Evapotranspiration mapping from remote sensing data: uncertainties and ensemble estimates based on multimodel-multidata simulations

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Contexte

- ET is a major component of the hydrological cycle, but
  - → in many situations, ET and its evolution are not well known
  - → there is a lot of uncertainties in ET monitoring

- Many models exist, but none looks satisfactory in every situations (season, type of climate, type of surfaces…

  → ensemble modelling

  Ensemble modelling approaches were developed in various field of research
  (ex. Climate, hydrology, agronomy…)
  assuming they are providing an optimal or suboptimal solution

- Work done in the frame of TRISHNA and LSTM mission preparations

Evapotranspiration (ET) can be derived using various models based on thermal infrared data

- → uncertainty in Ts:
  - instrument
  - atmosphere
- → large number of models → diversity of algorithms => uncertainties
- → lots of other data required :
  - albedo
  - vegetation density
  - meteorological data

  } various sources of data => uncertainties
- → time integration
  - instantaneous measurements
  - intermittent data (revisit, clouds)

  } → daily values => uncertainties

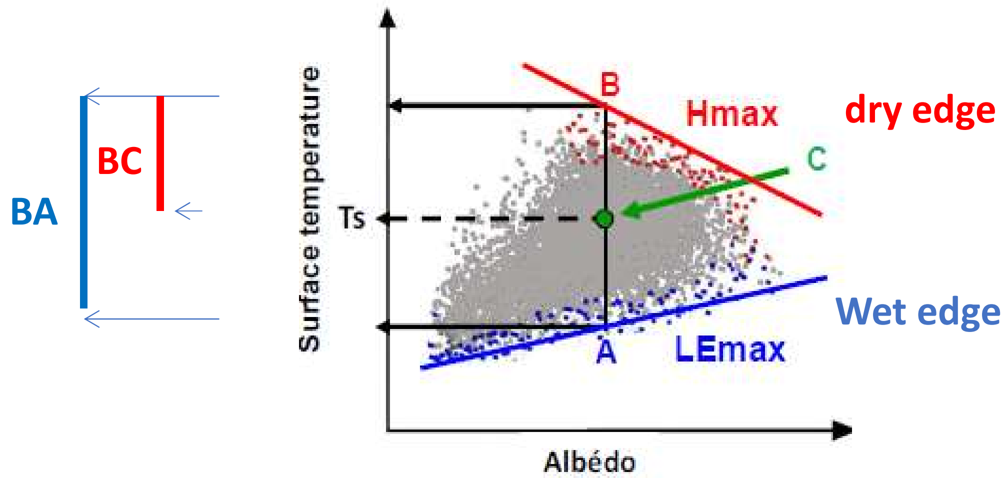
No consensus on a best model => ensemble averaging considering both models and data sources

Many unknowns remain concerning the uncertainties in the derivation of ET, in particular for discriminating uncertainties from input data and models

<u>Evapotranspiration model</u> : EVASPA (<u>EV</u>apotranspiration <u>A</u>ssessment from <u>SPA</u>ce)

-> Contextual model : *ET ~ EF* x *(Rn – G)*

The evaporative fraction *EF* = BC / BA



EF = evaporative fraction <- *Ts* vs. *albedo or NDVI or fraction cover*

Rn = net radiation <- albedo, emissivity, Ts, solar irradiance, atmospheric irradiance

ex: S-SEBI (Roerink et al. 2000)

G = ground heat flux <- *Rn, NDVI, fCOVER*

Ensemble calculations

$ET_{ensemble}$ defined as :

- median of ET_i (n ensemble members ~ n individual estimates)
- weighted average of ET_i with weighting coefficients : a_i

Computed pixels by pixels : $$ET_{ensemble} = \sum_{i=1}^{n} a_i \, ET_i$$

The weighting coefficient a_i may be set to:

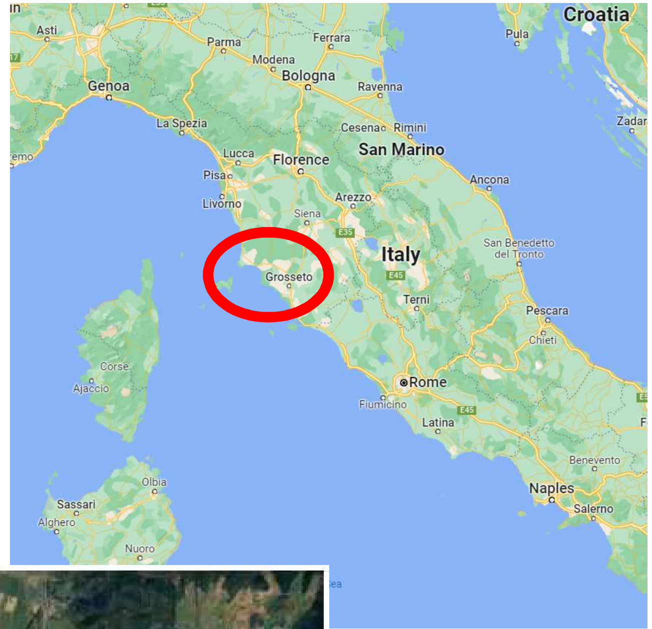
- to 1/n
- a priori values depending on a previous knowledge on the quality of the models
- values depending on the evaluation of each members against in-situ data

Uncertainty : defined as an indicator of the dispersion of the member values:

- the standard deviation of Eti
- the range

The impact of each input or model uncertainty in the global uncertainty in ET can be derived (one factor at a time variation, anova …)

Example 1 : uncertainty analysis, simple averaging



ESA experiment in Grosseto (Italy) in support of the LSTM program : July 2018

Airborne images in the solar and the thermal domains

Various sources for input data :

- **incident radiations,**
- **LAI,**
- **fCOVER,**
- **surface temperature…**

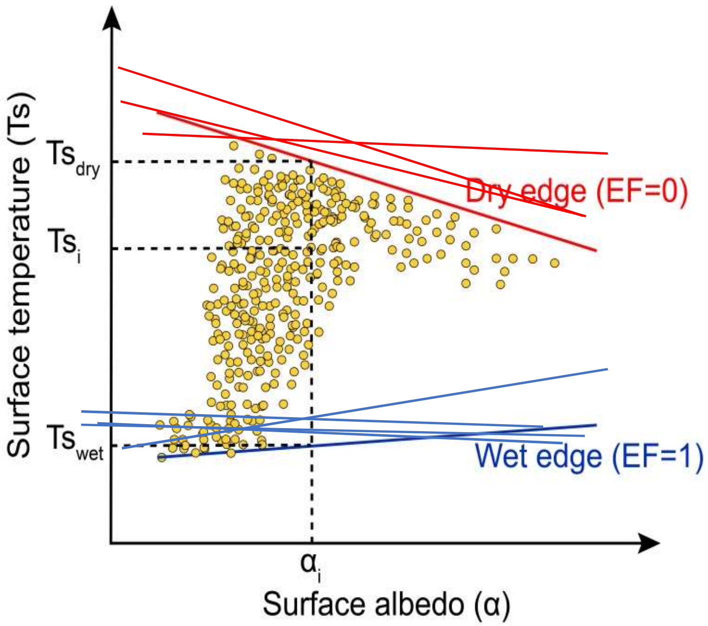
Various « models » for

- **Ground heat flux**
- **Evaporative fraction EF**

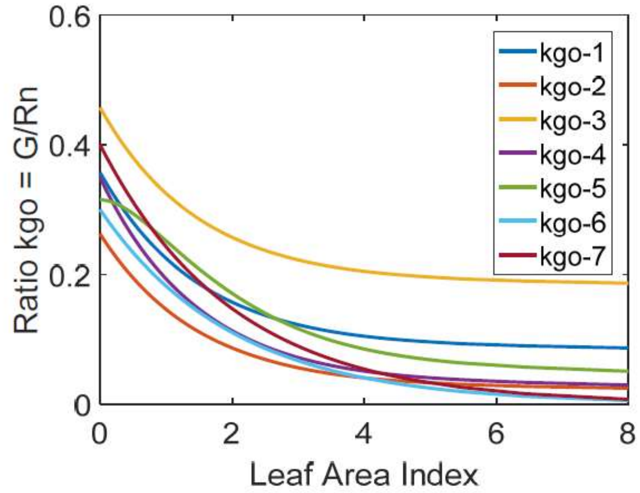
Agricultural area (~10 X 10 km)

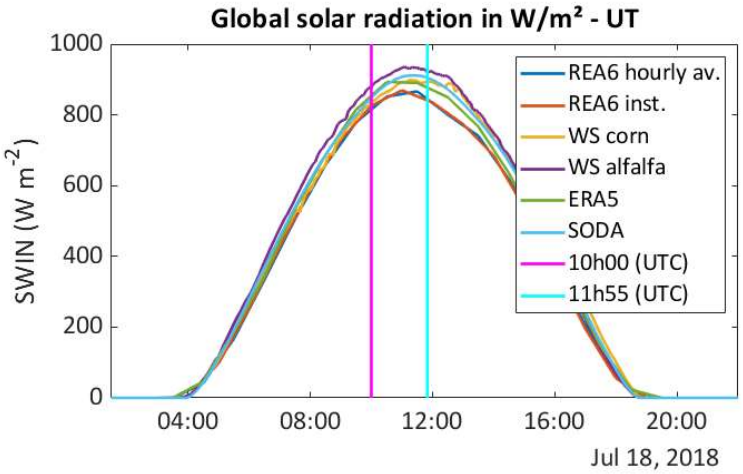
Example 1 : Example of variations (=> uncertainties) in data sources and models

