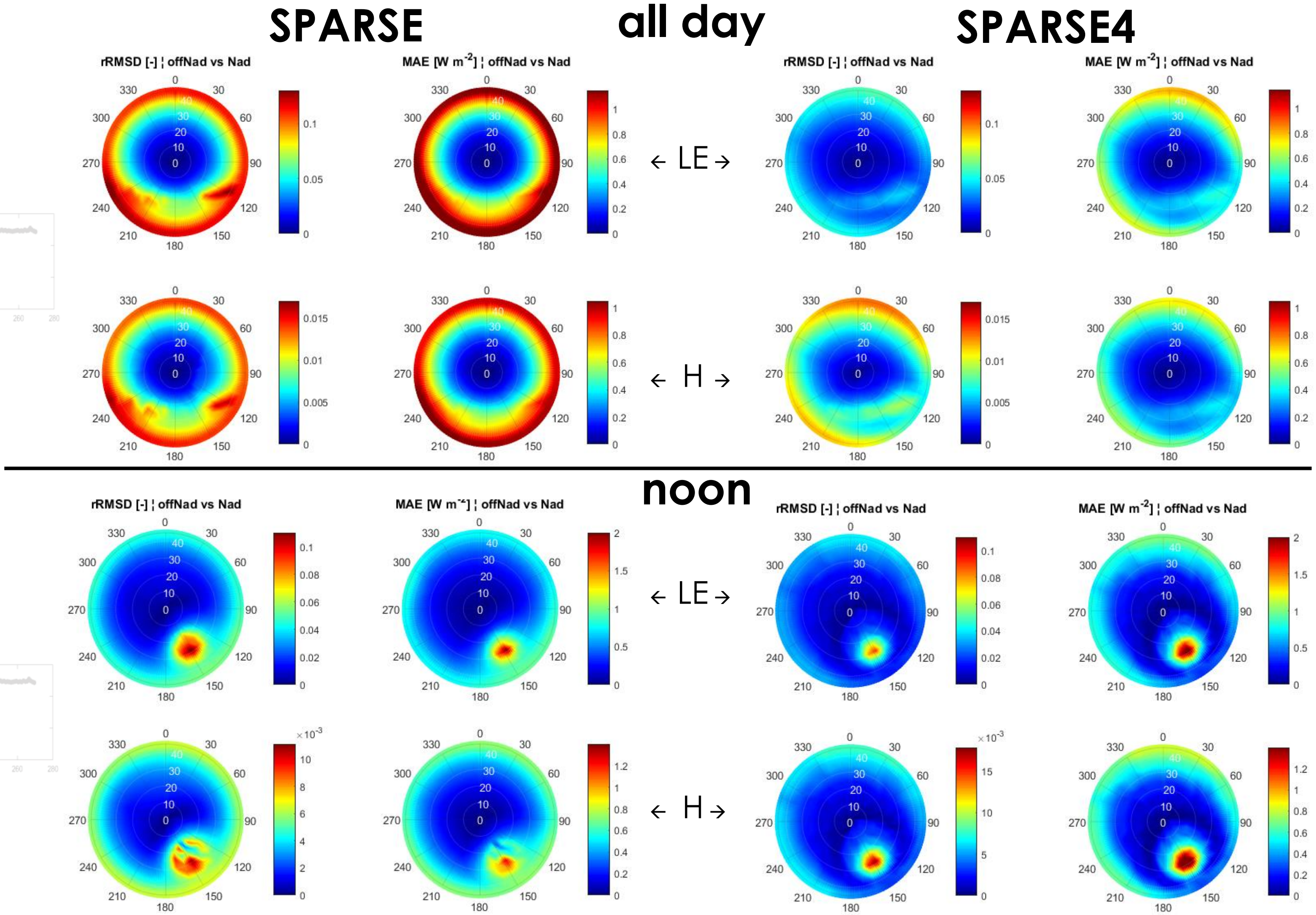
Illuminated soil

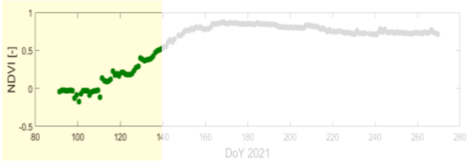


- Improved reproduction of elemental temperatures

modelling: directional consistency