Evaporative fraction



Ground heat flux ratio to Rn





Novice case -> all available data or models are used

Expert case -> previous knowledge => some of the data sources and algorithms are dropped

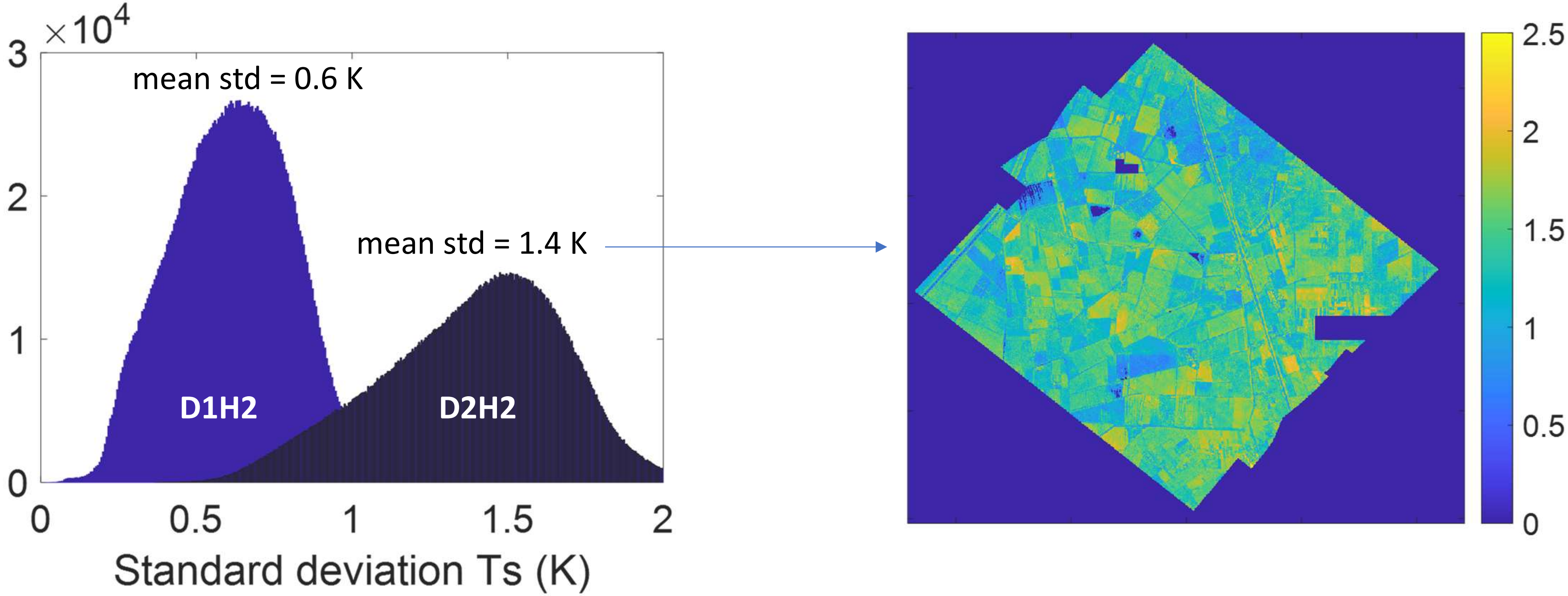
All together, ~400 000 cases (ET_i)

Example 1 : Uncertainty in Ts:

several processings were performed mainly differing in the atmospheric profiles used for the atmospheric corrections

Standard deviation of the 4 Ts maps

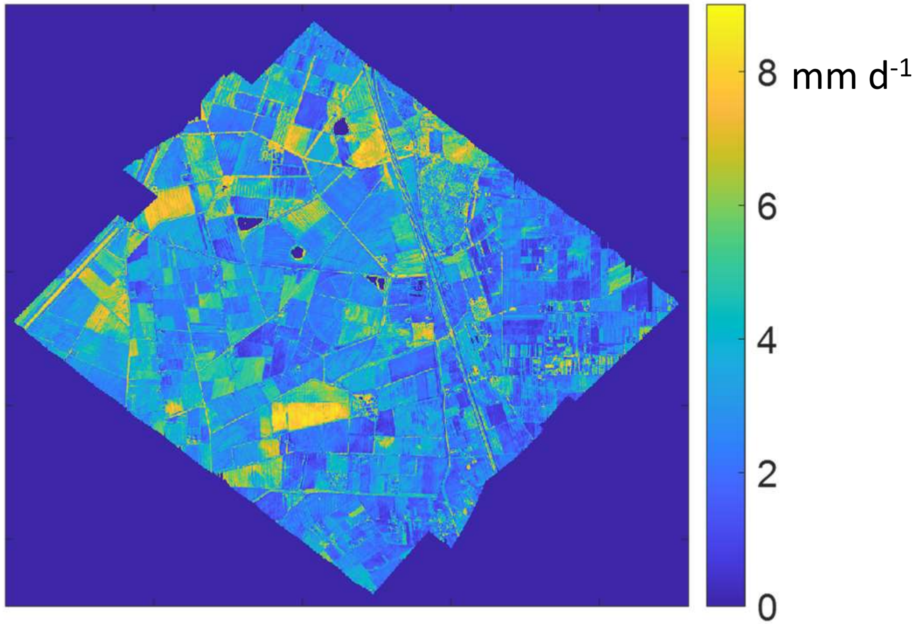
Ts standard deviation map D2H2 (K)



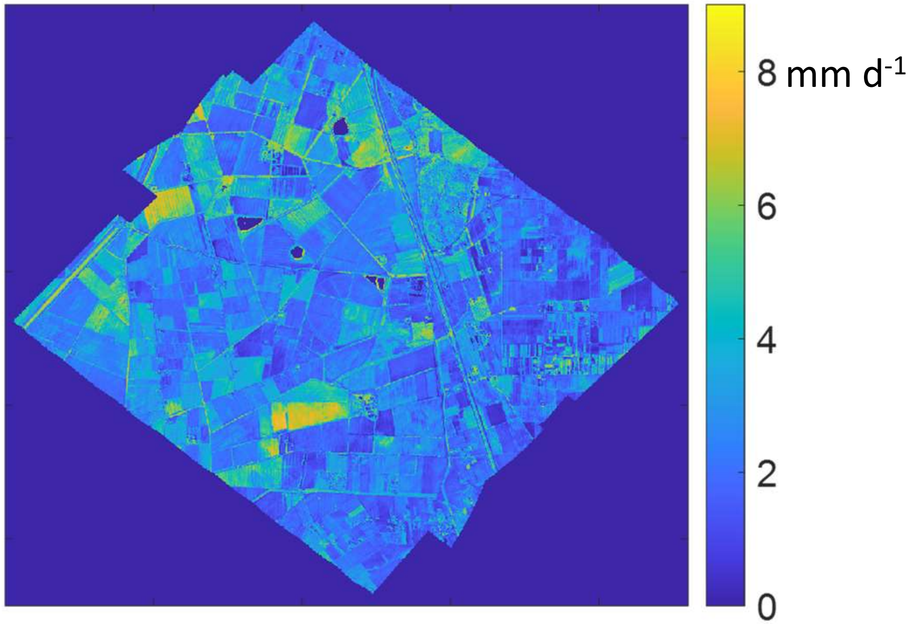
Example 1 : Evapotranspiration map

Average of all the calculations for D2H2

Novice case – average ET =3.4 mm d^{-1}



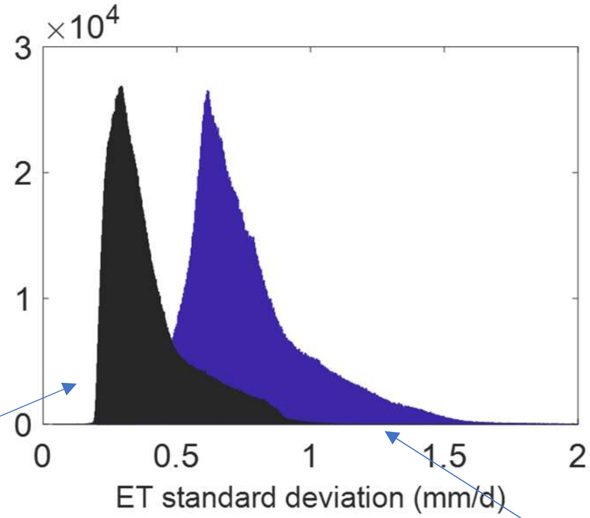
Expert case - average ET =2.8 mm d^{-1}



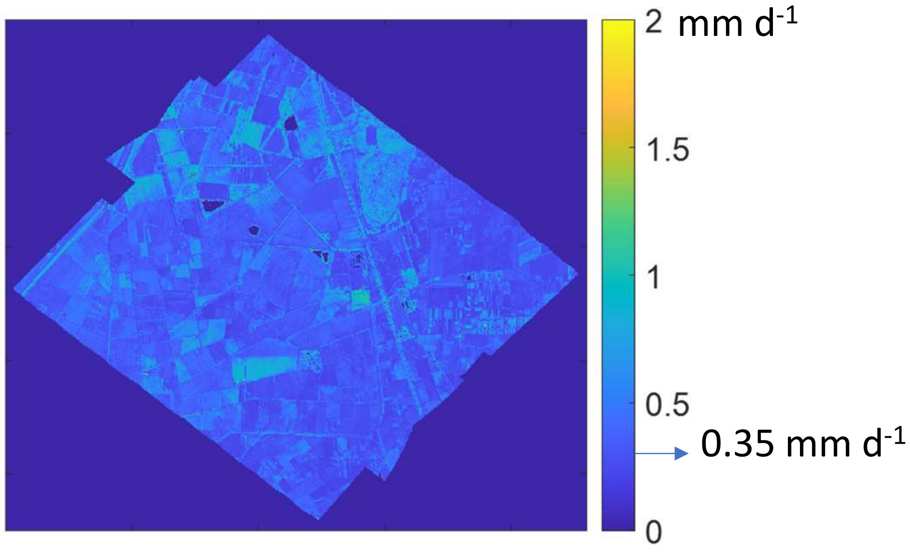
Example 1 : Uncertainty in ET

(standard deviation mm d^{-1})

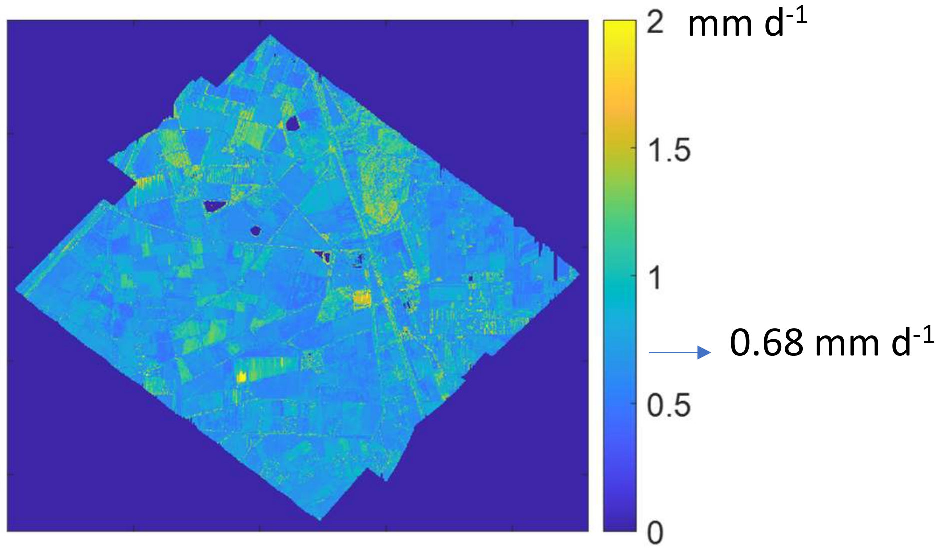
D2H2 case



Expert case

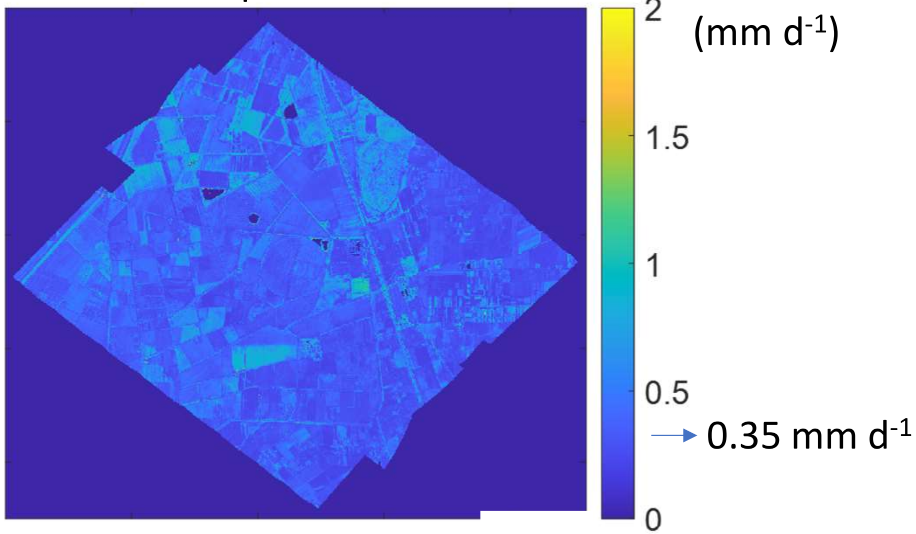


Novice case

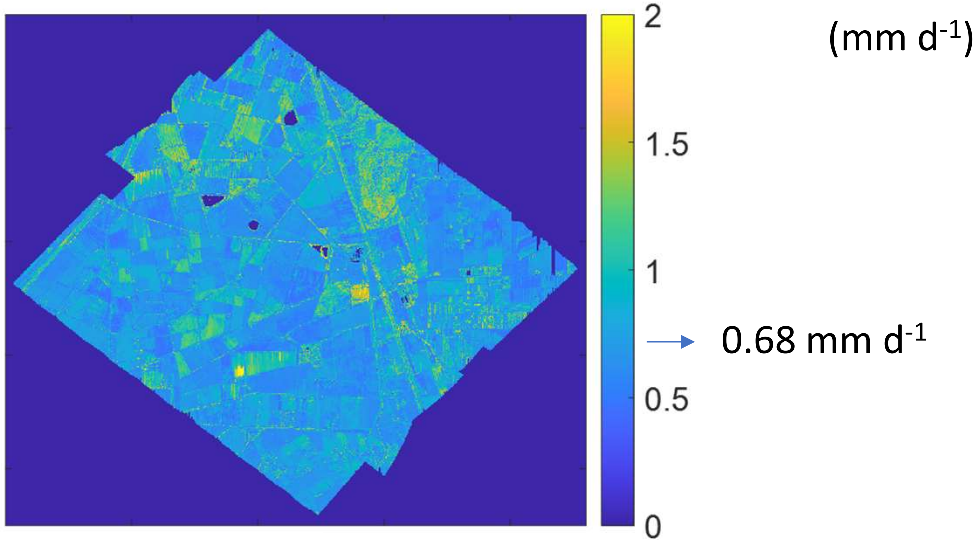


Example 1 : Uncertainty in ET (mm d^{-1}) D2H2 case

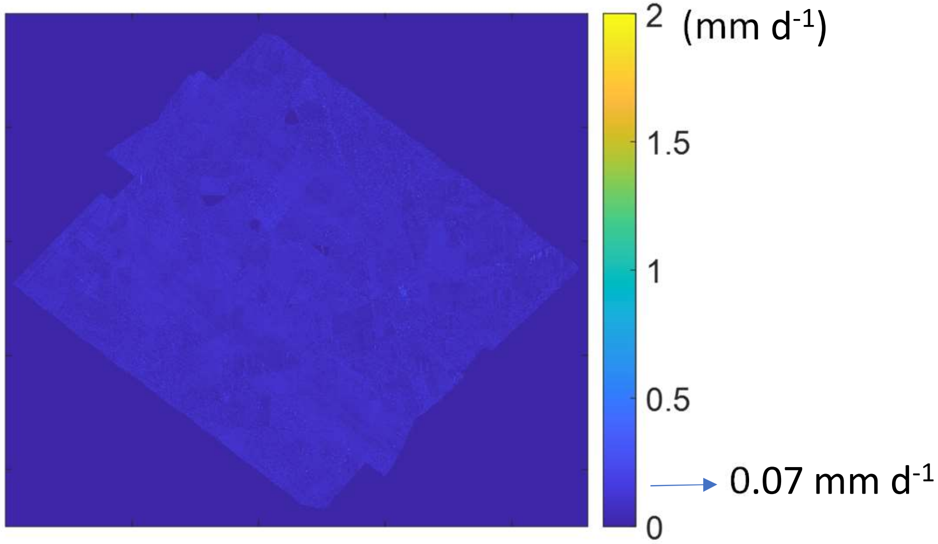
Expert case

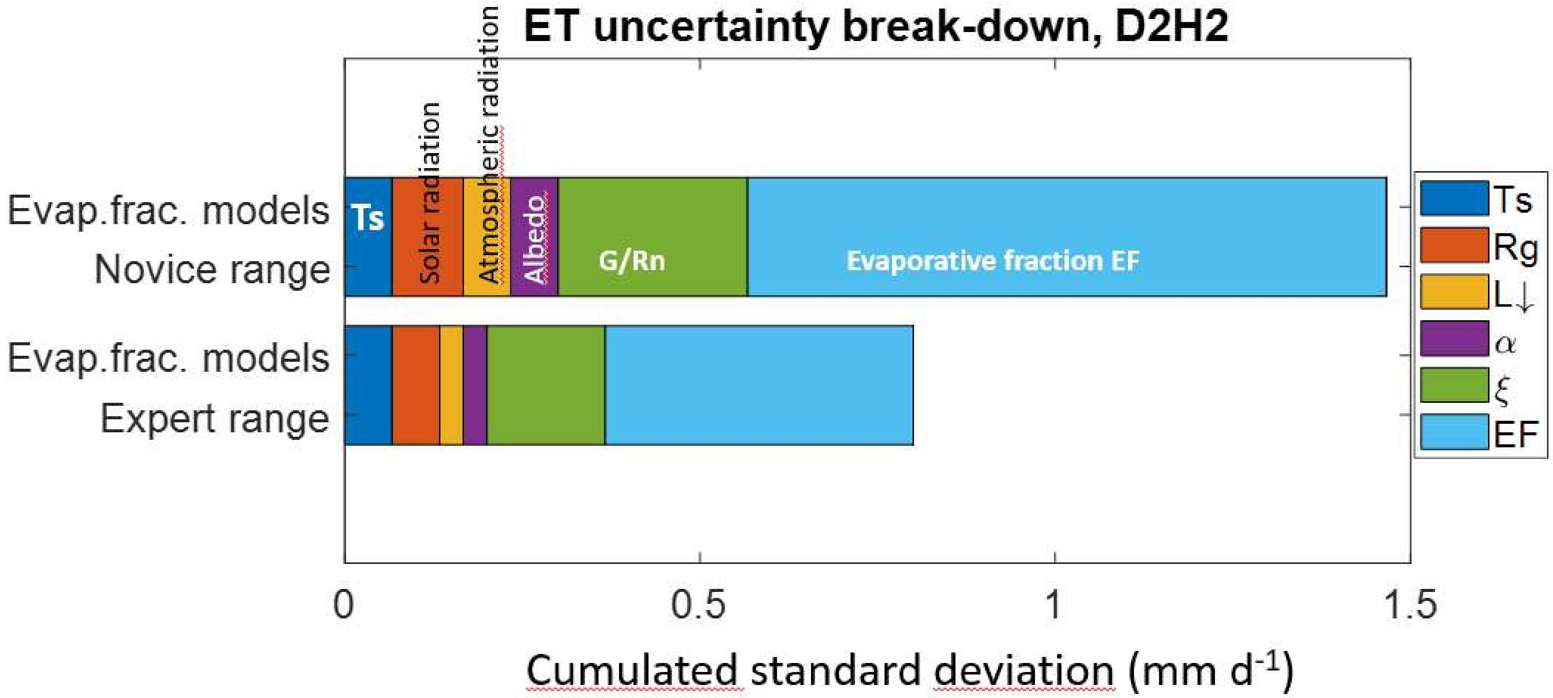


Novice case



Uncertainty related to Ts:

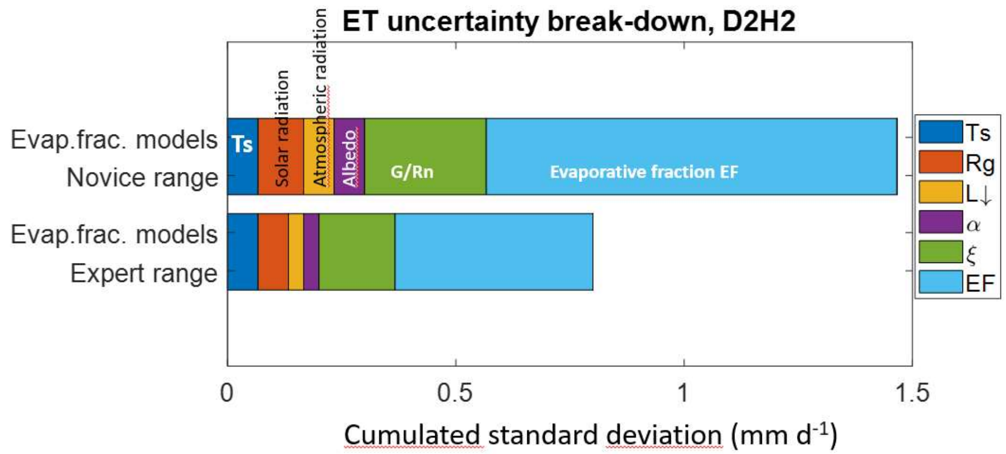




ET uncertainty break-down, D2H2
Evap.frac. models
Novice range
Evap.frac. models
Expert range
Ts
Solar radiation
Atmospheric radiation
Albedo
G/Rn
Evaporative fraction EF
Ts
Rg
L↓
α
ξ
EF
0
0.5
1
1.5
Cumulated standard deviation (mm d-1)