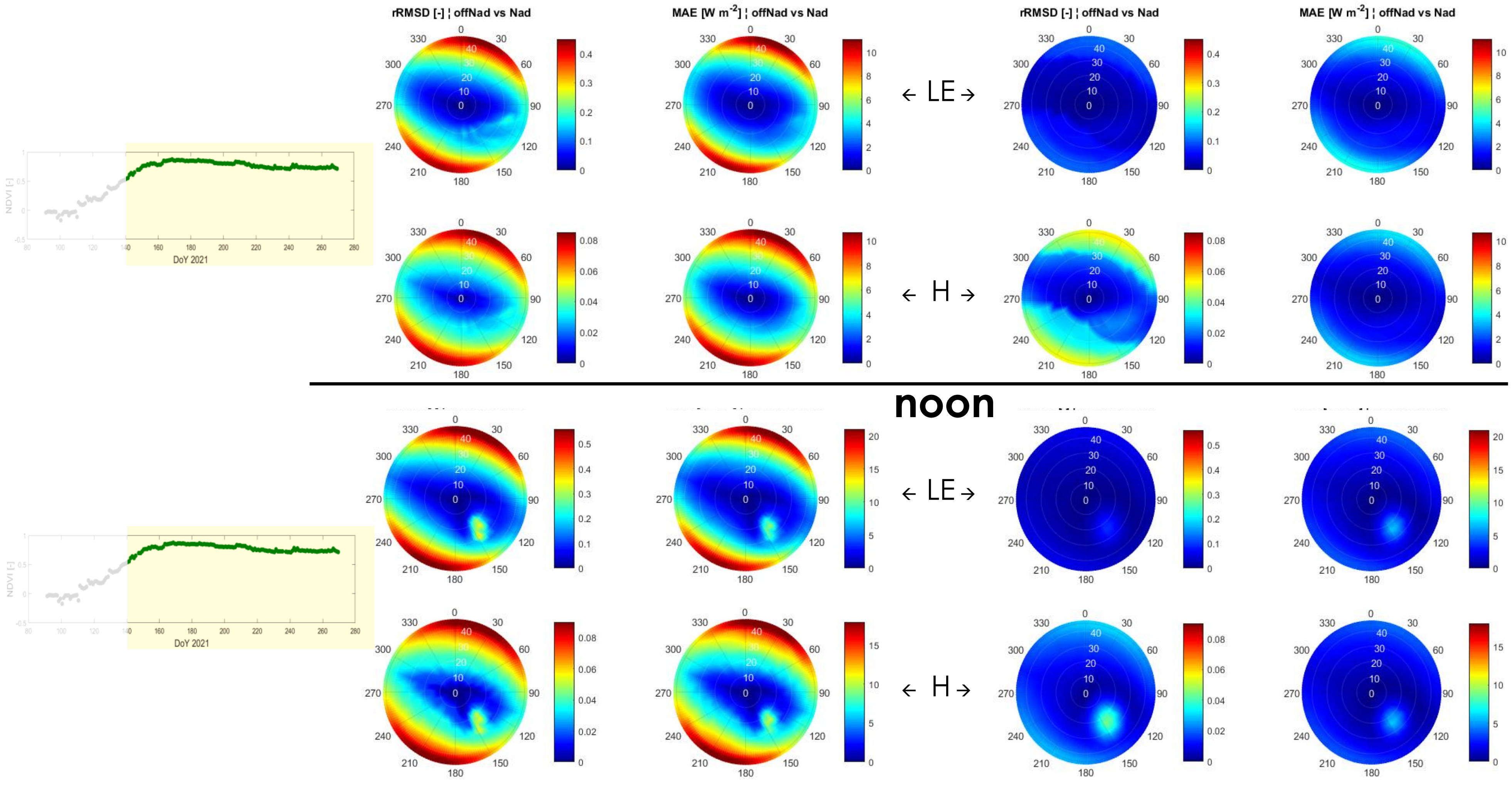




- Hotspot effects trends visible on the retrievals
- Directional inconsistency low in sparsely vegetated ground