Example 1 : Summary

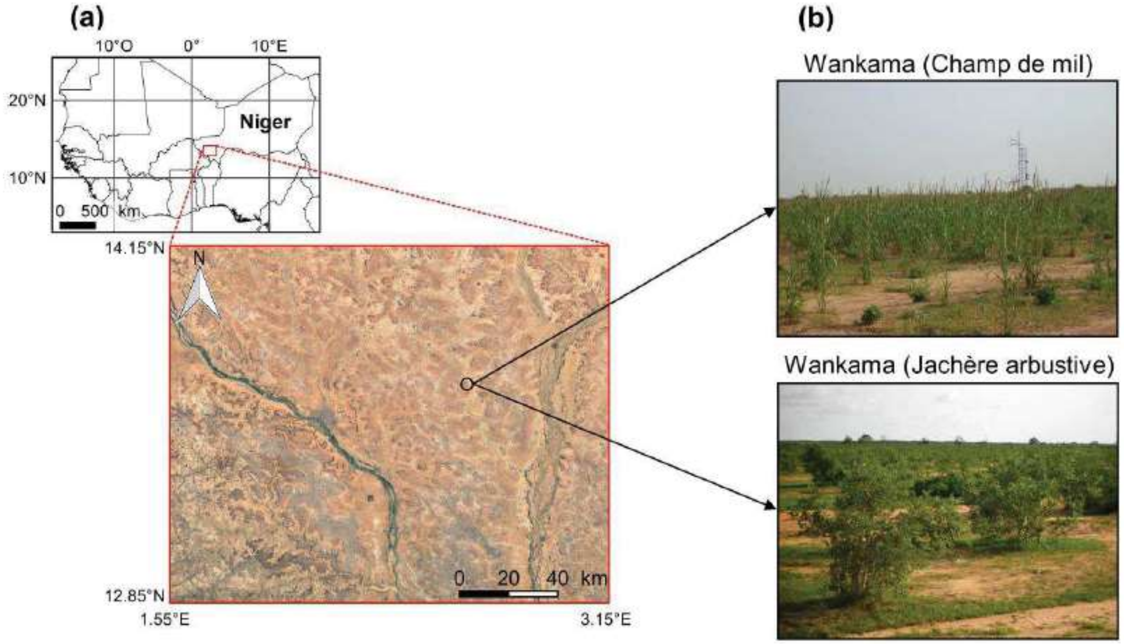
- uncertainty in ET is large, up to 1.5 mm.d^{-1} (for D2H2 and when expressed as standard deviation)
- uncertainty is significantly lower in the expert case than in the novice case
- ranking of uncertainty sources highlights
  - impact of Ts is low
  - largest impacts: evaporative fraction, G/Rn ratio
  - model formulations have a larger impact than input data



Example 2 : application to Niger with MODIS data : Weighted averaging

Sahelian area

EVASPA ->
variations in EF determination as a function of the season
(dry, rainy = monsoon, intermediary…)

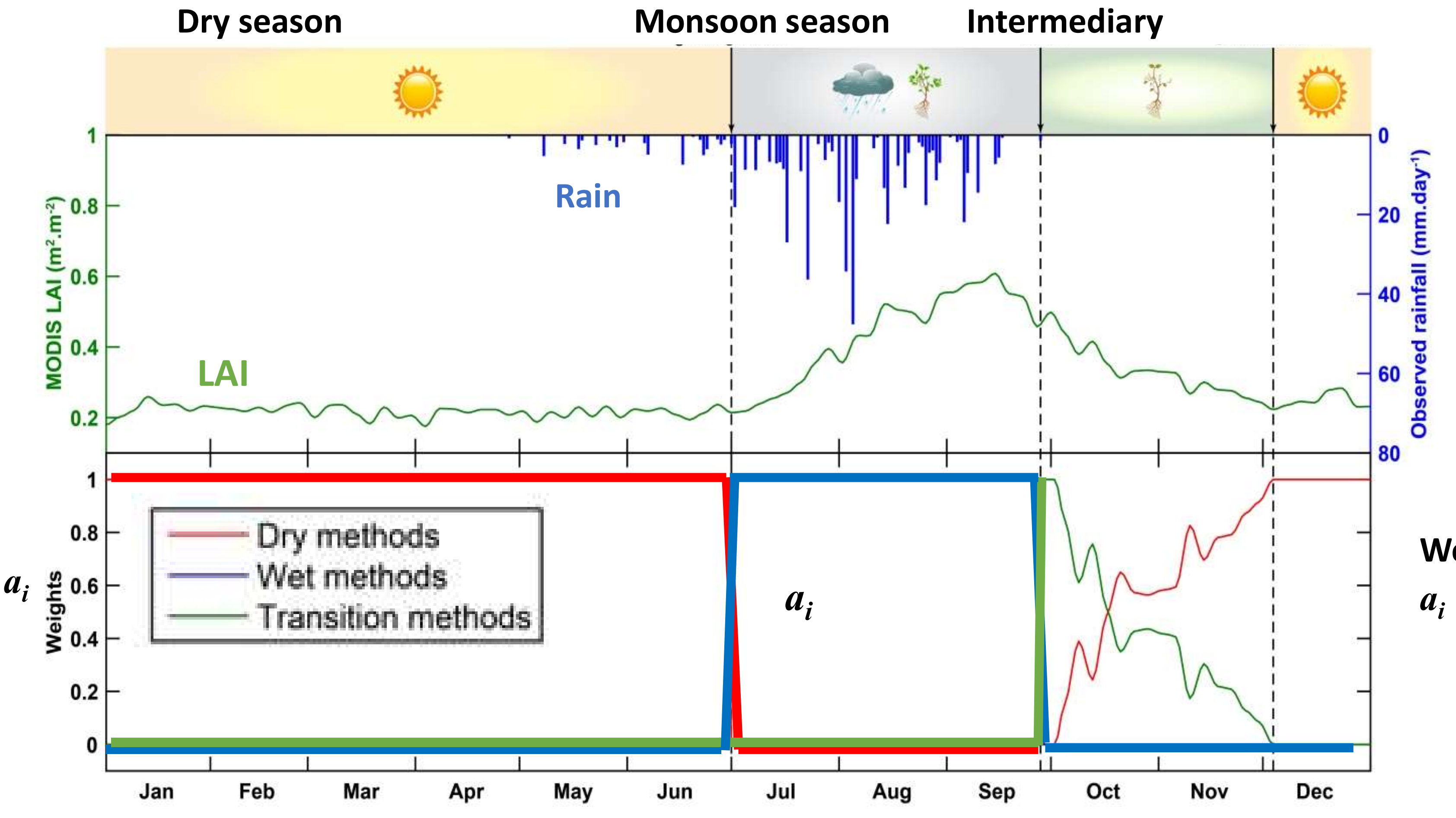


Evaluation against flux towers and comparison to other ET products

See papers by Allies et al. in Remote Sensing 2021 and Journal of Hydrology 2022

Example 2 :

EF calculation methods are more or less adapted to each season => a priori definition of the weighting coefficients



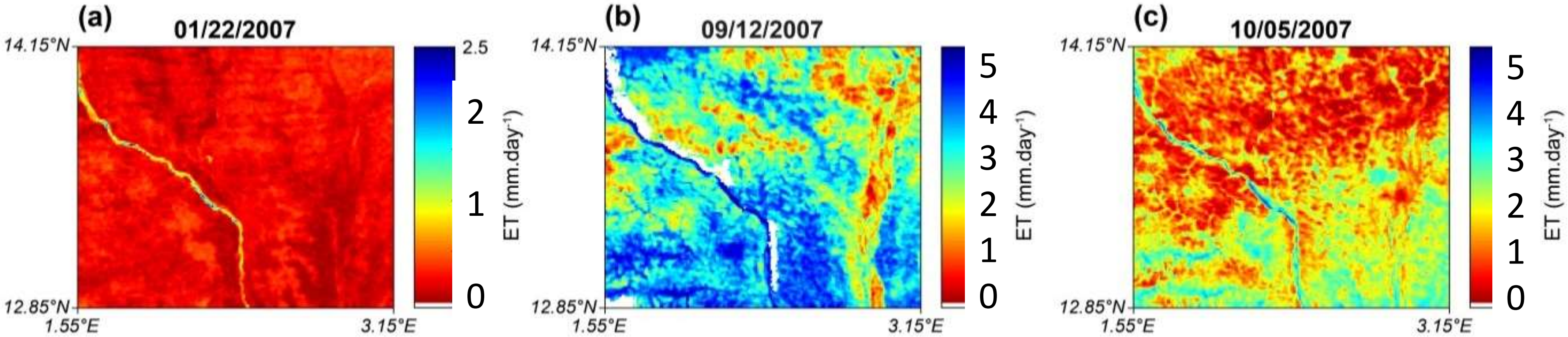
Weighting coefficients a_i depends on LAI

(Allies et al. 2021, Remote Sensing)

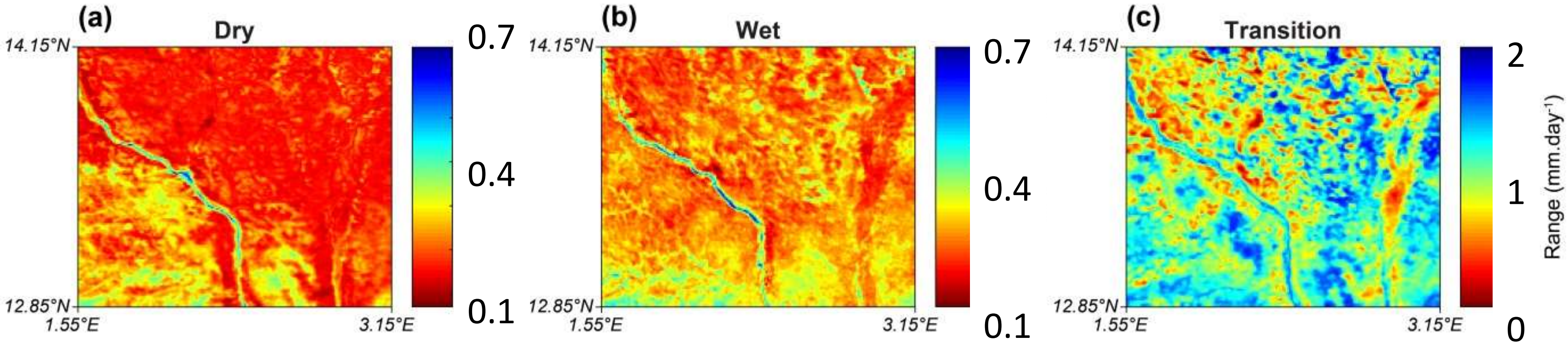
Example 2 :

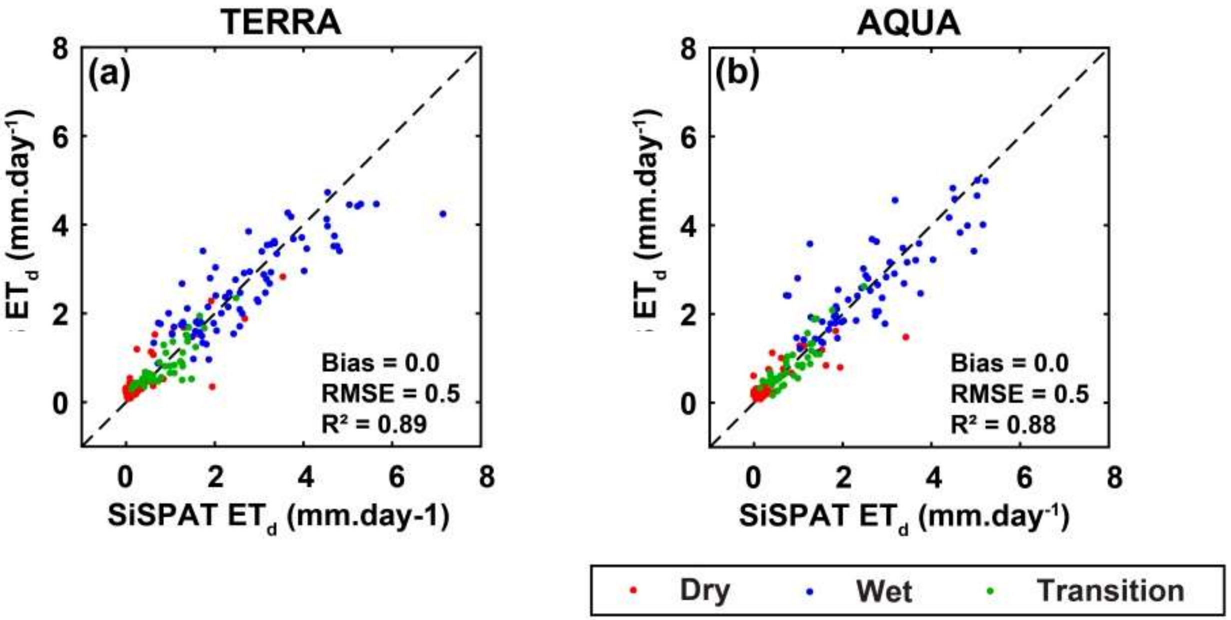
(Allies et al. 2021, Remote Sensing)

Top : ET maps (average)



Bottom : uncertainty maps (range of estimations ET_i)