modelling: directional consistency

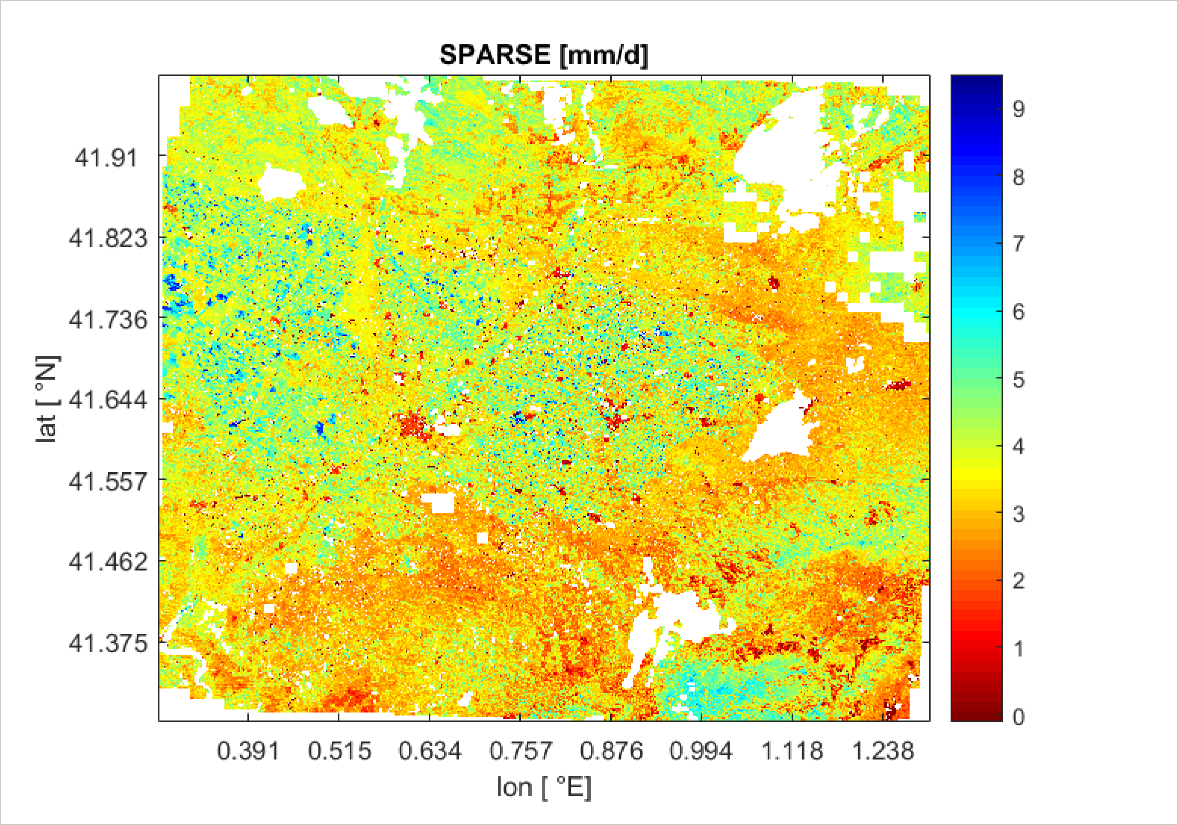
SPARSE **all day** **SPARSE4**

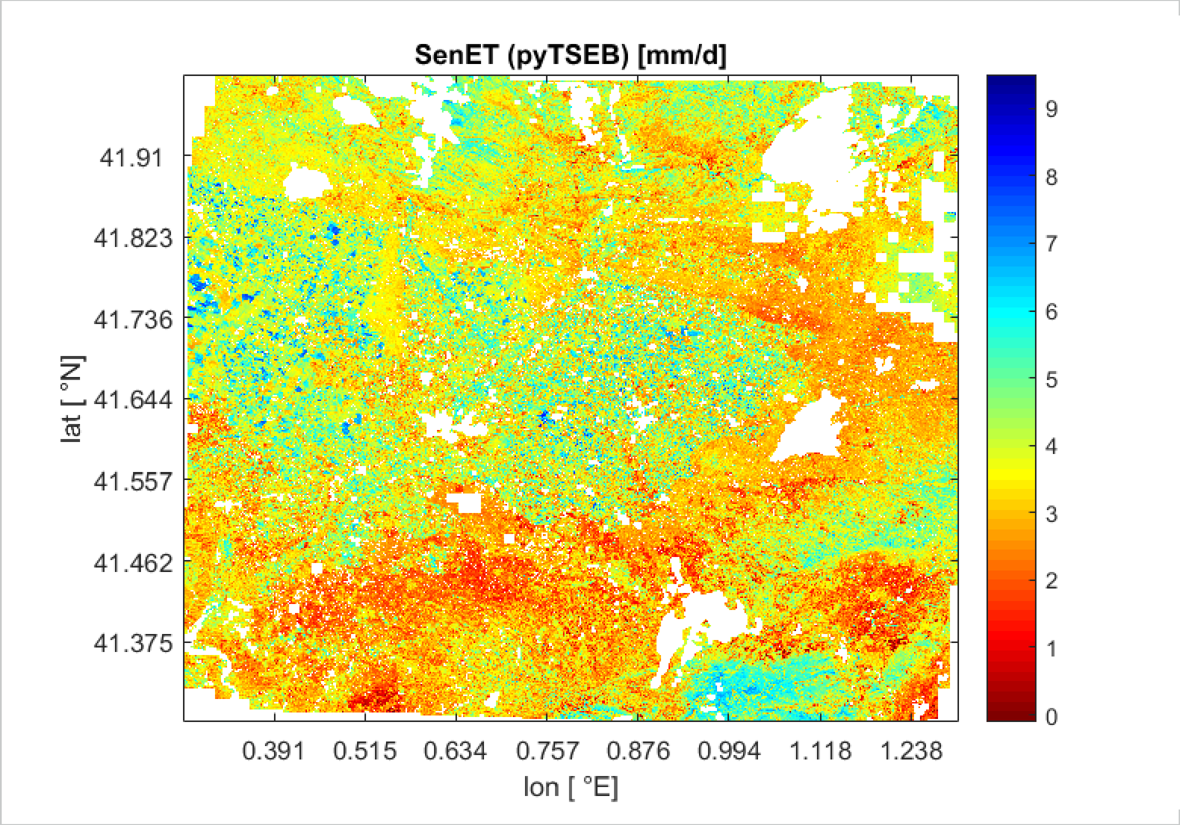


- × Hotspot effects trends visible on the retrievals
- × Better consistency in retrieval along-row
- × Cross-row, however, consistency is degraded
- × The biases are nonetheless reduced with the new scheme

Conclusion

- Inversion from a standard direction (nadir), overall fluxes simulated by both SPARSE algorithms are similar
- Degraded retrieval consistency observed in cross-row direction while better along the rows
- Discrimination between sunlit/shaded elements improves consistency in inversion of simultaneously measured multi-angular TIR data - sensitivity of flux retrievals to direction of view is reduced.


SPARSE [mm/d]
41.91
41.823
41.736
41.644
41.557
41.462
41.375
lat [°N]
0.391 0.515 0.634 0.757 0.876 0.994 1.118 1.238
lon [°E]
9
8
7
6
5
4
3
2
1
0


SenET (pyTSEB) [mm/d]
41.91
41.823
41.736
41.644
41.557
41.462
41.375
lat [°N]
0.391 0.515 0.634 0.757 0.876 0.994 1.118 1.238
lon [°E]
9
8
7
6
5
4
3
2
1
0

thank you !