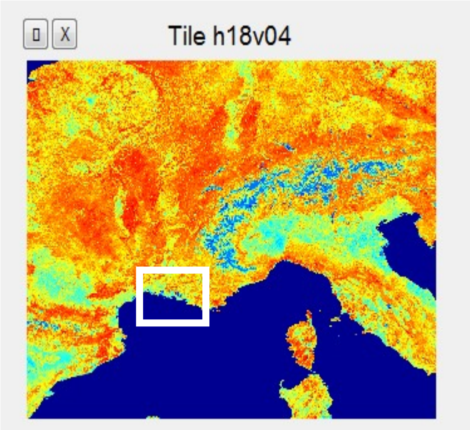


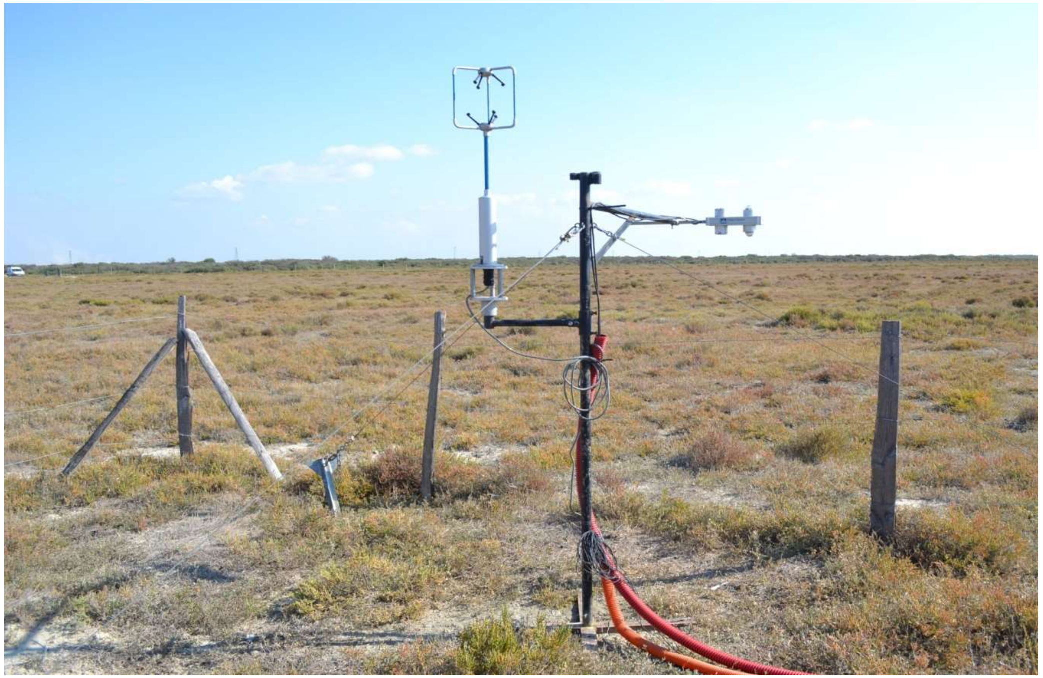
RMSE = 0.5 mm d^{-1}

(Allies et al. 2021, Remote Sensing)

Example 3 : training weighting coefficients using in situ data (« bayesian » model averaging)

ET monitoring in wetlands of the Rhône river delta from MODIS data (sansouire : saltmarsh scrubs in Camargue)





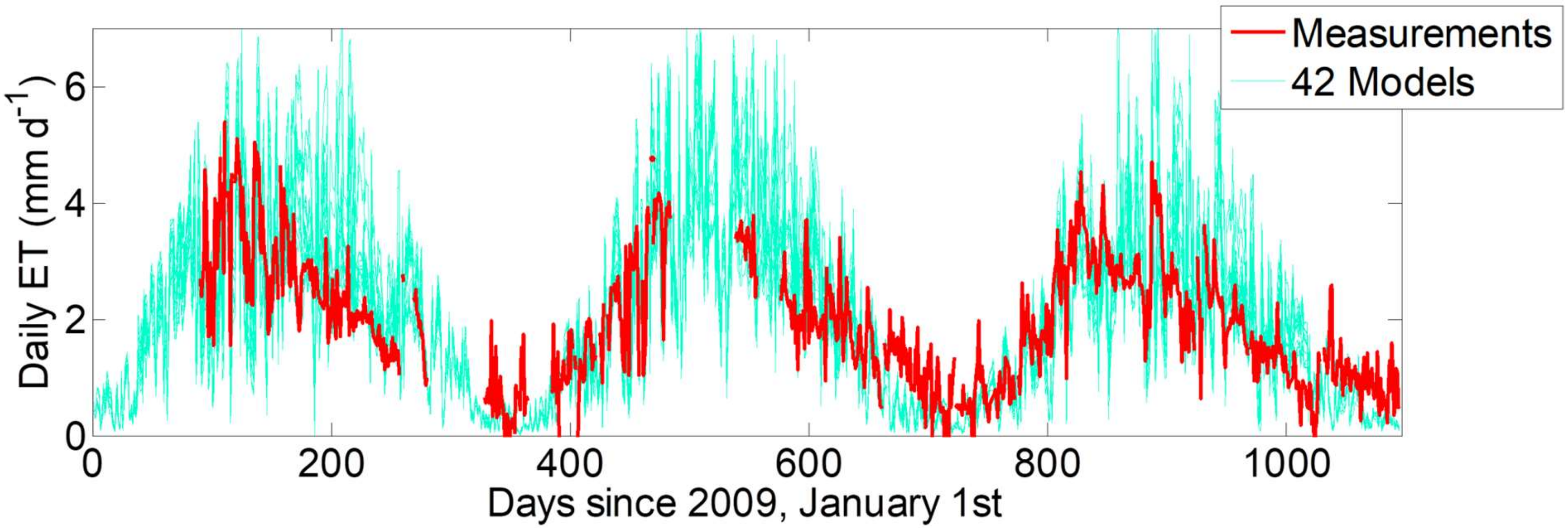
EVASPA ->
ensemble members ET_i calculated for various EF methods and incident radiation sources -> 42 members

3 years dataset (2009 – 2011)
+ 20 year dataset for application in hydrological modelling

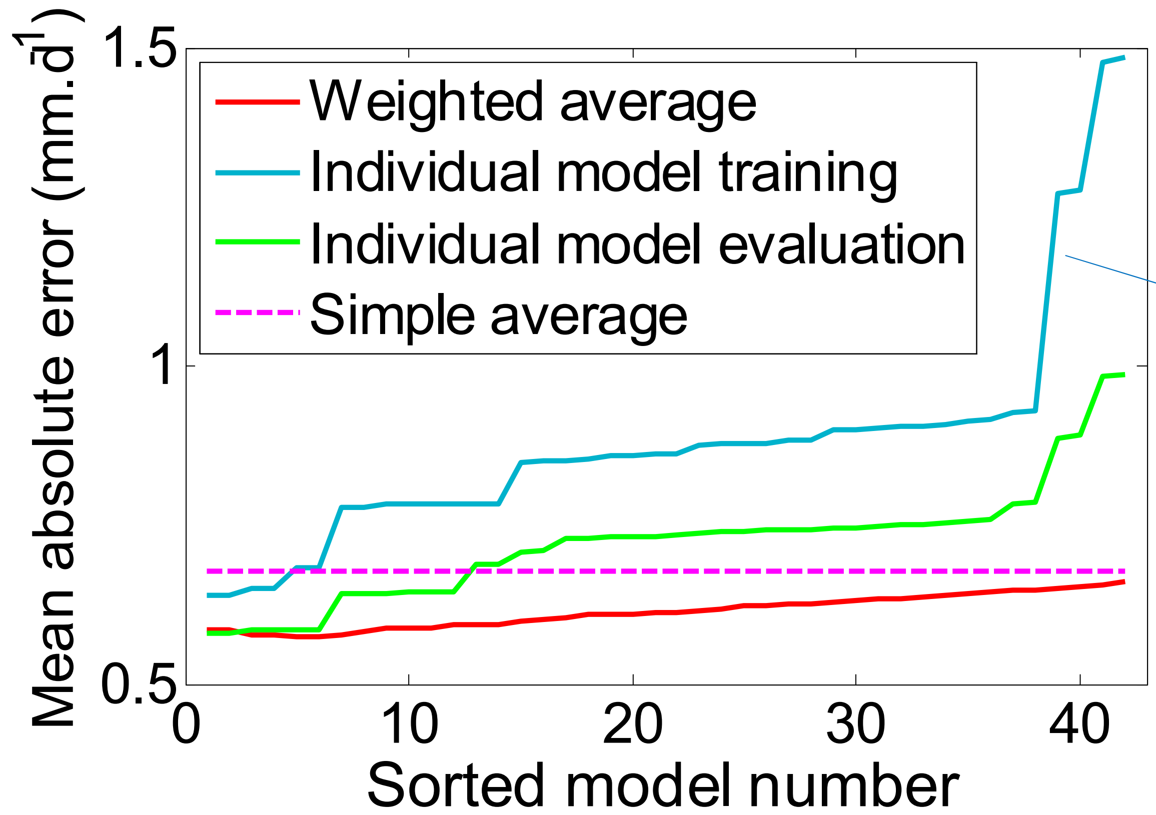
Example 3 : Evapotranspiration estimations compared to in situ data

- MODIS data (Ts, albedo, NDVI)
- several EF models
- several incoming radiation

} 42 estimations of ET



Example 3 : Evapotranspiration ensemble members evaluation, sorting and averaging

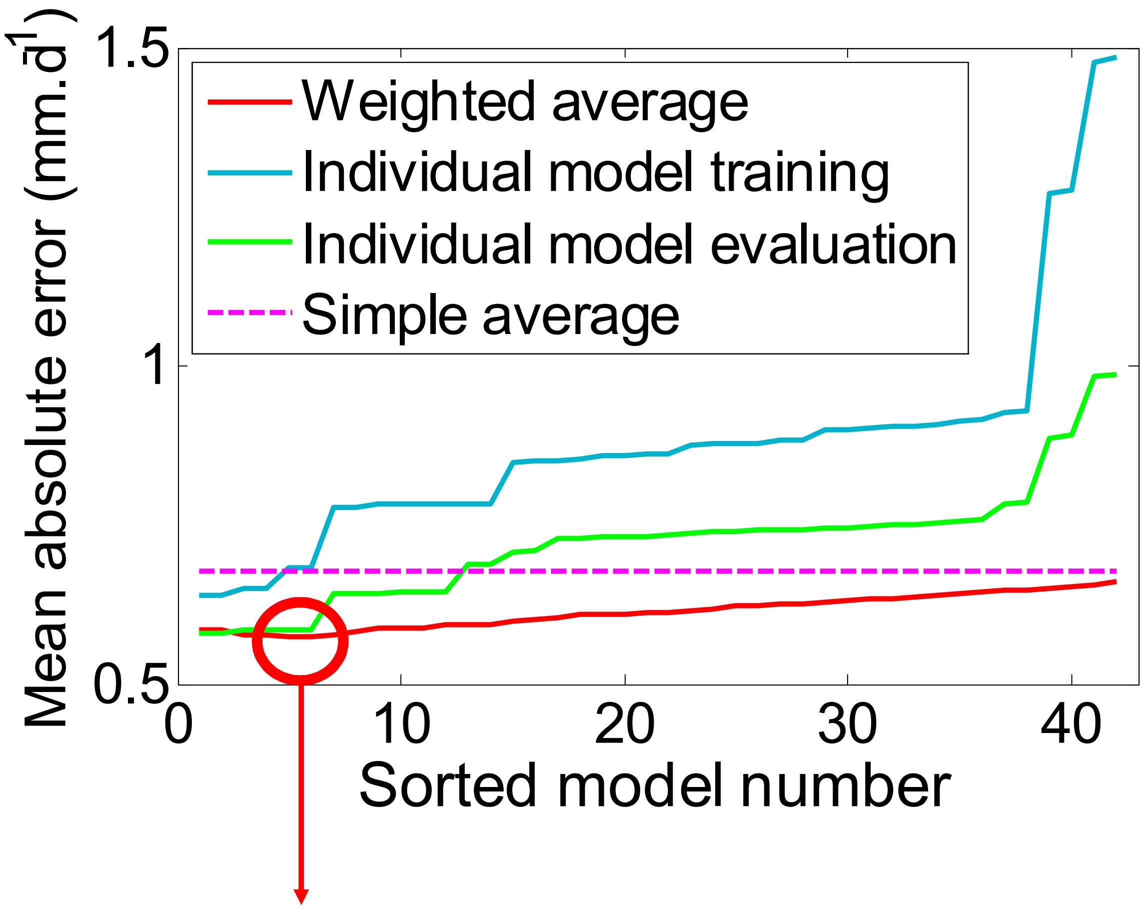


weighting coefficients

a_i related to $\frac{1}{|error|}$

$a_i = \frac{1}{|error|} \; / \; \sum_{i=1}^{n1} a_i$

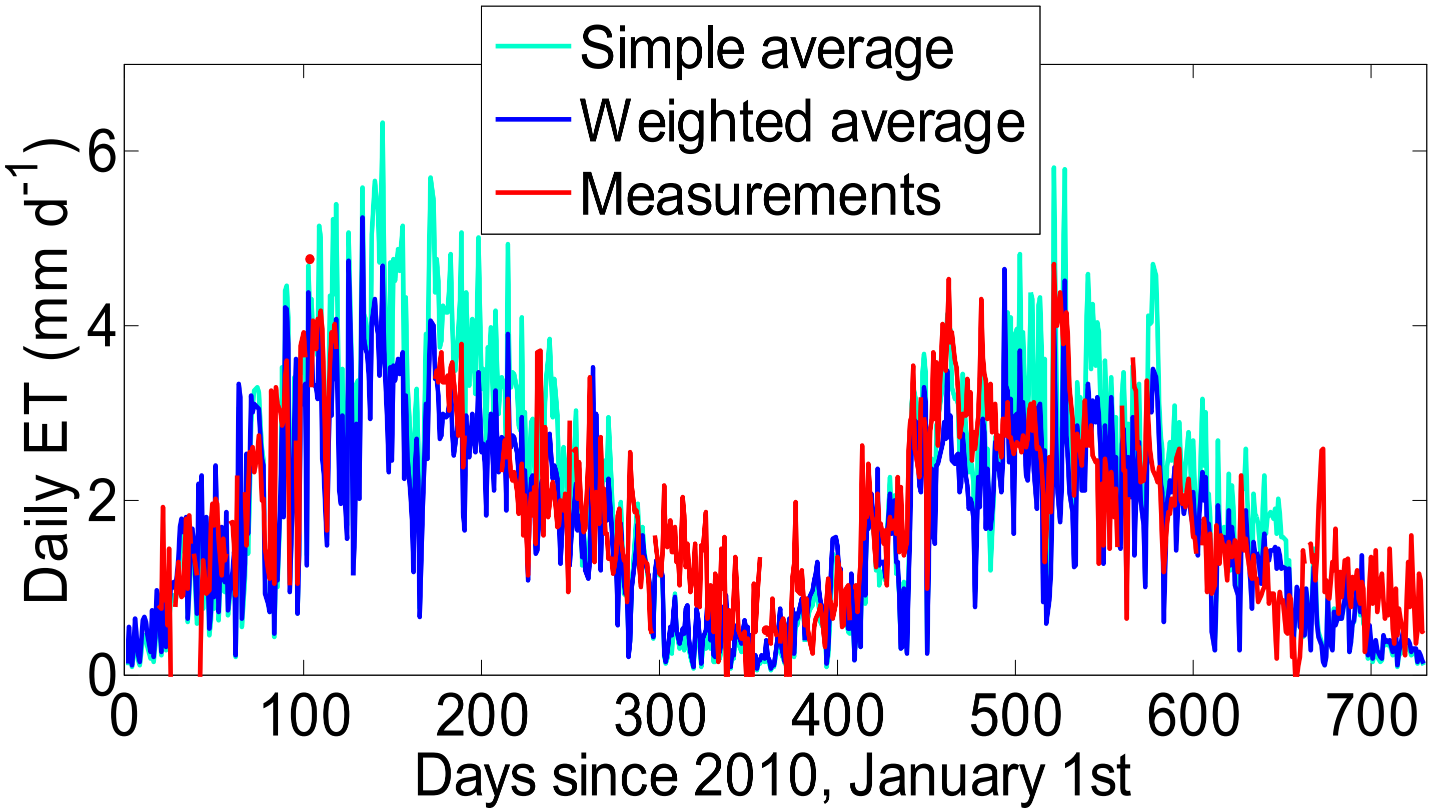
Example 3 : Evapotranspiration ensemble members evaluation, sorting and averaging



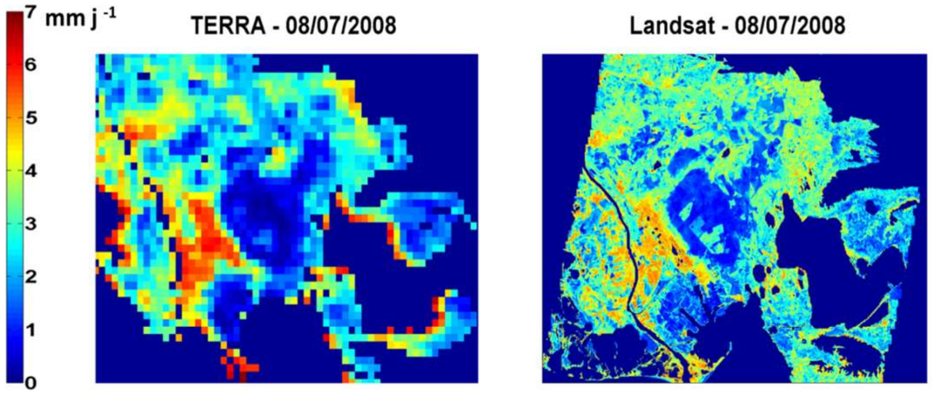
Best results in the training phase obtained by combining the 6 best members

RMSE = 0.57 mm d^{-1}

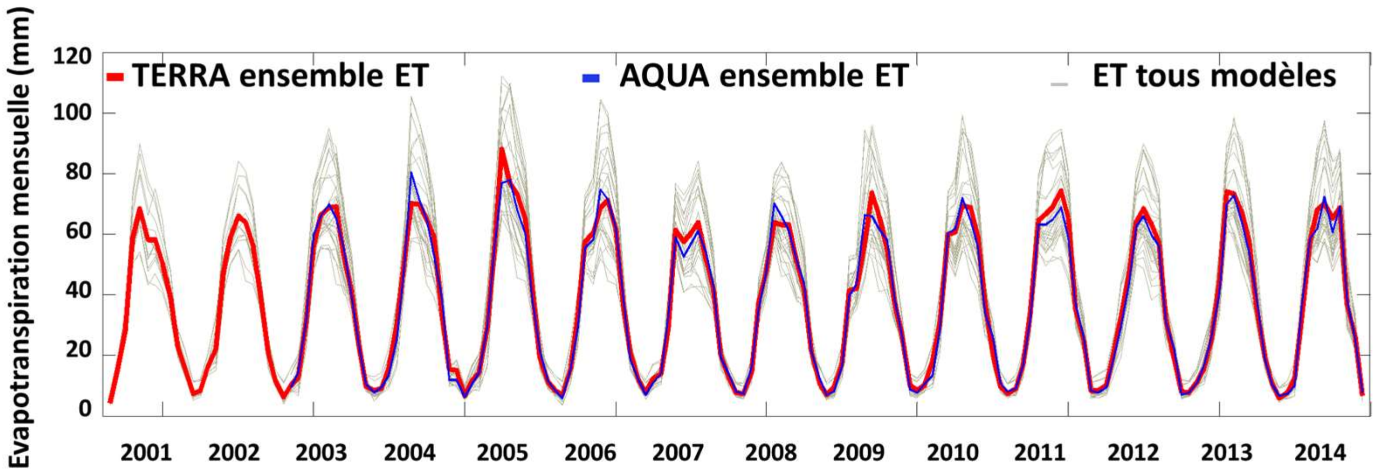
Example 3 : Evaluation of ensemble ET and weighted ensemble ET



Applications to the whole area



Monthly ET obtained over the Crau aquifer (600 km^2) for MODIS TERRA and MODIS AQUA data :



Summary

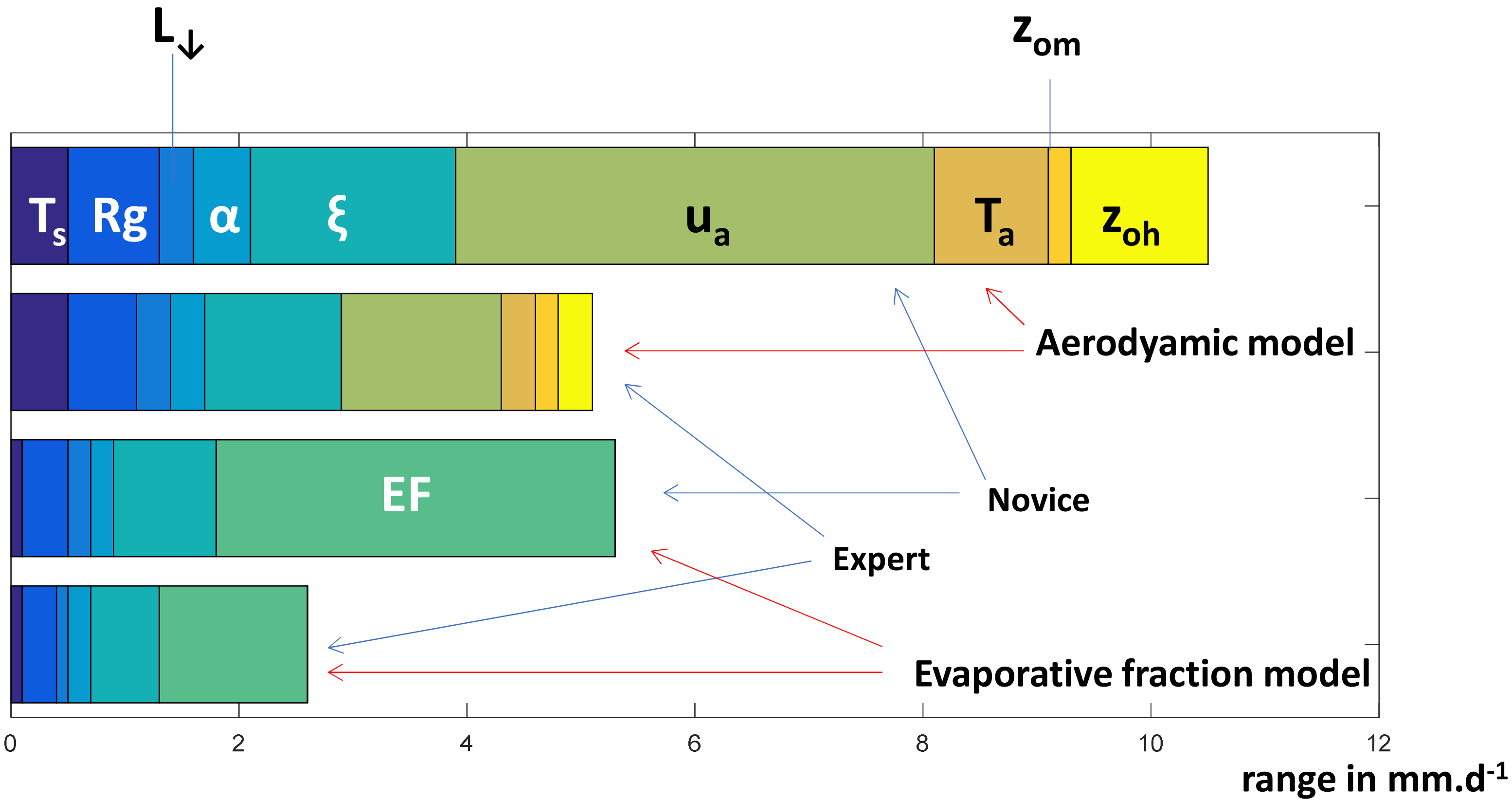
Ensemble modelling applied to multi-data source – multi-model (or algorithm) may be used for:

- **monitoring ET**
- **providing uncertainty in the estimates**

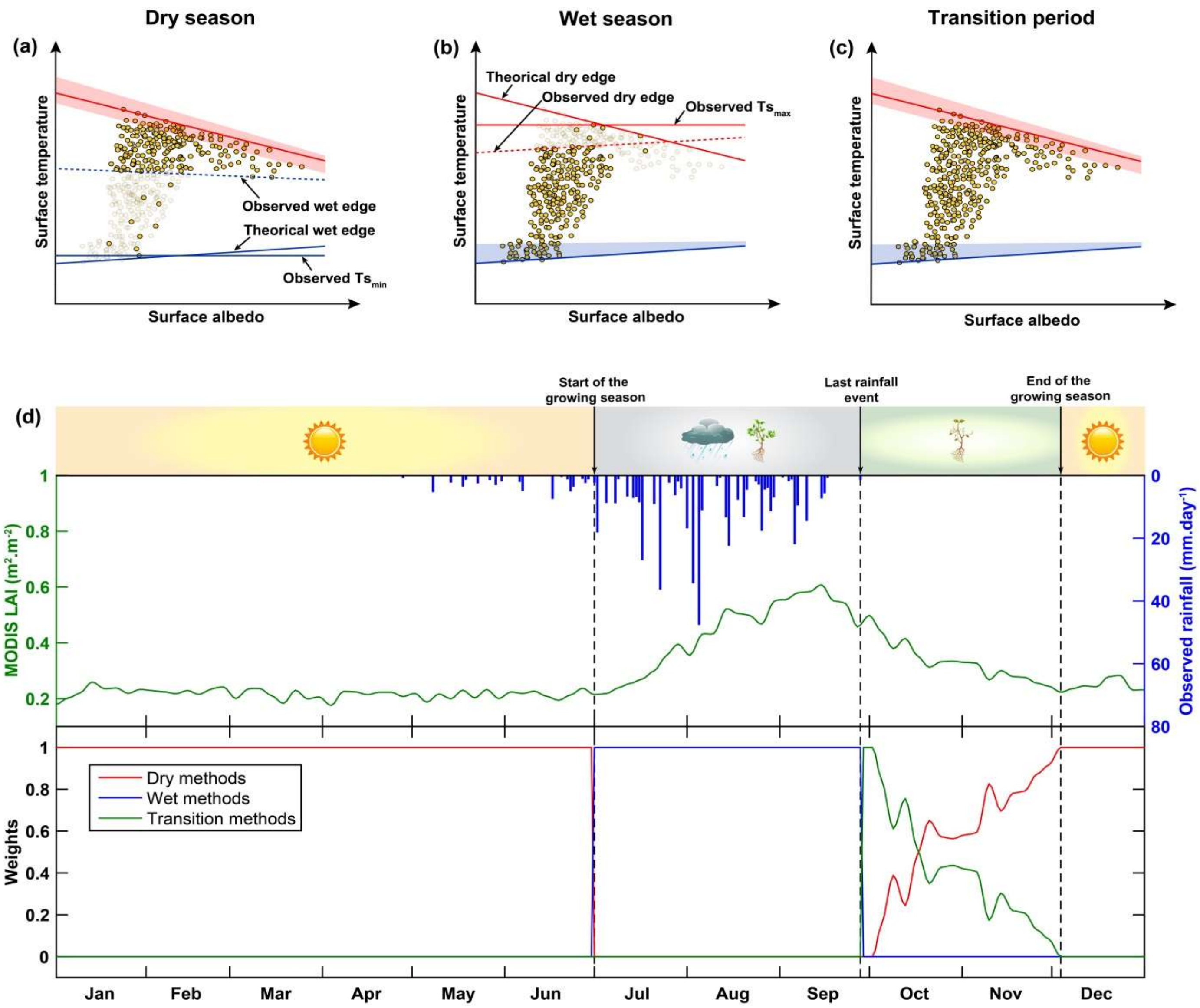
  (however this uncertainty is only epistemic and does not include estimation errors)
- **providing information on the main uncertainty factors:**
  - in all analysed cases, surface temperature was not the main limitation in ET estimations
  - for contextual models, the main sources of uncertainty concern algorithm (EF and ground heat flux)
  - for other models, including aerodynamic equations, meteorological forcing of wind speed and air temperature have also a strong impact (not shown here)

The EVASPA algorithm is a simple algorithm that will be the basis for implementing ET products in the frame of the TRISHNA program

Ranking of uncertainty sources



Uncertainty ranking for D2H1 (July 20th morning)



Dry season
Wet season
Transition period
(a)
(b)
(c)
Surface temperature
Surface albedo
Observed wet edge
Theorical wet edge
Observed Ts min
Theorical dry edge
Observed dry edge
Observed Ts max
(d)
Start of the growing season
Last rainfall event
End of the growing season
MODIS LAI (m².m⁻²)
Observed rainfall (mm.day⁻¹)
Weights
Dry methods
Wet methods
Transition methods
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec